NONRESIDENT
TRAINING
COURSE

Navy Electricity and Electronics Training Series

Module 9—Introduction to Wave Generation and Wave Shaping

NAVEDTRA 14181

PREFACE

About this course:

This is a self-study course. By studying this course, you can improve your professional/military knowledge, as well as prepare for the Navywide advancement-in-rate examination. It contains subject matter about day-to-day occupational knowledge and skill requirements and includes text, tables, and illustrations to help you understand the information. An additional important feature of this course is its references to useful information in other publications. The well-prepared Sailor will take the time to look up the additional information.

Any errata for this course can be found at https://www.advancement.cnet.navy.mil under Products.

Training series information:

This is Module 9 of a series. For a listing and description of the entire series, see NAVEDTRA 12061, *Catalog of Nonresident Training Courses*, at https://www.advancement.cnet.navy.mil.

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CHAPTER 1

TUNED CIRCUITS

LEARNING OBJECTIVES

Learning objectives are stated at the beginning of each chapter. These learning objectives serve as a preview of the information you are expected to learn in the chapter. The comprehensive check questions are based on the objectives. By successfully completing the OCC/ECC, you indicate that you have met the objectives and have learned the information. The learning objectives are listed below.

Upon completion of this chapter, you will be able to:

1. State the applications of a resonant circuit.
2. Identify the conditions that exist in a resonant circuit.
3. State and apply the formula for resonant frequency of an a.c. circuit.
4. State the effect of changes in inductance (L) and capacitance (C) on resonant frequency $(_{fr})$.
5. Identify the characteristics peculiar to a series resonant circuit.
6. Identify the characteristics peculiar to a parallel resonant circuit.
7. State and apply the formula for Q.
8. State what is meant by the bandwidth of a resonant circuit and compute the bandwidth for a given circuit.
9. Identify the four general types of filters.
10. Identify how the series- and parallel-resonant circuit can be used as a bandpass or a band-reject filter.

INTRODUCTION TO TUNED CIRCUITS

When your radio or television set is turned on, many events take place within the "receiver" before you hear the sound or see the picture being sent by the transmitting station.

Many different signals reach the antenna of a radio receiver at the same time. To select a station, the listener adjusts the tuning dial on the radio receiver until the desired station is heard. Within the radio or TV receiver, the actual "selecting" of the desired signal and the rejecting of the unwanted signals are accomplished by what is called a TUNED CIRCUIT. A tuned circuit consists of a coil and a capacitor connected in series or parallel. Later in this chapter you will see the application and advantages of both series- and parallel-tuned circuits. Whenever the characteristics of inductance and capacitance are found in a tuned circuit, the phenomenon as RESONANCE takes place.

You learned earlier in the *Navy Electricity and Electronics Training Series, Module 2*, chapter 4, that inductive reactance (X_L) and capacitive reactance (X_C) have opposite effects on circuit impedance (Z).

You also learned that if the frequency applied to an LCR circuit causes X_L and X_C to be equal, the circuit is RESONANT.

If you realize that X_L and X_C can be equal ONLY at ONE FREQUENCY (the resonant frequency), then you will have learned the most important single fact about resonant circuits. This fact is the principle that enables tuned circuits in the radio receiver to select one particular frequency and reject all others. This is the reason why so much emphasis is placed on X_L and X_C in the discussions that follow.

Examine figure 1-1. Notice that a basic tuned circuit consists of a coil and a capacitor, connected either in series, view (A), or in parallel, view (B). The resistance (R) in the circuit is usually limited to the inherent resistance of the components (particularly the resistance of the coil). For our purposes we are going to disregard this small resistance in future diagrams and explanations.

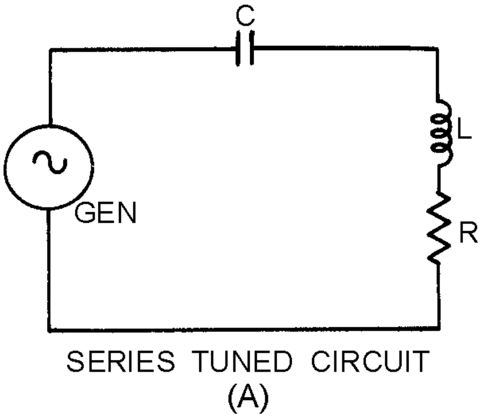


Figure 1-1A.—Basic tuned circuits. SERIES TUNED CIRCUIT

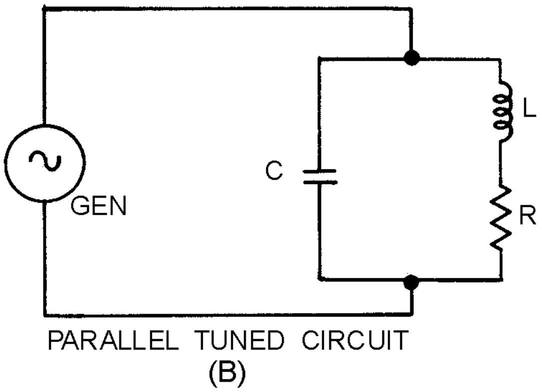


Figure 1-1B.—Basic tuned circuits. PARALLEL TUNED CIRCUIT

You have already learned how a coil and a capacitor in an a.c. circuit perform. This action will be the basis of the following discussion about tuned circuits.

Why should you study tuned circuits? Because the tuned circuit that has been described above is used in just about every electronic device, from remote-controlled model airplanes to the most sophisticated space satellite.

You can assume, if you are going to be involved in electricity or electronics, that you will need to have a good working knowledge of tuned circuits and how they are used in electronic and electrical circuits.

REVIEW OF SERIES/PARALLEL A.C. CIRCUITS

First we will review the effects of frequency on a circuit which contains resistance, inductance, and capacitance. This review recaps what you previously learned in the Inductive and Capacitive Reactance chapter in *module 2* of the *NEETS*.

FREQUENCY EFFECTS ON RLC CIRCUITS

Perhaps the most often used control of a radio or television set is the station or channel selector. Of course, the volume, tone, and picture quality controls are adjusted to suit the individual's taste, but very often they are not adjusted when the station is changed. What goes on behind this station selecting? In this chapter, you will learn the basic principles that account for the ability of circuits to "tune" to the desired station.

Effect of Frequency on Inductive Reactance

In an a.c. circuit, an inductor produces inductive reactance which causes the current to lag the voltage by 90 degrees. Because the inductor "reacts" to a changing current, it is known as a reactive component. The opposition that an inductor presents to a.c. is called inductive reactance (X_L). This opposition is caused by the inductor "reacting" to the changing current of the a.c. source. Both the inductance and the frequency determine the magnitude of this reactance. This relationship is stated by the formula:

$$X_L = 2\pi fL$$

Where:

X_L = the inductive reactance in ohms
f = the frequency in hertz
L = the inductance in henries
π = 3.1416

As shown in the equation, any increase in frequency, or "f," will cause a corresponding increase of inductive reactance, or "X_L." Therefore, the INDUCTIVE REACTANCE VARIES DIRECTLY WITH THE FREQUENCY. As you can see, the higher the frequency, the greater the inductive reactance; the lower the frequency, the less the inductive reactance for a given inductor. This relationship is illustrated in figure 1-2. Increasing values of X_L are plotted in terms of increasing frequency. Starting at the lower left corner with zero frequency, the inductive reactance is zero. As the frequency is increased (reading to the right), the inductive reactance is shown to increase in direct proportion.

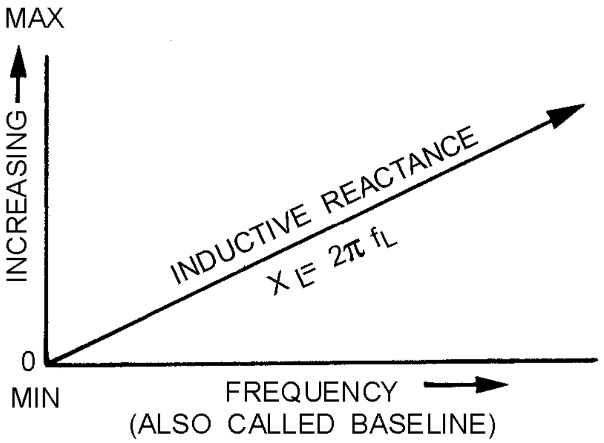


Figure 1-2.—Effect of frequency on inductive reactance.

Effect of Frequency on Capacitive Reactance

In an a.c. circuit, a capacitor produces a reactance which causes the current to lead the voltage by 90 degrees. Because the capacitor "reacts" to a changing voltage, it is known as a reactive component. The opposition a capacitor presents to a.c. is called capacitive reactance (X_C). The opposition is caused by the capacitor "reacting" to the changing voltage of the a.c. source. The formula for capacitive reactance is:

$$X_C = \frac{1}{2\pi f C}$$

Where:

X_C = the capacitive reactance in ohms
f = the frequency in hertz
C = the capacitance in farads
π = 3.1416

In contrast to the inductive reactance, this equation indicates that the CAPACITIVE REACTANCE VARIES INVERSELY WITH THE FREQUENCY. When $f = 0$, X_C is infinite (∞) and decreases as frequency increases. That is, the lower the frequency, the greater the capacitive reactance; the higher the frequency, the less the reactance for a given capacitor.

As shown in figure 1-3, the effect of capacitance is opposite to that of inductance. Remember, capacitance causes the current to lead the voltage by 90 degrees, while inductance causes the current to lag the voltage by 90 degrees.

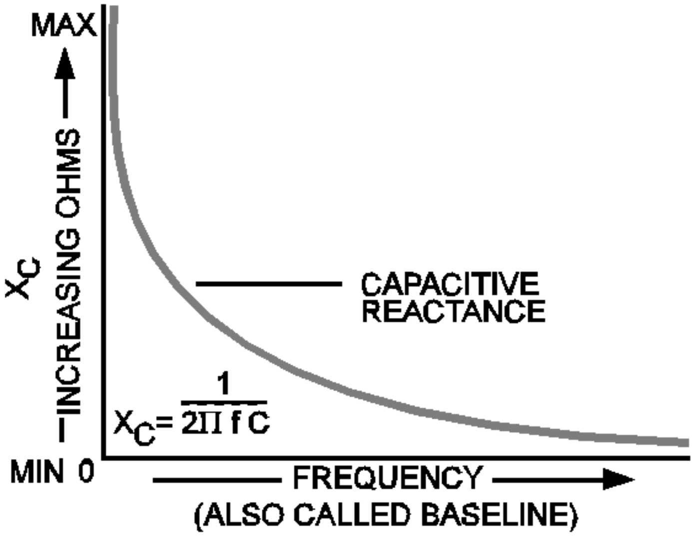


Figure 1-3.—Effect of frequency on capacitive reactance.

Effect of Frequency on Resistance

In the expression for inductive reactance, $X_L = 2\pi fL$, and in the expression for capacitive reactance,

$$X_C = \frac{1}{2\pi fC}$$

both contain "f" (frequency). Any change of frequency changes the reactance of the circuit components as already explained. So far, nothing has been said about the effect of frequency on resistance. In an Ohm's law relationship, such as R = E/I no "f" is involved. Thus, for all practical purposes, a change of frequency does not affect the resistance of the circuit. If a 60-hertz a.c. voltage causes 20 milliamperes of current in a resistive circuit, then the same voltage at 2000 hertz, for example, would still cause 20 milliamperes to flow.

NOTE: Remember that the total opposition to a.c. is called impedance (Z). Impedance is the combination of inductive reactance (X_L), capacitive reactance (X_C), and resistance (R). When dealing with a.c. circuits, the impedance is the factor with which you will ultimately be concerned. But, as you have just been shown, the resistance (R) is not affected by frequency. Therefore, the remainder of the discussion of a.c. circuits will only be concerned with the reactance of inductors and capacitors and will ignore resistance.

A.c. Circuits Containing Both Inductive and Capacitive Reactances

A.c. circuits that contain both an inductor and a capacitor have interesting characteristics because of the opposing effects of L and C. X_L and X_C may be treated as reactors which are 180 degrees out of phase. As shown in figure 1-2, the vector for X_L should be plotted above the baseline; vector for X_C, figure 1-3, should be plotted below the baseline. In a series circuit, the effective reactance, or what is termed the RESULTANT REACTANCE, is the difference between the individual reactances. As an equation, the resultant reactance is:

$$X = X_L - X_C$$

Suppose an a.c. circuit contains an X_L of 300 ohms and an X_C of 250 ohms. The resultant reactance is:

$$X = X_L - X_C = 300 - 250 = 50 \text{ ohms (inductive)}$$

In some cases, the X_C may be larger than the X_L. If $X_L = 1200$ ohms and $X_C = 4000$ ohms, the difference is: $X = X_L - X_C = 1200 - 4000 = -2800$ ohms (capacitive). The total carries the sign (+ or –) of the greater number (factor).

Q-1. What is the relationship between frequency and the values of (a) X_L, (b) X_C, and (c) R?

Q-2. In an a.c. circuit that contains both an inductor and a capacitor, what term is used for the difference between the individual reactances?

RESONANCE

For every combination of L and C, there is only ONE frequency (in both series and parallel circuits) that causes X_L to exactly equal X_C; this frequency is known as the RESONANT FREQUENCY. When the resonant frequency is fed to a series or parallel circuit, X_L becomes equal to X_C, and the circuit is said to be RESONANT to that frequency. The circuit is now called a RESONANT CIRCUIT; resonant circuits are tuned circuits. The circuit condition wherein X_L becomes equal to X_C is known as RESONANCE.

Each LCR circuit responds to resonant frequency differently than it does to any other frequency. Because of this, an LCR circuit has the ability to separate frequencies. For example, suppose the TV or radio station you want to see or hear is broadcasting at the resonant frequency. The LC "tuner" in your set can divide the frequencies, picking out the resonant frequency and rejecting the other frequencies. Thus, the tuner selects the station you want and rejects all other stations. If you decide to select another station, you can change the frequency by tuning the resonant circuit to the desired frequency.

RESONANT FREQUENCY

As stated before, the frequency at which X_L equals X_C (in a given circuit) is known as the resonant frequency of that circuit. Based on this, the following formula has been derived to find the exact resonant frequency when the values of circuit components are known:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

There are two important points to remember about this formula. First, the resonant frequency found when using the formula will cause the reactances (X_L and X_C) of the L and C components to be equal. Second, any change in the value of either L or C will cause a change in the resonant frequency.

An <u>increase</u> in the value of either L or C, or both L and C, will <u>lower</u> the resonant frequency of a given circuit. A <u>decrease</u> in the value of L or C, or both L and C, will <u>raise</u> the resonant frequency of a given circuit.

The symbol for resonant frequency used in this text is f. Different texts and references may use other symbols for resonant frequency, such as f_o, F_r, and fR. The symbols for many circuit parameters have been standardized while others have been left to the discretion of the writer. When you study, apply the rules given by the writer of the text or reference; by doing so, you should have no trouble with nonstandard symbols and designations.

The resonant frequency formula in this text is:

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

Where:
f_r = the resonant frequency in hertz
L = the inductance in henries
C = the capacitance in farads
π = 3.1416

By substituting the constant .159 for the quantity

$$\frac{1}{2\pi}$$

the formula can be simplified to the following:

$$f_r = \frac{.159}{\sqrt{LC}}$$

Let's use this formula to figure the resonant frequency (f_r). The circuit is shown in the practice tank circuit of figure 1-4.

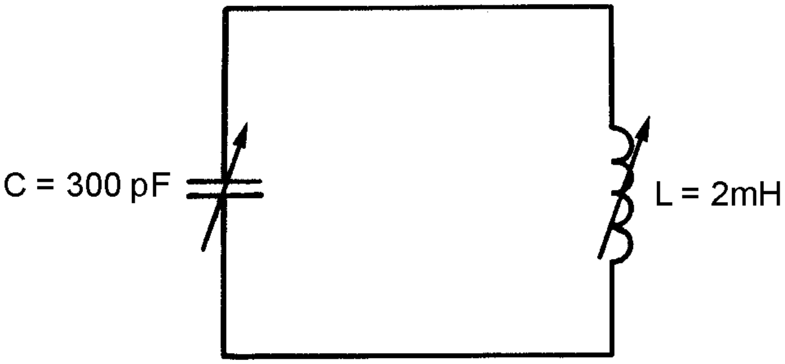


Figure 1-4.—Practice tank circuit.

Given:

$L = 2\text{mH}\ (2 \times 10^{-3}\ \text{H})$

$C = 300\text{pF}\ (300 \times 10^{-12}\ \text{F})$

Solution:

$$f_r = \frac{.159}{\sqrt{LC}}$$

$$f_r = \frac{.159}{\sqrt{(2 \times 10^{-3}\ \text{H}) \times (300 \times 10^{-12}\ \text{F})}}$$

$$f_r = \frac{.159}{\sqrt{600 \times 10^{-15}}}$$

(F and H are shown in this step to show units)

$$f_r = \frac{.159}{60 \times 10^{-14}}$$

(Solving for square root $60 = 7.75\ \ 10^{-14} = 10^{-7}$)

$$f_r = \frac{.159}{7.75 \times 10^{-7}}$$

$$f_r = \frac{.159 \times 10^{7}}{7.75}$$

$$f_r = \frac{.159 \times 10^{4}}{7.75}$$

$f_r = 20.5 \times 10^{4}$ (rounded off)

$f_r = 205{,}000$ Hz or 205 kHz

The important point here is not the formula nor the mathematics. In fact, you may never have to compute a resonant frequency. The important point is for you to see that any given combination of L and C can be resonant at only one frequency; in this case, 205 kHz.

The universal reactance curves of figures 1-2 and 1-3 are joined in figure 1-5 to show the relative values of X_L and X_L at resonance, below resonance, and above resonance.

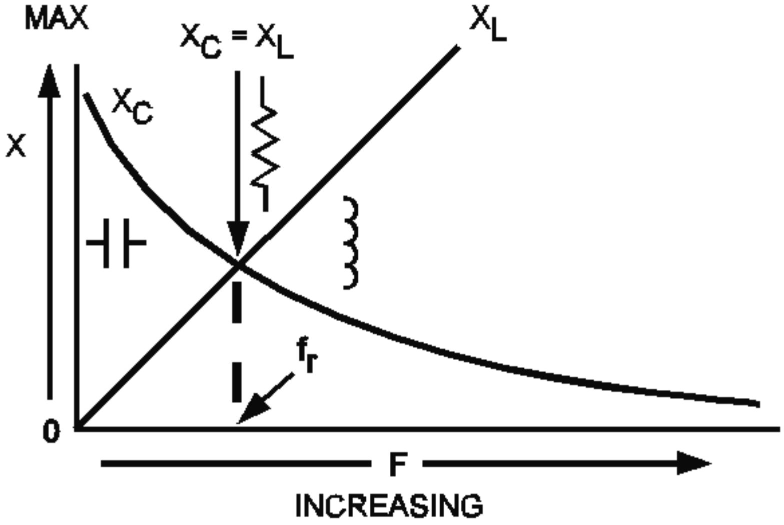


Figure 1-5.—Relationship between X_L and X_C as frequency increases.

First, note that f_r, (the resonant frequency) is that frequency (or point) where the two curves cross. At this point, and ONLY this point, X_L equals X_C. Therefore, the frequency indicated by f_r is the one and only frequency of resonance. Note the resistance symbol which indicates that at resonance all reactance is cancelled and the circuit impedance is effectively purely resistive. Remember, a.c. circuits that are resistive have no phase shift between voltage and current. Therefore, at resonance, phase shift is cancelled. The phase angle is effectively zero.

Second, look at the area of the curves to the left of f_r. This area shows the relative reactances of the circuit at frequencies BELOW resonance. To these LOWER frequencies, X_C will always be greater than X_L. There will always be some capacitive reactance left in the circuit after all inductive reactance has been cancelled. Because the impedance has a reactive component, there will be a phase shift. We can also state that below f_r the circuit will appear capacitive.

Lastly, look at the area of the curves to the right of f. This area shows the relative reactances of the circuit at frequencies ABOVE resonance. To these HIGHER frequencies, X_L will always be greater than X_C. There will always be some inductive reactance left in the circuit after all capacitive reactance has been cancelled. The inductor symbol shows that to these higher frequencies, the circuit will always appear to have some inductance. Because of this, there will be a phase shift.

RESONANT CIRCUITS

Resonant circuits may be designed as series resonant or parallel resonant. Each has the ability to discriminate between its resonant frequency and all other frequencies. How this is accomplished by both series- and parallel-LC circuits is the subject of the next section.

NOTE: Practical circuits are often more complex and difficult to understand than simplified versions. Simplified versions contain all of the basic features of a practical circuit, but leave out the nonessential features. For this reason, we will first look at the IDEAL SERIES-RESONANT CIRCUIT—a circuit that really doesn't exist except for our purposes here.

THE IDEAL SERIES-RESONANT CIRCUIT

The ideal series-resonant circuit contains no resistance; it consists of only inductance and capacitance in series with each other and with the source voltage. In this respect, it has the same characteristics of the series circuits you have studied previously. Remember that current is the same in all parts of a series circuit because there is only one path for current.

Each LC circuit responds differently to different input frequencies. In the following paragraphs, we will analyze what happens internally in a series-LC circuit when frequencies at resonance, below resonance, and above resonance are applied. The L and C values in the circuit are those used in the problem just studied under resonant-frequency. The frequencies applied are the three inputs from figure 1-6. Note that the resonant frequency of each of these components is 205 kHz, as figured in the problem.

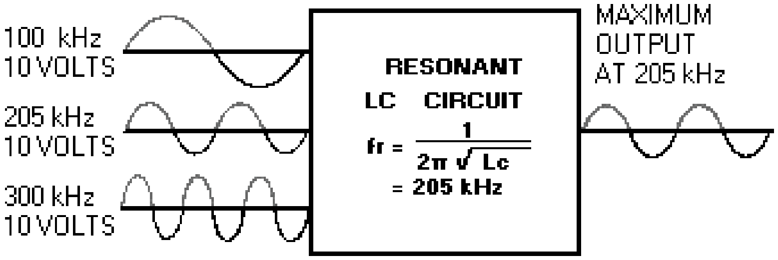


Figure 1-6.—Output of the resonant circuit.

How the Ideal Series-LC Circuit Responds to the Resonant Frequency (205 kHz)

Given:

$L = 2\text{ mH } (2 \times 10^{-3}\text{ H})$

$C = 300\text{ pF } (300 \times 10^{-12}\text{ F})$

$f_r = 205\text{ kHz (rounded off)}$

$f_r = \frac{.159}{\sqrt{LC}}$

$X_L = 2580\text{ ohms } (2\pi fL)$

$X_c = 2580\text{ ohms } (\frac{1}{2\pi FC})$

$E_S = 10$ volts at a frequency 205 kHz

Note: You are given the values of X_L, X_C, and f_r but you can apply the formulas to figure them. The values given are rounded off to make it easier to analyze the circuit.

First, note that X_L and X_C are equal. This shows that the circuit is resonant to the applied frequency of 205 kHz. X_L and X_C are opposite in effect; therefore, they subtract to zero. (2580 ohms – 2580 ohms = zero.) At resonance, then, X = zero. In our theoretically perfect circuit with zero resistance and zero reactance, the total opposition to current (Z) must also be zero.

Now, apply Ohm's law for a.c. circuits:

$$I = \frac{E}{Z}$$

$$I = \frac{10 \text{ volts}}{0 \text{ ohms}}$$

$$I = \text{ INFINITELY HIGH}$$

Don't be confused by this high value of current. Our perfect, but impossible, circuit has no opposition to current. Therefore, current flow will be extremely high. The important points here are that AT RESONANCE, impedance is VERY LOW, and the resulting current will be comparatively HIGH.

If we apply Ohm's law to the individual reactances, we can figure relative values of voltage across each reactance.

$$E_L = I \times X_L$$

$$E_C = I \times X_C$$

These are reactive voltages that you have studied previously. The voltage across each reactance will be comparatively high. A comparatively high current times 2580 ohms yields a high voltage. At any given instant, this voltage will be of opposite polarity because the reactances are opposite in effect. $E_L + E_C =$ zero volts

WARNING

THE INDIVIDUAL VOLTAGES MAY REACH QUITE HIGH VALUES. ALTHOUGH LITTLE POWER IS PRESENT, THE VOLTAGE IS REAL AND CARE SHOULD BE TAKEN IN WORKING WITH IT.

Let's summarize our findings so far. In a series-LC circuit with a resonant-frequency voltage applied, the following conditions exist:

- X_L and X_C are equal and subtract to zero.
- Resultant reactance is zero ohms.
- Impedance (Z) is reduced to a MINIMUM value.
- With minimum Z, current is MAXIMUM for a given voltage.
- Maximum current causes maximum voltage drops across the individual reactances.

All of the above follow in sequence from the fact that $X_L = X_C$ at the resonant frequency.

How the Ideal Series-LC Circuit Respond to a Frequency Below Resonance (100 kHz)

Given:

$L = 2$ mH (2×10^{-3}H)

$C = 300$ pF (300×10^{-12}F)

$f_r = 205$ kHz (at resonant frequency)

$$f_r = \frac{.159}{\sqrt{LC}}$$

$X_L =$ 1260 ohms (rounded off) (at 100 kHz)

$X_c =$ 5300 ohms (rounded off) (at 100 kHz)

$E_s =$ 10 volts (at 100 kHz)

(As in the previous analysis, you are
given values that are possible for you
to compute. If you do the computations,
remember that most values are rounded
off.)

First, note that X_L and X_C are no longer equal. X_C is larger than it was at resonance; X_L is smaller. By applying the formulas you have learned, you know that a lower frequency produces a higher capacitive reactance and a lower inductive reactance. The reactances subtract but do not cancel ($X_L - X_C = 1260 - 5300 = 4040$ ohms (capacitive)). At an input frequency of 100 kHz, the circuit (still resonant to 205 kHz) has a net reactance of 4040 ohms. In our theoretically perfect circuit, the total opposition (Z) is equal to X, or 4040 ohms.

As before, let's apply Ohm's law to the new conditions.

$$I = \frac{E}{Z}$$

$$I = \frac{10 \text{ volts}}{4040 \text{ ohms}}$$

$$I = .00248 \text{ ampere}$$
$$\text{(approximately 2.5 mA)}$$

The voltage drops across the reactances are as follows:

$$E_L = I \times X_L$$

$$E_L = .0025\text{ A} \times 1260\,\Omega$$

$$E_L = 3 \text{ volts (approximately)}$$

$$E_C = I \times X_C$$

$$E_C = .0025\text{ A} \times 5300\,\Omega$$

$$E_C = 13 \text{ volts (approximately)}$$

In summary, in a series-LC circuit with a source voltage that is below the resonant frequency (100 kHz in the example), the resultant reactance (X), and therefore impedance, is higher than at resonance. In addition current is lower, and the voltage drops across the reactances are lower. All of the above follow in sequence due to the fact that X_C is greater than X_L at any frequency lower than the resonant frequency.

How the Ideal Series-LC Circuit Responds to a Frequency Above Resonance (300 kHz)

Given:

$L = 2\text{ mH } (2 \times 10^{-3}\text{ H})$

$C = 300\text{ pF } (300 \times 10^{-12}\text{ F})$

$f_r = 205\text{ kHz}$ (at resonant frequency)

$X_L = 3770$ ohms (rounded off) (at 300 kHz)

$X_c = 1770$ ohms (rounded off) (at 300 kHz)

$E_S = 10$ volts (at 300 kHz)

Again, X_L and X_C are not equal. This time, X_L is larger than X_C. (If you don't know why, apply the formulas and review the past several pages.) The resultant reactance is 2000 ohms ($X_L - X_C = 3770 - 1770 = 2000$ ohms.) Therefore, the resultant reactance (X), or the impedance of our perfect circuit at 300 kHz, is 2000 ohms.

By applying Ohm's law as before:

$I = 5$ milliamperes

$E_L = 19$ volts (rounded off)

$E_C = 9$ volts (rounded off)

In summary, in a series-LC circuit with a source voltage that is above the resonant frequency (300 kHz in this example), impedance is higher than at resonance, current is lower, and the voltage drops across the reactances are lower. All of the above follow in sequence from the fact that X_L is greater than X_C at any frequency higher than the resonant frequency.

Summary of the Response of the Ideal Series-LC Circuit to Frequencies Above, Below, and at Resonance

The ideal series-resonant circuit has zero impedance. The impedance increases for frequencies higher and lower than the resonant frequency. The impedance characteristic of the ideal series-resonant circuit results because resultant reactance is zero ohms at resonance and ONLY at resonance. All other frequencies provide a resultant reactance greater than zero.

Zero impedance at resonance allows maximum current. All other frequencies have a reduced current because of the increased impedance. The voltage across the reactance is greatest at resonance because voltage drop is directly proportional to current. All discrimination between frequencies results from the fact that X_L and X_C completely counteract ONLY at the resonant frequency.

How the Typical Series-LC Circuit Differs From the Ideal

As you learned much earlier in this series, resistance is always present in practical electrical circuits; it is impossible to eliminate. A typical series-LC circuit, then, has R as well as L and C.

If our perfect (ideal) circuit has zero resistance, and a typical circuit has "some" resistance, then a circuit with a very small resistance is closer to being perfect than one that has a large resistance. Let's list what happens in a series-resonant circuit because resistance is present. This is not new to you - just a review of what you have learned previously.

In a series-resonant circuit that is basically L and C, but that contains "some" R, the following statements are true:

- X_L, X_C, and R components are all present and can be shown on a vector diagram, each at right angles with the resistance vector (baseline).
- At resonance, the resultant reactance is zero ohms. Thus, at resonance, The circuit impedance equals only the resistance (R). The circuit impedance can never be less than R because the original resistance will always be present in the circuit.
- At resonance, a practical series-RLC circuit ALWAYS has MINIMUM impedance. The actual value of impedance is that of the resistance present in the circuit ($Z = R$).

Now, if the designers do their very best (and they do) to keep the value of resistance in a practical series-RLC circuit LOW, then we can still get a fairly high current at resonance. The current is NOT "infinitely" high as in our ideal circuit, but is still higher than at any other frequency. The curve and vector relationships for the practical circuit are shown in figure 1-7.

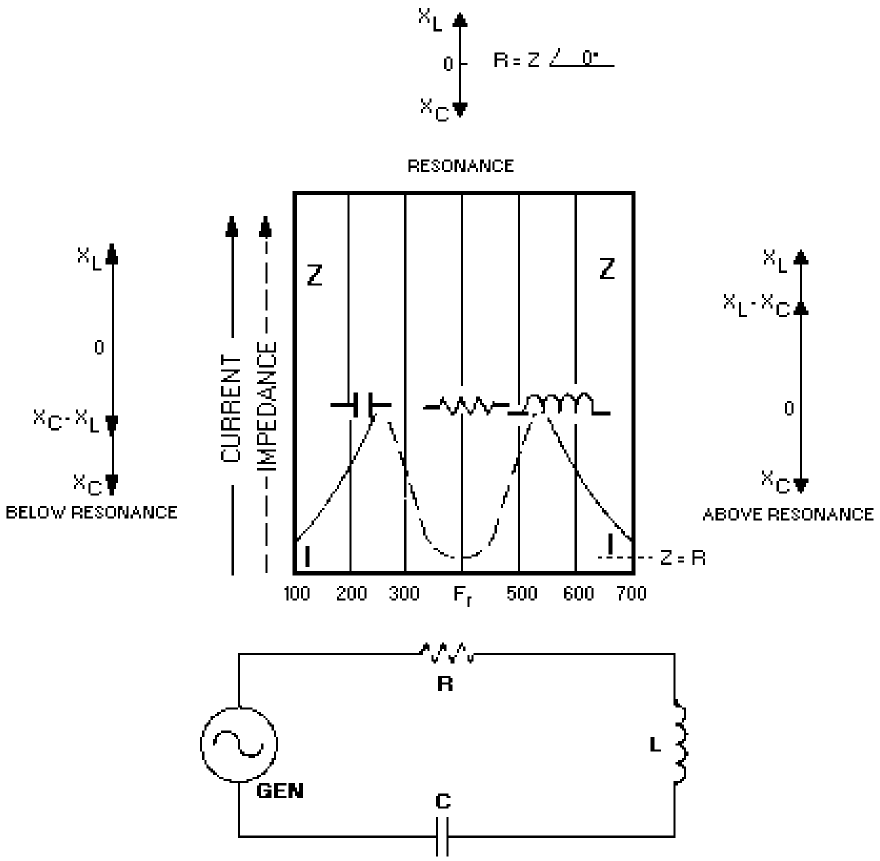


Figure 1-7.—Curves of impedance and current in an RLC series resonant circuit.

Note that the impedance curve does not reach zero at its minimum point. The vectors above and below resonance show that the phase shift of the circuit at these frequencies is less than 90 degrees because of the resistance.

The horizontal width of the curve is a measure of how well the circuit will pick out (discriminate) the one desired frequency. The width is called BANDWIDTH, and the ability to discriminate between frequencies is known as SELECTIVITY. Both of these characteristics are affected by resistance. Lower resistance allows narrower bandwidth, which is the same as saying the circuit has better selectivity. Resistance, then, is an unwanted quantity that cannot be eliminated but can be kept to a minimum by the circuit designers.

More on bandwidth, selectivity, and measuring the effects of resistance in resonant circuits will follow the discussion of parallel resonance.

Q-3. State the formula for resonant frequency.

Q-4. If the inductor and capacitor values are increased, what happens to the resonant frequency?

Q-5. In an "ideal" resonant circuit, what is the relationship between impedance and current?

Q-6. In a series-RLC circuit, what is the condition of the circuit if there is high impedance, low current, and low reactance voltages?

How the Parallel-LC Circuit Stores Energy

A parallel-LC circuit is often called a TANK CIRCUIT because it can store energy much as a tank stores liquid. It has the ability to take energy fed to it from a power source, store this energy alternately in the inductor and capacitor, and produce an output which is a continuous a.c. wave. You can understand how this is accomplished by carefully studying the sequence of events shown in figure 1-8. You must thoroughly understand the capacitor and inductor action in this figure before you proceed further in the study of parallel-resonant circuits.

In each view of figure 1-8, the waveform is of the charging and discharging CAPACITOR VOLTAGE. In view (A), the switch has been moved to position C. The d.c. voltage is applied across the capacitor, and the capacitor charges to the potential of the battery.

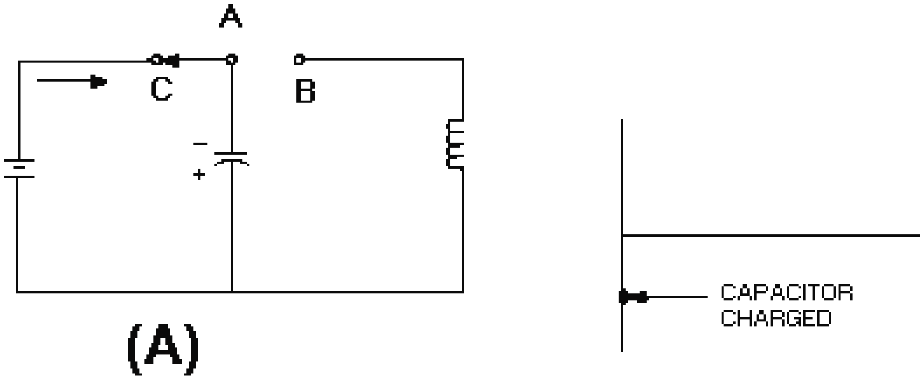


Figure 1-8A.—Capacitor and inductor action in a tank circuit.

In view (B), moving the switch to the right completes the circuit from the capacitor to the inductor and places the inductor in series with the capacitor. This furnishes a path for the excess electrons on the upper plate of the capacitor to flow to the lower plate, and thus starts neutralizing the capacitor charge. As these electrons flow through the coil, a magnetic field is built up around the coil. The energy which was first stored by the electrostatic field of the capacitor is now stored in the electromagnetic field of the inductor.

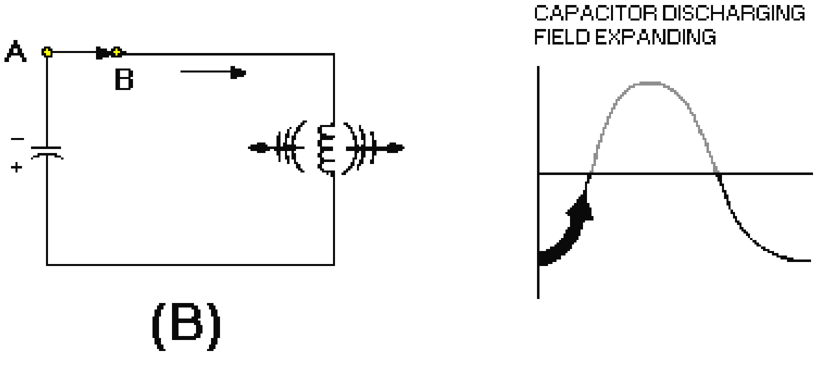


Figure 1-8B.—Capacitor and inductor action in a tank circuit.

View (C) shows the capacitor discharged and a maximum magnetic field around the coil. The energy originally stored in the capacitor is now stored entirely in the magnetic field of the coil.

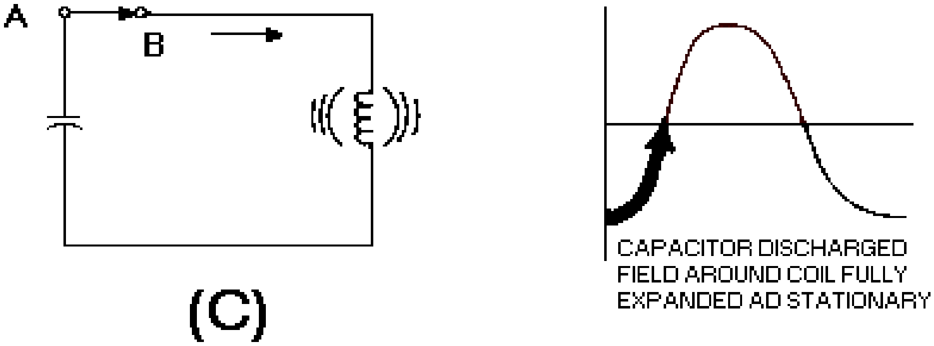


Figure 1-8C.—Capacitor and inductor action in a tank circuit.

Since the capacitor is now completely discharged, the magnetic field surrounding the coil starts to collapse. This induces a voltage in the coil which causes the current to continue flowing in the same direction and charges the capacitor again. This time the capacitor charges to the opposite polarity, view (D).

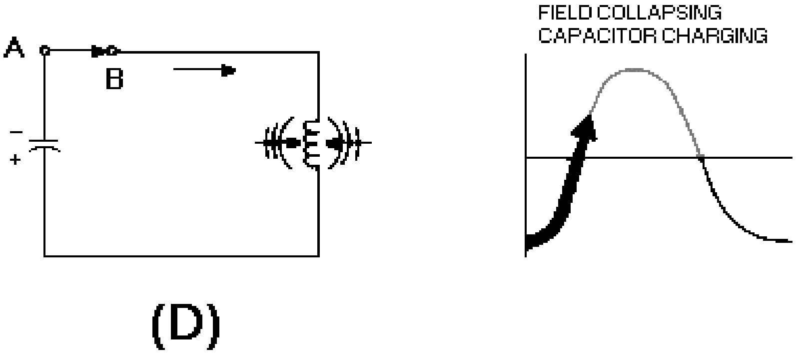


Figure 1-8D.—Capacitor and inductor action in a tank circuit.

In view (E), the magnetic field has completely collapsed, and the capacitor has become charged with the opposite polarity. All of the energy is again stored in the capacitor.

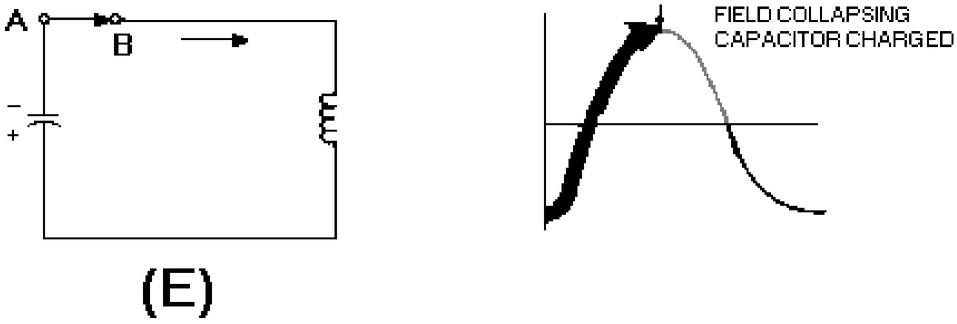


Figure 1-8E.—Capacitor and inductor action in a tank circuit.

In view (F), the capacitor now discharges back through the coil. This discharge current causes the magnetic field to build up again around the coil.

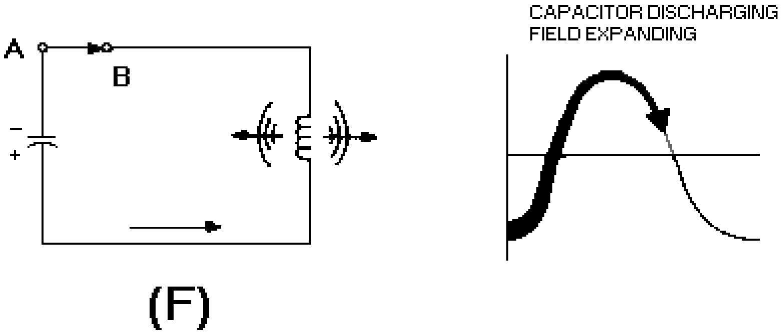


Figure 1-8F.—Capacitor and inductor action in a tank circuit.

In view (G), the capacitor is completely discharged. The magnetic field is again at maximum.

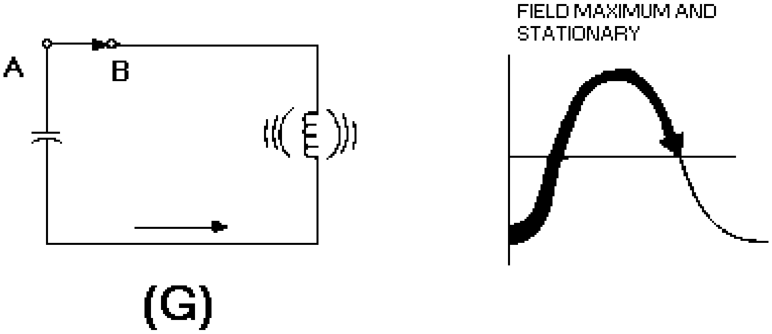


Figure 1-8G.—Capacitor and inductor action in a tank circuit.

In view (H), with the capacitor completely discharged, the magnetic field again starts collapsing. The induced voltage from the coil maintains current flowing toward the upper plate of the capacitor.

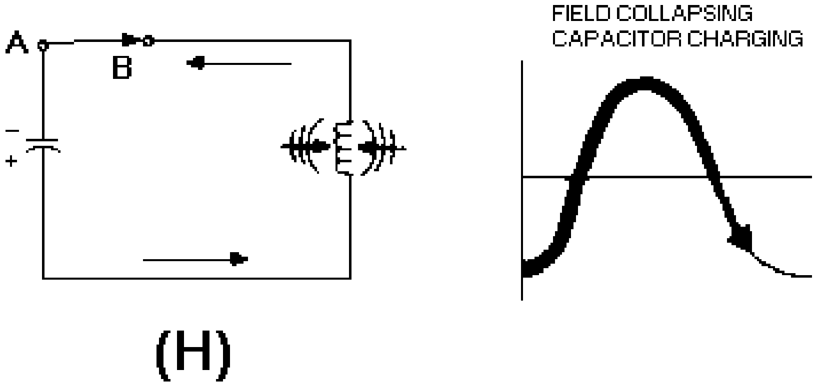


Figure 1-8H.—Capacitor and inductor action in a tank circuit.

In view (I), by the time the magnetic field has completely collapsed, the capacitor is again charged with the same polarity as it had in view (A). The energy is again stored in the capacitor, and the cycle is ready to start again.

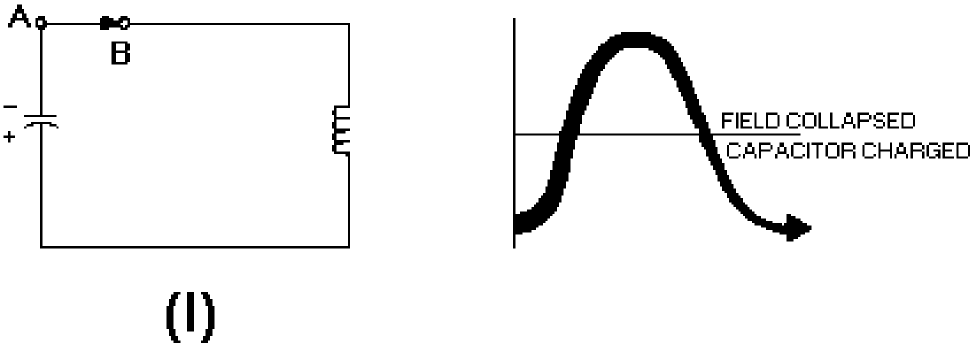


Figure 1-8I.—Capacitor and inductor action in a tank circuit.

The number of times per second that these events in figure 1-8 take place is called NATURAL FREQUENCY or RESONANT FREQUENCY of the circuit. Such a circuit is said to oscillate at its resonant frequency.

It might seem that these oscillations could go on forever. You know better, however, if you apply what you have already learned about electric circuits.

This circuit, as all others, has some resistance. Even the relatively small resistance of the coil and the connecting wires cause energy to be dissipated in the form of heat (I^2R loss). The heat loss in the circuit resistance causes the charge on the capacitor to be less for each subsequent cycle. The result is a DAMPED WAVE, as shown in figure 1-9. The charging and discharging action will continue until all of the energy has been radiated or dissipated as heat.

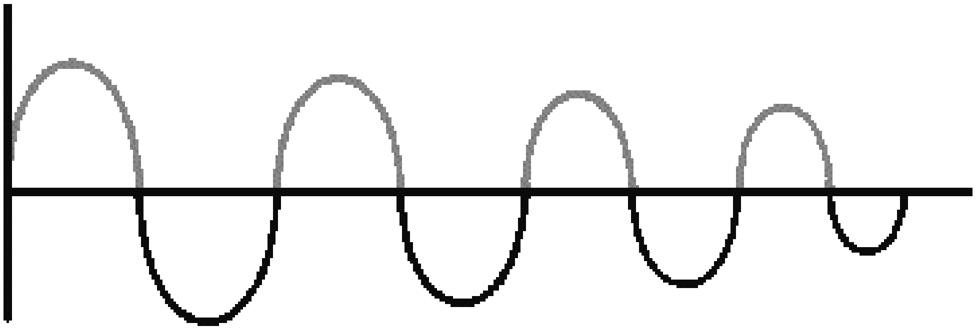


Figure 1-9.—Damped wave.

If it were possible to have a circuit with absolutely no resistance, there would be no heat loss, and the oscillations would tend to continue indefinitely. You have already learned that tuned circuits are designed to have very little resistance. Reducing I^2R losses is still another reason for having low resistance.

A "perfect" tuned circuit would produce the continuous sine wave shown in figure 1-10. Its frequency would be that of the circuit.

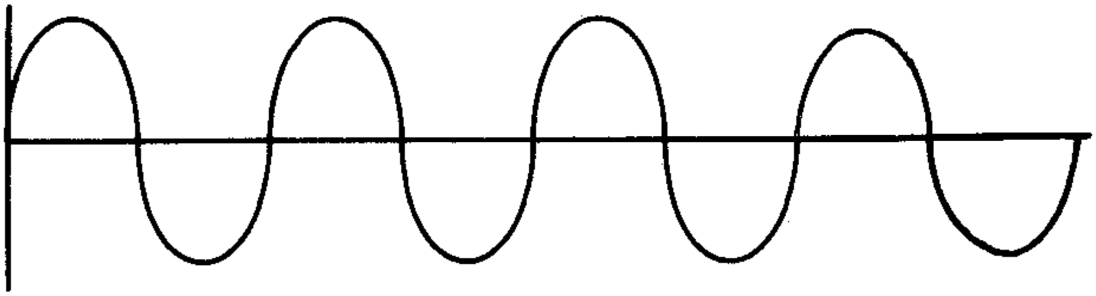


Figure 1-10.—Sine wave-resonant frequency.

Because we don't have perfection, another way of causing a circuit to oscillate indefinitely would be to apply a continuous a.c. or pulsing source to the circuit. If the source is at the resonant frequency of the circuit, the circuit will oscillate as long as the source is applied.

The reasons why the circuit in figure 1-8 oscillates at the resonant frequency have to do with the characteristics of resonant circuits. The discussion of parallel resonance will not be as detailed as that for series resonance because the idea of resonance is the same for both circuits. Certain characteristics differ as a result of L and C being in parallel rather than in series. These differences will be emphasized.

Q-7. When the capacitor is completely discharged, where is the energy of the tank circuit stored?

Q-8. When the magnetic field of the inductor is completely collapsed, where is the energy of the tank circuit stored?

PARALLEL RESONANCE

Much of what you have learned about resonance and series-LC circuits can be applied directly to parallel-LC circuits. The purpose of the two circuits is the same — to select a specific frequency and reject all others. X_L still equals X_C at resonance. Because the inductor and capacitor are in parallel, however, the circuit has the basic characteristics of an a.c. parallel circuit. The parallel hookup causes frequency selection to be accomplished in a different manner. It gives the circuit different characteristics. The first of these characteristics is the ability to store energy.

The Characteristics of a Typical Parallel-Resonant Circuit

Look at figure 1-11. In this circuit, as in other parallel circuits, the voltage is the same across the inductor and capacitor. The currents through the components vary inversely with their reactances in accordance with Ohm's law. The total current drawn by the circuit is the vector sum of the two individual component currents. Finally, these two currents, I_L and I_C, are 180 degrees out of phase because the effects of L and C are opposite. There is not a single fact new to you in the above. It is all based on what you have learned previously about parallel a.c. circuits that contain L and C.

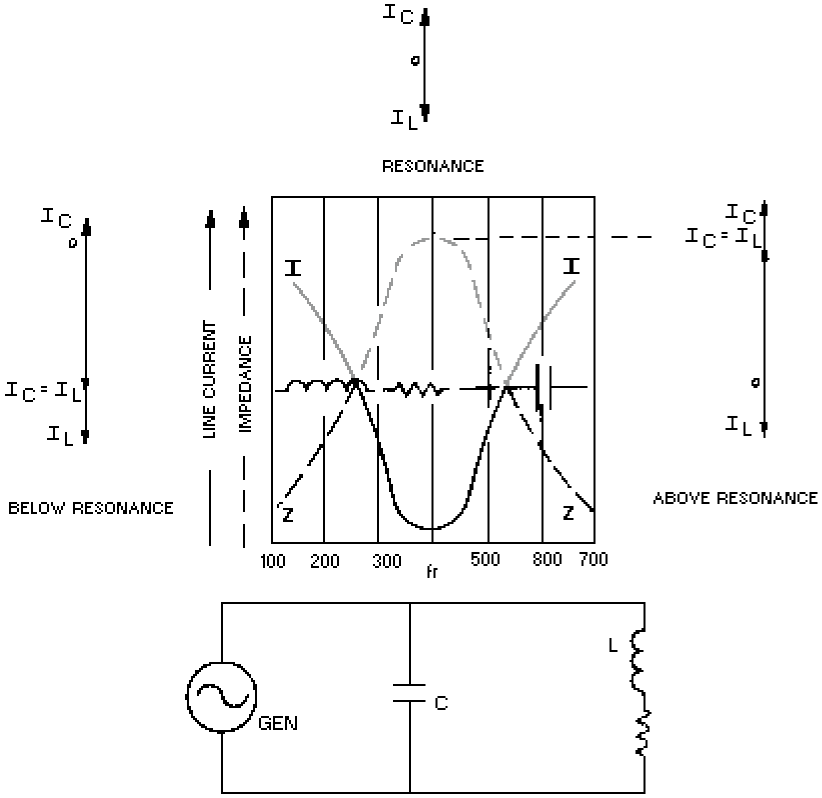


Figure 1-11.—Curves of impedance and current in an RLC parallel-resonant circuit.

Now, at resonance, X_L is still equal to X_C. Therefore, I_L must equal I_C. Remember, the voltage is the same; the reactances are equal; therefore, according to Ohm's law, the currents must be equal. But, don't forget, even though the currents are equal, they are still opposites. That is, if the current is flowing "up" in the capacitor, it is flowing "down" in the coil, and vice versa. In effect, while the one component draws current, the other returns it to the source. The net effect of this "give and take action" is that zero current is drawn from the source at resonance. The two currents yield a total current of zero amperes because they are exactly equal and opposite at resonance.

A circuit that is completed and has a voltage applied, but has zero current, must have an INFINITE IMPEDANCE (apply Ohm's law — any voltage divided by zero yields infinity).

By now you know that we have just ignored our old friend resistance from previous discussions. In an actual circuit, at resonance, the currents will not quite counteract each other because each component will have different resistance. This resistance is kept extremely low, but it is still there. The result is that a relatively small current flows from the source at resonance instead of zero current. Therefore, a basic characteristic of a practical parallel-LC circuit is that, at resonance, the circuit has MAXIMUM impedance which results in MINIMUM current from the source. This current is often called line current. This is shown by the peak of the waveform for impedance and the valley for the line current, both occurring at f_r the frequency of resonance in figure 1-11.

There is little difference between the circuit pulsed by the battery in figure 1-8 that oscillated at its resonant (or natural) frequency, and the circuit we have just discussed. The equal and opposite currents in the two components are the same as the currents that charged and discharged the capacitor through the coil.

For a given source voltage, the current oscillating between the reactive parts will be stronger at the resonant frequency of the circuit than at any other frequency. At frequencies below resonance, capacitive current will decrease; above the resonant frequency, inductive current will decrease. Therefore, the oscillating current (or circulating current, as it is sometimes called), being the lesser of the two reactive currents, will be maximum at resonance.

If you remember, the basic resonant circuit produced a "damped" wave. A steady amplitude wave was produced by giving the circuit energy that would keep it going. To do this, the energy had to be at the same frequency as the resonant frequency of the circuit.

So, if the resonant frequency is "timed" right, then all other frequencies are "out of time" and produce waves that tend to buck each other. Such frequencies cannot produce strong oscillating currents.

In our typical parallel-resonant (LC) circuit, the line current is minimum (because the impedance is maximum). At the same time, the internal oscillating current in the tank is maximum. Oscillating current may be several hundred times as great as line current at resonance.

In any case, this circuit reacts differently to the resonant frequency than it does to all other frequencies. This makes it an effective frequency selector.

Summary of Resonance

Both series- and parallel-LC circuits discriminate between the resonant frequency and all other frequencies by balancing an inductive reactance against an equal capacitive reactance.

In series, these reactances create a very low impedance. In parallel, they create a very high impedance. These characteristics govern how and where designers use resonant circuits. A low-impedance requirement would require a series-resonant circuit. A high-impedance requirement would require the designer to use a parallel-resonant circuit.

Tuning a Band of Frequencies

Our resonant circuits so far have been tuned to a single frequency - the resonant frequency. This is fine if only one frequency is required. However, there are hundreds of stations on many different frequencies.

Therefore, if we go back to our original application, that of tuning to different radio stations, our resonant circuits are not practical. The reason is because a tuner for each frequency would be required and this is not practical.

What is a practical solution to this problem? The answer is simple. Make either the capacitor or the inductor variable. Remember, changing either L or C changes the resonant frequency.

Now you know what has been happening all of these years when you "pushed" the button or "turned" the dial. You have been changing the L or C in the tuned circuits by the amount necessary to adjust the tuner to resonate at the desired frequency. No matter how complex a unit, if it has LC tuners, the tuners obey these basic laws.

Q-9. What is the term for the number of times per second that tank circuit energy is either stored in the inductor or capacitor?

Q-10. In a parallel-resonant circuit, what is the relationship between impedance and current?

Q-11. When is line current minimum in a parallel-LC circuit?

RESONANT CIRCUITS AS FILTER CIRCUITS

The principle of series- or parallel-resonant circuits have many applications in radio, television, communications, and the various other electronic fields throughout the Navy. As you have seen, by making the capacitance or inductance variable, the frequency at which a circuit will resonate can be controlled.

In addition to station selecting or tuning, resonant circuits can separate currents of certain frequencies from those of other frequencies.

Circuits in which resonant circuits are used to do this are called FILTER CIRCUITS.

If we can select the proper values of resistors, inductors, or capacitors, a FILTER NETWORK, or "frequency selector," can be produced which offers little opposition to one frequency, while BLOCKING or ATTENUATING other frequencies. A filter network can also be designed that will "pass" a band of frequencies and "reject" all other frequencies.

Most electronic circuits require the use of filters in one form or another. You have already studied several in modules 6, 7, and 8 of the NEETS.

One example of a filter being applied is in a rectifier circuit. As you know, an alternating voltage is changed by the rectifier to a direct current. However, the d.c. voltage is not pure; it is still pulsating and fluctuating. In other words, the signal still has an a.c. component in addition to the d.c. voltage. By feeding the signal through simple filter networks, the a.c. component is reduced. The remaining d.c. is as pure as the designers require.

Bypass capacitors, which you have already studied, are part of filter networks that, in effect, bypass, or shunt, unwanted a.c. components to ground.

THE IDEA OF "Q"

Several times in this chapter, we have discussed "ideal" or theoretically perfect circuits. In each case, you found that resistance kept our circuits from being perfect. You also found that low resistance in tuners was better than high resistance. Now you will learn about a factor that, in effect, measures just how close to perfect a tuner or tuner component can be. This same factor affects BANDWIDTH and SELECTIVITY. It can be used in figuring voltage across a coil or capacitor in a series-resonant circuit and the amount of circulating (tank) current in a parallel-resonant circuit. This factor is very important and useful to designers. Technicians should have some knowledge of the factor because it affects so many things. The factor is known as Q. Some say it stands for quality (or merit). The higher the Q, the better the circuit; the lower the losses (I^2R), the closer the circuit is to being perfect.

Having studied the first part of this chapter, you should not be surprised to learn that resistance (R) has a great effect on this figure of merit or quality.

Q Is a Ratio

Q is really very simple to understand if you think back to the tuned-circuit principles just covered. Inductance and capacitance are in all tuners. Resistance is an impurity that causes losses. Therefore, components that provide the reactance with a minimum of resistance are "purer" (more perfect) than those with higher resistance. The actual measure of this purity, merit, or quality must include the two basic quantities, X and R.

The ratio

$$\frac{X}{R}$$

does the job for us. Let's take a look at it and see just why it measures quality.

First, if a perfect circuit has zero resistance, then our ratio should give a very high value of Q to reflect the high quality of the circuit. Does it?

Assume any value for X and a zero value for R.

Then:

$$Q = \frac{X}{R} = \frac{\text{Some Value}}{0} = \text{Infinity}$$

Remember, any value divided by zero equals infinity. Thus, our ratio is infinitely high for a theoretically perfect circuit.

With components of higher resistance, the Q is reduced. Dividing by a larger number always yields a smaller quantity. Thus, lower quality components produce a lower Q. Q, then, is a direct and accurate measure of the quality of an LC circuit.

Q is just a ratio. It is always just a number — no units. The higher the number, the "better" the circuit. Later as you get into more practical circuits, you may find that low Q may be desirable to provide certain characteristics. For now, consider that higher is better.

Because capacitors have much, much less resistance in them than inductors, the Q of a circuit is very often expressed as the Q of the coil or:

$$Q = \frac{X_L}{R}$$

The answer you get from using this formula is very near correct for most purposes. Basically, the Q of a capacitor is so high that it does not limit the Q of the circuit in any practical way. For that reason, the technician may ignore it.

The Q of a Coil

Q is a feature that is designed into a coil. When the coil is used within the frequency range for which it is designed, Q is relatively constant. In this sense, it is a physical characteristic.

Inductance is a result of the physical makeup of a coil - number of turns, core, type of winding, etc. Inductance governs reactance at a given frequency. Resistance is inherent in the length, size, and material of the wire. Therefore, the Q of a coil is mostly dependent on physical characteristics.

Values of Q that are in the hundreds are very practical and often found in typical equipment.

Application of Q

For the most part, Q is the concern of designers, not technicians. Therefore, the chances of you having to figure the Q of a coil are remote. However, it is important for you to know some circuit relationships that are affected by Q.

Q Relationships in Series Circuits

Q can be used to determine the "gain" of series-resonant circuits. Gain refers to the fact that at resonance, the voltage drop across the reactances are greater than the applied voltage. Remember, when we applied Ohm's law in a series-resonant circuit, it gave us the following characteristics:

- Low impedance, high current.
- High current; high voltage across the comparatively high reactances.

This high voltage is usable where little power is required, such as in driving the grid of a vacuum tube or the gate of a field effect transistor (F.E.T.). The gain of a properly designed series-resonant circuit may be as great or greater than the amplification within the amplifier itself. The gain is a function of Q, as shown in the following example:

E = the input voltage to the tuned circuit

E_L = the voltage drop across the coil at resonance Q.

Q = the Q of the coil

Then:

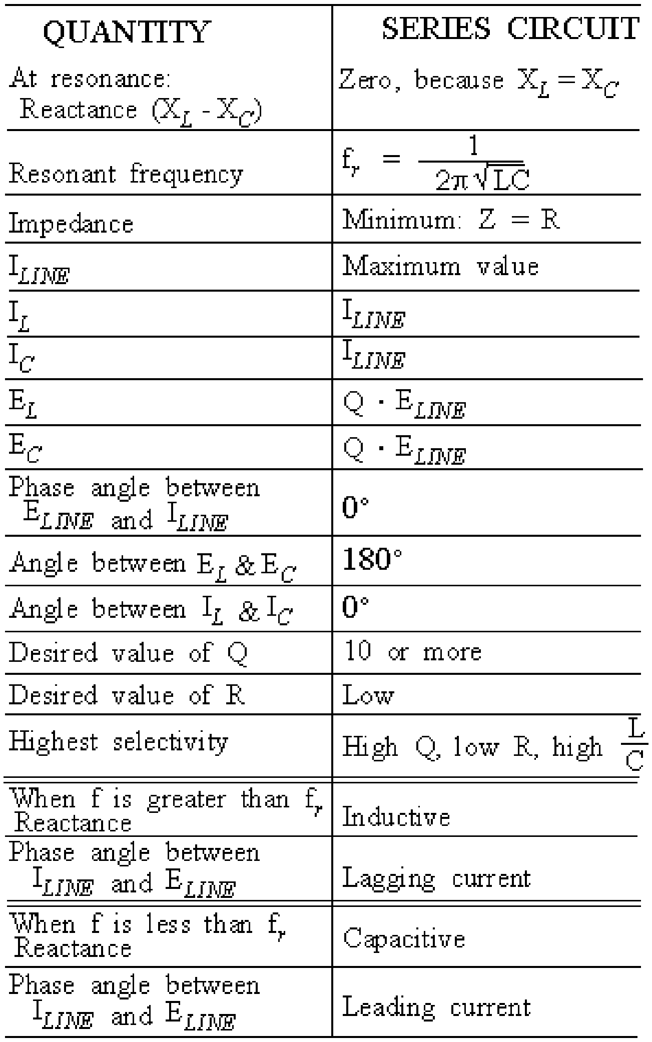
$$E_L = EQ$$

If the Q of the coil were 100, then the gain would be 100; that is, the voltage of the coil would be 100 times that of the input voltage to the series circuit.

Resistance affects the resonance curve of a series circuit in two ways — the lower the resistance, the higher the current; also, the lower the resistance, the sharper the curve. Because low resistance causes high Q, these two facts are usually expressed as functions of Q. That is, the higher the Q, the higher and sharper the curve and the more selective the circuit.

The lower the Q (because of higher resistance), the lower the current curve; therefore, the broader the curve, the less selective the circuit. A summary of the major characteristics of series RLC-circuits at resonance is given in table 1-1.

Table 1-1.—Major Characteristics of Series RLC Circuits at Resonance



QUANTITY	SERIES CIRCUIT
At resonance: Reactance ($X_L - X_C$)	Zero, because $X_L = X_C$
Resonant frequency	$f_r = \frac{1}{2\pi\sqrt{LC}}$
Impedance	Minimum: Z = R
I_{LINE}	Maximum value
I_L	I_{LINE}
I_C	I_{LINE}
E_L	$Q \cdot E_{LINE}$
E_C	$Q \cdot E_{LINE}$
Phase angle between E_{LINE} and I_{LINE}	0°
Angle between E_L & E_C	180°
Angle between I_L & I_C	0°
Desired value of Q	10 or more
Desired value of R	Low
Highest selectivity	High Q, low R, high $\frac{L}{C}$
When f is greater than f_r Reactance	Inductive
Phase angle between I_{LINE} and E_{LINE}	Lagging current
When f is less than f_r Reactance	Capacitive
Phase angle between I_{LINE} and E_{LINE}	Leading current

Q Relationships in a Parallel-Resonant Circuit

There is no voltage gain in a parallel-resonant circuit because voltage is the same across all parts of a parallel circuit. However, Q helps give us a measure of the current that circulates in the tank.

Given:

I_{LINE} = current drawn from the source

I_L = current through the coil (or circulating current)

Q = the Q of the coil

Then:

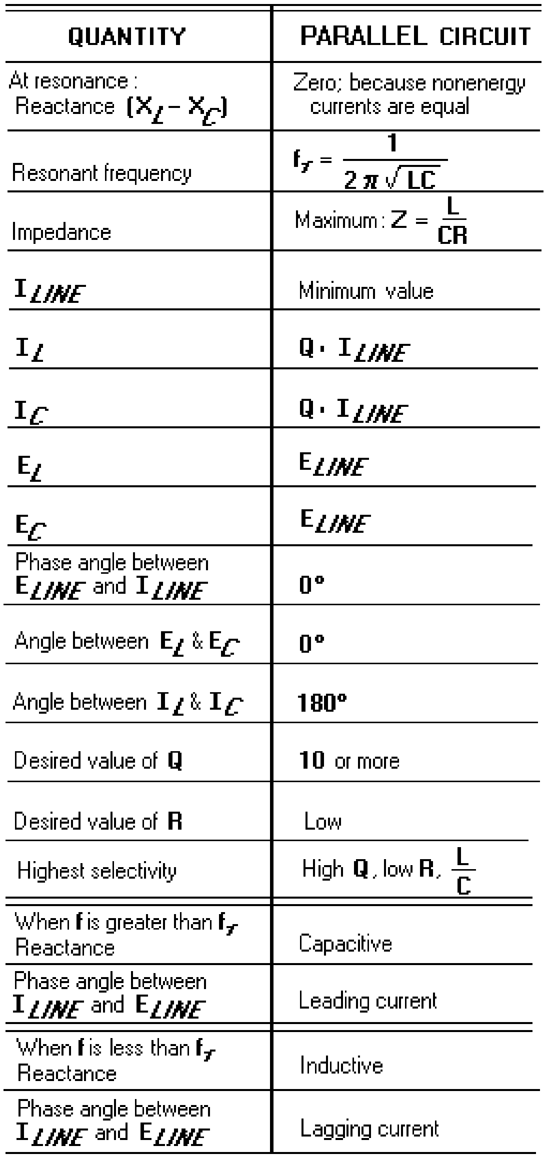
$$I_L = I_{LINE}\ Q$$

Again, if the Q were 100, the circulating current would be 100 times the value of the line current. This may help explain why some of the wire sizes are very large in high-power amplifying circuits.

The impedance curve of a parallel-resonant circuit is also affected by the Q of the circuit in a manner similar to the current curve of a series circuit. The Q of the circuit determines how much the impedance is increased across the parallel-LC circuit. ($Z = Q \times X_L$)

The higher the Q, the greater the impedance at resonance and the sharper the curve. The lower the Q, the lower impedance at resonance; therefore, the broader the curve, the less selective the circuit. The major characteristics of parallel-RLC circuits at resonance are given in table 1-2.

Table 1-2.—Major Characteristics of Parallel RLC Circuits at



QUANTITY	PARALLEL CIRCUIT
At resonance : Reactance $(X_L - X_C)$	Zero; because nonenergy currents are equal
Resonant frequency	$f_r = \frac{1}{2\pi\sqrt{LC}}$
Impedance	Maximum : $Z = \frac{L}{CR}$
I_{LINE}	Minimum value
I_L	$Q \cdot I_{LINE}$
I_C	$Q \cdot I_{LINE}$
E_L	E_{LINE}
E_C	E_{LINE}
Phase angle between E_{LINE} and I_{LINE}	0°
Angle between E_L & E_C	0°
Angle between I_L & I_C	180°
Desired value of **Q**	**10** or more
Desired value of **R**	Low
Highest selectivity	High **Q**, low **R**, $\frac{L}{C}$
When **f** is greater than f_r Reactance	Capacitive
Phase angle between I_{LINE} and E_{LINE}	Leading current
When **f** is less than f_r Reactance	Inductive
Phase angle between I_{LINE} and E_{LINE}	Lagging current

Resonance

Summary of Q

The ratio that is called Q is a measure of the quality of resonant circuits and circuit components. Basically, the value of Q is an inverse function of electrical power dissipated through circuit resistance. Q is the ratio of the power stored in the reactive components to the power dissipated in the resistance. That is, high power loss is low Q; low power loss is high Q.

Circuit designers provide the proper Q. As a technician, you should know what can change Q and what quantities in a circuit are affected by such a change.

BANDWIDTH

If circuit Q is low, the gain of the circuit at resonance is relatively small. The circuit does not discriminate sharply (reject the unwanted frequencies) between the resonant frequency and the frequencies on either side of resonance, as shown by the curve in figure 1-12, view (A). The range of frequencies included between the two frequencies (426.4 kHz and 483.6 kHz in this example) at which the current drops to 70 percent of its maximum value at resonance is called the BANDWIDTH of the circuit.

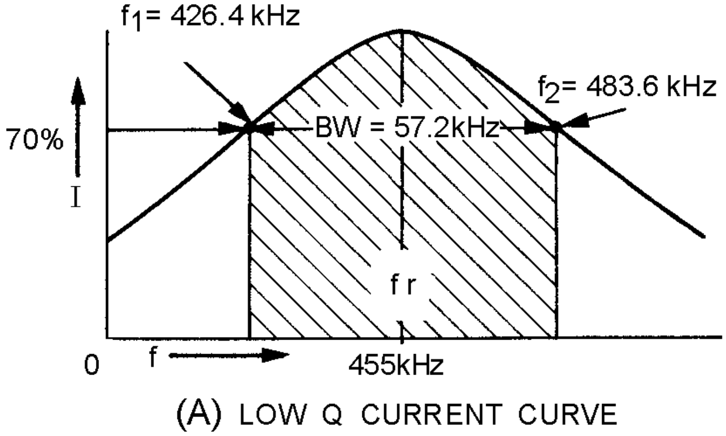


Figure 1-12A.—Bandwidth for high- and low-Q series circuit. LOW Q CURRENT CURVE.

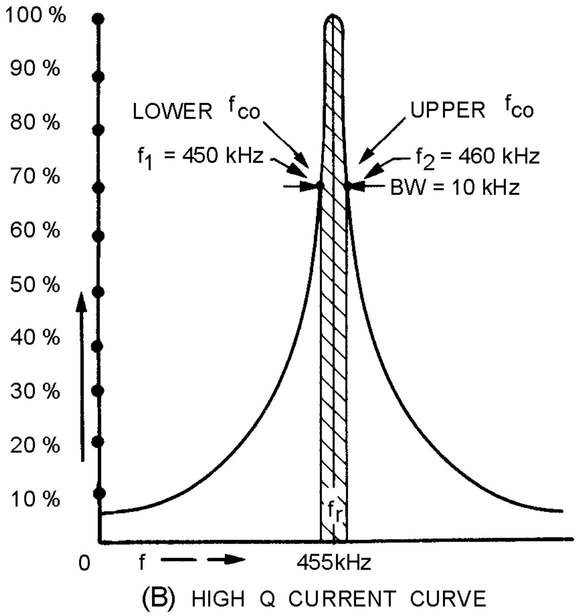


Figure 1-12B.—Bandwidth for high- and low-Q series circuit. HIGH Q CURRENT CURVE.

It is often necessary to state the band of frequencies that a circuit will pass. The following standard has been set up: the limiting frequencies are those at either side of resonance at which the curve falls to a point of .707 (approximately 70 percent) of the maximum value. This point is called the HALF-POWER point. Note that in figure 1-12, the series-resonant circuit has two half-power points, one above and one below the resonant frequency point. The two points are designated upper frequency cutoff (f_{co}) and lower frequency cutoff (f_{co}) or simply f_1 and f_2. The range of frequencies between these two points comprises the bandwidth. Views (A) and (B) of figure 1-12 illustrate the bandwidths for low- and high-Q resonant circuits. The bandwidth may be determined by use of the following formulas:

$$BW = \frac{f_r}{Q}$$

or

$$BW = f_2 - f_1$$

Where:

BW = bandwidth of a circuit in units of frequency

f_r = resonant frequency

f_2 = the upper cutoff frequency

f_1 = the lower cutoff frequency

For example, by applying the formula we can determine the bandwidth for the curve shown in figure 1-12, view (A).

Solution:

$$BW = f_2 - f_1$$

$$BW = 483.6\text{ kHz} - 426.4\text{ kHz}$$

$$BW = 57.2\text{ kHz}$$

If the Q of the circuit represented by the curve in figure 1-12, view (B), is 45.5, what would be the bandwidth?

Solution:

$$BW = \frac{f_r}{Q}$$

$$BW = \frac{455\text{ kHz}}{45.5}$$

$$BW = 10\text{ kHz}$$

If Q equals 7.95 for the low-Q circuit as in view (A) of figure 1-12, we can check our original calculation of the bandwidth.

Solution:

$$BW = \frac{f_r}{Q}$$

$$BW = \frac{455\text{ kHz}}{7.95}$$

$$BW = 57.2\text{ kHz}$$

The Q of the circuit can be determined by transposing the formula for bandwidth to:

$$Q = \frac{f_r}{BW}$$

To find the Q of the circuit using the information found in the last example problem:

Given:

$$f_r = 455\text{ kHz}$$

$$BW = 57.2\text{ kHz}$$

Solution:

$$Q = \frac{f_r}{BW}$$

$$Q = \frac{455\text{ kHz}}{57.2\text{ kHz}}$$

$$Q = 7.95$$

Q-12. What is the relationship of the coil to the resistance of a circuit with high "Q"?

Q-13. What is the band of frequencies called that is included between the two points at which current falls to 70 percent of its maximum value in a resonant circuit?

FILTERS

In many practical applications of complex circuits, various combinations of direct, low-frequency, audio-frequency, and radio-frequency currents may exist. It is frequently necessary to have a means for separating these component currents at any desired point. An electrical device for accomplishing this separation is called a FILTER.

A filter circuit consists of inductance, capacitance, and resistance used singularly or in combination, depending upon the purpose. It may be designed so that it will separate alternating current from direct current, or so that it will separate alternating current of one frequency (or a band of frequencies) from other alternating currents of different frequencies.

The use of resistance by itself in filter circuits does not provide any filtering action, because it opposes the flow of any current regardless of its frequency. What it does, when connected in series or parallel with an inductor or capacitor, is to decrease the "sharpness," or selectivity, of the filter. Hence, in some particular application, resistance might be used in conjunction with inductance or capacitance to provide filtering action over a wider band of frequencies.

Filter circuits may be divided into four general types: LOW-PASS, HIGH-PASS, BANDPASS, AND BAND-REJECT filters.

Electronic circuits often have currents of different frequencies. The reason is that a source produces current with the same frequency as the applied voltage. As an example, the a.c. signal input to an audio amplifier can have high- and low-audio frequencies; the input to an rf amplifier can have a wide range of radio frequencies.

In such applications where the current has different frequency components, it is usually necessary for the filter either to accept or reject one frequency or a group of frequencies. The electronic filter that can pass on the higher-frequency components to a load or to the next circuit is known as a HIGH-PASS filter. A LOW-PASS filter can be used to pass on lower-frequency components.

Before discussing filters further, we will review and apply some basic principles of the frequency-response characteristics of the capacitor and the inductor. Recall the basic formula for capacitive reactance and inductive reactance:

$$X_C = \frac{1}{2\pi fC}$$

and

$$X_L = 2\pi fL$$

Assume any given value of L and C. If we increase the applied frequency, X_C decreases and X_L increases. If we increase the frequency enough, the capacitor acts as a short and the inductor acts as an open. Of course, the opposite is also true. Decreasing frequency causes X_C to increase and X_L to decrease. Here again, if we make a large enough change, X_C acts as an open and X_L acts as a short. Figure 1-13 gives a pictorial representation of these two basic components and how they respond to low and high frequencies.

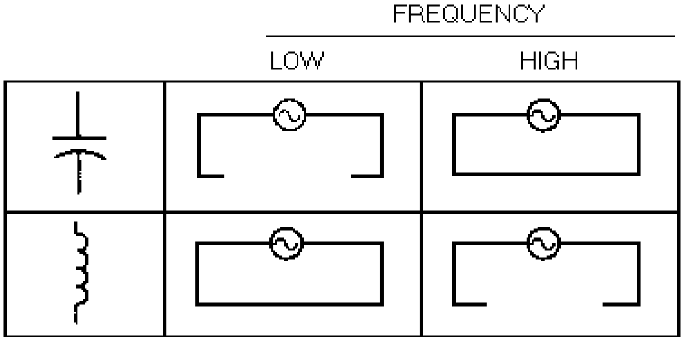


Figure 1-13.—Effect of frequency on capacitive and inductive reactance.

If we apply these same principles to simple circuits, such as the ones in figure 1-14, they affect input signals as shown. For example, in view (A) of the figure, a low frequency is blocked by the capacitor which acts as an open and at a high frequency the capacitor acts as a short. By studying the figure, it is easy to see how the various components will react in different configurations with a change in frequency.

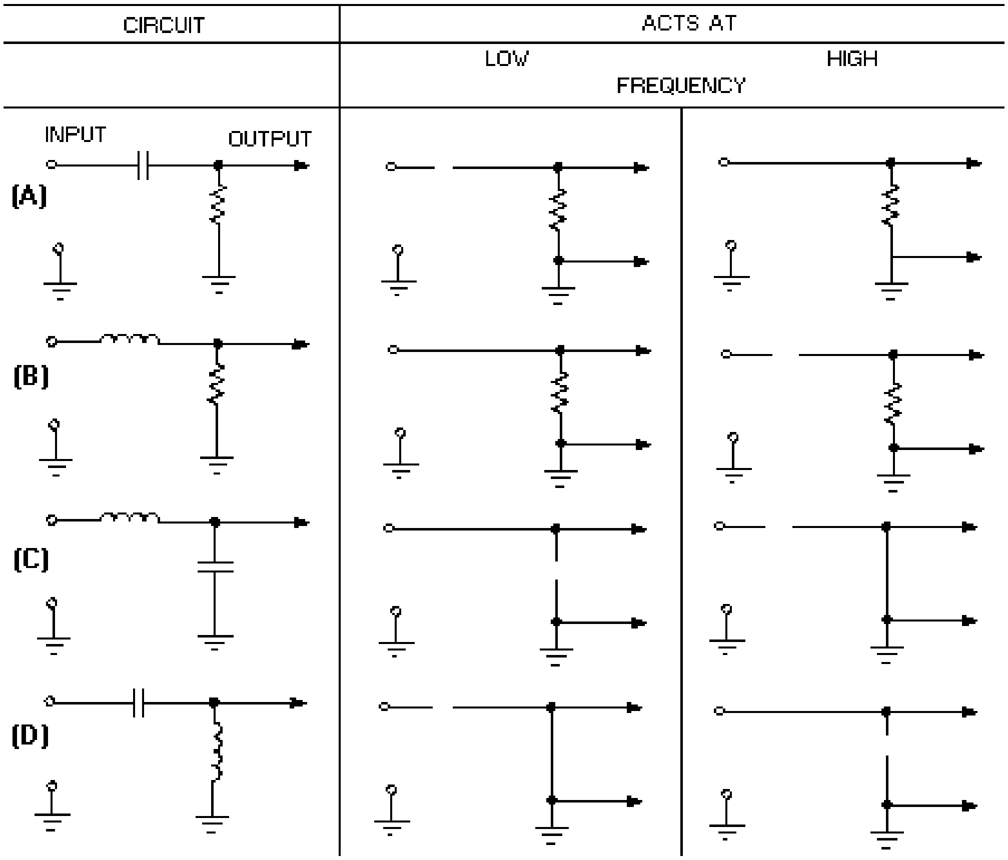


Figure 1-14.—Reaction to circuit by change in frequency.

As mentioned before, high-pass and low-pass filters pass the specific frequencies for which circuits are designed.

There can be a great deal of confusion when talking about high-pass, low-pass, discrimination, attenuation, and frequency cutoff, unless the terms are clearly understood. Since these terms are used widely throughout electronics texts and references, you should have a clear understanding before proceeding further.

- HIGH-PASS FILTER. A high-pass filter passes on a majority of the high frequencies to the next circuit and rejects or attenuates the lower frequencies. Sometimes it is called a low-frequency discriminator or low-frequency attenuator.
- LOW-PASS FILTER. A low-pass filter passes on a majority of the low frequencies to the next circuit and rejects or attenuates the higher frequencies. Sometimes it is called a high-frequency discriminator or high-frequency attenuator.

- DISCRIMINATION. The ability of the filter circuit to distinguish between high and low frequencies and to eliminate or reject the unwanted frequencies.

- ATTENUATION. The ability of the filter circuit to reduce the amplitude of the unwanted frequencies below the level of the desired output frequency.

- FREQUENCY CUTOFF (f_{co}). The frequency at which the filter circuit changes from the point of rejecting the unwanted frequencies to the point of passing the desired frequency; OR the point at which the filter circuit changes from the point of passing the desired frequency to the point of rejecting the undesired frequencies.

LOW-PASS FILTER

A low-pass filter passes all currents having a frequency below a specified frequency, while opposing all currents having a frequency above this specified frequency. This action is illustrated in its ideal form in view (A) of figure 1-15. At frequency cutoff, known as f_c the current decreases from maximum to zero. At all frequencies above f_c the filter presents infinite opposition and there is no current. However, this sharp division between no opposition and full opposition is impossible to attain. A more practical graph of the current is shown in view (B), where the filter gradually builds up opposition as the cutoff frequency (f) is approached. Notice that the filter cannot completely block current above the cutoff frequency.

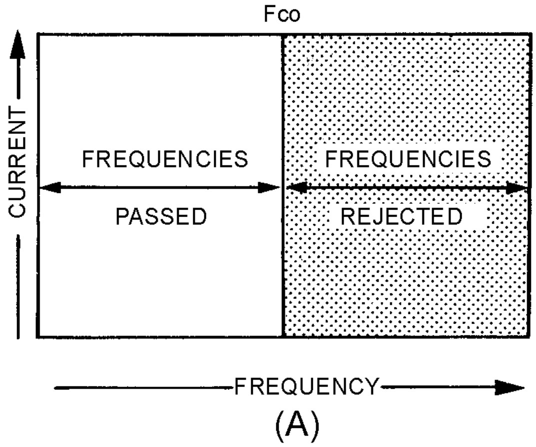


Figure 1-15A.—Low-pass filter.

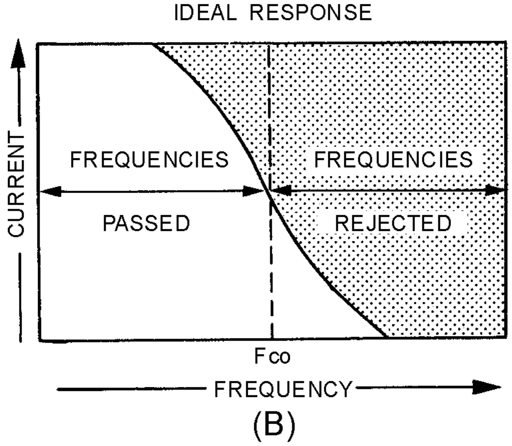


Figure 1-15B.—Low-pass filter.

View (A) of figure 1-16 shows the electrical construction of a low-pass filter with an inductor inserted in series with one side of a line carrying both low and high frequencies. The opposition offered by the reactance will be small at the lower frequencies and great at the higher frequencies. In order to divert the undesired high frequencies back to the source, a capacitor must be added across the line to bypass the higher frequencies around the load, as shown in view (B).

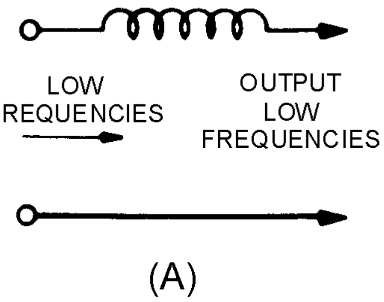


Figure 1-16A.—Components of a simple low-pass filter.

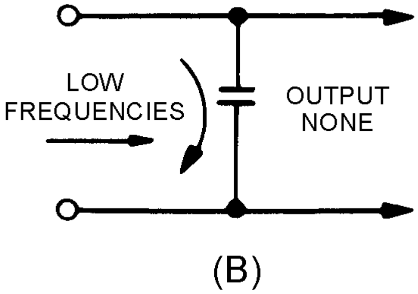


Figure 1-16B.—Components of a simple low-pass filter.

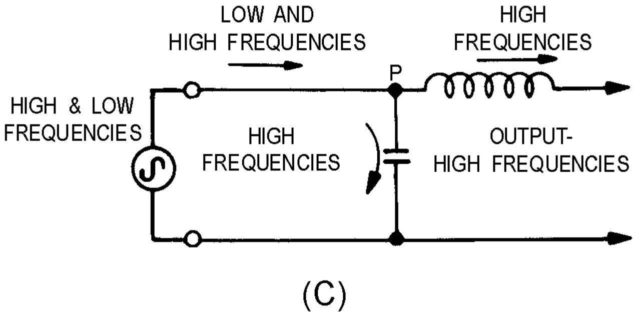


Figure 1-16C.—Components of a simple low-pass filter.

The capacitance of the capacitor must be such that its reactance will offer little opposition to frequencies above a definite value, and great opposition to frequencies below this value. By combining the series inductance and bypass capacitance, as shown in view (C), the simplest type of low-pass filter is obtained. At point P, a much higher opposition is offered to the low frequencies by the capacitor than by the inductor, and most of the low-frequency current takes the path of least opposition. On the other hand, the least amount of opposition is offered to the high frequencies by the capacitor, and most of the high-frequency energy returns to the source through the capacitor.

HIGH-PASS FILTER

A high-pass filter circuit passes all currents having a frequency higher than a specified frequency, while opposing all currents having a frequency lower than its specified frequency. This is illustrated in figure 1-17. A capacitor that is used in series with the source of both high and low frequencies, as shown in view (A) of figure 1-18, will respond differently to high-frequency, low-frequency, and direct currents. It will offer little opposition to the passage of high-frequency currents, great opposition to the passage of low-frequency currents, and completely block direct currents. The value of the capacitor must be chosen so that it allows the passage of all currents having frequencies above the desired value, and opposes those having frequencies below the desired value. Then, in order to shunt the undesired low-frequency currents back to the source, an inductor is used, as shown in view (B). This inductor must have a value that will allow it to pass currents having frequencies below the frequency cutoff point, and reject currents having frequencies above the frequency cutoff point, thus forcing them to pass through the capacitor. By combining inductance and capacitance, as shown in view (C), you obtain the simplest type of high-pass filter. At point P most of the high-frequency energy is passed on to the load by the capacitor, and most of the low-frequency energy is shunted back to the source through the inductor.

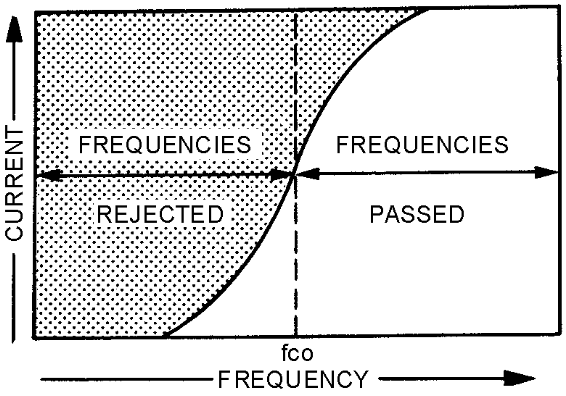


Figure 1-17.—High-pass filter response curve.

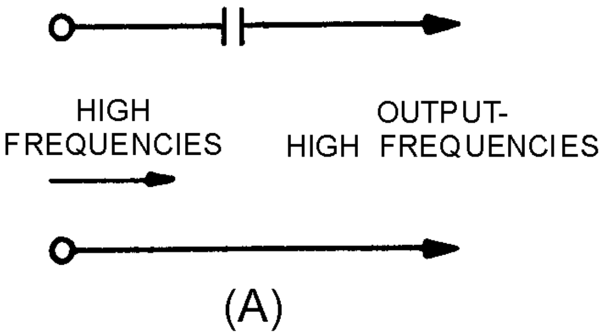


Figure 1-18A.—Components of a simple high-pass filter.

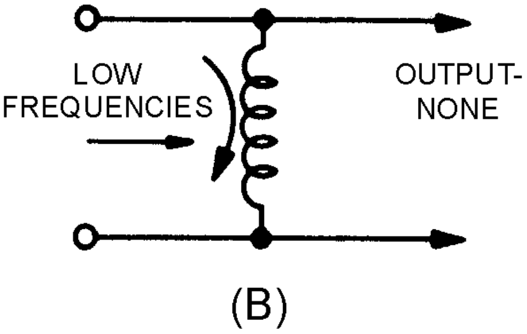


Figure 1-18B.—Components of a simple high-pass filter.

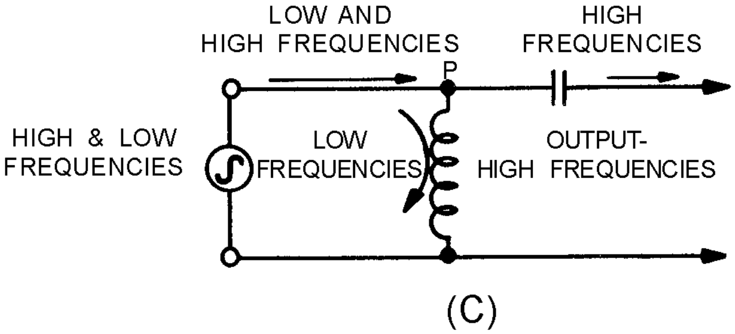


Figure 1-18C.—Components of a simple high-pass filter.

RESONANT CIRCUITS AS FILTERS

Resonant circuits can be made to serve as filters in a manner similar to the action of individual capacitors and inductors. As you know, the series-LC circuit offers minimum opposition to currents that have frequencies at or near the resonant frequency, and maximum opposition to currents of all other frequencies.

You also know that a parallel-LC circuit offers a very high impedance to currents that have frequencies at or near the resonant frequency, and a relatively low impedance to currents of all other frequencies.

If you use these two basic concepts, the BANDPASS and BAND-REJECT filters can be constructed. The bandpass filter and the band-reject filter are two common types of filters that use resonant circuits.

Bandpass Filter

A bandpass filter passes a narrow band of frequencies through a circuit and attenuates all other frequencies that are higher or lower than the desired band of frequencies. This is shown in figure 1-19 where the greatest current exists at the center frequency (f_r). Frequencies below resonance (f_1) and frequencies above resonance (f_2) drop off rapidly and are rejected.

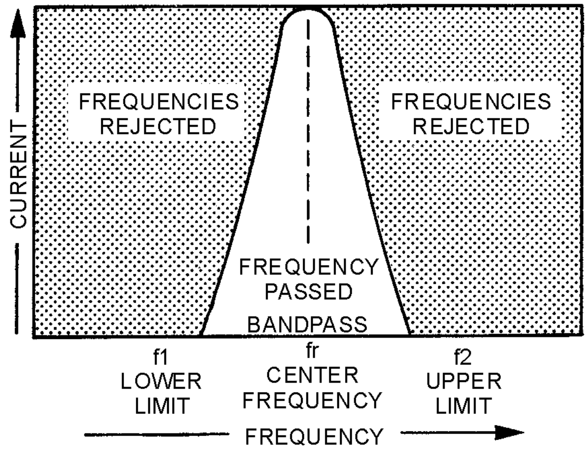


Figure 1-19.—Bandpass filter response curve.

In the circuit of figure 1-20, view (A), the series-LC circuit replaces the inductor of figure 1-16, view (A), and acts as a BANDPASS filter. It passes currents having frequencies at or near its resonant frequency, and opposes the passage of all currents having frequencies outside this band.

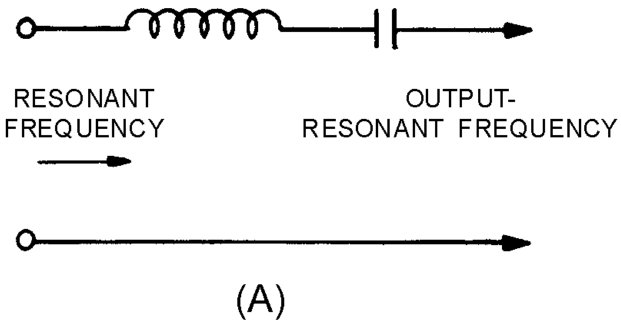


Figure 1-20A.—Components of a simple bandpass filter.

Thus, in the circuit of figure 1-20, view (B), the parallel-LC circuit replaces the capacitor of figure 1-16, view (B). If this circuit is tuned to the same frequency as the series-LC circuit, it will provide a path for all currents having frequencies outside the limits of the frequency band passed by the series-resonant circuit. The simplest type of bandpass filter is formed by connecting the two LC circuits as shown in figure 1-20, view (C). The upper and lower frequency limits of the filter action are filter cutoff points.

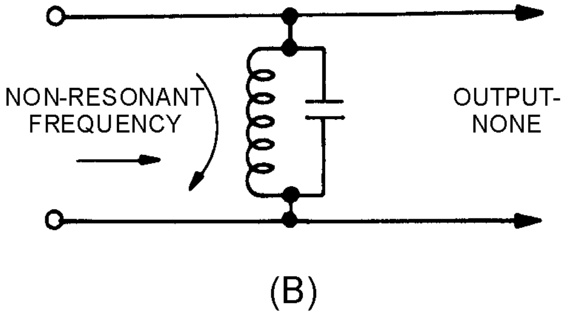


Figure 1-20B.—Components of a simple bandpass filter.

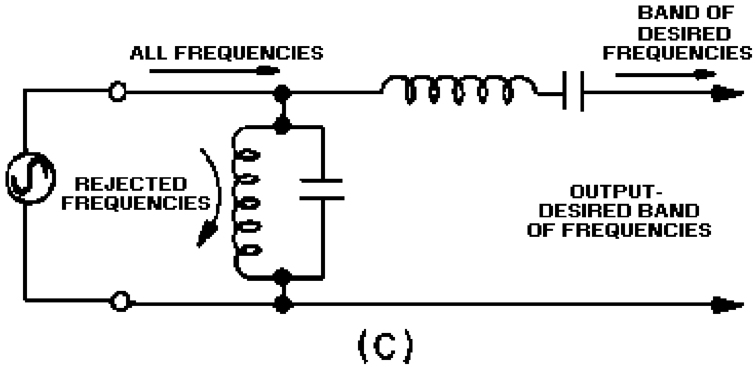


Figure 1-20C.—Components of a simple bandpass filter.

Band-Reject Filter

A band-reject filter circuit is used to block the passage of current for a narrow band of frequencies, while allowing current to flow at all frequencies above or below this band. This type of filter is also known as a BAND-SUPPRESSION or BAND-STOP filter. The way it responds is shown by the response curve of figure 1-21. Since the purpose of the band-reject filter is directly opposite to that of a bandpass filter, the relative positions of the resonant circuits in the filter are interchanged. The parallel-LC circuit shown in figure 1-22, view (A), replaces the capacitor of figure 1-18, view (A). It acts as a band-reject filter, blocking the passage of currents having frequencies at or near resonant frequency and passing all currents having frequencies outside this band. The series-LC circuit shown in figure 1-22, view (B), replaces the inductor of figure 1-18, view (B). If this series circuit is tuned, to the same frequency as the parallel circuit, it acts as a bypass for the band of rejected frequencies. Then, the simplest type of band-reject filter is obtained by connecting the two circuits as shown in figure 1-22, view (C).

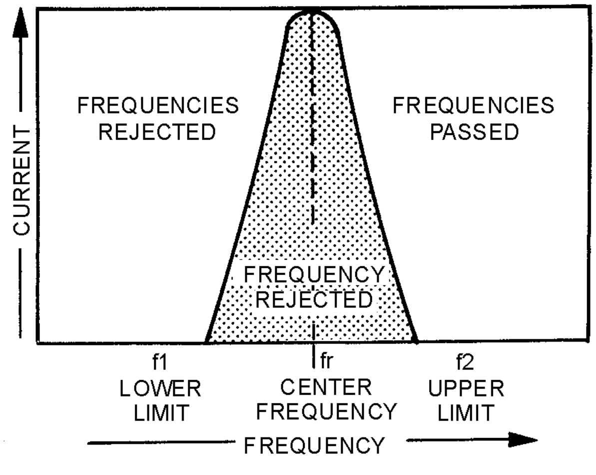


Figure 1-21.—Band-reject filter response curve.

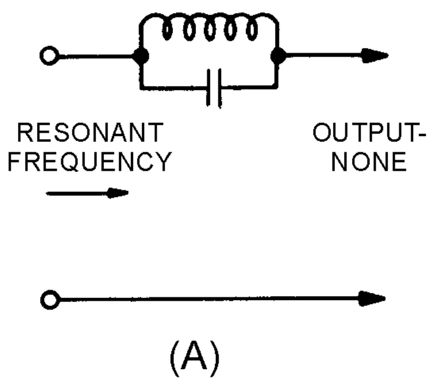


Figure 1-22A.—Components of a simple band-reject filter.

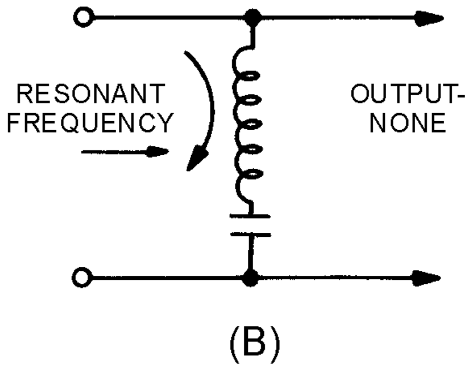


Figure 1-22B.—Components of a simple band-reject filter.

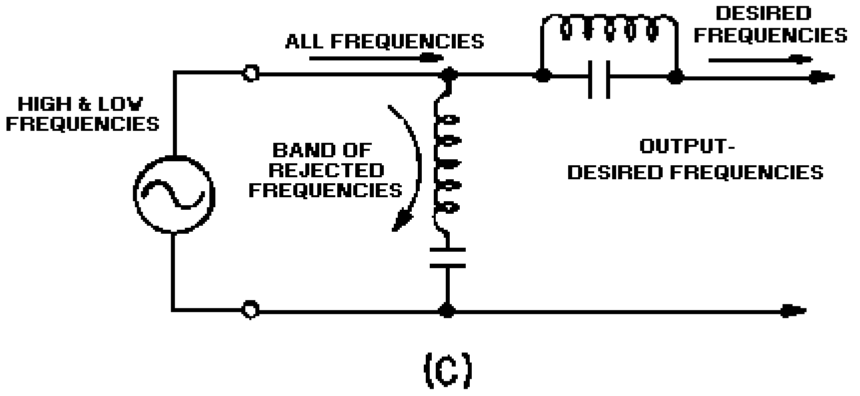


Figure 1-22C.—Components of a simple band-reject filter.

Q-14. What is the device called that will separate alternating current from direct current, or that will separate alternating current of one frequency from other alternating currents of different frequencies?

Q-15. What are the four general types of filters?

Q-16. What is the filter called in which the low frequencies do not produce a useful voltage?

Q-17. What is the filter called that passes low frequencies but rejects or attenuates high frequencies?

Q-18. How does a capacitor and an inductor react to (a) low frequency and (b) high frequency?

Q-19. What term is used to describe the frequency at which the filter circuit changes from the point of rejecting the unwanted frequencies to the point of passing the desired frequencies?

Q-20. What type filter is used to allow a narrow band of frequencies to pass through a circuit and attenuate all other frequencies above or below the desired band?

Q-21. What type filter is used to block the passage of current for a narrow band of frequencies, while allowing current to flow at all frequencies above or below this band?

MULTISECTION FILTERS

All of the various types of filters we have discussed so far have had only one section. In many cases, the use of such simple filter circuits does not provide sufficiently sharp cutoff points. But by adding a capacitor, an inductor, or a resonant circuit in series or in parallel (depending upon the type of filter action required), the ideal effect is more nearly approached. When such additional units are added to a filter circuit, the form of the resulting circuit will resemble the letter T, or the Greek letter π (pi). They are, therefore, called T- or π-type filters, depending upon which symbol they resemble. Two or more T- or π–type filters may be connected together to produce a still sharper cutoff point.

Figure 1-23, (view A) (view B) and (view C), and figure 1-24, (view A) (view B) and (view C) depict some of the common configurations of the T- and π-type filters. Further discussion about the theory of operation of these circuits is beyond the intended scope of this module. If you are interested in learning more about filters, a good source of information to study is the *Electronics Installation and Maintenance Handbook* (EIMB), section 4 (Electronics Circuits), NAVSEA 0967-LP-000-0120.

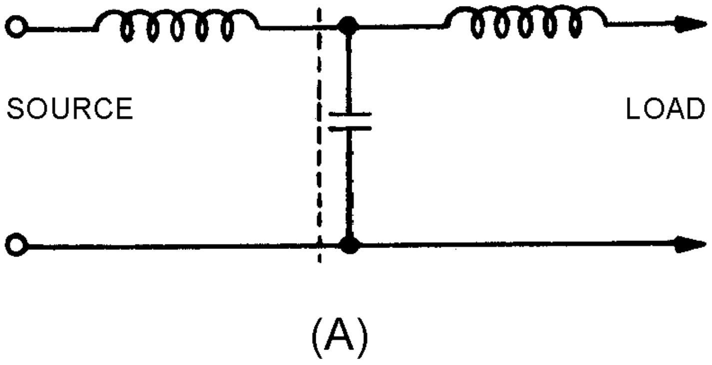


Figure 1-23A.—Formation of a T-type filter.

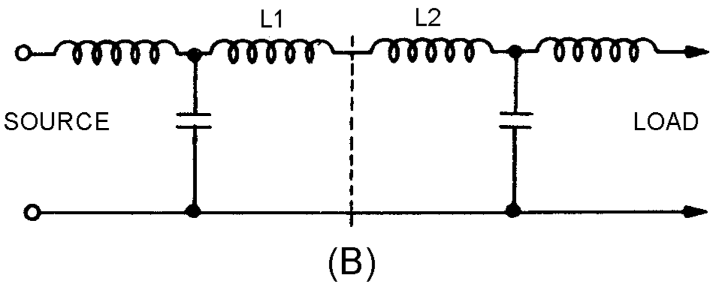


Figure 1-23B.—Formation of a T-type filter.

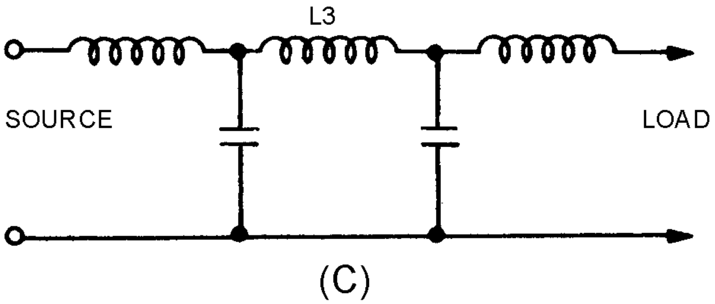


Figure 1-23C.—Formation of a T-type filter.

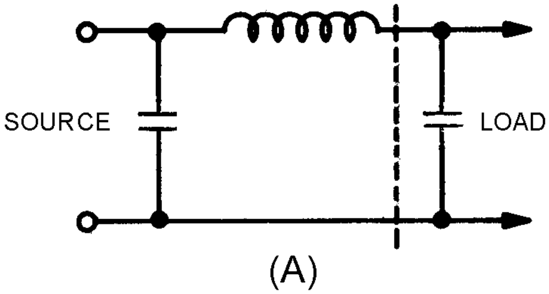


Figure 1-24A.—Formation of a π-type filter.

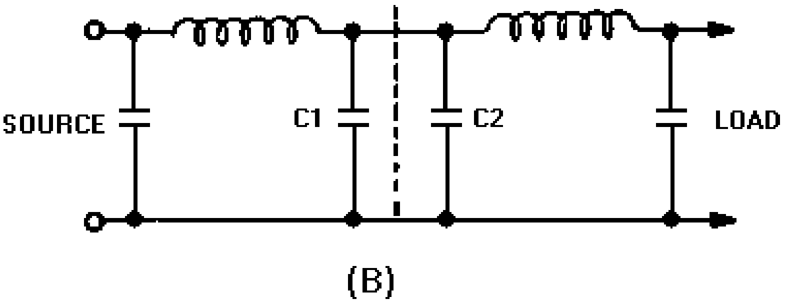


Figure 1-24B.—Formation of a π-type filter.

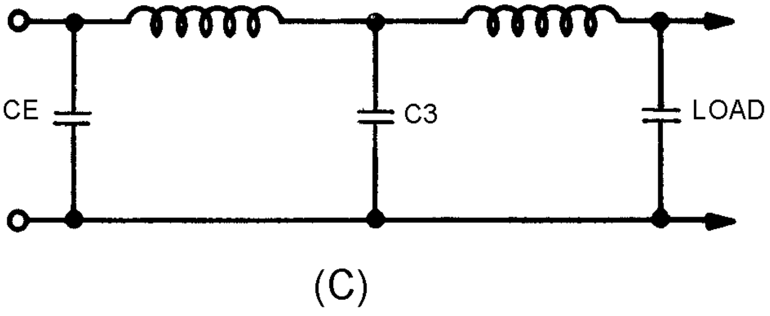


Figure 1-24C.—Formation of a π-type filter.

SAFETY PRECAUTIONS

When working with resonant circuits, or electrical circuits, you must be aware of the potentially high voltages. Look at figure 1-25. With the series circuit at resonance, the total impedance of the circuit is 5 ohms.

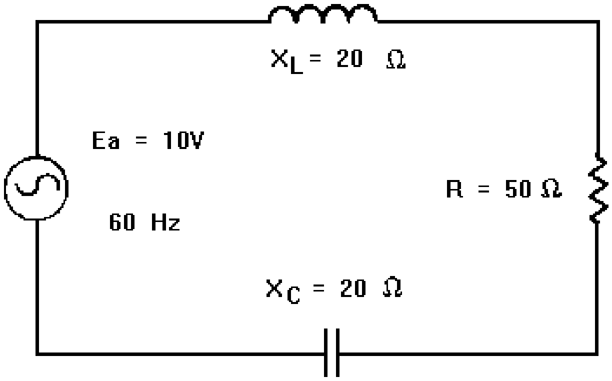


Figure 1-25.—Series RLC circuit at resonance.

Remember, the impedance of a series-RLC circuit at resonance depends on the resistive element. At resonance, the impedance (Z) equals the resistance (R). Resistance is minimum and current is maximum. Therefore, the current at resonance is:

$$I_T = \frac{E_a}{Z} = \frac{10\ V}{5\Omega} = 2\ A$$

The voltage drops around the circuit with 2 amperes of current flow are:

$$E_C = I_T \times X_C$$

$$E_C = 2 \times 20$$

$$E_C = 40 \text{ volts a.c.}$$

$$E_L = I_T \times X_L$$

$E_L = 2 \times 20$

$E_L = 40$ volts a.c.

$E_R = I_T \times R$

$E_R = 2 \times 5$

$E_R = 10$ volts a.c.

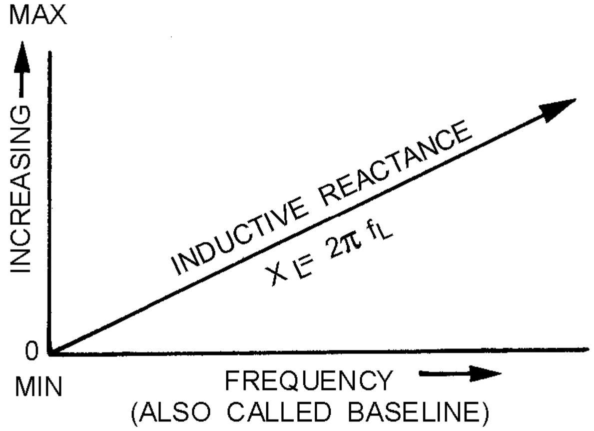
You can see that there is a voltage gain across the reactive components at resonance.

If the frequency was such that X_L and X_C were equal to 1000 ohms at the resonant frequency, the reactance voltage across the inductor or capacitor would increase to 2000 volts a.c. with 10 volts a.c. applied. Be aware that potentially high voltage can exist in series-resonant circuits.

SUMMARY

This chapter introduced you to the principles of tuned circuits. The following is a summary of the major subjects of this chapter.

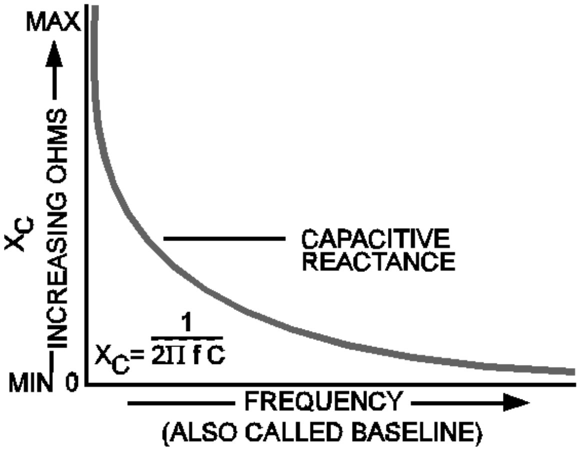
THE **EFFECT OF FREQUENCY** on an **INDUCTOR** is such that an increase in frequency will cause an increase in inductive reactance. Remember that $X_L = 2\pi fL$; therefore, X_L varies directly with frequency.



THE **EFFECT OF FREQUENCY** on a **CAPACITOR** is such that an increase in frequency will cause a decrease in capacitive reactance. Remember that

$$X_C = \frac{1}{2\pi fC}$$

therefore, the relationship between X_C and frequency is that X_C varies inversely with frequency.

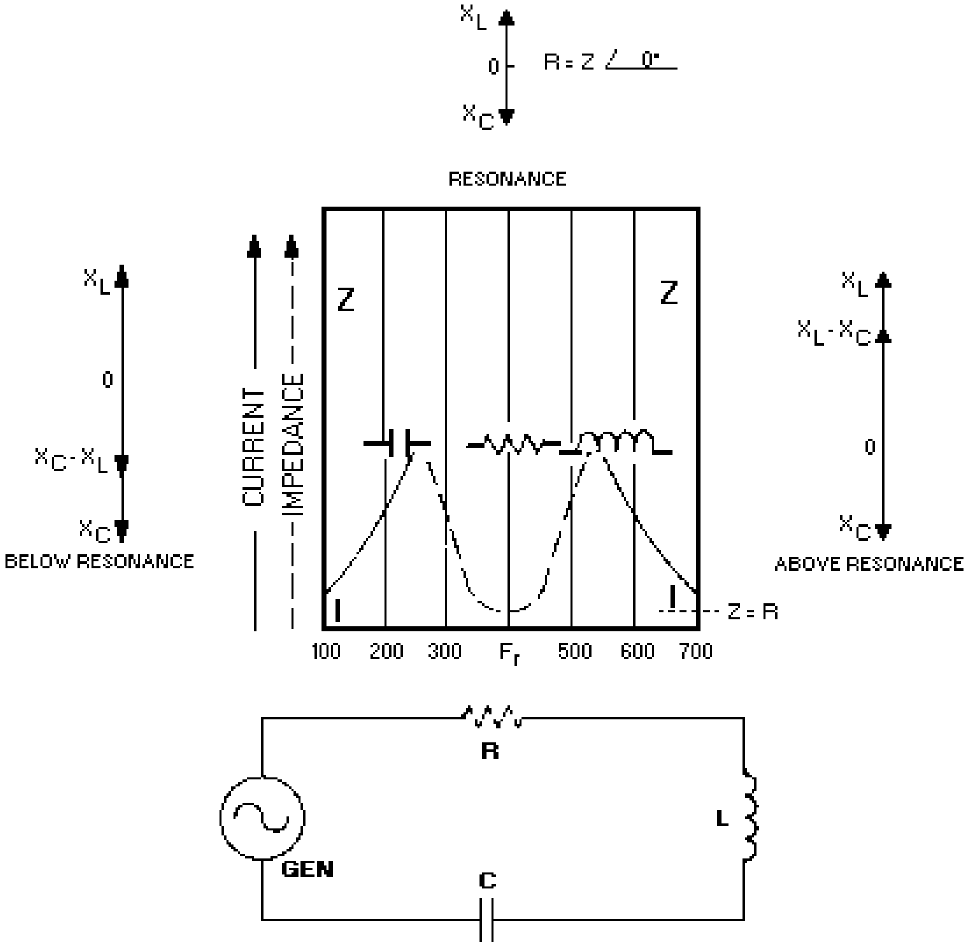


RESULTANT REACTANCE $X = (X_L - X_C)$ or $X = (X_C - X_L)$. X_L is usually plotted above the reference line and X_C below the reference line. Inductance and capacitance have opposite effects on the current in respect to the voltage in a.c. circuits. Below resonance, X_C is larger than X_L, and the series circuit appears capacitive. Above resonance, X_L is larger than X_C, and the series circuit appears inductive. At resonance, $X_L = X_C$, and the total impedance of the circuit is resistive.

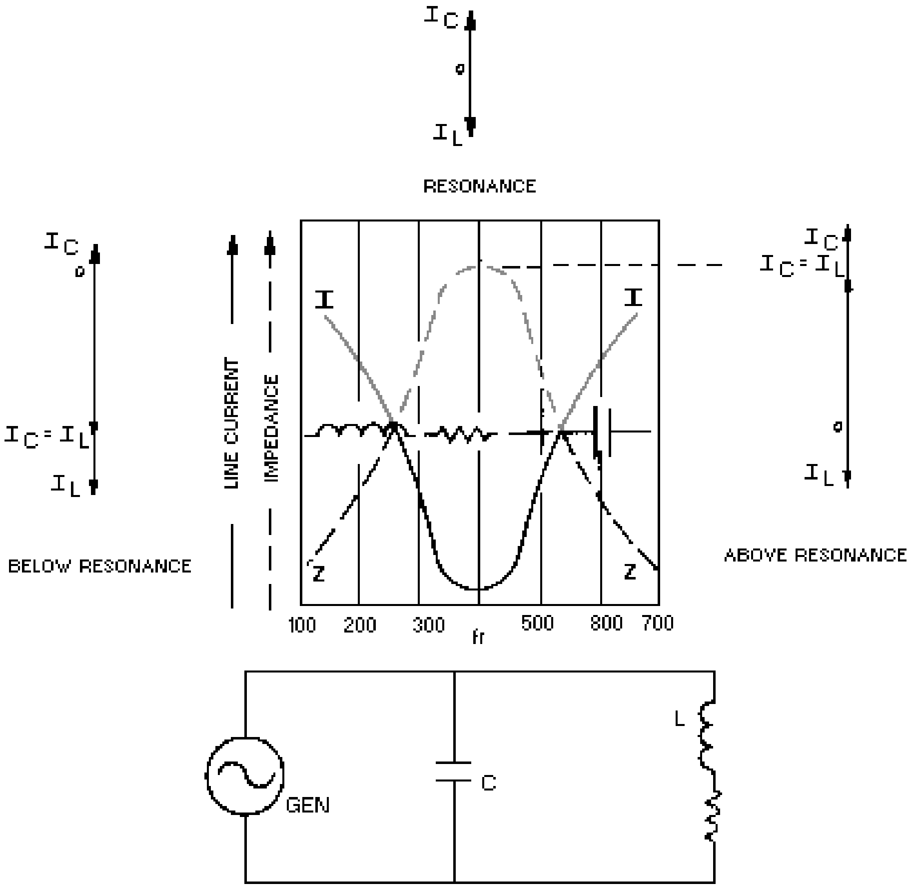
A **RESONANT CIRCUIT** is often called a **TANK CIRCUIT**. It has the ability to take energy fed from a power source, store the energy alternately in the inductor and capacitor, and produce an output which is a continuous a.c. wave. The number of times this set of events occurs per second is called the resonant frequency of the circuit. The actual frequency at which a tank circuit will oscillate is determined by the formula:

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

IN A **SERIES-LC CIRCUIT** <u>impedance is minimum and current is maximum</u>. Voltage is the variable, and voltage across the inductor and capacitor will be equal but of opposite phases at resonance. Above resonance it acts inductively, and below resonance it acts capacitively.



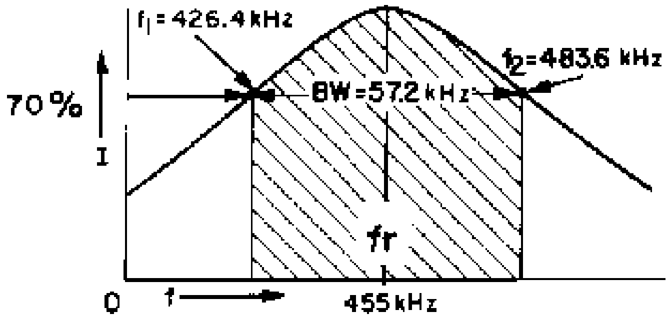
IN A **PARALLEL-LC CIRCUIT** impedance is maximum and current is minimum. Current is the variable and at resonance the two currents are 180 degrees out of phase with each other. Above resonance the current acts capacitively, and below resonance the current acts inductively.



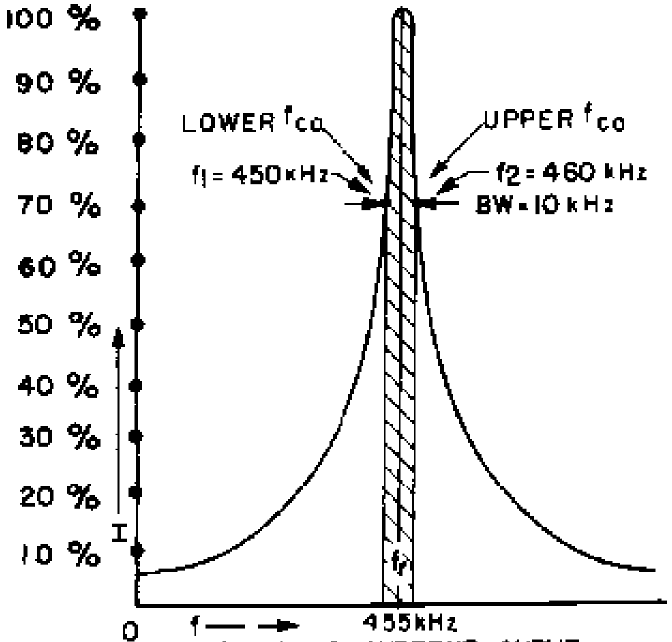
THE **"Q"** OR **FIGURE OF MERIT** of a circuit is the ratio of X_L to R. Since the capacitor has negligible losses, the circuit Q becomes equivalent to the Q of the coil.

$$(Q = \frac{X_L}{R})$$

THE **BANDWIDTH** of a circuit is the range of frequencies between the half-power points. The limiting frequencies are those at either side of resonance at which the curve falls to .707 of the maximum value. If circuit Q is low, you will have a wide bandpass. If circuit Q is high, you will have a narrow bandpass.



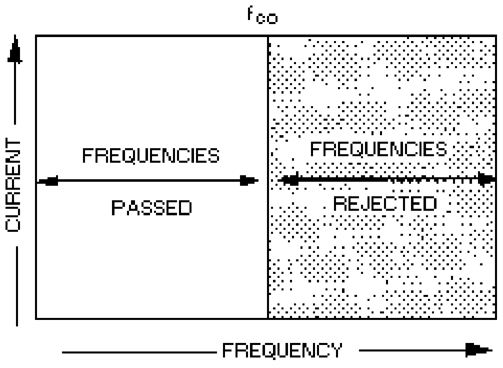
(A) LOW Q CURRENT CURVE



(B) HIGH Q CURRENT CURVE

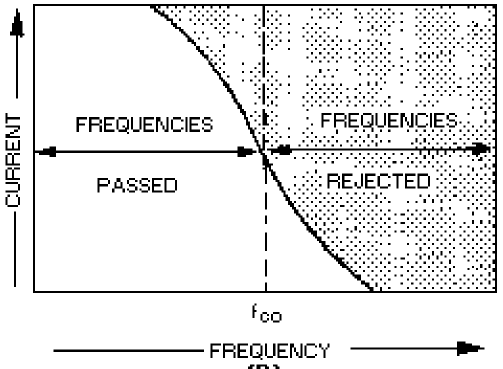
A **FILTER CIRCUIT** consists of a combination of capacitors, inductors, and resistors connected so that the filter will either permit or prevent passage of a certain band of frequencies.

A **LOW-PASS FILTER** passes low frequencies and attenuates high frequencies.



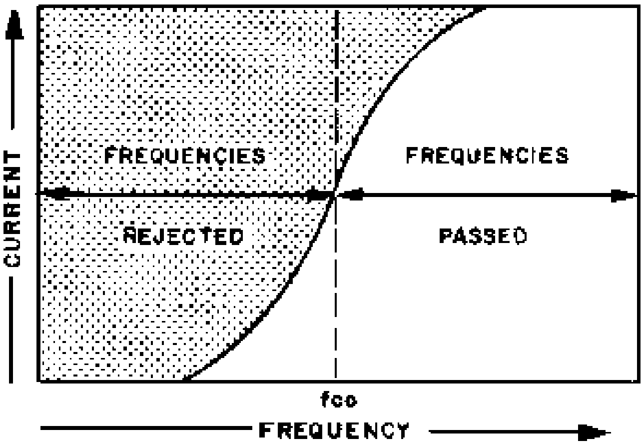
(A)

IDEAL RESPONSE

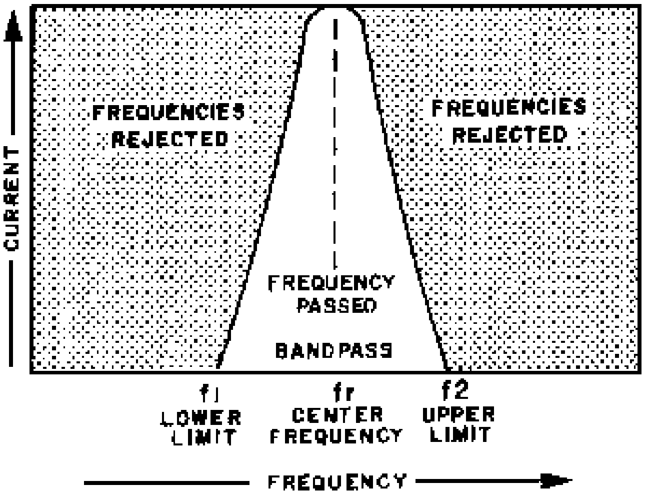


(B)

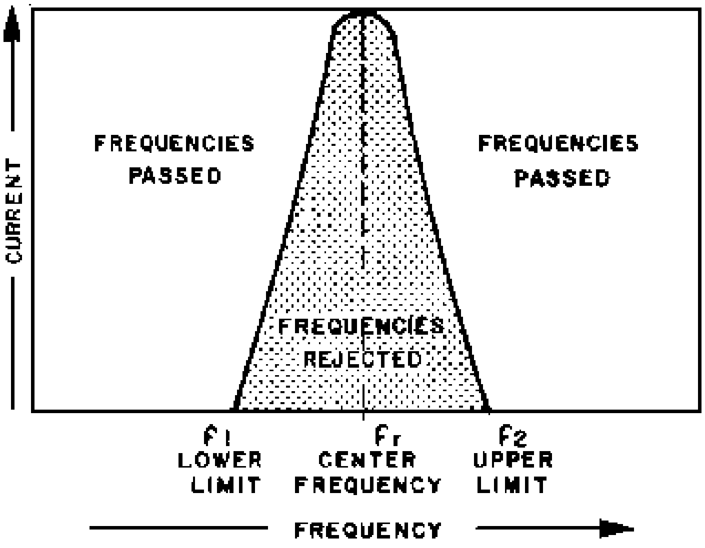
A **HIGH-PASS FILTER** passes high frequencies and attenuates low frequencies.



A **BANDPASS FILTER** will permit a certain band of frequencies to be passed.



A **BAND-REJECT FILTER** will reject a certain band of frequencies and pass all others.



A **SAFETY PRECAUTION** concerning series resonance: Very high reactive voltage can appear across L and C. Care must be taken against possible shock hazard.

ANSWERS TO QUESTIONS Q1. THROUGH Q21.

A-1.

- *a.* X_L *varies directly with frequency.*

  $X_L = 2\pi fL$

- *b.* X_C *varies inversely with frequency.*

  $$X_C = \frac{1}{2\pi fC}$$

- *c.* Frequency has no affect on resistance.

A-2. Resultant reactance.

A-3.

$$f_r = \frac{1}{2\pi\sqrt{LC}} \quad \text{or} \quad f_r = \frac{.159}{\sqrt{LC}}$$

A-4. Decreases.

A-5. Impedance low Current high.

A-6. Nonresonant (circuit is either above or below resonance).

A-7. Inductor magnetic field.

A-8. Capacitor.

A-9. Natural frequency or resonant frequency (f_r).

A-10. Maximum impedance, minimum current.

A-11. At the resonant frequency.

A-12.

$$(Q = \frac{X_L}{R})\ (\text{high } X_L,\ \text{low } R)$$

A-13. Bandwidth of the circuit.

A-14. A filter.

A-15.

- *a. Low-pass.*
- *b. High-pass*
- *c. Bandpass.*
- *d. Band-reject.*

A-16. High-pass filter, low-frequency discriminator, or low-frequency attenuator.

A-17. Low-pass filter, high-frequency discriminator or high-frequency attenuator.

A-18. At low-frequency, a capacitor acts as an open and an inductor acts as a short. At high-frequency, a capacitor acts as a short and an inductor acts as an open.

A-19. Frequency cutoff (f_{co}).

A-20. Bandpass.

A-21. Band-reject.

CHAPTER 2

OSCILLATORS

LEARNING OBJECTIVES

Upon completion of this chapter you will be able to:

1. List the two broad classifications of oscillators (wave generators).
2. Identify the three frequency-determining devices for sine-wave oscillators.
3. Describe the differences between series-fed and shunt-fed oscillators.
4. Explain how the crystal is equivalent to the series and parallel LC circuit.
5. Identify the Armstrong oscillator.
6. Identify the Hartley oscillator.
7. Identify the Colpitts oscillator.
8. Identify the resistive-capacitive oscillator.
9. Determine the frequency of a resistive-capacitive oscillator.
10. Explain the operation of a pulsed oscillator.
11. Determine how many cycles are present in the output of a pulsed oscillator.
12. Explain how frequency multiplication takes place.

INTRODUCTION

WAVE GENERATORS play a prominent role in the field of electronics. They generate signals from a few hertz to several gigahertz (10^9 hertz). Modern wave generators use many different circuits and generate such outputs as SINUSOIDAL, SQUARE, RECTANGULAR, SAWTOOTH, and TRAPEZOIDAL waveshapes. These waveshapes serve many useful purposes in the electronic circuits you will be studying. For example, they are used extensively throughout the television receiver to reproduce both picture and sound.

One type of wave generator is known as an OSCILLATOR. An oscillator can be regarded as an amplifier which provides its own input signal. Oscillators are classified according to the waveshapes they produce and the requirements needed for them to produce oscillations.

CLASSIFICATION OF OSCILLATORS (GENERATORS)

Wave generators can be classified into two broad categories according to their output waveshapes, SINUSOIDAL and NONSINUSOIDAL.

Sinusoidal Oscillators

A sinusoidal oscillator produces a sine-wave output signal. Ideally, the output signal is of constant amplitude with no variation in frequency. Actually, something less than this is usually obtained. The degree to which the ideal is approached depends upon such factors as class of amplifier operation, amplifier characteristics, frequency stability, and amplitude stability.

Sine-wave generators produce signals ranging from low audio frequencies to ultrahigh radio and microwave frequencies. Many low-frequency generators use resistors and capacitors to form their frequency-determining networks and are referred to as RC OSCILLATORS. They are widely used in the audio-frequency range.

Another type of sine-wave generator uses inductors and capacitors for its frequency-determining network. This type is known as the LC OSCILLATOR. LC oscillators, which use tank circuits, are commonly used for the higher radio frequencies. They are not suitable for use as extremely low-frequency oscillators because the inductors and capacitors would be large in size, heavy, and costly to manufacture.

A third type of sine-wave generator is the CRYSTAL-CONTROLLED OSCILLATOR. The crystal-controlled oscillator provides excellent frequency stability and is used from the middle of the audio range through the radio frequency range.

Nonsinusoidal Oscillators

Nonsinusoidal oscillators generate complex waveforms, such as square, rectangular, trigger, sawtooth, or trapezoidal. Because their outputs are generally characterized by a sudden change, or relaxation, they are often referred to as RELAXATION OSCILLATORS. The signal frequency of these oscillators is usually governed by the charge or discharge time of a capacitor in series with a resistor. Some types, however, contain inductors that affect the output frequency. Thus, like sinusoidal oscillators, both RC and LC networks are used for determining the frequency of oscillation. Within this category of nonsinusoidal oscillators are MULTIVIBRATORS, BLOCKING OSCILLATORS, SAWTOOTH GENERATORS, and TRAPEZOIDAL GENERATORS.

THE BASIC OSCILLATOR

An oscillator can be thought of as an amplifier that provides itself (through feedback) with an input signal. By definition, it is a nonrotating device for producing alternating current, the output frequency of which is determined by the characteristics of the device. The primary purpose of an oscillator is to generate a given waveform at a constant peak amplitude and specific frequency and to maintain this waveform within certain limits of amplitude and frequency.

An oscillator must provide amplification. Amplification of signal power occurs from input to output. In an oscillator, a portion of the output is fed back to sustain the input, as shown in figure 2-1. Enough power must be fed back to the input circuit for the oscillator to drive itself as does a signal generator. To cause the oscillator to be self-driven, the feedback signal must also be

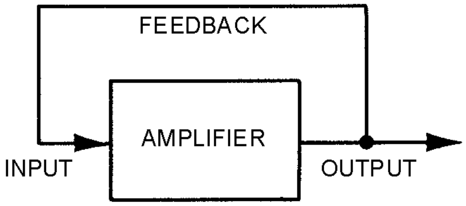


Figure 2-1.—Basic oscillator block diagram.

REGENERATIVE (positive). Regenerative signals must have enough power to compensate for circuit losses and to maintain oscillations.

Since a practical oscillator must oscillate at a predetermined frequency, a FREQUENCY-DETERMINING DEVICE (fdd), sometimes referred to as a FREQUENCY-DETERMINING NETWORK (fdn), is needed. This device acts as a filter, allowing only the desired frequency to pass. Without a frequency-determining device, the stage will oscillate in a random manner, and a constant frequency will not be maintained.

Before discussing oscillators further, let's review the requirements for an oscillator. First, amplification is required to provide the necessary gain for the signal. Second, sufficient regenerative feedback is required to sustain oscillations. Third, a frequency-determining device is needed to maintain the desired output frequency.

The basic oscillator requirements, in addition to the application, determine the type of oscillator to be used. Let's consider some factors that account for the complexity and unique characteristics of oscillators.

Virtually every piece of equipment that uses an oscillator has two stability requirements, AMPLITUDE STABILITY and FREQUENCY STABILITY. Amplitude stability refers to the ability of the oscillator to maintain a constant amplitude in the output waveform. The more constant the amplitude of the output waveform, the better the amplitude stability. Frequency stability refers to the ability of the oscillator to maintain its operating frequency. The less the oscillator varies from its operating frequency, the better the frequency stability.

A constant frequency and amplitude can be achieved by taking extreme care to prevent variations in LOAD, BIAS, and COMPONENT CHARACTERISTICS. Load variations can greatly affect the amplitude and frequency stability of the output of an oscillator. Therefore, maintaining the load as constant as possible is necessary to ensure a stable output.

As you should know from your study of transistor biasing, bias variations affect the operating point of the transistor. These variations may alter the amplification capabilities of the oscillator circuits as well. A well-regulated power supply and a bias-stabilizing circuit are required to ensure a constant, uniform signal output.

As a result of changing temperature and humidity conditions, the value or characteristics of components such as capacitors, resistors, and transistors can change. The changes in these components also cause changes in amplitude and frequency.

Output power is another consideration in the use of oscillators. Generally speaking, high power is obtained at some sacrifice to stability. When both requirements are to be met, a low-power, stable oscillator can be followed by a higher-power BUFFER AMPLIFIER. The buffer provides isolation between the oscillator and the load to prevent changes in the load from affecting the oscillator.

If the oscillator stage must develop high power, efficiency becomes important. Many oscillators use class C bias to increase efficiency. Other types of oscillators may use class A bias when a high efficiency is not required but distortion must be kept at a minimum. Other classes of bias may also be used with certain oscillators.

SINE-WAVE OSCILLATOR

RC networks, LC tanks, and crystals may appear in sine-wave oscillator circuits. An amplifier can be made into a sine-wave oscillator by providing regenerative feedback through an RC network.

RC Network

Figure 2-2, view (A), shows the block diagram of an amplifier with an RC network through which regenerative feedback is provided. The RC network also acts as the frequency-determining device. View (B) shows a vector analysis of the signal E at various points in the circuit.

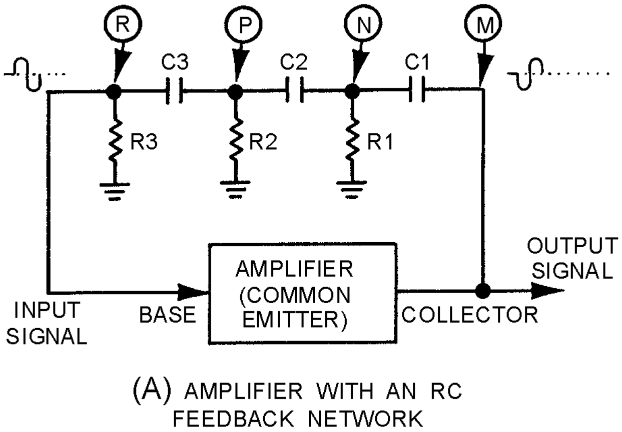


Figure 2-2A.—RC oscillator. AMPLIFIER WITH AND RC FEEDBACK NETWORK.

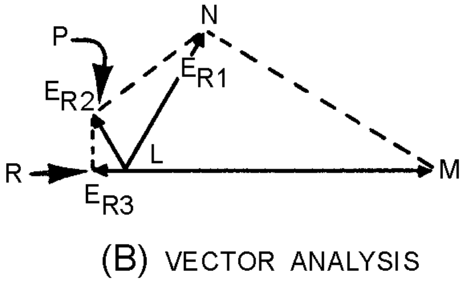


Figure 2-2B.—RC oscillator. VECTOR ANALYSIS

To analyze the operation of the circuit in view (A), assume that the amplifier is a common-emitter configuration. The signal on the collector (M) is 180 degrees out of phase with the signal (input) on the base (R). For the circuit to produce regenerative feedback, the RC network must provide a 180-degree phase shift of the collector signal. When power is applied to the circuit, a noise voltage (noise contains many different frequencies) will appear on the collector. This noise signal is represented by vector LM in view (B). As the signal couples through C1 and across R1 (view (A)), a phase shift occurs. The voltage across R1 (E_{R1}), represented by vector LN, has been shifted in phase (about 60 degrees) and reduced in amplitude. The signal at point N (view (A)) is then coupled to the next RC section (R2 and C2). Using the same size resistor and capacitor as before will cause another 60-degree phase shift to take place. The signal at point P is the voltage across R2, represented by vector LP. Now the signal at point P has been shifted about 120 degrees and its amplitude is reduced still further. The same actions occur for the last section (R3 and C3). This signal experiences another 60-degree phase shift and has further amplitude reduction. The signal at point R (E_{R3}) has been shifted 180 degrees and is represented by vector LR.

Notice that point R is the input to the base of the common-emitter amplifier. Also, vector LR shows that the signal on the base is regenerative (aiding the circuit operation). This meets the regenerative feedback requirement. An exact 60-degree phase shift per stage is not required, but the sum of the three phase shifts must equal 180 degrees.

For a given RC network, only one frequency of the initial noise signal will be shifted exactly 180 degrees. In other words, the network is frequency selective. Therefore, the RC network is the frequency-determining device since the lengths of the vectors and their phase relationships depend on frequency. The frequency of oscillations is governed by the values of resistance and capacitance in these sections. Variable resistors and capacitors may be used to provide tuning in the feedback network to allow for minor variations in phase shift. For an RC phase-shift oscillator, the amplifier is biased for class A operation to minimize distortion of the wave or signal.

LC Network

Some sine-wave oscillators use resonant circuits consisting of inductance and capacitance. For example, recall the tank circuit in which a resonant circuit stores energy alternately in the inductor and capacitor, producing a sine wave. You studied this action of the tank circuit in chapter 1.

If there were absolutely no internal resistances in a tank circuit, oscillations would continue indefinitely, as shown in figure 2-3, view (A). Each resonant circuit does, however, contain some resistance which dissipates power. This power loss causes the amplitude to decrease, as shown in views (B) and (C). The reduction of amplitude in an oscillator circuit is referred to as DAMPING. Damping is caused by both tank and load resistances. The larger the tank resistance, the greater the amount of damping. Loading the tank causes the same effect as increasing the internal resistance of the tank. The effect of this damping can be overcome by applying regenerative feedback.

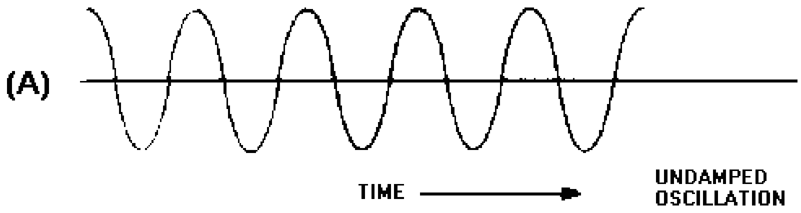


Figure 2-3A.—Effects of damping.

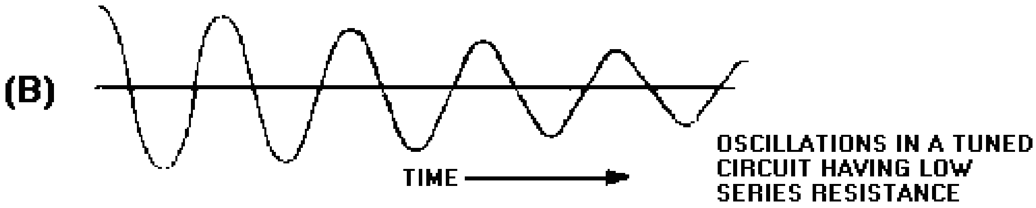


Figure 2-3B.—Effects of damping.

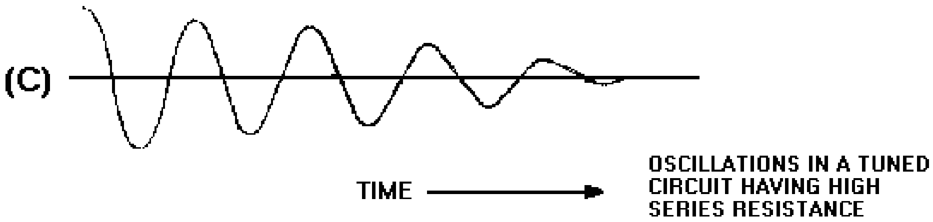


Figure 2-3C.—Effects of damping.

Figure 2-4 shows a block diagram of a typical LC oscillator. Notice that the oscillator contains the three basic requirements for sustained oscillations: amplification, a frequency-determining device, and regenerative feedback.

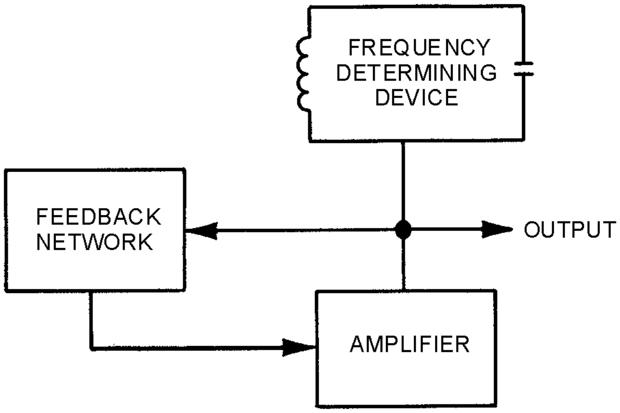


Figure 2-4.—LC oscillator.

The amplifier supplies energy to begin what is known as the FLYWHEEL EFFECT. The flywheel effect is the maintenance of oscillations in a circuit in the intervals between pulses of excitation energy. Recall that in chapter 1 the tank circuit alternately stored energy in the inductor and capacitor. The LC network provides initial oscillations. A portion of the output of the LC network is then returned to the input of the amplifier through the regenerative-feedback network to sustain the oscillations.

When a tank circuit is used to develop oscillations in an oscillator, the output frequency of the oscillator is primarily the resonant frequency of the tank circuit and can be found by the formula:

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

Crystals

Another frequency-determining device is the CRYSTAL. The crystal may be used with a tank circuit, or it may perform alone. Crystals exhibit a characteristic known as the PIEZOELECTRIC EFFECT. The piezoelectric effect is the property of a crystal by which mechanical forces produce electrical charges and, conversely, electrical charges produce mechanical forces. This effect is a form of oscillation similar to the flywheel effect of a tank circuit.

The piezoelectric effect can be seen in a number of crystal substances. The most important of these are the minerals quartz and Rochelle salt. Although quartz does not exhibit the piezoelectric effect to the degree that Rochelle salt does, quartz is used for frequency control in oscillators because of its greater mechanical strength. Another mineral, tourmaline, is physically strong like quartz; but because it is more expensive, it is not used extensively as an fdd. This discussion will deal only with the quartz crystal.

The crystals used in oscillator circuits are thin sheets, or wafers, cut from natural or synthetic quartz and ground to a specific thickness to obtain the desired resonant frequency. The crystals are mounted in holders, which support them physically and provide electrodes by which voltage is applied. The holder must allow the crystals freedom for vibration. There are many different types of holders. One type is shown in figure 2-5.

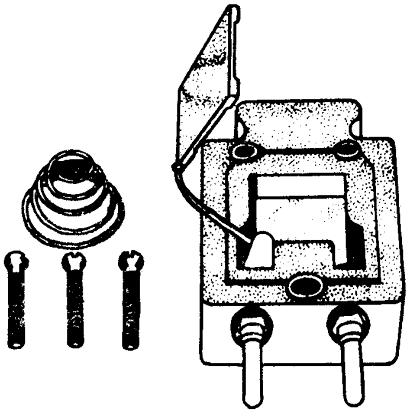


Figure 2-5.—Crystal holder.

The frequency for which a crystal is ground is referred to as the NATURAL RESONANT FREQUENCY of the crystal. Voltage applied to the crystal produces mechanical vibrations which, in turn, produce an output voltage at the natural resonant frequency of the crystal. A vibrating crystal can be represented by an equivalent electrical circuit composed of capacitance, inductance, and resistance.

Figure 2-6, view (A), illustrates the symbol of a crystal; view (B) shows an equivalent circuit for the crystal. View (C) shows an equivalent circuit for the crystal and the holder; C1 represents the capacitance between the metal plates of the holder.

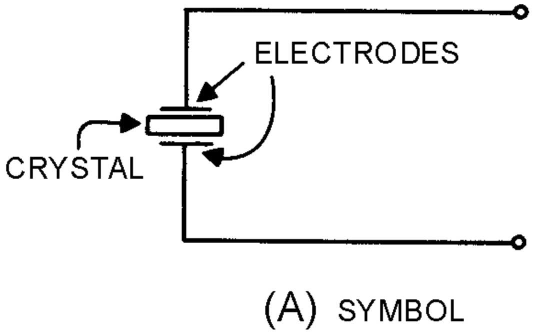


Figure 2-6A.—Crystal symbol and equivalent circuits. SYMBOL

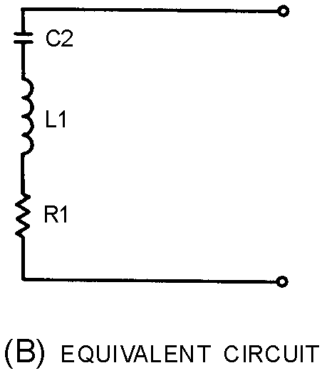


Figure 2-6B.—Crystal symbol and equivalent circuits. EQUIVALENT CIRCUIT.

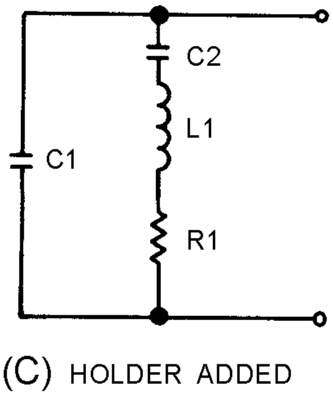


Figure 2-6C.—Crystal symbol and equivalent circuits. HOLDER ADDED

The Q (discussed in chapter 1) of a crystal is many times greater than that of an LC tank circuit. The high Q is present because the resistance in the crystal is extremely small. Commercially produced crystals range in Q from 5,000 to 30,000. The high Q causes the frequency stability to be much greater than that of an ordinary LC tank circuit. This is the reason a crystal is used in many sine-wave generator circuits.

Q-1. What are the two classifications of wave generators according to their output waveshapes?

Q-2. What are the three networks used for frequency-determining devices?

Q-3. What is another name for nonsinusoidal oscillators?

Q-4. What is a nonrotating device that produces alternating current?

Q-5. What are the three requirements necessary for oscillations to exist in a circuit?

SOLID-STATE LC OSCILLATORS

As you have just studied, a basic oscillator can be broken down into three main sections: a frequency-determining device, an amplifier, and a feedback circuit. The frequency-determining device in an LC oscillator is usually an LC tank circuit. Although the tank circuit is normally found in the input circuit of an oscillator (both electron tube and transistor), it sometimes appears in the output circuit. The differences in magnitude of plate and collector currents and shunting impedances are considerations in the designed locations of such tank circuits. In both solid-state and electron tube circuits, oscillations take place in the tuned circuit. Both the electron tube and the transistor function primarily as electrical valves that amplify and automatically deliver to the input circuit the proper amount of energy to sustain oscillations. In both tube and transistor oscillators, the feedback circuit couples energy of the proper amount and of the correct phase from the output to the input circuit to sustain oscillations.

FEEDBACK

Let's review what you have studied up to this point concerning feedback. Feedback is the process of transferring energy from a high-level point in a system to a low-level point in a system. This means transferring energy from the output of an amplifier back to its input. If the output feedback signal opposes the input signal, the signal is DEGENERATIVE or NEGATIVE FEEDBACK. However, if the feedback aids the input signal, the feedback is REGENERATIVE or POSITIVE FEEDBACK. Regenerative or positive feedback is one of the requirements to sustain oscillations in an oscillator. This feedback can be applied in any of several ways to produce a practical oscillator circuit.

TYPES OF FEEDBACK

Chapter 1 described the resonant or tank circuit and how a sinusoidal signal is generated by the action of an inductor and a capacitor. The feedback signal is coupled from this circuit by either of two means. The first method is to take some of the energy from the inductor. This can be done by any one of the three ways shown in figure 2-7, views (A), (B), and (C). When an oscillator uses a TICKLER COIL, as shown in view (A), it is referred to as an ARMSTRONG OSCILLATOR. When an oscillator uses a tapped coil (view (B)) or a split coil (view (C)), it is referred to as a HARTLEY OSCILLATOR. The second method of coupling the feedback signal is to use two capacitors in the tank circuit and tap the feedback signal between them. This is shown in view (D). An oscillator using this method is referred to as a COLPITTS OSCILLATOR. Each of these particular oscillators is named after the person who originally designed them.

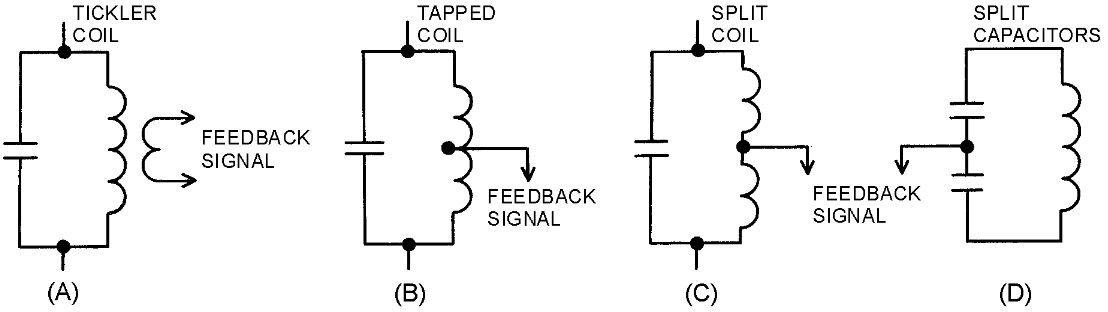
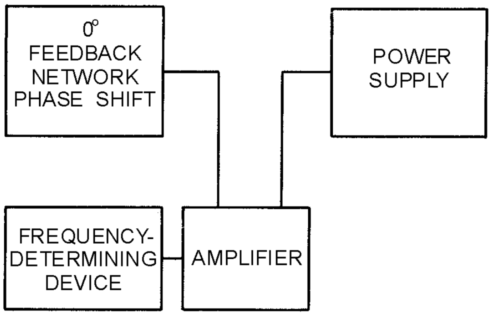


Figure 2-7.—Feedback signals.

CONFIGURATION OF OSCILLATORS

Any of the three basic amplifier configurations (common collector, common base, or common emitter) described in NEETS, Module 7, *Introduction to Solid-State Devices and Power Supplies*, Chapter 2, may be used for the oscillator circuit. However, certain considerations in the application of the circuit, such as the operating frequency and output power required, usually determine which of the three configurations is to be used. The three basic configurations are shown in figure 2-8, views (A), (B), and (C).



(A) COMMON-COLLECTOR CONFIGURATION

Figure 2-8A.—Basic configurations. COMMON-COLLECTOR CONFIGURATION

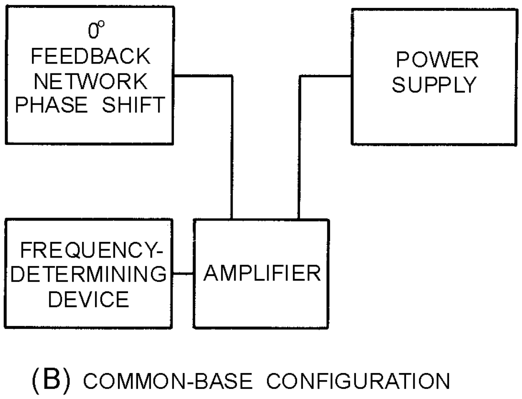


Figure 2-8B.—Basic configurations. COMMON-BASE CONFIGURATION.

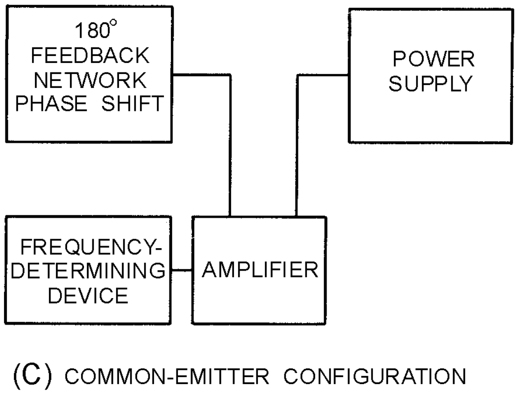


Figure 2-8C.—Basic configurations. COMMON-EMITTER CONFIGURATION.

COMMON-COLLECTOR CONFIGURATION

Since there is no phase reversal between the input and output circuits of a common-collector configuration, the feedback network does not need to provide a phase shift. However, since the voltage gain is less than unity and the power gain is low, the common-collector configuration is very seldom used in oscillator circuits.

COMMON-BASE CONFIGURATION

The power gain and voltage gain of the common-base configuration are high enough to give satisfactory operation in an oscillator circuit. The wide range between the input resistance and the output resistance make impedance matching slightly harder to achieve in the common-base circuit than in the common-emitter circuit. An advantage of the common-base configuration is that it exhibits better high-frequency response than does the common-emitter configuration.

COMMON-EMITTER CONFIGURATION

The common-emitter configuration has high power gain and is used in low-frequency applications. For the energy which is fed back from the output to be in phase with the energy at the input, the feedback network of a common-emitter oscillator must provide a phase shift of approximately 180 degrees. An advantage of the common-emitter configuration is that the medium resistance range of the input and output simplifies the job of impedance matching.

Q-6. What type of feedback aids an input signal?

Q-7. What are the two methods used for feedback coupling?

Q-8. Which oscillator uses a tickler coil for feedback?

Q-9. Which oscillator uses a tapped inductor for feedback?

Q-10. Which oscillator uses tapped capacitors for feedback?

Q-11. What are the three basic configurations of transistor oscillators?

OSCILLATOR CIRCUITS

Oscillators may be classified by name, such as Armstrong, Hartley, Colpitts, or by the manner in which dc power is applied. An oscillator in which dc power is supplied to the transistor through the tank circuit, or a portion of the tank circuit, is said to be SERIES FED. An oscillator which receives its dc power for the transistor through a path separate and parallel to the tank circuit is said to be PARALLEL FED OR SHUNT FED. All the oscillators in this chapter can be constructed either way, series or shunt fed. The construction depends on the characteristics of the oscillator circuit the designer is interested in.

A SERIES-FED, TUNED-COLLECTOR ARMSTRONG OSCILLATOR is illustrated in figure 2-9, view (A). The dc path is from the negative side (ground) of V_{CC} through R_E, Q1, T1, and back to the positive side of V_{CC}. The figure clearly illustrates that both the ac and dc components flow through the tank circuit.

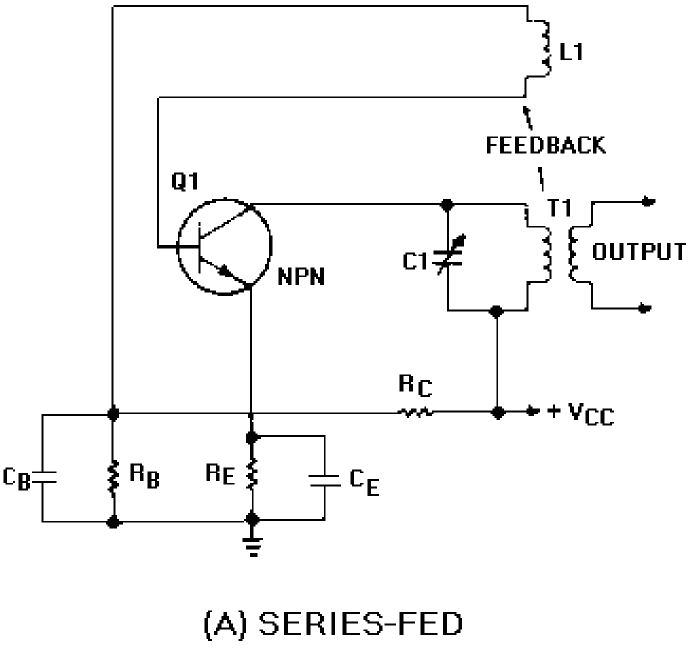


Figure 2-9A.—Series- and shunt-fed, tuned-collector Armstrong oscillators. SERIES-FED.

By modifying the circuit slightly, it becomes a SHUNT-FED, TUNED-COLLECTOR ARMSTRONG OSCILLATOR as shown in view (B). The dc component flows from ground through R_E to Q1 to positive V_{CC}. The dc is blocked from the tank circuit by capacitor C2. Only the ac component flows in the tank circuit.

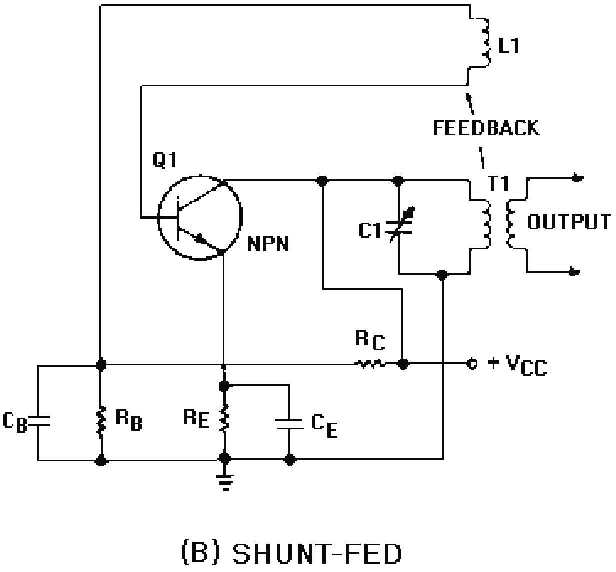


Figure 2-9B.—Series- and shunt-fed, tuned-collector Armstrong oscillators. SHUNT-FED.

The function of an oscillator is to produce a sinusoidal waveshape of a specific frequency and amplitude. In doing so, the stability of an oscillator is very important. Depending on its application, an oscillator may be required to have either good frequency stability or amplitude stability; in many circumstances, both are required. Of the two, good frequency stability is usually considered more important.

FREQUENCY STABILITY

The FREQUENCY STABILITY of an oscillator is a measure of the degree to which a constant frequency output is approached. The better the frequency stability, the closer the output will be to a constant frequency.

Frequency INSTABILITY (variations above and below the desired output frequency) may be caused by transistor characteristics or by variations in the external circuit elements.

As stated before, when output power is not of prime importance, transistor oscillators may be biased class A to ensure stability and minimize distortion. When this is done, the dc operating point established by the power supply is chosen so that the operation of the transistor oscillator occurs over the most linear portion of the transistor's characteristic curve. When the operation of the circuit falls into the nonlinear portion of the characteristic curve, the transistor's parameters (voltages and currents) vary. These parameters are basic to the stable frequency of the transistor oscillator. Operating frequency variations may occur with changes in these bias voltages. Thus, a constant supply voltage is a prime requirement for good frequency stability.

The use of a common bias source for both collector and emitter electrodes results in a relatively constant ratio of the two voltages. In effect, a change in one voltage is somewhat counteracted by the change in the other. This counteraction takes place because an increase in collector voltage causes an increase in the oscillating frequency, and an increase in emitter voltage causes a decrease in the oscillating frequency. This is a result of the change in capacitance between the junctions of the transistor. However, a common bias source does not completely compensate since the effects on other circuit parameters of each bias voltage differ.

Just as in any transistor circuit, changes in the transistor operating point and changes in temperature are encountered in the transistor oscillator. The effects of changes in temperature are to cause collector current to increase if the transistor is not stabilized. The increase in collector current can be prevented by reducing the forward bias.

AMPLITUDE STABILITY

The AMPLITUDE STABILITY of a transistor oscillator indicates the amount by which the actual output amplitude varies from the desired output amplitude.

The same parameters (voltages and currents) that affect frequency stability also affect amplitude stability. Output amplitude may be kept relatively constant by ensuring that the feedback is large enough that the collector current is maintained at the proper level. Feedback used in this manner makes the output voltage directly proportional to the supply voltage. Thus, regulation of the supply voltage ensures good amplitude stability.

ARMSTRONG OSCILLATOR

The ARMSTRONG OSCILLATOR is used to produce a sine-wave output of constant amplitude and of fairly constant frequency within the rf range. It is generally used as a local oscillator in receivers, as a source in signal generators, and as a radio-frequency oscillator in the medium- and high-frequency range.

The identifying characteristics of the Armstrong oscillator are that (1) it uses an LC tuned circuit to establish the frequency of oscillation, (2) feedback is accomplished by mutual inductive coupling between the tickler coil and the LC tuned circuit, and (3) it uses a class C amplifier with self-bias. Its frequency is fairly stable, and the output amplitude is relatively constant.

Views (A), (B), and (C) shown in figure 2-10 can be used to build the basic Armstrong oscillator. View (A) shows a conventional amplifier. R2 provides the forward bias for Q1, C2 is a coupling capacitor, and L1 and R1 form the collector load impedance. This is a common-emitter configuration which provides the 180-degree phase shift between the base and collector.

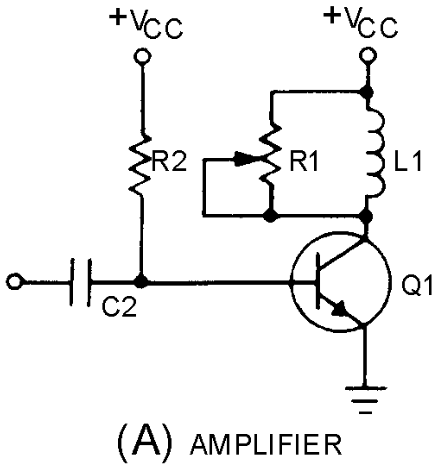


Figure 2-10A.—Basic Armstrong oscillator circuit. AMPLIFIER

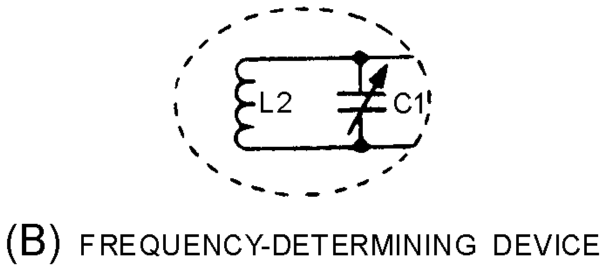


Figure 2-10B.—Basic Armstrong oscillator circuit. FREQUENCY-DETERMINING DEVICE.

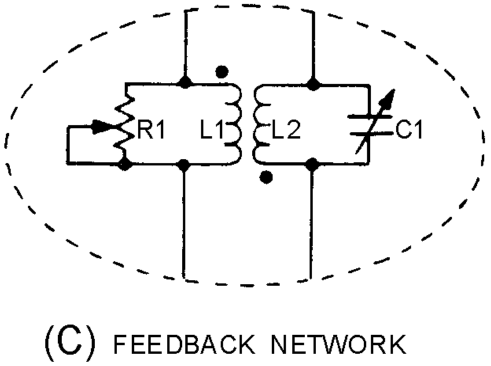


Figure 2-10C.—Basic Armstrong oscillator circuit. FEEDBACK NETWORK.

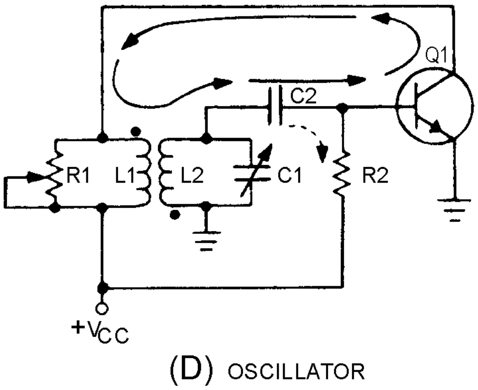


Figure 2-10D.—Basic Armstrong oscillator circuit. OSCILLATOR.

View (B) shows the frequency-determining device composed of inductor L2 and capacitor C1. C1 is a variable tuning capacitor which is used to adjust the resonant frequency to the desired value.

View (C) is the feedback network which uses L1 (the collector load) as the primary and L2 as the secondary winding of a coupling transformer to provide a 180-degree phase shift. Variable resistor R1 controls the amount of current through L1. When R1 is adjusted for maximum resistance, most of the current flows through L1. The transformer now couples a maximum signal which represents a large feedback amplitude into the tank circuit (L2, C1). If R1 is adjusted for a smaller resistance, less current flows through L1, and less energy is coupled to the tank circuit; therefore, feedback amplitude decreases. R1 is normally adjusted so that the L1 current is adequate to sustain tank oscillations.

View (D) shows the complete oscillator circuit. Connecting the feedback network through coupling capacitor C2 to the base of Q1 forms a "closed loop" for feedback (shown by the solid arrows). Let's verify that the feedback is regenerative. Assume a positive signal on the base of Q1. The transistor conducts heavily when forward biased. This current flow through L1 and R1 causes the voltage across L1 to increase. The voltage increase is inductively coupled to L2 and inverted. This action ensures that the voltage is positive at the base end of L2 and C1 and in phase with the base voltage. The positive signal is now coupled through C2 to the base of Q1. The regenerative feedback offsets the damping in the frequency-determining network and has sufficient amplitude to provide unity circuit gain.

The circuit in view (D) has all three requirements for an oscillator: (1) amplification, (2) a frequency-determining device, and (3) regenerative feedback. The oscillator in this schematic drawing is a tuned-base oscillator, because the fdd is in the base circuit. If the fdd were in the collector circuit, it would be a tuned-collector oscillator. The circuit in view (D) is basically an Armstrong oscillator.

Refer to figure 2-10, view (D), for the following discussion of the circuit operation of the Armstrong oscillator. When V_{CC} is applied to the circuit. a small amount of base current flows through R2 which sets the forward bias on Q1. This forward bias causes collector current to flow from ground through Q1, R1, and L1 to $+V_{CC}$. The current through L1 develops a magnetic field which induces a voltage into the tank circuit. The voltage is positive at the top of L2 and C1. At this time, two actions occur. First, resonant tank capacitor C1 charges to this voltage; the tank circuit now has stored energy. Second, coupling capacitor C2 couples the positive signal to the base of Q1. With a positive signal on its base, Q1 conducts harder. With Q1 conducting harder, more current flows through L1, a larger voltage is induced into L2, and a larger positive signal is coupled back to the base of Q1. While this is taking place, the frequency-determining device is storing more energy and C1 is charging to the voltage induced into L2.

The transistor will continue to increase in conduction until it reaches saturation. At saturation, the collector current of Q1 is at a maximum value and cannot increase any further. With a steady current through L1, the magnetic fields are not moving and no voltage is induced into the secondary.

With no external voltage applied, C1 acts as a voltage source and discharges. As the voltage across C1 decreases, its energy is transferred to the magnetic field of L2. Now, let's look at C2.

The coupling capacitor, C2, has charged to approximately the same voltage as C1. As C1 discharges, C2 discharges. The primary discharge path for C2 is through R2 (shown by the dashed arrow). As C2 discharges, the voltage drop across R2 opposes the forward bias on Q1 and collector current begins to decrease. This is caused by the decreasing positive potential at the base of Q1.

A decrease in collector current allows the magnetic field of L1 to collapse. The collapsing field of L1 induces a negative voltage into the secondary which is coupled through C2 and makes the base of Q1 more negative. This, again, is regenerative action; it continues until Q1 is driven into cutoff.

When Q1 is cut off, the tank circuit continues to flywheel, or oscillate. The flywheel effect not only produces a sine-wave signal, but it aids in keeping Q1 cut off. Without feedback, the oscillations of L2 and C1 would dampen out after several cycles.

To ensure that the amplitude of the signal remains constant, regenerative feedback is supplied to the tank once each cycle, as follows: As the voltage across C1 reaches maximum negative, C1 begins discharging toward 0 volts. Q1 is still below cutoff. C1 continues to discharge through 0 volts and becomes positively charged. The tank circuit voltage is again coupled to the base of Q1, so the base voltage becomes positive and allows collector current to flow. The collector current creates a magnetic field in L1, which is coupled into the tank. This feedback action replaces any lost energy in the tank circuit and drives Q1 toward saturation. After saturation is reached, the transistor is again driven into cutoff.

The operation of the Armstrong oscillator is basically this: Power applied to the transistor allows energy to be applied to the tank circuit causing it to oscillate. Once every cycle, the transistor conducts for a short period of time (class C operation) and returns enough energy to the tank to ensure a constant amplitude output signal.

Class C operation has high efficiency and low loading characteristics. The longer Q1 is cut off, the less the loading on the frequency-determining device.

Figure 2-11 shows a tuned-base Armstrong oscillator as you will probably see it. R3 has been added to improve temperature stability. Bypass capacitor C3 prevents degeneration. C4 is an output coupling capacitor, and impedance-matching transformer T2 provides a method of coupling the output signal. T2 is usually a loosely coupled rf transformer which reduces undesired reflected impedance from the load back to the oscillator.

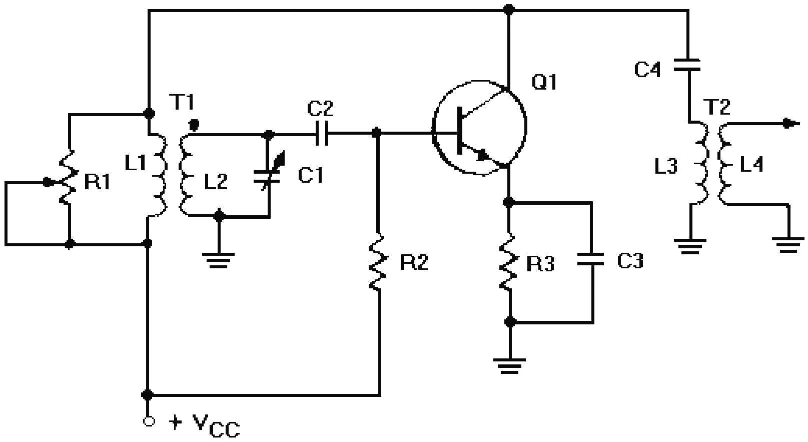


Figure 2-11.—Tuned-base Armstrong oscillator.

The Armstrong oscillator is an example of how a class C amplifier can produce a sine-wave output that is not distorted. Although class C operation is nonlinear and many harmonic frequencies are generated, only one frequency receives enough gain to cause the circuit to oscillate. This is the frequency of the resonant tank circuit. Thus, high efficiency and an undistorted output signal can be obtained.

The waveforms in figure 2-12 illustrate the relationship between the collector voltage and collector current. Notice that collector current (I_C) flows for only a short time during each cycle. While the tank circuit is oscillating (figure 2-11), L2 acts as the primary of the transformer and L1 acts as the secondary. The signal from the tank is, therefore, coupled through T1 to coupling capacitor C4, and the output voltage across L4 is a sine wave.

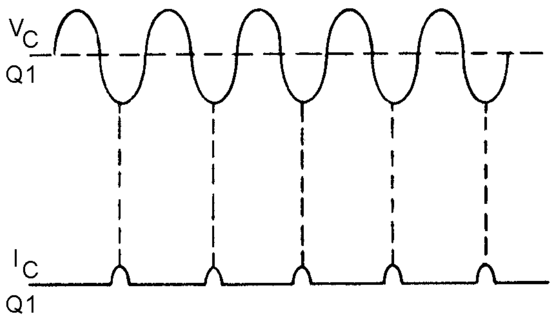


Figure 2-12.—Collector current and voltage waveforms of a class C oscillator.

HARTLEY OSCILLATOR

The HARTLEY OSCILLATOR is an improvement over the Armstrong oscillator. Although its frequency stability is not the best possible of all the oscillators, the Hartley oscillator can generate a wide range of frequencies and is very easy to tune. The Hartley will operate class C with self-bias for ordinary operation. It will operate class A when the output waveform must be of a constant voltage level or of a linear waveshape. The two versions of this oscillator are the series-fed and the shunt-fed. The main difference between the Armstrong and the Hartley oscillators lies in the design of the feedback (tickler) coil. A separate coil is not used. Instead, in the Hartley oscillator, the coil in the tank circuit is a split inductor. Current flow through one section induces a voltage in the other section to develop a feedback signal.

Series-Fed Hartley Oscillator

One version of a SERIES-FED HARTLEY OSCILLATOR is shown in figure 2-13. The tank circuit consists of the tapped coil (L1 and L2) and capacitor C2. The feedback circuit is from the tank circuit to the base of Q1 through the coupling capacitor C1. Coupling capacitor C1 prevents the low dc resistance of L2 from placing a short across the emitter-to-base junction and resistor R_E. Capacitor C3 bypasses the sine-wave signal around the battery, and resistor R_E is used for temperature stabilization to prevent thermal runaway. Degeneration is prevented by C_E in parallel with R_E. The amount of bias is determined by the values of R_B, the emitter-to-base resistance, the small amount of dc resistance of coil L1, and the resistance of R_E.

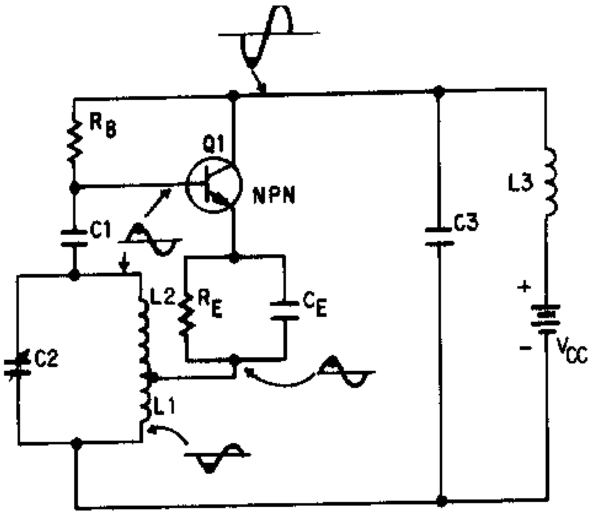


Figure 2-13.—Series-fed, tuned-base Hartley oscillator.

When a voltage is applied to the circuit, current from the battery flows through coil L1 and to the emitter through R_E. Current then flows from the emitter to the collector and back to the battery. The surge of current through coil L1 induces a voltage in coil L2 to start oscillations within the tank circuit.

When current first starts to flow through coil L1, the bottom of L1 is negative with respect to the top of L2. The voltage induced into coil L2 makes the top of L2 positive. As the top of L2 becomes positive, the positive potential is coupled to the base of Q1 by capacitor C1. A positive potential on the base results in an increase of the forward bias of Q1 and causes collector current to increase. The increased collector current also increases the emitter current flowing through coil L1. Increased current through L1 results in more energy being supplied to the tank circuit, which, in turn, increases the positive potential at the top of the tank (L2) and increases the forward bias of Q1. This action continues until the rate of current change through coil L1 can no longer increase. The current through coil L1 and the transistor cannot continue increasing indefinitely, or the coil and transistor will burn up. The circuit must be designed, by proper selection of the transistor and associated parts, so that some point is reached when the current can no longer continue to increase. At this point C2 has charged to the potential across L1 and L2. This is shown as the heavy dot on the base waveform. As the current through L1 decreases, the voltage induced in L2 decreases. The positive potential across the tank begins to decrease and C2 starts discharging through L1 and L2. This action maintains current flow through the tapped coil and causes a decrease in the forward bias of Q1. In turn, this decrease in the forward bias of Q1 causes the collector and emitter current to decrease. At the instant the potential across the tank circuit decreases to 0, the energy of the tank circuit is contained in the magnetic field of the coil. The oscillator has completed a half cycle of operation.

Next, the magnetic field around L2 collapses as the current from C2 stops. The action of the collapsing magnetic field causes the top of L2 to become negative at this instant. The negative charge causes capacitor C2 to begin to charge in the opposite direction. This negative potential is coupled to the base of Q1, opposing its forward bias. Most transistor oscillators are operated class A; therefore, the positive and negative signals applied to the base of Q1 will not cause it to go into saturation or cutoff. When the tank circuit reaches its maximum negative value, the collector and the emitter currents will still be present but at a minimum value. The magnetic field will have collapsed and the oscillator will have completed 3/4 cycle.

At this point C2 begins to discharge, decreasing the negative potential at the top of L2 (potential will swing in the positive direction). As the negative potential applied to the base of Q1 decreases, the opposition to the forward bias also decreases. This, in effect, causes the forward bias to begin increasing, resulting in increased emitter current flowing through L1. The increase in current through L1 causes additional energy to be fed to the tank circuit to replace lost energy. If the energy lost in the tank is replaced with an equal or larger amount of energy, oscillations will be sustained. The oscillator has now completed 1 cycle and will continue to repeat it over and over again.

Shunt-Fed Hartley Oscillator

A version of a SHUNT-FED HARTLEY OSCILLATOR is shown in figure 2-14. The parts in this circuit perform the same basic functions as do their counterparts in the series-fed Hartley oscillator. The difference between the series-fed and the shunt-fed circuit is that dc does not flow through the tank circuit. The shunt-fed circuit operation is essentially the same as the series-fed Hartley oscillator. When voltage is applied to the circuit, Q1 starts conducting. As the collector current of Q1 increases, the change (increase) is coupled through capacitor C3 to the tank circuit, causing it to oscillate. C3 also acts as an isolation capacitor to prevent dc from flowing through the feedback coil. The oscillations at the collector will be coupled through C3 (feedback) to supply energy lost within the tank.

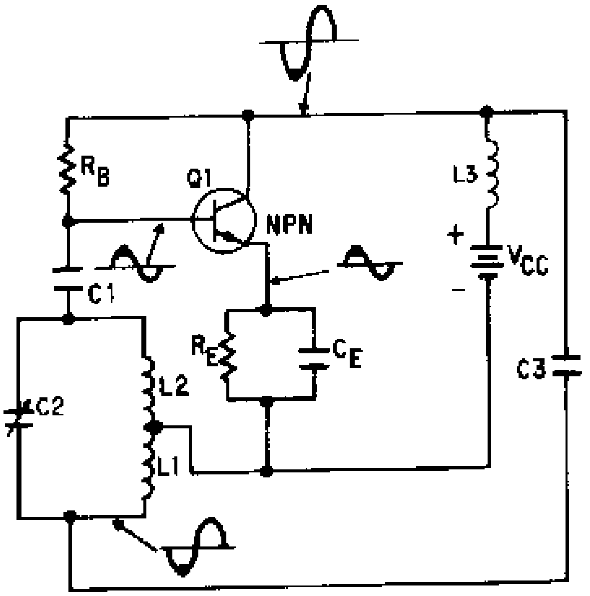


Figure 2-14.—Shunt-fed, tuned-base Hartley oscillator.

Q-12. What is the main difference between the Armstrong oscillator and the Hartley oscillator?

Q-13. What is the difference between the series-fed and the shunt-fed Hartley oscillator?

COLPITTS OSCILLATOR

Both the Armstrong and the Hartley oscillators have a tendency to be unstable in frequency because of junction capacitance. In comparison, the COLPITTS OSCILLATOR has fairly good frequency stability, is easy to tune, and can be used for a wide range of frequencies. The large value of split capacitance is in parallel with the junctions and minimizes the effect on frequency stability.

The Colpitts oscillator is very similar to the shunt-fed Hartley oscillator, except that two capacitors are used in the tank circuit instead of a tapped coil (figure 2-15). The Hartley oscillator has a tap between two coils, while the Colpitts has a tap between two capacitors. You can change the frequency of the Colpitts either by varying the inductance of the coil or by varying the capacitance of the two capacitors in the tank circuit. Notice that no coupling capacitor is used between the tank circuit and the base of Q1. Capacitors C1 and C2 of the tank circuit are in parallel with the input and the output interelement capacitance (capacitance between emitter, base, and collector) of the transistor. Thus the input and the output capacitive effect can be minimized on the tank circuit and better frequency stability can be obtained than with the Armstrong or the Hartley oscillator.

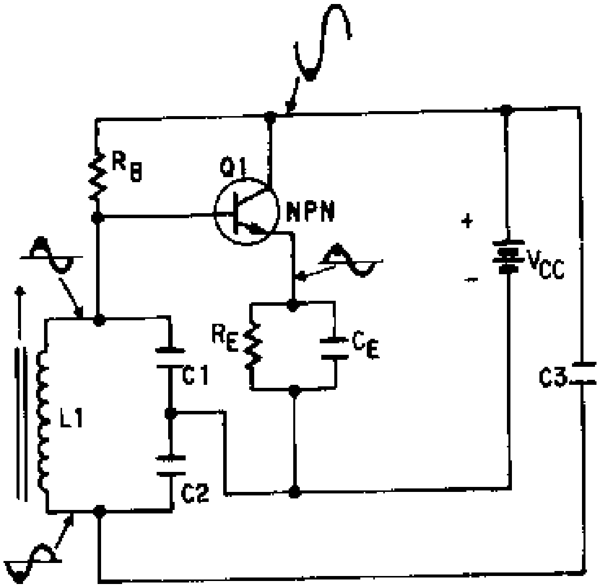


Figure 2-15.—Colpitts oscillator.

Figure 2-16 shows a common-base Colpitts oscillator using a pnp transistor as the amplifying device. Notice in this version of the Colpitts oscillator that regenerative feedback is obtained from the tank circuit and applied to the emitter. Base bias is provided by resistor R_B and R_F. Resistor R_C is the collector load resistor. Resistor R_E develops the input signal and also acts as the emitter swamping resistor. The tuned circuit consists of C1 and C2 in parallel with the primary winding of transformer T1. The voltage developed across C2 is the feedback voltage. Either or both capacitors may be adjusted to control the frequency. In the common-base configuration there is no phase difference between the signal at the collector and the emitter signal. Therefore, the phase of the feedback signal does not have to be changed. When the emitter swings negative, the collector also swings negative and C2 charges negatively at the junction of C1 and C2. This negative charge across C2 is fed back to the emitter. This increases the reverse bias on Q1. The collector of Q1 becomes more negative and C2 charges to a negative potential. This feedback effect continues until the collector of Q1 is unable to become any more negative. At that time the primary of T1 will act as a source because of normal tank circuit operation. As its field collapses, the tank potential will reverse and C1 and C2 will begin to discharge. As C2 becomes less negative, the reverse bias on Q1 decreases and its collector voltage swings in the positive direction. C1 and C2 will continue to discharge and then charge in a positive direction. This positive-going voltage across C2 will be fed back to the emitter as regenerative feedback. This will continue until the field around the primary of T1 collapses. At that time the collector of Q1 will be at a maximum positive value. C1 and C2 will begin to discharge and the potential at their junction will become less positive. This increases the reverse bias on Q1 and drives the collector negative, causing C1 and C2 to charge in a negative direction and to repeat the cycle.

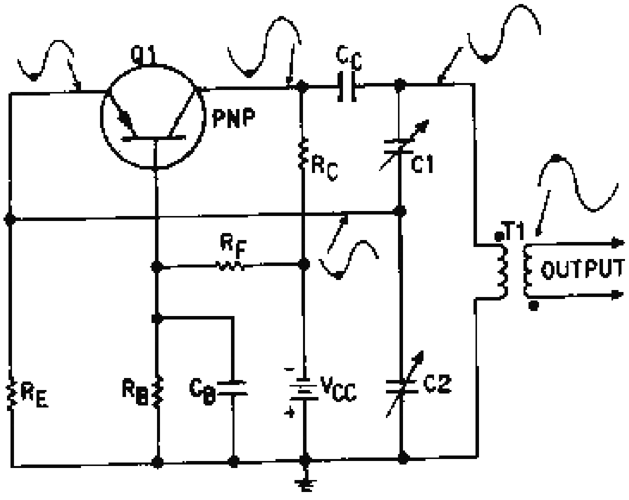


Figure 2-16.—Common-base Colpitts oscillator.

Q-14. What is the identifying feature of a Colpitts oscillator?

RESISTIVE-CAPACITIVE (RC) FEEDBACK OSCILLATOR

As mentioned earlier, resistive-capacitive (RC) networks provide regenerative feedback and determine the frequency of operation in RESISTIVE-CAPACITIVE (RC) OSCILLATORS.

The oscillators presented in this chapter have used resonant tank circuits (LC). You should already know how the LC tank circuit stores energy alternately in the inductor and capacitor.

The major difference between the LC and RC oscillator is that the frequency-determining device in the RC oscillator is not a tank circuit. Remember, the LC oscillator can operate with class A or C biasing because of the oscillator action of the resonant tank. The RC oscillator, however, must use class A biasing because the RC frequency-determining device doesn't have the oscillating ability of a tank circuit.

An RC FEEDBACK or PHASE-SHIFT oscillator is shown in figure 2-17. Components C1, R1, C2, R2, C3, and R_B are the feedback and frequency-determining network. This RC network also provides the needed phase shift between the collector and base.

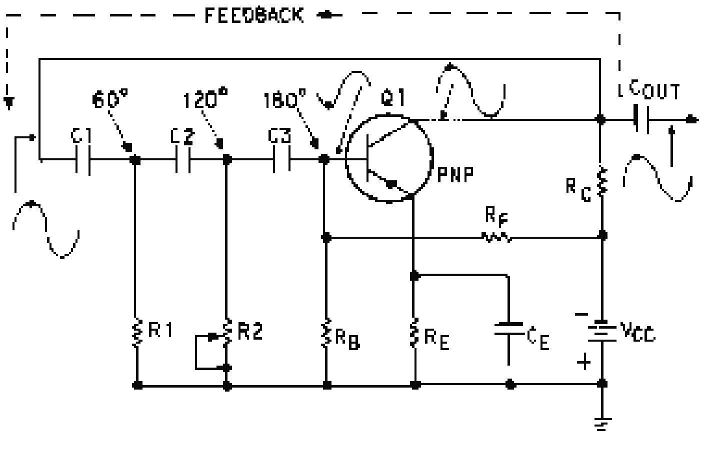


Figure 2-17.—Phase-shift oscillator.

Phase-Shift Oscillators

The PHASE-SHIFT OSCILLATOR, shown in figure 2-17, is a sine-wave generator that uses a resistive-capacitive (RC) network as its frequency-determining device.

As discussed earlier in the common-emitter amplifier configuration (figure 2-17), there is a 180-degree phase difference between the base and the collector signal. To obtain the regenerative feedback in the phase-shift oscillator, you need a phase shift of 180 degrees between the output and the input signal. An RC network consisting of three RC sections provides the proper feedback and phase inversion to provide this regenerative feedback. Each section shifts the feedback signal 60 degrees in phase.

Since the impedance of an RC network is capacitive, the current flowing through it leads the applied voltage by a specific phase angle. The phase angle is determined by the amount of resistance and capacitance of the RC section.

If the capacitance is a fixed value, a change in the resistance value will change the phase angle. If the resistance could be changed to zero, we could get a maximum phase angle of 90 degrees. But since a voltage cannot be developed across zero resistance, a 90-degree phase shift is not possible.

With a small value of resistance, however, the phase angle or phase shift is less than 90 degrees. In the phase-shift oscillator, therefore, at least three RC sections are needed to give the required 180-degree phase shift for regenerative feedback. The values of resistance and capacitance are generally chosen so that each section provides about a 60-degree phase shift.

Resistors R_B, R_F, and R_C provide base and collector bias. Capacitor C_E bypasses ac variations around the emitter resistor R_E. Capacitors C1, C2, and C3 and resistors R1, R2, and R_B form the feedback and phase-shifting network. Resistor R2 is variable for fine tuning to compensate for any small changes in value of the other components of the phase-shifting network.

When power is applied to the circuit, oscillations are started by any random noise (random electrical variations generated internally in electronic components). A change in the flow of base current results in an amplified change in collector current which is phase-shifted the 180 degrees. When the signal is returned to the base, it has been shifted 180 degrees by the action of the RC network, making the circuit regenerative. View (A) of figure 2-18 shows the amount of phase shift produced by C1 and R1. View (B) shows the amount of phase shift produced by C2 and R2 (signal received from C1 and R1), and view (C) shows the complete phase shift as the signal leaves the RC network. With the correct amount of resistance and capacitance in the phase-shifting network, the 180-degree phase shift occurs at only one frequency. At any other than the desired frequency, the capacitive reactance increases or decreases and causes an incorrect phase relationship (the feedback becomes degenerative). Thus, the oscillator works at only one frequency. To find the resonant frequency (f_r) of an RC phase shift oscillator, use the following formula:

$$f_r = \frac{1}{2\pi RC\sqrt{2n}}$$

where n is the number of RC sections.

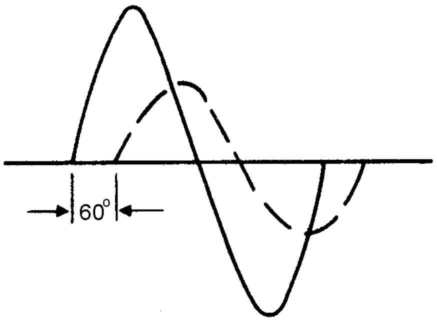


Figure 2-18A.—Three-section, phase-shifting RC network. PHASE-SHIFT NETWORK C1 AND R1.

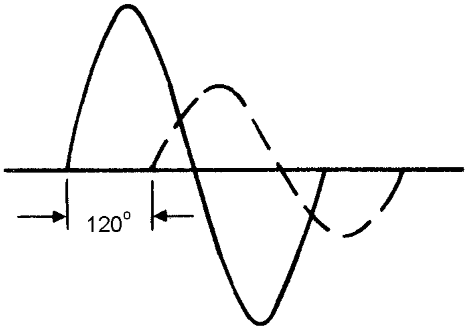


Figure 2-18B.—Three-section, phase-shifting RC network. PHASE-SHIFT NETWORK C2 AND R2.

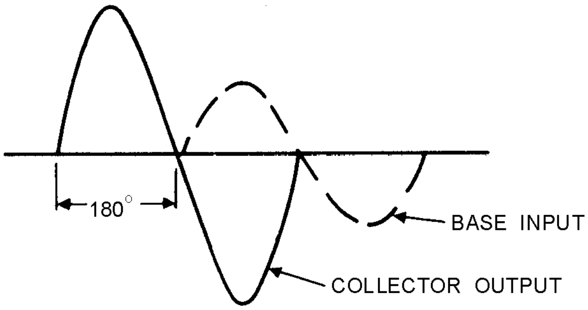


Figure 2-18C.—Three-section, phase-shifting RC network. PHASE-SHIFT NETWORK C3 AND R_B.

A high-gain transistor must be used with the three-section RC network because the losses in the network are high. Using more than three RC sections actually reduces the overall signal loss within the network. This is because additional RC sections reduce the phase shift necessary for each section, and the loss for each section is lowered as the phase shift is reduced. In addition, an oscillator that uses four or more RC networks has more stability than one that uses three RC networks. In a four-part RC network, each part shifts the phase of the feedback signal by approximately 45 degrees to give the total required 180-degree phase shift.

Q-15. Which components provide the regenerative feedback signal in the phase-shift oscillator?

Q-16. Why is a high-gain transistor used in the phase-shift oscillator?

Q-17. Which RC network provides better frequency stability, three-section or four-section?

CRYSTAL OSCILLATORS

Crystal oscillators are those in which a specially-cut crystal controls the frequency. CRYSTAL-CONTROLLED OSCILLATORS are the standard means used for maintaining the frequency of radio transmitting stations within their assigned frequency limits. A crystal-controlled oscillator is usually used to produce an output which is highly stable and at a very precise frequency.

As stated earlier, crystals used in electrical circuits are thin sheets cut from the natural crystal and are ground to the proper thickness for the desired resonant frequency. For any given crystal cut, the thinner the crystal, the higher the resonant frequency. The "cut" (X, Y, AT, and so forth) of the crystal means the precise way in which the usable crystal is cut from the natural crystal. Some typical crystal cuts may be seen in figure 2-19.

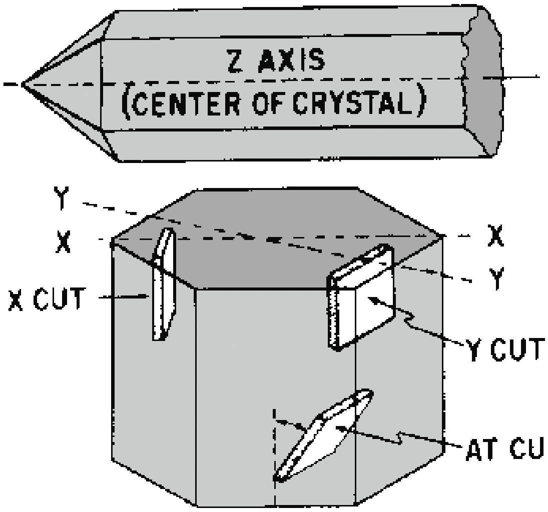


Figure 2-19.—Quartz crystal cuts.

Transmitters which require a very high degree of frequency stability, such as a broadcast transmitter, use temperature-controlled ovens to maintain a constant crystal temperature. These ovens are thermostatically controlled containers in which the crystals are placed.

The type of cut also determines the activity of the crystal. Some crystals vibrate at more than one frequency and thus will operate at harmonic frequencies. Crystals which are not of uniform thickness may have two or more resonant frequencies. Usually one resonant frequency is more pronounced than the others. The other less pronounced resonant frequencies are referred to as SPURIOUS frequencies. Sometimes such a crystal oscillates at two frequencies at the same time.

The amount of current that can safely pass through a crystal ranges from 50 to 200 milliamperes. When the rated current is exceeded, the amplitude of mechanical vibration becomes too great, and the crystal may crack. Overloading the crystal affects the frequency of vibration because the power dissipation and crystal temperature increase with the amount of load current.

Crystals as Tuned Circuits

A quartz crystal and its equivalent circuit are shown in figure 2-20, views (A) and (B). Capacitor C2, inductor L1, and resistor R1 in view (B) represent the electrical equivalent of the quartz crystal in view (A). Capacitance C1 in (view B) represents the capacitance between the crystal electrodes in view (A). Depending upon the circuit characteristics, the crystal can act as a capacitor, an inductor, a series-tuned circuit, or a parallel-tuned circuit.

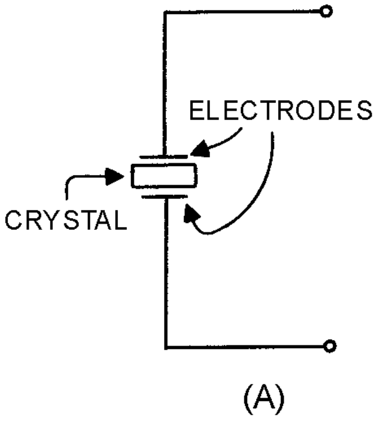


Figure 2-20A.—Quartz crystal and equivalent circuit.

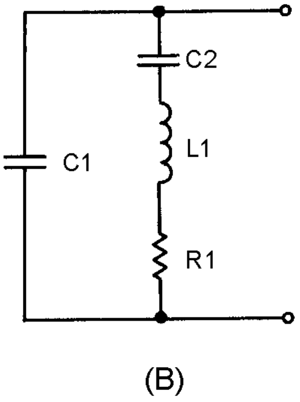


Figure 2-20B.—Quartz crystal and equivalent circuit.

At some frequency, the reactances of equivalent capacitor C1 and inductor L will be equal and the crystal will act as a series-tuned circuit. A series-tuned circuit has a minimum impedance at resonance (figure 2-21). Above resonance the series-tuned circuit acts INDUCTIVELY, and below resonance it acts CAPACITIVELY. In other words, the crystal unit has its lowest impedance at the series-resonance frequency. The impedance increases as the frequency is lowered because the unit acts as a capacitor. The impedance of the crystal unit also increases as the frequency is raised above the series-resonant point because the unit acts as an inductor. Therefore, the crystal unit reacts as a series-tuned circuit.

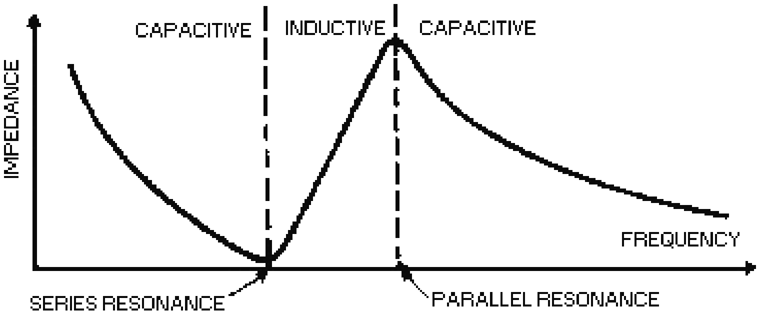


Figure 2-21.—Frequency response of a crystal.

Since the series-tuned circuit acts as an inductor above the resonant point, the crystal unit becomes equivalent to an inductor and is parallel with the equivalent capacitor C1 (view (B) of figure 2-20). At some frequency above the series-resonant point, the crystal unit will act as a parallel-tuned circuit. A parallel-tuned circuit has a MAXIMUM impedance at the parallel-resonant frequency and acts inductively below parallel resonance (figure 2-21). Therefore, at some frequency, depending upon the cut of the crystal, the crystal unit will act as a parallel-tuned circuit.

The frequency stability of crystal-controlled oscillators depends on the Q of the crystal. The Q of a crystal is very high. It may be more than 100 times greater than that obtained with an equivalent electrical circuit. The Q of the crystal is determined by the cut, the type of holder, and the accuracy of grinding. Commercially produced crystals range in Q from 5,000 to 30,000 while some laboratory experiment crystals range in Q up to 400,000.

Crystal-Controlled Armstrong Oscillator

The crystal-controlled Armstrong oscillator (figure 2-22) uses the series-tuned mode of operation. It works much the same as the Hartley oscillator except that frequency stability is improved by the crystal (in the feedback path). To operate the oscillator at different frequencies, you simply change crystals (each crystal operates at a different frequency).

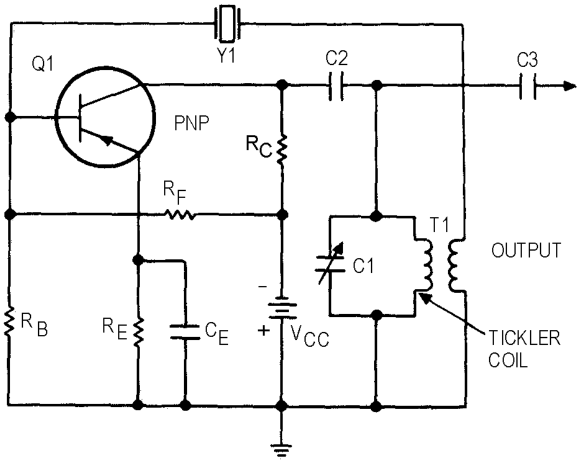


Figure 2-22.—Crystal-controlled Armstrong oscillator.

Variable capacitor C1 makes the circuit tunable to the selected crystal frequency. C1 is capable of tuning to a wide band of selected crystal frequencies. Regenerative feedback from the collector to base is through the mutual inductance between the transformer windings of T1. This provides the necessary 180-degree phase shift for the feedback signal. Resistors R_B, R_F, and R_C provide the base and collector bias voltage. Capacitor C_E bypasses ac variations around emitter resistor R_E.

At frequencies above and below the series-resonant frequency of the selected crystal, the impedance of the crystal increases and reduces the amount of feedback signal. This, in turn, prevents oscillations at frequencies other than the series-resonant frequency.

Crystal-Controlled Pierce Oscillator

The crystal-controlled PIERCE OSCILLATOR uses a crystal unit as a parallel-resonant circuit. The Pierce oscillator is a modified Colpitts oscillator. They operate in the same way except that the crystal unit replaces the parallel-resonant circuit of the Colpitts.

Figure 2-23 shows the common-base configuration of the Pierce oscillator. Feedback is supplied from the collector to the emitter through capacitor C1. Resistors R_B, R_C, and R_F provide the proper bias conditions for the circuit and resistor R_E is the emitter resistor. Capacitors C1 and C_E form a voltage divider connected across the output. Since no phase shift occurs in the common-base circuit, capacitor C1 feeds back a portion of the output signal to the emitter without a phase shift. The oscillating frequency is determined not only by the crystal but also by the parallel capacitance caused by capacitors C1 and C_E. This parallel capacitance affects the oscillator frequency by lowering it. Any change in capacitance of either C1 or C_E changes the frequency of the oscillator.

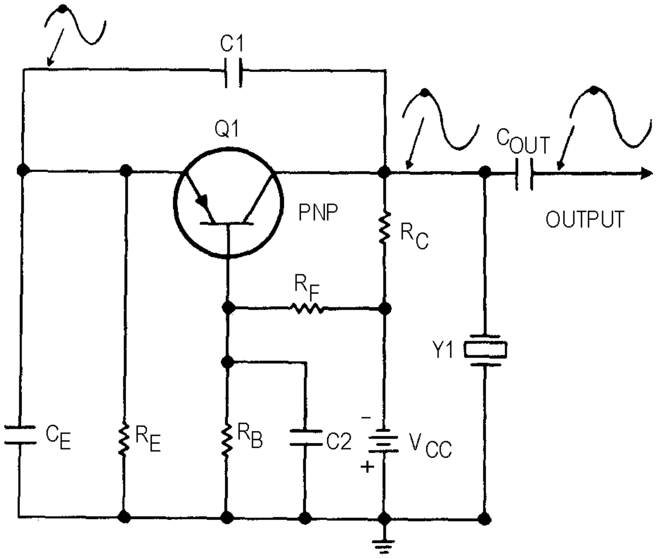


Figure 2-23.—Pierce oscillator, common-base configuration.

Figure 2-24 shows the common-emitter configuration of the Pierce oscillator. The resistors in the circuit provide the proper bias and stabilization conditions. The crystal unit and capacitors C1 and C2 determine the output frequency of the oscillator. The signal developed at the junction between Y1 and C1 is 180 degrees out of phase with the signal at the junction between Y1 and C2. Therefore, the signal at the Y1-C1 junction can be coupled back to the base of Q1 as a regenerative feedback signal to sustain oscillations.

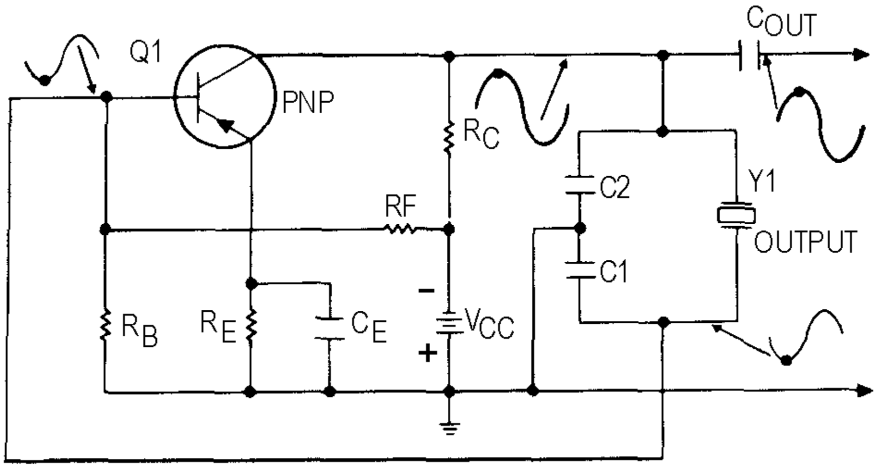


Figure 2-24.—Pierce oscillator, common-emitter configuration.

Q-18. What is the impedance of a crystal at its resonant frequency when it is used in the parallel mode?

Q-19. What is the impedance of a crystal at its resonant frequency when it is used in the series mode?

PULSED OSCILLATORS

A sinusoidal (sine-wave) oscillator is one that will produce output pulses at a predetermined frequency for an indefinite period of time; that is, it operates continuously. Many electronic circuits in equipment such as radar require that an oscillator be turned on for a specific period of time and that it remain in an off condition until required at a later time. These circuits are referred to as PULSED OSCILLATORS or RINGING OSCILLATORS. They are nothing more than sine-wave oscillators that are turned on and off at specific times.

Figure 2-25, view (A), shows a pulsed oscillator with the resonant tank in the emitter circuit. A positive input makes Q1 conduct heavily and current flow through L1; therefore no oscillations can take place. A negative-going input pulse (referred to as a gate) cuts off Q1, and the tank oscillates until the gate ends or until the ringing stops, whichever comes first.

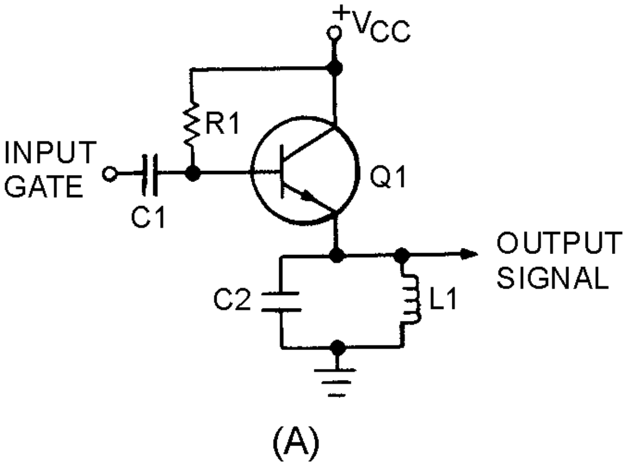
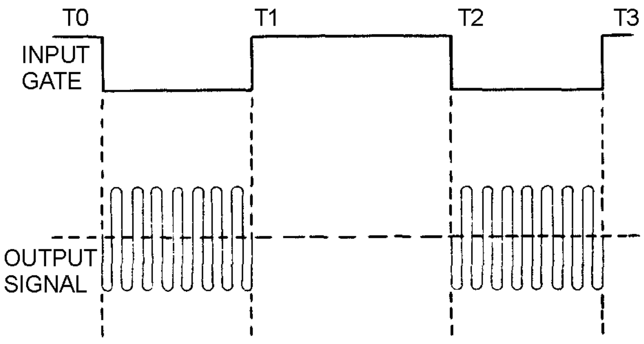


Figure 2-25A.—Pulsed oscillator.



(B)

Figure 2-25B.—Pulsed oscillator.

The waveforms in view (B) show the relationship of the input gate and the output signal from the pulsed oscillator. To see how this circuit operates, assume that the Q of the LC tank circuit is high enough to prevent damping. An output from the circuit is obtained when the input gate goes negative (T0 to T1 and T2 to T3). The remainder of the time (T1 to T2) the transistor conducts heavily and there is no output from the circuit. The width of the input gate controls the time for the output signal. Making the gate wider causes the output to be present (or ring) for a longer time.

Frequency of a Pulsed Oscillator

The frequency of a pulsed oscillator is determined by both the input gating signal and the resonant frequency of the tank circuit. When a sinusoidal oscillator is resonant at 1 megahertz, the output is 1 million cycles per second. In the case of a pulsed oscillator, the number of cycles present in the output is determined by the gating pulse width.

If a 1-megahertz oscillator is cut off for 1/2 second, or 50 percent of the time, then the output is 500,000 cycles at the 1 -megahertz rate. In other words, the frequency of the tank circuit is still 1 megahertz, but the oscillator is only allowed to produce 500,000 cycles each second.

The output frequency can be determined by controlling how long the tank circuit will oscillate. For example, suppose a negative input gate of 500 microseconds and a positive input gate of 999,500 microseconds (total of 1 second) are applied. The transistor will be cut off for 500 microseconds and the tank circuit will oscillate for that 500 microseconds, producing an output signal. The transistor will then conduct for 999,500 microseconds and the tank circuit will not oscillate during that time period. The 500 microseconds that the tank circuit is allowed to oscillate will allow only 500 cycles of the 1-megahertz tank frequency.

You can easily check this frequency by using the following formula:

$$t = \frac{1}{f}\text{(one cycle of resonant frequency)}$$

$t =$ time

$f =$ resonant frequency of tank circuit

One cycle of the 1-megahertz resonant frequency is equal to 1 microsecond.

$$\frac{1}{1{,}000{,}000} = .000001 \text{ or } 1 \times 10^{-6} \text{ seconds}$$

Then, by dividing the time for 1 cycle (1 microsecond) into gate length (500 microseconds), you will get the number of cycles (500).

There are several different varieties of pulsed oscillators for different applications. The schematic diagram shown in figure 2-25, view (A), is an emitter-loaded pulsed oscillator. The tank circuit can be placed in the collector circuit, in which case it is referred to as a collector-loaded pulsed oscillator. The difference between the emitter-loaded and the collector-loaded oscillator is in the output signal. The first alternation of an emitter-loaded npn pulsed oscillator is negative. The first alternation of the collector-loaded pulsed oscillator is positive. If a pnp is used, the oscillator will reverse the first alternation of both the emitter-loaded and the collector-loaded oscillator.

You probably have noticed by now that feedback has not been mentioned in this discussion. Remember that regenerative feedback was a requirement for sustained oscillations. In the case of the pulsed oscillator, oscillations are only required for a very short period of time. You should understand, however, that as the width of the input gate (which cuts off the transistor) is increased, the amplitude of the sine wave begins to decrease (dampen) near the end of the gate period because of the lack of feedback. If a long period of oscillation is required for a particular application, a pulsed oscillator with regenerative feedback is used. The principle of operation remains the same except that the feedback network sustains the oscillation period for the desired amount of time.

Q-20. Oscillators that are turned on and off at a specific time are known as what type of oscillators?

Q-21. What is the polarity of the first alternation of the tank circuit in an emitter-loaded npn pulsed oscillator?

HARMONICS

From your study of oscillators, you should know that the oscillator will oscillate at the resonant frequency of the tank circuit. Although the tank circuit is resonant at a particular frequency, many other frequencies other than the resonant frequency are present in the oscillator. These other frequencies are referred to as HARMONICS. A harmonic is defined as a sinusoidal wave having a frequency that is a multiple of the fundamental frequency. In other words, a sine wave that is twice that fundamental frequency is referred to as the SECOND HARMONIC.

What you must remember is that the current in circuits operating at the resonant frequency is relatively large in amplitude. The harmonic frequency amplitudes are relatively small. For example, the second harmonic of a fundamental frequency has only 20 percent of the amplitude of the resonant frequency. A third harmonic has perhaps 10 percent of the amplitude of the fundamental frequency.

One useful purpose of harmonics is that of frequency multiplication. It can be used in circuits to multiply the fundamental frequency to a higher frequency. The need for frequency-multiplier circuits results from the fact that the frequency stability of most oscillators decreases as frequency increases. Relatively good stability can be achieved at the lower frequencies. Thus, to achieve optimum stability, an oscillator is operated at a low frequency, and one or more stages of multiplication are used to raise the signal to the desired operating frequency.

FREQUENCY MULTIPLICATION

FREQUENCY MULTIPLIERS are special class C amplifiers that are biased at 3 to 10 times the normal cutoff bias. They are used to generate a frequency that is a multiple (harmonic) of a lower frequency. Such circuits are called frequency multipliers or harmonic generators.

Figure 2-26 illustrates a frequency multiplier known as a FREQUENCY DOUBLER or SECOND HARMONIC GENERATOR. As illustrated, the input is 1 megahertz and the output is 2 megahertz, or twice the input frequency. In other words, the second harmonic of 1 megahertz is 2 megahertz. The third harmonic (frequency tripler) would be 3 megahertz, or 3 times the input signal. The fourth harmonic (quadruplet) would be 4 megahertz, or 4 times the 1-megahertz input signal. The fourth harmonic generator (frequency quadruplet) is normally as high in multiplication as is practical, because at harmonics higher than the fourth, the output diminishes to a very weak output signal.

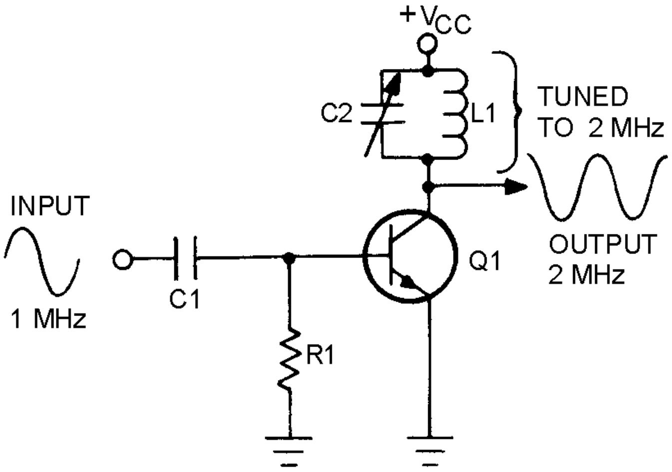


Figure 2-26.—Frequency doubler.

Frequency multipliers are operated by the pulses of collector current produced by a class C amplifier. Although the collector current flows in pulses, the alternating collector voltage is sinusoidal because of the action of the tank circuit. When the output tank circuit is tuned to the required harmonic, the tank circuit acts as a filter, accepting the desired frequency and rejecting all others.

Figure 2-27 illustrates the waveforms in a typical doubler circuit. You can see that the pulses of collector current are the same frequency as the input signal. These pulses of collector current energize the tank circuit and cause it to oscillate at twice the base signal frequency. Between the pulses of collector current, the tank circuit continues to oscillate. Therefore, the tank circuit receives a current pulse for every other cycle of its output.

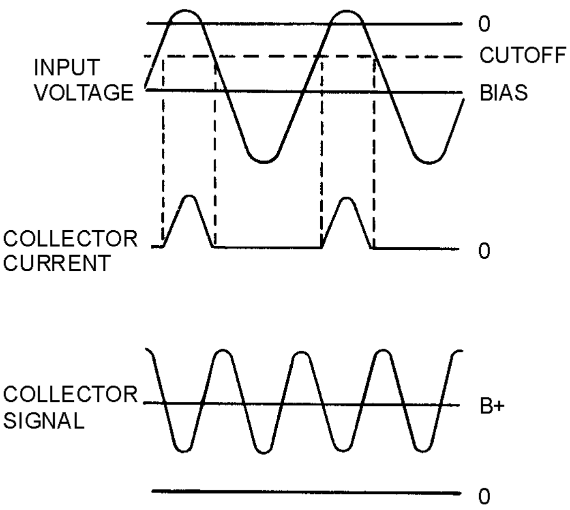


Figure 2-27.—Frequency doubler waveforms.

Buffer Amplifier

Coupling the resonant frequency from the oscillator by different coupling methods also affects the oscillator frequency and amplitude. A BUFFER AMPLIFIER decreases the loading effect on the oscillator by reducing the interaction (matching impedance) between the load and the oscillator.

Figure 2-28 is the schematic diagram of a buffer amplifier. This circuit is a common-collector amplifier. A common-collector amplifier has a high input impedance and a low output impedance. Since the output of an oscillator is connected to the high impedance of the common-collector amplifier, the buffer has little effect on the operation of the oscillator. The output of the common-collector buffer is then connected to an external load; therefore, the changes in the output load cannot reflect back to the oscillator circuit. Thus, the buffer amplifier reduces interaction between the load and the oscillator. Figure 2-29 illustrates a shunt-fed Hartley oscillator with a buffer amplifier. This is "one-way" coupling since the oscillator signal is coupled forward, but load changes are not coupled back to the oscillator.

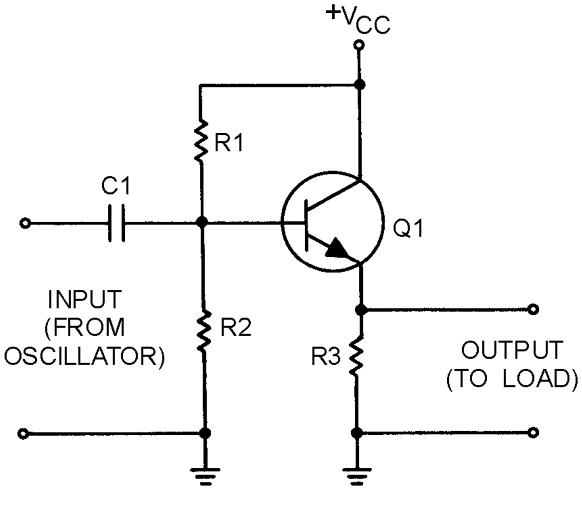


Figure 2-28.—Buffer amplifier.

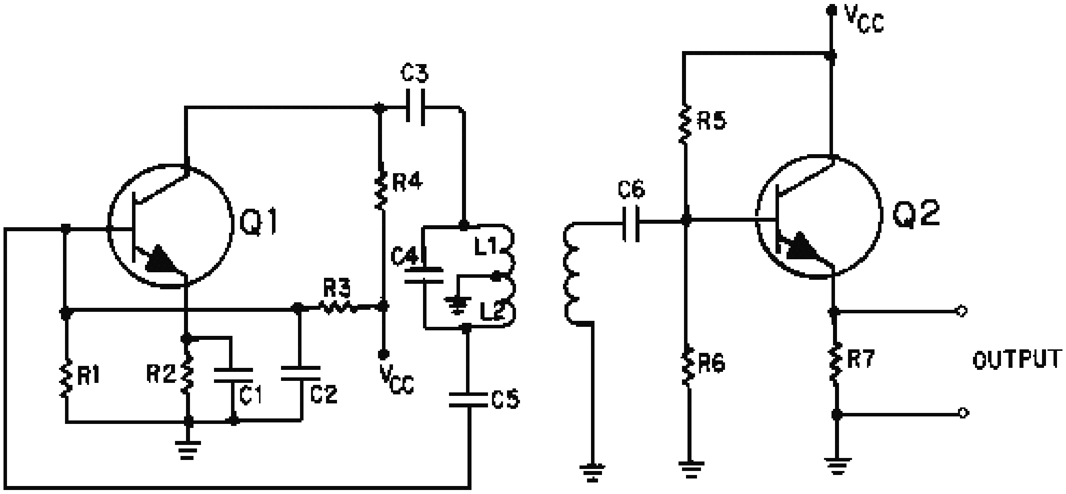


Figure 2-29.—Shunt-fed Hartley oscillator with buffer amplifier.

Q-22. What is the frequency that is twice the fundamental frequency?

Q-23. What is the purpose of the buffer amplifier?

SUMMARY

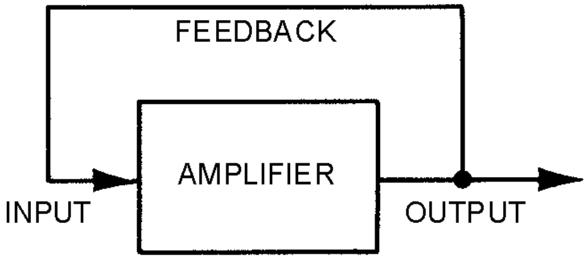
This chapter has presented information on oscillators. The information that follows summarizes the important points of this chapter.

WAVE GENERATORS can be classified according to the SINUSOIDAL or NONSINUSOIDAL waveforms produced.

SINUSOIDAL WAVE GENERATORS (oscillators) produce a sine wave of constant amplitude and frequency. There are three ways to control the frequency of sine-wave generators: (1) RC NETWORKS, (2) LC NETWORKS, and (3) CRYSTALS.

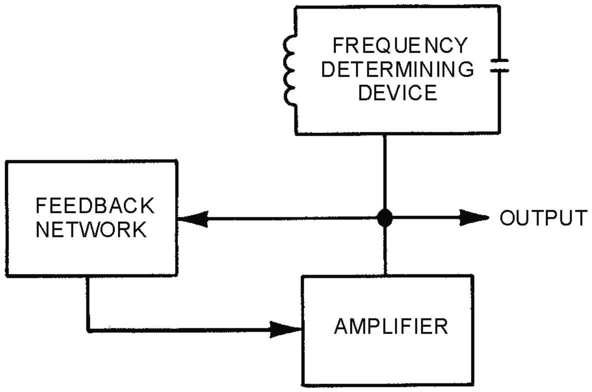
NONSINUSOIDAL WAVE GENERATORS (oscillators) generate complex waveforms such as SQUARE WAVES, RECTANGULAR WAVES, SAWTOOTH WAVES, TRAPEZOIDAL WAVES, and TRIGGERS. Nonsinusoidal wave generators are often called RELAXATION OSCILLATORS.

A **BASIC OSCILLATOR** can be thought of as an amplifier that provides itself with a signal input.



An **OSCILLATOR** is a device that converts dc power to ac power at a predetermined frequency.

The requirements for an oscillator are AMPLIFICATION, REGENERATIVE FEEDBACK, and a FREQUENCY-DETERMINING NETWORK.



An oscillator has two stability requirements, AMPLITUDE STABILITY and FREQUENCY STABILITY.

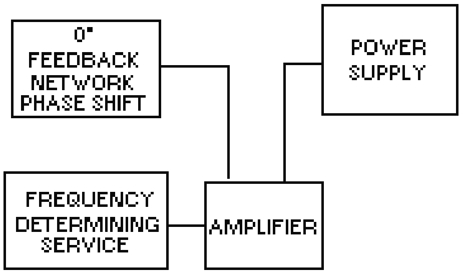
FEEDBACK is the process of transferring energy from a high-level point in a system to a low-level point. Feedback that aids the input signal is REGENERATIVE or POSITIVE. Feedback that opposes the input signal is DEGENERATIVE or NEGATIVE.

The three basic circuit configurations used for oscillators are **COMMON COLLECTOR**, **COMMON BASE**, and **COMMON EMITTER**.

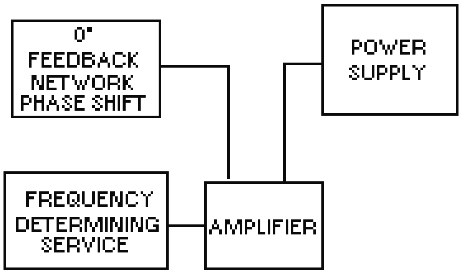
In the **COMMON-COLLECTOR** configuration there is no PHASE SHIFT between input and output. It is not necessary for the feedback network to provide a phase shift. Voltage gain is less than unity (one) and power gain is low so it is very seldom used as an oscillator.

In the **COMMON-BASE** configuration, there is no PHASE SHIFT between input and output. It is not necessary for the feedback network to provide a phase shift. Voltage and power gain are high enough to give satisfactory operation in an oscillator circuit.

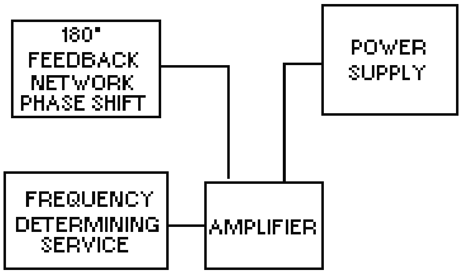
In the **COMMON-EMITTER** configuration, there is a 180-degree PHASE SHIFT between input and output. The feedback network must provide another phase shift of 180 degrees. It has a high power gain.



(A) COMMON- COLECTOR CONFIGURATION



(B) COMMON-BASE CONFIGURATION



(C) COMMON-EMITTER CONFIGURATION

The **ARMSTRONG OSCILLATOR** is used to produce a sine-wave output of constant amplitude and fairly constant frequency.

An oscillator in which dc power is supplied to the transistor through the tank circuit, or a portion of the tank circuit, is SERIES FED.

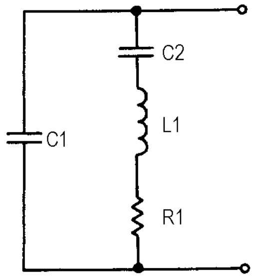
An oscillator in which dc power is supplied to the transistor through a path separate and parallel to the tank circuit is PARALLEL or SHUNT FED.

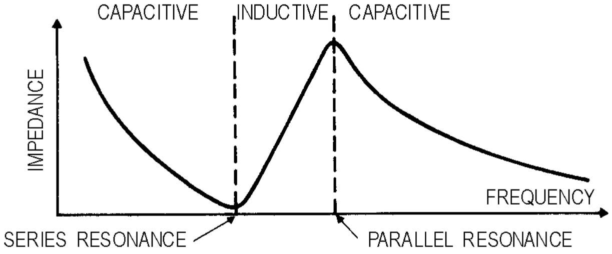
The **HARTLEY OSCILLATOR** is used to produce a sine-wave output of constant amplitude and fairly constant frequency.

The **COLPITTS OSCILLATOR** is used to produce a sine-wave output of constant amplitude and fairly constant frequency within the rf range. The identifying features of the Colpitts oscillator are the split capacitors.

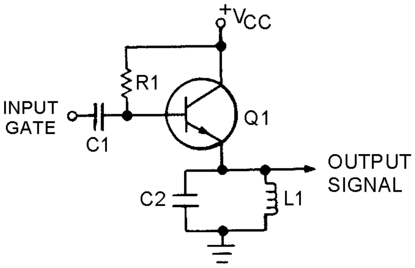
The **RESISTIVE-CAPACITIVE (RC) FEEDBACK OSCILLATOR** is used to produce a sine-wave output of relatively constant amplitude and frequency. It uses RC networks to produce feedback and eliminate the need for inductors in the resonant circuit.

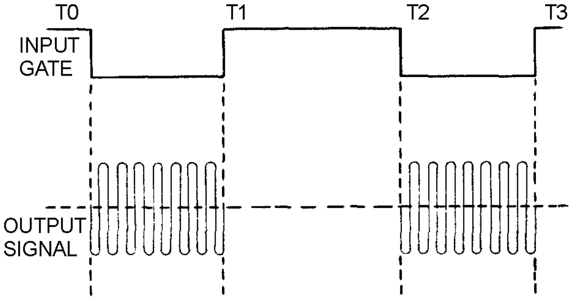
CRYSTAL OSCILLATORS are those oscillators that use a specially cut crystal to control the frequency. The crystal can act as either a capacitor or inductor, a series-tuned circuit, or a parallel-tuned circuit.





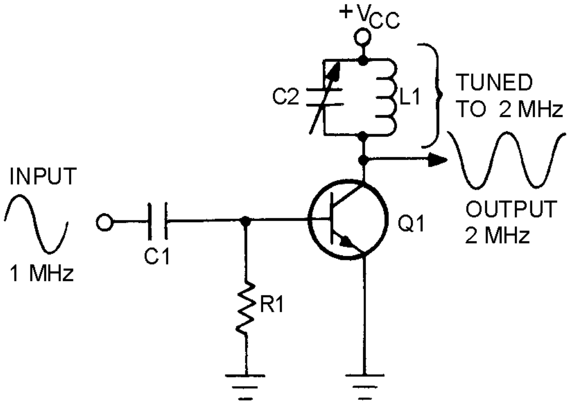
PULSED OSCILLATORS are sinusoidal oscillators that are turned on and off for a specific time duration. The frequency of a pulsed oscillator is determined by both the input gating pulse and the resonant frequency of the tank circuit.



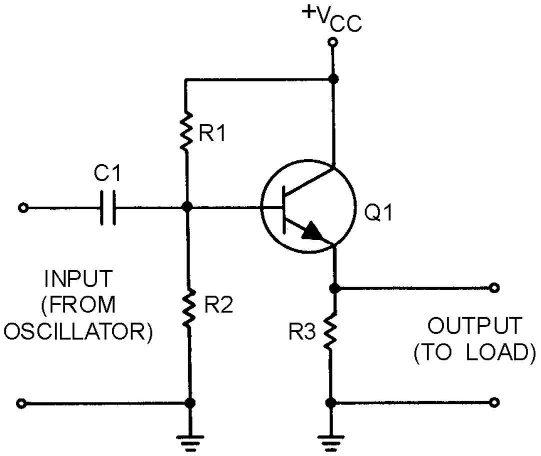


A **HARMONIC** is a sinusoidal wave having a frequency that is a multiple of the fundamental frequency.

FREQUENCY MULTIPLIERS (HARMONIC GENERATORS) are special class C amplifiers that are biased at 3 to 10 times the normal cutoff. They are used to generate a frequency that is a multiple or harmonic of a lower frequency.



A **BUFFER AMPLIFIER** decreases the loading effect on the oscillator by reducing the interaction between the load and the oscillator.



ANSWERS TO QUESTIONS Q1. THROUGH Q23.

A-1. Sinusoidal and nonsinusoidal.

A-2. RC, LC, and crystal.

A-3. Relaxation oscillators.

A-4. Oscillator.

A-5. Amplification, regenerative feedback, and frequency-determining device.

A-6. Regenerative or positive.

A-7. Inductive and capacitive.

A-8. Armstrong.

A-9. Hartley.

A-10. Colpitts.

A-11. Common collector (CC), common emitter (CE), and common base (CB).

A-12. Feedback coil. Armstrong uses a separate coil. Hartley uses a tapped coil.

A-13. In the series-fed Hartley oscillator, dc flows through the tank circuit.

A-14. Split capacitors.

A-15. Resistor-capacitor networks.

A-16. Because of the losses encountered in the RC networks.

A-17. Four-section.

A-18. Maximum.

A-19. Minimum.

A-20. Pulsed oscillators.

A-21. Negative.

A-22. Second harmonic.

A-23. Reduce interaction between oscillator and load.

CHAPTER 3

WAVEFORMS AND WAVE GENERATORS

LEARNING OBJECTIVES

Upon completion of this chapter you will be able to:

1. Explain the operation of a stable, monostable, and bistable multivibrators.
2. Explain the operation of a blocking oscillator.
3. Explain the operation of a sawtooth generator.
4. Explain the operation of a trapezoidal wave generator.
5. Explain how the jump voltage is produced in a trapezoidal wave generator.

WAVEFORMS

This chapter will present methods of generating waveforms. Before you begin to study how waveforms are generated, you need to know the basic characteristics of waveforms. This section will discuss basic periodic waveforms.

PERIODIC WAVEFORMS

A waveform which undergoes a pattern of changes, returns to its original pattern, and repeats the same pattern of changes is called a PERIODIC waveform. Periodic waveforms are nonsinusoidal except for the sine wave. Periodic waveforms which will be discussed are the sine wave, square wave, rectangular wave, sawtooth wave, trapezoidal wave, and trigger pulses.

Sine Wave

Each completed pattern of a periodic waveform is called a CYCLE, as shown by the SINE WAVE in figure 3-1, view (A). Sine waves were presented in NEETS, Module 2, *Alternating Current and Transformers*, Chapter 1.

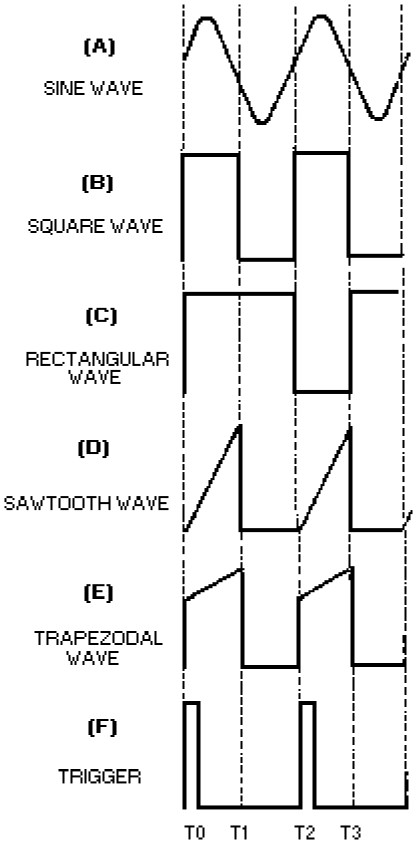


Figure 3-1.—Periodic waveforms.

Square Wave

A SQUARE WAVE is shown in figure 3-1, view (B). As shown, it has two alternations of equal duration and a square presentation for each complete cycle. Figure 3-2 shows a breakdown of the square wave and is the figure you should view throughout the square wave discussion. The amplitude is measured vertically. The time for a complete cycle is measured between corresponding points on the wave (T0 to T2, or T1 to T3).

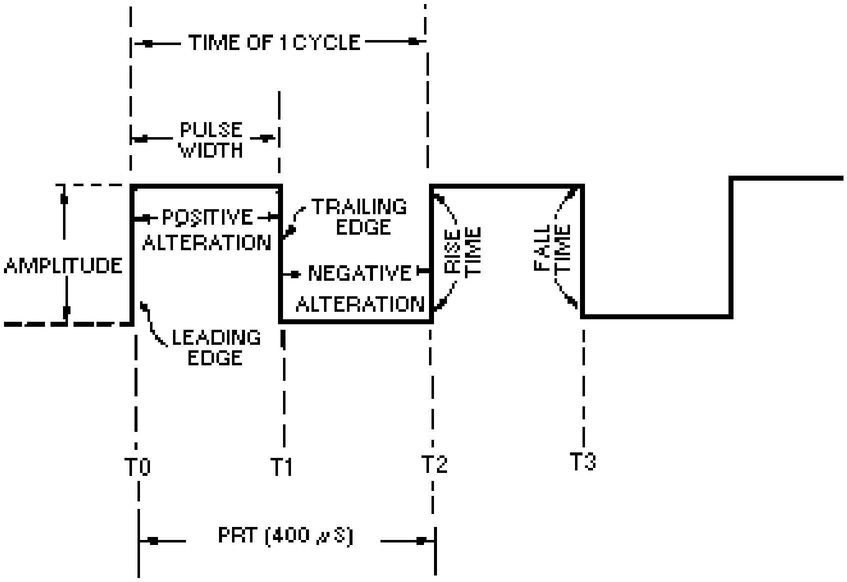


Figure 3-2.—Square wave.

One alternation is called a PULSE. The time for one complete cycle is called the PULSE-REPETITION TIME (prt). The number of times in 1 second that the cycle repeats itself is called the PULSE-REPETITION FREQUENCY (prf) or PULSE-REPETITION RATE (prr). If each alternation in figure 3-2 is 200 microseconds (μs), the prt will be 400 microseconds, and the prf will be 2,500 hertz. The following examples are provided to illustrate the mathematical relationship between prf and prt:

Given:

$$\mathrm{prf} = \frac{1}{\mathrm{prt}}$$

Where:

$$\mathrm{prf} = 400\mu s$$

Solution:

$$\mathrm{prf} = \frac{1}{\mathrm{prt}}$$

$$\mathrm{prf} = \frac{1}{400\mu s}$$

$$\mathrm{prf} = 2{,}500\ \mathrm{Hz}$$

You should readily see that prt is just the inverse of prf. Therefore: Given:

$$\text{prt} = \frac{1}{\text{prf}}$$

Where:

$\text{prf} = 2{,}500 \text{ Hz}$

Solution:

$$\text{prt} = \frac{1}{\text{prf}}$$

$$\text{prt} = \frac{1}{2{,}500 \text{ Hz}}$$

$$\text{prt} = 400 \text{ microseconds}$$

The length of the pulse measured in time (T0 to T1) is referred to as the PULSE WIDTH (pw). The left side of the pulse is called the LEADING EDGE and the right side is called the TRAILING EDGE.

Time is required for a voltage or current to change in amplitude. The interval of time needed for the voltage to go from 0 to 100 percent (or from 100 to 0 percent) of its maximum value is called the TRANSIENT INTERVAL. The two types of transient intervals are RISE TIME and FALL TIME. Rise time is more accurately defined as the time required for the voltage to build up from 10 percent to 90 percent of the maximum amplitude point. Fall time is the time required for the voltage to drop from 90 percent to 10 percent of the maximum amplitude point.

In this text you will be presented with information in which waveforms appear to have instantaneous rise and fall times. This is done to simplify the presentation of the material. In reality these waveforms do have rise and fall times (transient intervals).

Rectangular Wave

A rectangular wave is similar to the square wave. The difference is that in the rectangular waveform, the two alternations of the waveform are of unequal time duration. Figure 3-1, view (C), shows that the negative alternation (pulse) is shorter (in time) than the positive alternation. The negative alternation could be represented as the longer of the two alternations. Either way, the appearance is that of a rectangle.

Sawtooth Wave

The SAWTOOTH waveform is shown in figure 3-1, view (D). A sawtooth wave resembles the teeth of a saw blade. There is a rapid vertical rise of voltage from T0 to T1, which is linear (straight). At T1 this voltage abruptly falls (essentially no time used) to its previous static value. The voltage remains at this value until T2 when it again has a linear rise. You can see this action in an oscilloscope where there are two voltage input locations, vertical and horizontal. If you apply a linear voltage to the vertical input, the electron beam will be forced to move in a vertical direction on the crt. A linear voltage applied to the horizontal input will cause the electron beam to move horizontally across the crt. The application of two linear voltages, one to the vertical input and one to the horizontal input at the same time, will cause the beam to move in both a vertical and horizontal (diagonal) direction at the same time. This then is how a sawtooth wave is made to appear on an oscilloscope. You should refer to NEETS, Module 6, *Electronic Emission, Tubes, and Power Supplies*, Chapter 2, for a review of oscilloscopes.

Trapezoidal Wave

A TRAPEZOIDAL wave looks like a sawtooth wave on top of a square or rectangular wave, as shown in figure 3-1, view (E). The leading edge of a trapezoidal wave is called the JUMP voltage. The next portion of the wave is the linear rise or SLOPE. The trailing edge is called the FALL or DECAY. A trapezoidal wave is used to furnish deflection current in the electromagnetic cathode ray tube and is found in television and radar display systems. Electromagnetic cathode ray tubes use coils for the deflection system, and a linear rise in current is required for an accurate horizontal display. The square or rectangular wave portion provides the jump voltage for a linear rise in current through the resistance of the coil. This will be explained further in a discussion of the trapezoidal sweep generator.

Triggers

A trigger is a very narrow pulse, as shown in figure 3-1, view (F). Trigger pulses are normally used to turn other circuits on or off.

WAVEFORM GENERATOR

Nonsinusoidal oscillators generate complex waveforms such as those just discussed. Because the outputs of these oscillators are generally characterized by a sudden change, or relaxation, these oscillators are often called RELAXATION OSCILLATORS. The pulse repetition rate of these oscillators is usually governed by the charge and discharge timing of a capacitor in series with a resistor. However, some oscillators contain inductors that, along with circuit resistance, affect the output frequency. These RC and LC networks within oscillator circuits are used for frequency determination. Within this category of relaxation oscillators are MULTIVIBRATORS, BLOCKING OSCILLATORS, and SAWTOOTH- and TRAPEZOIDAL-WAVE GENERATORS.

Many electronic circuits are not in an "on" condition all of the time. In computers, for example, waveforms must be turned on and off for specific lengths of time. The time intervals vary from tenths of microseconds to several thousand microseconds. Square and rectangular waveforms are normally used to turn such circuits on and off because the sharp leading and trailing edges make them ideal for timing purposes.

MULTIVIBRATORS

The type of circuit most often used to generate square or rectangular waves is the multivibrator. A multivibrator, as shown in figure 3-3, is basically two amplifier circuits arranged with regenerative feedback. One of the amplifiers is conducting while the other is cut off.

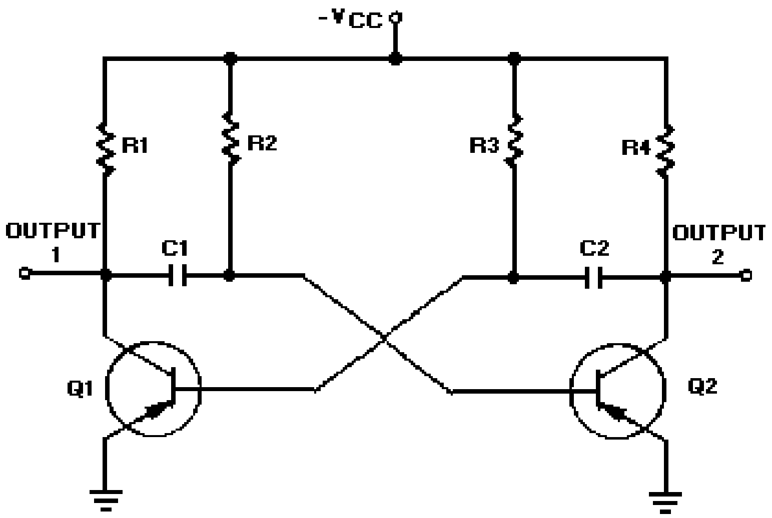


Figure 3-3.—Astable Multivibrator.

When an input signal to one amplifier is large enough, the transistor can be driven into cutoff, and its collector voltage will be almost V_{CC}. However, when the transistor is driven into saturation, its collector voltage will be about 0 volts. A circuit that is designed to go quickly from cutoff to saturation will produce a square or rectangular wave at its output. This principle is used in multivibrators.

Multivibrators are classified according to the number of steady (stable) states of the circuit. A steady state exists when circuit operation is essentially constant; that is, one transistor remains in conduction and the other remains cut off until an external signal is applied. The three types of multivibrators are the ASTABLE, MONOSTABLE, and BISTABLE.

The astable circuit has no stable state. With no external signal applied, the transistors alternately switch from cutoff to saturation at a frequency determined by the RC time constants of the coupling circuits.

The monostable circuit has one stable state; one transistor conducts while the other is cut off. A signal must be applied to change this condition. After a period of time, determined by the internal RC components, the circuit will return to its original condition where it remains until the next signal arrives.

The bistable multivibrator has two stable states. It remains in one of the stable states until a trigger is applied. It then FLIPS to the other stable condition and remains there until another trigger is applied. The multivibrator then changes back (FLOPS) to its first stable state.

Q1. What type circuit is used to produce square or rectangular waves?

Q2. What type of multivibrator does not have a stable state?

Q3. What type of multvibrator has one stable state?

Q4. What type of multivibrator has two stable states?

Astable Multivibrator

An astable multivibrator is also known as a FREE-RUNNING MULTIVIBRATOR. It is called free-running because it alternates between two different output voltage levels during the time it is on. The output remains at each voltage level for a definite period of time. If you looked at this output on an oscilloscope, you would see continuous square or rectangular waveforms. The astable multivibrator has two outputs, but NO inputs.

Let's look at the multivibrator in figure 3-3 again. This is an astable multivibrator. The astable multivibrator is said to oscillate. To understand why the astable multivibrator oscillates, assume that transistor Q1 saturates and transistor Q2 cuts off when the circuit is energized. This situation is shown in figure 3-4. We assume Q1 saturates and Q2 is in cutoff because the circuit is symmetrical; that is, R1 = R4, R2 = R3, C1 = C2, and Q1 = Q2. It is impossible to tell which transistor will actually conduct when the circuit is energized. For this reason, either of the transistors may be assumed to conduct for circuit analysis purposes.

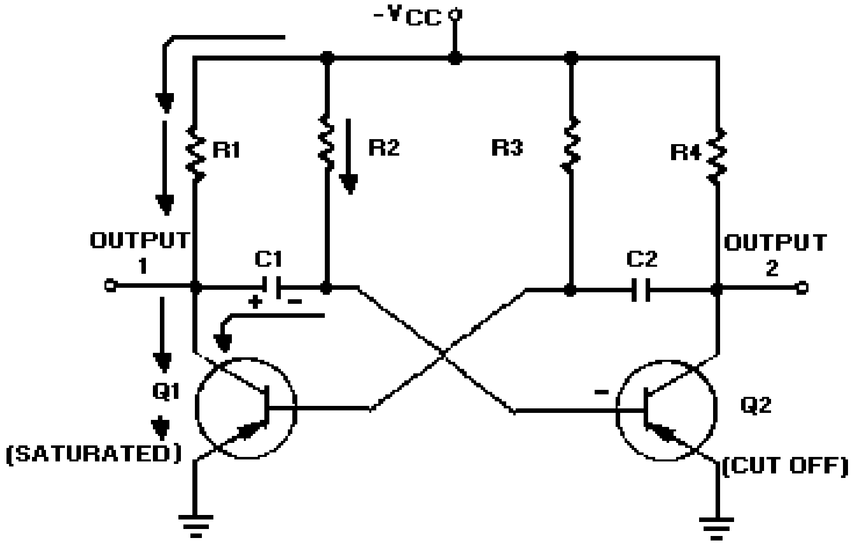


Figure 3-4.—Astable multivibrator (Q1 saturated).

Essentially, all the current in the circuit flows through Q1; Q1 offers almost no resistance to current flow. Notice that capacitor C1 is charging. Since Q1 offers almost no resistance in its saturated state, the rate of charge of C1 depends only on the time constant of R2 and C1 (recall that TC = RC). Notice that the right-hand side of capacitor C1 is connected to the base of transistor Q2, which is now at cutoff.

Let's analyze what is happening. The right-hand side of capacitor C1 is becoming increasingly negative. If the base of Q2 becomes sufficiently negative, Q2 will conduct. After a certain period of time, the base of Q2 will become sufficiently negative to cause Q2 to change states from cutoff to conduction. The time necessary for Q2 to become saturated is determined by the time constant R2C1.

The next state is shown in figure 3-5. The negative voltage accumulated on the right side on capacitor C1 has caused Q2 to conduct. Now the following sequence of events takes place almost instantaneously. Q2 starts conducting and quickly saturates, and the voltage at output 2 changes from approximately $-V_{CC}$ to approximately 0 volts. This change in voltage is coupled through C2 to the base of Q1, forcing Q1 to cutoff. Now Q1 is in cutoff and Q2 is in saturation. This is the circuit situation shown in figure 3-6.

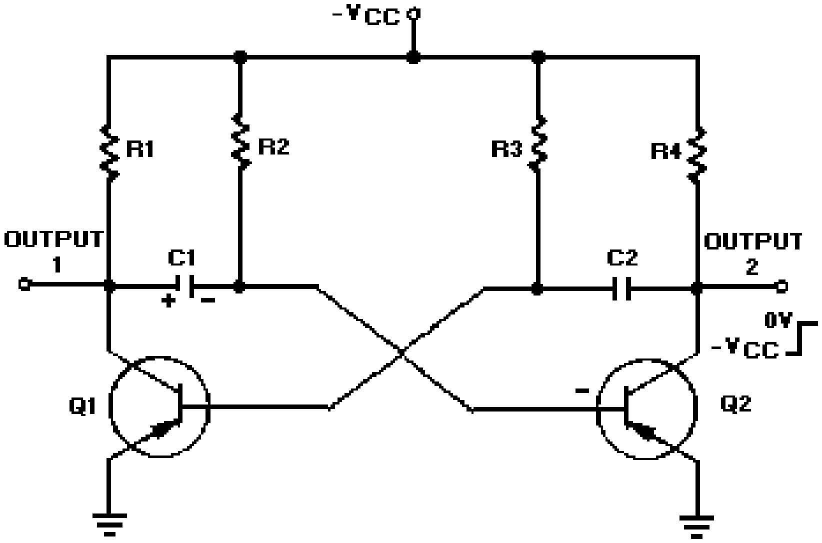


Figure 3-5.—Astable multivibrator.

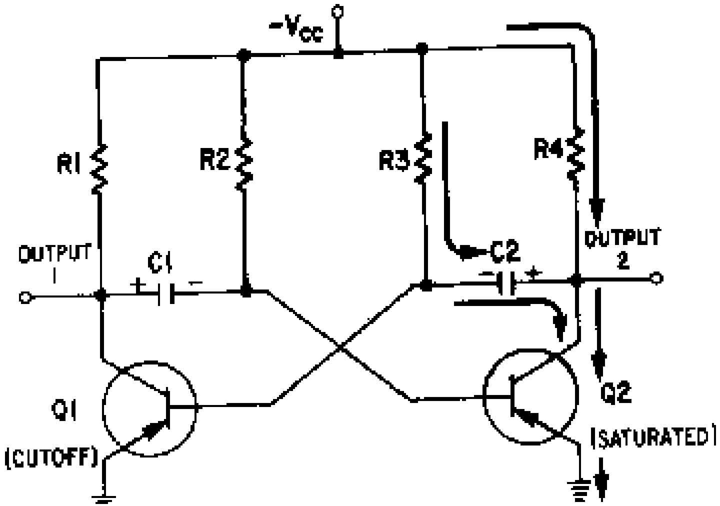


Figure 3-6.—Astable multivibrator. (Q2 saturated).

Notice that figure 3-6 is the mirror image of figure 3-4. In figure 3-6 the left side of capacitor C2 becomes more negative at a rate determined by the time constant R3C2. As the left side of C2 becomes more negative, the base of Q1 also becomes more negative. When the base of Q1 becomes negative enough to allow Q1 to conduct, Q1 will again go into saturation. The resulting change in voltage at output 1 will cause Q2 to return to the cutoff state.

Look at the output waveform from transistor Q2, as shown in figure 3-7. The output voltage (from either output of the multivibrator) alternates from approximately 0 volts to approximately $-V_{CC}$, remaining in each state for a definite period of time. The time may range from a microsecond to as much as a second or two. In some applications, the time period of higher voltage ($-V_{CC}$) and the time period of lower voltage (0 volts) will be equal. Other applications require differing higher- and lower-voltage times. For example, timing and gating circuits often have different pulse widths as shown in figure 3-8.

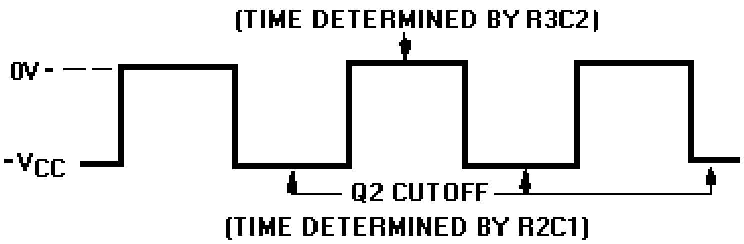


Figure 3-7.—Square wave output from Q2.

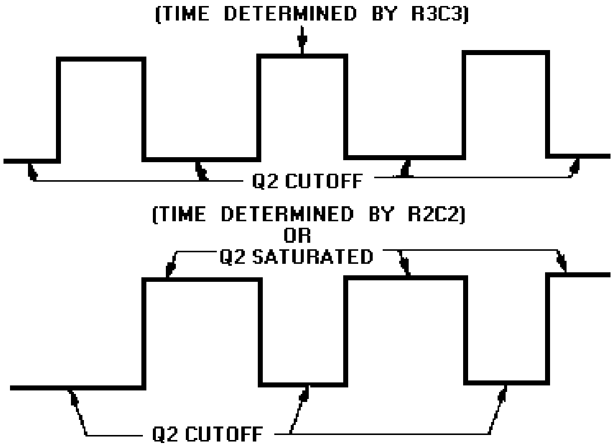


Figure 3-8.—Rectangular waves.

FREQUENCY STABILITY.—Some astable multivibrators must have a high degree of frequency stability. One way to obtain a high degree of frequency stability is to apply triggers. Figure 3-9, view (A), shows the diagram of a triggered, astable multivibrator. At time T0, a negative input trigger to the base of Q1 (through C1) causes Q1 to go into saturation, which drives Q2 to cutoff. The circuit will remain in this condition as long as the base voltage of Q2 is positive. The length of time the base of Q2 will remain positive is determined by C3, R3, and R6. Observe the parallel paths for C3 to discharge.

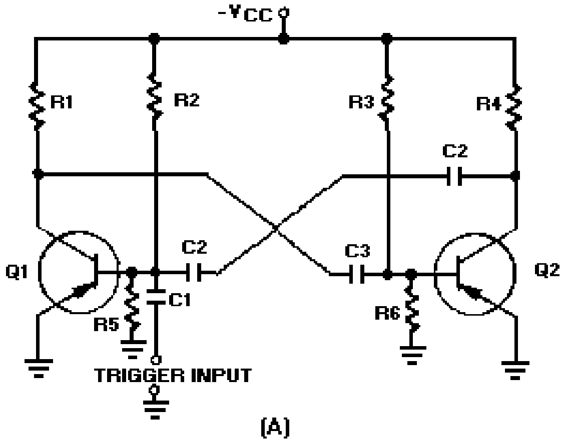


Figure 3-9A.—Triggered astable multivibrator and output.

View (B) of figure 3-9 shows the waveforms associated with the circuit. At time T1, Q2 comes out of cutoff and goes into saturation. Also, Q1 is caused to come out of saturation and is cut off. The base voltage waveform of Q1 shows a positive potential that is holding Q1 at cutoff. This voltage would normally hold Q1 at cutoff until a point between T2 and T3. However, at time T2 another trigger is applied to the base of Q1, causing it to begin conducting. Q1 goes into saturation and Q2 is caused to cut off. This action repeats each time a trigger (T2, T4, T6) is applied.

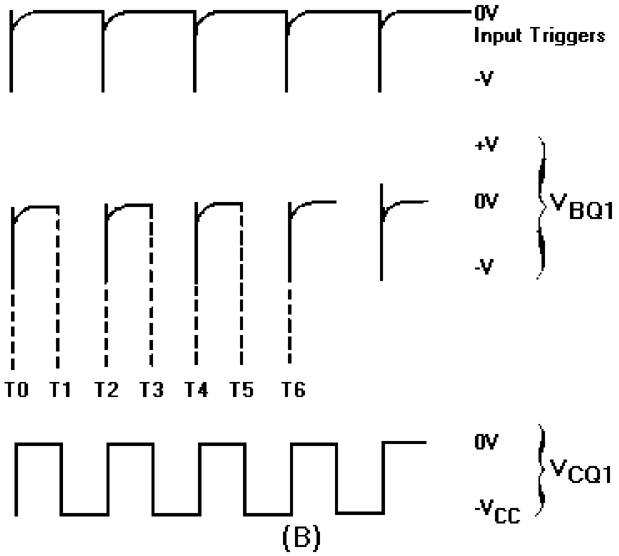


Figure 3-9B.—Triggered astable multivibrator and output.

The prt of the input triggers must be shorter than the natural free-running prt of the astable multivibrator, or the trigger prf must be slightly higher than the free-running prf of the circuit. This is to make certain the triggers control the prt of the output.

Monostable Multivibrator

The monostable multivibrator (sometimes called a ONE-SHOT MULTIVIBRATOR) is a square- or rectangular-wave generator with just one stable condition. With no input signal (quiescent condition) one amplifier conducts and the other is in cutoff. The monostable multivibrator is basically used for pulse stretching. It is used in computer logic systems and communication navigation equipment.

The operation of the monostable multivibrator is relatively simple. The input is triggered with a pulse of voltage. The output changes from one voltage level to a different voltage level. The output remains at this new voltage level for a definite period of time. Then the circuit automatically reverts to its original condition and remains that way until another trigger pulse is applied to the input. The monostable multivibrator actually takes this series of input triggers and converts them to uniform square pulses, as shown in figure 3-10. All of the square output pulses are of the same amplitude and time duration.

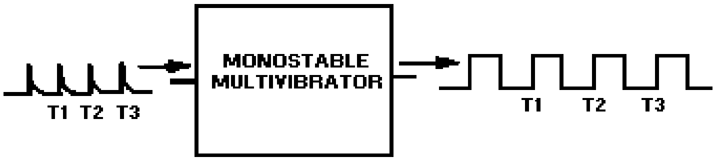


Figure 3-10.—Monostable multivibrator block diagram.

The schematic for a monostable multivibrator is shown in figure 3-11. Like the astable multivibrator, one transistor conducts and the other cuts off when the circuit is energized.

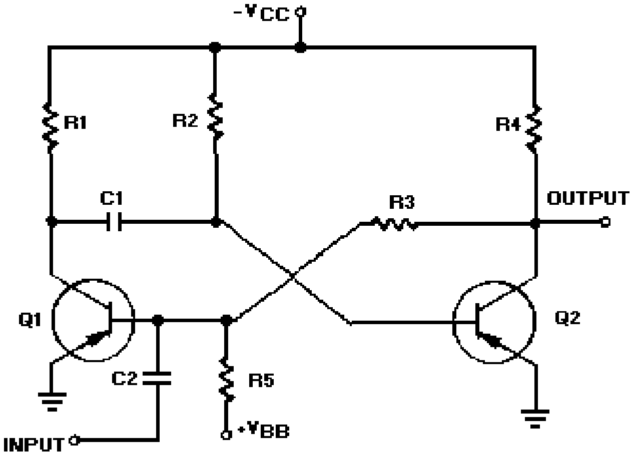


Figure 3-11.—Monostable multivibrator schematic.

Recall that when the astable multivibrator was first energized, it was impossible to predict which transistor would initially go to cutoff because of circuit symmetry. The one-shot circuit is not symmetrical like the astable multivibrator. Positive voltage V_{BB} is applied through R5 to the base of Q1. This positive voltage causes Q1 to cut off. Transistor Q2 saturates because of the negative voltage applied from $-V_{CC}$ to its base through R2. Therefore, Q1 is cut off and Q2 is saturated before a trigger pulse is applied, as shown in figure 3-12. The circuit is shown in its stable state.

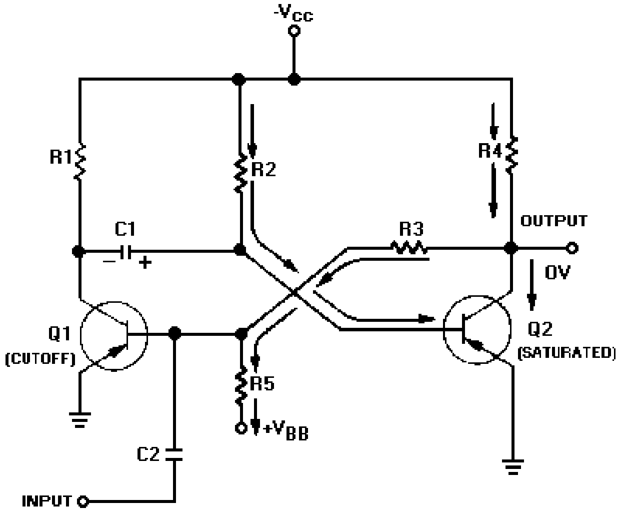


Figure 3-12.—Monostable multivibrator (stable state).

Let's take a more detailed look at the circuit conditions in this stable state (refer to figure 3-12). As stated above, Q1 is cut off, so no current flows through R1, and the collector of Q1 is at $-V_{CC}$. Q2 is saturated and has practically no voltage drop across it, so its collector is essentially at 0 volts. R5 and R3 form a voltage divider from V_{BB} to the ground potential at the collector of Q2. The tie point between these two resistors will be positive. Thus, the base of Q1 is held positive, ensuring that Q1 remains cutoff. Q2 will remain saturated because the base of Q2 is very slightly negative as a result of the voltage drop across R2. If the collector of Q1 is near $-V_{CC}$ and the base of Q2 is near ground, C1 must be charged to nearly V_{CC} volts with the polarity shown.

Now that all the components and voltages have been described for the stable state, let us see how the circuit operates (see figure 3-13). Assume that a negative pulse is applied at the input terminal. C2 couples this voltage change to the base of Q1 and starts Q1 conducting. Q1 quickly saturates, and its collector voltage immediately rises to ground potential. This sharp voltage increase is coupled through C1 to the base of Q2, causing Q2 to cut off; the collector voltage of Q2 immediately drops to V_{CC}. The voltage divider formed by R5 and R3 then holds the base of Q1 negative, and Q1 is locked in saturation.

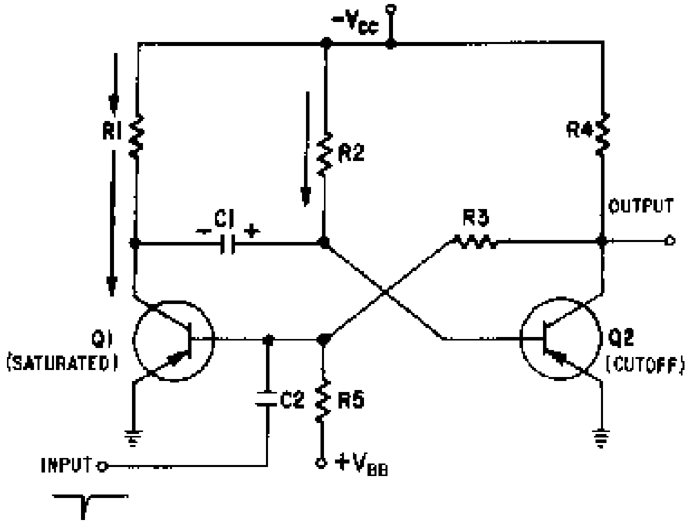


Figure 3-13.—Monostable multivibrator (triggered).

The one-shot multivibrator has now been turned on by applying a pulse at the input. It will turn itself off after a period of time. To see how it does this, look at figure 3-13 again. Q1 is held in saturation by the negative voltage applied through R3 to its base, so the circuit cannot be turned off here. Notice that the base of Q2 is connected to C1. The positive charge on C1 keeps Q2 cutoff. Remember that a positive voltage change (essentially a pulse) was coupled from the collector of Q1 when it began conducting to the base of Q2, placing Q2 in cutoff. When the collector of Q1 switches from $-V_{CC}$ volts to 0 volts, the charge on C1 acts like a battery with its negative terminal on the collector of Q1, and its positive terminal connected to the base of Q2. This voltage is what cuts off Q2. C1 will now begin to discharge through Q1 to ground, back through $-V_{CC}$, through R2 to the other side of C1. The time required for C1 to discharge depends on the RC time constant of C1 and R2. Figure 3-14 is a timing diagram that shows the negative input pulse and the resultant waveforms that you would expect to see for this circuit description.

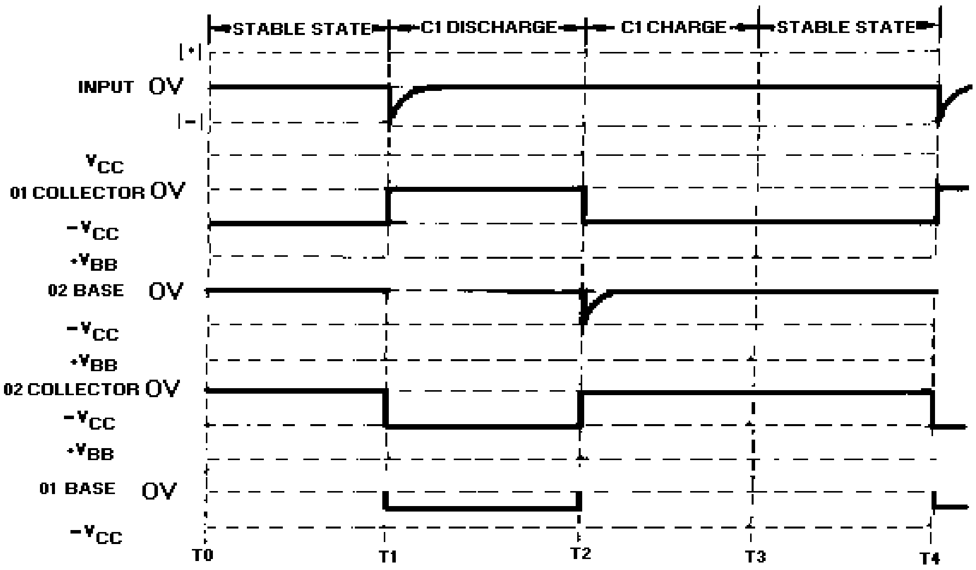


Figure 3-14.—Waveforms of a monostable multivibrator (triggered).

The only part of the operation not described so far is the short C1 charge time that occurs right after Q1 and Q2 return to their stable states. This is simply the time required for C1 to gain electrons on its left side. This charge time is determined by the R1C1 time constant.

Another version of the monostable multivibrator is shown in figure 3-15. View (A) is the circuit and view (B) shows the associated waveforms. In its stable condition (T0), Q1 is cut off and Q2 is conducting. The input trigger (positive pulse at T1) is applied to the collector of Q1 and coupled by C1 to the base of Q2 causing Q2 to be cut off. The collector voltage of Q2 then goes $-V_{CC}$. The more negative voltage at the collector of Q2 forward biases Q1 through R4. With the forward bias, Q1 conducts, and the collector voltage of Q1 goes to about 0 volts. C1 now discharges and keeps Q2 cut off. Q2 remains cut off until C1 discharges enough to allow Q2 to conduct again (T2). When Q2 conducts again, its collector voltage goes toward 0 volts and Q1 is cut off. The circuit returns to its quiescent state and has completed a cycle. The circuit remains in this stable state until the next trigger arrives (T3).

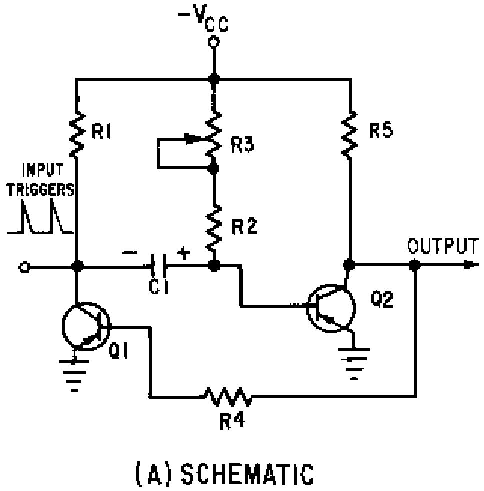


Figure 3-15A.—Monostable miltivibrator and waveshapes. Schematic.

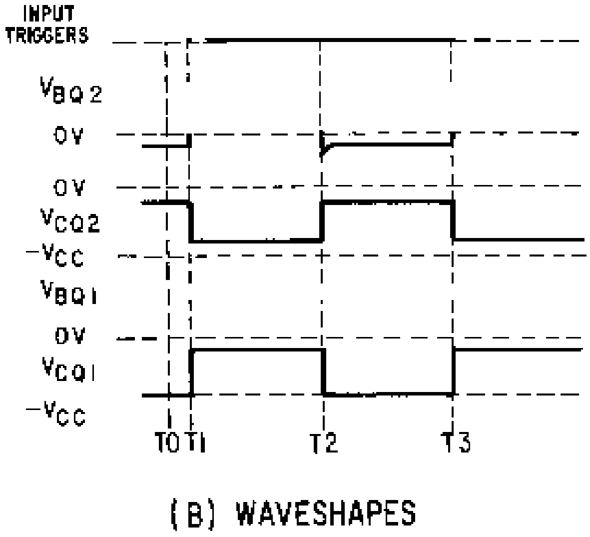


Figure 3-15B.—Monostable miltivibrator and waveshapes. Waveshapes

Note that R3 is variable to allow adjustment of the gate width. Increasing R3 increases the discharge time for C1 which increases the cutoff time for Q2. Increasing the value of R3 widens the gate. To decrease the gate width, decrease the value of R3. Figure 3-16 shows the relationships between the trigger and the output signal. View (A) of the figure shows the input trigger; views (B) and (C) show the different gate widths made available by R3. Although the durations of the gates are different, the duration of the complete cycle remains the same as the pulse repetition time of the triggers. View (D) of the figure illustrates that the trailing edge of the positive alternation is variable.

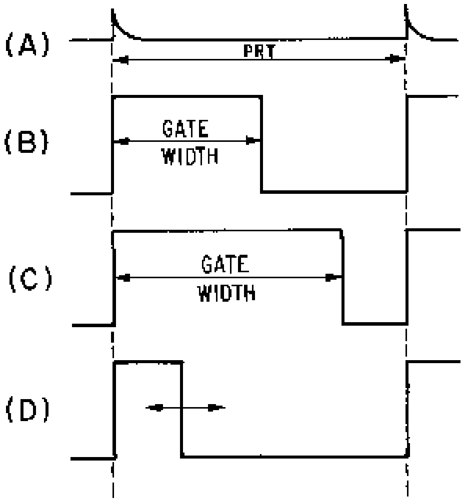


Figure 3-16.—Monostable multivibrator waveforms with a variable gate.

The reason the monostable multivibrator is also called a one-shot multivibrator can easily be seen. For every trigger pulse applied to the multivibrator, a complete cycle, or a positive and negative alternation of the output, is completed.

Q5. In an astable multivibrator, which components determine the pulse repetition frequency?

Q6. What is another name for the monostable multivibrator?

Bistable Multivibrator

As the name implies, the bistable multivibrator has two stable states. If a trigger of the correct polarity and amplitude is applied to the circuit, it will change states and remain there until triggered again. The trigger need not have a fixed prf; in fact, triggers from different sources, occurring at different times, can be used to switch this circuit.

The bistable multivibrator circuit and the associated waveforms are shown in figure 3-17, views (A) and (B), respectively. In this circuit, R1 and R7 are the collector load resistors. Voltage dividers R1, R2, and R5 provide forward bias for Q2; R7, R6, and R3 provide forward bias for Q1. These resistors also couple the collector signal from one transistor to the base of the other. Observe that this is direct coupling of feedback. This type of coupling is required because the circuit depends on input triggers for operation, not on RC time constants inside the circuit. Both transistors use common emitter resistor R4 which provides emitter coupling. C1 and C2 couple the input triggers to the transistor bases.

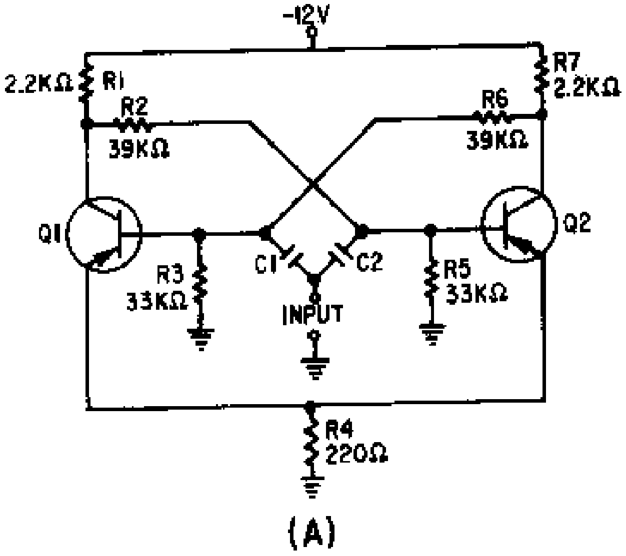


Figure 3-17A.—Bistable multivibrator and waveforms.

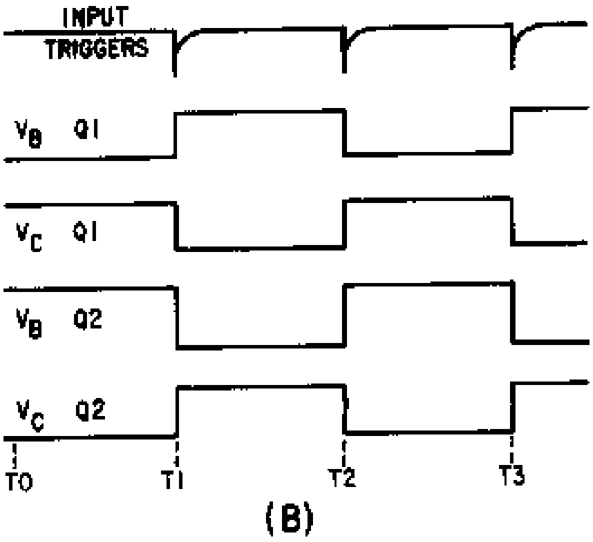


Figure 3-17B.—Bistable multivibrator and waveforms.

Notice that the circuit is symmetrical; that is, each transistor amplifier has the same component values. When power is first applied, the voltage divider networks place a negative voltage at the bases of Q1 and Q2. Both transistors have forward bias and both conduct.

Due to some slight difference between the two circuits, one transistor will conduct more than the other. Assume that Q1 conducts more than Q2. The increased conduction of Q1 causes the collector voltage of Q1 to be less negative (more voltage drop across R1). This decreases the forward bias of Q2 and decreases the conduction of Q2. When Q2 conducts less, its collector voltage becomes more negative. The negative-going change at the collector of Q2 is coupled to the base of Q1 and causes Q1 to conduct even more heavily. This regenerative action continues until Q2 is cut off and Q1 is saturated. The circuit is in a stable state and will remain there until a trigger is applied to change the state.

At T1, a negative trigger is applied to both bases through C1 and C2. The trigger does not affect Q1 since it is already conducting. The trigger overcomes cutoff bias on Q2 and causes it to conduct. As Q2 goes into conduction, its collector voltage becomes positive. The positive-going change at the Q2 collector causes a reverse bias on the base of Q1. As the conduction of Q1 decreases to the cutoff point, the collector voltage becomes negative. This switching action causes a very rapid change of state with Q2 now conducting and Q1 cut off.

At T2, a negative trigger is again applied to both bases. This time, Q1 is brought into conduction and the regenerative switching action cuts off Q2. The bistable multivibrator will continue to change states as long as triggers are applied. Notice that two input triggers are required to produce one gate; one to turn it on and the other to turn it off. The input trigger frequency is twice the output frequency.

The bistable multivibrator that most technicians know is commonly known by other names: the ECCLES-JORDAN circuit and, more commonly, the FLIP-FLOP circuit (figure 3-18). The flip-flop is a bistable multivibrator, "bi" meaning two; that is, the flip-flop has two stable states. The flip-flop (f/f) can rapidly flip from one state to the other and then flop back to its original state. If a voltmeter were connected to the output of a flip-flop, it would measure either a small positive or negative voltage, or a particularly low voltage (essentially 0 volts). No matter which voltage is measured, the flip-flop would be stable. Remember, stable means that the flip-flop will remain in a particular state indefinitely. It will not change states unless the proper type of trigger pulse is applied.

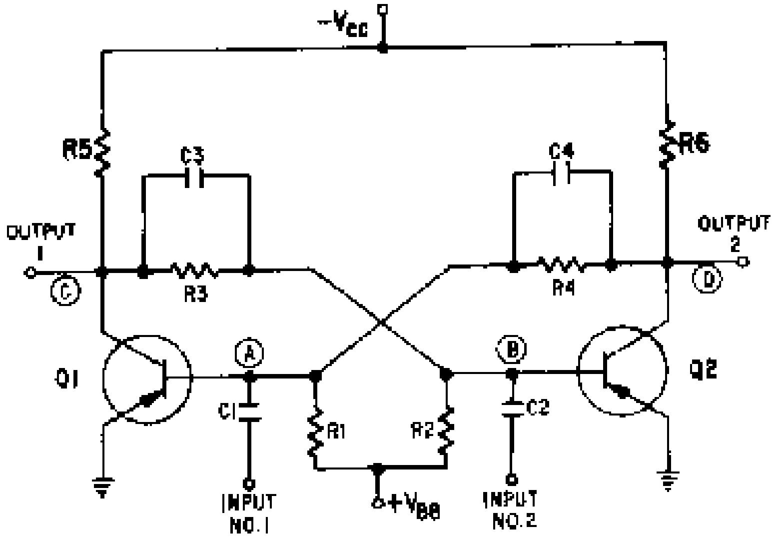


Figure 3-18.—Basic flip-flop.

Flip-flops are used in switching-circuit applications (computer logic operations) as counters, shift registers, clock pulse generators, and in memory circuits. They are also used for relay-control functions and for a variety of similar applications in radar and communications systems.

Notice that the basic flip-flop, illustrated in figure 3-18, has two inputs and two outputs. The inputs are coupled to the bases of the transistors and the outputs are coupled from the collectors of the transistors. Think of the flip-flop as two common-emitter amplifier circuits, where the output of one amplifier is connected to the input of the other amplifier, and vice-versa. Point (D) is connected through R4 to C4 to point (A). Point (A) is the input to transistor Q1. By the same token, point (C), which is the output of Q1, is connected through R3 and C3 to the input (point (B)) of transistor Q2.

Taking a close look at the flip-flop circuit, you should be able to see how it maintains its stable condition. Typical values for the resistors and applied voltages are shown in figure 3-19. The capacitors have been removed for simplicity.

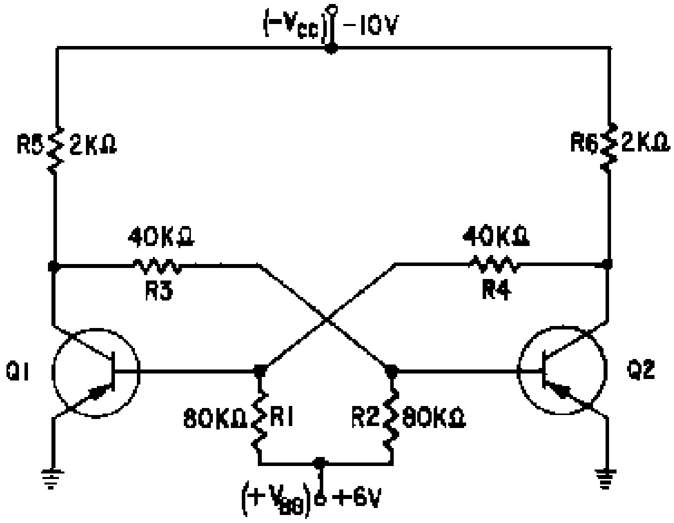


Figure 3-19.—Flip-flop (capacitors removed).

Two voltage-divider networks extend from -10 volts (V_{CC}) to +6 volts (V_{BB}). One voltage divider consisting of resistors R1, R4, and R6 supplies the bias voltage to the base of Q1. The other voltage divider consists of R2, R3, and R5 and supplies the bias voltage to the base of Q2.

Assume that Q1 (figure 3-20) is initially saturated and Q2 is cut off. Recall that the voltage drop from the base to the emitter of a saturated transistor is essentially 0 volts. In effect, this places the base of Q1 at ground potential. The voltages developed in the voltage divider, $-V_{CC}$, R6, R4, R1, and $+V_{BB}$, are shown in the figure.

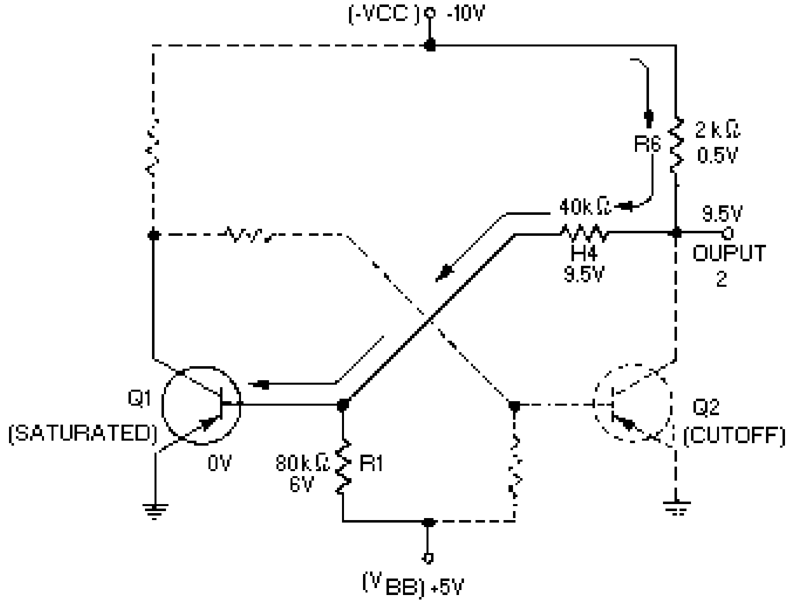


Figure 3-20.—Flip-flop (Q1 voltage divider).

Since no current flows through Q2, very little voltage is dropped across R6 (approximately 0.5 volt). The voltage at output 2 would measure -9.5 volts to ground (approximately $-V_{CC}$).

This voltage (−9.5 volts) is considered to be a HIGH output. Figure 3-21 shows the values of the other voltage-divider network.

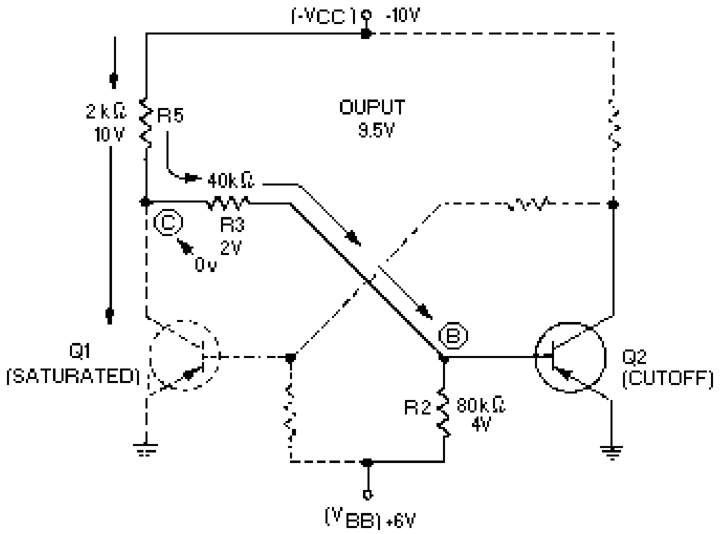


Figure 3-21.—Flip-flop (Q2 voltage divider).

With Q1 saturated, a large current flows through R5. The meter would measure approximately 0 volts (ground potential) at point (C). Notice that point (B) is located between point (C) (at 0 volts) and $+V_{BB}$ (at +6 volts). The meter would measure a positive voltage (between 0 volts and +6 volts) at the base of Q2 (point (B)).

A positive voltage on the base of a pnp transistor will cause that transistor to cut off. If one transistor is saturated, the other must be cut off. The flip-flop is stable in this state.

The capacitors that were removed from figure 3-19 must be returned to the flip-flop as shown in figure 3-22 to change the state of the flip-flop from one condition to the other. Capacitors C3 and C4 transmit almost instantaneously any changes in voltage from the collector of one transistor to the base of the other. Capacitors C1 and C2 are input coupling capacitors.

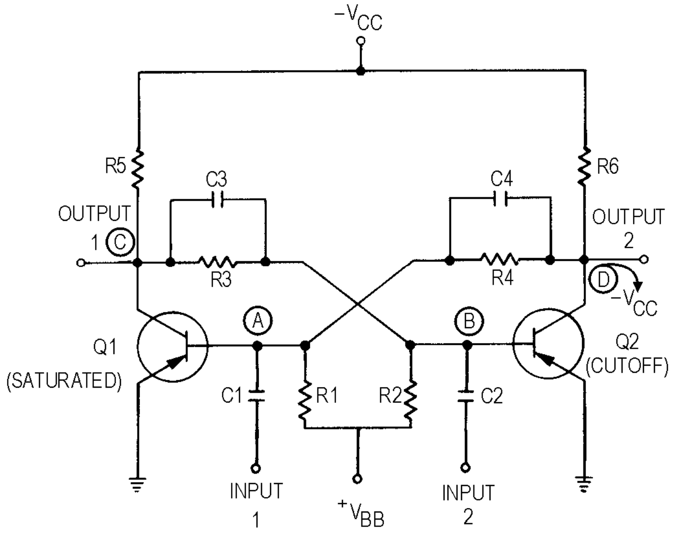


Figure 3-22.—Flip-flop.

As before, assume that transistor Q1 is saturated and transistor Q2 is cut off. Two methods are available to cause the flip-flop to change states. First, a positive-going pulse can be applied to input 1 to cause Q1 to change from saturation to cutoff. Second, the same result can be achieved by applying a negative-going pulse to input 2. Transistor Q2 would then change from Cutoff to saturation. Normally, a pulse is applied to the saturated transistor causing it to cut off. An input pulse which is of the correct polarity to change the state of the flip-flop is, as before, called a trigger pulse.

In figure 3-23 a positive-going trigger pulse has been applied to input 1. The flip-flop has now changed states; Q1 is cut off and Q2 is saturated. If a second positive-going trigger pulse is applied to input 1, it has no effect. This is because Q1 is already cut off; therefore, a positive pulse on its base has no effect. But if a positive-going trigger pulse were applied to input 2, the flip-flop would change back to its original state as shown in figure 3-24.

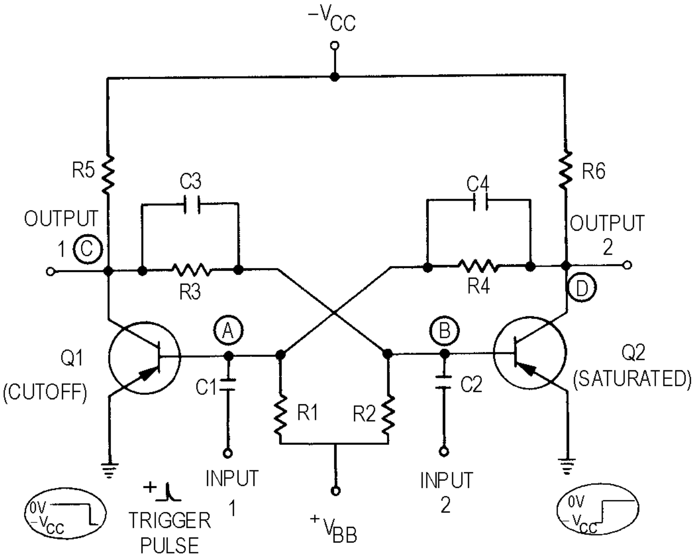


Figure 3-23.—Bistable multivibrator (flip-flop).

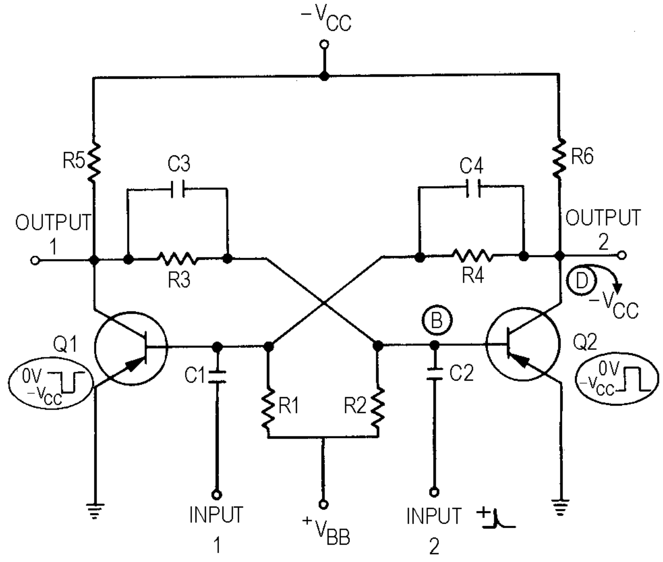


Figure 3-24.—Flip-flop (original state).

So far, the basic flip-flop has used only pnp transistors. It could have just as easily used npn transistors. The functional operation would not change; only the polarities required for conduction and cutoff change. As a technician, you may see either type of transistor used, npn or pnp. A symbolic block diagram is sometimes used to avoid confusion about voltage polarities.

A special kind of block diagram has been adopted as a standard symbol for the flip-flop and is shown in figures 3-25 and 3-26. The two inputs are represented by the lines on the left and the outputs by the lines on the right. INPUTS to a flip-flop are S (SET) and C (CLEAR) and OUTPUTS from a flip-flop are "1" and "0." A trigger pulse applied to the SET input causes the "1" output to be a positive or negative voltage, depending on the type of transistor. At the same time, the "0" output equals 0 volts. This condition is called the SET STATE.

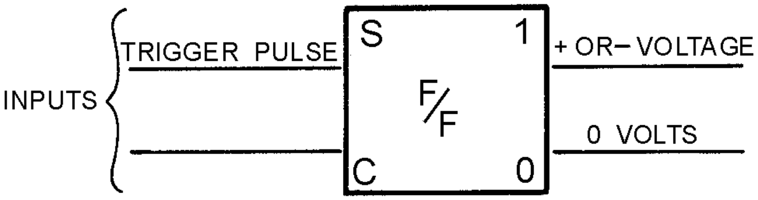


Figure 3-25.—Flip-flop (SET state).

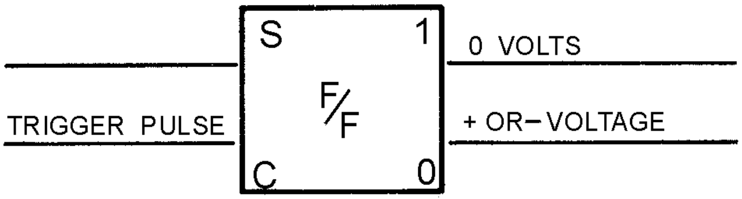


Figure 3-26.—Flip-flop (CLEAR state).

If a trigger pulse is applied to the CLEAR input, a positive or negative voltage is produced at the "0" output. The "1" output goes to 0 volts. This condition is called the CLEAR STATE, as shown in figure 3-26.

To determine what state the flip-flop is in, you can measure either the "1" or the "0" output. Measuring 0 volts at the "1" output indicates that the flip-flop is in the CLEAR state. If the "0" output is measured, a positive or negative voltage would also indicate that the flip-flop is in the CLEAR state. Either way, only one reading is necessary.

In figure 3-27, the flip-flop is in the SET state prior to T0 (negative voltage on the "1" output). Now compare the changes in output voltage at each point in time (T0, T1, T2, and T3) with the input pulse. Studying this figure should help you understand how the flip-flop works. The positive pulse at T0 on the CLEAR input shifts the f/f to the CLEAR state (negative voltage at the "0" output). At T1 a positive pulse on the SET input drives the "1" output to the SET state. At T2 a positive pulse on the CLEAR input drives the "0" output to a CLEAR state. At T3 another positive pulse is applied to the CLEAR input. This input has no effect since the f/f is already in the CLEAR state.

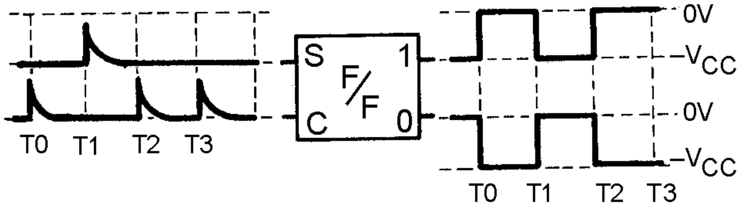


Figure 3-27.—Flip-flop with trigger pulse on SET and inputs.

Some flip-flops use a third input lead, as shown in figure 3-28. This third input lead is called a TOGGLE (T) input. Every time a pulse is applied to the T input, the flip-flop will change states from whatever its state was previously. The two diodes (CR1, CR2) form a STEERING NETWORK. This steering network directs a positive input pulse to the saturated transistor, causing it to cut off. Negative pulses are blocked by the diodes. Note that if npn transistors were used, the diodes would have to be reversed and the TOGGLE signal would have to be negative. For example, assume that Q1 is saturated, Q2 is cut off, and a positive pulse is applied the at T input. The input pulse will be directed to both transistors. The positive pulse will not affect Q2 since it is already in cutoff. Q1 however, which is conducting, will cut off and will cause Q2 to become saturated. The transistors have reversed states. A block diagram which represents a multivibrator and its outputs with only a TOGGLE input signal is shown in figure 3-29. Studying this figure should help you understand how this flip-flop works. Each TOGGLE input causes the output to change states. Figure 3-30 shows what happens when triggers are applied to all three inputs of the flip-flop shown in figure 3-28. Assume that the flip-flop in figure 3-30 is in the CLEAR state ("1" output is 0 volts, "0" output is high) prior to T0. At T0 a trigger is applied to the set input and the flip-flop changes states. Next, the CLEAR input is triggered and the flip-flop returns to the CLEAR state at T1. A TOGGLE at T2 causes the flip-flop to change state, so it is once again SET. Another TOGGLE changes the flip-flop to the CLEAR state at T3 (notice that TOGGLE triggers flip the multivibrator regardless of its previous state). Now, a SET input trigger at T4 sets the flip-flop. The CLEAR input pulse at T5 causes the circuit to CLEAR, and the CLEAR input at T6 has no effect on the flip-flop, for it is already in the CLEAR state.

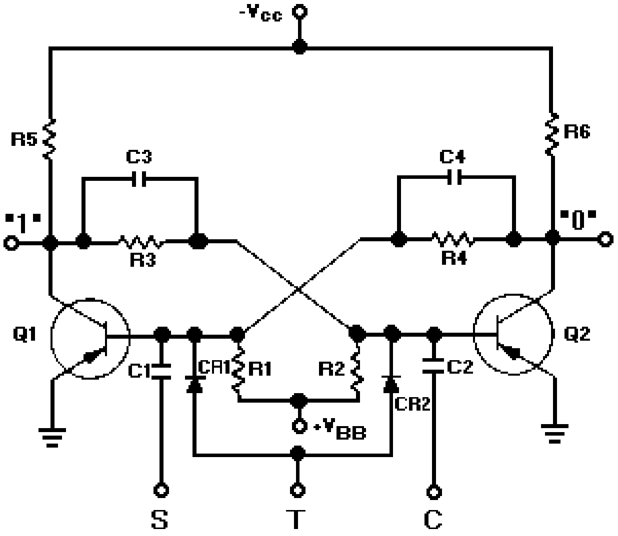


Figure 3-28.—Flip-flop with three inputs.

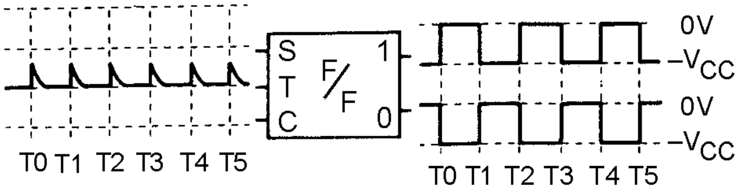


Figure 3-29.—Block diagram of a flip-flop with a toggle input.

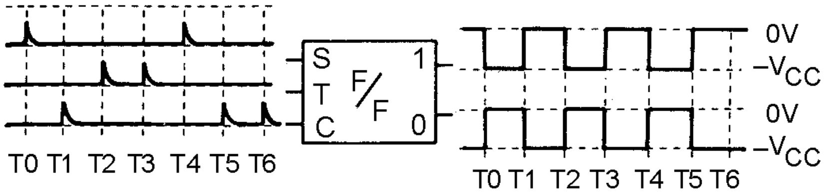


Figure 3-30.—Flip-flop with three inputs (block diagram).

Remember, a SET input will SET the flip-flop if it is in the CLEAR state, otherwise, it will not do anything; a trigger at the CLEAR input can only CLEAR the circuit if it is SET; and a trigger applied to the TOGGLE input will cause the bistable multivibrator to change states regardless of what state it is in.

Q7. In a bistable multivibrator, how many trigger pulses are needed to produce one complete cycle in the output?

Q8. How many stable states are there for a flip-flop?

Q9. If a voltage (positive or negative) is measured on the "1" output of a flip-flop, what state is it in?

BLOCKING OSCILLATOR

The BLOCKING OSCILLATOR is a special type of wave generator used to produce a narrow pulse, or trigger. Blocking oscillators have many uses, most of which are concerned with the timing of some other circuit. They can be used as frequency dividers or counter circuits and for switching other circuits on and off at specific times.

In a blocking oscillator the pulse width (pw), pulse repetition time (prt), and pulse repetition rate (prr) are all controlled by the size of certain capacitors and resistors and by the operating characteristics of the transformer. The transformer primary determines the duration and shape of the output. Because of their importance in the circuit, transformer action and series RL circuits will be discussed briefly. You may want to review transformer action in NEETS, Module 2, *Introduction to Alternating Current and Transformers* before going to the next section.

Transformer Action

Figure 3-31, view (A), shows a transformer with resistance in both the primary and secondary circuits. If S1 is closed, current will flow through R1 and L1. As the current increases in L1, it induces a voltage into L2 and causes current flow through R2. The voltage induced into L2 depends on the ratio of turns between L1 and L2 as well as the current flow through L1.

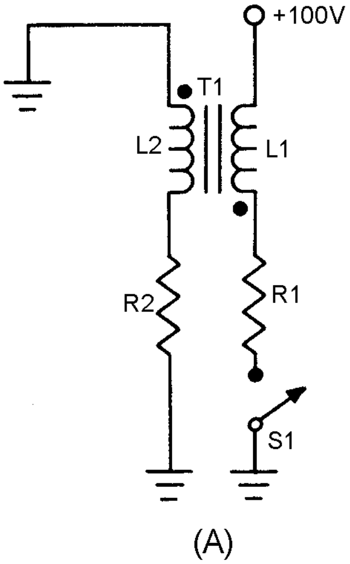


Figure 3-31A.—RL circuit.

The secondary load impedance, R2, affects the primary impedance through reflection from secondary to primary. If the load on the secondary is increased (R2 decreased), the load on the primary is also increased and primary and secondary currents are increased.

T1 can be shown as an inductor and R1-R2 as a combined or equivalent series resistance (R_E) since T1 has an effective inductance and any change in R1 or R2 will change the current. The equivalent circuit is shown in figure 3-31, view (B). It acts as a series RL circuit and will be discussed in those terms.

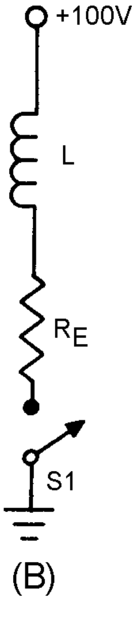


Figure 3-31B.—RL circuit.

Simple Series RL Circuit

When S1 is closed in the series RL circuit (view (B) of figure 3-31) L acts as an open at the first instant as source voltage appears across it. As current begins to flow, E_L decreases and E_R and I increase, all at exponential rates. Figure 3-32, view (A), shows these exponential curves. In a time equal to 5 time constants the resistor voltage and current are maximum and E_L is zero. This relationship is shown in the following formula:

$$5TC = \frac{L}{R_E} \times 5$$

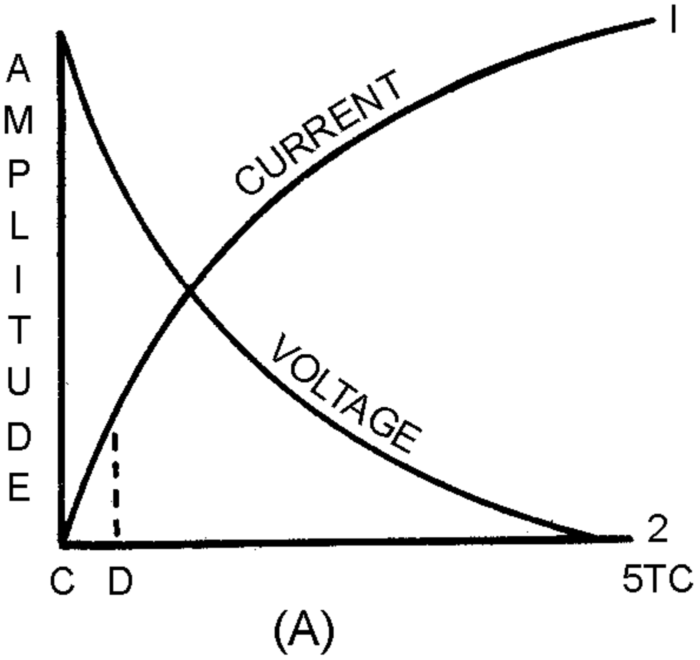


Figure 3-32A.—Voltage across a coil.

If S1 is closed, as shown in figure 3-31, view (B), the current will follow curve 1 as shown in figure 3-32, view (A). The time required for the current to reach maximum depends on the size of L and R_E. If R_E is small, then the RL circuit has a long time constant. If only a small portion of curve 1 (C to D of view (A)) is used, then the current increase will have maximum change in a given time period. Further, the smaller the time increment the more nearly linear is the current rise. A constant current increase through the coil is a key factor in a blocking oscillator.

Blocking Oscillator Applications

A basic principle of inductance is that if the increase of current through a coil is linear; that is, the rate of current increase is constant with respect to time, then the induced voltage will be constant. This is true in both the primary and secondary of a transformer. Figure 3-32, view (B), shows the voltage waveform across the coil when the current through it increases at a constant rate. Notice that this waveform is similar in shape to the trigger pulse shown earlier in figure 3-1, view (E). By definition, a blocking oscillator is a special type of oscillator which uses inductive regenerative feedback. The output duration and frequency of such pulses are determined by the characteristics of a transformer and its relationship to the circuit. Figure 3-33 shows a blocking oscillator. This is a simplified form used to illustrate circuit operation.

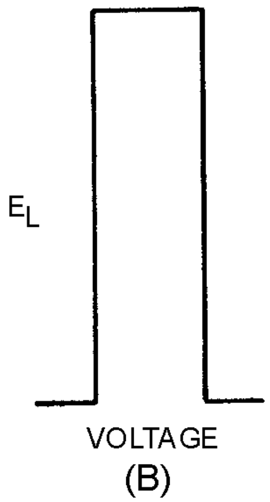


Figure 3-32B.—Voltage across a coil.

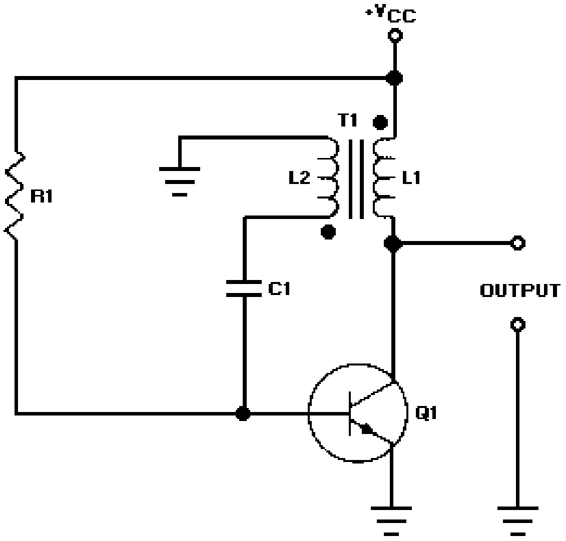


Figure 3-33.—Blocking oscillator.

When power is applied to the circuit, R1 provides forward bias and transistor Q1 conducts. Current flow through Q1 and the primary of T1 induces a voltage in L2. The phasing dots on the transformer indicate a 180-degree phase shift. As the bottom side of L1 is going negative, the bottom side of L2 is going positive. The positive voltage of L2 is coupled to the base of the transistor through C1, and Q1 conducts more. This provides more collector current and more current through L1. This action is regenerative feedback. Very rapidly, sufficient voltage is applied to saturate the base of Q1. Once the base becomes saturated, it loses control over collector current. The circuit now can be compared to a small resistor (Q1) in series with a relatively large inductor (L1), or a series RL circuit.

The operation of the circuit to this point has generated a very steep leading edge for the output pulse. Figure 3-34 shows the idealized collector and base waveforms. Once the base of Q1 (figure 3-33) becomes saturated, the current increase in L1 is determined by the time constant of L1 and the total series resistance. From T0 to T1 in figure 3-34 the current increase (not shown) is approximately linear. The voltage across L1 will be a constant value as long as the current increase through L1 is linear.

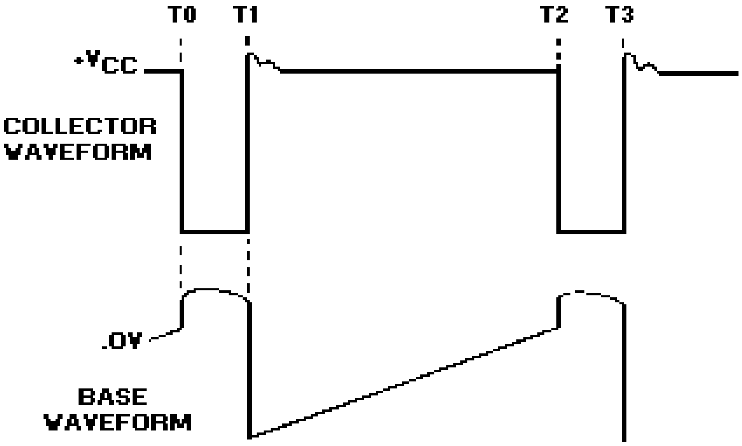


Figure 3-34.—Blocking oscillator idealized waveforms.

At time T1, L1 saturates. At this time, there is no further change in magnetic flux and no coupling from L1 to L2. C1, which has charged during time TO to T1, will now discharge through R1 and cut off Q1. This causes collector current to stop, and the voltage across L1 returns to 0.

The length of time between T0 and T1 (and T2 to T3 in the next cycle) is the pulse width, which depends mainly on the characteristics of the transformer and the point at which the transformer saturates. A transformer is chosen that will saturate at about 10 percent of the total circuit current. This ensures that the current increase is nearly linear. The transformer controls the pulse width because it controls the slope of collector current increase between points T0 and T1. Since TC = L ÷ R , the greater the L, the longer the TC. The longer the time constant, the slower the rate of current increase. When the rate of current increase is slow, the voltage across L1 is constant for a longer time. This primarily determines the pulse width.

From T1 to T2 (figure 3-34), transistor Q1 is held at cutoff by C1 discharging through R1 (figure 3-33). The transistor is now said to be "blocked." As C1 gradually loses its charge, the voltage on the base of Q1 returns to a forward-bias condition. At T2, the voltage on the base has become sufficiently positive to forward bias Q1, and the cycle is repeated.

The collector waveform may have an INDUCTIVE OVERSHOOT (PARASITIC OSCILLATIONS) at the end of the pulse. When Q1 cuts off, current through L1 ceases, and the magnetic field collapses, inducing a positive voltage at the collector of Q1. These oscillations are not desirable, so some means must be employed to reduce them. The transformer primary may be designed to have a high dc resistance resulting in a low Q; this resistance will decrease the amplitude of the oscillations. However, more damping may be necessary than such a low-Q transformer primary alone can achieve. If so, a DAMPING resistor can be placed in parallel with L1, as shown in figure 3-35.

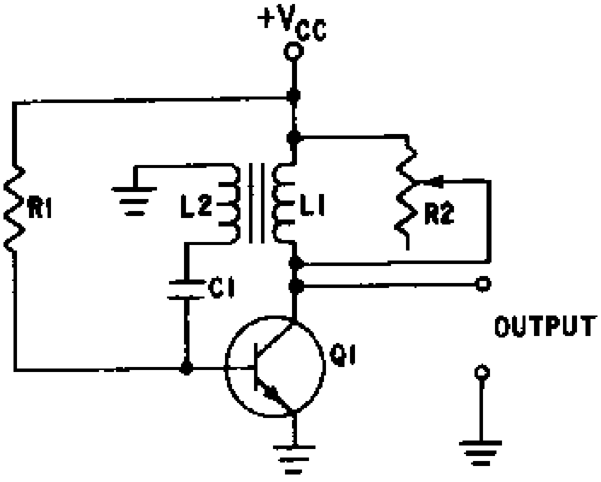


Figure 3-35.—Circuit damping.

When an external resistance is placed across a tank, the formula for the Q of the tank circuit is $Q = R/X_L$, where R is the equivalent total circuit resistance in parallel with L. You should be able to see from the equation that the Q is directly proportional to the damping resistance (R). In figure 3-35, damping resistor R2 is used to adjust the Q which reduces the amplitude of overshoot parasitic oscillations. As R2 is varied from infinity toward zero, the decreasing resistance will load the transformer to the point that pulse amplitude, pulse width, and prf are affected. If reduced enough, the oscillator will cease to function. By varying R2, varying degrees of damping can be achieved, three of which are shown in figure 3-36, view (A), view (B and view (C).

Figure 3-36A.—Waveform damping. CRITICAL DAMPING.

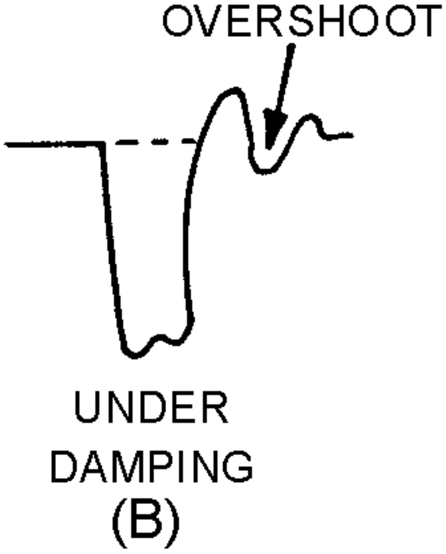


Figure 3-36B.—Waveform damping. UNDER DAMPING.

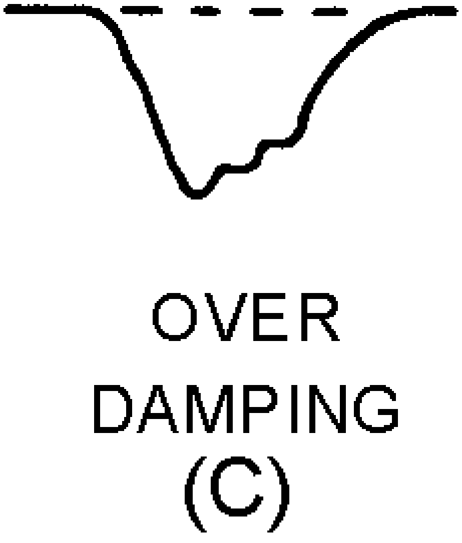


Figure 3-36C.—Waveform damping. OVER DAMPING.

CRITICAL DAMPING gives the most rapid transient response without overshoot. This is accomplished by adjusting R2 to achieve a waveform as shown in figure 3-36, view (A). The resistance of R2 depends upon the Q of the transformer. View (A) shows that oscillations, including the overshoot, are damping out.

UNDERDAMPING gives rapid transient response with overshoot caused by high or infinite resistance as shown in figure 3-36, view (B). OVERDAMPING is caused by very low resistance and gives a slow transient response. It may reduce the pulse amplitude as shown in figure 3-36, view (C).

The blocking oscillator discussed is a free-running circuit. For a fixed prf, some means of stabilizing the frequency is needed. One method is to apply external synchronization triggers (figure 3-37), view (A) and view (B). Coupling capacitor C2 feeds input synchronization (sync) triggers to the base of Q1.

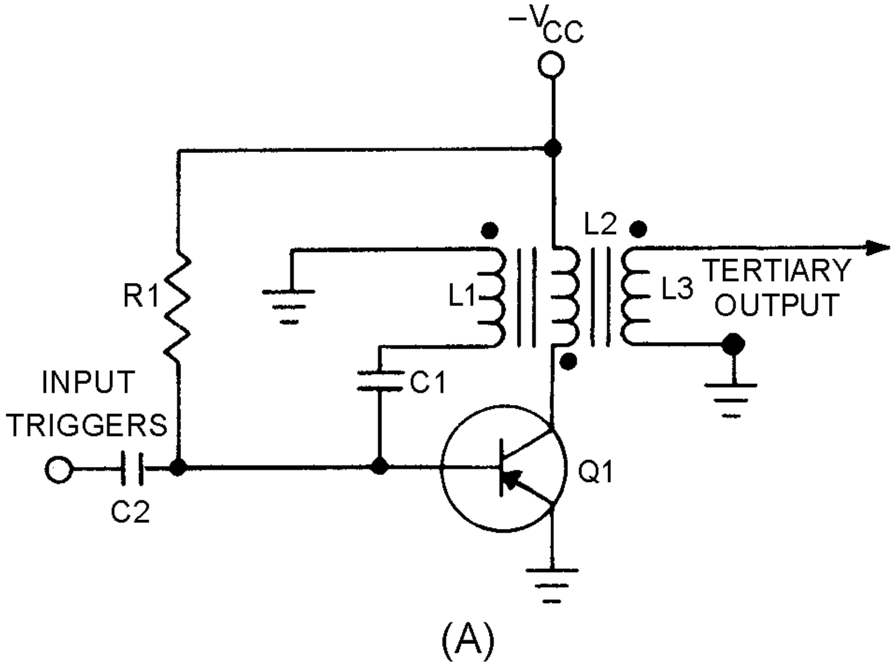


Figure 3-37A.—Blocking oscillator (synchronized).

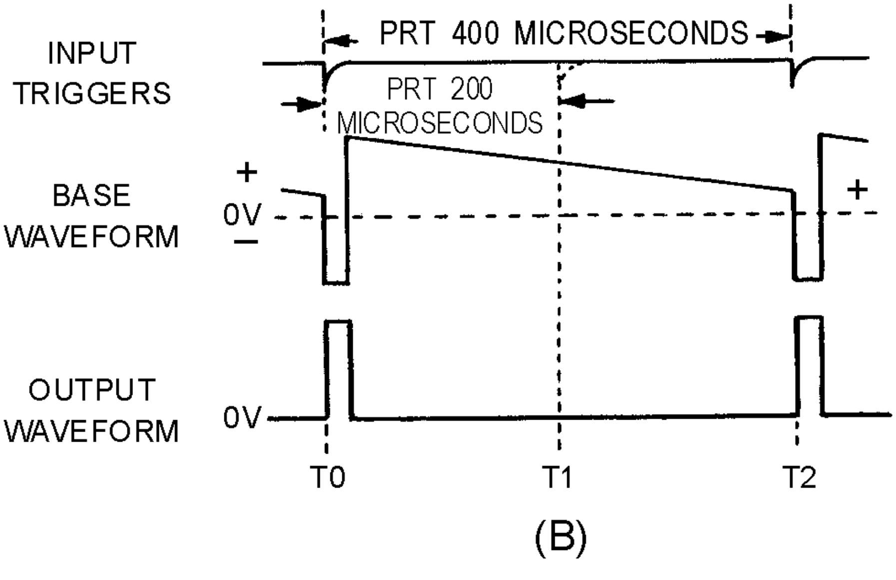


Figure 3-37B.—Blocking oscillator (synchronized).

If the trigger frequency is made slightly higher than the free-running frequency, the blocking oscillator will "lock in" at the higher frequency. For instance, assume the free-running frequency of this blocking oscillator is 2 kilohertz, with a prt of 500 microseconds. If sync pulses with a prt of 400 microseconds, or 2.5 kilohertz, are applied to the base, the blocking oscillator will "lock in" and run at 2.5 kilohertz. If the sync prf is too high, however, frequency division will occur. This means that if the sync prt is too short, some of the triggers occur when the base is far below cutoff. The blocking oscillator may then synchronize with every second or third sync pulse.

For example, in figure 3-37, view (A) and view (B) if trigger pulses are applied every 200 microseconds (5 kilohertz), the trigger that appears at T1 is not of sufficient amplitude to overcome the cutoff bias and turn on Q1. At T2, capacitor C1 has nearly discharged and the trigger causes Q1 to conduct. Note that with a 200-microsecond input trigger, the output prt is 400 microseconds. The output frequency is one-half the input trigger frequency and the blocking oscillator becomes a frequency divider.

Q10. What component in a blocking oscillator controls pulse width?

TIME-BASE GENERATORS

Radar sets, oscilloscopes, and computer circuits all use sawtooth (voltage or current) waveforms. A sawtooth waveshape must have a linear rise. The sawtooth waveform is often used to produce a uniform, progressive movement of an electron beam across the face of an electrostatic cathode ray tube. This movement of the electron beam is known as a SWEEP. The voltage which causes this movement is known as SWEEP VOLTAGE and the circuit which produces this voltage is the SWEEP GENERATOR, or TIME-BASE GENERATOR. Most common types of time-base generators develop the sawtooth waveform by using some type of switching action with either the charge or discharge of an RC or RL circuit.

Sawtooth Wave

A sawtooth wave can be generated by using an RC network. Possibly the simplest sawtooth generator is that which is shown in figure 3-38, view (A). Assume that at T0 (view (B)), S1 is placed in position P. At the instant the switch closes, the applied voltage (E_a) appears at R. C begins to charge to E_a through R. If S1 remains closed long enough, C will fully charge to E_a. You should remember from NEETS, Module 2, *Alternating Current and Transformers*, that a capacitor takes 5 time constants (5TC) to fully charge. As the capacitor charges to the applied voltage, the rate of charge follows an exponential curve. If a linear voltage is desired, the full charge time of the capacitor cannot be used because the exponential curve becomes nonlinear during the first time constant.

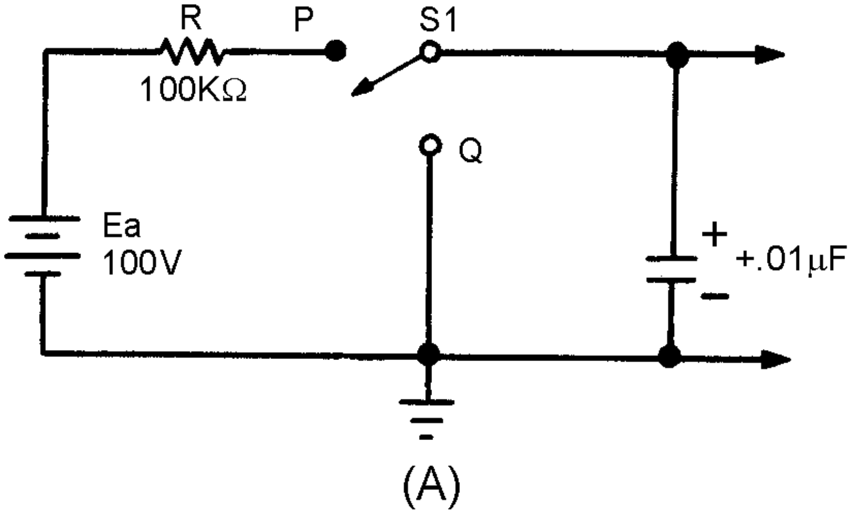


Figure 3-38A.—Series RC circuit.

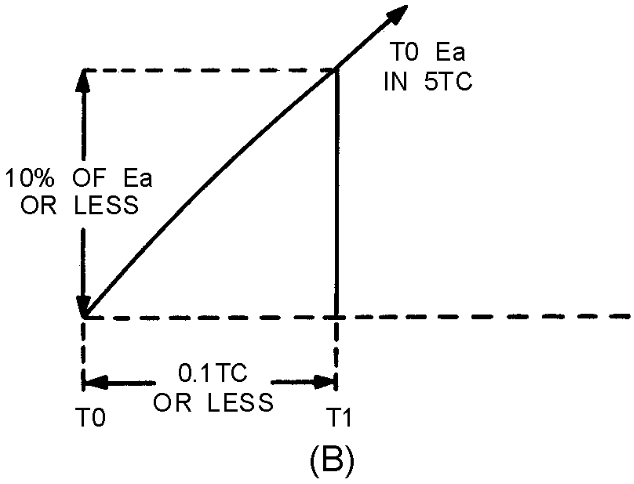


Figure 3-38B.—Series RC circuit.

However, during the first 10 percent of the first time constant, the rate of voltage change across the capacitor is almost constant (linear). Suppose that S1 is placed in position P at T0, and C is allowed to charge for 0.1 time constant. This is shown as T0 to T1 in view (B). Notice that the rate of voltage change across C is nearly constant between T0 and T1. Now, assume that at T1 the switch is moved from position P to position Q. This shorts the capacitor, and it discharges very rapidly. If the switch is placed back in position P, the capacitor will start charging again.

By selecting the sizes of R and C, you can have a time constant of any value you desire. Further, by controlling the time S1 remains closed, you can generate a sawtooth of any duration. Figure 3-39 is the Universal Time Constant Chart. Notice in the chart that if 1 time constant is 1,000 microseconds, S1 (figure 3-38, view (A)) can be closed no longer than 100 microseconds to obtain a reasonable linear sawtooth. In this example, C1 will charge to nearly 10 volts in 0.1 time constant.

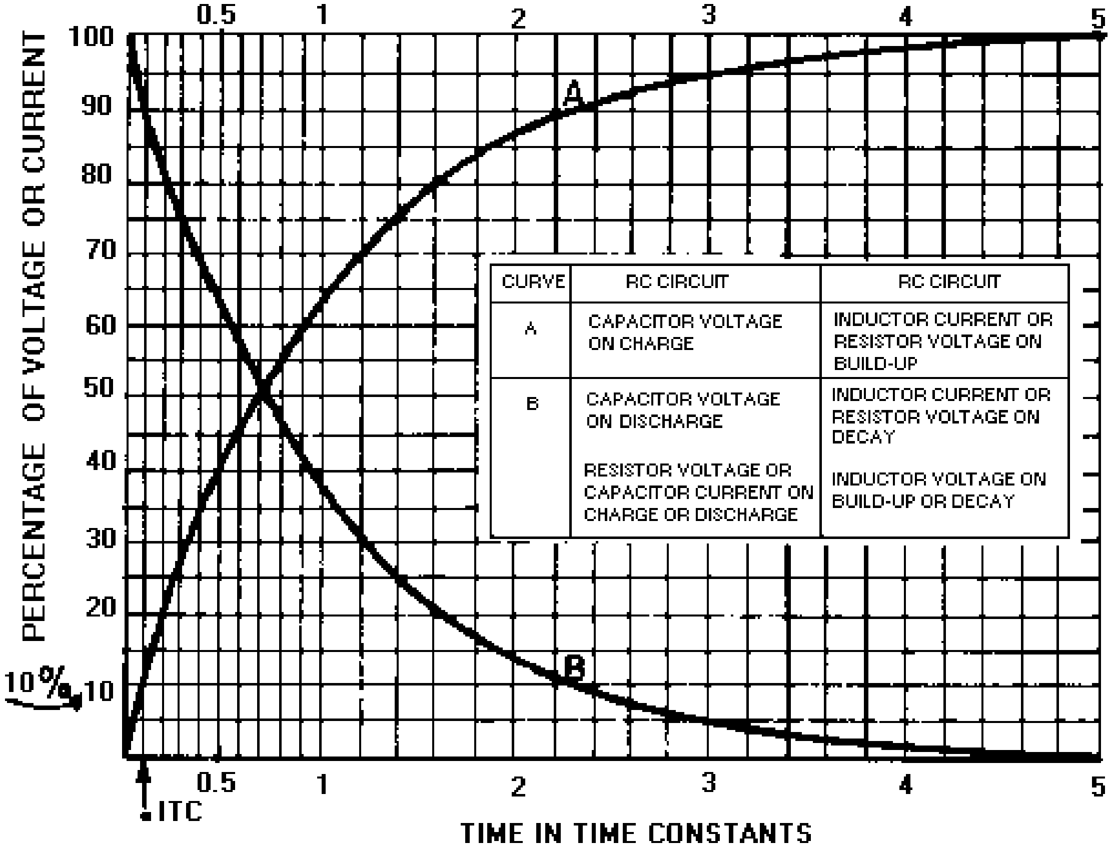


Figure 3-39.—Universal Time Constant Chart.

The dimensions of the sawtooth waveform used in oscilloscopes need to be discussed before going any further. Figure 3-40 shows a sawtooth waveform with the various dimensions labeled. The duration of the rise of voltage (T0 to T1) is known as the SWEEP TIME or ELECTRICAL LENGTH. The electron beam of an oscilloscope moves across the face of the cathode ray tube during this sweep time. The amount of voltage rise per unit of time is referred to as the SLOPE of the waveform. The time from T1 to T2 is the capacitor discharge time and is known as FALL TIME or FLYBACK TIME. This discharge time is known as flyback time because during this period the electron beam returns, or "flys" back, from the end of a scanning line to begin the next line.

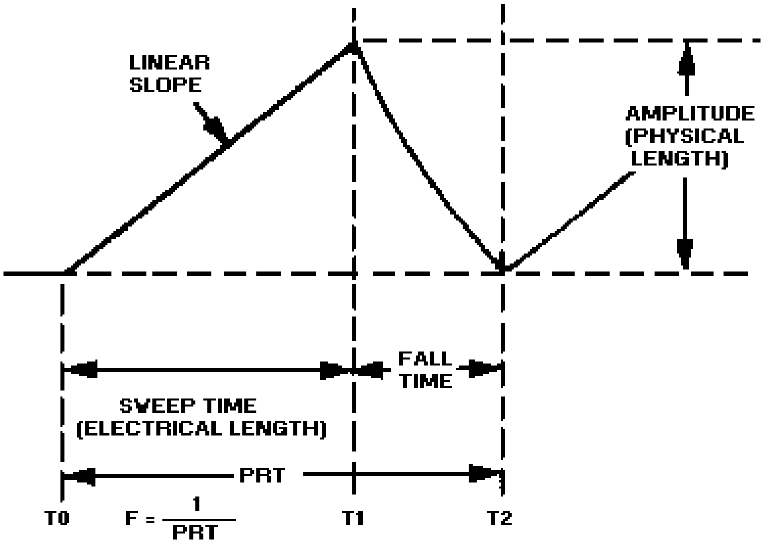


Figure 3-40.—Sawtooth waveform.

The amplitude of the rise of voltage is known as the PHYSICAL LENGTH. It is called physical length because the greater the peak voltage, the greater physical distance the beam will move. For example, the amount of voltage needed to move an electron beam 4 inches is twice the amount needed to move the beam 2 inches across the face of a given crt.

The voltage rise between T0 to T1 is the LINEAR SLOPE of the wave. The linearity of the rise of voltage is determined by the amount of time the capacitor is allowed to charge. If the charge time is kept short (10 percent or less of 1TC), the linearity is reasonably good.

As stated in the discussion of time-base generators, the waveform produced from any sawtooth generator must be linear. A LINEAR SAWTOOTH is one that has an equal change in voltage for an equal change in time. Referring to the Universal Time Constant Chart in figure 3-39, you can see that the most desirable part of the charge curve is the first one-tenth (0.1) of the first TC.

Figure 3-41, view (A), is a transistor sawtooth generator. In this figure R1 is a forward-biasing resistor for Q1, C1 is a coupling capacitor, and Q1 is serving as a switch for the RC network consisting of R2 and C2. With forward bias applied to Q1, the generator conducts at saturation, and its collector voltage (the output) is near 0 volts as indicated by the waveform in view (B). The charge felt by C1 is nearly 0. A negative gate is applied to the base of Q1 to cut off Q1 and allow C2 to charge. The length of time that the gate is negative determines how long Q1 will remain cut off and, in turn, how long C2 will be allowed to charge. The length of time that C2 is allowed to charge is referred to as the electrical length of the sawtooth that is produced.

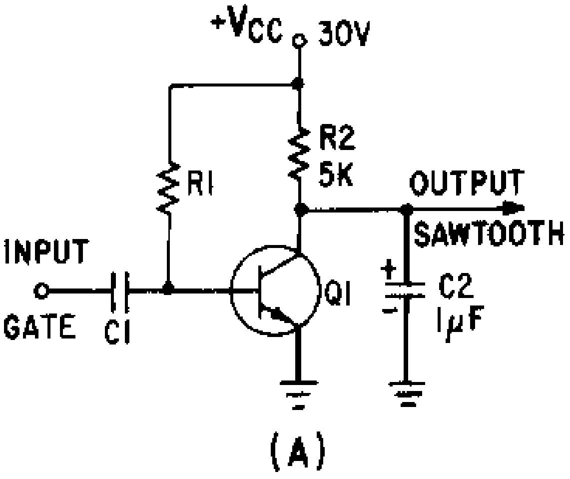


Figure 3-41A.—Transistor sawtooth generator.

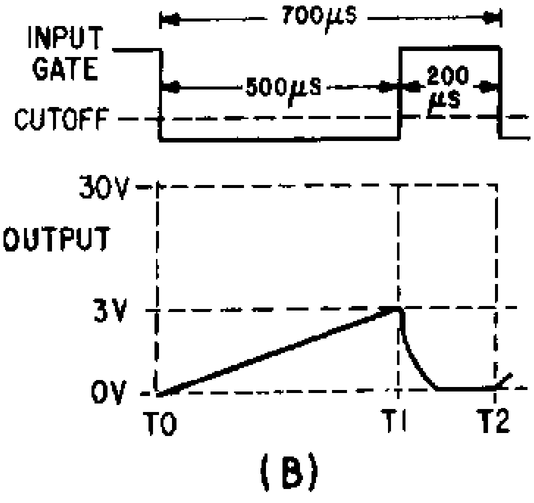


Figure 3-41B.—Transistor sawtooth generator.

The amplitude of the sawtooth that is produced is limited by the value of V_{CC} that is used in the circuit. For example, if the voltage is 30 volts, and the capacitor (C2) is allowed to charge to 10 percent of 30 volts, then the amplitude of the sawtooth will be 3 volts (see figure 3-41, view (B)). If V_{CC} is increased to 40 volts, C2 will charge to 10 percent of 40 volts and the output will increase in amplitude to 4 volts. Changing the value of V_{CC} in the circuit changes the amplitude of the sawtooth waveform that is produced; amplitude determines the physical length. Since the number of time constants used in the circuit has not been changed, linearity does not change with a change in V_{CC}.

The linear slope that is produced by the circuit is dependent on two variables; (1) the time constant of the RC circuit and (2) the gate length of the gate applied to the circuit. The circuit will produce a linear sawtooth waveshape if the components selected are such that only one-tenth of 1 TC or less is used. The GATE LENGTH is the amount of time that the gate is applied to the circuit and controls the time that the capacitor is allowed to charge. The value of R2 and C2 determines the time for 1 time constant

(TC = RC). To determine the number of time constants (or the fraction of 1TC) used, divide the time for 1 time constant into the time that the capacitor is allowed to charge:

$$\text{number of time constants} = \frac{\text{gate length}}{\text{TC}}$$

In figure 3-41, view (B), gate length is 500 microseconds and TC is the product of R2 (5 kilohms) and C2 (1 microfarad). The number of time constants is computed as follows:

$$\text{number of time constants}$$

$$= \frac{500 \times 10^{-6}\ \text{seconds}}{(5 \times 10^{3})(1 \times 10^{-6}\ \text{farads})}$$

$$= \frac{500 \times 10^{-6}}{5 \times 10^{-3}}$$

$$= 100 \times 10^{-3}$$

$$= 0.1\ \text{TC}$$

Therefore, 0.1TC is the length of time required to produce a linear rise in the sawtooth waveform.

The formula:

$$\text{number of time constants} = \frac{\text{gate length}}{\text{TC}}$$

shows that an increase in gate length increases the number of time constants. An increase in the number of time constants decreases linearity. The reason is that C2 now charges to a greater percentage of the applied voltage, and a portion of the charge curve is being used that is less linear. The waveform in figure 3-42, view (A), shows an increase in amplitude (physical length), an increase in the time that C2 is allowed to charge (electrical length), and a decrease in linearity. If a smaller percentage of V_{CC} is used, the gate length is decreased. As shown in view (B), this decreased gate length results in an increase in linearity, a decrease in the time that C2 is allowed to charge (electrical length), and a decrease in amplitude (physical length).

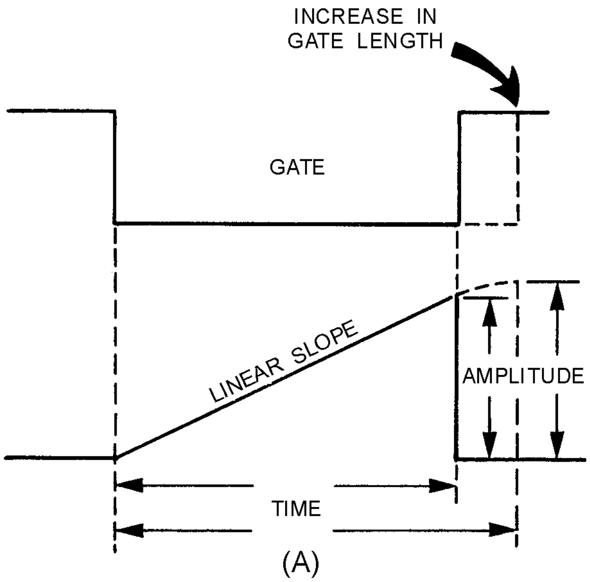


Figure 3-42A.—Relationship of gate to linearity.

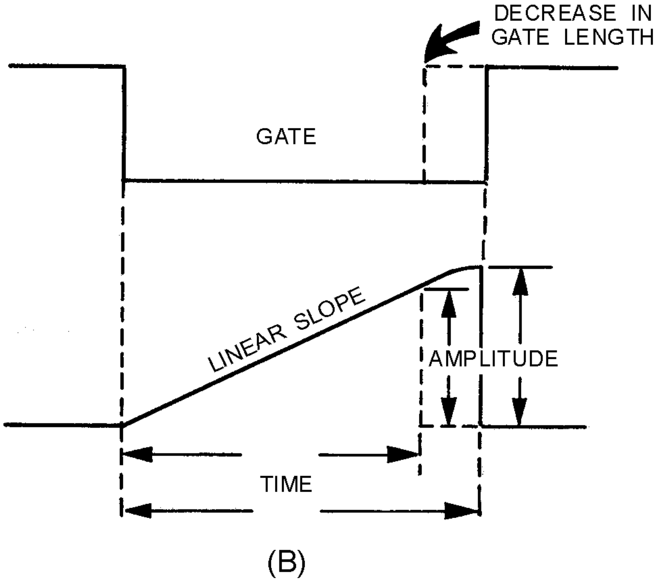


Figure 3-42B.—Relationship of gate to linearity.

Changing the value of R and C in the circuit affects linearity since they control the time for 1 time constant. For example, if the value of C2 is increased in the circuit, as shown in figure 3-43, view (A), the time for 1 time constant increases and the number of time constants then decreases. With a decrease in the number of time constants, linearity increases. The reason is that a smaller percentage of V_{CC} is used, and the circuit is operating in a more linear portion of the charge curve. Increasing the value of the TC (C2 or R2) decreases the amplitude of the sawtooth (physical length) because C2 now charges to a smaller percentage V_{CC} for a given time. The electrical length remains the same because the length of time that C2 is allowed to charge has not been changed.

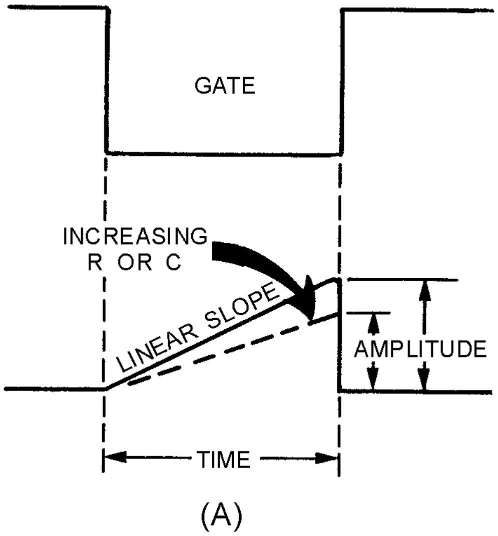


Figure 3-43A.—Relationship of R and C to linearity.

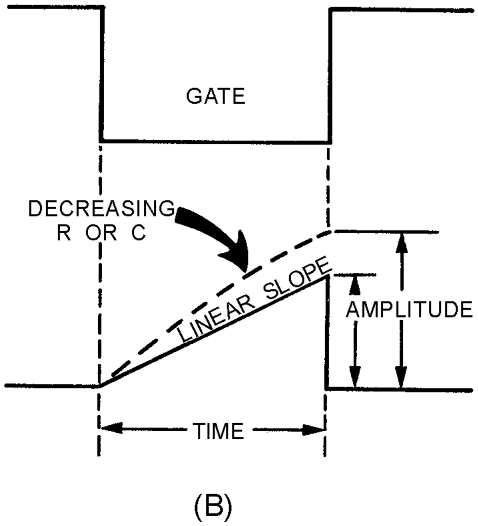


Figure 3-43B.—Relationship of R and C to linearity.

Decreasing the value of the TC (R2 or C2), as shown in figure 3-43, view (B), results in an increase in the number of time constants and therefore causes linearity to decrease. Anytime the number of time constants increases, the percentage of charge increases (see the Universal Time Constant Chart, figure 3-39), and amplitude (physical length) increases. Without an increase in gate length, the time that C2 is allowed to charge through R2 remains the same; therefore, electrical length remains the same. Linearity is affected by gate length, the value of R, and the value of C; but is not affected by changing the value of V_{CC}. Increasing the gate length decreases linearity, and decreasing gate length increases linearity. Increasing R or C in the circuit increases linearity, and decreasing R or C in the circuit decreases linearity.

The entire time of the sawtooth, from the time at which the capacitor begins charging (T0 in figure 3-41, view (B)) to the time when it starts charging again (T2), is known as the prt of the wave. The pulse repetition frequency of the sawtooth wave is:

$$prf = \frac{1}{prt}$$

UNIJUNCTION SAWTOOTH GENERATOR.—So far, you have learned in this chapter that a switch and an RC network can generate a sawtooth waveform. When using a unijunction transistor as the switch, a simple sawtooth generator looks like the circuit in figure 3-44, view (A); the output waveshapes are shown in view (B). You may want to review unijunction transistors in NEETS, Module 7, *Introduction to Solid-State Devices and Power Supplies*, chapter 3, before continuing.

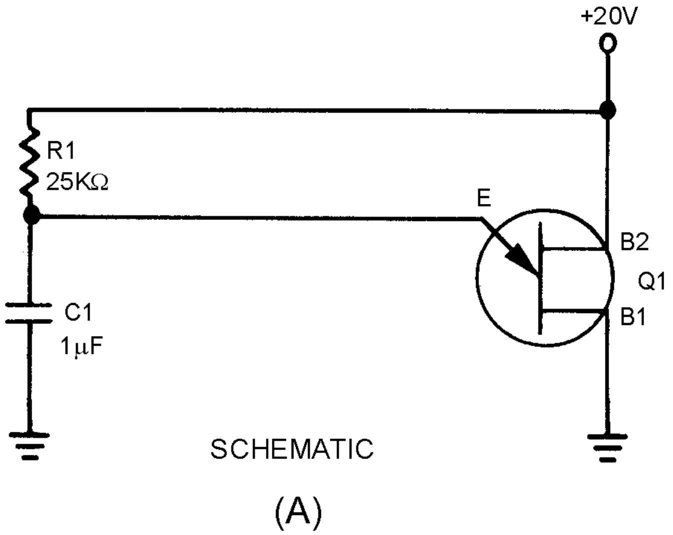


Figure 3-44A.—Unijunction sawtooth generator. SCHEMATIC.

When the 20 volts is applied across B2 and B1, the n-type bar acts as a voltage- divider. A voltage of 12.8 volts appears at a point near the emitter. At the first instant, C1 has no voltage across it, so the output of the circuit, which is taken across the capacitor (C1), is equal to 0 volts. (The voltage across C1 is also the voltage that is applied to the emitter of the unijunction.) The unijunction is now reverse biased. After T0, C1 begins to charge toward 20 volts.

At T1, the voltage across the capacitor (the voltage on the emitter) has reached approximately 12.8 volts. This is the peak point for the unijunction, and it now becomes forward biased. With the emitter forward biased, the impedance between the emitter and B1 is just a few ohms. This is similar to placing a short across the capacitor. The capacitor discharges very rapidly through the low resistance of B1 to E.

As C1 discharges, the voltage from the emitter to B1 also decreases. Q1 will continue to be forward biased as long as the voltage across C1 is larger than the valley point of the unijunction.

At T2 the 3-volt valley point of the unijunction has been reached. The emitter now becomes reverse biased and the impedance from the emitter to B1 returns to a high value. Immediately after T2, Q1 is reverse biased and the capacitor has a charge of approximately 3 volts. C1 now starts to charge toward 20 volts as it did originally (just after T0). This is shown from T2 to T3 in figure 3-44, view (B).

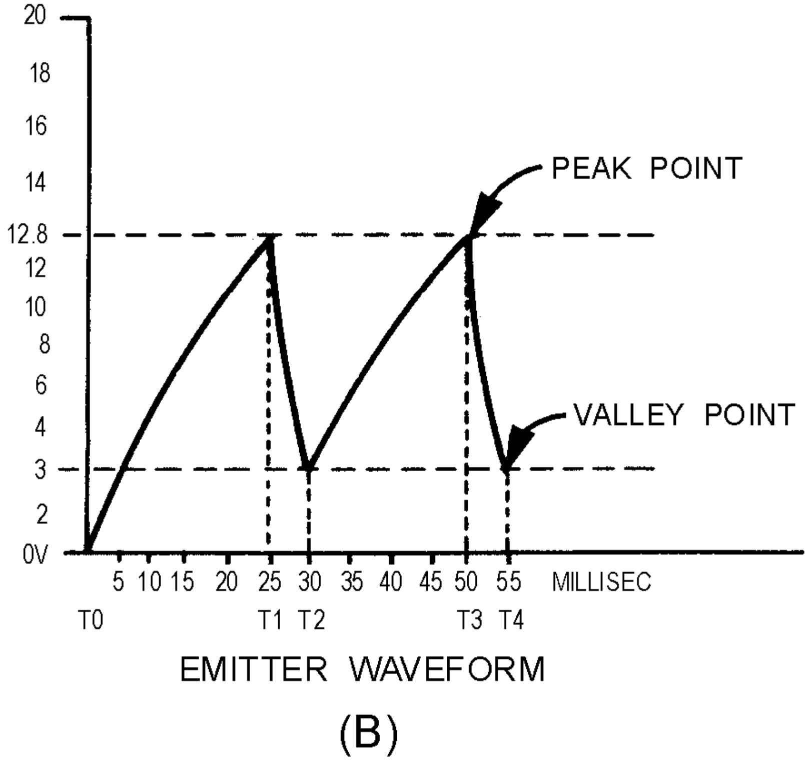


Figure 3-44B.—Unijunction sawtooth generator. EMITTER WAVEFORM.

The circuit operation from now on is just a continuous repetition of the actions between T2 and T4. The capacitor charges until the emitter becomes forward biased, the unijunction conducts and C1 discharges, and Q1 becomes reverse biased and C1 again starts charging.

Now, let's determine the linearity, electrical length, and amplitude of the output waveform. First, the linearity: To charge the circuit to the full 20 volts will take 5 time constants. In the circuit shown in figure 3-44, view (B), C1 is allowed to charge from T2 to T3. To find the percentage of charge, use the equation:

$$\text{percent of charge} = \frac{E_{\text{peak}} - E_{\text{valley}}}{E_a - E_{\text{valley}}} \times 100$$

$$= \frac{12.8 - 3}{20.0 - 3} \times 100$$

$$= \frac{9.9}{17} \times 100$$

$$= 57 \text{ percent}$$

This works out to be about 57 percent and is far beyond the 10 percent required for a linear sweep voltage. The linearity is very poor in this example.

The electrical length (sweep time), which is measured from T2 to T3, can be found by multiplying RC times the number of time constants. Refer to the Universal Time Constant Chart (figure 3-39) again to find that 57 percent is 0.83TC. By multiplying 0.83 times R1C1, you will find that the electrical length is approximately 21 milliseconds:

$$\begin{aligned}\text{electrical length} &= RC \times \text{number of TC}\\ &= 25\,k\Omega \times 1\mu F \times .83TC\\ &= 20.75 \times 10^{-3}\ \text{seconds}\\ &= 21\ \text{milliseconds}\end{aligned}$$

The physical length (amplitude) is determined by subtracting the valley point from the peak point. This is 9.8 volts in the example (12.8 volts – 3 volts).

For a sweep generator that produces a more linear output sawtooth waveform, refer to the circuit in figure 3-45, view (A). R1 and C1 form the RC time constant. Notice that the capacitor charges toward 35 volts (V_E) in this circuit.

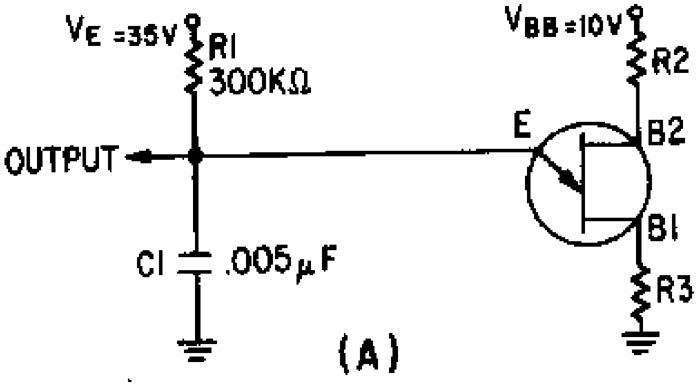


Figure 3-45A.—Improved unijunction sawtooth generator.

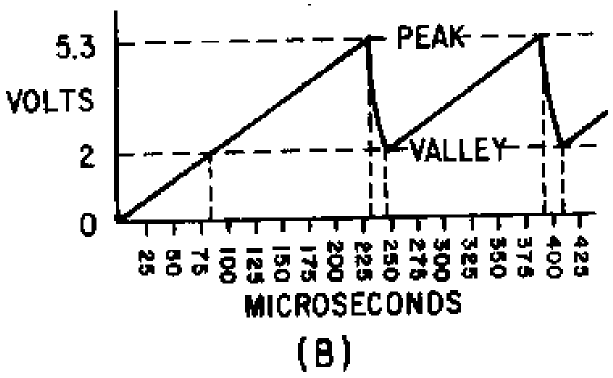


Figure 3-45B.—Improved unijunction sawtooth generator.

The output waveform is shown in figure 3-45, view (B). With a lower voltage applied from B1 to B2, the peak and valley points are closer together. Calculating the percentage of charge:

$$\text{percent of charge} = \frac{E_p - E_v}{E_a - E_v} \times 100$$

$$= \frac{5.3 - 2}{35 - 2} \times 100$$

$$= \frac{3.3}{33} \times 100$$

$$= 10 \text{ percent}$$

The linearity in this case is good. Using the Universal Time Constant Chart, a 10-percent charge amounts to 0.1 time constant. The electrical length is, again, RC times the number of time constants. With R1 at 300 kilohms and C1 at .005 microfarads, the time constant is 1,500 microseconds. One-tenth of a time constant is equal to 150 microseconds; so the electrical length is 150 microseconds. Prt is the electrical length plus the fall or flyback time. If C1 discharges from 5.3 volts to 2 volts in 15 microseconds, then the prt is 150 + 15, or 165 microseconds. The prf is about 6 kilohertz

$$(\text{prf} = \frac{1}{\text{prt}})$$

Some unijunction circuits are triggered to obtain a very stable prf. One method is to apply triggers to B2, as shown in figure 3-46. Negative triggers applied to B2 reduce the inter-base voltage enough to cause a forward bias condition in the emitter circuit. This cuts off the sweep and allows C1 to discharge through the B1-to-emitter circuit. Then, C1 recharges until the next trigger arrives and C1 discharges. Circuit operation and parameters are figured in the same manner as in the previous sawtooth circuits.

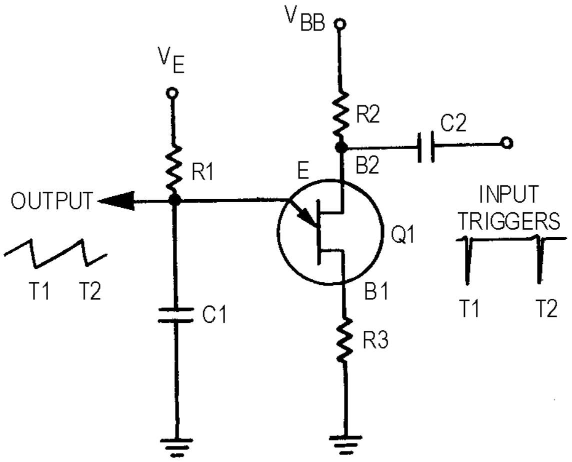


Figure 3-46.—Synchronized sawtooth generator.

TRANSISTOR SAWTOOTH GENERATOR.—The next sawtooth generator uses a conventional pnp transistor, as shown in figure 3-47, view (A). This generator also uses an RC network, and the transistor provides the switching action.

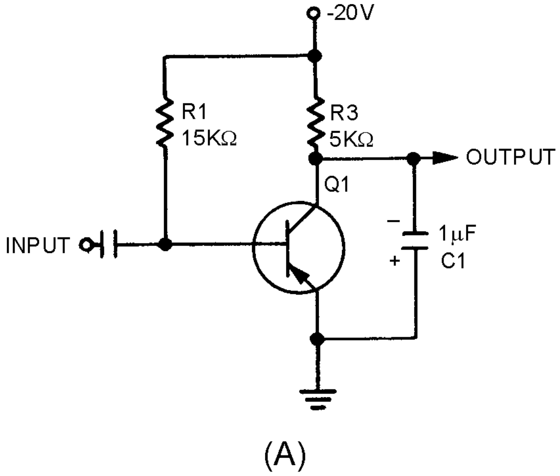


Figure 3-47A.—Transistor sawtooth generator (pnp).

The waveforms for the circuit are shown in views (B) and (C). With no input signals, Q1 is biased near saturation by R1. The voltage across C1 is very low (-2.5 volts) because load resistor R3 drops most of the applied voltage. The transistor must be cut off to allow C1 to charge. To cut off Q1, a positive rectangular wave is used.

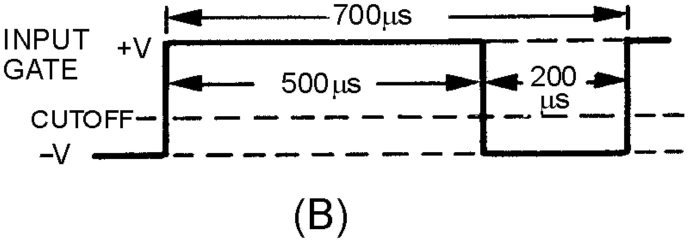


Figure 3-47B.—Transistor sawtooth generator (pnp).

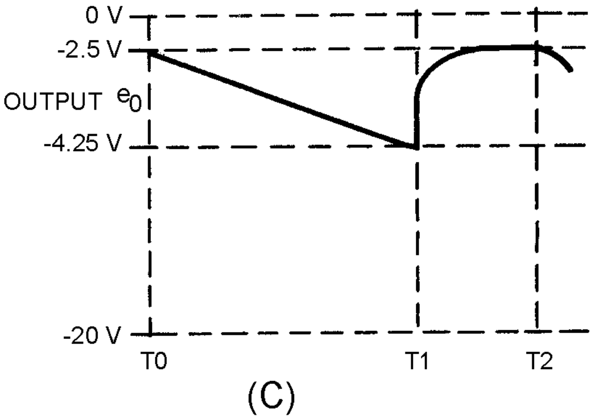


Figure 3-47C.—Transistor sawtooth generator (pnp).

Since Q1 is a pnp transistor, a positive voltage must be used to drive it to cutoff. Figure 3-47, view (B), shows a rectangular wave input 500 microseconds long on the positive alternation. At T0, the positive gate applied to the base of Q1 cuts off Q1. This effectively removes the transistor from the circuit (opens the switch), and C1 charges through R3 toward 20 volts. Starting with a charge of −2.5 volts at T0, C1 charges (T0 to T1) for 500 microseconds to -4.25 volts at T1. Let's determine the percent of charge:

$$\text{percent of charge} = \frac{E_C\text{max} - E_C\text{min}}{V_{CC} - E_C\text{min}} \times 100$$

$$= \frac{4.25 - 2.5}{20 - 2.5} \times 100$$

$$= \frac{1.75}{17.5} \times 100 = 10\%$$

This allows nearly a linear rise of voltage across C1.

Increasing the value of R3 or C1 increases the time constant. The capacitor will not charge to as high a voltage in the same period of time. Decreasing the width of the gate and maintaining the same time constant also prevents the capacitor from charging as much. With less charge on the capacitor, and the same voltage applied, linearity has been improved. Decreasing R3 or C1 or increasing gate width decreases linearity. Changing the applied voltage will change the charge on the capacitor. The percentage of charge remains constant; however, it does not affect linearity.

At T1, the positive alternation of the input gate ends, and Q1 returns to a forward-bias condition. A transistor that is near saturation has very low resistance, so C1 discharges rapidly between T1 and T2, as shown in figure 3-47, view (C). The capacitor discharges in less than 200 microseconds, the length of the negative alternation of the gate. The negative gate is made longer than the discharge time of the capacitor to ensure that the circuit has returned to its original condition.

From T1 to T2, the capacitor discharges and the circuit returns to its original condition, ready for another positive gate to arrive. The next positive gate arrives at T2 and the actions repeats.

The amplitude of the output sawtooth wave is equal to 1.75 volts (4.25 volts minus 2.5 volts). The electrical length is the same as the positive alternation of the input gate, or 500 microseconds. The prt is 700 microseconds (500 + 200) and the prf is 1/prt or 1,428 hertz.

Trapezoidal Sweep Generator

Normally, oscilloscopes and synchroscopes use ELECTROSTATIC DEFLECTION and, as the name implies, electrostatic fields move the electron beam. The need here is for a sawtooth voltage waveform.

Another method of electron beam deflection is ELECTROMAGNETIC DEFLECTION. Currents through a coil produce electromagnetic fields which position the beam of electrons. The electromagnetic system requires a sawtooth of current which increases at a linear rate. Because of the inherent characteristics of a coil, a sawtooth voltage does not cause a linear increase of current. A linear increase of current requires a TRAPEZOIDAL voltage waveform applied to a coil. This section discusses the generation of a trapezoidal wave.

Figure 3-48 shows a trapezoidal wave. The wave consists of a sharp, almost instantaneous jump in voltage followed by a linear rise to some peak value. The initial change in voltage at T0 is called a JUMP or STEP. The jump is followed by a linear sawtooth voltage rise. The time from the jump to the peak amplitude is the sum of the jump voltage and the sawtooth peak; where the peak value occurs is the electrical length. The peak voltage amplitude is the sum of the jump voltage and the sawtooth peak voltage. The waveshape can be considered a combination of a rectangular wave and a sawtooth wave.

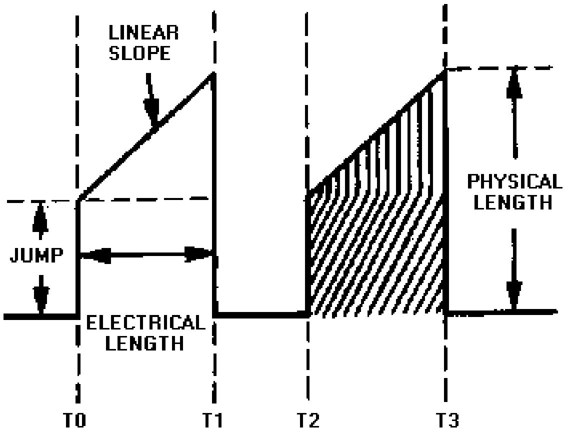


Figure 3-48.—Trapezoidal waveform.

The inductance and resistance of a coil form a series RL circuit. The voltage drop across this inductance and resistance must be added to obtain the voltage waveform required to produce a linear rise in current. A linear rise of current produces a linear rise of voltage across the resistance of the coil and a constant voltage drop across the inductance of the coil.

Assume figure 3-49, view (A), represents deflection coils. If we apply a voltage waveshape to the circuit, which will provide a square wave across inductor L, and a sawtooth across resistor R, then a linear current rise will result.

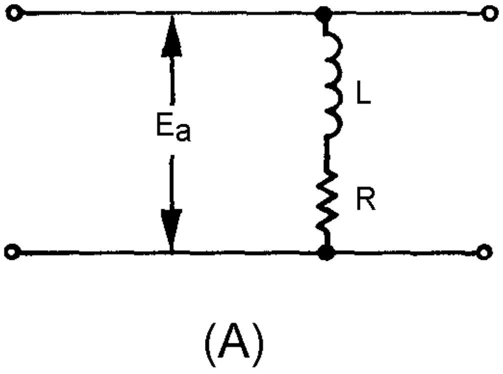


Figure 3-49A.—Series LR circuit.

View (B) of figure 3-49 shows the waveforms when E_a is a square wave. Recall that the inductor acts as an open circuit at this first instant. Current now starts to flow and develops a voltage across the resistor. With a square wave applied, the voltage across the inductor starts to drop as soon as any voltage appears across the resistor. This is due to the fact that the voltage across the inductor and resistor must add up to the applied voltage.

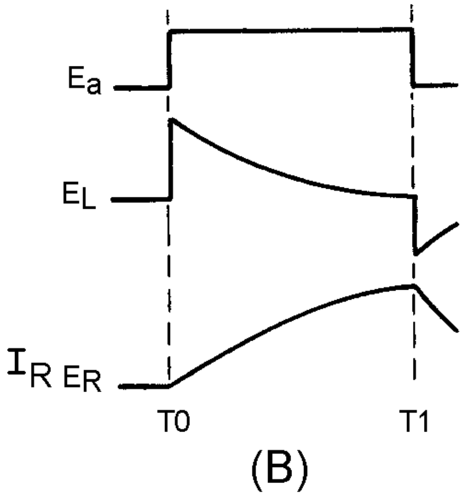


Figure 3-49B.—Series LR circuit.

With E_a being a trapezoidal voltage, as shown in figure 3-49, view (C), the instant current flows, a voltage appears across the resistor, and the applied voltage increases. With an increasing applied voltage, the inductor voltage remains constant (E_L) at the jump level and circuit current (I_R) rises at a linear rate from the jump voltage point. Notice that if you add the inductor voltage (E_L) and resistor voltage (E_R) at any point between times T0 and T1, the sum is the applied voltage (E_a). The key fact here is that a trapezoidal voltage must be applied to a sweep coil to cause a linear rise of current. The linear rise of current will cause a uniform, changing magnetic field which, in turn, will cause an electron beam to move at a constant rate across a crt.

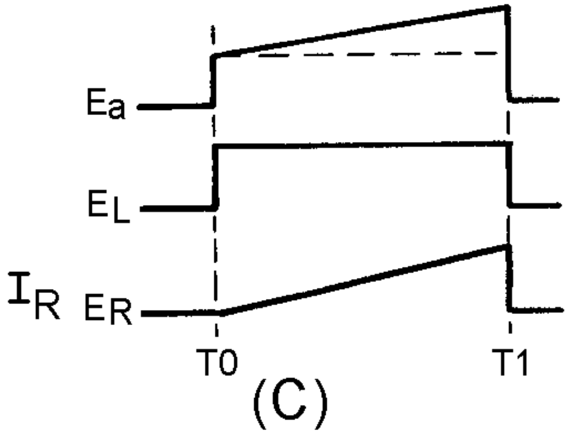


Figure 3-49C.—Series LR circuit.

There are many ways to generate a trapezoidal waveshape. For example, the rectangular part could be generated in one circuit, the sawtooth portion in another, and the two combined waveforms in still a third circuit. A far easier, and less complex, way is to use an RC circuit in combination with a transistor to generate the trapezoidal waveshape in one stage.

Figure 3-50, view (A), shows the schematic diagram of a trapezoidal generator. The waveshapes for the circuit are shown in view (B). R1 provides forward bias for Q1 and, without an input gate, Q1 conducts very hard (near saturation), C1 couples the input gate signal to the base of Q1. R2, R3, and C2 form the RC network which forms the trapezoidal wave. The output is taken across R3 and C2.

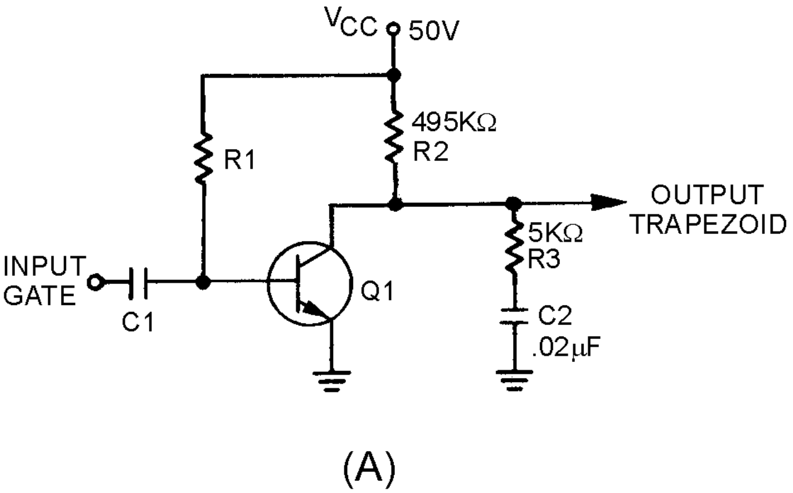


Figure 3-50A.—Trapezoidal waveform generator.

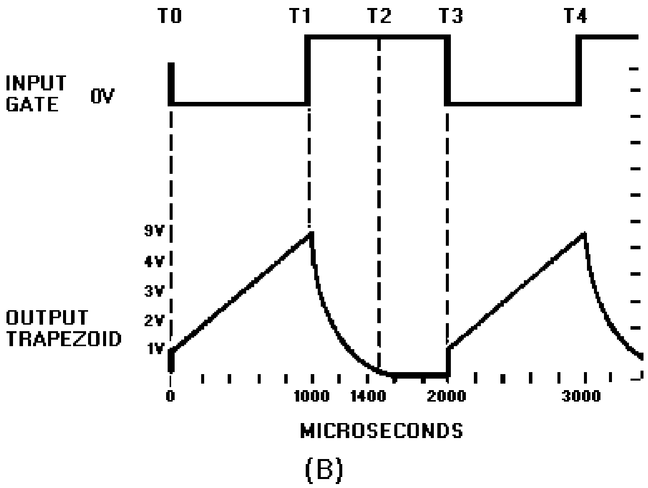


Figure 3-50B.—Trapezoidal waveform generator.

With Q1 conducting very hard, collector voltage is near 0 volts prior to the gate being applied. The voltage across R2 is about 50 volts. This means no current flows across R3, and C2 has no charge.

At T0, the negative alternation of the input gate is applied to the base of Q1, driving it into cutoff. At this time the transistor is effectively removed from the circuit. The circuit is now a series-RC network with 50 volts applied. At the instant Q1 cuts off, 50 volts will appear across the combination of R2 and R3 (the capacitor being a short at the first instant). The 50 volts will divide proportionally, according to the size of the two resistors. R2 then will have 49.5 volts and R3 will have 0.5 volt. The 0.5 volt across R3 (jump resistor) is the amplitude of the jump voltage. Since the output is taken across R3 and C2 in series, the output "jumps" to 0.5 volt.

Observe how a trapezoidal generator differs from a sawtooth generator. If the output were taken across the capacitor alone, the output voltage would be 0 at the first instant. But splitting the R of the RC network so that the output is taken across the capacitor and part of the total resistance produces the jump voltage.

Refer again to figure 3-50, view (A) and view (B). From T0 to T1, C2 begins charging toward 50 volts through R2 and R3. The time constant for this circuit is 10 milliseconds. If the input gate is 1,000 microseconds, the capacitor can charge for only 10 percent of 1TC, and the sawtooth part of the trapezoidal wave will be linear.

At T1, the input gate ends and Q1 begins to conduct heavily. C2 discharges through R3 and Q1. The time required to discharge C2 is primarily determined by the values of R3 and C2. The minimum discharge time (in this circuit) is 500 microseconds (5KΩ × .02μF × 5). At T2, the capacitor has discharged back to 0 volts and the circuit is quiescent. It remains in this condition until T3 when another gate is applied to the transistor.

The amplitude of the jump voltage was calculated to be 0.5 volt. The sawtooth portion of the wave is linear because the time, T0 to T1, is only 10 percent of the total charge time. The amplitude of the trapezoidal wave is approximately 5 volts. The electrical length is the same as the input gate length, or 1,000 microseconds. Linearity is affected in the same manner as in the sawtooth generator. Increasing R2 or C2, or decreasing gate width, will improve linearity. Changing the applied voltage will increase output amplitude, but will not affect linearity.

Linearity of the trapezoidal waveform, produced by the circuit in figure 3-50, view (A) and view (B) depends on two factors, gate length and the time constant of the RC circuit. Recall that these are the same factors that controlled linearity in the sawtooth generator. The formula developed earlier still remains true and enables us to determine what effect these factors have on linearity.

$$\text{number of time constants} = \frac{\text{gate length}}{\text{TC}}$$

An increase in gate length results in an increase in the number of time constants and an increase in the percentage of charge that the capacitor will take on during this time interval. As stated earlier, if the number of time constants were to exceed 0.1, linearity would decrease. The reason for a decrease in linearity is that a greater percentage of V_{CC} is used. The Universal Time Constant Chart (figure 3-39) shows that the charge line begins to curve. A decrease in gate length has the opposite effect on linearity in that it causes linearity to increase. The reason for this increase is that a smaller number of time constants are used and, in turn, a smaller percentage of the applied V_{CC} is used.

Changing the value of resistance or capacitance in the circuit also affects linearity. If the value of C2 or R3 is increased, the time is increased for 1 time constant. An increase in the time for 1TC results in a decrease in the number of time constants required for good linearity. As stated earlier, a decrease in the number of time constants results in an increase in linearity (less than 0.1TC). In addition to an increase in jump voltage (larger value of R3) and a decrease in the amplitude (physical length) of the sawtooth produced by the circuit, electrical length remains the same because the length of the gate was not changed.

R2 has a similar effect on linearity because it is in series with R3. As an example, decreasing the value of R2 results in a decrease in linearity. The equation

$$\text{number of time constants} = \frac{\text{gate length}}{\text{TC}}$$

illustrates that by decreasing R (TC = RC), TC decreases and an increase in the number of time constants causes a decrease in linearity. Other effects are an increase in jump voltage and an increase in the amplitude (physical length) of the sawtooth.

Changing the value of V_{CC} does not affect linearity. Linearity is dependent on gate length, R, and C. V_{CC} does affect the amplitude of the waveform and the value of jump voltage that is obtained.

Q11. For an RC circuit to produce a linear output across the capacitor, the voltage across the capacitor may not exceed what percent of the applied voltage?

Q12. Increasing gate length in a sawtooth generator does what to linearity?

Q13. In a sawtooth generator, why is the transistor turned on for a longer time than the discharge time of the RC network?

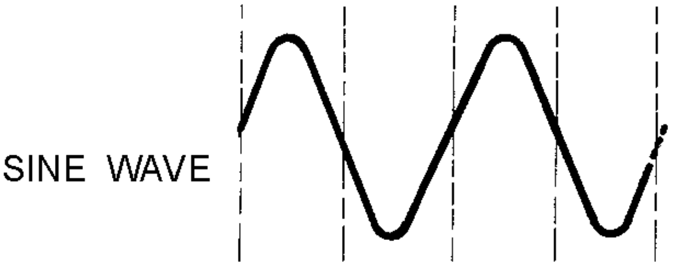
Q14. What is added to a sawtooth generator to produce a trapezoidal wave?

SUMMARY

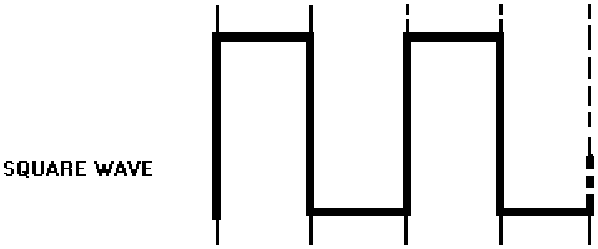
This chapter has presented information on waveforms and wave generators. The information that follows summarizes the important points of this chapter.

A waveform which undergoes a pattern of changes, returns to its original pattern, and repeats that same pattern of changes is called a PERIODIC waveform.

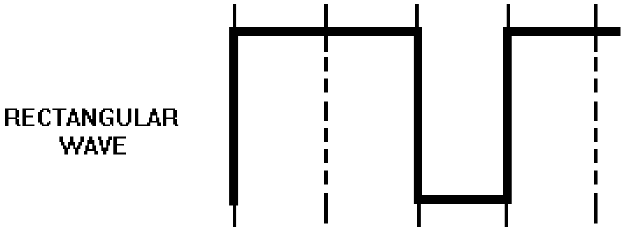
Each completed pattern of a waveform is called a CYCLE.



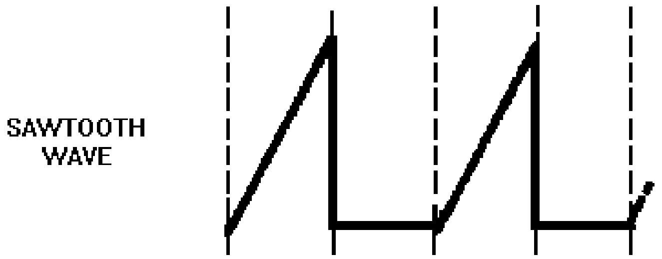
A **SQUARE WAVE** is identified by, two alternations equal in time that are square in appearance. One alternation is called a PULSE. The time for one complete cycle is called the PULSE REPETITION TIME (prt). The number of times in one second that the cycle repeats itself is called PULSE REPETITION RATE (prr) or PULSE REPETITION FREQUENCY (prf). The length of the pulse measured in the figure (T0 to T1) is referred to as the PULSE WIDTH (pw). The left side of the pulse is referred to as the LEADING EDGE and the right side as the TRAILING EDGE.



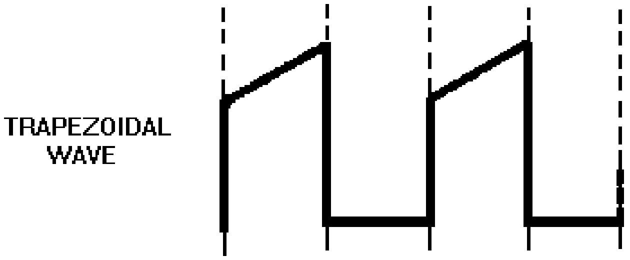
A **RECTANGULAR WAVE** has two alternations that are unequal in time.



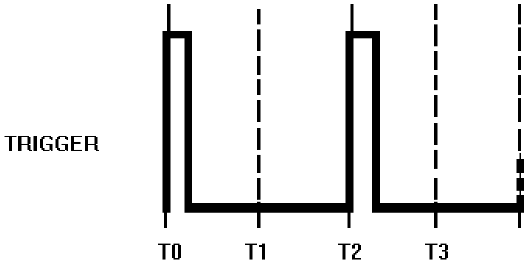
A **SAWTOOTH WAVE** has a linear increase in voltage followed by a rapid decrease of voltage at the end of the waveform.



A **TRAPEZOIDAL WAVE** looks like a sawtooth wave sitting on top of a square wave. The leading edge is called the JUMP voltage.

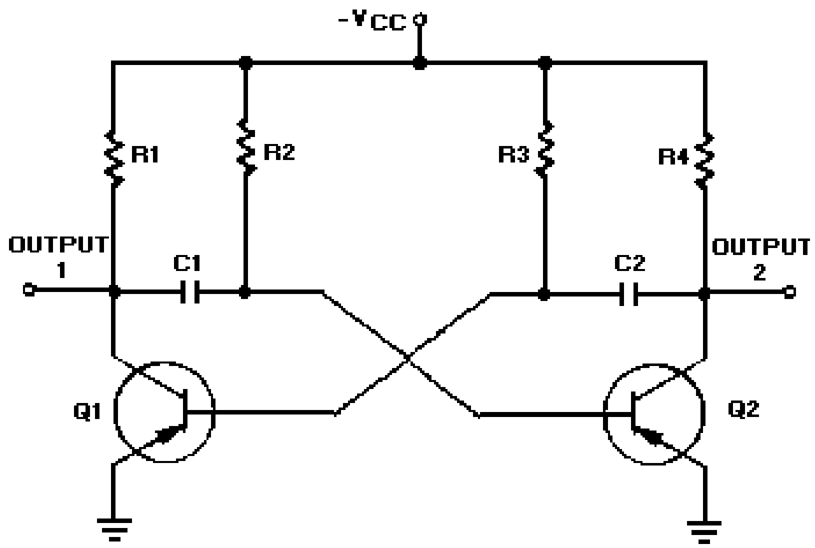


A **TRIGGER** is a very narrow pulse used to turn on or off another circuit.

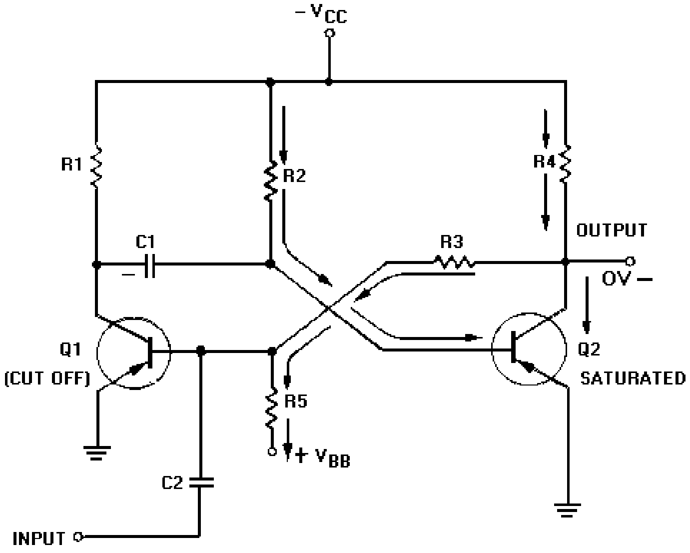


A **MULTIVIBRATOR** is used to generate a square or rectangular wave. A multivibrator is basically two amplifiers with regenerative feedback.

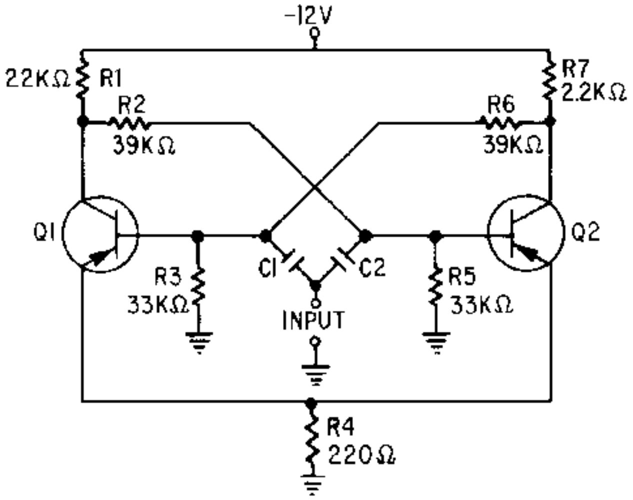
The **ASTABLE MULTIVIBRATOR** has no stable state. The transistors alternately switch from cutoff to saturation at a frequency determined by the RC time constants of the coupling circuits.



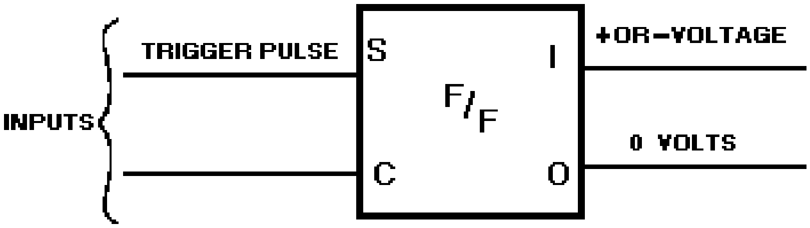
The **MONOSTABLE MULTIVIBRATOR** has one stable state. One transistor conducts while the other is cut off. An external trigger must be applied to change this condition.



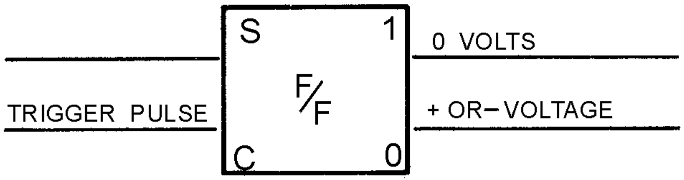
The **BISTABLE MULTIVIBRATOR** has two steady states. It remains in one of the stable states until a trigger is applied. It then switches to the other stable state until another trigger is applied.



The bistable multivibrator is also known as a FLIP-FLOP. The two inputs are SET and CLEAR. The two outputs are "1" and "0." A trigger pulse on the set input will cause the "1" output (negative or positive voltage depending on the type transistor used). At the same time the "0" output will equal 0 volts. This is the SET state.

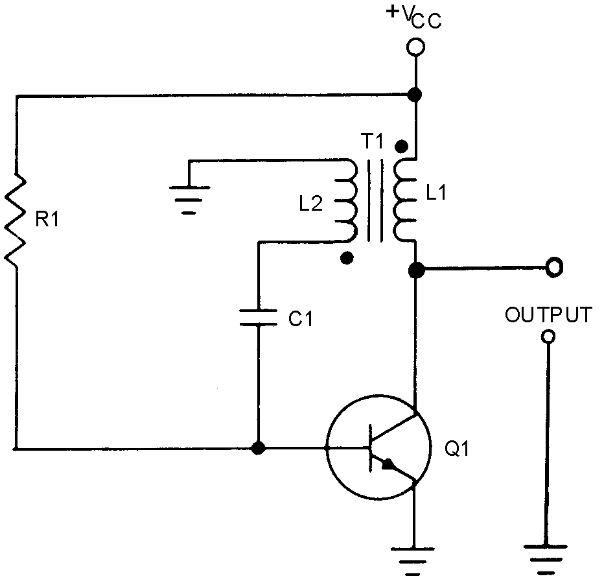


A **CLEAR STATE** of a flip-flop exists when the "1" output measures low voltage (or 0 volts) and the "0" output is high voltage. The flip-flop will flop to the CLEAR state only upon application of a trigger pulse to the CLEAR (C) input.

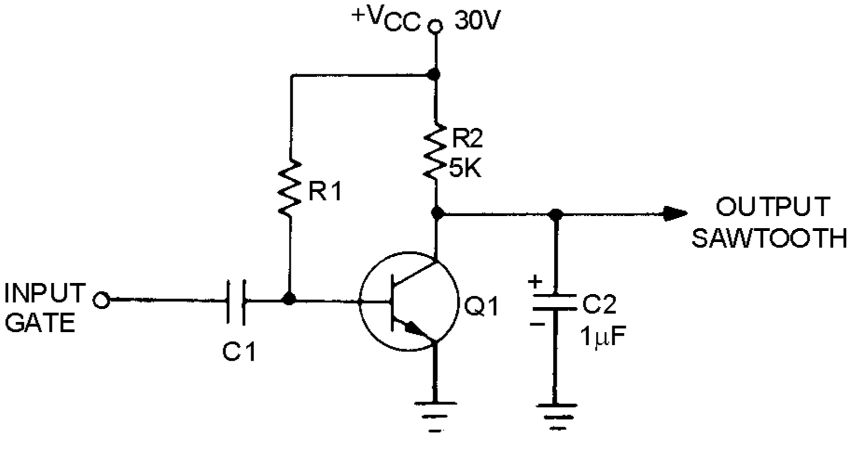


There is a third lead on some flip-flops. This lead is the TOGGLE (T) input. Every time a trigger pulse is applied to the (T) input, the flip-flop will change states.

BLOCKING OSCILLATORS are used in applications which require a narrow pulse with sharp leading and trailing edges. They are used as TRIGGER GENERATORS or FREQUENCY DIVIDERS.

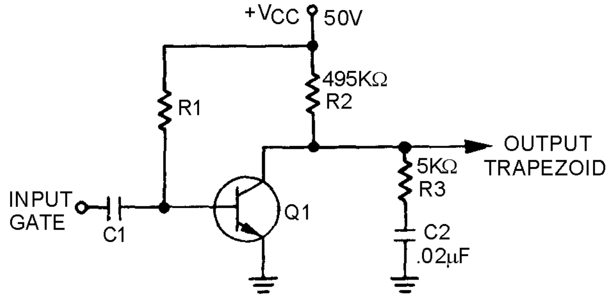


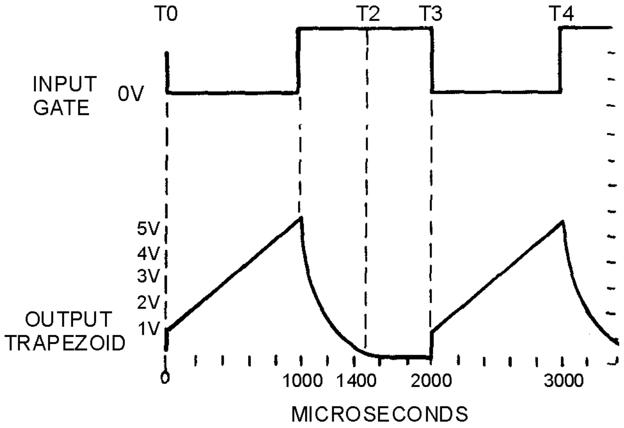
A **SAWTOOTH GENERATOR** voltage waveform has a linear change in voltage and a fast recovery time. The linear change in voltage is generated by taking the output from a capacitor. The sawtooth voltage waveform is used to provide electrostatic deflection in oscilloscopes.



(A)

A **TRAPEZOIDAL GENERATOR** voltage waveform is used to provide, a linear increase in current through a coil. A trapezoidal wave begins with a step or jump voltage, then a sawtooth wave. A trapezoidal wave of voltage is used in electromagnetic deflection display devices.





ANSWERS TO QUESTIONS Q1. THROUGH Q14.

A1. Multivibrator.

A2. Astable.

A3. Monostable.

A4. Bistable.

A5. RC coupling networks.

A6. One-shot.

A7. Two.

A8. Two.

A9. SET state.

A10. Transformer.

A11. Ten percent.

A12. Decreases linearity.

A13. To allow the capacitor time to discharge.

A14. A resistor.

CHAPTER 4

WAVE SHAPING

LEARNING OBJECTIVES

Upon completion of this chapter you will be able to:

1. Explain the operation of series-limiter circuits.
2. Explain the operation of parallel-limiter circuits.
3. Describe the operation of a dual-diode limiter circuit.
4. Explain the operation of clamper circuits.
5. Explain the composition of nonsinusoidal waves.
6. Explain how RC and RL circuits are used as integrators.
7. Explain how RC and RL circuits are used as differentiators.
8. Explain the operation of a counting circuit.
9. Explain the operation of a step-by-step counter used as a frequency divider.

LIMITERS

As a technician, you will be confronted with many different types of LIMITING circuits. A LIMITER is defined as a device which limits some part of a waveform from exceeding a specified value. Limiting circuits are used primarily for wave shaping and circuit-protection applications.

A limiter is little more than the half-wave rectifier you studied in *NEETS, Module 6, Introduction to Electronic Emission, Tubes, and Power Supplies*. By using a diode, a resistor, and sometimes a dc bias voltage, you can build a limiter that will eliminate the positive or negative alternations of an input waveform. Such a circuit can also limit a portion of the alternations to a specific voltage level. In this chapter you will be introduced to five types of limiters: SERIES-POSITIVE, SERIES-NEGATIVE, PARALLEL-POSITIVE, PARALLEL-NEGATIVE, and DUAL-DIODE LIMITERS. Both series- and parallel-positive and negative limiters use biasing to obtain certain wave shapes. They will be discussed in this chapter.

The diode in these circuits is the voltage-limiting component. Its polarity and location, with respect to ground, are the factors that determine circuit action. In series limiters, the diode is in series with the output. In parallel limiters, the diode is in parallel with the output.

SERIES LIMITERS

You should remember, from NEETS, Module 7, *Introduction to Solid-State Devices and Power Supplies*, that a diode will conduct when the anode voltage is positive with respect to the cathode voltage. The diode will not conduct when the anode is negative in respect to the cathode. Keeping these two simple facts in mind as you study limiters will help you understand their operation. Your knowledge of voltage divider action from NEETS, Module 1, *Introduction to Matter, Energy, and Direct Current* will also help you understand limiters.

In a SERIES LIMITER, a diode is connected in series with the output, as shown in view (A) of figure 4-1. The input signal is applied across the diode and resistor and the output is taken across the resistor. The series-limiter circuit can limit either the positive or negative alternation, depending on the polarity of the diode connection with respect to ground. The circuit shown in figure 4-1, view (B), is a SERIES-POSITIVE LIMITER. Reversing D1 would change the circuit to a SERIES-NEGATIVE LIMITER.

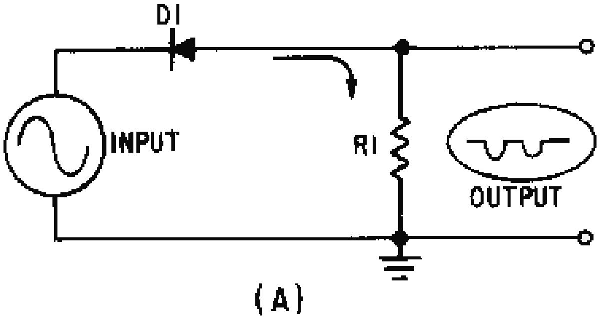


Figure 4-1A.—Series-positive limiter.

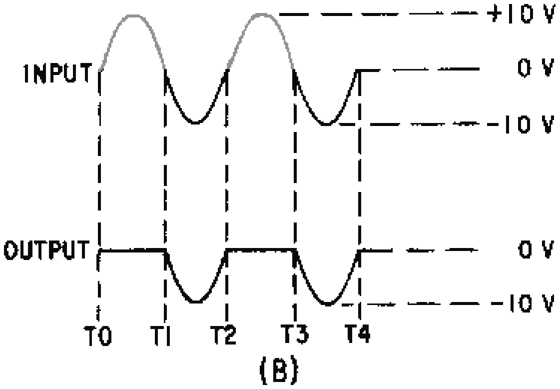


Figure 4-1B.—Series-positive limiter.

Series-Positive Limiter

Let's look at the series-positive limiter and its outputs in figure 4-1. Diode D1 is in series with the output and the output is taken across resistor R1. The input must be negative with respect to the anode of the diode to make the diode conduct. When the positive alternation of the input signal (T0 to T1) is applied to the circuit, the cathode is positive with respect to the anode. The diode is reverse biased and will not conduct. Since no current can flow, no output is developed across the resistor during the positive alternation of the input signal.

During the negative half cycle of the input signal (T1 to T2), the cathode is negative with respect to the anode. This causes D1 to be forward biased. Current flows through R1 and an output is developed.

The output during each negative alternation of the input is approximately the same as the input (−10 volts) because most of the voltage is developed across the resistor.

Ideally, the output wave shape should be exactly the same as the input wave shape with only the limited portion removed. When the diode is reverse biased, the circuit has a small amount of reverse current flow, as shown just above the 0-volt reference line in figure 4-2. During the limiting portion of the input signal, the diode resistance should be high compared to the resistor. During the time the diode is conducting, the resistance of the diode should be small as compared to that of the resistor. In other words, the diode should have a very high front-to-back ratio (forward resistance compared to reverse resistance). This relationship can be better understood if you study the effects that a front-to-back resistance ratio has on circuit output.

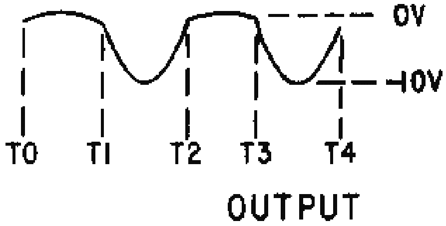


Figure 4-2.—Actual output of a series-positive limiter.

The following formula can be used to determine the output amplitude of the signal:

$$E_{out} = \frac{R}{R + R_{ac}} \cdot E_{in}$$

Where:

E_{out} = amplitude voltage

R = value of R_1

R_{ac} = value of ac resistance of the diode (under forward- and reverse-biased conditions)

E_{in} = input of signal amplitude

Let's use the formula to compare the front-to-back ratio of the diode in the forward- and reverse-biased conditions.

Given:

$R_1 = 1{,}000$ ohms

$R_{ac} = 1$ ohm (forward-biased condition)

$R_{ac} = 100{,}000$ ohms (reversed biased condition)

$E_{in} = 10$ volts

FORWARD BIAS

$$E_{out} = \frac{R}{R + R_{ac}} \cdot E_{in}$$

$$E_{out} = \frac{1{,}000}{1{,}000 + 1} \cdot 10\text{volts}$$

$$E_{out} = \frac{1{,}000}{1{,}001} \cdot 10\text{volts}$$

$$E_{out} = 0.999 \cdot 10\text{volts}$$

$$E_{out} = 0.09\text{volt}$$

REVERSE BIAS

$$E_{out} = \frac{R}{R + R_{ac}} \cdot E_{in}$$

$$E_{out} = \frac{1{,}000}{1{,}000 + 100{,}000} \cdot 10 \text{ volts}$$

$$E_{out} = \frac{1{,}000}{101{,}000} \cdot 10 \text{ volts}$$

$$E_{out} = 0.09 \cdot 10 \text{ volts}$$

$$E_{out} = 0.09 \text{ volt}$$

You can readily see that the formula comparison of the forward- and reverse-bias resistance conditions shows that a small amount of reverse current will flow during the limited portion of the input waveform. This small amount of reverse current will develop as the small positive voltage (0.09 volt) shown in figure 4-2 (T0 to T1 and T2 to T3). The actual amount of voltage developed will depend on the type of diode used. For the remainder of this chapter, we will use only idealized waveforms and disregard this small voltage.

SERIES-POSITIVE LIMITER WITH BIAS.—In the series-positive limiter (figure 4-1, view (A)), the reference point at the bottom of resistor R1 is ground, or 0 volts. By placing a dc potential at point (1) in figure 4-3 (views (A) and (B)), you can change the reference point. The reference point changes by the amount of dc potential that is supplied by the battery. The battery can either aid or oppose the flow of current in the series-limiter circuit. POSITIVE BIAS (aiding) is shown in view (A) and NEGATIVE BIAS (opposing) is shown in view (B).

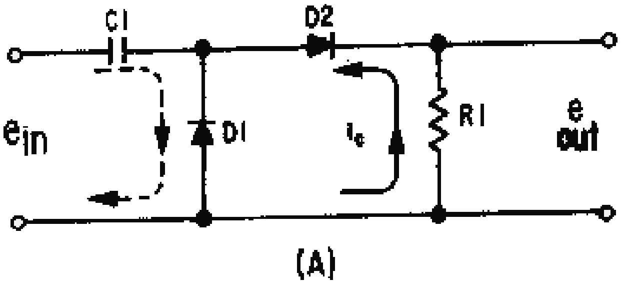


Figure 4-3A.—Positive and negative bias. POSITIVE BIAS.

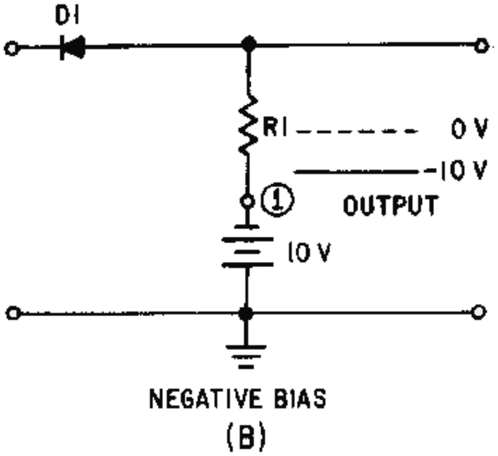


Figure 4-3B.—Positive and negative bias. NEGATIVE BIAS.

When the dc aids forward bias, as in view (A), the diode conducts even with no signal applied. An input signal sufficiently positive to overcome the dc bias potential is required to reverse bias and cut off the diode.

Let's look at a series-positive limiter with positive bias as shown in figure 4-4, views (A) and (B). The diode will conduct until the input signal exceeds +5 at T1 on the positive alternation of the input signal. When the positive alternation exceeds +5 volts, the diode becomes reverse biased and limits the positive alternation of the output signal to +5 volts. This is because there is no current flow through resistor R1 and battery voltage is felt at point (B). The diode will remain reverse biased until the positive alternation of the input signal decreases to just under +5 volts at T2. At this time, the diode again becomes forward biased and conducts. The diode will remain forward biased from T2 to T3. During this period the negative alternation of the input is passed through the diode without being limited. From T3 to T4 the diode is again reverse biased and the output is again limited.

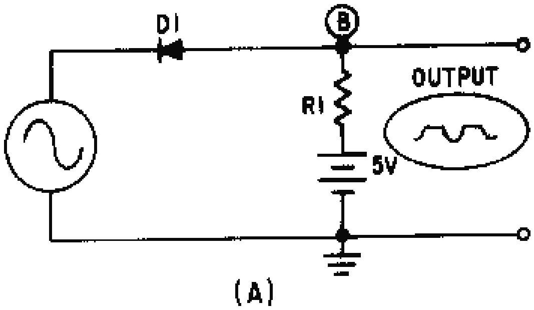


Figure 4-4A.—Series-positive limiter with positive bias.

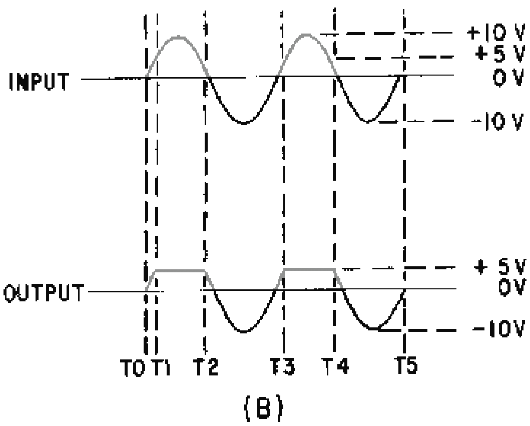


Figure 4-4B.—Series-positive limiter with positive bias.

Now let's look at what takes place when reverse bias is aided, as shown in figure 4-5, view (A). The diode is negatively biased with -5 volts from the battery. In view (B), compare the output to the input signal applied. From T0 to T1 the diode is reverse biased and limiting takes place. The output is at -5 volts (battery voltage) during this period. As the negative alternation increases toward -10 volts (T1), the cathode of the diode becomes more negative than the anode and is forward biased. From T1 to T2 the input signal is passed to the output. The diode remains forward biased until the negative alternation has decreased to −5 volts at T2. At T2 the cathode of the diode becomes more positive than the anode, and the diode is again reverse biased and remains so until T3.

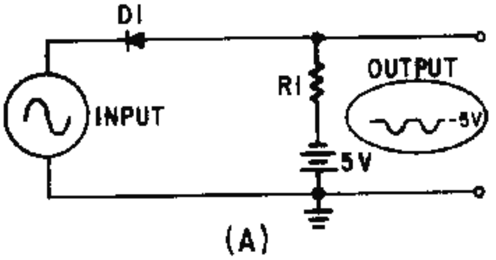


Figure 4-5A.—Series-positive limiter with negative bias.

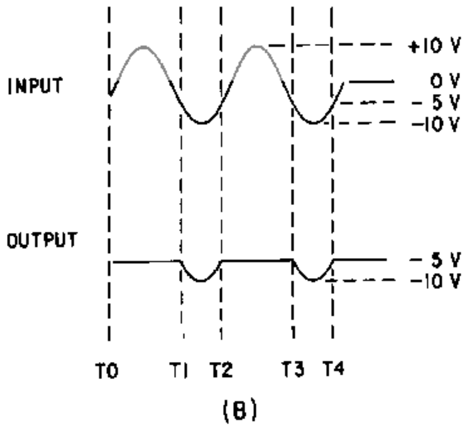


Figure 4-5B.—Series-positive limiter with negative bias.

Series-Negative Limiter

In view (A) of figure 4-6, the SERIES-NEGATIVE LIMITER limits the negative portion of the waveform, as shown in view (B). Let's consider the input signal and determine how the output is produced. During T0 to T1 (view (B)), the anode is more positive than the cathode and the diode conducts. Current flows up through the resistor and the diode, and a positive voltage is developed at the output. The voltage across the resistor is essentially the same as the voltage applied to the circuit.

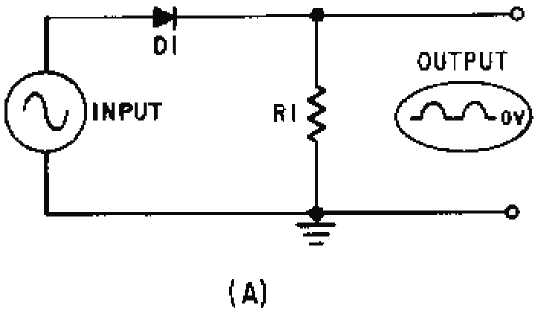


Figure 4-6A.—Series-negative limiter.

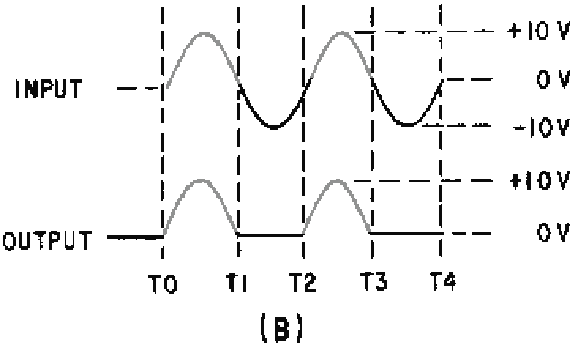
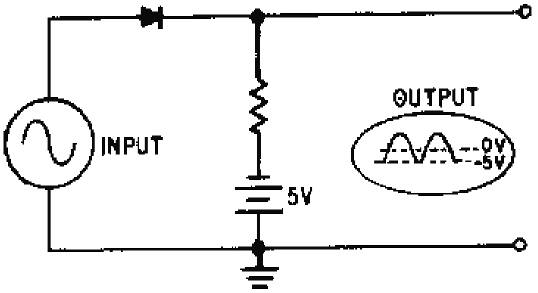


Figure 4-6B.—Series-negative limiter.

During T1 to T2 the anode is negative with respect to the cathode and the diode does not conduct. This portion of the output is limited because no current flows through the resistor.

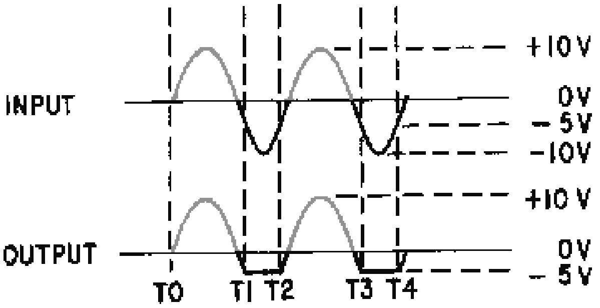
As you can see, the only difference between series-positive and series-negative limiters is that the diode is reversed in the negative limiters.

SERIES-NEGATIVE LIMITER WITH BIAS.—View (A) of figure 4-7 shows a series-negative limiter with negative bias. The diode is forward biased and conducts with no input signal. In view (B) it will continue to conduct as the input signal swings first positive and then negative (but only to −5 volts) from T0 through T1. At T1 the input becomes negative with respect to the −5 volt battery bias. The diode becomes reverse biased and is cutoff until T2 when the anode again becomes positive with respect to the battery voltage (−5 volts) on the cathode. No voltage is developed in the output by R1 (no current flow) and the output is held at −5 volts from T1 to T2. With negative bias applied to a series-negative limiter, only a portion of the negative signal is limited.



(A)

Figure 4-7A.—Series-negative limiter with negative bias.



(B)

Figure 4-7B.—Series-negative limiter with negative bias.

Now let's look at a series-negative limiter with positive bias, as shown in figure 4-8, view (A). Here we will remove all of the negative alternation and part of the positive alternation of the input signal. We have given a full explanation of the series-positive limiter, series-positive limiter with bias, series-negative limiter, and series-negative limiter with negative bias; therefore, you should have little difficulty understanding what is happening in the circuit in the figure.

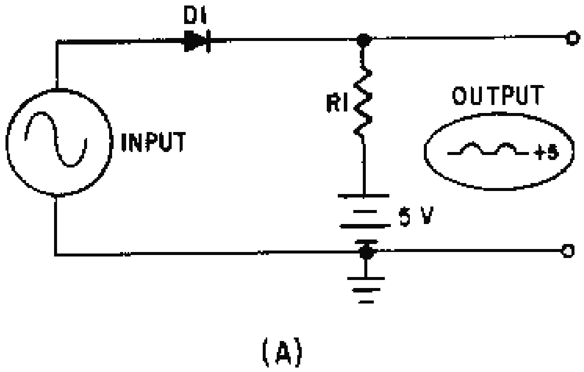


Figure 4-8A.—Series-negative limiter with positive bins.

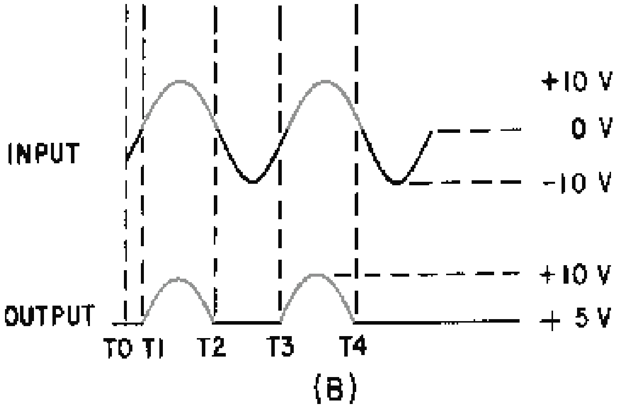


Figure 4-8B.—Series-negative limiter with positive bins.

The series-negative limiter with positive bias is different in only one aspect from the series-positive limiter with bias (figure 4-5) discussed earlier. The difference is that the diode is reversed and the output is of the opposite polarity.

Q1. Which portion of a sine-wave input is retained in the output of a series-positive limiter?

Q2. Which portion of a sine-wave input is retained in the output of a series-negative limiter?

Q3. How can a series-positive limiter be modified to limit unwanted negative portions of the input signal?

PARALLEL LIMITERS

A PARALLEL-LIMITER circuit uses the same diode theory and voltage divider action as series limiters. A resistor and diode are connected in series with the input signal and the output signal is developed across the diode. The output is in parallel with the diode, hence the circuit name, parallel limiter. The parallel limiter can limit either the positive or negative alternation of the input signal.

Recall that in the series limiter the output was developed while the diode was conducting. In the parallel limiter the output will develop when the diode is cut off. You should not try to memorize the outputs of these circuits; rather, you should study their actions and be able to figure them out.

Parallel-Positive Limiter.

The schematic diagram shown in figure 4-9, view (A), is a PARALLEL-POSITIVE LIMITER. The diode is in parallel with the output and only the positive half cycle of the input is limited. When the positive alternation of the input signal is applied to the circuit (T0 to T1), the diode is forward biased and conducts. This action may be seen in view (B). As current flows up through the diode and the resistor, a voltage is dropped across each. Since R1 is much larger than the forward resistance of D1, most of the input signal is developed across R1. This leaves only a very small voltage across the diode (output). The positive alternation of the input signal has been limited.

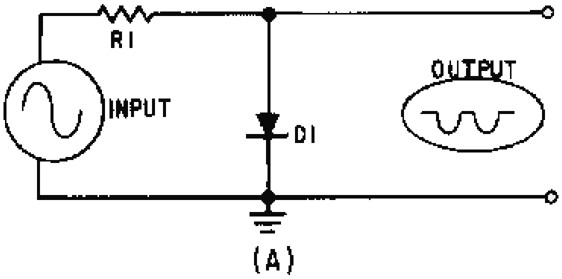


Figure 4-9A.—Parallel-positive limiter.

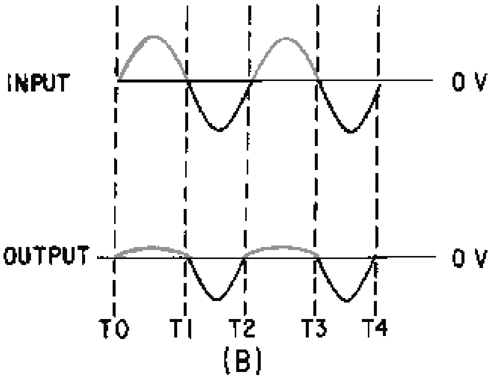


Figure 4-9B.—Parallel-positive limiter.

From T1 to T2 the diode is reverse biased and acts as an extremely high resistance. The negative alternation of the input signal appears across the diode at approximately the same amplitude as the input. The negative alternation of the input is not limited.

As with the series limiter, the parallel limiter should provide maximum output voltage for the unlimited part of the signal. The reverse-bias resistance of the diode must be very large compared to the series resistor. To determine the output amplitude, use the following formula:

$$E_{out} = \frac{R}{R + R_{ac}} \cdot E_{in}$$

Where:

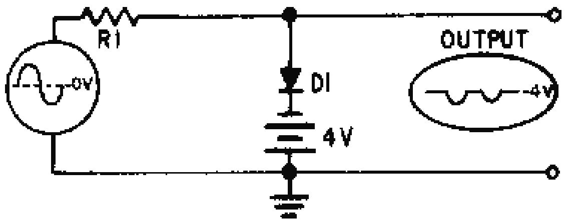
E_{out} = amplitude voltage

R = value of R_1

R_{ac} = value of ac resistance of the diode (under forward - and reverse - biased conditions)

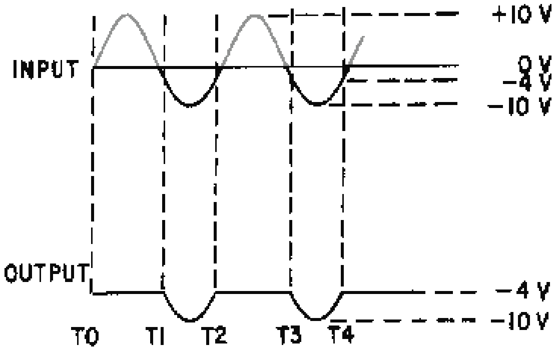
E_{in} = input of signal amplitude

PARALLEL-POSITIVE LIMITER WITH BIAS.—Figure 4-10, view (A), shows the schematic diagram of a PARALLEL-POSITIVE LIMITER WITH NEGATIVE BIAS. The diode is forward biased and conducts without an input signal. D1 is essentially a short circuit. The voltage at the output terminals is -4 volts.



(A)

Figure 4-10A.—Parallel limiter with negative bias.



(B)

Figure 4-10B.—Parallel limiter with negative bias.

As the positive alternation of the input signal is applied to the circuit, the diode remains forward biased and limits the entire positive alternation, as shown in view (B). As the signal goes in a negative direction Oust before T1), the diode remains forward biased (limiting is still present) until the input signal exceeds –4 volts (T1). D1 becomes reverse biased as the anode becomes more negative than the cathode. While the input signal is more negative than the –4 volts of the bias battery (T1 to T2), the diode is reverse biased and remains cut off. The output follows the input signal from T1 to T2. At all other times during that cycle, the diode is forward biased and limiting occurs. This circuit is called a parallel-positive limiter with negative bias because the positive output is limited and the bias in the circuit is negative with reference to ground. Limiting takes place at all points more positive than –4 volts.

The circuit shown in figure 4-11, view (A), is a PARALLEL-POSITIVE LIMITER WITH POSITIVE BIAS. The positive terminal of the battery is connected to the cathode of the diode. This causes the diode to be reverse biased at all times except when the input signal is more positive than the bias voltage (T1 to T2), as shown in view (B).

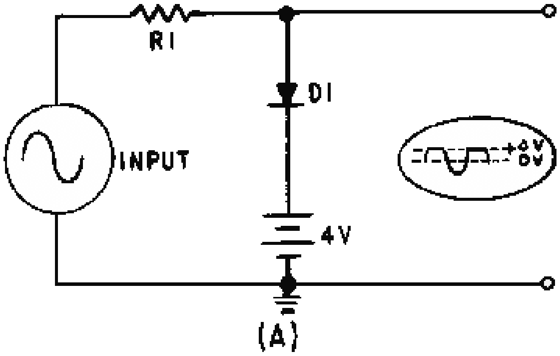


Figure 4-11A.—Parallel-positive Limiter with positive bias.

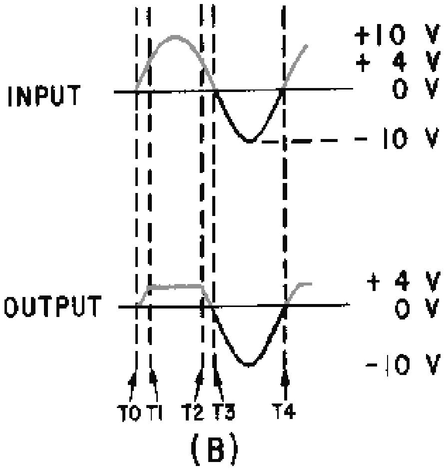


Figure 4-11B.—Parallel-positive Limiter with positive bias.

As the positive alternation of the input signal is applied (T0), the output voltage follows the input signal. From T1 to T2 the input signal is more positive than + 4 volts. The diode is forward biased and conducts. At this time the output voltage equals the bias voltage and limiting takes place. From T2 to T4 of the input signal, the diode is reverse biased and does not conduct. The output signal follows the input signal and no limiting takes place.

This circuit is called a parallel-positive limiter with positive bias because limiting takes place in the positive alternation and positive bias is used on the diode.

Parallel-Negative Limiter

A PARALLEL-NEGATIVE LIMITER is shown in view (A) of figure 4-12. Notice the similarity of the parallel-negative limiter and the parallel-positive limiter shown in view (A) of figure 4-9. From T0 to T1 of the input signal, the diode is reverse biased and does not conduct, as shown in view (B) of figure 4-12. The output signal follows the input signal and the positive alternation is not limited.

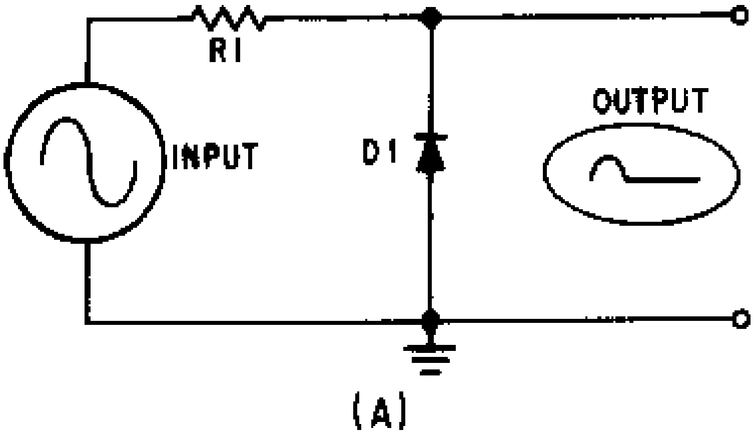


Figure 4-12A.—Parallel-negative limiter.

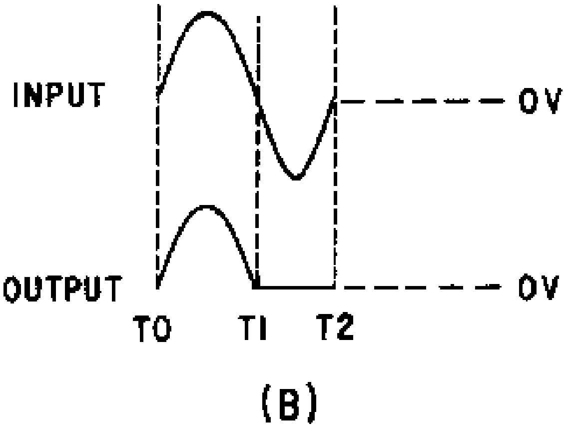


Figure 4-12B.—Parallel-negative limiter.

During the negative alternation of the input signal (T1 to T2), the diode is forward biased and conducts. The relatively low forward bias of D1 develops a very small voltage and, therefore, limits the output to nearly 0 volts. A voltage is developed across the resistor as current flows through the resistor and diode.

PARALLEL-NEGATIVE LIMITER WITH BIAS.—The circuit shown in figure 4-13, view (A), is a parallel-negative limiter with negative bias. With no input, the battery maintains D1 in a reverse-bias condition. D1 cannot conduct until its cathode is more negative than its anode. D1 acts as an open until the input signal dips below −4 volts at T2 in view (B). At T2 the input signal becomes negative enough to forward bias the diode, D1 conducts and acts like a short, and the output is limited to the −4 volts from the battery from T2 to T3. Between T3 and T4 the diode is again reverse biased. The output signal follows the input signal and no limiting occurs.

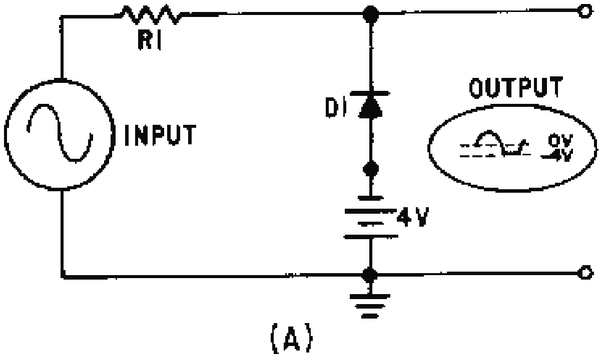


Figure 4-13A.—Parallel-negative limiter with negative bias.

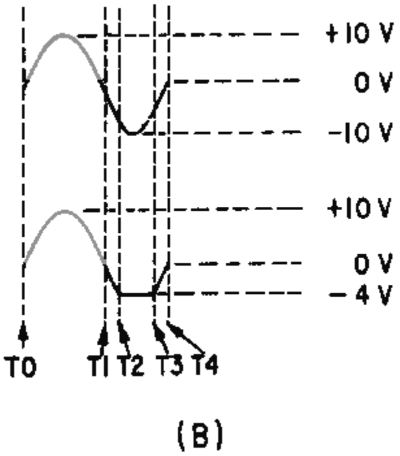


Figure 4-13B.—Parallel-negative limiter with negative bias.

Figure 4-14, view (A), shows a parallel-negative limiter with positive bias. The operation is similar to those circuits already explained. Limiting occurs when the diode conducts. No limiting occurs when the diode is reverse biased. In this circuit, the bias battery provides forward bias to the diode without an input signal. The output is at +4 volts, except where the input goes above +4 volts (T1 to T2), as shown in view (B). The parts of the signal more negative than +4 volts are limited.

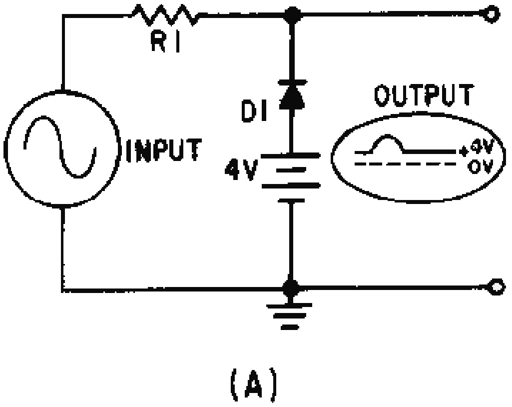


Figure 4-14A.—Parallel-negative limiter with positive bias.

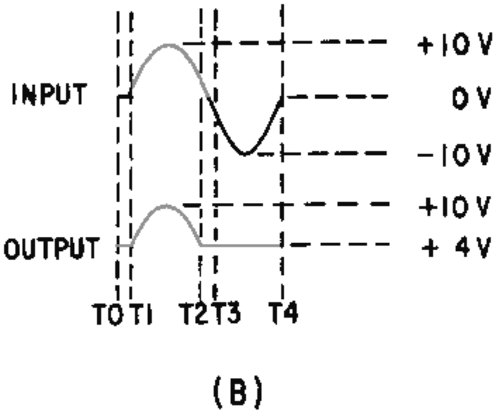


Figure 4-14B.—Parallel-negative limiter with positive bias.

Q4. What component is in parallel with the output in a parallel limiter?

Q5. What is the condition of the diode in a series limiter when an output is developed? In a parallel limiter?

DUAL-DIODE LIMITER

The last type of limiter to be discussed in this chapter is the DUAL-DIODE LIMITER, shown in figure 4-15, view (A). This limiter combines a parallel-negative limiter with negative bias (D1 and B1) and a parallel-positive limiter with positive bias (D2 and B2). Parts of both the positive and negative alternations are removed in this circuit. Each battery aids the reverse bias of the diode in its circuit; the circuit has no current flow with no input signal. When the input signal is below the value of the biasing batteries, both D1 and D2 are reverse biased. With D1 and D2 reverse biased, the output follows the input. When the input signal becomes more positive than +20 volts (view (B)), D2 conducts and limits the output to +20 volts. When the input signal becomes more negative than –20 volts, D1 conducts and limits the output to this, value. When neither diode conducts, the output follows the input waveform.

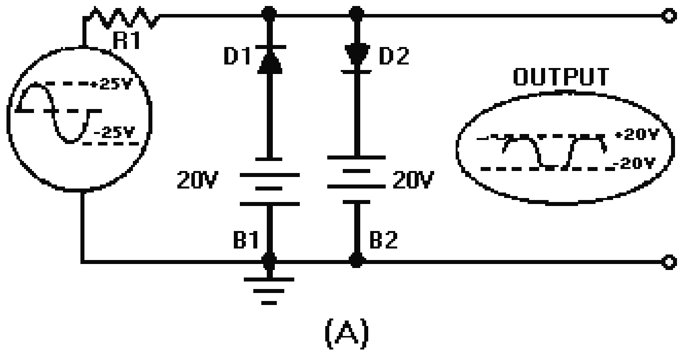


Figure 4-15A.—Dual-diode limiter.

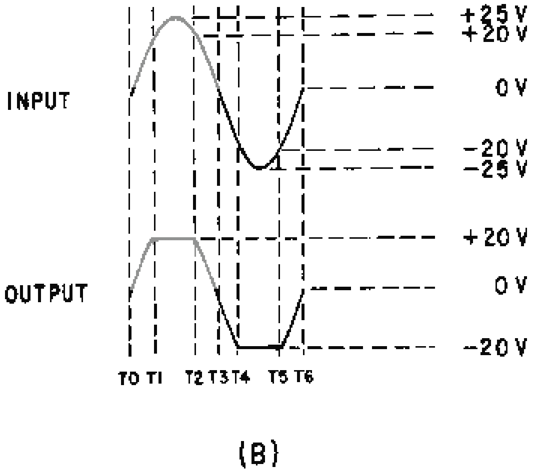


Figure 4-15B.—Dual-diode limiter.

CLAMPERS

Certain applications in electronics require that the upper or lower extremity of a wave be fixed at a specific value. In such applications, a CLAMPING (or CLAMPER) circuit is used. A clamping circuit clamps or restrains either the upper or lower extremity of a waveform to a fixed dc potential. This circuit is also known as a DIRECT-CURRENT RESTORER or a BASE-LINE STABILIZER. Such circuits are used in test equipment, radar systems, electronic countermeasure systems, and sonar systems. Depending upon the equipment, you could find negative or positive clampers with or without bias. Figure 4-16, views (A) through (E), illustrates some examples of waveforms created by clampers. However, before we discuss clampers, we will review some relevant points about series RC circuits.

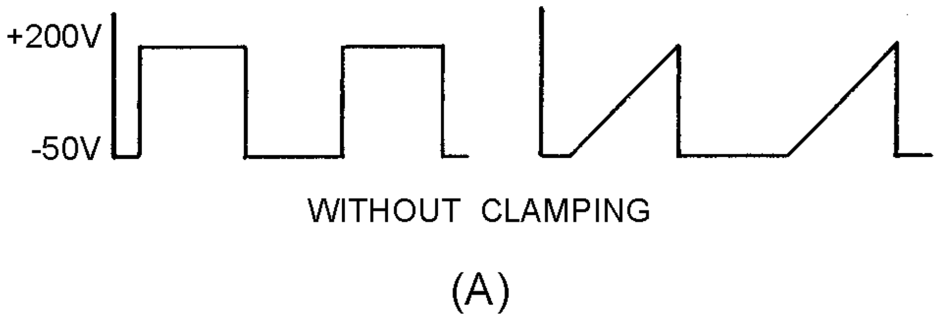


Figure 4-16A.—Clamping waveforms. WITHOUT CLAMPING.

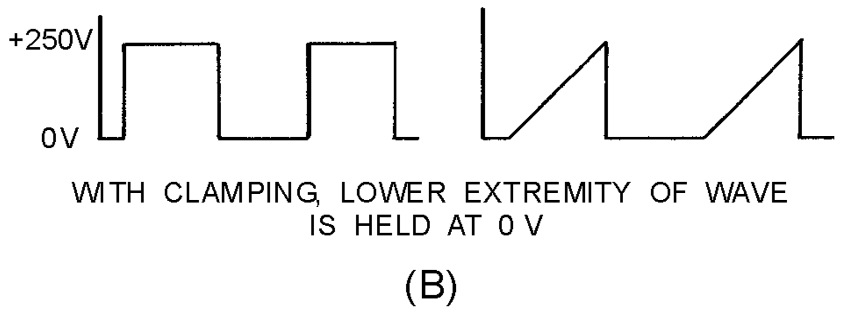


Figure 4-16B.—Clamping waveforms. WITH CLAMPING, LOWER EXTREMITY OF WAVE IS HELD AT 0V.

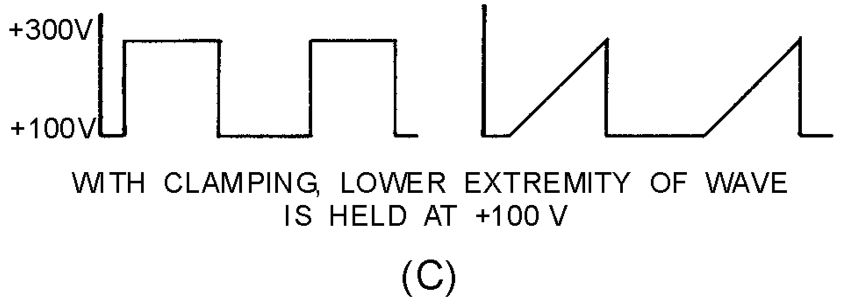


Figure 4-16C.—Clamping waveforms. WITH CLAMPING, LOWER EXTREMITY OF WAVE IS HELD AT +100 V.

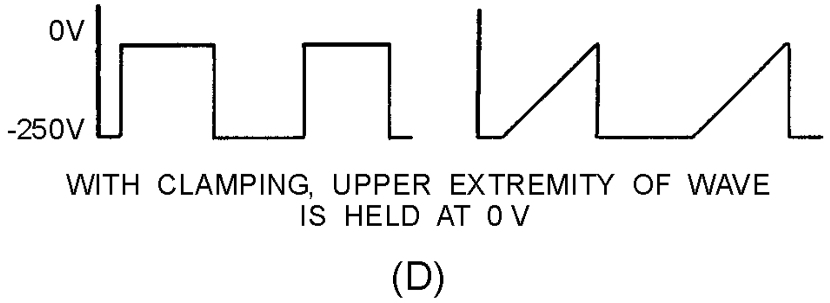


Figure 4-16D.—Clamping waveforms. WITH CLAMPING, UPPER EXTREMITY OF WAVE IS HELD AT 0V.

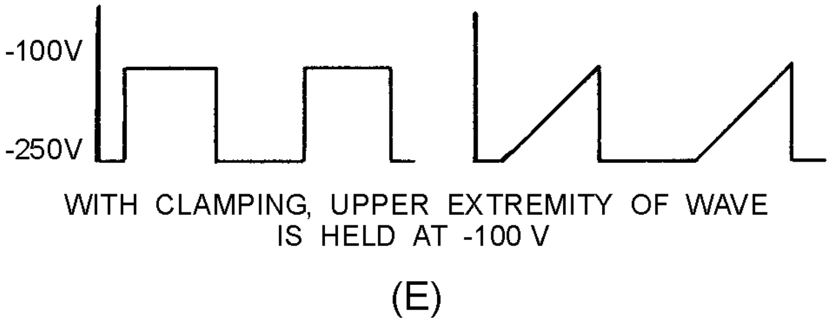


Figure 4-16E.—Clamping waveforms. WITH CLAMPING, UPPER EXTREMITY OF WAVE IS HELD AT –100 V.

SERIES RC CIRCUITS

Series RC circuits are widely used for coupling signals from one stage to another. If the time constant of the coupling circuit is comparatively long, the shape of the output waveform will be almost identical to that of the input. However, the output dc reference level may be different from that of the input. Figure 4-17, view (A), shows a typical RC coupling circuit in which the output reference level has been changed to 0 volts. In this circuit, the values of R1 and C1 are chosen so that the capacitor will charge (during T0 to T1) to 20 percent of the applied voltage, as shown in view (B). With this in mind, let's consider the operation of the circuit.

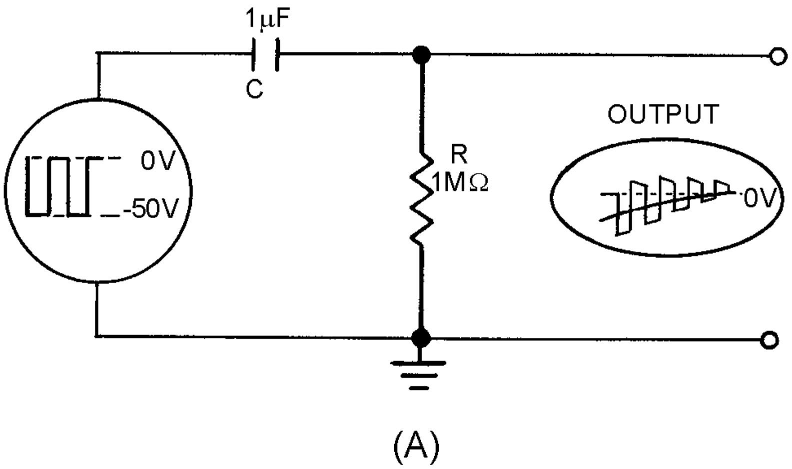


Figure 4-17A.—RC coupling.

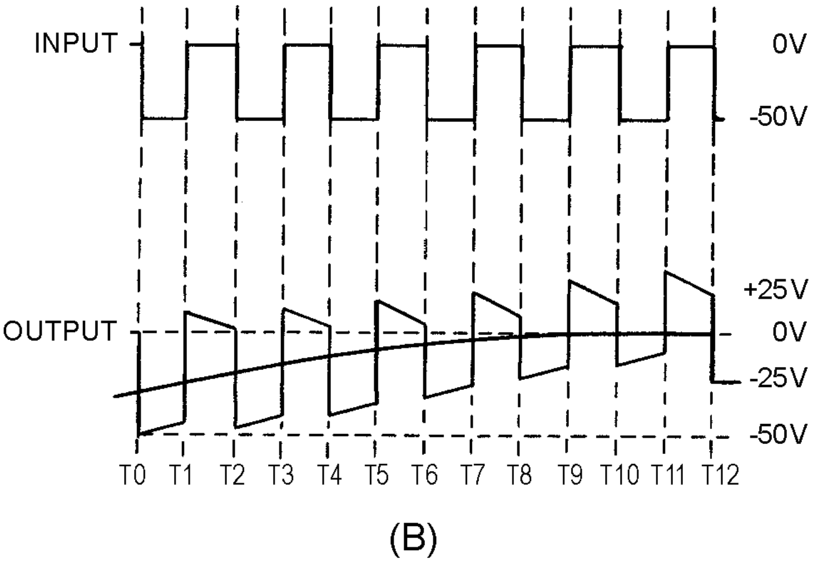


Figure 4-17B.—RC coupling.

At T0 the input voltage is –50 volts and the capacitor begins charging. At the first instant the voltage across C is 0 and the voltage across R is –50 volts. As C charges, its voltage increases. The voltage across R, which is the output voltage, begins to drop as the voltage across C increases. At T1 the capacitor has charged to 20 percent of the –50 volts input, or –10 volts. Because the input voltage is now 0 volts, the capacitor must discharge. It discharges through the low impedance of the signal source and through R, developing +10 volts across R at the first instant. C discharges 20 percent of the original 10-volt charge from T1 to T2. Thus, C discharges to +8 volts and the output voltage also drops to 8 volts.

At T2 the input signal becomes –50 volts again. This –50 volts is in series opposition to the 8-volt charge on the capacitor. Thus, the voltage across R totals –42 volts (–50 plus +8 volts). Notice that this value of voltage (–42 volts) is smaller in amplitude than the amplitude of the output voltage which occurred at TO (–50 volts). Capacitor C now charges from +8 to +16 volts. If we were to continue to follow the operation of the circuit, we would find that the output wave shape would become exactly distributed around the 0-volt reference point. At that time the circuit operation would have reached a stable operating point. Note that the output wave shape has the same amplitude and approximately the same shape as the input wave shape, but now "rides" equally above and below 0 volts. Clampers use this RC time so that the input and output waveforms will be almost identical, as shown from T11 to T12.

POSITIVE-DIODE CLAMPERS

Figure 4-18, view (A), illustrates the circuit of a positive-diode clamper. Resistor R1 provides a discharge path for C1. This resistance is large in value so that the discharge time of C1 will be long compared to the input pulse width. The diode provides a fast charge path for C1. After C1 becomes charged it acts as a voltage source. The input wave shape shown in view (B) is a square wave and varies between +25 volts and –25 volts. Compare each portion of the input wave shape with the corresponding output wave shape. Keep Kirchhoff's law in mind: The algebraic sum of the voltage drops around a closed loop is 0 at any instant.

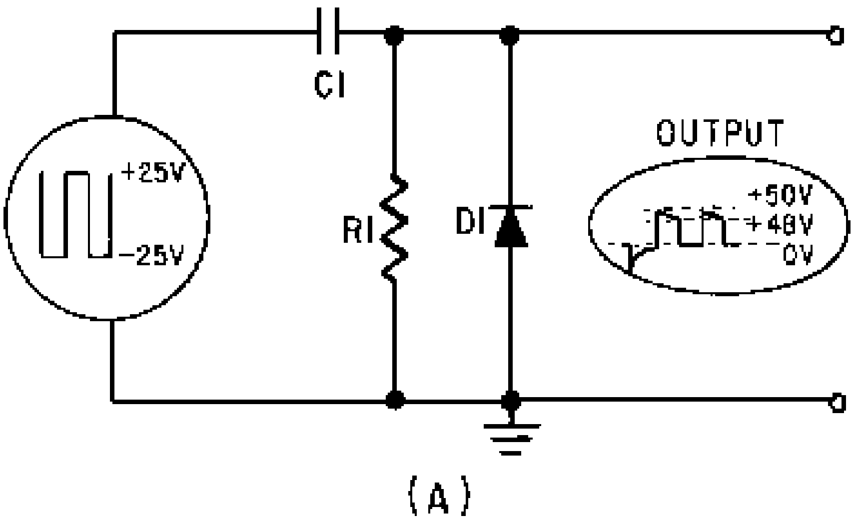


Figure 4-18A.—Positive damper and waveform.

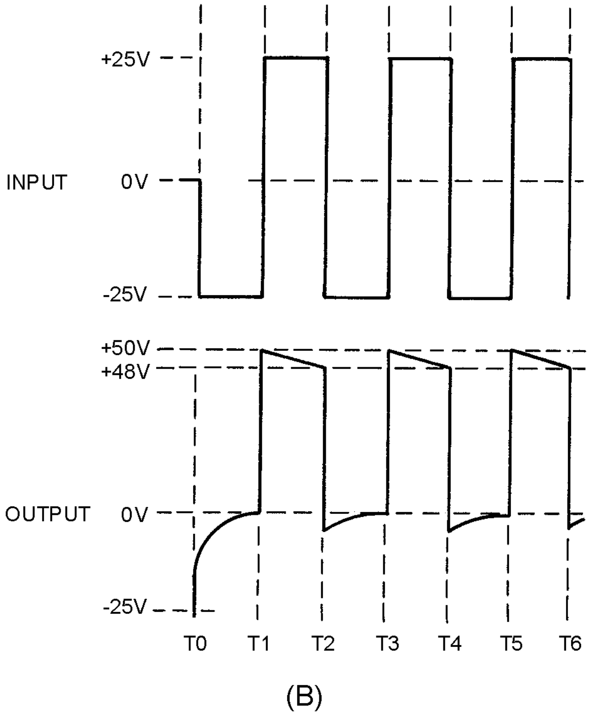


Figure 4-18B.—Positive damper and waveform.

At T0 the –25 volt input signal appears across R1 and D1 (the capacitor is a short at the first instant). The initial voltage across R1 and D1 causes a voltage spike in the output. Because the charge time of C1 through D1 is almost instantaneous, the duration of the pulse is so short that it has only a negligible effect on the output. The –25 volts across D1 makes the cathode negative with respect to the anode and the diode conducts heavily. C1 quickly charges through the small resistance of D1. As the voltage across C1 increases, the output voltage decreases at the same rate. The voltage across C1 reaches -25 volts and the output is at 0 volts.

At T1 the +25 volts already across the capacitor and the +25 volts from the input signal are in series and aid each other (SERIES AIDING). Thus, +50 volts appears across R1 and D1. At this time, the cathode of D1 is positive with respect to the anode, and the diode does not conduct. From T1 to T2, C1 discharges to approximately +23 volts (because of the large values of R and C) and the output voltage drops from +50 volts to +48 volts.

At T2 the input signal changes from +25 volts to −25 volts. The input is now SERIES OPPOSING with the +23 volts across C1. This leaves an output voltage of −2 volts (−25 plus +23 volts). The cathode of D1 is negative with respect to the anode and D1 conducts. From T2 to T3, C1 quickly charges through D1 from +23 volts to +25 volts; the output voltage changes from −2 volts to 0 volts.

At T3 the input signal and capacitor voltage are again series aiding. Thus, the output voltage felt across R1 and D1 is again +50 volts. During T3 and T4, C1 discharges 2 volts through R1. Notice that circuit operation from T3 to T4 is the same as it was from T1 to T2. The circuit operation for each square-wave cycle repeats the operation which occurred from T2 to T4.

Compare the input wave shape of figure 4-18, view (B), with the output wave shape. Note the following important points: (1) The peak-to-peak amplitude of the input wave shape has not been changed by the clamper circuit; (2) the shape of the output wave shape has not been significantly changed from that of the input by the action of the clamper circuit; and (3) the output wave shape is now all above 0 volts whereas the input wave shape is both above and below 0 volts. Thus, the lower part of the input wave shape has been clamped to a dc potential of 0 volts in the output. This circuit is referred to as a positive clamper since all of the output wave shape is above 0 volts and the bottom is clamped at 0 volts.

The positive clamper circuit is self-adjusting. This means that the bottom of the output waveform remains clamped at 0 volts during changes in input signal amplitude. Also, the output wave shape retains the form and peak-to-peak amplitude (50 volts in this case) of the input wave shape. When the input amplitude becomes greater, the charge of the capacitor becomes greater and the output amplitude becomes larger. When the input amplitude decreases, the capacitor does not charge as high as before and clamping occurs at a lower output voltage. The capacitor charge, therefore, changes with signal strength.

The size of R1 and C1 has a direct effect upon the operation of the clamper. Because of the small resistance of the diode, the capacitor charge time is short. If either R1 or C1 is made smaller, the capacitor discharges faster ($TC = R \cdot C$).

The ability of a smaller value capacitor to quickly discharge to a lower voltage is an *advantage* when the amplitude of the input wave shape is suddenly reduced. However, for normal clamper operation, quick discharge time is a *disadvantage*. This is because one objective of clamping is to keep the output wave shape the same as the input wave shape. If the small capacitor allows a relatively large amount of the voltage to discharge with each cycle, then distortion occurs in the output wave shape. A larger portion of the wave shape then appears on the wrong side of the reference line.

Increasing the value of the resistor increases the discharge time (again, $TC = R \cdot C$). This increased value causes the capacitor to discharge more slowly and produces an output wave shape which is a better reproduction of the input wave shape. A *disadvantage* of increasing the resistance value is that the larger resistance increases the discharge time of the capacitor and slows the self-adjustment rate of the circuit, particularly in case a sudden decrease in input amplitude should occur. The larger resistance has no effect on self-adjustment with a sudden *rise* in input amplitude. This is because the capacitor charges through the small resistance of the conducting diode.

Circuits often incorporate a compromise between a short RC time constant (for self-adjustment purposes) and a long RC time constant for less distortion. A point to observe is that the reverse resistance of the diode sometimes replaces the, physical resistor in the discharge path of the capacitor.

Positive-Diode Clamper With Bias

Biased clamping circuits operate in exactly the same manner as unbiased clampers, with one exception. That exception is the addition of a dc bias voltage in series with the diode and resistor. The size and polarity of this bias voltage determines the output clamping reference.

View (A) of figure 4-19 illustrates the circuit of a positive clamper with positive bias. It can be identified as a positive clamper because the cathode of the diode is connected to the capacitor. Positive bias can be observed by noting that the negative side of the battery is connected to ground. The purposes and actions of the capacitor, resistor, and diode are the same as in the unbiased clamper circuit just discussed.

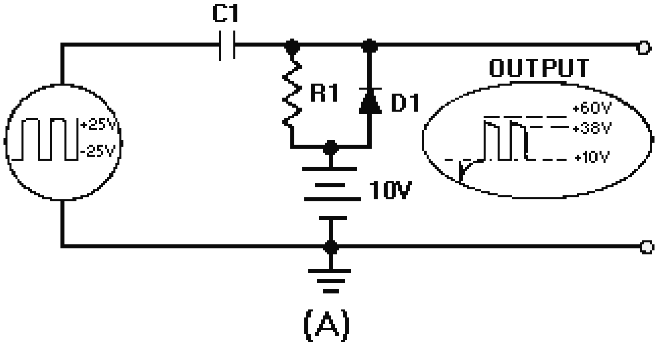


Figure 4-19A.—Positive clamper with positive bias.

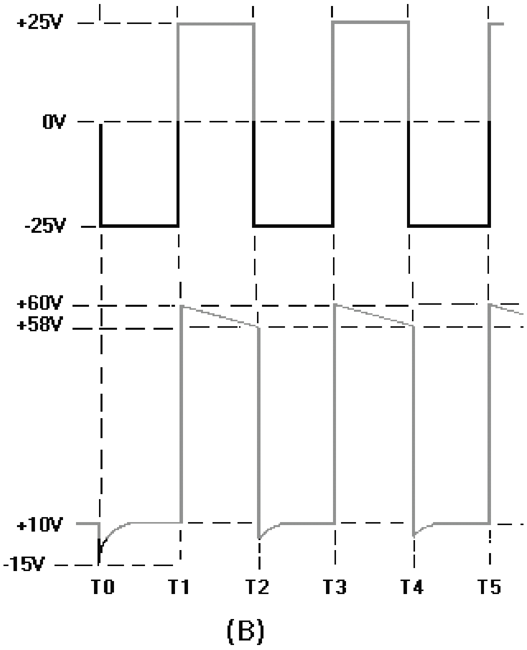


Figure 4-19B.—Positive clamper with positive bias.

With no input, D1 is forward biased and the +10 V battery is the output. C1 will charge to +10 V and hold this charge until the first pulse is applied. The battery establishes the dc reference level at +10 volts. The input wave shape at the top of view (B) is a square wave which alternates between +25 and −25 volts. The output wave shape is shown at the bottom half of view (B).

Here, as with previous circuits, let's apply Kirchhoff's voltage law to determine circuit operation. With no input signal, the output is just the +10 volts supplied by the battery.

At time T0 the −25 volt signal applied to the circuit is instantly felt across R1 and D1. The −25 volt input signal forward biases D1, and C1 quickly charges to 35 volts. This leaves +10 volts across the output terminals for much of the period from T0 to T1. The polarity of the charged capacitor is, from the left to the right, minus to plus.

At T1 the 35 volts across the capacitor is series aiding with the +25 volt input signal. At this point (T1) the output voltage becomes +60 volts; the voltage across R1 and D1 is +50 volts, and the battery is +10 volts. The cathode of D1 is positive with respect to the anode and the diode does not conduct. From T1 to T2, C1 discharges only slightly through the large resistance of R1. Assume that, because of the size of R1 and C1, the capacitor discharges just 2 volts (from +35 volts to +33 volts) during this period. Thus, the output voltage drops from +60 volts to +58 volts.

At T2 the −25 volt input signal and the +33 volts across C1 are series opposing. This makes the voltage across the output terminals +8 volts. The cathode of the diode is 2 volts negative with respect to its anode and D1 conducts. Again, since the forward-biased diode is essentially a short, C1 quickly charges from +33 volts to +35 volts. During most of the time from T2 to T3, then, we find the output voltage is +10 volts.

At T3 the +25 volts of the input signal is series aiding with the +35 volts across C1. Again the output voltage is +60 volts. Observe that at T3 the conditions in the circuit are the same as they were at T1. Therefore, the circuit operation from T3 to T4 is the same as it was from T1 to T2. Circuit operation continues as a duplication of the operations which occurred from T1 to T3.

By comparing the input and output wave shapes, you should note the following: (1) The peak-to-peak amplitude of the input wave shape has not been changed in the output (for all practical purposes) by the action of the clamper circuit; (2) the shape of the input wave has not been changed; (3) the output wave shape is now clamped above +10 volts. Remember that this clamping level (+10 volts) is determined by the bias battery.

Positive-Diode Clamper With Negative Bias

View (A) of figure 4-20 is a positive clamper with negative bias. Observe that with no input signal, the capacitor charges through R1 to the bias battery voltage; the output voltage equals −10 volts. The circuit has negative bias because the positive side of the battery is grounded. The output waveform is shown in view (B). Study the figure and waveforms carefully and note the following important points. Once again the peak-to-peak amplitude and shape of the output wave are, for all practical purposes, the same as the input wave. The lower extremity of the output wave is clamped to −10 volts, the value of the battery. Let's look at the circuit operation. The capacitor is initially charged to −10 volts with no input signal, and diode D1 does not conduct.

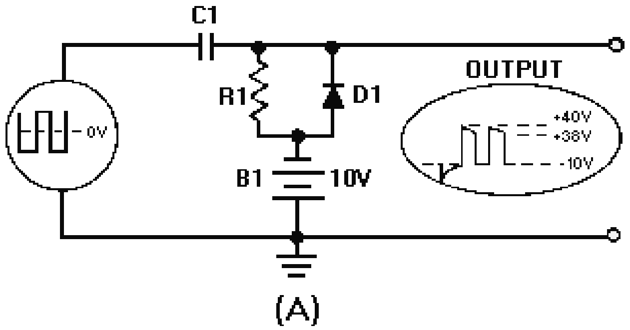


Figure 4-20A.—Positive clamper with negative bias.

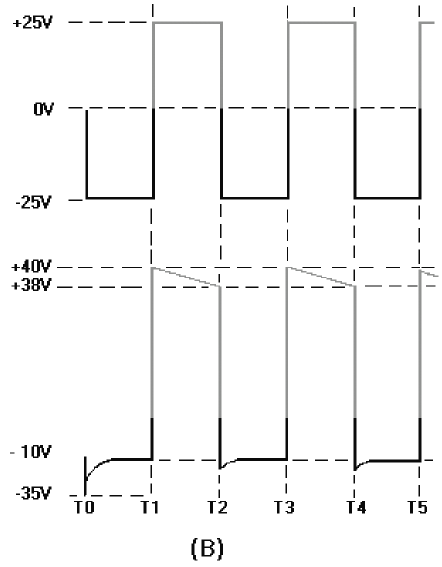


Figure 4-20B.—Positive clamper with negative bias.

The –25 volt input signal provides forward bias for D1. The capacitor charges to +15 volts and retains most of its charge because its discharge through R1 is negligible. The +25 volt input signal is series aiding the capacitor voltage and develops +40 volts between the output terminals. When the input voltage is –25 volts, D1 conducts and the output voltage is –10 volts (–25 volts plus +15 volts). In this way the output reference is clamped at –10 volts. Changing the size of the battery changes the clamping reference level to the new voltage.

NEGATIVE-DIODE CLAMPERS

Figure 4-21, view (A), illustrates the circuit of a negative-diode clamper. Compare this with the positive-diode clamper in view (A) of figure 4-18. Note that the diode is reversed with reference to ground. Like the positive clamper, resistor R1 provides a discharge path for C1; the resistance must be a large value for C1 to have a long discharge time. The low resistance of the diode provides a fast charge path for C1. Once C1 becomes charged, it acts as a source of voltage which will help determine the maximum and minimum voltage levels of the output wave shape. The input wave shape shown in view (B) is a square wave which varies between +25 and –25 volts. The output wave shapes are shown in the bottom half of view (B). You will find that the operation of the negative clamper is similar to that of the positive clamper, except for the reversal of polarities.

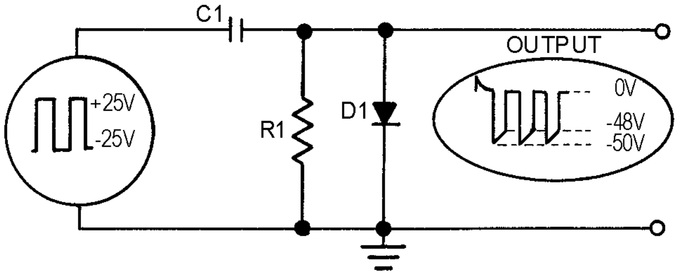


Figure 4-21A.—Negative clamper and waveform.

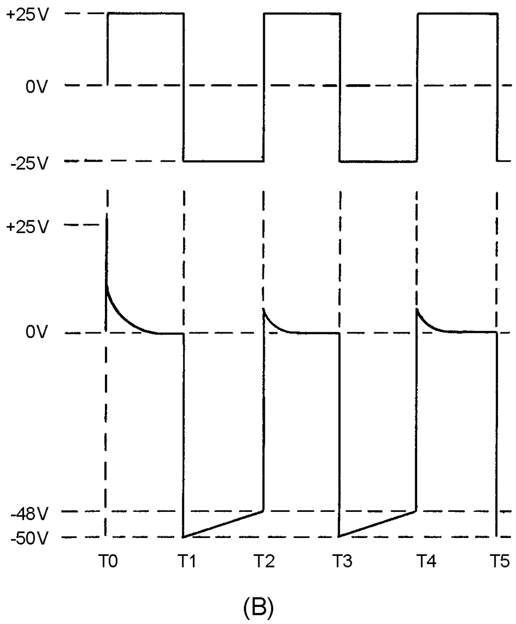


Figure 4-21B.—Negative clamper and waveform.

At T0 the +25 volt input signal applied to the circuit appears across R1 and D1. This makes the anode of D1 positive with respect to the cathode and it conducts heavily. Diode resistance is very small causing C1 to charge quickly. As the voltage across C1 increases, the output voltage decreases. The voltage across C1 reaches 25 volts quickly; during most of T0 to T1, the output voltage is 0.

At T1 the voltage across the capacitor and the input voltage are series aiding and result in −50 volts appearing at the output. At this time the diode is reverse biased and does not conduct. Because of the size of R and C, the capacitor discharges only 2 volts to approximately 23 volts from T1 to T2. Using Kirchhoff's voltage law to determine voltage in the circuit, we find that the output voltage decreases from −50 to −48 volts.

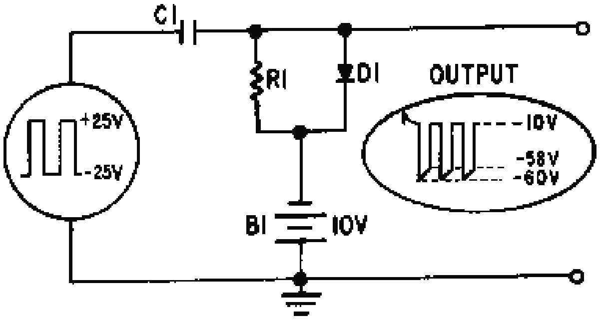
At T2 the +25 volt input signal and the 23 volts across C1 are series opposing. The output voltage is +2 volts. The anode of D1 is positive with respect to the cathode and D1 will conduct. From T2 to T3, C1 charges quickly from 23 to 25 volts through D1. At the same time, the output voltage falls from +2 to 0 volts.

At T3 the input and capacitor voltages are series aiding and the total output voltage is −50 volts. From T3 to T4, D1 is reverse biased and C discharges through R. The circuit operation is now the same as it was from T1 to T2. The circuit operation for the following square-wave cycles duplicates the operation which occurred from T1 to T3.

As was the case with the positive clamper, the amplitude and wave, shape of the output is almost identical to that of the input. However, note that the upper extremity of the output wave shape is clamped to 0 volts; that is, the output wave shape, for all practical purposes, lies entirely below the 0-volt reference level.

Negative-Diode Clamper With Negative Bias

View (A) of figure 4-22 is the circuit of a negative clamper with negative bias. Again, with no input signal the capacitor charges to the battery voltage and the output is negative because the positive side of the battery is ground. The bottom of view (B) shows the output of the circuit. Study the figure carefully, and note the following important points. The peak-to-peak amplitude and shape of the output wave, for all practical purposes, are the same as that of the input wave. The output wave is clamped to −10 volts which is the value of the battery. Since this is a negative clamper, the upper extremity of the waveform touches the −10 volt reference line (and the rest of it lies below this voltage level).



(A)

Figure 4-22A.—Negative damper with negative bias.

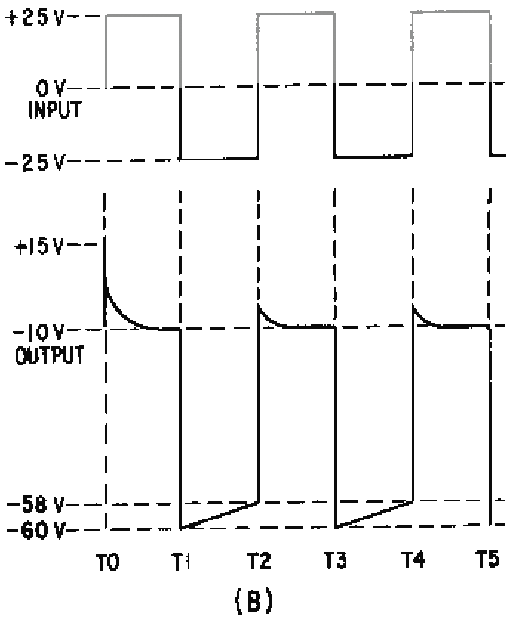


Figure 4-22B.—Negative damper with negative bias.

Let's review the important points of circuit operation. The capacitor is initially charged to –10 volts with no input signal. Applying Kirchhoff's law we find that the +25 volt input signal and the 10-volt battery are series opposing. This series opposing forward biases D1 and the capacitor charges to –35 volts. The output voltage is equal to the sum of the capacitor voltage and the input voltage. Thus, the output voltage is –10 volts and the wave shape is clamped to –10 volts. With a –25 volt input, the charge maintained across C1 and the input are series aiding and provide a –60 volt output. C1 will discharge just before the next cycle begins and the input becomes positive. The +25 volt input signal and the approximately –23 volt charge remaining on C1 will forward bias D1 and the output will be clamped to the battery voltage. C1 will quickly charge to the input signal level. Thus, the output voltage varies between –10 and –60 volts and the wave shape is clamped to –10 volts.

Negative Clamper With Positive Bias

View (A) of figure 4-23 illustrates the circuit of a negative clamper with positive bias. With no input signal the capacitor charges to the battery voltage and the output is positive because the negative side of the battery is grounded. The output is illustrated in the bottom half of view (B). Study the figure carefully and note the following important points. The peak-to-peak amplitude and shape of the output waveform, for all practical purposes, are the same as that of the input. The output wave is clamped to +10 volts, the value of the battery. Since this is a negative clamper (cathode to ground), the top of the output wave touches the +10 volt reference line.

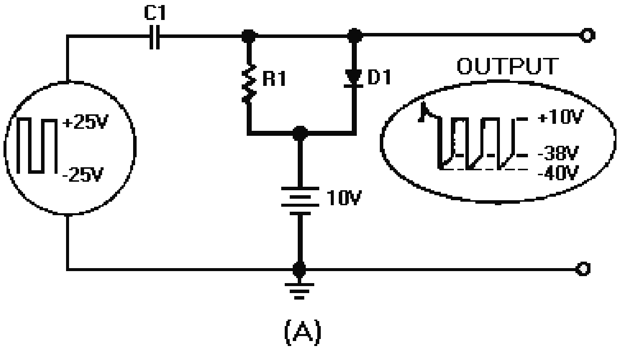


Figure 4-23A.—Negative clamper with positive bias.

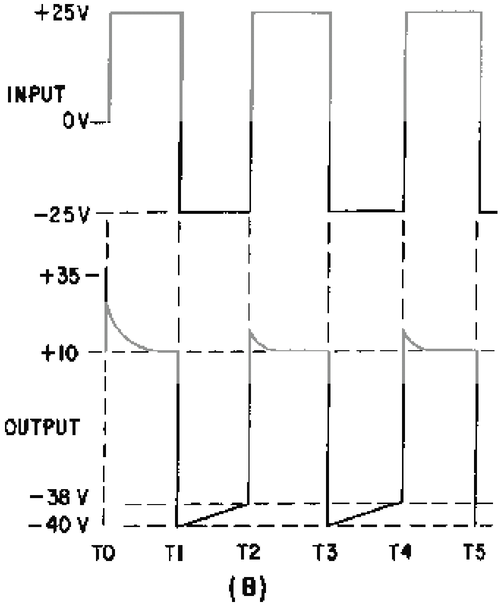


Figure 4-23B.—Negative clamper with positive bias.

Let's go over a summary of the circuit operation. With no input signal the capacitor charges to 10 volts. The +25 volt input signal forward biases D1. With the 10-volt battery and the input in series, the capacitor charges to −15 volts. The capacitor remains charged, for all practical purposes, since its discharge through R1 (very large) is almost negligible. The output voltage is equal to the algebraic sum of the capacitor voltage and the input voltage. The +25 volt input signal added to the −15 volt capacitor charge provides a +10 volt output. With a −25 volt input at T1, D1 is reverse-biased and the charge across C 1 adds to the input voltage to provide a −40 volt output. From T1 to T2, the capacitor loses only a small portion of its charge. At T2 the input signal is +25 volts and the input returns to +10 volts. The wave shape is negatively clamped to +10 volts by the battery.

We can say, then, that positive clamping sets the wave shape above (negative peak on) the reference level, and negative clamping places the wave shape below (positive peak on) the reference level.

Q6. What is the relative length of the time constant for the diode-capacitor combination in a damper (long or short)?

Q7. What is the relative length of the discharge time constant with respect to the charge time constant of a damper (long or short)?

Q8. A positive damper clamps which extremity of the output signal to 0 volts?

Q9. To which polarity does a positive damper with positive bins clamp the most negative extremity of the output waveform (positive or negative)?

Q10. What type damper (with bias) clamps the most negative extremity of the output waveform to a negative potential?

Q11. A negative damper damps which extremity of the output waveshape to 0 volts?

Q12. A negative damper with negative bias clamps the most positive extremity of the output wave shape to what polarity (positive or negative)?

Q13. What type of bias (positive or negative) is added to a negative damper for the most positive extremity of the wave shape to be clamped above 0 volts?

Q14. What would be the output of a negative clamper with a bias potential of –5 volts and an input voltage swing from +50 to –50 volts?

COMMON-BASE TRANSISTOR CLAMPER

The common-base transistor clamper is similar to the dual diode limiter in figure 4-15, except for the addition of a transistor. In the previous clampers, we have clamped the output signal to a reference. In the transistor common-base clamper, we want to clamp the amplitude of the input to no more than nor less than certain values in the output. Also, we do not want phase inversion in the output. View (A) of figure 4-24 shows such a circuit. The transistor does not amplify the input and the output is not inverted. However, the two diode circuits serve to clamp the output between –2 volts and –8 volts, no matter what the varying input positive and negative extremes.

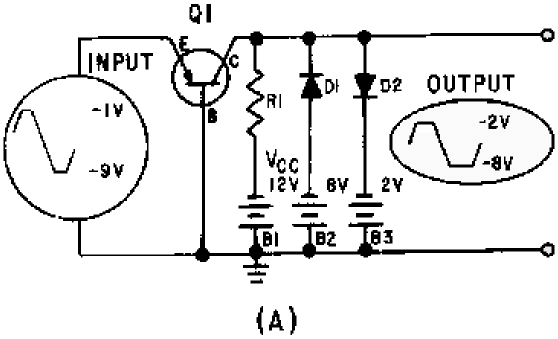


Figure 4-24A.—Common-base configuration clamper.

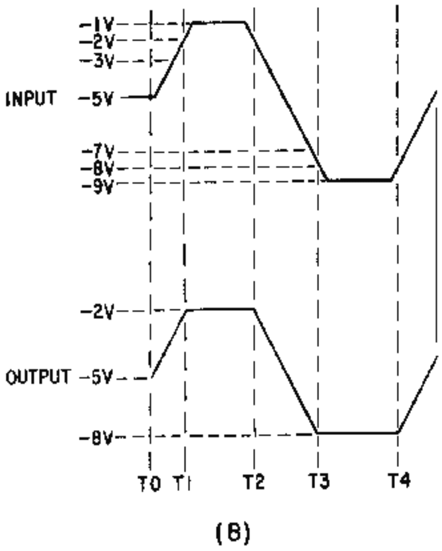


Figure 4-24B.—Common-base configuration clamper.

Look at view (B) as we continue. The input signal is a square-wave pulse type signal that varies in amplitude. Without an input signal, Q1 conducts and provides current through R1. This develops the output (collector to ground) potential which is assumed to be approximately −5 volts ($V_{CC} - E_{R1}$) for this discussion.

From T0 to T1 the output follows the input because of the increasing emitter-base forward bias. However, at T1 the collector voltage reaches −2 volts and D2 is forward biased. D2 conducts and limits the output to −2 volts (the value of B3). D2 conducts until T2 when the input decreases below −2 volts. At this time, D2 cuts off and the output again follows the input because of the decreasing forward bias on Q1. At T3 the input reaches −8 volts and forward biases D1. D1 conducts and any further increase (beyond −8 volts) of the input has no effect on the output. When the input returns to a value more positive than −8 volts, D1 cuts off and the output again follows the input. This circuit action is the same for all inputs. The output remains the same as the input except that both positive and negative extremes are clamped at −2 and −8 volts, respectively.

SHAPING CIRCUITS

Timing circuits and circuits which require a particular shape or "spike" of voltage, may use SHAPING circuits. Shaping circuits can be used to cause wave shapes, such as square waves, sawtooth waves, and trapezoidal waves, to change their shape. Shaping circuits may be either series RC or series RL circuits. The time constant is controlled in respect to the duration of the applied waveform. Notice that the wave shapes mentioned did not include the sine wave. These RC or RL shaping circuits do not change the shape of a pure sine wave.

The series RC and RL circuits electrically perform the mathematical operations of INTEGRATION and DIFFERENTIATION. Therefore, the circuits used to perform these operations are called INTEGRATORS and DIFFERENTIATORS. These names are applied to these circuits even though they do not always completely perform the operations of mathematical integration and differentiation.

COMPOSITION OF NONSINUSOIDAL WAVES

Pure sine waves are basic wave shapes from which other wave shapes can be constructed. Any waveform that is not a pure sine wave consists of two or more sine waves. Adding the correct frequencies at the proper phase and amplitude will form square waves, sawtooth waves, and other nonsinusoidal waveforms.

A waveform other than a sine wave is called a COMPLEX WAVE. You will see that a complex wave consists of a fundamental frequency plus one or more HARMONIC frequencies. The shape of a nonsinusoidal waveform is dependent upon the type of harmonics present as part of the waveform, their relative amplitudes, and their relative phase relationships. In general, the steeper the sides of a waveform, that is, the more rapid its rise and fall, the more harmonics it contains.

The sine wave which has the lowest frequency in the complex periodic wave is referred to as the FUNDAMENTAL FREQUENCY. The type and number of harmonics included in the waveform are dependent upon the shape of the waveform. Harmonics have two classifications — EVEN numbered and ODD numbered. Harmonics are always a whole number of times higher than the fundamental frequency and are designated by an integer (whole number). For example, the frequency twice as high as the fundamental frequency is the SECOND HARMONIC (or the first even harmonic).

View (A) of figure 4-25 compares a square wave with sine waves. Sine wave K is the same frequency as the square wave (its fundamental frequency). If another sine wave (L) of smaller amplitude but three times the frequency (referred to as the third harmonic) is added to sine wave K, curve M is produced. The addition of these two waveforms is accomplished by adding the instantaneous values of both sine waves algebraically. Curve M is called the resultant. Notice that curve M begins to assume the shape of a square wave. Curve M is shown again in view (B).

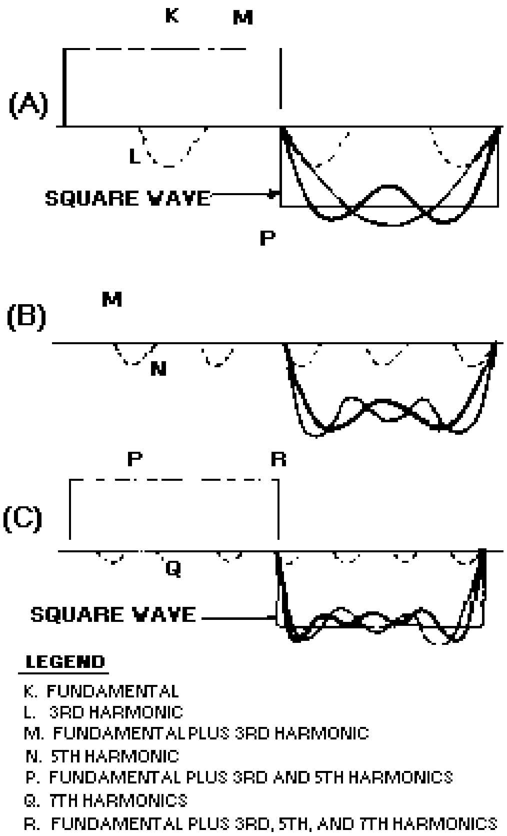


Figure 4-25.—Harmonic composition of a square wave.

As shown in view (B), when the fifth harmonic (curve N with its decreased amplitude) is added, the sides of the new resultant (curve P) are steeper than before. In view (C), the addition of the seventh harmonic (curve Q), which is of even smaller amplitude, makes the sides of the composite waveform (R) still steeper. The addition of more odd harmonics will bring the composite waveform nearer the shape of the perfect square wave. A perfect square wave is, therefore, composed of an infinite number of odd harmonics. In the composition of square waves, all the odd harmonics cross the reference line in phase with the fundamental.

A sawtooth wave, shown in figure 4-26, is made up of both even and odd harmonics. Notice that each higher harmonic is added in phase as it crosses the 0 reference in view (A), view (B), view (C), and view (D). The resultant, shown in view (D), closely resembles a sawtooth waveform.

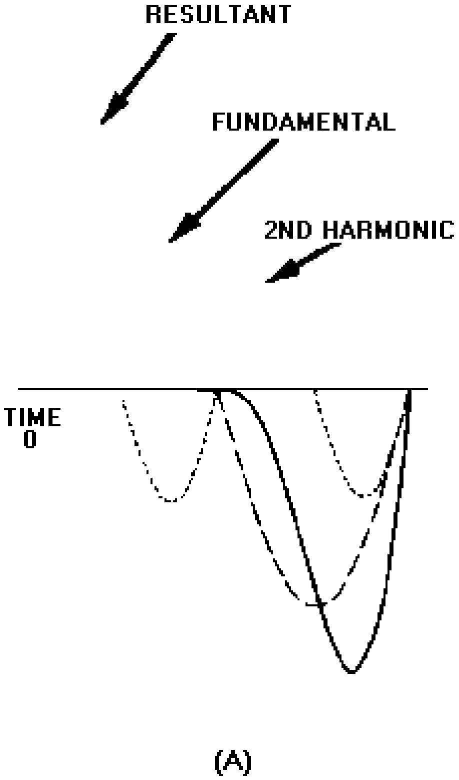


Figure 4-26A.—Composition of a sawtooth wave.

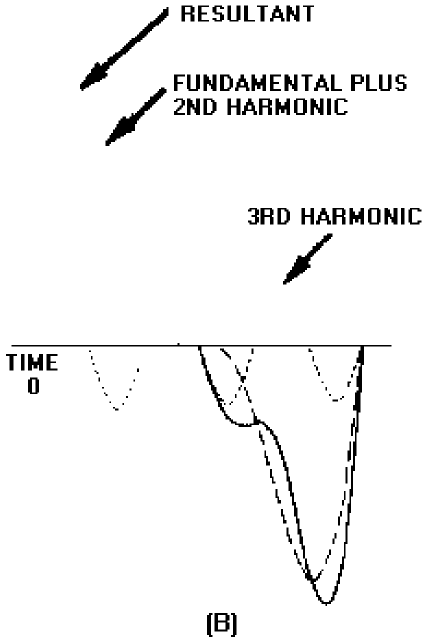


Figure 4-26B.—Composition of a sawtooth wave.

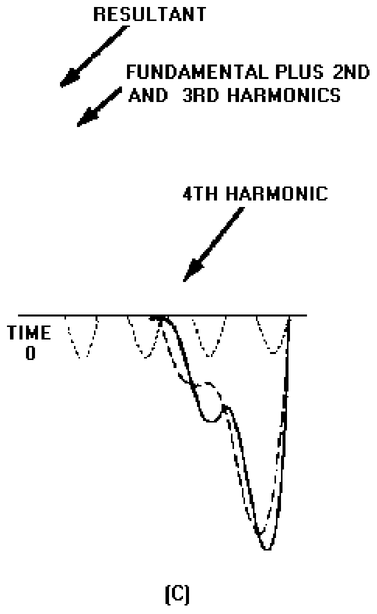


Figure 4-26C.—Composition of a sawtooth wave.

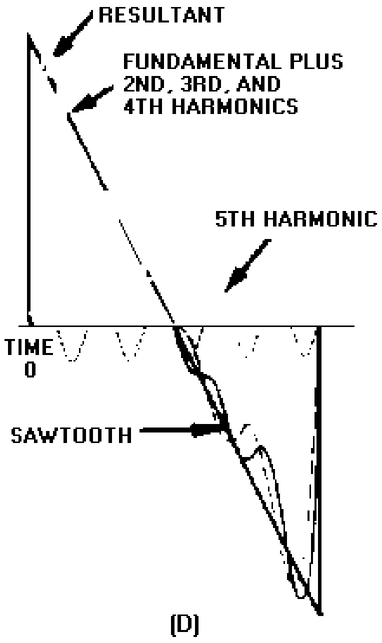


Figure 4-26D.—Composition of a sawtooth wave.

Figure 4-27 shows the composition of a peaked wave. Notice how the addition of each odd harmonic makes the peak of the resultant higher and the sides steeper. The phase relationship between the harmonics of the peaked wave is different from the phase relationship of the harmonics in the composition of the square wave. In the composition of the square wave, all the odd harmonics cross the reference line in phase with the fundamental. In the peaked wave, harmonics such as the third, seventh, and so forth, cross the reference line 180 degrees out of phase with the fundamental; the fifth, ninth, and so forth, cross the reference line in phase with the fundamental.

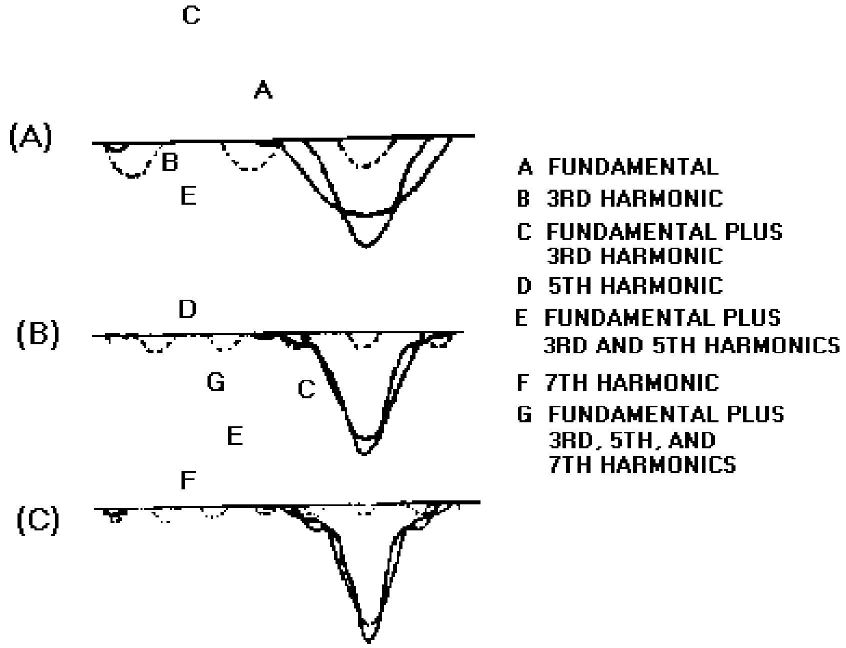


Figure 4-27.—Composition of a peaked wave.

Q15. What is the harmonic composition of a square wave?

Q16. What is the peaked wave composed of?

Q17. What is the fundamental difference between the phase relationship of the harmonics of the square wave as compared to the harmonics of a peaked wave?

Nonsinusoidal Voltages Applied to an RC Circuit

The harmonic content of a square wave must be complete to produce a pure square wave. If the harmonics of the square wave are not of the proper phase and amplitude relationships, the square wave will not be pure. The term PURE, as applied to square waves, means that the waveform must be perfectly square.

Figure 4-28 shows a pure square wave that is applied to a series-resistive circuit. If the values of the two resistors are equal, the voltage developed across each resistor will be equal; that is, from one pure square-wave input, two pure square waves of a lower amplitude will be produced. The value of the resistors does not affect the phase or amplitude relationships of the harmonics contained within the square waves. This is true because the same opposition is offered by the resistors to all the harmonics presented. However, if the same square wave is applied to a series RC circuit, as shown in figure 4-29, the circuit action is not the same.

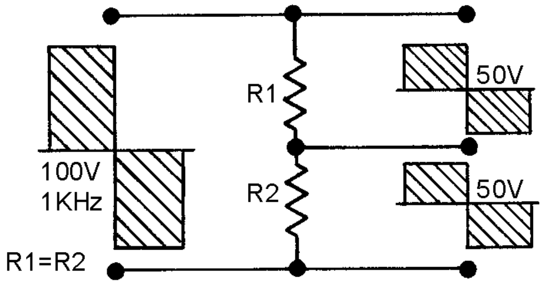


Figure 4-28.—Square wave applied to a resistive circuit.

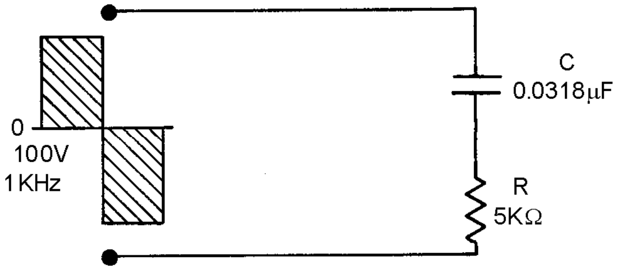


Figure 4-29.—Square wave applied to an RC circuit.

RC INTEGRATORS

The RC INTEGRATOR is used as a waveshaping network in communications, radar, and computers. The harmonic content of the square wave is made up of odd multiples of the fundamental frequency. Therefore SIGNIFICANT HARMONICS (those that have an effect on the circuit) as high as 50 or 60 times the fundamental frequency will be present in the wave. The capacitor will offer a reactance (X_C) of a different magnitude to each of the harmonics

$$X_C = \frac{1}{2\pi fC}$$

This means that the voltage drop across the capacitor for each harmonic frequency present will not be the same. To low frequencies, the capacitor will offer a large opposition, providing a large voltage drop across the capacitor. To high frequencies, the reactance of the capacitor will be extremely small, causing a small voltage drop across the capacitor. This is no different than was the case for low- and high-pass filters (discriminators) presented in chapter 1. If the voltage component of the harmonic is not developed across the reactance of the capacitor, it will be developed across the resistor, if we observe Kirchhoff's voltage law. The harmonic amplitude and phase relationship across the capacitor is not the same as that of the original frequency input; therefore, a perfect square wave will not be produced across the capacitor. You should remember that the reactance offered to each harmonic frequency will cause a change in both the amplitude and phase of each of the individual harmonic frequencies with respect to the current reference. The amount of phase and amplitude change taking place across the capacitor depends on the X_C of the capacitor. The value of the resistance offered by the resistor must also be considered here; it is part of the ratio of the voltage development across the network.

The circuit in figure 4-30 will help show the relationships of R and X_C more clearly. The square wave applied to the circuit is 100 volts peak at a frequency of 1 kilohertz. The odd harmonics will be 3 kilohertz, 5 kilohertz, 7 kilohertz, etc. Table 4-1 shows the values of X_C and R offered to several harmonics and indicates the approximate value of the cutoff frequency ($X_C = R$). The table clearly shows that the cutoff frequency lies between the fifth and seventh harmonics. Between these two values, the capacitive reactance will equal the resistance. Therefore, for all harmonic frequencies above the fifth, the majority of the output voltage will not be developed across the output capacitor. Rather, most of the output will be developed across R. The absence of the higher order harmonics will cause the leading edge of the waveform developed across the capacitor to be rounded. An example of this effect is shown in figure 4-31. If the value of the capacitance is increased, the reactances to each harmonic frequency will be further decreased. This means that even fewer harmonics will be developed across the capacitor.

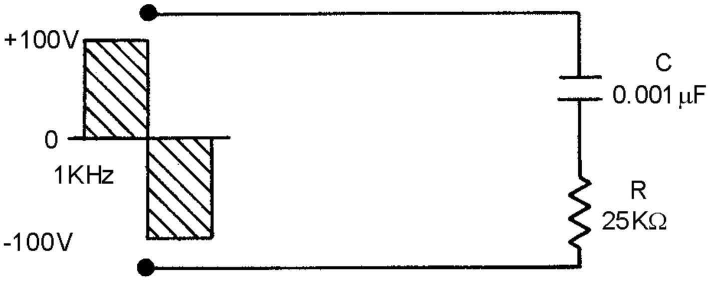


Figure 4-30.—Partial integration circuit.

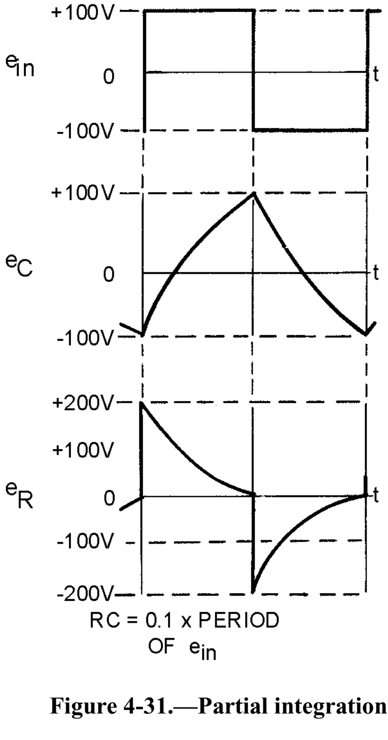


Figure 4-31.—Partial integration.

Table 4-1.—Resistive and reactive values

HARMONIC	X_C	R
FUNDAMENTAL	159 K Ω	25 K Ω
3rd	53 K Ω	25 K Ω
5th	31.8 K Ω	25 K Ω
7th	22.7 K Ω	25 K Ω
9th	17.7 K Ω	25 K Ω
11th	14.5KΩ	25 KΩ

The harmonics not effectively developed across the capacitor must be developed across the resistor to satisfy Kirchhoff's voltage law. Note the pattern of the voltage waveforms across the resistor and capacitor. If the waveforms across both the resistor and the capacitor were added graphically, the resultant would be an exact duplication of the input square wave.

When the capacitance is increased sufficiently, full integration of the input signal takes place in the output across the capacitor. An example of complete integration is shown in figure 4-32 (waveform e_C). This effect can be caused by significantly decreasing the value of capacitive reactance. The same effect would take place by increasing the value of the resistance. Integration takes place in an RC circuit when the output is taken across the capacitor.

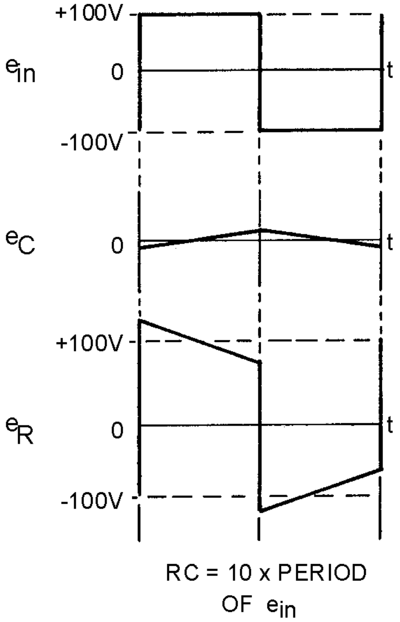


Figure 4-32.—Integration.

The amount of integration is dependent upon the values of R and C. The amount of integration may also be dependent upon the time constant of the circuit. The time constant of the circuit should be at least 10 TIMES GREATER than the time duration of the input pulse for integration to occur. The value of 10 is only an approximation. When the time constant of the circuit is 10 or more times the value of the duration of the input pulse, the circuit is said to possess a long time constant. When the time constant is long, the capacitor does not have the ability to charge instantly to the value of the applied voltage. Therefore, the result is the long, sloping, integrated waveform.

Q18. What are the requirements for an integration circuit?

Q19. Can a pure sine wave be integrated? Why?

RL INTEGRATORS

The RL circuit may also be used as an integrating circuit. An integrated waveform may be obtained from the series RL circuit by taking the output across the resistor. The characteristics of the inductor are such that at the first instant of time in which voltage is applied, current flow through the inductor is minimum and the voltage developed across it is maximum. Therefore, the value of the voltage drop across the series resistor at that first instant must be 0 volts because there is no current flow through it. As time passes, current begins to flow through the circuit and voltage develops across the resistor. Since the circuit has a long time constant, the voltage across the resistor does NOT respond to the rapid changes in voltage of the input square wave. Therefore, the conditions for integration in an RL circuit are a long time constant with the output taken across the resistor. These conditions are shown in figure 4-33.

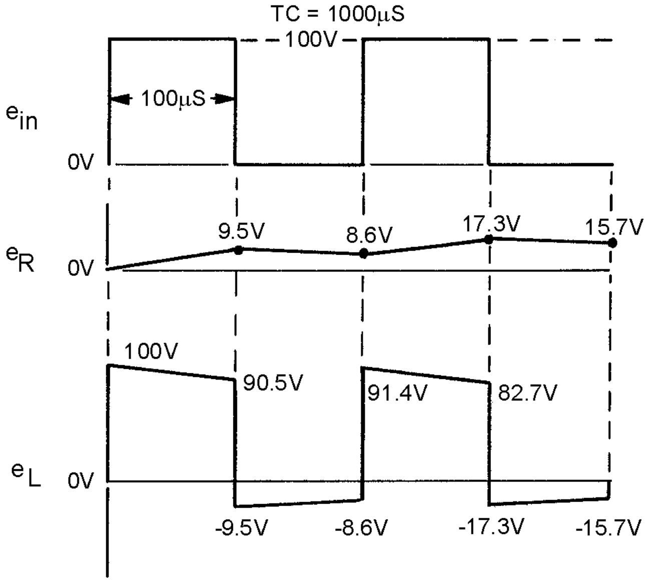
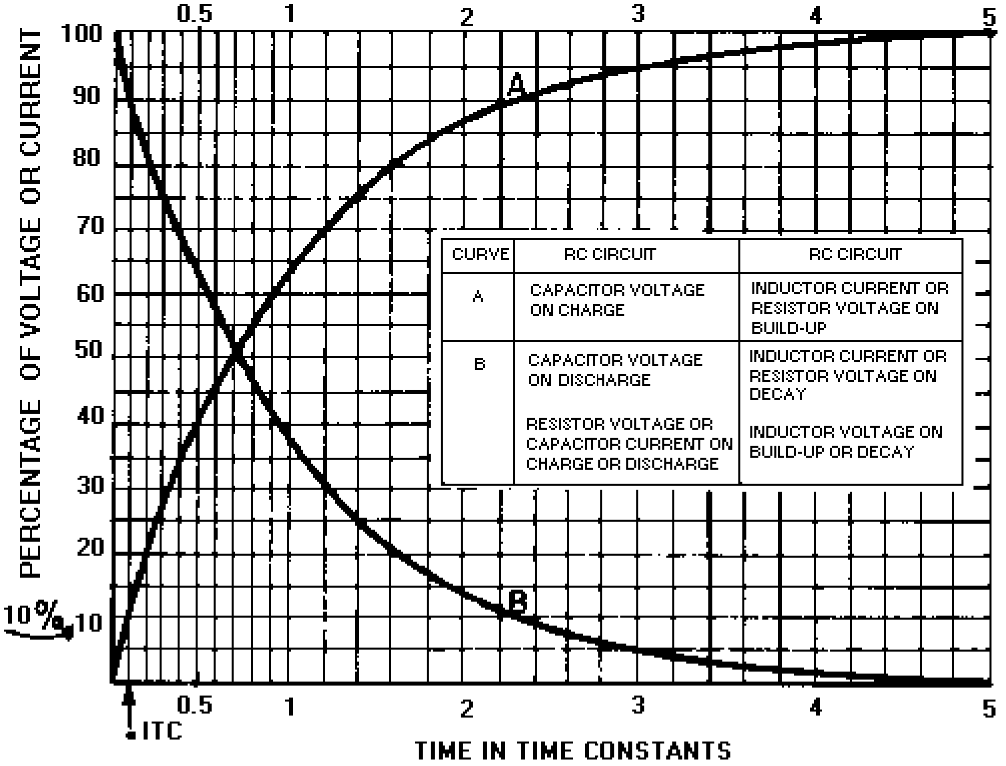


Figure 4-33.—RL integrator waveform.

Q20. What characteristic of an RL circuit allows it to act as an integrator?

INTEGRATOR WAVEFORM ANALYSIS

If either an RC or RL circuit has a time constant 10 times greater than the duration of the input pulse, the circuits are capable of integration. Let's compute and graph the actual waveform that would result from a long time constant (10 times the pulse duration), a short time constant (1/10 of the pulse duration), and a medium time constant (that time constant between the long and the short). To accurately plot values for the capacitor output voltage, we will use the Universal Time Constant Chart shown in figure 4-34.



CURVE	RC CIRCUIT	RC CIRCUIT
A	CAPACITOR VOLTAGE ON CHARGE	INDUCTOR CURRENT OR RESISTOR VOLTAGE ON BUILD-UP
B	CAPACITOR VOLTAGE ON DISCHARGE RESISTOR VOLTAGE OR CAPACITOR CURRENT ON CHARGE OR DISCHARGE	INDUCTOR CURRENT OR RESISTOR VOLTAGE ON DECAY INDUCTOR VOLTAGE ON BUILD-UP OR DECAY

Figure 4-34.—Universal Time Constant Chart.

You already know that capacitor charge follows the shape of the curve shown in figure 4-34. This curve may be used to determine the amount of voltage across either component in the series RC circuit. As long as the time constant or a fractional part of the time constant is known, the voltage across either component may be determined.

Short Time-Constant Integrator

In figure 4-35, a 100-microsecond pulse at an amplitude of 100 volts is applied to the circuit. The circuit is composed of the, 0.01μF capacitor and the variable resistor, R. The square wave applied is a pure square wave. The resistance of the variable resistor is set at a value of 1,000 ohms. The time constant of the circuit is given by the equation:

$$TC = RC$$

Substituting values:

$$T = 1{,}000 \cdot 0.01\mu F$$

$$T = (1 \times 10^{3}) \cdot (1 \times^{-8})$$

$T = 1 \times 10^{-5}$ vor 10 microseconds

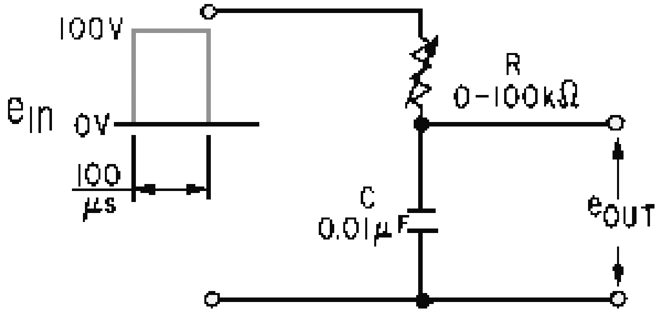


Figure 4-35.—RC integrator circuit.

Since the time constant of the circuit is 10 microseconds and the pulse duration is 100 microseconds, the time constant is short (1/10 of the pulse duration). The capacitor is charged exponentially through the resistor. In 5 time constants, the capacitor will be, for all practical purposes, completely charged. At the first time constant, the capacitor is charged to 63.2 volts, at the second 86.5 volts, at the third 95 volts, at the fourth 98 volts, and finally at the end of the fifth time constant (50 microseconds), the capacitor is fully charged. This is shown in figure 4-36.

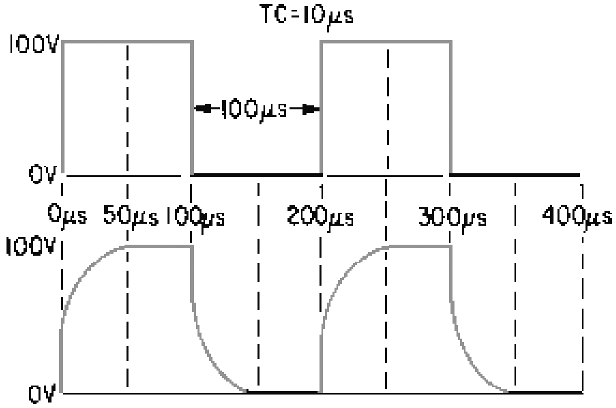


Figure 4-36.—Square wave applied to a short time-constant integrator.

Notice that the leading edge of the square wave taken across the capacitor is rounded. If the time constant were made extremely short, the rounded edge would become square.

Medium Time-Constant Integrator

The time constant, in figure 4-36 can be changed by increasing the value of the variable resistor (figure 4-35) to 10,000 ohms. The time constant will then be equal to 100 microseconds.

This time constant is known as a medium time constant. Its value lies between the extreme ranges of the short and long time constants. In this case, its value happens to be exactly equal to the duration of the input pulse, 100 microseconds. The output waveform, after several time constants, is shown in figure

4-37. The long, sloping rise and fall of voltage is caused by the inability of the capacitor to charge and discharge rapidly through the 10,000-ohm series resistance.

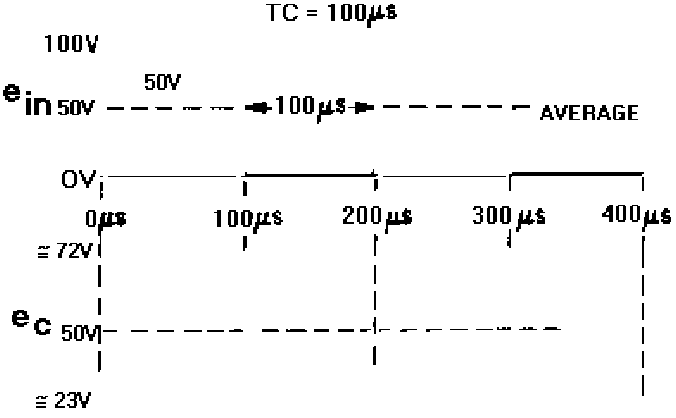


Figure 4-37.—Medium time-constant integrator.

At the first instant of time, 100 volts is applied to the medium time-constant circuit. In this circuit, 1TC is exactly equal to the duration of the input pulse. After 1TC the capacitor has charged to 63.2 percent of the input voltage (100 volts). Therefore, at the end of 1TC (100 microseconds), the voltage across the capacitor is equal to 63.2 volts. However, as soon as 100 microseconds has elapsed, and the initial charge on the capacitor has risen to 63.2 volts, the input voltage suddenly drops to 0. It remains there for 100 microseconds. The capacitor will now discharge for 100 microseconds. Since the discharge time is 100 microseconds (1TC), the capacitor will discharge 63.2 percent of its total 63.2-volt charge, a value of 23.3 volts. During the next 100 microseconds, the input voltage will increase from 0 to 100 volts instantaneously. The capacitor will again charge for 100 microseconds (1TC). The voltage available for this charge is the difference between the voltage applied and the charge on the capacitor (100 - 23.3 volts), or 76.7 volts. Since the capacitor will only be able to charge for 1TC, it will charge to 63.2 percent of the 76.7 volts, or 48.4 volts. The total charge on the capacitor at the end of 300 microseconds will be 23.3 + 48.4 volts, or 71.7 volts.

Notice that the capacitor voltage at the end of 300 microseconds is greater than the capacitor voltage at the end of 100 microseconds. The voltage at the end of 100 microseconds is 63.2 volts, and the capacitor voltage at the end of 300 microseconds is 71.7 volts, an increase of 8.5 volts.

The output waveform in this graph (e_C) is the waveform that will be produced after many cycles of input signal to the integrator. The capacitor will charge and discharge in a step-by-step manner until it finally charges and discharges above and below a 50-volt level. The 50-volt level is controlled by the maximum amplitude of the symmetrical input pulse, the average value of which is 50 volts.

Long Time-Constant Integrator

If the resistance in the circuit of figure 4-35 is increased to 100,000 ohms, the time constant of the circuit will be 1,000 microseconds. This time constant is 10 times the pulse duration of the input pulse. It is, therefore, a long time-constant circuit.

The shape of the output waveform across the capacitor is shown in figure 4-38. The shape of the output waveform is characterized by a long, sloping rise and fall of capacitor voltage.

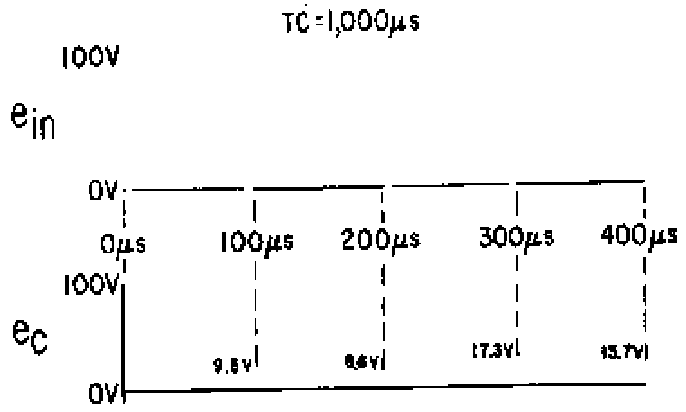


Figure 4-38.—Square wave applied to a long time-constant integrator.

At the first instant of time, 100 volts is applied to the long time-constant circuit. The value of charge on the capacitor at the end of the first 100 microseconds of the input signal can be found by using the Universal Time Constant Chart (figure 4-34). Assume that a line is projected up from the point on the base line corresponding to 0.1TC. The line will intersect the curve at a point that is the percentage of voltage across the capacitor at the end of the first 100 microseconds. Since the applied voltage is 100 volts, the charge on the capacitor at the end of the first 100 microseconds will be approximately 9.5 volts. At the end of the first 100 microseconds, the input signal will fall suddenly to 0 and the capacitor will begin to discharge. It will be able to discharge for 100 microseconds. Therefore, the capacitor will discharge 9.5 percent of its accumulated 9.5 volts (.095 × 9.5 = 0.90 volt). The discharge of the 0.90 volt will result in a remaining charge on the capacitor of 8.6 volts. At the end of 200 microseconds, the input signal will again suddenly rise to a value of 100 volts. The capacitor will be able to charge to 9.5 percent of the difference (100 – 8.6 = 91.4 volts). This may also be figured as a value of 8.7 volts plus the initial 8.6 volts. This results in a total charge on the capacitor (at the end of the first 300 microseconds) of 8.7 + 8.6 = 17.3 volts.

Notice that the capacitor voltage at the end of the first 300 microseconds is greater than the capacitor voltage at the end of the first 100 microseconds. The voltage at the end of the first 100 microseconds is 9.5 volts; the capacitor voltage at the end of the first 300 microseconds is 17.3 volts, an increase of 7.8 volts.

The capacitor charges and discharges in this step-by-step manner until, finally, the capacitor charges and discharges above and below a 50-volt level. The 50-volt level is controlled by the maximum amplitude of the square-wave input pulse, the average value of which is 50 volts.

Q21. What is the numerical difference (in terms of the time constant) between a long and a short time-constant circuit?

Q22. What would happen to the integrator output if the capacitor were made extremely large (all other factors remaining the same)?

DIFFERENTIATORS

DIFFERENTIATION is the direct opposite of integration. In the RC integrator, the output is taken from the capacitor. In the differentiator, the output is taken across the resistor. Likewise, this means that when the RL circuit is used as a differentiator, the differentiated output is taken across the inductor.

An application of Kirchhoff's law shows the relationship between the waveforms across the resistor and capacitor in a series network. Since the sum of the voltage drops in a closed loop must equal the total applied voltage, the graphical sum of the voltage waveforms in a closed loop must equal the applied waveform. Figure 4-39 shows a differentiator circuit with the output taken across a variable resistor.

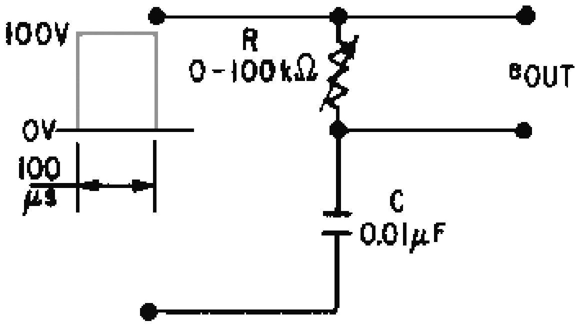


Figure 4-39.—RC circuit as a differentiator.

Short Time-Constant Differentiator

With the variable resistor set at 1,000 ohms and the capacitor value of 0.01 microfarad, the time constant of the circuit is 10 microseconds. Since the input waveform has a duration of 100 microseconds, the circuit is a short time-constant circuit.

At the first instant of time in the short time-constant circuit, the voltage across the capacitor is 0. Current flows through the resistor and causes a maximum voltage to be developed across it. This is shown at the first instant of time in the graph of figure 4-40.

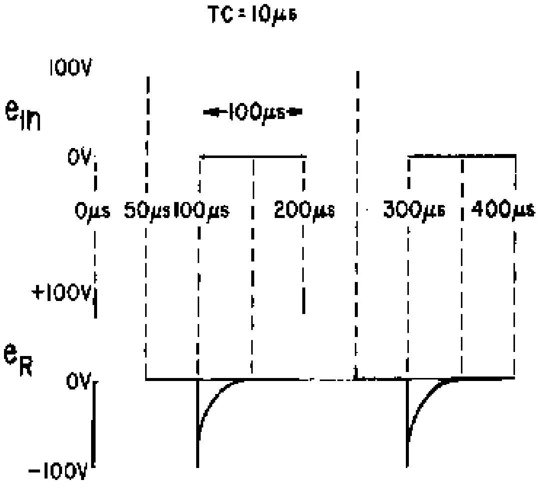


Figure 4-40.—Square wave applied to a short time-constant differentiator.

As the capacitor begins accumulating a charge, the voltage developed across the resistor will begin to decrease. At the end of the first time constant, the voltage developed across the resistor will have decreased by a value equal to 63.2 percent of the applied voltage. Since 100 volts is applied, the voltage across the resistor after 1TC will be equal to 36.8 volts. After the second time constant, the voltage across the resistor will be down to 13.5 volts. At the end of the third time constant, e_R will be 5 volts and at the end of the fourth time constant, 2 volts. At the end of the fifth time constant, the voltage across the resistor will be very close to 0 volts. Since the time constant is equal to 10 microseconds, it will take a total of 50 microseconds to completely charge the capacitor and stop current flow in the circuit.

As shown in figure 4-40 the slope of the charge curve will be very sharp. The voltage across the resistor will remain at 0 volts until the end of 100 microseconds. At that time, the applied voltage suddenly drops to 0, and the capacitor will now discharge through the resistor. At this time, the discharge current will be maximum causing a large discharge voltage to develop across the resistor. This is shown as the negative spike in figure 4-40. Since the current flow from the capacitor, which now acts like a source, is decreasing exponentially, the voltage across the resistor will also decrease. The resistor voltage will decrease exponentially to 0 volts in 5 time constants. All of this discharge action will take a total of 50 microseconds. The discharge curve is also shown in figure 4-40. At the end of 200 microseconds, the action begins again. The output waveform taken across the resistor in this short time-constant circuit is an example of differentiation. With the square wave applied, positive and negative spikes are produced in the output. These spikes approximate the rate of change of the input square wave.

Medium Time-Constant Differentiator

The output across the resistor in an RC circuit of a medium time constant is shown in figure 4-41. The value of the variable resistor has been increased to a value of 10,000 ohms. This means that the time constant of the circuit is equal to the duration of the input pulse or 100 microseconds. For clarity, the voltage waveforms developed across both the resistor and the capacitor are shown. As before, the sum of the voltages across the resistor and capacitor must be equal to the applied voltage of 100 volts.

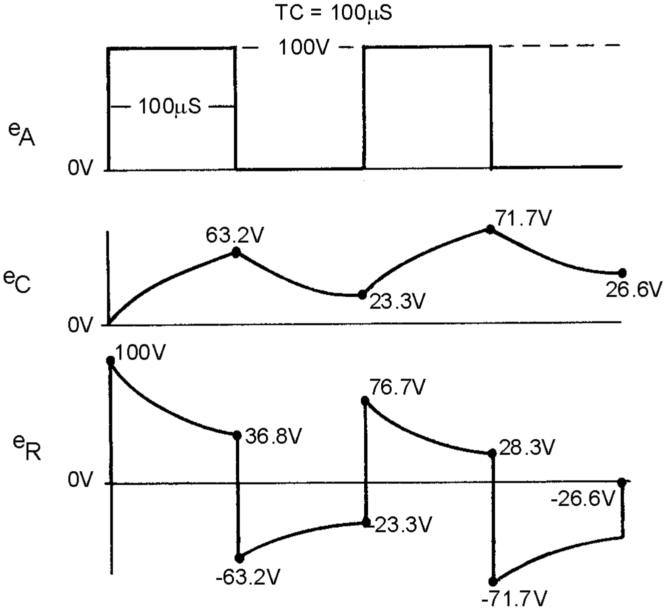


Figure 4-41.—Voltage outputs in a medium time-constant differentiator.

At the first instant of time, a pulse of 100 volts in amplitude with a duration of 100 microseconds is applied. Since the capacitor cannot respond quickly to the change in voltage, all of the applied voltage is felt across the resistor. Figure 4-41 shows the voltage across the resistor (e_R) to be 100 volts and the voltage across the capacitor (e_C) to be 0 volts. As time progresses, the capacitor charges. As the capacitor voltage increases, the resistor voltage decreases. Since the time that the capacitor is permitted to charge is 100 microseconds (equal to 1TC in this circuit), the capacitor will charge to 63.2 percent of the applied voltage at the end of 1TC, or 63.2 volts. Because Kirchhoff's law must be followed at all times, the voltage across the resistor must be equal to the difference between the applied voltage and the charge on the capacitor (100 – 63.2 volts), or 36.8 volts.

At the end of the first 100 microseconds, the input voltage suddenly drops to 0 volts. The charge on the capacitor (–63.2 volts) becomes the source and the entire voltage is developed across the resistor for the first instant.

The capacitor discharges during the next 100 microseconds. The voltage across the resistor decreases at the same rate as the capacitor voltage and total voltage is maintained at 0. This exponential decrease in resistor voltage is shown during the second 100 microseconds in figure 4-41. The capacitor will discharge 63.2 percent of its charge to a value of 23.3 volts at the end of the second 100 microseconds. The resistor voltage will rise in the positive direction to a value of –23.3 volts to maintain the total voltage at 0 volts.

At the end of 200 microseconds, the input voltage again rises suddenly to 100 volts. Since the capacitor cannot respond to the 100-volt increase instantaneously, the 100-volt change takes place across the resistor. The voltage across the resistor suddenly rises from –23.3 volts to +76.7 volts. The capacitor will now begin to charge for 100 microseconds. The voltage will decrease across the resistor. This charge and discharge action will continue for many cycles. Finally, the voltage across the capacitor will rise and fall by equal amounts both above and below about a 50-volt level. The resistor voltage will also rise and fall by equal amounts to about a 0-volt level.

Long Time-Constant Differentiator

If the time constant for the circuit in figure 4-39 is increased to make it a long time-constant circuit, the differentiator output will appear more like the input. The time constant for the circuit can be changed by either increasing the value of capacitance or resistance. In this circuit, the time constant will be increased by increasing the value of resistance from 10,000 ohms to 100,000 ohms. Increasing the value of resistance will result in a time constant of 1,000 microseconds. The time constant is 10 times the duration of the input pulse. The output of this long time-constant circuit is shown in figure 4-42.

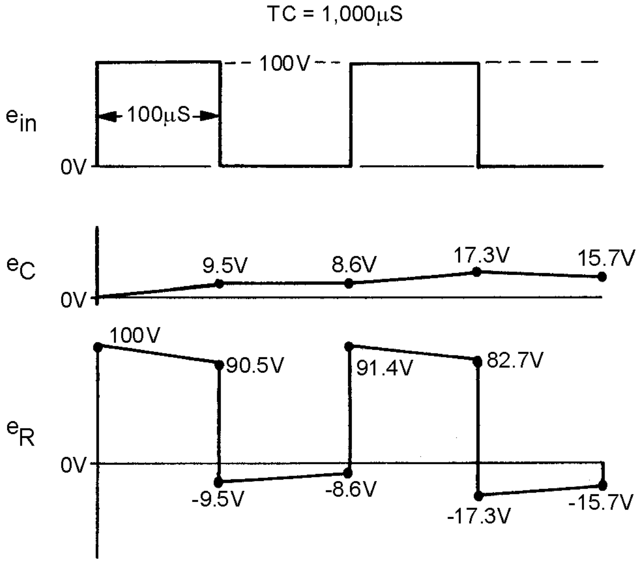


Figure 4-42.—Voltage outputs in a long time-constant differentiator.

At the first instant of time, a pulse of 100-volts amplitude with a duration of 100 microseconds is applied. Since the capacitor cannot respond instantaneously to a change in voltage, all of the applied voltage is felt across the resistor. As time progresses, the capacitor will charge and the voltage across the resistor will be reduced. Since the time that the capacitor is permitted to charge is 100 microseconds, the capacitor will charge for only 1/10 of 1TC or to 9.5 percent of the applied voltage. The voltage across the resistor must be equal to the difference between the applied voltage and the charge on the capacitor (100 – 9.5 volts), or 90.5 volts.

At the end of the first 100 microseconds of input, the applied voltage suddenly drops to 0 volts, a change of 100 volts. Since the capacitor is not able to respond to so rapid a voltage change, it becomes the source of 9.5 volts. This causes a –9.5 voltage to be felt across the resistor in the first instant of time. The sum of the voltage across the two components is now 0 volts.

During the next 100 microseconds, the capacitor discharges. The total circuit voltage is maintained at 0 by the voltage across the resistor decreasing at exactly the same rate as the capacitor discharge. This exponential decrease in resistor voltage is shown during the second 100 microseconds of operation. The capacitor will now discharge 9.5 percent of its charge to a value of 8.6 volts. At the end of the second 100 microseconds, the resistor voltage will rise in a positive direction to a value of –8.6 volts to maintain the total circuit voltage at 0 volts.

At the end of 200 microseconds, the input voltage again suddenly rises to 100 volts. Since the capacitor cannot respond to the 100-volt change instantaneously, the 100-volt change takes place across the resistor. This step-by-step action will continue until the circuit stabilizes. After many cycles have passed, the capacitor voltage varies by equal amounts above and below the 50-volt level. The resistor voltage varies by equal amounts both above and below a 0-volt level.

The RC networks which have been discussed in this chapter may also be used as coupling networks. When an RC circuit is used as a coupling circuit, the output is taken from across the resistor. Normally, a long time-constant circuit is used. This, of course, will cause an integrated wave shape across the capacitor if the applied signal is nonsinusoidal. However, in a coupling circuit, the signal across the resistor should closely resemble the input signal and will if the time constant is sufficiently long. By referring to the diagram in figure 4-42, you can see that the voltage across the resistor closely resembles the input signal. Consider what would happen if a pure sine wave were applied to a long time-constant RC circuit (R is much greater than X_C). A large percentage of the applied voltage would be developed across the resistor and only a small amount across the capacitor.

Q23. What is the difference between an RC and an RL differentiator in terms of where the output is developed?

COUNTERS

A counting circuit receives uniform pulses representing units to be counted. It provides a voltage that is proportional to the frequency of the units.

With slight modification, the counting circuit can be used with a blocking oscillator to produce trigger pulses which are a submultiple of the frequency of the pulses applied. In this case the circuit acts as a frequency divider.

The pulses applied to the counting circuit must be of the same time duration if accurate frequency division is to be made. Counting circuits are generally preceded by shaping circuits and limiting circuits (both discussed in this chapter) to ensure uniformity of amplitude and pulse width. Under those conditions, the pulse repetition frequency is the only variable and frequency variations may be measured.

Q24. Name a common application of counting circuits.

Positive Counters

The POSITIVE-DIODE COUNTER circuit is used in timing or counting circuits in which the number of input pulses are represented by the output voltage. The output may indicate frequency, count the rpm of a shaft, or register a number of operations. The counter establishes a direct relationship between the input frequency and the average dc output voltage. As the input frequency increases, the output voltage also increases; conversely, as the input frequency decreases, the output voltage decreases. In effect, the positive counter counts the number of positive input pulses by producing an average dc output voltage proportional to the repetition frequency of the input signal. For accurate counting, the pulse repetition frequency must be the only variable parameter in the input signal. Therefore, careful shaping and limiting of the input signal is essential for you to ensure that the pulses are of uniform width and that the amplitude is constant. When properly filtered and smoothed, the dc output voltage of the counter may be used to operate a direct reading indicator.

Solid-state and electron-tube counters operate in manners similar to each other. The basic solid-state (diode) counter circuit is shown in view (A) of figure 4-43. Capacitor C1 is the input coupling capacitor. Resistor R1 is the load resistor across which the output voltage is developed. For the purpose of circuit discussion, assume that the input pulses (shown in view (B)) are of constant amplitude and time duration and that only the pulse repetition frequency changes. At time T0, the positive-going input pulse is applied to C1 and causes the anode of D2 to become positive. D2 conducts and current i_c flows through R1 and D2 to charge C1. Current i_c, develops an output voltage across R1, shown as e_{out}.

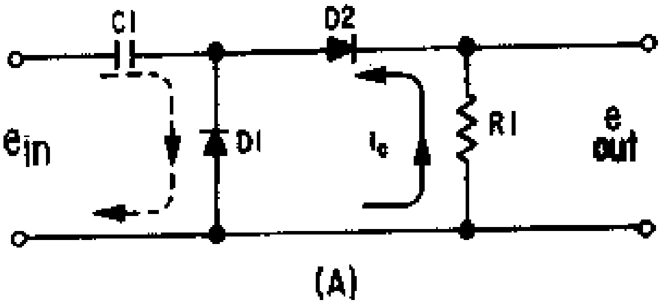


Figure 4-43A.—Positive-diode counter and waveform.

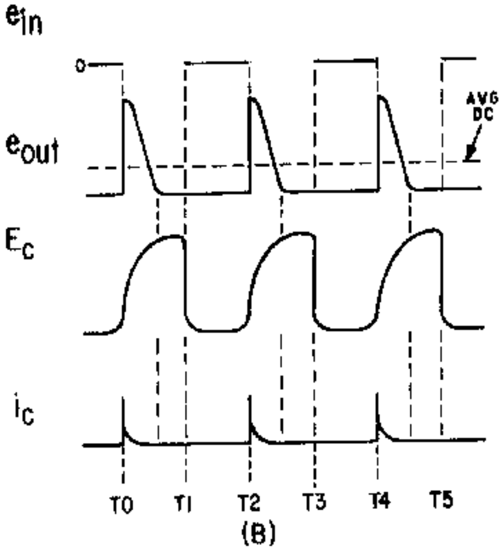


Figure 4-43B.—Positive-diode counter and waveform.

The initial heavy flow of current produces a large voltage across R1 which tapers off exponentially as C1 charges. The charge on C1 is determined by the time constant of R1 and the conducting resistance of the diode times the capacitance of C1. For ease of explanation, assume that C1 is charged to the peak value before T1.

At T1 the input signal reverses polarity and becomes negative-going. Although the charge on capacitor C1 cannot change instantly, the applied negative voltage is equal to or greater than the charge on C1. This causes the anode of D2 to become negative and conduction ceases. When D2 stops conducting e_{out} is at 0. C1 quickly discharges through D1 since its cathode is now negative with respect to ground. Between T1 and T2 the input pulse is again at the 0-volt level and D2 remains in a nonconducting state. Since the very short time constant provided by the conduction resistance of D1 and C1 is so much less than the long time constant offered by D2 and R1 during the conduction period, C1 is always completely discharged between pulses. Thus, for each input pulse, a precise level of charge is deposited on C1. For each charge of C1 an identical output pulse is produced by the flow of ic through R1. Since this current flow always occurs in the direction indicated by the solid arrow, the dc output voltage is positive.

At T2 the input signal again becomes positive and the cycle repeats. The time duration between pulses is the interval represented by the period between T1 and T2 or between T3 and T4. If the input-pulse frequency is reduced, these time periods become longer. On the other hand, if the frequency is increased, these time intervals become shorter. With shorter periods, more pulses occur in a given length of time and a higher average dc output voltage is produced; with longer periods, fewer pulses occur and a lower average dc output voltage is produced. Thus, the dc output is directly proportional to the repetition frequency of the input pulses. If the current and voltage are sufficiently large, a direct-reading meter can be used to indicate the count. If they are not large enough to actuate a meter directly, a dc amplifier may be added. In the latter case, a pi-type filter network is inserted at the output of R1 to absorb the instantaneous pulse variations and produce a smooth direct current for amplification.

From the preceding discussion, you should see that the voltage across the output varies in direct proportion to the input pulse repetition rate. Hence, if the repetition rate of the incoming pulses increases, the voltage across R1 also increases. For the circuit to function as a frequency counter, some method must be employed to use this frequency-to-voltage relationship to operate an indicator. The block diagram in view (A) of figure 4-44 represents one simple circuit which may be used to perform this function. In this circuit, the basic counter is fed into a low-pass filter and an amplifier with a meter that is calibrated in units of frequency.

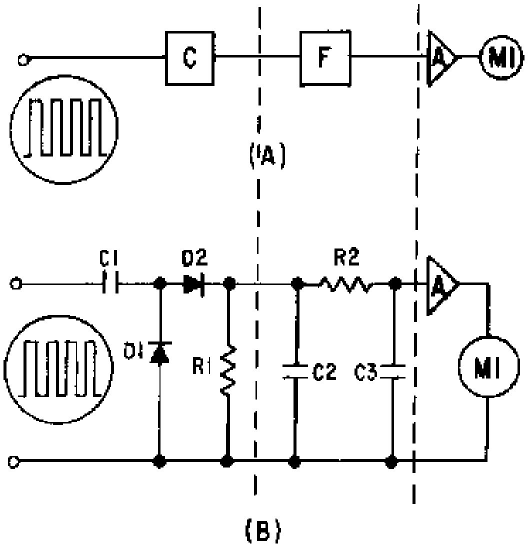


Figure 4-44.—Basic frequency counter.

A typical schematic diagram is shown in view (B). The positive pulses from the counter are filtered by C2, R2, and C3. The positive dc voltage from the filter is applied to the input of amplifier A. This voltage increases with frequency; as a consequence, the current through the device increases. Since emitter or cathode current flows through M1, an increase in amplifier current causes an increase in meter deflection. The meter may be calibrated in units of time, frequency, revolutions per minute, or any function based upon the relationship of output voltage to input frequency.

Q25. What establishes the value of the current that flows in the output of figure 4-43?

Q26. What is the purpose of D1 in figure 4-43?

Negative Counters

Reversing the connections of diodes D1 and D2 in the positive-counter circuit (view (A) of figure 4-43) will cause the circuit to respond to negative pulses and become a negative-counter circuit. Diode D2 conducts during the time the negative pulse is applied and current flows in the opposite direction through R1, as was indicated by the arrow. At the end of the negative pulse, D1 conducts and discharges C1. The current through R1 increases with an increase in pulse frequency as before. However, if the voltage developed across R1 is applied to the same control circuit, as shown in view (A) of figure 4-44, the increase in current will be in a negative direction and the amplifier will conduct less. Thus, the effect is opposite to that of the positive counter.

Step-by-Step (Step) Counters

The STEP-BY-STEP (STEP) COUNTER is used as a voltage multiplier when a stepped voltage must be provided to any device which requires such an input. The step counter provides an output which increases in one-step increments for each cycle of the input. At some predetermined level, the output voltage reaches a point which causes a circuit, such as a blocking oscillator, to be triggered.

A schematic diagram of a positive step counter is shown in view (A) of figure 4-45. For step counting, the load resistor of the positive-counting circuit is replaced by capacitor C2. This capacitor is relatively large in comparison to C1. Each time D2 conducts, the charge on C2 increases as shown in view (B). The steps are not the same height each time. They decrease exponentially with time as the voltage across C2 approaches the input voltage.

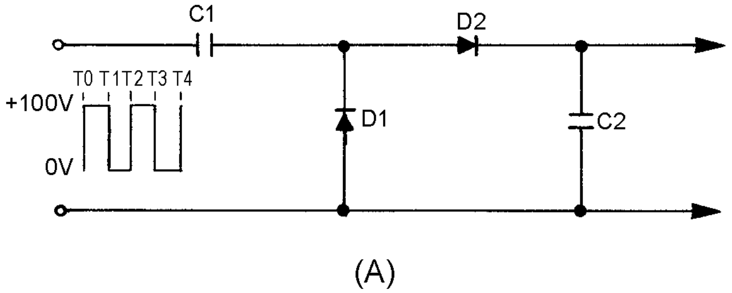


Figure 4-45A.—Basic step counter and waveforms.

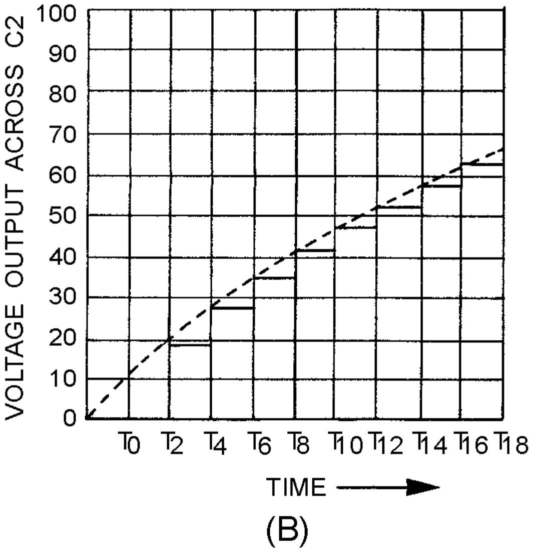


Figure 4-45B.—Basic step counter and waveforms.

As long as C2 has no discharge path, the voltage across its terminals increases with each successive step until it is equal in amplitude to the applied pulse. The voltage across C2 could be applied to a blocking-oscillator circuit to cause the oscillator to pulse after a certain amount of voltage is applied to it.

The circuit in figure 4-46, (view A) and (view B), may be used as a frequency divider. When used in this manner, Q1 is used as a single-swing blocking oscillator that is triggered when the voltage across C2 becomes great enough to forward bias Q1. At other times, the transistor is cut off by the bias voltage developed in the section of R2 that is between the ground and the slide.

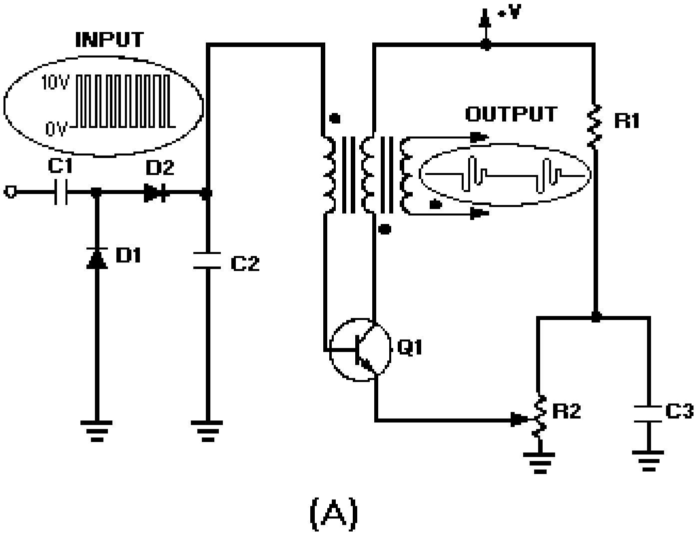


Figure 4-46A.—Step counter as a frequency divider and waveforms.

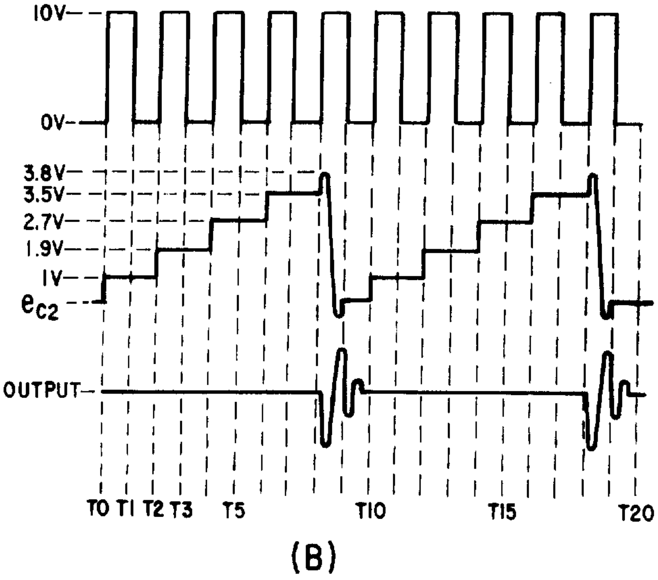


Figure 4-46B.—Step counter as a frequency divider and waveforms.

The action of the counter can best be understood by referring back to figure 4-45. Assume C2 is 10 times larger than C1 and the peak voltage is 10 volts. C1 will assume 9/10 of the positive input voltage at T0, while C2 will assume only 1/10, or 1 volt in this example. At T1 the input will drop in a negative direction and D2 will be cut off. The cathode of D1 will become more negative than its anode and conduct, discharging C1. The charge on C2 will remain at 1 volt because it has no discharge path. At T2 the second pulse will be applied. The 1-volt charge on C2 will oppose the 10 volts of the second pulse, and the applied voltage for the capacitors to charge will be 9 volts. C2 will again charge 10 percent, or 0.9 volt. This is in addition to the initial charge of volt. At the end of the second pulse, the voltage on C2 will be 1.9 volts. At T3 the third pulse will be 10 volts, but 1.9 volts will oppose it. Therefore, the applied voltage will be 10 – 1.9 volts, or 8.1 volts. C2 will charge to 10 percent of 8.1 volts, or .81 volt. The voltage on C2 will become 1 + .9 + .81, or 2.71 volts. Successive input pulses will raise C2 by 10 percent of the remaining voltage toward 10 volts until the blocking oscillator works. If the oscillator bias is set so that Q1 begins conduction at 3.8 volts, this will continue until 3.8 volts is exceeded. Since the fourth step is 3.5 volts and the fifth is 4.1 volts, the 3.8-volt level is crossed at the fifth step. If the oscillator goes through 1 cycle of operation every fifth step and C2 is discharged at this point, this circuit would be a 5-to-1 divider.

The circuit can be made to divide by 3, 4, or some other value by setting the bias at a different level. For example, if the bias is set at 2.9 volts, conduction will occur at the fourth step, making it a 4-to-1 divider.

The counting stability of the step counter is dependent upon the exponential charging rate of capacitor C2. As C2 increases to higher steps, the voltage increments are less and less. If the ratio becomes too great, the higher steps become almost indiscernible. For this reason, accuracy decreases as the ratio increases. When you desire to count by a large number, 24 for example, a 6-to-1 counter and a 4-to-1 counter are connected in cascade (series). A more stable method of counting 24 would be to use a 2:1, 3:1, 4:1 counter connected in cascade. Most step counters operate on a ratio of 5 to 1 or less.

Q27. What is the difference between a positive counter and a step counter?

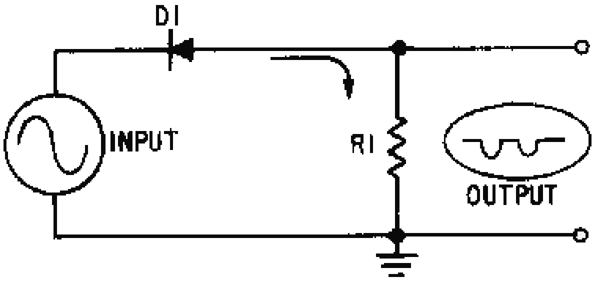
SUMMARY

This chapter has presented information on wave shaping. The information that follows summarizes the important points of this chapter.

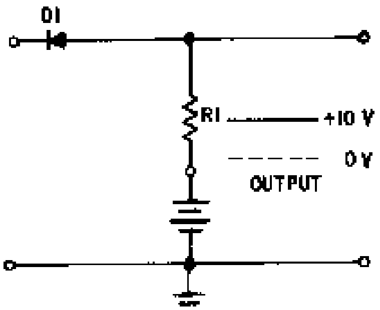
A **LIMITER** is a device which limits or prevents some part of a waveform from exceeding a specified value.

In a **SERIES LIMITER**, the diode is in series with the output. It can limit either the negative or positive alternation of the input signal.

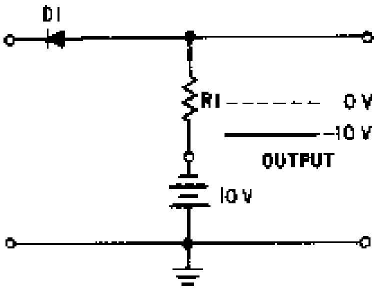
In a **SERIES-POSITIVE LIMITER**, the diode is in series with the output which is taken across the resistor. It removes the positive alternation of the input signal.



In a **SERIES-POSITIVE LIMITER WITH BIAS,** the bias potential will either aid or oppose the flow of current. When aiding forward bias, only a portion of the positive input pulse is removed. When the bias aids the reverse bias, all of the positive and a portion of the negative pulse is removed.

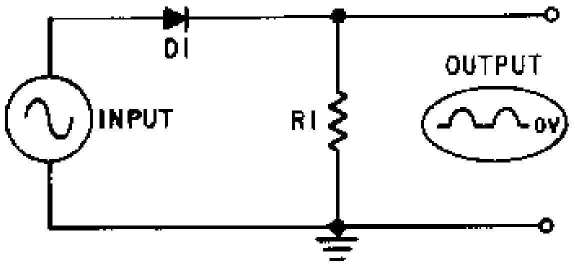


POSITIVE BIAS

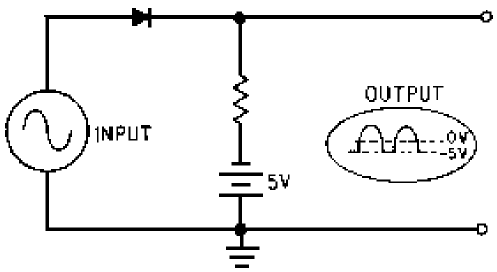


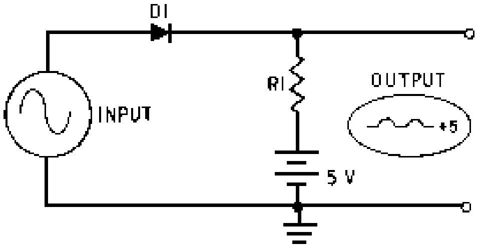
NEGATIVE BIAS

The **SERIES-NEGATIVE LIMITER** limits the negative portion of the input pulse. The difference between a series-negative limiter and a series-positive limiter is that the diode is reversed in the negative limiter.



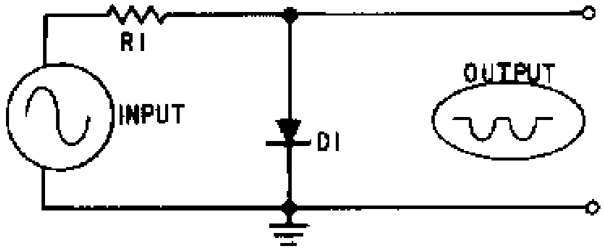
A **SERIES-NEGATIVE LIMITER** with bias is the same as the series-positive limiter with bias, but the outputs are opposite. When bias aids forward bias, only a portion of the negative input is removed. When bias aids reverse bias, all of the negative and a portion of the positive input is removed.



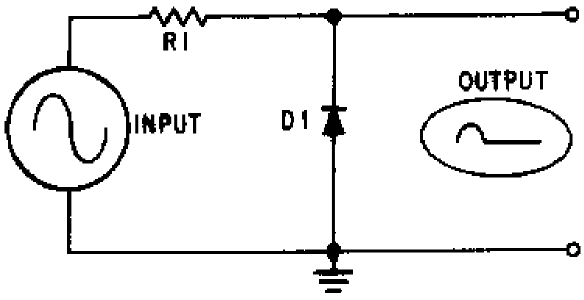


In a **PARALLEL LIMITER**, a resistor and diode are connected in series with the input signal. The output is taken across the diode.

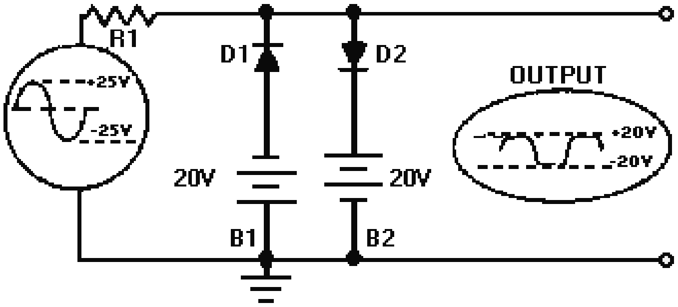
In the **PARALLEL-POSITIVE LIMITER**, the positive portion of the input signal is limited when the diode conducts.



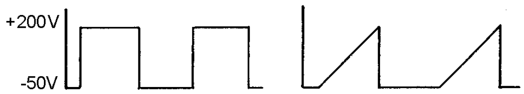
The **PARALLEL-NEGATIVE LIMITER** diode is reversed from that of the parallel positive limiter to limit only a portion of the negative input signal.



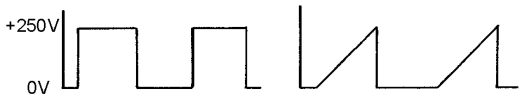
The **DUAL-DIODE LIMITER** combines the parallel negative limiter with negative bias (reverse bias) and the parallel positive limiter with positive bias (reverse bias). It will remove parts of the positive and negative input signal.



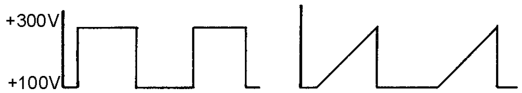
A **CLAMPING CIRCUIT** effectively clamps or ties down the upper or lower extremity of a waveform to a fixed dc potential. Clamping does not change the amplitude or shape of the input waveform.



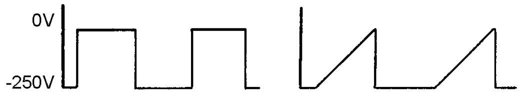
WITHOUT CLAMPING



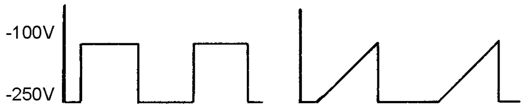
WITH CLAMPING, LOWER EXTREMITY OF WAVE IS HELD AT 0 V



WITH CLAMPING, LOWER EXTREMITY OF WAVE IS HELD AT +100 V

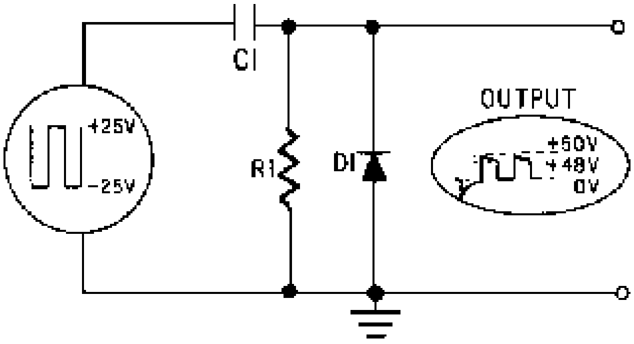


WITH CLAMPING, UPPER EXTREMITY OF WAVE IS HELD AT 0 V

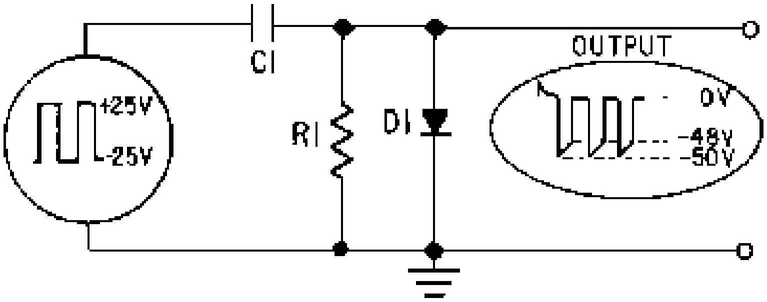


WITH CLAMPING, UPPER EXTREMITY OF WAVE IS HELD AT -100 V

A **POSITIVE CLAMPER** will clamp the lower extremity of the input waveform to a dc potential of 0 volts.



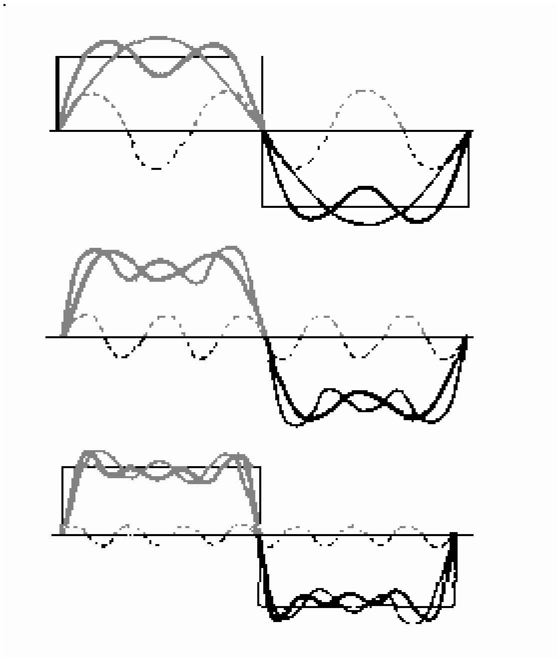
A **NEGATIVE CLAMPER** will clamp the upper extremity of the input waveform to a dc potential of 0 volts.



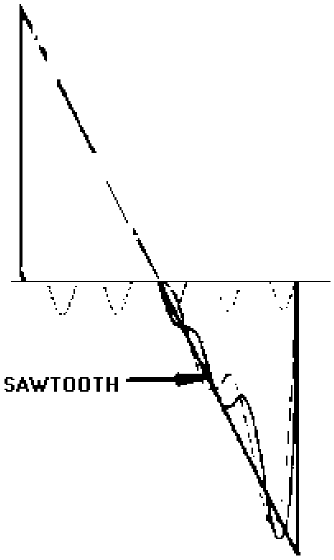
A **COMMON-BASE TRANSISTOR CLAMPER** clamps the collector voltage to a reference level.

A waveform other than a sine wave is called a COMPLEX WAVE.

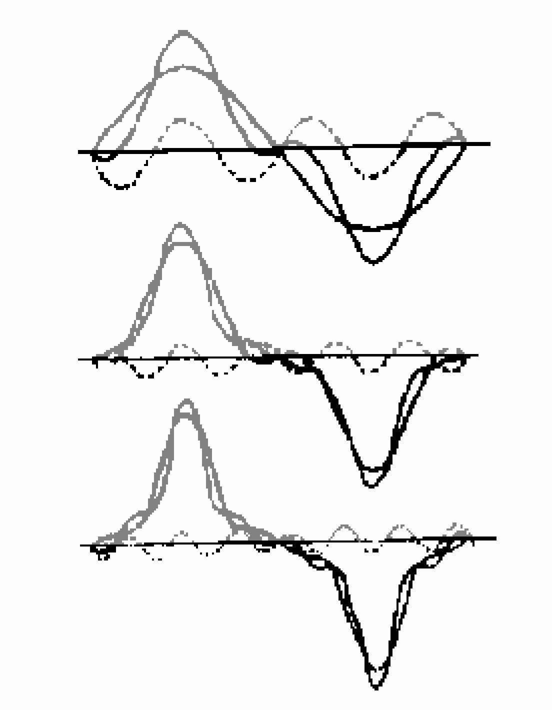
If the odd harmonics of a sine wave are added algebraically, the result is a square wave. A PERFECT SQUARE WAVE is composed of an infinite number of odd harmonics in phase with the fundamental wave.



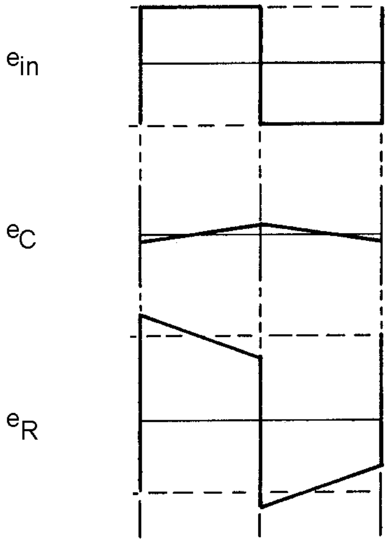
A **SAWTOOTH WAVE** is made up of different harmonics, both odd and even.



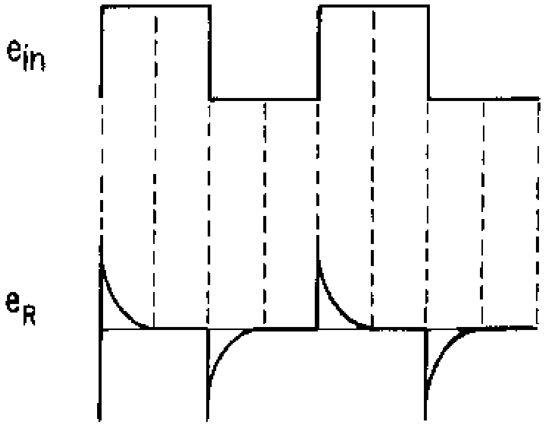
A **PEAKED WAVE** is made up of odd harmonics that are in phase and out of phase with the fundamental.



INTEGRATION takes place in an RC circuit with the output taken across the capacitor. The amount of integration is dependent upon the time constant of the circuit. Full integration takes place when the time constant of the RC circuit is at least 10 times greater than the duration of the input pulse. An RL circuit is also used as an integration circuit. The output is taken across the resistor and the time constant of the circuit is 10 times greater than the input pulse.



DIFFERENTIATION is the opposite of integration. In the differentiator, the output is taken across the resistor. Full differentiation takes place when the time constant of the circuit is 1/10 that of the input pulse.



A **COUNTING CIRCUIT** receives uniform pulses, representing units to be counted, and produces a voltage output proportional to its frequency.

ANSWERS TO QUESTION Q1. THROUGH Q27.

A1. Negative.

A2. Positive.

A3. Biasing.

A4. The diode.

A5. Conducting, cutoff.

A6. Short time constant.

A7. Long time constant.

A8. Most negative.

A9. Positive potential.

A10. Positive clamper with negative bias.

A11. Most positive.

A12. Negative potential.

A13. Positive bias.

A14. -5 volts.

A15. It is composed of an infinite number of odd harmonics in phase with the fundamental.

A16. It is composed of odd harmonics some of which are out phase with the fundamental.

A17. All the odd harmonics are in phase with the fundamental in the square wave. This is not true of the odd harmonics in the peaked wave.

A18. The time constant is long and the output is taken across the capacitor in an RC circuit.

A19. A pure sine wave cannot be integrated; it contains no harmonics.

A20. The ability of the inductor to oppose a change in current.

A21. The time-constant value of a long time constant-circuit is 10 times the value of the input pulse duration. The short time-constant circuit has a time constant of 1/10 of the pulse duration.

A22. A more complete integration of the waveform would result from the long time constant.

A23. In an RC circuit the output is taken across the resistor. In the RL circuit the output is taken across the inductor.

A24. Frequency counters or frequency dividers.

A25. The frequency of the voltage input.

A26. To provide a quick discharge path for C1.

A27. The load resistor in a positive counter is replaced by a capacitor in a step counter.

APPENDIX I

GLOSSARY

AMPLITUDE STABILITY—Amplitude stability refers to the ability of the oscillator to maintain a constant amplitude in the output waveform.

ASTABLE MULTIVIBRATOR—A multivibrator which has no stable state. Also called free-running because it alternates between two different output voltage levels during the time it is on. The frequency is determined by the RC time constant of the coupling circuit.

ATTENUATION—The ability of a filter circuit to reduce the amplitude of unwanted frequencies to a level below that of the desired output frequency.

BANDPASS FILTER—A filter which allows a narrow band of frequencies to pass through the circuit. Rejects or attenuates frequencies which are either higher or lower than the desired band of frequencies.

BAND-REJECT FILTER—Rejects the passage of current for a small band of frequencies. Allows current to flow at frequencies either above or below this band.

BANDWIDTH—The range of frequencies included between upper and lower frequencies.

BISTABLE MULTIVIBRATOR—A multivibrator that has two stable states. It remains in one of the states until a trigger is applied. It then flips to the other stable state and remains there until another trigger is applied. Also referred to as a flip-flop.

BUFFER AMPLIFIER—An amplifier which isolates one circuit from another. It decreases the loading effect on an oscillator by reducing the interaction between the load and the oscillator.

CAPACITIVE REACTANCE—The opposition, expressed in ohms, offered to the flow of an alternating current by capacitance. The symbol for capacitive reactance is Xc.

CLAMPER—A circuit in which either the upper or lower extremity of a waveform is fixed at a desired value.

COMPLEX WAVE—A waveform other than a sine wave.

COUNTER—A circuit which counts input pulses.

CRYSTAL OVEN—Closed oven maintained at a constant temperature in which a crystal and its holder are enclosed to reduce frequency drift.

DAMPED WAVE—A sinusoidal wave in which the amplitude steadily decreases with time. Often associated with energy loss.

FILTER CIRCUIT—Network of resistors, inductors, and/or capacitors which offers opposition to certain frequencies.

FLYWHEEL EFFECT—The ability of a resonant circuit to operate continuously because of stored energy or energy pulses.

FREQUENCY CUTOFF—The frequency at which the filter circuit changes from an action of rejecting the unwanted frequencies to an action of passing the desired frequencies. Conversely, the point at which the filter circuit changes from an action in which it passes the desired frequencies to an action in which it rejects the undesired frequencies.

FREQUENCY STABILITY—Refers to the ability of an oscillator to accurately maintain its operating frequency.

HALF-POWER POINT—Point on either side of resonance curve at which the power is approximately 70 percent of the maximum value.

HARMONIC—Integral multiples of a fundamental frequency. For example, the harmonics of 60 hertz are 120 hertz, 180 hertz, 240 hertz, and so forth.

HIGH-PASS FILTER—A filter that passes a majority of the high frequencies on to the next circuit and rejects, or attenuates, the lower frequencies. Also called a low-frequency discriminator.

INDUCTIVE REACTANCE—The opposition to the flow of an alternating current (expressed in ohms) caused by the inductance of a circuit. The symbol for inductive reactance is X_L.

IMPEDANCE—Total opposition to alternating current flow. Impedance may consist of any combination of resistance, inductive reactance, and capacitive reactance. The symbol for impedance is Z.

LIMITER—A device which prevents (limits) a waveform from exceeding a specified value.

LOWER-FREQUENCY CUTOFF—The lowest frequency a circuit will pass.

LOW-PASS FILTER—A filter that passes a majority of the low frequencies on to the next circuit and rejects, or attenuates, the higher frequencies. Also called a high-frequency discriminator.

MULTIVIBRATOR—A form of relaxation oscillator which comprises two stages that are coupled so that the input of one is derived from the output of the other.

MONOSTABLE MULTIVIBRATOR—A multivibrator which has one steady state. A signal (trigger) must be applied to cause change of states.

NATURAL FREQUENCY—See Resonance Frequency.

NEGATIVE CLAMPER—The upper extremity of the output waveshape is clamped to a dc potential of 0 volts.

OSCILLATOR—An oscillator is a nonrotating device which produces alternating current. The frequency is determined by the characteristics of the device.

PARALLEL LIMITER—A resistor and diode connected in series with the input signal. The output is taken across the diode.

PARALLEL-NEGATIVE LIMITER—A resistor and diode connected in series with the input signal. The output is taken across the diode and the negative alternation is eliminated.

PARALLEL-POSITIVE LIMITER—A resistor and diode connected in series with the input signal. The output is taken across the diode and the positive alternation of the input signal is eliminated.

PARALLEL-RESONANT CIRCUIT—A resonant circuit in which the source voltage is connected across a parallel circuit (formed by a capacitor and an inductor) to furnish a high impedance to the frequency at which the circuit is resonant. Often referred to as a tank circuit.

PERIODIC WAVE—A waveform that undergoes a pattern of changes, returns to its original pattern, and then repeats the same pattern of changes. Examples are square waves, rectangular waves, and sawtooth waves.

POSITIVE CLAMPER—The lower extremity of the output waveshape is clamped to a dc potential of 0 volts.

PULSE—Signal characterized by a rapid rise and decay from an initial level.

PULSE OSCILLATOR—A sine-wave oscillator that is turned on and off at specific times. Also known as a ringing oscillator.

PULSE-REPETITION FREQUENCY (PRF)—The number of times in 1 second that a waveform repeats itself.

PULSE-REPETITION RATE (PRR)—Same as Pulse-Repetition Frequency (prf).

Q—Figure of merit (efficiency) of a circuit or coil. Ratio of inductive reactance to resistance.

QUIESCENT STATE—Time during which a tube or transistor of an electrical circuit is not performing its active function.

RC CONSTANT—Time constant of a resistor-capacitor circuit. Equal in seconds to the resistance value multiplied by capacitance value.

RC DIFFERENTIATOR—An RC circuit in which the output is taken from the resistor.

RC INTEGRATOR—An RC circuit in which the output is taken from the capacitor.

RC NETWORK—A circuit containing resistances and capacitances arranged in a particular manner to perform a specific function.

RC OSCILLATOR—An oscillator in which the frequency is determined by resistive and capacitive elements.

REGENERATIVE FEEDBACK—The process by which a portion of the output power of an amplifying device is fed back to reinforce the input.

RESONANCE—The condition in a circuit containing inductance and capacitance in which the inductive reactance is equal and opposite to the capacitive reactance. This condition occurs at only one frequency and the circuit in that condition is said to be in resonance. The resonant frequency can be changed by varying the values of either the capacitance or inductance.

RESONANT CIRCUIT—A circuit that contains both inductance and capacitance and is resonant at one frequency ($X_L = X_C$).

RESONANT FREQUENCY—That frequency in a given resonant circuit at which the inductive and capacitive values are equal and cancel each other.

RL DIFFERENTIATOR—An RL circuit in which the output is taken from the inductor.

RL INTEGRATOR—An RL circuit in which the output is taken from the resistor.

SELECTIVITY—The ability of a circuit to discriminate between frequencies.

SERIES-FED OSCILLATOR—An oscillator in which dc power is supplied to the amplifier through the tank circuit or a portion of the tank circuit.

SERIES LIMITER—The diode is connected in series with the output and the output is taken across the resistor. Either the positive or negative alternation of the input wave is eliminated.

SERIES-NEGATIVE LIMITER—The diode is connected in series with the output and the output is taken across the resistor. Eliminates the negative alternation of the input wave.

SERIES-PARALLEL CIRCUIT—A circuit in which two or more parallel or series combinations are in series with each other.

SERIES-POSITIVE LIMITER—The diode is connected in series with the output and the output is taken across a resistor. Eliminates the positive alternation of the input wave.

SERIES-RESONANT CIRCUIT—A resonant circuit in which the source voltage is connected in series with a capacitor and an inductor (also in series) to furnish a low impedance at the frequency at which the circuit is resonant.

SHAPING CIRCUIT—A circuit which alters the shapes of input waveforms.

STEP-BY-STEP-COUNTER—A counter which provides an output for each cycle of the input in one-step increments.

SHUNT-FED OSCILLATOR—An oscillator which receives its dc power for the transistor or tube through a path both separate from and parallel to the tank circuit.

TANK CIRCUIT—A tuned circuit used to temporarily store energy. Also referred to as a parallel-resonant circuit.

TICKLER COIL—Small coil connected in series with the collector or plate circuit of a transistor or tube and inductively coupled to a base or grid-circuit coil to establish feedback or regeneration.

TIME CONSTANT—Time required for an exponential quantity to change by an amount equal to .632 times the total change that can occur.

TRIGGER—Short pulse, either positive or negative, which can be used to cause an electrical function to take place.

TUNED CIRCUIT—Circuit consisting of inductance and capacitance which can be adjusted for resonance at a desired frequency.

UPPER-FREQUENCY CUTOFF—The highest frequency a circuit can pass.

APPENDIX II

SQUARE AND SQUARE ROOTS

N	N^2	$\sqrt{N}$	N	N^2	$\sqrt{N}$	N	N^2	$\sqrt{N}$
1	1	1.000	41	1681	6.4031	81	6561	9.0000
2	4	1.414	42	1764	6.4807	82	6724	9.0554
3	9	1.732	43	1849	6.5574	83	6889	9.1104
4	16	2.000	44	1936	6.6332	84	7056	9.1652
5	25	2.236	45	2025	6.7082	85	7225	9.2195
6	36	2.449	46	2116	6.7823	86	7396	9.2736
7	49	2.646	47	2209	6.8557	87	7569	9.3274
8	64	2.828	48	2304	6.9282	88	7744	9.3808
9	81	3.000	49	2401	7.0000	89	7921	9.4340
10	100	3.162	50	2500	7.0711	90	8100	9.4868
11	121	3.3166	51	2601	7.1414	91	8281	9.5394
12	144	3.4641	52	2704	7.2111	92	8464	9.5917
13	169	3.6056	53	2809	7.2801	93	8649	9.6437
14	196	3.7417	54	2916	7.3485	94	8836	9.6954
15	225	3.8730	55	3025	7.4162	95	9025	9.7468
16	256	4.0000	56	3136	7.4833	96	9216	9.7980
17	289	4.1231	57	3249	7.5498	97	9409	9.8489
18	324	4.2426	58	3364	7.6158	98	9604	9.8995
19	361	4.3589	59	3481	7.6811	99	9801	9.9499
20	400	4.4721	60	3600	7.7460	100	10000	10.0000
21	441	4.5826	61	3721	7.8102	101	10201	10.0499
22	484	4.6904	62	3844	7.8740	102	10404	10.0995
23	529	4.7958	63	3969	7.9373	103	10609	10.1489
24	576	4.8990	64	4096	8.0000	104	10816	10.1980
25	625	5.0000	65	4225	8.0623	105	11025	10.2470
26	676	5.0990	66	4356	8.1240	106	11236	10.2956
27	729	5.1962	67	4489	8.1854	107	11449	10.3441
28	784	5.2915	68	4624	8.2462	108	11664	10.3923
29	841	5.3852	69	4761	8.3066	109	11881	10.4403
30	900	5.4772	70	4900	8.3666	110	12100	10.4881
31	961	5.5678	71	5041	8.4261	111	12321	10.5357
32	1024	5.6569	72	5184	8.4853	112	12544	10.5830
33	1089	5.7447	73	5329	8.5440	113	12769	10.6301
34	1156	5.8310	74	5476	8.6023	114	12996	10.6771
35	1225	5.9161	75	5625	8.6603	115	13225	10.7238
36	1296	6.0000	76	5776	8.7178	116	13456	10.7703
37	1369	6.0828	77	5929	8.7750	117	13689	10.8167
38	1444	6.1644	78	6084	8.8318	118	13924	10.8628
39	1521	6.2450	79	6241	8.8882	119	14161	10.9087
40	1600	6.3246	80	6400	8.9443	120	14400	10.9545

For numbers up to 120. For larger numbers divide into factors smaller than 120.

Examples: $\sqrt{225}$ and $\sqrt{16200}$

$225 = 5 \times 45$	$16200 = 100 \times 81 \times 2$
$\sqrt{225} = \sqrt{5} \times \sqrt{45}$	$\sqrt{16200} = \sqrt{100} \times \sqrt{81} \times \sqrt{2}$
$\sqrt{225} = 2.236 \times 6.7082$	$\sqrt{16200} = 10 \times 9 \times 1.414$
$\sqrt{225} = 15$	$\sqrt{16200} = 127.26$

MODULE 9 INDEX

ASSIGNMENT 1

Textbook assignment: Chapter 1, “Tuned Circuits,” pages 1-1 through 1-52.

1-1. An inductor presents which of the following types of electrical opposition to ac current flow?

1. Reactance
2. Resistance
3. Inductance
4. Capacitance

1-2. Which of the following electrical characteristics determines the magnitude of inductive reactance?

1. Resistance
2. Frequency only
3. Inductance only
4. Frequency and inductance

1-3. Which of the following values represents an inductive reactance?

1. X_C = 2,220 ohms
2. X_L = 220 ohms
3. L = 22 millihenries
4. C = 22 microfarads

1-4. What formula is used to calculate inductive reactance?

1. $X_L = 2\pi fC$
2. $X_L = 2\pi fL$
3. $X_L = \frac{1}{2\pi fL}$
4. $X_L = \frac{1}{2\pi fC}$

1-5. In an ac circuit, how does inductive reactance respond to an increase in applied frequency?

1. Inductive reactance increases
2. Inductive reactance decreases
3. Inductive reactance remains the same

1-6. What term describes the opposition to ac that causes current to lead voltage?

1. Resistance
2. Conductance
3. Inductive reactance
4. Capacitive reactance

1-7. In an ac circuit, how does capacitive reactance respond to an increase in applied frequency?

1. Capacitive reactance increases
2. Capacitive reactance decreases
3. Capacitive reactance remains the same

1-8. In an ac circuit, what is the term that describes the TOTAL opposition to current flow?

1. Impedance
2. Inductance
3. Resistance
4. Capacitance

1-9. In an ac circuit that contains an inductive reactance of 7,250 ohms and a capacitive reactance of 9,775 ohms, what is the resultant reactance?

1. - 2,525 ohms
2. -10,250 ohms
3. 2,525 ohms
4. 10,250 ohms

1-10. When an ac circuit is at resonance, what is the relationship between X_L and X_C

1. X_L is equal to X_C
2. X_L is less than X_C
3. X_L is greater than X_C

1-11. What formula is used to calculate resonant frequency?

1. $f_r = \dfrac{1}{2\pi f L}$
2. $f_r = \dfrac{1}{2\pi f C}$
3. $f_r = \dfrac{1}{2\pi\sqrt{LR}}$
4. $f_r = \dfrac{1}{2\pi\sqrt{LC}}$

1-12. In a tank circuit, how does the resonant frequency of the circuit respond to an increase in (a) capacitance and (b) inductance?

1. (a) Increases (b) increases
2. (a) Increases (b) decreases
3. (a) Decreases (b) decreases
4. (a) Decreases (b) increases

1-13. In a resonant circuit, what is the phase angle between voltage and current?

1. 0 degrees
2. 90 degrees
3. 180 degrees
4. 270 degrees

1-14. In a resonant circuit, how does resistance change, if at all, in response to an increase in frequency?

1. Increases
2. Decreases
3. Remains the same

1-15. In a series-LC circuit, which of the following component characteristics describes circuit action (a) below the resonant frequency and (b) above the resonant frequency?

1. (a) Inductive (b) Capacitive
2. (a) Inductive (b) Resistive
3. (a) Capacitive (b) Inductive
4. (a) Capacitive (b) Resistive

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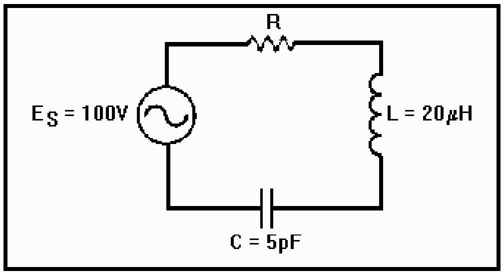

Figure 1A.—Series-resonant circuit.

IN ANSWERING QUESTIONS 1-16 THROUGH 1-21, REFER TO FIGURE 1A.

1-16. What is the resonant frequency for the circuit?

1. 1.592 MHz
2. 15.92 MHz
3. 159.2 MHz
4. 1,592 MHz

1-17. What is the value of inductive reactance?

1. 1.97 ohms
2. 97 ohms
3. 199.7 ohms
4. 1,997 ohms

1-18. If the resonant frequency is 7.96 MHz, what is the value of capacitive reactance?

1. 500 ohms
2. 1,000 ohms
3. 2,000 ohms
4. 4,000 ohms

IN ANSWERING QUESTIONS 1-19 THROUGH 1-21, ASSUME THE SOURCE FREQUENCY IN FIGURE 1A IS ABOVE THE RESONANT FREQUENCY. SELECT THE ANSWERS THAT DESCRIBE HOW AN ABOVE-RESONANCE FREQUENCY WILL CAUSE THE CIRCUIT CHARACTERISTICS IN THE QUESTIONS TO RESPOND WHEN COMPARED TO THEIR VALUES AT RESONANCE.

1-19. Impedance.

1. Increases
2. Decreases
3. Remains the same

1-20. Current.

1. Increases
2. Decreases
3. Remains the same

1-21. Voltage drops across the reactances.

1. Increases
2. Decreases
3. Remains the same

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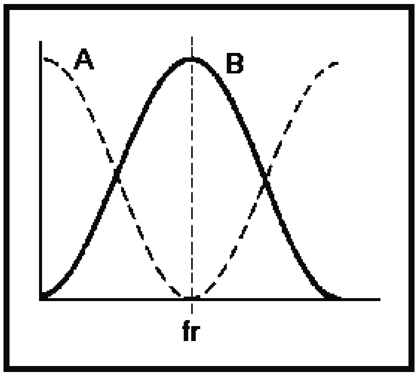

Figure 1B.—Series-resonant circuit curves.

IN ANSWERING QUESTIONS 1-22 AND 1-23, REFER TO FIGURE 1B.

1-22. Response curve B for a series-resonant circuit represents which of the following circuit characteristics?

1. Power
2. Voltage
3. Current
4. Impedance

1-23. At resonance, which of the following series-resonant circuit values is at a maximum value?

1. Circuit current
2. Voltage across L
3. Voltage across C
4. Circuit impedance

1-24. In a series-resonant circuit operating at $_{fr}$, what term describes the impedance of the circuit?

1. Resistive
2. Inductive only
3. Capacitive only
4. Capacitive-inductive

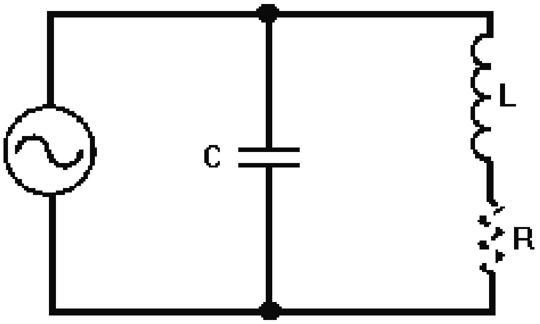

Figure 1C.—Parallel-resonant circuit.

IN ANSWERING QUESTIONS 1-25 THROUGH 1-27, REFER TO FIGURE 1C.

1-25. In the parallel-resonant circuit, what is the phase relationship between the current in the inductor and the current in the capacitor?

1. Inductor current is in phase with capacitor current
2. Inductor current is 45 degrees out of phase with capacitor current
3. Inductor current is 90 degrees out of phase with capacitor current
4. Inductor current is 180 degrees out of phase with capacitor current

1-26. In the parallel-resonant circuit, what is the phase relationship between voltage in the inductor and the voltage in the capacitor.

1. Inductor voltage is in phase with capacitor voltage
2. Inductor voltage is 45 degrees out of phase with capacitor voltage
3. Inductor voltage is 90 degrees out of phase with capacitor voltage
4. Inductor voltage is 180 degrees out of phase with capacitor voltage

1-27. In the parallel-resonant circuit, which of the following circuit conditions is NOT normal?

1. X_C equals X_L
2. I_C equals I_L
3. I_{line} is minimum
4. I_{line} is maximum

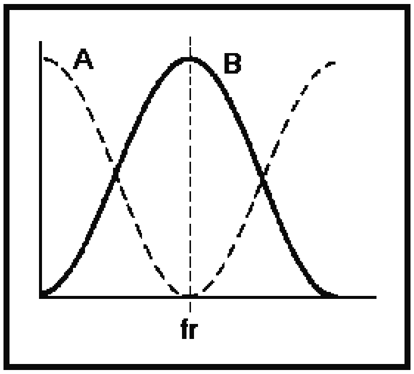

Figure 1D.—Parallel-resonant circuit curves.

IN ANSWERING QUESTIONS 1-28 AND 1-29, REFER TO FIGURE 1D.

1-28. In the figure, what does response curve A represent?

1. Current
2. Impedance
3. Reactance
4. Resistance

1-29. What does response curve B represent?

1. Power
2. Impedance
3. Reactance
4. Resistance

1-30. As a parallel-resonant circuit approaches resonance, which of the following circuit actions takes place?

1. Impedance decreases
2. Oscillating current increases
3. Inductance increases
4. Capacitance decreases

1-31. When a parallel-resonant circuit operates BELOW resonance, which of the following component characteristics describes circuit action?

1. Inductive
2. Capacitive
3. Resistive

1-32. When a parallel-resonant circuit operates ABOVE resonance, which of the following component characteristics describes circuit actions?

1. Inductive
2. Capacitive
3. Resistive

1-33. In a parallel-resonant circuit, which of the following circuit conditions is observed?

1. Oscillating current is less than line current
2. Oscillating current is greater than line current
3. Line current is maximum
4. Impedance is minimum

1-34. What is the level of impedance offered at resonance in (a) a series-resonant circuit and (b) a parallel-resonant circuit?

1. (a) High (b) high
2. (a) High (b) low
3. (a) Low (b) low
4. (a) Low (b) high

1-35. The ability of a resonant circuit to separate currents of desired frequencies from those of undesired frequencies makes them useful in which of the following circuit applications?

1. Filters
2. Counters
3. Amplifiers
4. Voltage dividers

1-36. The Q of a circuit is a measure of circuit

1. quality
2. permeance
3. conductance
4. inductive reactance

1-37. Which of the following circuit values has the greatest effect on the figure of merit of the circuit?

1. Reactance
2. Inductance
3. Resistance
4. Capacitance

1-38. What formula is used to figure the Q of a coil?

1. $Q = \frac{R}{Z}$
2. $Q = \frac{X_L}{Z}$
3. $Q = \frac{R}{X_L}$
4. $Q = \frac{X_L}{R}$

1-39. On which of the following coil characteristics is the Q of a coil dependent?

1. Size
2. Length
3. Material
4. All of the above

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1-40. A series-resonant circuit, which of the following conditions results in a voltage gain?

1. $\frac{X_L}{R}$ increasing
2. $\frac{X_L}{R}$ decreasing
3. $\frac{R}{X_L}$ increasing
4. $\frac{R}{X_L}$ decreasing

1-41. In a parallel-resonant circuit, Q is used to figure which of the following circuit values?

1. Voltage gain
2. Voltage loss
3. Circulating tank current
4. Circulating line current

1-42. To determine bandwidth, you would use which of the following mathematical expressions?

1. $BW = \frac{f_r}{Q}$
2. $BW = \frac{f_r \times X_L}{f_r}$
3. $BW = \frac{R \times X_L}{f_r}$
4. $BW = \frac{R}{f_r \times X_L}$

1-43. To calculate (figure) the half-power points of a resonant circuit, which of the following mathematical expressions should you use?

1. .707 x I_{min}
2. .707 x I_{max}
3. .637 x I_{min}
4. .637 x I_{max}

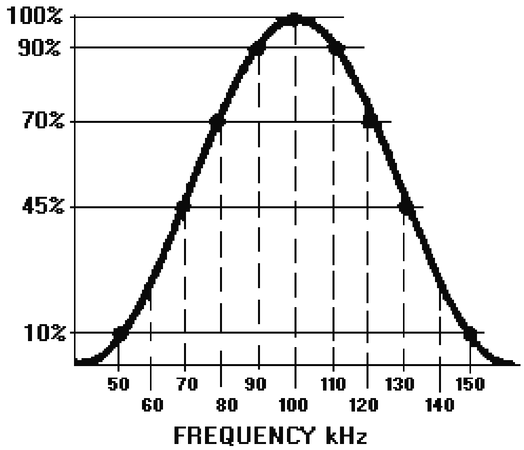

Figure 1E.—Response curve.

IN ANSWERING QUESTIONS 1-44 THROUGH 1-46, REFER TO FIGURE 1E.

1-44. In the response curve, what is the resonant frequency?

1. 50 kHz
2. 70 kHz
3. 100 kHz
4. 140 kHz

1-45. What is the bandwidth?

1. 10 kHz
2. 20 kHz
3. 30 kHz
4. 40 kHz

1-46. If the Q of the circuit represented by the response curve is 100, what is the bandwidth?

1. 1 kHz
2. 10 kHz
3. 20 kHz
4. 30 khz

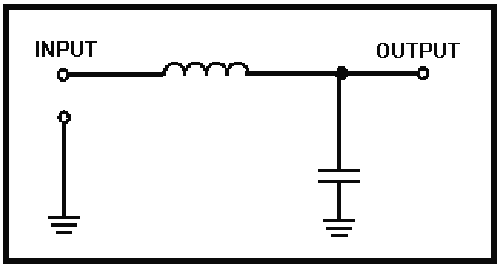

Figure 1F.—Filter circuit.

IN ANSWERING QUESTION 1-47, REFER TO FIGURE 1F.

1-47. If the applied frequency to the circuit is increased, what is the response of (a) X_C and (b) X_L

1. (a) X_C increases (b) X_L increases
2. (a) X_C increases (b) X_L decreases
3. (a) X_C decreases (b) X_L decreases
4. (a) X_C decreases (b) X_L increases

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TO ANSWER QUESTIONS 1-48 THROUGH 1-50, SELECT FROM COLUMN B THE CIRCUIT WHICH DESCRIBES THE CIRCUIT OPERATION IN COLUMN A. CHOICES IN COLUMN B MAY BE USED ONCE, MORE THAN ONCE, OR NOT AT ALL.

A. CIRCUIT OPERATION

1-48. Passes the majority of current below a specific frequency and opposes current above that frequency.

1-49. Passes the majority of current above a specific frequency and opposes current below that frequency.

1-50. Passes a narrow band of frequencies and opposes all others.

B. CIRCUIT

1. Band-pass filter
2. High-pass filter
3. Low-pass filter
4. Band-reject filter

1-51. The action of a filter circuit that reduces the amplitude of unwanted frequencies below the amplitude of the desired frequency is known as

1. attenuation
2. amplification
3. discrimination
4. impedance matching

1-52. The frequency beyond which a filter circuit no longer passes current is referred to as the

1. filter frequency
2. cutoff frequency
3. resonant frequency
4. response frequency

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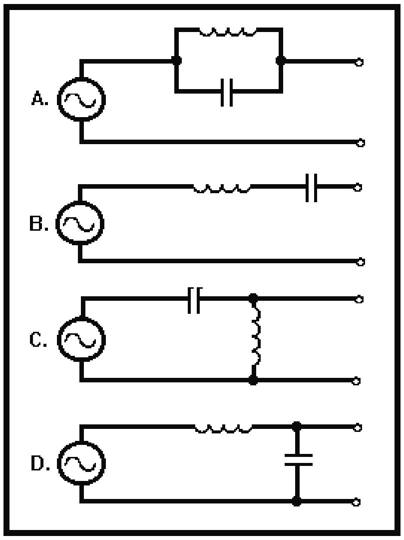


Figure 1G.—Filter circuits.

TO ANSWER QUESTIONS 1-53 AND 1-54, SELECT FROM FIGURE 1G THE CIRCUIT DIAGRAM WHICH MATCHES THE CIRCUIT NAME IN EACH QUESTION. CHOICES IN THE FIGURE MAY BE USED ONCE, MORE THAN ONCE, OR NOT AT ALL.

1-53. Band-reject filter.

1. A
2. B
3. C
4. D

1-54. High-pass filter.

1. A
2. B
3. C
4. D

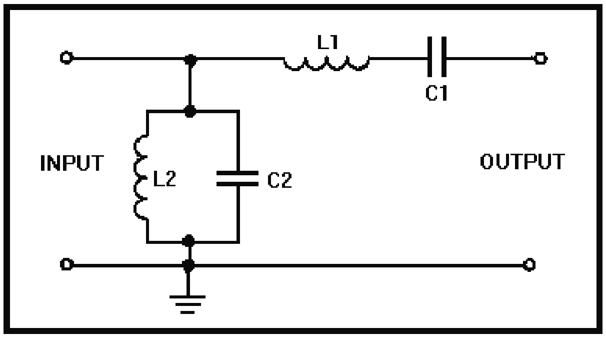


Figure 1H.—Filter circuit.

IN ANSWERING QUESTIONS 1-55 AND 1-56, REFER TO THE CIRCUIT IN FIGURE 1H.

1-55. L1 and C1 in the circuit offer what type of opposition to (a) frequencies near resonance and (b) all other frequencies?

1. (a) Minimum (b) minimum
2. (a) Minimum (b) maximum
3. (a) Maximum (b) maximum
4. (a) Maximum (b) minimum

1-56. In the type of filter circuit in the figure, what is/are the "cutoff point(s)?"

1. Upper frequency limit only
2. Lower frequency limit only
3. Both upper and lower frequency limits

1-57. In a series-resonant circuit that is operating at resonance, what is the amplitude of the applied voltage compared to (a) inductor voltage and (b) capacitor voltage?

1. (a) Lower (b) lower
2. (a) Lower (b) higher
3. (a) Higher (b) higher
4. (a) Higher (b) lower

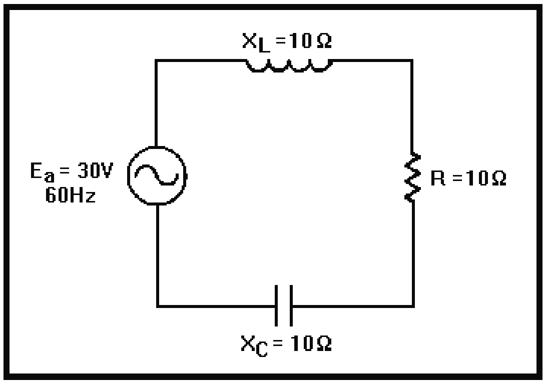


Figure 1I.—Series-RCL circuit at resonance.

IN ANSWERING QUESTIONS 1-58 THROUGH 1-60, REFER TO FIGURE 1I.

1-58. With the circuit in the figure at resonance, what is the circuit current?

1. 1 ampere
2. 2 amperes
3. 3 amperes
4. 0.5 ampere

1-59. If E_a were increased to 60 volts at the resonant frequency, what would be the voltage drop across the capacitor?

1. 10 volts
2. 20 volts
3. 30 volts
4. 60 volts

1-60. If the circuit is at resonance, what is circuit impedance?

1. 10 ohms
2. 20 ohms
3. 30 ohms
4. 40 ohms

ASSIGNMENT 2

Textbook assignment: Chapter 2, "Oscillators," pages 2-1 through 2-38.

2-1. A sinusoidal oscillator can be regarded as which of the following types of amplifiers?

1. One that produces a trapezoidal wave
2. One that produces a sine wave
3. One that produces a square wave
4. One that produces a sawtooth wave

2-2. Wave generators are classified according to the

1. input wave shape
2. output wave shape
3. current in the output
4. voltage in the output

2-3. An IDEAL sinusoidal oscillator would produce which of the following outputs?

1. A square wave of constant frequency and amplitude
2. A square wave of varying frequency and amplitude
3. A sine wave of constant frequency and amplitude
4. A sine wave of varying frequency and constant amplitude

2-4. What three circuits are most commonly used as frequency determining devices?

1. Class C amplifier, class B amplifier, and class A amplifier
2. Crystal-controlled oscillator, RC oscillator, and LC oscillator
3. Common-emitter amplifier, common-base amplifier, and common-collector amplifier
4. Transformer coupler, RC coupler, and direct coupler

2-5. Which of the following circuits is NOT a relaxation oscillator?

1. A multivibrator
2. A sawtooth generator
3. A blocking oscillator
4. A sinusoidal oscillator

2-6. Which of the following definitions describes the basic oscillator?

1. A nonrotating device producing alternating current
2. A rotating device producing alternating current
3. A nonrotating device producing direct current
4. A rotating device producing direct current

2-7. Amplitude stability in an oscillator is the ability to

1. produce an increased amplitude in the output
2. produce a variable amplitude in the output
3. maintain a constant frequency in the output
4. maintain a constant amplitude in the output

2-8. Frequency stability in an oscillator refer to its ability to

1. maintain a constant operating frequency
2. maintain a variable operating amplitude
3. maintain a constant amplitude
4. vary operating frequency

2-9. What is the purpose of a buffer amplifier?

1. To provide a direct connection between the oscillator and the load
2. To amplify the output signal of the oscillator
3. To remove frequency distortion from the oscillator
4. To prevent load variations from affecting the oscillator

2-10. Why is class A bias used in oscillators?

1. To develop low power
2. To develop maximum power
3. To maintain low distortion
4. To maintain high efficiency

2-11. When a group of RC networks is used for regenerative feedback, which of the following waveform actions takes place in each successive stage?

1. Waveform is rectified
2. Amplitude is decreased
3. Amplitude is increased
4. Amplitude is held constant

2-12. When RC networks are connected in cascade (series), what amount of phase shift should you see?

1. The sum of the phase shifts of each RC network
2. The difference between the phase shifts of each RC network
3. The product of the phase shifts of each RC network
4. The square of the phase shifts of each RC network

2-13. Which of the following terms describes the gradual amplitude reduction in an oscillator?

1. Damping
2. Phase shift
3. Regeneration
4. Flywheel effect

2-14. Which of the following formulas can be used to figure frequency in an LC tank circuit?

1. $f_r = \frac{1}{2\pi LC}$
2. $f_r = \frac{1}{2\pi\sqrt{LC}}$
3. $f_r = \frac{1}{2\pi\sqrt{X_C}}$
4. $f_r = \frac{1}{2\pi\sqrt{X_C L_C}}$

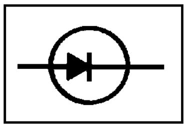
2-15. Which of the following actions best describes the piezoelectric effect?

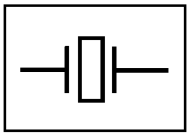
1. Produces an dc output voltage for a given ac input voltage
2. Produces an output voltage for a given mechanical input
3. Produces a mechanical output for a given input voltage
4. Both 2 and 3 above

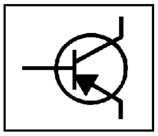
2-16. The piezoelectric effect is the property of a crystal which produces which of the following electrical characteristics?

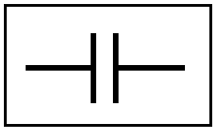
1. Resistance
2. Inductance
3. Capacitance
4. Each of the above

2-17. What is the schematic symbol for a crystal?

1. 

2. 

3. 

4. 

2-18. What electrical characteristic makes the frequency stability of a crystal better than that of an LC tank circuit?

1. Higher Q
2. Higher inductance
3. Higher resistance
4. Higher capacitance

2-19. How is feedback described?

1. Control of a circuit output signal by the input signal
2. Control of a circuit input signal by the output of the previous circuit
3. Transfer of a portion of the output circuit energy to control the input of the circuit
4. Transfer of a portion of the input circuit energy to control the output circuit

2-20. Which of the following terms describes the types of feedback?

1. Degenerative and regenerative
2. Negative and positive
3. Both 1 and 2 above
4. Bypassed and unbypassed

2-21. What type of feedback aids an input signal?

1. Positive
2. Negative
3. Bypassed
4. Degenerative

2-22. What type of feedback opposes an input signal?

1. Positive
2. Unbypassed
3. Degenerative
4. Regenerative

2-23. What type of feedback is used to sustain oscillations?

1. Bypassed
2. Negative
3. Degenerative
4. Regenerative

2-24. What oscillator uses a tickler coil for feedback?

1. Hartley
2. Colpitts
3. Armstrong
4. RC phase-shift

2-25. What oscillator uses a tapped coil for feedback?

1. Hartley
2. Colpitts
3. Armstrong
4. RC phase-shift

2-26. What oscillator uses split capacitors for feedback?

1. Hartley
2. Colpitts
3. Armstrong
4. RC phase-shift

TO ANSWER QUESTIONS 2-27 THROUGH 2-29, SELECT THE CONFIGURATIONS IN COLUMN B THAT MATCH THE AMPLIFIER CHARACTERISTICS IN COLUMN A. CHOICES IN COLUMN B MAY BE USED ONCE, MORE THAN ONCE OR NOT AT ALL.

A. CHARACTERISTICS	B. CONFIGURATIONS
2-27. Voltage gain is less than unity	1. Common-base 2. Common-gate 3. Common-emitter
2-28. Low power gain	4. Common-collector
2-29. Feedback signal requires phase shift	

2-30. Which of the following statements best describes tank current in a series-fed oscillator?

1. The dc path is through the tank circuit
2. The dc path does not go through the tank circuit
3. The ac path is through the tank circuit
4. The ac path does not go through the tank circuit

2-31. In a shunt-fed, tuned-collector Armstrong oscillator, what blocks the dc component from the tank circuit?

1. A resistor
2. A capacitor
3. An inductor
4. A transistor

2-32. Which of the following circuit arrangements aid in the frequency stability of an oscillator?

1. A regulated power supply
2. A common bias source for the emitter and collector
3. Both 1 and 2 above
4. Separate bias sources

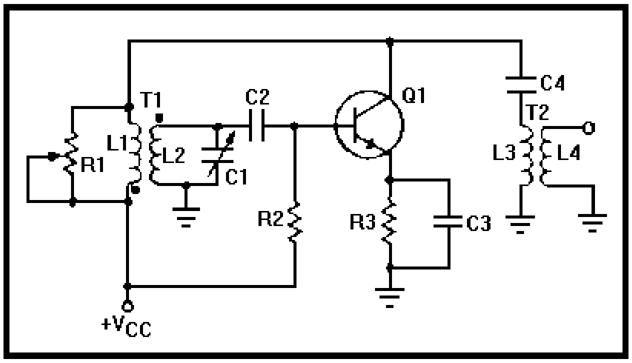


Figure 2A.—Tuned-base Armstrong oscillator.

IN ANSWERING QUESTIONS 2-33 THROUGH 2-37, REFER TO FIGURE 2A.

2-33. The frequency of the output signal of the oscillator is determined by what components?

1. R1 and L1
2. L2 and C1
3. L3 and C4
4. R3 and C3

2-34. Forward bias for the amplifier is developed by what component?

1. R1
2. R2
3. R3
4. L1

2-35. The resonant frequency is tuned to the desired value by what component?

1. C1
2. C2
3. L3
4. L1

2-36. What is the maximum degree of phase shift provided between the base and collector of Q1?

1. 0 degrees
2. 90 degrees
3. 120 degrees
4. 180 degrees

2-37. Temperature stability of the oscillator is improved by what component?

1. R1
2. R2
3. R3
4. C4

2-38. What feature in a Hartley oscillator differs from an Armstrong oscillator?

1. Tickler coil
2. Split inductor
3. Split coupling
4. Split capacitance

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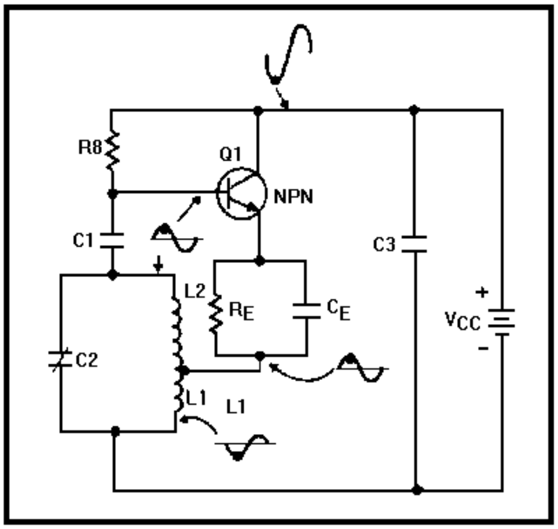

Figure 2B.—Series-fed, tuned-base Hartley oscillator.

IN ANSWERING QUESTIONS 2-39 THROUGH 2-42, REFER TO FIGURE 2B.

2-39. What components are part of the frequency-determining device of this oscillator?

1. C1, L1, and L2
2. C2, L1, and L2
3. C3, L1, and L2
4. C_E, R_E, and R_B

2-40. What circuit component prevents thermal runaway?

1. L1
2. C_E
3. R_B
4. R_E

2-41. The low resistance of L2 could place a short across the emitter-to-base junction network of Q1 and R_E. What component in the circuit prevents this from happening?

1. C1
2. C2
3. C3
4. C_E

2-42. When a positive signal is coupled to the base of Q1, what happens to (a) collector current and (b) emitter current?

1. (a) Increases (b) increases
2. (a) Increases (b) decreases
3. (a) Decreases (b) decreases
4. (a) Decreases (b) increases

2-43. A tuned-base Hartley oscillator is described as "shunt fed" when

1. ac flows through the tank circuit
2. dc flows through the tank circuit
3. ac does not flow through the tank circuit
4. dc does not flow through the tank circuit

2-44. Which of the following advantages does the Colpitts oscillator have over the Armstrong and Hartley oscillators?

1. Easier to tune
2. Wider frequency range
3. Better frequency stability
4. All of the above

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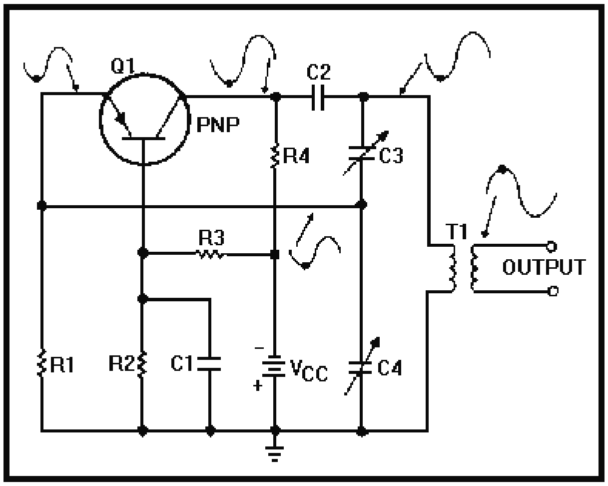

Figure 2C.—Oscillator.

IN ANSWERING QUESTIONS 2-45 THROUGH 2-47, REFER TO FIGURE 2C.

2-45. What type of oscillator is shown in the figure?

1. Common-base Hartley
2. Common-base Colpitts
3. Common-emitter Colpitts
4. Common-collector Hartley

2-46. What component is the collector load resistor?

1. R1
2. R2
3. R3
4. R4

2-47. What resistors provide the base bias?

1. R1, R2
2. R2, R3
3. R3, R4
4. R2, R4

2-48. What class of biasing does the RC oscillator use?

1. A
2. B
3. C
4. AB

2-49. In an RC network, (a) what type of impedance is presented and (b) does the current lead or lag?

1. (a) Inductive (b) leads
2. (a) Inductive (b) lags
3. (a) Capacitive (b) lags
4. (a) Capacitive (b) leads

2-50. In the phase-shift oscillator, a phase shift of 180 degrees for regenerative feedback is provided by what minimum number of RC networks?

1. One
2. Two
3. Three
4. Four

2-51. What determines the phase angle of an RC network?

1. Input voltage
2. Output voltage
3. Values of resistance and inductance
4. Values of resistance and capacitance

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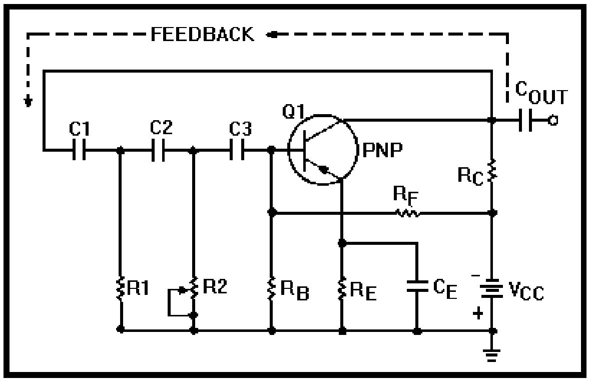

Figure 2D.—Phase-shift oscillator.

IN ANSWERING QUESTIONS 2-52 THROUGH 2-56, REFER TO FIGURE 2D.

2-52. What is the maximum amount of phase shift provided by Q1 in the figure?

1. 0 degrees
2. 60 degrees
3. 90 degrees
4. 180 degrees

2-53. What type of feedback is provided through the RC networks to the base of Q1?

1. Neutral
2. Negative
3. Regenerative
4. Degenerative

2-54. At any other than the desired frequency, what type of feedback is provided by the circuit?

1. Neutral
2. Positive
3. Regenerative
4. Degenerative

2-55. What components make up the frequency-determining device?

1. C1, C2, C_E, R1, R2, R_B
2. C2, C3, C_E, R2, R_B, R_E
3. C1, C2, C3, R1, R2, R_B
4. C_{out}, C1, C2, R1, R2, R_E

2-56. What is the maximum amount of phase shift provided by the C3-R_B network?

1. 90 degrees
2. 80 degrees
3. 70 degrees
4. 60 degrees

2-57. Which of the following is the correct formula for the resonant frequency of a phase-shift oscillator?

1. $f_r = \frac{1}{2\pi\sqrt{LC}}$
2. $f_r = \frac{1}{2\pi RC\sqrt{2n}}$
3. $f_r = \frac{1}{2\pi\sqrt{fL}}$
4. $f_r = \frac{1}{2\pi\sqrt{RC}}$

2-58. Which of the following oscillators is used to provide a highly stable output at a very precise frequency?

1. Crystal
2. Hartley
3. Colpitts
4. Armstrong

2-59. The frequency of a crystal-controlled oscillator is determined by which of the following physical actions?

1. Type of cut
2. Accuracy of cut
3. Thickness of grinding
4. All of the above

2-60. Why is the crystal in a crystal-controlled oscillator often installed in a temperature-controlled oven?

1. To increase frequency without changing the crystal
2. To decrease frequency without changing the crystal
3. To provide better amplitude stability
4. To provide better frequency stability

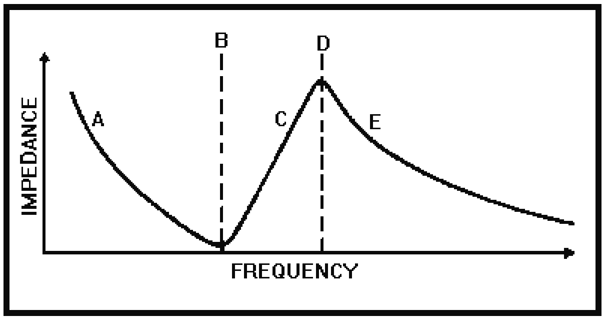

Figure 2E.—Frequency response of a crystal.

IN ANSWERING QUESTIONS 2-61 THROUGH 2-64, REFER TO FIGURE 2E. THE LETTERS A, B, C, D, AND E ARE POINTS ON THE FREQUENCY-RESPONSE CURVE FROM WHICH YOU SHOULD SELECT ANSWERS TO THE QUESTIONS.

2-61. At what point on the curve does a crystal act as a series-tuned circuit?

1. A
2. B
3. C
4. D

2-62. At what point does the crystal act inductively?

1. A
2. B
3. C
4. D

2-63. Below series resonance, a crystal acts capacitively at what point on the curve?

1. A
2. B
3. C
4. E

2-64. At what point does the crystal act purely as a parallel-resonant circuit?

1. B
2. C
3. D
4. E

2-65. How is the Q of a crystal determined?

1. Type of cut used
2. Type of holder used
3. Accuracy of the grinding
4. All of the above

2-66. An oscillator that is turned ON for a specific period of time, then is turned OFF and remains OFF until required at a later time, is which of following types?

1. LC
2. Pierce
3. Pulsed
4. Crystal

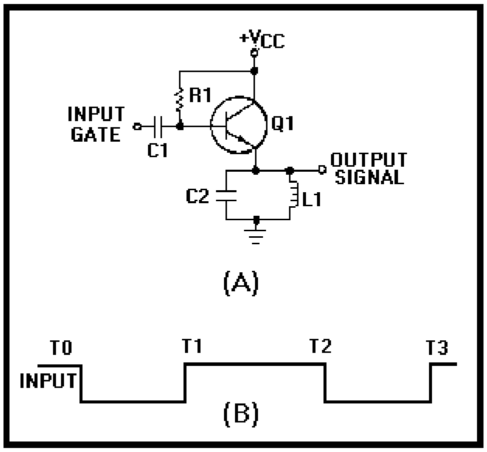

Figure 2F.—Oscillator circuit.

IN ANSWERING QUESTIONS 2-67 THROUGH 2-70, REFER TO FIGURE 2F.

2-67. What circuit is shown in the figure?

1. Pierce oscillator
2. Pulsed oscillator
3. Colpitts oscillator
4. Armstrong oscillator

2-68. Sine waves are generated in the emitter circuit of Q1 during which of the following time periods of the input gate?

1. T0 to T1 and T1 to T2
2. T0 to T1 and T2 to T3
3. T1 to T2 and T3 to T4
4. T1 to T3 and T0 to T4

2-69. The frequencies in the output are determined by what two circuit parameters?

1. Input gate time and the time the circuit is turned OFF
2. Output gate time and the time the circuit is turned ON
3. Input gate time and the resonant frequency of the tank circuit
4. Output gate time and the resonant frequency of the tank circuit,

2-70. If the resonant frequency of the tank circuit were 5 megahertz and transistor Q1 were cut off for 500 microseconds, what maximum number of cycles of the tank frequency would be present in each pulse of the output?

1. 500 cycles
2. 1,500 cycles
3. 2,500 cycles
4. 3,500 cycles

2-71. What is the fourth harmonic of a 2-megahertz signal?

1. 6 megahertz
2. 2 megahertz
3. 8 megahertz
4. 4 megahertz

2-72. What is the highest multiplication factor normally used in frequency multipliers?

1. One
2. Two
3. Three
4. Four

2-73. As the multiplication factor in a frequency multiplier circuit is increased, what happens to the output signal (a) amplitude and (b) frequency?

1. (a) Increases (b) increases
2. (a) Increases (b) decreases
3. (a) Decreases (b) decreases
4. (a) Decreases (b) increases

2-74. In a buffer amplifier, what is the impedance in the (a) input and (b) output?

1. (a) Low (b) low
2. (a) Low (b) high
3. (a) High (b) high
4. (a) High (b) low

ASSIGNMENT 3

Textbook assignment: Chapter 3, "Waveforms and Wave Generators," pages 3-1 through 3-56.

3-1. A waveform that repeats the same pattern of changes is a/an

1. periodic wave
2. sporadic wave
3. aperiodic wave
4. transverse wave

3-2. Which of the following waveforms is sinusoidal?

1. Sine wave
2. Square wave
3. Sawtooth wave
4. Rectangular wave

3-3. The time required to complete one full cycle of a square wave is referred to as the

1. pulse-repetition rate
2. pulse-repetition time
3. pulse-repetition cycle
4. pulse-repetition frequency

3-4. What term(s) describes the number of times in one second that a square wave repeats itself?

1. The pulse-repetition frequency (prf)
2. The pulse-repetition rate (prr)
3. Both 1 and 2 above
4. The pulse-repetition time (prt)

3-5. A square wave with a prf of 1,250 hertz has a prt of

1. 8 microseconds
2. 80 microseconds
3. 800 microseconds
4. 8,000 microseconds

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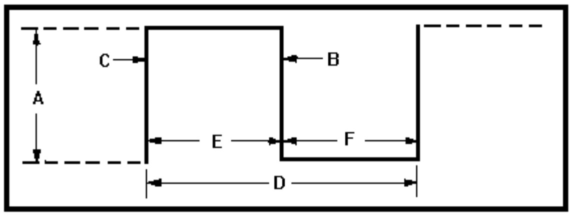


Figure 3A.—Square wave.

IN ANSWERING QUESTIONS 3-6 THROUGH 3-10, SELECT THE CORRESPONDING LETTER IN FIGURE 3A WHICH DESCRIBES THE PORTION OF THE WAVEFORM IN EACH OF THE FOLLOWING QUESTIONS.

3-6. The leading edge of the pulse.

1. C
2. D
3. E
4. F

3-7. The trailing edge of the pulse.

1. A
2. B
3. C
4. D

3-8. The positive alternation.

1. C
2. D
3. E
4. F

3-9. The amplitude of the pulse.

1. A
2. B
3. C
4. D

3-10. The pulse-repetition time of the pulse.

1. C
2. D
3. E
4. F

3-11. What type of waveform is used to furnish a linear rise in current for electromagnetic cathode ray tubes?

1. Square wave
2. Sawtooth wave
3. Trapezoidal wave
4. Rectangular wave

3-12. Which of the following multivibrators must have a signal applied (triggered) to change states?

1. Astable
2. Bistable
3. Monostable
4. Both 2 and 3 above

3-13. Which of the following multivibrators is also called a free running multivibrator?

1. Astable
2. Bistable
3. Monostable
4. Both 2 and 3 above

3-14. Which of the following waveforms could be the output of the astable multivibrator?

1. Sine wave
2. Sawtooth wave
3. Rectangular wave
4. Trapezoidal wave

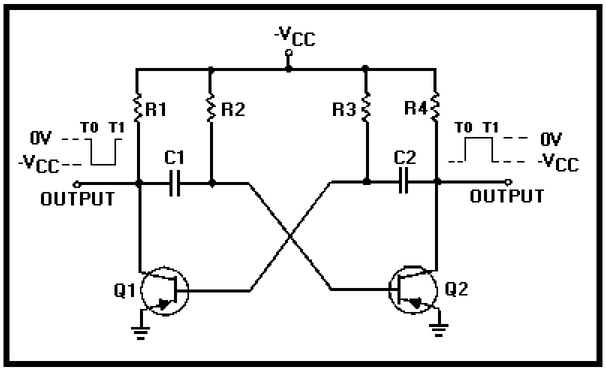


Figure 3B.—Multivibrator.

IN ANSWERING QUESTIONS 3-15 AND 3-16, REFER TO FIGURE 3B.

3-15. The time necessary for Q2 in the circuit to become saturated is controlled by what RC network?

1. R1, C1
2. R2, C1
3. R3, C2
4. R4, C2

3-16. Which of the following conditions exist in the outputs of the figure from T0 to T1?

1. Q1 saturated, Q2 saturated
2. Q1 saturated, Q2 cutoff
3. Q1 cutoff, Q2 cutoff
4. Q1 cutoff, Q2 saturated

3-17. What multivibrator is a square or rectangular-wave generator with only one stable condition?

1. Astable
2. Bistable
3. Monostable
4. Eccles-Jordan

3-18. What is the primary use for the monostable multivibrator circuit?

1. Filter
2. Amplifier
3. Oscillator
4. Pulse stretcher

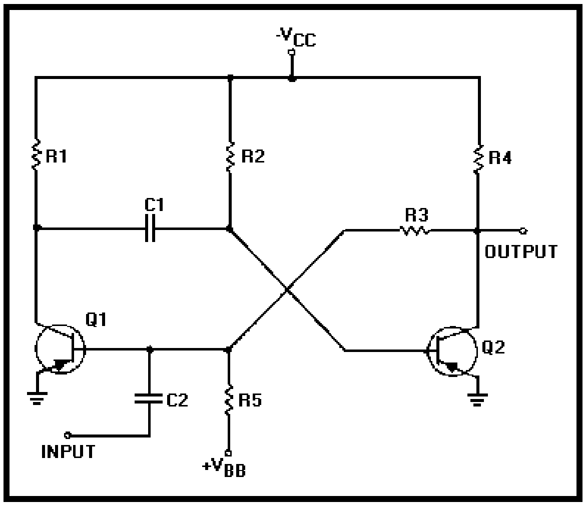


Figure 3C.—Monostable multivibrator circuit.

IN ANSWERING QUESTIONS 3-19 AND 3-20, REFER TO FIGURE 3C.

3-19. In the stable state of the circuit, what will be the condition of (a) Q1 and (b) Q2?

1. (a) Cutoff (b) cutoff
2. (a) Cutoff (b) saturated
3. (a) Saturated (b) saturated
4. (a) Saturated (b) cutoff

3-20. What is the discharge path for C1?

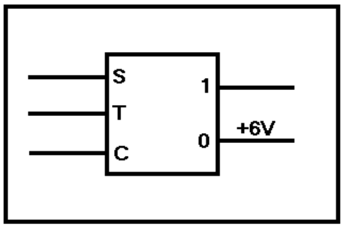
1. C1, Q2, ground, $-V_{CC}$, Q1, and C1
2. C1, Q2, ground, $+V_{BB}$, R5, Q1, and C1
3. C1, Q2, R4, R2, $+V_{BB}$, $-V_{CC}$, R2, and C1
4. C1, Q1, ground, $-V_{CC}$, R2, and C1

3-21. In a bistable multivibrator, what minimum number of triggers is required to produce one gate?

1. One
2. Two
3. Three
4. Four

3-22. Which of the flip flops shown below is in the SET state?

1.



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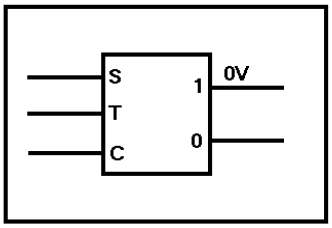
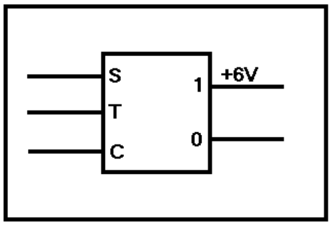


3.



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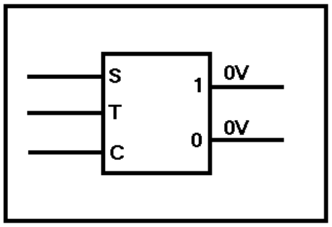
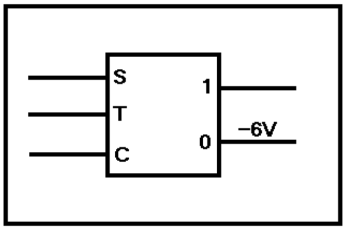
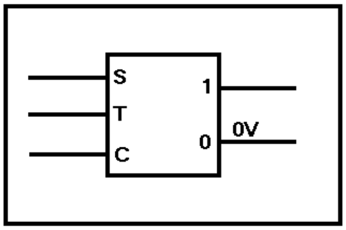


3-23. Which of the flip flops shown below is in the CLEAR state?

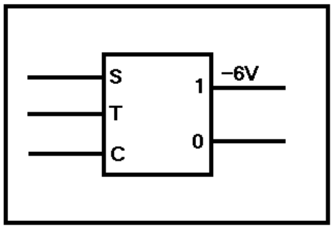
1.



2.



3.



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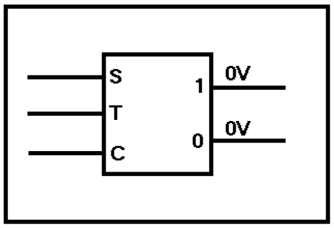


3-24. Which of the following pulses is used to change states in a flip flop?

1. A trigger pulse
2. A clipping pulse
3. A modulating pulse
4. An interference pulse

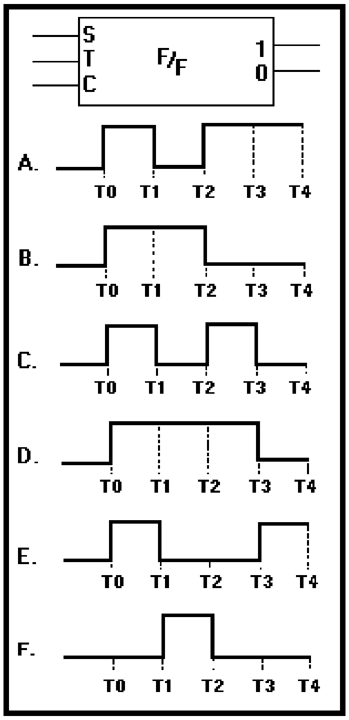
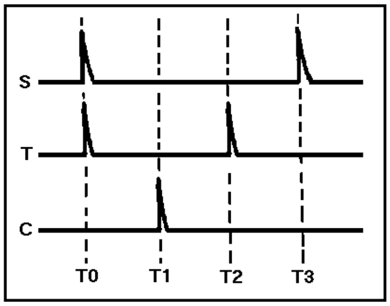


Figure 3D.—Flip-flop output 1 waveforms.

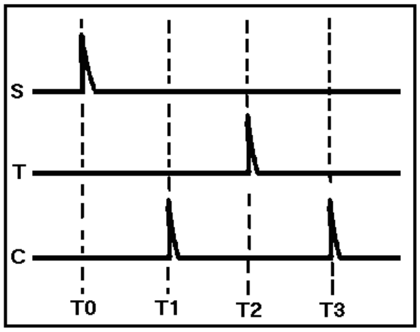
IN ANSWERING QUESTIONS 3-25 THROUGH 3-29, REFER TO FIGURE 3D. ASSUME THE FLIP-FLOP IS INITIALLY IN THE CLEAR STATE. SELECT THE WAVEFORM AT THE "1" OUTPUT IN THE FIGURE THAT WILL RESULT FROM THE INPUT PULSES SHOWN IN THE QUESTIONS. SOME CHOICES MAY BE USED ONCE, MORE THAN ONCE, OR NOT AT ALL.

3-25.



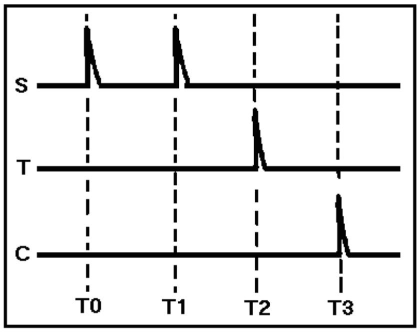
1. A
2. B
3. C
4. D

3-26.



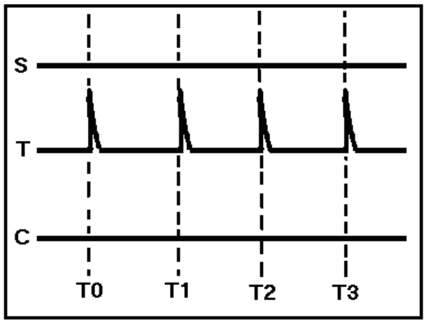
1. A
2. B
3. C
4. D

3-27.



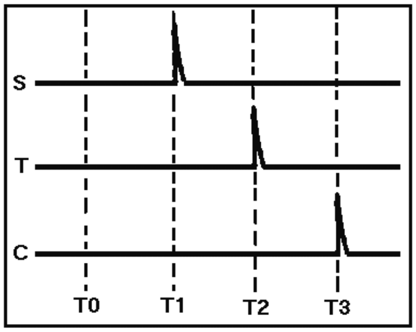
1. A
2. B
3. D
4. E

3-28.



1. B
2. C
3. D
4. F

3-29.



1. A
2. B
3. E
4. F

3-30. The toggle input on a flip flop is used to cause which of the following circuit actions?

1. SET the flip flop
2. CLEAR the flip flop
3. Both 1 and 2 above
4. Sample the condition of the flip flop

3-31. The blocking oscillator is NOT suitable for which of the following circuit applications?

1. Counter circuit
2. Frequency divider
3. Switching circuit
4. Sine-wave generator

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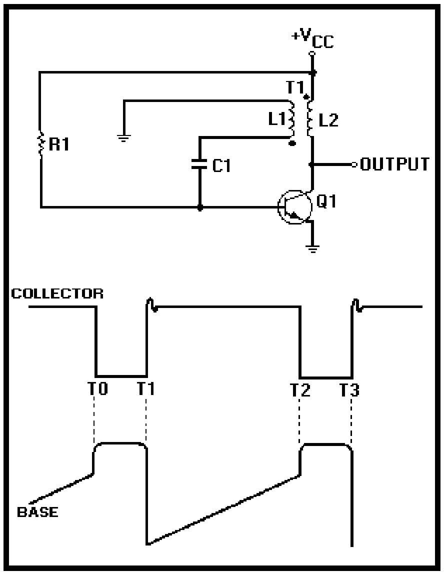

Figure 3E.—Blocking oscillator.

IN ANSWERING QUESTIONS 3-32 THROUGH 3-37, REFER TO FIGURE 3E.

3-32. What is indicated by the dots at each end of T1 in the figure?

1. 0-degree phase shift
2. 90-degree phase shift
3. 160-degree phase shift
4. 180-degree phase shift

3-33. Regenerative feedback to the base of Q1 is provided by what circuit component(s)?

1. L1 only
2. L2 only
3. L1 and L2 only
4. L1, L2, and C1

3-34. What circuit action is taking place from T0 to T1?

1. C1 is charging
2. C1 is discharging
3. L1 is discharging
4. I_C is decreasing

3-35. THIS QUESTION HAS BEEN DELETED.

3-36. During what total time period is Q1 blocked?

1. T0 to T1
2. T1 to T2
3. T0 to T2
4. T2 to T3

3-37. In the blocking oscillator, which of the following circuit actions is the primary cause of parasitic oscillations?

1. Collapse of the magnetic field of L1
2. Expansion of the magnetic field of L1
3. Inductive coupling between L1 and L2
4. C1 discharging through Q1

3-38. Which of the following circuit actions is a result of critical damping?

1. Rapid transient response without overshoot
2. Rapid transient response with overshoot
3. Slow transient response without overshoot
4. Slow transient response with overshoot

3-39. What type of damping is caused by (a) high resistance and (b) low resistance?

1. (a) Overdamping
   (b) Underdamping
2. (a) Underdamping
   (b) Overdamping
3. (a) Critical damping
   (b) Underdamping
4. (a) Overdamping
   (b) Critical damping

3-40. Applying synchronizing triggers with a frequency that is SLIGHTLY higher than the free-running frequency will cause a synchronized blocking oscillator to

1. divide in frequency
2. double in frequency
3. lock in at the higher frequency
4. stay locked at the free-running frequency

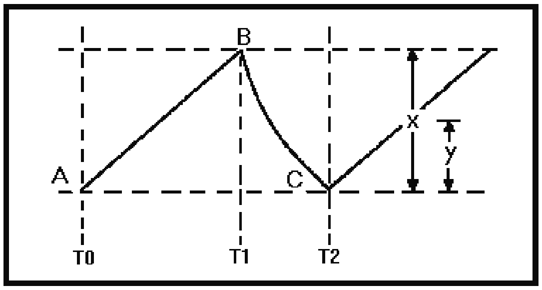

Figure 3F.—Sawtooth waveform.

IN ANSWERING QUESTIONS 3-41 THROUGH 3-46, REFER TO FIGURE 3F AND MATCH THE WAVEFORM POINTS (OR TIME REFERENCES) TO THE TERMS IN THE QUESTIONS. SOME CHOICES MAY BE USED ONCE, MORE THAN ONCE, OR NOT AT ALL.

3-41. Linear slope.

1. A to B
2. B to C
3. T0 to T2
4. T1 to T2

3-42. Physical length.

1. A to B
2. B to C
3. X
4. Y

3-43. Sweep time.

1. A to B
2. B to C
3. T0 to T1
4. T1 to T2

3-44. Fall time.

1. A to C
2. T0 to T1
3. T1 to T2
4. T0 to T2

3-45. Electrical length.

1. B to C
2. T0 to T1
3. T1 to T2
4. T0 to T2

3-46. Amplitude.

1. A to B
2. B to C
3. X
4. Y

3-47. The linearity of the rise voltage in a sawtooth wave is determined by which of the following circuit timing actions?

1. The time the capacitor is allowed to charge
2. The time it takes the capacitor to fully charge
3. The time the capacitor is allowed to discharge
4. The time it takes the capacitor to fully discharge

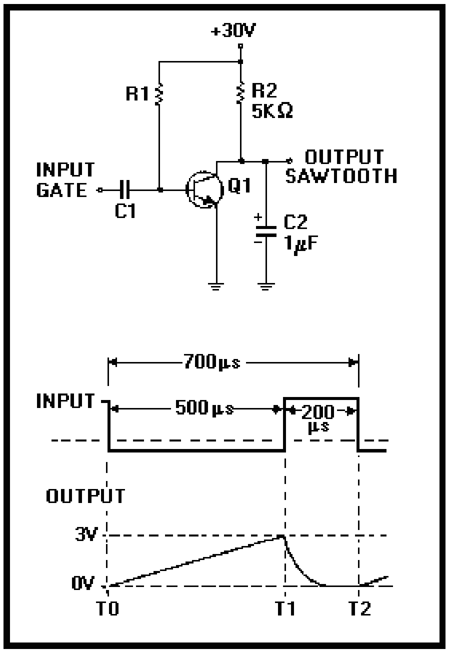

Figure 3G.—Transistor sawtooth generator.

IN ANSWERING QUESTIONS 3-48 THROUGH 3-53, REFER TO FIGURE 3G.

3-48. What component in the circuit develops the output sawtooth waveform?

1. R1
2. R2
3. C1
4. C2

3-49. What is the purpose of Q1?

1. Acts as a switch
2. Allows C2 to charge
3. Inverts the negative gate
4. Serves as a common-collector amplifier

3-50. What is the maximum length of time C2 is allowed to charge?

1. 200 microseconds
2. 500 microseconds
3. 700 microseconds
4. 900 microseconds

3-51. If V_{CC} were increased to 40 volts, which of the following parameters in the output sawtooth wave would increase?

1. Fall time
2. Amplitude
3. Sweep time
4. Linearity

3-52. What would be the effect on C2 if the negative gate length were increased?

1. Charge to V_{CC}
2. Discharge to V_{CC}
3. Charge to a larger percentage of V_{CC}
4. Charge to a smaller percentage of V_{CC}

3-53. What is the prf of the circuit?

1. 1,428 pulses per second
2. 1,450 pulses per second
3. 1,470 pulses per second
4. 1,482 pulses per second

3-54. In a sawtooth generator, a change in which of the following parameters will NOT affect the linearity of the output?

1. V_{CC}
2. Resistance
3. Capacitance
4. Gate length

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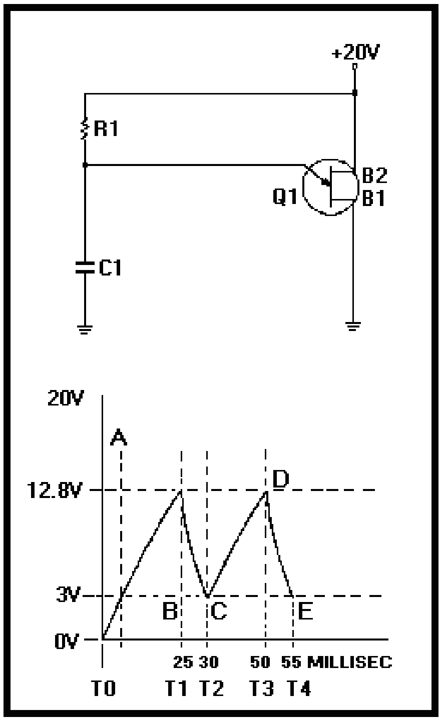

Figure 3H.—Unijunction sawtooth generator.

IN ANSWERING QUESTIONS 3-55 THROUGH 3-59, REFER TO FIGURE 3H.

3-55. The output in the circuit is taken across what component.

1. R1
2. B2
3. R1
4. C1

3-56. What is the discharge path for C1?

1. C1, R1, V_{CC}, ground, and C1
2. C1, emitter B2, V_{CC}, ground, and C1
3. C1, B1, emitter, and C1
4. C1, B1, B2, V_{CC}, ground, and C1

3-57. What part of the waveform is sweep time?

1. A to D
2. B to C
3. C to D
4. C to E

3-58. What is the action of C1 when the emitter-to-B1 junction is (a) reverse biased and (b) forward biased?

1. (a) Charging (b) Discharging
2. (a) Discharging (b) Charging
3. (a) Charging (b) Charging
4. (a) Discharging (b) Discharging

3-59. To obtain a more stable output frequency, you could modify the circuit by applying (a) what type of triggers to (b) what circuit element.

1. (a) Positive (b) B1
2. (a) Positive (b) B2
3. (a) Negative (b) B2
4. (a) Negative (b) B1

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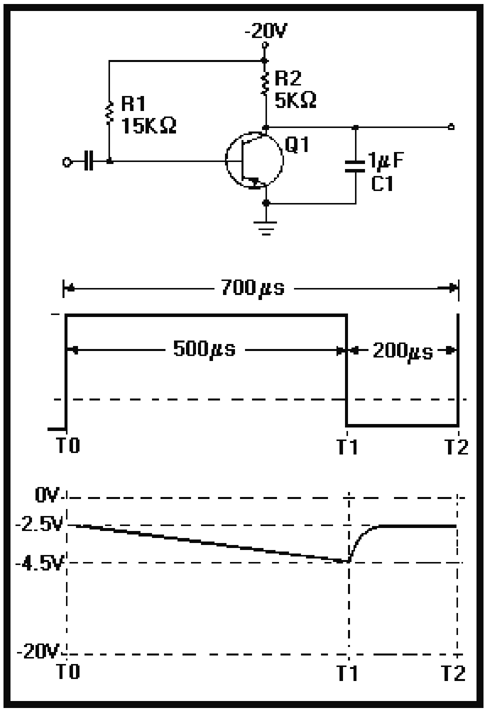

Figure 3I.—Transistor sawtooth generator.

IN ANSWERING QUESTIONS 3-60 THROUGH 3-64, REFER TO FIGURE 3I.

3-60. With no input voltage applied to the circuit, what voltage should you read at the collector?

1. -20 volts
2. -17.5 volts
3. -2.5 volts
4. 0 volts

3-61. To what voltage is C1 allowed to charge?

1. 0 volts
2. -2.5 volts
3. -4.5 volts
4. -20 volts

3-62. To determine the percent of charge on C1, what formula is used?

1. $\dfrac{E_C \max - V_{CC}}{E_C \min - E_C \max} \times 100$
2. $\dfrac{E_C \max - V_{CC}}{E_C \min + E_C \max} \times 100$
3. $\dfrac{E_C \max + E_C \min}{V_{CC} - E_C \min} \times 100$
4. $\dfrac{E_C \max - E_C \min}{V_{CC} - E_C \min} \times 100$

3-63. Which of the following actions will improve the linearity of the sawtooth?

1. Increasing the value of C1
2. Increasing the value of R1
3. Increasing the gate length
4. Each of the above

3-64. What is the maximum amplitude of the output sawtooth signal?

1. 1.75 volts
2. 2.0 volts
3. 2.5 volts
4. 4.5 volts

3-65. If applied to a coil, what voltage waveform will cause a linear rise in current?

1. Square wave
2. Sawtooth wave
3. Rectangular wave
4. Trapezoidal wave

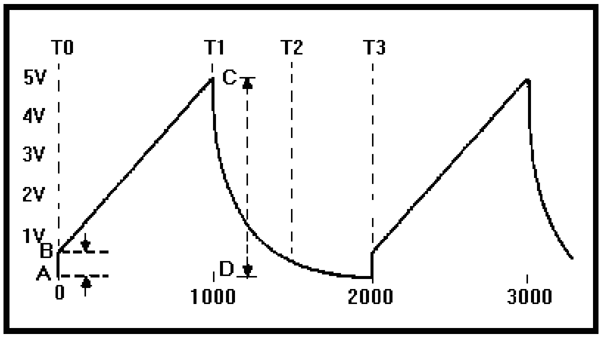

Figure 3J.—Trapezoidal waveform.

IN ANSWERING QUESTIONS 3-66 THROUGH 3-70, REFER TO FIGURE 3J AND MATCH THE WAVEFORM POINTS (OR TIME REFERENCES) TO THE TERMS IN THE QUESTIONS. SOME CHOICES MAY BE USED ONCE, MORE THAN ONCE, OR NOT AT ALL.

3-66. Pulse-repetition time (prt).

1. T1 to T2
2. T0 to T3
3. A to B
4. B to C

3-67. Physical length.

1. T0 to T3
2. A to B
3. B to C
4. C to D

3-68. Electrical length.

1. T0 to T1
2. T1 to T2
3. T0 to T3
4. A to B

3-69. Jump voltage.

1. T0 to T1
2. T1 to T2
3. T0 to T3
4. A to B

3-70. Linear slope.

1. C to D
2. B to C
3. A to B
4. T0 to T3

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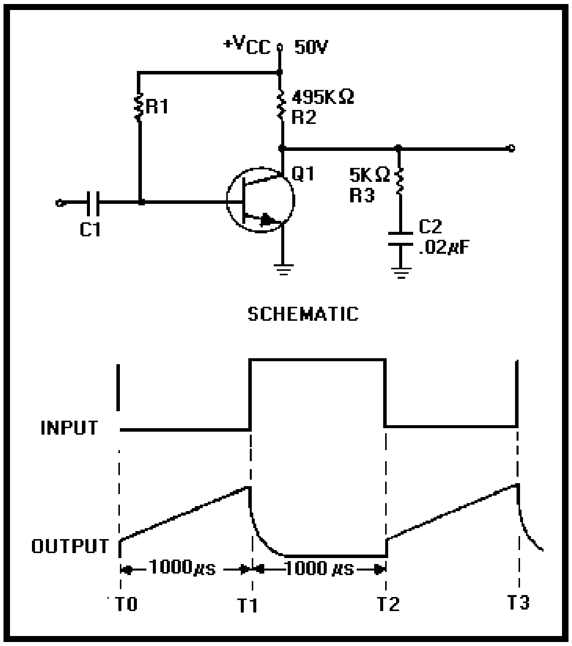


Figure 3K.—Trapezoidal-wave generator with input and output waveforms.

IN ANSWERING QUESTIONS 3-71 THROUGH 3-74, REFER TO FIGURE 3K.

3-71. The amplitude of the jump voltage is approximately

(a)
0.5V, 5V

and the amplitude of the trapezoidal wave is

(b)
0.5V, 5V.

1. (a) 0.5 volts (b) 5 volts
2. (a) 0.5 volts (b) 0.5 volts
3. (a) 5 volts (b) 0.5 volts
4. (a) 5 volts (b) 5 volts

3-72. Which of the following components and/or value(s) determines the amplitude of the jump voltage?

1. V_{CC} only
2. R2 and V_{CC} only
3. R3 and V_{CC} only
4. R2, R3, and V_{CC}

3-73. What is the minimum discharge time for C2?

1. 50 microseconds
2. 500 microseconds
3. 1,000 microseconds
4. 2,000 microseconds

3-74. Increasing which of the following values will NOT affect linearity of the circuit?

1. Resistance of R2
2. Capacitance of C2
3. Gate width
4. V_{CC}

ASSIGNMENT 4

Textbook assignment: Chapter 4, “Wave Shaping,” pages 4-1 through 4-61.

4-1. A wave-shaping circuit which restricts some portion of a waveform from exceeding a specified value is known as a/an

1. divider
2. clamper
3. limiter
4. oscillator

4-2. Limiting circuits are used in which of the following circuit applications?

1. Counting
2. Amplification
3. Wave generation
4. Circuit protection

4-3. In a series limiter, the diode is connected in

(a)
parallel, series

With the

(b)
input, output

1. (a) Parallel (b) output
2. (a) Parallel (b) input
3. (a) Series (b) input
4. (a) Series (b) output

4-4. In a series limiter, a voltage is developed across the output resistor when

1. the anode of the diode is negative with respect to the cathode
2. the anode of the diode is positive with respect to the cathode
3. the cathode of the diode is positive with respect to the anode
4. no current flows through the diode

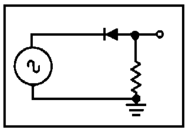
4-5. The diode in a series-positive limiter is (a) forward biased by what portion of the input signal and (b) reverse biased by what portion of the input signal?

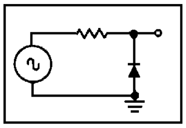
1. (a) Positive (b) positive
2. (a) Positive (b) negative
3. (a) Negative (b) negative
4. (a) Negative (b) positive

4-6. How does the value of diode resistance compare to that of the resistor (a) during the limiting portion of the input and (b) during the nonlimiting portion?

1. (a) High (b) high
2. (a) High (b) low
3. (a) Low (b) low
4. (a) Low (b) high

4-7. Which of the following circuits is a series-positive limiter?

1.


3.


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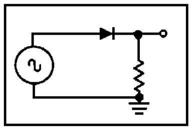
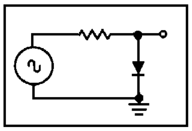
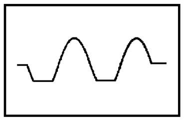
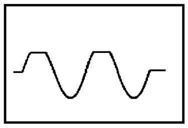
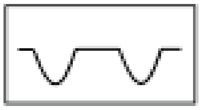


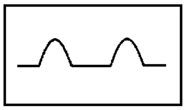
4.


4-8. If a sine wave is applied to the input of a series-positive limiter, which of the following waveforms describes the output?

1.


2.


3.


4.


4-9. The amplitude of the output of a series-diode limiter is figured using which of the following formulas?

1. $$E_{out} = \frac{R + R_{ac}}{R} \times E_{in}$$

2. $$E_{out} = \frac{R}{R + R_{ac}} \times E_{in}$$

3. $$E_{out} = \frac{R_{ac}}{R_{ac} + R} \times E_{in}$$

4. $$E_{out} = \frac{R_{ac} + R}{R_{ac}} \times E_{in}$$

IN ANSWERING QUESTIONS 4-10 AND 4-11, ASSUME YOU ARE FIGURING OUTPUT AMPLITUDES FOR SERIES-POSITIVE LIMITERS AND CIRCUIT CONDITIONS ARE AS FOLLOWS:

E_{in} = 30 vac
R1 = 20,000Ω
R_{ac} = 100 Ω (forward bias)
R_{ac} = 150,000Ω (reverse bias)

4-10. With forward bias, what is the output amplitude?

1. 28.95 volts
2. 29 volts
3. 29.85 volts
4. 29.95 volts

4-11. With reverse bias, what is the output amplitude?

1. .175 volt
2. 1.75 volts
3. 3.53 volts
4. 3.75 volts

4-12. In a series-positive limiter, where is the input signal applied?

1. Directly to the anode of the diode
2. Directly to the cathode of the diode
3. To the anode of the diode through a series input resistor
4. To the cathode of the diode through the output resistor

4-13. With a sine wave applied, which of the following circuits limits only a portion of the positive input signal?

1. Series-negative limiter with negative bias
2. Series-negative limiter with positive bias
3. Series-positive limiter with negative bias
4. Series-positive limiter with positive bias

4-14. With a sine-wave input, which of the following types of series limiter allows only a portion of the negative input to be developed in the output?

1. Series-positive limiter without bias
2. Series-positive limiter with negative bias
3. Series-positive limiter with positive bias
4. Series-negative limiter without bias

4-15. In a series-negative limiter, how is the diode biased (a) by the positive half of the input sine wave and (b) by the negative half?

1. (a) Reverse (b) forward
2. (a) Reverse (b) reverse
3. (a) Forward (b) reverse
4. (a) Forward (b) forward

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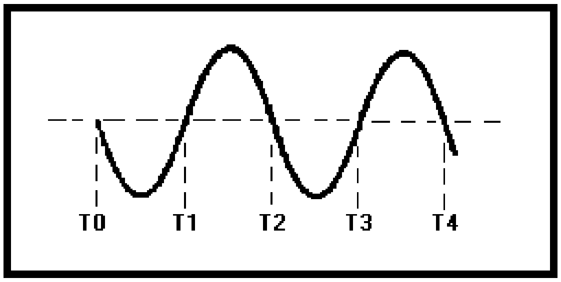
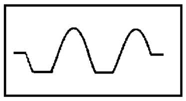
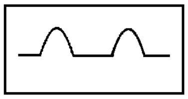


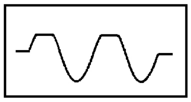
Figure 4A.—Sine-wave input.

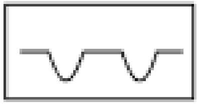
IN ANSWERING QUESTION 4-16, REFER TO FIGURE 4A.

4-16. If the input waveform shown in the figure is applied to a series-negative limiter, which of the following waveforms will be the output?

1. 

3. 

2. 

4. 

4-17. In a series-negative limiter with positive bias, which of the following output circuit actions takes place?

1. Both positive half cycles are eliminated
2. Both negative half cycles are eliminated
3. All of the positive half cycles and a portion of the negative half cycles are eliminated
4. All of the negative half cycles and a portion of the positive half cycles are eliminated

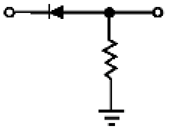
IN QUESTIONS 4-18 THROUGH 4-22, MATCH THE LIMITER CIRCUIT IN COLUMN A TO THE CIRCUIT DESCRIPTION IN COLUMN B. CHOICES MAY BE USED ONCE, MORE THAN ONCE, OR NOT AT ALL.

A. LIMITER CIRCUIT

B. CIRCUIT DESCRIPTION

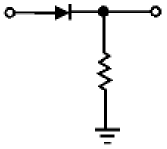
A. Series-positive limiter with no bias
B. Series-negative limiter with no bias
C. Series-positive limiter with negative bias
D. Series-positive limiter with positive bias
E. Series-negative limiter with negative bias
F. Series-negative limiter with positive bias

4-18.



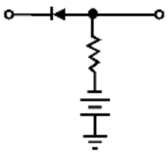
1. A
2. B
3. C
4. D

4-19.



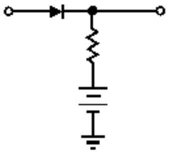
1. A
2. B
3. E
4. F

4-20.



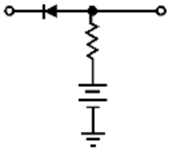
1. C
2. D
3. E
4. F

4-21.



1. C
2. D
3. E
4. F

4-22.



1. C
2. D
3. E
4. F

4-23. In a parallel-diode limiter, (a) how is the output taken and (b) under what diode condition is it developed?

1. (a) Across the resistor
   (b) When the diode is cut off
2. (a) Across the resistor
   (b) When the diode is conducting
3. (a) Across the diode
   (b) When the diode is conducting
4. (a) Across the diode
   (b) When the diode is cut off

4-24. In a parallel-positive limiter, where is the input sine wave applied?

1. At the anode of the diode
2. At the cathode of the diode
3. Through a series resistor to the anode of the diode
4. Through a series resistor to the cathode of the diode

4-25. Which of the following formulas is used to figure the output amplitude of a parallel-diode limiter?

1. $$E_{out} = \frac{R_{ac} + R}{R_{ac}} \times E_{in}$$

2. $$E_{out} = \frac{R}{R_{ac} + R} \times E_{in}$$

3. $$E_{out} = \frac{R_{ac}}{R_{ac} + R} \times E_{in}$$

4. $$E_{out} = \frac{R_{ac} + R}{R_{ac} - R} \times E_{in}$$

4-26. THIS QUESTION HAS BEEN DELETED.

4-27. THIS QUESTION HAS BEEN DELETED.

4-28. In a parallel-negative limiter, how is the diode biased (a) by the positive half of the input sine wave and (b) by the negative half?

1.	(a) Forward	(b) forward
2.	(a) Forward	(b) reverse
3.	(a) Reverse	(b) reverse
4.	(a) Reverse	(b) forward

4-29. If a sine wave is applied to a parallel-negative limiter with positive bias, what is the polarity of the output voltage?

1. Positive at all times
2. Negative at all times
3. Positive during the positive portion of the input cycle and negative during the negative portion
4. Negative during the positive portion of the input cycle and positive during the negative portion

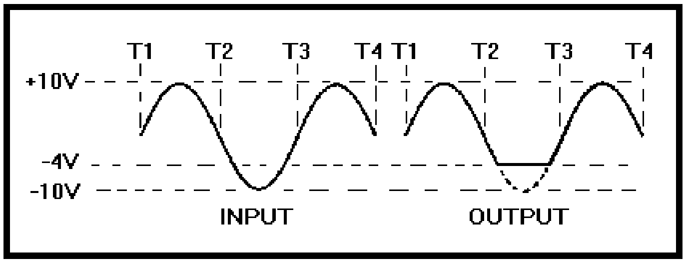


Figure 4B.—Parallel-limiter input and output waveforms.

IN ANSWERING QUESTION 4-30, REFER TO FIGURE 4B.

4-30. If the diode in the parallel limiter were reversed, what portions of the input waveform would be limited?

1. Positive peaks only
2. Negative peaks only
3. All hut the positive peaks would be limited
4. All but the negative peaks would be limited

4-31. Which of the following circuits would be used to fix the upper or lower extremity of a waveform at a specific value?

1. Clamper
2. Limiter
3. Counter
4. Amplifier

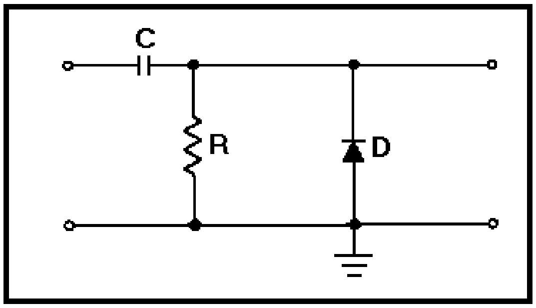


Figure 4C.—Positive clamper.

IN ANSWERING QUESTIONS 4-32 AND 4-33, REFER TO FIGURE 4C.

4-32. When a negative input signal is present, what components provide(s) the charge path for the capacitor?

1. Diode only
2. Resistor only
3. Both the resistor and diode

4-33. How does the length of time required for the capacitor to charge compare to the time for it to discharge?

1. Charge time is longer than discharge time
2. Charge time is shorter than discharge time
3. Charge and discharge times are the same

4-34. In a positive clamper with positive bias, (a) what extremity of the waveform is clamped and (b) to what potential is it clamped?

1. (a) Upper (b) positive
2. (a) Upper (b) negative
3. (a) Lower (b) positive
4. (a) Lower (b) negative

4-35. In a positive clamper with negative bias, (a) what extremity of the waveform is clamped and (b) to what potential is it clamped?

1. (a) Upper (b) positive
2. (a) Upper (b) negative
3. (a) Lower (b) negative
4. (a) Lower (b) positive

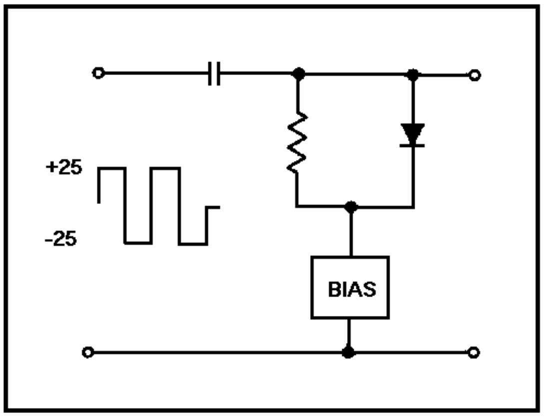


Figure 4D.—Clamper with bias.

IN ANSWERING QUESTIONS 4-36 AND 4-37, REFER TO FIGURE 4D.

4-36. With +10 volts of bias in the circuit, what is the maximum negative output voltage?

1. -15 volts
2. -25 volts
3. -40 volts
4. -50 volts

4-37. With -15 volts of bias, to what voltage level is the output clamped?

1. +75 volts
2. +45 volts
3. -15 volts
4. -75 volts

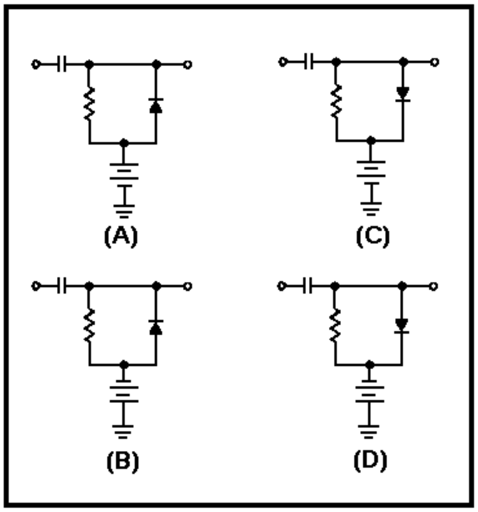


Figure 4E.—Clamper circuits.

IN ANSWERING QUESTIONS 4-38 THROUGH 4-40, SELECT THE CIRCUIT IN FIGURE 4E THAT MATCHES THE CIRCUIT NAMED IN THE QUESTIONS. CHOICES MAY BE USED ONCE, MORE THAN ONCE, OR NOT AT ALL.

4-38. Positive clamper with negative bias.

1. A
2. B
3. C
4. D

4-39. Negative clamper with negative bias.

1. A
2. B
3. C
4. D

4-40. Positive clamper with positive bias.

1. A
2. B
3. C
4. D

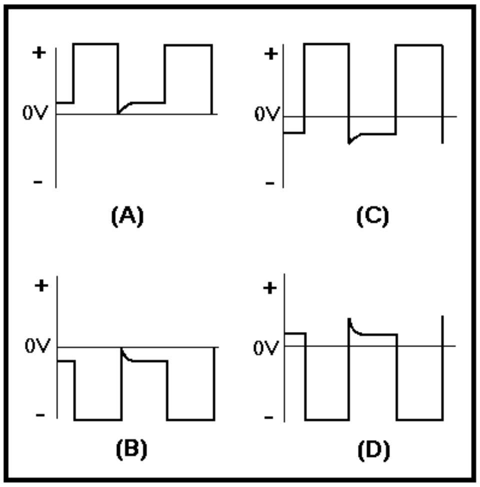


Figure 4F—Clamper circuit outputs.

IN ANSWERING QUESTIONS 4-41 THROUGH 4-43, SELECT THE OUTPUT IN FIGURE 4F WHICH IS PRODUCED BY THE CIRCUITS IN THE QUESTIONS. CHOICES MAY BE USED ONCE, MORE THAN ONCE, OR NOT AT ALL.

4-41. Positive clamper with positive bias.

1. A
2. B
3. C
4. D

4-42. Negative clamper with positive bias.

1. A
2. B
3. C
4. D

4-43. Negative clamper with negative bias.

1. A
2. B
3. C
4. D

4-44. Which of the following waves is NOT a complex wave?

1. Sine wave
2. Square wave
3. Rectangular wave
4. Trapezoidal wave

4-45. What is the harmonic content of a square wave?

1. A combination of odd harmonics only
2. A combination of even harmonics only
3. Both even and odd harmonic combinations

4-46. What is the harmonic composition within a sawtooth wave?

1. Odd harmonics only
2. Even harmonics only
3. Both even and odd harmonics

4-47. With a square wave applied to a resistive network, the circuit values of what components will NOT affect either the phases or amplitudes of the harmonics within the square wave?

1. Inductors
2. Resistors
3. Capacitors
4. Transformers

4-48. The time constant for full integration in an RC circuit should be what minimum number of times greater than the input-pulse duration?

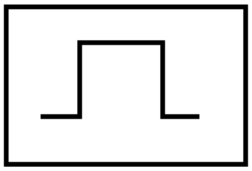
1. 1
2. 5
3. 10
4. 20

4-49. Integration in a circuit takes place when the output is taken (a) across the capacitor in what type of circuit and (b) across the resistor in what type of circuit?

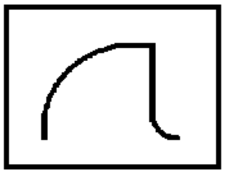
1. (a) Resistive only
   (b) Resistive only
2. (a) Resistive only
   (b) Resistive-inductive
3. (a) Resistive only
   (b) Resistive-capacitive
4. (a) Resistive-capacitive
   (b) Resistive-inductive

4-50. In an RC integrator, which of the following waveforms has the longest time constant?

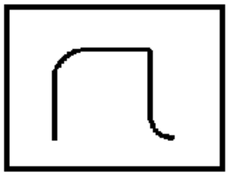
1.



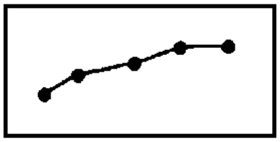
2.



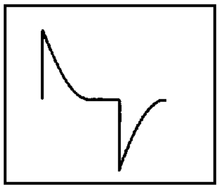
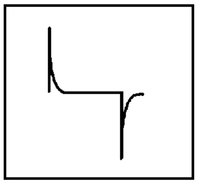
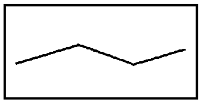
3.



4.



4-51. In an RC differentiator, which of the following waveforms has the shortest time constant?

1. 
2. 
3. 
4. 

4-52. In a short time-constant integrator circuit, the maximum amplitude of the input pulse is 100 volts and the time constant of the circuit is 1/10 the duration of the input pulse. At the end of three time constants, what is the maximum voltage across the capacitor?

1. 36.8 volts
2. 63.2 volts
3. 86.5 volts
4. 95 volts

4-53. In a medium time-constant circuit, the maximum amplitude of the input pulse is 100 volts and the pulse length is one time constant. At the end of two time constants, what is the maximum voltage across the capacitor?

1. 23.3 volts
2. 48.4 volts
3. 71.7 volts
4. 100 volts

4-54. In a short time-constant differentiator circuit, the maximum amplitude of the input pulse is 100 volts and the time constant of the circuit is 1/10 that of the input pulse. At the end of four time constants, what is the maximum voltage across the resistor?

1. 5 volts
2. 2 volts
3. 23.3 volts
4. 48.4 volts

4-55. In an RC differentiator circuit, the time constant for the circuit and the input pulse are equal. At the end of one time constant, to what maximum percentage of the applied voltage is the capacitor charged?

1. 5 percent
2. 13.5 percent
3. 36.8 percent
4. 63.2 percent

4-56. In an RC network that is used as a coupling circuit, (a) across what component is the output normally taken and (b) what is the relative length of the time constant?

1. (a) Capacitor (b) short
2. (a) Capacitor (b) long
3. (a) Resistor (b) long
4. (a) Resistor (b) short

4-57. In a positive-diode counter that provides accurate counting, what is the only variable allowed in the input signal?

1. Pulse width
2. Pulse duration
3. Pulse amplitude
4. Pulse-repetition frequency

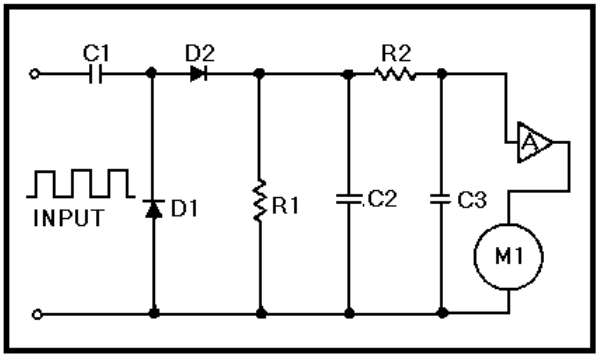


Figure 4G.—Basic frequency counter.

IN ANSWERING QUESTIONS 4-58 THROUGH 4-60, REFER TO FIGURE 4G.

4-58. An input signal to the counter will cause (a) what capacitor to charge through R1 and D2 and (b) what capacitor to discharge through D1?

1. (a) C1 (b) C1
2. (a) C1 (b) C2
3. (a) C2 (b) C1
4. (a) C2 (b) C2

4-59. What components produce the smooth dc output-voltage level?

1. C1, D1, and R1
2. C1, D2, and R1
3. C1, C2, and R1
4. C2, C3, and R2

4-60. When the input frequency is increased, what is the effect on (a) the input interval, (b) the number of pulses per given time and (c) the dc output voltage?

1. (a) Longer (b) less (c) higher
2. (a) Longer (b) more (c) lower
3. (a) Shorter (b) less (c) higher
4. (a) Shorter (b) more (c) higher

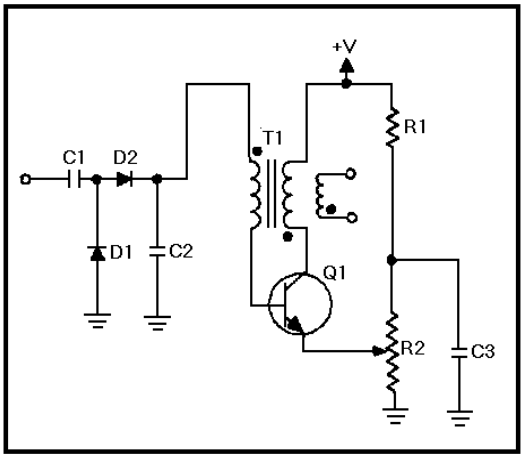


Figure 4H.—Step-counter frequency divider.

IN ANSWERING QUESTIONS 4-61 AND 4-62, REFER TO FIGURE 4H.

4-61. An output pulse will occur when the charge on C2

1. builds a magnetic field in the base winding
2. drops below the cutoff-bias level of Q1
3. exceeds the bias level of Q1
4. reaches the source potential of the voltage applied

4-62. What component develops the bias for Q1?

1. R1
2. R2
3. C2
4. T1