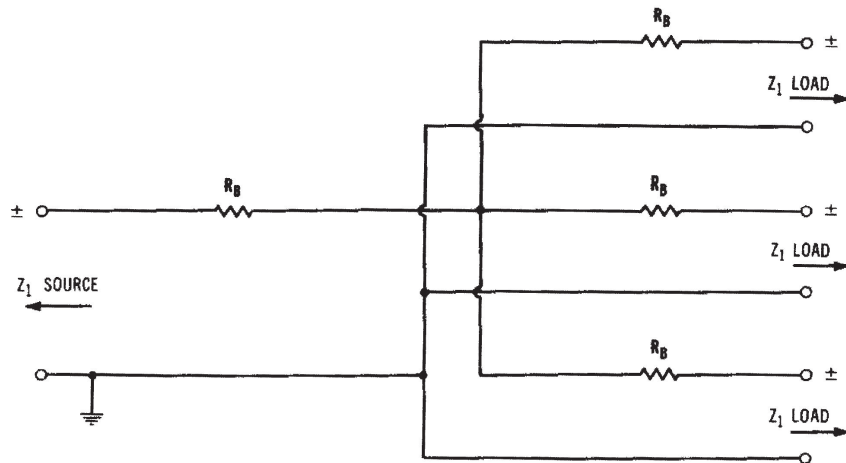
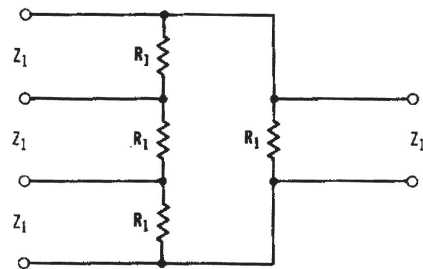




(A) Combining or dividing network for matching a single circuit to three others.



(B) Series combining network for combining one circuit to three others.

Figure 16-10 Two configurations for designing combining or branching networks.

If a T pad is to work between equal impedances, the resistor values will be

$$R_1 = R_2 \quad (16-26)$$

$$= [(K - 1)/(K + 1)]Z$$

$$R_3 = [K/(K^2 - 1)]2Z \quad (16-27)$$

where,

Z is the input and output impedance,

R_1 and R_2 are the series resistors,

R_3 is the shunt arm or resistor.

A T-type attenuator may be designed for any value of loss if designed to operate between equal impedances. The numerical value of the foregoing expressions may be obtained from Table 16-1.

The resistors for a T pad of unequal impedances are calculated with the following equations:

$$R_1 = Z_1 \left(\frac{K^2 + 1}{K^2 - 1} \right) - 2\sqrt{Z_1 Z_2} \left(\frac{K}{K^2 - 1} \right) \quad (16-28)$$

$$R_2 = Z_2 \left(\frac{K^2 + 1}{K^2 - 1} \right) - 2\sqrt{Z_1 Z_2} \left(\frac{K}{K^2 - 1} \right) \quad (16-29)$$

$$R_3 = 2\sqrt{Z_1 Z_2} \left(\frac{K}{K^2 - 1} \right) \quad (16-30)$$

where,

Z_1 is the larger of the two impedances.

The numerical values for these expressions may be taken from Table 16-1. Thus, for a network to match 600 Ω to a circuit of 250 Ω with a loss of 20 dB, the resistor values are

$$\begin{aligned} R_1 &= 600(1.0202) - 2(\sqrt{150,000})(0.10101) \\ &= 612.1 - 2(387.3)(0.10101) \\ &= 533.88 \Omega \end{aligned}$$

$$\begin{aligned} R_2 &= 250(1.0202) - 2(\sqrt{150,000})(0.10101) \\ &= 255.05 - 2(387.3)(0.10101) \\ &= 176.81 \Omega \end{aligned}$$

$$\begin{aligned} R_3 &= 2(\sqrt{150,000})(0.10101) \\ &= 2(387.3)(0.10101) \\ &= 78.7 \Omega \end{aligned}$$

A balanced-T pad is called an H pad. The pad is first calculated as an unbalanced-T configuration. The series resistance elements are then divided, and half are connected in each side of the line, as shown in Fig. 16-2. The

shunt resistor remains the same value as for the unbalanced configuration. A tap is placed at the exact electrical center of the shunt resistor for connection to ground.

The average noise level for a T pad is -100 dB and constant; therefore, the signal-to-noise level varies with the amount of attenuation.

16.4 BRIDGED-T ATTENUATORS

A bridged-T pad is an attenuator network containing four resistive elements, as shown in Fig. 16-11. The resistors are equal in value to the line impedance; therefore, they require no calculation. This network is designed to work between impedances of equal value only. The contact arms for resistors R_5 and R_6 are connected mechanically by a common shaft and vary inversely in value with respect to each other.

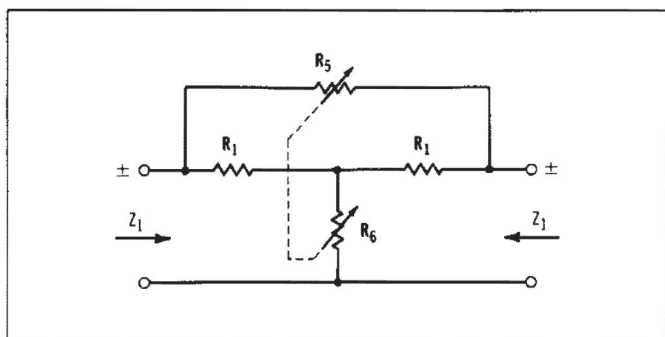


Figure 16-11 A bridged-T attenuator. For variable pads, the arms R_5 and R_6 are variable.

A balanced bridged-T attenuator is a configuration similar to the unbalanced bridged-T attenuator, except the resistor elements are divided and placed in each side of the line as shown in Fig. 16-12. The principal objection to the use of this configuration, if made variable, is that the shunt resistor R_6 must be divided into two separate arms to provide a ground connection at the exact electrical center. However, if the circuit feeding or terminating the attenuator is balanced to the ground, the ground connection at the attenuator center will not be required.

The resistor values are calculated with the following formulas:

$$R_1 = Z \quad (16-31)$$

$$R_5 = (K - 1)Z \quad (16-32)$$

$$R_6 = [1/(K - 1)]Z \quad (16-33)$$

where,

Z is the line impedance,

R_5 is the bridging resistor,

R_6 is the shunt resistor.

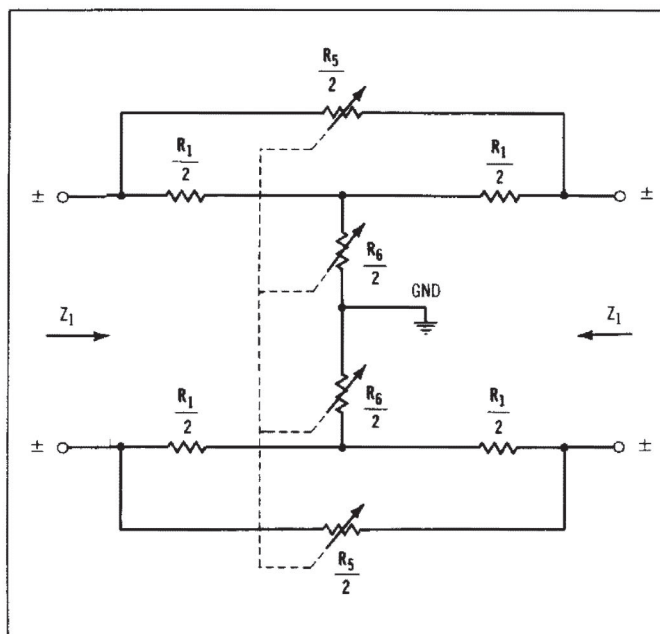


Figure 16-12 Balanced bridged-T attenuator. For a variable configuration, variable arms are required.

Again, the K factors may be taken from the tabulations of Table 16-1.

The impedance variations for a typical high-quality attenuator used in a mixer network are shown in Fig. 16-13. The greatest impedance variation occurs as the attenuator arm approaches zero attenuation and amounts to about 80Ω . This impedance variation is not too serious, since the mixer-combining network with its building-out resistors isolates this variation to a great extent from associated attenuators.

16.5 PI ATTENUATORS

A pi (or delta) attenuator is a resistive network resembling the Greek letter pi, or delta, as shown in Fig. 16-14. Such networks may be used between impedances of equal or unequal values.

For networks operating between impedances of equal value,

$$R_1 = Z[(K + 1)/(K - 1)] \quad (16-34)$$

$$R_2 = \left(\frac{Z}{2}\right) \left(\frac{K^2 - 1}{K}\right) \quad (16-35)$$

where,

R_1 is the input and output resistor,

R_2 is the series resistor,

Z is the input and output impedance.

When the impedances are unequal values, the resistors are calculated with the following equations:

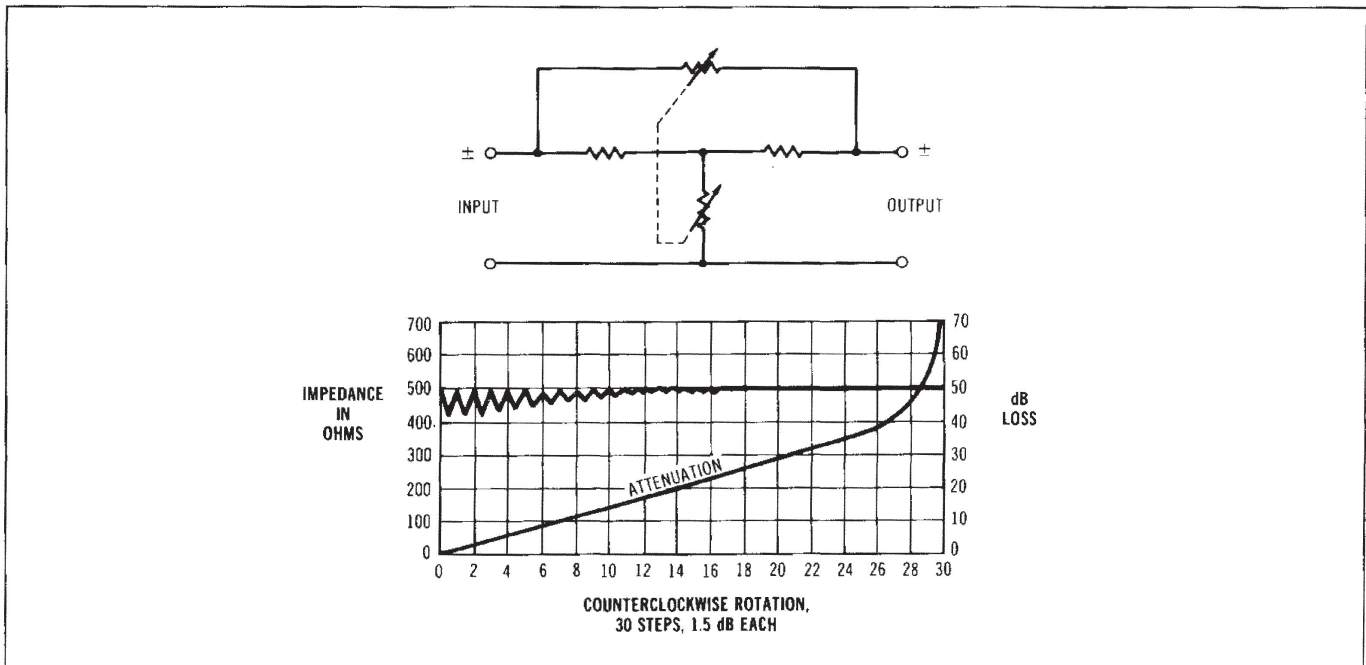


Figure 16-13 Impedance characteristics for a high-quality variable bridged-T attenuator.

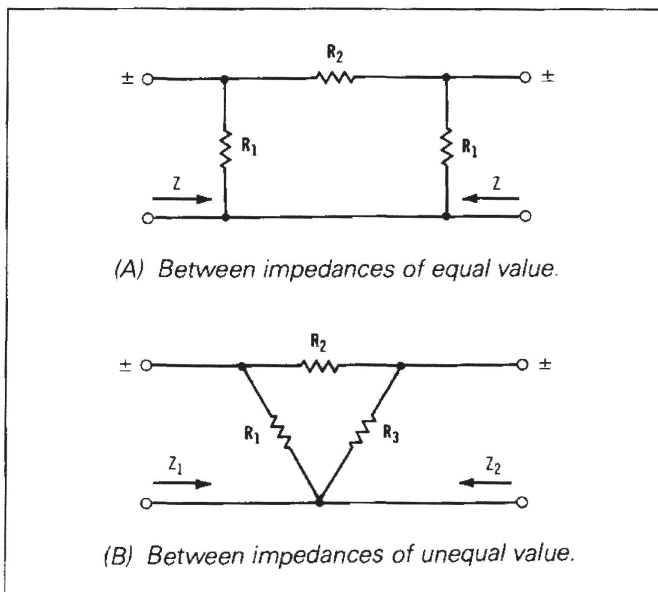


Figure 16-14 Pi-type or delta-type attenuator.

where,

R_1 and R_3 are shunt resistors,

R_2 is the series resistor,

Z_1 is the input impedance,

Z_2 is the output impedance,

S is Z_1/Z_2 .

To simplify the calculations, the values of the factors may be selected from Table 16-1.

An O attenuator is a balanced pi attenuator configuration. The circuit element values may be obtained by first calculating for a pi-type configuration, then dividing the series resistor and placing half in each side of the line as shown in Fig. 16-15. The shunt resistors remain the same value.

16.6 U ATTENUATORS

U attenuators (Fig. 16-16) may be of a symmetrical or balanced-type configuration and are useful for matching a high impedance to a low impedance. The impedance match is of first importance, the loss being secondary. For a symmetrical configuration to work between unequal impedances when the impedance match of Z_1 is important, the resistors may be calculated as follows:

$$R_1 = Z_1 \left(\frac{K^2 - 1}{K^2 - 2KS + 1} \right) \quad (16-36)$$

$$R_2 = \left(\frac{\sqrt{Z_1/Z_2}}{2} \right) \left(\frac{K^2 - 1}{K} \right) \quad (16-37)$$

$$R_3 = Z_2 \left(\frac{K^2 - 1}{K^2 - 2(K/S) + 1} \right) \quad (16-38)$$

$$R_1 = (Z_1/2S)[(KS - 1)/K] \quad (16-39)$$

$$R_2 = (Z_1/S)[1/(K - S)] \quad (16-40)$$

where,

R_1 is the series resistor,

R_2 is the shunt resistor,
 Z_1 is the larger impedance,
 Z_2 is the smaller impedance,
 S equals $\sqrt{Z_1/Z_2}$.

When the low impedance, Z_2 , is to be matched the equations are

$$R_1 = (Z_1/2S)(K - S) \quad (16-41)$$

$$R_2 = (Z_1/S)[K/(KS - 1)] \quad (16-42)$$

Any U pad may be balanced to ground by connecting a ground to the electrical center of the shunt resistor.

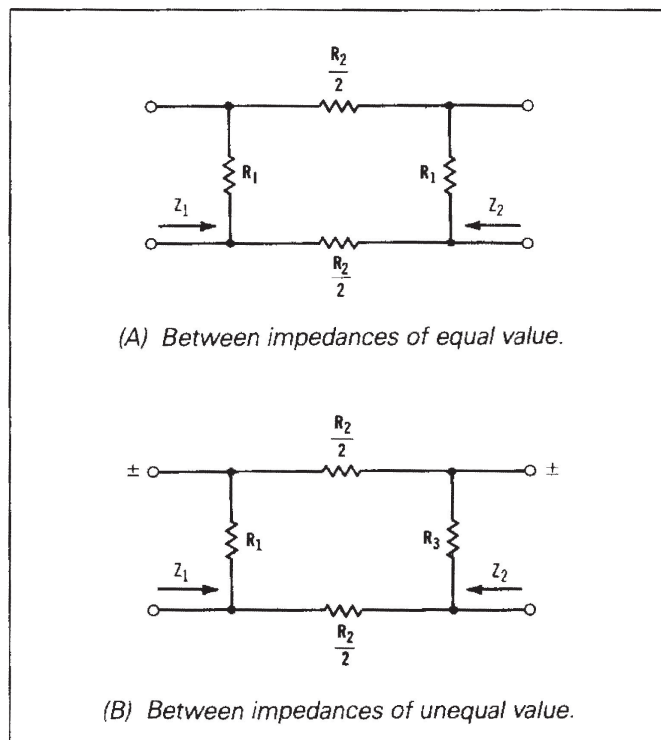


Figure 16-15 Balanced pi-type or O-type attenuator.

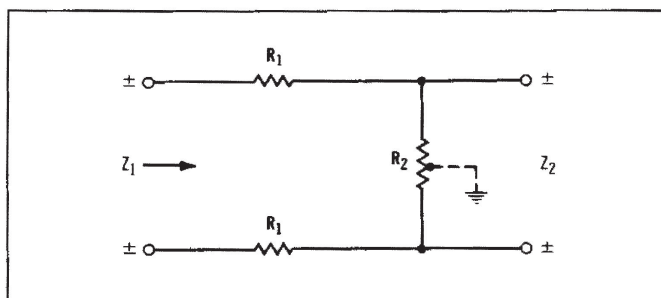


Figure 16-16 A U-pad configuration for operation between impedances of unequal value.

16.7 LADDER ATTENUATORS

Ladder-type pads are so named because they look like ladders lying on their sides as shown in Fig. 16-17. The ladder pad is actually a group of pi attenuators in tandem, R_2 being common to each section. Because of the resistor R_4 , this type attenuator has a fixed 6-dB loss, exclusive of the attenuator setting. This must be taken into account when designing a circuit using a ladder attenuator. The ladder attenuator does not have a constant input and output impedance throughout its range of attenuation; however, it does reflect a stable impedance into its source.

Ladder pots for mixer-control use may be obtained in two types of construction—slide-wire and contact types.

For motion-picture rerecording mixers, the slide-wire-type control is generally employed, because it permits a smooth, even attenuation over a wide range. The contact type, although not quite as smooth in operation as the slide-wire, has only one row of contacts, which reduce the noise and maintenance.

Ladder networks may also be designed for balanced operation. This is accomplished by connecting two unbalanced networks side by side, as shown in Fig. 16-18. However, the circuit elements are not divided in the same manner as for other types of balanced networks. If an unbalanced ladder network is compared with a balanced ladder network, resistors R_1 are divided by two, resistors R_4 are also divided by two, and, at the output, R_2 is now twice the value for the unbalanced configuration. Resistor R_3 remains at its original value on each side of ground.

The equations used to calculate the resistor values are

$$R_1 = [(K^2 - 1)/2K]Z \quad (16-43)$$

$$R_2 = [(K + 1)/(K - 1)]Z \quad (16-44)$$

$$R_3 = (R_2Z)/(R_2 + Z) \quad (16-45)$$

$$R_4 = Z/2 \quad (16-46)$$

$$Z_{in} = Z_{out}$$

where,

R_1 is the series resistance,

R_2 is the shunt resistance,

R_3 is the input shunt resistor,

R_4 is the series resistance in the contact arm circuit.

The value of K is dependent on the loss per step—not the total loss.

The noise level for a ladder attenuator is in the order of -120 dB, and as the attenuation increases, the signal-to-noise ratio increases. This type attenuator will show impedance variations at both the input and output and between steps. However, when used in a combining network with the proper building-out resistors, these

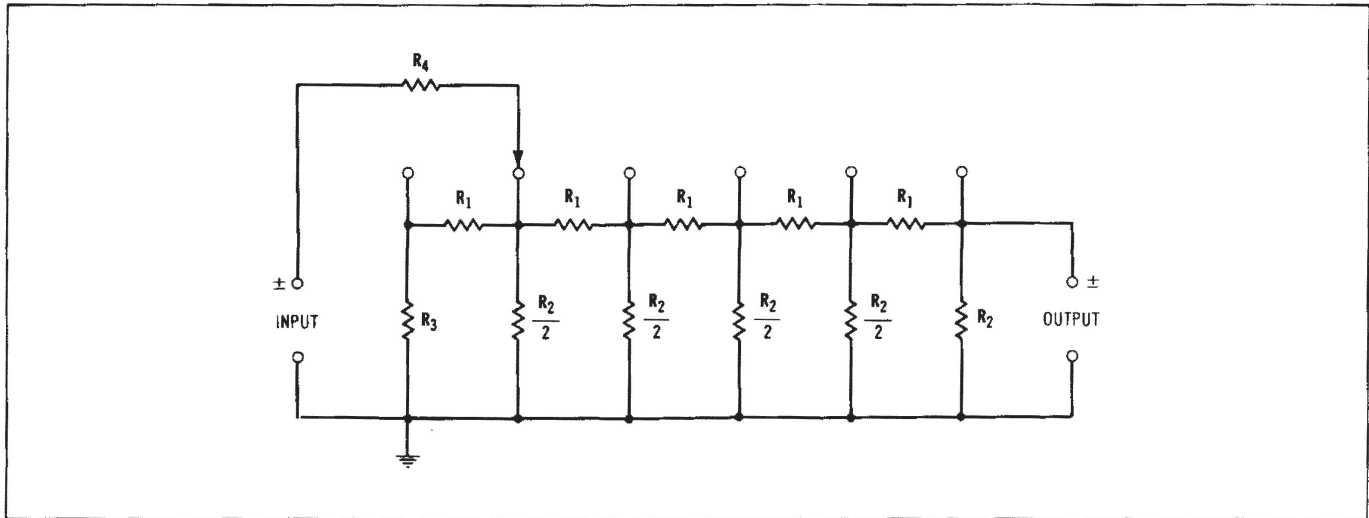


Figure 16-17 Unbalanced ladder attenuator with five fixed steps of loss.

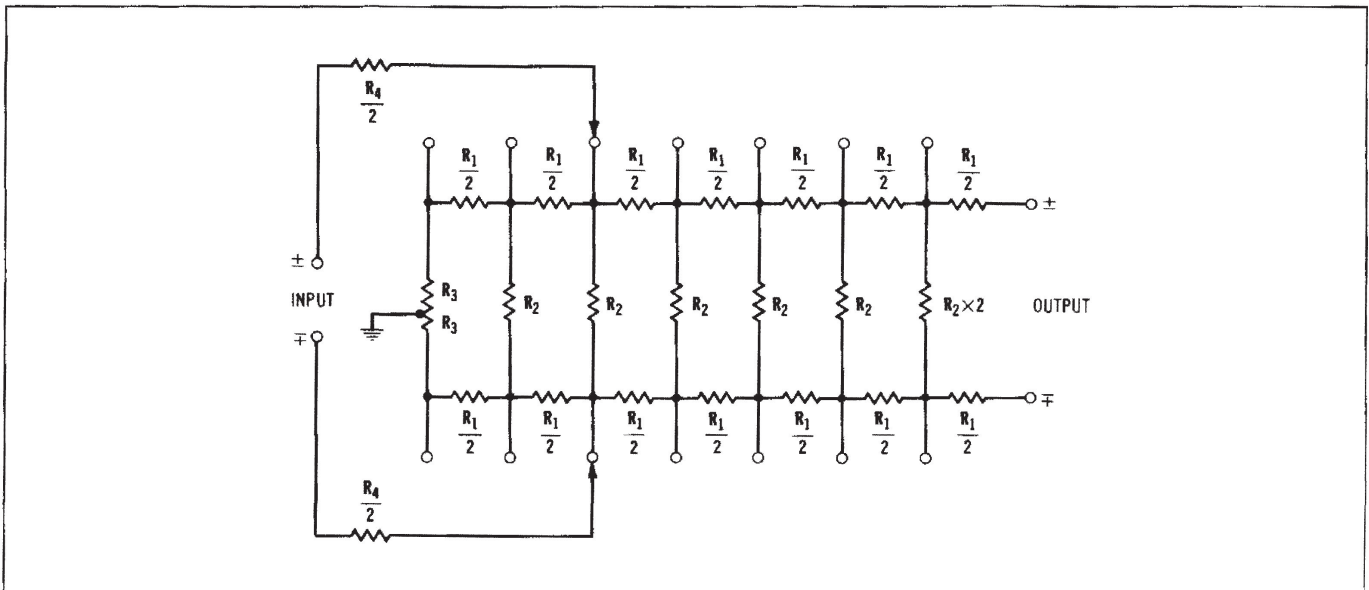


Figure 16-18 Balanced ladder attenuator.

variations are of little consequence. A typical impedance curve is shown in Fig. 16-19.

The output voltage is calculated with the following equation:

16.8 SIMPLE VOLUME AND LOUDNESS CONTROLS

A simple volume control consists of a potentiometer with the two ends connected to the source and the wiper, and one end connected to the load, as shown in Fig. 16-20. The volume control should be a high impedance with respect to the source so it will not load it, and the load impedance should be high enough so as not to affect the control.

$$V_{out} = \left(\frac{\frac{R_1 Z_2}{R_2 + Z_2}}{R_1 + \frac{R_2 Z_2}{R_2 + Z_2}} \right) \quad (16-47)$$

where,

R_1 is the upper section of control,

R_2 is the lower section of control.

If the load impedance is high compared to R_2 , the equation is simplified to

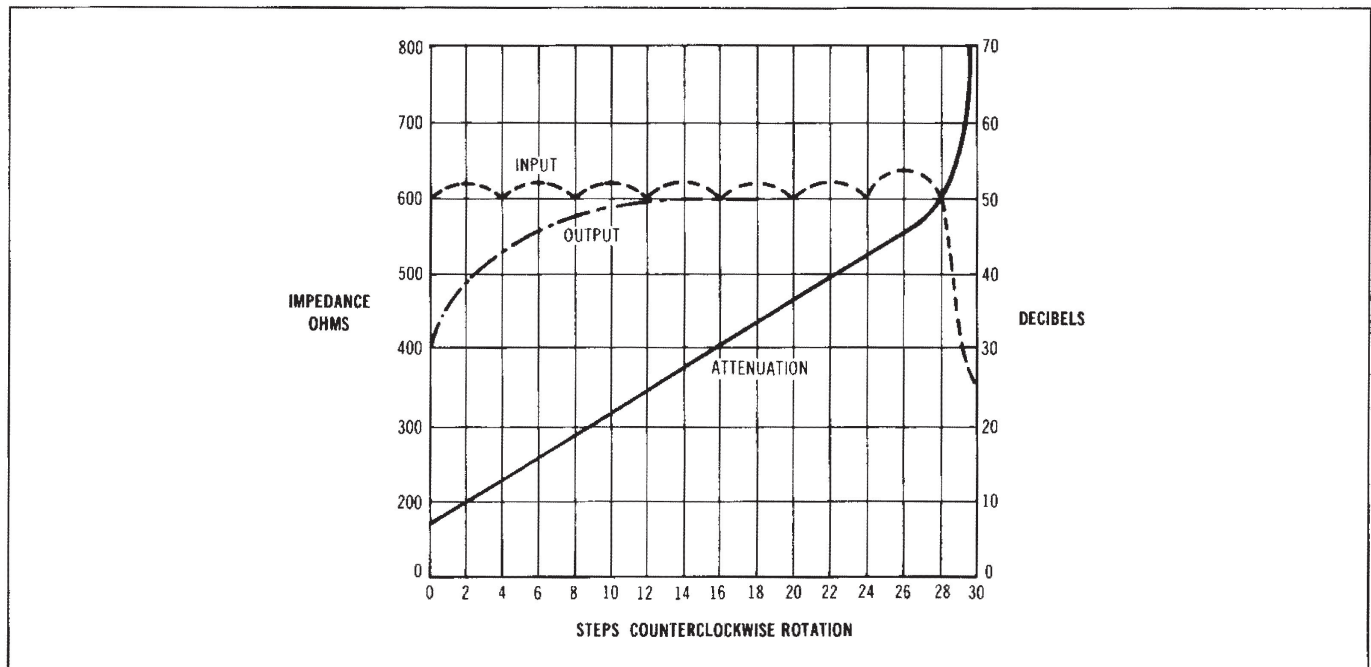


Figure 16-19 Impedance characteristics of a 600-Ω ladder-type attenuator.

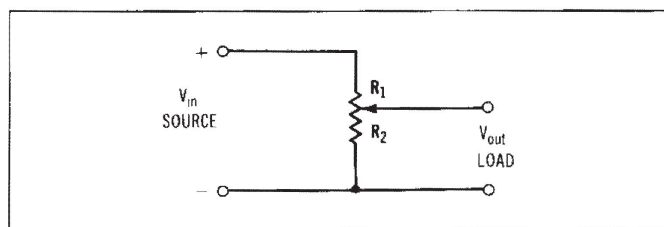


Figure 16-20 Simple volume control.

$$V_{out} = V_{in} [R_2 / (R_1 + R_2)] \quad (16-48)$$

The attenuation is

$$\text{dB} = 10 \log 4 \left[\frac{\left(R_1 + \frac{R_2 Z_2}{R_2 + Z_2} \right)^2}{Z_1 Z_2} \right] \quad (16-49)$$

Normally, volume controls have a logarithmic taper, so the first 50% of the pot only represents a change of 7 to 8%, following the sensitivity of the ear.

If a special taper is required, a linear pot can be altered to change its characteristics by the shunting of a fixed resistance from one end of the resistance to the wiper. Three methods of shunting a straight-line potentiometer are shown in Fig. 16-21. In the first method, the shunt resistor is connected from the wiper to the ground. With the correct value shunt resistance, the potentiometer will have a taper relative to the angular rotation, as shown below the schematic diagram. The second method makes use of a second potentiometer ganged with the straight-

line potentiometer. In the third method, two shunt resistors connected at each side of the wiper results in a taper resembling a sine wave. A fourth method, not shown, uses a shunt resistance connected from the wiper to the top of the potentiometer.

A loudness control incorporates a circuit to alter the frequency response to follow the Fletcher-Munson curves of equal loudness (i.e., the softer the level, the more the low frequencies must be boosted with respect to 1 kHz and above).

To approximate this a capacitor is tapped off the volume control at about 50% rotation. As the wiper is rotated below the tap, the signal has the high frequencies rolled off giving the effect of low-frequency boost.

16.9 LIGHT-DEPENDENT ATTENUATORS

In a light-dependent attenuator the attenuation is controlled by varying the intensity of a light source on a *light-dependent resistor (LDR)* (cadmium sulfide cell). Light-sensitive attenuators eliminate problems with noisy potentiometers as the potentiometers operate the lamp circuit. This type of circuit is also very useful for remote control as the remote control line carries lamp control voltage.

A simple volume control can be seen in Fig. 16-22. R and LDR form an attenuator. When the light source is bright, the resistance of the LDR is low; therefore, most of the signal is dropped across R. When the light intensity is decreased, the resistance of LDR increases, and more signal appears across the LDR. This circuit has constantly varying impedances.

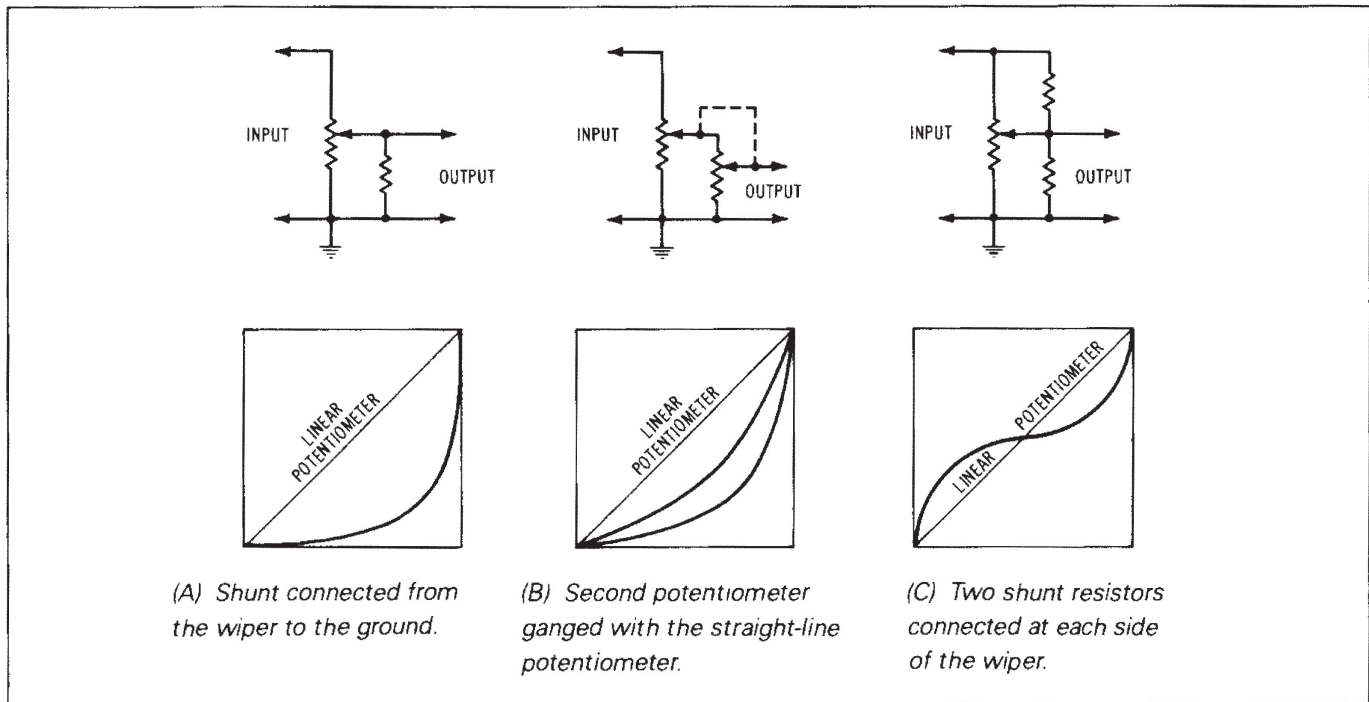


Figure 16-21 Method of varying the response of a plain potentiometer.

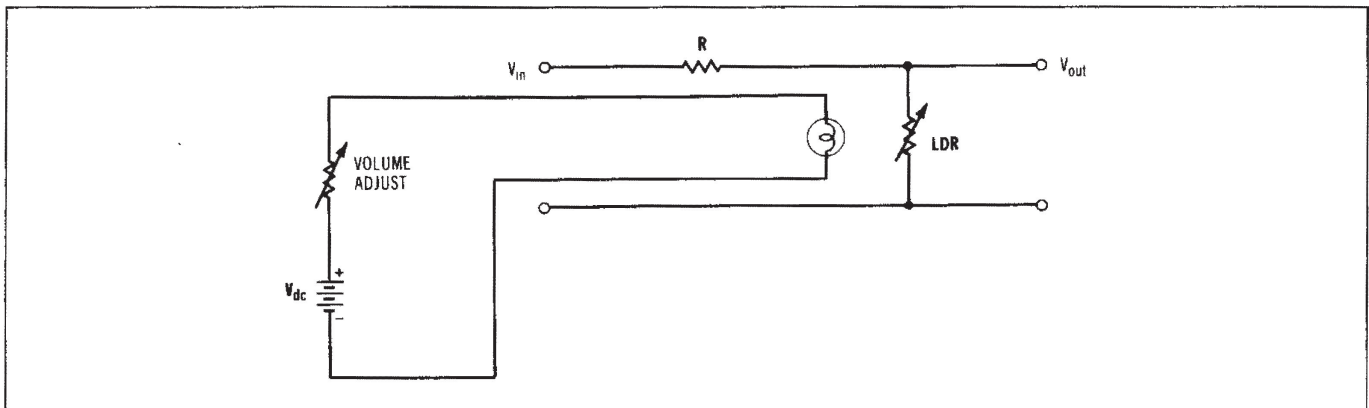


Figure 16-22 Volume control using a light-dependent resistor.

A constant-impedance attenuator would require more LDRs and light sources to approximate a constant-impedance type of attenuator.

The advantages of a light-dependent attenuator are:

1. No wiper noise,
2. Easy to connect one control to many attenuators,
3. Controls can be remoted from the attenuator.

The disadvantages are:

1. Lamp burnout or aging,
2. Slow response time.

16.10 FEEDBACK-TYPE VOLUME CONTROL

In a feedback-type volume control, attenuation is controlled by the amount of feedback in the circuit. Gain of a closed-loop circuit is

$$A_c = A_o / (1 + \beta A_o) \quad (16-50)$$

where,

A_c is the closed-loop gain,

A_o is the open-loop gain,

β is the feedback factor.

By varying β , the amplifier gain can be changed, hence,

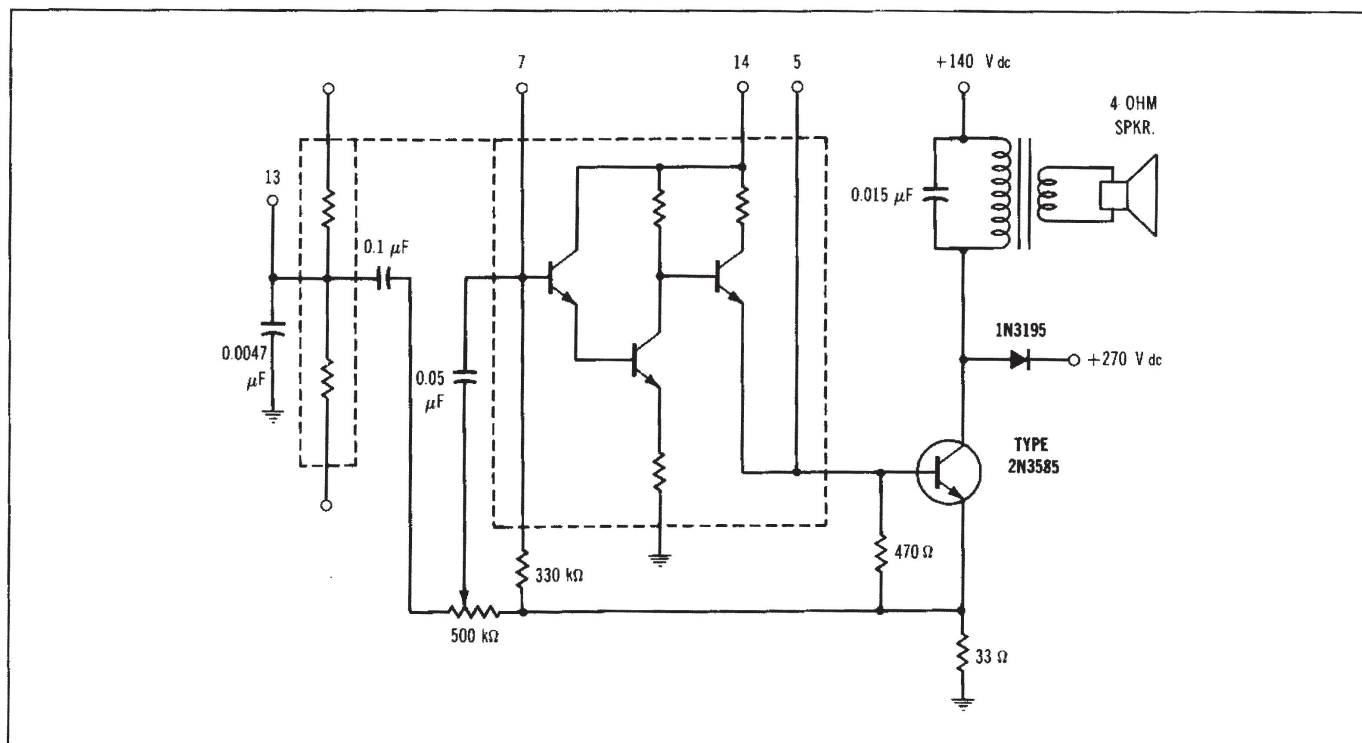


Figure 16-23 Feedback-type volume control. (Courtesy Radio Corporation of America)

giving the effect of a volume control. Feedback-type volume controls have the advantage of reduced hum and noise as they reduce the gain of the active network rather than reducing just the signal level.

In Fig. 16-23, the system gain can be defined as

$$\frac{E_o}{E_s} = \frac{G_s(1 - g_m/G_f)}{(G_s + G_i)(1 + G_L/G_f) + G_m + G_L}$$

where,

E_o is the output signal,

E_s is the input signal,

G_s, G_f, G_i, G_L are the conductances of the source, feedback, input, and load resistance.

At maximum gain, the expression reduces to

$$E_o/E_s = (R_L - g_m R_f R_L)/(R_L + R_f)$$

A feedback volume control using an RCA CA3042 integrated-circuit unit is shown in Fig. 16-23.

16.11 VOLTAGE-CONTROLLED AMPLIFIERS

A voltage-controlled amplifier is used as an attenuator by varying a dc control voltage. Voltage-controlled amplifiers (VCA) are often used for automatic mixing since the control voltage can be stored in analog form or in digital form. Upon command through a digital-to-analog con-

verter, it can be programmed back into the console and VCA.

VCAs are also useful for remote-control operation and in compressors or expanders. VCAs have attenuation ranges from 0 to 130 dB and response time better than 100 μs. A typical circuit for a DBX Model 202 VCA is shown in Fig. 16-24. Since the input is a virtual-ground summing point, R_i is used so as not to load the preceding

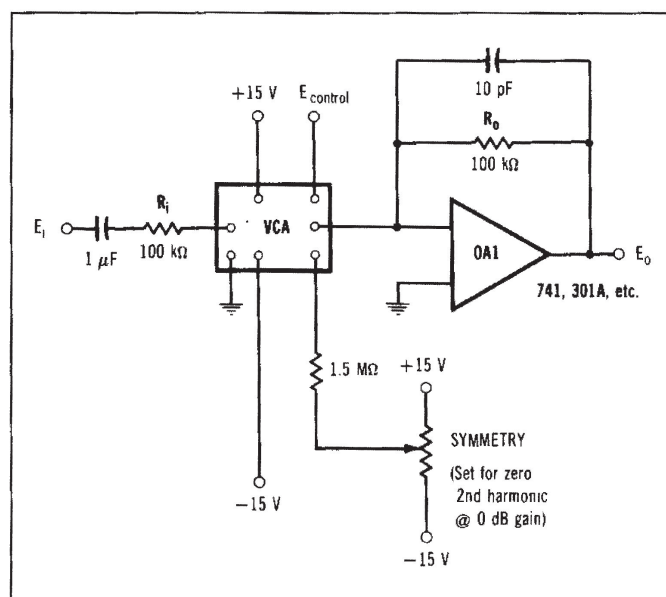


Figure 16-24 Voltage-controlled amplifier volume control.

circuit. The output circuit must feed a virtual ground so an operational amplifier current-to-voltage converter (any operational amplifier with a resistor from output to inverting input and with the noninverting input grounded) must be used. The DBX 202 can be used with a linear taper potentiometer to give a linear decibel control characteristic.

16.12 FIELD-EFFECT TRANSISTOR ATTENUATORS

An FET attenuator is one where an FET (field-effect transistor) is used to control gain. Field-effect transistors

have characteristics much like a tube, that is, high input impedance and moderate output impedance. In its simplest form, the FET is used as the lower leg of a voltage divider, as shown in Fig. 16-25A.

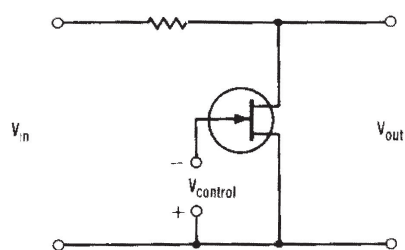
The voltage out is

$$V_{out} = V_{in} r_{DS(on)} + V_{out(max)} \\ = V_{in} / [R + r_{DS(on)}]$$

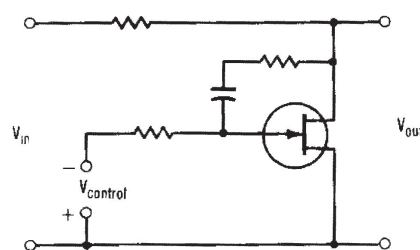
where,

r_{DS} is the resistance of the source to drain.

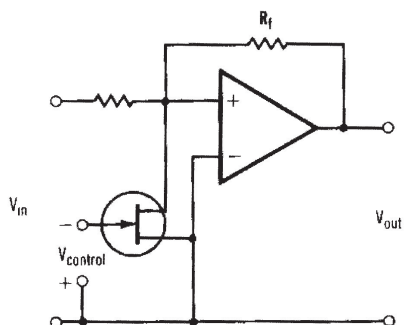
To improve distortion and linearity, feedback is required around the FET, as shown in Fig. 16-25B.



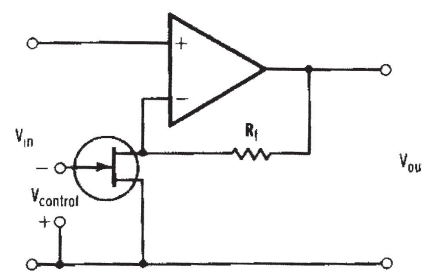
(A) FET as the lower leg of a voltage divider.



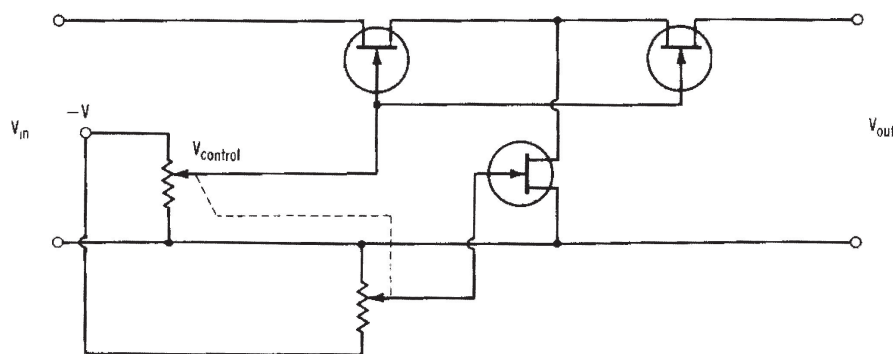
(B) Feedback required around the FET.



(C) An op amp used in conjunction with an FET.



(D) An FET used to control feedback.



(E) An FET as a T attenuator.

Figure 16-25 FET attenuators.

If a low-output impedance is required, an op amp can be used in conjunction with the FET (Fig. 16-25C). In this circuit, the op-amp is used to match impedances. The FET can also be used to control feedback (Fig. 16-25D). The gain in this circuit is $AV = 1 + R_F/r_{DS}$. When r_{DS} is minimum, gain is maximum as most of the feedback is shorted to ground.

The FET can also be used as a T attenuator. This provides optimum dynamic linear range attenuation and tends to hold the impedances more even (Fig. 16-25E).

16.13 AUTOMATED FADERS

In an *automated fader*, the fade control can be programmed into a data storage device (tape) and used to adjust the fader settings during mixdown.

The method operates in the following manner (Fig. 16-26). The fader is adjusted manually, and, when the desired setting is made, a write voltage is injected into the programmer (encoder) that supplies data to the data track of the tape recorder. During playback, the data track is decoded and, through the read control, adjusts the attenuator to the recorded level. If the mixdown is not proper, any control can be adjusted or updated and the tape played over again.

16.14 AUTOMATIC ATTENUATORS

In an *automatic attenuator*, the attenuation varies automatically between two points, usually off and a prescribed setting. Automatic attenuators are often voice operated but can be manually operated. They are used to automatically turn off unused inputs, as a "Ducker" and gating.

A Shure Model M625 Voicegate is an automatic attenuator. The circuit is illustrated in Fig. 16-27 (pages 566 and 567) and operates in the following manner. The audio signal arrives through the microphone connector J_1 , through Q_{101} and Q_{102} , and out the microphone connector J_2 . R_{106} – R_{108} sets the gain of the off threshold.

The signal also goes to an amplifier-filter consisting of Q_{103} – Q_{112} . The filtered signal is then rectified by D_{102} . This turns on Q_{116} , increasing the gain of the Q_{101} circuit, passing the signal. The circuit remains on after the signal has ceased until C_{122} discharges through R_{3B} .

16.15 MIXERS

A *mixer* is a device used to mix two or more signals into one composite signal. Mixers may be adjustable or non-adjustable and either active or passive.

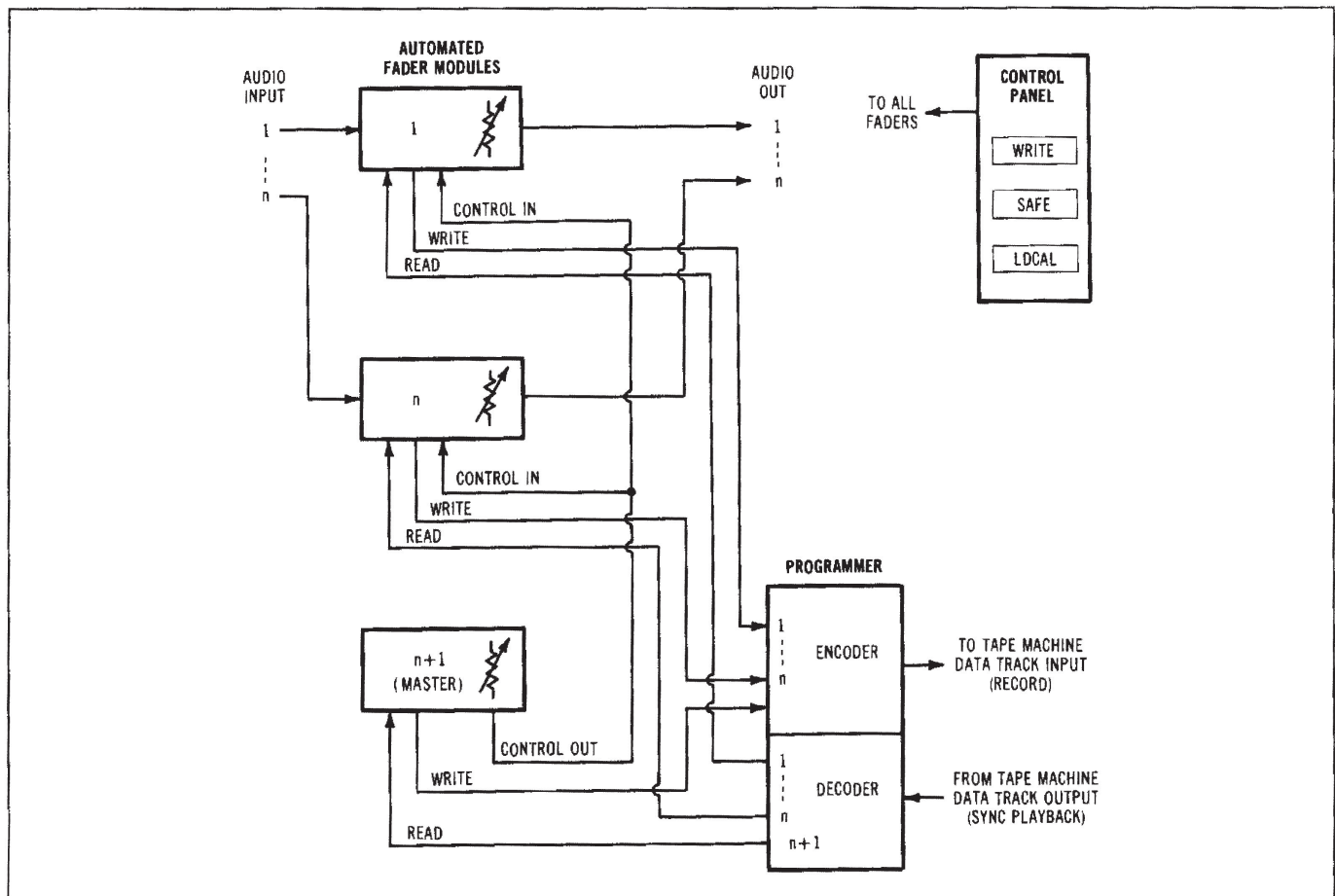


Figure 16-26 Functional block diagram of an automated fader.

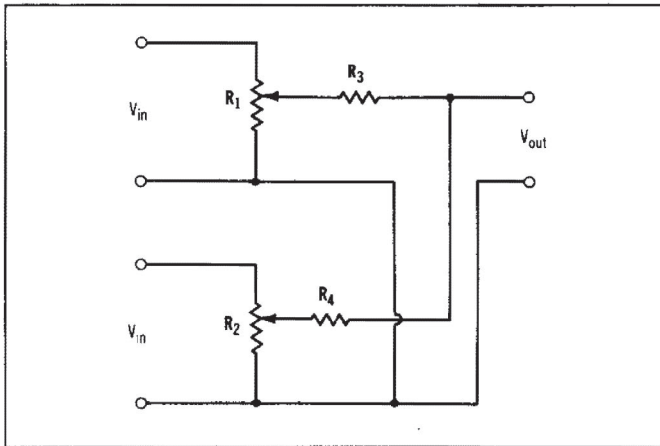


Figure 16-28 Passive mixer circuit.

A *passive* mixer uses only passive devices (i.e., resistors and potentiometers), as shown in Fig. 16-28.

The main disadvantage of passive mixing is that an amplifier is required after mixing to boost the gain back to the level at the input of the mixer. As the attenuator controls are lowered, the signal on the mixing bus is reduced; however, the mixing bus noise remains the same, so the signal-to-noise ratio is reduced.

In Fig. 16-29A the input of -125 dBm is not atten-

uated; therefore, the signal out of the booster amplifier is -73 dBm, while the noise is -92 dBm. Thus, the signal is 19 dB above the noise.

In Fig. 16-29B the input of -125 dBm is attenuated 20 dB in the mixer so the signal out of the booster amplifier is -93 dBm, while the noise remained -92 dBm. Thus, the signal is 1 dBm less than the noise.

An active mixer is one that uses operational amplifiers or some other active device along with resistors and/or potentiometers to control gain or attenuation.

A unity-gain current-summing amplifier using an op amp is a standard active mixer. The mixer is usually designed for an input impedance of about $5\text{ k}\Omega$ to $10\text{ k}\Omega$, an output impedance of less than $200\text{ }\Omega$ and a gain of 0 to 50. A typical active mixer is shown in Fig. 16-30.

In unity-gain current-summing amplifiers feedback to the minus or inverting input presents an extremely low apparent input impedance or virtual ground on the inverting input.

The positive input is also essentially ground since the current through R_N will only produce about a half millivolt. While the positive input can be grounded, it is better to make the R_N a value about the same as the parallel combination of $R_1 + R_2 + R_F$ to reduce offset voltage.

Any small, positive-going input applied to the left end of R_1 is amplified by the high-gain op amp and drives the output negative since the input signal is on the inverting

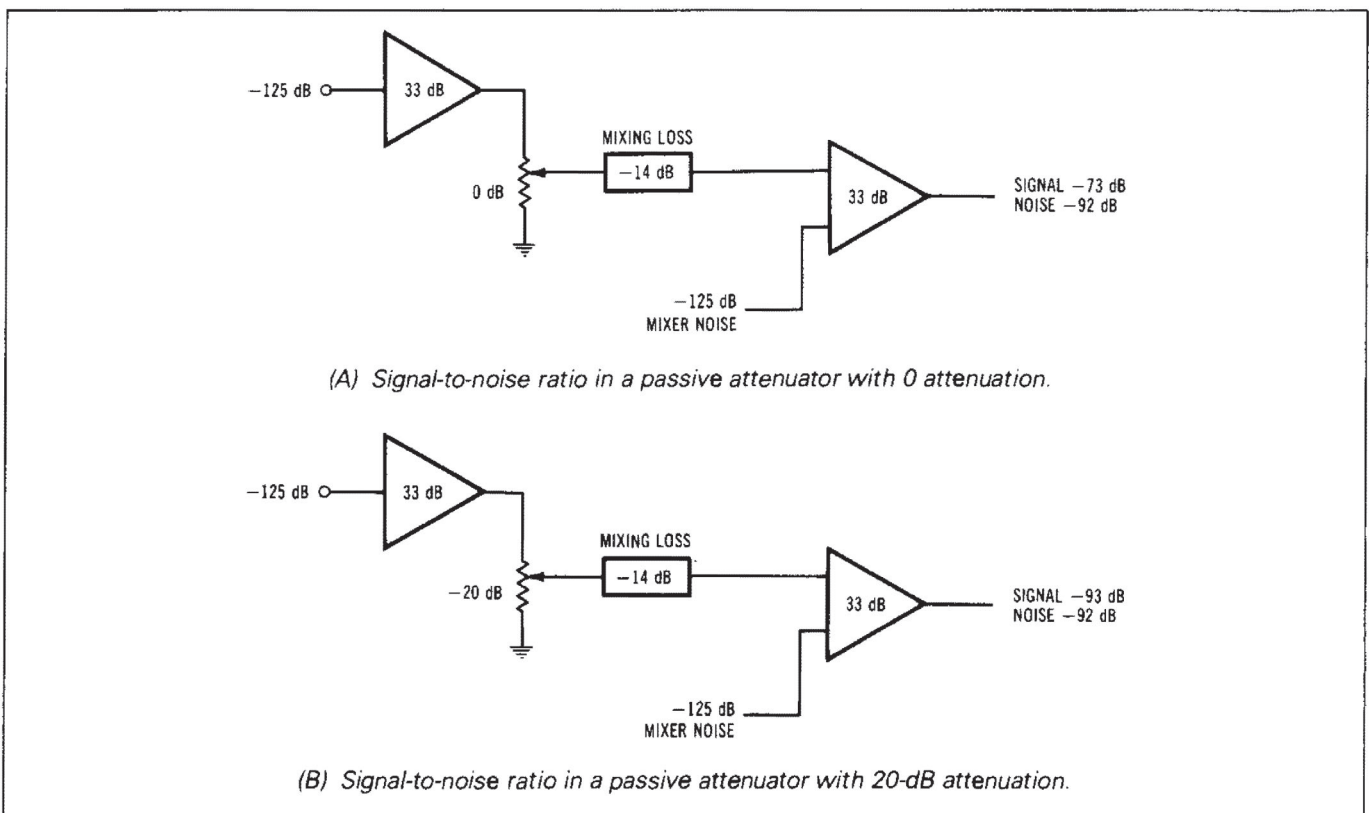
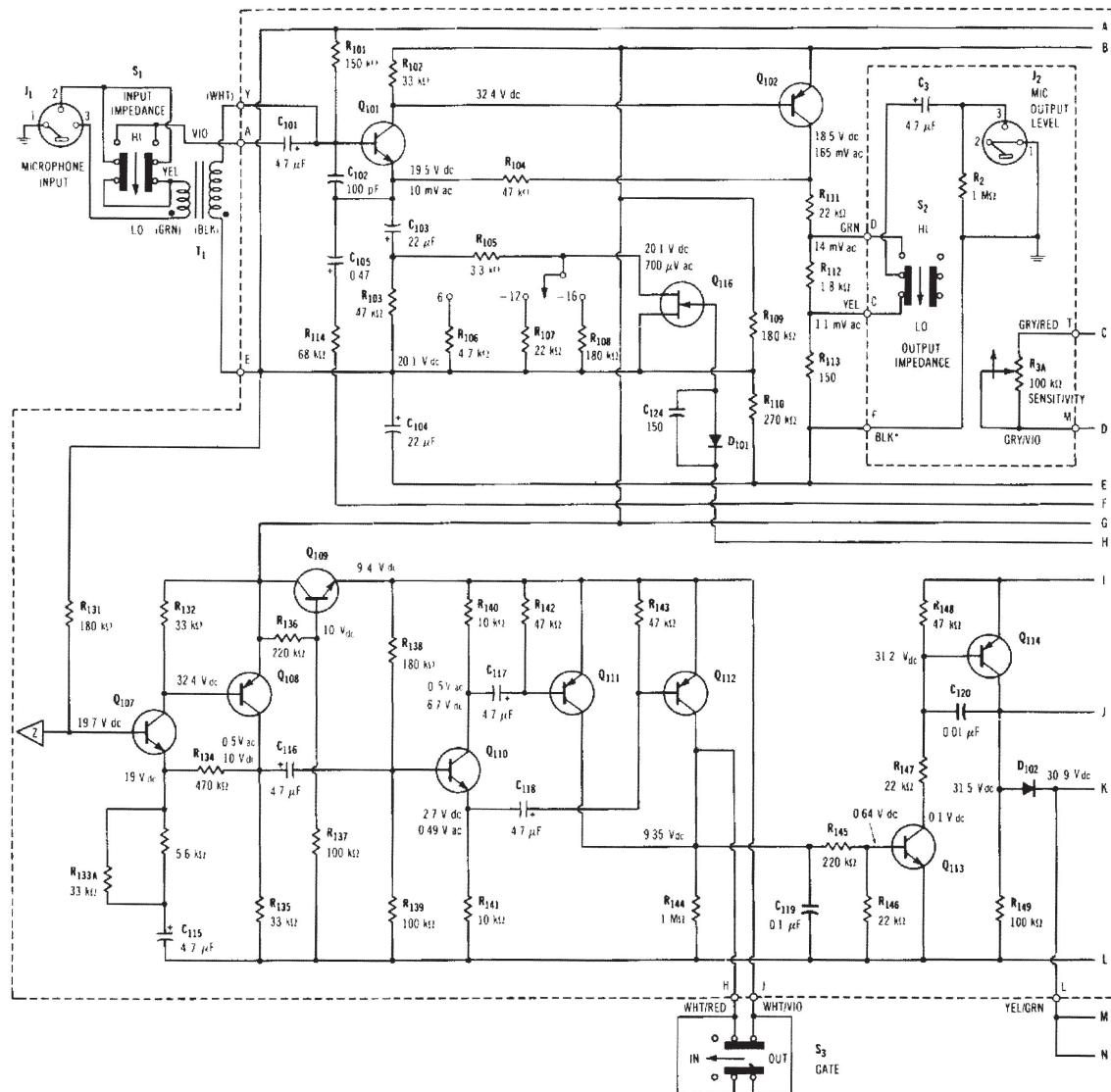
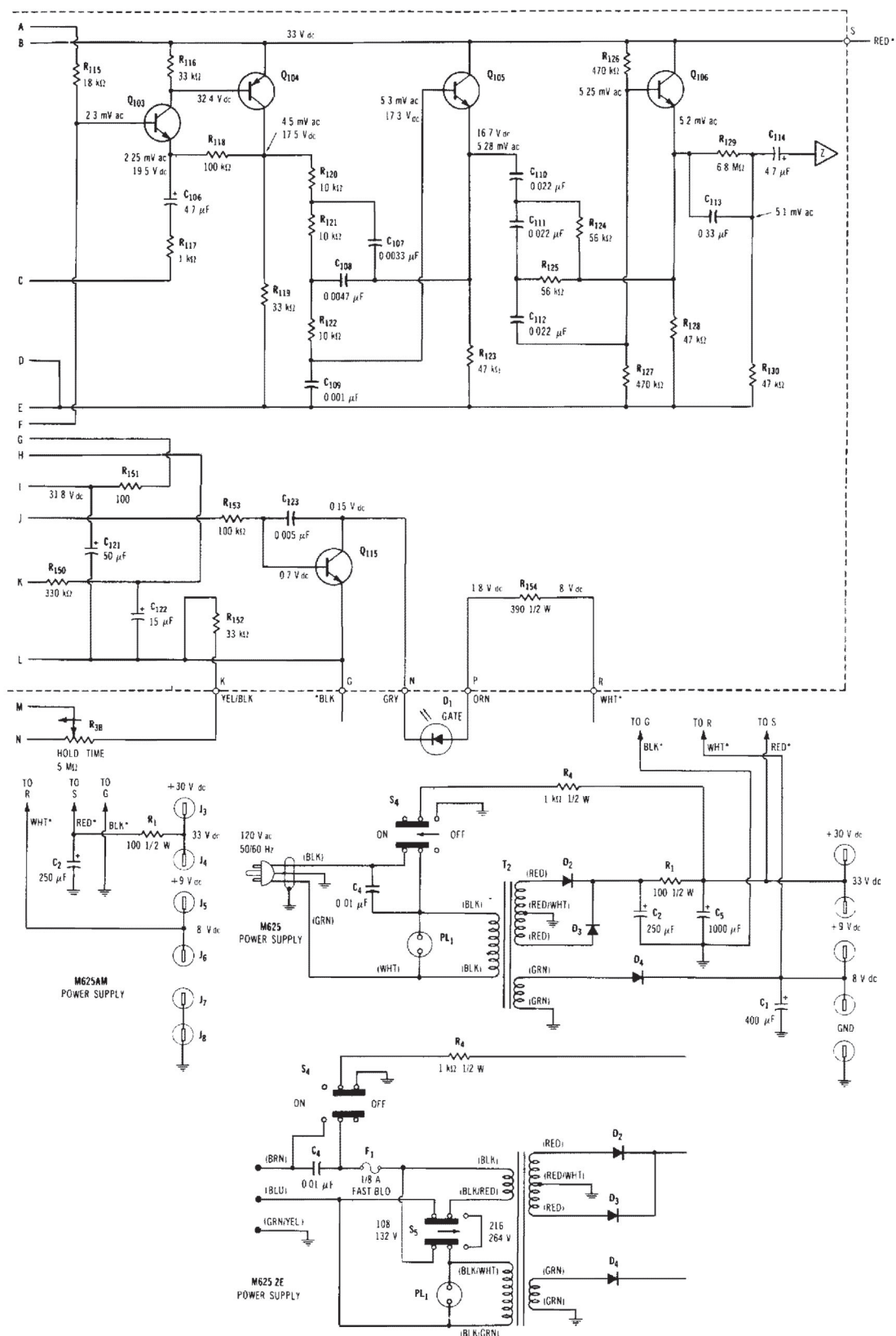


Figure 16-29 Passive-type mixer.



- 1 All resistors in ohms $1/4$ W $\pm 10\%$ unless otherwise specified k Ω =1 000 M Ω =1 000 000
- 2 All capacitors in μ F
- 3 Arrows on switches and Potentiometers denote right or up position or clockwise rotation as viewed from actuator
- 4 Supply voltages 33 V and 8 V at J_2 and J_5 All ac voltages taken with 2 kHz 1 mV ac input to impedance thru 150 Ω output to impedance terminated with 1 k Ω and measured with 2.2 M Ω or greater ac voltmeter All dc voltages measured with 10 M Ω VTVM impedance switches set to lo in out switch set to out and sensitivity and hold time controls set full counterclockwise dc voltages are typical and may vary $\pm 15\%$ to -35% depending on the number of units attached to power supply Ac voltages are typical and may vary $\pm 15\%$
- 5 Wires are No. 24 AWG except * No. 20 AWG integral component lead

Figure 16-27 Shure model M625 Voicegate automatic



attenuator. (Courtesy Shure Brothers, Inc.)

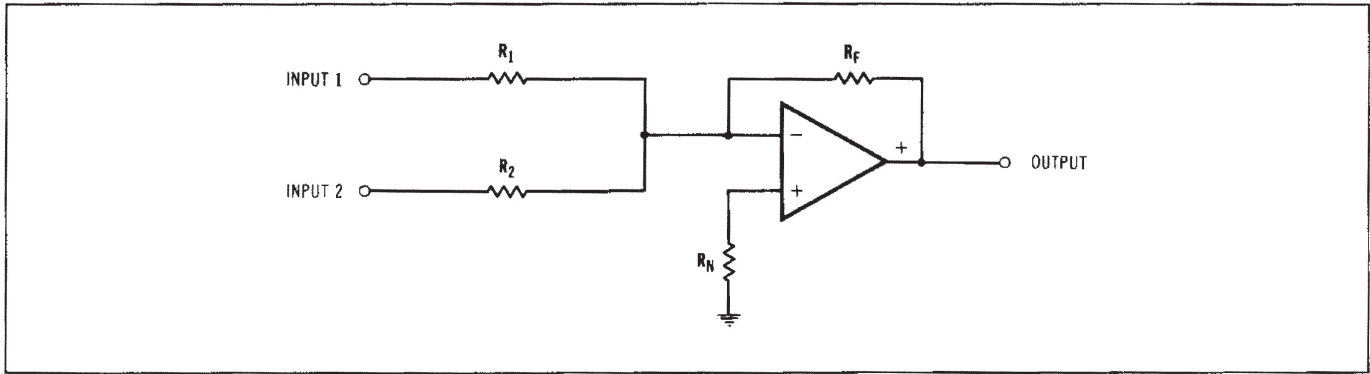


Figure 16-30 An active mixer block diagram.

input. The output signal is fed back through R_F , the feedback resistor, and continuously attempts to drive the voltage on the input to ground.

Since the input is a virtual ground, the input impedances are determined by R_1 and R_2 . The gain of the circuit is $\text{gain 1} = R_F/R_1$, $\text{gain 2} = R_F/R_2$. If the gain of both inputs were to be the same, R_1 and R_2 would remain constant, and R_F would be varied. Mixers, however, usually require separate gain control for each input so R_1 and R_2 are varied to change the gain of the system. Increasing

R_1 or R_2 decreases the gain. The main disadvantage of this system is that the input impedance varies with gain.

The advantage of an active mixer is that gain is included in the mixing circuit; therefore, it does not need a gain makeup amplifier that amplifies both the signal and the mixing noise after the mixer. With active mixing, the mixing noise is also reduced along with the signal, improving the signal-to-noise ratio, particularly at lower levels.