SECTION 12

MIXER CIRCUITS

PART A. ELECTRON-TUBE CIRCUITS

AUDIO MIXERS.

Audio-frequency mixing is defined as the combining of two or more audio-frequency (20 to 20,000 cycles per second) signals from separate sources in any desired proportion at the input to an audio-amplifier system.

The term **audio mixer** should not be confused with the term **mixer** used to designate the nonlinear circuit that heterodynes the r-f and local-oscillator signals in a superheterodyne receiver. Audio mixers are considered as "combining" circuits and are operated as linear circuits.

Audio mixing circuits are used in public-address, sound-distribution, and similar audio systems to combine two or more input-channel signals for further amplification in the main channel of an audio-amplifier system. It is necessary to control the individual input-channel signal levels before mixing occurs. Also, if frequency compensation of the individual input signals is required, the frequency compensation must be accomplished before the signals are applied to the mixer input. It is desirable to have the individual signals to each mixer input as nearly equal to one another as possible so that similar control settings of the mixer circuit will produce similar output signal levels. This is especially true where the mixer circuit (channel) controls are front-panel controls which are easily accessible to the operator and require frequent operation or adjustment.

When a low-amplitude signal is to be mixed with a signal of greater amplitude, an audio-amplifier stage, called a **preamplifier**, is used to increase the amplitude of the smaller signal so that it is approximately equal to the amplitude of the larger signal; then the two input signals will be of approximately the same amplitude (level) before mixing occurs. In some instances, if the smaller of the two signals is at a satisfactory level for application to the mixer circuit, the signal with the larger amplitude is simply attenuated to a level which is equal to that of the smaller signal.

Audio mixer circuits can be classified as either electron-tube type or resistance-network type. Mixers may be further classified as high- or low-impedance, constant- or nonconstant-impedance, and high- or low-level mixers. The audio mixer circuits briefly described in this section are representative of typical electron-tube audio mixers.

COMMON PLATE-LOAD AUDIO MIXER.

APPLICATION.

The common plate-load audio mixer circuit is used to combine two (or more) input audio signals by amplifying the signals and combining them in a common load impedance. The mixer circuit is generally used in public-address and sound-distribution systems to provide for the control and mixing of several input channels.

CHARACTERISTICS.

Operates Class A with cathode bias.

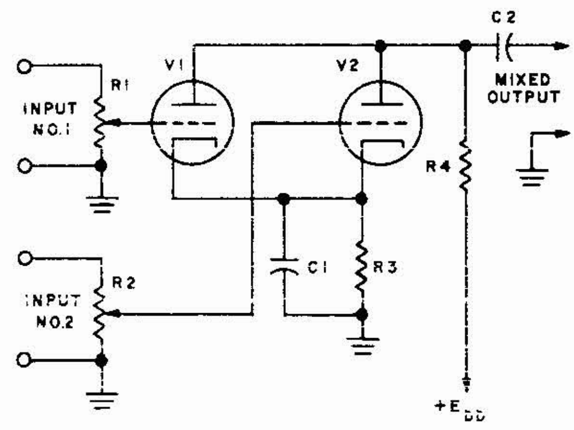
Combines two individual input signals; each input signal is amplified, inverted, and combined in a common plate-load impedance with relatively low distortion.

Additional circuits can be connected in parallel to provide for additional input channels.

CIRCUIT ANALYSIS.

General. The common plate-load audio mixer combines two input signals. The circuit is fundamentally two Class A audio amplifiers in parallel with a common plate-load resistance. The combined output signal is taken from across the plate-load resistance. More than two input signals can be mixed by applying each signal to a separate amplifier tube; each tube in turn, operates into the common plate-load resistance.

Circuit Operation. The accompanying circuit schematic illustrates two triode electron tubes in a common plate-load audio mixer circuit. Electron tubes V1 and V2 are identical-type triode tubes; although two separate triodes are shown, a twin-triode is commonly used in this circuit. Potentiometer (variable resistors) R1 and R2 are the grid resistors for V1 and V2, respectively. Also, R1 and R2 are used to terminate a preamplifier, crystal pickup, or other high-impedance signal source, and control the level of signal applied to each grid of the mixer circuit. Resistor R3 is the common cathode-bias resistor for V1 and V2; capacitor C1 is the cathode bypass capacitor. Resistor R4 is



Common Plate-Load Audio Mixer

the common plate-load resistor for both V1 and V2; capacitor C2 is the output coupling capacitor.

In this mixer circuit, the two input circuits are isolated from one another, so that the setting of one control (R1 or R2) will have no effect upon the other. The two inputs are relatively high impedance; potentiometers R1 and R2 generally range from 500K to several megohms. In practice, no great attempt is made to achieve an exact match of impedances at the input to the mixer circuit. However, the

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values of R1 and R2 are usually made sufficiently high to act as a load or terminating impedance for a preamplifier stage, a crystal pickup, or a high-impedance, high-output microphone. If the signal source is a low impedance, an input matching transformer is required to obtain impedance transformation from the low-impedance source to the relatively high-impedance input of the mixer circuit.

The operation of each tube in the common plate-load audio mixer is similar to the operation of the R-C coupled triode voltage amplifier, described in Section 6, for individual input signals. For example, assume a condition where an audio signal is applied to Input No. 1 but no signal is applied to Input No. 2. In this instance, assuming that potentiometer R1 is adjusted for a suitable input level to the grid of V1, the output signal developed across the plate-load resistor, R4, is 180 degrees out of phase with the input signal and is a reproduction of the input signal as it would be for any R-C coupled voltage amplifier. When audio signals are applied to both inputs of the mixer circuit, the combined signals appear across the plate-load resistor, R4, and are coupled through capacitor C2 to the grid circuit of the following audio amplifier stage. If the grid circuit of the following stage uses a potentiometer as the grid resistance (R-C coupling), then this potentiometer functions as a master gain control for the amplifier, since it controls the amplitude of the mixed audio signals applied to the grid of the following stage.

The mixer circuit illustrated is very satisfactory for two input channels. It uses two tubes sharing a common plate-load resistor. When more than two inputs are desired, as for example three or four inputs, various circuit combinations incorporating three or four tubes may be used; however, there is a limitation to the number of tubes which can share a common plate-load resistance without suffering considerable loss of gain and introducing some distortion. Therefore, common plate-load mixers are generally limited to two or possibly three tubes. (Where more input channels are desired, modification of the basic circuit is necessary to provide a degree of plate-load isolation.) Since the plate resistances of the two tubes (V1 and V2) are in parallel, each tube works into a load impedance which is always less than its own plate resistance. Under such conditions of operation, the output voltage obtainable from the circuit is seriously limited.

Since one tube operates into a load consisting of the other tube's plate resistance effectively in parallel with the load impedance (R4), it is obvious that the gain of the two tubes as shown in the schematic will be less than the gain of a single voltage-amplifier tube because the load impedance for either tube is always less than its own plate resistance (r_p). Therefore, the gain of each tube will always be less than one-half the gain obtained from a normal voltage amplifier. If the normal voltage amplifier is considered to be a constant-voltage generator, as shown in part A of the accompanying illustration, the a-c component of plate current (i_p) is:

$$i_p = \frac{-\mu e_s}{r_p + Z_L}$$

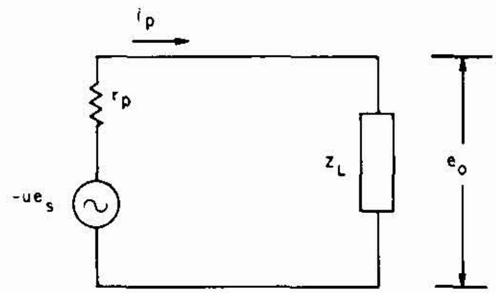
and the a-c component of output voltage (e_o) that appears across the load impedance, Z_L, is:

$$e_o = i_p Z_L$$

By substitution then:

$$e_o = \frac{-\mu e_s}{r_p + Z_L} Z_L$$

$$= \frac{-\mu e_s Z_L}{r_p + Z_L}$$



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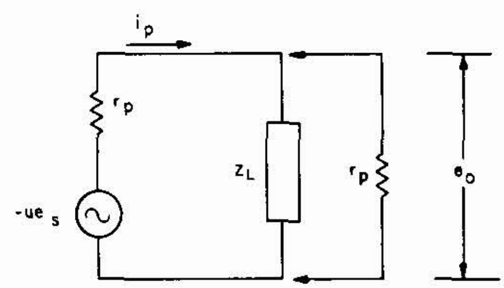


B

Simplified Amplifier Circuit

It is apparent that the output voltage (e_o) of a normal voltage amplifier is not μ times the applied signal (e_s), because some voltage is lost in the internal resistance (r_p) of the tube and is not developed across the load impedance, Z_L: In part B of the illustration, the plate resistance (r_p) of a second tube is shown in parallel with the load impedance, as would be the case for a two-tube mixer circuit. The load impedance for this condition can now be expressed as:

$$\frac{r_{p2} Z_L}{r_{p2} + Z_L}$$

where: Z_L = load impedance
r_{p2} = plate resistance of second tube

However, since identical tubes (V1 and V2) are used in the mixer circuit, the plate resistance of each tube can be considered to be equal to that of the other; therefore, r_{p2} is equal to r_p. The a-c component of output voltage (e_o) for the two-tube mixer can now be expressed as:

$$e_o = \frac{-\mu e_s Z_L}{r_p + Z_L}$$

Substituting $\frac{r_p Z_L}{r_p + Z_L}$ for Z_L:

$$e_o = \frac{-\mu e_s \frac{r_p Z_L}{r_p + Z_L}}{r_p + \frac{r_p Z_L}{r_p + Z_L}}$$

$$= \frac{-\mu e_s Z_L r_p}{Z_L r_p + r_p^2 + Z_L r_p}$$

$$= \frac{-\mu e_s Z_L r_p}{r_p^2 + 2Z_L r_p}$$

$$e_o = \frac{-\mu e_s Z_L}{r_p + 2Z_L}$$

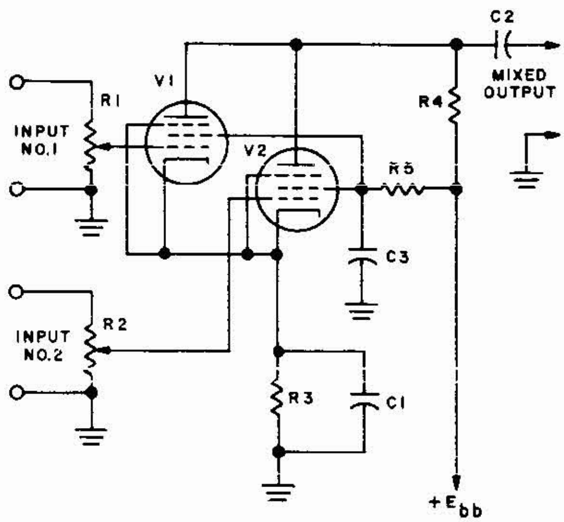
From this expression it can be seen that, for two triodes in parallel, the output voltage (e_o) will always be less than one-half that obtained with a normal voltage amplifier. Similarly, for a three-tube mixer the gain will be less than one-third the gain obtained from a normal voltage amplifier; for a four-tube mixer it will be less than one-fourth.

Improved performance can be obtained by using pentode instead of triode tubes. The accompanying circuit schematic illustrates two pentode electron tubes in a common plate-load audio mixer circuit. Electron tubes V1 and V2 are identical-type, sharp-cutoff pentodes. The circuit is fundamentally the same as that previously described for triode tubes except for the addition of the screen-dropping resistor, R5, and the screen bypass capacitor, C3. The circuit operation is the same as that described for the triode mixer circuit.

When pentodes are used in the common plate-load mixer circuit, the loss of gain due to the shunting of the load impedance by other tubes is slight and, for all practical purposes, may be neglected. The plate resistance of a pentode as a resistance-coupled amplifier is extremely high compared to that of a triode, so that nearly the full gain of the pentode can be realized in this circuit.

FAILURE ANALYSIS.

No Output. The common plate-load audio mixer circuit is similar in many respects to a resistance-coupled voltage amplifier circuit insofar as failures are concerned. Failure of the plate-voltage supply will disrupt operation of the circuit, as will an open circuit in the cathode. With tubes known to be good installed in the circuit, the filament and plate voltages should be measured, as well as the d-c



Pentodes Using Common Plate-Load

voltage developed across the cathode resistance, to determine whether the applied voltages are within tolerance and whether the plate load resistor (R4) or cathode resistor (R3) is open. Each input should be checked with an oscilloscope to determine whether signals are applied to the input of the circuit and whether they are of the proper amplitude. An open output coupling capacitor (C2) will prevent signals from reaching the stage following the mixer.

If the mixer circuit uses pentode tubes, the voltage applied to the screen grid should be measured, to determine whether it is within tolerance and whether the screen bypass capacitor (C3) is shorted. A shorted screen bypass capacitor will remove screen voltage from the tubes and may cause the screen-dropping resistor, R5, to burn out. When normal output is obtained from one channel but not from the other, the input to the faulty channel should be checked with an oscilloscope to determine whether the trouble is due to an open input potentiometer (R1 or R2) or failure of the input-signal source.

Low or Distorted Output. The applied plate voltage should be measured to determine whether it is within tolerance. Also the output coupling capacitor, C2, should be checked to determine whether it is leaking; leakage of this capacitor will drop the applied plate voltage and permit voltage-divider action to affect the operation of the following stage. Thus, if the input resistor of the following stage is returned to ground, the voltage at the plates of V1 and V2 will be reduced, and the operation of the following stage will be upset by the change in voltage applied to its grid. An open cathode bypass capacitor C1 will cause the mixer circuit to be degenerative, and will also result in "cross-biasing" of the tubes so that the stage gain will be severely decreased. A shorted cathode bypass capacitor will result in a loss of bias and distortion of the output signal. Depending upon the configuration of the preceding stage (for example, a preamplifier stage, R-C coupled), it is possible that a d-c voltage may be applied to the input potentiometer (R1 or R2) because of a leaky or shorted coupling capacitor. In this case, a d-c voltage which is dependent upon the setting of the potentiometer will be applied to the grid, and the tube bias will be affected.

In the pentode audio mixer circuit, a leaky screen bypass capacitor (C3) or an increase in the value of the screen-dropping resistor (R5) will cause reduced gain because of the decreased screen voltage, while an open screen bypass will cause reduced gain because of degeneration within the stage.

SEPARATE PLATE-LOAD AUDIO MIXER.

APPLICATION.

The separate plate-load audio mixer circuit is used to combine two (or more) input audio signals by amplifying the signals and combining them at the common input of a following stage. The mixer circuit is commonly used in public-address and sound distribution systems to provide for the control and mixing of several input channels.

CHARACTERISTICS.

Operates Class A with cathode bias.

Combines two individual input signals; each input signal is amplified, inverted, and fed through an isolation resistance to the common input of a following stage.

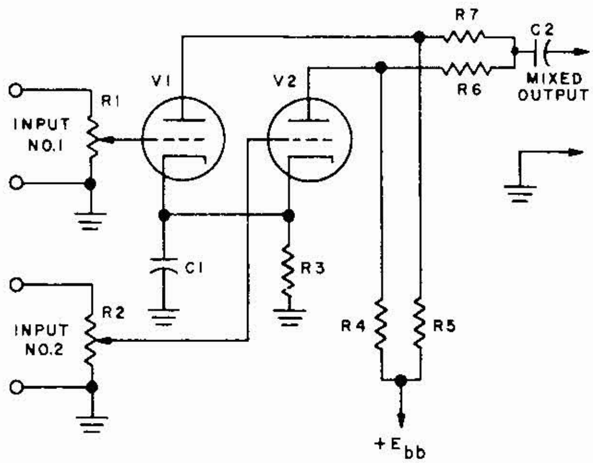
Additional circuits can be connected in parallel to provide for additional input channels.

CIRCUIT ANALYSIS.

General. The separate plate-load audio mixer circuit combines two input signals. The circuit is fundamentally two separate Class A audio amplifiers with each output fed through an isolation resistor to a common input impedance of the following stage. More than two input signals can be mixed by applying each additional signal to a separate amplifier which has its own plate-load resistance, and feeding the amplifier output through an isolation resistance to a common input impedance of the following stage.

Circuit Operation. The accompanying circuit schematic illustrates two triode electron tubes in a separate plate-load audio mixer circuit. Electron tubes V1 and V2 are identical-type triode tubes; two separate triodes are shown, but a twin-triode is commonly used in this circuit. Potentiometers (variable resistors) R1 and R2 are the grid resistors for V1 and V2, respectively. Also, R1 and R2 are used to terminate a preamplifier, crystal pickup, or other high-impedance signal source, and control the level of signal applied to each grid of the mixer circuit. Resistor R3 is the common cathode-bias resistor for V1 and V2; capacitor C1 is the cathode bypass capacitor. Resistors R4 and R5 are the plate-load resistors for V2 and V1, respectively; resistors R6 and R7 are the output-isolation resistors. Capacitor C2 is the output coupling capacitor.

In this mixer circuit, the two input circuits are isolated from one another, so that the setting of one control (R1 or R2) will have no effect upon the other. The two inputs each have a relatively high impedance; potentiometers R1 and R2 generally range in value from 500K to several megohms. In practice, no great attempt is made to achieve an exact match of impedances at the input to the mixer circuit. However, the values of R1 and R2 are usually made sufficiently high to act as a load or terminating impedance for a preamplifier stage, a crystal pickup, or a high-impedance, high-output microphone. If the signal source is a low impedance, an input matching transformer is required to obtain impedance transformation from the low-impedance source to the relatively high-impedance input of the mixer circuit.

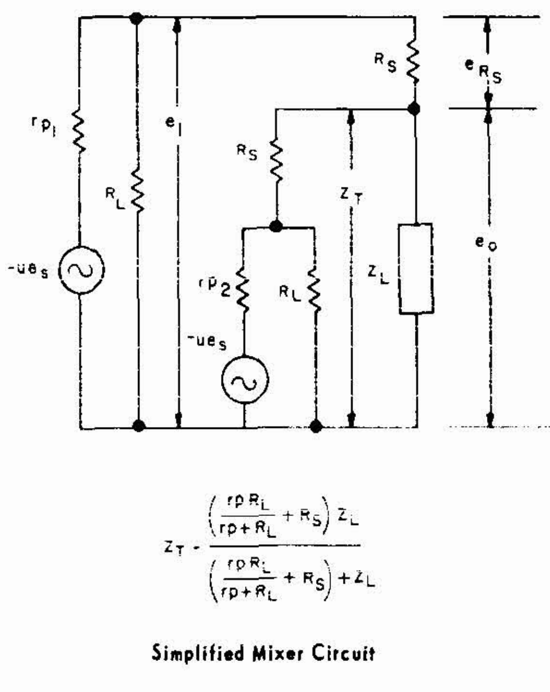


Separate Plate-Load Audio Mixer

The operation of each tube in the separate plate-load audio mixer is similar to the operation of the R-C coupled triode voltage amplifier, described in Section 6. When audio signals are applied to both inputs of the mixer circuit, the individual amplified signals appear across the respective plate-load resistors, R5 and R4. The individual signals are then applied through the series isolation resistors (R6 and R7) to the output coupling capacitor, C2, which couples the combined signals to the grid circuit of the following audio amplifier stage. If the grid circuit of the latter stage uses a potentiometer as the grid resistance, then this potentiometer functions as a master gain control for the amplifier, since it controls the amplitude of the mixed audio signals applied to the amplifier grid.

The mixer circuit illustrated is very satisfactory for two input channels. When more than two inputs are desired, as for example three or four inputs, an additional tube is connected to the circuit for each additonal input desired, and its individual plate load resistance is coupled to the common output circuit by means of an isolation resistor to provide a degree of isolation between amplifier tubes. Thus, some of the inherent disadvantages of the basic common plate-load audio mixer are overcome. The isolation resistors (R6 and R7) are usually two to five times the value of the individual plate-load resistors (R4 and R5). As a result, each tube in the mixer circuit works into a complex load impedance which approaches a normal load for a voltage amplifier stage; therefore, distortion due to nonlinearity is considerably reduced. Although the normal stage gain is obtained when the tube works into a normal load, the output signal voltage available at the input of the following stage is considerably reduced because of the loss introduced by the signal-voltage drop across the isolation resistor. However, the net result is that the higher output voltage from the mixer is available at the input of the following stage for a given percentage of distortion, as compared to the output voltage obtainable from other triode mixer circuits, such as the common plate-load audio mixer.

The voltage delivered to the input of the following stage by the mixer is always less than one half that obtainable with a normal voltage amplifier. In the accompanying illustration, the complex load impedance into which one tube works is simplified to show the amplified-signal voltage division and the resulting useful signal output available across the load impedance, Z_L, corresponding to the input of the succeeding stage. Since both tubes (V1 and V2) employed in the mixer are identical-type tubes, the plate resistances (r_p) can be considered to be equal. Also, the isolating resistors (R_s) are equal to each other,



$$Z_T = \frac{\left(\frac{rp R_L}{rp + R_L} + R_S\right) Z_L}{\left(\frac{rp R_L}{rp + R_L} + R_S\right) + Z_L}$$

Simplified Mixer Circuit

and the plate-load resistors (R_L) are equal to each other. The a-c component of output voltage (e_o) for the mixer using isolation resistors, expressed as a voltage relationship, is as follows:

$$e_o = e_1 - e_{Rs}$$

where: e_1 = voltage developed across R_L

e_{Rs} = voltage developed across isolating resistor R_s

Since the resistance of R_s is greater than the impedance, Z_T, a greater signal voltage appears across R_s than across Z_T. Therefore, the output voltage (e_o) developed across Z_L must always be less than the voltage developed across the isolating resistor, R_s, and less than one-half the voltage obtainable from a normal voltage amplifier. Depending upon the value of the load impedance, Z_L, the output voltage (e_o) may be as low as one-third the voltage obtainable from a normal voltage amplifier.

Pentodes can be used to advantage in this circuit because the plate resistance of a pentode is extremely high compared to that of a triode. The value of the isolation resistor need only be several times the value of the plate-load resistor and, since nearly the full gain capability of the pentode can be realized, the output voltage available at the load impedance will be greater than one-half the output voltage obtained from a normal amplifier.

FAILURE ANALYSIS.

No Output. The separate plate-load audio mixer circuit is similar in many respects to a resistance-coupled voltage amplifier circuit insofar as failures are concerned. Failure of the plate-voltage supply will disrupt operation of the circuit, as will an open circuit in the cathode. With tubes known to be good installed in the circuit, the filament and plate voltages should be measured, as well as the d-c voltage developed across the cathode resistance, to determine whether the applied voltages are within tolerance and whether the individual plate-load resistors (R4 and R5) or cathode resistor (R3) is open. Each input should be checked with an oscilloscope to determine whether signals are applied to the input of the circuit. An open output coupling capacitor (C2) will prevent signals from reaching the stage following the mixer.

If the mixer circuit uses pentode tubes, the voltage applied to each screen grid should be measured, to determine whether it is within tolerance and whether the screen bypass capacitor is shorted. A shorted screen bypass capacitor will remove screen voltage from the tubes and may cause the screen-dropping resistor to burn out.

When normal output is obtained from one channel but not from the other, the input to the faulty channel should be checked with an oscilloscope to determine whether the trouble is due to an open input potentiometer (R1 or R2) or failure of the input-signal source.

Low or Distorted Output. The applied plate voltage should be measured to determine whether it is within tolerance. Also the output coupling capacitor, C2, should be checked to determine whether it is leaking. A leaky (or shorted) output coupling capacitor will form a voltage divider comprised of both isolating resistors (R6 and R7) effectively in parallel, and this combination is in series with the input resistor of the following stage. Thus, the voltage at the plates of V1 and V2 will be reduced somewhat, and the operation of the following stage will be upset by the positive voltage applied to its grid. An open cathode bypass capacitor C1 will cause the circuit to be degenerative, and will also result in "cross-biasing" of the tubes so that the stage gain will be decreased. A shorted cathode bypass capacitor will result in a loss of bias and distortion of the output signal. Depending upon the configuration of the preceding stage (for example, a preamplifier stage, R-C coupled), it is possible that a positive d-c voltage may be applied to the input potentiometer (R1 or R2) because of a leaky or shorted coupling capacitor. In this case, a positive d-c voltage, the amount of which is determined by the setting of the potentiometer, will be applied to the grid and affect the bias.

If plate-load resistor R4 (or R5) should open, the plate voltage applied to V2 (or V1) will be considerably below normal, since the plate voltage will be applied to the tube through both isolating resistors in series with the plate-load resistor, R5 (or R4) of the other tube, V1 (or V2). As a result, the signal output from the tube with the plate voltage below normal will be extremely low.

If the mixer circuit uses pentode tubes, a leaky screen bypass capacitor or an increase in the value of the screen-dropping resistor will cause reduced gain because of the decreased screen voltage, while an open screen bypass will cause reduced gain because of degeneration within the stage

VIDEO MIXERS.

Video mixing is defined as the combining of two or more video signals. The video signals to be combined consist of various forms of pulse information and may include any number of the following: radar video, beacon video, range markers, range strobe, azimuth markers, IFF video, blanking gates or pulses, and other special forms of information.

The term **video mixer** should not be confused with the term **mixer** used to designate the circuit that heterodynes the r-f and local-oscillator signals in a superheterodyne receiver. Video mixers are considered as "adding" circuits and perform algebraic addition of pulse information; the pulses can be of either polarity and need not be in coincidence. In certain applications, video mixers are designed to combine signals of a given polarity only. Also, in many radar applications, video mixers are designed to combine time-coincidence pulses in a nonadditive manner; operation in this manner prevents excessive output amplitude and possible overloading in subsequent video amplifier stages, and thus prevents "blooming" of the indicator display.

The majority of electron-tube video mixing circuits presently in use are variations of two basic types: the common-cathode video mixer and the common-plate video mixer. Most video mixer requirements can be met by one or the other of these two circuits. The common-cathode video mixer does not invert the signal but acts in a manner similar to the cathode follower, whereas the common-plate video mixer does invert the signal. The common-cathode video mixer is degenerative, and the amplitude of the combined output of the two input signals in coincidence is less than that of the larger input signal. The common-plate video mixer normally has some gain; as a result, the amplitude of the combined output of the two input signals in coincidence is generally greater than the larger of the two input signals. Therefore, if the amplitude of the combined output signal from the common-plate mixer is excessive for the application, modifications to the basic circuit are necessary to reduce the adding effect. Otherwise, the output is likely to overload subsequent video amplifier stages when coincident signals are applied to the input.

A video mixer is normally required to handle pulse information having pulse widths of 0.5 to 500 microseconds and pulse repetition rates of 200 to 2000 pulses per second. Common-cathode video mixers are capable of handling very fast rise-time pulses because of the cathode-follower action of the circuit. Common-plate video mixers are purposely designed with high frequency compensation, to enable them to handle the rise time of the input video pulses.

COMMON-CATHODE VIDEO MIXER.

APPLICATION.

The common-cathode video mixer circuit is used to combine two (or more) input video or pulse signals. Depending upon the circuit configuration, when input signals are in time-coincidence the output signal can be a limited-amplitude combination of the input signals or a nonadditive output signal which is representative of the larger input signal only.

CHARACTERISTICS.

Input signals are of positive polarity; output signal is of positive polarity. Negative input signals can be combined (by the basic mixer circuit) only at very low levels.

Gain of video mixer (as a cathode follower) is approximately 0.75.

Degenerative circuit (cathode follower) provides limited-amplitude additive mixing of time-coincident signal pulses because of common-cathode biasing arrangement. Modification of basic circuit to include fixed bias near cutoff provides nonadditive mixing of time-coincident signal pulses.

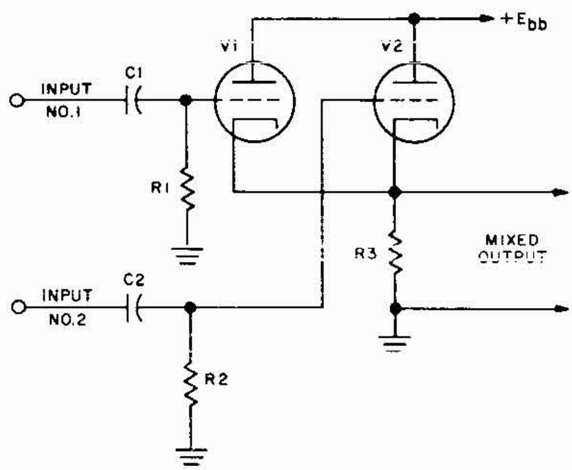
When more than two input signals are to be combined, additional common-cathode video-mixer circuits may be connected in parallel with little change in operating characteristics.

Output impedance is relatively low.

CIRCUIT ANALYSIS.

General. The basic common-cathode video mixer combines two positive video signals. The circuit is fundamentally two cathode followers in parallel with a common cathode resistance. The output polarity is positive, and the combined signal is taken from across the cathode resistance. Any number of positive input signals can be mixed by applying each signal to a separate cathode follower; each cathode follower, in turn, operates into the common cathode resistance. Whether or not any addition of signals occurs in the output depends upon the biasing of the cathode-follower stages.

Circuit Operation. The accompanying circuit schematic illustrates two triode electron tubes in a common-cathode video mixer circuit. Electron tubes V1 and V2 are identical-type triode tubes; although the accompanying schematic illustrates two separate triodes, a twin-triode is commonly used in this circuit. Capacitor C1 couples one input signal to the grid of V1; capacitor C2 couples the other input signal to the grid of V2. Resistors R1 and R2 are the grid resistors for V1 and V2, respectively. Resistor R3 is the common cathode-bias resistor for V1 and



Basic Common-Cathode Video Mixer Circuit

V2, and it is also the cathode load resistance for the video-mixer circuit across which the combined, or mixed, pulse output signal appears. The plate of each tube is tied directly to the supply voltage, $+E_{bb}$. The tolerance of component values in this circuit is not critical, and 10-percent-tolerance parts are normally used.

When voltage is first applied to the circuit, the grids (of V1 and V2) are at zero bias, and the combined plate current of both tubes passes through common-cathode resistor R3 to quickly establish the no-signal, or quiescent, bias. The electron tubes, V1 and V2, are assumed to be identical-type tubes, or a single-envelope twin-triode with identical characteristics; however, a small unbalance in tube characteristics will not greatly affect the circuit operation.

The operation of each tube in the common-cathode video mixer circuit is similar to the operation of the cathode follower, described in Section 6, when the input signals **are not** in time-coincidence. For example, assume a condition where a positive pulse is applied to the input of V1 but no signal is applied to the input of V2. In this instance, as the input signal to V1 increases in a positive direction, the plate current of V1 increases, causing an increased voltage drop across cathode-load resistor R3. As the input signal to V1 falls, the plate current decreases to its former value, causing a decrease in the voltage drop across cathode-load resistor R3. Thus, the output-signal voltage developed across the cathode-load resistor is a reproduction of the original input signal applied to the grid of V1. Furthermore, since the input signal produces a change in the cathode bias, this bias voltage is in phase with the input signal and therefore reduces the amplitude of the grid-to-cathode voltage of V1, producing degeneration of the output voltage. (Cathode-follower gain is always less than one.) Note that as the plate current of V1 increases with signal the voltage developed across cathode-load resistor R3 also increases, and that this instantaneous voltage, in turn, changes the no-signal bias for the grid of V2. Thus, the instantaneous voltage increase developed across R3 by the signal applied to V1 effectively decreases the plate current of V2 and results in a decrease in the plate current of V2 through the common cathode-load resistor, R3. The net result is a decrease in the signal current through the cathode-load resistor because of the cathode-follower action of V1 and the degenerative action of V2. Therefore, the output-signal amplitude for one input signal is always less than the original input-signal amplitude.

The operation of the common-cathode video mixer when two input signals **are** in time-coincidence produces some adding of signals to give a combined output which is always less than the amplitude of the larger of the two coincident input signals and greater than the output signal that results when only one input signal is present. The limited addition of time-coincident positive input signals results from the use of a common cathode-load resistance which causes "cross-biasing" of the two tubes. The extent of signal adding is primarily a function of the value of the cathode resistor, R3, and the level of the input signals. Where the value of the cathode resistor is such that the gain of each stage is considerably less than unity (relatively small value cathode resistor), the biasing action is not complete and some addition of signals will always occur. When the no-signal bias is large (relative large value cathode resistor), but not sufficient to completely cut off the plate current, the gain of the cathode follower is less for small positive signals than for the larger positive signals. This effect is caused by nonlinearity in the gain characteristic at low input levels. Also, the gain is reduced, resulting in the addition of the input signals. Since some additive effect can be tolerated, initial cutoff of plate current for each tube is not necessary, and grid bias is normally obtained by cathode-resistor action only.

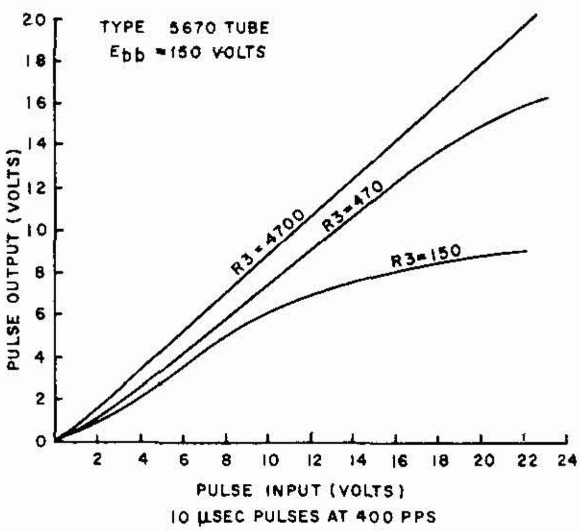
If the output of the common-cathode video mixer is required to operate into a low-impedance coaxial cable which is terminated in a low impedance, the effective value of the cathode-load resistance is also a low value. When this is the case, the gain of the mixer is decreased because of the lower output impedance; therefore, less cross-biasing is produced by coincident signals appearing at the cathode-load resistance.

If the mixer is biased to cutoff, it combines coincident input signals of identical pulse width (duty cycle) in such a manner that only the input with the largest amplitude appears at the output; this manner of operation is called **nonadditive mixing**, and is described later as a modification to the basic mixer circuit.

The following tabulation compares the performance of a typical common-cathode video mixer circuit for three values of cathode-load resistance, 4700, 470, and 150 ohms. Two input signals of different pulse widths were used to obtain the data given. Each individual input level was adjusted to provide the output voltage given in the table, and then the input signals were applied simultaneously to each respective input to obtain time-coincident signals.

The effect in each case was to obtain a combined output which was greater than the output obtained from either signal alone.

Cathode-Load Resistor (ohms)	4700	470	150
Output Volts (for one input)	3.0	3.0	3.0
Output Volts (two inputs in coincidence)	3.6	3.9	4.3
Input No. 1 (volts): 180-μsec pulse at 400 pps	4.1	4.9	8.0
Input No. 2 (volts): 10-μsec pulse at 400 pps	4.0	4.9	6.0



Gain Characteristic of Common-Cathode Mixer

The accompanying graph illustrates the gain characteristic and linearity of a single cathode-follower stage in a typical common-cathode video mixer circuit for three values of cathode-load resistance. Note that the largest value of cathode-load resisistance offers the largest gain and provides the greatest range of linearity; whereas, the smallest value of cathode-load resistance provides less gain and poor linearity. Furthermore, the **additive factor** for time-coincident input signals will increase for the lower values of cathode-load resistance because the stage gain decreases; as a result, less cross-biasing is produced by the combined output signals developed at the common cathode-load resistor.

As previously stated, the output of the common-cathode video mixer for signals in time coincidence is always less than the amplitude of the largest input signal and greater than the output obtained from either input signal alone. An indication of the amount of addition of two signals in time coincidence is given by the **additive factor.** The additive factor (in percent) is expressed as:

$$\text{Additive factor} = 100\,\frac{E_R - E_H}{E_L}$$

where E_R = resultant (combined) output voltage for inputs in coincidence
E_H = output voltage for highest input level
E_L = output voltage for lowest input level

The effect of the value of cathode-load resistance (R3) upon the combined output pulse amplitude and the additive factor can be seen by comparing the results obtained when using different values of cathode-load resistance. In the first example, a 4700-ohm cathode-load resistor is used; in the second example, a 150-ohm cathode-load resistor is used.

a. The value of cathode-load resistor for a video mixer is 4700 ohms. Assume two positive input signals of 4.8 and 4.1 volts amplitude and corresponding output signals of 3.6 and 3.0 volts amplitude. When the input signals are in coincidence, the measured output-signal amplitude is 4.2 volts. Using the formula given above to determine the additive factor:

Given: $E_R = 4.2$
$E_H = 3.6$
$E_L = 3.0$

Therefore:

$$\text{Additive factor} = 100\,\frac{4.2 - 3.6}{3.0} = 100\,\frac{0.6}{3.0}$$

$$= 20 \text{ percent}$$

b. The value of cathode-load resistor for the video mixer is changed to 150 ohms. Again, assume two positive input signals of 4.8 and 4.1 volts amplitude and corresponding output signals of 2.0 and 1.8 volts amplitude. When the input signals are in coincidence, the measured output-signal amplitude is 2.8 volts. Using the formula given above to determine the additive factor:

Given: $E_R = 2.8$
$E_H = 2.0$
$E_L = 1.8$

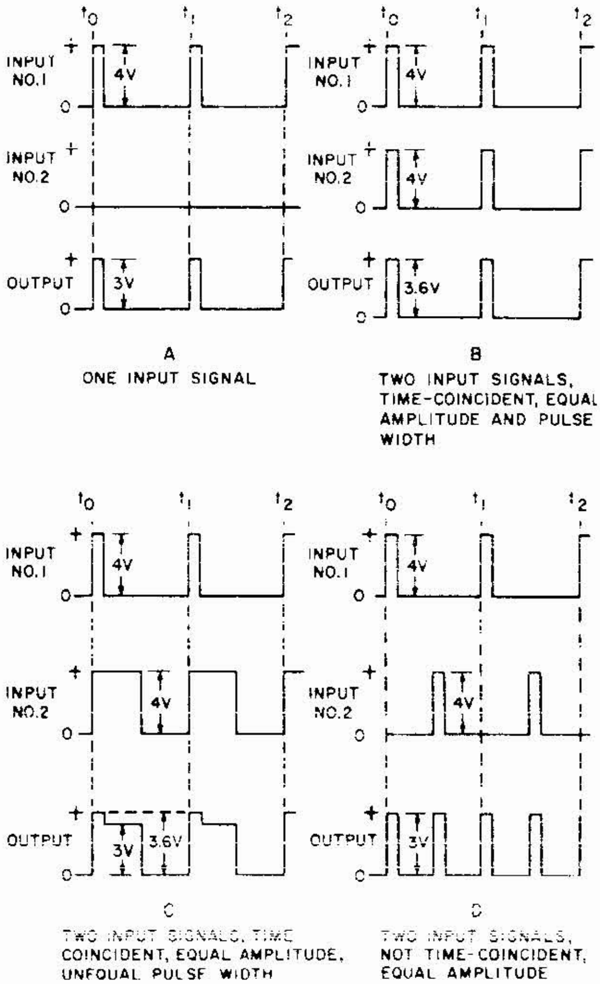
Therefore:

$$\text{Additive factor} = 100\,\frac{2.8 - 2.0}{1.8} = 100\,\frac{0.8}{1.8}$$

$$= 44 \text{ percent}$$

In the two examples given above, when the cathode-load resistor is decreased in value, the gain is also decreased; however, as the gain is decreased the additive factor increases. Conversely, as the cathode-load resistor is increased in value, the gain approaches unity; however, as the gain is increased, the additive factor decreases.

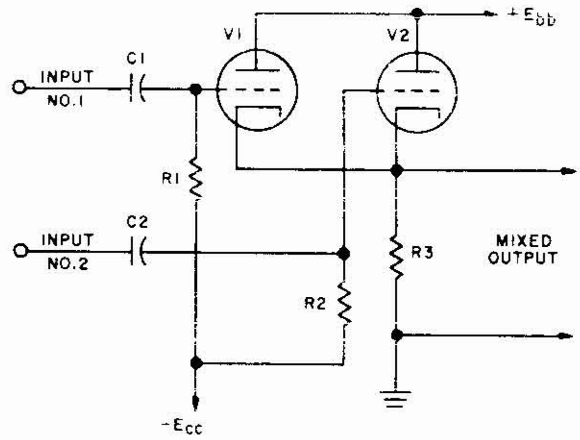
The accompanying waveforms illustrate the signal-combining characteristics of a typical basic common-cathode video mixer for four different signal-input conditions. In part A of the illustration, a 4-volt positive input pulse is applied to one input only, and the resulting output is a 3-volt signal. In part B, a 4-volt input pulse is applied to each input, and the resulting output is a 3.6-volt signal. This output signal results from the additive mixing effect when two input signals of equal amplitude and pulse width combine to produce an output pulse which is greater than the 3-volt output signal of part A (resulting from only one input signal) but which is less than either input signal. In part C, two equal-amplitude input signals of unequal pulse width are applied to the video mixer circuit. This waveform group illustrates the effect of duty cycle on the mixing action. In this case, the additive mixing effect is readily



Theoretical Signal-Combining Characteristics of Basic Common-Cathode Video Mixer

apparent, since the combined signals produce a stepped output waveform which is 3.6 volts at maximum amplitude for the duration of the short pulse, and 3.0 volts amplitude for the remainder of the long pulse. For all practical purposes, upon termination of the short pulse, the output can be assumed to be the result of a single input signal. In part D, two equal-amplitude input signals which are not time-coincident combine to produce a series of 3-volt output pulses. This condition is representative of time-delayed or random pulses (neither input signal in coincidence) and, therefore, each signal produces an output voltage similar to that obtained in part A with one input signal.

In some radar applications, especially where the output pulse information is displayed on a cathode-ray tube indicator as video or range marks, it is desirable to provide some form of limiting for time-coincident pulses so that the output voltage will be the result of the largest signal



Modified Common-Cathode Video Mixer, Nonadditive Circuit

only. The process of combining two signals so that only the larger of the two signals is present in the output is called **nonadditive** mixing.

Modification to the basic common-cathode video mixer to achieve nonadditive mixing consists of biasing the tubes, V1 and V2, approximately to plate-current cutoff. This is accomplished by returning grid resistors R1 and R2 to a source of negative voltage, as illustrated in the accompanying circuit schematic. Then, if the common cathode-load resistance, R3, is made relatively large so that the voltage gain of each cathode-follower stage approaches unity, a signal applied to one grid in excess of the value of fixed bias will produce in the common cathode circuit sufficient cathode bias to prevent the other tube from conducting. For example, assume that the fixed negative bias has been adjusted to provide a quiescent condition at or near plate-current cutoff for both tubes. If a positive video pulse of approximately 10 volts is applied to the grid of V1, the resulting signal appearing across cathode-load resistor R3 will produce approximately 8.5 volts output, which is applied as additional (cathode) bias to the grid of V2. Thus, a signal of less than 10 volts amplitude at the input of V2 cannot overcome the total effective instantaneous grid bias, and the signal does not appear in the output developed across cathode-load resistor R3. As can be seen from this example, the largest input signal at any instant of time effectively takes over the circuit and masks input signals of lesser amplitide. This is true provided that the time-coincident signals have the same pulse width (duty cycle); however, if the signals are of different pulse widths and of sufficient amplitude to overcome the fixed bias, the signal with the longest pulse width will always appear in the output.

FAILURE ANALYSIS.

No Output. The common-cathode video mixer circuit is similar in many respects to a cathode-follower circuit insofar as failures are concerned. Failure of the plate voltage supply will disrupt operation of the circuit, as will an open circuit in the cathode. With a tube known to be good installed in the circuit the filament and plate voltages should be measured, as well as the d-c voltage developed across the cathode-load resistance, to determine whether the applied voltages are within tolerance and whether the cathode resistor, R3, is open. Each input should be checked with an oscilloscope to determine whether signals are applied to the circuit and whether they are of the proper amplitude. Lack of signals at the grid of V1 or V2 can be due to an open coupling capacitor (C1 or C2) or to failure of the external input-signal source. The output circuit should be checked to determine whether the load impedance has decreased or whether the output is shorted. Such a condition would effectively place the cathode at ground potential, resulting in very low or no output; for example, a low value of terminating resistance or a shorted coaxial cable could cause this effect. Also, if the output is taken through an output coupling capacitor, an open in the capacitor would prevent signals from reaching the stage following the mixer.

No Mixed or Combined Output. Assuming that applied voltages are within tolerance and the tube is known to be good, each input signal should be checked with an oscilloscope to determine whether both signals are of correct amplitude and are present at the respective grid of V1 and V2. Lack of a signal at the grid of V1 or V2 can be due to an open coupling capacitor (C1 or C2) or failure of the external input-signal source. If the circuit uses fixed grid bias to place each tube at or near plate-current cutoff, the applied bias should be measured at each grid to determine whether the bias voltage is excessive, thus preventing signals from combining in the cathode circuit.

Low or Distorted Output. If capacitor C1 or C2 is leaky or shorted, any value of d-c voltage present at the input from the previous stage will be applied to the grid of V1 or V2. If the grid is made positive as a result, the tube will conduct additional plate current and cause the cathode voltage to be higher than normal. Thus, positive pulses on the grid will be severely limited in the cathode circuit. Where fixed bias is applied to the grid of V1 and V2, a leaky or shorted coupling capacitor C1 or C2 will cause voltage-divider action to change the value of bias at the grid. This will cause the tube to shift its operating point on the E_g - I_p characteristic curve. Depending upon the previous stage and the input circuit configuration, the bias may be shifted to place the tube in either the cutoff or saturation region.

If the cathode-load resistor (R3) is paralleled with a terminating or impedance-matching resistor, a decrease in the value of either resistance will affect the output voltage. Also, if the output is taken through an output coupling capacitor, a shorted capacitor will affect the output voltage, since the impedance in the cathode circuit will be decreased and a d-c path will be provided in parallel with the cathode-load resistance.

COMMON-PLATE VIDEO MIXER.

APPLICATION.

The common-plate video mixer circuit is used to combine two (or more) input video or pulse signals. The mixer circuit normally has some gain. When two positive input signals are in time-coincidence, the circuit performs algebraic addition to produce a combined output signal which is of greater amplitude than the output produced by either input signal alone.

CHARACTERISTICS.

Produces inverted signal in output; input signals of positive polarity produce output signals of negative polarity. The circuit is capable of combining small negative input signals to produce positive output signals.

Gain of normal video mixer (as designed) is slightly greater than unity for single input signal; gain is always greater than unity for time-coincident input signals.

When more than two input signals are to be combined, additional common-plate video-mixer circuits may be connected in parallel with little change in operating characteristics.

Output impedance is approximately equal to the value of plate-load resistance at low and medium frequencies, but decreases at high frequencies unless compensation is used.

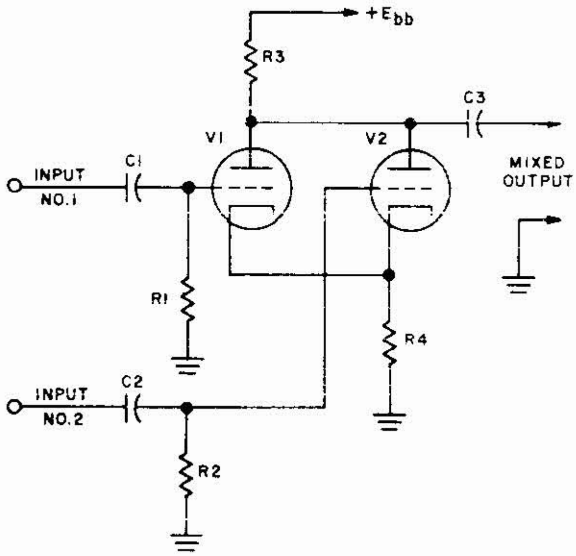
High-frequency compensation, if required, is accomplished by the addition of a series plate-load inductance or a cathode bypass capacitor of relatively small value.

CIRCUIT ANALYSIS.

General. The basic common-plate video mixer combines two positive input signals. The circuit is fundamentally two video amplifiers in parallel with a common plate-load resistance. The output polarity is negative, and the combined signal is taken from the plate circuit.

The common-plate video mixer has good adding characteristics for signals in time-coincidence. For this reason, when the input signals are time-coincident, the circuit may not be satisfactory for certain radar applications unless modifications are made to reduce the adding effect and prevent overloading of subsequent video amplifier stages. In some applications the video mixer circuit is followed by a limiter or cathode follower, or each input is preceded by a limiter. The circuit described here purposely has a very low plate-load resistance and an unbypassed cathode resistance, to keep the gain as low as possible. Also, the use of a low value of plate-load resistance makes frequency compensation unnecessary.

Circuit Operation. The accompanying circuit schematic illustrates two triode electron tubes in a common-plate video mixer circuit. Electron tubes V1 and V2 are identical-type triode tubes; although the accompanying schematic illustrates two separate triodes, a twin-triode is commonly used in this circuit. Capacitor C1 couples one input signal to the grid of V1; capacitor C2 couples the



Basic Common-Plate Video Mixer Circuit

other input signal to the grid of V2. Resistors R1 and R2 are the grid resistors for V1 and V2, respectively. Resistor R3 is the common plate-load resistor for V1 and V2 and is generally a low-value resistance. Capacitor C3 is the output-coupling capacitor. Resistor R4 is the common cathode-bias resistor. The circuit utilizes a low value of plate-load resistance to achieve an extremely short rise time; no high-frequency compensation (plate-load inductance or cathode bypass) is used. The unbypassed cathode resistor makes the circuit degenerative, and also keeps the stage gain stabilized throughout the life of the tube to compensate for tube aging. The tolerance of component values in this circuit is not critical; 10-percent-tolerance parts are normally used.

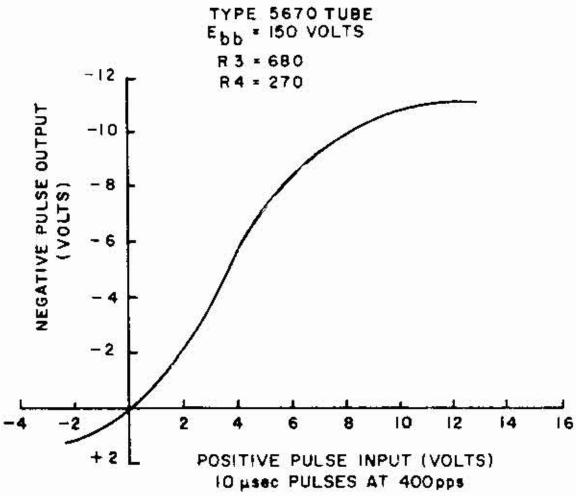
When voltage is first applied to the circuit, the grids (of V1 and V2) are at zero bias, and the combined plate current of both tubes passes through common-cathode resistor R4 to quickly establish the no-signal, or quiescent, bias. The electron tubes, V1 and V2, are assumed to be identical-type tubes, or a single-envelope twin-triode with identical characteristics; however, a small unbalance in tube characteristics will not greatly affect the circuit operation.

The operation of each tube in the common-plate video mixer circuit is similar to the operation of the triode video amplifier, described in Section 6, when the input signals **are not** in time-coincidence. For example, assume a condition where a positive pulse is applied to the input of V1 but no signal is applied to the input of V2. In this instance, as the input signal to V1 increases in a positive direction, the plate current of V1 increases, causing an increased voltage drop across plate-load resistor R3; therefore, the voltage at the plate of V1 falls. As the input signal to V1 falls, the plate current decreases to its former value, causing a decrease in the voltage drop across plate-load resistor R3, and the plate voltage at V1 returns to its former value. Thus, a positive-going pulse applied to the grid has produced a negative-going pulse at the plate, resulting in signal inversion. However, since the cathode resistor, R4, is not bypassed, degeneration is introduced in the circuit, and the signal developed across cathode resistor R4 resulting from the change in V1 plate current is in phase with the input signal; therefore, the amplitude of the instantaneous grid-to-cathode signal voltage of V1 is reduced. The stage gain is also reduced, and, as a result, the amplitude of the negative signal developed in the plate circuit is effectively limited. The plate-load resistor, R3, is purposely a low value of resistance, and because of degeneration in the cathode circuit (resistor R4 is not bypassed) the gain of the stage is practically reduced to unity for a single input signal.

Note that as the plate current of V1 increases with signal, the voltage developed across cathode resistor R4 also increases, and that this instantaneous voltage, in turn, changes the no-signal bias for the grid of V2. Thus, the instantaneous voltage increase, developed across cathode resistor R4 by the signal applied to V1, appears as additional bias to the grid of V2 and effectively decreases the plate current of V2 through the common plate-load resistor, R3, and the common cathode resistor, R4. The net result is a limiting of the maximum instantaneous signal current through R3 and R4 because of the cathode-follower action of V1 and the degenerative action of V2. Thus, the negative output-signal amplitude at the plate for one input signal is only slightly greater than the original input-signal amplitude.

The operation of the common-plate video mixer when two positive input signals **are** in time-coincidence produces addition of the signals, to give a combined negative output signal which is always greater than either of the two coincident input signals and greater than the output signal that results when only one input signal is present. The common cathode resistor, R4, is purposely left unbypassed to obtain degeneration and "cross-biasing" of the tubes; therefore, the amplitude addition of time-coincident signals is somewhat limited.

The accompanying graph illustrates the gain characteristic of a common-plate video mixer for one input signal. In practice, the circuit is normally supplied positive input pulses. Since the gain characteristic is nonlinear, a small positive input pulse will produce a negative output pulse which is only slightly greater than the input (gain approximately unity); whereas input pulses from approximately 3 to 9 volts result in a gain greater than unity, and input pulses greater than 9 volts result in a gain less than unity. Note that if small negative pulses are applied to an input, a small positive output pulse will be obtained.



Gain Characteristic of Common-Plate Mixer

Two additional tubes can be paralleled with the mixer circuit, if desired, to provide four inputs. If the values of the plate and cathode resistors (R3 and R4) are not changed, the gain of each stage will be reduced to half the gain obtained for two tubes; however, if cathode resistor R4 is reduced accordingly to keep the bias approximately the same as for two tubes, the gain of each of the four tubes will be slightly greater than unity.

An indication of the amount of addition of two signals in time coincidence is given by the **additive factor.** The additive factor (in percent) is expressed as:

$$\text{Additive factor} = 100\ \frac{E_R - E_H}{E_L}$$

where: E_R = resultant (combined) output voltage for inputs in coincidence

E_H = output voltage for highest input level

E_L = output voltage for lowest input level

The signal addition occurring at the plate as a result of combining two time-coincident input signals compared to the output obtained for a single input can be seen from the measured results obtained from a typical common-plate video mixer. The mixer in this example used a plate-load resistor (R3) of 680 ohms, a cathode resistor (R4) of 270 ohms, and a supply voltage (E_{bb}) of 150 volts. Two equal positive input signals of 3.5 volts amplitude produced equal corresponding negative output signals of 4.0 volts amplitude. When the two input signals were applied to the mixer input circuit in time-coincidence, the measured output-signal amplitude at the plate was 6.2 volts. Using the formula given above to determine the additive factor:

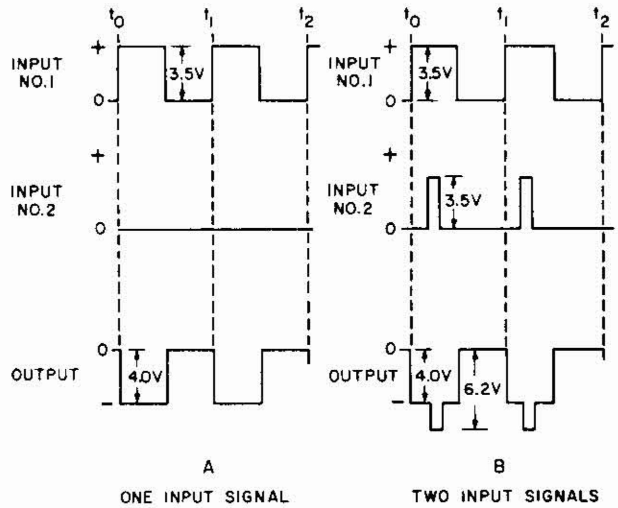
Given: E_R = 6.2

E_H = E_L = 4.0

Therefore: Additive factor =

$$100\ \frac{6.2 - 4.0}{4.0} = 100\ \frac{2.2}{4.0} = 55 \text{ percent}$$

From the example it is seen that the common-plate video mixer combines time-coincident input signals in an additive manner.



Theoretical Signal-Combining Characteristics of Basic Common-Plate Video Mixer

The accompanying waveforms illustrate the signal-combing characteristics of a typical basic common-plate video mixer for two different signal-input conditions. In part A of the illustration, a 3.5-volt positive input pulse is applied to one input only, and the resulting negative output is a 4-volt signal. In part B, a 3.5-volt input pulse is applied to each input; the pulses are of equal amplitude but are of unequal pulse width (duty cycle). The resulting combined output signal is a negative pulse which is 6.2 volts maximum amplitude when the two signals are time-coincident. Note that the longer input pulse produces a 4-volt output signal and that, when the short input pulse is applied to the circuit, the combined output signal is increased to 6.2 volts for the duration of the short pulse.

This type of mixer cannot prevent overloading of subsequent video amplifier stages by time-coincident input signals; therefore, the mixer is usually followed by a limiter stage to limit the output signal applied to the video amplifier chain. The limiting level is determined by the highest output-signal amplitude resulting from one input signal; any additional output-signal amplitude resulting from two input signals in time-coincidence will result in clipping at the limiter stage.

FAILURE ANALYSIS.

No Output. The common-plate video mixer circuit is similar in many respects to a video-amplifier circuit insofar as failures are concerned. Failure of the plate-voltage supply will disrupt operation of the circuit, as will an open circuit in the cathode. With a tube known to be good installed in the circuit, the filament and plate voltages should be measured, as well as the d-c voltage developed across the cathode resistance, to determine whether the applied voltages are within tolerance and whether the plate-load resistor (R3) or cathode resistor (R4) is open. Each input should be checked with an oscilloscope to determine whether signals are applied to the circuit and whether they are of the proper amplitude. Lack of signals at the grid of V1 or V2 can be due to an open coupling capacitor (C1 or C2) or to failure of the external input-signal source. An open output coupling capacitor (C3) will prevent signals from reaching the stage following the mixer; a leaky or shorted output coupling capacitor will form a voltage divider with the input resistor of the following stage. Thus if the input resistor of the following stage is returned to ground or to a negative supply, the voltage at the plates of V1 and V2 will be reduced, and the operation of the following stage will be upset by the change in voltage applied to the grid.

No Mixed or Combined Output. Assuming that the applied voltages are within tolerance and the tube is known to be good, each input signal should be checked with an oscilloscope to determine whether it is of correct amplitude and is present at the respective grid of V1 and V2. Lack of a signal at the grid of V1 or V2 can be due to an open coupling capacitor (C1 or C2), an open grid resistor (R1 or R2), or failure of the external input-signal source.

Low or Distorted Output. If one input coupling capacitor (C1 or C2) is leaky or shorted, any value of d-c voltage present at the input from the previous stage will be applied to the grid (V1 or V2) by voltage-divider action of the capacitor and grid resistor (R1 or R2). If the grid is made positive, the tube will conduct additional plate current and cause the cathode voltage developed across R4 to be higher than normal. Thus, the bias of one tube is shifted because of a change in voltage at the grid, and the bias of the other tube is changed as a result of a change in cathode voltage. Since the input pulses are positive, it is possible that plate-current saturation will occur for the first tube and that the second tube will provide an output pulse of reduced amplitude when time-coincident signals are applied to the circuit. The output, therefore, will be low or distorted and will not be representative of a normal mixed or combined output.