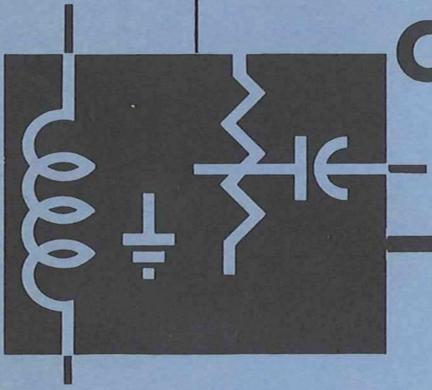
SOME BASIC VACUUM TUBE CIRCUITS



used in

TEKTRONIX INSTRUMENTS

FIP-11

An expansion of lecture notes prepared in 1958
by John Mulvey, Product Information

Third Revision, Sept. 1964

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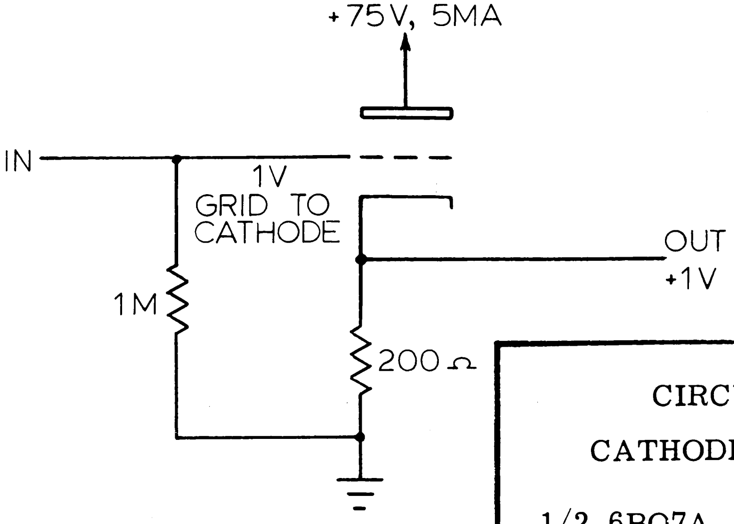
SOME BASIC VACUUM TUBE CIRCUITS
USED IN
TEKTRONIX INSTRUMENTS

FOREWORD

Similar configurations appear throughout Tektronix circuitry. A good understanding of these basic circuits aids in maintenance and calibration of the various instruments. Furthermore, troubleshooting procedures often involve these circuits. Some engineering aspects are discussed where it might prove helpful, although generally the treatments are as brief as possible.

The sequence of the descriptions is arranged so that very little repetition of certain principles need be made; an understanding of one circuit should pave the way for easier understanding of subsequent ones. Accordingly, any random reference to the descriptions should be made with the realization that an understanding of foregoing principles may be required.

The notes do not cover all the basic circuits used in Tektronix instruments. Only those circuits are described that are considered to be especially important or unconventional.



CIRCUIT NO. 1

CATHODE FOLLOWER

1/2 6BQ7A, GM ABOUT 5000

CATHODE FOLLOWER
(GENERAL)

The cathode follower has two special characteristics that make it essential in some applications: low output impedance and low input capacitance.

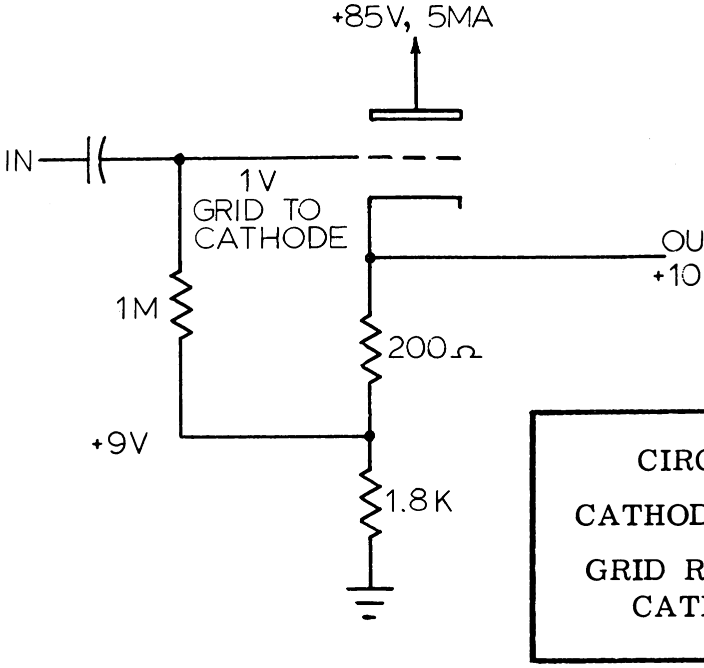
Basically the output impedance of a cathode follower is not determined by the value of the cathode resistor; rather, it is roughly equivalent to the reciprocal of the transconductance of the vacuum tube used, at the point where it biases itself. Output impedance is typically on the order of a few hundred ohms. For instance, a tube that can be operated as a cathode follower in a condition where its transconductance is 5000 micromhos (.005 mhos) will have an internal impedance of about 1/.005 or 200 ohms. If, in this situation, the proper cathode resistor should also work out to be 200 ohms (as in Circuit No. 1), the output will be a load equal to the cathode follower impedance; consequently, only about one-half of the signal voltage appearing at the grid will appear at the cathode. Cathode followers that swing down, as well as up, from a quiescent level will usually be biased about halfway between cut-off and zero bias.

Cathode followers with low-impedance loads cannot follow large grid signals without the tube cutting off on negative swings, or without severe distortion caused by grid-current flow on positive-going swings.

There are two reasons why the input capacitance of a cathode follower is lower than that of other configurations:

1. There is no Miller-effect capacitance because the plate voltage does not change.
2. Since the charge on the grid-cathode capacitance changes by only a fraction of the voltage through which the grid swings, only part of this capacitance adds to the input capacitance.

The manner in which the effective grid-cathode capacitance is reduced can be visualized in another way by considering the low-impedance cathode signal as assisting the grid signal. This principle can be used to raise the low-frequency input impedance as well as the high-frequency input impedance (see Circuit No. 2).



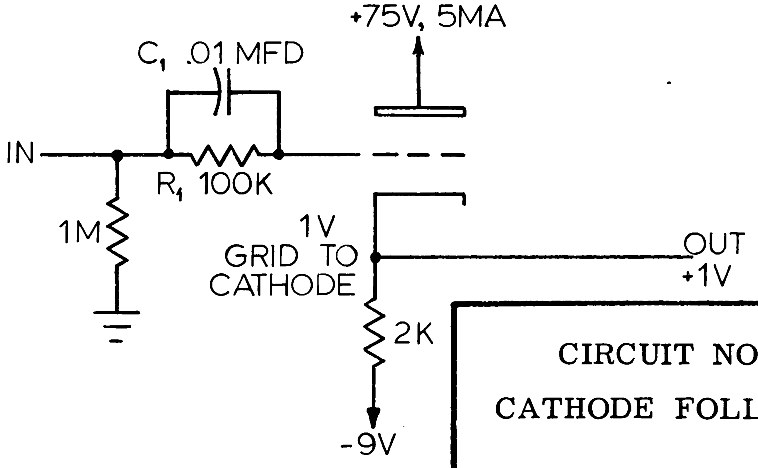
CIRCUIT NO. 2
CATHODE FOLLOWER
GRID RETURNED TO
CATHODE CKT.

CATHODE FOLLOWER
(GRID RETURNED TO CATHODE CIRCUIT)

The low-frequency input impedance of this circuit is raised much higher than the value of the one-megohm grid resistor. The signal voltage at the bottom end of the grid resistor follows and is nearly equal to the grid voltage; the difference between input and output appears across the grid resistor. This difference voltage is only about 10 percent of the input voltage (in this case); the current through the one-megohm resistor, therefore, is only about one-tenth of what it would be with full signal voltage across it. The current that does flow is a measure of input impedance, and indicates that the input impedance (for low frequencies) is raised about 10 times to about 10 megohms.

The total cathode resistance is 2000 ohms for this figure, 10 times what it was when the bias resistor was returned directly to ground. For a given input signal the cathode signal will be nearly double what it was with a 200-ohm load. That is, the cathode will follow the grid about 90 percent (instead of about 50 percent) of the way through its voltage excursions. The reason for the improved following-action is that a much smaller cathode-current change is required through 2000 ohms than through 200 ohms to produce a given cathode-voltage change. The grid-cathode voltage (difference voltage between input and output) then will be only large enough to account for the small current change needed to establish the output voltage, and the output will be more nearly equal to the input.

An input capacitor is shown to indicate the probable need to isolate the quiescent +9 volt grid-to-ground voltage from the signal source.



CIRCUIT NO. 3
CATHODE FOLLOWER
LONG-TAILED

CATHODE FOLLOWERS
(LONG-TAILED OR CONSTANT-CURRENT)

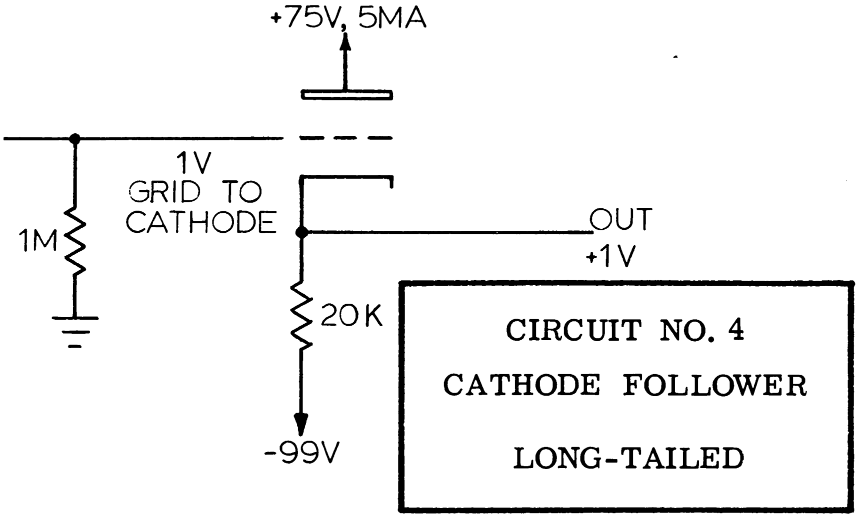
If the cathode resistor of a cathode follower returns to a voltage well below the grid level, the cathode is said to have a long tail. When the quiescent grid voltage is at ground level (zero volts), a negative supply voltage is of course required. This is a good arrangement for input circuits since it makes an input capacitor unnecessary, permitting DC coupling when desired.

The further the cathode supply voltage is below the grid level, the higher the value of the cathode resistor must be to maintain equivalent bias and current for the cathode follower. The higher the cathode resistance, the more favorable the following-action of the cathode, and higher amplitudes of grid-signal swing can be handled.

Long-tailing of cathodes adds another important feature: stability of gain. For a given tube operated with a given plate (or screen) voltage, the transconductance is primarily a function of the cathode current. Constant cathode current is therefore important for gain stability in any amplifier circuit where the gain depends primarily on transconductance. Cathode-emission changes occur with changes in filament voltage (temperature) and with tube aging, and tend to change the cathode current. Ordinarily, self-biasing circuits reduce such changes, but long-tailing of cathodes further reduces the changes and approximates a condition of constant current.

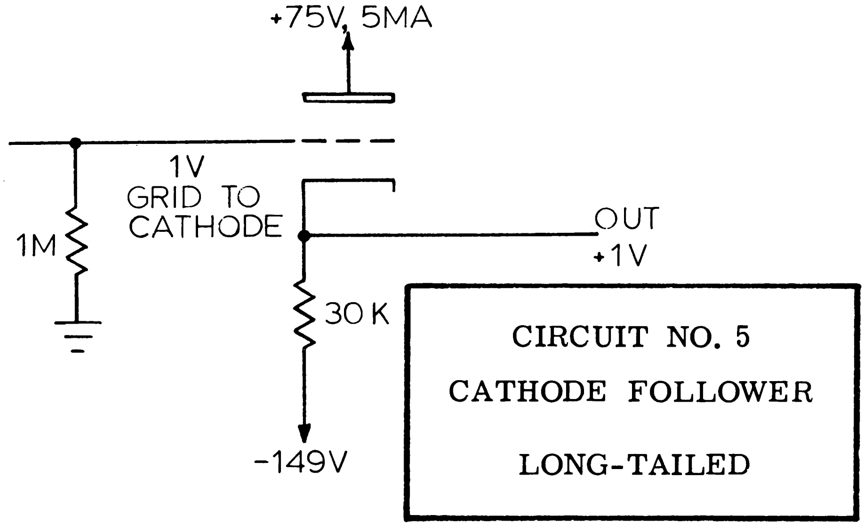
When a long-tailed cathode follower has to drive a large capacitive load, a rather unusual thing happens: The cathode follower can follow better (faster) going up than coming down. The rate at which it can charge going up is limited only by the rate at which zero-bias (full) cathode current will charge the capacitance. Coming down, the discharge rate is limited by the time constant of the cathode resistor and the load capacitance. At high frequencies (or short risetimes), even very small capacitive loads may impose limitations on the following-action of long-tailed cathode followers.

Circuit No. 3 behaves very much the same way as No. 2 except that the input impedance is no higher than the grid-to-ground resistor. Because the grid returns to ground, however, the input signal can be coupled directly to the grid. The network consisting of R_1 and C_1 can be inserted with no effect upon the normal operation of the circuit. The purpose of the network would be to prevent excessive grid current should too high a positive voltage be applied to the input.



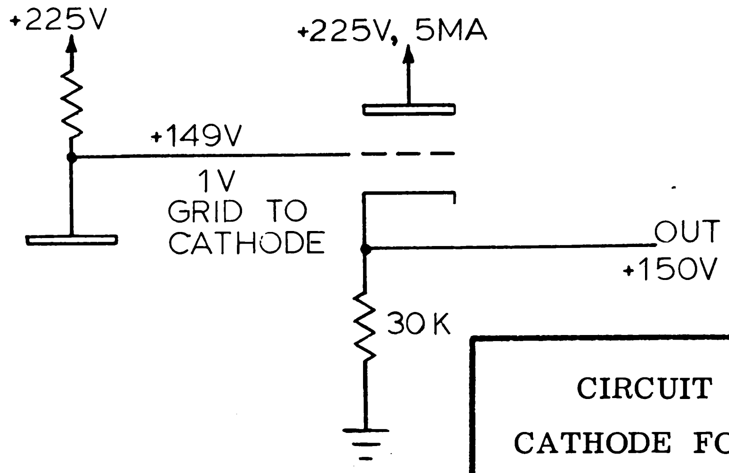
CIRCUIT NO. 4
CATHODE FOLLOWER
LONG-TAILED

Circuit No. 4 acts essentially the same as No. 3, with improved following-action, improved gain stability, and the ability to handle larger grid signals.



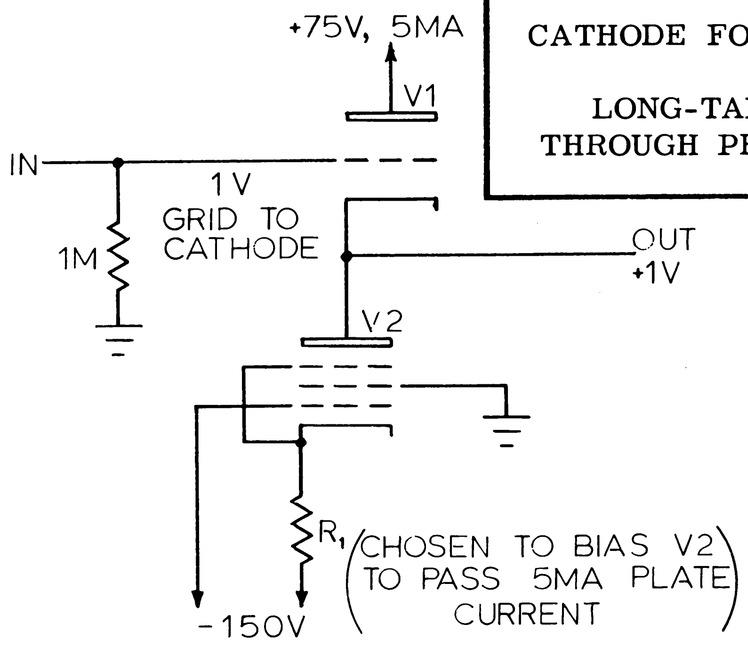
CIRCUIT NO. 5
CATHODE FOLLOWER
LONG-TAILED

Circuit No. 5 is a slight improvement on No. 4 for the same reasons that No. 4 is an improvement on No. 3. Its cathode supply voltage of -149 volts is nearly typical of the -150 volts used so frequently. In fact, if the supply had actually been made -150 volts, the current would be different by only three-fourths of one percent. Even normal variations in tolerance of one-percent resistors could account for as much difference.



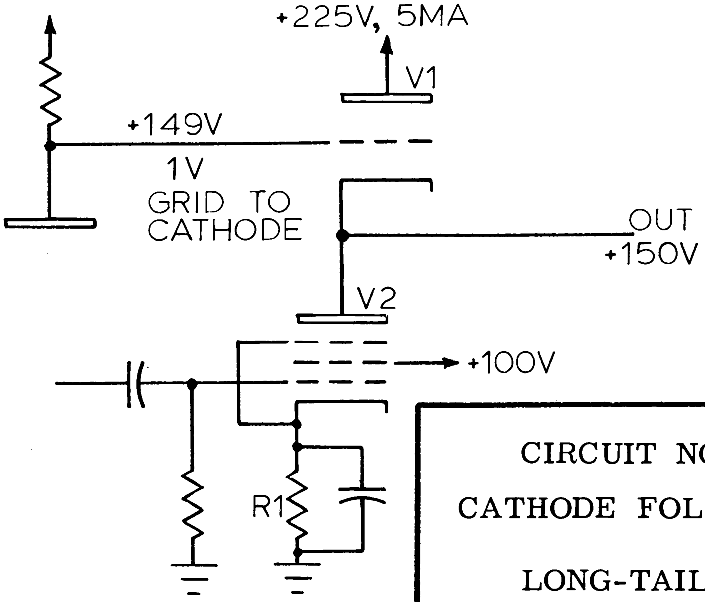
CIRCUIT NO. 6
CATHODE FOLLOWER
LONG-TAILED

Circuit No. 6 is the same as No. 5 except that the grid is 149 volts above ground, which allows the cathode to return to ground instead of to a voltage below ground.



CIRCUIT NO. 7
CATHODE FOLLOWER
LONG-TAILED
THROUGH PENTODE

Circuit No. 7 shows a pentode tube substituting for the cathode resistor. Pentodes can be operated with very high plate resistance (on the order of a megohm); in this way their effect is to extend the negative supply voltage many hundreds of volts and make the constant-current characteristic extremely flat.

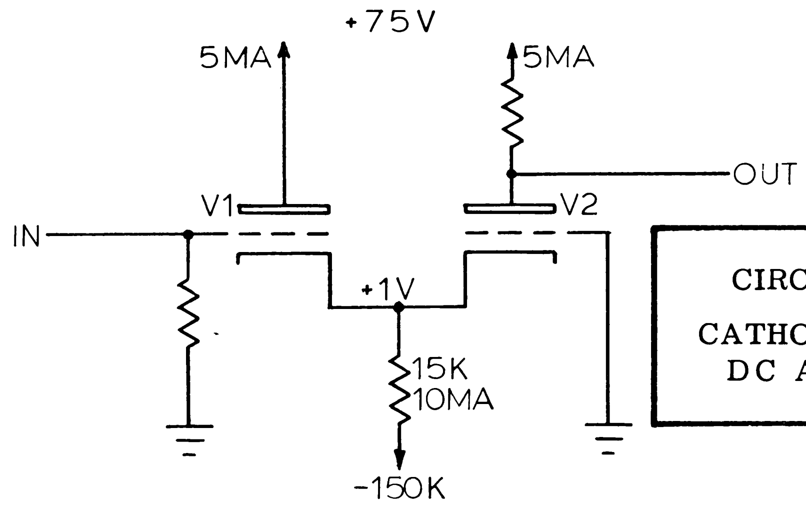


CIRCUIT NO. 8

CATHODE FOLLOWER

**LONG-TAILED
THROUGH PENTODE**

Circuit No. 8 is the same as No. 7 except that the cathode of the pentode is supplied from ground. The grid circuit is shown able to accept special control voltages; this permits the cathode resistance of V_1 to become dynamic. One use of this special characteristic is to permit any cathode-follower load capacitance to discharge faster than it otherwise would be able to, as for fast negative-going sawtooth (sweep) voltages. In this case, a suitable control voltage is available by differentiating a simultaneous positive-going sawtooth voltage. A differentiated sawtooth voltage, except at its very beginning, produces a constant voltage proportional to the rate of voltage change.

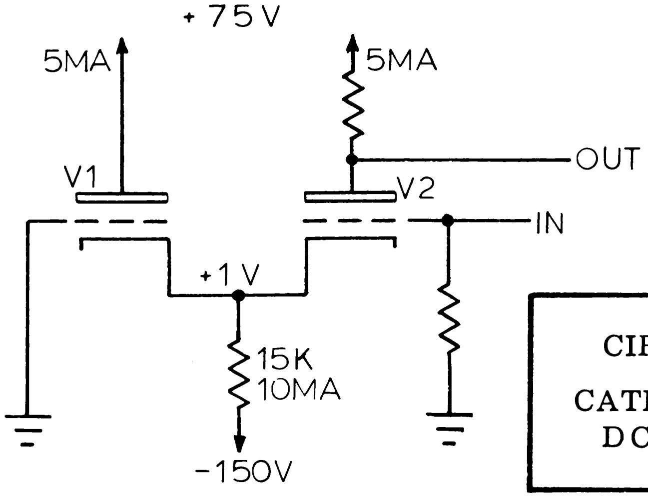


CIRCUIT NO. 9

CATHODE-COUPLED DC AMPLIFIER

CATHODE-COUPLED DC AMPLIFIERS

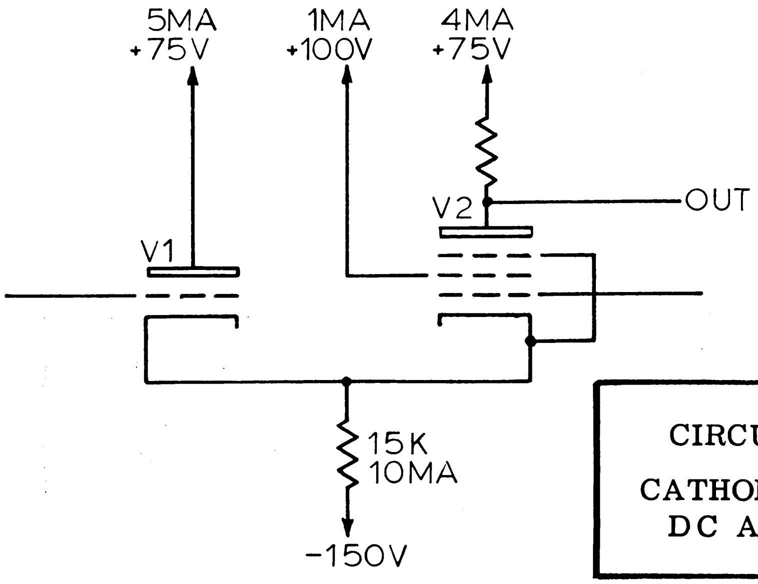
If a cathode follower is used to drive the cathode, rather than the grid, of a second tube (Circuit No. 9), the grid may be operated at a fixed voltage and the advantages of grounded-grid operation will result. Such a circuit permits the two cathodes to share the same resistor. If both tubes have the same transconductance, and the plate-load resistor is small (less than 1 k), only about one-half of the input signal will appear at the cathode, for the cathode impedance of V_2 will be the load for the cathode follower V_1. The gain through such a circuit will be only about one-half of what might be expected, since the signal at the cathode (about one-half of the input signal) will be the grid-cathode signal for V_2. If V_2 has less transconductance than V_1, the cathode impedance of V_2 will be considerably higher than that of V_1; consequently, more than one-half of the grid signal of V_1 will appear as a cathode signal. Under such conditions the gain will be higher. A large plate load on V_2 will reduce its effective transconductance. This will not be true, however, if V_2 is a pentode. Notice that there is no phase reversal between the output signal and the input signal.



CIRCUIT NO. 10

CATHODE-COUPLED DC AMPLIFIER

In Circuit No. 10 the input signal is introduced on the other grid; the grid of V_1 is grounded. V_1, which serves to decouple the cathode signal, is about 50 percent effective, leaving about half of the input signal at the cathode as degeneration. The gain either way, then, is about the same. The primary difference is that the improved bandpass of grounded-grid operation may be lost due to the Miller-effect when operated in the way described above. If the transconductance of V_1 is considerably higher than that of V_2, the cathode signal will be reduced to considerably less than 50% of the grid signal of V_2, and the amplifier will have higher gain.



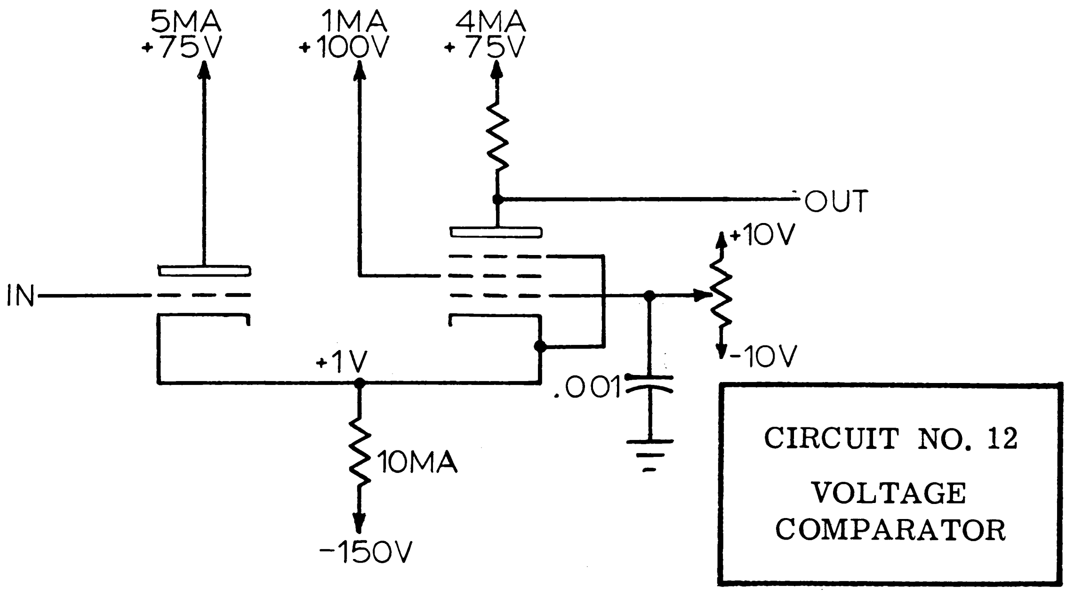
CIRCUIT NO. 11

CATHODE-COUPLED DC AMPLIFIER

If a suitable pentode is used for the second half, the Miller-effect is reduced, and nearly equal gain and bandwidth characteristics result for the two modes, as in Circuit No. 11.

CATHODE-COUPLED VOLTAGE-COMPARATOR AMPLIFIERS

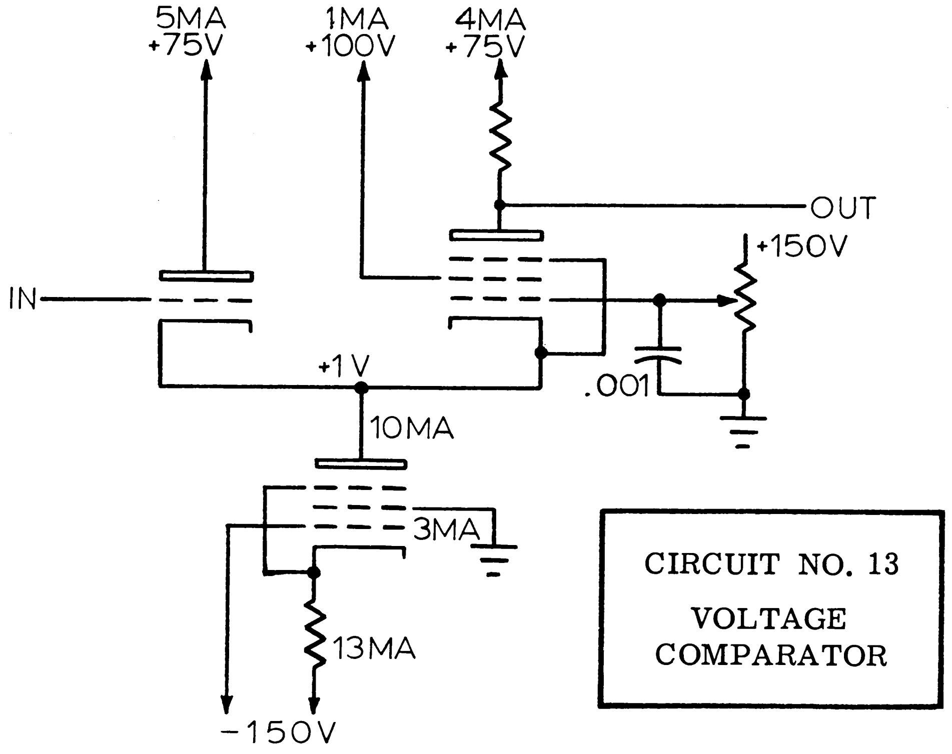
In the foregoing cathode-coupled circuits, the quiescent DC level of both grids was ground. If there were a difference between the two DC levels, the DC output level would indicate which input level was higher. That is, if the grid of V_1 were slightly higher than the grid of V_2, the output plate voltage would be considerably higher than normal; if the grid of V_2 were slightly higher than the grid of V_1, the output voltage would be considerably lower than normal. The output voltage, then, is a measure of how closely the instantaneous voltage on the two grids compares, and is an indication of which is higher. The circuit is a voltage comparator as well as amplifier.



CIRCUIT NO. 12

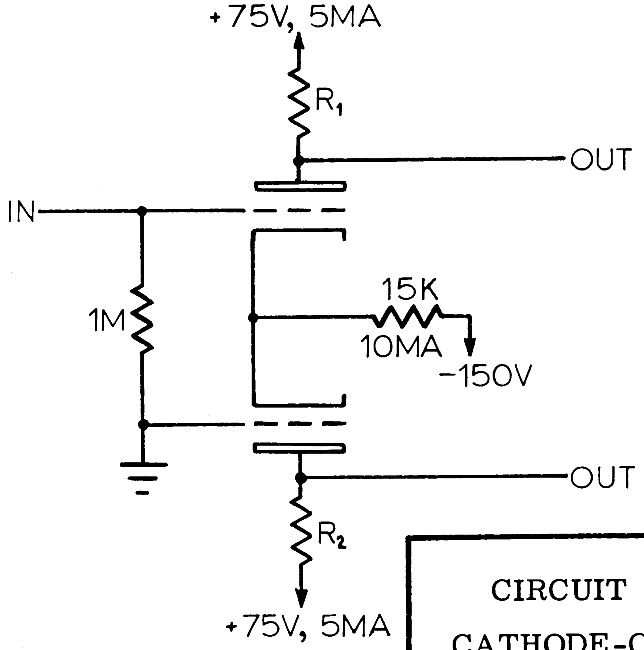
VOLTAGE COMPARATOR

If a means is provided for manually fixing the DC level of one grid, as in Circuit No. 12, the output plate voltage will swing through a definite region whenever the input signal voltage crosses through a level equal to that of the fixed grid. To allow fast-changing cathode voltages fully to charge and discharge the grid-cathode capacitance, the fixed grid is bypassed with a capacitor considerably larger than the grid-cathode capacitance. As long as the cathodes are long-tailed, the range of level adjustment can be quite large, giving the circuit the ability to compare widely different levels on any signal. The use of a pentode for the common cathode resistor permits more accurate comparisons over a wider voltage range, especially for upward swings (see Circuit No. 13).



CIRCUIT NO. 13

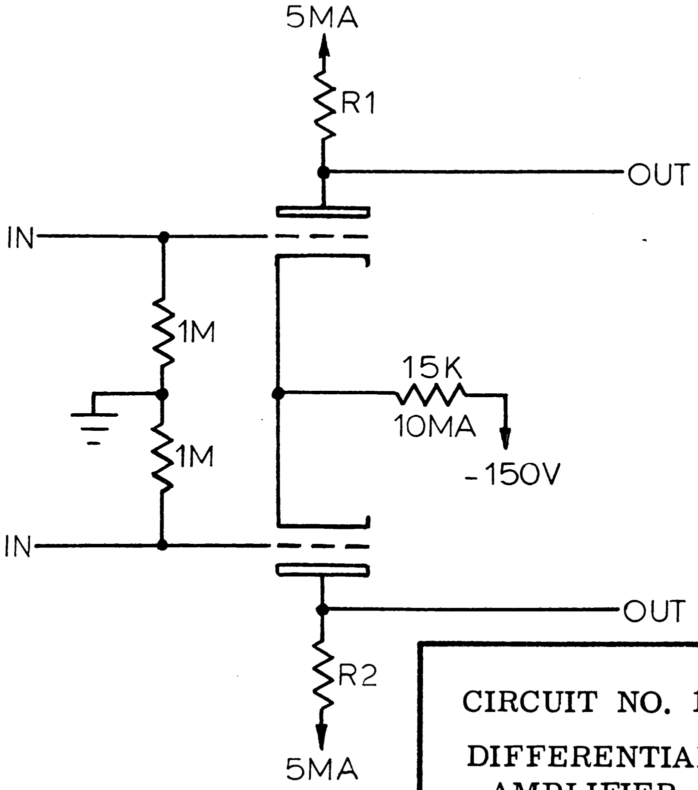
VOLTAGE COMPARATOR



CIRCUIT NO. 14
CATHODE-COUPLED
PHASE INVERTER

If a plate resistor is added to the plate circuit of the cathode-follower section of Circuits 9, 10, and 11, output signals of both phases are available simultaneously. If the two tubes are of the same type and have plate resistors of equal values, as in Circuit No. 14, the two output signals will be well balanced push-pull voltages. This circuit is a paraphase inverter with a long tail. The long tail provides especially well balanced output signals as well as good gain stability. The 50 percent loss of gain is recovered by having a push-pull signal result from a single-ended input.

The circuit, by being symmetrical, has very good hum-free, drift-free characteristics. Power supply ripple voltages at the two plates will be equal and of the same phase, and so will produce no push-pull output.



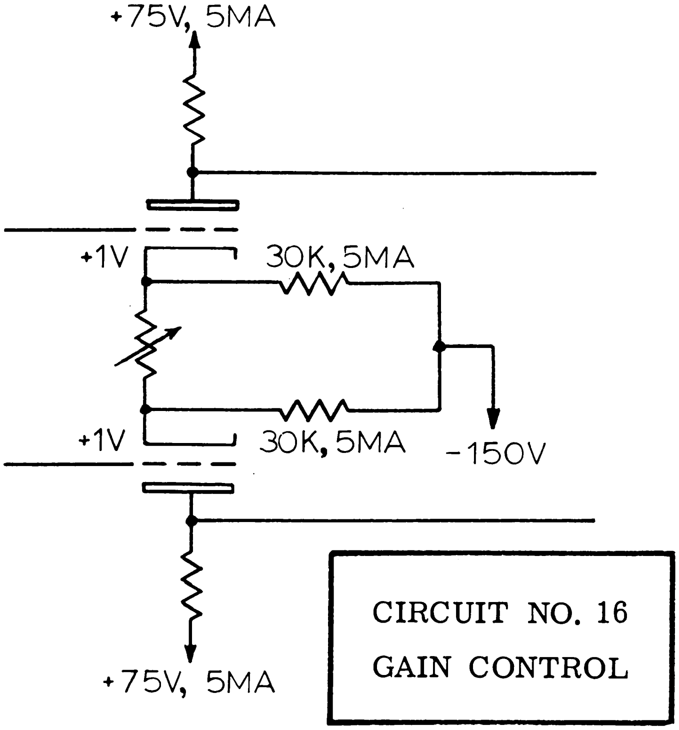
CIRCUIT NO. 15
DIFFERENTIAL AMPLIFIER

DIFFERENTIAL AMPLIFIER

If balanced push-pull signals are applied to each grid of Circuit No. 14 (as in Circuit No. 15), there will be no cathode signal and no degeneration. Balanced signals are those that have equal amplitudes but opposite phase. As long as a positive-going signal on one grid is accompanied by an equal negative-going signal on the other grid, an increase in current in the first tube will be accompanied by an equal decrease in current in the second tube; the net change in current through the cathode resistance will be zero. This holds true essentially as long as either tube does not get cut off or draw grid current: Class A operation. If one tube should get cut off, strong degeneration to the opposite tube takes place and is usually desirable. If quiescent bias is not too close to zero volts, one tube will cut off before the other draws grid current. The conducting tube, then, will act like a cathode follower and will not draw grid current even with large positive-going signals.

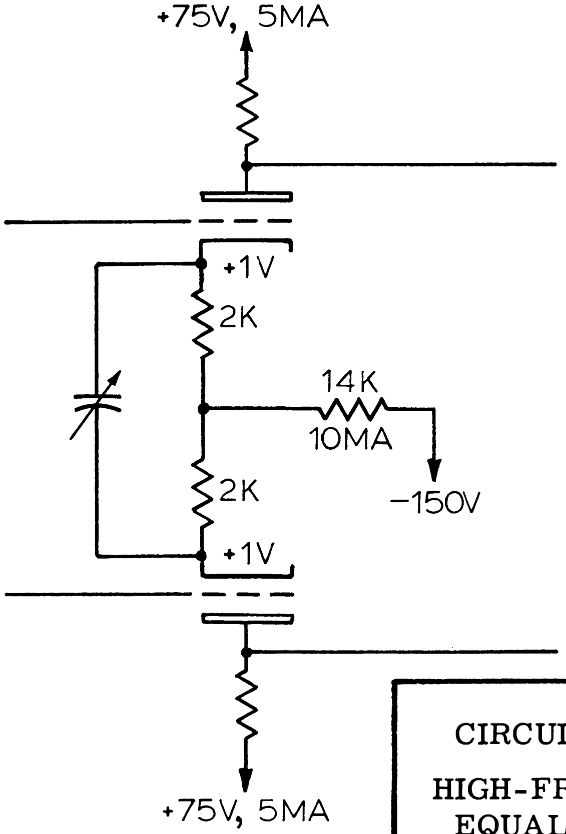
In a push-pull amplifier with common long-tailed cathodes, it is the out-of-phase signals in the two halves that are amplified; in-phase signals suffer strong degeneration and are attenuated. Besides being attenuated, equal in-phase signals that reach the output deflection plates are basically incapable of producing deflection anyway, because beam deflection is determined by the difference in deflection plate voltages rather than by the deflection plate voltage with respect to ground.

A push-pull amplifier that does a good job of cancelling equal in-phase (common-mode) signals is called a differential amplifier, since only the difference between two input signals is manifested at the output. The manner in which cancellation of common-mode signals takes place may be explained further. To test for common-mode cancellation, one signal is applied to both inputs. If necessary, the input signal amplitude should be increased until some output is observable. The common-mode rejection ratio will be the ratio of the input signal amplitude applied in this way to the input signal amplitude required to produce the same deflection when applied to one input only. Using only one signal at both input grids requires that the two grids be tied together. Since the grids are tied together and the cathodes also are tied together, the two inputs behave as one input with very strong cathode degeneration. That is, a grid signal produces very little change in cathode current, so there is very little plate signal. Even with plate resistors equal in value to the cathode resistor, only about one-half as much signal voltage would appear at the plates as appears at the grids; a loss instead of a gain. Subsequent stages further attenuate the signal.



PUSH-PULL STAGE GAIN CONTROL

If, instead of using just one cathode resistor in a push-pull stage, two are used (that have a parallel equivalent value equal to the one), a single variable resistor between the cathodes will control the gain. To understand why, imagine the resistor to be variable between zero ohms and infinity. Thus, when the resistance is zero ohms, the top as well as bottom ends of the two resistors are tied together and appear as one resistance; the circuit has maximum gain. With the variable resistor at infinity, the cathode circuits are completely isolated, and there will be maximum cathode degeneration. The variable resistor serves as a degeneration control for both tubes.

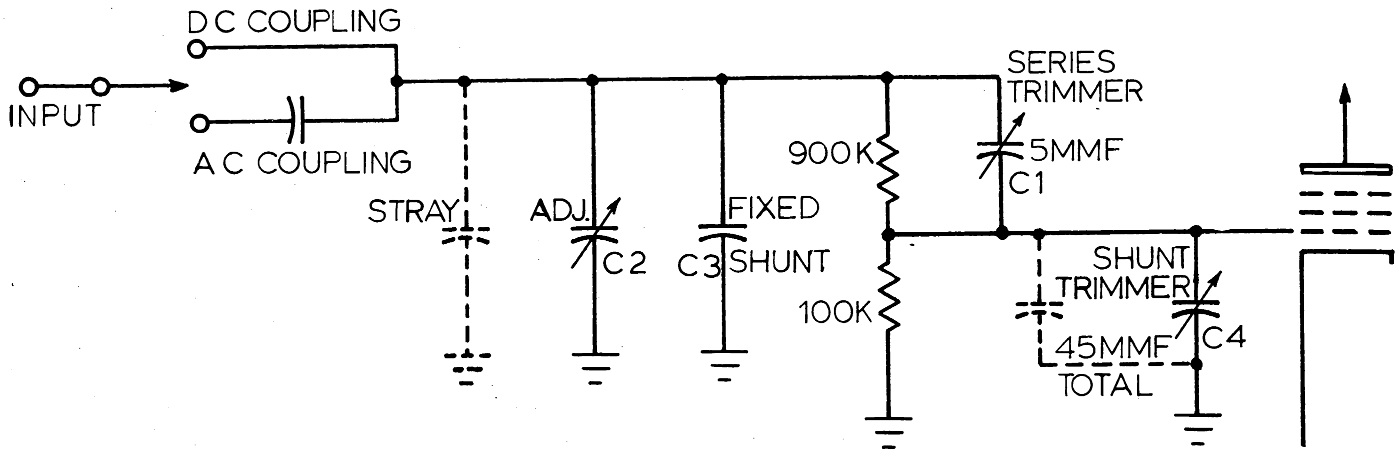


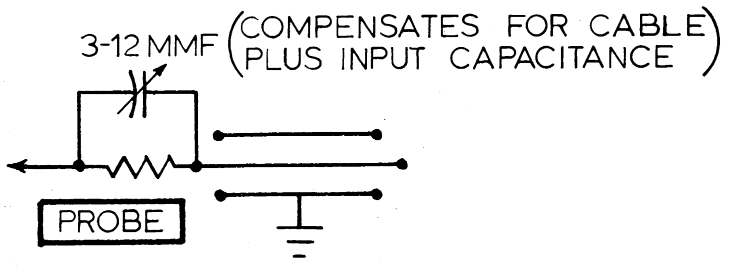
CIRCUIT NO. 17

HIGH-FREQUENCY EQUALIZATION

HIGH-FREQUENCY EQUALIZATION

To extend the high-frequency response of an amplifier, at the expense of low-frequency gain, a frequency-discriminating degeneration control can be used. A small cathode-bypass capacitor is practical in single-ended amplifiers. In a push-pull stage, a similar arrangement is shown.





CIRCUIT NO. 18

RC ATTENUATOR

RC VOLTAGE DIVIDER
(CIRCUIT NO. 18)

An RC voltage divider (or attenuator) is basically a resistance divider modified to divide high frequencies by the same amount as low frequencies and DC. Any capacitive load connected at the junction of a resistance divider (i.e., grid capacitance) can affect the attenuation ratio. The reactance is negligible at low frequencies; at high frequencies the effective divider ratio will increase. A capacitor (C_1) may be added to the non-loaded leg of the divider to compensate for the capacitance of the load. As a result we have a resistance divider in parallel with a capacitance divider. It is usually necessary to use an adjustable capacitor to provide precise compensation.

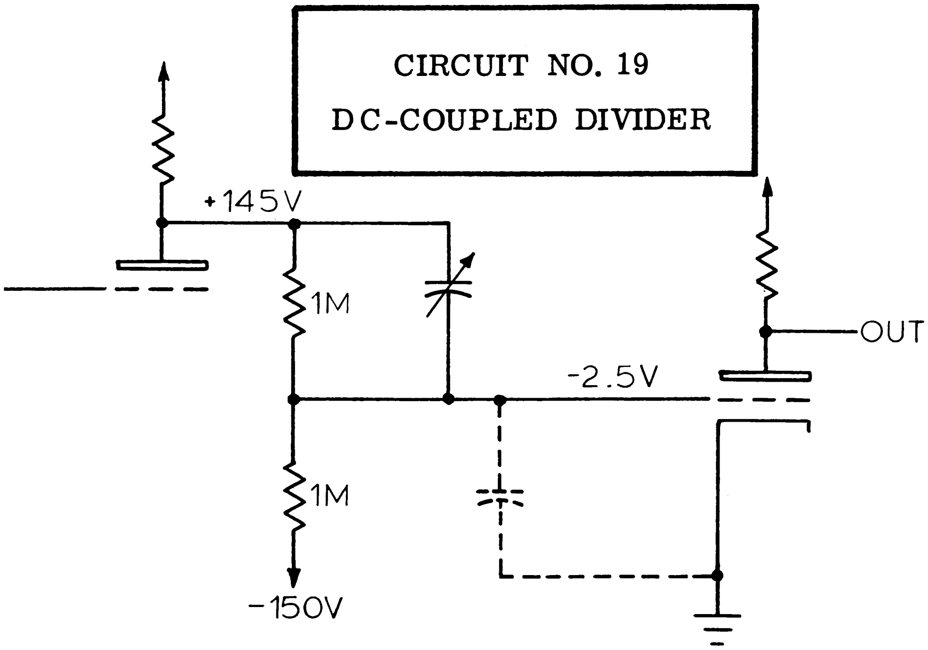
When a complex waveform is fed through an ideal properly compensated RC divider, all of its frequency components are attenuated equally, and the true wave shape is preserved. This suggests a simple method for proper compensation of an RC divider. Square waves have both high and low-frequency components, and their shape is easily recognized; they make an ideal test signal for adjusting or for verifying proper adjustment of an RC divider.

The square wave itself must have sufficiently short risetime, no overshoot, and a flat top. A suitable frequency is determined mainly by the RC time constants of the RC divider. It is interesting to note that, when the divider is properly adjusted, the time constant for the RC elements in the top half of an RC divider equals the time constant for the RC elements in the bottom half.

There is no specific square-wave frequency that is ideal for adjusting a given RC divider. The main requirement is that the frequency be low enough so that the period for one half-cycle is longer than one RC time constant of the divider. The risetime of a square wave suitable for adjusting RC attenuators does not necessarily have to be as short as that needed to adjust the transient response of the amplifier following the RC attenuators. If the risetime is shorter than about one-tenth of the RC time constant of the attenuator, adequate adjustments can usually be made if strict attention is given to matching the actual shape of leading corners rather than to making each corner appear as square as possible.

The passive high-impedance probes usually needed to introduce the signal into the scope essentially are compensated voltage dividers. Use of these probes requires that the impedance of a stepped input attenuator remain constant through its range of steps. Shunt trimmers are provided for making the input capacitance to the scope constant from range to range (C_2 and C_3).

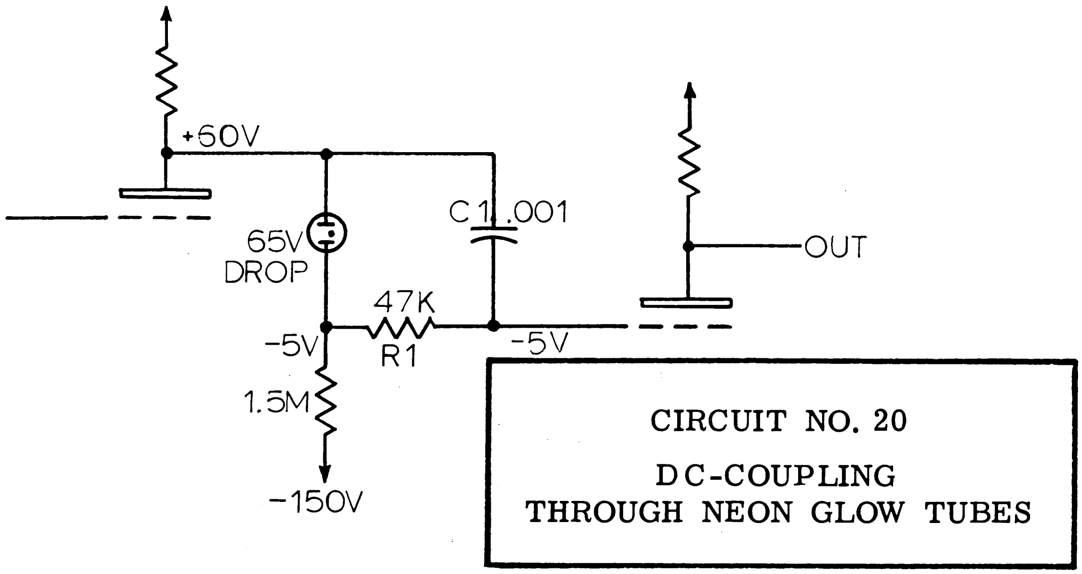
C_4 is another type of shunt trimmer often provided. This one trimmer permits re-establishment of proper RC compensation for the entire set of step-attenuator adjustments whenever the input tube characteristics change enough to alter the input capacitance of the tube, or the tube is replaced. The same trimmer can be used to standardize the input capacitance of different inputs (either on separate scopes or separate channels in one scope) to reduce the need to recompensate a probe ,that is used interchangeably. Some amplifiers use additional stages (for higher gain) that are not used when large signals are handled. This means that two different tubes are used as input tubes. A shunt trimmer on one or both of these tubes permits standardizing the direct input capacitance to the two tubes.


CIRCUIT NO. 19
DC-COUPLED DIVIDER

LONG-TAILED DC-COUPLED DIVIDERS

When it is desirable to DC-couple a signal at one DC level to another DC level (i.e., plate level to ground level) without attenuating the signal too much, the long-tail or constant-current principle can be used. In Circuit No. 19 the divider consists of two equal resistances; the DC level at the center, therefore, will be half-way between the level at the top and level at the bottom, or -2.5 volts. If the plate level changes by two volts, the grid level will change by half of that, or by one volt. This is an attenuation of two to one; the signal, however, is changed in level by 147.5 volts back down to a level where it can be amplified again with only one +225 volt supply.

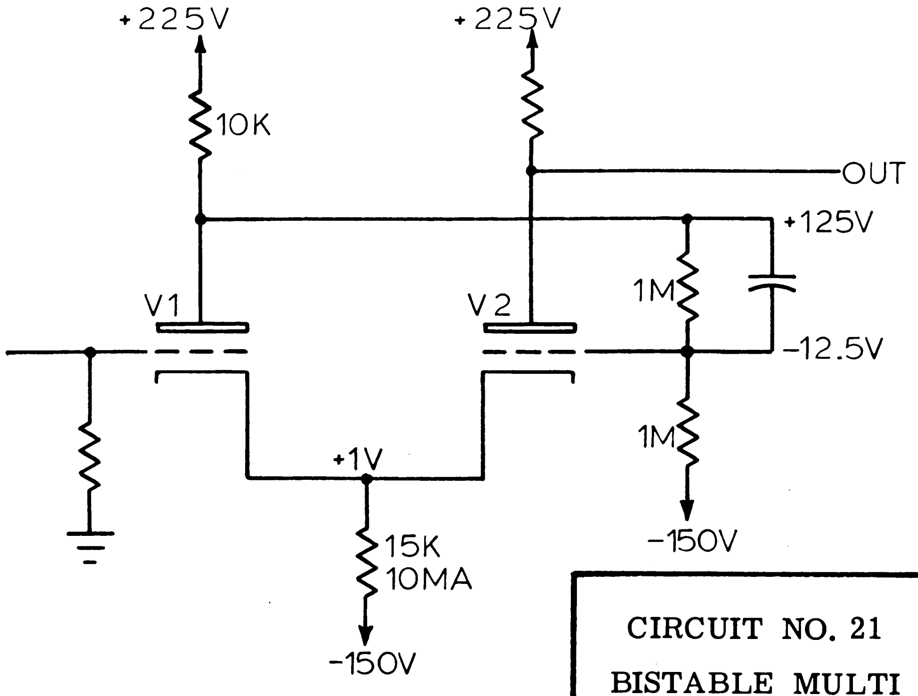
A trimmer capacitor is shown across the top half of the divider, making it an RC divider.



CIRCUIT NO. 20
DC-COUPLING
THROUGH NEON GLOW TUBES

DC-COUPLING THROUGH NEON TUBES

By using NE-2 neon bulbs, DC-coupling from one voltage level to another can be accomplished in some circuits with practically no attenuation of the signal in the process; an example is shown in Circuit No. 20. These bulbs have constant voltage characteristics similar to V.R. tubes, and therefore can be used to provide a rather constant drop in voltage in a divider circuit. Since the neons tend to fluctuate under certain conditions and require a certain ionization and deionization time, they are usually used to handle only large signals or are part of feedback loops, or both. The capacitor couples fast-changing signal components to the grid without requiring a change in ionization of the NE-2 during such intervals.

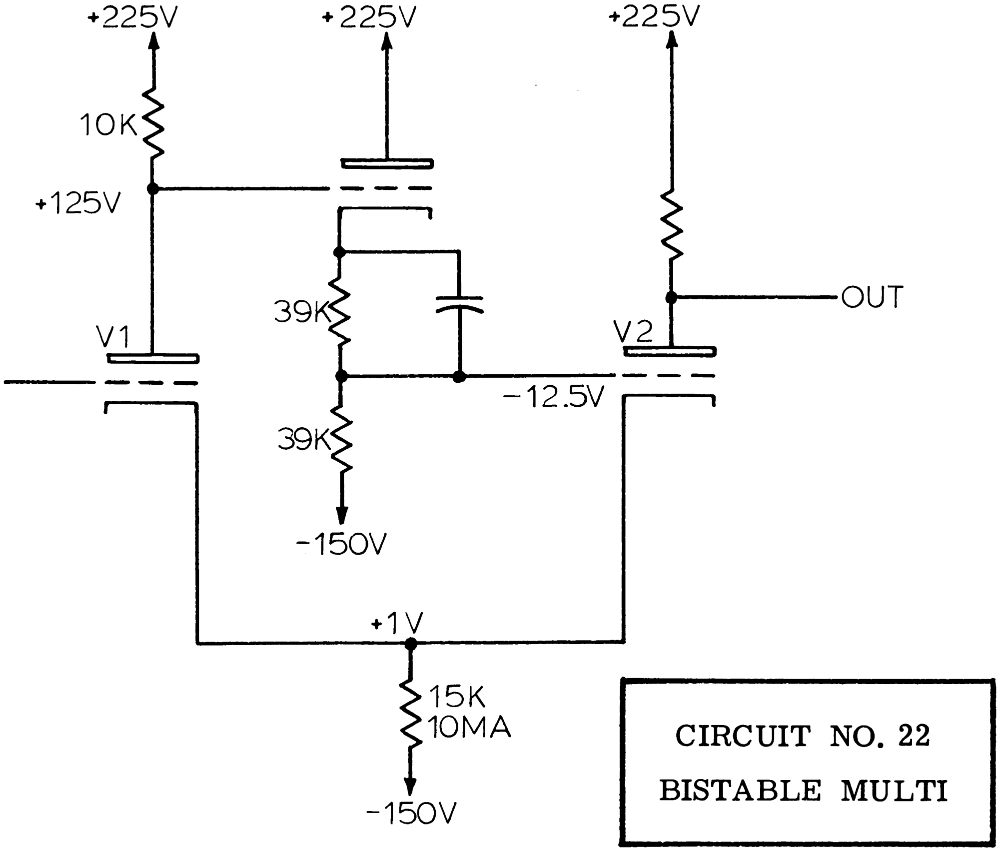


CIRCUIT NO. 21
BISTABLE MULTI

CATHODE-COUPLED BISTABLE MULTIVIBRATORS (DC-COUPLED SCHMITT CIRCUITS)

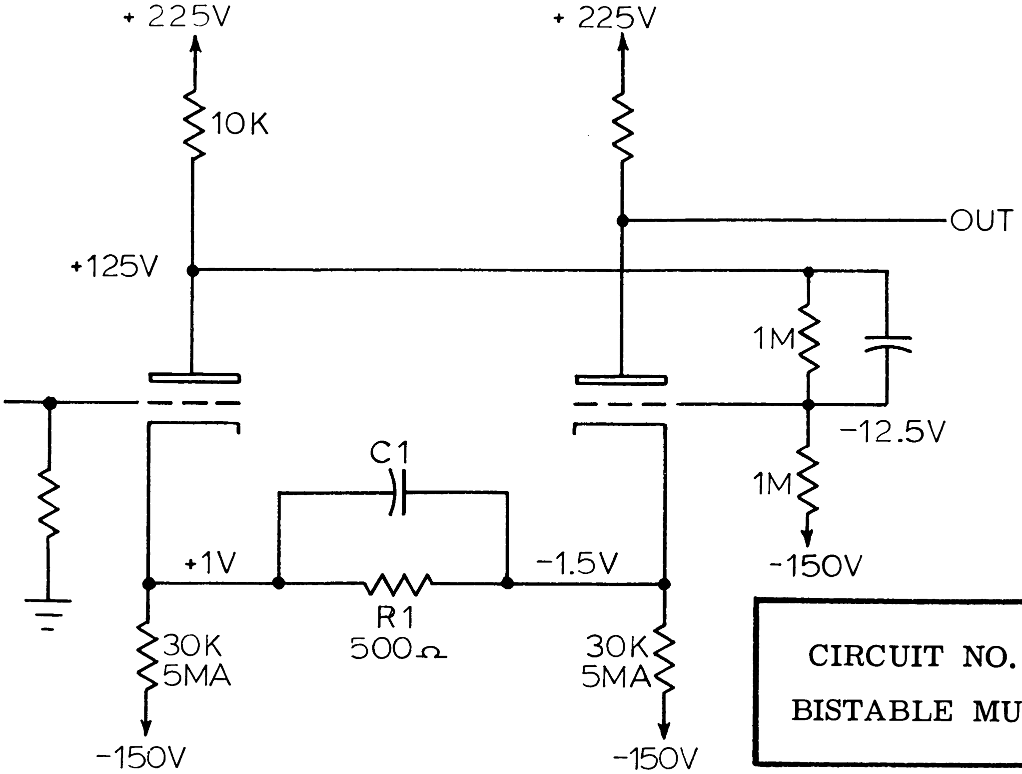
A bistable multivibrator is one that is stable indefinitely with either half conducting and the opposite half cut off. Bistable multivibrators are usually made to operate with a control voltage on one grid; in this case the multivibrator frequency will be the same as the grid signal frequency, providing the signal amplitude is sufficient and the frequency is not too high.

Circuit No. 21: If the grid of V_1 is high enough, V_1 will conduct. Conduction in V_1 lowers its plate voltage and drives the grid of V_2 down into cut-off. Since the plate voltage is DC-coupled to the grid, the right-hand tube will remain off until the grid of the left half comes down again. With V_2 cut off, the cathode voltage will closely follow the grid of V_1. When the cathode lowers sufficiently, conduction starts in the right-hand tube and diminishes in the left-hand tube. As soon as this happens, the transition is accelerated by the increase in plate voltage of V_1 which rapidly raises the grid of V_2, hastening cut-off of V_1. V_2 will then conduct until the grid of V_1 rises enough to let the left side conduct again.



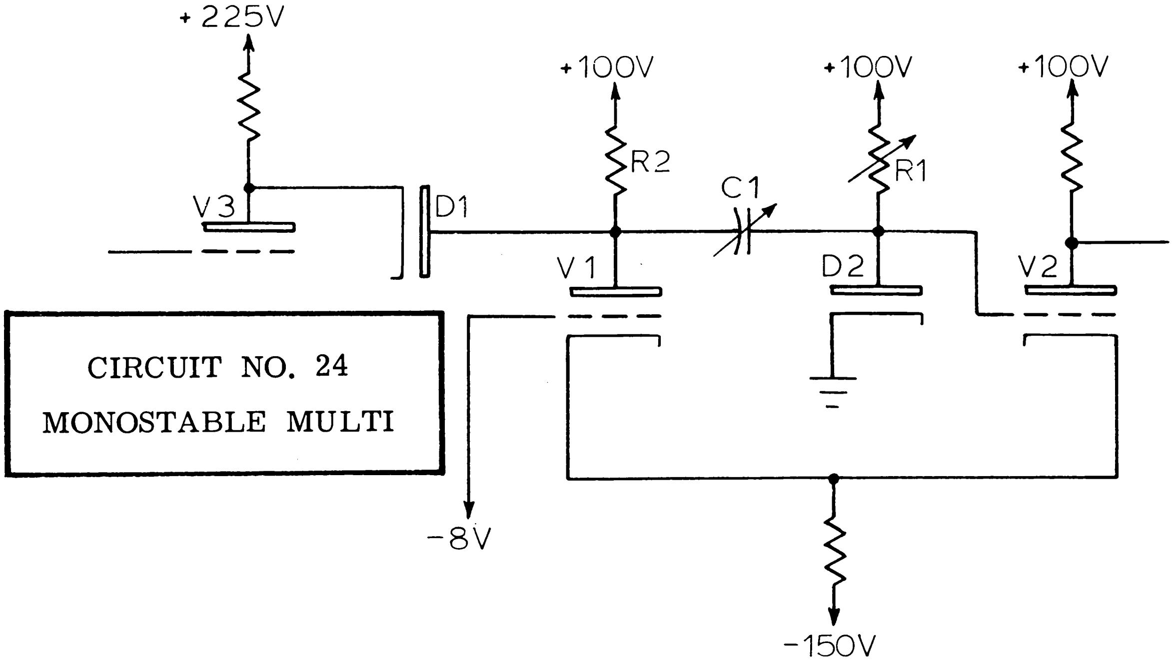
CIRCUIT NO. 22
BISTABLE MULTI

Circuit No. 22: A cathode follower may be inserted between stages to speed up the transition from one state to another by reducing the capacitance that the first tube must drive, and by providing low-impedance drive for the input capacitance of the right-hand tube.



CIRCUIT NO. 23
BISTABLE MULTI

Circuit No. 23: All of these multivibrators have hysteresis. That is, in order to produce a transition coming down, the grid signal must come down past the voltage level where a transition took place going up. Multivibrators with much hysteresis require large signals for operation. In order to control the multivibrator with a small signal, the hysteresis must be small. Hysteresis can be reduced by separating the cathodes slightly by a variable resistor. With this arrangement, the cathode level of the tube that is not conducting will be somewhat lower than the other cathode and thereby biased closer to conduction. If hysteresis is reduced too much, the circuit will be unstable. The capacitor C_1 maintains the voltage drop across R_1 for an instant during transitions to improve stability during these critical periods.



CATHODE-COUPLED MONOSTABLE MULTIBRATORS

The monostable multivibrator is stable in only one mode. If triggered into the opposite conducting state, it will revert to its stable state on its own after a certain period.

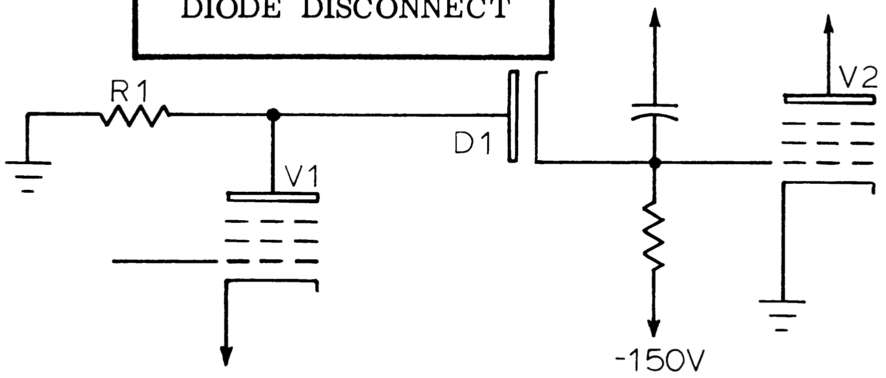
Circuit No. 24: In the stable state, D_2 is conducting up through R_1, clamping the bottom end of R_1 close to ground. This puts the grid of V_2 about eight volts higher than the grid of V_1; therefore V_2 is conducting and V_1 is cut off. C_1, then, is charged to the full value of B+, in this case 100 volts. If D_1 conducts for an instant, the plate voltage of V_1 is lowered for an instant, and the negative-going wavefront is coupled through C_1 to the grid of V_2. If this voltage lowers the cathode of V_2 enough, current will start to flow in V_1; the plate of V_1 then is lowered further, assisting in switching V_2 off completely. C_1 will then discharge through R_1 until the current diminishes sufficiently to allow the grid of V_2 to rise to where it may again conduct. When V_2 starts to conduct, its cathode starts to rise, and current through V_1 diminishes. Reduction of current through V_1 allows its plate to rise. This stops the discharge of C_1, hastening the rise of the grid voltage of V_2 and the transition back to the stable mode. In the unstable mode, while the plate of V_1 and D_1 is down, D_1 cannot conduct. As soon as the plate of V_1 goes up, however, C_1 quickly recharges through R_2 and D_2, and the circuit is ready to be re-triggered.

DIODE DISCONNECT

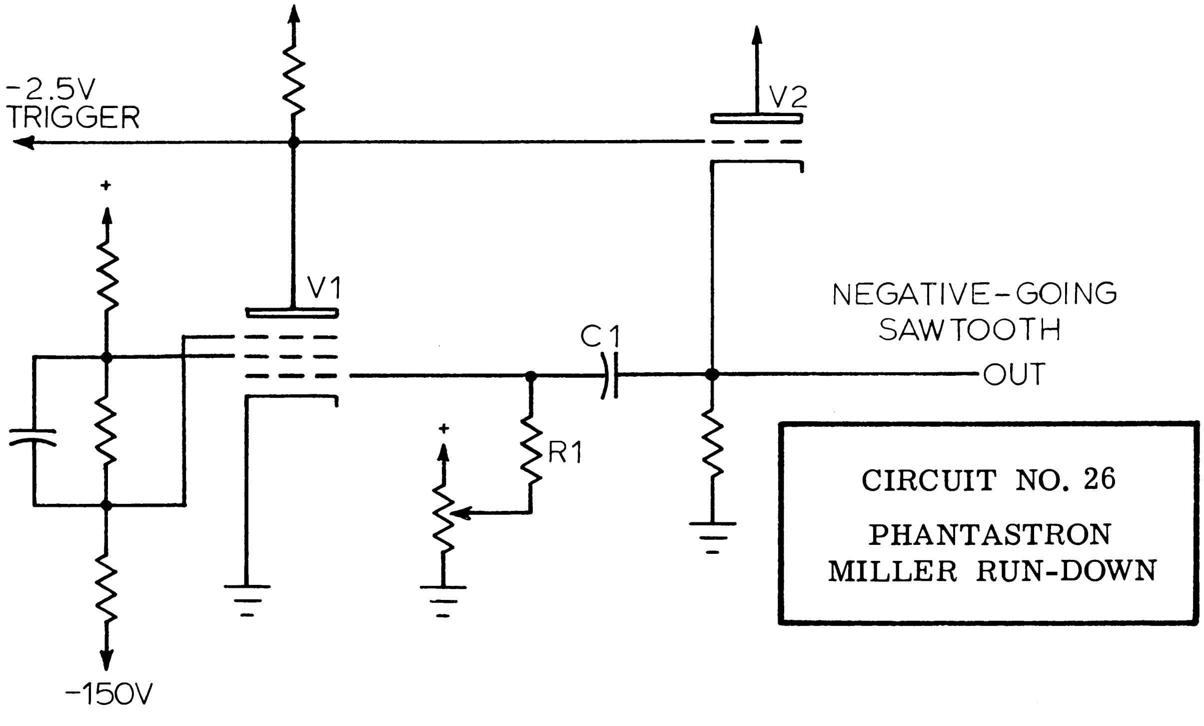
Diodes are useful for disconnecting one circuit from another at proper moments. By driving the cathode up (or the plate down), current through a diode can be stopped.

In Circuit No. 24 a triggering current can be made to pass from the plate of V_3 to the plate of V_1 whenever the plate voltage of V_3 is lowered farther than that existing at the plate of V_1. Whenever this happens, the multivibrator is triggered, and diode D_1 disconnects V_3 as soon as the plate of V_1 comes down on its own. The diode then holds V_3 disconnected as long as the plate of V_1 is down, keeping untimely triggering signals at the plate of V_3 from affecting the multivibrator.

CIRCUIT NO. 25
DIODE DISCONNECT



In Circuit No. 25, a positive gate at the grid of V_1 makes V_1 conduct heavily, driving the plates of V_1 and D_1 below ground. The grid of V_2 is then disconnected from ground and seeks a new level.



CIRCUIT NO. 26

**PHANTASTRON
MILLER RUN-DOWN**

PHANTASTRON SAWTOOTH GENERATOR
(MILLER INTEGRATOR)

Circuit No. 26: The Phantastron is a self-gating sawtooth generator. In the quiescent mode, the grid of V_1 is clamped close to ground by grid current through R_1. In this condition, screen current is so heavy that the screen voltage is very low. Since the screen is DC-coupled to the suppressor, the suppressor voltage is so low that it completely cuts off the plate current.

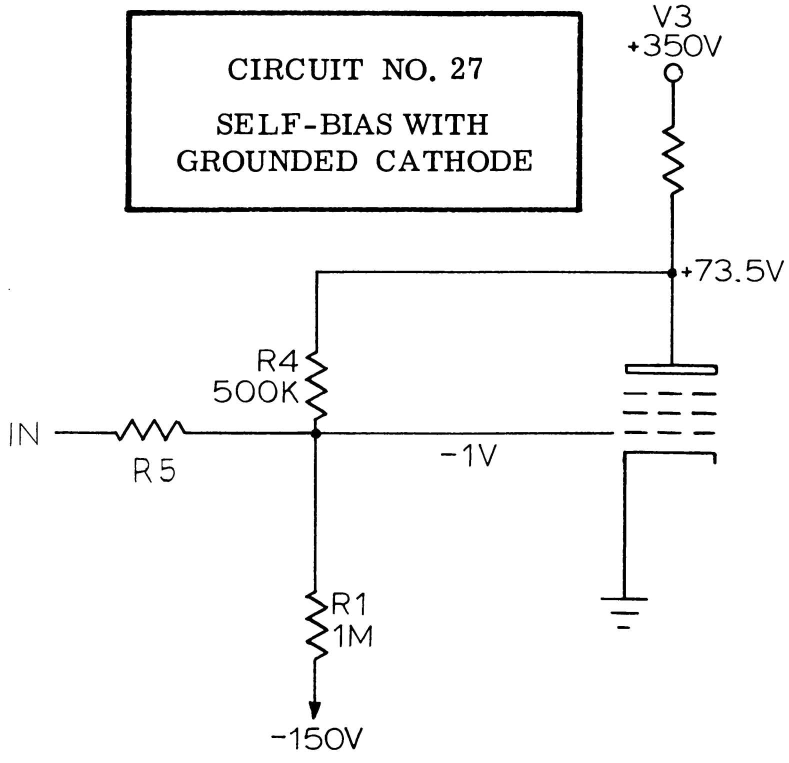
A small negative pulse coupled into the plate circuit of V_1 goes to the grid of V_2 and is coupled back over to the grid of V_1 by way of the cathode follower and C_1. If the amplitude of the pulse is not too small, screen current is reduced enough (raising the suppressor voltage) to permit plate current to flow. If this happens, the plate quickly drives its own grid (through V_2) nearly to cut-off where both screen and plate current are low. The grid starts to rise, however, as C_1 immediately begins to lose its charge, but the rise of grid voltage is slowed down and linearized by inverse feedback from the plate. That is, C_1 is forced to discharge just fast enough into R_1 to keep the current into R_1 nearly constant. Constant current into or out of a capacitor results in a linear change in voltage across it; its output, therefore, is a sawtooth.

As the grid rises and the plate runs down, the screen gets a larger and larger share of current, until finally the suppressor is lowered enough to affect the plate current, which is switched suddenly and entirely to the screen. The plate voltage of V_1 then suddenly rises and C_1 quickly recharges through V_2 with grid current from V_1. The main purpose of V_2 is to shorten the retrace (recharge) time.

The waveform from the Phantastron is very linear. At the beginning of each sawtooth, however, a fast step occurs when the plate voltage is driving the grid close to cut-off to start the run-down.

CIRCUIT NO. 27

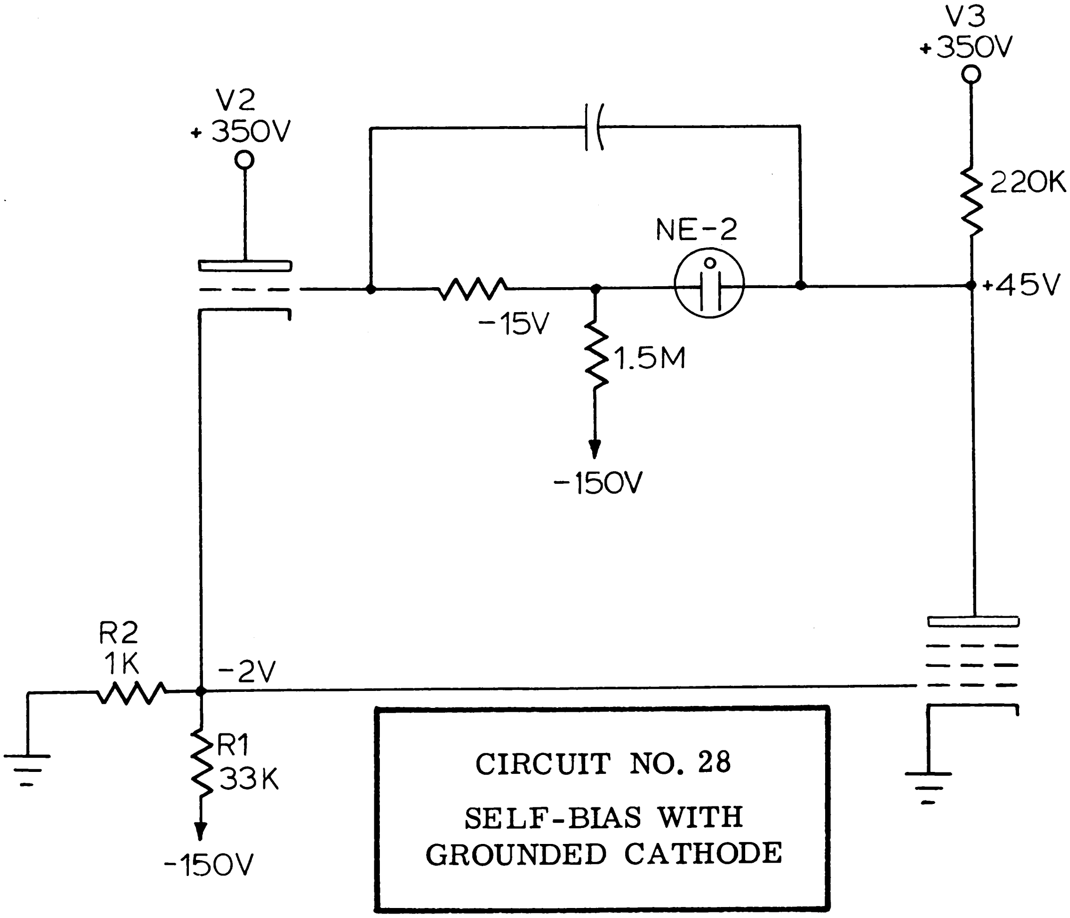
SELF-BIAS WITH GROUNDED CATHODE



SELF-BIAS WITH GROUNDED CATHODE

(ANODE FOLLOWER)

Circuit No. 27: Self-bias can be achieved without a cathode resistor by inverse voltage feedback between plate and grid as shown in Circuit 27. This circuit operates basically the same way as a circuit using a self-biasing resistor in the cathode circuit; that is, any current flowing develops a grid-cathode voltage that limits and actually establishes the operating current. With no plate current, the plate voltage of V_3 would go up high enough that it would tend to operate the grid of V_3 above the cathode (full current). With heavy plate current the plate of V_3 would tend to drive the grid below cut-off. Only one value of plate current will satisfy the conditions established by tube type, screen voltage, plate supply voltage, plate load, and divider ratio. The circuit will have a gain close to unity (anode follower) if R_4 and R_5 are approximately of the same value, and if the source impedance of the input signal is relatively low.



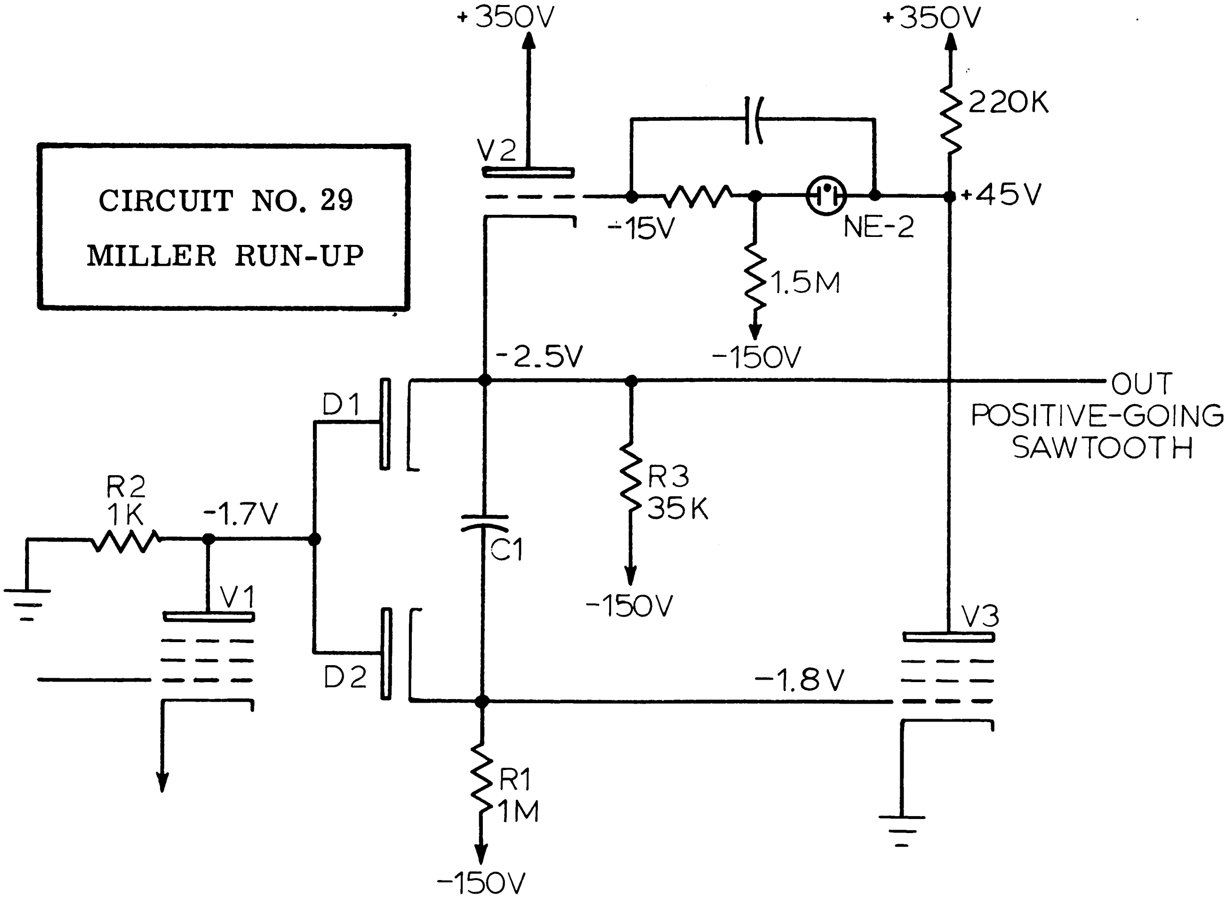
SELF-BIAS WITH GROUNDED CATHODE

Circuit No. 28: If a cathode follower is inserted in the feedback path, low-impedance drive for the grid circuit of V_3 is provided. R_2 would not have to be used for the circuit to operate; its presence does influence the DC levels in the circuit somewhat, because some of the current through R_1 is diverted from V_2 through R_2.

ROPIQUET-KOBBE SAWTOOTH GENERATOR
(MILLER INTEGRATOR)

Circuit No. 29: In the quiescent state, before a sweep starts, V_1 is cut off and the circuit is in a stable condition and remains that way until V_1 is gated on. In the stable state the grid voltage of V_3 is established by DC feedback from its plate as in Circuit 28. The similarity of Circuit 29 and Circuit 28 should be pointed out: Because V_1 is not conducting, it need not be shown in Circuit 28. Similarly, because D_1 and D_2 are conducting and represent a low impedance path, they can be considered shorted and are therefore not shown in Circuit 28. With both D_1 and D_2 shorted, C_1 would be shorted; it also is not shown. With both D_1 and D_2 shorted, the top as well as bottom of R_1 and R_3 are shorted together and represent only one resistance; therefore, R_3 is not shown.

CIRCUIT NO. 29
MILLER RUN-UP



In Circuit No. 29 current passes through R_3; part goes through V_2, with some being diverted through D_1 and R_2 to ground. At the same time current passes through R_1, this time being diverted through D_2 and R_2 to ground. Since there is very little voltage drop across D_2, the grid voltage of V_3 is essentially the same as that established across R_2, the actual amount being determined by the one satisfactory set of conditions for self-bias.

As soon as V_1 conducts fully, the drop across R_2 increases, D_1 and D_2 are disconnected, and the grid of V_3 starts to go down. It is retarded, however, by inverse feedback from the plate of V_3 through cathode follower V_2 and capacitor C_1. The current through R_1, now having no other path, starts to charge C_1 and at the same time establishes the grid voltage for V_3. The feedback, by opposing any change in the voltage at the grid of V_3, maintains essentially constant current into C_1; this assures a linear increase of charge voltage across it. Almost all of the voltage increase across C_1 appears at the top end of C_1 as a positive-going linear ramp (sweep). A small percentage of the voltage increase appears at the bottom end of C_1 (V_3 grid) as a negative-going signal. R_1 and C_1 are essentially the only two components that control the rate of rise.

If, at any time during the sawtooth rise, V_1 stops conducting, the plate of D_2 will rise above its cathode. The grid of V_3 will then start to rise and C_1 will discharge (through D_2 and R_2) at a rate that again attempts to keep the grid of V_3 at a constant voltage. The discharge rate is determined, then, primarily by the value of C_1 and R_2. Discharge will stop soon after the cathode of D_1 comes down to the level of its plate. At this instant, D_1 starts to conduct and current through D_2 diminishes as the current through D_1 increases. The quiescent mode is re-established the instant sufficient current is diverted from V_2 through D_1 to set the grid voltage of V_3 at the particular level that satisfies the quiescent conditions.

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