Good voltage regulation must be one of the outstanding characteristics of bias supplies employed with class-B linear r.f. amplifiers, class-B modulators, and grid-modulated class-C r.f. amplifiers. Equally important with regulation in the bias supply for a class-B modulator is the requirement that the actual value of voltage be within 5% of the required value.

The simple bias supply circuit previously described may be converted into a regulated unit by the addition of small VR-type gaseous voltage-regulator tubes when the desired bias voltage corresponds to the normal drop across one or more of these simple tubes, or by the addition of more complex tube-type voltage regulator sub-circuits. When the desired bias voltage corresponds to the drop normally appearing across a single VR tube the familiar single VR tube circuit is applicable; when it is higher than the drop across one tube, several tubes may be connected in series, provided the total drop across the series combination corresponds to the desired bias voltage.

The manner of connection is illustrated by Figure 3. The value of the limiting resistor, R, is such that 25 milliamperes will flow through the tube or tube combination. The power rating of this resistor must be sufficient to dissipate safely the power developed by the total current of tube and load.

When two or more VR tubes are connected in series, as in Figure 3, taps, such as T, taken from the junction points will supply intermediate bias voltages equal to the total drop across all tubes between the tap and ground. It is clear that a number of series combinations may be worked out with VR75, VR90, VR105, and VR150 type tubes to give various regulated voltages from a single bias supply. When the d.c. grid current of the biased amplifier exceeds 25 milliamperes, two VR tubes must be connected in parallel wherever one such tube is normally indicated. Each branch of the parallel circuit can safely handle 25 milliamperes.

Other types of voltage-regulated power supply circuits are likewise useful as bias units, provided the total resistance of the bleeder in such a circuit is not an appreciable percentage of the normal grid leak recommended for the biased stage. An example of such a circuit is the familiar triode-pentode-neon tube unit, such as the 6SJ7-6A3 and 57-2A3 arrangements. When power supplies of this type are employed for class-B audio bias, the bleeder resistor must be especially low in value.

As mentioned in connection with the simple a.c. circuit safety bias may also be obtained from a voltage-regulated supply unit, the remainder of the grid voltage being developed by a series grid leak. This scheme cannot be used, however, with class-B audio and grid-modulated class-C telephony.

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Transmitter Bias Supplies

By the Engineering Department, Aerovox Corporation

PROPER operation of the audio-frequency and radio-frequency stages of a transmitter requires that certain recommended values of d.c. bias voltage be applied to each tube grid. When a transmitter r.f. amplifier is operating efficiently, plate current flows in brief pulses over a small portion of each cycle of r.f. exciting voltage. The peak value of each of these pulses is several times as large as the average d.c. value indicated by the plate-circuit milliammeter. The length of each pulse is determined by the magnitude of the grid bias voltage.

Bias requirements vary with each application of tubes in a transmitter. The bias voltage for doublers and other frequency multipliers, for example, must be maintained quite high, far beyond the value required for plate current cut-off. Final r.f. amplifiers and a.f. modulators, on the other hand, require grid voltages between cut-off and slightly lower, to twice cut-off.

Bias for class-B audio tubes must be supplied by a low-resistance source of extremely good regulation. This calls for batteries or a line-operated power supply incorporating a voltage-regulating device. But a poorly-regulated supply is desirable for class-C telephony, since linear operation (and consequent good audio quality) so important in plate-modulated radiotelephony, requires that the value of grid bias voltage change with the plate-circuit modulation.

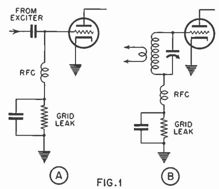

FIG. 1

Bias requirements for other types of transmitter stages differ in still other respects, as will be pointed out later in the article. The choice of any bias system, or combination of systems, will be influenced by efficiency and economy.

It was once common practice to use batteries for transmitter biasing. Modern design, however, dictates a.c.-operated bias supplies or some form of automatic device. A description of these modern systems follows.

GRID-LEAK BIAS

One of the simplest methods of obtaining grid bias voltage is by means of a grid leak resistance. This resistor, which is generally of high ohmic value, is connected between the control grid and ground as shown in Figure 1. On positive half-cycles of excitation voltage, the grid of the transmitter tube, acting as a diode plate, attracts electrons from the cathode, giving rise to a direct current (the grid current) which flows across the electron-filled space from grid to cathode, through the grid leak resistor, and back to the grid. The grid current produces a voltage drop across the resistor, the grid end of the latter assuming negative polarity and the ground end positive, and this voltage is applied to the grid as negative bias.

The radio-frequency chokes shown in the circuits in Figure 1 prevent the excitation power from flowing through the grid resistor. The capacitor shunting each grid leak presents a low-impedance path to any r.f. energy that might succeed in passing through the choke.

Grid-leak bias is somewhat limited in application. It cannot be used successfully, for example, with linear class-B r.f. amplifiers, class-B or class-AB a.f. amplifiers, or grid-modulated class-C stages, since in each of these amplifiers the grid current is continually changing and the bias voltage developed by the resistor would vary in unison.

Where grid-leak bias is useable, it may be applied very simply to the circuit. The value of grid leak resistance for a given bias voltage may be determined from the following formula:

(1) $$R = \frac{1000\ E_g}{I_g}$$

R = Value of the grid leak (ohms)
E_g = Desired grid voltage (volts)
I_g = Required grid current (milliamperes)

The power dissipated in this resistor is:

(2) $$P = .000001\ I_g^2\ R_g$$

P = Power developed (watts)
R_g = Grid leak value (ohms)
I_g = D.C. grid current (milliamperes)

For two tubes (either push-pull or parallel connection) the grid current would be double, therefore the grid leak resistance would only be half the value obtained by means of Formula (1). Similarly, the power value obtained with Formula (2) would be four times as great as with one tube.

When the proper value of grid bias for a triode is not known, but other tube characteristics are known, the value of the grid leak may be determined in terms of the plate voltage and amplification factor, thus:

(3) $$R_g = \frac{1000\ E_p}{\mu I_g} \text{ for Cut-off}$$

R_g = Value of the grid leak resistance (ohms)
E_p = Triode plate voltage (volts)
μ = Triode amplification factor (micromhos)
I_g = Recommended triode grid current (milliamperes)

Grid-leak bias is not a safe supply for r.f. power amplifiers. In all tubes except those designed specifically for zero-bias class-B a.f. operation, plate current will rise rapidly to a dangerous value in a grid leak-biased amplifier if the excitation is interrupted. Except in the case of some tantalum-plate tubes which are able to withstand such plate-current overloads more effectively than other types, such plate-current excursions will damage the tube immediately or shorten its life. This leading deficiency of grid-leak bias may be offset in one of two ways: by employing a reasonable amount of fixed bias (battery or line-operated power pack) in series with the grid leak to hold the plate current to a safe value in the event of excitation failure, or by including a safety device (such as a fuse or low-current overload circuit breaker) in the plate supply circuit. Small-sized circuit breakers, insulated for high d.c. transmitter plate voltages and operable at a few milliamperes above the resonant value of plate current, are now available. The advantages of grid leak bias, including its simplicity and economy, are sufficiently attractive in some r.f. amplifier applications, to warrant inclusion in the transmitter circuit of some such safety device.

Since it is the r.f. excitation voltage delivered by the intermediate stages of the transmitter that develops bias by the grid leak method, the r.f. exciter or a.f. driver must be able to supply the power consumed in the grid circuit. The magnitude of the required power may be determined approximately by multiplying the grid voltage by the recommended grid current in *amperes.* The figure obtained will be the actual d.c. watts and does not take into account certain losses appearing in the grid circuit, which must likewise be supplied by the exciter or driver.

The poor grid-bias voltage regulation desired for linearity in class-C radiotelephony may be obtained easily with a grid leak, since bias secured by this method changes with modulation in the plate circuit.

CATHODE BIAS

Cathode bias, familiar in receiver practice, is another simple type of bias supply that finds use in transmitter circuits. This type, known also as *automatic bias,* utilizes the familiar resistor in series with the tube cathode and ground. The total steady plate and screen currents flow through this resistor, and the voltage drop this current flow develops across the cathode resistor is applied to the grid as negative bias. The method of connecting a cathode resistor into transmitter tube circuits is shown in Figure 2.

It is readily seen from the nature of the cathode-biased circuit that the actual value of bias voltage will depend upon the magnitude of the total cathode current and will vary with it. Cathode bias is therefore not generally useable in stages in which the d.c. plate current undergoes large fluctuations in the course of normal operation.

Cathode bias may be used with class-B *r.f.* amplifiers, but not with class-B audio amplifiers for the reason just given. In class-B r.f. service, the resistor must be by-passed adequately for radio frequencies and for audio frequencies as well when the amplifier is used in radiotelephony.

The cathode by-pass capacitor provides a low-impedance path for the a.c. component of plate current which otherwise would vary the bias voltage. If this capacitor is omitted from the circuit or if its capacitance is too low, degeneration will take place and will act to reduce the amplification in this manner: The bias voltage will be altered in accordance with the a.c. plate-current variations, the bias changes then operating against the plate current changes that are due to the signal. The cathode resistor in a radio-frequency stage must always be by-passed for r.f. to prevent degeneration. Occasionally, degeneration is desired in an audio amplifier to reduce distortion, although it reduces gain and power amplification at the same time. In this case, the by-pass capacitor is omitted. Always, the cathode by-pass capacitance is chosen to have negligible reactance at the lowest operating frequency.

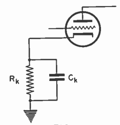

FIG. 2

Since the total cathode current, consisting of plate, screen, and suppressor currents (plate current only in triodes) flowing through the tube and cathode resistor in series, produces the voltage drop, the value of this drop must be subtracted from the total voltage of the plate power supply when designing a cathode-biased stage. This is necessary because the effective plate-cathode voltage is reduced by the amount of the drop across the cathode resistor. In order to obtain any given plate voltage, it is necessary therefore to design the plate power supply to deliver the desired plate voltage *plus* the cathode-resistor drop (grid voltage). This requirement frequently calls for an unreasonably large power supply for a small transmitter; and this reason, more so than several others, has lessened the popularity of cathode bias in transmitters.

Some transmitter power stages utilize a small amount of cathode bias as safety voltage in conjunction with grid leak bias. And this has proven quite successful; since only half of the required grid voltage is then developed by the cathode resistor, the other half being developed across the grid leak.

The required value for any cathode resistance may be determined from Ohm's Law:

(4) $$R_k = \frac{1000\ E_g}{I_k}$$

R_k = Resistance of the cathode resistor (ohms)
E_g = Desired d.c. grid voltage (volts)
I_k = Total cathode current in *milliamperes.* (For triodes, plate current only; for tetrodes, plate and screen current; for pentodes with externally-biased suppressor grids, plate, screen and suppressor currents).

The power developed in a cathode resistor is:

(5) $$P = .000001\ I_k^2\ R_k$$

P = Power developed (watts)
I_k = Total cathode current (milliamperes)
R_k = Cathode resistance (ohms)

If two tubes are connected in parallel or push-pull and the bias for both obtained from a common cathode resistor, the cathode current will be doubled and the value of resistance obtained by means of Formula (4) will be one-half the value for one tube. Similarly, the power value obtained with Formula (5) will be four times the value for one tube.

In r.f. amplifiers, the grid is driven positive. Grid current accordingly flows through the cathode resistor in the same direction as the screen and plate currents, and is added to the latter. As a result, the total cathode current in an r.f. power amplifier will be found to be larger than indicated by Formula (4). It is necessary, therefore, in calculating the resistance for cathode-biased r.f. amplifiers to add the d.c. grid current of the tube when determining the total cathode current.

A. C. SUPPLIES

Rectified and filtered a.c. supplies have entirely supplanted dry and storage batteries for fixed bias in modern transmitters and are gradually replacing grid-bias motor-generator sets. Line-operated supplies are noiseless in operation, require no periodic replacements, except tubes which are replaced at relatively infrequent intervals, and do not generally present problems of high initial cost.

The design of an a.c.-operated bias supply differs somewhat from that of the more familiar plate power supply in several particulars that are occasioned by its manner of operation. The bias supply, for example, furnishes no power to the amplifier to which it is connected. It must always employ full-wave rectification in order to prevent accidental modulation of the amplifier grid. The value of the bleeder resistance must be held within limits advisable for proper operation of the biased amplifier. The bias supply is a "positive-grounded" power unit; i. e., the output connections are reversed.

For class-B audio, class-B r.f., class-C telegraphy, and grid-modulated class-C telephony, the grid voltage supply unit must be well regulated. Voltage delivered to class-B a.f. grids must be within 5 percent of the value recommended by the tube manufacturer. Class-C telegraphy and plate-modulated class-C telephony are not so critical as regards the actual value of the grid voltage as long as it is at least twice the cut-off value. For highest efficiency, the grid voltage in those services is often adjusted to values equal to several times cut-off.

For plate-modulated class-C telephony, the a.c.-operated bias supply must be designed to have *poor* regulation, since the requirement of linearity in plate modulation necessitates that the class-C grid voltage level change with the modulation. When modulation of the class-C stage is transferred from the plate to the grid, however, the bias supply must be well regulated.

R. F. amplifier grid current flows through the bleeder resistor of the bias supply and the voltage drop developed across this resistor will alter the value of negative voltage applied to the amplifier grid. It is important, therefore, to keep the bleeder resistance low in order to reduce the effect of its grid-leak action.

A typical a.c.-operated bias supply circuit is essentially identical with any conventional power supply unit, except that its positive output terminal and positive filter capacitor terminals are grounded. Electrolytic capacitors having negatively-polarized cans cannot be fastened directly to the chassis of a bias supply for that reason. The filter chokes will be found in the negative line.

A unit of this type would be entirely satisfactory for class-C telegraphy, plate-modulated class-C telephony, and class-A a.f. modulator service, but is not suitable for biasing class-B audio or grid-modulated class-C radiotelephone amplifiers because its voltage regulation is not apt to be good.

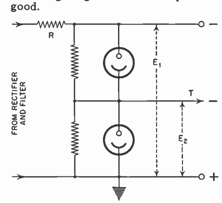

FIG. 3

The supply is by-passed for r.f. by a small capacitor, the capacitance of which is chosen to offer low impedance at the transmitter frequency. This capacitor should be a good-grade mica component.

For low- and medium-voltage bias supplies, the rectifier tube may be either a high-vacuum or mercury-vapor type, although some designers advise against the use of mercury-vapor tubes in bias supplies since in some cases their discharge has been observed to modulate the biased-amplifier grid.

For class-C telegraphy, the resistance of the bleeder must be kept low in order to minimize grid-voltage variations due to presence of amplifier grid current in this resistor. The entire maximum transformer secondary current should be taken up by the bleeder whose resistance should be small with respect to the recommended grid leak resistance. The transformer must so be chosen that its secondary voltage and current will be adequate to develop the required grid voltage across an untapped bleeder resistor.

The bleeder must be rated to withstand (with a good safety factor) the power developed in the resistor by the rectifier output current and the amplifier grid current.

It is better to develop the required grid voltage across the entire bleeder than to employ a tapped voltage divider. To facilitate the design of grid-voltage supplies, several manufacturers have made available special power transformers with tapped secondary windings to provide the common bias voltages within 5% of the stated values. These transformers obviate the necessity of a tapped voltage divider.

The matter of filtering depends upon which transmitter stage the bias supply is intended to operate into. In general, r.f. output amplifiers do not require as much bias-supply filtration as do low-level r.f. and a.f. stages and modulators. For a modulator supply, for example, two filter chokes and capacitors would be recommended, while one choke and perhaps one capacitor as well, might be eliminated if the bias supply were designed for the r.f. output amplifier. The filter capacitors must be rated to withstand the peak secondary voltage delivered by the transformer (RMS voltage of one-half secondary winding x 1.41).

Very often, it is desired to obtain only safety bias from an a.c.-operated supply (as in plate-modulated class-C telephony) and to secure the remainder of the required grid voltage from a grid leak. The total voltage supplied by the two sources can then be made equal to the value recommended for the biased stage. In such an arrangement, the grid leak is connected in series with the output of the bias unit. The bias supply is adjusted to deliver exact cut-off voltage at the grid terminal of the amplifier—in the absence of excitation. And the value of the grid leak is chosen such that the total resistance of grid leak and bias-supply bleeder (or the used section of the bleeder between the tap and ground—when the bleeder is a voltage divider as well) will give a voltage drop with the normal amplifier grid-current flow sufficient to furnish the remainder of the desired grid voltage. In the case of the class-C amplifier, which is normally biased to twice cut-off, the bias supply would be designed to deliver cut-off voltage. The drop across leak and bleeder, due to grid-current flow, would likewise be made equal to cut-off by properly apportioning these resistances. The two voltages would combine to produce twice cut-off. When the bias supply thus furnishes grid voltage of cut-off value, it is necessary only that the total resistance of leak and bleeder equal half the recommended grid-leak value.