Practical Applications of Simple Math

Part I—Bias Calculations

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Although complicated mathematical expressions are often seen in connection with theoretical developments of radio circuits, many of the practical problems encountered may be solved by the use of relatively simple forms. In this series, the author illustrates through the use of typical examples how a level of math within the grasp of any amateur may become a definite aid in the solution of many of the every-day radio problems which confront him.

The average amateur is apt to have an innate fear of mathematics. The sight of voluminous formulas, complex notation and expressions involving the calculus often dazzles him to the extent that he is sometimes reluctant to attempt an understanding of even the simplest of mathematical computations. Consequently, he neglects the very practical applications of the mathematics he already knows or could easily grasp. A thorough understanding of these simple mathematical applications in vacuum-tube circuits will bring an understanding of the more advanced forms a step nearer. Furthermore, these relatively simple manipulations suffice for the larger percentage of practical circuit computations.

While the radioman may already understand the basic principles of algebra and trigonometry, too often he may be able to utilize that knowledge only on a strictly textbook basis because he has not been shown how to reduce his knowledge to practice by explanation and typical illustrations. Many pages have been written on the derivation of formulas and their purpose and use, but in many cases the angle of attack has omitted practical examples and adequate explanation. The latter, however, are of considerable value to the practical radioman, since they not only close the gap between mathematics and practical application but also bring about a more complete understanding of any circuit.

In this first article of the series, therefore, the application of Ohm's Law and simple mathematics to various circuits commonly used for obtaining grid bias will be discussed.

In the following examples, it is assumed that vacuum-tube amplifiers are used which are adjusted for Class-A operation, so that no current flows in the grid-cathode circuit. Receiver r.f. and i.f. amplifiers as well as Class-A audio stages are adjusted for this type of operation. Therefore, the grid resistor, R_g, serves only as a means for applying the biasing voltage to the grid without short-circuiting the tube input. Its purpose is the same as that of the grid choke in any parallel-fed grid circuit, and it does not contribute to the biasing voltage applied to the grid because there is no current flow through it.

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Also, it should be pointed out that a true electrode voltage is the voltage measured between any selected electrode and the *cathode*, and that the resulting polarity is in respect to the cathode. Therefore, the grid-biasing voltage is the d.c. voltage measured between grid and cathode and not the voltage between grid and chassis or ground. In many applications the latter voltage will be zero.

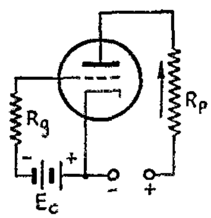

Fig. 1

Following the most common convention, current is assumed to flow from positive to negative and from a positive electrode to the cathode within the tube. Actually, the direction of the current flow makes no difference insofar as calculations are concerned, provided the same direction is assumed for any related series of calculations.

No calculations are involved in determining the grid bias in the circuit of Fig. 1, since it is obvious that it is determined simply by the voltage of the battery. There is no current flow through R_g, and so it does not contribute to the biasing voltage.

In Fig. 2-A, plate current flows through the cathode resistor, R_k, as indicated by the arrows, so that there is a voltage drop between cathode and grid, making the cathode positive in respect to the grid. The grid, therefore, is negative in respect to the cathode. The voltage drop across R_k depends upon the product of its resistance and the current flowing through it. The current flowing through R_k is the same as the plate current flowing through R_p. Thus $E_c = I_pR_k$.

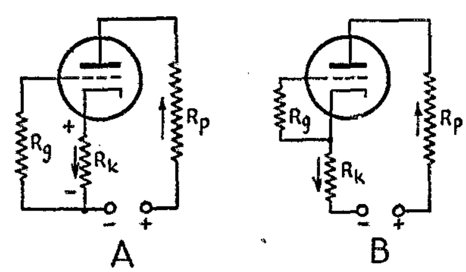

Fig. 2

Example: $I_p = 4$ ma. $R_k = 1500$ ohms
$E_c = (0.004)\ (1500) = 6$ volts

Although the same voltage drop is developed across R_k in Fig. 2-B, it does not appear between grid and cathode and therefore the bias is zero in this instance. In the circuit of Fig. 3, the grid is returned to a tap on the cathode resistor. The voltage drop across only that part of the resistance included between cathode and grid is applied as bias.

Example: $R_1 = 800$ ohms. $R_2 = 700$ ohms.
$I_p = 4$ ma.
$E_c = (0.004)\ (800) = 3.2$ volts

In the circuit of Fig. 4, the screen current, I_s, as well as the plate current, I_p, flows through the cathode resistor, so that these two currents must be added together in determining the voltage drop across R_k.

Example: $I_s = 1$ ma. $I_p = 6$ ma. $R_k = 800$ ohms
$E_c = (0.001 + 0.006)\ (800) = 5.6$ volts

It is obvious that simple cathode-resistance biasing cannot be used in cases where complete

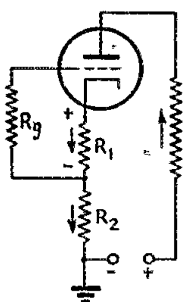

Fig. 3

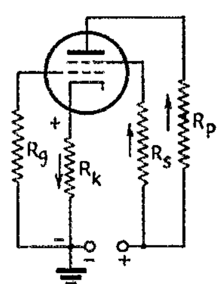

Fig. 4

plate-current cut off is desired, because a cessation of plate current would mean that no bias would be developed across the cathode resistance. To make cut-off bias possible, the circuit of Fig. 5 is sometimes used. In this case, the current flowing through R_k is the sum of the plate current and the current flowing through R_b. If plate current ceases, a voltage drop is still developed across R_k by virtue of the current flowing through R_b. The equivalent circuit is shown in Fig. 6. R_{pt} represents the sum of R_p and the internal plate resistance of the tube.

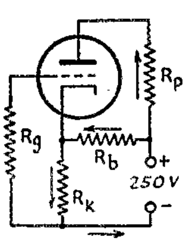

Fig. 5— (Equivalent circuit is shown in Fig. 6.)

Example:

$E = 250$ volts. $I_p = 4$ ma. $R_b = 50{,}000$ ohms. $R_k = 1000$ ohms. What is the biasing voltage developed across R_k?

$E_b = I_bR_b$
$E_k = I_kR_k$
$I_k = I_p + I_b = 0.004 + I_b$
$E_k = (0.004 + I_b)\ (1000) = 1000I_b + 4$
$E_b = 50{,}000\ I_b$
$E = 250 = E_b + E_k = 50{,}000\ I_b + 1000\ I_b + 4$
$51{,}000\ I_b = 250 - 4 = 246$

$$I_b = \frac{246}{51{,}000} = 0.00482$$

$E_b = (0.00482)\ (50{,}000) = 241$
$E_k = E - E_b = 250 - 241 = 9$ volts

Fig. 6

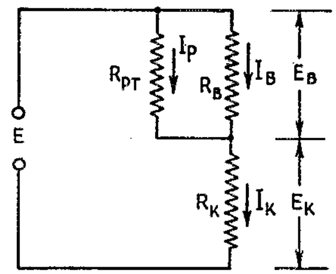

Fig. 7 shows a circuit which is sometimes used in certain volume expansion-compression circuits. The grid is returned to a positive point (in respect to the ground) on a voltage divider connected across the "B" supply. The biasing voltage applied to the grid is then the algebraic difference between the voltage drop across the cathode resistor and this positive voltage.

Example:
$I_p = 10$ ma. $R_k = 800$ ohms. $R_1 = 50{,}000$ ohms. $R_2 = 1000$ ohms.
The current through the voltage divider, R_1R_2, is given by

$$I_{vd} = \frac{250}{50{,}000 + 1000} = 4.1 \text{ ma.}$$

Since no current is being drawn from the junction of R_1 and R_2, the voltage across R_2 is then
$(1000)\ (0.0041) = 4.1$ volts positive *in respect to ground.*
$E_k = (R_k)\ (I_p) = (800)\ (0.01) = 8$ volts.

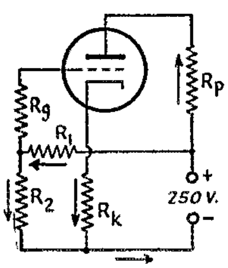

Fig. 7

Therefore, the *cathode* is 8 volts positive in respect to ground. Since the grid is 4.1 volts positive in respect to ground while the cathode is 8 volts positive in respect to the same point, the grid must be $8 - 4.1 = 3.9$ volts *negative* in respect to the cathode.

In Fig. 8, a common cathode resistor is used for two tubes, the plate currents of both tubes therefore flowing through R_k.

Example: $I_{p1} = 2$ ma. $I_{p2} = 5$ ma. $R_k = 800$ ohms.
$E_k = (0.002 + 0.005)\ (800) = 5.6$ volts.

If both grids are returned to negative "B," this same bias will be applied to both grids. If, however, one of the grids is returned directly to cathode, the bias on this grid will be zero while the other grid will have a bias of 5.6 volts.

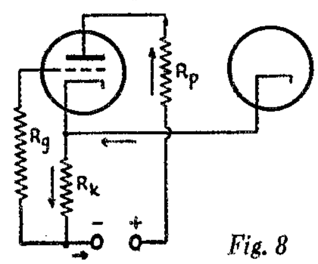

Fig. 8