SECTION 3

ELECTRICAL DESIGN CONSIDERATIONS

3.1 CLASS OF OPERATION

Most power grid tubes can be operated in any classification, although a few types are not recommended for operation in the positive grid region. This is because the control grid structures are designed for very high gain, and therefore the grid dissipation rating is quite low. The 4CX1000A and the 4CX350A are tubes of this type.

The angle of plate current flow determines the class of operation. Class A is generally considered to be a 360° conduction angle, Class B is 180° conduction angle and Class C is less than 180° Class AB is in the region between 180° and 360° of conduction angle. The subscript "1" means that no grid current flows. The subscript "2" means that grid current flows.

Example: Class AB_2 - operation denotes a plate current conduction angle of 180 to 360 degrees and that grid current is flowing.

The class of operation has nothing to do with whether the amplifier is grid-driven or cathode-driven. A cathode-driven amplifier, for example, can be operated in any desired class. The class of operation is only a function of the plate current conduction angle. The efficiency of an amplifier is also a function of the plate current conduction angle.

The efficiency of conversion of d-c to a-f or r-f power is one of the important characteristics of a vacuum tube. The d-c power which is not converted to useful output power is, for the most part, converted to heat. This heat represents wasted power, and the result of low efficiency is increased operating cost for power. Low efficiency compounds itself. The wasted power must be dissipated, requiring increased blower ratings.

Heat exchangers may be needed to cool the equipment. The increased dissipation requires tubes with increased power ratings, and also requires increased ratings on all power supply components. Thus, for a given application, and in all but the very lowest power applications, the efficiency must be carefully considered, consistent with the other requirements of the system. Figure 21 presents the theoretical efficiency attainable with a tuned, or resistive, load assuming peak a-c plate voltage is equal to plate supply voltage.

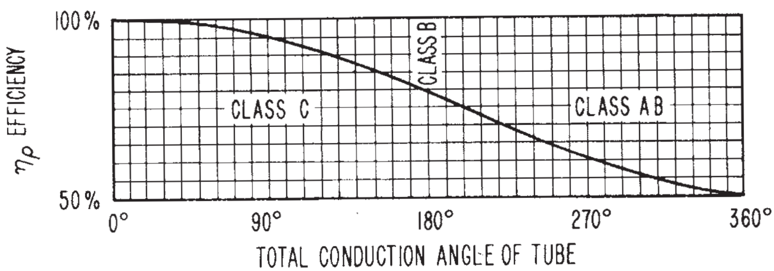

Figure 21. **Plate efficiency vs. conduction angle for an amplifier with tuned load. (From Thomas L. Martin, Jr., "Electronic Circuits," p. 452, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1955).**

A Class A power amplifier is used in applications requiring large amounts of low harmonic distortion power output. A Class A amplifier can be operated with very low intermodulation distortion in linear r-f amplifier service (see section 4). Typical plate efficiency for a Class A amplifier is about 30 percent. The power gain is quite high due to the very low drive power required. Gains as high as 30 dB are typical. Class A service is widely used in audio amplifier service and regulator service.

A Class AB power amplifier is capable of generating more power, with the same tube, than the Class A amplifier, but more intermodulation distortion is generated at the same time. A Class B r-f linear amplifier will generate still more intermodulation distortion, but is acceptable in certain applications. The plate efficiency is typically 66 percent, and stage gain is about 20 to 25 dB. Class B is used widely in audio amplifier applications, such as modulators for high level amplitude modulation.

A Class C power amplifier is used where large amounts of r-f power are to be generated with high efficiency. A Class C amplifier operates much like a limiter; therefore, it cannot amplify a modulated driver without serious distortion. Class C amplifiers are used for high level amplitude modulation wherein the plate voltage, or plate and screen voltage for tetrodes, is varied at an audio rate. Class C amplifiers must be used with tuned circuits or with a commutating output circuit with filtering. Class C cannot be used in the normal audio amplifier circuit.

3.2 TUBE PERFORMANCE COMPUTER FOR R-F AMPLIFIERS

It is quite easy to make a close estimate of the performance of a vacuum tube in radio-frequency power amplifier service, or an approximation in the case of harmonic amplifier service. Such estimates will give r-f output power, d-c input power, grid driving power, and all d-c current values.

These estimates can be easily made by using the EIMAC Tube Performance Computer. This can be obtained at no cost by writing to: Application Engineering Department, CPI, EIMAC Division, 301 Industrial Way, San Carlos, CA 94070 USA. The computer is used with the characteristic curves of the tube, as plotted on the plate voltage/grid voltage coordinates (constant current curves).

By graphically laying out the trace of the plate and grid voltages as they rise and fall about the applied d-c plate voltage and d-c grid bias, a clear understanding of the action taking place within a tube is possible. With such an understanding, the operating conditions can be readily altered to suit individual requirements.

3.2.1 Simple Action in Class C R-F Amplifiers

In an amplifier a varying voltage is applied to the control grid of the tube. Simultaneously the plate voltage will vary in a similar manner, due to the action of the amplified current flowing in the plate circuit. In radio-frequency applications with resonant circuits, these voltage variations are smooth sine-wave variations, 180° out of phase (as the grid voltage rises and becomes **more** positive, the plate voltage falls and becomes **less** positive), as indicated in Figure 22. Note how these variations center about the d-c plate voltage and the d-c control grid bias.

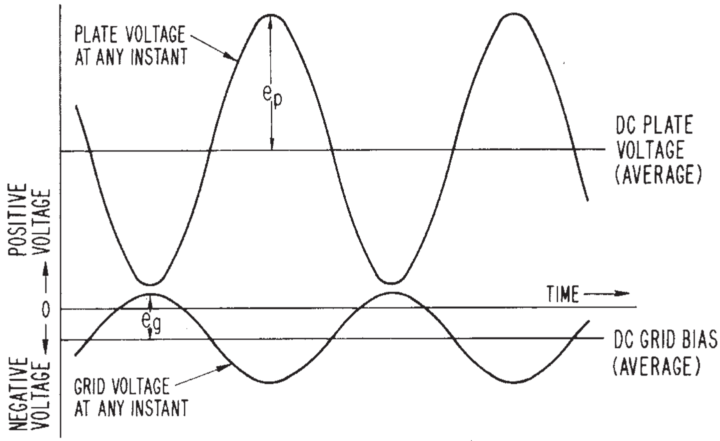

Figure 22. Variation of plate and grid voltage

Now let us see how such variations of the plate and grid voltages of a tube appear on the constant-current curves of a tube. In Figure 23 these variations have been indicated next to the plate voltage and grid voltage scales of a typical constant current curve. At some instant of time, shown as "t" on the time scales, the grid voltage has a value which is the point marked "e_g" on the grid-voltage sine wave. If one finds the point on the tube curves corresponding to these

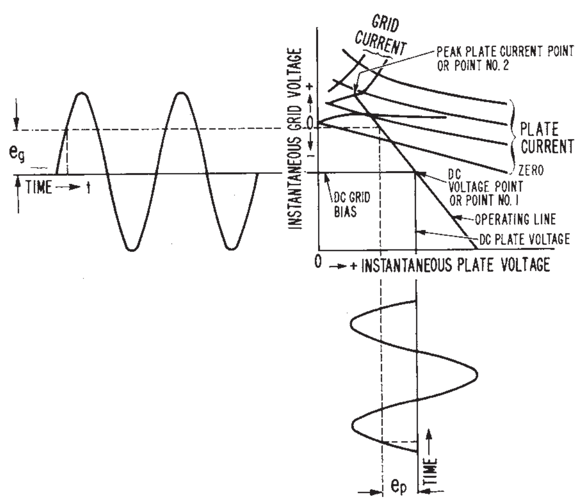

Figure 23. Plate voltage and grid voltage scales

values (where a line drawn from "e_g" and a line drawn from "e_p" cross) he will be at Point A in Figure 23. As the values of the grid voltage "e_g" and plate voltage "e_p" vary over the r-f cycle, Point A moves up and down a line, which in the case of the normal r-f power amplifier is a straight line. This line is called the "Operating Line."

Any point on the operating line (when drawn on constant current curves as illustrated in Figures 23 or 24) tells the instantaneous values of plate current, screen current, and grid current which must flow when these particular values of grid and plate voltage are applied to the tube. Thus, by reading off the values of the currents and plotting them against time "t", one can obtain a curve of instantaneous values of plate and grid current (Figure 17).

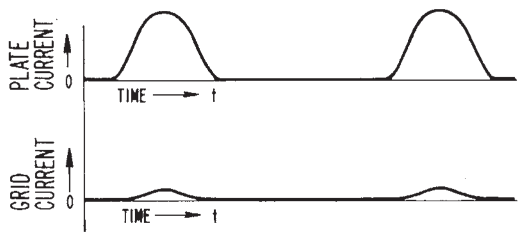

Figure 24. Instantaneous values of plate and grid current.

If we analyze the plate and grid-current values shown, we can predict that they will cause a d-c ammeter to show a particular reading. This is called the d-c component of the current. Also, we can predict that if the plate current flows through a properly-loaded resonant r-f circuit, a certain amount of radio-frequency power will be delivered to that circuit. If the circuit is tuned to the fundamental frequency (same frequency as the r-f grid voltage) the power delivered will be due to the fundamental, or principal, radio-frequency component of plate current. If the circuit is tuned to a harmonic of the grid-voltage frequency, e.g., two or three times the frequency, the power delivered will be due to a harmonic component of the plate current.

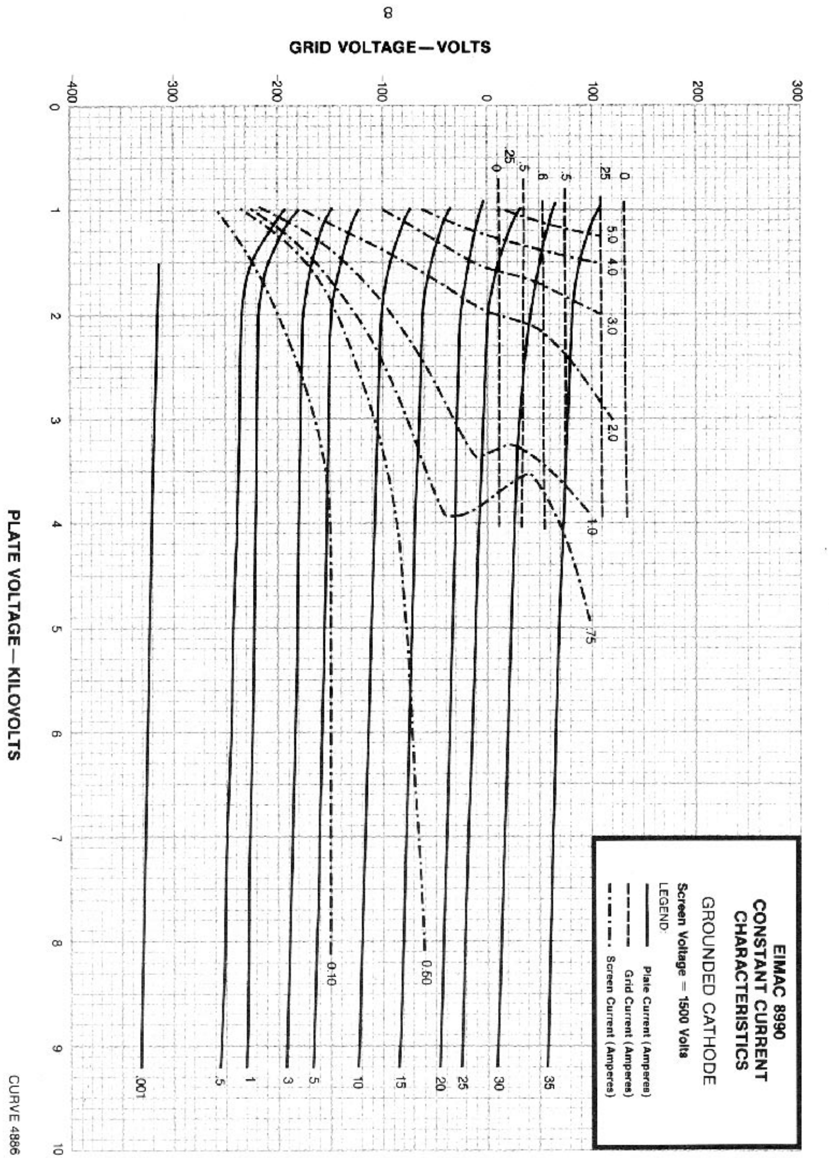

Figure 25. **Constant current characteristics for 4CX20,000E/ 8990 tetrode.**

3.2.2 Use of the EIMAC Tube Performance Computer

The EIMAC Tube Performance Computer provides the means to make these simple calculations. It is a means to determine the d-c component, the fundamental r-f component, or the approximate harmonic component of the current flowing in a tube when the tube is operating as a radio-frequency amplifier. It also enables one to state what all meter readings will be, and to predict the r-f output power and the required driving power. With these factors known, we are able to forecast what will happen if any of the operating conditions are changed.

The EIMAC Tube Performance Computer is a simple aid to enable the selection of suitable values from the characteristic curves of a tube, and by means of simple calculations to forecast the performance of the tube in radio-frequency power amplifier applications.

The basic steps are outlined under “Instructions” on the computer. This requires selecting d-c plate and grid-bias voltages, being guided by the typical operating values given on the technical data sheet for the tube type under investigation. Next, a suitable “operating line” must be chosen on the constant-current curves for the tube type (plotted on the grid-voltage/plate-voltage coordinates).

The computer, when properly placed over this operating line, permits one to obtain instantaneous values of the currents flowing at every 15° of the electrical cycle. The formulas given on the computer were derived by Chaffee[1] to give the various average and harmonic components of the resulting currents. Knowing these current component values and the radio-frequency voltage values which are indicated through use of the computer, one can readily calculate the complete performance of the tube.

The fundamental methods of making such computations, the considerations necessary to stay within the ratings of the tube types while accomplishing various forms of modulation have been covered in literature.[2, 3, 4, 5, 6] The method for the case of harmonic amplifier service is approximate and should be used only for tetrode and pentode tubes where the plate voltage has little effect on the amount of plate current flowing. A more exact method, showing that for harmonic operating the operating line is a simple Lissajou figure, has been described by Brown.

The results obtained by using this computer for power-amplifier

1 E. L. Chaffeel ”A Simplified Harmonic Anaiysis,” Review - Sci. Inst. 7, October 1936, p. 384.

service can be applied in combination with the other methods given in the literature to give good accuracy with simplified procedures. The resulting accuracy is well within the normal variation of tube characteristics due to the normal variation in manufacturing dimensions of a tube. Since the published curves are only typical of the characteristics to be expected of a particular tube type, the calculated performance will be well within the values obtained when different tubes of a given tube type are operated under the assumed conditions.

3.2.3 Example Showing Detailed Use of the Computer in Class C R-F Power Amplifiers

Assume that we have an EIMAC 4CX20,000A/8990 tetrode and want to make it work efficiently. Also assume that we have a 10 kilovolt d-c power supply available.

Within frequency limits, we know that a tube should be able to run in Class C amplifier service with about 75% efficiency or higher, or in other words, to convert 75% of the d-c plate input power to r-f output power. The difference, or 25% of the input power, is dissipated and lost as heat on the plate of the tube. The d-c plate input power is then about four times the power dissipated on the plate.

The 4CX20,000A/8990 tetrode has a maximum rated plate dissipation of 20 kilowatts. To illustrate performance near the maximum rating, we will choose an input power about 1.5 to 2 times the dissipation rating, or about 30 - 40 kilowatts. At 10 kilovolts the dc plate current must then be 3 to 4 A. We will use 3.2 Amperes of plate current for our example, striving for 80% efficiency we hope to obtain at least 25 kiloWatts of output power. It is usual practice in the case of tetrodes and medium or low μ triodes in Class C amplifier service for the d-c grid bias voltage to be roughly two to three times the grid voltage necessary to cut off the flow of plate current. By referring to the curves for the 4CX20,000A/8990 we decide to use a d-c grid bias voltage of -400 volts. Higher bias

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2 H. P. Thomas, "Determination of Grid Driving Power in Radio Frequency Power Amplifiers," Proc. IRE, Vol. 21, Aug. 1933, pp. 1134-1141.

3 W. G. Wagener, "Simplified Methods for Computing Performance of Transmitting Tubes," Proc. IRE, January 1937.

4 R. 1. Sarbacher, "Graphical Determination of PA Performance," Electronics, December 1942.

5 R. 1. Sarbacher, "Performance of Self Biased Modulated Amplifier," Electronics, April 1943.

6 Robert H. Brown, "Harmonic Amplifier Design,"Proc. IRE, Vol. 35, August 1947, pp. 771 - 777.

voltage may be employed in applications where highest possible efficiency is desired (and additional drive power is available) in such a case points will have to be established below the bottom-most line in the data sheet which is –400 Volts by scaling a new grid Voltage line horizontally, below the existing line. Scaling for higher plate Voltage can also be done in this way (within the absolute maximum ratings established for a given tube type).

Let us now locate the operating line on the constant-current curves for the 4CX20,000A/8990. (See Figure 25). First, mark the point where the d-c grid bias and d-c plate voltage cross. The operating line must go through this point, which can be referred to as “Point No. I.” Next, we must decide what the peak value of plate current must be and how low we can let the instantaneous value of plate voltage (ebmin) be when the tube is passing this much current. This is necessary in order to locate the other end of the operating line, e.g., “Point No. 2 “.

The peak value of plate current in Class C amplifiers can range from three to five times the value of d-c (average) plate current, the actual value determined by the conduction angle (narrower conduction angles result in a higher peak-to-dc ratio); less than 120 degrees is a typical conduction angle and a peak-to-average ratio of 5 is typical in high efficiency class-C service. The minimum value of ebmin is usually limited by the fact that if it is too low, the grid current in triodes or the screen current in tetrodes will be needlessly high, resulting in high grid or screen dissipation. Little will be gained as far as output power is concerned if the tube is driven “harder.” The minimum value of plate voltage is usually in the region where the plate constant-current curves bend upward (entering saturation, see Figure 25.) In the case of triodes, this is near the “diode line,” where the instantaneous plate and grid voltages are equal. The practical procedure in calculating tube performance is to arbitrarily choose Point No. 2, complete the calculations, and compare the data to target values and repeat the process until the desired results are obtained.

In the case of the 4CX20,000A/8990, let us choose a peak value of plate current about five times that of the d-c plate current of 3.2 Amperes, or approx. 16 A. Let us choose a minimum instantaneous plate voltage of 1 kilovolt, the same value of screen voltage used when the curves were taken. This defines the upper end of the *operating line*. Locate this point on the tube curves, and refer to it as Point No. 2 in Figure 25. (The plate currents which flow at various combinations of plate and grid voltages are shown by the plate-current lines.) The value of current for each line is noted. In-between values can be estimated closely enough for our purposes.

Draw a straight line between Points 1 and 2. This line is the *operating line*, and shows the current and voltage values at each instant in the r-f cycle when the current is being taken from the tube. The nonconducting half of the r-f cycle would be shown by extending the line an equal distance on the opposite side of Point No. 1. There is little to be gained by this line extension, since no current flows during this half of the cycle.

The EIMAC Tube Performance Computer can now be used to obtain the average currents (what will become meter readings in actual operating conditions) and anticipated power values from this *operating line*. Overlay the computer on the constant-current curve so that the “guide lines” of the computer are parallel with the *operating line*. Slide the computer (without turning it) until the line **OG** passes through the d-c voltage point No. 1, and line **OA** passes through the peak-current Point No. 2. Be sure the guide lines are still parallel to the *operating line*.

Note that the lines OB, OC, OD, OE, and OF all cross over the *operating line*.

At each point where the lines OA, OB, etc. cross the *operating line*, we must determine the instantaneous values of plate current and grid current (and screen current if a tetrode or pentode is used) which are flowing at that particular moment in the r-f cycle. Later, from these key values of current, values of plate current, grid current, screen current, and the r-f components of the plate current may be calculated.

These current values should be listed for each point where the lines OA, OB, etc. cross the *operating line* so that they can be combined later to calculate the various tube currents. At points where OE and OF cross, the current values are insignificant or zero in Class C operation.

In the examples chosen, read off the instantaneous plate current values where these lines cross the “operating line.” At the point where the line OA crosses the operating line, the plate current is 16 A. Where OB crosses the operating line, the plate current is 15 A. At OC the plate current is about 9 A, OD is 3 A, OE is 0.25 A, and OF and OG are 0 mA. Similarly, the instantaneous screen current at the crossing of OA and the operating line is 2.25 A, and the instantaneous grid current is 0.25 A. Values are read for the other crossover points and written down. These values are put into columns for calculation:

Crossing of Line	Simplified name in Formulas	Instantaneous current values Plate	Screen	Control Grid
OA	A	16A	2.25A	0.25A
OB	B	15	1.5	0.14
OC	C	9	0.5	0
OD	D	3	0.1	0
OE	E	0.25	0	0
OF	F	0	0	0

In order to obtain the d-c value of plate, screen, and control grid currents the formula (see computer) indicated that the above values should be added, using only one-half the A values (giving 8 A for plate, 1.125 A for screen, and 125 mA for grid), and then divided by 12 (or multiplied by .0833), as follows

D-C meter reading = 1/12 times (0.5A+B+C+D+E+F)

Plate	Screen	Contol Grid
8A	1.125A	125 mA
15	1.5	140
9	0.5	0
3	0.1	0
0.25	0	0
0	0	0

D-C current = 1/12 totals = (approximately)

2.9A	269mA	22mA

To calculate the r-f output power it is necessary to use the formula for the peak r-f current which is present in the tube plate current. Since the tube is being used as a straight r-f power amplifier, use the formula for “Peak Fundamental R-F” as shown on the computer. If estimating the performance of a doubler or tripler, use the formula for “Peak 2nd Harmonic R-F” or “Peak 3rd Harmonic R-F.”

From the computer, it may be seen that the formula for the peak fundamental r-f current is:

1/12 (A+1.93B+1.73C+1.41D+E+0.52F)

A	=	8	=	16 A
1.93B	=	1.93 x 15	=	28.95
1.73C	=	1.73 x 9	=	15.57
1.41D	=	1.41 x 3	=	4.23
E	=	0.25	=	0.25
Total				65.0 A

Peak fundamental current = 1/12 total or 65/12 = 5.4 A

The various current values are now at hand. In order to calculate the powers involved, it is necessary to know not only the d-c voltage values but also the greatest amount each value swings away from the d-c value. This is known as the peak value of the r-f voltage. Because the plate voltage swings from 10 kilovolts down to 1 kV, the peak r-f plate voltage is the difference between these two figures, or 9 kilovolts. Similarly, the grid voltage must rise and fall between the operating points No. 1 and No. 2, or from -400 volts to +20 volts. This is a peak swing of 420 volts, and the peak r-f grid voltage is +20 volts.

Now use the formula for output power and driving power: Output power = one-half r-f plate current x peak r-f plate voltage.

The peak r-f plate current is found to be 5.4 ampere, and the peak r-f plate voltage is found to be 9 kilovolts.

So: Output Power	=	5.4 x 9000 x 0.5 = 24.3 kilowatts.
and Input Power	=	d-c Plate Current x d-c Plate Voltage = 2.9 x 10,000 = 29 kilowatts
Plate Dissipation	=	d-c Input Power - r-f Output Power = 29 – 24.3 = 4.7 kilowatts
Efficiency	=	r - f Output Power divided by d - c Input Power
	=	24.3/29 = 83%
Driving Power	=	d-c Grid Current x Peak R-F Grid Voltage
	=	0.0265 x 420 = 111 watts

The power consumed by the bias source is the product of the d-c grid current and the d-c grid voltage, or 0.022 x 400 = 88 Watts.

The difference between the driving power and the power consumed by the bias source is the power dissipated on the control grid, or 111 - 88 = 23 Watts.

The power dissipated on the screen grid is the product of the d-c screen current and the d-c screen voltage, because the screen grid has no impedance between it and the d-c screen supply. Thus it is 0.269 x 1000 = 269 Watts.

The performance of the tube can be summarized:

d-c Plate Voltage	10,000	Volts	Driving Power	111	Watts
d-c Screen Voltage	1000	Volts	Grid Dissipation	23	Watts
d-c Grid Voltage	-400	Volts	Screen Dissipation	269	Watts
d-c Plate Current	2.9	A	Plate Input Power	29	kW
d-c Screen Current	269	mA	Plate Output Power	24.3	kW
Peak r-f Grid Voltage	420	Volts	Plate Dissipation	4.7	kW
calculated efficiency	83%				

We see that the resulting calculated value of dc plate current (2.9 A) is lower than our initially chosen value of 3.2 by approx. ten percent, evidence that calculated efficiency of 83% is higher than the target value of 80% we initially anticipated. In the “real world” actual transmitter output power will be somewhat lower than calculated values because of rf losses in the output matching network. One should also be aware that there may be variations in output from one tube to another due to varying electrical characteristics and that a tube that has been in service for an appreciable length of time may deliver less output than it did when it was new. Varying the dc screen voltage on a tetrode is an excellent method for varying output power and is employed for maintaining a fixed power requirement; as a given tube ages and loses emission from the filament its output power will decline. Compensating for losses over time is easily accomplished by using a voltage source for the screen that is adjustable by means of a closed-loop regulator system. If one wishes to calculate tube performance of a tetrode at screen voltages other than those at which the constant current curves were taken, a compensating factor using the three-halves power law can be employed (see sec 6.4). To account for loss of output over time a good designer will choose a tube that has output power capabilities well above the specified requirement, using as much conservatism as practicable. In the case of the 4CX20,000A/8990 in FM broadcast service actual tube life of 20,000 to 40,000 hours is common, indicating this tube is a good choice for supplying rf power from approx. 20 to 30 kiloWatts in continuous commercial service.

3.2.4 Use of EIMAC Tube Performance Computer for Class A, AB, and B Service

While the EIMAC Tube Performance Computer is primarily designed for use in Class C service, it may be used for Class A, AB, and B service where the idling (quiescent) plate current is not zero. To calculate performance for operating conditions having a large order of idling plate current, the plate current flow during the positive half of the plate voltage swing becomes appreciable and cannot be ignored. When the tube functions over 180 degrees or more of the operating cycle, a full set of ordinate points must be employed for the computations. The computer is therefore used in a two-step process.

First, determine the operating line. The computer is used in the normal fashion to derive the instantaneous values of plate, screen, and grid current during the negative half of the plate voltage swing. These current points are logged as explained under the Class C service description.

Now, determine the instantaneous current points over the positive portion of the plate voltage cycle. Combine these with the points taken for the negative half of the cycle. This is done in the following fashion: a line is penciled on the computer over the operating line, and of equivalent length. The computer is now inverted and rotated 180° and again aligned with the chosen operating line on the constant current curve, so that inverted point G falls on the idling current value (Point No. 1) and inverted point A passes through a minimum peak current point representing maximum positive plate voltage swing. The penciled line on the computer now represents an extension of the operating line into the area of positive peak voltage swing. The extended operating line is a straight line, twice as long as the original operating line. Instantaneous values of plate, screen, and grid current (if any) are those observed where the reversed ordinate lines on the computer cross the extended operating line.

The current points measured with the computer inverted are logged and these, together with the points obtained in the first operation (computer right side up) provide a full set of instantaneous peak current values necessary for the calculation of Class A, AB, or B parameters. With the first set of computer readings termed A, B, C, D, E, F and G, the second (inverted) set of figures may be termed A', B', C', D', El, and F', with the sets used in the following formulae, which are modifications of Chaffee's permitting the use of current values directly from the constant current curves:

(1) D. C. Current (Meter Reading) $= \frac{1}{12}\left[\frac{A+A'}{2} + (B+B') + (C+C') + (D+D') + (E+E') + (F+F') + G\right]$

(2) Peak Fundamental RF Current $= \frac{1}{12}\left[(A-A') + 1.93\,(B-B') + 1.73\,(C-C') + 1.41\,(D-D') + (E-E') + 0.52\,(F-F')\right]$

(3) Approx. 2d Harmonic RF current (tetrodes or pentodes only) $= \frac{1}{12}\left[(A+A') + 1.73\,(B+B') + (C+C') - (E+E') - 1.73\,(F+F') - 2G\right]$

(4) Approx. 3d Harmonic RF current (tetrodes or pentodes only) $= \frac{1}{12}\left[(A-A') + 1.41\,(B-B') - 1.41\,(D-D') - 2(E-E') - 1.41\,(F-F')\right]$

(5) Power Output $= \frac{\text{Peak Fundamental RF current x Peak RF voltage}}{2}$

(6) Resonant Load Impedance $= \frac{\text{Peak RF Voltage}}{\text{Peak Fund. RF Current}}$

3.2.5 An Example: Using the Computer for Class AB, Service

Operating data is to be derived for an EIMAC 4CW100,000D tetrode operating at a plate potential of 1 0 kV with a screen potential of 1.5 kV. Assume that power output design goal for this particular application is about 6OkW. Grid current is zero; that is, the tube is operated in the Class AB1 mode, with the grid never being driven positive.

Within frequency limits, a plate circuit efficiency of about 55-60% may be assumed for Class AB 1 operation. Maximum d-c plate input is therefore 2.2 to 2.75 times the anode dissipation. A maximum power input of 2.2 x 50,000 =.110 kW is chosen. At I0kV, the maximum d-c plate current is then 11.0 A. This is within the maximum rated plate current of 15 A for Class AB 1 service as specified on the data sheet.

For Class AB service the tube does not operate in a cut-off condition, but rather a certain value of idling plate current exists. This must be taken into account when choosing Point 1 on the constant current curve. Generally speaking, high levels of resting plate current provide reduced levels of intermodulation distortion products and somewhat lower plate efficiency. Idling plate current is usually chosen so that anode dissipation under quiescent conditions is about 50-70% of the maximum dissipation rating. In the following example, idling plate current is chosen to be 4.5 amperes. From Figure 26, it may be determined that a grid potential of about -295 volts is required to produce the desired plate current at the chosen screen and plate potentials. The intersection of the -295 volt bias line and the 10 kV plate line determines the idling point on the operating line (Point No. 1).

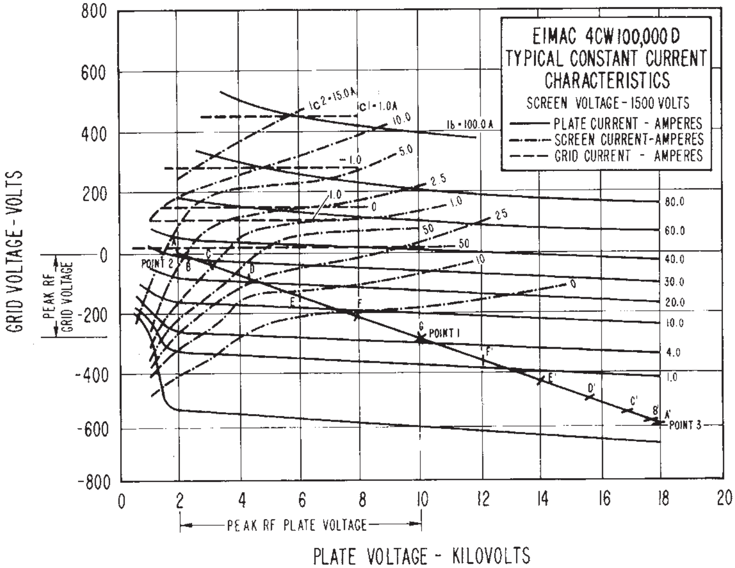

Figure 26. Constant current characteristics for 4CWI00,000D tetrode.

Next, the peak value of plate current must be determined, and the minimum amount of instantaneous plate voltage chosen to pass this amount of current. Determination of these values will locate Point No. 2 and will thus define the operating line.

Class AB1 service limits grid voltage excursions to negative grid regions on the constant current graph. Point No. 2 therefore may never be located above the zero grid voltage line. In addition, the minimum instantaneous plate voltage is usually not allowed to swing as low as the d-c screen potential, since screen dissipation tends to become abnormally high. The location of Point No. 2 thus has certain restrictive limits defined by screen dissipation and the maximum positive grid signal voltage. In this case, for the 4CW100,000D, minimum instantaneous place voltage is about 2 kV. Peak r-f voltage is thus 10,000 - 2,000 = 8,000 volts.

Peak r-f plate current in a Class ABI amplifier usually runs about 2.5 to 3.0 times the average d-c plate current. In this case, a maximum peak plate current of about 2.9 times the maximum signal d-c plate current of 11.0 A, or 32 amperes, is chosen. This defines Point No. 2, which is at the intersection of the 2 kV minimum plate voltage line and thus falls within the limits discussed in the preceding paragraph. A straight line is drawn between Point No. 1 and Point No. 2 which is the negative plate cycle portion of the operating line.

When the operating line is extended to the right of Point No. 1, it can be observed that the tube conducts over the rest of the cycle where (by virtue of the “flywheel” effect of the resonant tank circuit) the instantaneous plate voltage swings as far above the normal d-c value as it swings below. It is important to note that operation with less than cutoff bias requires that the EIMAC Tube Performance Computer employ points on the operating line failing to the right of Point No. 1. The operating line is accordingly extended and the computer is used in a two-part operation, as shown in the following example:

4CW100,000D COMPUTATIONS

d-c Plate Voltage = 10 kV	Power Input	=	110 kW
d-c Screen Voltage =1.5 kV	Max. d-c Plate Current	=	11 amp.
	Zero-Signal Plate Current	=	4.5 amp.
	d-c Grid Voltage	=	-295 volts
Constant Current Graph and	Peak Plate Current	=	32 amp.
Operating Line determine:	Peak RF Voltage	=	8,000

Step One

EIMAC Computer Readings
Instantaneous Peak Current (amps)

Ordinate Crossing	**Plate**	**Screen**
A	32	3
B	31	2
C	28	1.2
D	22	0.25
E	15	0.07
F	9	—
G	4.5	—

Step Two

Inverted Computer Readings
Instantaneous Peak Current (amps)

Ordinate Crossing	**Plate**	**Screen**
A’	0.20	—
B’	0.25	—
C’	0.30	—
D’	0.50	—
E’	0.80	—
F’	1.50	—

d-c Plate Current $= \frac{1}{12}\left[\frac{32.2}{2} + 31.25 + 28.3 + 22.5 + 15.8 + 10.5 + 4.5\right] = 10.75$ amp.

Plate Power Input = 10 KV x 10.75A = 107,500 watts

Peak Fundamental RF Current $= \frac{1}{12}\left[31.8 + 59.4 + 47.7 + 30.3 + 14.2 + 3.9\right] = 15.6$ amp.

Power Output $= \frac{15.6 \times 8000}{2} = 62{,}500$ watts

Plate Dissipation = 45,000 watts

Efficiency $= \frac{62{,}500}{107{,}500} \times 100 = 58.2\%$

Resonant Load Impedance $= \frac{8000}{15.6} = 512$ ohms

d-c Screen Current $= \frac{1}{12}\left[\frac{3}{2} + 2 + 1.2 + 0.25 + 0.07\right] = 417$ mA.

3.3 TYPICAL R-F AMPLIFIER CIRCUIT DESIGNS

In the previous discussion of tube performance calculations, an example was worked out using the 4-65A in Class C r-f service. Using the obtained operating parameters, it is now possible to demonstrate the next step in the circuit design. For the benefit of discussion, it will be assumed the desired output circuit is a shunt-fed pi-network; it will also be assumed that the grid circuit is to be tuned by a conventional parallel tuned circuit. The circuit will be as shown in Figure 27.

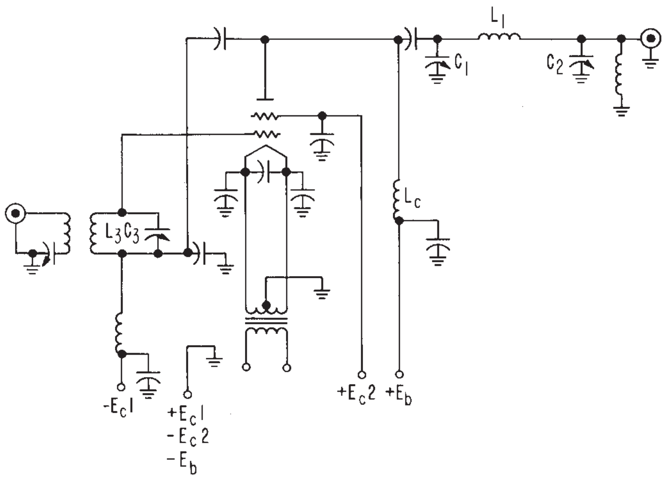

Figure 27. A typical circuit for an R-F amplifier.

$$\text{Resonant Load Impedance} = \frac{\text{Peak r-f Voltage}}{\text{Peak Fundamental r-f Current}}$$

$$R_L = \frac{1750 \text{ volts}}{.230 \text{ amps}} = 7600 \text{ ohms}$$

The first step in designing the output circuit is to specify the resonant load impedance of the tube, the loaded Q of the circuit and the desired output impedance of the network. The resonant plate load impedance for the 4-65A is determined by dividing the plate peak r-f voltage swing by the plate peak fundamental r-f current.

If it is assumed that the output impedance of the network is to be 50 ohms, and the loaded Q is to be 15, the output tuned circuit may now be designed. The output impedance of 50 ohms will match into a properly terminated 50 ohm transmission line. The loaded Q of 15 is a compromise between circuit efficiency and harmonic attenuation (see Figure 28). Figures 29, 30 and 31 are design graphs for matching typical tube load impedances into 50 ohms

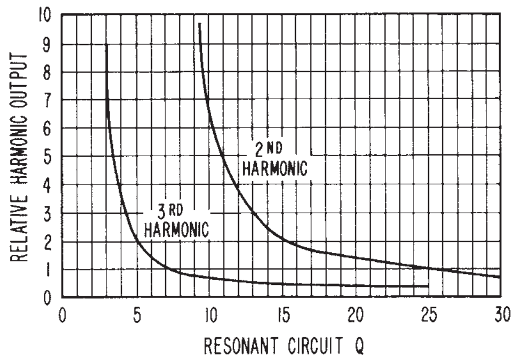

Figure 28. Relative harmonic output vs. resonant circuit Q.

A resonant circuit with a loaded Q of 10 to 20 is usually considered optimum. A lower loaded Q will result in greater harmonic output. A higher loaded Q will result in higher circulating current with increased loss in the coil. The loaded Q is determined by the L/C ratio and the load resistance.

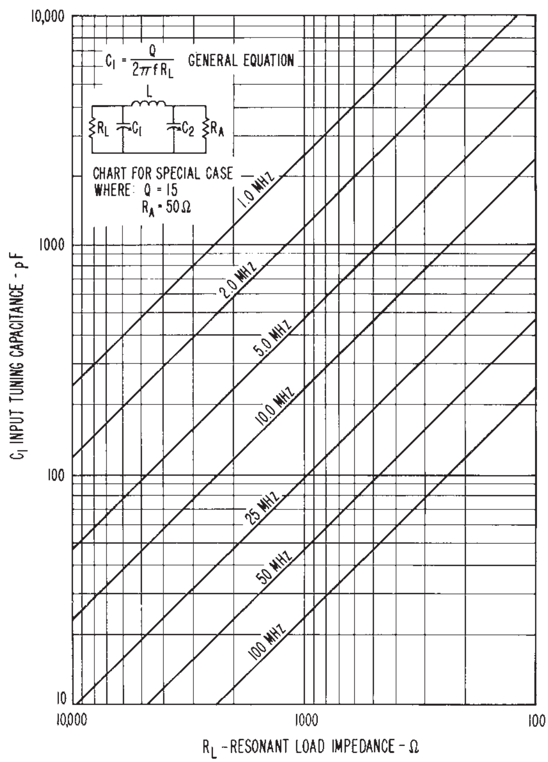

Figure 29. Determination of input capacitor C1.

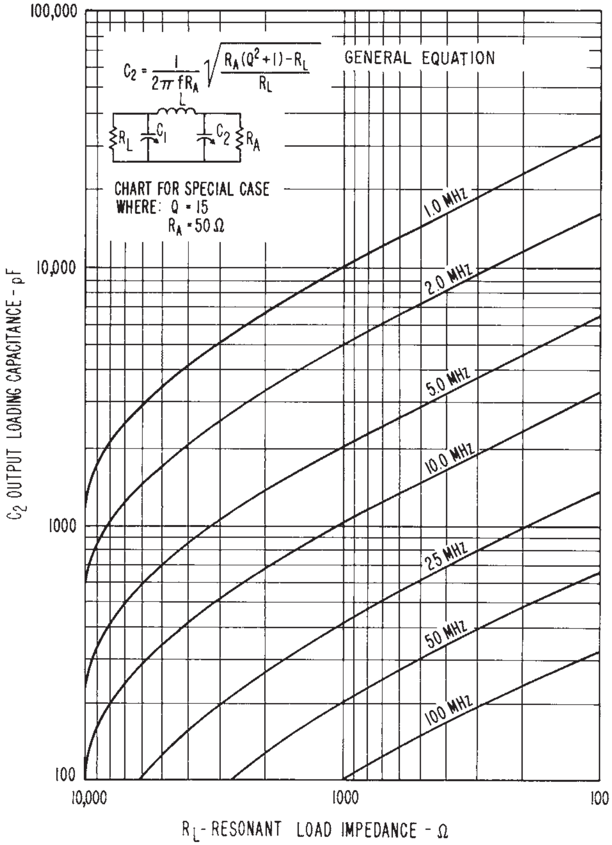

Figure 30. Determination of Loading Capacitor C_2

with a loaded Q of 15. The general equations are given for other loads and other Q's. For the purpose of this example, the parameters for 7 megahertz will be determined. At 7.0 megahertz the value of Cl (Figure 29) will be 45 pf, C2 will be 317 pf and the value of Ll will be 11 microhenries. The C1 value of 45 pF includes the tube output capacitance, the stray capacitance from tube to ground, and the lumped capacitance added to the circuit. The output capacitance of the tube is given in the individual tube data sheet. Capacitance is measured in a shielded fixture and therefore the value obtained is confined to the tube. The measurements are made in an r-f bridge at a frequency of 100 to 465 kilohertz.

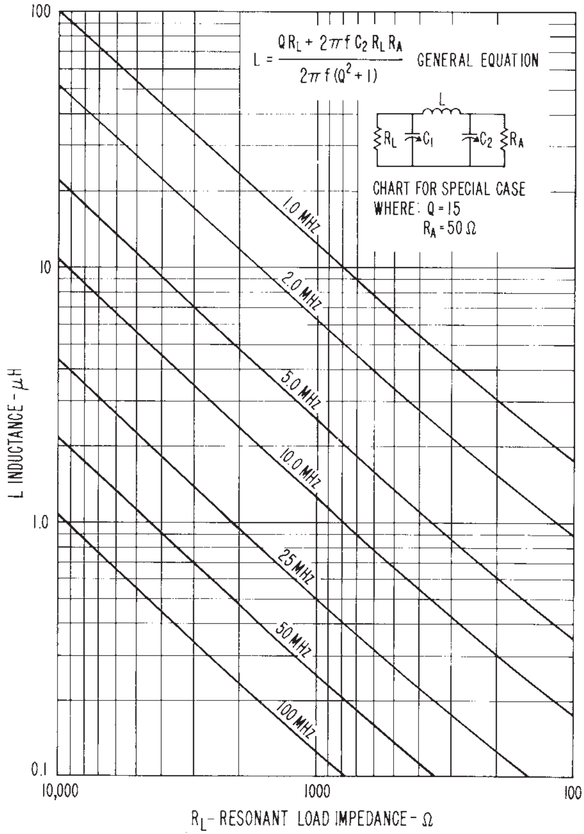

Figure 31A. Determination of Inductor L

The inductance of the plate choke, L_C, in Figure 31 may be determined by noting that it is in shunt with the tuned circuit. If the r-f current through the choke is to be limited to one per cent of the tuned circuit circulating current, the inductance of Lc must be 100 times that of coil L. The inductance of L_C would then be 1.2 millihenries. The series resonant frequency of the choke must be determined to be outside of the operating range of the amplifier. This can be checked by shorting the ends of the choke together with a low inductance strap and measuring the series resonant frequency by means of a grid-dip meter.

It is also important to determine the parallel resonant frequency of the choke due to its stray capacitance. The choke will exhibit inductive reactance below the parallel resonant frequency and capacitive reactance above the parallel resonant frequency. The parallel resonant frequency must therefore be above the operating frequency of the amplifier by a small amount.

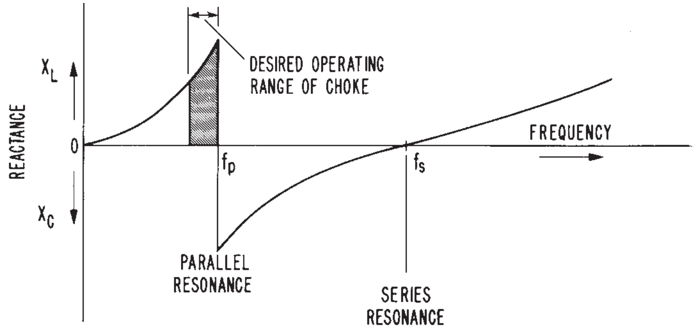

Figure 31B. Reactance of an r-f choke vs. frequency.

The design of a typical grid tuned circuit is quite similar to the design of the plate resonant circuit. For Class C operation, or any class where there is grid current flow, the input circuit must have sufficient Q to maintain a sinusoidal grid waveshape. The input resistance loads the grid tuned circuit. It is generally considered good engineering practice to have a Q of between 12 and 15. In any class of operation with no grid current flowing, the grid circuit requirements are not as stringent.

For the 4-65A example, the input resistance is approximately the power delivered to the grid of the tube divided by the square of the d-c grid current.

$$R = \frac{P}{I^2}$$

R = input resistance
P = power delivered to grid
I = d-c grid current

$$R = \frac{1.4 \text{ watts}}{(.014 \text{ amps})^2} = 7140 \text{ ohms}$$

$$X_c = X_L = \frac{R}{Q}$$

X_c = capacitive reactance of input circuit
X_L = inductive reactance of input circuit
Q = loaded Q of grid circuit

$$X_c = X_L = \frac{7140}{15} = 476 \text{ ohms}$$

The input circuit capacitance, C_3, for 7 megahertz operation will, therefore, be 48 pF. The input circuit inductance, L_3 will be about 10 microhenries.

A further point of interest is the magnitude of the current necessary to charge the input and output capacitances of a vacuum tube. These capacitances must be charged and discharged during each cycle. The input capacitance of the 4-65A is 6.0 to 8.3 pF. Output capacitance is 1.9 to 2.6 pF. For this discussion, it will be assumed the input capacitance is 7 pF, and the output capacitance is 2 pF. With these values of capacitance, the input capacitive reactance at 7 megahertz is 3400 ohms and the output reactance is about 12,000 ohms. In the 4-65A example the grid voltage swing is 220 volts. Therefore, the grid peak charging current will be 220/340 or 0.647 amperes. The peak plate voltage swing is 1750 volts. Therefore, the plate peak charging current will be 1750/ 12,000 or 0.146 amperes. Current values are quite low in this case, because the frequency of operation and the tube capacitances are low. If the 4-65A is operated under the same conditions at ten times the frequency (70 MHz), the charging currents will be ten times the 7 MHz example. The greater the charging currents the greater the tube seal heating, electrode heating, circuit losses, and the greater the current in the screen by-pass capacitor. At the higher frequencies, it is sometimes better to limit the plate voltage swing and raise the plate current. This technique reduces the magnitude of the plate circuit charging current.

3.4 COMPONENT PARTS

If one is to maintain the isolate on of the output and input circuits, some thought must be given to the location of the component parts of the amplifier. All component parts of the grid or input circuit and any earlier stages must be kept out of the plate circuit compartment. Similarly, plate circuit parts must be kept out of the input compartment. It must be noted, however, that in the case of the tetrode and pentode the screen lead of the tube and connections via the socket are common to both the output and input resonant circuits. Due to the plate to screen capacitance of a tetrode or pentode, the r-f plate voltage (developed in the output circuit) causes an r-f current to flow out the screen lead to the chassis. In the case of a push-pull stage, this current may flow from the screen terminal of one tube to the screen terminal of the other tube. Similarly, due to the grid-to-screen capacitance of the tube, the r-f voltage in the input circuit will cause an r-f current to flow in this same screen lead to the chassis, or to the opposite tube of the push-pull circuit.

The inductance of the lead common to both the output and input circuits has the desirable feature of providing voltage of opposite polarity to neutralize the feedback voltage of the residual plate to control grid capacitance of the tube (this is discussed under "Neutralization," Section 5). It should be noted, however, that the mutual coupling from the screen lead to the input resonant circuit may be a possible source of trouble if accentuated.

In the case of the grounded-grid triode control grid and associated leads are common to the output and input circuits. The inductance of the control grid lead can help or hinder the stabilization of a grounded-grid amplifier (this is discussed under "Neutralization," Section 5).

3.5 LEAD LENGTHS

Some of the interconnecting lead wires close to the tube should be designed with extremely low inductance to minimize the chances of forming possible VHF parasitic circuits. If two or more tubes are used they should be placed reasonably close together to help provide short interconnecting leads. The lead lengths of radio frequency circuits involving the fundamental frequency can usually be much longer; the length will depend a good deal upon the frequency of the fundamental. All of the d-c, keying, modulating, and control circuit wires can be quite long if properly filtered and arranged away from the active r-f circuits.

The following interconnecting lead wires in a tetrode or pentode power amplifier should preferably have quite low inductance: filament and screen by-pass leads, suppressor by-pass leads, leads from the grid and the plate to the tuning capacitor of the r-f circuit and return, and the interconnections from tube to tube in push-pull or parallel arrangements (except for parasitic suppressors in the plate). For a lead to have low inductance, it must have a large surface and be short in length, as in a strap or a ribbon. This consideration also applies to that portion of a lead inside a by-pass capacitor.

3.6 FILAMENT BY-PASSING

Low inductance by-pass capacitors should be used in bypassing the filament. It is good practice to place a capacitor directly between the filament socket terminals. If the circuit allows it, strap one filament directly to the chassis, and if not, use a second by-pass capacitor from one terminal to the chassis.

If two or more tubes are in a push-pull or parallel circuits, one can use a short strap interconnecting one of the filament terminals of each socket. The mid-point of the interconnecting strap can be by-passed or grounded directly.

With tubes having a completely isolating screen cone terminal, the general circuit arrangment is usually different. The filament or cathode should go directly or through by-passes to the cavity wall or chassis to which the screen terminal is by-passed.

3.7 SCREEN AND SUPPRESSOR GRID BY-PASSING AND SCREEN TUNING

Low inductance leads are generally advisable for screen and suppressor grid terminal connections. For all frequencies, it is good practice to route the screen and suppressor by-pass capacitors directly from the screen to one filament terminal. The suppressor grid is by-passed in the same manner when the suppressor is operated with a potential other than cathode potential. With the suppressor operating at cathode potential, the suppressor should be grounded to the chassis directly in a circuit where the cathode is at chassis potential. This applies to tubes in push-pull as well as single tubes. In the VHF region, the connection to the screen terminals, for those tubes with two screen pins, should be made to the mid-point of a strap placed between the two screen terminals of the socket. This provides for equal division of the r-f currents in the screen leads and minimizes the heating effects.

Above the self-neutralizing frequency (see “Neutralization,” Section 5) of the tetrode or pentode, the screen by-pass capacitors are sometimes variable. By proper adjustment of this variable capacitor, the amount and phase of the screen r-f voltage can be made to cancel the effects of the feedback capacitance within the tubes. Thus, neutralization is accomplished. The screen lead inductance and the variable capacitor are **not** series resonant. The variable capacitor is adjusted so that a net inductive reactance remains to provide the proper voltage and phase for neutralization.

The preceding paragraphs apply directly to tubes having the screen and suppressor grids mounted on internal supporting lead rods.

The tube types having isolating screen cone terminals seem to work best when the screen or suppressor by-pass capacitor is a flat sandwich type capacitor built directly on to the peripheral screen contacting collet of the socket. The size of the by-pass is a function of the operating frequency. The dielectric material can be Teflon, Mica, Isomica or similar materials.

3.8 GROUNDED-GRID CIRCUITS

The zero-bias triodes, such as the 3-400Z and 3-1000Z, generally are used in grounded grid circuits. The control grid is operated at r-f ground and therefore is similar to the screen grid in a tetrode or pentode. The control grid may be by-passed directly at the socket or operated at d-c ground. The d-c grounded approach is favored because no by-pass capacitors are required. Figures 32 and 33 illustrate the two circuit configurations.

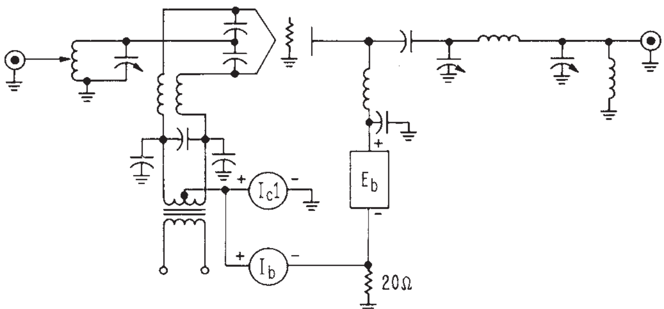

Figure 32. **A typical circuit using "zero-bias" triodes showing metering circuits and method of grounding the grid to r-f. The grid current is measured in the return lead from ground to filament.**

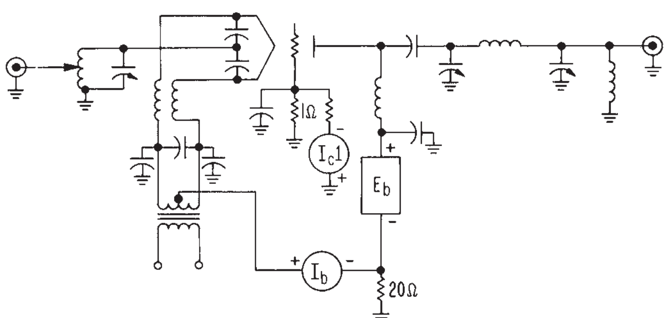

Figure 33. **A typical circuit using "Zero-bias" triodes showing metering circuits. The grid is grounded to r-f with a by-pass capacitor. The grid is raised 1Ω above d-c ground to allow the grid current to be measured.**

3.9 PROTECTION

EIMAC Power Grid Tubes are designed to stand considerable abuse. For instance, the excess anode dissipation resulting from detuning the plate circuit of the tube will have no ill effects if not applied for periods of time sufficient to overheat the envelope and the seal structure.

Similarly, the control, screen and suppressor grids will stand some excess dissipation. The maximum dissipation for each grid indicated on the-data sheet should not be exceeded except for time intervals of less than one second. The maximum dissipation rating for each grid structure is usually considerably above typical values used for maximum output so that ample operating leeway is provided. The time of duration of overloads on a grid structure is necessarily short because of the small heat storage capacity of the wires. Furthermore, grid temperatures cannot be seen, so no visual warning of accidental overload is apparent.

The type and degree of protection required in an r-f amplifier against circuit failure will vary with the type of screen and grid voltage supply. Figure 34 is a chart of tetrode and pentode protection as related to certain kinds of circuit failures.

CIRCUIT FAILURE	FIXED SCREEN SUPPLY		SCREEN VOLTAGE THROUGH DROPPING RESISTOR	
	FIXED GRID BIAS	RESISTOR GRID BIAS	FIXED GRID BIAS	RESISTOR GRID BIAS
Loss of Excitation	No Protection Required	Plate Current Relay	Plate Current Relay	Plate Current Relay or Screen Control Circuit
Loss of Antenna Loading	Screen Current Relay	Screen Current Relay	Grid Current Relay	Nothing Required
Excess Antenna Loading	Screen Under-Current Relay	Screen Under-Current Relay	Plate Current Relay	Plate Current Relay
Failure of Plate Supply	Screen Current Relay	Screen Current Relay	Grid Current Relay	Nothing Required
Failure of Screen Supply	Grid Current Relay	Nothing Required	—	—
Failure of Grid Bias Supply	Plate Current Relay or Screen Current Relay	—	Plate Current Relay Grid Current Relay	—

Figure 34. Tetrode and pentode protection chart.

This chart indicates the location of a suitable relay which should act to remove the principal supply voltage from the stage or transmitter to prevent damage to the tubes.

For screen voltage taken through a dropping resistor from he plate supply, a plate relay provides almost universal protection. For a fixed screen supply a relay provides protection in most cases. For protection against excess antenna loading and consequent high plate dissipation, a screen underurrent relay may also be used in some services.

The plate, screen and bias voltages may be applied simulaneously to a tetrode. The same holds true for a pentode, plus the application of the suppressor voltage. In a grid driven amplifier, the grid bias and excitation can usually be applied alone to the tube, especially if a grid leak resistor is used. late voltage can be applied to the tetrode and pentode before he screen voltage with or without excitation to the control grid. NEVER APPLY SCREEN VOLTAGE BEFORE PLATE VOLTAGE. The only exception would be when the tube is cut off so that no space current (screen or plate current) will flow, or when the excitation and screen voltage are low. If screen voltage is applied before the plate voltage and screen current an flow, the maximum allowable screen dissipation will almost always be exceeded and tube damage will result.

Figure 35 is a chart for the protection of a triode tube. This chart covers the grid driven triode amplifier and the high-μ (zero bias) cathode driven triode amplifier. Drive voltage must never be applied to a zero-bias triode amplifier without plate voltage being applied.

CIRCUIT FAILURE	TRIODE		ZERO-BIASED TRIODE
	FIXED GRID BIAS	RESISTOR GRID BIAS	
Loss of Excitation	No Protection Required	Plate Over-Current Relay	No Protection Required
Loss of Antenna Loading	RF Output Detector & Relay	RF Output Detector & Relay	Grid Over-Current Relay
Excess Antenna Loading	RF Output Detector & Relay	RF Output Detector & Relay	RF Output Detector & Relay
Failure of Plate Supply	No Protection Required	No Protection Required	Grid Over-Current Relay
Failure of Grid Bias Supply	Plate Over-Current Relay	—	—

Figure 35. Triode protection chart

This chart indicates the location of a suitable relay which should act to remove the principal supply voltage from the stage or transmitter to prevent damage to the tube or transmitter.

3.10 KEYING

The tetrode and pentode power amplifier can be keyed using the same basic principles employed with any power amplifier. In addition, the screen electrode provides another low power circuit where keying can be introduced. Suitable filters must be used so that the make and break is slow enough to avoid high frequency sidebands known as "key clicks." The usual "key click" filter techniques apply.

There are several good methods of controlling the tetrode and pentode r-f power amplifier when exciter keying is used. With the screen voltage fixed and with fixed bias greater than cutoff, the tube will pass no current when the excitation is removed. A low or medium- μ triode amplifier can be keyed in the same manner. With the high-μ (zero bias) triodes, it is even simpler. When the drive is removed, the plate current falls to the normal, safe quiescent plate current.

It is also possible to key the exciter stage when the screen voltage for a tetrode or pentode is obtained through a dropping resistor and grid leak bias is used (see Figure 36A). In this system a high transconductance, low-μ triode is connected between screen and cathode, and the controlling bias for the small triode is taken from

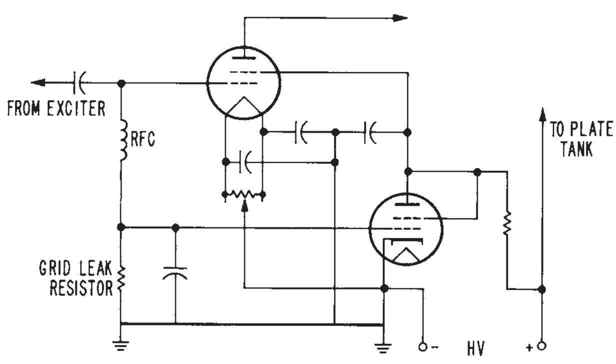

Figure 36A. Screen voltage control circuit for exciter keying or protection against loss of excitation when supplying screen from high voltage source.

the tetrode or pentode bias developed in the grid leak resistor. When normal excitation is present on the r-f amplifier and grid bias is developed, the triode control tube is cut off and the screen voltage circuit operates normally. If excitation voltage is removed from the tetrode or pentode power amplifier, the bias voltage developed in the resistor drops to zero and the control triode becomes conducting. The current drawn by the triode control tube will increase the voltage drop across the series screen resistor and lower the screen voltage to a very low value.

There is still some voltage on the tetrode or pentode screen and a small static plate current flows. Usually this remaining current is not enough for the plate dissipation rating to be exceeded. This value can be reduced further by the use of a second control triode in parallel with the first (this redundancy is also insurance against failure of the single triode), by putting a gas regulator tube in series with the lead to the screen before the screen r-f by-pass capacitor, or by introducing a small amount of fixed bias on the power amplifier between the grid resistor and the power tube grid.

Figure 36B shows a method of keying a tetrode or pentode r-f power amplifier where the low voltage power supply for the screen of the power tube and for the plate and screen of the driver stage is keyed directly. This permits keying in a relatively low voltage, low current circuit. The key click filter capacitor, resistor, and choke are simple and assure positive control of the keying waveshape.

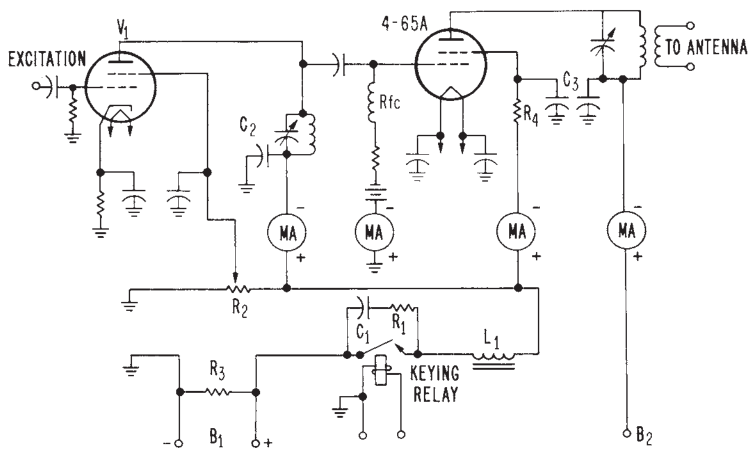

Figure 36B. A typical method of keying a tetrode or pentode amplifier.

3. 11 AMPLITUDE MODULATION

A triode r-f amplifier can be plate; grid- or cathode-modulated. Plate modulation is the type most extensively used. A triode may also be operated under a linear set of conditions for amplifying an amplitude modulated driver.

A tetrode or pentode r-f amplifier can be plate and screen, screen grid, control grid or cathode-modulated. Usually the system chosen is a combination of any of the previously listed

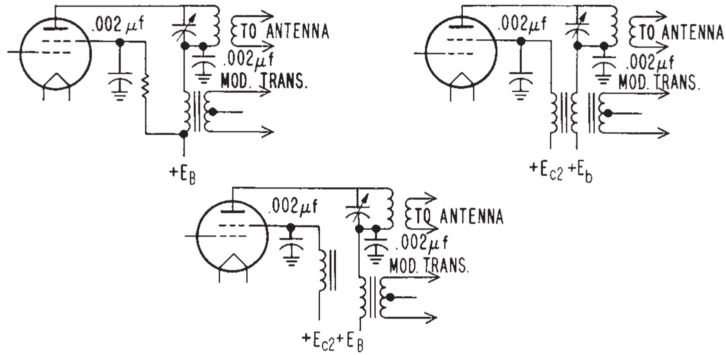

Figure 37. Basic screen and plate modulation circuits.

techniques. The most extensively used technique is a combination of plate and screen modulation. Often additional modulation must be provided on the control grid to reach 100 per cent modulation on the positive peaks. Figure 37 shows three of the basic plate and screen modulation circuits.

In plate and screen modulation it is necessary to introduce not only amplitude modulation of the plate voltage, but also to develop 70 to 100 per cent amplitude modulation of the screen voltage for 100 per cent carrier modulation. Modulation of the screen voltage can be developed in one of the folowing three ways:

(a) By supplying the screen voltage through a dropping resistor connected to the unmodulated d-c plate supply.
(b) When a low voltage fixed screen supply is used, a modulation choke is placed in series with the supply. In the case of voice modulation, this is about a 5 to 10 henry choke.
(c) A third winding on the modulation transformer designed to develop the required screen modulation voltage.

It is interesting to note that in all three cases the screen of the tetrode or pentode tube supplies the necessary audio power. During the portion of the modulation cycle, when the plate voltage is increased, the screen current decreases. If the screen is supplied through an impedance, such as the screen dropping resistor of a modulation choke, the voltage drop in this series impedance becomes less and the screen voltage rises in the desired manner. On the part of the modulation cycle when the plate voltage is decreased, the screen current increases causing a greater voltage drop in the screen series impedance and thus lowering the voltage on the screen of the tube. The screen by-pass capacitor value in the Class stage is a compromise between good r-f bypassing and the shunting effect of this capacitance on the screen modulation circuit.

Where 100 per cent modulation capabilities are desired, the tube efficiency under carrier conditions is about half that expected in the r-f amplifier when plate and screen modulation is used. This efficiency is usually on the order of 35 to 40 per cent. Grid and screen modulation is used when there is a desire to save on physical size and cost of the modulation source.

When grid modulation is used, the screen voltage and grid bias must be taken from sources with good regulation. This usually means a separate low voltage power supply source. In the case of screen modulation, the grid bias should be taken from a grid leak bias resistor to provide some drive modulation.

The output of a pentode Class C amplifier can be controlled by applying to the suppressor grid a modulating voltage superimposed upon a suitable bias. As the suppressor grid in such an arrangement becomes more negative, the minimum instantaneous plate potential at which current can be drawn to the plate is increased. Thus, as the modulation varies the suppressor-grid potential, the output varies.

The suppressor-grid modulated amplifier has about the same plate efficiency as the grid modulated Class C amplifier. The overall efficiency is somewhat less because of the screen-grid losses. The modulating power is about the same. The linearity of modulation is not particularly high.

The screen-grid losses are higher because as the plate potential decreases, the current to the screen increases. This tendency toward high screen losses is the factor that usually limits the output power obtainable from a suppressor-grid modulated amplifier.

3.12 POWER SUPPLY CONSIDERATION

The power supply requirements for a triode are straightforward. The degree of regulation and ripple depends upon the requirements of the system. In the case of a linear r-f amplifier, it is important to have good plate power supply regulation. Without good regulation, the plate voltage will drop during the time the plate is conducting current heavily. This tendency for the voltage to drop will cause “flat topping” and will appear as distortion in the output. In a push-pull audio application where grid current flows, it is important to keep the grid circuit resistance to a minimum. If this is not done, positive peak clipping will occur. In the case of the tetrode and pentode, the need for screen voltage introduces some new considerations and provides some new possibilities.

Voltage for the screen grid of a low power tetrode or pentode can readily be taken from the power supply used for the plate of the tube. In this case, a series resistor, or potential dividing resistor, is chosen so that with the intended screen current flowing the voltage drop through the resistor is adequate to give the desired screen voltage. The potential dividing resistor is the preferred technique for those tubes with significant secondary screen emission (see Figure 6).

It is possible to take the screen voltage from a low voltage supply, frequently using an already available source in the equipment. There is considerable latitude so that an available voltage can be used. Sometimes a combination might be employed, where a dropping resistor is used in conjunction with a low voltage or intermediate voltage supply. Frequently a combination of series resistor and voltage source can be chosen so that the rated screen dissipation will not be exceeded regardless of the variations in screen current. With a fixed screen supply, there are advantages in using an appreciable amount of fixed grid bias so as to provide protection against loss of excitation, or for cases where the driver stage is being keyed.

If the screen voltage is taken through a dropping resistor from the plate supply, there is usually little point in using a fixed grid bias because an unreasonable amount of bias would be required to protect the tube if the excitation failed. When a screen dropping resistor is used, most of the bias is normally supplied through a grid resistor and other means are used for tube protection.

Under operating conditions with normal screen voltage, the cutoff bias is low (screen voltage divided by the screen μ). When a stage loses excitation and runs statically, the screen current falls close to zero. (See static curves of tube in question.) If the screen voltage is obtained through a simple dropping resistor from the plate supply, the screen voltage will then rise close to full plate voltage. Because the cutoff bias required is proportional to the screen voltage, the grid bias required will be much greater than the amount of bias desired under normal operating conditions.

The power output from a tetrode or pentode is very sensitive to screen voltage. For this reason, any application requiring a high degree of linearity through the amplifier requires a well regulated screen power suppy. A screen ropping resistor from the plate supply is not recommended in such applications.

The suppressor grid power supply requirements are quite similar to the control grid power supply. The suppressor grid intercepts very little current, and therefore a low power supply may be used. Any variation in suppressor voltage due to ripple or lack of regulation will appear in the output of the amplifier due to the suppressor grid modulation of the plate current.

3.13 STABILIZING THE AMPLIFIER

3.1 3. 1Testing for parasitic oscillations

In the case of an r-f amplifier, it will be necessary to investigate not only the possibility of self-oscillation, but also lack of feedback on the fundamental frequency. The basic steps of checking for self oscillation are threefold:

(a) The amplifier should be operated without r-f excitation and without fixed grid bias, with light loading and with low voltages applied to the plate and to the screen of a tetrode or pentode.

The voltage should be high enough to develop full plate dissipation. For this test, grid leak bias should be used. If the screen and plate voltage supplied cannot be adjusted directly to low voltages, suitable series resistance should be used, either in series with the rectifier output or transformer primary so that the voltages developed at the tube will be low.

Light bulbs of the correct size will serve as resistors in series with the primary of the rectifier transformers. The r-f circuits should be tuned off-resonance to see if self-oscillation of the amplifier can be started. The indication of any current by the grid milliammeter means that self-oscillation is present.

(b) The frequency of the self-oscillation must be determined. A simple neon bulb will indicate whether the frequency of oscillation is high or low. The lower the frequency the more orange will be the glow. A purple color indicates a VHF or UHF oscillation. With a little experience, it will become possible to guess the approximate frequency very closely. A wavemeter or an oscilloscope will then determine the exact frequency.

(c) After the frequency of oscillation is measured, it remains to identify the circuit supporting the oscillation. The circuit must then be altered without disturbing the performance of the amplifier on the normal frequency of the amplifier.

3.13.2 Correction of Parasitic Oscillations

The usual self-oscillations in r-f power amplifiers have been found to fall in the following three classes:

(a) Oscillation at VHF from about 40 MHz to 200 MHz, regardless of the normal frequency of the amplifier.

(b) Self-oscillation on the fundamental frequency of the amplifier.

(c) Oscillation at a low radio frequency below the normal frequency of the amplifier.

The low frequency oscillation in an amplifier usually involves the r-f chokes, especially when chokes are used in both the output and input circuits.

Oscillation near the fundamental frequency involves the normal resonant circuits, and brings up the question of neutralizing the r-f power amplifier. This general subject is discussed under "Neutralization," Section (5).

When a parasitic self-oscillation is found on a very high frequency, the interconnecting leads of the tube, the tuning capacitor and the by-pass capacitors are involved. This type of oscillation does not usually occur when the power amplifier is designed for operation in the VHF region and where the r-f circuits external to the tube have negligibly small tuning capacitors. Without tuning capacitors, the highest frequency oscillating circuit possible is then the fundamental, and there would be no higher frequency circuit available for the parasitic. The only exception would be where higher order modes of transmission line circuits might provide a parasitic circuit.

The VHF oscillation occurs commonly in amplifierconstructions where the radio frequency circuits are coils and capacitors, as in the HF and LF region, in audio amplifiers or voltage regulators. As in Figure 31, the parasitic oscillation uses the capacitors and the associated grid and plate leads for the inductances of the parasitic circuit. The tube capacitances help form the tuned-plate tuned-grid oscillation circuits. The circuit is indicated by the heavy lines in Figure 38.

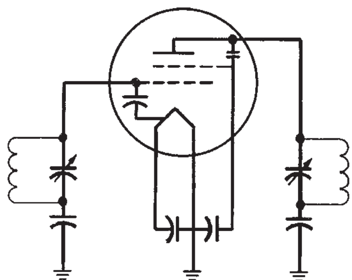

Figure 38. **Usual circuit supporting VHF parasitic oscillation in HF r-f amplifiers.**

There are several straightforward ways to suppress VHF parasitic oscillation. In general, it will probably be more easily suppressed if the general layout and by-passing methods indicated earlier are followed.

It turns out that the frequency usually met in a VHF parasitic oscillation is well above the self-neutralizing frequency of the tube (see Section 5). However, if the self-neutralizing frequency of the tube can be increased and the frequency of the parasitic lowered, complete suppression of the parasitic may result, or its suppression by resistor-coil parasitic suppressors may be made easier.

It is also possible to predict fairly closely with a grid dip wavemeter the parasitic frequency to be expected in a given equipment. The circuit should be complete and with no voltages on the tube. Couple the meter to the plate or screen lead and determine the resonant frequency. The following two methods of eliminating the VHF parasitic oscillation have been used successfully:

(a) By placing a small coil and resistor combination in the plate lead between the plate of the tube and the tank circuit (see Figure 32). The resistor-coil combination is usually made up of a non-inductive resistor of about 25 to 100 ohms, shunted by three or four turns approximately one-half inch in diameter and frequently wound right around the resistor. In some cases it may be necessary to use such a suppressor in both the plate and grid leads. The resistor-coil combination operates on the principle that the resistor

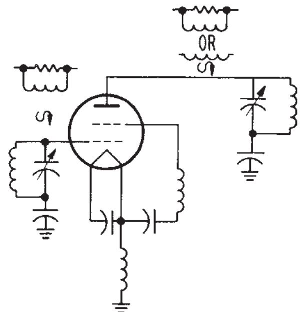

Figure39: Placement of parasitic suppressors to eliminate VHF parasitic oscillations in HF r-f amplifiers.

loads the VHF circuit but is shunted by the coil for the lower fundamental frequency. In the process of adjusting the resistor-coil combination, it is often found that the resistor runs too hot. The heat is usually caused by the dissipation of fundamental power in the resistor. This is an indication of too many turns in the suppressor coil. Just enough turns should be used to suppress the parasitic and no more. Once the parasitic has been suppressed there will be no parasitic voltage or current present. Therefore, there is no parasitic power to be dissipated.

(b) By the use of small parasitic chokes in the plate lead (see Figure 39). The size of this coil will vary considerably depending upon the tube and the circuit layout, and may run from about four to ten turns of about a one-half inch diameter. The presence of this choke in the frequency determining part of the circuit lowers the frequency of a possible VHF parasitic so that it falls near the self-neutralizing frequency of the tube and by-pass leads. In addition to varying the size of the suppressor choke, the amount of inductance common to the screen and filament in the filament grounding strap may be a factor. This can be varied simultaneously with the suppressor choke.

Of the two methods indicated above for suppressing VHF parasitic oscillations, the first one is probably the simpler to use and has been widely employed.

The procedure of checking for self-oscillation in an r-f power amplifier described previously will normally show up most trouble and allow for its correction. If, however, the correction is marginal, it may sometimes happen that under operating conditions the self-oscillation will be triggered off. The oscillation may occur only on the peaks of amplitude modulation or on keying surges. By observing the r-f envelope on a cathode ray oscilloscope, the oscillation can usually be seen. The trouble can be fully eliminated by pursuing further the outlined corrective procedure.

A more difficult self-oscillation to locate is one occurring on a harmonic of the fundamental frequency and occurring only when the stage is operating. It will show up when testing for the presence of abnormal power in the harmonics under operating conditions.

In the case of an audio amplifier employing tetrodes or pentodes, small non-inductive resistors of about 100 ohms resistance should be placed in series with the plate, and possibly the grid as well, in case self-oscillation of the amplifier occurs in the very high frequency portion of the r-f spectrum. Should the audio or d-c voltage drop in the resistor be objectionable, it can be shunted with a small coil.

Another form of commonly encountered self-oscillation is known as “dynatron” oscillation. Dynatron oscillation is caused when any electrode in a vacuum tube has negative resistance. Secondary emission characteristics of the screen grid in a tetrode were discussed in Section 2.2; it was pointed out that at times there may be more electrons leaving the screen grid than are arriving. If the screen voltage is allowed to increase under these conditions, even more electrons will leave the grid; the phenomenon implies a negative resistance characteristic. If there is high alternating current impedance in the circuit from the screen grid through the screen grid power supply, and from the plate power supply to the plate, dynatron oscillation may be sustained.

Dynatron oscillation typically occurs in the region of one to 20 Hz. This low-frequency oscillation is usually accompanied by another oscillation in the 1000-2000 kHz region. Suppression of these oscillations can be accomplished by placing a large bypass capacitor (1000 μF) across the output of the screen grid power supply. The circuit supporting the oscillation can also be detuned by a large inductor. Increasing the circuit losses at the frequency of oscillation is also effective.