

THE CARE AND FEEDING OF POWER TETRODES



APPLICATION BULLETIN NUMBER EIGHT

EITEL-McCULLOUGH-INC.

SAN BRUNO CALIFORNIA

THE CARE AND FEEDING OF POWER TETRODES

CONTENTS

SECTION	PAGE
A. INTRODUCTION - - - - -	1
B. LAYOUT - - - - -	2
1. General - - - - -	2
(a) Shielding - - - - -	2
(b) Air Cooling - - - - -	4
2. Component Parts - - - - -	5
3. Lead Lengths - - - - -	5
4. Filament Bypassing - - - - -	6
5. Screen Bypassing and Series Screen Tuning - - - - -	6
C. CIRCUIT DESIGN CONSIDERATIONS - - - - -	7
1. Basic Circuits - - - - -	7
2. Bypassing, Filtering, Screening - - - - -	8
3. Power Supply Considerations - - - - -	8
4. Protection - - - - -	9
5. Keying - - - - -	10
6. Modulating - - - - -	11
D. CIRCUIT ADJUSTMENT AND CHOICE OF OPERATING CONDITIONS - - - - -	12
1. Stabilizing the Amplifier - - - - -	12
(a) Testing for Parasitic Oscillations - - - - -	12
(b) Correction of Parasitic Oscillations - - - - -	12
2. Neutralization - - - - -	14
(a) Procedure - - - - -	16
(b) Analysis of Circuits - - - - -	17
(c) Self-Neutralization of VHF Parasitics - - - - -	18
3. Properly Adjusting Loading and Excitation - - - - -	19
4. Operating Voltages and Currents for Various Applications - - - - -	19
5. Effect of Different Screen Voltages - - - - -	20
6. Balance of Push-Pull Amplifiers - - - - -	20
7. Harmonic Amplifiers and Control of Harmonics - - - - -	21
8. Driving Power Requirements - - - - -	21
9. VHF and UHF Operating Conditions - - - - -	22
E. LIFE - - - - -	22
1. Maximum Tube Ratings - - - - -	22
2. Cooling - - - - -	23
3. VHF and UHF Life Considerations - - - - -	23
(a) Connectors - - - - -	23
(b) Tube Temperatures - - - - -	23
(c) Backheating by Electrons - - - - -	24
F. TECHNICAL ASSISTANCE - - - - -	25
REFERENCES - - - - -	25

INTRODUCTION

The user of transmitting tubes is no doubt familiar with the usual r-f circuits built around neutralized triodes, and the many considerations in layout, circuit design, adjustment, keying, modulation, and care required to get the best performance and life for his particular needs. He probably is not so familiar with an accumulation of factual experience using the latest designs of the four-electrode transmitting tube, the tetrode.

It is the purpose of this application bulletin to cite some of the experience which has been had with current and new tetrodes to help users obtain the full capabilities of the tubes.

Briefly stated these new tubes:

1. Have internal feedback coupling reduced to a very small value.
2. Permit design of amplifier stages which operate with driving power less than 1% of output power in most cases, and with negligible driving power in many audio cases.
3. Operate efficiently and with good life at audio and radio frequencies, including the VHF region (30 to 300 Mc.) and in some cases into the UHF region (300 to 3000 Mc.).

4. Take abuse (providing it's done intelligently and not with a hammer).
5. Allow designers to build compact, simple, flexible equipment with the least chance of spurious interfering radiations.

The practical desired results, however, can not be had unless the design, adjustment and operation of the complete equipment are right. This recital of some experience with Eimac tetrodes can not presume to supply the normal skill and good techniques necessary to build successful electronic equipment. It may make it easier by showing layouts, circuit considerations, adjustment techniques, and operating values, which have worked. In many ways the problem is little different from building successful equipment with triodes.

The bulletin tries to give a general understanding, and clues to understanding, some of the behavior of circuits using tetrodes. For specific ratings, operating values and information on a particular tube type, the technical data sheet for the tube type should be studied. It comes with the tube, or may be had for the asking.

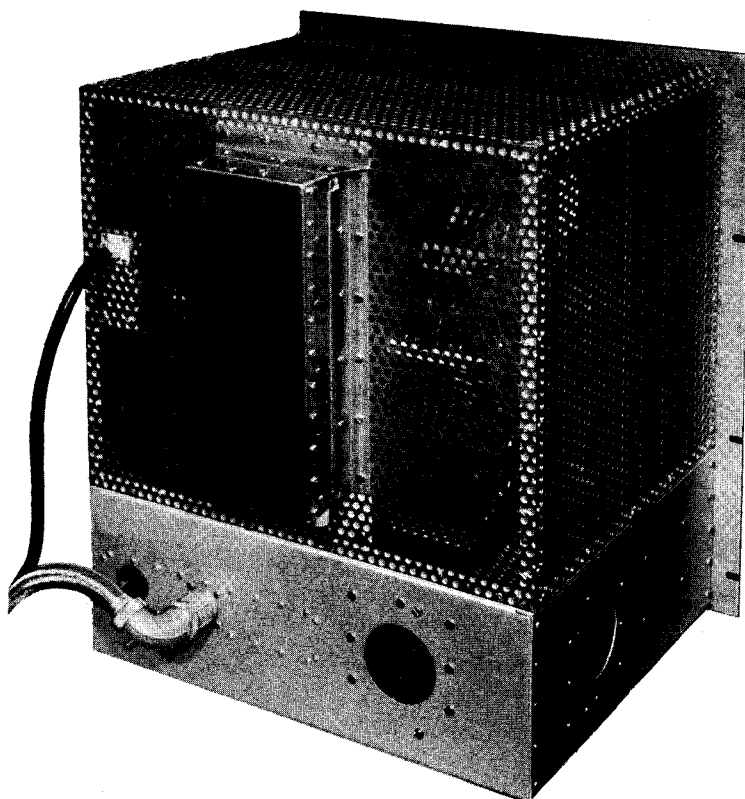


Fig. 1

Well arranged, filtered, and shielded r-f amplifier. Designed and built by R. L. Norton (W6CEM), and in use at WIFH.

LAYOUT

B-1. General

The metallic enclosure in which the tetrode or tetrodes operate serves the following three purposes:

1. Completes the shielding between the output (plate circuit) and the input (grid circuit).
2. It channels the forced cooling air, or convection air currents, so as to cool the tube adequately and, incidentally, the associated component parts as well.
3. It confines the radio frequency energy and helps permit selection of the desired frequency as the only one to be coupled out to the useful load circuit.

A good example of a suitable enclosure is shown in Fig 1.

B-1-a. Shielding

By referring to Figs. 2, 3, 4, 5, and 6, one

can readily see several r-f layouts which have been satisfactory in practice. Note that in all cases the tube is mounted vertically with the base down, and the socket is mounted flush with the deck separating the compartment below the tube and the compartment above the tube. In all cases the grid and filament (or cathode terminals) are on the base end of the tube and extend into the lower compartment. The plate circuit and plate terminal are in the upper compartment.

In the case of tubes having metal base shells, grounding clips should be carried by the bolts mounting the socket so as to bring the base shell to chassis potential. This completes the shielding between the output and input circuits since the base shell of the tube comes up opposite the screen shield within the tube itself.

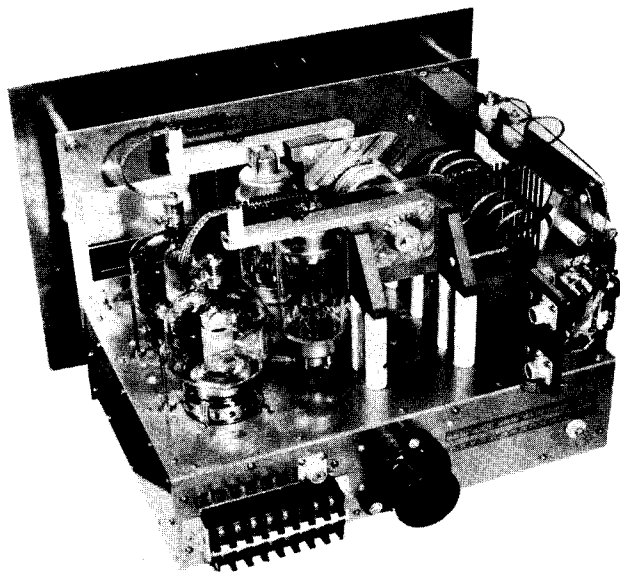
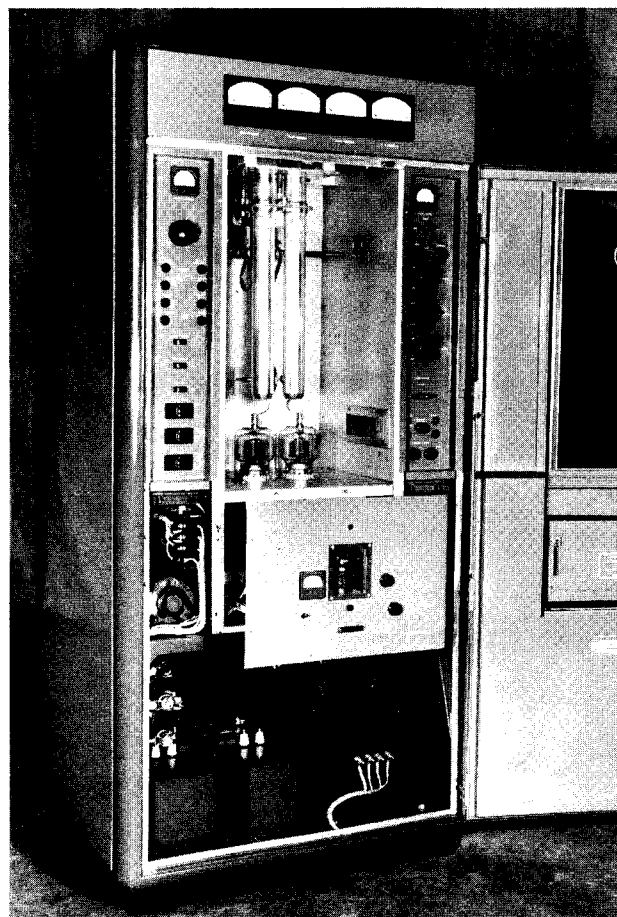


Fig. 2

Push-pull r-f amplifier employing 4-250A tetrodes.
Designed and built by C. F. Bane (W6WB)².

Fig. 3

Push-pull 88-108 Mc. 1 Kw. amplifier employing
4-400A tetrodes. Radio Engineering Laboratories,
Model 701 transmitter.



SECTION **B**

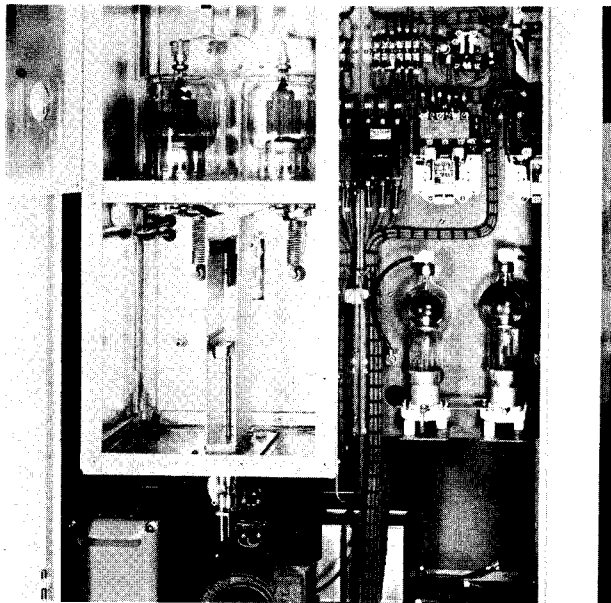


Fig. 4

Push-pull 110 Mc. amplifier employing 4-1000A tetrodes. Gates Radio Co. Model BF 3 kw transmitter.

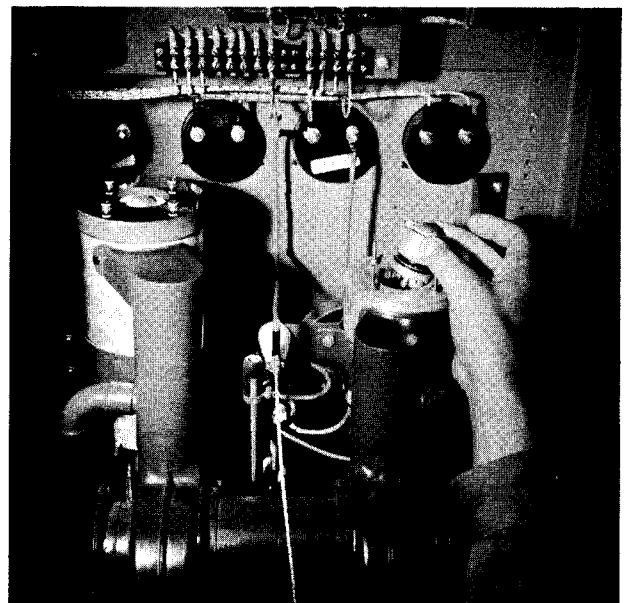


Fig. 6

Experimental 950 Mc. doubler final and tripler driver employing 4X150A tetrodes. Designed and built by Eitel-McCullough Laboratories.

By having the tube and circuits in completely enclosed compartments and by properly filtering incoming supply wires, it is possible to prevent the coupling out of radio frequency energy by means other than the desired output coupling.

Such filtering prevents the coupling out of energy which may be radiated promiscuously or

be fed back to the input or earlier stages to cause trouble. Energy fed back to the input circuit causes undesirable interaction in tuning, or self oscillation. If energy is fed back to the earlier stages, the trouble may be greater due to the larger power gain over several stages.

The layout for an audio stage follows similar general arrangements. See Fig. 7.

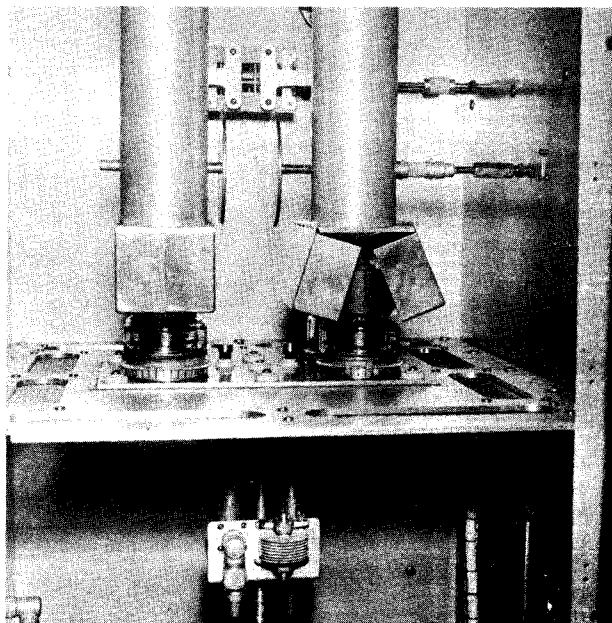


Fig. 5

Experimental push-pull parallel 110 Mc. 3 kw amplifier employing 4X500A tetrodes. Designed and built by Eitel-McCullough Laboratories.

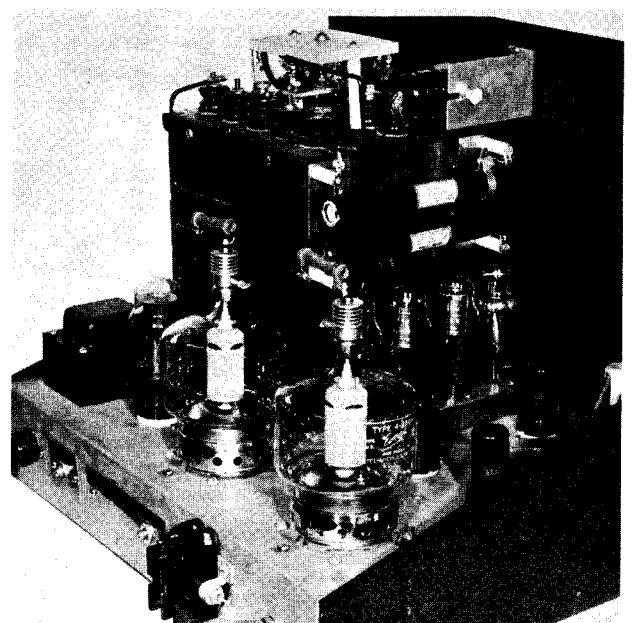


Fig. 7

Experimental 500 watt Class-AB₁ audio amplifier. Designed and built by Eitel-McCullough Laboratories.

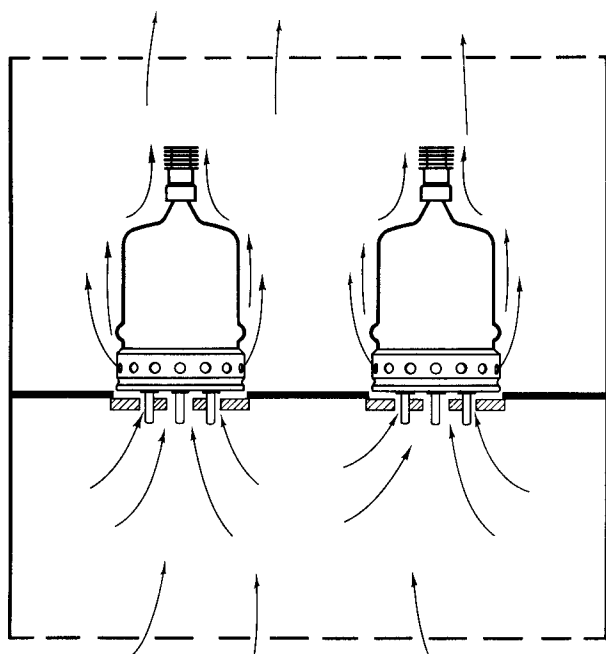


Fig. 8

4-125A mounting providing cooling, shielding and isolation of output and input compartments.

B-1-b. Air Cooling

If the flow of cooling air is upward it will be consistent with the normal flow of convection currents. See Figs. 8 and 9. In all cases the socket is an open structure or has adequate vent holes to allow cooling of the base end of the tube. Cooling air enters through the grid circuit compartment below the socket through a screened opening, passes through the socket cooling the base end of the tube, sweeps upward cooling the

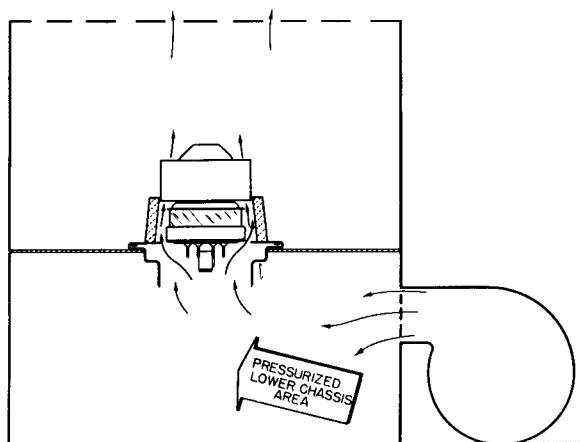


Fig. 9

4X150A chassis mounting providing cooling, shielding and isolation of output and input compartments.

glass envelope and into the output circuit compartment. The output compartment also has a mesh-covered opening which permits the air to vent out readily. These arrangements apply whether the tube is cooled by forced air or convection circulated air. If the tube is to be forced-

air cooled, a suitable fan or blower is used to pressurize the compartment below the tubes. No holes should be provided for the air to pass from the lower to the upper compartment other than the passages through the socket and tube base. Some pressure must be built up to force the proper amount of air through the socket. In the case of convection cooling, open louvers or screened areas permit ready entrance of cool air, and all access holes or vents should have large areas to provide a minimum resistance to the flow of air.

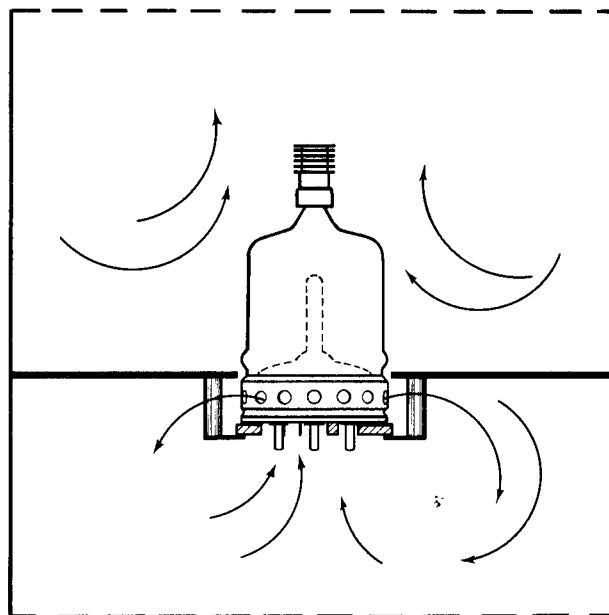


Fig. 10

DO NOT SUB-MOUNT A METAL BASE SHELL TUBE. Base cooling is prevented and no improvement in shielding results.

DO NOT SUB-MOUNT A TUBE WITH METAL BASE SHELL SO THAT THE CHASSIS DECK OR MOUNTING DECK COMES UP ABOVE THE VENT HOLES OF THE BASE SHELL OF THE TUBE. See Fig. 10. No improvement in isolating output and input circuits results, and such an arrangement prevents the flow of cooling air, whether forced or by convection currents. If a tube must be recessed into the mounting deck because of space limitations, a recessing cylinder with wide clearances should be used to permit the air from the base holes to vent into the compartment above deck.

The method shown in Figs. 8 and 9 of supplying the cooling air to the tube has worked successfully, provided the desired flow is obtained, and it is to be preferred over methods which try to force cooling air transversely across the tube base.

SECTION B

In the case of the 4X150A, 4-400A, and 4-1000A tetrodes, there are available complete air system sockets. See Fig. 11. These permit cooling air to be blown axially onto the base of the tube, through or past the base, confined by a suitable chimney to cool the glass portion of the tube, and then forced onto the plate terminal or through the anode cooler. This combined system permits a single stream of air to cool a tube completely in a manner determined to be well balanced by the manufacturer. Since the air channel is well defined and its resistance to the flow of air standardized, a simple measurement of the air pressure at the input indicates the proper flow of air. This assumes that there are no other air flow restrictions.

B-2. Component Parts

If one is to maintain the isolation of the output and input circuits indicated on the general layout, there must be some thought given to the location of the component parts. 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 the screen lead of the tube and connections to it via the socket are common to both the output and input resonant circuits. Due to the plate-screen capacitance of the tube, 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 lead to chassis, or to the opposite tube of the push-pull circuit.

Curiously enough, the inductance of this 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 section D-2 "Neutralization".) It should be noted, however, that the mutual coupling from the screen lead to the input resonant circuit might possibly be a source of trouble if accentuated.

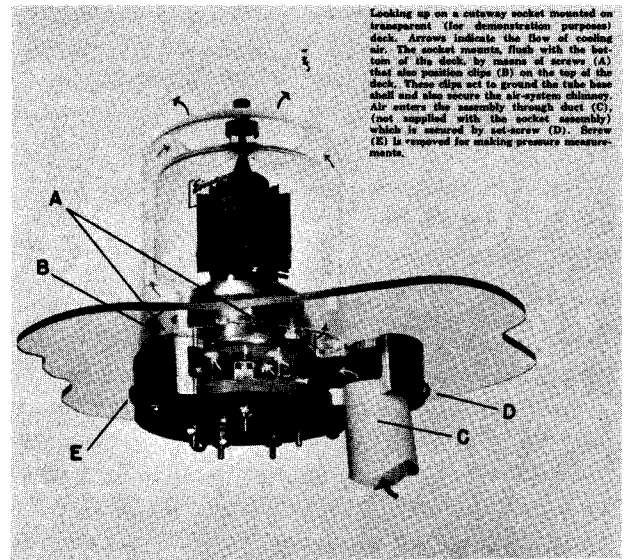


Fig 11

Eimac 4-400A/4000 Air System Socket providing balanced tube cooling by a single stream of air.

Parasitic oscillations are usually unavoidably present in new designs. Such parasitic oscillations result from the minor characteristics of some of the lead wires and circuit components and such incidental circuits must be altered to prevent their occurrence. This is a straight-forward "de-bugging" and will not affect the performance of the fundamental frequency.

Thus, after the general arrangement of the layout of the new amplifier is known, the location of the component parts is the next step. No attempt is made to discuss details other than those which are peculiar to power tetrodes.

No given layout can be guaranteed to be a cure-all for trouble. It is believed that certain basic ideas and arrangements can be considered as good practice, which will make "de-bugging" easier. Certain of the component parts might just as well be laid out following one of these arrangements.

The photographs of equipment are examples of good layout. The bypassing arrangements near the tetrode socket illustrated in Figs. 12, 13 and 14 are examples of successful arrangements. They are not presumed to be perfect nor the only possible good arrangements.

B-3. Lead Lengths

Some of the inter-connecting lead wires close to the tube should be made 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

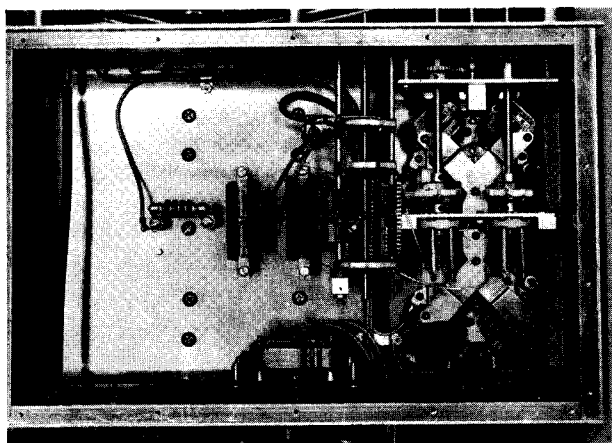


Fig 12

Underside of push-pull multi-band r-f amplifier employing 4-250A tetrodes. Designed and built by C. F. Bane (W6WB)⁵.

close together to help provide short inter-connecting leads. The lead lengths of radio frequency circuits involving the fundamental frequency can usually be much longer and will depend a good deal on the frequency of the fundamental. All of the d-c, keying, modulating, and control circuit wires can be quite long, if properly arranged, and so be kept away from the active r-f circuits.

The following inter-connecting leads in a tetrode power amplifier should preferably have quite low inductance: the filament and screen bypassing leads, the leads from grid and plate to the tuning capacitor of the r-f circuit and return, and the inter-connections from tube to tube in push-pull or parallel arrangements. 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 of a bypass capacitor.

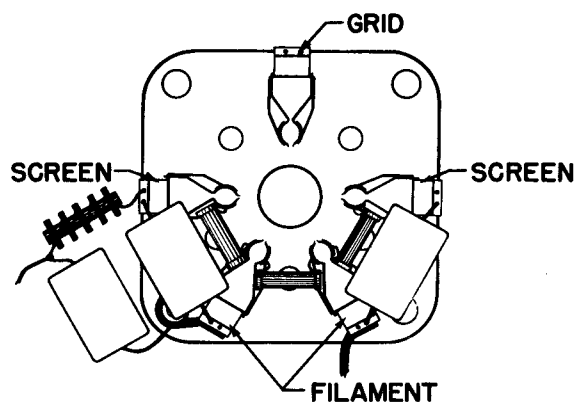


Fig. 13

Typical socket bypassing of screen and filament terminals as used by C. F. Murdock (W6OMC). Note use of parallel low inductance ceramic and larger mica capacitors.

B-4. Filament Bypassing

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

If two or more tubes are in a push-pull or parallel circuit, one can use a short strap inter-connecting one of the filament terminals of each socket, Fig. 14c, g; or the tubes can be bypassed as in the single tube case, Fig 14b, f. The mid-point of the inter-connecting strap can be bypassed or grounded directly.

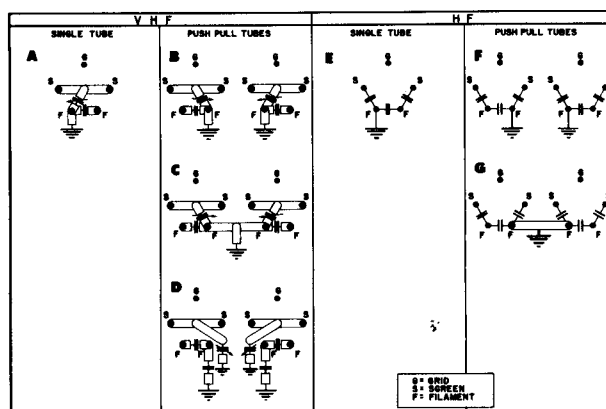


Fig. 14

Various screen and filament bypassing arrangements.

In case separate filament supplies are used, as in individual metering circuits, filament bypasses as shown in Fig. 14d have been found satisfactory.

With tubes having a completely isolating screen cone terminal such as the 4X500A and 4X150A, the general circuit arrangement is usually different. The filament or cathode should go directly or through bypasses to the cavity wall or chassis to which the screen terminal is bypassed. Typical cavities or arrangements are shown in Figs. 5, 6, 9 and 17. In the case of the 4X150A air system socket, the cathode terminals are secured to the mounting cup which also forms one plate of the screen bypass capacitor.

B-5. Screen Bypassing and Screen Series Tuning

Low inductance leads are generally advisable for screen terminal connections. For all frequencies it has been found good practice for the

SECTION B-C

screen bypass capacitor to go directly from screen to one filament terminal. This applies to tubes in push-pull as well as single tubes. In the VHF region the connection to the screen terminals 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 current in the two screen leads and minimizes the heating effects.

Above the self neutralizing frequency of the tetrode (about 25 Mc. for the 4-1000A and around 80 Mc. for the 4-125A) the screen bypass capacitors are usually variable capacitors. (See section D-2 "Neutralization"). The variable capacitors are placed in the circuit at the same location as the bypass capacitors. Care should be taken to keep the inductance of the leads low.

The information in Fig. 14 and paragraphs

above apply directly to tubes having the screen grid mounted on internal supporting lead rods, as in the types 4-65A, 4-125A, 4-250A, 4-400A, 4X500F and 4-1000A.

The types 4X150A, 4X150G, and 4X500A have isolating screen cone terminals. These tubes seem to work best when the screen bypass capacitor is a flat sandwich type of capacitor (using silver coated mica for a dielectric) built directly onto the peripheral screen contacting collet of the socket. This arrangement is illustrated in Figs. 5, 6, and 17. Provided the screen contacting collets do not introduce appreciable inductance, it has been found that capacitors having values of about 800 micro-microfarads or greater are suitable for VHF and UHF frequencies. At lower frequencies the usual bypass capacitor values of about .001 to .003 mfd are suitable.

CIRCUIT CONSIDERATIONS

C-1. Basic Circuits

The basic circuits of tetrode amplifiers for both audio and r-f power amplifiers are in general similar to those for triode amplifiers. The tubes perform the same functions and differ principally in having much lower driving power requirements and much greater inherent isolation between output and input circuits. Such differences as exist in the details and associated circuits are discussed in the following paragraphs and sub-sections.

In designing the basic r-f circuits, reference should be made to the technical data sheet of the particular tube type for the electrode voltages and currents, and the output and driving power to be expected.

Because of the ability of the screen to assist in the flow of plate current, the grid can control a large plate current without going positive. For this reason low distortion audio amplifiers in class AB₁ are possible. Thus, the tube requires audio driving voltage only (with no grid current flowing) while delivering large audio power, such as 750 watts from a pair of 4-250A's or 3 kw from a pair of 4-1000A tetrodes. For such a circuit refer to Fig. 15 where a pair of receiving tubes in a resistance coupled, phase inverting circuit is all that is required to drive the tetrode. For a typical equipment design see Atkins & Mandoli¹, and Fig. 7.

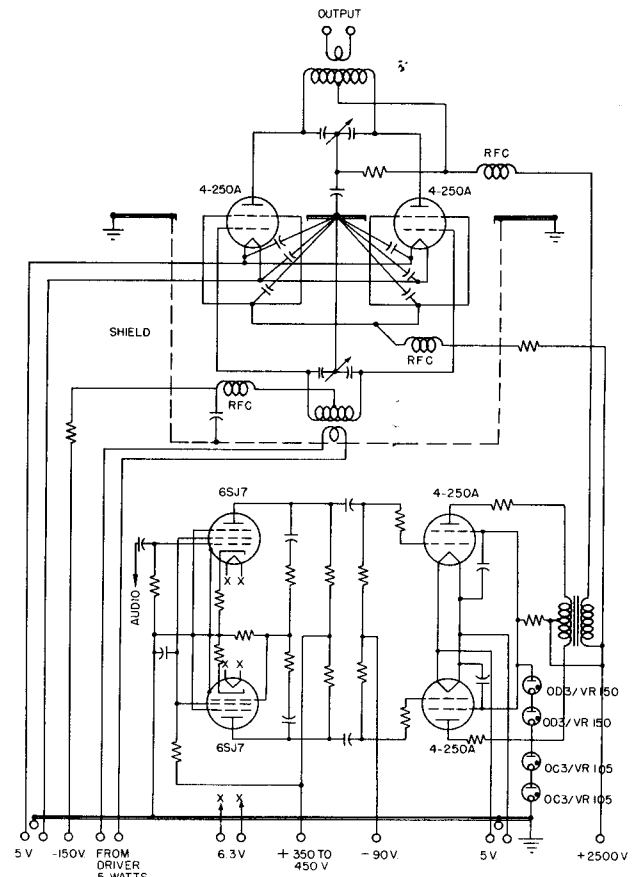


Fig. 15

Typical high-level-modulated r-f amplifier circuit with modulator and driver stages, 1000 watts input.

VHF circuits appear very simple and clean as shown in Figs. 3, 4, and 5. Care in bypassing and neutralizing (if required) is very important. For details see Sections B-4, B-5 and D-2. A typical schematic circuit is shown in Fig. 16. An understanding of transmission line circuits is helpful though no more necessary in tetrode circuits than triode circuits.

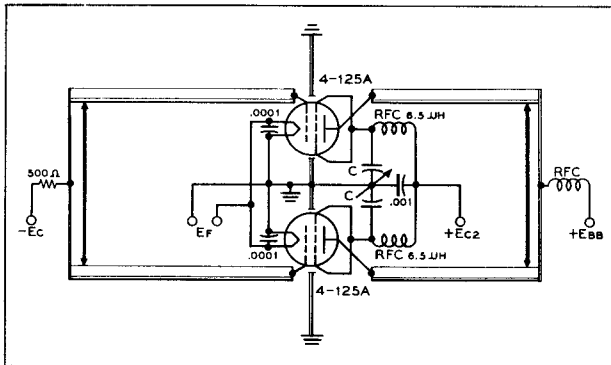


Fig. 16

Screen-tuning neutralization circuit for use above 100 Mc. with 4-125A tetrode.

Some tetrodes are able to operate well into the UHF region, and coaxial type cavity circuits are normally employed. In general, microwave and cavity techniques apply to the cavity construction. As indicated in Fig. 17, screen bypassing is introduced as part of the cavity construction.

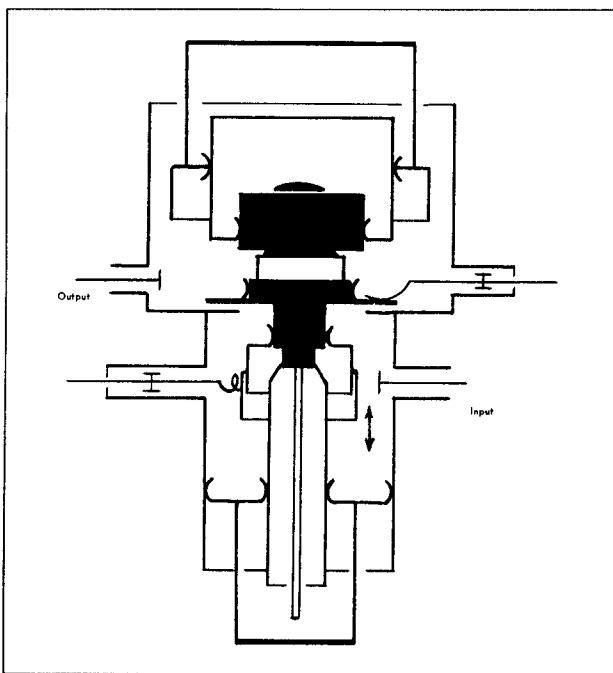


Fig. 17

Schematic cavity section of 1250 Mc. amplifier employing 4X150G tetrode.

C-2. Bypassing, Filtering, Screening

Essentially the requirements for confining the r-f energy to the desired circuits by bypassing, filtering, and screening are the same with tetrode power amplifiers as with triode amplifiers. See section B-1, 4, 5 and D-2 for discussion of best arrangements.

C-3. Power Supply Consideration

In general, power supply problems for the plate and grid are the same as for the triode amplifier. The need for screen voltage introduces some new considerations and provides some new possibilities.

Voltage for the screen grid of a power tetrode 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 the voltage drop through the resistor is adequate to give the desired screen voltage. It is, of course, possible to take the screen voltage from a low voltage supply, frequently using one already available 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 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 cut-off bias is low (about 1/5 the screen voltage). 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 cut-off 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. For further discussion see C-4 "Protection" and C-5 "Keying".

If the output power of a transmitter or amplifier stage is to be adjustable by varying the plate voltage, it is advisable to take the screen voltage through a dropping resistor from the plate supply. Then, as the plate supply voltage is raised or lowered, the screen voltage rises or falls also and the plate current will follow. Alternatively, the screen supply could be separate but with large series resistance to give poor regulation, and the changes in screen current would cause the screen voltage to rise or fall. It is necessary to have the plate current proportional to the plate voltage if the same loading adjustment (load resistance) is to serve for all power levels. If the plate current does not follow the plate voltage, the loading would have to be changed for each power level. This added control over the screen voltage is necessary because the plate current in a tetrode is principally controlled by screen voltage when excitation is present, and very little by plate voltage alone.

FIXED SCREEN SUPPLY		SCREEN VOLTAGE THROUGH DROPPING RESISTOR
FIXED GRID BIAS	RESISTOR GRID BIAS	RESISTOR GRID BIAS
All variable grid drive applications, i.e. Audio Amplifiers. Video Amplifiers. Linear R-F Amplifiers. Grid Mod. R-F Amp. Provides protection against loss of excitation, or keyed driver.	Screen Mod. R-F Amp. Reduces effects of excitation variations.	Plate Mod. R-F Amp. Variable loading applications. Power level adjustable by changing plate voltage. Protection can be had for loss of excitation or keyed excitor stage by using the screen voltage control of Fig. 20.

Fig. 18

Applications and circuits to which fixed and resistor type screen and grid supplies are best suited.

In Fig. 18 a chart summarizes some of the reasons for choosing either a fixed screen supply or dropping resistor type of screen supply. Similarly the type of the grid bias is important and should be chosen with both the application and the protection of the tube in mind. The d-c screen and grid currents are sensitive to changes in excitation and loading, and these changes affect the d-c grid and screen voltages if the supplies have appreciable internal resistance. These effects may be very beneficial if properly employed but in some cases are undesirable. For all variable grid drive applications a fixed screen supply and a fixed control grid bias are necessary. It should be noted, however, that for a plate modulated r-f amplifier, an r-f amplifier where a variable loading condition is expected, or where output power is to be controlled by changing plate voltage, a screen source with poor regulation is desirable, i.e., screen voltage obtained through a screen dropping resistor.

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—Fig. 20
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	—

Fig. 19 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.

C-4. Protection

Eimac tetrodes 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 bulb and the seal structure.

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

The type and degree of protection required in an r-f amplifier against circuit failures will vary with the type of screen and grid voltage supply. Fig. 18 indicates some of the inherent protection provided by certain types of supplies, and Fig. 19 presents a chart of protection as related to certain kinds of circuit failures. For screen voltage taken through a dropping resistor from the plate supply, a plate relay provides almost universal protection. For a fixed screen supply a screen relay provides protection in most cases, and, for protection against excess antenna loading and consequent high plate dissipation, a screen undercurrent relay should also be used. (Starting up in the latter case will, of course, require a temporary hold-in circuit.)

Plate, screen, and grid bias voltages may be applied simultaneously to a tetrode. Grid bias and excitation can usually be applied alone to the tube, especially if a grid leak resistor is used. Plate voltage can be applied to the tetrode before the screen voltage, with or without excitation to the control grid. NEVER APPLY SCREEN VOLTAGE BEFORE PLATE VOLTAGE. The only exceptions would be when the tube is cut off so that no space current (screen or plate current) will flow, or the excitation and screen voltage are low. If screen voltage is applied before the plate voltage and space current can flow, the maximum allowable screen dissipation will almost always be exceeded and damage to the tube will result.

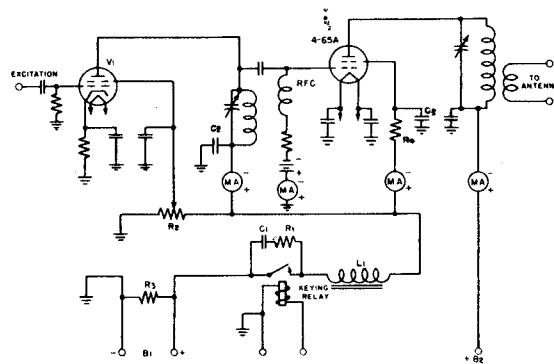


Fig. 21

Tetrode amplifier keying circuit used by B. O. Ballou (W6BET)².

C-5. Keying

The tetrode 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, of course, 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 r-f power amplifier when exciter keying is used. With the screen voltage fixed and with fixed bias greater than cut-off, the tube will pass no current when the excitation is removed.

It is also possible to key the exciter stage when the screen voltage is taken through a dropping resistor and grid leak bias is used. See Fig. 20. In this system a high transconductance, low mu triode is connected between screen and cathode, and the controlling bias for the small triode is taken from the tetrode bias developed in the grid leak resistor. When normal excitation is present on the tetrode 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 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 IR drop in the screen dropping resistor and lower the screen voltage to a very low value.

There is still some screen voltage on the tetrode and a small static plate current flows which, however, is usually not enough for the plate dissipation rating to be exceeded. This value can be reduced further by putting a second control triode in parallel with the first (also a smart precaution 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 bypass capacitor, or by introducing a small amount of fixed bias on the tetrode between the grid resistor and the tetrode grid. These procedures are usually not required. In fact, the static plate current gives a desirable bleeder action for the plate supply.

Fig. 21 shows a method of keying a tetrode r-f power amplifier where the low voltage power supply for the screen of the tetrode and for the plate and screen of the driver stage is

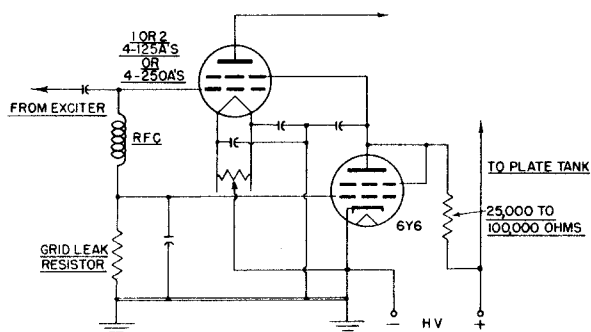


Fig. 20

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

SECTION C

keyed directly. The circuit is described by Ballou^{2, 11}. 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 wave shape.

C-6. Modulating

A tetrode r-f amplifier can be amplitude modulated in all the usual ways: plate modulation, screen modulation, grid modulation, or cathode modulation. Of these, plate modulation is the type most extensively used, and a discussion of several simple methods of obtaining simultaneous modulation of the screen will be helpful in this respect.

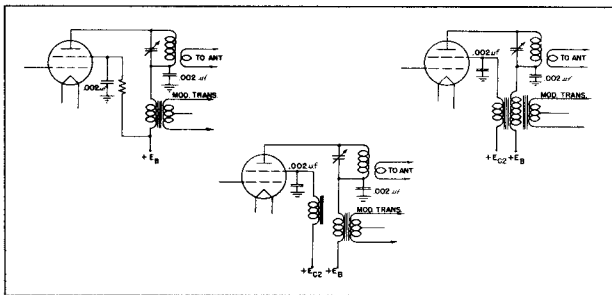


Fig. 22

Basic high-level-modulating circuits for tetrodes.

Fig. 22 shows three of the basic plate modulation (or high level modulating) circuits, and Fig. 15 shows a complete schematic involving a plate modulated r-f amplifier and the audio modulator stage, using a pair of 4-250A tetrodes to modulate a pair of 4-250A tetrodes.

In plate modulation it is necessary to introduce not only amplitude modulation of the plate voltage, but also to develop about 70% amplitude modulation of the screen voltage of the tube as well, for 100% carrier modulation. Modulation of the screen voltage can be developed in one of the following three ways:

1. By supplying the screen voltage through a dropping resistor connected to the unmodulated d-c plate supply.
2. 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 10 henry choke.
3. 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 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, or modulation choke, the voltage drop in this series impedance becomes less and the screen voltage rises in the desired manner. On the other 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, thus lowering the voltage on the screen of the tube.

It will be noted that in the plate circuit as the plate voltage increases, the plate current increases, which requires power to be supplied from the audio modulator. In the screen circuit however, as the screen voltage increases, the screen current decreases. This corresponds to audio power being supplied from the tetrode and d-c screen voltage source, and delivered to the dropping resistor or series impedance. In the case of the modulation transformer the power is supplied back to the audio source. In all cases, this power is a few per cent of the plate power input to the tube and is therefore negligible.

Where modulation voltage appears on an electrode of a tube, the r-f bypass capacitor of this electrode should be kept to about .002 mmfd or less in order to avoid bypassing high modulation frequencies.

In grid modulation or screen modulation, where 100% modulation capabilities are desired, the tube efficiency under carrier conditions is about half that expected in the r-f amplifier when plate (high level) modulation is used. This efficiency is usually on the order of 35% and thus grid or screen modulation is not used unless there is a desire to save on the physical size 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. The procedure in screen modulation is otherwise similar

to the standard procedure of modulating with an electrode other than the plate. The r-f amplifier is adjusted to good class-C operating conditions, and then the grid bias is increased, or the screen voltage is reduced, until the output antenna current falls to half its former value. This gives a

carrier condition which will permit 100% amplitude modulation. Under these conditions the unmodulated carrier power is about $\frac{1}{3}$ that of the corresponding unmodulated class-C amplifier. The grid bias or screen voltage can then be modulated up and down about this carrier point.

CIRCUIT ADJUSTMENT AND CHOICE OF OPERATING CONDITIONS

D-1 Stabilizing the Amplifier

At this point it is assumed that the amplifier has been built, supply and control circuits tested out, the filament voltage checked at the tube sockets, air cooling is correct, and the grid and plate circuits resonate at the desired frequency. The next step is to apply voltage to the amplifier and test for stability.

D-1-a. Testing for Parasitic Oscillations

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

1. The amplifier should be operated without r-f excitation and without fixed grid bias, with light loading and with low voltages applied to the screen and plate. The voltage should be high enough to develop full plate dissipation, however. For this test grid leak bias should be used. If the screen and plate voltage supplies 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. (Simple light bulbs of the right 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 presence of any current on the grid milliammeter means that self oscillation is present.
2. By means of a wave meter the frequency of self oscillation of the r-f power amplifier is found.

3. The circuit supporting the self oscillation must be determined and altered so that such oscillations cannot exist, and without disturbing the performance on the normal frequency of the amplifier.

The subject of parasitic oscillations in amplifiers has been well covered in the literature, and the following references will be helpful: Mix³, Fyler⁴, Bane⁵.

D-1-b. Correction of Parasitic Oscillation

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

1. Oscillation at a VHF frequency from about 40 to 150 Mc., regardless of the normal frequency of the amplifier.
2. Self oscillation on the fundamental frequency of the amplifier.
3. 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. Because the possible feedback coupling in a tetrode is negligible at such low frequencies, this type of oscillation due to feedback through the tube is generally not found in the tetrodes under discussion.

Oscillation near the fundamental frequency, if it occurs, involves the normal resonant circuits, and brings up the question of neutralizing the r-f power amplifier. This general subject is discussed thoroughly under "Neutralization" section D-2.

In case a parasitic self oscillation is found on a very high frequency, the inter-connecting leads of the tube, the tuning capacitor and 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

SECTION D

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 line circuits might provide a parasitic circuit. However, little trouble has been found in this respect.)

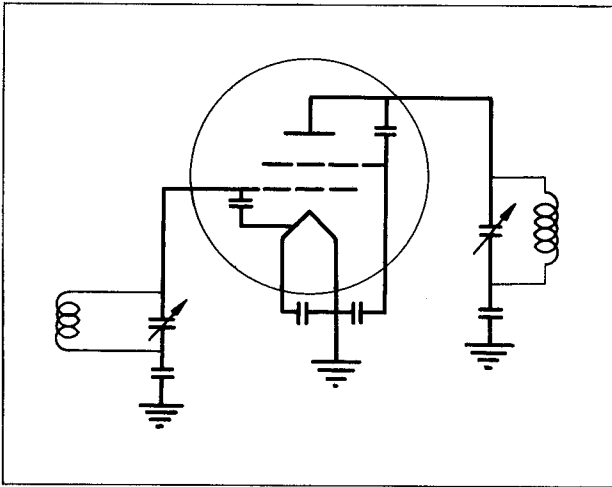


Fig. 23

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

The VHF oscillation occurs commonly in amplifier constructions where the radio frequency circuits are composed of coils and capacitors, as in the HF and LF region. As will be seen in Fig. 23, the parasitic oscillation uses the capacitors of the fundamental resonant circuit as bypass 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 Fig. 23.

There are several straight-forward ways to suppress the VHF parasitic oscillation. In general, it will probably be more easily suppressed if the general layout and bypassing 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 D-2-b "Analysis of Neutralizing Circuits".) 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 made easier.

The following table lists the usual frequency around which the VHF parasitic may occur with usual circuit lead lengths:

4-1000A	90-110-Mc.
4X500F	130-145 Mc.
4X500A	Approx. 225 Mc.
4-400A	130-150 Mc.
4-250A	130-150 Mc.
4-125A	130-145 Mc.
4-65A	130-170 Mc.

It is also possible to predict fairly closely with a grid dip wavemeter the frequency to be expected in a given equipment. The circuit should be complete and no voltages on the tube. The grid terminal may be strapped to the filament or screen because the grid circuit does not usually seem to be involved. Couple the meter to the plate or screen lead.

The following two methods of eliminating the VHF parasitic oscillation have been used successfully:

1. By placing a small coil and resistor combination in the plate lead between the plate of the tube and the tank circuit. See Fig. 24. The resistor-coil combination is usually made up of a non-inductive resistor of about 50 to 100 ohms, shunted by 3 or 4 turns about $\frac{1}{2}$ " 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 loads the VHF circuit but is shunted by the coil for the lower fundamental frequency.

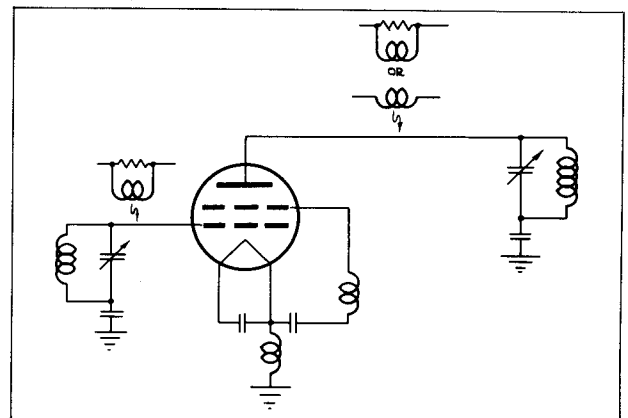


Fig. 24

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

2. By the use of small parasitic chokes in the plate lead. See Fig. 24. The size of this coil will vary considerably depending upon the tube and the circuit layout, and may run from about 4 to 10 turns of about a $\frac{1}{2}$ " diameter. Apparently, 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 bypass leads. (See D-2-b "Analysis of Neutralizing Circuits.") 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. No detailed study has been made of the circuits involved in the second method, but the method has been used successfully as indicated by Mix³ and Bane⁵. A further discussion of the theory believed active in the second case is given under section D-2 "Neutralization".

The procedure of checking for self oscillation in an r-f power amplifier described above in section D-1 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 corrective procedures outlined under D-1-b above.

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, 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.

D-2. Neutralization

Whether or not a tetrode should be neutralized seems to be an open question. As stated previously, the feedback within tetrodes is a very small fraction of the feedback present in triodes. In a great many cases the isolation provided by a tetrode is enough so that there is no need to use any neutralization to counteract the negligible feedback. This applies to all low frequency r-f amplifiers. Whether or not neutralization should be used in the HF, the VHF and UHF regions depends entirely upon the particular tube type, the operating conditions and the desired isolation of output and input circuits. In the case of tubes having isolating screen cone terminals, as for instance the 4X150A and 4X150G, no neutralization has been found necessary up through their highest useful amplifier frequency, approximately 500 Mc. and 1000 Mc. respectively. In the case of the 4X500A, also employing the isolating screen cone terminal, it is occasionally found desirable to use neutralization at 100 Mc., though this is frequently not necessary. In the case of tetrodes having internal screen support lead rods, such as the 4-125A and 4-250A types, the need to employ neutralization in the HF region may be found in amplifiers operating with high power gain and high plate voltages, if complete isolation of output and input circuits is desired. Frequently it is not necessary.

At frequencies below the VHF region, neutralization usually employs a capacitance bridge circuit to balance out the feedback due to the residual plate to grid capacitance. This assumes that the screen is well bypassed to ground and so provides the expected screening action. In the VHF and UHF regions the screen is not necessarily at r-f ground potential and the neutralizing circuit becomes more involved. For suitable VHF circuits and simple explanation, see Section D-2-b "Analysis of Neutralizing Circuits".

SECTION D

If neutralization on the fundamental frequency below the VHF region is found desirable, normal cross-neutralization of push-pull amplifiers is simplest. The neutralizing capacitors are small and each capacitor need only be a wire connected to each side of the grid circuit, brought through the chassis deck, and allowed to "look" at the plate of the tube on the opposite half of the circuit. This is illustrated in Fig. 2. The wire or rod can be $\frac{1}{2}$ " to 1" away from the glass, and by adjusting its length or spacing the last trace of coupling can be eliminated from the amplifier. A simple insulating collet mounted on the chassis deck will support the wire or rod and allow it to be adjusted.

In the case of a single-ended stage, either a push-pull output or a push-pull input circuit can be used to provide the out-of-phase voltage necessary for neutralization. Because of the low voltage and the small size of the r-f input circuit, it is usually simpler to make the input circuit push-pull, and the circuit becomes a "grid neutralization" circuit. See Fig. 25. The neutralizing capacitor, C_n , is again very small and similar to those described above under cross-neutralization. To maintain the balance of the input circuit while tuning, it is desirable to have a padding capacitor, C_i , equal in size to the input capacitance of the tetrode.

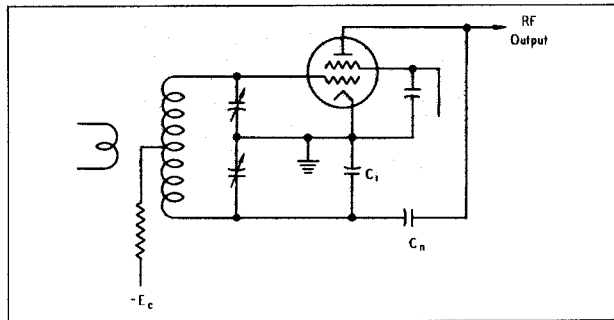


Fig. 25

Push-pull grid neutralization, basic circuit.

Single-ended r-f stages can also be easily grid-neutralized without using a conventional push-pull input circuit. See Fig. 26. In this method described by Bruene⁶, the input resonant circuit is taken off ground a small amount by making the input circuit bypass capacitor, C , somewhat smaller than usual. The voltage to ground across capacitor, C , is out of phase with the grid voltage and can be fed back to plate to provide neutralization. In this case the neutralizing capacitor, C_n , is considerably larger than the capacitance plate to grid and is about the size of those used for neutralizing triodes.

The basic circuit of the Bruene method is shown in Fig. 26a. It can be redrawn as a capaci-

tance bridge showing clearly the grid neutralization circuit. See Fig. 26b. Balance is had when $\frac{C_n}{C} = \frac{C_{gp}}{C_{gf}}$ where C_{gp} is the feedback capacitance grid to plate of the tetrode, and C_{gf} is the total input capacitance, including tube and stray capacitance.

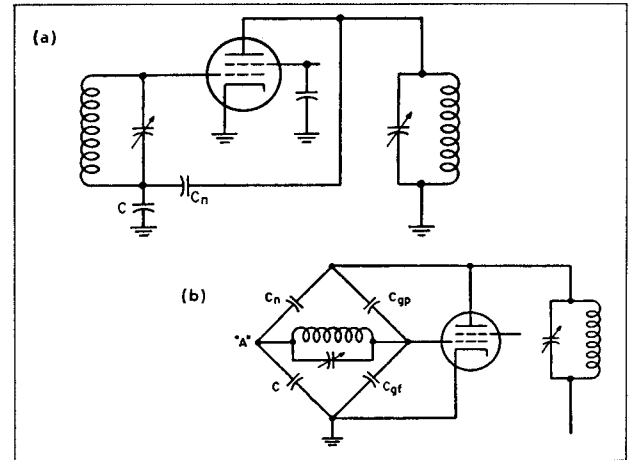


Fig. 26

Single-ended grid neutralization described by Bruene⁶.

a) Basic Circuit. b) Arranged as capacitance bridge.

Single-ended amplifiers can also be neutralized by taking the plate circuit a small amount off ground as was done in the single-ended grid neutralizing scheme, and by using the tube capacitances as part of the bridge circuit. This method has been described by Hultberg⁷.

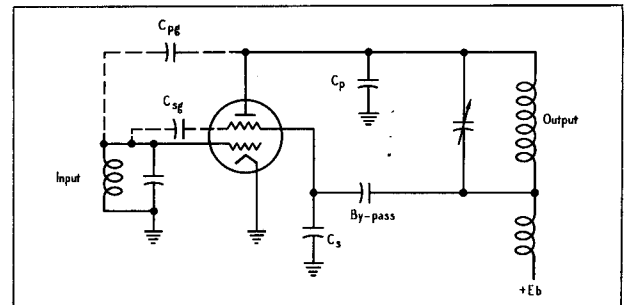


Fig. 27

Single-ended plate neutralization, basic circuit. See Hultberg⁷.

Such a circuit is shown in Fig. 27. It differs from the usual r-f amplifier circuit in that the plate bypass capacitor is returned to the screen side of the screen bypass capacitor, C_s , and in adding stray capacitance from plate to ground, C_p . The size of screen bypass capacitor, C_s , and the amount of stray capacitance in C_p are chosen to balance out the voltages induced in the input

circuit by the internal tube capacitances plate to grid, C_{pg} , and screen to grid, C_{sg} .

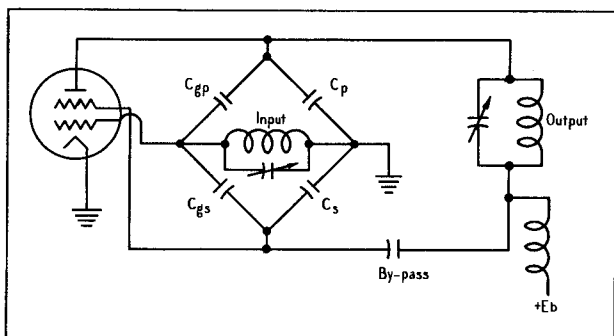


Fig. 28

Single-ended plate neutralization showing capacitance bridge circuit present.

The circuit is redrawn in Fig. 28 in the usual bridge circuit form. Balance is had when

$$\frac{C_p}{C_s} = \frac{C_{pg}}{C_{gs}}$$

In usual tetrode structures the capacitance from screen to grid is roughly half the published tube input capacitance. (The tube input capacitance is mainly the sum of the capacitance of the grid to screen and the capacitance grid to cathode. Since as a first guess these two capacitances are roughly equal, one is not far off in using half the listed tube input capacitance.)

It should be noted that in all neutralizing capacitance bridge circuits it is assumed that the frequency is low enough so that inductances in the connecting leads and tube structures can be neglected. This is usually not the case in the VHF region, especially in single-ended tetrode stages where bridge circuits balance with a very small voltage in part of the bridge circuit. At VHF the small amount of voltage developed in the residual inductance of the screen circuit can be enough to accomplish neutralization in itself. See section D-2-b "Analysis of Neutralizing Circuits."

D-2-a. Procedure

The neutralizing process for tetrodes follows the standard procedure. The first step in rough adjustment is to break the d-c connections of the plate voltage and screen voltage leaving the r-f circuits intact. (If the d-c current path is not broken, some current is found to flow in either one of these circuits even though their voltages are zero, and the presence of this current causes the amplifier to work in the normal

manner, generating r-f power in the plate circuit. It will then be incorrect to adjust for zero power in the plate circuit.)

As an indicator of neutralization adjustment, one can use either a sensitive r-f meter coupled to the plate circuit or observe the reaction on the grid current as the plate circuit is tuned. When the plate circuit is tuned through resonance, the grid current will dip when the circuit is out of neutralization in the same manner as it does with triode neutralization adjustments. The neutralizing circuit is adjusted until the indication has been reduced to a minimum.

For the final trimming of the neutralization adjustment, the stage should be returned to operating condition at reduced power similar to that used when testing for parasitic oscillations, or under the final loaded operating conditions. At the higher frequencies and in the VHF region, it will be found that a small additional trimming adjustment of the neutralizing circuit is usually required. When the plate circuit is tuned through resonance, the minimum plate current and maximum control grid current should occur simultaneously. The d-c screen current should be maximum at the same time.

The neutralizing procedures indicated above apply not only to the HF radio frequencies, but also apply in the VHF or UHF regions. In the latter cases the neutralizing circuit is different and the conventional cross-neutralization schemes will not be applicable. See below.

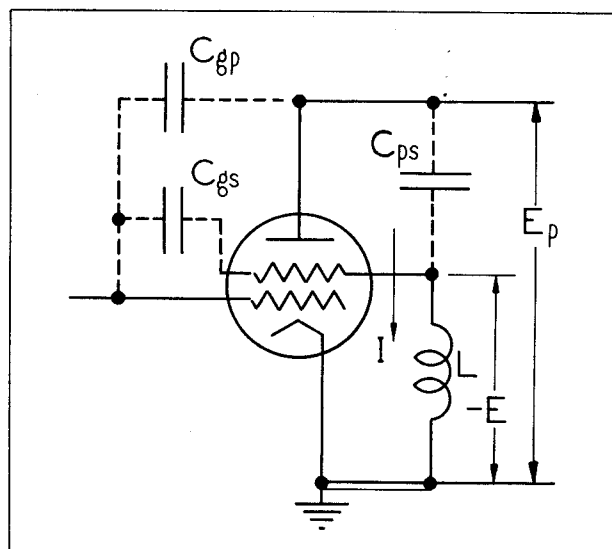


Fig 29

Tetrode characteristics involved in feedback circuit.

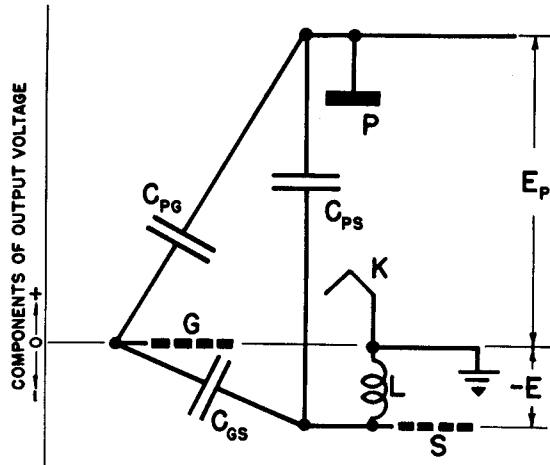


Fig. 30

Graphical presentation of components of output circuit voltages in tetrode when self neutralized.

D-2-b. Analysis of Neutralizing Circuits

Careful analysis of the feedback circuits of tetrodes in the VHF region has been made⁸ and the basic concepts follow. In Fig. 29 the tetrode circuit elements involved in the feedback circuits are indicated. These circuit elements are inherent and inside the vacuum enclosure of the tube, and involve the residual capacitance plate-to-grid, the capacitance from plate to screen, the capacitance from screen to grid, and the inductance of the screen lead to the tube. It will be noted that the r-f voltage developed in the plate circuit E_p causes a current I to flow through the plate to screen C_{ps} , and the inductance L in the screen leads. The passage of this current through the inductance L develops a voltage $-E$ which has a polarity opposite to that of the plate voltage E_p .

In Fig. 30 these same circuit elements and voltages have been arranged with a graphical representation where the height above or below the zero line represents magnitude and polarity of the r-f voltage of that part of the circuit with respect to zero or filament voltage. Because all of the circuit components involved are pure reactances, the voltages are either in phase or out of phase and so can be represented as positive and negative with respect to each other. The voltages plotted are the components only of the r-f output circuit voltage E_p and no attempt is made to show the normal driving voltage on the grid. The plate "P" is shown at a high positive potential above zero and the magnitude is represented by

the distance above the zero line as shown by the dimension E_p . The voltage developed in the screen lead inductance places the screen at a negative voltage with respect to the plate voltage. The screen of the tube "S" is shown to be below the filament line, or negative, by the amount $-E$. If the circuit were perfectly neutralized, the control grid "G" would lie on the zero potential line or at filament potential insofar as any action of the r-f plate voltage " E_p " on the input circuit is concerned. If there is no component of output voltage developed between grid and filament, the circuit is neutralized.

The total r-f voltage between plate and screen comprises plate voltage E_p and screen lead inductance voltage $-E$. This total voltage is applied across a potential divider consisting of the capacitance plate to grid, C_{pg} , in series with the capacitance grid to screen, C_{gs} . When this potential divider is suitably matched to the magnitudes of the voltage E_p and screen lead voltage $-E$, the control grid will have no voltage difference to filament as a result of the output circuit voltage E_p .

It should be noted in Fig. 30 that the potential dividing action between capacitances plate-to-grid, C_{pg} , and grid-to-screen, C_{gs} , will not be affected by the operating frequency. It should be noted also that the division of voltage between plate and screen and screen and ground due to the charging current, I , will vary greatly with frequency. There will, therefore, be some particular frequency at which this potential dividing circuit places the grid at filament potential as far as the plate circuit action is concerned, and this is called the *self neutralizing frequency* of the tetrode. At this particular frequency the tetrode is inherently neutralized due to the circuit elements within the tube structure and any external added screen lead inductance to ground. Typical self neutralizing frequencies with normal screen by-passing circuits are as follows:

Approximate Self Neutralizing Frequencies of Tetrodes

4-1000A	25 to 30 Mc.
4-400A	45 Mc.
4-250A	45 Mc.
4X500F	75 to 90 Mc.
4-125A	75 to 90 Mc.
4-65A	80 to 120 Mc.
4X150A	} apparently above the useful range of the tube.
4X150G	
4X500A	

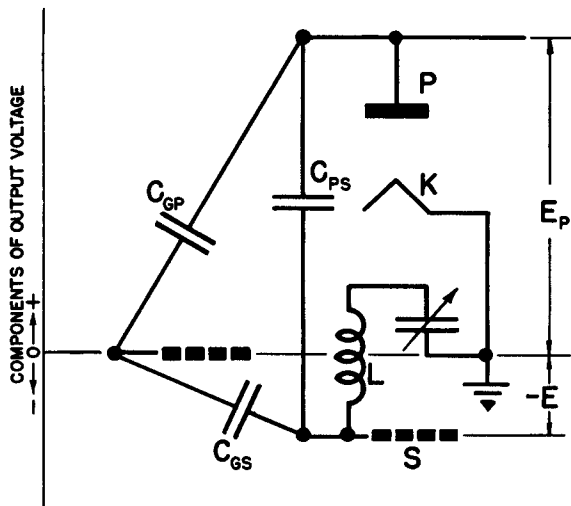


Fig. 31

Components of output voltage of a tetrode when neutralized by added series screen-lead capacitance.

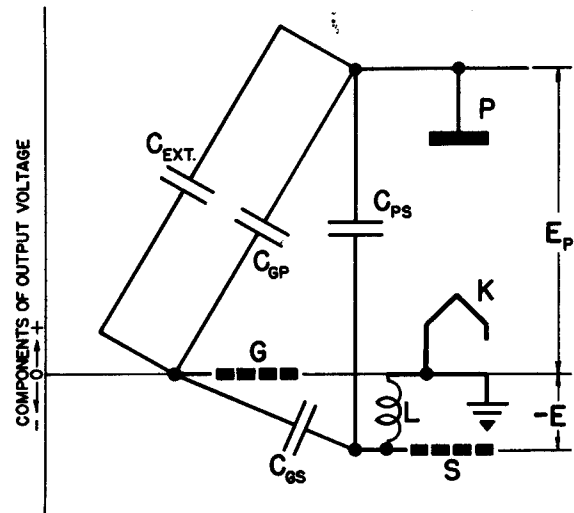


Fig. 32

Components of output voltage of a tetrode when neutralized by added external grid-to-plate capacitance.

When the tube is operated below the self neutralizing frequency, the normal cross neutralizing circuits apply. In this case a neutralizing capacitor approximately equal to the plate grid capacitance of the tube brings voltage of opposite polarity from the output circuit to the grid or from the input circuit to the plate.

If the operating frequency is higher than the self neutralizing frequency of the tetrode, the voltage $-E$ developed in the screen grid lead inductance is too large to give the proper voltage division between the internal capacitances of the tube. One obvious method of reducing the voltage in the screen lead reactance is to series tune the screen lead to ground so as to lower the total reactance. This takes the form of a series variable capacitor as shown in the graphical representation in Fig. 31.

Another method would be to change the potential divider network made up of the tube capacitances. This could be done by adding capacitance external to the tube between grid and plate. The method is shown in Fig. 32. This added capacitance plate-to-grid is on the same order of size as the residual grid plate capacitance of the tetrode and hence is similar in construction to the neutralizing capacitance used at lower frequency. However, in this case the small wire or rod standing up beside the tube "looking" at the plate (and so forming a neutral-

izing capacitor) is connected to the grid of the tube rather than to an opposite polarity in the input circuit.

If the r-f power amplifier, operating above the self neutralizing frequency of the tube, must tune over a range of frequencies, it is probably easier to use the screen series tuning capacitor method and make this control available to the operator. If operation is desired over a range of frequencies including the self neutralizing frequency of the tube, this circuit is also desirable because the incidental lead inductance in the variable tuning capacitor lowers the self neutralizing frequency of the circuit so that the neutralizing series capacitor can be made to operate over the total desired frequency range. Obviously, if the range is too great, switching of neutralizing circuits will be required. Usually, a small 50 or 100 mmfd variable capacitor in the screen lead has been found satisfactory.

D-2-c. Self-Neutralization of the VHF Parasitic

Another method of changing the self neutralizing frequency of a tetrode is had when using the general bypassing arrangement of screen and filament shown in Fig. 23. The screen lead is bypassed with minimum inductance to the filament terminal of the tube. Some inductance is introduced in the common filament and screen grounding lead.

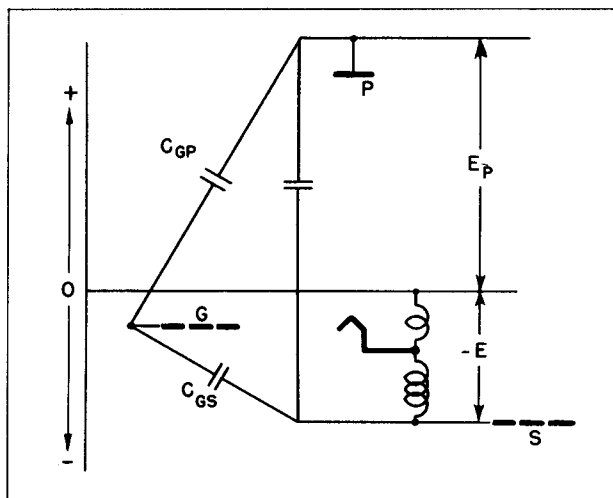


Fig. 33

Components of output voltage of a tetrode neutralized by adding inductance common to screen and cathode return.

The circuit arrangement is plotted with components of plate voltage in Fig. 33. The grid is shown below the zero voltage or chassis potential, indicating that the voltage developed in the total screen lead inductance to chassis is excessive. If now the filament is tapped up on this inductance, a point can be found where the voltage difference between grid and filament is zero as far as the components of plate voltage are concerned. The arrangement will be found to self neutralize at a higher frequency than if the filament and screen were separately bypassed to chassis.

It has been found in tubes, such as the 4-65A, 4-125A, 4-250A, 4-400A and 4-1000A, that the usual VHF parasitic is higher in frequency than the normal self neutralizing frequency of the tube. Thus, by increasing the self neutralizing frequency of the tube and screen bypass arrangement, the tendency of the VHF parasitic to occur is reduced.

If now the frequency of the VHF parasitic is reduced by increasing the inductance of the plate lead (presuming this is the principle frequency defining circuit), it can be made to approach the self neutralizing frequency of the tube and so suppress the parasitic.

It is interesting to note that the later addition of cross-neutralization for the fundamental HF or LF frequency should not disturb this VHF neutralization provided the fundamental neutralizing circuit involves only voltages of the lower or fundamental frequency.

In its purest form this might mean having

zero impedance for the VHF parasitic frequency between the point in the grid circuit where the neutralizing capacitor is connected and the chassis.

D-3. Properly Adjusting Excitation and Loading

In adjusting an r-f amplifier for proper excitation and proper loading, it will be noticed that the procedure is different, depending upon whether the screen voltage is taken from a fixed supply or a dropping resistor supply with poor regulation.

In the case where both the screen supply and grid bias are from fixed sources with good regulation, the plate current is almost entirely controlled by the r-f excitation. One should first vary the excitation until the desired plate current flows. The loading is then varied until the maximum power output is obtained. Following these adjustments the excitation is then trimmed along with the loading until the desired control grid, and screen grid currents are had.

In the case of an r-f amplifier where both the screen and grid bias are taken from sources with poor regulation, the stage will handle very much like the triode r-f power amplifier. The plate current will be adjusted principally by varying the loading, and the excitation will be trimmed to give the desired control grid current. In this case the screen current will be almost entirely set by the choice of the dropping resistor. It will be found that excitation and loading will vary the screen voltage considerably and these should be trimmed to give about the normal screen voltage.

D-4. Operating Voltages and Currents for Various Applications

Probably the simplest way to get an idea of the capabilities of the tube, and the voltages and currents to be used on the various electrodes, is to refer to the technical data sheet for that tube type. A number of typical operating conditions are given for various classes of service. A great many other operating conditions are possible, but these particular ones are usually selected to show the maximum capabilities of the tube for different plate voltages. At no time should the maximum ratings for that class of service be exceeded.

As long as none of the maximum ratings of the tube are exceeded, a wide choice of voltages on the plate, screen, or grid, and a wide range of plate current values is available. In general it will be found that for efficient operation the

ratios of d-c grid current, d-c screen current, d-c plate current should be kept somewhere near the ratios indicated on the data sheet. Thus, if $\frac{1}{2}$ or $\frac{2}{3}$ of the indicated plate current is to be used, the d-c grid current and d-c screen current should be approximately $\frac{1}{2}$ or $\frac{2}{3}$ of the values indicated on the data sheet.

For those interested in estimating tube performance from the characteristic curves of the tube, two application bulletins are available^{9, 10}. These application bulletins describe simple means of calculating or estimating from characteristic curves the performance of tubes as class-C r-f amplifiers.

In referring to the characteristic curves of a tube, it should be recognized that these curves are typical of a normal tube. As in all manufactured products, some tolerance is allowed. In general, the currents indicated will be within plus or minus 10% of the values shown.

D-5. Effect of Different Screen Voltages

Typical operating values for a tetrode for a particular value of screen voltage are given on the published data sheet. The screen voltage is not critical and the value used has been chosen as a convenient value consistent with low driving power and reasonable screen dissipation. If lower values of screen voltage are used, more driving power will be required on the grid to obtain the same plate current. If higher values of screen voltage are used less driving power will be required. Thus, high power gain can be had provided the circuit has adequate stability. Care should be observed that the screen dissipation limit is not exceeded. The value of screen voltage can be chosen to suit available power supplies or amplifier conditions.

For a method of altering the coordinate and curve scales of the tube curves to obtain a set of curves for another screen voltage, see page 5 of the Eimac 4-65A Technical Data Sheet¹¹.

D-6. Balance of Push-Pull Amplifiers

In a push-pull r-f amplifier lack of balance of plate circuit or plate dissipation is usually due to lack of symmetry in the r-f circuit. Normally, the tetrodes are similar enough that such unbalance is not associated with the tube and its characteristics. This point can readily be checked by interchanging the tubes in the sockets (provided both tubes have the d-c voltages to plate, screen, and grid in common) and seeing whether the unbalanced condition remains with the socket location or moves with the tubes. If it remains

with the socket location, the circuit requires adjustment. If appreciable unbalance is associated with the tubes, it is possible that one tube is not normal and should be investigated further.

The basic indicators of balance are the plate current per tube and the plate dissipation of each tube. It is assumed that the circuit applies the same d-c plate voltage, d-c screen voltage, and d-c grid bias to each tube from common supplies. Also, it is assumed that the plate circuit is mechanically and electrically symmetrical or approximately so to begin with.

Unbalance in a push-pull r-f amplifier is usually caused by unequal r-f voltages applied to the grids of the tubes, or by the r-f plate circuit applying unequal r-f voltages to the plates of the tubes. The r-f grid excitation should first be balanced until equal d-c plate currents flow in each tube. Then the r-f plate circuit should be balanced until equal plate dissipation appears on each tube.

The balance of plate current is a more important criterion than equality of screen current or grid current. This results from the fact that tubes are more uniform in the plate current characteristics, and also that the screen current is very sensitive to lack of voltage balance in the r-f plate circuit.

Once the d-c plate currents per tube have been made equal by adjusting the r-f grid circuit, the r-f plate circuit can be adjusted to give equal plate dissipations, as noted. Or, if the tubes have equal screen current characteristics, the r-f plate circuit could be balanced until equal screen currents result. If the tubes differ somewhat in screen current characteristics, and the circuit has common d-c supply voltages, the final trimming of the plate circuit balance could be made by interchanging tubes and adjusting the circuit to give the same screen current for each tube regardless of its location.

It should be noted that the d-c grid current has not been used as an indicator of balance of the r-f power amplifier. It is probable that after following the above procedure the grid currents will be fairly well balanced, but in itself it is not a safe indicator of balance of grid excitation.

In audio power amplifiers operating in Class-AB₁ or Class-AB₂, the idle d-c plate current per tube should be balanced by separate bias adjustments for each tube. In many cases some lack of balance of the plate currents will have negligible effect on the overall performance of the amplifier.

SECTION D

When tubes are operating in the idle position close to cut-off, operation is in a region where the plate current cannot be held to a close percentage tolerance. At this point the action of the positive screen and plate voltages is in delicate balance with the opposing negative grid voltage. The state of balance is indicated by the plate current. Very minor variations of individual grid wires or diameter of grid wires upset the balance, and it is practically impossible to control such minor variations in manufacture. In many audio amplifier applications, especially where the larger power tetrodes are used, the circuit should be designed to permit the bias to be adjusted individually on the tubes.

D-7. Harmonic Amplifiers and Control of Harmonics

The use of power tetrodes to give good efficiency in harmonic amplifiers and to control the presence of unwanted harmonics in the output circuit is inherently sound. Because of the shielding built into the tetrode, the coupling between the output and input circuits (and the input and output circuits) has been reduced to a negligibly small value. (To estimate harmonic amplifier performance see Brown¹² and the Eimac application bulletin "Tube Performance Computer"¹⁰.)

A pulse of plate current delivered by the tube to the output circuit contains energy on the fundamental and most harmonic frequencies. The output plate circuit resonance, coupling, and shielding must be designed to select the desired frequency and avoid radiation of the undesired frequencies.

It is not generally appreciated that the pulse of grid current also contains energy on the harmonic frequencies and control of these harmonic energies may be quite important. The ability of the tetrode to isolate the output circuit from the input circuit over a very wide range of frequencies is important in avoiding feed-through of harmonic voltages from the grid circuit. An important part of this shielding is the fact that properly designed tetrodes permit the construction of complete shielding in the amplifier layout so that coupling external to the tube is also prevented.

It has been found that the plate circuit efficiency of tetrode harmonic amplifiers is quite high. In triode amplifiers, if feed-back of the output harmonic frequency occurs, the phase of the voltage fed back is usually such as to reduce the harmonic content of the plate pulse, and thereby lower the plate circuit efficiency. Since

tetrodes have negligible feedback, the efficiency of a harmonic amplifier is usually up to expected efficiencies.

Also, the high amplification factor of a tetrode causes the plate voltage to have little effect on the flow of plate current, and it is easier to obtain plate pulses with high harmonic energies without using excessive grid bias. A well designed tetrode also permits large r-f voltages to be developed in the plate circuit while still passing high peaks of plate current in the r-f pulse. These two factors help further to increase the plate efficiency.

In r-f amplifiers operating either on the fundamental or a desired harmonic frequency, the control of unwanted harmonics is very important. The subject is well covered in the literature discussing the reduction of interference with television receivers. The following steps permit reduction of the unwanted harmonic energies present in the output circuit:

1. The circuit impedance between plate and cathode should be very low for the high harmonic frequencies. Usually this is obtained by having some or all of the tuning capacitance of the resonant circuit close to the tube.
2. Complete shielding of the output compartment.
3. The use of inductive output coupling from the resonant plate circuit and possibly a capacitive or Faraday shield between the coupling coil and the tank coil, or a high frequency attenuating circuit such as a pi, or pi-L net.
4. The use of low pass filters for all supply leads and wires coming into the output and input compartments.
5. The use of resonant traps for particular frequencies.

D-8. Driving Power Requirements

The technical data sheet for a particular tube gives the approximate driving power required. For radio frequencies below the VHF region, the driving powers are obtained by calculation and confirmed by direct tests. The listed driving power gives the total power taken by the tube grid and the bias circuit. This driving power figure does not allow for losses in the r-f resonant circuit since such losses depend principally on the design of that circuit. The circuit losses can be kept to a low value by proper design. Some allowance for them must be made, however, in determining the total driving power to be supplied by the driver stage.

In the case of tetrodes operating in the VHF and UHF region, the approximate driving power given under typical operation on the data sheets is obtained by direct measurement in operating equipment. Because it is impossible to separate the circuit action and the tube action, the driving power listed is the total power taken by the tube and a practical amplifier circuit.

The total driving power required from the exciter stage in the VHF and UHF region is presumably composed of the following:

1. The power taken by the grid itself and the bias circuit (which is equal to that for the same grid voltages and current acting in a low frequency circuit).
2. The resistance losses caused by the r-f charging currents passing through the leads of the tube into the tube capacitances.
3. Power fed through to the output circuit and power dissipated on plate and screen due to the presence of cathode lead inductance.
4. Excess energies taken on by the space current electrons within the tube due to the rapidly varying grid voltage. Some of this excess energy shows up in bombardment of the cathode and general tube structure.
5. Some dielectric loss in the insulating material of the tube envelope.
6. Losses in the r-f grid circuit and a portion of the input line coupled to the driving circuit.

The total driving power in the VHF and UHF region is often greater than the grid dissipation capability of the tube. As indicated above, the portion of the driving power which appears as grid dissipation can be calculated in the normal manner¹³ (d-c grid current times the peak positive grid voltage).

D-9. VHF and UHF Operating Conditions for Satisfactory Plate Efficiency and Minimum Drive.

When operating a tube in the VHF and UHF region the driving power can usually be minimized without appreciably affecting the plate conversion efficiency, by the following steps:

1. A minimum d-c control grid bias should be used. Frequently, it is advisable to bring this down to approximately cut-off.
2. A high value of d-c screen voltage is advisable even though it appears to increase the fraction of the cycle during which plate current flows.
3. Using the minimum r-f excitation voltage necessary to obtain plate circuit performance, even though the d-c grid current is considerably lower than one would expect at lower frequencies.
4. The cathode lead inductance common to the output and input circuits should be kept to a low value.

It is found that the choice of driving conditions as indicated above does not necessarily decrease the plate efficiency as much as at lower radio frequencies. The steps indicated above should be tried experimentally to determine whether or not the plate circuit efficiency is appreciably effected. As will be indicated below under section E-3, it is preferable to sacrifice plate efficiency somewhat and improve the life expectancy of the tube in the VHF and UHF region.

It has also been observed that optimum output power at these frequencies is obtained when the loading is greater than would be used at lower frequencies. Apparently the use of lower r-f voltage in the plate circuit is desirable. Fortunately, this same condition reduces driving power and screen current and, as will be noted later, improves life expectancy.

LIFE

E-1. Maximum Tube Ratings.

The technical data sheet for each tube type gives the basic maximum ratings for each class of service. Also on the technical data sheet will be found references to cooling air and maximum temperature, and mechanical considerations as they may affect life. Careful observance of the information on the data sheet will avoid damage to the tube and shortening of its useful life. A

reprint on Vacuum Tube Ratings is available¹³.

In general, the tube ratings are so chosen that operation within the ratings will give a minimum of 1000 hours of guaranteed life. The typical life expectancy is therefore considerably greater and will depend upon a great many factors, some of which are discussed below. In general, operation below the maximum ratings will increase the life expectancy of the tube. This

SECTION E

is especially true with reduction in the plate dissipation of the tube. Very roughly speaking, the life expectancy will go up directly as the plate dissipation and total watts being handled by the tube go down.

If tubes are to be used in pulse service with short pulses and appreciable off-time between pulses, the tube ratings are quite different. For information and assistance on pulse application write to the Field Engineering Department of Eitel-McCullough, Inc., San Bruno, California, or refer to Application Bulletin No. 3 "Pulse Service Notes"¹⁴.

E-2. Cooling

Adequate cooling of the tube envelope and metal-to-glass seals is one of the principle factors affecting tube life. Deteriorating effects increase directly with the temperature of the tube envelope and seals. The technical data sheet for the particular tube type should be studied thoroughly with reference to the air cooling requirements. Even if no air cooling is specified, ample free space for circulation of air around the tube is required or else some air must be forced past the tube.

Excess cooling air will have only beneficial results and inadequate cooling air is almost certain to invite premature failure of the tube.

Tubes operated in the VHF and UHF region are inherently subjected to greater heating action than tubes operated at lower frequencies. This results directly from the flow of larger r-f charging currents into the tube capacitances, dielectric losses, and a tendency for electrons to bombard parts of the tube structure other than the normal grid and plate. See section E-3 for a discussion of "VHF and UHF Life Considerations." Greater cooling air is therefore required at these higher frequencies. For tubes designed to operate in the VHF and UHF region, such as the Eimac tetrodes, the cooling air is specified for the normal top frequencies of the tube.

E-3. VHF and UHF Life Considerations

A tube designed for VHF and UHF work must have very small size if practical resonant circuits are to be built around them. Furthermore, these tubes operate less efficiently and have much greater incidental losses than at lower frequency. For these reasons, the power which must be dissipated from the electrodes and tube envelope seals is very much greater per unit of area than for tubes designed solely for low frequency.

If the tubes are to become a part of a VHF line circuit or cavity UHF circuit, the inductance associated with the electrode supports and leads must be reduced to a very small value. In the case of the 4X150A, 4X150G, and 4X500A, some of the electrode leads and supports take the form of large surfaces, conical or cylindrical in shape, and extremely short. This means that the amount of heat conducted out through the metal-to-glass seals is greatly increased. It also means that the terminal connections of the tube are large surfaces with relatively thin walls.

The mechanical layout of sockets, connections, and circuits close to the tube must allow ample cooling air to be blown against the tube seals and surfaces. Also ample contacting surface to carry the heavy radio frequency charging currents must be provided. Since these two requirements may tend to conflict, considerable thought must be given to an adequate layout.

E-3-a. Connectors

Where the tube terminals are large cylindrical surfaces, the contacting portions of the socket are either spring collets or a multiplicity of spring fingers. Usually these multiple contacting surfaces are made of beryllium copper to preserve the spring tension at the relative high temperatures present on tube terminals and are silver plated to reduce r-f resistance.

Rigid clamping connectors should be avoided even though the radius of the curvature seems to be close to that of the cylindrical contacting surface of the tube. It has been found that such rigid clamping connectors will distort the tube terminal and fracture the adjacent metal-to-glass seal. Similarly set screw connecting devices are questionable on large cylindrical tube terminals unless they act to distribute the pressure uniformly and without any distorting effects.

If the connectors fail to provide multiple contacts to the cylindrical tube seals, concentration of r-f charging current will result and the overheating may be destructive. Once the connector loses its spring action the heating is aggravated and damage to the tube is very apt to occur. All tube connectors should be inspected and serviced regularly to be sure that uniform, good contact to the tube results.

E-3-b. Tube Temperatures

Forced air cooling of the seals and tube envelope, as well as of an external anode, is imperative. Both air flow and maximum temperatures are given on the data sheets and both

should be measured to be certain that ample air and cooling results. The problem of making temperature measurements under these conditions is severe. The most practical technique has been to use a very light spray of very thin temperature indicating paint, such as Tempilaq—made by the Tempil Corporation, 132 West 22nd Street, New York 11, N. Y. By using an extremely thin spray and not covering solidly, a temperature gradient across the indicating paint due to the action of the cooling air will be avoided. For further discussion see Eimac application bulletin¹⁵ on the subject.

E-3-c. Backheating by Electrons

Another action involving the motion of electrons within the tube is present at VHF and UHF and has been commonly referred to as backheating of the cathode. Due to the fact that the time of flight of the electrons from the cathode through the grid structure to the plate becomes an appreciable part of the cycle, the electrons can be stopped in flight and turned back by the rapidly changing grid voltage. Under these conditions the electrons are turned back or deflected from their normal paths and given excess energy with which the electrons bombard the cathode and other portions of the tube structure. This effect can be greatly aggravated by the choice of operating conditions to the extent that very destructive effects occur. The tube can even be destroyed within a few minutes under severe conditions.

Fortunately, the conditions which tend to minimize this back-bombardment by electrons are the same as those giving minimum driving conditions as discussed under "VHF Operating Conditions" section D-9. The tendency for electrons to be turned back in flight is reduced by the use of the lowest possible r-f grid voltage on the tube. This is obtained by using the lowest possible d-c grid bias. In tetrodes this effect is inherently much lower because of the action of the d-c accelerating voltage on the screen of the tube. The d-c screen voltage acts to continue accelerating the electrons toward the anode, and also inherently permits the use of very much smaller grid voltages. Consequently, under favorable conditions the number of electrons turned back to heat the cathode and tube structure can be kept to a practical low level. In addition to the use of low d-c grid bias, a high screen voltage is desirable.

At the same time the plate circuit should

always operate with heavy loading (low external plate impedance) so that the minimum instantaneous value of plate voltage shall stay sufficiently positive to continue accelerating electrons to the anode. For this reason best life is had when the tetrode amplifier is heavily loaded as indicated by having small values of d-c screen and d-c control grid current.

NEVER OPERATE WITH LIGHT PLATE LOADING. If the plate load is removed so that the minimum instantaneous plate voltage tends to fall to values around cathode potential (as it must do when the loading is removed completely and excitation is present), the number of electrons turned back can be completely destructive to the tube. It has been found that under conditions of "no loading" the electron bombardment of the insulating glass portion of the tube is often sufficient to cause a suck-in of the glass. Automatic protection should be installed to remove all voltages from the tube when the plate circuit loading becomes too light for the amount of excitation applied.

It should be noted that parasitic oscillations are seldom loaded heavily, as indicated by the high grid currents often had during such self oscillation. Thus excessive r-f plate voltages are developed which at VHF can be damaging in the same manner as unloaded operation on a VHF fundamental frequency. Should such unloaded VHF parasitic oscillation be present simultaneously with apparently satisfactory operation on the fundamental, unexplained reduction of life may result.

Occasionally, also, an output line circuit can resonate simultaneously to a harmonic frequency as well as to the fundamental frequency. The higher resonant modes of practical line circuits are not normally harmonically related, but sometimes the tuning curve of a mode will cross the fundamental tuning curve and at that point the circuit will build up resonant voltages at both the harmonic frequency and fundamental frequency. The harmonic resonance is usually lightly loaded and the damaging action is similar to that of lightly loaded parasitic or fundamental operation. Again the operation of the tube and circuit on the fundamental may appear normal, but with lower than expected efficiency, and damaging action to some degree can occur.

In addition to operating the tube with minimum bias, high screen voltage, and heavy loading on the plate circuit, some degree of com-

SECTION F

compensation for the remaining back heating of the cathode may be required. This can be accomplished by lowering the filament voltage or heater voltage until the cathode operates at normal temperature. It has been found with tetrodes that by taking precautions necessary to minimize

back bombardment by electrons the compensation for back heating of the cathode is not large and may often be neglected. In cases where it is suspected, it is advisable to discuss the subject in detail with the Field Engineering Department of Eitel-McCullough, Inc., in San Bruno, California.

TECHNICAL ASSISTANCE

The Field Engineering Department of Eitel-McCullough, Inc., will gladly assist tube users in the choice of tubes and operating conditions. This is especially important where a prototype design of

equipment and later manufacture is planned. Such assistance makes use of the accumulated detailed experience with the tube types involved and is handled confidentially and without charge.

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