RADIOTRONICS

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# Damping for Loudspeakers Accoustical and Electro-Magnetic

*By F. Langford-Smith and A. R. Chesterman.*

The most prominent resonance displayed by a loudspeaker is the bass resonance which, if lightly damped, is most objectionable, giving rise to "one note bass", "hang-over", and poor transient response. For any set of conditions and for any one listener, there is an optimum amount of damping, to give the most pleasing results. It is important to remember that the amount of damping has only a small effect outside the region of the bass resonant frequency. Taking a typical case with a bass resonant frequency as 85 c/s, the effects of damping would be small above 150 c/s.

## Introduction to damping

Loudspeakers have some damping inherent in the speaker, but all additional damping to meet the requirements of good musical reproduction must come from external electro-magnetic or acoustical damping, or both. Most modern amplifiers and radio receivers use negative voltage feedback to give a low output resistance, that is, a high "damping factor". Damping factor is defined as $R_L/R_o$, where $R_L$ is the nominal load impedance and $R_o$ is the amplifier output resistance. High fidelity amplifiers are sometimes advertised as having very high damping factors. E.g. 45, or in another case infinity. This term "damping factor" is quite misleading, since the damping is in no way proportional to the damping factor. The writers prefer to express this in the alternative inverse form where the output resistance is given as a fraction or percentage of the load resistance (Ref. 1). Thus an output resistance of zero (corresponding to a "damping factor" of infinity) gives a more accurate impression, particularly the non-technical person. However, the use of the term "Damping Factor" is so strongly entrenched that it cannot be displaced, and it will therefore be used in this article.

The effects of damping are shown by the equivalent circuit of Fig. 1 (Ref. 2). This may be applied to an infinite flat baffle merely by short-circuiting $C_c$. It will be seen that this is a series resonant circuit, with an applied voltage $E_s$ across $R$, $L$ and $C$ in series. The Q of the circuit is given by

$$Q = \frac{2\pi f\ L_u}{R_s + R_u} \qquad (1)$$

and the acoustical output of the loudspeaker is proportional to $E_{LU}$.

$$\text{Now } R_S \propto \frac{B^2}{R_o + R_{vc}} \text{ at low frequency} \qquad (2)$$

where $B$ = flux density in gap
$R_o$ = output resistance of amplifier referred to the voice coil circuit
and $R_{vc}$ = resistance of voice coil.

Two important facts are shown by eqn. (2). The first is that, so long as $R_o$ is positive, the damping is limited by $R_{vc}$, and changing $R_o$ from 10 to one-tenth of $R_{vc}$ to zero (i.e. changing damping factor from 10 to infinity) only effects the damping resistance by 10%. The damping can only be truly infinite if $R_o$ is made negative—ways of accomplishing this result will be described later in this article.

The second important fact shown by eqn. (2) is that $R_S$ is directly proportional to the square of the flux density and inversely proportional to $R_o + R_{vc}$. Loudspeakers with low flux density may have insufficient damping even when $R_o$ is made zero, whereas those with high flux density may be too heavily damped when $R_o$ is zero. It is thus quite obvious that it is impracticable to select any value of "damping factor" which will give optimum results with any loudspeaker.

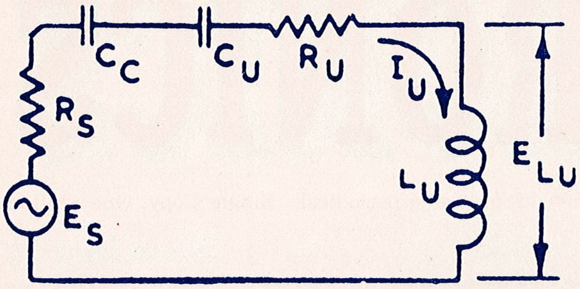


*Fig. 1. Equivalent electrical circuit of loudspeaker in enclosed cabinet at low frequencies. [RT35 = RDH Fig. 20.11].*

## Effect on frequency response

Varying the damping on a loudspeaker has a second, and very important, effect which is not always fully realized. Its effect on frequency response is shown in Fig. 2 for a particular case with a totally enclosed cabinet. A similar effect occurs with a flat baffle, but the curves show that values of $Q$ below about 1 result in bass attenuation. There are two common practices to meet this difficulty. The first is to maintain the loudspeaker $Q$ about 1, or slightly over, to avoid the attenuation. The second is to accept the bass attenuation as a price to pay for high damping, and to make it good by adding bass boosting—about 7 db at the bass resonant frequency. There is absolutely no point in reducing $Q$ below 0.5, the value to give critical damping.

*Fig. 2. Theoretical response of enclosed cabinet loudspeaker for various values of damping resistance $R_S$. Resonance frequency 45 c/s. [RT36 = RDH Fig. 20.12].*

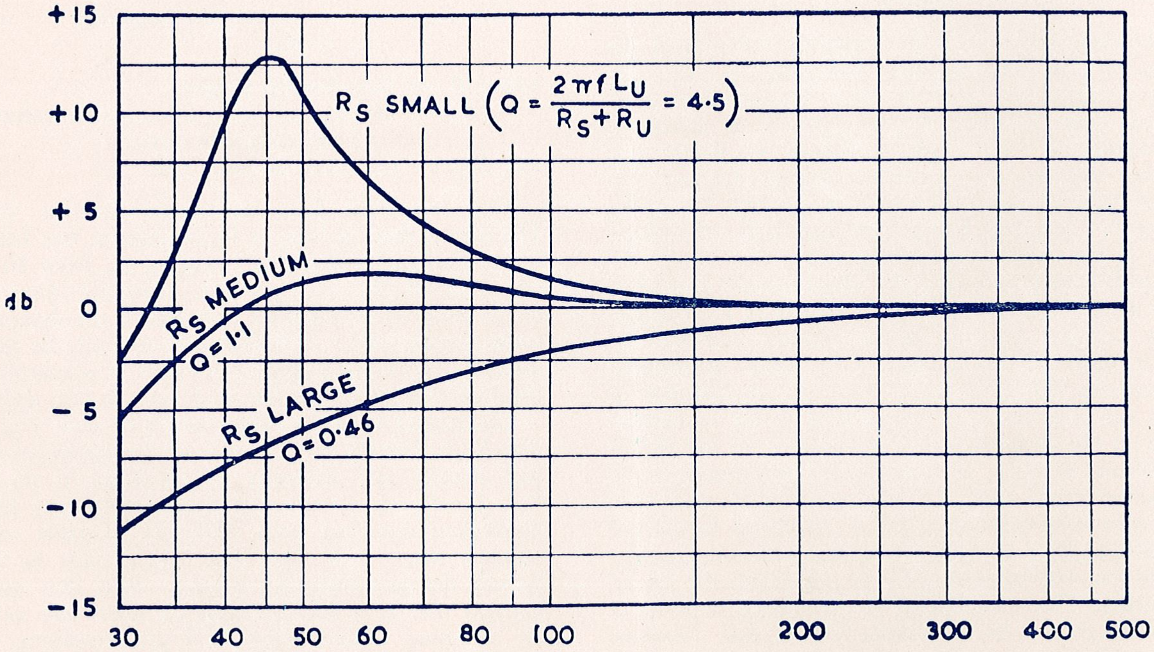
## Damping controls

This introduces the desirability, in high fidelity amplifiers, of adding a control to alter the "damping factor". Two methods of achieving this result are shown in Figs. 3 and 4. Both use a combination of negative voltage feedback and positive current feedback. Although these add further control to the already formidable array on many amplifiers, it does serve a useful purpose. Normally it would be pre-set to suit a particular loudspeaker and listener, and not used as a regular control.

It has been stated above that loudspeakers with low flux density may have insufficient damping when $R_o$ is made zero. What can be done about it? Short of changing the loudspeaker for one with higher flux density, there are two possible courses—to provide a negative output resistance, or to add acoustical damping. Both of these methods are described in this article.

## Negative output resistance

A negative output resistance is produced by sufficient positive current feedback. This must be accompanied by an increased negative voltage feedback to reduce the harmonic distortion to a desirable level. Only one such commercial amplifier is



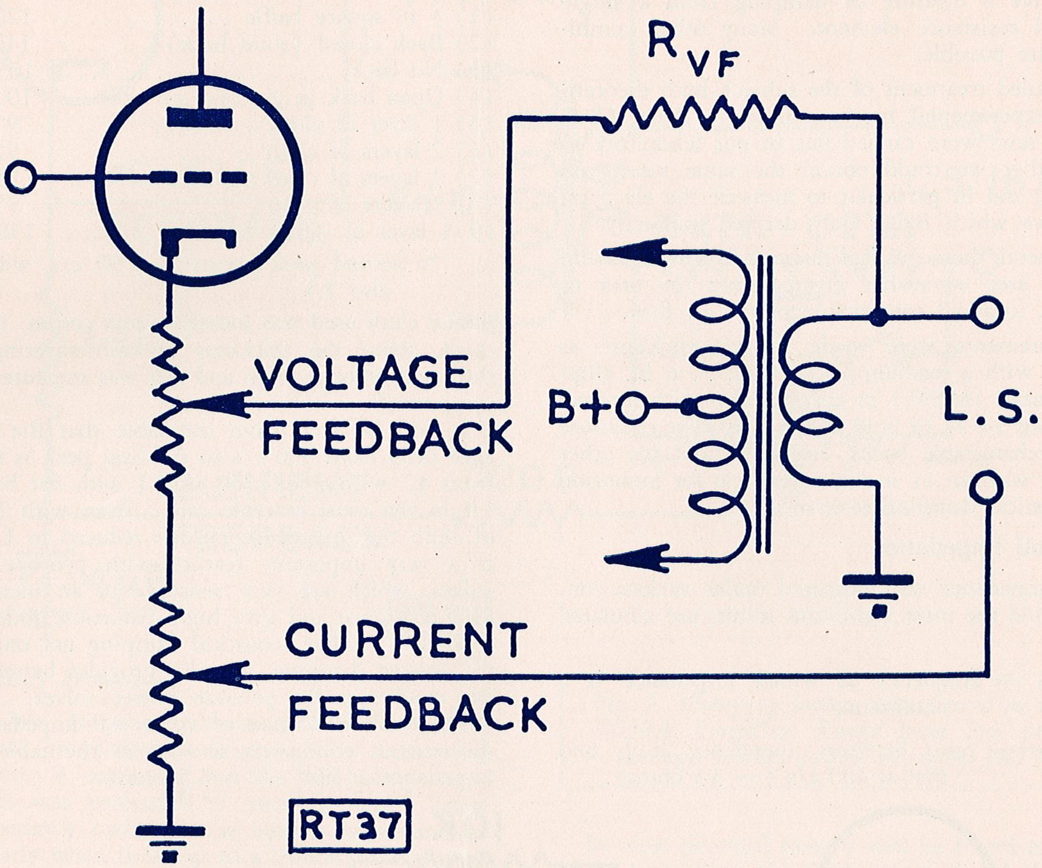


*Fig. 3. Damping factor control used in Electro-Voice Amplifiers A-20C and A-30. .Range 0.1 to 15. [RT 37].*

known at the present time — the Bogen Model D030A. The circuit is shown in Fig. 5 (Ref. 3). It uses 25 db negative voltage feedback, with current feedback controllable from negative to positive. When the switch is closed there is no positive feedback and the amplifier operates normally. When the switch is opened, with the damping control at the extreme negative current feedback position, the damping factor is positive and low (+2). As the damping control is moved towards the positive end the damping factor passes through the normal value (i.e. with switch closed) and then increases to infinity and beyond to high negative values, and finally low negative values (−2). The 4 μF condenser is used to limit the current feedback to low frequencies.

With such a control the amplifier will oscillate if the control is turned too far in the negative direction. Care is necessary to avoid possible damage to the loudspeaker. It is doubtful whether such an "unlimited" control will be widely used, but it would be of great interest in a laboratory or when carefully handled by an expert.

### Acoustical damping

Acoustical damping has received scant attention in the literature, but it is a very helpful tool, and, as will be shown below, it can be used to reduce the peak of loudspeaker impedance at the bass resonant frequency — being the only known method of producing this result without horn loading or the vented baffle. The latter does not come within the scope of the present article, but it may be covered at some future date.

The present subject is limited to open back cabinets, the back of which may be closed by a sheet of expanded metal on which is glued a piece of suitable cloth (Fig. 6A). However, the same principles may be applied to various forms of enclosures. Fig. 6B shows the small enclosure attached to a large baffle to increase its low frequency response. In C, a totally enclosed cabinet is damped by the small enclosure shown. D is similar to C, except that a damped port is provided for a vented baffle. In E, a port has been added to the enclosure A, while F shows an arrangement similar to D, in which both the speaker and the port derive a measure of damping from a single acoustical resistance element. Many other combinations are possible.

A detailed treatment of the subject, both theoretical and experimental, has been made by Bauer (Ref. 4), and tests were carried out in our laboratory to see whether we could obtain the same results on damping, and in particular to measure the electrical impedance which Bauer only derived indirectly.

In general, the acoustical resistance element should have an area somewhat greater than the area of the cone, to avoid constriction of the air flow.

Measurements were made on an enclosure as Fig. 6A, with a medium-priced 9 in. × 6 in. elliptical speaker (M.S.P.) in an enclosure with internal dimensions 14 × 14 × 9 inches deep. The enclosure has interchangeable backs, one solid, and the other provided with an 11 in. diameter hole for mounting the acoustical damping resistance.

### voice coil impedance

The impedance was measured under various conditions, and the most significant results are tabulated below.

$f_1$ = frequency at which impedance is a maximum,

ratio = ratio between impedance at $f_1$ and that at 400 c/s (= 3.5 ohms).

| Condition | $f_1$ | ratio |
|---|---|---|
| (1) 3 ft. square baffle | 120 | 4.1 |
| (2) Back closed (solid back) | 143 | 4.7 |
| (3) No back | 105 | 3.5 |
| (4) Open back in position, no cloth | 100 | 3.1 |
| (5) 1 layer of cloth | 95 | 2.5 |
| (6) 2 layers of cloth | 95 | 2.1 |
| (7) 3 layers of cloth | 95 | 1.8 |
| (8) 5 layers of cloth | 95 | 1.5 |
| (9) 1 layer of $\frac{1}{16}$ in. felt | 150* | 1.4 |

*a second peak occurred at 95 c/s, with ratio also 1.4.

The cloth used was loosely-woven cotton, 12 thou. thick, about the thickness of thin sheeting. The thickness of both cloth and felt was measured when compressed.

It will be seen from the table that the impedance ratio from 400 c/s to the bass peak is reduced from 4.7 with solid back, or 4.1 with flat baffle, to 1.4 in the most extreme case. Even with 3 layers of cloth the impedance ratio is reduced to 1.8. This is a very important feature with pentode power valves, which are very sensitive to an increase in load resistance and give high distortion under these conditions. Thus acoustical damping not only gives the desired damping, but also provides better working conditions for pentode power valves.

Fig. 7 shows curves of voice coil impedance for the various conditions set out in the table. The impedance at 400 c/s is 3.5 ohms.

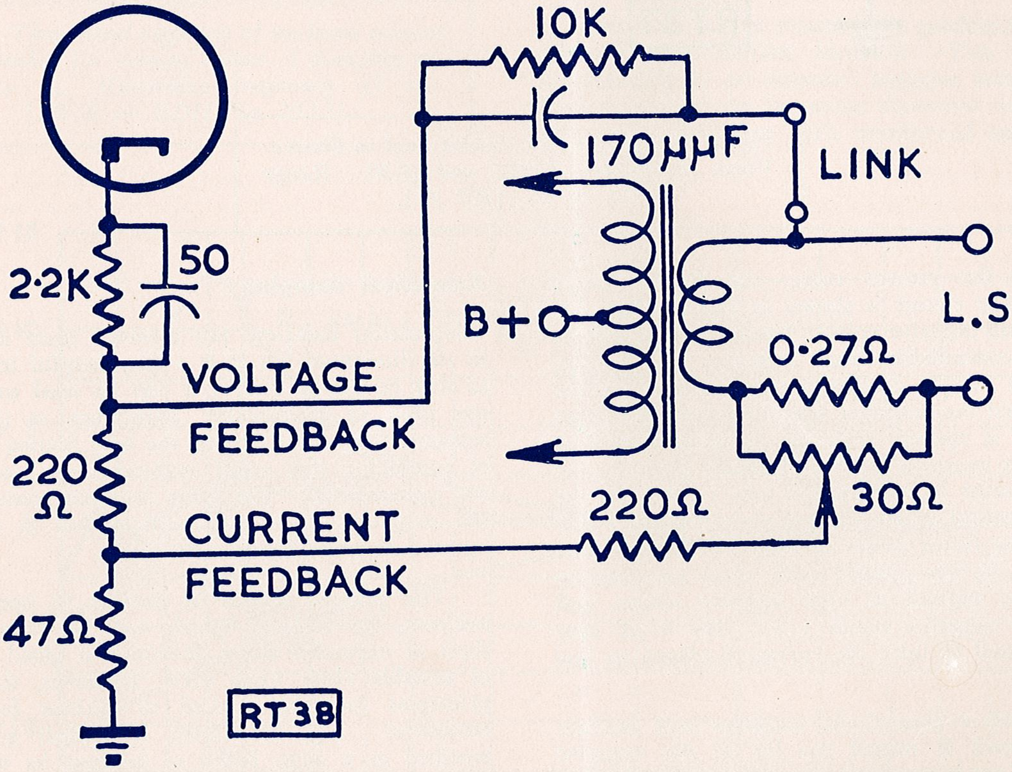


*Fig. 4. Damping factor control used in Pye Model PF91 and Pamphonic Model 1002. Range up to infinity. [RT38].*

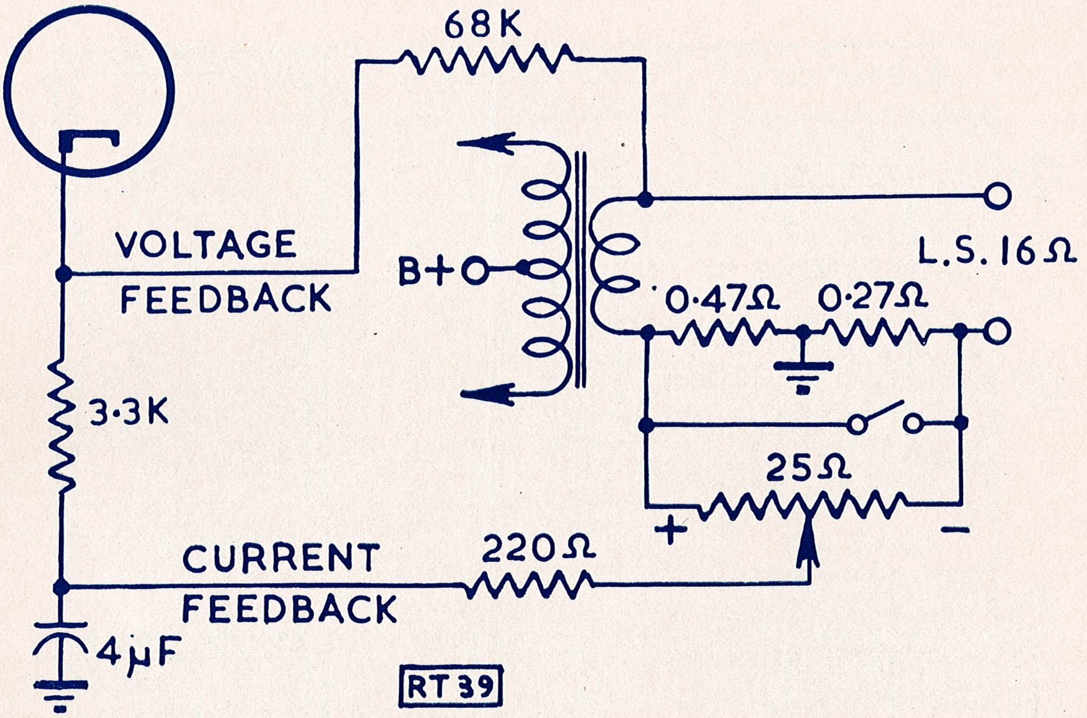


*Fig. 5. Damping factor control used in Bogen D030A Amplifier. Range from low positive through infinity to low negative. [RT39].*

**Frequency response**

The low frequency response curves for three conditions are shown in Fig. 8. On a listening test curve B seems to be the best compromise. Curve A was preferred by some untrained listeners, apparently owing to the heavier apparent bass, particularly when listening to a certain male singer's voice. Curve C suffered from some attenuation in the bass, but was preferred to Curve A by two trained listeners.

**Transient response**

The transient response was tested using a Cintel pulse generator operating with a pulse 0.3 μsec. into a large amplifier driving the loudspeaker. A microphone was placed 1 foot in front of the loudspeaker and its output applied to an oscilloscope. Fig. 9 shows tracings made on the screen under various conditions. The increased damping is indicated by the decreasing height of the upwards peak immediately following the pulse. These results substantially agree with those published by Bauer.

**General remarks**

There is no doubt that acoustical damping is an effective and cheap way of getting damping, or increased damping. It has the valuable additional feature of reducing the loudspeaker impedance peak at low frequencies. It is therefore particularly suitable for use in expensive radio receivers and radio gramophones using a pentode output stage. This may be used with an unbypassed cathode resistor to give negative current feedback with reduction in distortion, and the whole of the damping will be provided acoustically. This may necessitate somewhat heavier damping cloth than that used in the tests above, which were all carried out with a low output resistance.

In most practical cases it will be found most convenient to adjust the thickness of the cloth to give the desired low frequency response, leaving the damping to look after itself.

Normally, a material will be found which will give the desired damping in one thickness. In our tests multiple thickness of thin cloth were only used as a convenient way of increasing the damping by known amounts.

**Measuring voice coil impedance**

When carrying out tests with acoustical damping, it is also advisable to measure the impedance of the voice coil at the low frequency peak to provide a measure of the damping. A very simple approximate test is to use a B.F.O. or other form of low frequency oscillator, and to connect it to the voice coil through a series resistance of at least 40 times the nominal voice coil impedance, and to measure the voltage across the voice coil by a rectifier type voltmeter.

All that is necessary for the purpose of this article is to measure the maximum value of the impedance below 400 c/s.

The series resistance provides nearly constant current, and the voltmeter reading is approximately proportional to the voice coil impedance. It may be calibrated by replacing the voice coil by a known resistance. Alternatively the impedance of the voice coil at 400 c/s may be taken as unity, and the voltmeter will then read the impedance ratio from the low frequency peak to 400 c/s.

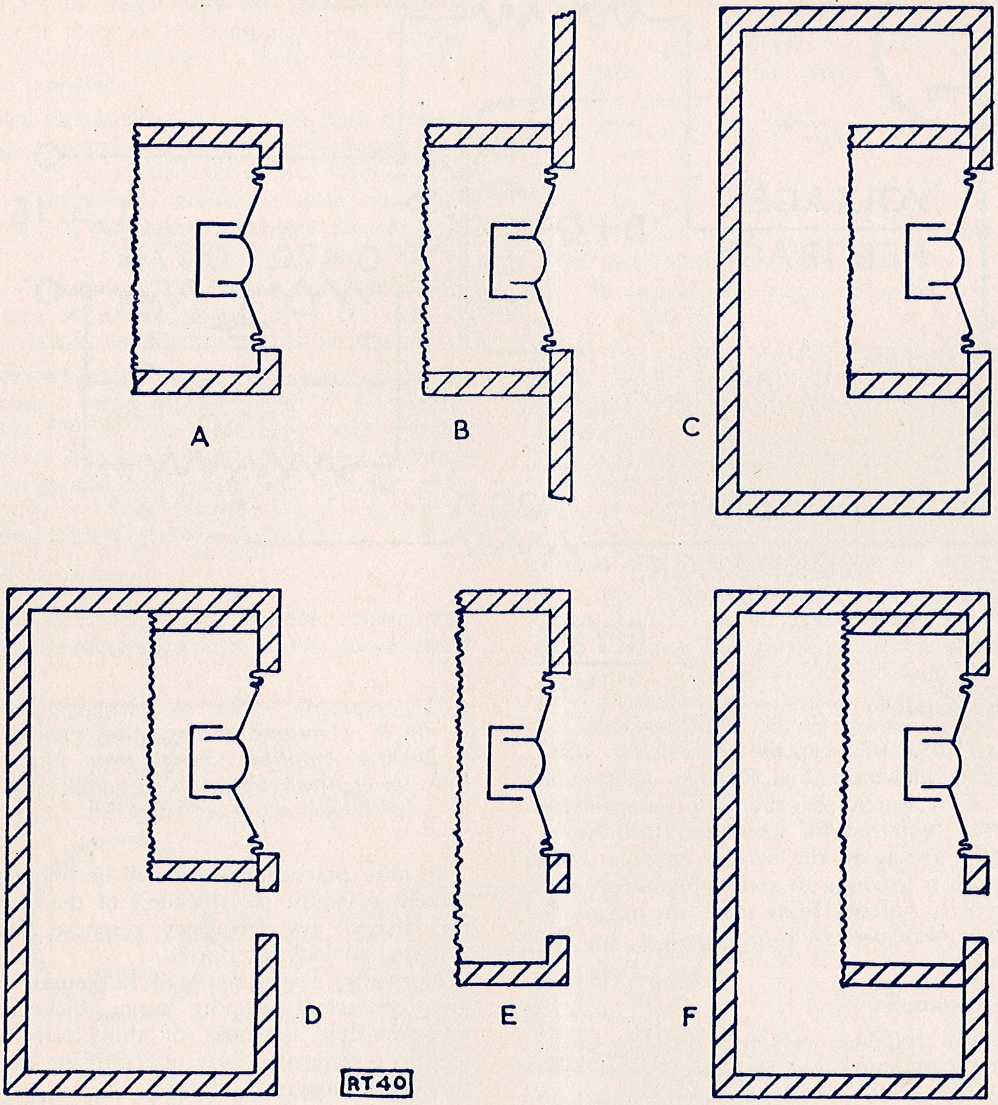


*Fig. 6. Methods of applying acoustical damping to loudspeakers. After Bauer, Ref. 4.* [*RT40*].

$L_u$ represents cone mass + effect of radiation reactance.

$R_u$ represents radiation resistance (which varies with frequency).
Note that $R_u$ is small compared with other impedances in the circuit.

$C_c$ represents acoustical capacitance of cabinet volume.

$C_u$ represents equivalent capacitance of cone suspension.

$R_s$ represents effect of electrical circuit of loudspeaker and driving amplifier reflected into acoustical circuit. The mechanical resistance of the cone suspension may be taken as being included with $R_s$.

$E_s$ = constant voltage generator.

$I_u$ = alternating air current produced by cone, which is proportional to cone velocity.

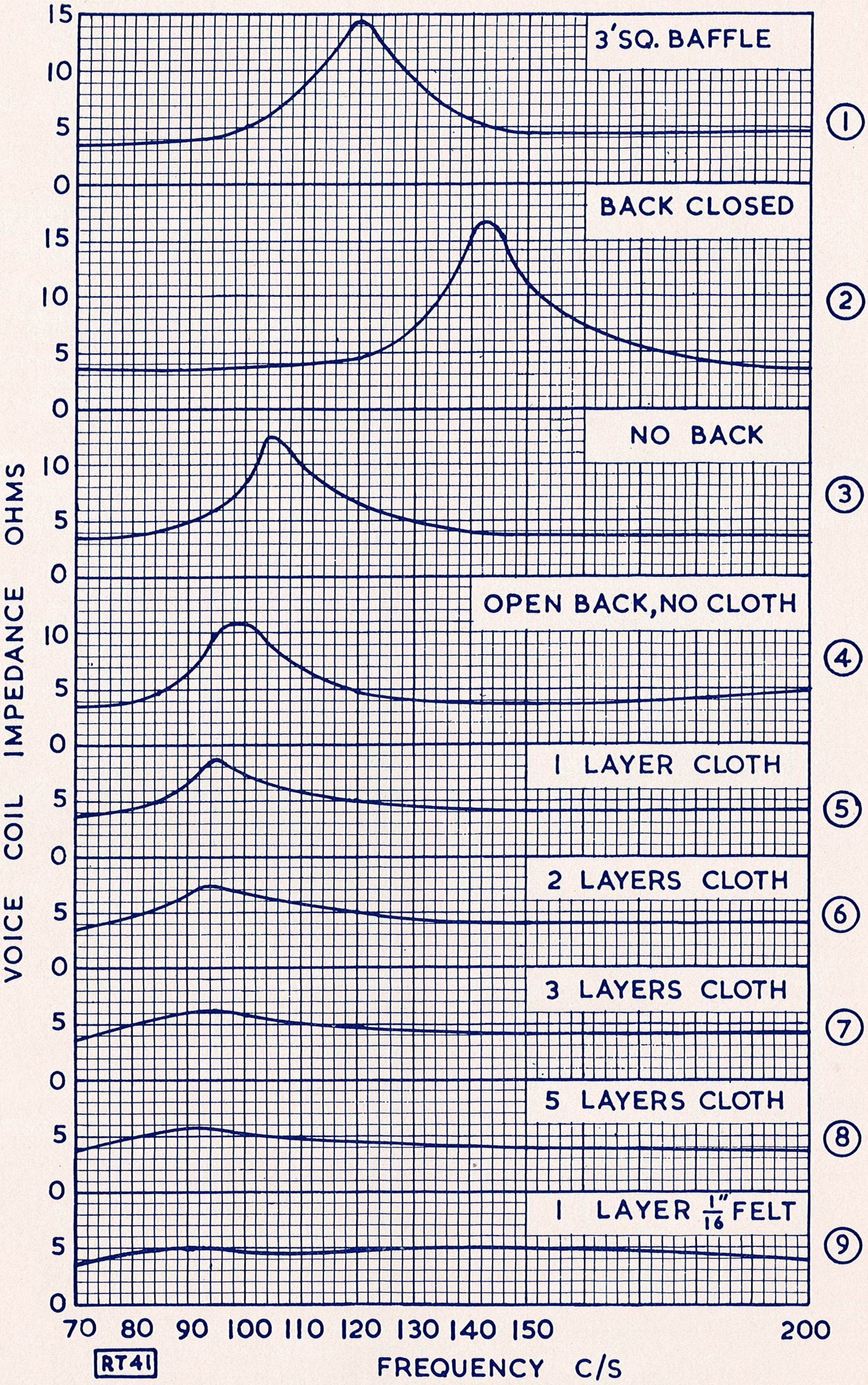


*Fig. 7. Curves of voice control impedance under conditions specified in table. [RT41].*

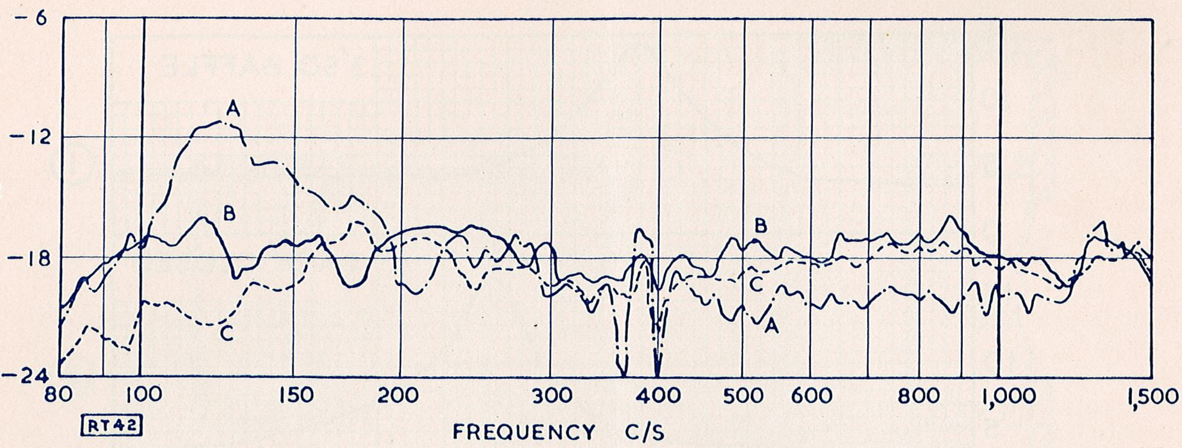
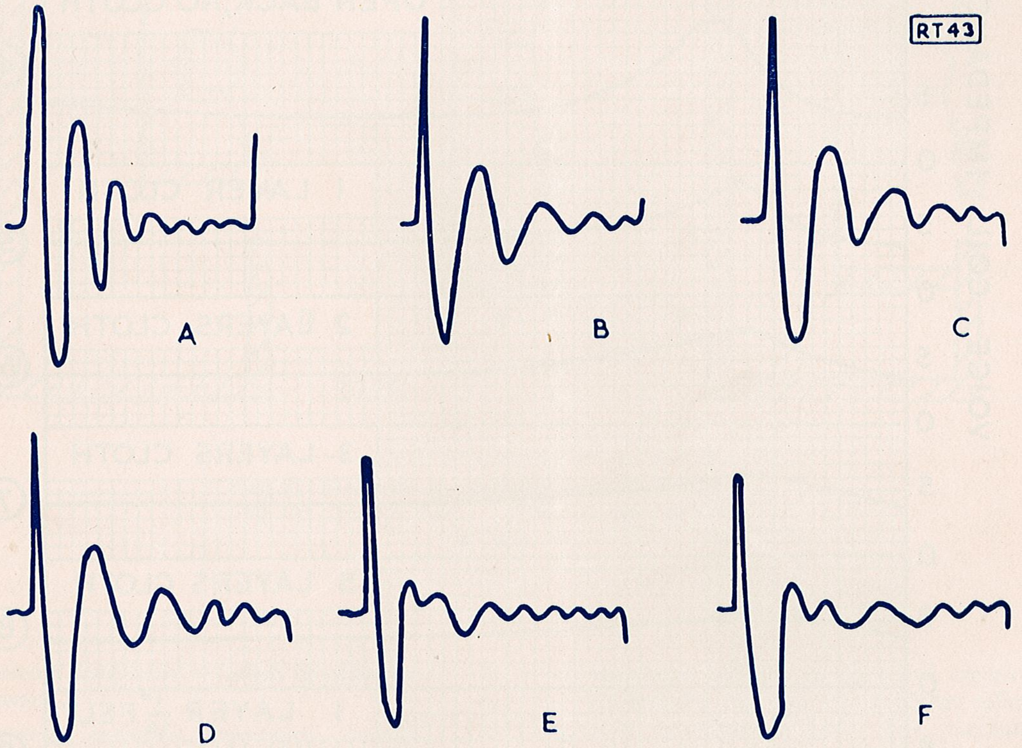


*Fig. 8. Frequency response of loudspeaker—microphone 1 ft. in front of speaker. (A) on 3 ft. baffle; (B) in cabinet with 3 layers of cloth; (C) in cabinet with 1 layer of $\frac{1}{16}$ in. felt. [RT42].*

*Fig. 9. Transient response; (A) solid back; (B) open back, no cloth; (C) 1 layer of cloth; (D) 2 layers; (E) 3 layers; (F) 5 layers. [RT43].*



## References

1. Radiotron Designer's Handbook, 4th ed., p.600.
2. Taken from Radiotron Designer's Handbook, 4th ed., p.844.
3. Wilkins, C. A., "Variable damping factor control", Audio 38.9 (Sept., 1954), 31. See also High Fidelity (Nov., 1954), 89.
4. Bauer, B. B., "Acoustic damping for loudspeakers", Trans. I.R.E. — PG A AU1.3 (May/June, 1953), 23.

Introduction & illustration on P.17.
See March '58 P.46 for further operating instructions.

# RADIOTRON 5762/7C24

# TRIODE - FORCED AIR COOLED

**Radiotron 5762/7C24** is a forced-air cooled power triode designed for TV, FM, AM and industrial services. It has a maximum plate dissipation of 3 kilowatts and is rated for operation up to 220 megacycles per second.

The flanged-header grid terminal is a design feature of particular value when the 5762 is used in cathode-drive (also called grounded-grid) circuits. In such circuits, this terminal, when used with a large circular connector, effectively isolates the filament circuit from the plate circuit, and provides a direct low-inductance path to the grid. As a result, neutralization is generally unnecessary in cathode-drive service.

The design of the 5762 includes three multiple-ribbon filament leads, one of which is a centre tap to facilitate the reduction of filament-lead inductance in high-frequency circuits. Within the tube the leads to the thoriated-tungsten filament are short and direct. An efficient external radiator provides for plate cooling by means of forced air. The conical grid support is structurally strong, serves to cool the grid, and effectively reduces grid-lead inductance. These various design features all contribute to the excellent performance of the 5762 in very high-frequency applications.

The 5762 can deliver a synchronizing-level power output of 4 kilowatts in broad-band television service at 220 Mc; a carrier power output of 3.7 kilowatts in plate-modulated telephony service using conventional grid-drive circuits at frequencies up to 30 Mc; and a power output of 7 kilowatts in class C telegraphy service using cathode-drive circuits at frequencies up to 30 Mc, or 5.5 kilowatts at 110 Mc.

The 5762/7C24 supersedes the 7C24.

## RADIOTRON 5762/7C24 POWER TRIODE
## Forced-Air Cooled
## GENERAL DATA

**Electrical:**

Filament, Thoriated Tungsten:

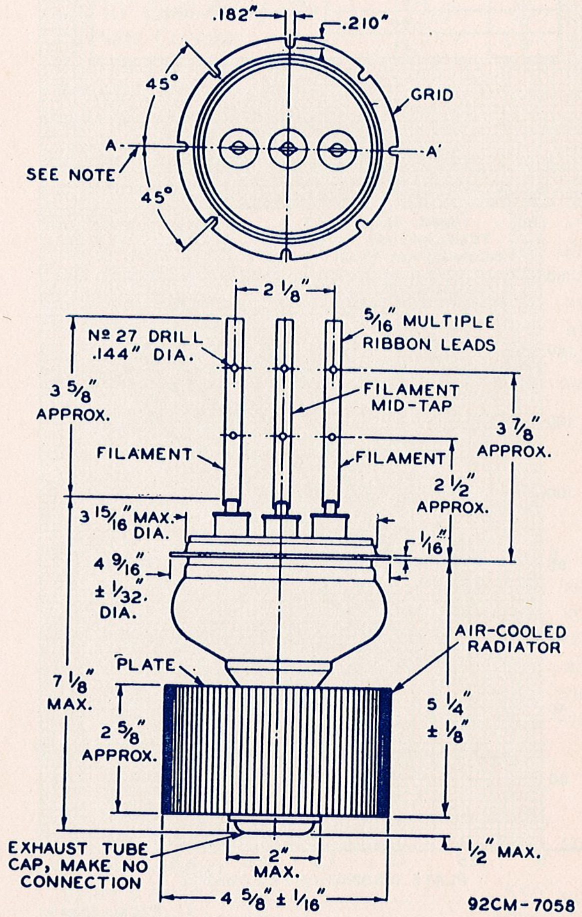
| | | |
|---|---|---|
| Voltage (AC or DC) ... | 12.6 ± 0.6 | volts |
| Current ............... | 29 | amperes |

Starting Current: The filament current must never exceed 175 amperes, even momentarily

| | | |
|---|---|---|
| Cold Resistance ........ | 0.052 | ohm |

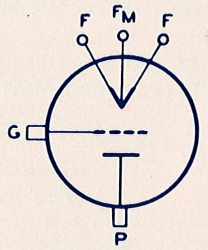
## DIMENSIONAL OUTLINE

TOP VIEW OF TUBE



NOTE: PLANE OF FILAMENT LEADS WILL NOT DEVIATE MORE THAN 3-1/2° FROM PLANE PASSING THROUGH AA' NORMAL TO GRID FLANGE.

## TERMINAL CONNECTIONS



F : FILAMENT
FM: FILAMENT MID-TAP
G : GRID FLANGE
P : RADIATOR-COOLED PLATE

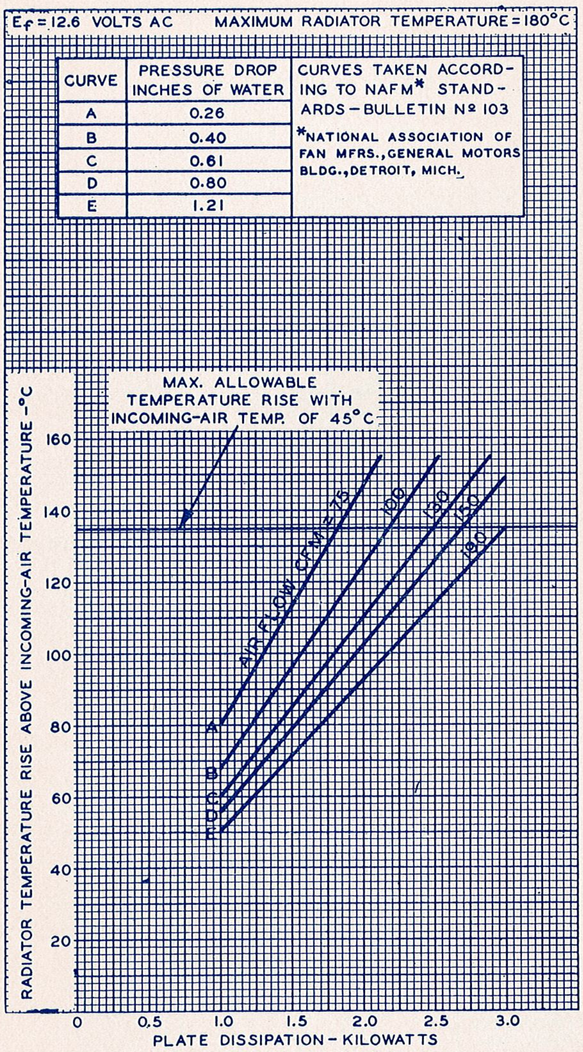


*Fig. 1. Cooling Requirements of Type 5762/7C24.*

| | | |
|---|---|---|
| Amplification Factor . . . . . . | 29 | |
| Direct Interelectrode Capacitances: | | |
| Grid to Plate . . . . . . . . . . | 18.5 | μμf |
| Grid to Filament . . . . . . . | 19 | μμf |
| Plate to Filament . . . . . . . | 0.5 | μμf |

**Mechanical:**

Mounting Position
Vertical, filament end up or down
Maximum Overall Length (excluding flexible leads) . . . . . . . . . . . . . . . . . . . . . . . . . . $7\frac{1}{8}''$
Maximum Diameter . . . . . . . . . . . . . . . . . . . . $4\frac{11}{16}''$
Terminal Connections . . . . . . See *Outline Drawing*
Radiator . . . . . . . . . . . . . . . . . . Integral part of tube
Air Flow:

*Through Radiator*—The specified flow of incoming air at a temperature of 45°C for various plate dissipations, as indicated in the tabulation below, should be delivered by a blower through the radiator before and during the application of any voltages. Filament power, plate power, and air may be removed simultaneously.

| | | | | |
|---|---|---|---|---|
| Percentage of Max. Rated Plate Dissipation for each Class of Service . | 100 | 80 | 60 | per cent. |
| Min. Air Flow . . | 190 | 125 | 75 | cfm |
| Static Pressure . . | 1.21 | 0.58 | 0.26 | in. of water |

*To Header and Filament Seals* . . 10 min. cfm

The specified air flow from a 1″ diameter nozzle should be directed into the filament header before and during the application of any voltages in order to limit the temperature of the filament seals and the grid seal to their maximum value.

| | | |
|---|---|---|
| Incoming Air Temperature . . . . . . | 45 max. | °C |
| Radiator Temperature (Measured on the core at end away from incoming air) . . . . . . . . . . . . . . | 180 max. | °C |
| Bulb Temperature (at hottest part) | 180 max. | °C |
| Seal Temperature: | | |
| Filament, Grid, and Plate . . . . . | 180 max. | °C |

**Fittings:**

*For use with the 5762/7C24 when it is operated at frequencies up to about 60 Mc. At higher frequencies, cavity-type circuits with special built-in fittings are utilized.*

Air Jacket
Air Manifold
Bracelet
} For details refer A.W.V.

## AF POWER AMPLIFIER & MODULATOR — Class B

**Maximum CCS• Ratings,** *Absolute Values*:

| | | | |
|---|---|---|---|
| DC Plate Voltage . . . . . . . . . . . | 6200 | max. | volts |
| Max.-Signal DC Plate Current* . | 1.5 | max. | amp |
| Max.-Signal Plate Input* . . . . . . | 8700 | max. | watts |
| Plate Dissipation* . . . . . . . . . . . . | 3000 | max. | watts |

**Typical Operation:**

*Values are for 2 tubes*

| | | |
|---|---|---|
| DC Plate Voltage . . . . . . . . . . . . . . . . | 4700 | volts |
| DC Grid Voltage . . . . . . . . . . . . . . . . | –200 | volts |
| Peak AF Grid-to-Grid Voltage . . . . . . | 900 | volts |
| Zero-Signal DC Plate Current . . . . . . . | 0.3 | amp |
| Max.-Signal DC Plate Current . . . . . . . | 2.8 | amp |
| Effective Load Resistance (Plate to Plate) . . . . . . . . . . . . . . . . . . . . . . . . | 3640 | ohms |
| Max.-Signal Driving Power (Approx.) | 195 | watts |
| Max.-Signal Power Output (Approx.) . | 8800 | watts |

## RF POWER AMPLIFIER — Class B

### Television Service

C.C.I.R. Standard — 625 Line System

*Synchronizing-level conditions unless otherwise specified.*

**Maximum CCS• Ratings,** *Absolute Values*:

| | *54 to 216 Mc.* | | |
|---|---|---|---|
| DC Plate Voltage . . . . . . . . . . . | 3700 | max. | volts |
| DC Plate Current . . . . . . . . . . . | 1.9 | max. | amp |
| DC Grid Current (Pedestal Level) | 0.225 | max. | amp |
| Plate Input . . . . . . . . . . . . . . . . . | 6500 | max. | watts |
| Plate Dissipation . . . . . . . . . . . . | 3000 | max. | watts |

### Typical Operation in Cathode-Drive Circuit:

| *Bandwidth*▲ *of* | *10 Mc.* | *8.5 Mc.* | |
|---|---|---|---|
| DC Plate Voltage | 3000 | 3200 | volts |
| DC Grid Voltage | –105 | –110 | volts |
| Peak RF Grid Voltage: | | | |
| Synchronizing Level | 380 | 435 | volts |
| Pedestal Level | 290 | 310 | volts |
| DC Plate Current: | | | |
| Synchronizing Level | 1.8 | 1.8 | amp |
| Pedestal Level | 1.36 | 1.35 | amp |
| DC Grid Current: | | | |
| Synchronizing Level | 0.265 | 0.400 | amp |
| Pedestal Level | 0.115 | 0.130 | amp |
| Driving Power (Approx.)♯ | | | |
| Synchronizing Level | 625 | 770 | watts |
| Power Output (Approx.): | | | |
| Synchronizing Level | 3150 | 4000 | watts |
| Pedestal Level | 1800 | 2300 | watts |

## GRID-MODULATED RF POWER AMPLIFER — Class C Television Service

C.C.I.R. Standard — 625 Line System.

*Synchronizing-level conditions unless otherwise specified.*

### Maximum CCS• Ratings, *Absolute Values*:

| | *54 to 216 Mc.* | | |
|---|---|---|---|
| DC Plate Voltage | 3700 | max. | volts |
| DC Grid Voltage (White Level) | –800 | max. | volts |
| DC Plate Current | 1.9 | max. | amp |
| DC Grid Current (Pedestal Level) | 0.225 | max. | amp |
| Plate Input | 6500 | max. | watts |
| Plate Dissipation | 3000 | max. | watts |

### Typical Operation in Cathode-Drive Circuit:

| *Bandwidth*▲ *of* | *8.5 Mc.* | |
|---|---|---|
| DC Plate Voltage | 3200 | volts |
| DC Grid Voltage: | | |
| Synchronizing Level | –110 | volts |
| Pedestal Level | –220 | volts |
| White Level | –520 | volts |
| Peak RF Grid Voltage | 435 | volts |
| DC Plate Current: | | |
| Synchronizing Level | 1.8 | amp |
| Pedestal Level | 1.25 | amp |
| DC Grid Current (Approx.): | | |
| Synchronizing Level | 0.400 | amp |
| Pedestal Level | 0.130 | amp |
| Driving Power (Approx.):♯ | | |
| Synchronizing Level | 770 | watts |
| Power Output (Approx.): | | |
| Synchronizing Level | 4000 | watts |
| Pedestal Level | 2300 | watts |

## PLATE-MODULATED RF POWER AMPLIFIER — Class C Telephony

*Carrier conditions per tube for use with a maximum modulation factor of 1.0.*

### Maximum CCS• Ratings, *Absolute Values*:♦

| | | | |
|---|---|---|---|
| DC Plate Voltage | 5000 | max. | volts |
| DC Grid Voltage★ | –1000 | max. | volts |
| DC Plate Current | 1 | max. | amp |
| DC Grid Current★ | 0.3 | max. | amp |
| Plate Input | 5000 | max. | watts |
| Plate Dissipation | 2000 | max. | watts |

### Typical Operation in Grid-Drive Circuit:

| | *Up to 30 Mc.* | *At 110 Mc.* | |
|---|---|---|---|
| DC Plate Voltage | 4700 | 4000 | volts |
| DC Grid Voltage | –400 | –350 | volts |
| From a grid resistor of | 1425 | 1460 | ohms |
| Peak RF Grid Voltage□ | 675 | 600 | volts |
| DC Plate Current | 0.96 | 0.93 | amp |
| DC Grid Current (Approx.) | 0.28 | 0.24 | amp |
| Driving Power (Approx.) | 170 | 130 | watts |
| Power Output (Approx.) | 3700 | 2800 | watts |

### Typical Operation in Cathode-Drive Circuit:

| | | | |
|---|---|---|---|
| DC Plate Voltage | 4700 | 4000 | volts |
| DC Grid Voltage | –400 | –350 | volts |
| From a grid resistor of | 1425 | 1460 | ohms |
| Peak RF Grid Voltage | 675 | 600 | volts |
| DC Plate Current | 0.96 | 0.93 | amp |
| DC Grid Current (Approx.) | 0.28 | 0.24 | amp |
| Driving Power (Approx.)■ | 720 | 600 | watts |
| Power Output (Approx.) | 4200 | 3200 | watts |

## RF POWER AMPLIFIER & OSC. — Class C Telegraphy† and RF POWER AMPLIFIER — Class C FM Telephony

### Maximum CCS• Ratings, *Absolute Values*:♦

| | | | |
|---|---|---|---|
| DC Plate Voltage | 6200 | max. | volts |
| DC Grid Voltage★ | –1000 | max. | volts |
| DC Plate Current | 1.4 | max. | amp |
| DC Grid Current★ | 0.3 | max. | amp |
| Plate Input | 8700 | max. | watts |
| Plate Dissipation | 3000 | max. | watts |

### Typical Operation in Grid-Drive Circuit:

| | *Up to 30 Mc.* | |
|---|---|---|
| DC Plate Voltage | 6000 | volts |
| DC Grid Voltage: | | |
| From a fixed supply of | –550 | volts |
| From a grid resistor of | 1900 | ohms |
| From a cathode resistor of | 360 | ohms |
| Peak RF Grid Voltage | 875 | volts |
| DC Plate Current | 1.25 | amp |
| DC Grid Current (Approx.) | 0.290 | amp |
| Driving Power (Approx.) | 225 | watts |
| Power Output (Approx.) | 6000 | watts |

### Typical Operation in Cathode-Drive Circuit:

| | *Up to 30 Mc.* | *At 110 Mc.* | *At 220 Mc.* | |
|---|---|---|---|---|
| DC Plate Voltage | 6000 | 5000 | 3000 | volts |
| DC Grid Voltage: | | | | |
| From a fixed supply of | –550 | –1000 | –160 | volts |
| From a grid resistor of | 1900 | 4100 | 670 | ohms |
| From a cathode resistor of | 360 | 740 | 110 | ohms |
| Peak RF Grid Voltage | 875 | 1350 | 410 | volts |
| DC Plate Current | 1.25 | 1.1 | 1.25 | amp |
| DC Grid Current (Approx.) | 0.290 | 0.245 | 0.240 | amp |
| Driving Power (Approx.) | 1225 | 1680 | 510 | watts |
| Power Output (Approx.) | 7000 | 5500 | 2650 | watts |

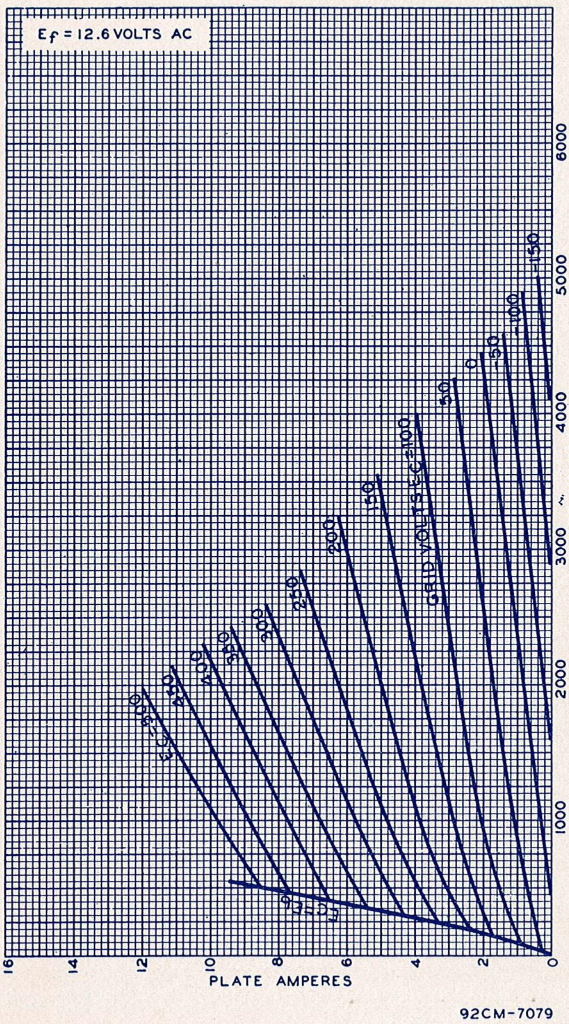


*Fig. 2. Average Plate Characteristics of Type 5762/7C24.*

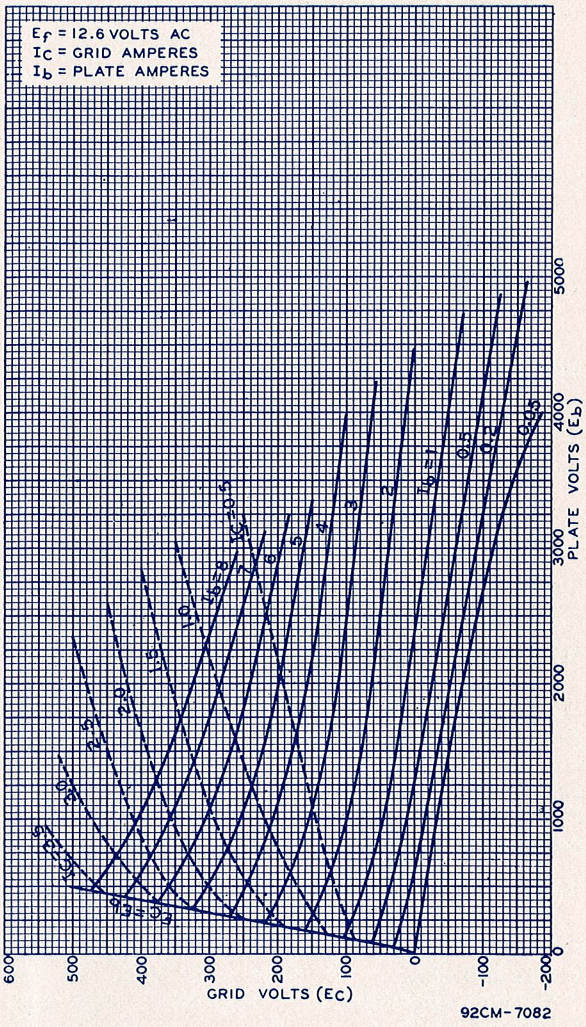


*Fig. 3. Average Constant-Current Characteristics of Type 5762/7C24.*

### SELF-RECTIFYING OSCILLATOR or AMPLIFIER — Class C

**Maximum CCS• Ratings,** *Absolute Values:*♦

| | | |
|---|---|---|
| AC Plate Voltage (RMS) . . . . . | 7000 max. | volts |
| DC Grid Voltage★ . . . . . . . . . . . | –300 max. | volts |
| DC Plate Current . . . . . . . . . . . . | 0.635 max. | amp |
| DC Grid Current★ . . . . . . . . . . . | 0.135 max. | amp |
| Plate Input‡ . . . . . . . . . . . . . . . . | 4900 max. | watts |
| Plate Dissipation . . . . . . . . . . . . | 3000 max. | watts |

**Typical Operation:**

| | | |
|---|---|---|
| AC Plate Voltage (RMS) . . . . . . . . . . | 6600 | volts |
| DC Grid Voltage . . . . . . . . . . . . . . . . . | –127 | volts |
| DC Plate Current . . . . . . . . . . . . . . . . | 0.625 | amp |
| DC Grid Current (Approx.) . . . . . . . | 0.105 | amp |
| Driving Power (Approx.)♂ . . . . . . . . | 60 | watts |
| 3350 wattsPower Output (Approx.) . . . . . . . . . . | | |

### AMPLIFIER or OSCILLATOR — Class C

*With separate, rectified, unfiltered, single-phase, full-wave plate supply.*

**Maximum CCS• Ratings,** *Absolute Values:*♦

| | | |
|---|---|---|
| DC Plate Voltage . . . . . . . . . . . . | 5600 max. | volts |
| DC Grid Voltage★ . . . . . . . . . . . | –600 max. | volts |
| DC Plate Current . . . . . . . . . . . . | 1.25 max. | amp |
| DC Grid Current★ . . . . . . . . . . . | 0.270 max. | amp |
| Plate Input‡‡ . . . . . . . . . . . . . . . | 8600 max. | watts |
| Plate Dissipation . . . . . . . . . . . . | 3000 max. | watts |

**Typical Operation:**

| | | |
|---|---|---|
| DC Plate Voltage . . . . . . . . . . . . . . . . . | 5000 | volts |
| DC Grid Voltage . . . . . . . . . . . . . . . . . | –260 | volts |
| DC Plate Current . . . . . . . . . . . . . . . . . | 1.2 | amp |
| DC Grid Current (Approx.) . . . . . . . | 0.260 | amp |
| Driving Power (Approx.)□□ . . . . . . | 150 | watts |
| Power Output (Approx.) . . . . . . . . . . | 5650 | watts |

## RATINGS vs. FREQUENCY

| Frequency | 30 | 110 | 220 | Mc. |
|---|---|---|---|---|
| Max. permissible percentage of max. Rated Plate Voltage and Plate Input: | | | | |
| Class B Television Service | Full Ratings—54 to 216 Mc. | | | |
| Class C Television Service | Full Ratings—54 to 216 Mc. | | | |
| Class C Telephony, Plate-Modulated | 100 | 84 | 52 | % |
| Class C Telegraphy and FM Telephony | 100 | 84 | 52 | % |
| Class C Amplifier or Osc., Self-Rectifying | 100 | 84 | 52 | % |
| Class C Amplifier or Osc. with Separate, Rectified, Unfiltered Plate Supply | 100 | 84 | 52 | % |

Max. permissible percentage of max. rated DC Grid Voltage and DC Grid Current:

| | | | | | |
|---|---|---|---|---|---|
| Class B Television Service | Full Ratings—54 to 216 Mc. | | | | |
| Class C Television Service | Full Ratings—54 to 216 Mc. | | | | |
| | | | *Volt.* | *Cur.* | |
| Class C Telephony, Plate-Modulated | 100 | 100 | 60 | 83 | % |
| Class C Telegraphy and FM Telephony | 100 | 100 | 60 | 83 | % |
| Class C Amplifier or Osc., Self-Rectifying | 100 | 100 | 60 | 83 | % |
| Class C Amplifier or Osc. with Separate, Rectified, Unfiltered Plate Supply | 100 | 100 | 60 | 83 | % |

## CHARACTERISTICS RANGE VALUES FOR EQUIPMENT DESIGN

| | *Note* | *Min.* | *Max.* | |
|---|---|---|---|---|
| Filament Current | 1 | 27 | 31 | amp |
| Filament Starting Current | — | — | 175 | amp |
| Amplification Factor | 1, 2 | 25 | 33 | |
| Grid-Plate Capacitance | — | 16.5 | 20.5 | μμf |
| Grid-Filament Capacitance | — | 15.5 | 22.5 | μμf |
| Plate-Filament Capacitance | — | 0.38 | 0.62 | μμf |
| Grid Voltage | 1, 3 | –125 | –190 | volts |
| Plate Voltage | 1, 4 | 1350 | 1750 | volts |
| Plate Voltage | 1, 5 | 2600 | 3400 | volts |
| Peak Cathode Current | 6 | 10 | — | amp |
| Useful Power Output | 1, 7 | 3 | — | kw |

Note 1: With 12.6 volts rms on filament.

Note 2: With dc grid voltage –25 volts measured from centre tap of filament supply, and dc plate voltage adjusted to give dc plate current of 0.5 ampere.

Note 3: With dc plate voltage of 4000 volts, and dc grid voltage adjusted to give dc plate current of 0.05 ampere.

Note 4: With dc grid voltage of 0 volts measured from centre tap of filament supply, and dc plate voltage adjusted to give dc plate current of 0.5 ampere.

Note 5: With dc grid voltage of –50 volts measured from centre tap of filament supply, and dc plate voltage adjusted to give dc plate current of 0.5 ampere.

Note 6: Designers should limit the maximum useable cathode current (plate current and grid current) to this value under any condition of operation.

Note 7: In a self-excited, coaxial, oscillator circuit and with dc plate voltage of 5000 volts, dc plate current of 1.1 amperes, grid resistor of 1500 ± 10% ohms, dc grid current of 0.250 to 0.300 ampere, and frequency of 110 Mc.

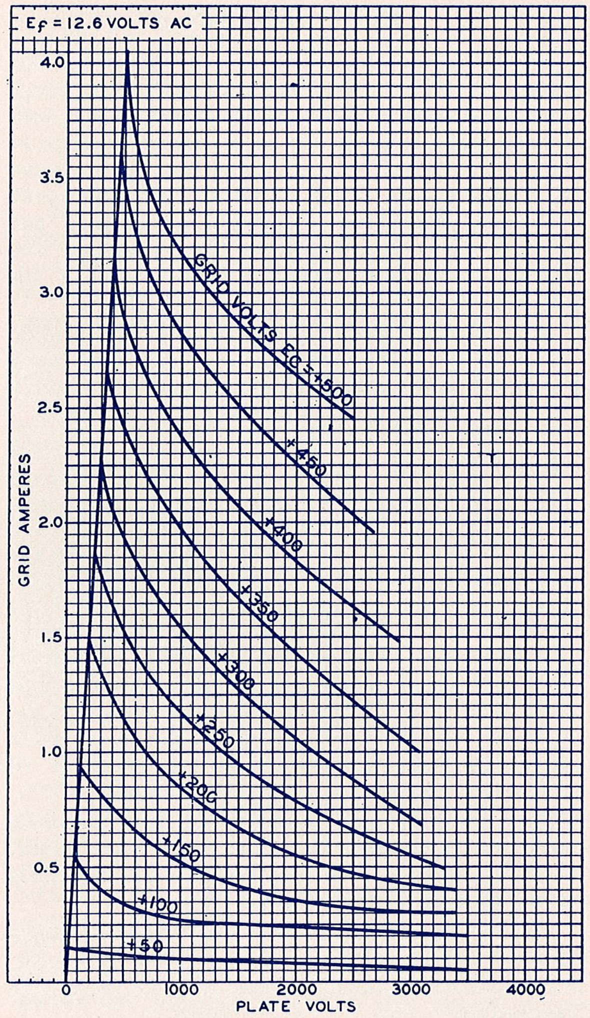


*Fig. 4. Typical Grid Characteristics of Type 5762/7C24.*

---

| | |
|---|---|
| ● | Continuous Commercial Service. |
| * | Averaged over any radio-frequency cycle of sine-wave form. |
| ▲ | Computed between half-power points and based on tube output capacitance only. |
| ‡ | Computed value to supply grid losses and feed-through power. Additional power will be required to supply circuit losses. |
| ♦ | These ratings hold for operation up to 30 Mc; for ratings at higher frequencies, see Ratings vs. Frequency Table. |
| ★ | See Ratings vs. Frequency Table in tabulated data. |
| □ | Driver modulated approximately 30%. |
| ■ | Carrier power of driver modulated 100%. |
| † | Key-down conditions per tube without amplitude modulation. Modulation essentially negative may be used if the positive peak of the audio-frequency envelope does not exceed 115% of the carrier conditions. |
| ‡ | Plate input is 1.11 times the product of the ac voltage (rms) and the dc plate current. |
| ♂ | From a self-rectified driver. |
| ‡‡ | Plate input is 1.23 times the product of the dc plate voltage and the dc plate current. |
| □□ | From a driver with a rectified, unfiltered, single-phase, full-wave plate supply. |

## INSTALLATION

In *transportation and storage* of the 5762, care should be taken to protect the tube from rough handling that would damage the metal-to-glass seals or other parts. Each tube is suspended within its shipping container so that it will not come in contact with the sides during shipment. The tube should be stored in the container with the filament end up and should be protected from moisture and extreme temperature changes. The weight of the tube is about 6¼ pounds.

It is recommended that the tube be tested upon receipt in the equipment in which it is to be used. Before the tube is placed in operation, any foreign material clinging to the tube should be removed.

The *mounting* for the 5762 requires a clamp support for the radiator (plate connection), a flexible connector for the grid-terminal flange, and three connectors for the filament leads. The tube should be supported in a vertical position with the filament end either up or down. The entire weight of the tube must be supported by the clamp for the radiator. If the tube is subjected in service to considerable vibration, it is advisable to support the mounting by means of a spring suspension. The installation of all wires and connections must be made so that they will not be close to or touch the glass parts. This precaution is necessary to prevent almost certain puncture of the glass.

*Connections* to the filament and grid terminals must be kept flexible in order not to put strain on the glass-to-metal seals. None of the terminals should be used to support circuit parts.

Because of the relatively large high-frequency currents carried by the grid and plate terminals, heavy conductors should be used to make the circuit connections.

*Cooling* of the 5762 is accomplished by passing a stream of clean air through the radiator toward the filament end, and by directing a stream of air into the filament header. A suitable air filter is required in the air supply for the radiator. Care should be given to cleaning or replacing the filter at intervals in order that accumulated dirt will not obstruct the required flow of air through the radiator. The required air flow through the radiator for various plate dissipations is shown in Fig. 1. In using these curves for determining the cooling requirements of the tube as a plate-modulated rf power amplifier, it should be remembered that 100% sine-wave modulation causes a 50% increase in the plate dissipation above that obtained under carrier conditions. The header and filament seals are cooled by an air flow of not less than 10 cubic feet per minute from a nozzle about 1 inch in diameter into the header.

The cooling systems should be properly installed to ensure safe operation of the tube under all conditions and for this reason should be electrically interconnected with the filament and plate power supplies. This arrangement is necessary to make sure that the tube is supplied with air before any voltages are applied. Air pressure interlocks which open the power transformer primaries are desirable for protecting the tube when the air flow is insufficient or ceases.

The maximum radiator temperature of 180°C is a tube rating and is to be observed in the same manner as other ratings. The temperature of the radiator should be measured on the core at the end away from the incoming air. The temperature may be measured either with a thermocouple or with temperature-sensitive paint.

Similarly, the maximum temperature of 180°C for the bulb as well as for the filament, grid, and plate seals is to be observed in the same manner as other ratings.

The *filament* of the 5762 is of the thoriated-tungsten type. Under normal full-load conditions, the filament should be maintained at the rated voltage within ± 5%; with light loads, reduction of the filament voltage by as much as 5% is permissible. In the latter case, care must be taken that the reduction of the filament voltage and, therefore, of emission is not so great that the peak current requirements cannot be met. In intermittent service where the standby periods are no longer than 15 minutes, it is recommended that the filament voltage be reduced to 80% of normal during standbys; for longer periods, the filament voltage should be turned off.

The filament is centre-tapped in order to minimize the effect of filament lead inductance, and not to permit operation of the two sections in parallel. At the higher frequencies, all three filament leads should be connected in parallel by means of rf bypass capacitors. Any one of these three leads may then be used as the rf return to the filament.

Having a maximum value of starting current about 6 times higher than the normal operating value, the filament can generally be operated from commercial transformers without a filament starter.

Such transformers usually have adequate secondary impedance to hold the starting current below the maximum value of 175 amperes. If, however, the starting current should exceed, even momentarily, the value of 175 amperes, some means of limiting it will be required. Usually, a small increase in the resistance of the transformer-secondary circuit supplying the filament will be all that is required. Increasing the lead lengths between secondary and filament terminals is a convenient method of providing the desired increase in circuit resistance.

The *plate circuit* should be provided with a time-delay relay which will prevent the application of plate voltage before the filament has reached normal operating temperature.

A protective device, such as a high-voltage fuse, should be used to protect the plate against overloads. It should remove the high voltage when the average value of plate current reaches a value of 50% above normal.

*Overheating* of the 5762 by severe overload may decrease the filament emission. The filament activity can sometimes be restored by operating the filament at rated voltage for 10 minutes or more with no voltage on the plate or grid. This process may be accelerated by raising the filament voltage of 15 volts (not higher) for a few minutes.

*The rated plate voltage of this tube is high enough to be dangerous to the user.* Great care should be taken during the adjustment of circuits, especially when exposed parts are at high dc potential.

## APPLICATION

The *maximum ratings* shown in the tabulated data are limiting values above which the serviceability of the 5762 may be impaired from the viewpoint of life and satisfactory performance. Therefore, in order not to exceed these absolute ratings, the equipment designer has the responsibility of determining an average design value for each rating below the absolute value of that rating by an amount such that the absolute values will never be exceeded under any usual condition of supply-voltage variation, load variation, or manufacturing variation in the equipment itself.

In *class B af modulator service,* the 5762 should be operated with grid bias obtained from a battery or other source of dc voltage having good regulation. It should not be obtained from a high-resistance source such as a grid resistor, nor from a rectifier unless the rectifier has exceptionally good voltage regulation. Each grid circuit should be provided with a separate bias adjustment to balance the grid and plate currents.

In *class B television service,* the bias requirements are the same as those indicated under *class B af modulator service.*

In *class C television service,* the 5762 is supplied with unmodulated rf grid voltage and with a video-modulated grid voltage.

In *plate-modulated class C rf power amplifier service,* the 5762 should be supplied with bias from a grid resistor, or from a suitable combination of grid resistor and fixed supply or grid resistor and cathode resistor. The cathode resistor should be bypassed for both audio and radio frequencies. The combination method of grid resistor and fixed supply has the advantage of not only protecting the tube from damage through loss of excitation but also of minimizing distortion by bias-supply compensation. Grid-bias is not particularly critical so that correct adjustment may be obtained with values differing widely from the calculated values.

In *cathode-drive plate-modulated class C telephony service,* the 5762 can be modulated 100 per cent. if the rf driver stage is also modulated 100 per cent. simultaneously. Care should be taken to ensure that the driver-modulation and the amplifier-modulation voltages are exactly in phase. In such service, the 5762 requires increased driving power, but increased power output is obtained as shown in the tabulated data.

In *class C rf telegraphy service,* the 5762 may be supplied with bias by any convenient method. When the tube is used in the final amplifier or a preceding stage of a transmitter designed for break-in operation and oscillator keying, a small amount of fixed bias must be used to limit the plate current and, therefore, the plate dissipation to a safe value. If the 5762 is operated at a plate voltage of 5000 volts, a fixed bias of at least −190 volts should be used.

In *class C FM telephony service,* the 5762 may be supplied with bias by any convenient method. This type of service is similar to conventional class C rf telegraphy service.

In *class C service* primarily for industrial applications, the 5762 can be operated as a *self-rectifying oscillator or amplifier,* or as *an amplifier or oscillator* with a separate, rectified, single-phase, full-wave plate supply without a filter. In such service, the 5762 can be biased by any convenient method but the use of a grid resistor is preferred because the bias is automatically adjusted as the load on the circuit varies. In those applications where grid current and grid voltage may vary widely because of fluctuating loads, it is important to design equipment so that the maximum grid-current and grid-voltage ratings are nexer exceeded for any load. An approximate rule is to adjust the grid-current and grid-voltage values at full load to one-half of the corresponding maximum values. This operating condition permits grid-current and grid-voltage values to rise from zero load to twice their full-load values, and usually provides adequaate leeway.

In *grid-drive circuits,* the grid current and driving power required to obtain the desired power output will vary with the plate loading. If the plate circuit presents a relatively low resistance to the tube, the desired output can be obtained with relatively low grid current and driving power, but plate-circuit efficiency is sacrificed. Conversely, if the tube operates into a relatively high load resistance, relatively high grid current and driving power are required to obtain the desired output and the plate-circuit efficiency will be high. In practice, a compromise must be made between these extremes. The typical operating conditions given in the tabulated data represent compromise conditions which give good plate-circuit efficiency with reasonable driving power.

In order to permit considerable range of adjustment, and also to provide for losses in the grid circuit and the coupling circuits, the driver stage should have considerably more output capability than the typical driving power shown in the tabulated data. This recommendation is particularly important near the maximum rated frequency where there are other losses of driving power, such as those caused by radiation and transit-time effects.

In *cathode-drive circuits,* there is a further increase in required driving power due to the fact that the grid-driving voltage and the developed rf plate voltage act in series to supply the load circuit. The increased driving power is not lost because it appears as output from the cathode-drive stage. If the driving voltage and grid current are increased, the output will always increase. Such is not the case in a grid-drive circuit where a saturation effect takes place, i.e., above a certain value of driving voltage and current, the output increases very slowly and may even decrease. It is important to recognise this difference and not try to saturate a cathode-drive stage because the rated maximum grid current may easily be exceeded.

Care must be exercised to shield completely the filament-grid circuit from the grid-plate circuit when the 5762 is used in cathode-drive circuits at the higher frequencies.

In tuning a cathode-drive rf amplifier, it must be remembered that variations in the load on the output stage will produce corresponding variations in the load on the driving stage. This effect will be noticed by the simultaneous increase in plate currents of both the output and driving stages.

*Push-pull or parallel circuit arrangements* may be used when more radio-frequency power is required than can be obtained from a single tube. Two tubes in parallel or push-pull will give approximately twice the power output of one tube. The parallel connection requires no increase in exciting voltage necessary to drive a single tube. With either connection, the driving power required is approximately twice that for a single tube. The push-pull arrangement has the advantage of cancelling the even-order harmonics from the output and of simplifying the balancing of high-frequency circuits. When two or more tubes are used in the circuit, precautions should be taken to balance the plate currents.

### REFERENCE

E. E. Spitzer, "*Grounded-Grid Power Amplifiers*", Electronics, Vol. 19, No. 4, pp. 138-141 (April, 1946).

# DIRECT READING OF PHASE ANGLES ON AN OSCILLOSCOPE

*By the Staff of the Radiotronics Laboratory*

(Based on an article by Carl R. Wischmeyer and Paul E. Pfeiffer, Review of Scientific Instruments, January, 1954, p. 41.)

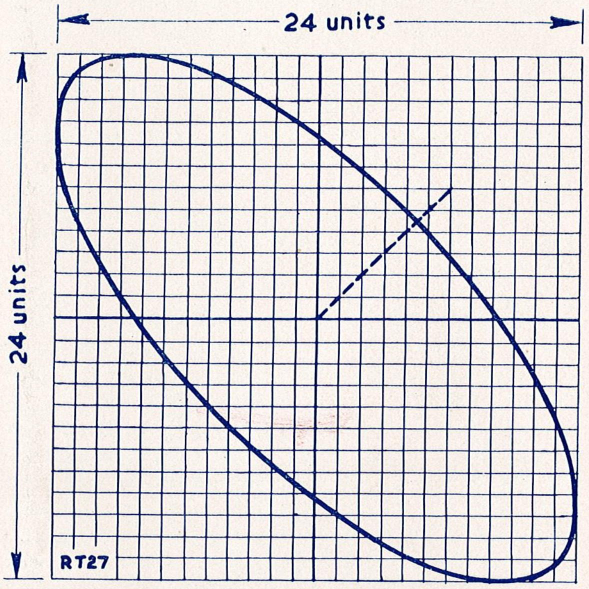
Apply the unknown voltage to the vertical input terminals of the oscilloscope. Adjust the gain to give 24 units deflection. Disconnect this voltage, and apply the reference voltage to the horizontal input terminals. Adjust this to 24 units deflection. Reconnect the input to the vertical amplifier terminals. The resultant ellipse will then be contained in a square with sides of 24 units. The phase angle is then read directly by measuring the minor radius in diagonal units, each unit measuring 10°. A diagonal unit is the length of the diagonal of one unit (i.e., one square).

A correction must be made for readings of between 70° and 90°, by adding 0.2° for each degree in excess of 70°. The correction at 90° is thus 4°.

The results are fundamentally correct within 1°, additional reading errors depending on the accuracy with which the scale can be read. A check showed that under comparatively poor conditions, readings could be repeated within 3°.

It should be noted that the sense of the phase difference angle is not displayed on the oscilloscope. Further, when 90° is exceeded, the elliptical pattern becomes inclined along the opposite diagonal of the square, and hence the phase is now read along the new minor radius. In this case 9 units represent 90°, 8 units represent 100°, 7 units 110°, etc.

We are not aware of any simple method of checking the sense of the phase difference (positive or negative). One method is given by J. F. Sodaro in Electronics, May, 1953, page 192, using superimposed sawtooth voltages.



*Direct reading of phase angles on oscilloscope. Sketch shows minor radius of 4½ diagonal units = 45° (RT27).*

Editor .. .. .. .. .. .. .. .. .. .. .. .. .. .. .. D. Cunliffe-Jones
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