SOCKETLESS TUBE CIRCUIT TECHNIQUES

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In most VHF, UHF, and microwave applications non-conventional vacuum tube structures are essential. Examples of such structures are the door knob tube, the acorn tube, the rocket tube, the pencil tube, the lighthouse tube, and the more recent metal-ceramic tube structures. Designing and manufacturing efficient and reliable sockets for these tubes has been a problem. To minimize this problem many circuit designers have used "semi-socket" designs combined with soldering directly to the tube elements. In most cases separate socket-like assemblies to which connections could be soldered, were built and attached to the tube. In addition to making connection to the tube elements some means of tube support was also necessary.

It has been the circuit designer's desire to solder directly to the tube. Until recently this has not been practical because the tube envelope or seals could not tolerate soldering temperatures or the tube element was not physically strong enough to be used for tube support. This latter socket requirement was a particular problem for circuitry to be subjected to high shock and vibration.

Recent tube manufacturing techniques have permitted the introduction of a line of planar ceramic vacuum tubes* that are both tolerant to soldering temperatures and can be physically mounted by the tube elements themselves. In addition to the several coaxial cavity designs for microwave service other types** were also introduced that were designed specifically for direct soldering. The tubes feature solder lugs and "T" bolt mounting of the tube envelope to a print-board or metal chassis. (See Fig. 1 and 2 illustrating the mechanical features of the "T" bolt.) Other lead attachment procedures such as wire wrap, spot welding, brazing and mechanical clips can also be used.

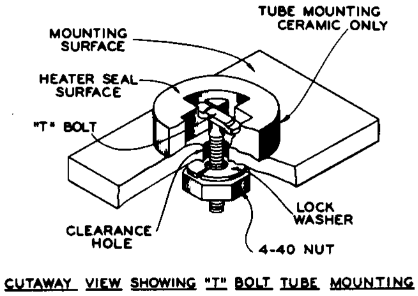

Fig. 1

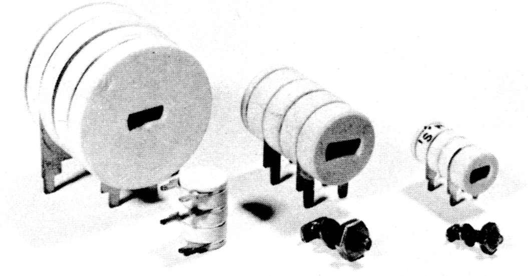

Fig. 2

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* EIA type number 7077, 7266, 7486, 7481
GE Development types Z-2823, Z-2835, Z-2869, Z-2866, Z-2897

** EIA numbers: 7462, 7720, 7625, 7588, 7296, 8081, 8082, 8083
GE Development types: Z-2868, Z-2354, Z-2870, Z-2731, Z-2692

For coaxial circuits it is feasible to solder cavity components directly to the tube elements (See Fig. 3). This procedure not only provides physical support in some cases but also reduces the problem of obtaining good RF contact between tube and cavity elements. With proper care the tube-circuit assembly can be replated after assembly.

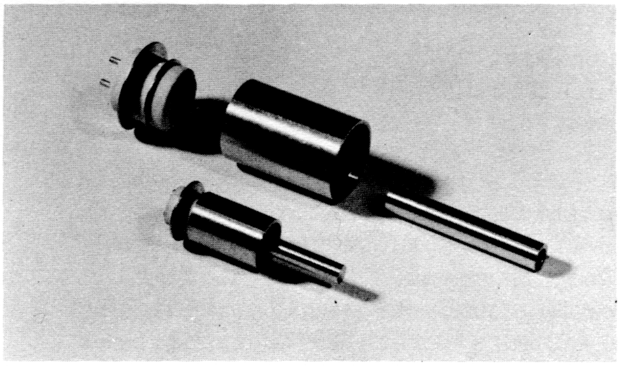


Fig. 3

The application of coaxial resonant circuits soldered directly to the tube elements is illustrated by an assembled, small tube-cavity combination, and an unassembled, larger tube-cavity, tube-circuit combination. This particular combination would be useful for a half-wave grid resonator cavity for a re-entrance oscillator. The two tubes shown are designed for grounded cathode usage.

THEORETICAL ADVANTAGES

By eliminating tube sockets in their usual form, several theoretical performance advantages are obtained. In most cases, for reasons of economy or moldability, the insulator portion of a tube socket is usually a higher loss factor material. With the elimination of the socket insulator losses, higher circuit "Q's" can be realized. Higher unloaded "Q's" lead to better circuit performance through higher circuit efficiency.

In many modern electronic circuits maximum gain-bandwidth must be obtained to process the high definition and complex signal pulse. The more general relation for broadband gain in a vacuum tube is:

$$G \cong g_m R_o$$

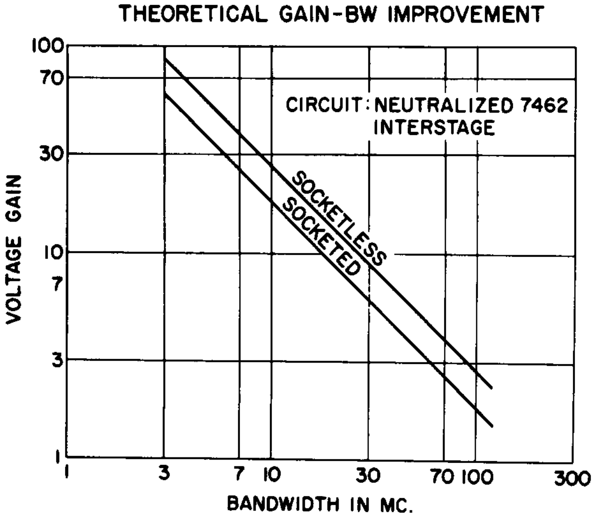


Fig. 4

The gain, G, depends most upon tube transconductance, gm, and the circuit load resistance, R_o (See Fig. 4). For a simple interstage circuit the bandwidth, BW, can be estimated to be:

$$BW = \frac{1}{2\pi R_o C_t}$$

C_t is the total shunt interstage capacitance. If we then construct the expression for gain-bandwidth product:

$$G\text{-}BW = \frac{gm}{2\pi\ C_t}$$

This relationship shows that for wide band amplification maximum available transconductance and minimum tube and circuit capacitances are essential. The available tube transconductances are high, up to 50,000 micromhos, and this is obtained with relatively small tube capacitances. To use the resulting high tube gain-bandwidth product the applied circuitry must have a low value of shunt capacitance. The use of direct soldering connections to the tube or soldering to clamps or clips supported by the tube assures maximum tube-circuit gain-bandwidth.

In addition to better gain-bandwidth products at any given center frequency, lower tube circuit capacitances permit operation at higher frequencies. By using resonant elements that clamp or solder to the tube itself, lumped constant circuitry may be used up to 1500 mc. Similar application of slab or flat parallel line elements provides efficient performance up to at least 3000 mc (See Fig. 5 and 6).

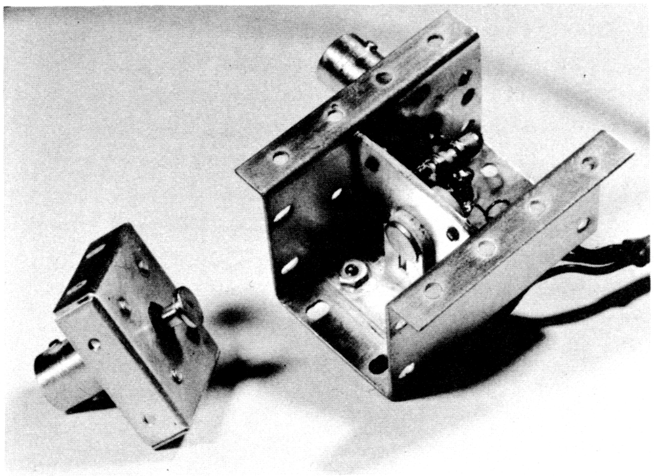


Fig. 5

A 2700-mc grounded-grid amplifier featuring the socketless techniques to obtain good performance into the kilomegacycle region. The tube anode is resonated by a short section of strip line functioning as a parallel tuned plate circuit. The base of this plate line is by-passed for RF at the bottom of the amplifier chassis. Power is coupled out by means of an adjustable series output capacitor (shown removed from the amplifier). A clip-on connector (not visible) is used to connect an input coupling capacitor to the tube cathode. Heater chokes have been soldered directly to the tube heater buttons. The grid is grounded by a flat washer held down by four 4-40 screws.

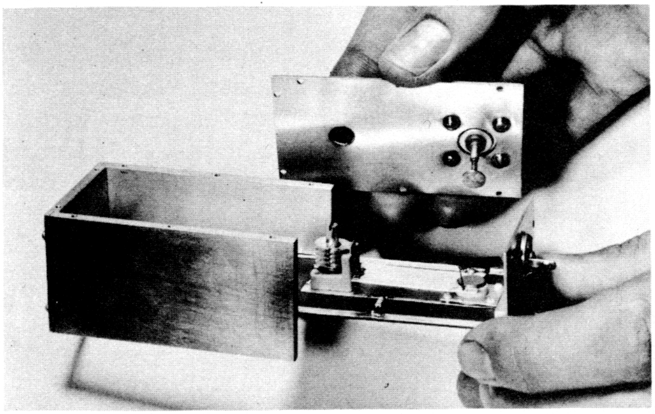


Fig. 6

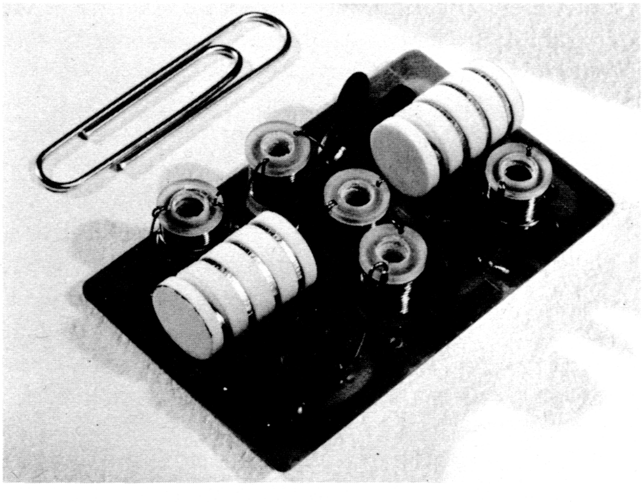
A 1200 mc oscillator featuring snap-on slab-line resonators and screwed-down grid clamps. This circuit is a modified Colpitts configuration. The grid line is an un-etched portion of the print board base. The tube fore-shortens the half wave line on one end and the tuning capacitor fore-shortens the other. A grid leak resistor is soldered at a low impedance point.

For many years the degenerative effect of cathode lead inductance has limited the high-frequency capabilities for conventional vacuum tubes as much as transit time effects. For this reason and others, the non-conventional structures of microwave tubes are used. The very low value of lead inductances in many cases was wasted by using high socket lead inductances. For the same reason tube instability was often due to poor grid grounding.

PRACTICAL ADVANTAGES

The use of socketless circuit techniques provides several practical advantages. Better system reliability is one of the more important. Since the socket can be eliminated, troubles due to contact wear, failure or corrosion are reduced. No socket insulators are present which may crack or deteriorate. Very low contact resistances can be obtained using direct soldering techniques. Better tube reliability can be obtained if known and consistent heat sinks are established for the tube. In some cases tubes have failed as a result of additional acceleration forces resulting from poor socket designs. Physical clamping of the tube directly to the chassis assures that the tube sees no more shock and vibration than the chassis itself. The increased performance gained by socketless circuitry means fewer stages for the same system gain. In some cases tubes in sockets being easy to remove, are selected to compensate for the loss of performance due to a faulty component. This repair procedure usually leads to a more catastrophic failure later on. Screwed-on or soldered connections to the tube are more easily inspected and do not depend upon assumed contact pressure.

Many of the microwave triodes are made very small to obtain low capacitance and transit time characteristics. Often the sockets for these tubes are much larger than the tubes themselves. This means that system size and weight can be lowered if alternate connection techniques are used (See Fig. 7). In some cases the tube itself also serves as a terminal strip for the connection and support of other circuit components such as resistors and capacitors. Socketless techniques also reduce the cost and design time associated with a socket design. Some of the ceramic triodes are fitted with mounting hardware requiring only a hole in a chassis or printboard. These tubes can be used with all connections being made on one side of the board or chassis. This leads to simplified circuitry or permits the use of dip-soldering techniques. (See Fig. 8 for suggested connectors for the coaxial types.)



A complete cascode circuit showing two soldered-in titanium metal ceramic triodes. This circuit features small size and weight through the elimination of sockets and the use of printed circuit techniques.

Fig. 7

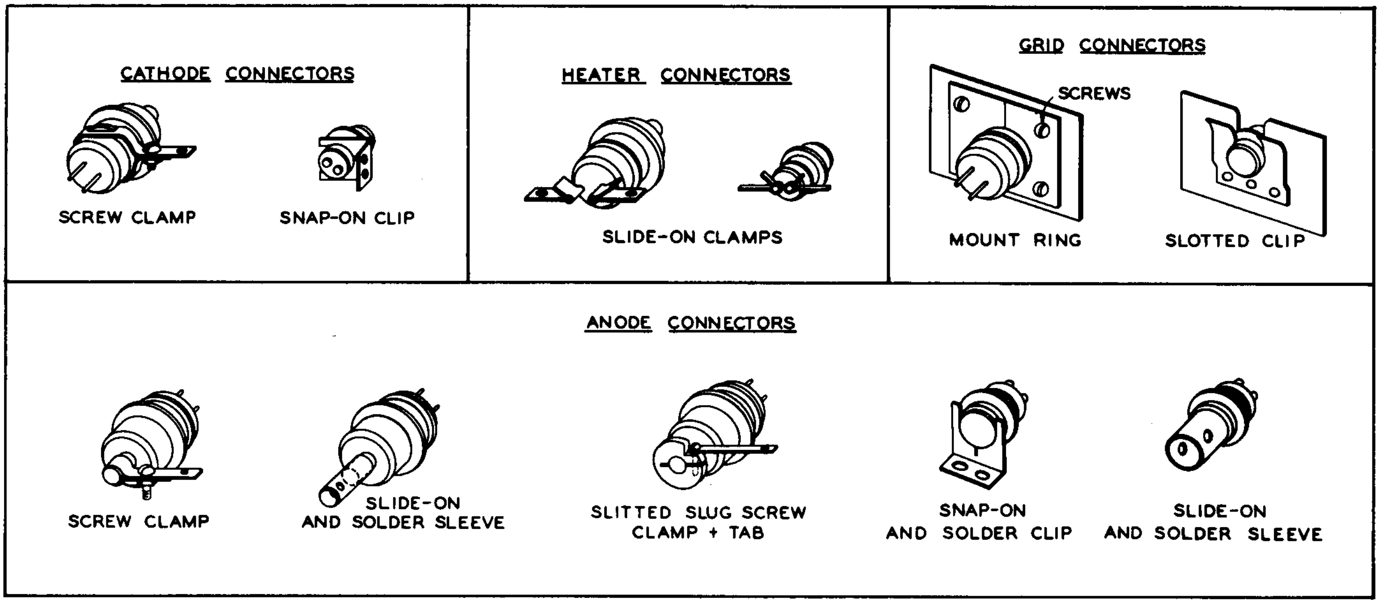


Fig. 8

SOLDERING TECHNIQUES

The use of socketless circuitry with good reliability usually requires soldering either to a tube clamp or tube element. When soldering to an auxiliary clamp or to the tube itself the usual care should be taken. If soldering directly to the tube is attempted on non-tolerant tube structures, failure can result from damaged seals. Although the use of high temperature seals and ceramic insulators greatly reduces the chance of this happening, the tubes are not indestructable. Ceramic tube structures are tolerant to soldering temperature as evidenced by tube life tests at temperatures up to 450°C. However, due to their small sizes, very large thermal gradients across the tube seals can and do cause tube failures and a resulting loss of reliability.

To reduce the possibility of tube damage a few precautions should be taken:

1. Use a solder with as low a melting point as possible for the intended tube circuit ambient operating temperature.

2. Use small wattage soldering irons to reduce the thermal inertia of the soldering heat.

3. Preheat the tube whenever possible to reduce further the thermal in-rush when heat is applied. Ovens, hot plates, I-R lamps, etc. can be used to preheat the tube prior to soldering. If these are not available, thermal shock can be reduced by operating the tube filaments for several minutes before soldering.

These precautions are most important on the smaller coaxial types since the thermal mass of these designs is small and very little thermal resistance is present between the solder surface and the tube seals. The use of solder-forms is highly recommended. The lug versions can be used with no more than the usual precaution and can be treated as any other solder-in circuit component. It should be noted that the suggested soldering procedures are conducive to cold soldering joints. This is true and care must be taken in this respect.

The basic tube structure used for these solderable tubes is made of titanium metal and ceramic. The titanium is essential for several reasons but its most important feature is the almost identical thermal coefficient of expansion when compared to good RF ceramic materials. Titanium on the other hand is very difficult to plate and no ordinary techniques have yet been devised to plate in the usual fashion. To provide solderable surfaces the titanium is first nickel plated and a thin gold layer is then applied. This gold layer is consumed by amalgamation into the solder. The nickel undercoat is the surface to which the solder connection is actually made. After many solderings, this nickel plating can be consumed. When this happens, the titanium base metal is exposed and one is confronted with the difficult task of soldering to titanium.

The thickness of the nickel plating must be carefully controlled between two limits. If the plating is too thin only a limited number of solderings can readily be made. If the plating is too thick peeling results. In development work where tubes are removed or resoldered many times increased difficulty may be expected in soldering operations.

TUBE REMOVAL

When it becomes necessary to remove the soldered-in tube the usual techniques apply. The tube can be treated as any other soldered-in component.

If the coaxial tube outline is used, it becomes expedient to use auxiliary clamps not only for soldering connections in some cases but also for the mechanical support of the tube. At microwave frequencies most circuits use the tube in a grounded grid configuration and the tube is mounted by clamping the grid element to a chassis shield or wall. In most cases DC "floating" of the grid is not essential and by-passing is not necessary. Where by-passing is required, mica or suitable spacers can be used without loss of mechanical support. Due to the physical location of the cathode of the coaxial designs, cathode clamps are usually used to provide connections and soldering surfaces at more convenient distances from the tube. Such clamps also greatly improve the ease of tube removal. Soldering or clamping is usually optional on the heater and anode terminals. Soldering is desirable for the heater connections since contact resistance at these points may seriously lower the tube heater voltage.

EXAMPLE EQUIPMENT

Figure 9 shows a 10-frequency crystal controlled "STALO" developed by the Light Military Electronics Department of General Electric Co. Socketless circuit techniques are used to reduce size and weight, to obtain mechanical and electrical stability, and to fulfill the need for maximum gain-bandwidths for the broadbanded multipliers and amplifiers. Small "T" bolt ceramic triodes are used in each of the 10 crystal channels and frequency selection is made by applying B+ to the desired channel. At the center of the 10 oscillators a "clamp-on" cathode connector is used as a common input to a grounded grid stage and connections are made around the

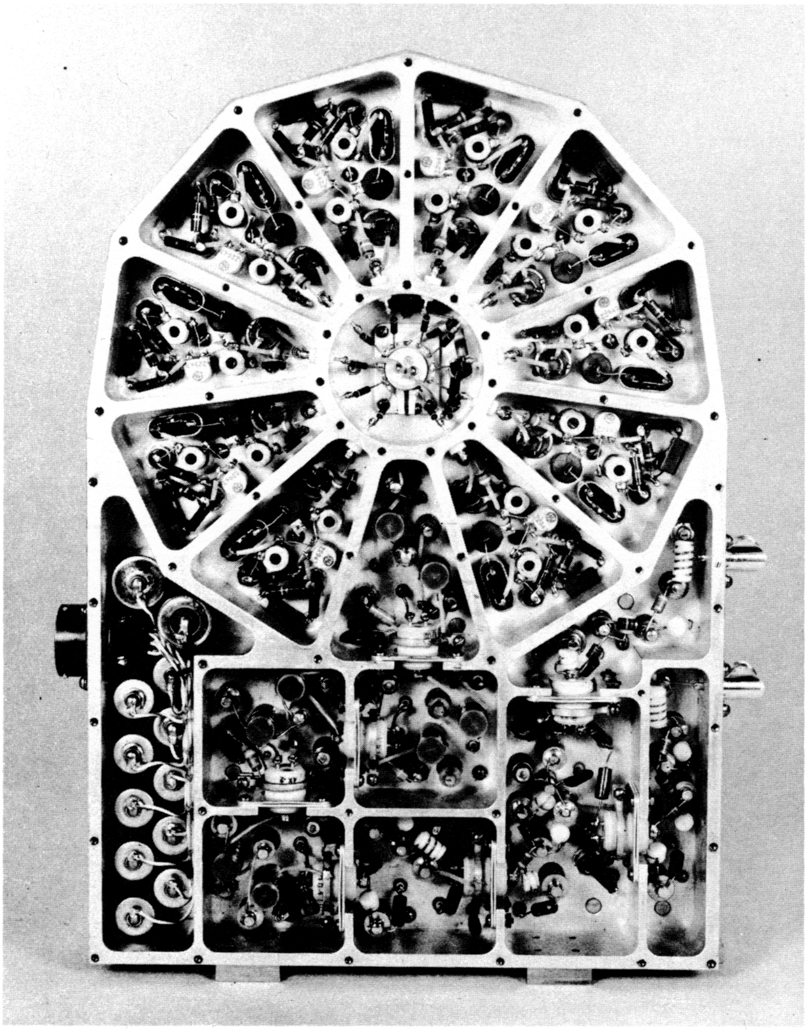


Fig. 9

circumference of the cathode clamp. The grid of this tube and the remaining larger coaxial triodes, eight in all, use flat sandwich or surface clamps. The same cathode clamp is used for all the coaxial outline tubes. The wide bandwidths were essential to provide multiplying and amplification over about a 10% bandwidth at near 500mc center frequency. The maximum gain per stage was essential to keep the total number of stages to a minimum for maximum reliability. Multiplying at wide band-widths is traditionally difficult and high transconductance triodes as well as socketless circuitry were required for acceptable performance.

CONCLUSION

With the advent of new vacuum tube manufacturing techniques it has become practical to use new socketless circuit techniques. Where sockets are not specified, circuit performance and reliability are improved. Such techniques permit the use of vacuum tubes at higher frequencies as well as providing a companion component to improve the state-of-the art for lumped constant and slab line circuitry.

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NOISE FIGURE AND THE GRIDDED VACUUM TUBE

The three most important types of noise in the gridded triode vacuum tube are shot noise, flicker noise, and induced grid noise.

Shot noise is characterized by its independence from frequency effects and its dependence upon tube currents and transconductance.

Flicker noise or one-over-frequency-noise usually follows the simple rule of varying inversely with frequency at the rate of three decibels per octave. Flicker noise usually limits the sensitivity of very low frequency amplifiers and produces instability in DC amplifiers. The exact cause of flicker noise is not well defined but reduction of this effect can be best obtained by using triodes with high transconductance at low plate currents. To reduce both shot and flicker noise effects, triodes with maximum transconductance to plate current ratios should be used. The planar ceramic triode is outstanding in this respect.

Induced grid noise is caused by transit-time effects which induce shot noise into the signal grid. This source of noise is characterized by its six decibels per octave increase with frequency. Figure 1 is an approximate representation of these three noise sources as a function of frequency.

Johnson or thermal noise can also be generated by tube and circuit losses or if any unbypassed resistances are used. This noise source is usually not a serious problem if proper components and circuitry are used.

When a tube is subjected to shock or vibration, another source of noise called microphonics can occur. The frequency profile of this noise varies greatly with tube structure. Although microphonics usually produce AM signals in audio amplifiers, some AM and FM effects can occur in RF amplifiers. The planar ceramic tubes are usually less microphonic than other competing tube structures and the use of bonded-heater techniques has practically eliminated this source of noise.

Equivalent Noise Circuits

Figure 2 shows two simplified forms of a commonly used noise figure equation[1]. An equivalent noise circuit is also shown. The noise figure equation can be solved for minimum noise figure with respect to R_s or G_s. This relationship is:

$$NF_{min} = 1 + 2\sqrt{5G_t \text{ Req}}$$

The resulting optimum source resistance equation is:

$$R_s \text{ opt.} = \sqrt{\text{Req.} \div 5\ G_t}$$

To calculate the minimum available noise figure and the source resistance required to obtain this, the absolute values of Req and G_t must be known. The above equations assume G_c to be insignificant and in most cases this condition exists. Req can be estimated by the equation:

$$Req = 2.5 \div \text{triode transconductance}$$

G_t results from transit time effects which produce out-of-phase grid currents and voltages and has a noise output five times thermal.

A second equivalent noise circuit[2] has been developed using Req and a new term G_n. See Figure 3. Req is identical to the Req used in Figure 2 and G_n is equal to 5 G_t. The equations for minimum noise figure and optimum source resistance are then simplified as shown in Figure 3. This simplified equivalent circuit technique leads directly to the measurement of Req and G_n. If an input conductance tuning curve is obtained as described, the equation of this curve is:

$$G_{tot} - G_n = W^2 \quad \Delta C^2 \; Req$$

G_n is obtained immediately as shown and the above equation can then be solved for Req. G_{tot} and ΔC are obtained for two points A and B on the curve. The curve shown in Figure 3 can be generated from tests conducted on a circuit similar to the one shown in Figure 7. L_1 can be calibrated for an equivalent capacitance change or a tuning capacitor can be added in shunt with the input inductor. R_s is omitted.

The measured values of Req can be checked against the previous approximate equation. The factor of 2.5 appears to vary from about 2 to 3.5 depending on the tube size and geometric configuration. The approximate value of G_t can be obtained by dividing G_n by five. This value of G_t can then be used to determine input circuit bandwidths if all loading is due to transit-time effects.

Measured Results

The procedure outlined in Figure 3 was used to determine the equivalent noise parameters for several low noise planar ceramic triodes:

Type	Req (ohms)	G_n at 90 MC (mohms)
6299	170	160
7077	300	100
7462	300	100
7588	45	500
7644	170	160
7768	40	500
7784	170	160
8083	300	100

It should be noted that minimum noise figure is a function of the product of Req and G_n. For similar cathode current densities, grid wire sizes, grid wire spacing, and grid to cathode spacing, this ratio appears to be relatively constant. These geometric and electrical conditions exist on the low noise planar triodes and similar noise figures are quoted for all types. See the "Optimum Noise Condition vs Frequency" curves shown at the front of the ceramic tube reference manual. The value of optimum source resistance varies directly with the ratio of Req and G_n. The larger triodes provide more transconductance and lower values of Req. The larger tubes also have higher values of transit-time conductance and G_n. These conditions result in much lower values of optimum source resistance for the larger tubes, 7588 and 7768, at any given frequency.

Noise Parameters vs Frequency

The table shown above records measured values of G_n at 90 megacycles. The value of Req has been described to be independent of frequency and G_n to be a function of frequency squared. Using the values of Req and Gn measured at f_o equal to 90 mcs, minimum noise figures and optimum source resistance at any other frequency, f, can be calculated. See Figure 4. Reasonably good correlation between measured and calculated performance has been obtained between frequencies from 30 to 3000 megacycles.[3]

Tube Selction

One might ask, why use the larger tubes if similar noise figures can be obtained with the smaller tubes? For minimum over-all noise figures, the gain of the first stage and noise figure of the second stage are important. The noise figures previously discussed apply only to the first stage of an amplifier chain. The relationships are equated as follows:

$$NF_{1,2} = NF_1 + \frac{NF_2 - 1}{GL}$$

The noise figure subscripts apply to the first and second stages and G_1 is the available gain of the first stage. Wide bandwidths are usually required in most modern low noise amplifiers. For wideband circuits, the larger tubes are desirable to obtain both maximum gain and lower values of optimum source resistance. The smaller tubes can be used most effectively for narrow-band low noise circuits where their size, weight, low-input powers, and economy are more important. In both cases, the second stage should also be a low noise tube if lowest noise figures are desired.

Noise Performance vs Operating Conditions

The low noise triode must be properly applied if optimum noise performance is desired. Tests have shown that variations in heater voltage within rated values produce little effect on noise figure. The voltage changes normally associated with plate voltage supplies are also unimportant if the initial value is properly chosen. Generally speaking, the triode should be operated under those conditions which provide a maximum transconductance to plate current ratio, produce no grid currents, and provide suitable gain to reduce second stage noise effects. In most cases, the tube is operated with about .5 volt bias, rated heater voltage, and maximum rated plate dissipation if maximum noise performance is required.

There are three acceptable methods of biasing the triode and these are shown in Figure 5. Condition "a" is the simplest and uses a low value of cathode resistor and a fixed plate voltage. This method produces the widest variation in operating conditions from tube to tube. The type shown in Figure 5 is the 7462 and each small square represents one tube. Condition "b" uses the same value of cathode resistor but more constant plate currents are obtained through the use of a large plate dropping resistor. Higher plate voltages must be used and the power loss in R_B must be tolerated. Referring to Figure 6, it can be seen that minimum noise figures are obtained along a bias line slightly less than .5 volts. These curves were taken on the type 7588. In Figure 5, condition "b" gives the smallest variation in bias and the level is maintained near the desired value of about .5 volts. For this reason, condition "b" is the best bias method for obtaining good initial noise performance from tube to tube and maintenance of low noise with life. Condition "c" uses a fixed value of plate voltage and a large cathode resistor to maintain constant plate currents. A negative voltage at the cathode or a positive voltage at the grid is necessary to provide the proper bias between the grid and cathode. This bias method results in wide variations in bias from tube to tube with a large percentage of the tubes operating at very low bias. Three reject 7462's were purposely included in Figure 5. These three tubes required zero bias to maintain the recorded plate currents near 6.5 ma. for condition "c". These same three tubes were the three highest noise figure tubes shown for condition "c" but gave lower noise figures using condition "b" bias.

High Current Density Effects

To improve the noise performance of the triode at RF frequencies the effect of transit-time must be reduced. This can be done with closer grid to cathode spacing or by increasing the accelerating forces on the electron. In some cases closer grid to cathode spacings are practical but noise figure tests show no significant improvements. Most types are designed to make maximum use of cathode space-charge smoothing and this is not always the closest grid to cathode spacing. The second method, using greater accelerating potentials, is present when the tube is operated at higher current densities. In addition to reducing the transit times, much higher transconductance result and lower values of Req are present. The type 7077 triode is normally tested at about .15 amperes per sq cm and noise figures around 8 db are measured at 1200 mcs. Noise tests were made at .6 a/cm^2 and an over-all noise figure of 4.8 db was measured. Some of the ceramic tubes listed in the reference manual have good life at .6 a/cm^2 and lower than published noise figures can be obtained.

Circuit Considerations

The neutralized grounded cathode and grounded grid stage are most used for low noise amplifiers. The input impedances for these two circuits are radically different and require different noise considerations. In theory, both circuits have similar minimum noise figure, and optimum source resistance. The theory also predicts that power match and minimum noise figure conditions cannot exist at the same time. Therefore, the effect of mismatch between the source and tube input becomes important. The grounded cathode circuit is most useful at lower frequencies because less mismatch exists. For wide band circuits the lower optimum source resitance types should be used as previously discussed. Figure 8 shows the measured input bandwidth, measured over-all noise figures, and calculated first stage noise figure for a cascoded pair of 7462 triods at 30 mcs. The results on this grounded cathode input circuit also shows that relatively large changes in source resistance result in small changes in noise figure if values near the optimum value are initially chosen.

At higher frequencies much lower source resistances are required and the grounded grid stage provides less mismatch under optimum noise conditions. In most cases above about 800 mcs, for all practical purposes, minimum noise is obtained under minimum VSWR adjustments. It is very difficult to determine the frequency at which similar noise results are obtained for both circuit arrangements. Calculations are complicated and various assumptions are necessary. The best method of obtaining minimum noise figures uses commercially available automatic noise figure test equipment. This equipment continuously reads noise figure as a circuit is adjusted and both circuits can be easily compared. The curves shown in Figure 6 were obtained using an automatic noise figure test set. Although under power match conditions the theoretical noise figure is over 5 db, a measured figure of slightly over 3 db was obtained. The tube input was about 25 ohms and the optimum source resistance is over 200 ohms. The automatic test set permitted an optimum low noise adjustment between conjugate and optimum source resistance conditions.

Conclusions

To assist the designer of low noise circuits simplified techniques have been developed for triodes. Both theoretical and measured results confirm that lowest noise figures require the best tube choice for a given frequency and bandwidth, proper DC operation, and proper circuit arrangements and adjustments. State-of-the-art results are very seldom if ever obtained without careful and laborious procedure.

References:

1. Vacuum Tube Amplifiers Valley and Wallman, pp 634
2. "Theory of Noisy Four Poles" Rothe and Dalke Proc. of IRE, June 1956
3. "A Comparison of Domestic and Foreign RF Amplifier Tubes for UHF-TV" C. Metelman Die Telefunken Rohre, 1959.

VACUUM TUBE NOISE

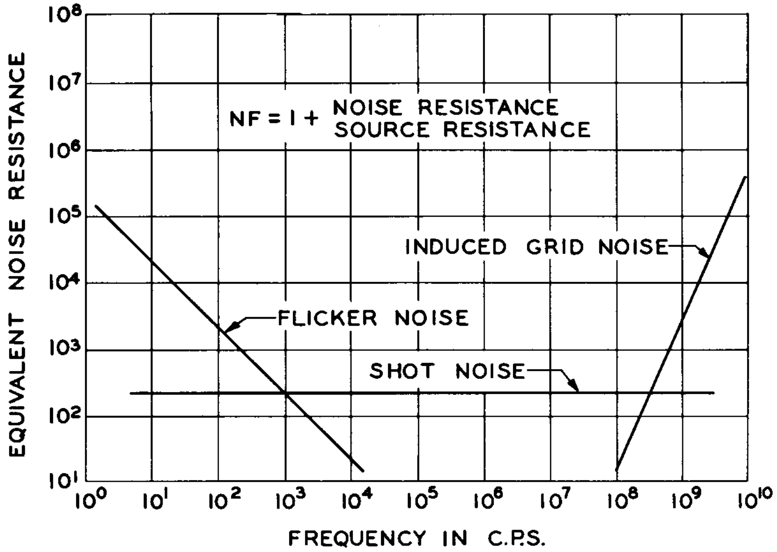


Fig. 1

NOISE FIGURE EQUATIONS

REFERRED TO TUBE INPUT:- $NF_1 = 1 + \frac{G_C}{G_S} + \frac{5G_\tau}{G_S} + \frac{R_{EQ}|G_S + G_\tau|^2}{G_S}$

OR:-

$$NF_1 = 1 + \frac{R_S}{R_C} + \frac{5R_S}{R_\tau} + \frac{R_{EQ}}{R_S}\left|\frac{R_S + R_\tau}{R_\tau}\right|^2$$

WHERE:- NF_1 = FIRST STAGE NOISE FIGURE (POWER RATIO)

NF_1 IN DB. = 10 LOG NF_1

$R_S - G_S$ = SOURCE RESISTANCE OR CONDUCTANCE TRANSFORMED TO INPUT GRID

$R_\tau - G_\tau$ = TRANSIT TIME LOADING OR CONDUCTANCE

$R_C - G_C$ = COLD INPUT RESISTANCE OR CONDUCTANCE

R_{EQ} = EQUIVALENT SHOT NOISE RESISTANCE

EQUIVALENT NOISE CIRCUIT:-

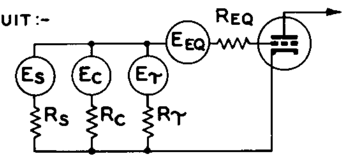
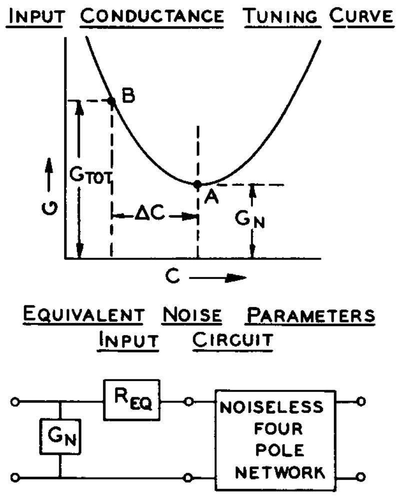


Fig. 2

EQUIVALENT INPUT NOISE PARAMETERS



G_N = $20 I_D$ AT MINIMUM INPUT CONDUCTANCE (A)

G_{TOT} = $20 I_D$ AT DETUNED POINT (B)

ΔC = CHANGE IN TOTAL INPUT SHUNT CAPACITANCE BETWEEN A AND B

I_D = NOISE DIODE CURRENT TO DOUBLE NOISE OUTPUT OF TUBE UNDER TEST

$$G_{TOT} - G_N = \omega^2 \Delta C^2 R_{EQ}$$

$$NF_1 - 1 = 2\sqrt{G_N R_{EQ}}$$

$$R_{S(OPT)} = \sqrt{\frac{R_{EQ}}{G_N}}$$ (IF CIRCUIT LOSSES ARE NOT CONSIDERED)

Fig. 3

$$R_s \text{ (optimum)} = \frac{f_o}{f}\sqrt{\frac{R_{eq}}{G_n}}$$

Where: R_s **(optimum)** = **Optimum source resistance in ohms**

f_o = **Frequency in megacycles at which** G_n **was measured**

f = **Desired frequency of operation in megacycles**

Minimum attainable noise figure in decibels may be calculated with the following formula:

$$NF\ \min = 10 \log\left(1 + 2\frac{f}{f_o}\sqrt{R_{eq} G_n}\right)$$

Fig. 4

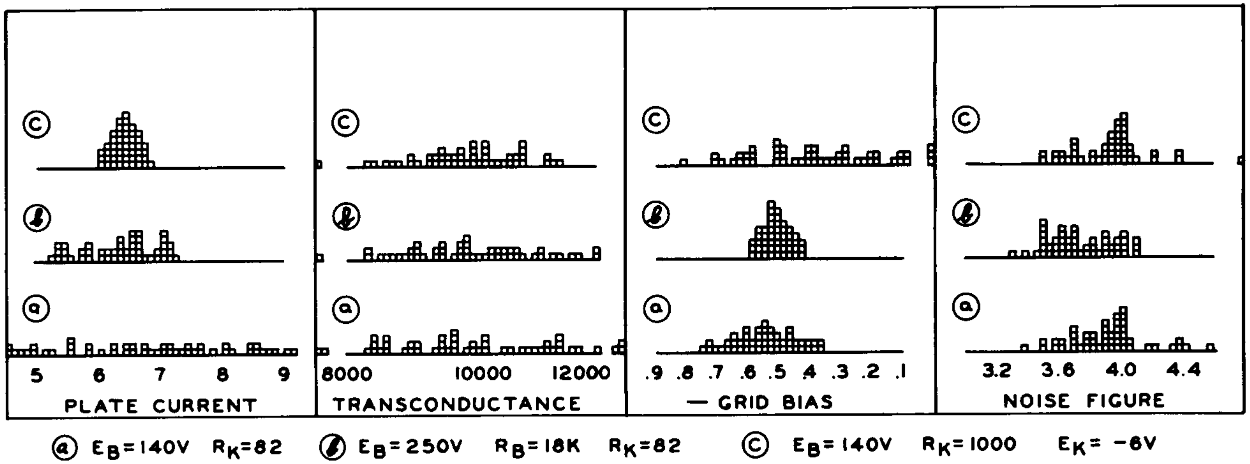


Fig. 5

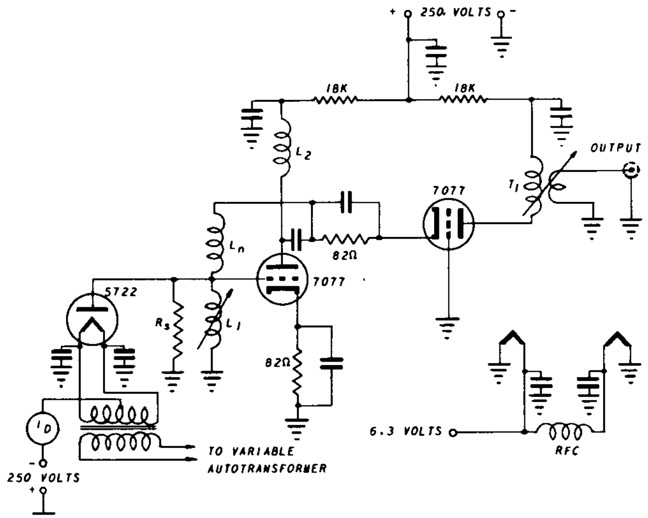


Fig. 7

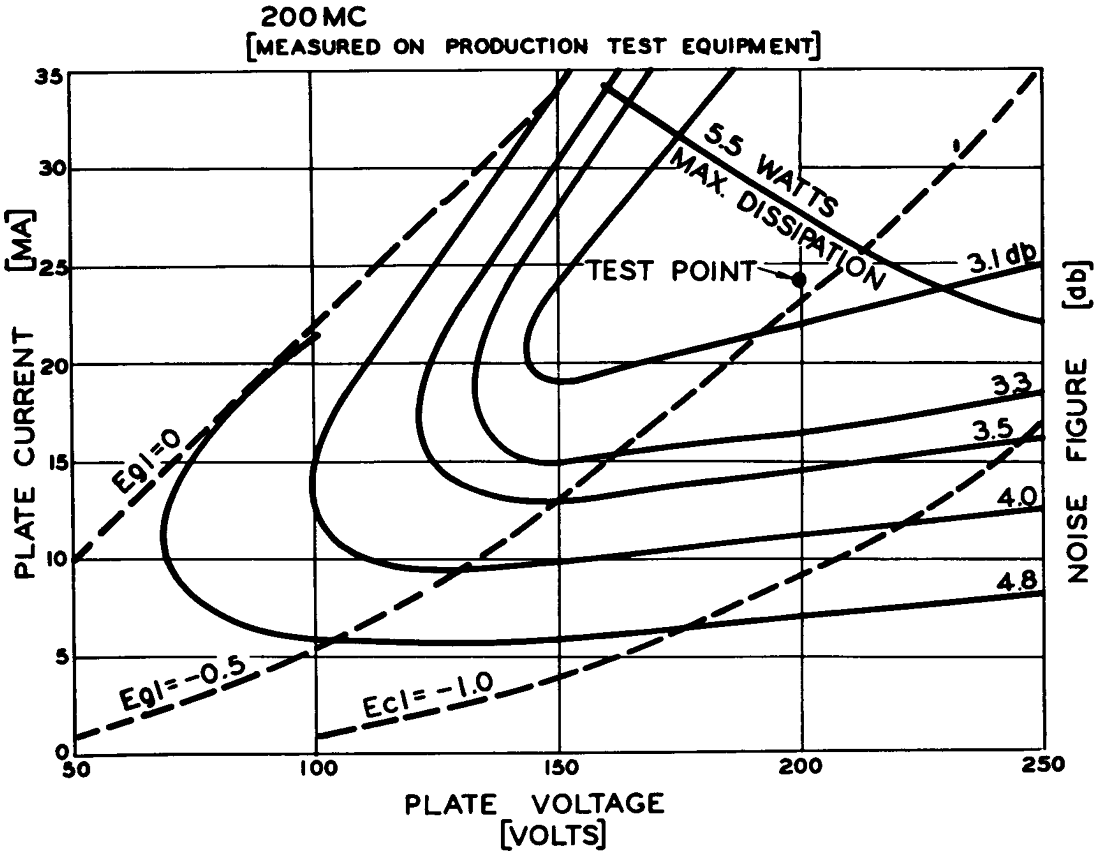


Fig. 6

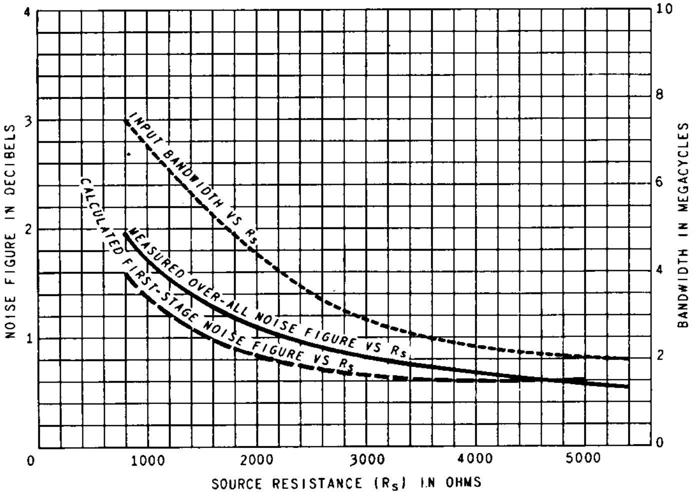


Fig. 8

TUBE DEPARTMENT
GENERAL ELECTRIC
Owensboro, Kentucky

THE USE OF GRIDDED CERAMIC VACUUM TUBES IN PHASED-ARRAY LONG-PULSE UHF RADARS

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Introduction

Until recently, existing radars have been able to handle the traffic of satellites, space probes, and missiles. To handle the expected traffic resulting from the stepped-up space efforts, new radars are being conceived and designed.

Many of these recent radar designs feature electronically steerable, phased arrays to obtain the high pulse powers, beam definition, and efficient low noise reception necessary for long range, three dimensional, multitarget tracking.

System studies have been made,[1] and operating frequencies in the low UHF and/or high VHF spectrum appear to be attractive. Part of this conclusion was based on the simplicyty, ease of application, cost per kilowatt of power, stability, and the wide type and size selection associated with the gridded vacuum tube. It is the purpose of this paper to display the approximate performance capabilities of the gridded tube, and only limited comparison with competing devices is attempted. This is necessary because of the lack of available data, either known or unknown.

This paper is principally concerned with the radar functions of pulsed power generation and low noise reception. The requirements of extreme phase fidelity and the desire for rapid frequency shift dictate the use of broadband amplifiers in both the transmitting and receiving functions. Broadband performance from 425 mc. to 1400 mc. is presented and amplifier bandwidths up to 15% are discussed. Power levels from thermal to kilowatts are assumed.

Transmitter

The vacuum tube appears to be one of the most useful and economical sources[2] of RF power for the frequencies being considered. Since both high

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[1] "Phased Arrays selected for New Generation Radars" Manfred Meisels July 1962 Microwaves

[2] See article "Array Radars - A Survey of their Potential and their Limitations" J. L. Allen (Note excellent bibliography) May 1962, Microwave Journal

power and long pulses are desired, the radar performance depends primarily upon the long life and performance capabilities of the vacuum tube chosen.

The most important requirements for the transmitter are:

1. High pulse power outputs.
2. Long duration pulsing.
3. Broadband amplification for phase fidelity.
4. Long life.

Long Pulse Derating:

Tube manufacturers have been reluctant to provide tube performance data and ratings for long pulses, greater than about 10 microseconds, without specific life testing. To provide a preliminary design derating curve, all available long pulse data was collected and the curves shown in Figure 1 were plotted.

Due to the lack of actual life test data over the wide range of pulse widths shown, the data plotted was taken from several sources. The data plotted up to about 6 µsec has been published by several tube companies and represents earlier and presently used pulse widths for UHF gridded tubes. In the 10 to 1000 µsec region only limited data was available. Video pulse life tests, at about 20 µsec have been made by one company active in the phased array field. One tube company[3] has been running some life tests at 100 µsecs and most of the 1000 µsec data was taken on pulse life tests run on computer tubes.[4]

The data shown in Figure 1 was purposely plotted in terms of unit cathode area and unit grid-to-plate spacing to make the curves applicable to all tubes. It is impractical to present this data on one tube or even on a family of tubes. Using the chart all tube sizes and spacings can be "tested" for their intended application. The transmitter designer must obtain the required dimensions from the tube manufacturer.

These ratings have not been proven with exhaustive life tests and should be used only as a guide in the early choice of tube sizes and configurations. The curves apply only for plate pulsing and additional derating is necessary for grid and/or cathode pulsing. This derating will apply both for input video and RF pulsing. A rule-of-thumb for plate voltage derating might be one-half to three-fifths of the permissible peak plate-pulsed value. This rule generally

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[3] Private communication from D. W. Hawkins, GE Company, Bldg. 269, Schenectady, N. Y.

[4] Subminiature Electron Tube Life Factors: Edwards, Lammers & Zoellner Reinhold Pub. Corp.

applies to oxide coated cathodes. Current deratings are unknown factors and usually do not require the degree of derating necessary for plate voltages. This is generally true because excessive and damaging arcing occurs at the steady state high stress conditions common for input pulsing. In both input and plate pulsing applications the current derating is more dependent upon the long life capabilities of the cathode. Cathode life also depends on other factors in addition to current loading and voltage stresses.

Tube Choice:

Using the design curves shown in Figure 1 the circuit designer can work backwards to obtain the appropriate tube area and spacings for a given desired power output. For maximum efficiency the tube should be used near these rated conditions. However, when this is done, power gain usually suffers and the final operating point must be selected with both efficiency and desired power gain in mind. In practice, an optimum approach to the proper tube complement would use the tube at least in one stage at its maximum rating for maximum efficiency and the same tube in previous stages for increased stage gain. This philosophy can be applied until the efficiency becomes so low that a smaller tube would be more practical from the standpoint of size, cost, and/or power consumption.

Tube Characteristics:

It is interesting to note the effect of normal tube characteristics upon power outputs and power gains for a given input power. To determine this, special engineering tubes were built with a wide variety of both mu and transconductance values. Test results on these tubes, given on Figure 2, show that although mu and transconductance are not important considerations where power output and efficiency are concerned, they are important with respect to power gain. The curve clearly shows the desirability of both high mu and high transconductance.

The curves shown on Figure 2 were developed from performance measured on about forty tubes. The various mu's and transconductances were obtained by varying such things as grid wires per inch, plate to grid spacing, grid wire sizes and grid configurations. There would be other variables such as tube capacitances but at 425 mc the different values obtained on the relatively small tubes evaluated were not important. On larger tubes the capacitances would be more important. Actually the higher mu tubes, which were also the higher transconductance tubes, had the lowest plate to grid capacitance.

Gain vs Power Output:

It is difficult to determine the theoretical gain as a function of drive level and one must usually resort to actual measurements. Figure 3 shows the test results obtained on two different ceramic triodes, Z-2869 and 7768, when driven at various levels. These data were taken using the triodes as class C amplifiers and gating the tube "on" with an RF pulse of 500 microseconds duration. The measured values of power output, efficiency, and power gain were recorded as a function of cathode loading in ma. per square centimeter of active cathode surface. The mu's are different with similar transconductances. The Z-2869 has a mu of about 100 and the 7768 has a mu of about 225. Although these results would not apply to all triodes, they would be useful in predicting at least qualitative results. The tests were made at 425 mc using single-tuned plate circuits and narrow bandwidths.

Wide Band Performance:

As stated previously, it is important that the tube performance be determined at the desired bandwidths. To do this, a lumped-constant, double-tuned plate circuit, grounded-grid amplifier was constructed and the test results are shown in Figure 4. It is difficult to accurately establish the broadband high level pulsed characteristics due to the lack of suitable sweep generators. The results shown here represent bandwidths obtained by point to point measurements and for a double tuned circuit optimized near the anticipated required bandwidths. The cathode loading was approximately 1.2 amperes per square centimeter. At lower drive levels one would expect higher gains and lower power outputs. The available power gains would increase to the values obtainable for class A conditions. The performance of the 7768 under these conditions will be discussed later.

Grid and/or Cathode Plate Pulsing:

For simplicity, the performance data shown in Figures 2, 3, and 4 were taken on RF cathode pulsed class C stages. However, as previously discussed, the tube must be operated at plate voltages lower than permissible using pulsed plate voltages. Where maximum power output is most important more pulsed power can be obtained from the plate pulsed stage. This latter method, however, requires higher voltages and more elaborate modulating equipment. Another factor in favor of plate pulsing would be the reduction in transit-time effects with the higher voltages. This may be important for the larger tubes which have wider element to element spacings. These various factors, plus others which may not be so obvious, suggest that the individual designer must make his own decision as to the type of amplifier gating he should use.

Triodes vs Multi-Grid Structures:

Available test results do not clearly define the comparative UHF performance between the tetrode (or pentode) and an equivalent triode. The performance advantages of the multigrid tube, where they exist, must be weighed against the extra cost and circuit complexity.

Using the design curves shown in Figure 1 and substituting the plate-to-screen-grid spacing for plate-to-control-grid values, the resultant ratings were spot checked on a power tetrode, the 7399, and the measured power outputs agree basically with predicted values using plate efficiencies common for this tube size and at the test frequency. The spacing between the screen and control grids must also be considered to prevent arcing between these two grids. Although this spacing is usually much less than the spacing from screen grid to anode, the voltages are also much lower. Data on the 7399 has been taken at about 400 mc using plate pulses of 100 microseconds and operating at a duty factor of .005. Good life test results have been obtained out to at least 5000 hours. Life also depends upon other factors such as cathode and envelope temperatures. This sort of information must be obtained from the individual tube manufacturer.

If the broadbanded triode and multigrid structures are compared in a simplified theoretical fashion, the advantages of the multigrid tube may be questionable. For example, the voltage gain for the tetrode or pentode can be estimated by:

$|A| = gmRo$ where Ro is the load resistance and gm is the tube transconductance. The gain-bandwidth product is:

$|A|\ \Delta f = \frac{gm}{2\pi Ct}$ where Δf is the

half-power bandwidth and Ct is the total interstage shunt capacitance. When the grounded grid triode stage is considered, the broad-band gain is approximately the same as the multigrid tube when Ro is much less than the tube's plate resistance. For the equivalent interstage circuitry, the grounded grid triode gain-bandwidth product is theoretically approximately equal to the multigrid tube. At narrow band the very high plate resistance values of the multigrid tube make this tube parameter relatively unimportant. This is not true for triodes.[5]

Available Cathode Sizes:

The curves shown in Figure 1 suggest that available power outputs are limited only by cathode areas and tube spacings. This is true except for the usual limitations applied to vacuum tubes used at low UHF. Large areas and wide spacings cannot be used and only the well-designed high-frequency structures are applicable. Cathode areas up to about 10 square centimeters have been designed into efficient ceramic tube structures and useful peak powers up to 100 kilowatts are obtainable at pulse widths of around 100 microseconds.

Life vs Performance:

Tube manufacturers have known for years that efficiency can be improved by running the tube's cathode at high current densities. The resultant high performance is short lived, and for long life applications the tube must be used more conservatively. In an effort to determine the performance versus life capabilities, life tests have and are being conducted and in some cases by the systems design people themselves. Significant life tests have been conducted

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[5] Chap. 7 Electronic Designers Handbook Landee, Davis, and Albrecht McGraw Hill

at about two to three amperes per square centimeters loading at pulse lengths of useful value. The results obtained on the 7399 have been mentioned. Figure 5 shows the early results obtained on the Z-2869 and 7768 previously mentioned. These life tests are being run at about 1.5 amps peak video per square centimeter with a duty factor of .005 and for a pulse duration of 500 microseconds. For simplicity, the tubes are being life tested as grid-pulsed oscillators.

Receiver

The most desirable performance features for the receiver are:

1. Low noise.
2. High broadband gain.
3. Long life.
4. Wide dynamic range.
5. Tolerance to overloads.

The metal ceramic planar triode can best provide all of these features. In view of the low noise figures obtainable from competing devices it is important that the best available tube be used that can operate efficiently at UHF.

Preamplifier Design and Performance:

From a theoretical standpoint, since maximum gain-bandwidth is desirable, multituned interstages should be used. For example, if equal "Q" double-tuned interstage circuits are assumed and the primary and secondary capacitances are equal, a double-tuned circuit will give $\sqrt{2}$ more gain-bandwidth than a single tuned interstage. Triple tuning and so on will give additional performance. For multistage amplifiers, alignment becomes very difficult and practical designs might limit themselves to double and triple tuned interstages. It should be noted from a theoretical standpoint that the maximum available gain-bandwidth product in multituned circuits can be obtained only if the required conditions of circuit "Q", coefficient of coupling, primary and secondary capacitances, and so on, are used.

Using two 7768's as cascaded grounded grid amplifiers, a 425 mc. amplifier has been constructed using lumped constant circuitry and double tuned interstages between the two tubes and at the amplifier output plate circuit. A typical performance of 35 db gain and a 4.0 to 4.5 db noise figure was obtained with a 3 db bandwidth of about 7.5%. This measured gain-bandwidth product of about 1600 mc. per stage agrees with the theoretical value. Similar products have been measured at 1000 and 1350 mc.

Dynamic Signal Range:

To permit simultaneous tracking of close-in targets as well as threshold return signals, it is important that the receiver have a wide dynamic signal range. Figure 6 shows the power gain of the 7768 measured for input signals from noise level to distortion due to overdrive. A useful dynamic range of about 100 db is evident.

Tolerance to Over-signals:

Two types of signal overload can be present in any radar. One of these is the ever-present transmitter power leakage due to poor or inadequate TR techniques. This leakage tends to reduce receiver life and represents a problem of operating cost. Another type of signal overload is a transitory one and results from either TR failures or intentional power jamming. In both cases the most logical solution is the use of tolerant receiver components. This results in less stringent TR requirements and better protection against unpredictable signal levels.

The exact signal overload tolerances of the various receiver components are difficult to find and in most cases to measure. To illustrate the relative tolerances of the various receiver techniques, best available results are shown in Figure 7.

If gating voltages are available, additional protection can be obtained by turning the receivers off during the transmitted pulse period. This resulting mismatch reflects energy normally received. This type of extra protection is usually more effective using vacuum tubes because of the larger obtainable mismatches without such problems as reverse bias breakdown and burnout.

Some degree of mismatch and resulting reflection of unwanted signals exists when the receiver is overdriven due to changes in device input impedances. This would only be permissible if the overdrive does not shorten the receiver life.

Long Life and Reliability:

Previously mentioned transmitting tube life test results and the results shown in Figure 8 demonstrate the high performance obtainable from the vacuum tube. If similar tube structures with proven pulse capabilities are used in the receiver the survival under high pulsed conditions due to signal overload is assured.

Conclusion

Preliminary evaluation of the usefulness of the vacuum tube in the phased-array long-pulse radar concept has been made. Test results show power outputs sufficient to provide very large radiated pulsed powers. With the simplicity and low cost of the vacuum tube approach these powers can be obtained economically. Life test results both in the transmitting and receiving function have demonstrated tube life sufficiently long to minimize the maintenance problems present in such a large and complicated radar concept.

Gridded vacuum tubes are easier to apply in the receiver function than other devices and are much more tolerant to over-signals both anticipated and unanticipated. Broadband gains of sufficient value have been demonstrated to reduce the problem of second stage noise contribution. The measured overall low UHF noise figures are sufficiently close to values obtained from competing solid-state devices to warrant the serious consideration of vacuum tubes. With the extra protection necessary for the solid-state receiver and the insertion losses and costs of the required additional circuitry, the performance differentials most often quoted between the solid state and vacuum tube approaches should be carefully evaluated.

The writer wishes to thank W. P. Kimker and C. E. Finley of the Receiving Tube Department and R. P. Watson of the Power Tube Department of the General Electric Company for their assistance in the preparation of this paper and in obtaining the test results shown therein.

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JW Rush/ka

PULSE VOLTAGE AND CURRENT VS. PULSE DURATION*

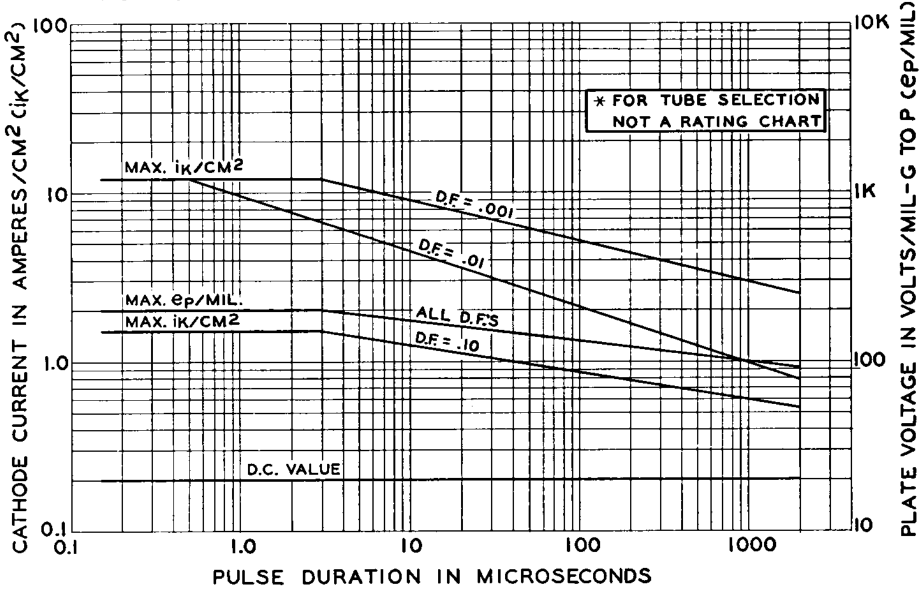


FIG. 1

PULSED PERFORMANCE AS A FUNCTION OF TRIODE CHARACTERISTICS

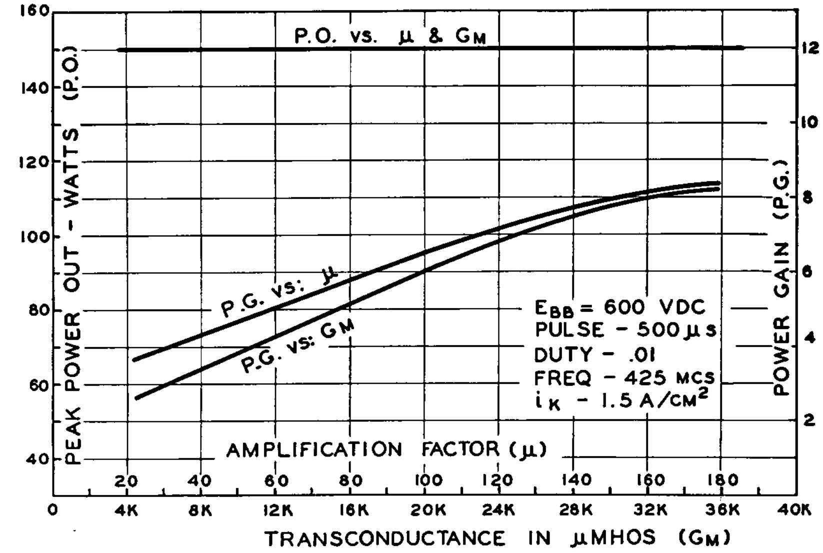


FIG. 2

PULSED PERFORMANCE AS A FUNCTION OF CATHODE LOADING

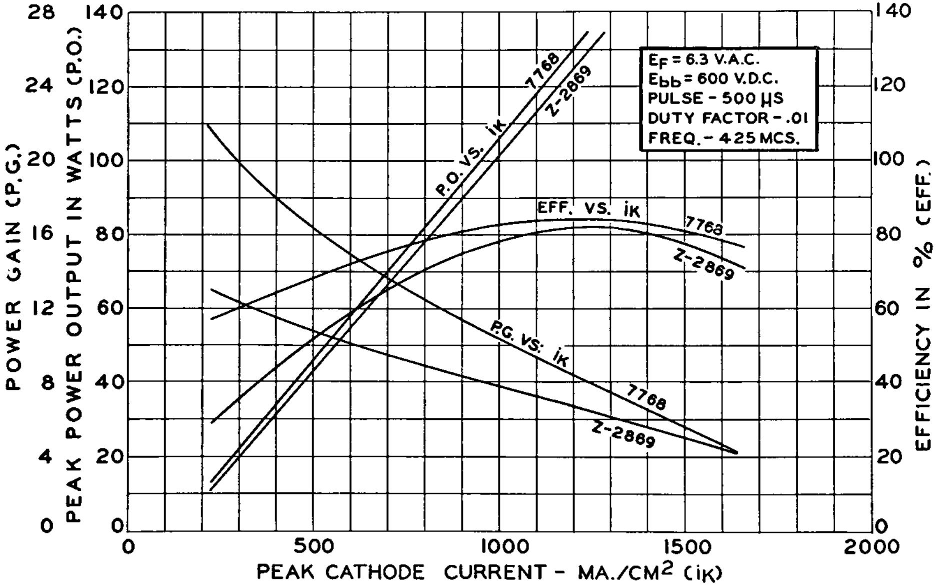


FIG. 3

PULSED CLASS C PERFORMANCE

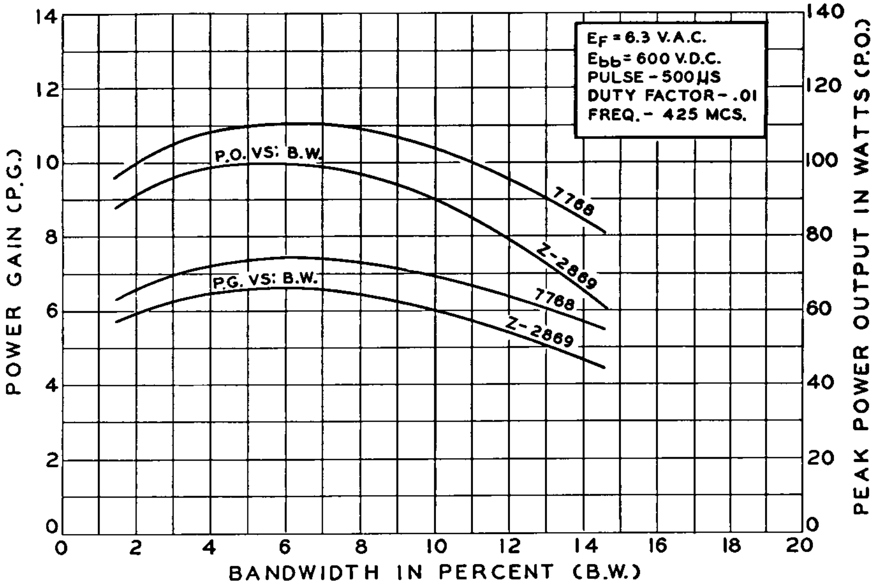


FIG. 4

GRID PULSED OSCILLATOR LIFE TEST

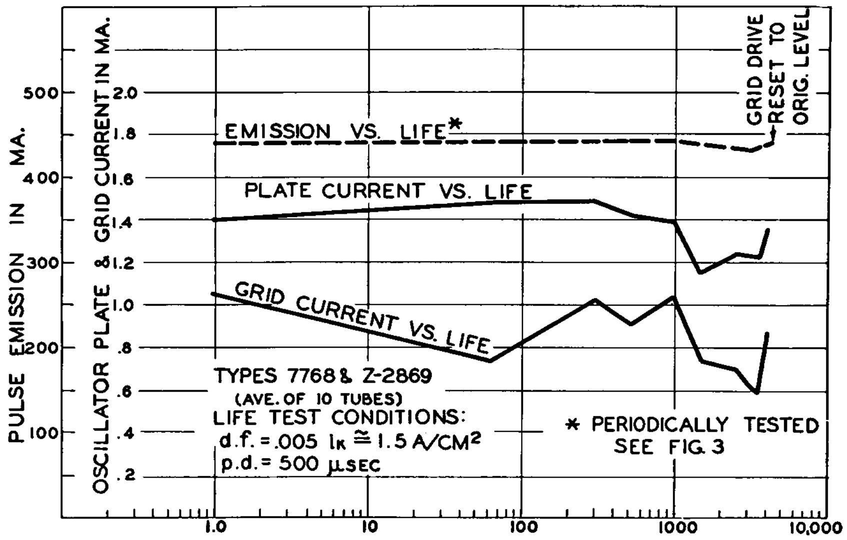


FIG. 5

USEFUL CLASS A DYNAMIC RANGE

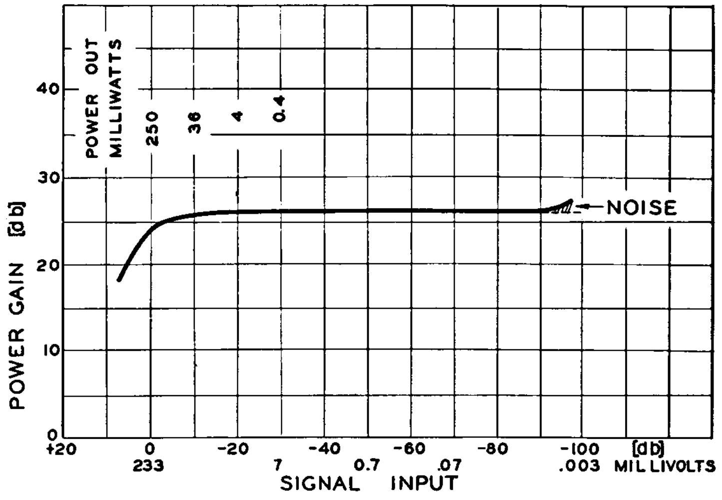


FIG. 6

TOLERANCES TO SIGNAL OVERLOADS

(ESTIMATED BURN-OUT)

CRYSTAL MIXERS AND DETECTORS	- 10 ERGS
TUNNEL DIODE	- 100 ERGS
LOW NOISE PARAMETRIC DIODES	- 1000 ERGS
EPITAXIAL PARAMETRIC DIODES	- 10^{+4} ERGS
CERAMIC VACUUM TUBE	- 10^{+8} ERGS

FIG. 7

NOISE FIGURE VS. LIFE

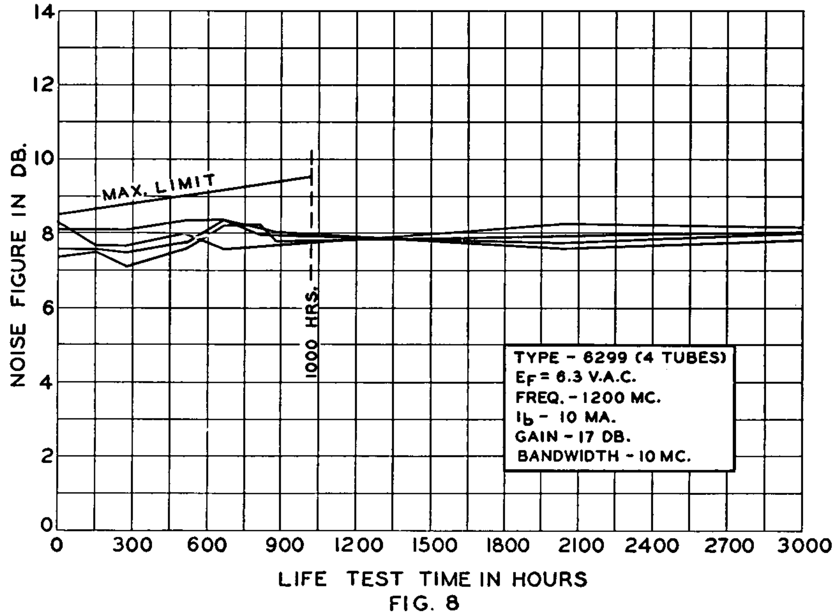


FIG. 8

EI-43A
November 29, 1962

LIFE TEST SUMMARY OF CERAMIC TYPES UNDER HIGH TEMPERATURE AND HIGH HUMIDITY CONDITIONS

High Temperature Life Tests

There has been a continuous interest in the high temperature capabilities of ceramic tubes at temperatures above those permitted by the published ratings. Through our regular lot acceptance life testing, considerable data have been accumulated which substantiate the published temperature ratings. However, other special life tests have been conducted to evaluate the tubes at higher-than-rated temperatures and a summary of some of these tests is presented in this report. Attached are life test data consisting of Plate Current and Transconductance medians versus time for the following tests:

Type	Lot	Amb. Temp.	Env. Temp.	Ef*	L.T. Duration	n
7296	472	400°C	450°C	5.4 V	2000 Hrs.	10
7296	305	500°C	550°C	4.3 V	4000 Hrs.	10
7296	45	240°C	300°C	6.3 V	15000 Hrs.	10
7296	46	240°C	300°C	6.3 V	15000 Hrs.	10
Z-2354	253	400°C	450°C	5.0 V	17000 Hrs.	10

* Note that lots 472 and 305 of the 7296, and lot 253 of the Z-2354, were life-tested at reduced heater voltage. This was done to obtain longer tube life by keeping the cathode temperature within bounds. However, the particular value of heater voltages used in these tests are not necessarily the optimum values. The lower plate current and transconductance values of lot 305, as compared with lot 472, are caused, at least in part, by the higher envelope temperature of lot 305. Higher envelope temperature increases the spacings between the tube elements, thus reducing the transconductance and plate current. It may be that with the particular heater voltage used, the cathode temperature was lower for lot 305, causing part of the difference in characteristics. However, this was not verified by measuring cathode temperatures.

Humidity Test

In addition to the high ambient life test operation summary, test data of a special humidity test are included. This test was performed to investigate the effect on tube properties due to absorption of moisture into the ceramic and seal areas. The test consisted of type 7768 tubes placed in a chamber and subjected to a steam vapor of approximately 100°C and 95-100 percent relative humidity for an extended period. These test conditions are in accordance with MIL-E-1, Par. 4.9.9, with the exception of a longer duration. The tubes were taken out of the chamber at various intervals, conditioned at room ambient for several hours, and read for heater current and plate current characteristics to detect any air leaks or other degradation in electrical characteristics. Of the two lots being tested, one has completed 1030 hours and the other has completed 466 hours. The results indicate no significant change in plate current or heater current throughout the test. These readings are good indicators of tube condition and it is evident that the tubes have withstood the humidity environment without deleterious effects.

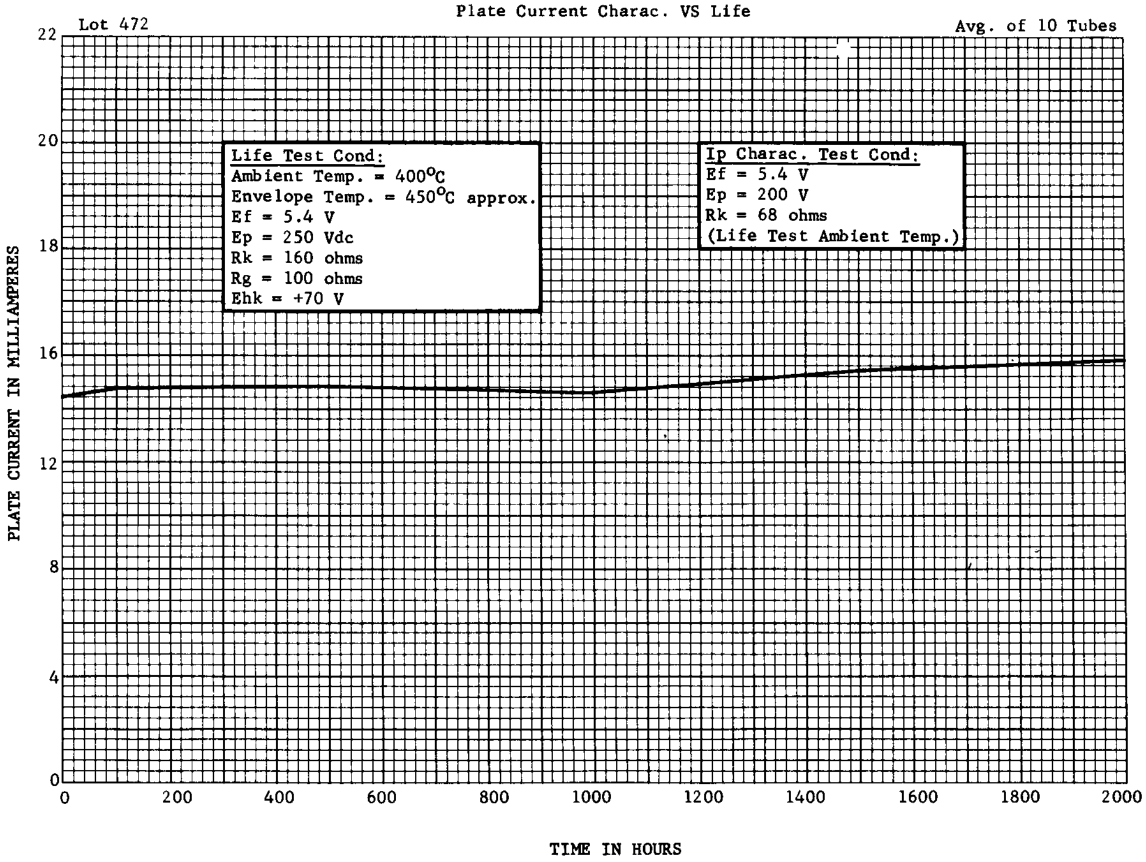
These data, of course, are insufficient to provide a great deal of statistical proof, but the long-duration life performance data do present an encouraging indication of reliable operation under high ambient and high humidity conditions.

This material was prepared by W. H. Lemaster, Specification Development, General and I&M Tubes, Receiving Tube Engineering, and distributed by Technical Data Unit, Receiving Tube Department.

TYPE - 7296

HIGH TEMPERATURE LIFE TEST DATA

Plate Current Charac. VS Life


Lot 472

Avg. of 10 Tubes

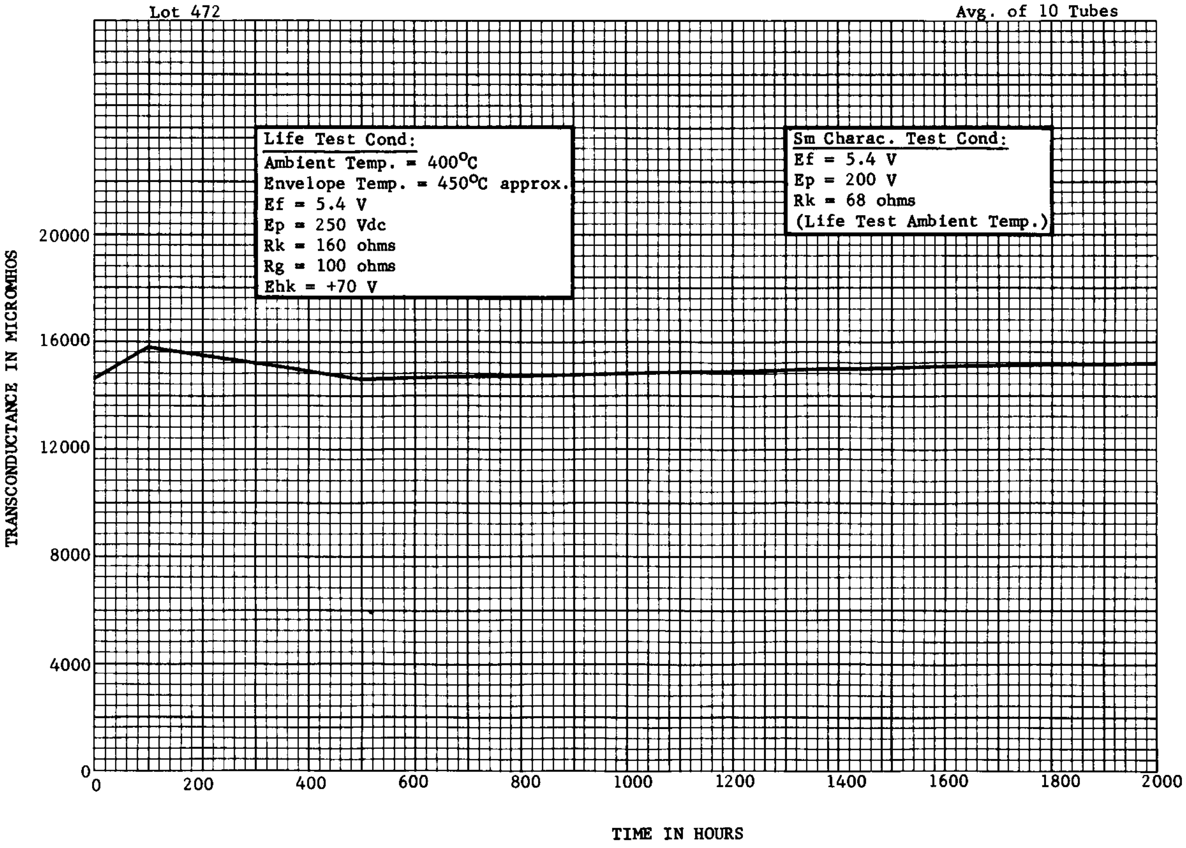
Life Test Cond:
Ambient Temp. = 400°C
Envelope Temp. = 450°C approx.
Ef = 5.4 V
Ep = 250 Vdc
Rk = 160 ohms
Rg = 100 ohms
Ehk = +70 V

Ip Charac. Test Cond:
Ef = 5.4 V
Ep = 200 V
Rk = 68 ohms
(Life Test Ambient Temp.)

TYPE - 7296

HIGH TEMPERATURE LIFE TEST DATA

Transconductance Charac. VS Life


Lot 472

Avg. of 10 Tubes

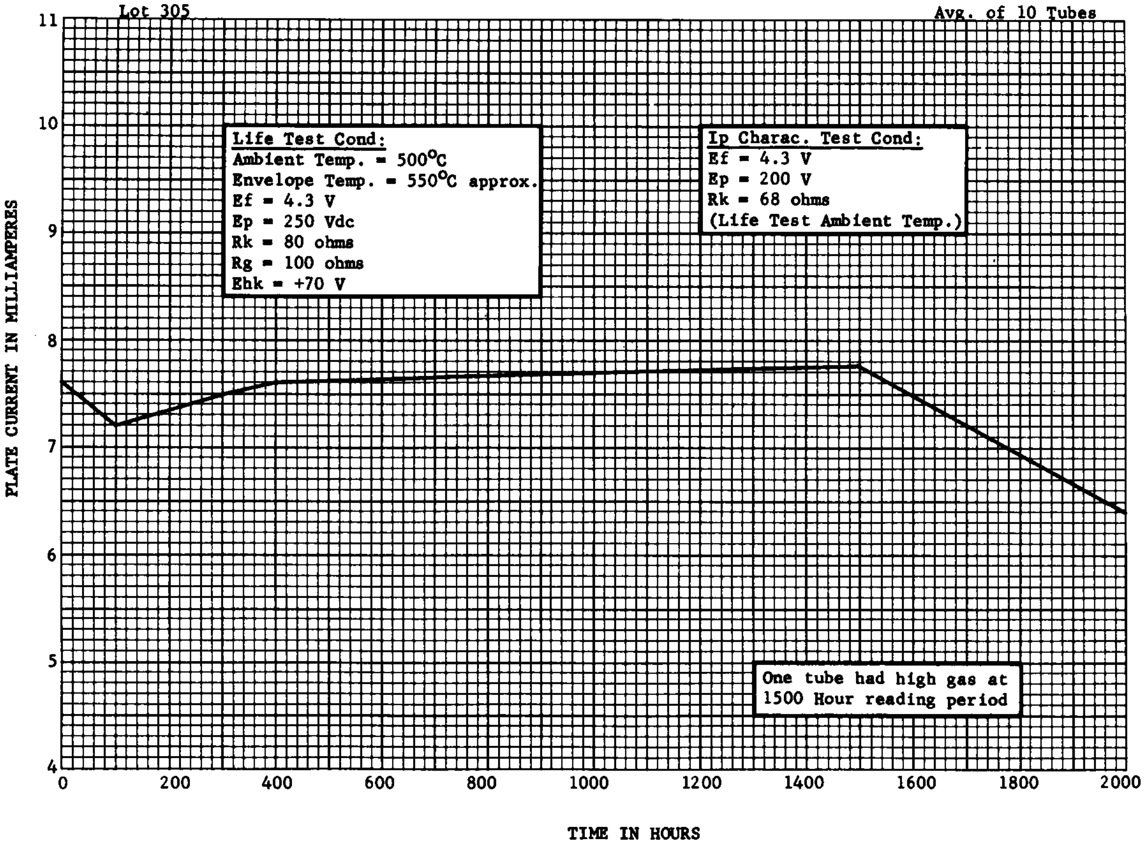
Life Test Cond:
Ambient Temp. = 400°C
Envelope Temp. = 450°C approx.
Ef = 5.4 V
Ep = 250 Vdc
Rk = 160 ohms
Rg = 100 ohms
Ehk = +70 V

Sm Charac. Test Cond:
Ef = 5.4 V
Ep = 200 V
Rk = 68 ohms
(Life Test Ambient Temp.)

TYPE - 7296

HIGH TEMPERATURE LIFE TEST DATA

Plate Current Charac. VS Life



TYPE - 7296

HIGH TEMPERATURE LIFE TEST DATA

Transconductance Charac. VS Life

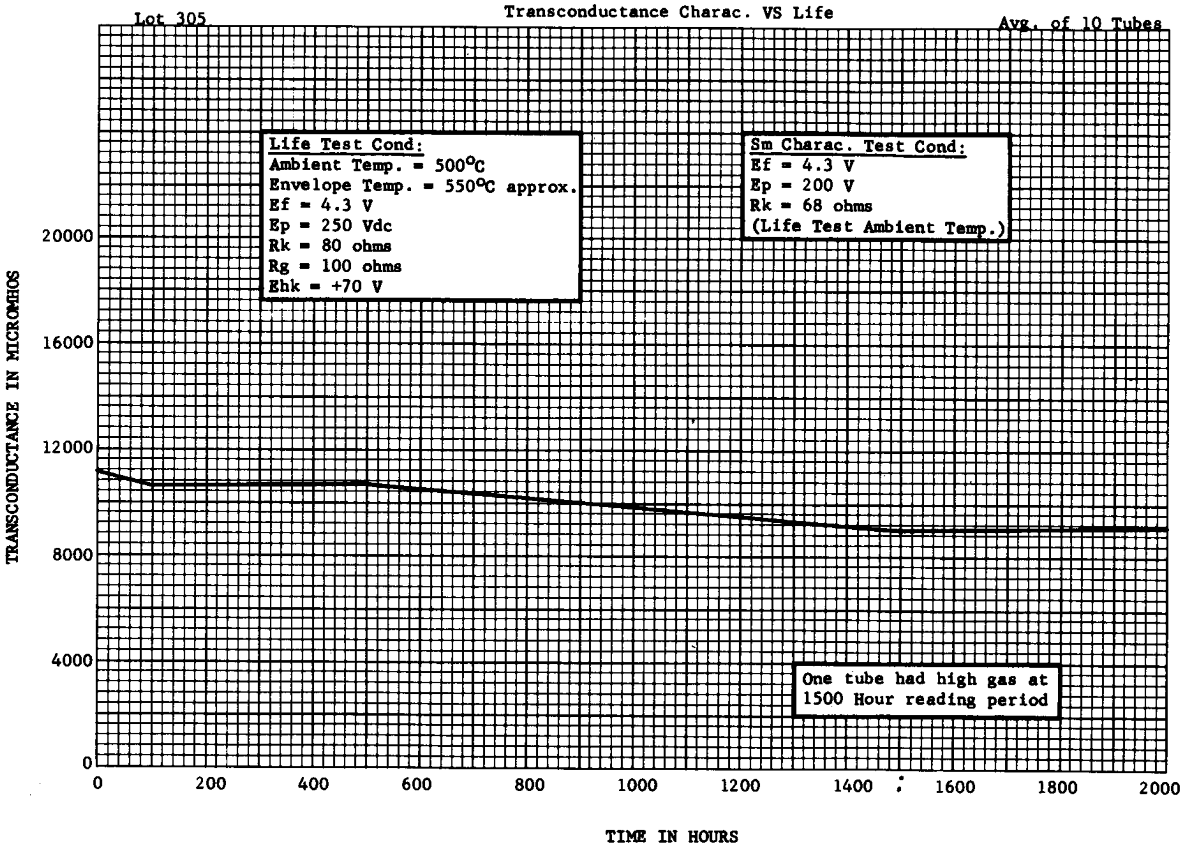


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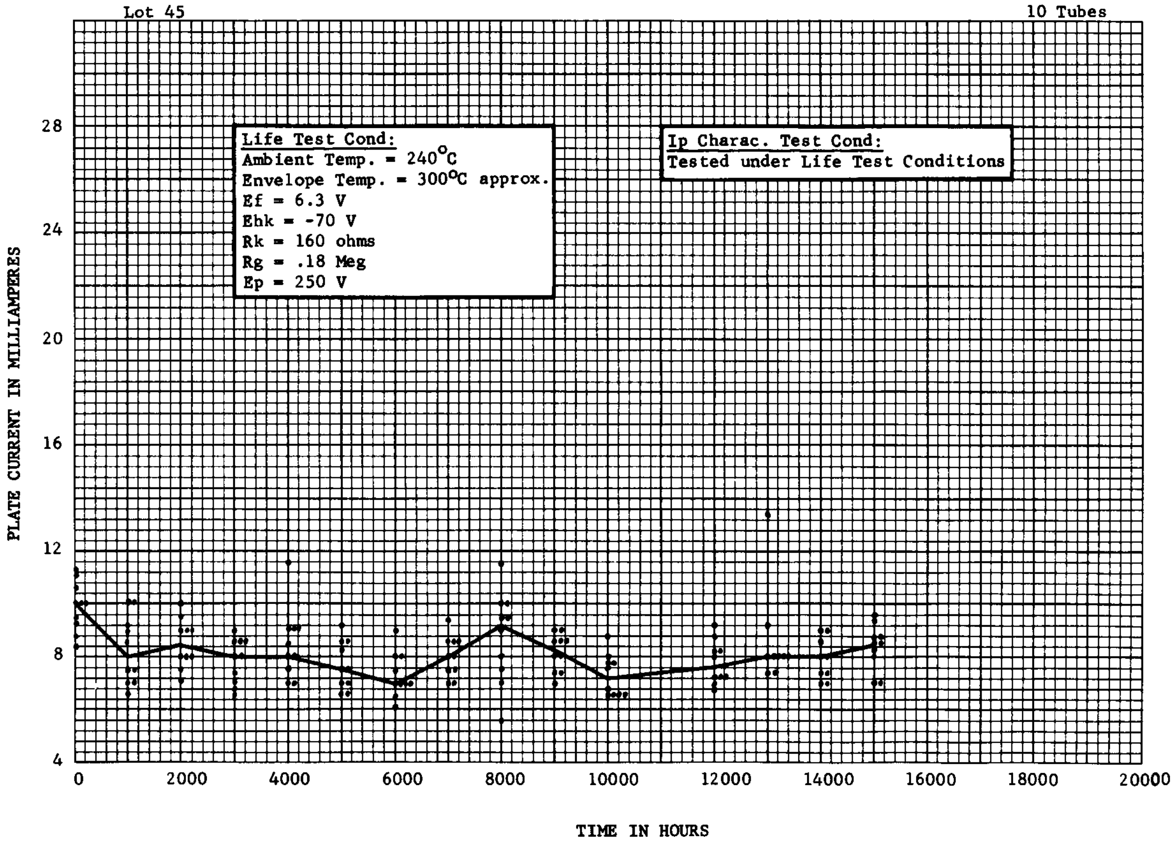
Plate Current Charac. VS Life



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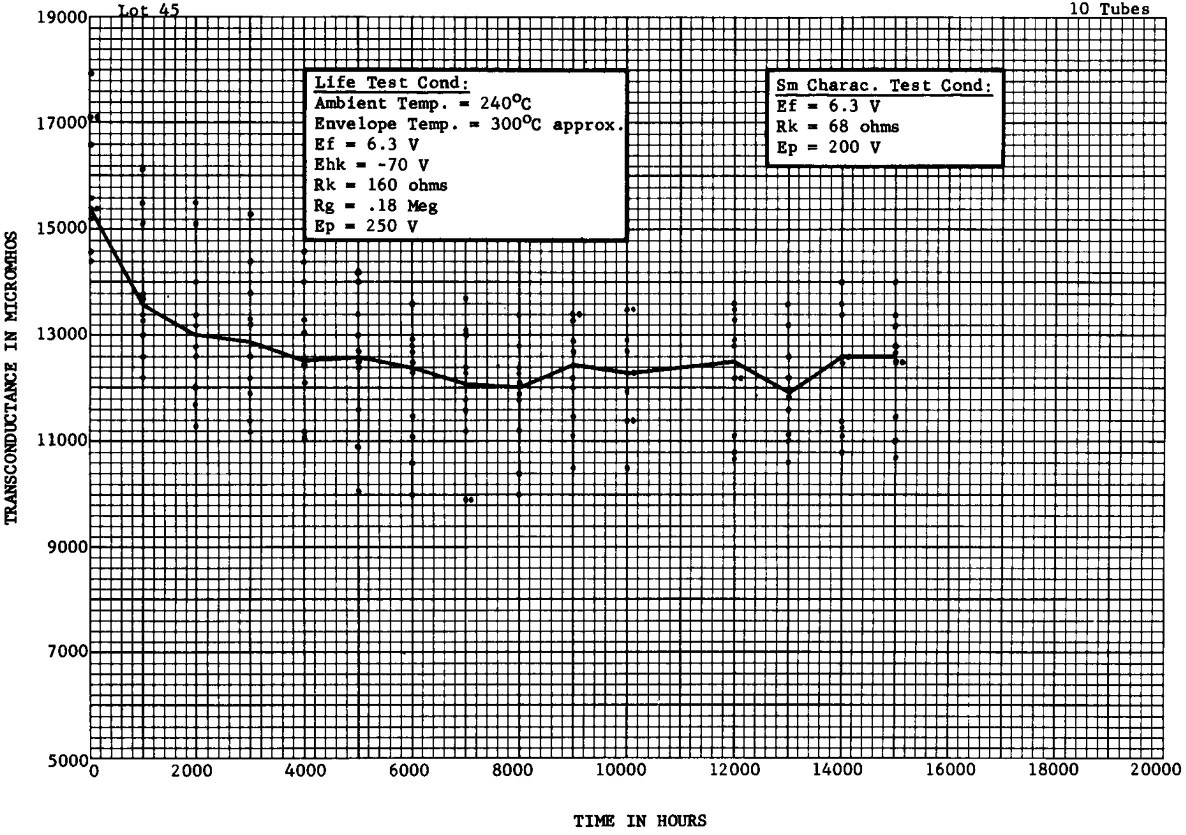
HIGH TEMPERATURE LIFE TEST DATA

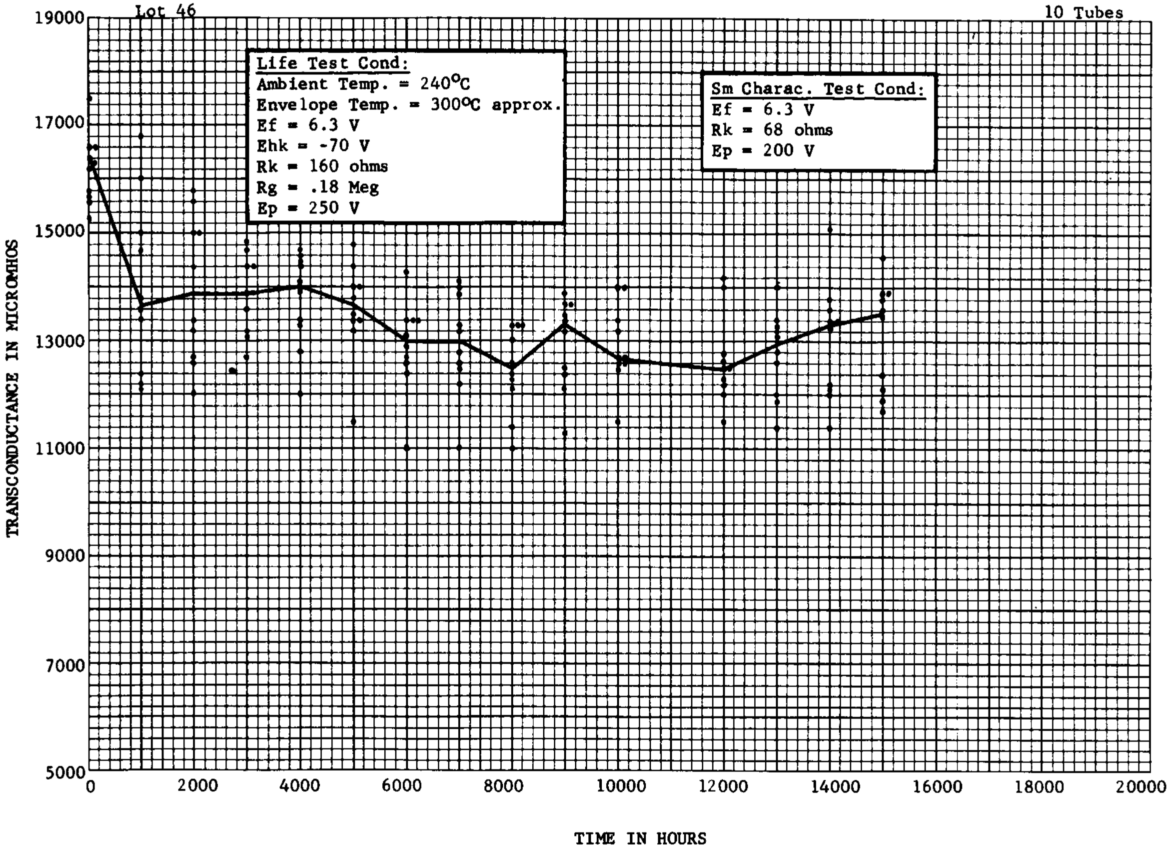
Transconductance Charac. VS Life



TYPE - 7296

HIGH TEMPERATURE LIFE TEST DATA

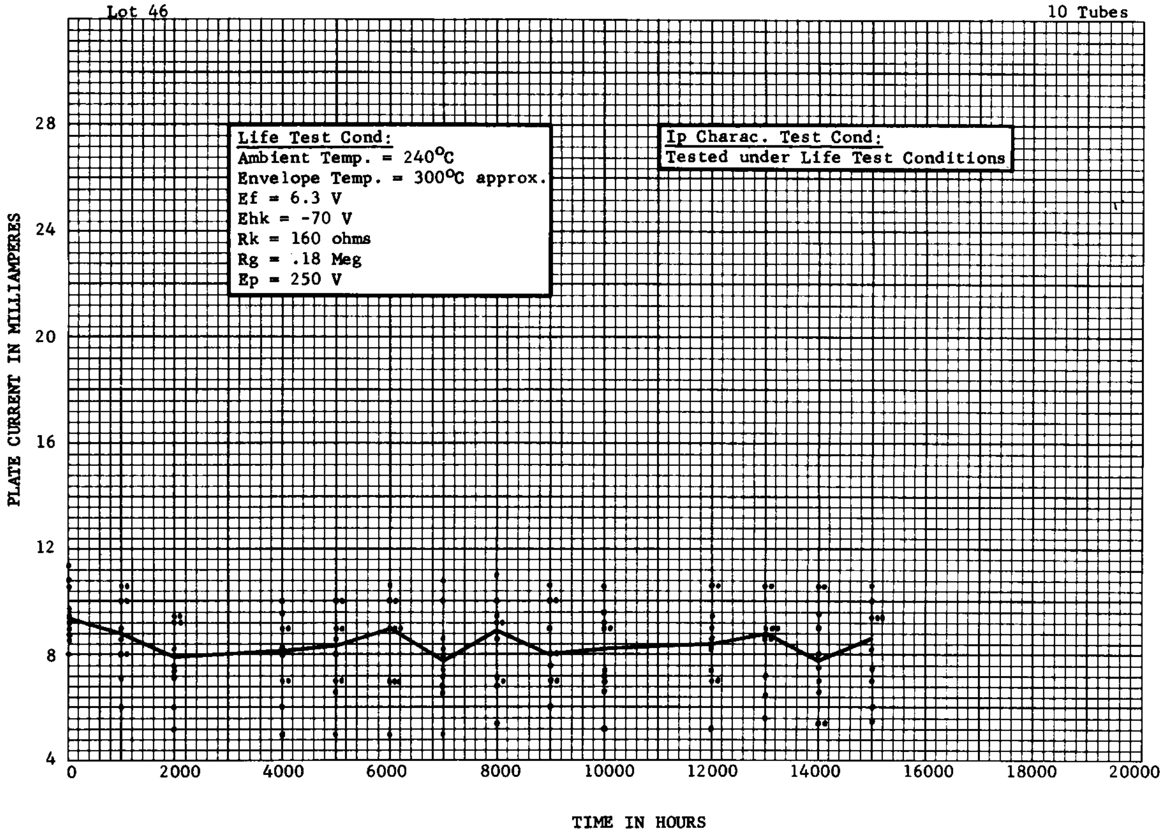
Transconductance Charac. VS Life



TYPE - 7296

HIGH TEMPERATURE LIFE TEST DATA

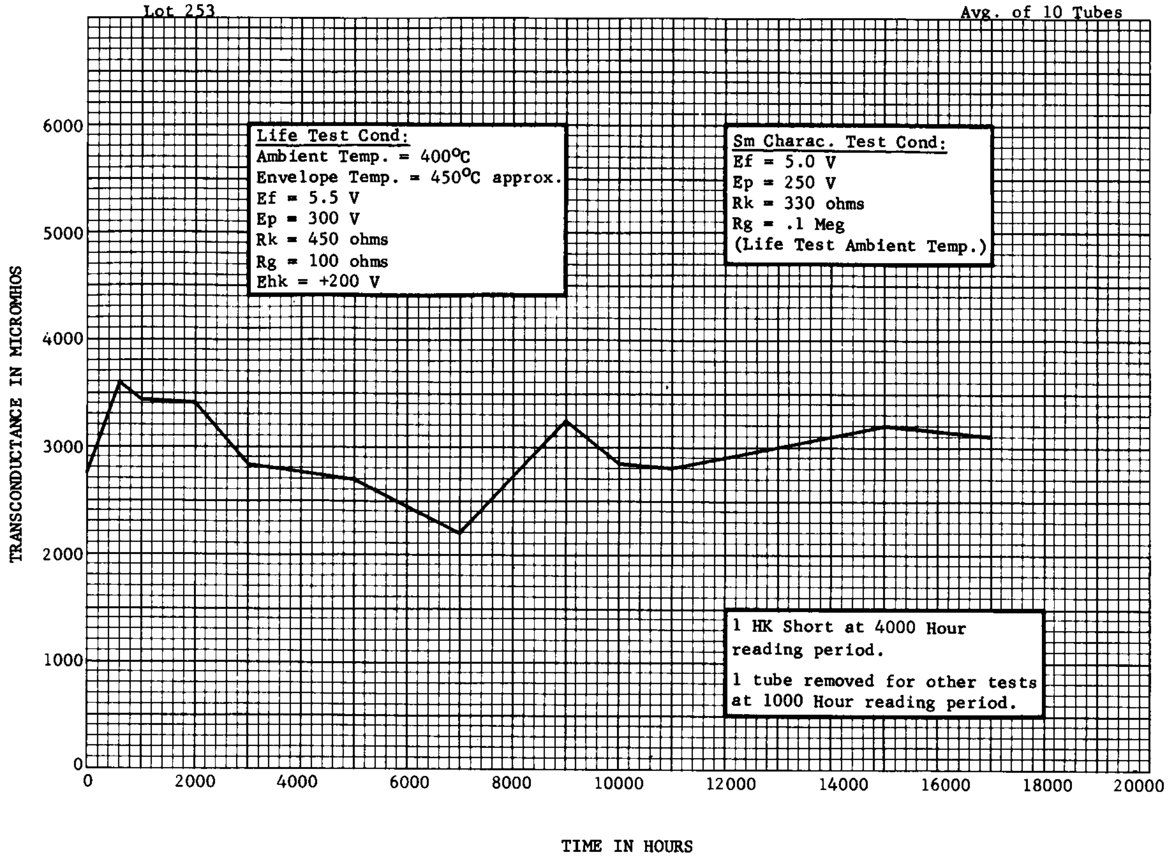
Plate Current Charac. VS Life



TYPE Z-2354

HIGH TEMPERATURE LIFE TEST DATA

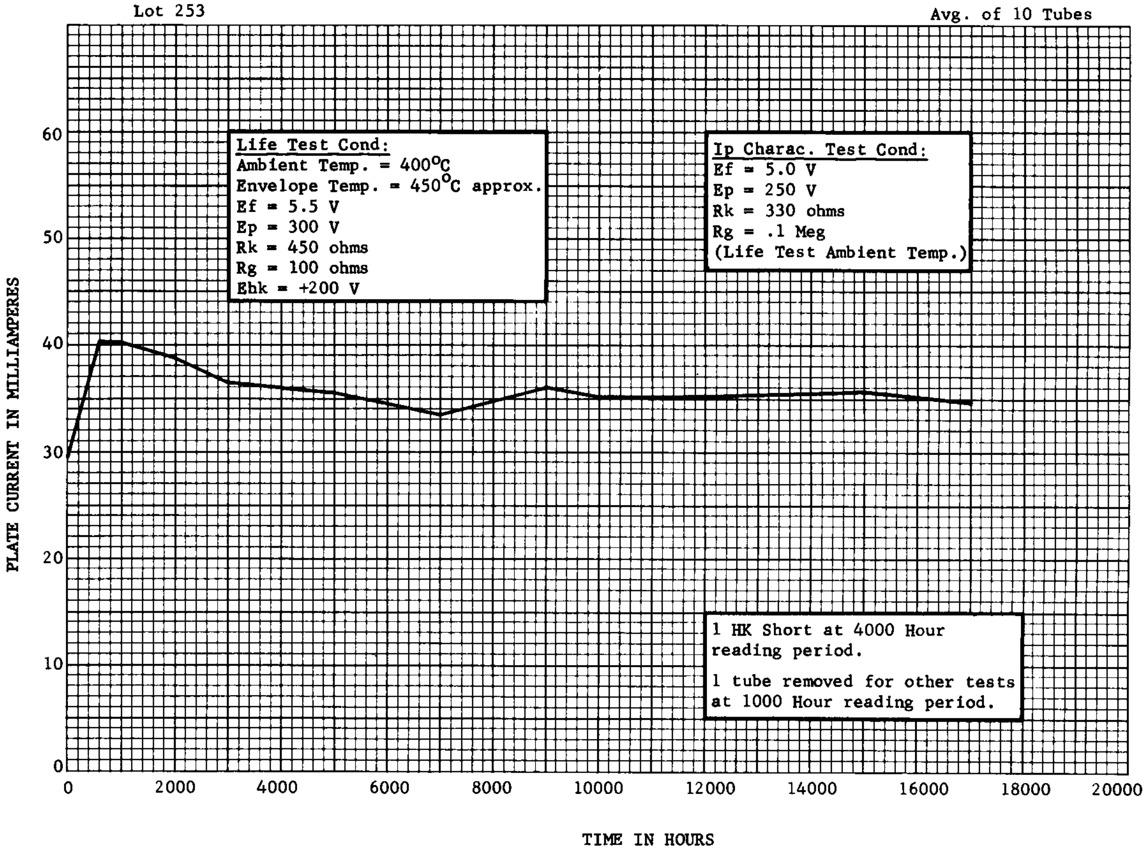
Transconductance Charac. VS Life



TYPE - Z-2354

HIGH TEMPERATURE LIFE TEST DATA

Plate Current Charac. VS Life



Humidity Test Results of Ceramic Type 7768

Test Conditions Per MIL-E-1 4.9.9

Group #1

Tube #		0 Hr.	92 Hr.	261 Hr.	404 Hr.	568 Hr.	706 1/2 Hr.	845 Hr.	1031 Hr.
1P-26	If(mA)	---	400	399	400	400	400	400	400
	Ip(mA)	32.0	31.5	31.0	32.8	31.8	34.0	32.2	34.9
1P-28		---	400	400	400	400	400	400	390
		24.0	27.0	27.0	28.0	27.0	38.0	27.5	26.0
1P-41		---	400	402	401	401	402	402	402
		24.5	26.5	27.0	27.0	26.9	27.8	26.9	26.5
1P-43		---	419	420	419	420	420	420	415
		25.0	25.0	25.0	26.0	28.0	29.0	29.0	28.8
1P-49		---	399	400	395	400	400	400	398
		21.0	23.5	23.5	24.5	24.5	25.0	24.0	25.0
1P-68		---	402	400	400	405	400	402	400
		18.0	22.5	21.0	22.0	23.0	21.0	20.8	21.5
1P-72		---	398	399	395	399	399	398	398
		24.0	30.0	30.0	30.0	30.9	30.0	27.2	30.2
1P-77		---	399	399	399	399	399	399	395
		26.0	28.0	27.0	27.5	26.9	27.0	27.5	28.9
1S-10		---	405	405	405	408	405	405	405
		25.0	29.0	28.0	29.0	30.0	30.0	29.9	29.0

Group #2

Tube #		0 Hr.	138 1/2 Hr.	280 Hr.	466 Hr.
1L-1	If(mA)	400	400	400	395
	Ip(mA)	21.0	21.0	21.0	21.0
1L-13		392	395	398	395
		28.0	29.0	28.0	29.0
1L2-13		409	410	410	405
		26.0	26.5	25.9	25.8
1K4-23		400	402	405	400
		19.5	20.0	19.5	19.5
1K6-3		410	410	400	398
		21.5	20.9	20.0	19.0
1K6-7		395	405	400	400
		26.8	27.0	26.0	26.0
1P-59		402	402	405	400
		24.1	25.0	24.0	24.0
1P-65		405	405	405	405
		25.5	25.0	25.0	26.0
1P-75		398	400	400	399
		26.0	26.8	26.0	26.2
1P-78		400	400	400	400
		24.0	24.5	23.0	24.5

EI-48
March 18, 1963

RESULTS OF RECENT TESTS OF CERAMIC TUBES DURING EXPOSURE TO NUCLEAR RADIATION

A number of General Electric ceramic tubes were recently operated in the field of a nuclear reactor with provisions made for periodic monitoring of the tube and circuit performance before, during, and after exposure to nuclear radiation.

Five type 6442's, 5 type 7588's, and 5 type 7077's were operated with the tubes, sockets, and connecting wires only adjacent to the reactor and all other circuitry removed from the vicinity of the reactor, while 18 type 7462's were operated in three 60-megacycle intermediate-frequency amplifiers, adjacent to the reactor. In addition, one tube of each type and one 60-megacycle amplifier were operated simultaneously away from the reactor to provide readings for comparison.

The reactor was operated for 128 hours, achieving a 3-megawatt level at 20 hours, and maintaining it to the end of the test. At intervals, measurements were made of plate current, plate current versus grid voltages, and plate current at reduced heater voltage for all tubes not in the 60-megacycle amplifiers; and plate current of each tube, gain, bandwidth, and tangential noise for the four 60-megacycle amplifiers.

During the test, there was very little change in average plate current of any of the tubes. However, two of the 60-megacycle amplifiers failed at approximately 57 hours, without plate current changes. Within two hours after shutdown of the reactor, both of the amplifiers that failed had recovered and would perform approximately as well as they did initially.

It is believed that coaxial cables carrying r-f signals to and from the amplifiers were severly affected by the heat from a hot-air line, and that this accounts for the amplifier failures, since there was no significant difference between the plate current readings for the tubes in the non-operative amplifiers and those in the amplifier that continued to function.

Detailed results of the tests are presented below in graphical form with explanatory notes.

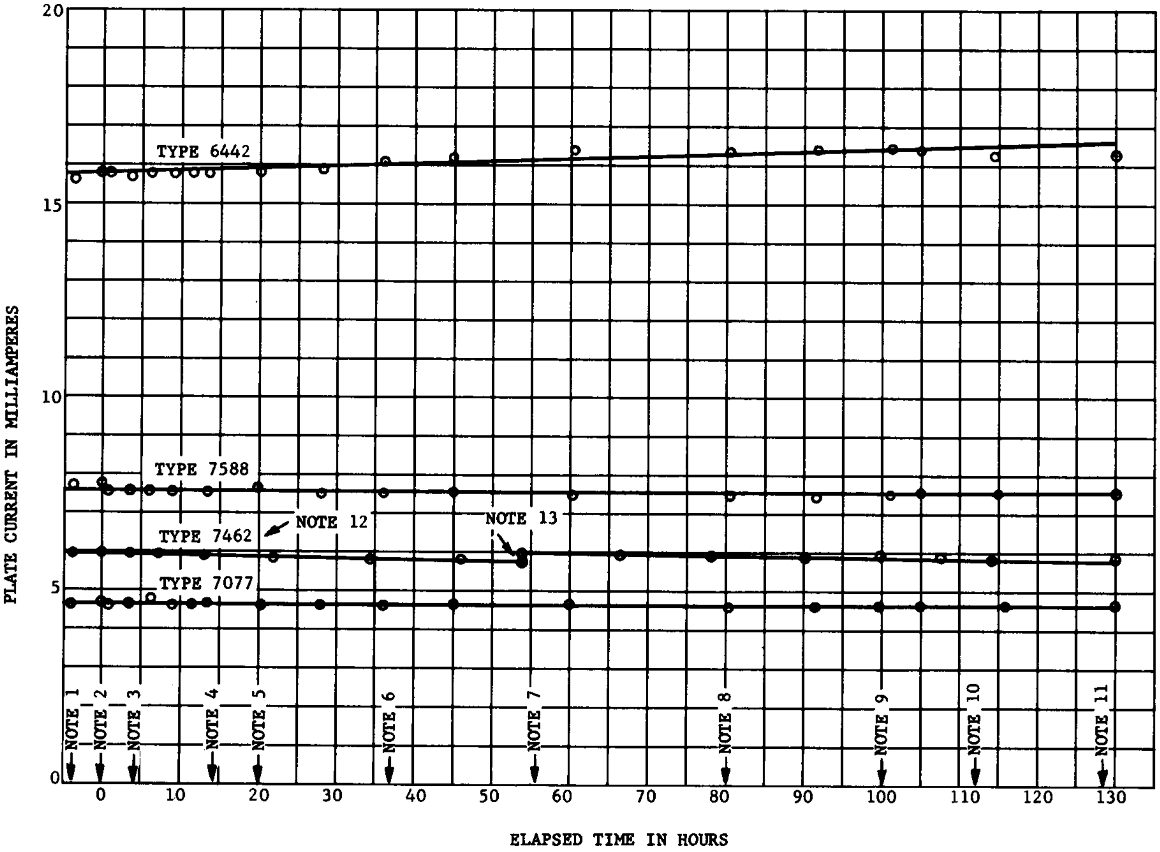


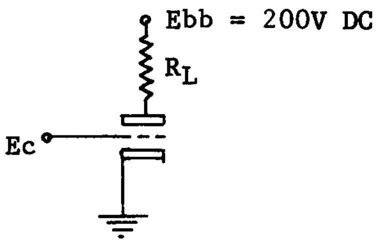
FIGURE 1

Notes:

1. Reactor output level = 0 Kilowatts
2. Reactor output level = 50 Kilowatts
3. Reactor output level = 150 Kilowatts
4. Reactor output level = 1 Megawatt
5. Reactor output level = 3 Megawatts
6. Estimated dosage = $1.5x10^{-16}$ NVT ($E > 0.3$ Mev) and $1.8x10^{10}$ Ergs/GM(c) All dosages are estimated on the basis of previous dosimetry of the source.

7. Estimated dosage = 3×10^{16} NVT ($E > 0.3$ Mev) and 3×10^{10} Ergs/GM(c)
8. Estimated dosage = 5.5×10^{16} NVT ($E > 0.3$ Mev) and 5×10^{10} Ergs/GM(c)
9. Estimated dosage = 7.5×10^{16} NVT ($E > 0.3$ Mev) and 7×10^{10} Ergs/GM(c)
10. Final estimated dosage = 1×10^{17} NVT ($E > 0.3$ Mev) and 9×10^{10} Ergs/GM(c)
11. Reactor shut down at 128 hours.
12. The 7462's were approximately 10 inches further away from the reactor than the other tubes. Therefore, for these tubes divide both neutron dose and gamma dose by 2.
13. The bias battery for the amplifiers was changed at this point.

Test Circuit



No. of Tubes	Type	Test Conditions	
		Ec	R_L
5	6442	-1.0V	3.3K
5	7588	-0.5V	10K
5	7077	-0.5V	20K

Plate current of the 18 type 7462's in the 60 MC amplifiers was obtained by measuring voltage drop across each cathode-bias resistor.

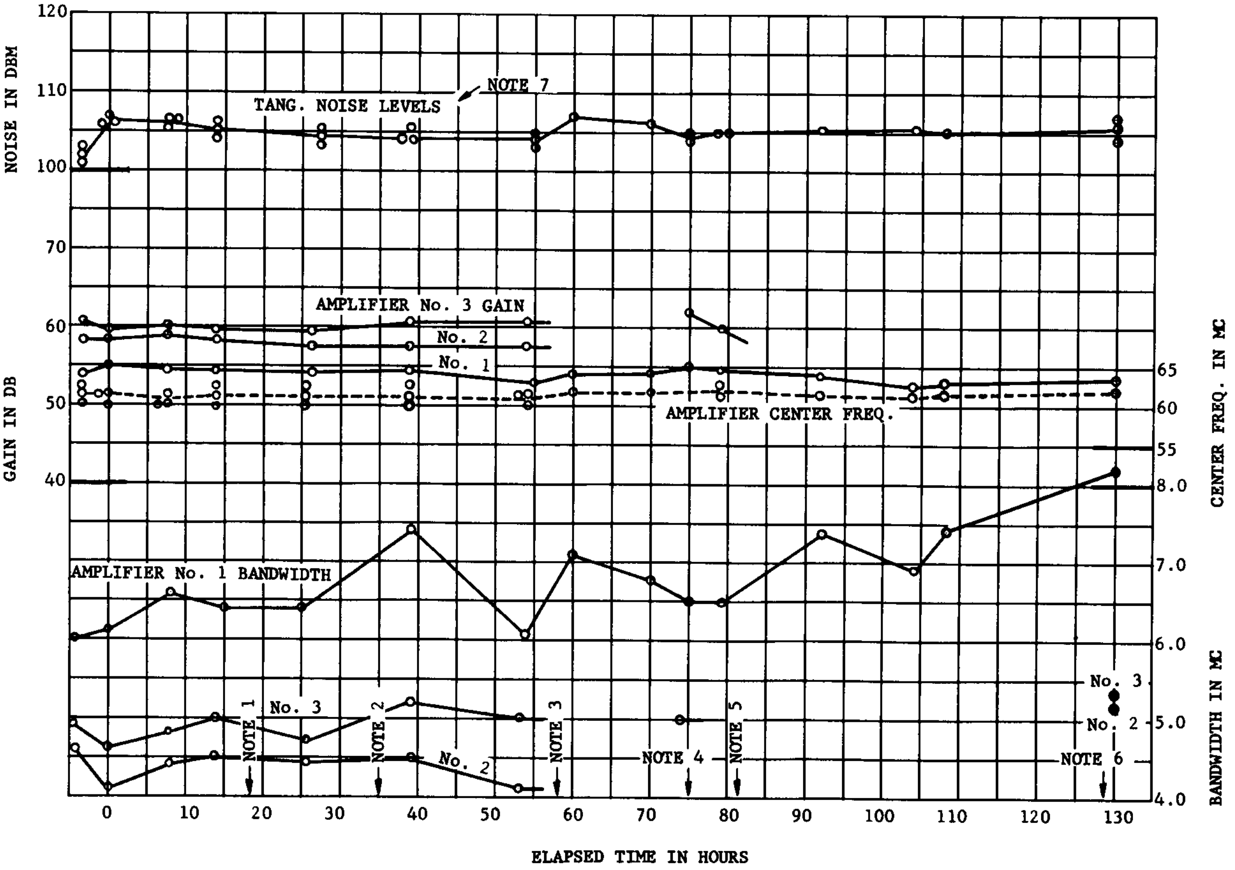


FIGURE 2

Notes:

1. Design and test gamma dosage goal - $3x10^9$ Ergs/GM(c)
2. Design and test gamma dosage goal - $1x10^{16}$ NVT ($E > 0.3$ Mev)
3. Amplifiers #2 and #3 failed. Estimated dosage - $2.5x10^{16}$ NVT ($E > 0.3$ Mev) and $3X10^{10}$ Ergs/GM(c)
4. Amplifier #3 operating again and stable
5. Amplifier #3 intermittent from here to shutdown
6. Reactor shut down at 128 hours. All three amplifiers operating within two hours after shutdown.
7. Noise levels not best obtainable. Amplifier inputs were loaded with 2.2K grid resistors and matched to a 50-ohm input cable for desired bandwidth and minimum VSWR.

Gain - Insertion gain was measured using a small-signal r-f pulse.

Noise - Tangential noise is the DBM level of small-signal r-f pulse equal in amplitude to the noise. This does not show the low noise capabilities of the 7462, because the shunt resistor used in the input of the 60-MC amplifier was chosen to obtain the desired bandwidth and low VSWR rather than minimum noise.

Center Frequency and Bandwidth - These were both measured by observing, with an oscilloscope, the swept response of the 60-megacycle amplifiers. The length of coaxial cable required (200 feet) between the amplifiers and the measuring equipment, and its exposure to the reactor environment, are believed responsible for most of the variations in bandwidth recorded.

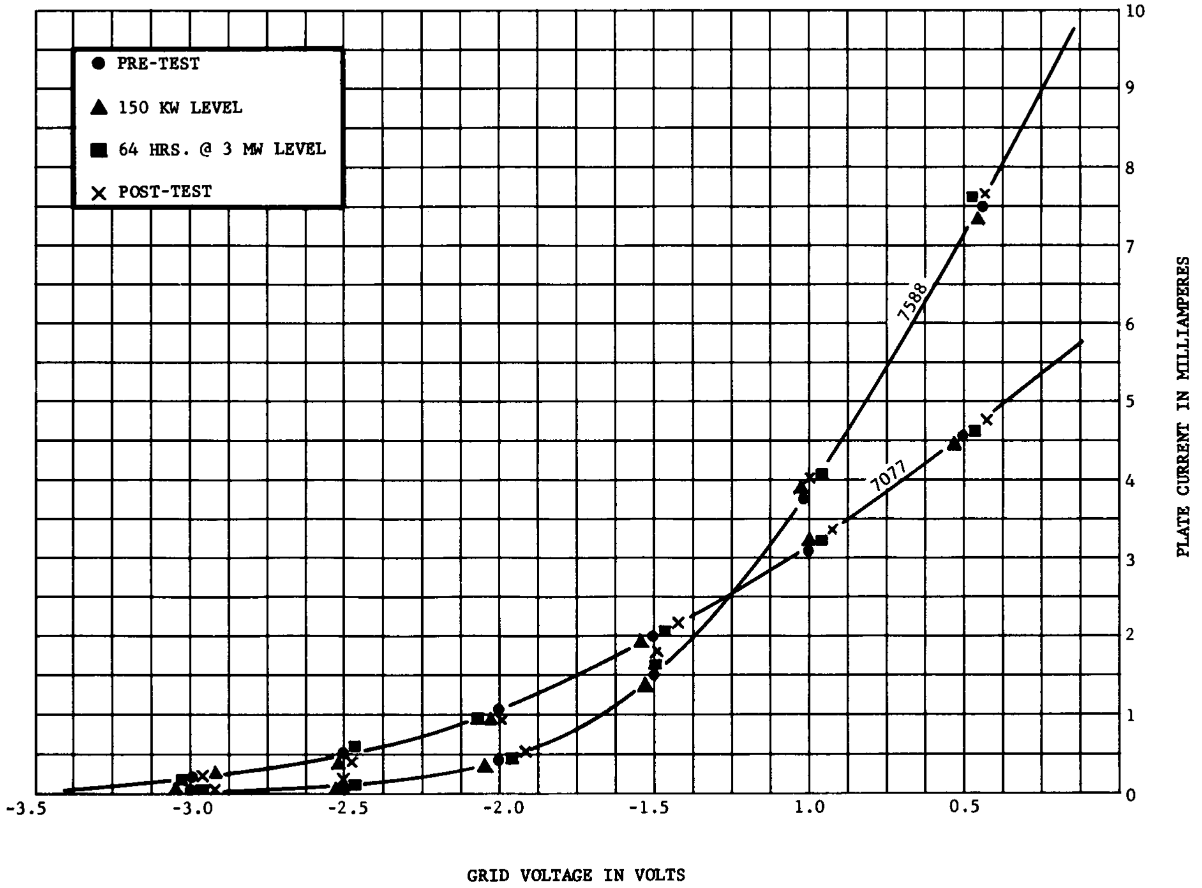


FIGURE 3

Figure 3 shows the average variation in plate current with bias for 5-tube samples of the 7077 and 7588. These measurements were made four times during the tests. Where the four readings are shown in line with the curve, they were so close together that they could not be distinguished when the curve was plotted.

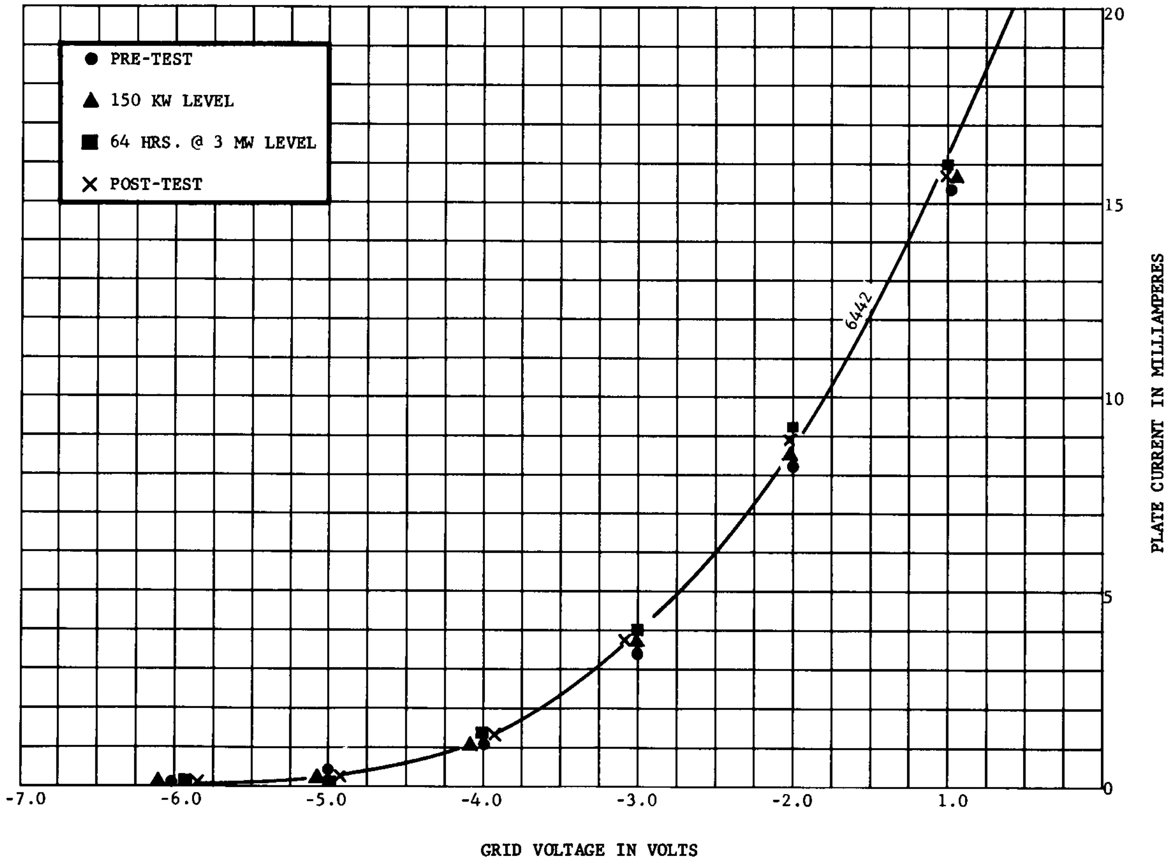


FIGURE 4

Figure 4 presents data for the 6442, similar to that presented in Figure 3 for the 7077 and 7588.

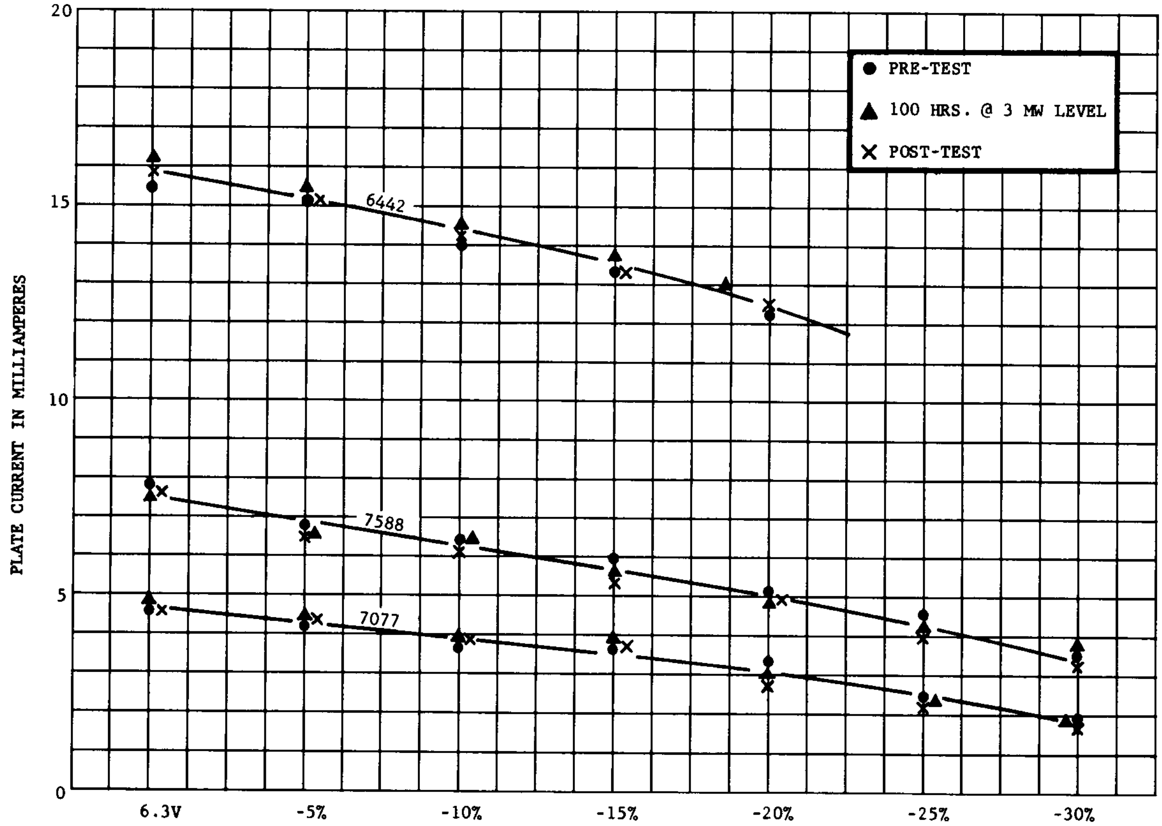


FIGURE 5

Figure 5 shows changes in plate current resulting from variation in heater voltage for the 6442, 7077, and 7588. A ten-minute period was allowed between each heater voltage change in order to stabilize the readings.

Prepared and distributed by Technical Data Unit, Receiving Tube Engineering, Owensboro, Kentucky on the basis of information obtained in tests that were made under Air Force Contract AF33(657) 8686 for which a manufacturer other than General Electric was the prime contractor.

#62-463

APPLICATION NOTES ON A NEW 50,000 MICROMHO PLANAR CERAMIC TRIODE

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Introduction

More recent electronic systems feature performance that demands maximum gain at wide bandwidths and state-of-the-art noise figures. Compromises have been made in system performance because the best active components, vacuum tubes for example, could not operate reliably in the required environments. Recent advances in vacuum tube technology have in fact, constituted a breakthrough which provides structures yielding both high electrical performance and tolerance to high shock and vibration, high temperature and strong nuclear radiation.

To provide maximum performance the planar ceramic triode, 7768, was designed for maximum transconductance, minimum capacitance, and minimum transit times. The use of planar structures, ceramic insulators, high temperature seals, and a newly developed grid structure makes these high performance features useful in almost all military and commercial applications. The 7768 triode is about one inch long and about three quarters of one inch in diameter. See Figure 1. This figure shows the grounded grid configuration chosen for the tube. The cutaway view illustrates the internal planar structure. The most significant internal dimensions of the 7768 are its hot grid to cathode spacing of about 1.3 mils, its 768 turns per inch grid with .4 mil grid wires, and .34 square centimeters of active cathode surface.

For low microphonics and resistance to shock and vibration the grid structure has two support wires wound at right angles to the smaller grid wires. Each .4 mil wire is brazed to the larger support wires to obtain a reliable grid as well as provide more efficient heat flow from the grid. These features greatly increase the tube's tolerance to abnormal signal overloads.

The 7768 has been subjected to 450 G's in three planes without damage in a Mil Spec test. Other development types similar to the 7768 have survived centrifuge testing up to 20,000 G's when properly oriented for maximum tolerance. Soft moon-landings have been simulated and the 7768 structure has survived 3,000 G's for 3 to 5 milliseconds. The structure has also survived pressures greater than found at the deepest known ocean depths.

Input Impedance

It is difficult to accurately define the equivalent input circuit for a tube designed for grounded grid service. Existing measuring techniques are not very accurate and the transit time loading is masked by the low dynamic input resistance of this mode of tube operation. To minimize measurement errors, a special slotted line was built to maintain a constant Zo to the tube cathode ring. Since the input impedance is affected by the tube plate load short-circuited input impedance measurements were made by by-passing the tube grid and anode at the measured frequencies. The results of these measurements are shown in Figure 2, for a cold tube and an operating tube drawing rated plate currents. The "C_{in}-cold" curve represents the passive input reactance of the tube. The "R_{in}-cold" plot is definitive of both the input ceramic losses and the tube's cold cathode coating loss. To minimize ceramic losses both low loss ceramics and built-in sublimation shields are used. The "C_{in}-hot" plot illustrates the rise in input capacitance due to space charge effects and the thermal expansion of the cathode support cylinder. The latter effect has been minimized by the proper selection of materials. No Miller effect is present since the tube anode is at RF ground.

The "R_{in}-hot" curve illustrates the low dynamic input resistance of the grounded grid stage. At low frequencies this is approximately equal to the reciprocal of the tube's transconductance. The reduction in input resistance with increasing frequency can be used to estimate transit time loading. One normally assumes the input resistance consists of the parallel combination of 1/gm and the transit time resistance. The results shown here agree approximately with the determination of transit time loading from the noise contributed by induced grid noise.* One would normally assume that the tube's input reactance would be independent of frequency and the changes in input capacitances at the highest frequencies would be questioned. The rise in cold capacitance and the fall in hot capacitance is assumed to be due to series inductances in the test jig and the internal tube parts.

RF Performance

One of the major design objectives for the 7768 was low noise figure. To obtain minimum noise figures, the circuit designer must remember that low loss circuitry must be used and the tube cathode must see the tube's optimum source resistance. Figure 3 shows the optimum source impedance for the 7768 as a function of frequency. The plotted minimum available noise figures assume no circuit losses, no second stage noise, and optimum source impedance for the tube.

It must also be remembered that minimum noise figures also require proper DC biasing. Figure 4 shows noise figure contours drawn over the tube's plate characteristics. Minimum noise figure is obtained at maximum transconductance and bias levels sufficient to prevent any grid current flow.

Figure 5 shows the 7768 small signal power gain compared to the smaller planar ceramic triodes, the 6299 and 7077. The active cathode surfaces of the 7768, being much larger than that of the two smaller types, provides higher

*Rothe, H. and Dahlke, W. "Theory of Noisy Four Poles", Proceedings of the I.R.E. June 1956.

levels of transconductance at lower values of cathode current density. The high transconductance and high mu, about 225, of the 7768 provides state-of-the-art gain figures. The low transit times obtainable from planar structures provide useful gains well into the kilomegacycle region.

Tube to Tube Variation

The extremely close spacings necessary for efficient use of available emitting surfaces and high frequency performance require mechanical tolerances much smaller than practical for conventional tube structures. Even though extreme care is used in the mechanical construction of the 7768, tube-to-tube variations may still occur due to other causes such as cathode activity. Reasonable production maximum and minimum limits are used based on both economical and acceptable performance spread considerations. To provide additional reduction in the variation of performance from tube to tube and to permit use of the tube near its maximum ratings, various biasing methods can be used.

Figure 6 shows three typical biasing methods. Method A uses a fixed E_{bb} and a cathode biasing resistor. Method B uses a higher value of E_{bb}, a plate dropping resistor, and the same value of cathode resistor used in Method A. Method C is called a buck-boost circuit. The same E_{bb} voltage shown in Method A is used with a cathode resistor much larger than before. To provide the proper tube bias, an external bias voltage is required. Method A represents the simpliest bias circuit. To prevent limit tubes from drawing excessive plate current, the average tube must be operated at relatively low plate currents. This results in a lower average transconductance. Method B requires no external bias source to obtain a narrower plate current spread but does so at the expense of higher E_{bb} values and the power loss in the plate dropping resistor. Method B provides almost constant bias from tube to tube. Method C is the most efficient bias method. A very narrow spread in plate currents is obtained and a similar tight control of plate dissipation results. Methods B and C would also provide more uniform performance with life when compared to Method A. Figure 6 also serves to illustrate the approximate quantitative characteristic spreads from tube to tube. The plotted data represents about fifty tubes from two production lots.

Socketing

The mechanical configuration of the 7768 was chosen to permit tube usage from low frequencies to maximum usable frequencies limited only by tube transit time effects. At lower frequencies commercially available sockets can be used. At strip-line and coaxial circuit frequencies, connection can be made directly to the tube elements. At higher frequencies the use of socketless techniques are recommended since the tube's latent performance can be seriously degraded by socket loss and capacitance. The 7768 construction, being of temperature tolerant metal and ceramic, also permits solder-in circuit techniques. This feature can offer advantages of more reliable connections, socketless circuitry, and rigid tube mounting for extreme mechanical environments. Although the structure is tolerant to temperatures much higher than used for normal soldering, care must be taken to minimize excessive thermal transients at the tube seals. Figure 7 suggests several methods of connection to the 7768 triode. These techniques are useful at all frequencies where the lead inductances are not critical and where maximum gain-bandwidth performance is desired.

Measured Performance

Although the high value of gain-bandwidth product available from the 7768 makes it most attractive in wide-band circuitry, its usefulness is not limited to these applications alone. The tubes have seen usage at sub-audio frequencies where flicker noise predominates and the basic structure has been evaluated to C band frequencies.

Most of the established performance has been determined in VHF and lower UHF regions. Figure 8 shows the measured gain and noise figures for a two stage 7768 amplifier covering the complete VHF telemetering band from 225 to 260 mc. Figure 9 shows the triple tuned interstage circuit used. A broadband single-tuned input circuit is used to present the optimum source resistance to the first stage. Figure 10 shows a top and bottom view of a similar two stage amplifier.* These photographs illustrate the use of commercially available sockets and the relative simplicity of the triple-tuned circuitry used. This particular amplifier is broadbanded from 225 to 245 mc. and uses a passive resistive network to provide three identical outputs.

Figure 11 is a photograph of a two stage double-tuned 1000 mc. amplifier. This circuit features socketless circuitry and the use of flat resonant lines foreshortened with variable capacitors. Coupling between resonant elements is obtained by means of two small ceramic bypass capacitors placed thru two small holes in the inter-section shields. An overall gain of 38 db. at a 3 db. bandwidth of 15 mc. was measured. A single stage double-tuned 7768 amplifier was constructed using similar techniques. Various gains were measured as a function of amplifier bandwidths. An approximate calculation of tube-circuit bandwidth can be determined by:

$$G\text{-}BW = \frac{gm}{2\pi C_T}$$

where C_T is the total interstage grounded grid capacitance. Estimating the stray capacitances, one obtains a C_T of about 5 pf including the tube's grid to plate capacitance. This gives a G-BW product of about 1600 mc. Actual measurements on the single stage 1000 mc. amplifier gave the following results:

Gain	3 db BW	G-BW
12.0 db	100 mc	1600 mc
14.5 db	50 mc	1400 mc
17.0 db	20 mc	1000 mc
19.0 db	10 mc	800 mc

These results show among other things the effect of poorer circuit efficiency at narrower bandwidths. Power gain is estimated to be equal to:

$$G = gmR_L$$

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*Photo courtesy of the U. S. Naval Avionics Facility in Indianapolis, Indiana.

where R_L is the plate circuit load. This is an approximation assuming broadband conditions where $R_L \ll r_p$ of the tube which is about 4500 ohms.

Life Tests

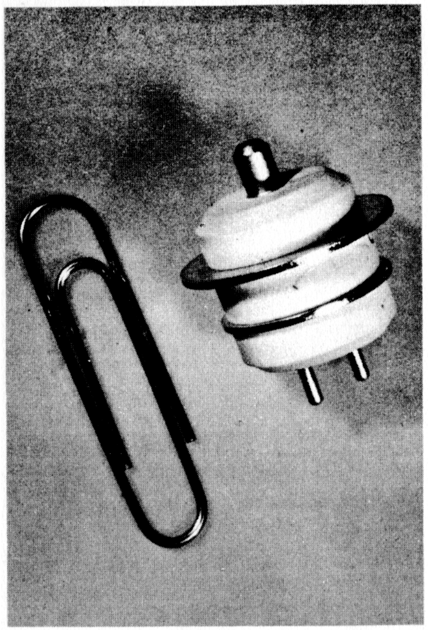
Although extensive life tests have not been completed for the 7768, its lug type counterpart has been life tested in excess of 5000 hours. Figure 12 illustrates the excellent life characteristic obtained from this tube construction. The cathode temperature is designed for long life at rated heater voltage, 6.3 volts, and this temperature has been found to be sufficient for all Class A service and optimum for minimum noise figure. Tests at lower and higher heater voltages have shown no useful improvements in noise performance when operated at rated Class A conditions.

Conclusion

The 7768, a new metal-ceramic triode, has demonstrated the excellent RF performance predicted on the basis of the tube's very high transconductance and efficient high frequency construction. High gain and low noise figures can be obtained under conditions of long life and high reliability.

The writer wishes to thank W. P. Kimker, Coy Jackson and J. D. Campbell of the General Electric Company, Receiving Tube Department, for their assistance in the preparation of this paper and the test results shown therein.

NOTE: The disclosure of any information or arrangement herein conveys no license under any patents of General Electric Company or others. In the absence of an express written agreement to the contrary, the General Electric Company assumes no liability for patent infringement (or any other liability) arising from the use of such information by others.



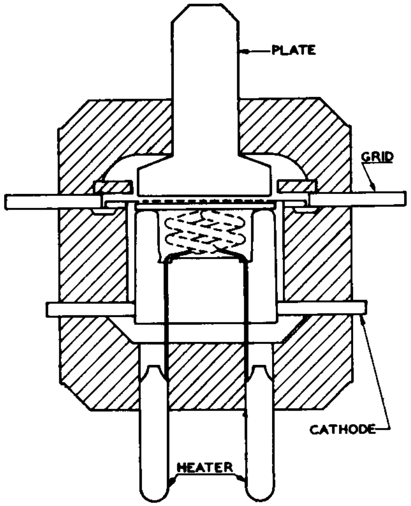


FIGURE I

7768 INPUT CHARACTERISTICS

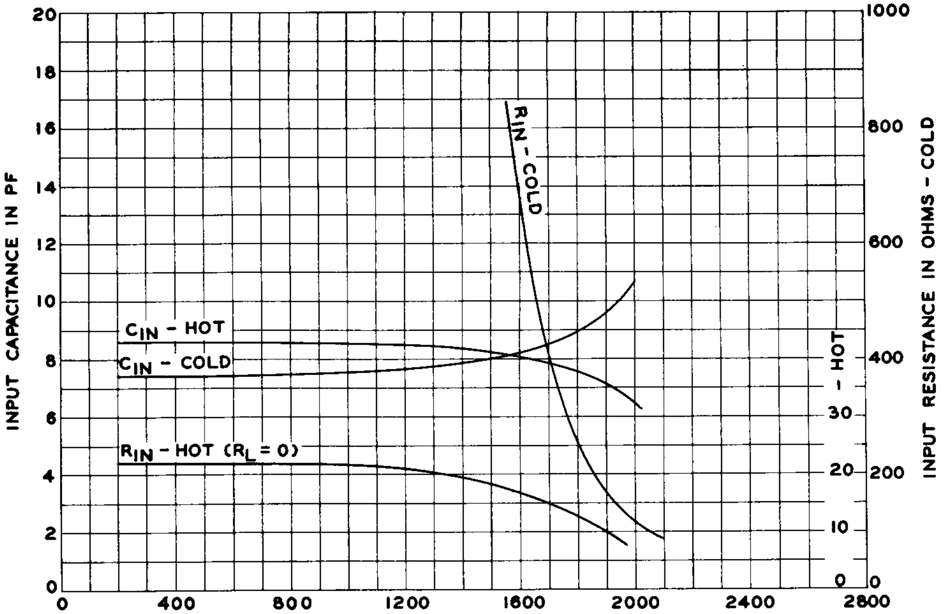


FIGURE 2

7768 NOISE PERFORMANCE

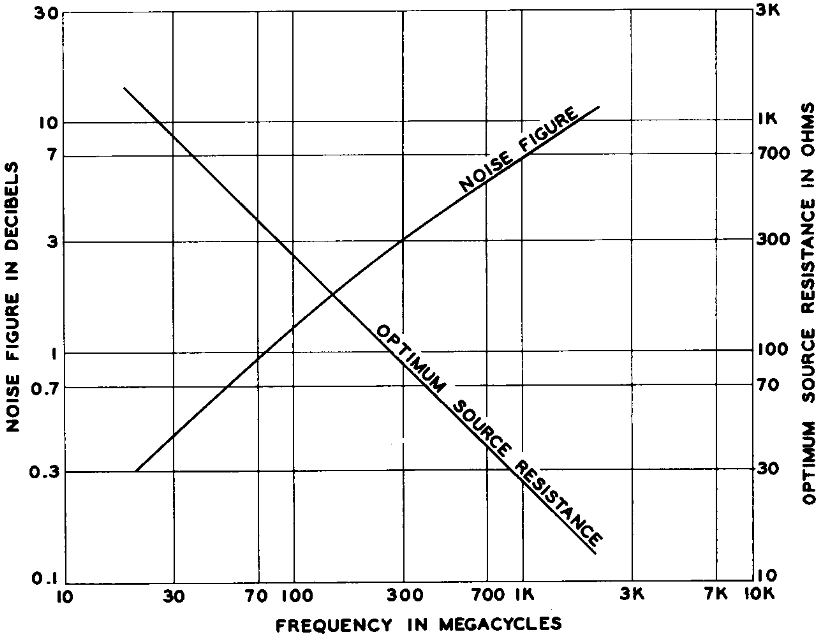


FIGURE 3

TYPE 7768

AVERAGE PLATE CHARACTERISTICS

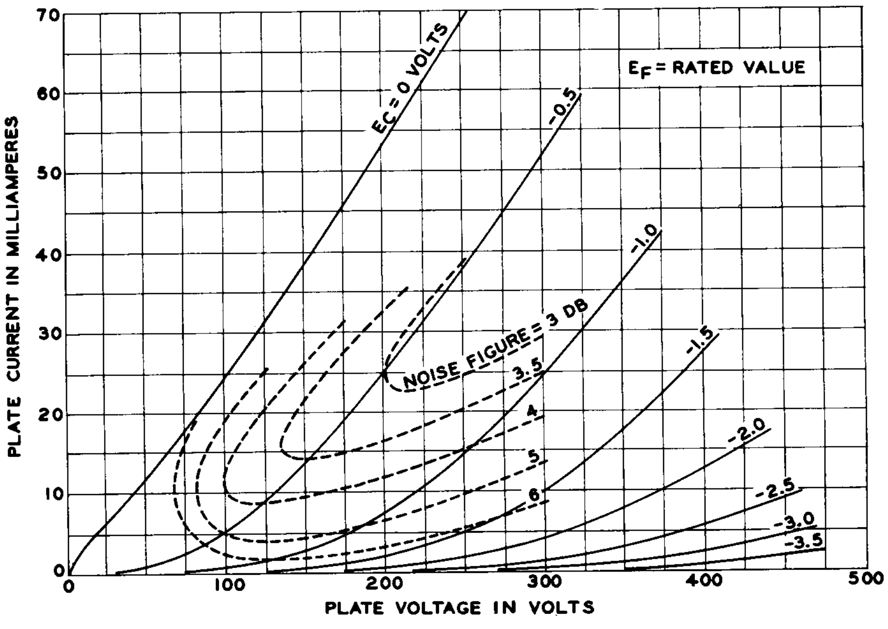


FIGURE 4

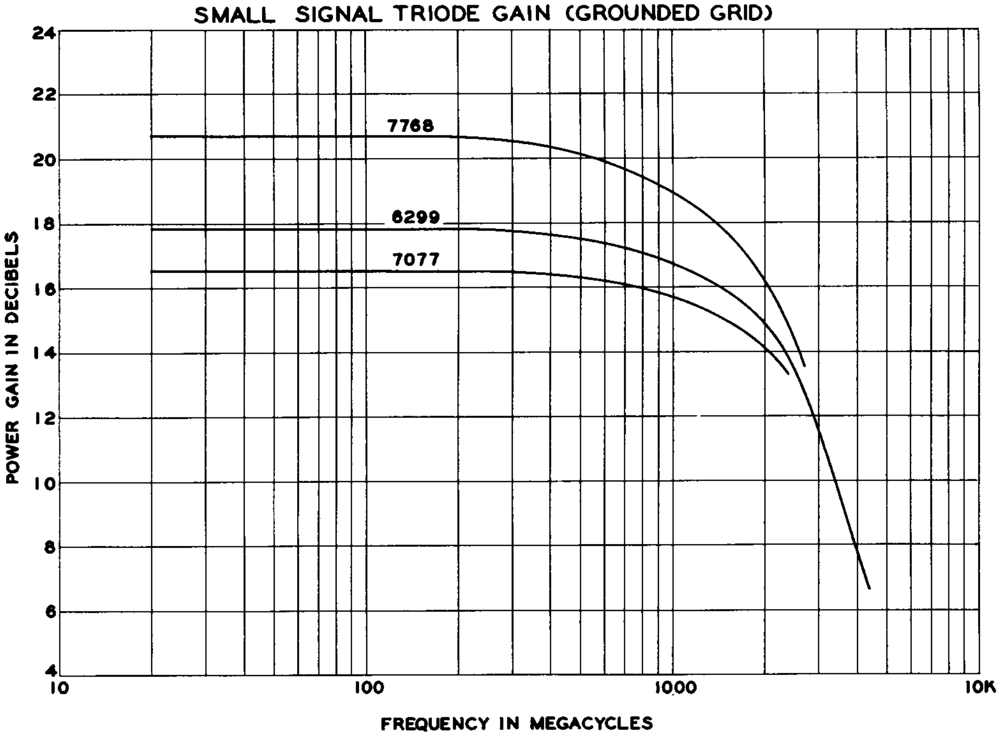


FIGURE 5

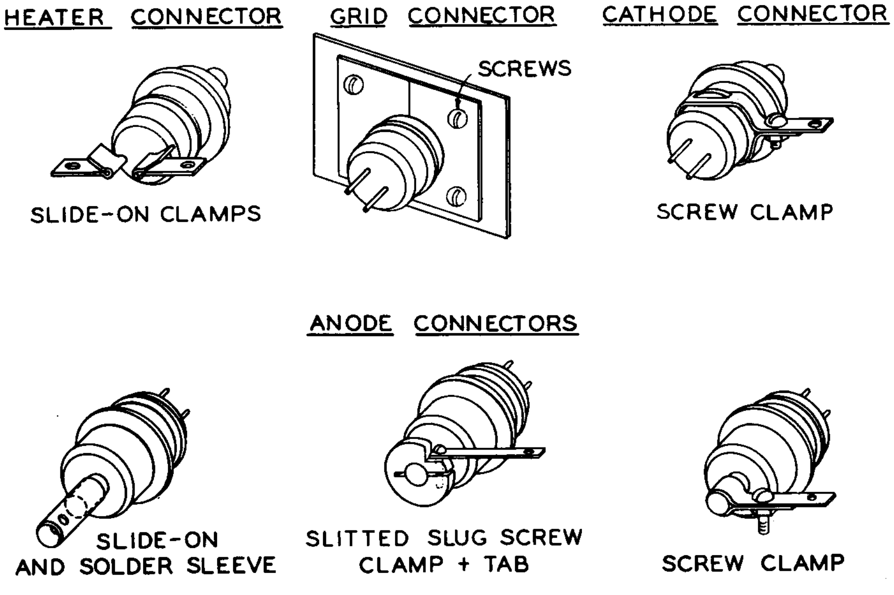


FIGURE 7

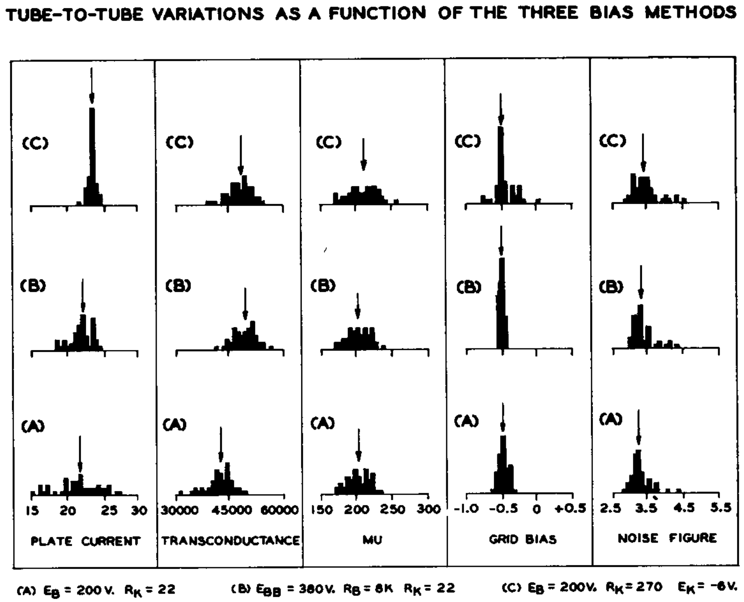


FIGURE 6

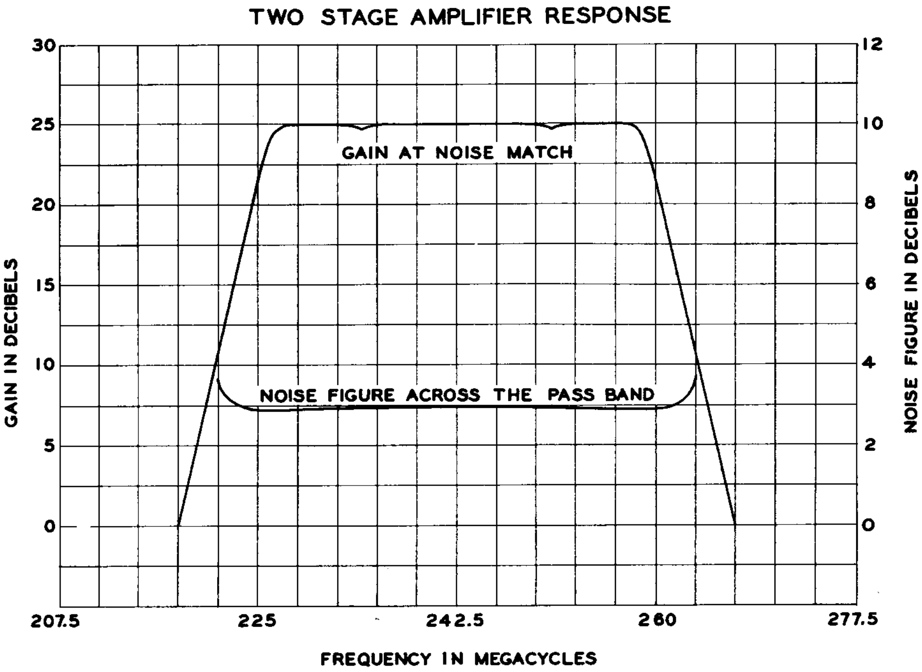
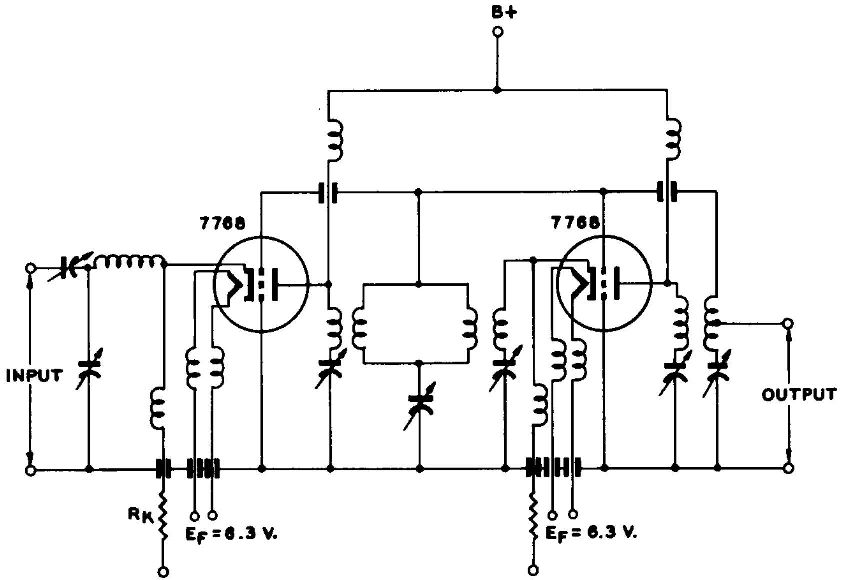


FIGURE 8



VHF BROADBAND AMPLIFIER

FIGURE 9

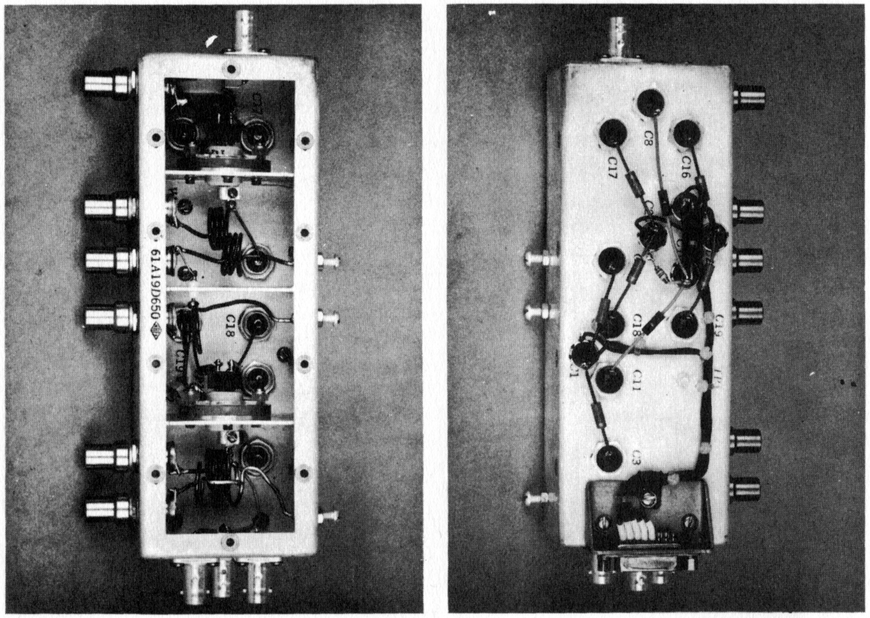


FIGURE 10

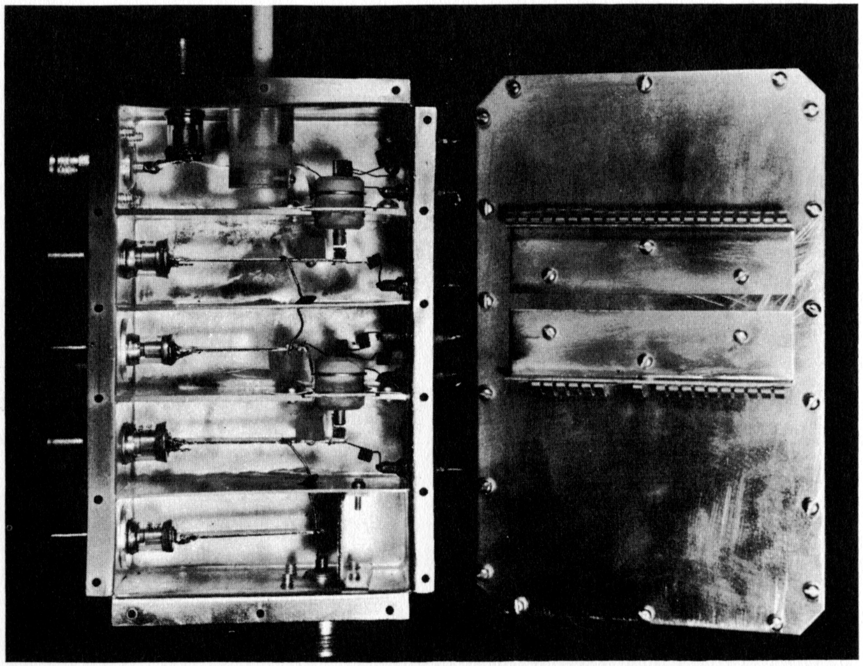
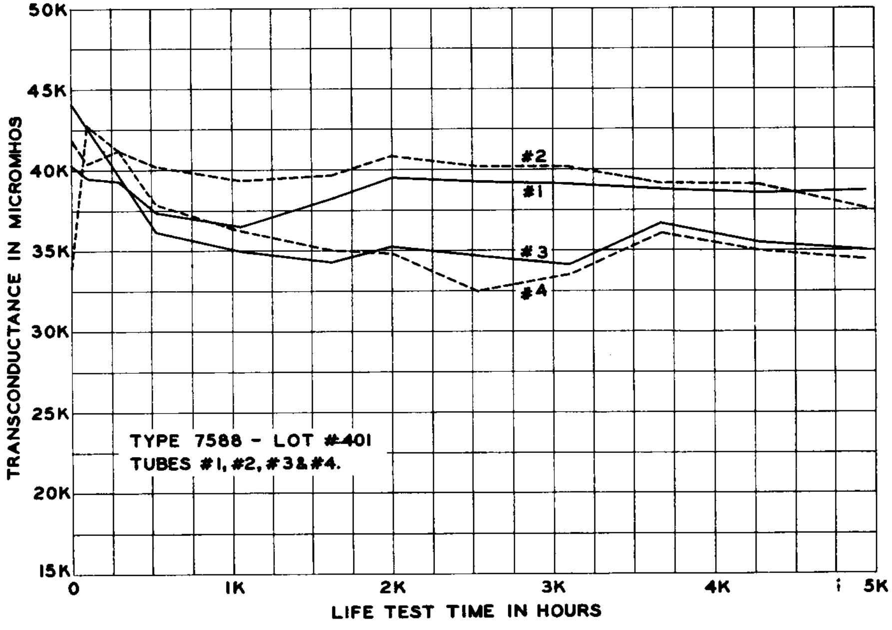


FIGURE 11



TRANSCONDUCTANCE VS. TUBE LIFE

FIGURE 12

EI-49
March 27, 1963

PRECAUTIONS TO BE OBSERVED IN TESTING HIGH-FREQUENCY PLANAR TUBES

Introduction - Testing of close-spaced, high-performance, high-frequency planar tubes presents difficulties that may be overlooked and may account for misleading results or damage to the tubes being tested. Many commercially available tube checkers are not satisfactory for checking these tubes, and an effort should be made to determine if the checkers meet the requirements listed below before they are used.

Short and Leakage Tests - When grid-to-cathode leakage and shorts are checked, the maximum voltage applied between grid and cathode should be 100 volts, with the grid negative with respect to the cathode. Some checkers use a neon bulb in series with an a-c source and a capacitor to check for shorts and leakage, and apply peak-to-peak voltages as high as 250 volts between grid and cathode. This type of circuit can indicate shorts and leakage when it should not, and its use may permanently damage the tube being tested.

Test Conditions - In order to obtain values of plate current and transconductance comparable to those listed on the tube data sheets as "Initial Characteristics Limits", it is necessary that the tubes be tested under the conditions given on these sheets. This includes using the indicated values of heater voltage, plate voltage, and grid voltage.

Oscillation - When high-Gm tubes are tested, radio-frequency tank circuits are often formed by the leads external to the tube, and oscillation often results. This oscillation will give misleading results and is usually manifest by variations in plate current as leads external to the tube are moved or a hand is brought near the tube. This oscillation can usually be stopped with chokes and bypass capacitors at the test socket.

Cooling - It is important that the envelope temperature rating is not exceeded during testing. If testing is prolonged, some means of cooling may be required. This may be accomplished by means of a heat sink or with forced air.

Sockets for Testing - Sockets suitable for use in fabricating adapters, and complete adapters for some tube types, may be obtained from several socket manufacturers. The following manufacturers may be contacted for information on sockets and adapters:

Community Engineering Corporation
State College, Pennsylvania

Instruments for Industry, Inc.
101 New South Road
Hicksville, New York

Jettron Products, Inc.
56 Route 10
Hanover, New Jersey

In Case of Difficulty - If your results in testing planar tubes are unsatisfactory, contact your General Electric Sales Representative, giving details of your test.

Prepared and distributed by Technical
Data Unit, Receiving Tube Engineering,
Owensboro, Kentucky, on the basis of
information supplied by Mr. S. E. Peach
of Application Engineering.

A NEW MICROWAVE TRIODE FOR PULSED OSCILLATOR SERVICE

J. D. Campbell J. W. Rush
General Electric Company

Introduction

Many types of microwave equipment require a few kilowatts of pulsed power output where small size, light weight, and low power consumption are important. Typical examples of these kinds of equipments are altimeters, radar beacon transponders, and distance measuring equipment. While existing pulse triodes were designed primarily for service up to 3500 megacycles, many applications require a performance range including frequencies up to 6000 megacycles.

The most important requirements for a tube in this service are low power consumption, small size, low interelectrode capacitances, low loss insulators, low inductance connectors and low transit-time loading. The planar metal-ceramic structure of the Z-2867 incorporates an optimum combination of these design requirements. Its size is smaller than either of the pulse triode types 6442 or 7815 as shown in Figure 1. However, the Z-2867 is larger than the Z-2866, a 100 watt pulsed triode shown for comparison. The Z-2867 has a maximum contact ring diameter of 3/4" and is 7/8" long including heater pins and anode connector.

Tube Design Features

The configuration and spacing of the electrode contacts (Figure 2) were chosen to present acceptable impedance values and feedback in a reentrant cavity oscillator. The anode diameter is reduced in the seal area to compensate for the dielectric constant of the ceramic and reduce the discontinuity in the impedance of the grid-anode circuit. The anode insulator was made as thin as possible, consistent with anode dissipation requirements, so that the short grid cylinder required for 6000 Mc operation would have a relatively small portion of its volume occupied by ceramic material and thereby minimize losses. The ceramic material used is especially designed for low dielectric loss at UHF frequencies.

All external contacts are titanium base material which is first nickel plated and then gold plated to provide the best possible contact to cavity components. Losses may be further reduced by soldering the components directly to the tube contacts. This practice is especially desirable for the heater supply voltage connection, since this will eliminate any voltage drop due to contact oxidation during life. The resulting stability of cathode temperature serves to assure longer life. However, the life tests described in this paper were not conducted with soldered connections since the test cavities were not subjected to a corrosive atmosphere.

The high peak cathode currents required for best performance of pulsed oscillators generally require higher cathode temperature than for CW operation. Therefore, maximum heat transfer from heater to cathode should be employed to hold heater power consumption to a minimum. In addition, good heat transfer would allow the heater to operate at a low temperature, thus improving life expectancy. The flat spiral heater-cathode structure shown in Figure 2 requires 20% less power for the same cathode temperature than is required by the more commonly employed helical coil. A heat shield which holds the coil in place reflects heat to the coated cathode cup and conducts heat to the outer perimeter of the cup.

A ceramic sublimation shield prevents changes in insulation and capacitance between grid and anode during life. This provides good frequency stability and holds RF losses to a minimum.

The cathode support cylinder of this tube is uniformly welded to the cathode and cathode contact so that no deformation will occur at acceleration levels up to 4000 G, with no voltages applied. If the tube is mounted in the preferred position so that the acceleration places the support in tension, levels up to 15,000 G will give only slight distortion of the cathode. The other tube components will survive even higher accelerations.

The component parts of this tube are vacuum fired prior to assembly to remove residual gases. The tube is sealed by aligning all the parts in a jig which applies axial pressure. The tube assembly is pumped to a high vacuum and baked out to remove gases and water vapor. As the temperature is further raised, cathode activation gases escape between the unsealed surfaces of the tube. The tube is finally sealed at about 1000° C by a nickel titanium eutectic. The high temperature of these parts during sealing results in a relatively gas free tube which should not suffer emission slump during life due to gas poisoning.

Other pulse triodes have frequently employed active cathode base material to obtain maximum initial pulse capability. It is well known that active materials allow emission to deteriorate and interface resistance to form more rapidly during life than do passive materials. The Z-2867 uses passive cathode nickel with an optimum processing schedule to achieve the required pulse emission capability. This insures more stable performance on life due to a slower cathode activation rate.

Test Cavity

To determine the pulsed power outputs available from the Z-2867 a laboratory test cavity was developed (see Figure 3). During the development of the Z-2867 it was necessary to test a wide variety of development samples and the test cavity design required as many adjustable features as practical. The basic design is the familiar re-entrant configuration. The frequency of operation is determined principally by the length of the grid cylinder and the position of the anode by-pass plunger or choke. The feedback is principally adjusted by the position of the cathode with respect to the short circuit at the cathode end of the cavity. This distance is about 1/4 of an inch for optimum feedback at about 4200 megacycles. This length was determined by substituting an adjustable cathode assembly not shown. The cavity loading is optimized by sliding the complete center assembly with respect to the fixed output probe. Best results were obtained with relatively close coupling to the grid cylinder, approximately at the position shown in Figure 3.

To obtain maximum power output at other frequencies, optimum adjustment of feedback, grid cylinder length, output probe coupling and anode choke position were necessary. The anode choke is basically a single frequency device and three different lengths were required to obtain the performance from about 4000 to 6000 megacycles. For reference, the cavity body is about five inches long and the inside diameter is one inch. The scaled cavity drawing can be used to estimate the size of the remaining cavity components. A practical production cavity at 4200 megacycles need not be as large as the development cavity shown.

Construction Studies

One objective of this tube development was to obtain maximum utilization of the cathode current by designing for a high plate-to-grid current ratio. This could be achieved by increasing the transparency or percent open area of the grid, but consideration must be given to other characteristics for maximum plate efficiency. Test lots were made with grid wire diameters of .0004" and .001" and grid turns-per-inch from 400 to 750. The grid-to-plate spacing was varied from .0007" to .015", resulting in tubes with Mu's ranging from 13 to 225. The curve in Figure 4 verifies that for the selected test conditions the current division is directly proportional to the transparency, and wire size has a negligible effect. For a given transparency, power output increased as grid wire size decreased, and .0004" diameter wire was selected as the smallest practical wire for the required mechanical strength and dissipation rating. A transparency of 84% was selected for the point of best efficiency.

Transit time loading in plate pulsed triodes where high cathode current densities exist is not as difficult to overcome as in CW operation. However, at microwave frequencies transit time is important even in pulse tubes. The minimum grid-to-cathode spacing of .0025" was chosen, since a closer spacing would have increased the possibility of arcing at the high voltages employed in a typical plate pulsed oscillator.

The original development tubes had an anode insulator of the same thickness as the cathode and heater insulators, which gave a maximum oscillation frequency of about 5200 megacycles with the test cavity described. A reduction in thickness of the anode insulator from .175" to .125" improved performance slightly at the lower frequencies and made it possible for the tube to produce approximately 1.0 kilowatt at 6000 megacycles.

Figure 5 is a plot of power output as a function of frequency for the Z-2867. The performance from 4000 to over 6000 megacycles was measured in the cavity shown in Figure 3. The performance below 4000 megacycles was estimated assuming that the efficiencies at lower frequencies would be similar to that of other pulse triodes. The pulsed input was 3Kv for 1 microsecond at a pulse rate of 1000 pulses per second, thereby providing a duty factor of .001. The peak anode current from the pulse driver was adjusted to 2.5 amperes, and typical peak grid current was .3 ampere, representing a significant improvement in plate-to-grid current ratio over existing pulse triodes. Peak plate voltages and currents were measured using an oscilloscope. The peak grid current was measured by using a milliamp meter in the grid circuit and applying the duty factor to the average meter reading to determine the peak value. The high efficiency at higher frequencies can be attributed directly to the unique design features of the Z-2867 previously discussed.

Life Tests

Tubes were evaluated on the life test units shown in Figure 6.

The pulse driver unit employs conventional lumped-constant delay line circuitry working into a stepup transformer. Pulse output wave shape is relatively flat on top and has rise and fall time characteristics normally found in this type of pulse generator. The one microsecond pulse output is coupled to a 50 ohm 30 db attenuating load from which power output may be measured without disturbing the oscillator circuit.

Life tests were conducted at several levels of heater power in order to select the optimum cathode temperature for longest life (Figure 7). The peak current delivered to the anode by the modulator was held at the rated 2.5 amperes by adjustment of grid bias. A heater power of approximately 3.2 watts (.5 ampere at 6.3 volts) was selected as that required for the optimum cathode temperature for most stable life performance even though initial power output was slightly lower than for the 3.5 watt condition. Visual observation of the cathode coating on the tubes that operated at 3.5 watts showed excessive sintering at 700 hours. Although this life data on the most recent design modifications represents only about 700 hours life, its stability and data on interim design tubes indicate that good performance can be expected to a minimum of 1000 hours. Grid pulse life tests will also be conducted on this tube to give an indication of expected performance in grid pulsed oscillators.

Stability of power output with change in heater voltage was observed in the region of the heater power selected for best life stability (Figure 8). It will be noted that the curve for a fixed grid bias resistor has only a slightly greater slope than for constant plate current.

Plate versus Cathode and/or Grid Pulsing

All of the peak power outputs presented in this paper are plate pulsed values. For maximum available power outputs plate pulsing is essential. The plate pulsed tube can accept more peak voltage for short periods of time without destructive arcing than a tube used with a steady state DC plate voltage pulsed "on" at the cathode or grid. However, input pulsing, grid pulsing, or cathode pulsing, requires considerably less modulating power and where suitable power outputs can be obtained this method of pulsing can be used.

To determine the input pulsed capabilities of the Z-2867, the tube-cavity combination was tested at lower plate-pulsed voltages. Oscillation started at about 800 volts and at 1500 volts about one kilowatt of peak power was measured at 4200 megacycles. At 1500 volts and optimum cavity adjustments, the peak cathode currents observed were considerably less than the maximum rated value using simple grid leak bias. Power outputs in excess of one kilowatt can be obtained by driving the Z-2867 towards zero bias and into the positive grid region. This would require a "stiff" driving pulse, and other problems such as "squegging" and/or "CW-moding" might occur if care is not used. These problems are usually less prevalent when plate or putput pulsing is used.

Conclusion

The Z-2867, a new triode for plate pulsed oscillators, has demonstrated its capability of delivering higher outputs at higher frequencies than other similar devices. Its improved heater and plate efficiency, plus its small size resulting from this advanced design, make a very small pulsed oscillator package possible for the power capability of 1 to 3 kilowatts in the frequency range from 4000 to 6000 megacycles. The high processing temperatures employed in making this tube and the gas clean-up properties of the titanium parts can be expected to contribute to a long-life, reliable tube.

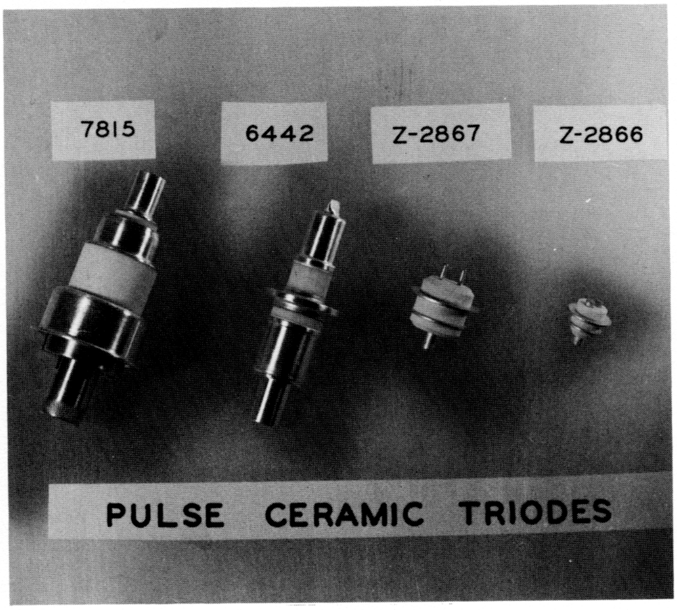
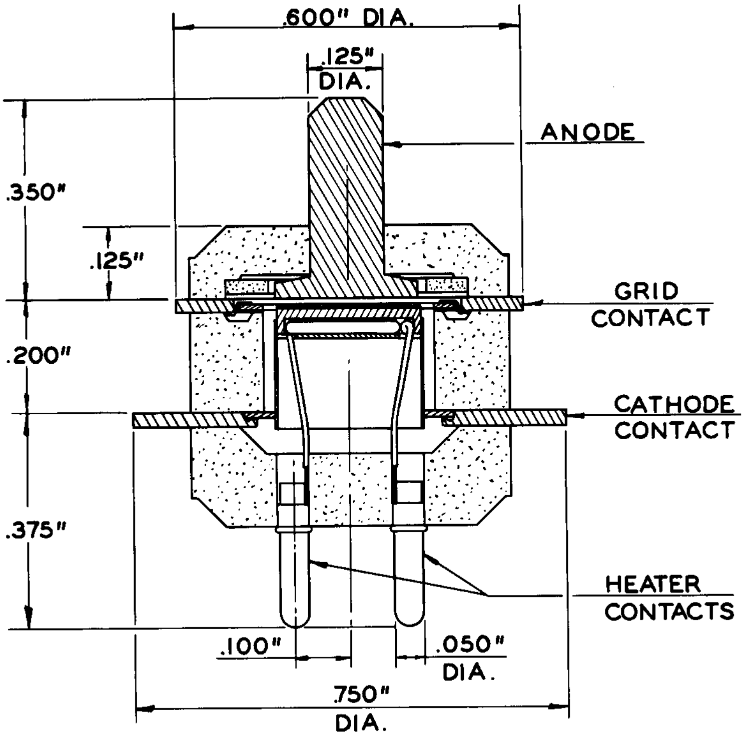
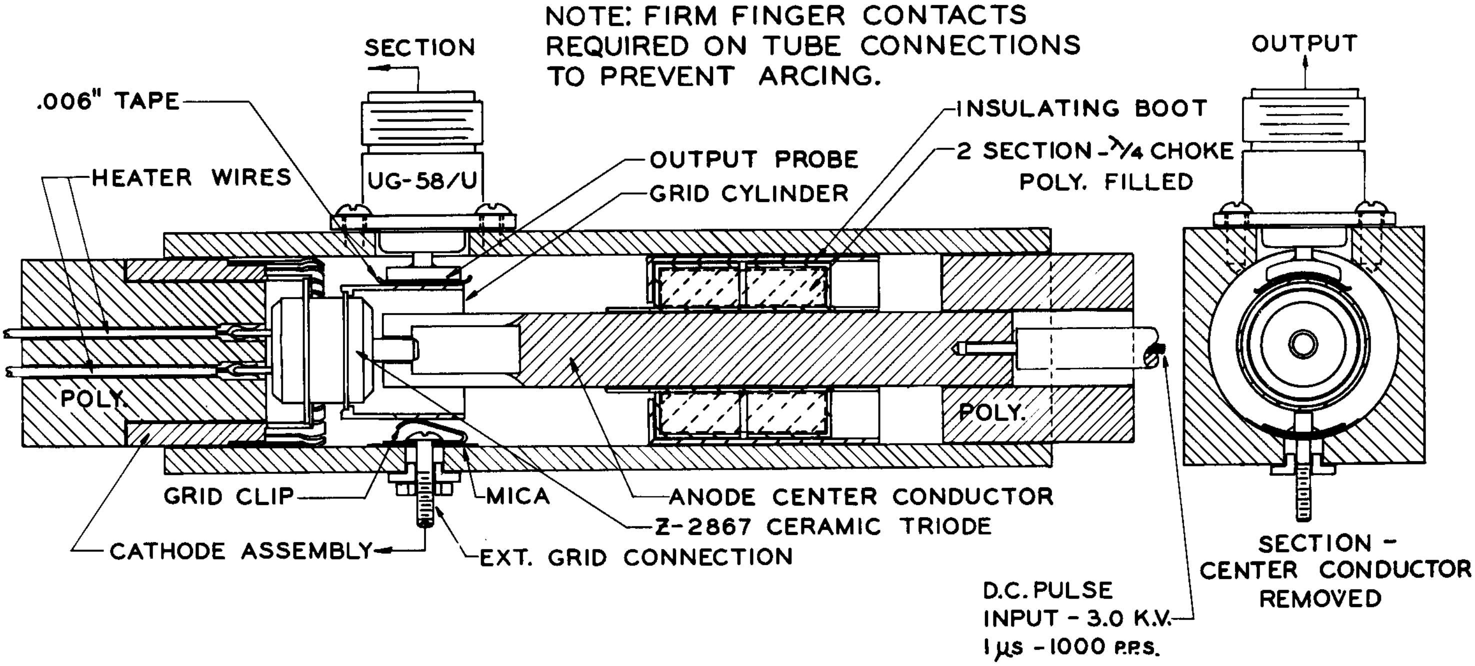


FIGURE 1



Z-2867 CROSS SECTION

FIGURE 2



Z-2867 4200 MC. COAXIAL TEST CAVITY

FIGURE 3

CATHODE CURRENT DIVISION
VS:
GRID TRANSPARENCY

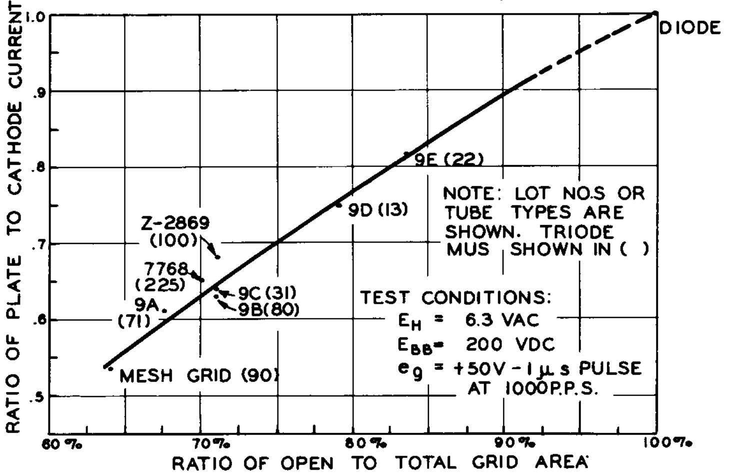
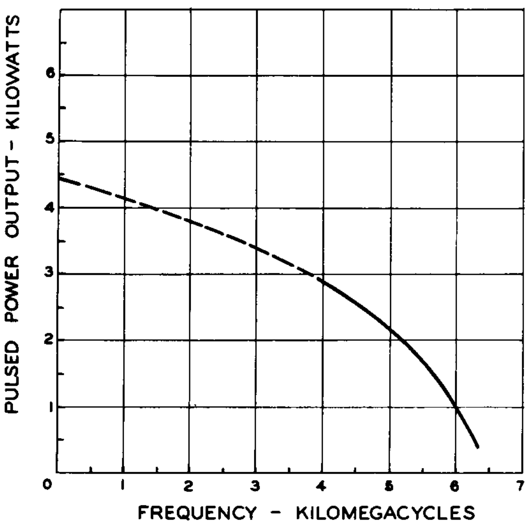


FIGURE 4

Z-2867 PULSED POWER OUTPUT VS: FREQUENCY



TEST CONDITIONS:

E_H = 6.3 VAC
ep = 3 KV
ip = 2.5 AMPS
p.d. = 1 μsec
p.r.f. = 1000 p.p.s.
d.f. = .001

FIGURE 5

FIGURE 6

Z-2867 PULSED OSCILLATOR LIFE

TEST CONDITIONS

ep = 3000 V, 1 MICROSECOND PULSE, DUTY .001
Rg ADJUSTED FOR ip = 2.5 AMPERES PEAK
FREQUENCY - 4200 MEGACYCLES

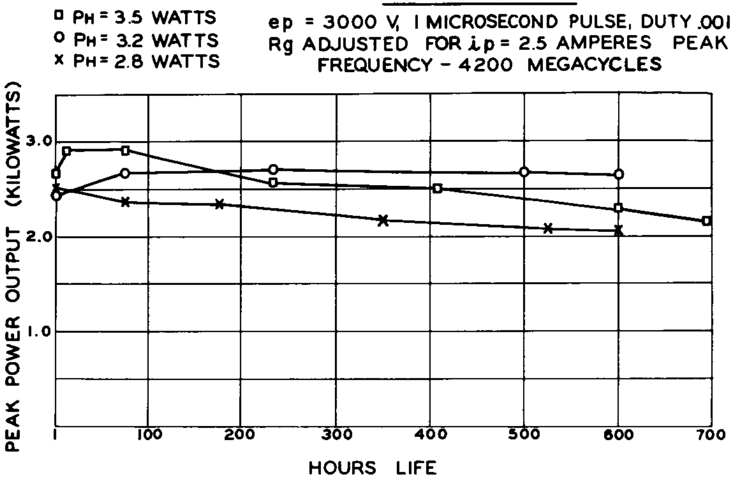


FIGURE 7

TYPE Z-2867

PULSED POWER OUTPUT VS. HEATER VOLTAGE

TEST CONDITIONS: ep = 3000 V, 1 MICROSECOND PULSE, DUTY .001
o - Rg ADJUSTED FOR ip = 2.5 AMPERES FOR EACH HEATER VOLTAGE
x - Rg ADJUSTED FOR ip = 2.5 AMPERES AT EF = 6.3 ONLY

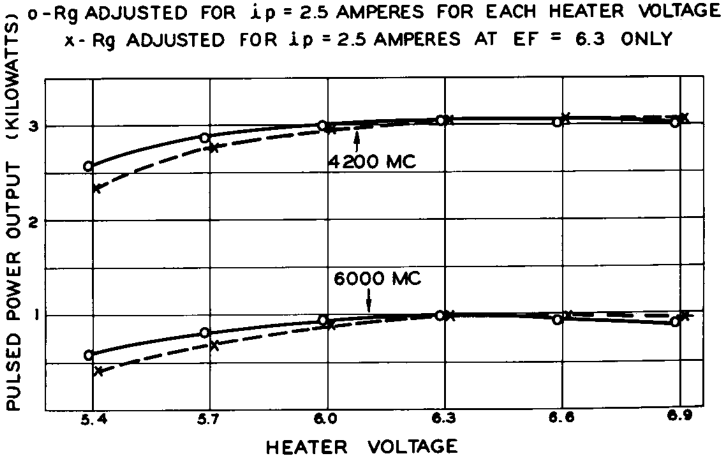


FIGURE 8