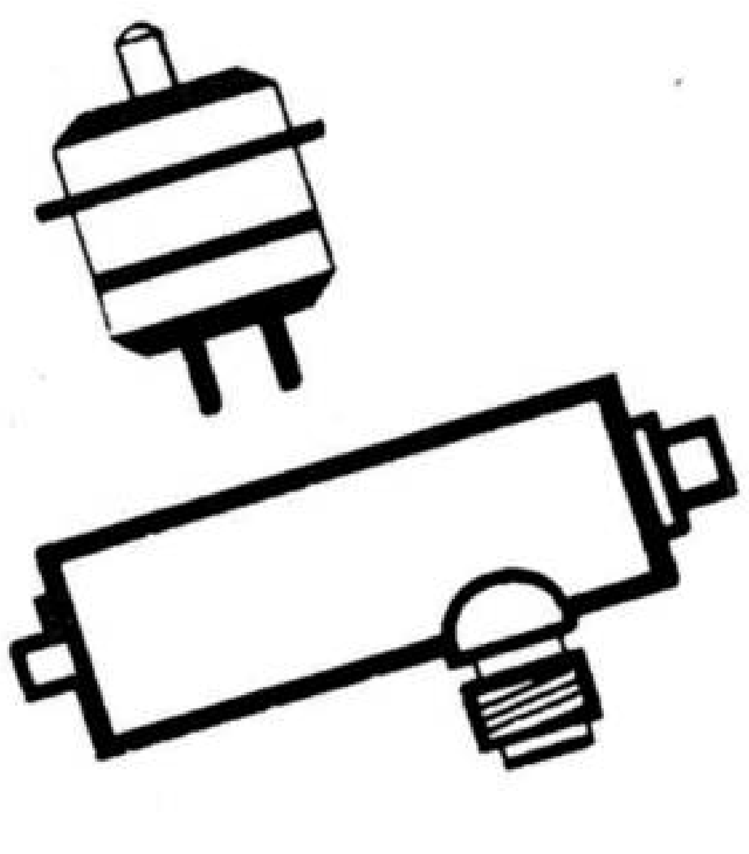
Performance and application of Microwave Gridded Vacuum Tubes and Microwave Circuit Modules

to meet
the challenge of
the new generation.



GENERAL ELECTRIC

Notes on the performance and application of the Planar Triode:

MODERN ELECTRONIC SYSTEM NEEDS

Modern electronics has seen significant changes in recent years. For example, radar has become more and more complex.

- Elaborate schemes using pulse compression and doppler returns are operational.
- Very large radars have been designed using electronically steerable arrays capable of tracking many targets at the same time.
- New, higher-performance navigational aids are being designed.

New telemetry systems are using complex coding and operating at higher frequencies. These and other electronic systems have placed more stringent requirements on active electronic components.

More CW power at higher frequencies is being used; therefore overall efficiencies are very important. Operation at frequencies up to 10 gigahertz is common with many designs using frequencies to K-Band, 16 gigahertz and higher. Frequency agility and phase fidelity are requiring wider instantaneous bandwidths. Advanced doppler radars are limited in target-recognition ability by the noise sidebands on the transmitted frequency and by the sidebands present on the receiver local oscillators. The usefulness of adaptive filters is also limited by the generation of undesirable modulation distortion products. Extreme linearity and wide dynamic range radar receivers are very difficult to design.

Pulse radars, radar beacons and other pulsed electronic systems require larger power outputs from smaller and more efficient power sources. C and X Bands are being used more and more — and gridded tube transmitters are being designed to their maximum capabilities. Magnetrons, klystrons, BWO's and C.F.A. are often too large and expensive. Solid-state sources cannot provide the minimum acceptable power outputs. In addition to more power, some systems must meet other difficult requirements. A good example is the pulsed radar altimeter. The transmitted pulse must be as short as possible with very fast rise-times. For better accuracy and range, high duties must be used. Any jitter present on the transmitted pulse destroys the radar accuracy. The radar altimeter as well as almost all other pulsed systems cannot tolerate FM or AM distortion during the pulse period. Pulsed phased array radars require the maximum state-of-the-art gain bandwidth products to become practical, and steering accuracy is limited by the phase distortion introduced during amplification of the transmitted or received signals.

Many other needs are present in addition to the electrical requirements already mentioned. There is a constant desire to reduce system size and weights. The mechanical features of the active components must be compatible with the circuit techniques used. Component packaging is important. Many missile or airborne systems meet extreme variations of temperature, tolerate high levels of shock and vibration, and in some cases, tolerance to nuclear radiation is required. Certain new electronic systems must operate instantly or within a few seconds after voltages are applied. The equipment must not only tolerate wide ranges of ambient temperature but must also operate in a stable fashion at the same time. Long life and extreme reliability are essential in almost all systems, either because of their complexity, vital function or to provide economical operation.

All circuit designers are familiar with most, if not all, of these requirements. **The component designer must also appreciate the circuit designer's needs.** The discussion presented here relates recent efforts by one gridded vacuum tube manufacturer to meet all, or as many as possible, of the requirements mentioned. It is recognized that all microwave functions cannot be performed by the gridded tube, but recent improvements are resulting in tube usage in many functions previously relegated to more expensive and complex modulated electron beam devices. Solid-state equipments have found usage only at the lower power and frequency levels.

NECESSARY GRIDDED TUBE IMPROVEMENTS

The vacuum tube of yesterday must be significantly improved if it is to be competitive for today's needs. To satisfy these needs, certain tube characteristics and geometries are essential. To reduce transit-time loading and phase delay, closer element-to-element spacings must be used. Smaller cathode areas must be used since transit-time effects are proportional to the active emission areas. Smaller element-to-element capacitances are mandatory to resonate tube and circuit at higher frequencies. Series inductance inside the vacuum enclosure can have serious effects on tube operation. More efficient conduction of internally generated heat away from the tube itself is necessary if smaller size and weight and more power output is to be obtained. All insulating portions of the tube must be of low loss materials at temperatures much higher than ambient.

Immobile internal structures are essential. The most difficult components in this respect are the heater-cathode structure and the grid. For efficient use in strip-line, cavity and/or waveguide circuit, the external surfaces of the tube must be suitable for proper RF connection. Another mechanical requirement is the maintenance of uniform element-to-element spacing over wide temperature ranges. Use of very low coefficient of expansion materials is essential if complex compensating circuitry is to be avoided.

For microwave use, many additional improved electrical characteristics are essential. High levels of transconductance are required to provide acceptable levels of gain-bandwidth product, and in narrowband circuits the pulsed start or rise-times are highly dependent upon tube transconductance. In large signal devices, such as class C operation, high transconductance, well into the positive grid region, is essential. Not only must the tube cathode supply very high currents from small areas, but long life at the same time must be assumed. The goal is always to obtain more and more emission from cooler cathodes. Many recent successes with high current density cathode materials cannot be applied to the microwave gridded tube. Even moderate cathode sublimation can seriously affect the grid performance. Lower cathode temperatures also improve tube life and reduce the required heater power. To obtain lower heater power at the same cathode temperature, efficient heat transfer from the heater to the cathode is important. Closer mechanical contact must be used and more mechanically rugged designs result. Closer bonding of the heater to the cathode also helps fulfill the system need for fast warm-up. Another electro-mechanical characteristic not often appreciated is the elimination of serious RF discontinuities due to complex seals, radical changes in tube dimensions and other internal features that produce parasitic capacitance or inductance. In other words, it is essential that a minimum amount of any circuit must be inside the vacuum enclosure.

This is a partial summary of the required electrical and mechanical features of a gridded tube designed to work into the higher microwave frequencies. The following describes a new family of tubes using manufacturing techniques proven most successful in improving the present tube state-of-the-art.

A NEW FAMILY OF GRIDDED TUBES

One of the most important design features of a high performance tube is a low loss, high temperature and vacuum tight metal-to-ceramic seal. One of the biggest obstacles in this respect has been in obtaining a seal between the ceramic material and a metal of equal or similar coefficient of expansion. This has been done using a special ceramic designed to duplicate the coefficient of expansion of titanium metal. Titanium is also used to provide the efficient tube gettering action necessary to reduce the effect of gas on tube life and cathode poisoning. **Figure 1** is an enlargement of a titanium-to-ceramic seal using nickel as a eutectic. This seal is made at over 1000°C and some of the most successful life tests made on a tube design using this sealing technique were made at 400°C ambients. This tolerance to high temperature is more important in obtaining higher levels of plate dissipation since 400°C ambients are seldom required.

ENLARGED VIEW OF A NICKEL-TITANIUM SEAL

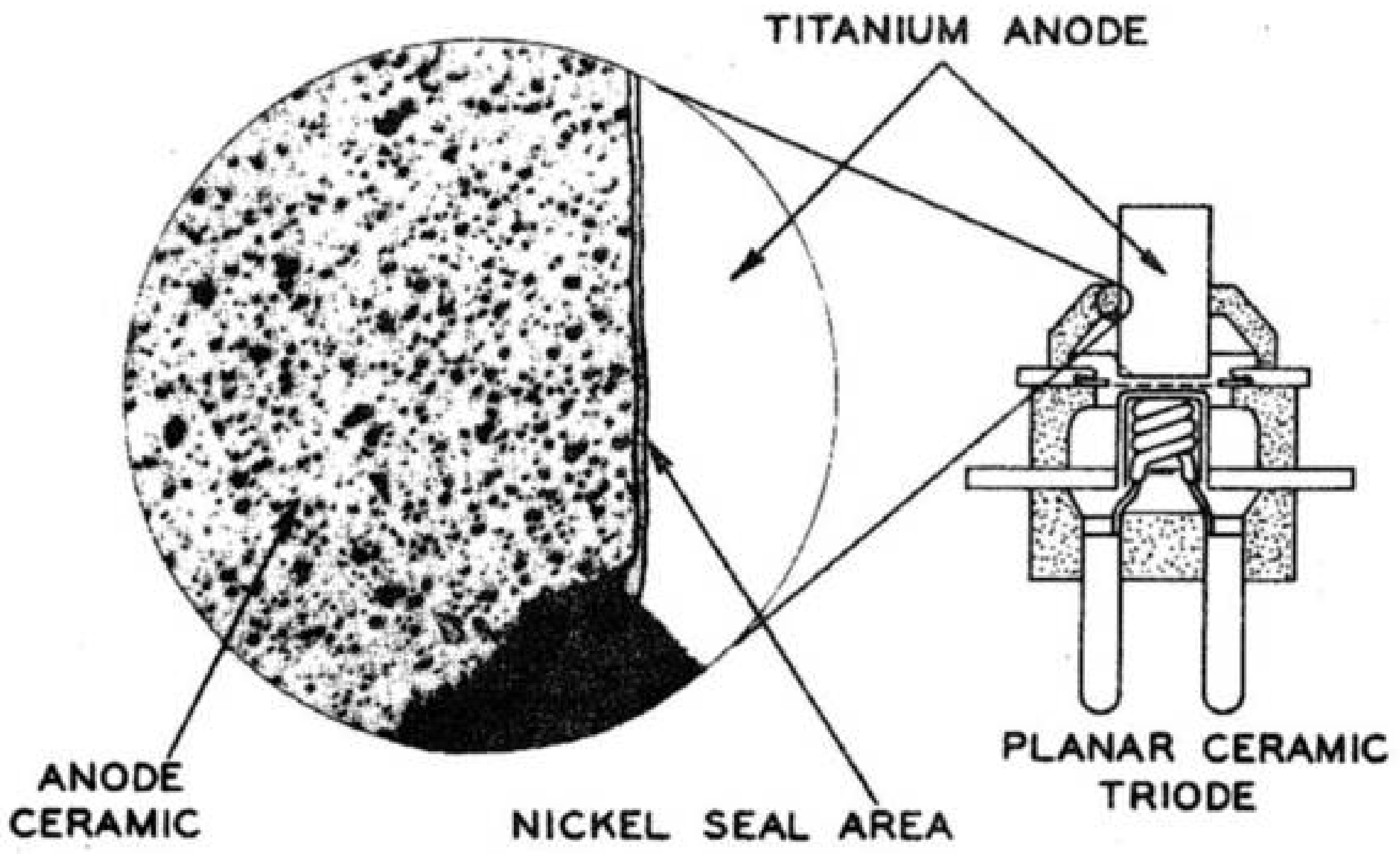
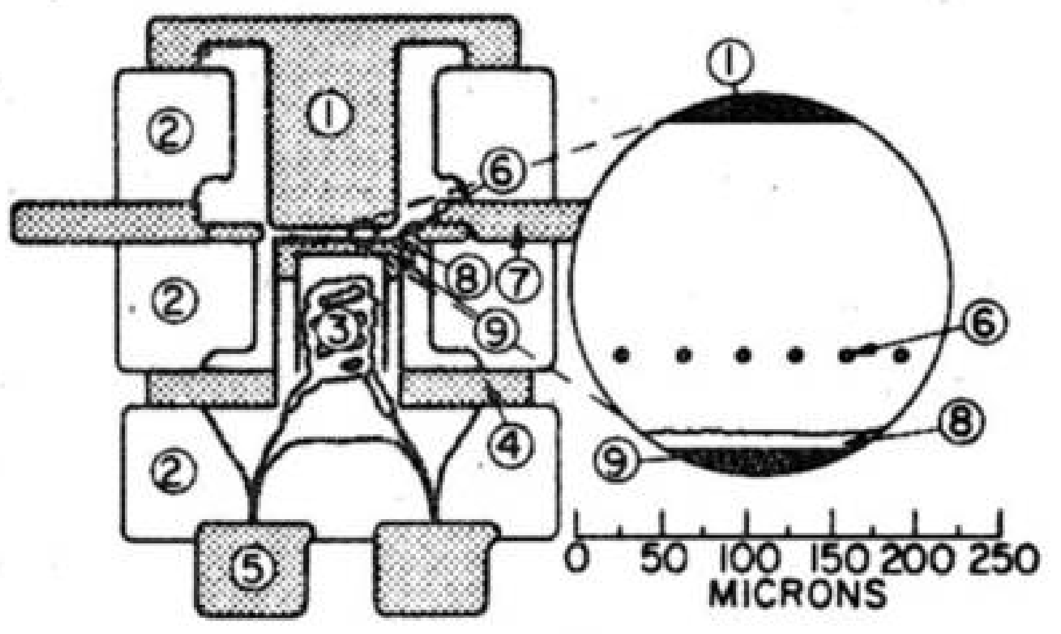


FIG. I

Using this basic sealing technique, very accurate control of tube dimensions can be maintained. **Figure 2** demonstrates this feature, as well as other features to be described later. This is an artist's sketch of a cutaway section of the 7077 triode — a tube marketed using nickel-titanium-metal-to-ceramic seals. In this tube type, all seals are parallel and planar. The ceramics are diamond-lapped to close tolerances. The active cathode area is about 0.05 square centimeters for about 10 ma per volt transconductance at about 7 ma of plate current. This small area results in low capacitance and high electrical performance at higher frequencies. The heater used in the 7077 uses radiation to heat the cathode, since little or no direct contact is made to the cathode itself.

SECTIONED CERAMIC TRIODE



① ANODE
② CERAMIC SPACERS
③ HEATER
④ CATHODE RING
⑤ HEATER CONTACTS
⑥ GRID WIRE
⑦ GRID RING
⑧ OXIDE COATED CATHODE
⑨ CATHODE

FIG. 2

CUTAWAY SKETCH OF THE Y-1124 TRIODE

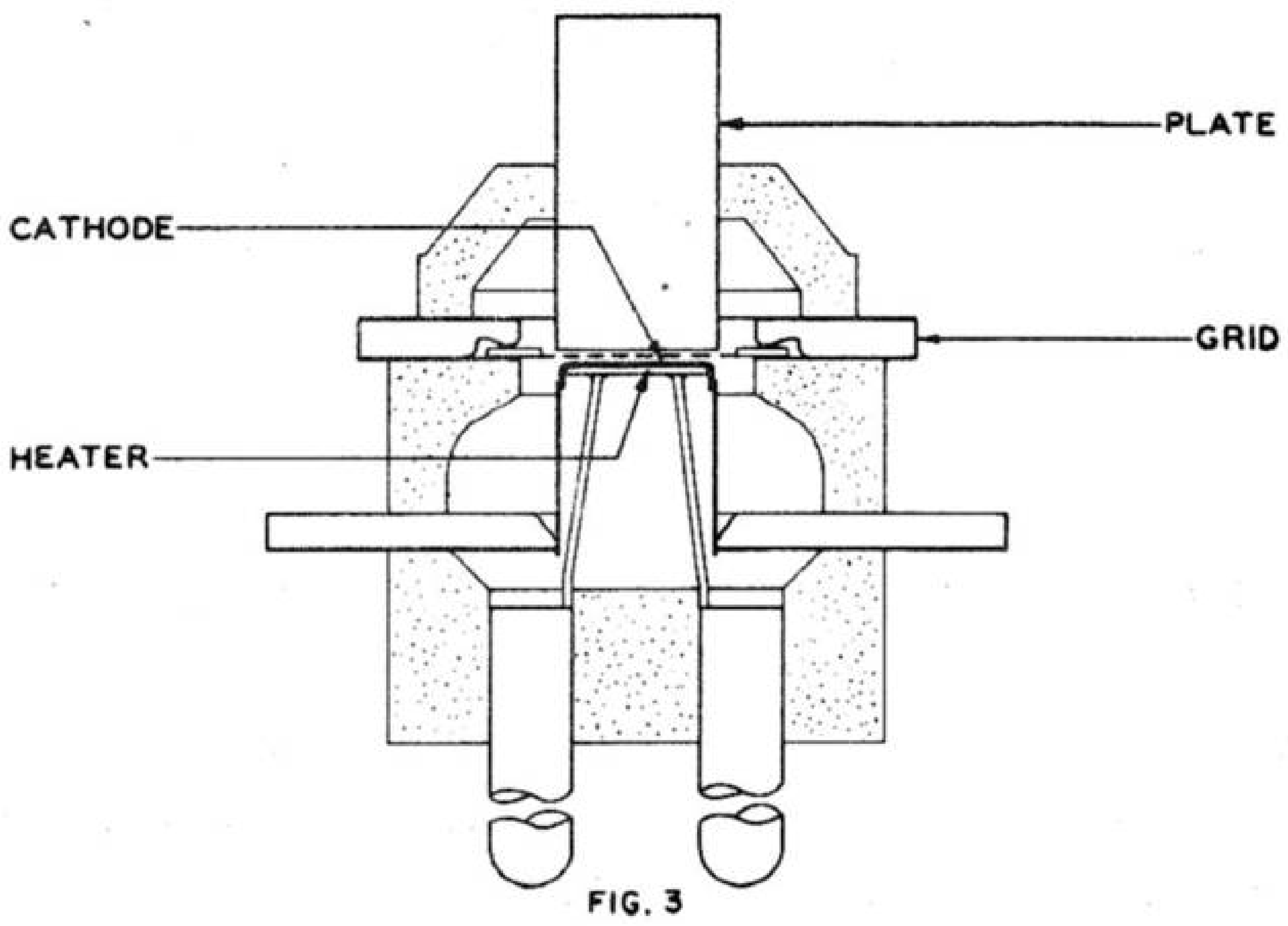


FIG. 3

Figure 3 is a simplified sketch of a more recent design, developmental type Y-1124. Note the reduced volume of ceramic used. The Y-1124 also uses a combination of planar and coaxial seals. The coaxial anode seal provides a lower capacitance and more efficient RF design. This basic configuration has been used commercially to 9.6 gigahertz as a radar beacon local oscillator. **Figure 3** also shows the basic features of a new bonded heater-cathode structure. The heater is bonded inside a flat insulating material attached to the back side of the oxide coated cathode. The cathode is heated by conduction rather than by radiation. Several advantages result from this bonded heater. One of the most important is a drastic reduction in warm-up time required for the plate current to reach 90% of the steady-state value after heater power is applied. **Figure 4** shows this. The reduced mass curve is the basic structure

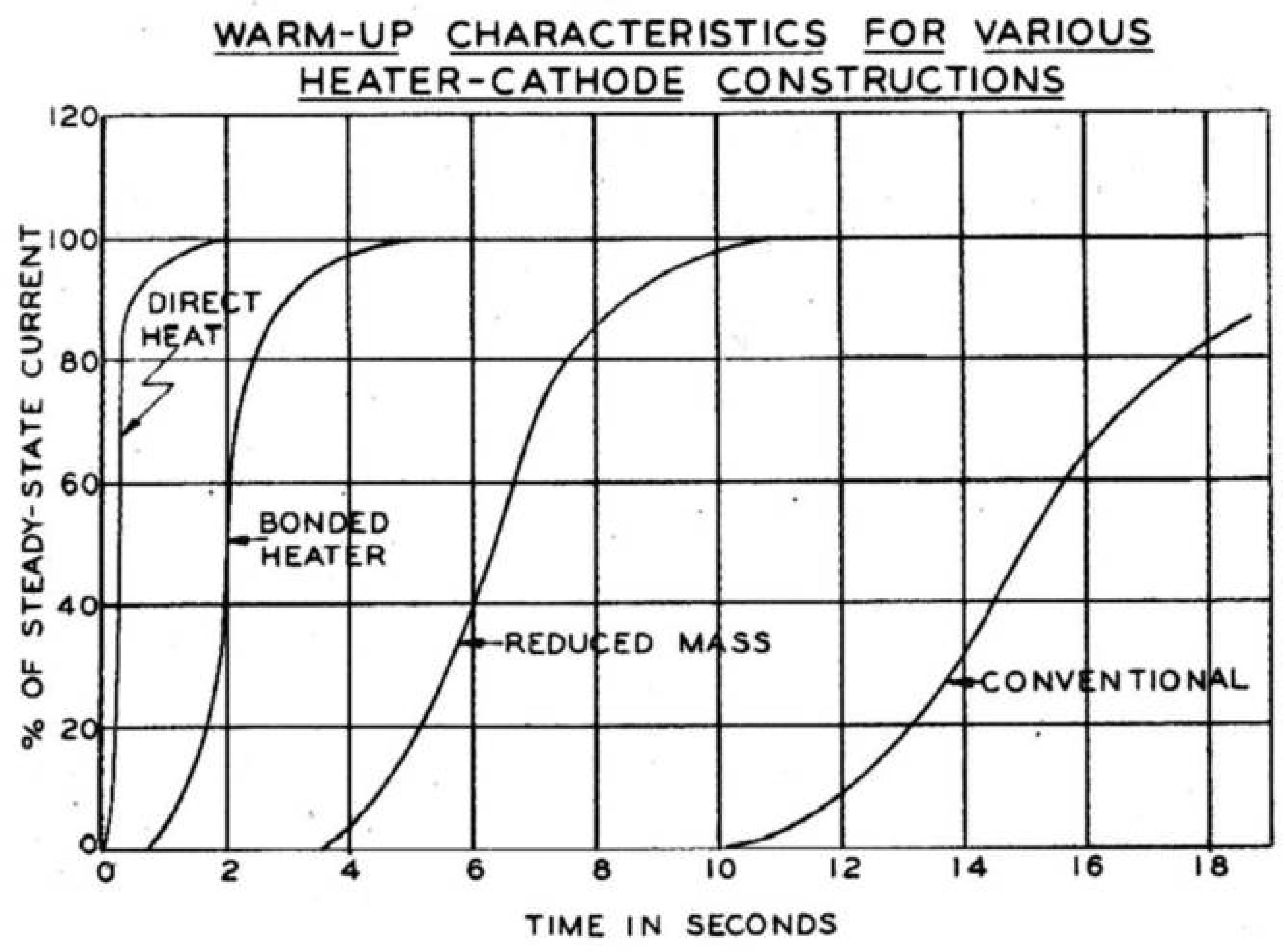


FIG. 4

shown in the 7077, **Figure 2,** using low cathode mass and extremely thin support wall material. This structure was not mechanically secure, and the regular 7077 dimensions must be used. The regular 7077 is shown on the right. The fourth curve shows the warm-up characteristics of a developmental directly heated cathode. This design is not presently offered for sale but is adaptable to the planar structure.

A second advantage of the bonded heater design is the very significant reduction of tube microphonics. (Microphonics are electrical signal outputs generated by internal element movements when the tube is shocked or vibrated).

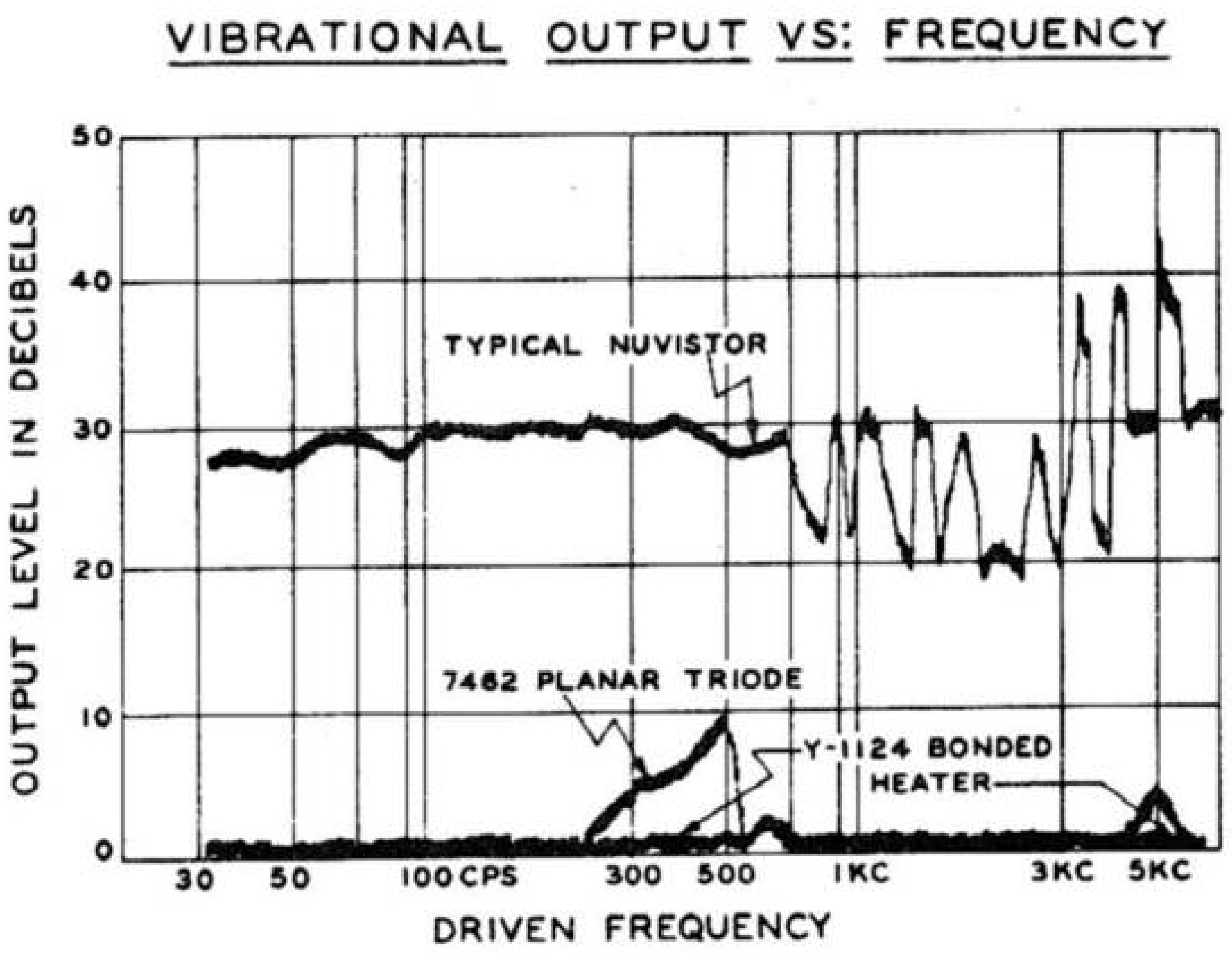


FIG. 5

Figure 5 is a reproduction of the microphonic outputs as a function of frequency as the tube under test is vibrated at a 10g level from 30 hertz to 5 kilohertz. Note the bonded heater construction is for all practical purposes microphonic free. Microphonic levels can be used to predict microwave performance where such undesirable results, such as pulse jitter, pulse bounce, and FM and AM distortion can limit tube usefulness.

The extra performance available when the tube is operated at high cathode current densities is useful only if acceptable life can be obtained. The use of titanium as the major metallic portion of the tube, use of high temperature bake-out and the use of very good vacuums available from bell-jar exhaust systems result in extremely low levels of gas within the tube. The ability of any gas to cause cathode poisoning and short life increases when the tube is operated at high current densities. The proof of very low gas levels in the new tube family is shown in **Figure 6.** This data shows that

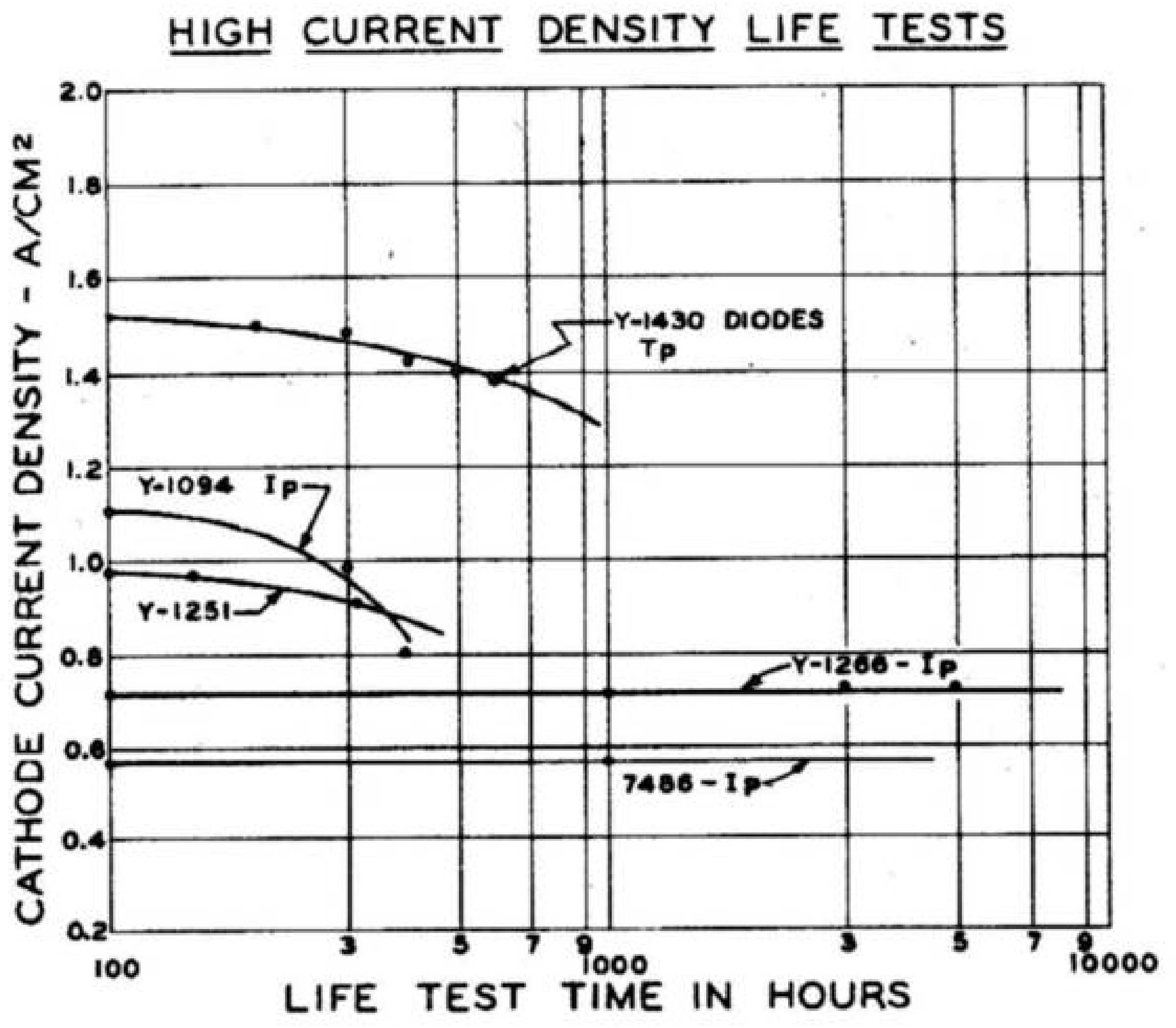


FIG. 6

excellent life is obtained at current densities greater than 1 ampere per sq cm of active cathode area. This level of operation can be compared to the highest level of current density used in a TV set, less than 100 ma per sq cm. Similar good results have been obtained on pulsed rated types. **Figure 7** is a plot of pulse power output as a function of tube life. This data was taken on the 7911 triode operating at about 9 amperes per sq cm during the plate pulsed period. The peak RF currents would be near 30 amperes per sq cm. The top curve is a plot of power output vs. time with the tubes actually being life tested with only the heater voltage applied. In some applications, this type of life test is more difficult than actual operating life. This standby life is the average of 12 tubes. The second curve is a plot of power output vs. time with the tubes operating in a 4100 mhz life test cavity. This is the average result on 16 tubes.

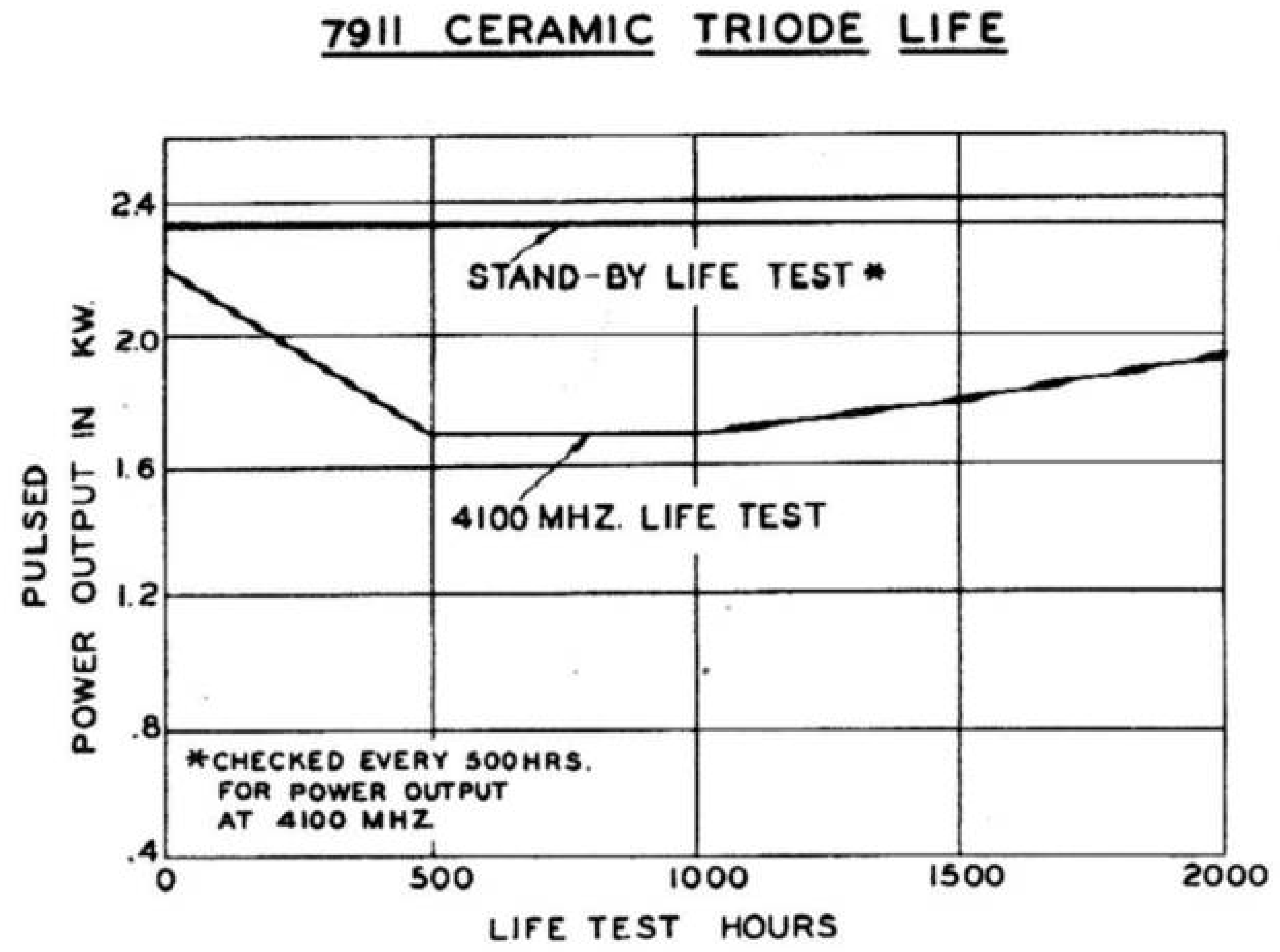


FIG. 7

Significant improvements in the electrical, mechanical and thermal characteristics of the grids used for the new family were necessary. Two basic grid fabrication techniques are used. **Figure 8** is a sketch of the two constructions used. The sketch on the upper left is a mechanism for obtaining a very high degree of grid wire tensioning. The materials and mechanical features are arranged so that as the grid cools after the exhaust bake-out, the difference between the coefficient of expansion of the tungsten grid frame and the

PLANAR TUBE GRID AND ANODE CONSTRUCTION

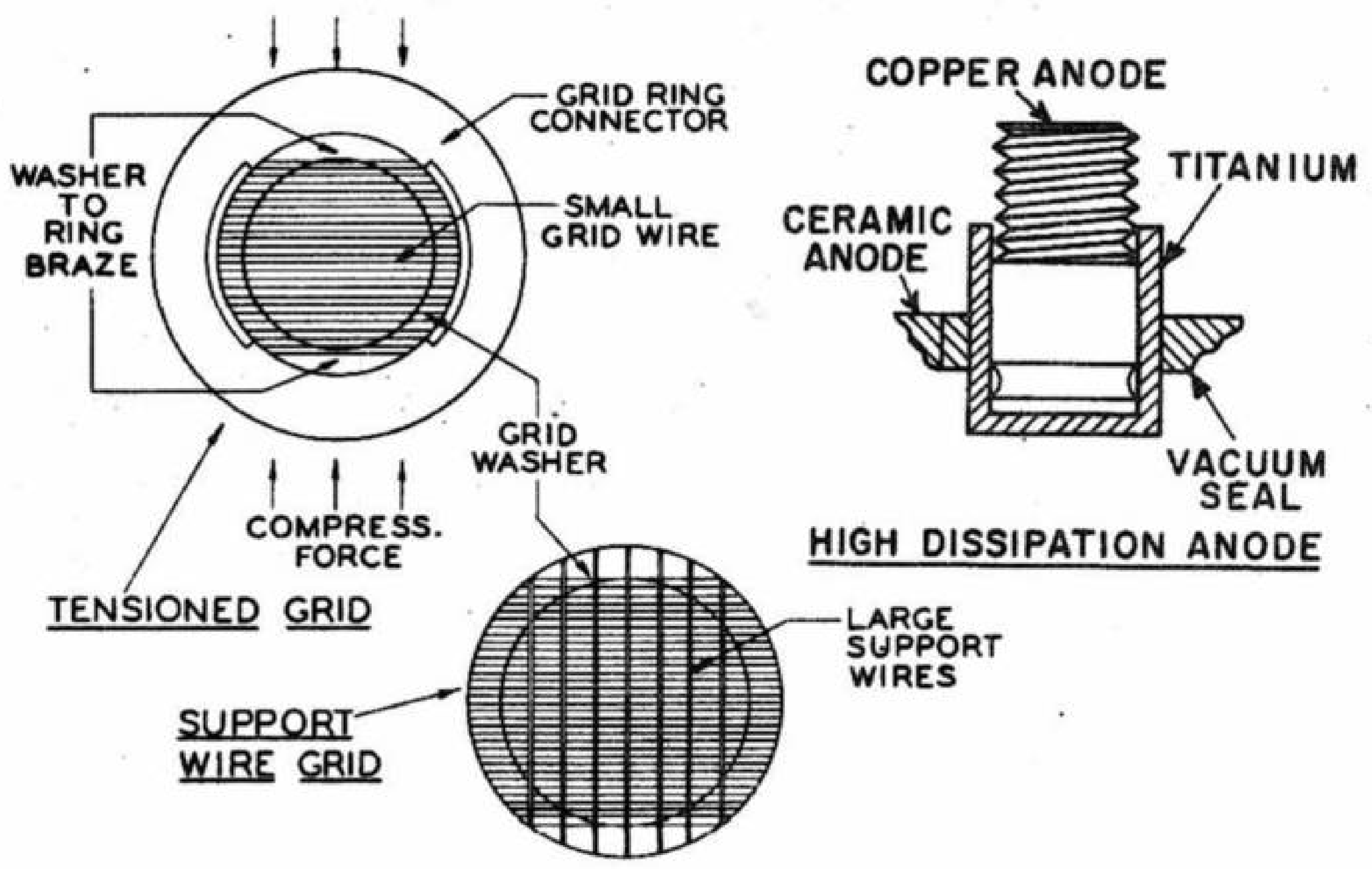


FIG. 8

titanium distorts the grid frame in a direction that tensions the small lateral wires on the grid frame washer. This construction has resulted in significant reductions in the level of microphonics measured on tubes using more conventional grid-making techniques. The sketch at the bottom-center uses a grid ring similar to the other sketch on the left, but in this case, heavy support wires are wound at right angles to the small grid wires. All physical connections between both wire sizes and the grid ring are brazed together in a high temperature furnace. This grid receives its rigid characteristics from the rigidity of the large support wires. These large wires also greatly improve the thermal properties of the grid. The higher powered tube types use the support-wire grid for this reason. Further work is being done at this time to provide even better grids to provide even higher performing tubes.

Most recent efforts to obtain the optimum grid has resulted in an etched-frame support grid structure. This mechanical configuration is shown in the photo, **Figure 8A.** The large vertical bars are electro-etched and are typically 20 to 40 mils wide. The smaller horizontal bars are chemically-etched and are typically 2 to 4 mils wide. The actual high performance portions of the grid are the small wires running diagonally. These wires are typically .3 to 1.0 mils in diameter depending upon the triode performance desired. After final assembly, high temperature brazing bonds each portion of the grid to its adjacent component. Each of the small wires are inspected under a microscope to assure proper brazing between each wire and its etched frame support. Grids can be constructed with various combinations of these techniques. The large vertical bars can be nested into slots in the cathode to provide close spacing between the small grid wires and the active portion of the cathode. Grids using only the chemically-etched frame can be used with the frame facing the tube anode and more efficient use of the available cathode area is possible. This structure results in grids capable of conducting larger amounts of heat, covering larger active cathode areas and extra high performance. Triodes using these techniques have been built with cathode areas of over two square centimeters, transconductance approaching one mho, and extra high dissipation capabilities.

Most of the heat generated in the tube must be dissipated by the anode and its heat-sink. Unfortunately, titanium is not an excellent conductor of heat, and other than solid titanium anodes must be used on higher power rated types. The sketch of a cutaway view of a combination copper and titanium anode is shown on the left in **Figure 8.** Heat dissipation capabilities sufficient to prevent tube failure at maximum cathode current capabilities has been obtained using this bi-metal anode design.

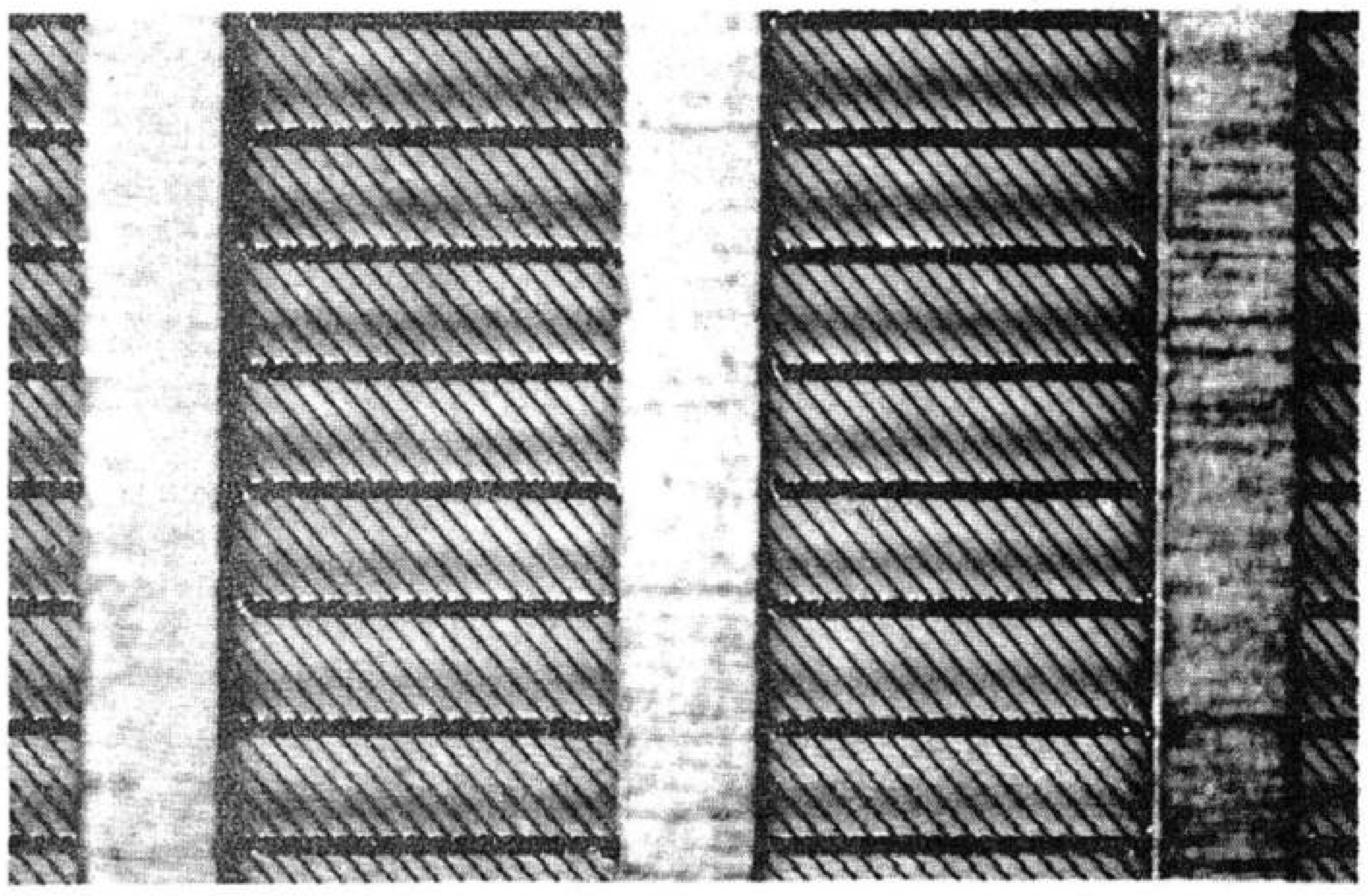


FIG. 8 A

The basic construction techniques used on the new tube family permits the modular construction of several possible external configurations with identical internal features. **Figure 9** shows this feature. The types 7077, GE 14501 and Y-1266 have similar internal construction. All three types have the same grid connector size and configuration. The 7077 uses button-type heater connections with a recessed cathode terminal. This provides an external outline more suited to clip-type sockets useful at the lower microwave frequencies, and the GE 14501 is the small tube adapted for use in coaxial cavity circuits. The Y-1266 is similar to the GE 14501 except for the anode. The larger Y-1266 anode can dissipate more heat since more contact and heat-sinking areas are provided.

VARIOUS GEOMETRIES SHOWING MODULAR CONSTRUCTION

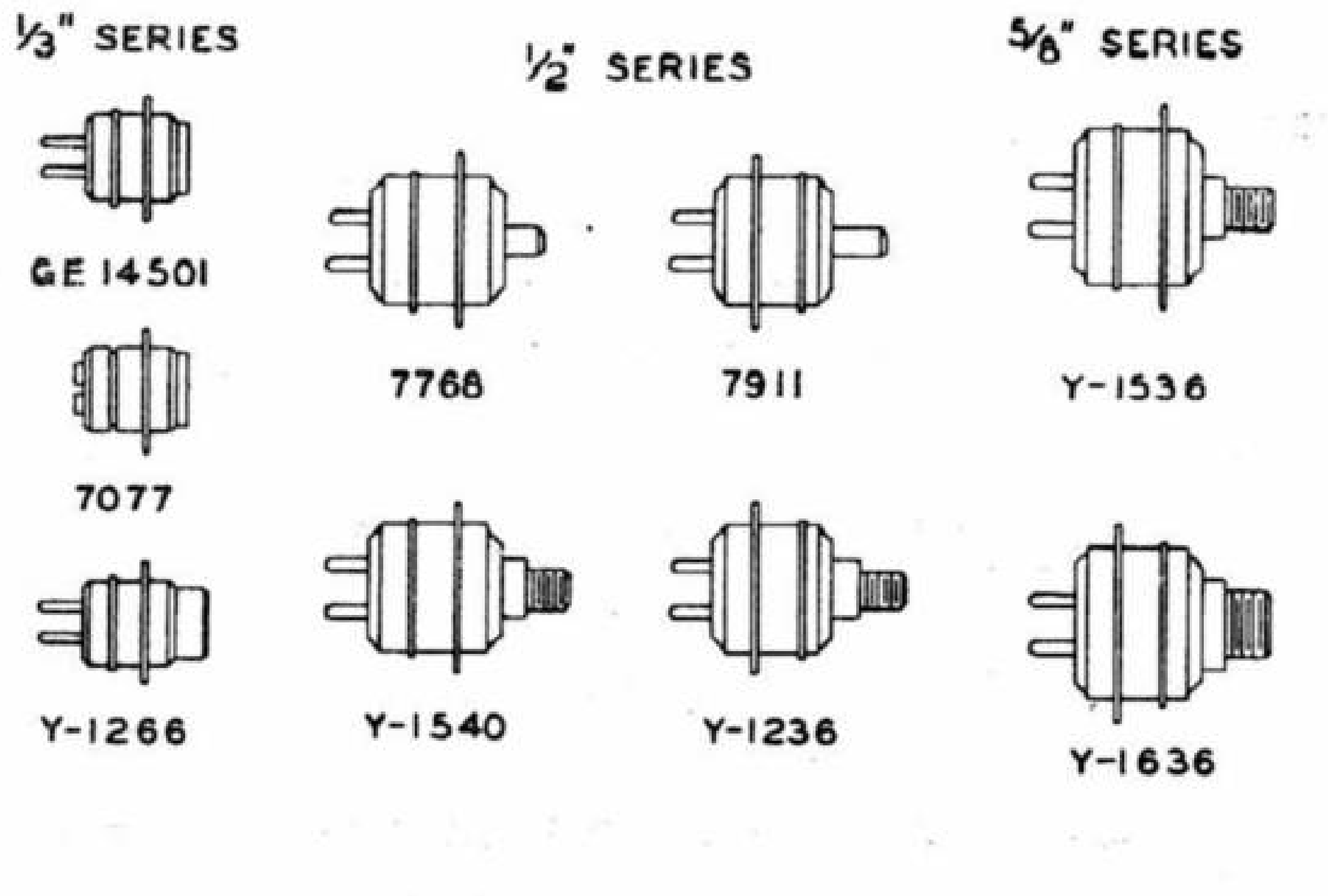


FIG. 9

In the half-inch series (approximate diameter of the ceramics) the 7768 can be compared directly with the Y-1540. The 7911 can be compared with the Y-1236. Each one is identical to its counterpart, except for the anode. The 7768 and 7911 are rated for about 6 watts of anode dissipation. The Y-1540 and Y-1236 are rated at 30 watts and use the anode design shown in **Figure 8.** The largest series (five-eighths of an inch ceramic diameter) is shown at the right. The first two developmental types are the Y-1536 and Y-1636. The Y-1536 has 0.6 sq cm of cathode surface and is designed for grounded grid amplifier use. The Y-1636 has 0.8 sq cm of cathode area and is the largest of the new family. This type has an enlarged copper-titanium anode that has dissipated 100 watts. The Y-1636 is designed for grounded cathode use in a re-entrant cavity oscillator.

Significant data has been taken to demonstrate the power output versus frequency capabilities of the new ceramic tube family.

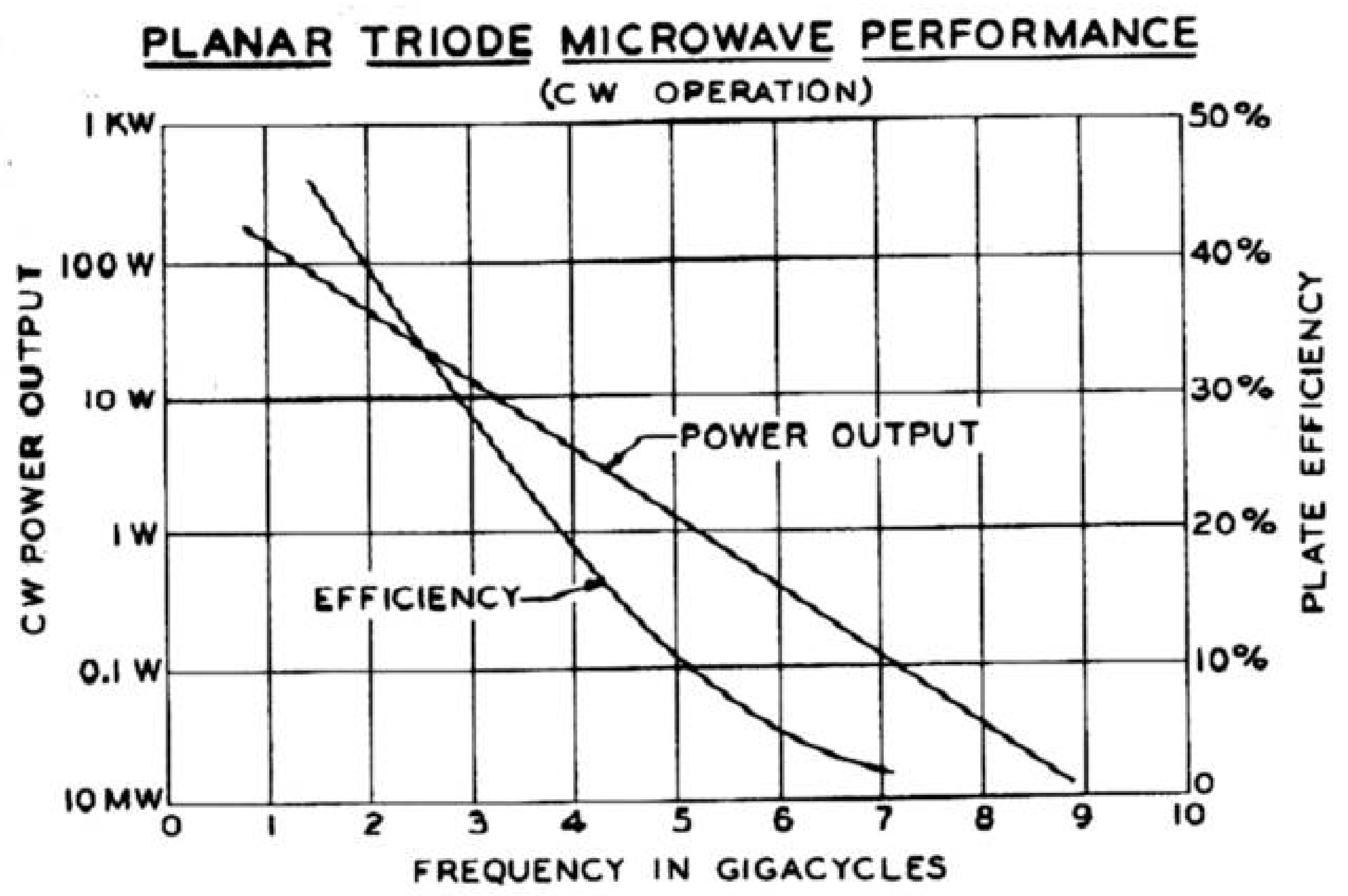


FIG. 10

Figure 10 is a plot of CW output versus frequencies. The approximate plate efficiency is also shown. This curve was constructed from a variety of measured results on a variety of tube types. At lower frequencies, the larger tubes are recommended. At higher frequency the smaller tubes were evaluated to determine the power outputs available within tube maximum rating. The data shown in **Figure 11** shows the plate pulsed capability of the pulse rated types. This data was obtained in a similar fashion.

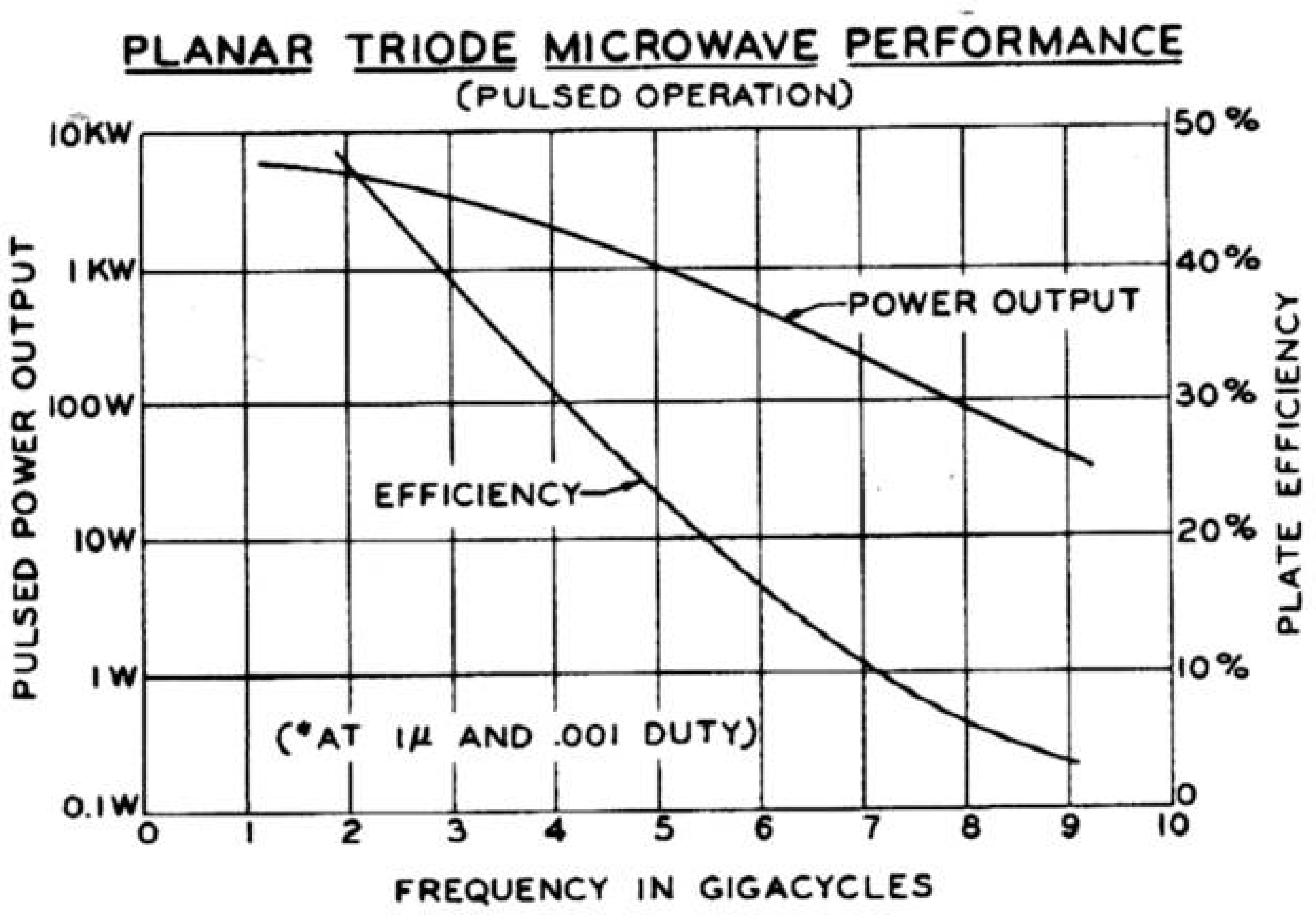
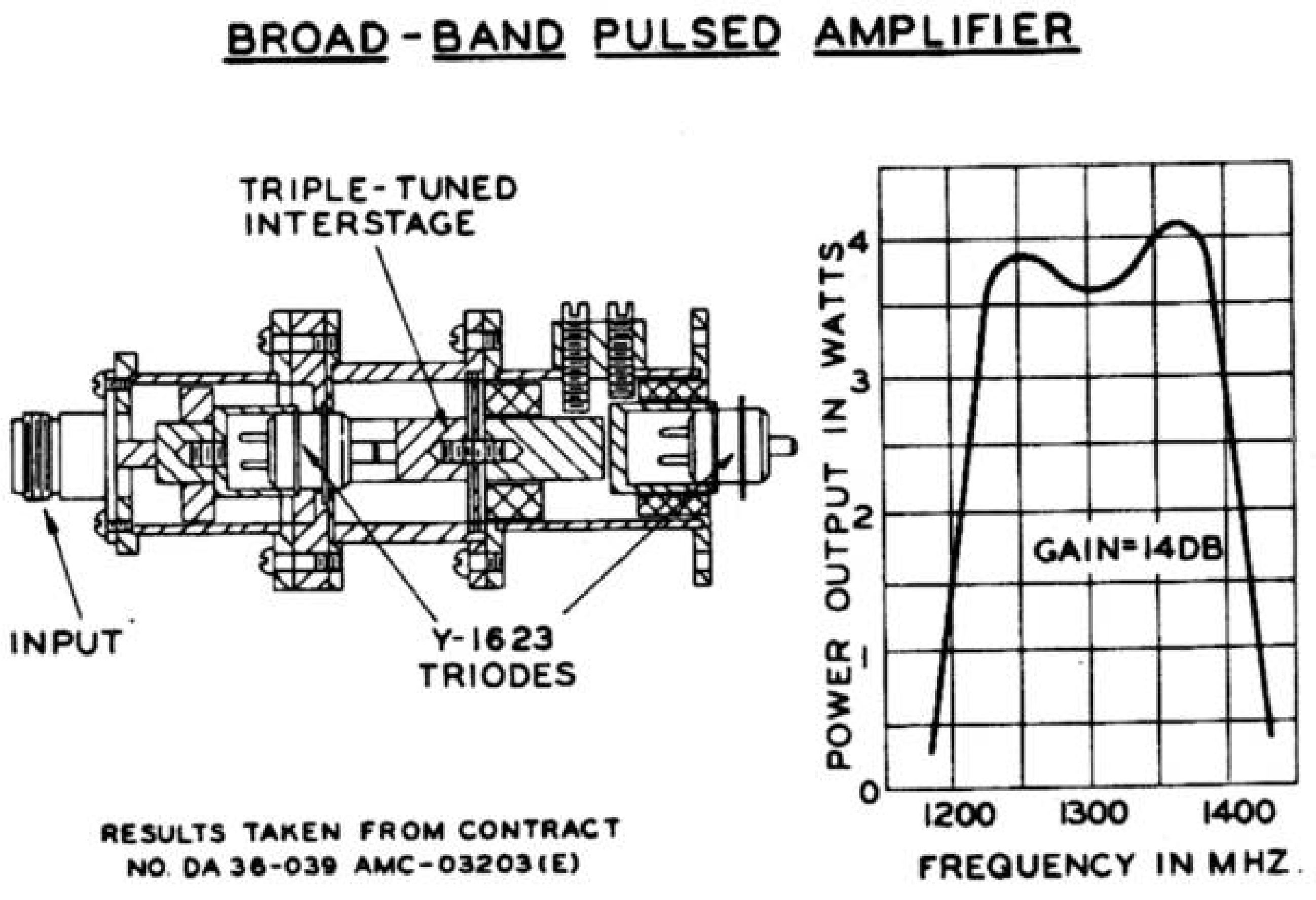


FIG. 11

Using the grid techniques shown in **Figure 8,** very high levels of transconductance are obtained. For example, the type 7768 is specified at about 50 ma per volt and this is obtained with about 25 ma of plate current. The 7768 has demonstrated very high levels of small signal gain-bandwidth products. The 7768 has been evaluated in a triple-tuned pulsed circuit at 1.3 gigahertz. A gain of about 14 db was measured with a three db bandwidth of near 165 megahertz. This calculates to about 4800 megahertz gain-bandwidth. **Figure 12** also shows the circuit arrangement used for the triple-tuned 1.3 gigahertz amplifier. The response obtained is also shown.



RESULTS TAKEN FROM CONTRACT
NO. DA 36-039 AMC-03203(E)

FIG. 12

CERAMIC TUBE TOLERANCES TO ADVERSE ENVIRONMENTS*

1. NO DAMAGE TO 10^{19} NEUTRONS FAST
2. NO DAMAGE TO 10^{11} ERGS PER GRAM CARBON
3. NO RADIATION RATE EFFECTS NOTED
4. SURVIVES 20,000 G'S CONSTANT ACCELERATION-CENTRIFUGE TESTS
5. SURVIVES 20 G'S FOR 10'S OF HOURS AT MOST CRITICAL FREQUENCY
6. OPERATE IN A $1G^2$ PER CYCLE PER SECOND AT 50-2000 CPS.
7. EXCELLENT LIFE AT 400°C AMBIENT
8. SURVIVES AT LEAST 20,000 G'S IN "GUN-SHOT" TESTS
9. SURVIVAL AT 3000G'S FOR 3 TO 5 MILLISEC.

*ON SELECTED TYPES

FIG. 13

New military electronics systems must tolerate a large variety of adverse environments. **Figure 13** is a brief resume of the conditions which the metal ceramic triode has survived. The most severe of these required the combination of the bonded heater-cathode structure, extra strong ceramics, mechanically rugged grids and new sealing techniques available only in the new planar ceramic tube family.

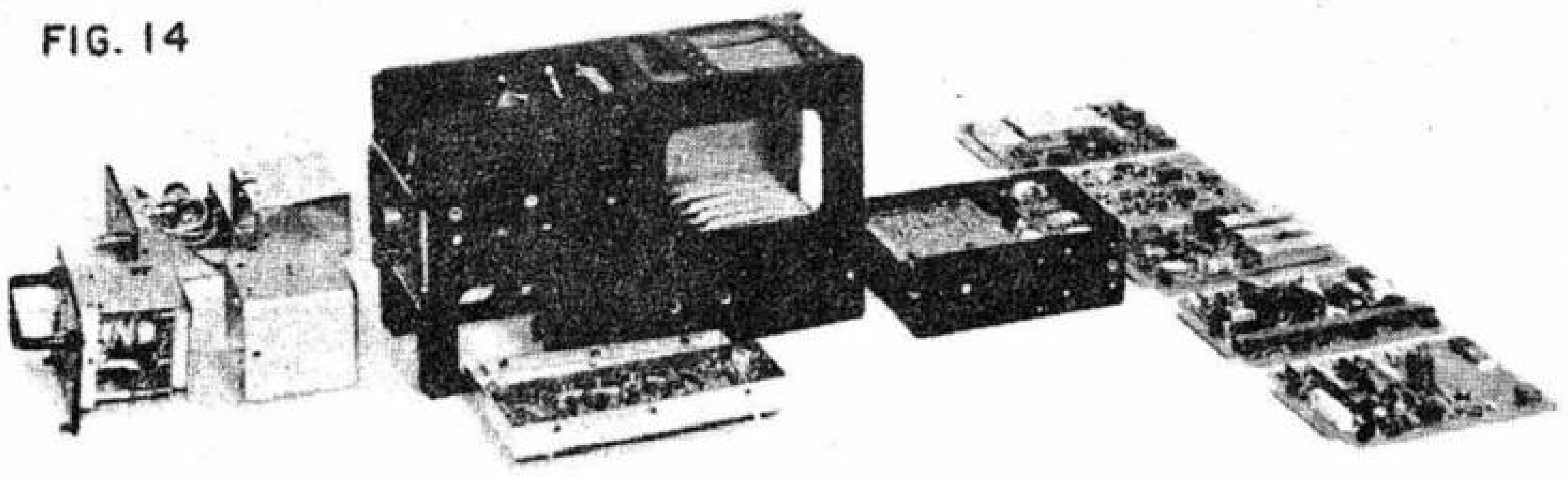
NEW AND IMPROVED EQUIPMENTS MADE PRACTICAL

It is, however, fair to state that many new equipment concepts have been made practical as a result of the extra performance available from the new tube designs. There are several examples of this.

Distance measuring transponders are being used today aboard military, commercial and private aircraft. These units send out coded pulses which interrogate a special transmitter located at a known location. The roundtrip time of the interrogating and reply pulse are used to determine the line of sight distance from the aircraft to the ground station. These equipments are used in the military TACAN and VORTAC systems. In commercial and private usage, they are referred to as DME (distance measuring equipments). To identify the large number of ground stations, many different frequencies must be used. The most used spectrum is from 1125 megahertz to 1250 megahertz with one megahertz channel separation. Previous designs use four stages of single-tuned RF amplifiers that must be mechanically tuned and tracked across the assigned spectrum. This equipment was large, expensive and heavy. The newer version of TACAN-DME will use four stages of double-tuned RF amplifiers broadbanded to cover the complete spectrum of 125 megahertz. One designer reports a 10 to 1 reduction in both size and weight using the new ceramic tubes described here. There are at least five companies in the United States with this new system concept in design or prototype production. Almost without exception all stages for all five companies are using the new ceramic tube family.

Radar altimeters for aircraft use have been in service for years. However, for modern aircraft, more accurate instruments are needed. More accuracy requires higher transmitting frequencies and shorter rise-times and durations for pulsed systems. The small planar tube has met these needs. Pulse durations of a fraction of one microsecond are easily obtained and pulse powers up to over one kilowatt are practical for long-life transmitters. **Figure 14** is a photo of the APN-171 pulsed radar altimeter. Pulsed powers of over 150 watts are available for pulse durations of less than 100 nanoseconds. The transmitted frequency is approximately 4300 megahertz. This unit also uses a small planar ceramic tube as the local oscillator for the receiver portion of the altimeter.

FIG. 14



The higher transconductance triode types are being used in other broadband applications. The 7768 test results shown in **Figure 12** relate the performance in the preamplifier stages of a phased array module. Triodes were evaluated in these tests because of their low phase distortion and delay. The complete module which is not shown here was being developed to compete with the TWT. Other broadband amplifications include ECM amplifiers and broadband Doppler radar amplifier chains. The triode offers small size, high efficiency and an economical solution to the problem of obtaining wideband operation and high power outputs.

In the United States, there is a program to up-date the present aircraft handling facilities at large, metropolitan airports. There is a similar program to provide better identification for military aircraft. These programs have been combined under the **AIMS** Program. The hoped-for mass employment of identification beacons on all aircraft of all sizes demands a low cost, small size and high performance beacon transmitter. One offering by General Electric uses two of the new family for a master oscillator-power amplifier arrangement. This is done to provide the required frequency stability. **Figure 15** is a photo of this unit. The Y-1537 triode is designed specifically for this application requiring long life and good reliability. These equipments are often referred to as ATC, air traffic control, and/or IFF, identification friend or foe, transponders.

Most radars used for aircraft and missile tracking use radar beacons to augment the radar returns. These beacons must operate at the radar frequency. Several designs have been manufactured using the new ceramic planar triodes. The local oscillator for the beacon receiver uses the smaller triodes up to about 10 gigahertz. Some designs operating at lower frequencies, up to 6 gigahertz, also use the triode in a pulsed oscillator transmitter. Triodes are being used here because of their small size, low cost and simple power supply requirements. The frequency stability of the triode is important in these applications. Triodes have also been shown to produce less sideband noise when compared to the reflex klystron, magnetron and varactor multiplier. This desirable feature is very important in low noise receivers and in Doppler radar transmitters.

Another high frequency use for the small planar triode is in hand-held radar applications. Many of the performance features mentioned for the radar beacons apply here with the extra requirement for low power consumption. The triode is being evaluated for use as both a local oscillator and a pulsed transmitter.

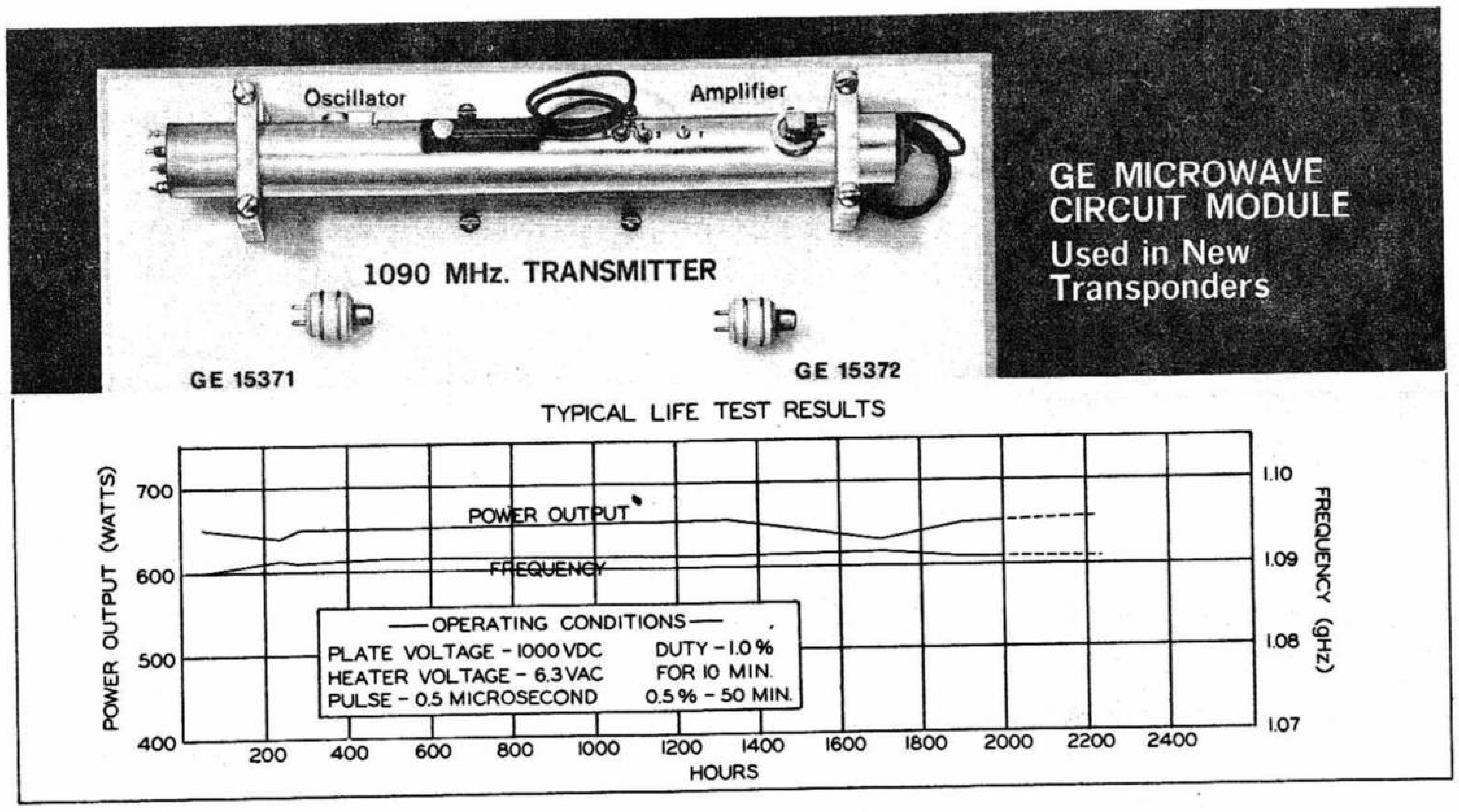


FIG. 15

The 215-260 megahertz telemetry band now being used must be vacated before 1970 to release these frequencies for other services. The new bands are 1435-1535 and 2200-2300 megahertz. Planar ceramic triodes are being used as power drivers and output stages in the new equipments designed for these higher frequency bands. **Figure 16** is a photo of a small 2200-2300 megahertz transmitter using a Y-1266 triode. This unit delivers 2 to 3 watts of CW output with a large signal gain of over 10 db and an overall efficiency of over 25%, including heater power. The Y-1266 is shown beside the grounded grid coaxial amplifier. Other systems near these frequencies use similar types and circuitry. One of these is a recent collision warning system. This equipment requires narrowband amplifiers with about 35 db of gain and approximately 1 kilowatt of pulsed power output. Only three stages are required if tubes from this new family are used.

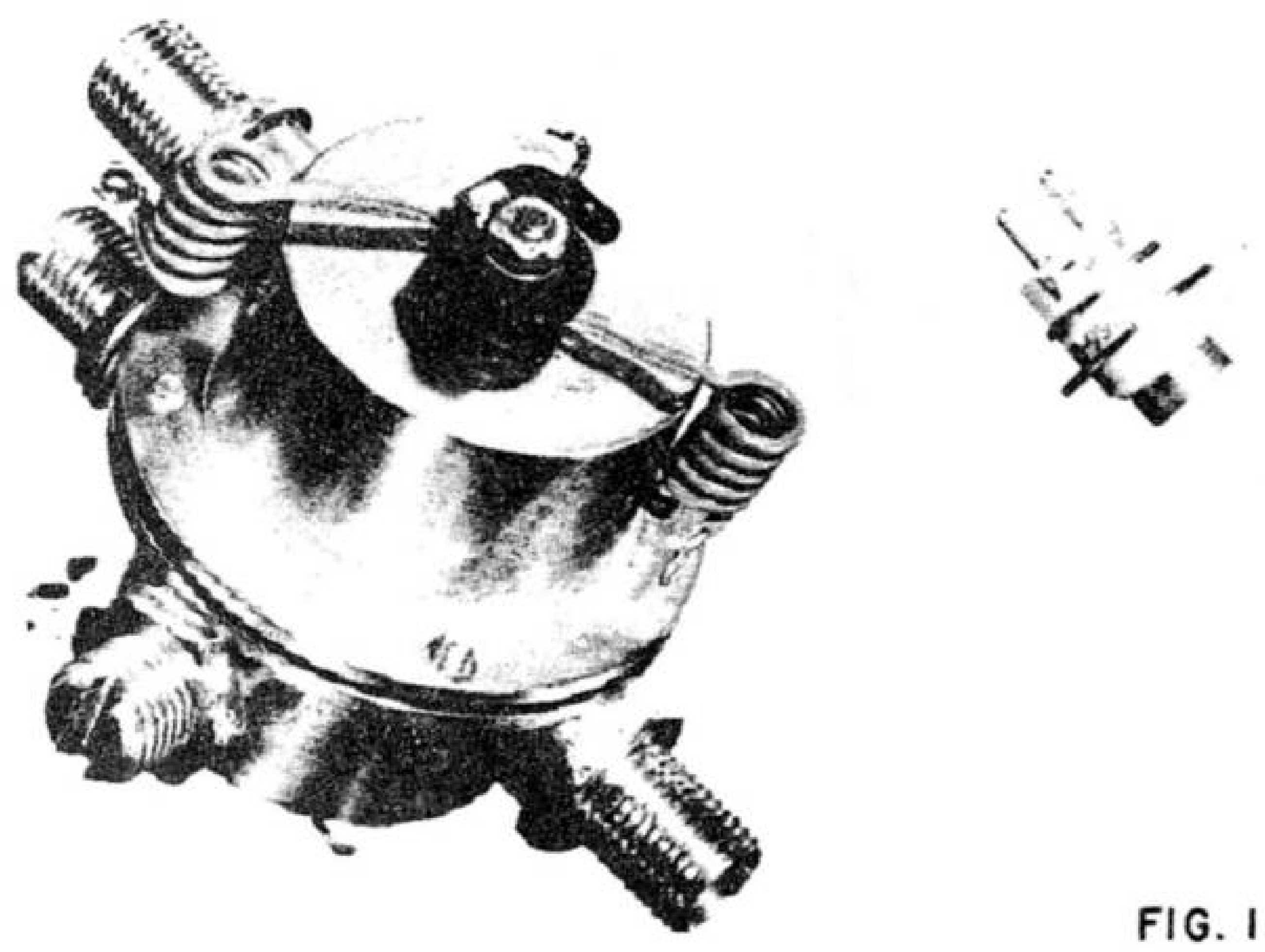


FIG. 16

The last, but not least, application for the new planar triodes mentioned here is in high frequency signal generators. The small Y-1266 is being designed into two new oscillators by one manufacturer. The almost equal grid to cathode and grid to plate capacitance makes the Y-1266 ideal for butterfly type circuits. The photo shown in **Figure 17** shows the Y-1266 and 7768 being used in a new design signal generator recently released by General Radio. In addition to the wide tuning range available from the Y-1266, the tube was demonstrated to be superior to other competitive triodes in terms of short term and long term frequency stability. The 7768 is used as a broadbanded power amplifier to provide additional signal generator power output and to improve frequency stability under wide variations of load impedance. The Y-1641 bonded heater version of the **7486** is being used in a very stable, local oscillator for a new spectrum analyzer being manufactured by the Tektronic Corporation. Most of the significant new uses for the new ceramic family have been mentioned. There are numerous other uses which cannot be described here. These uses were described in terms of the functions required and the equipments in which they are used. More detailed application information will now be discussed.

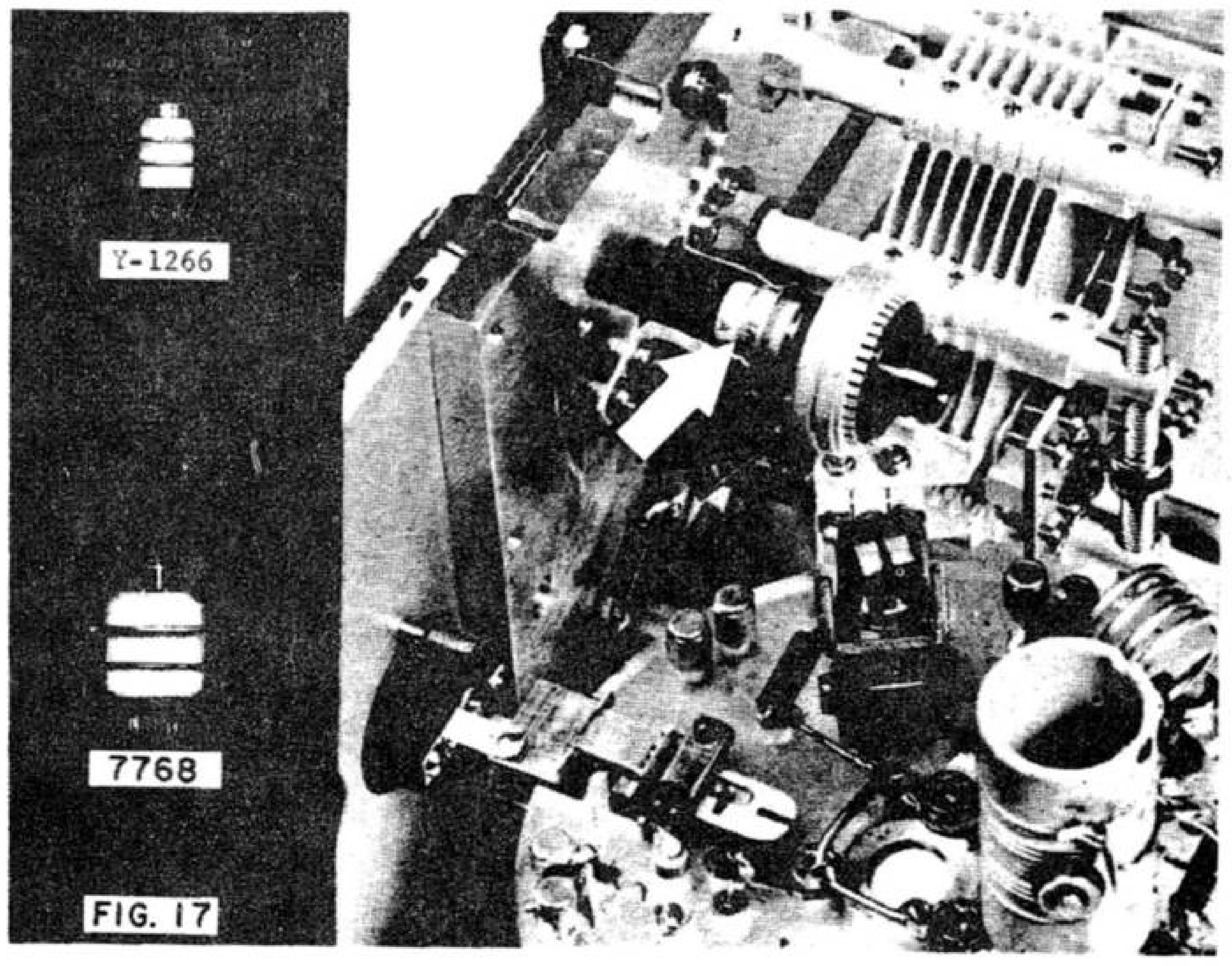


FIG. 17

APPLICATION NOTES ON PLANAR TRIODES

TUBE CONNECTIONS AND CONTACTS

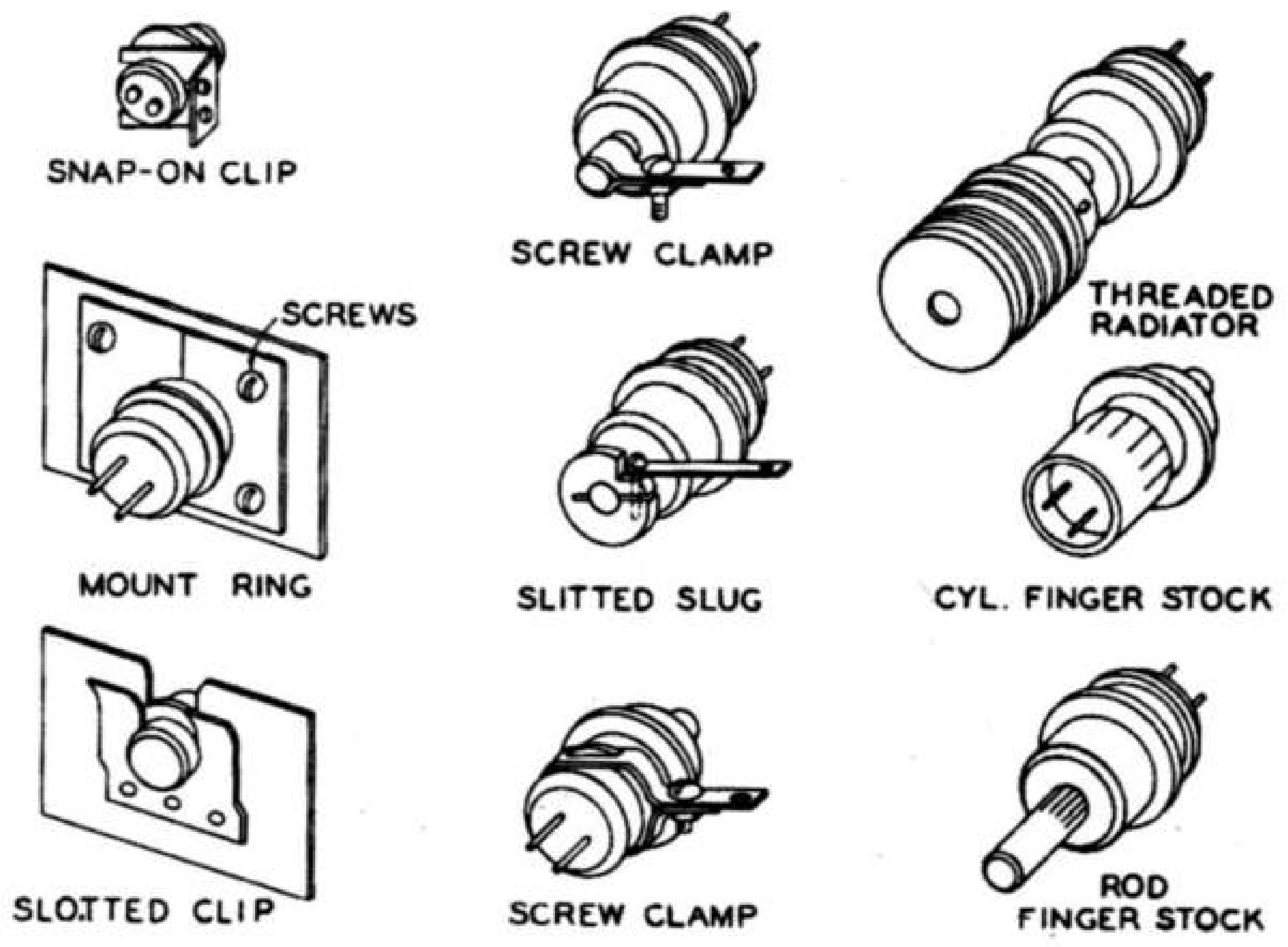


FIG. 18

At high frequencies, good RF connections to the active elements of the tube to be used are fundamental. **Figure 18** shows several sketches of the various methods of connecting to the desired tube element. One additional significant feature of the new tube family is the ability to solder directly to the tube elements. It has been found almost essential to use soldered connections on circuits that must take very high levels of shock and vibration. This method of connection is recommended wherever practical.

Two basic cavity designs have been used most often for the higher microwave frequencies. Most oscillators use a re-entrant type circuit which is basically a grounded cathode amplifier with built-in feedback. The amplifier stage is almost always a grounded grid circuit.

TUBE - CAVITY COMBINATION

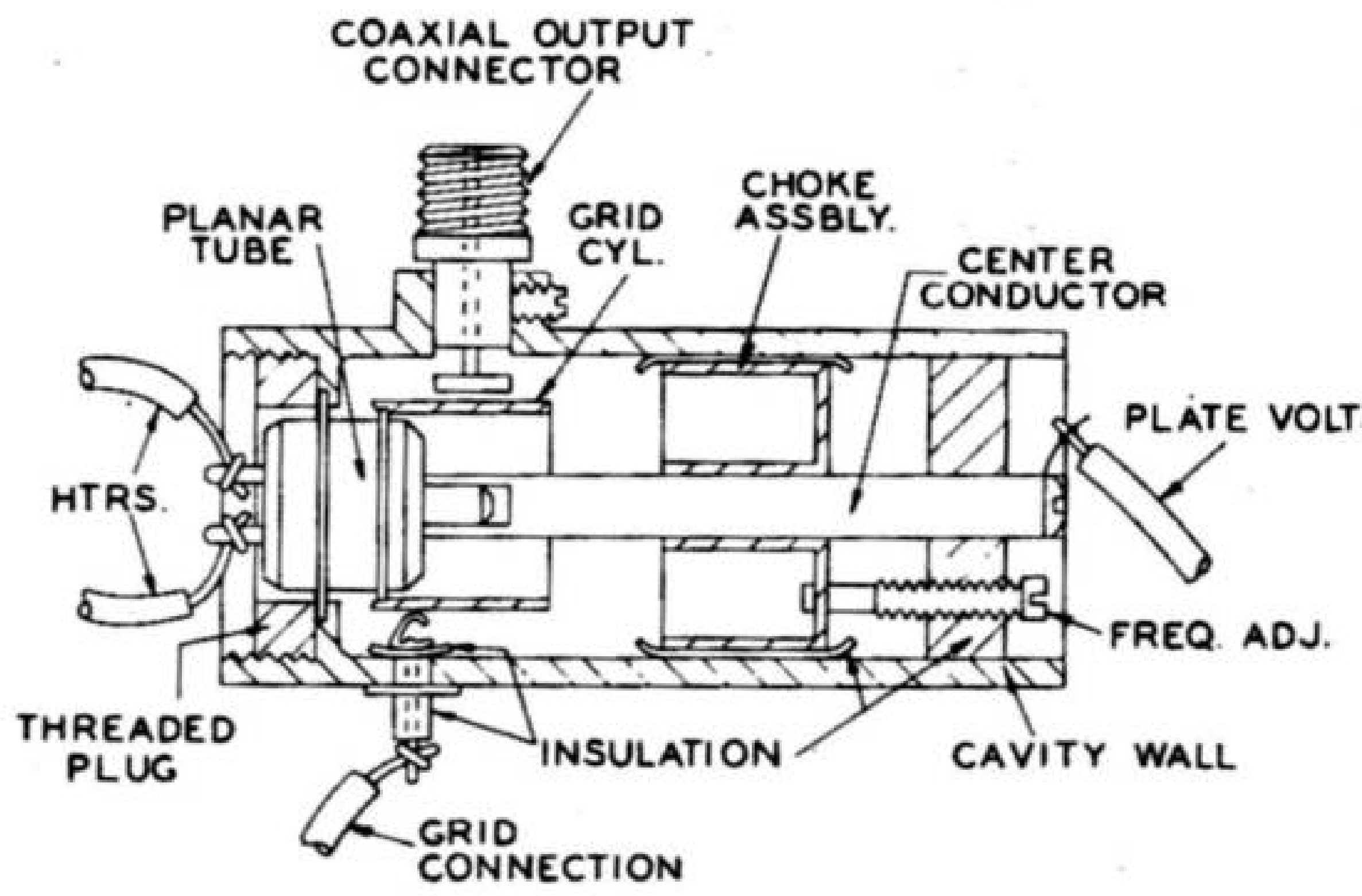


FIG. 19

Figure 19 is an artist-sketch of a common configuration used for oscillator tube-cavity combinations. The most useful tube geometry is the outline which has the cathode as the largest external diameter element. The cathode can then be clamped or soldered to the cavity body with a diameter large enough to accommodate the other cavity elements. The heater voltage can be applied with ease and without consideration of RF bypass or decoupling. A grid cylinder is attached to the grid flange. The length of this cylinder is chosen to resonate as a half-wave resonant circuit. One portion of the half-wave circuit is foreshortened by the grid to plate capacitance of the tube and the other end of the half-wave circuit is open-ended and untuned. This places a voltage maximum at the open end of the grid cylinder. At this point, the voltage is further resonated by tuning the remainder of the plate coaxial cavity to the same desired frequency. This usually is a quarterwave circuit tuned by the placement of the anode choke. This choke can take many forms but the basic purpose is to provide a short-circuit for the tuned RF voltage present on the anode center conductor while providing an open-circuit for the DC applied to the anode. The choke shown in **Figure 19** is a single-tuned, quarter-wave choke. The open circuit seen by the choke looking out of the cavity towards the DC connection is transformed into a short circuit at the inside end of the anode choke. The short circuit at this point is required to prevent RF leakage. Chokes using two or more quarter-wave sections can also be used where extra choking action is required and space is no problem. The oscillator frequency can be changed up to about 10% in frequency by moving the position of the anode choke inside the cavity body. Further frequency range can be obtained if the grid cylinder length can be varied at the same time. The design of the cavity circuit from the end of the grid cylinder looking back toward the cathode end of the cavity is important. This length most often must look like a three quarter wavelength circuit to provide proper phasing at the end of the grid cylinder. Feedback is provided, since the basic circuit resembles a Colpitts oscillator circuit. Resonance is established between the grid and anode and feedback is provided by the voltage developed across the grid to cathode capacitance. Power output can be extracted by inserting a capacitive probe near a high RF voltage point inside the tube-cavity combination or an inductive loop near a high RF current point. This is usually done along the grid cylinder for mechanical reasons. In some cases, a combination loop-probe is used when, for mechanical reasons, a current or voltage maximum point is not easily located.

COAXIAL CAVITY AMPLIFIER

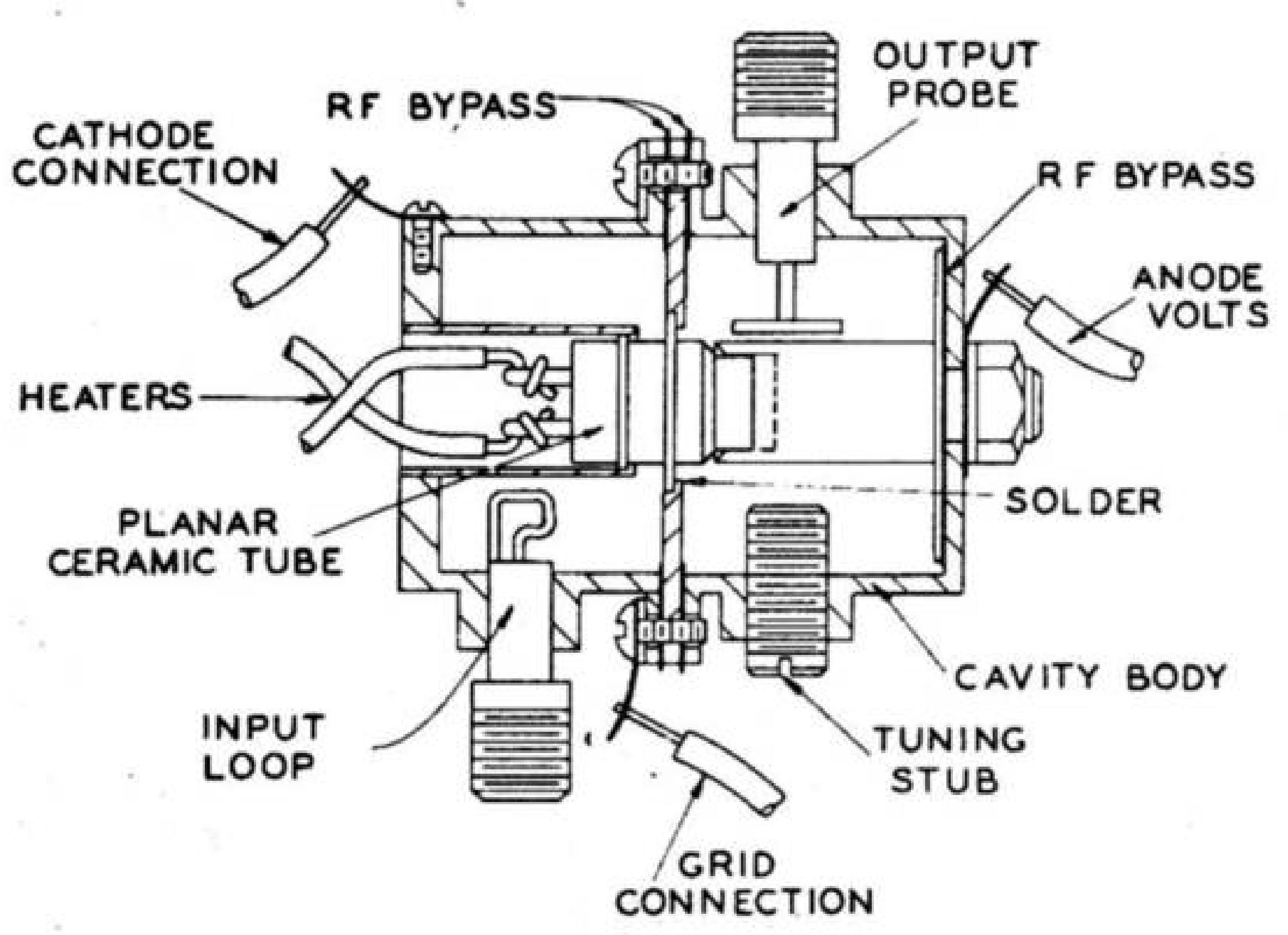


FIG. 20

Figure 20 is a cutaway sketch of a typical amplifier circuit. This is the basic circuit used for the Y-1266 tube-cavity shown in **Figure 16**. At 2300 megahertz, the capacitances of the Y-1266 are sufficiently low to permit use of quarter-wave resonators in the cathode and anode circuits of this grounded grid configuration. Quarterwave circuits produce, among other things, smaller size and weight devices but limit the upper useful amplifier frequency. In the arrangement shown in **Figure 20,** the grid is DC isolated using mica by-passes. Bias can be fixed using a DC value of grid voltage, or a grid leak or cathode resistor can be used for variable bias. The input signal is applied using an inductive loop. The input capacitance is usually larger than the output capacitance, and it is more difficult to obtain a high RF voltage point inside the cathode cavity. The output is taken from a voltage probe in the anode cavity. The cathode cavity is loaded heavily with the low impedance of the grounded grid input and is usually tuned near the desired frequency. Further tuning is not necessary over a relatively wide frequency range. The anode circuit must resonate the input frequency, and in this amplifier the anode cavity is tuned by susceptance loading of the output cavity. Brass slugs are inserted which in effect raise the resonant frequency. Two slugs were necessary to tune the desired range of 2200 to 2300 megahertz. In some cases, the plate circuit can be tuned to a frequency much higher than the cathode circuit. In this case, where higher frequencies are desired, a half or three-quarter wavelength cathode circuit is used. This lengthens the cavity length and increases the size and weight.

In most amplifier applications, bandwidths as well as other RF performances are important. For maximum bandwidth, only quarterwave circuits should be used as suggested by **Figure 21.** This is particularly true for the anode cavity or circuit. However, for oscillators, multi-wave length circuits are actually recommended for maximum stability and extending usefulness to higher frequencies. The narrowbandedness of the multi-tuned circuit improves stability by providing higher effective Q's, and half-wave circuits provide resonance at higher frequencies. Half and three-quarter wavelength amplifiers are used to extend the upper frequency of some of the large power triodes and tetrodes. In multi-tuned circuits used for broadbanded circuits, it is sometimes impractical to use quarter-wave circuits throughout.

BANDWIDTH SHRINKAGE EFFECTS OF A CAVITY VS. THEORETICAL AVAILABLE BANDWIDTH

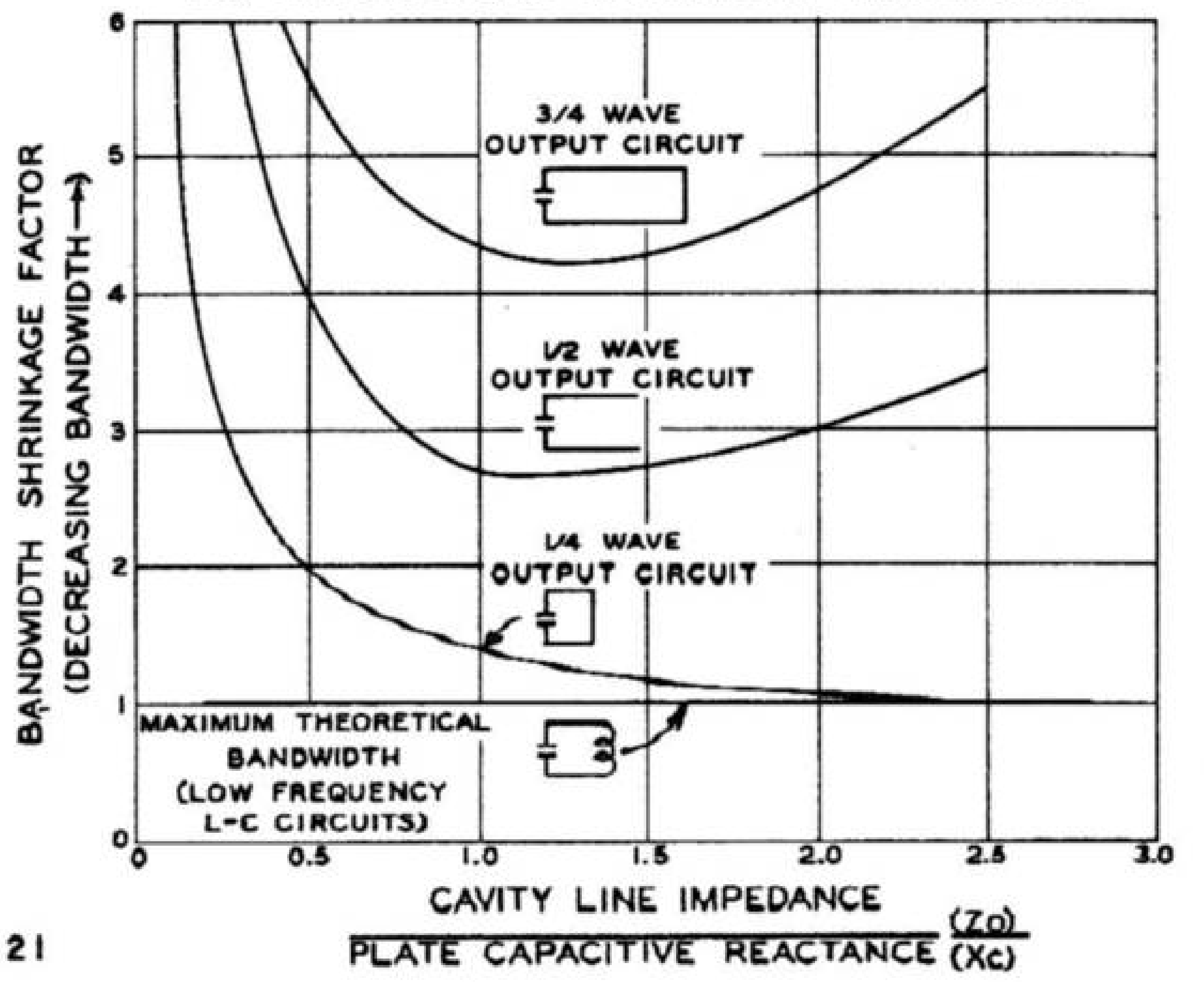
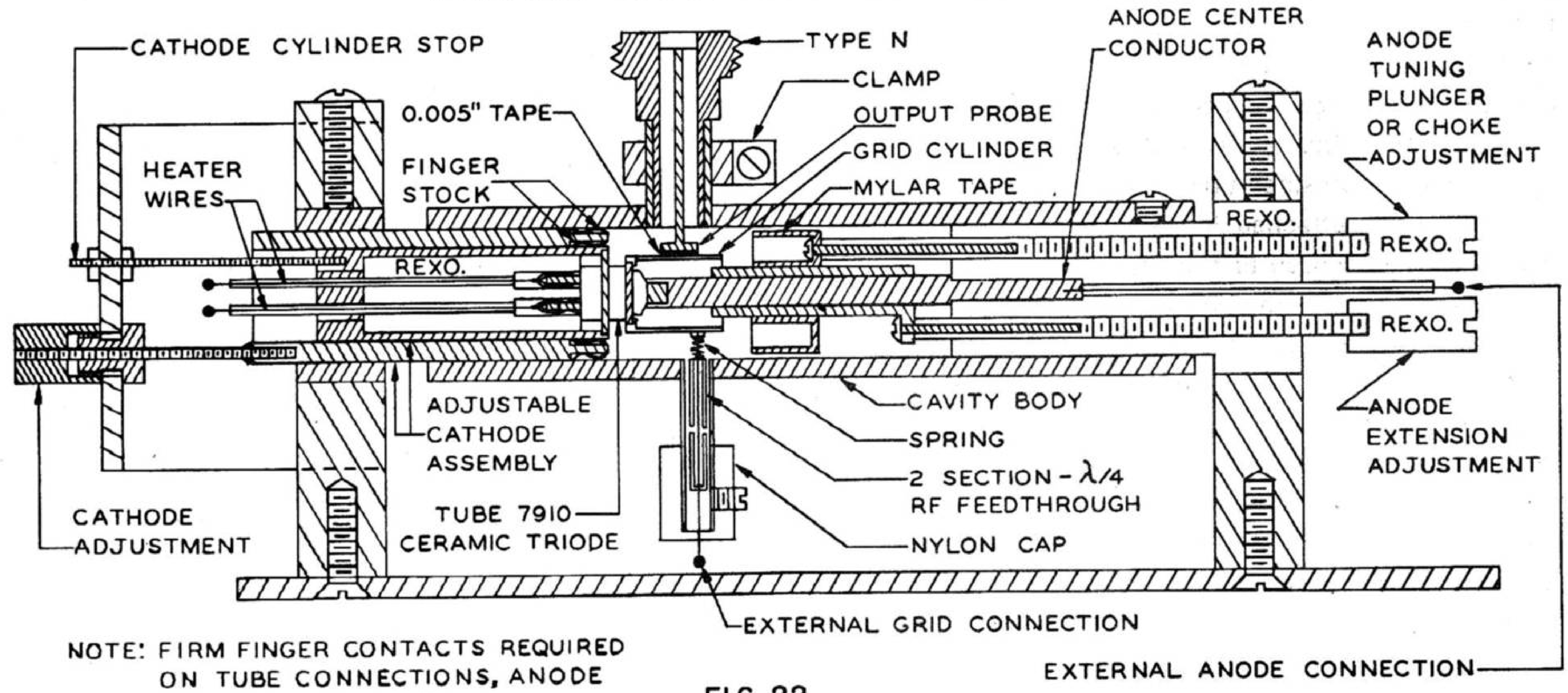


FIG. 21

There are many insidious design features in most success-

PLANAR CERAMIC TUBE TEST CAVITY



NOTE: FIRM FINGER CONTACTS REQUIRED ON TUBE CONNECTIONS, ANODE CHOKE, AND EXTENSION.

FIG. 22

ful tube-cavity designs which the designer is usually hesitant to describe, and there are also no sure-fire design equations. For these reasons, original designs require a large amount of trial and error. To provide a maximum number of variables, the cavity shown in **Figure 22** was built. The feedback can be adjusted by adding lengths of coaxial line at the cathode end. Various lengths of grid cylinder can be inserted. The anode choke assembly can be moved to change frequency. Various kinds of bias can be applied, and the output coupling can be adjusted as desired. Using this cavity, the type 7910 was evaluated over the frequency range and cathode current densities shown in **Figure 23.** These results also show the significance of high current density operation already discussed.

MICROWAVE PERFORMANCE AT HIGH CURRENT DENSITIES

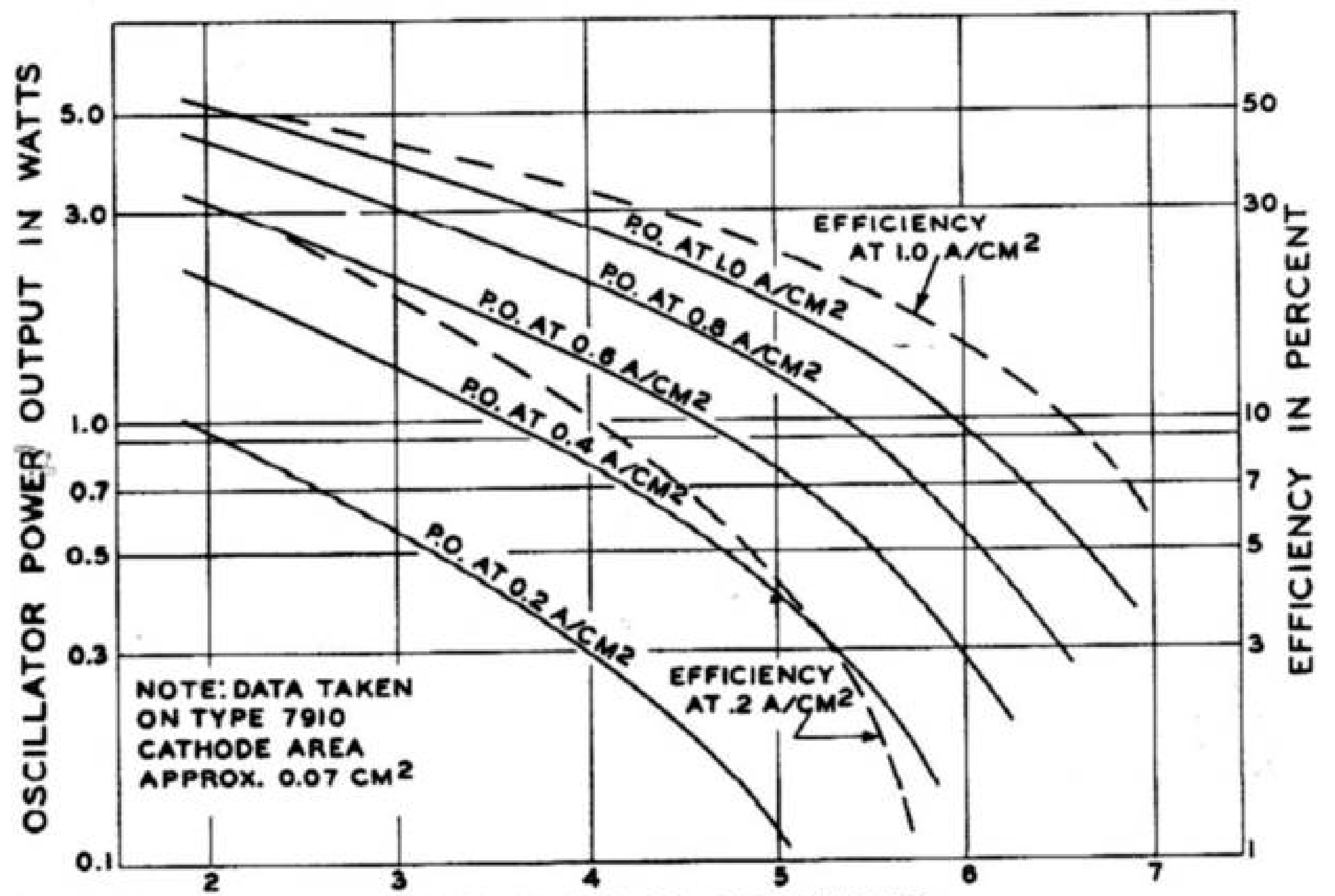
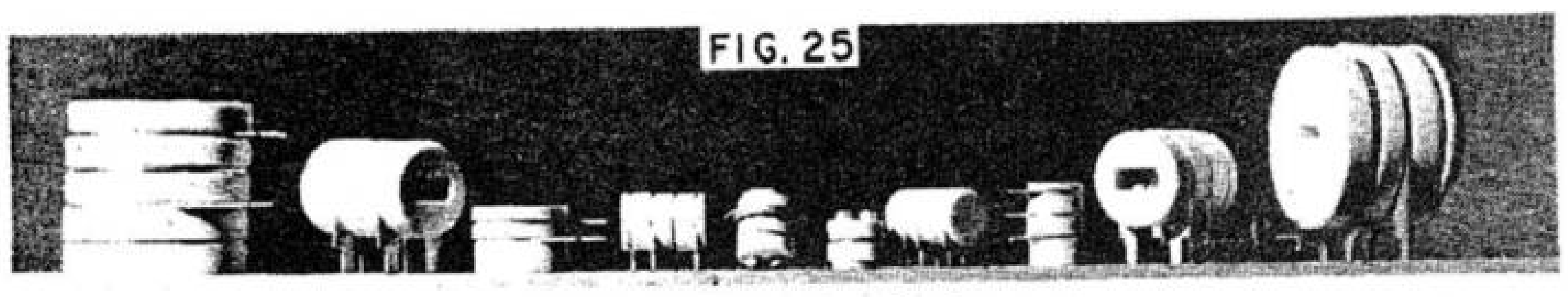


FIG. 23

PRESENT STATUS OF NEW TUBE FAMILY

A new family of lug terminal planar tubes has been developed for lower frequency use. The high temperature tolerance, extreme mechanical ruggedness and high electrical performance available from the internal dimensions of the new tube fabrication techniques result in their usefulness at low frequencies. **Figure 25** is a photo of most of the available external outlines. These tubes are well suited for socketed circuits, printed circuits and socketless circuits. Some of the outlines use a "T" bolt which is attached to the heater-end ceramic. The tube can be mounted to any supporting surface, and the tube serves as its own terminal strip. This method of tube mounting is particularly useful where wire-wrap joints are used. **Figure 26** is a brief list of successful low frequency applications. **Figure 27** is a photo showing the available high frequency or microwave outlines. These are the types most discussed in this paper but some of the types shown are older designs using conventional sealing techniques. **Figure 28** is a photo of the latest developmental types. Only a portion of these tubes is available. The most significant of these are the two larger tubes shown at the center of the photo. Up to one kilowatt of CW power output at 1.3 gigahertz has been obtained at about 65% efficiency. Transconductance over 500 ma per volt has been obtained. The smaller tubes have been operated as oscillators to frequencies up to 16 gigahertz.

FIG. 25



LOW FREQUENCY APPLICATIONS

- POWER SUPPLIES - HIGH-VOLTAGE AND IN ADVERSE ENVIRONMENTS
- VIDEO AMPLIFIERS - HIGH-TEMPERATURE, SHOCK AND VIBRATION USE
- I.F. PRE-AMPS - LOW NOISE AND S.T.C. CIRCUITS
- ION AND STRAIN GAGE PRE-AMPS - HIGH-Z AND VIBRATION USE
- PULSE MODULATORS AND AMPS - HIGH-VOLTAGE AND FAST RISE TIME NEEDS
- DETECTOR PROBES - HIGH-Z AND BROADBAND INSTRUMENTS
- DC, AUDIO AND SERVO AMPS - IN ADVERSE ENVIRONMENTS
- DIFFERENTIAL AMPS - TEMPERATURE AND TIME STABLE CIRCUITS
- MOBILE TRANSMITTERS - REDUCES SIZE AND WEIGHT
- RECONAISSANCE RECEIVER PRE-AMPS - ELINT

FIG. 26

FIG. 27

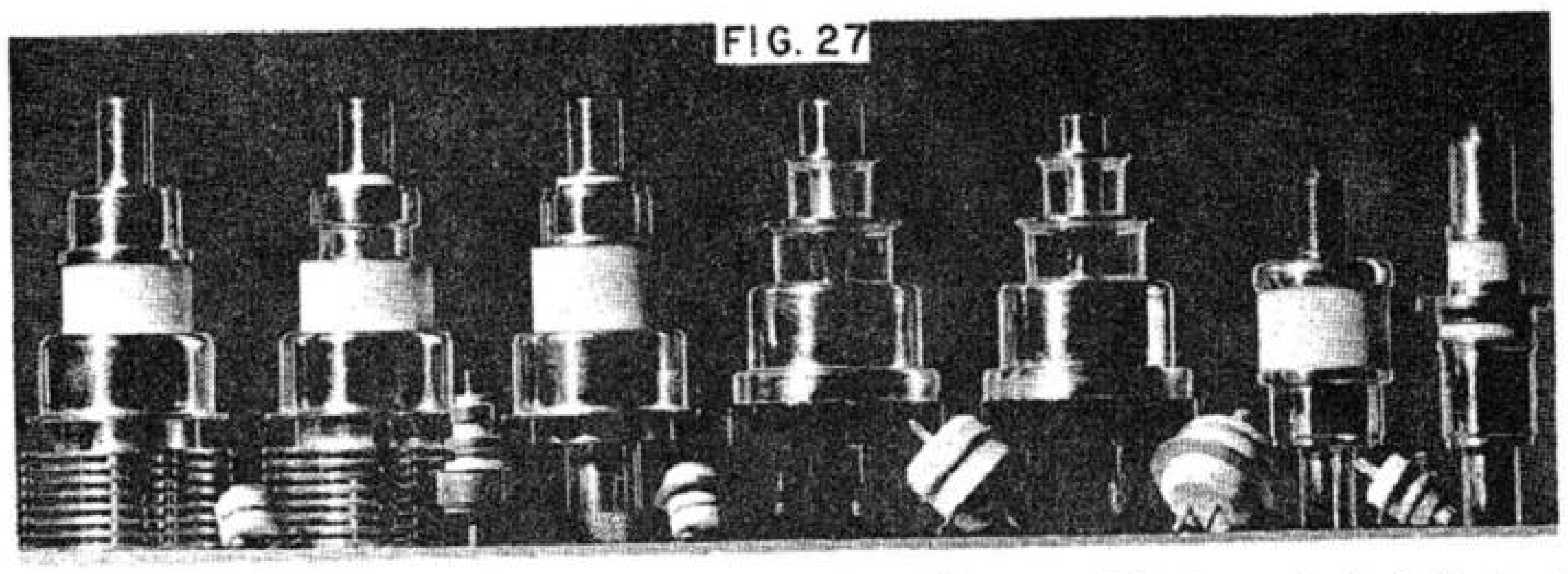


FIG. 28