High-Power UHF-TV KLYSTRON

Two-stage klystron provides power gain of 250 with bandwidth of 5.6 mc between 1-db points in uhf television band. Special bombardment cathode design permits replacement of worn out cathodes to extend life of tube almost indefinitely

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EXPANSION of present television broadcasting facilities to include the uhf band is imminent. One of the main stumbling blocks lying in the path of uhf-tv has been the lack of power tubes capable of operating at these frequencies and having other properties necessary for the final amplifier of a television transmitter.

Conventional tubes designed for uhf operation require small sizes and spacings, requirements inconsistent with high power. Transit time becomes a major problem, and low gain per stage adds complexity in both construction and operation. A successful final amplifier tube should combine high power capability with high power gain and bandwidth. The klystron has proved to be capable of such performance.

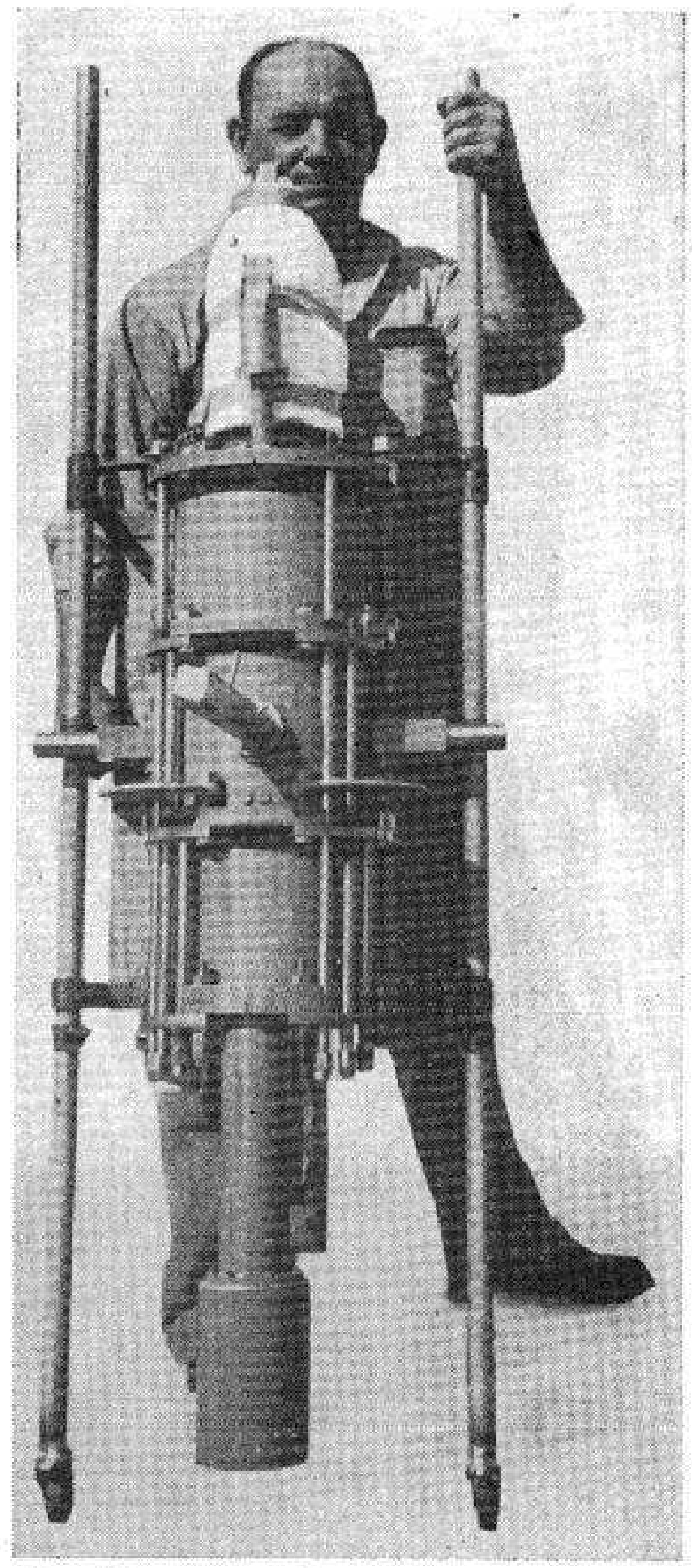
High-power uhf klystrons have been built. In 1939, John Woodyard of Stanford University built a two-cavity oscillator that had a power output of 250 watts continuous at 750 mc. A three-cavity amplifier tube with two kilowatts output at 750 megacycles was used in a c-w radar, type TPS-7, in 1943. A 5-kw tube for 500 mc was designed and built independently by R. Warnecke in the Research Laboratories of the Compagnie Generale de Telegraphie Sans Fil in Paris at about the same time that the work described below was initiated but no data are available concerning the performance under field conditions.

General Design

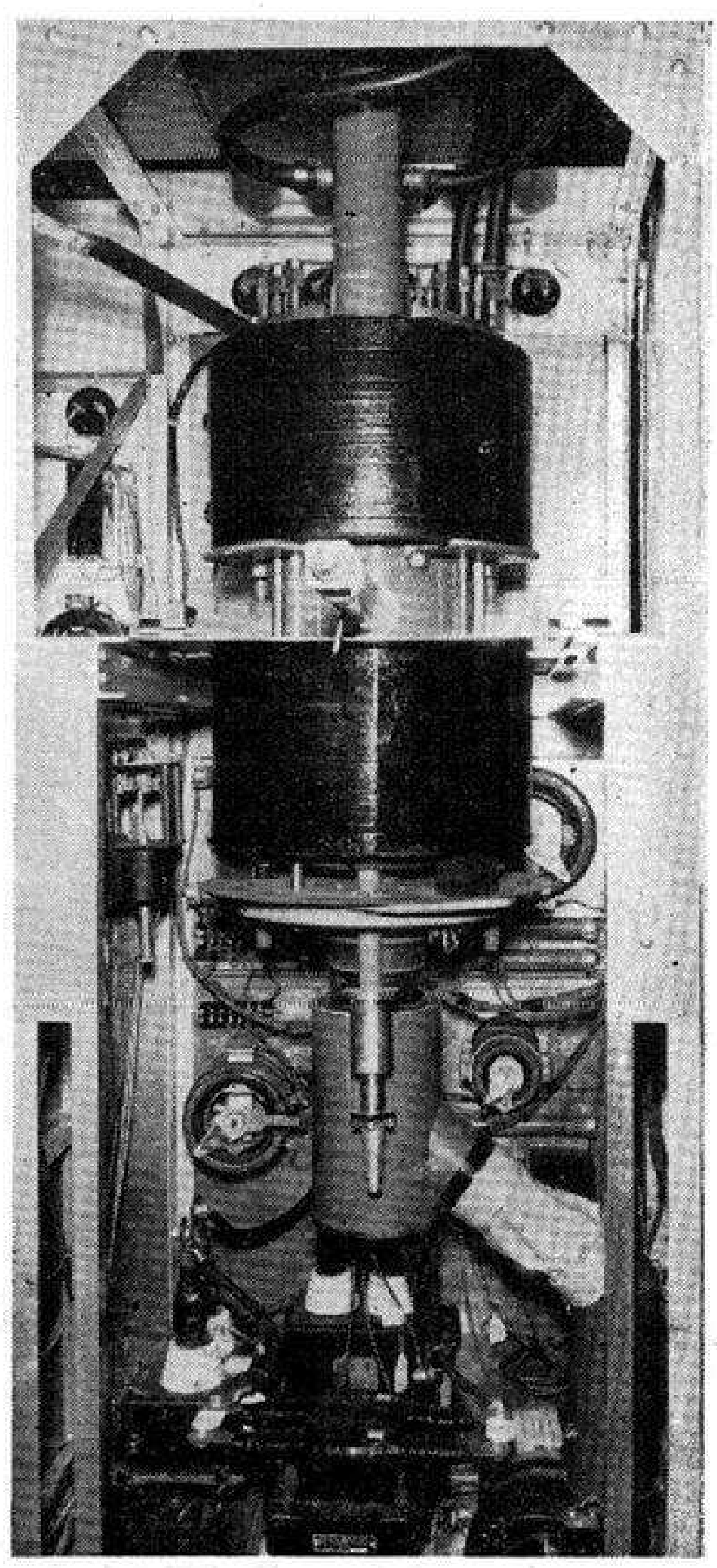
The tube to be described was developed by Varian Associates to specifications provided by General Electric. It is now part of the GE uhf-tv transmitter described in the June 1951 issue of ELECTRONICS.

As a starting point in the adaptation of the klystron for television transmitter service, the following specifications were set up: (1) 5 kw c-w output, (2) power gain of 100, and (3) bandwidth of 6 mc between 1-db points. The proposed power output and gain were chosen to take advantage of conventional 50-watt driver tubes of the lighthouse and planar electrode types.

Other important requirements were linearity and freedom from noise and spurious modulation. In both these respects the klystron has inherent advantages. The output of a klystron varies with the input as a Bessel function of the first order. For low levels this is exactly linear, and it does not depart much from linearity until the out-



Amplifier, complete with cavities, is shown ready for shipping



Five-kilowatt uhf-tv klystron is shown installed in transmitter put is approximately 80 percent of the maximum power. Even this last 20 percent of power need not be wasted, however, since only the synchronizing peaks occur at this level, and these can be predistorted to give the desired output shape. Thus, in the range where linearity is needed for picture clarity, the klystron is inherently linear and the full peak power can be utilized in a transmitter.

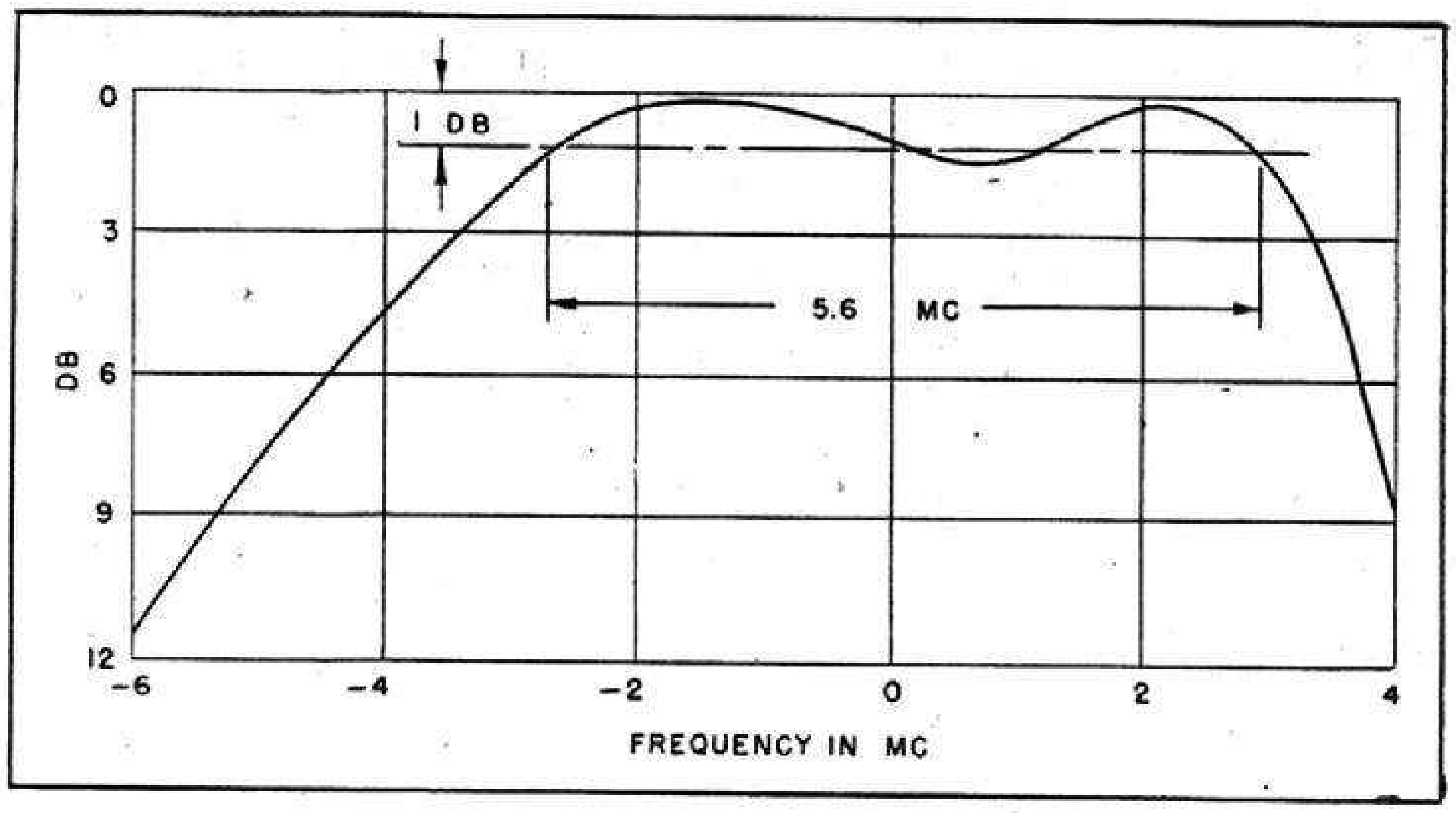


FIG. 3—Response curve shows bandwidth of amplifier

Random noise and spurious modulation present no problems in a klystron operating at transmitting power levels. Since the grids have been eliminated, there is no partition noise. All the tube structures are big and rugged, making the tube insensitive to vibration. The heater for the cathode is at one end of the tube, far removed from the interaction space, so the alternating current in the heater can produce no hum. The greatest source of spurious modulation appears to be the power supply ripple, but even the simplest filtering reduces this to a point more than 60 db below the carrier.

In connection with the power supply, there is another advantage of a klystron amplifier to be noted. Since the current drain from the power supply is independent of the r-f level, a regulated or low-impedance power supply is not required to handle modulation peaks.

Development of a klystron at the low end of the uhf band (instead of at a higher frequency such as 800 or 900 megacycles) was a case of attacking the harder problem first. To klystron designers, 500 mc is a very-low frequency rather than an ultra-high frequency and presents special problems. Cavity sizes at this frequency tend to become excessive. Tubes similar to the one described here have produced more than 5 kilowatts of c-w power at over 1,000 mc. Thus it is clearly practical to produce an amplifier with more than 5 kilowatts output at any frequency between 500 and 1,200 mc.

Figure 1 is a schematic diagram of the new tube, showing how the design problem reduces to three separate and distinct parts. First, there is the problem of producing a direct-current beam of electrons of suitable size and density. This is accomplished by the cathode assembly. Second, there must be structures for the radio-frequency interaction with the beam. These are the cavities. Finally, the disposal of the residual energy of the electrons is accomplished in the collector.

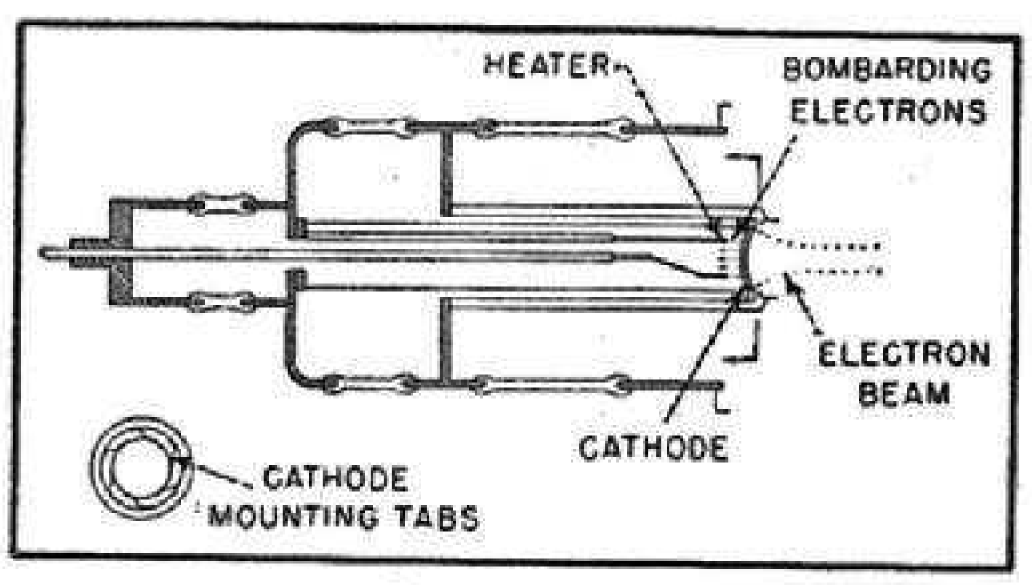


FIG. 2—Bombardment cathode is free from poisoning and may be replaced periodically to make new tube out of old

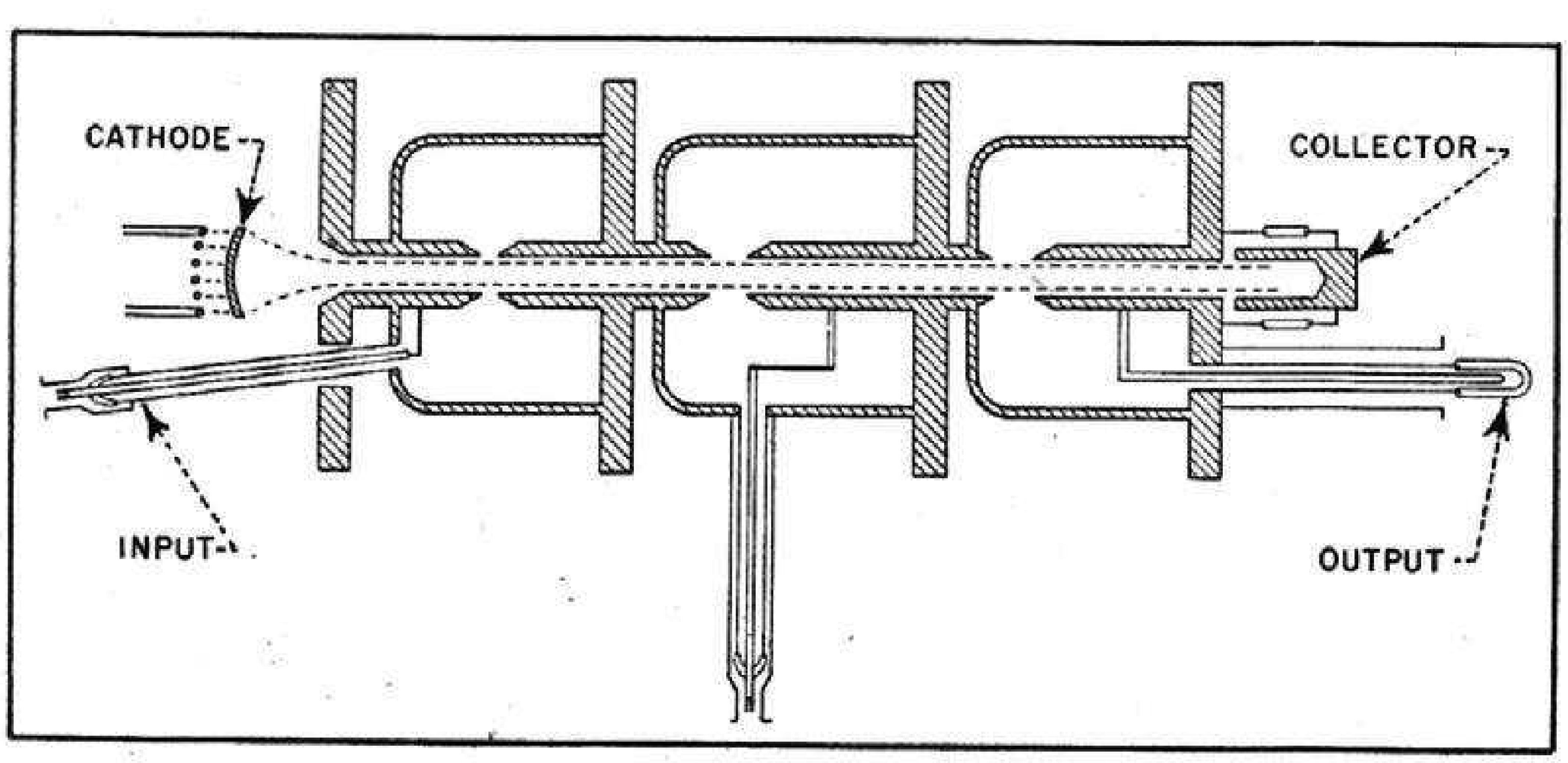


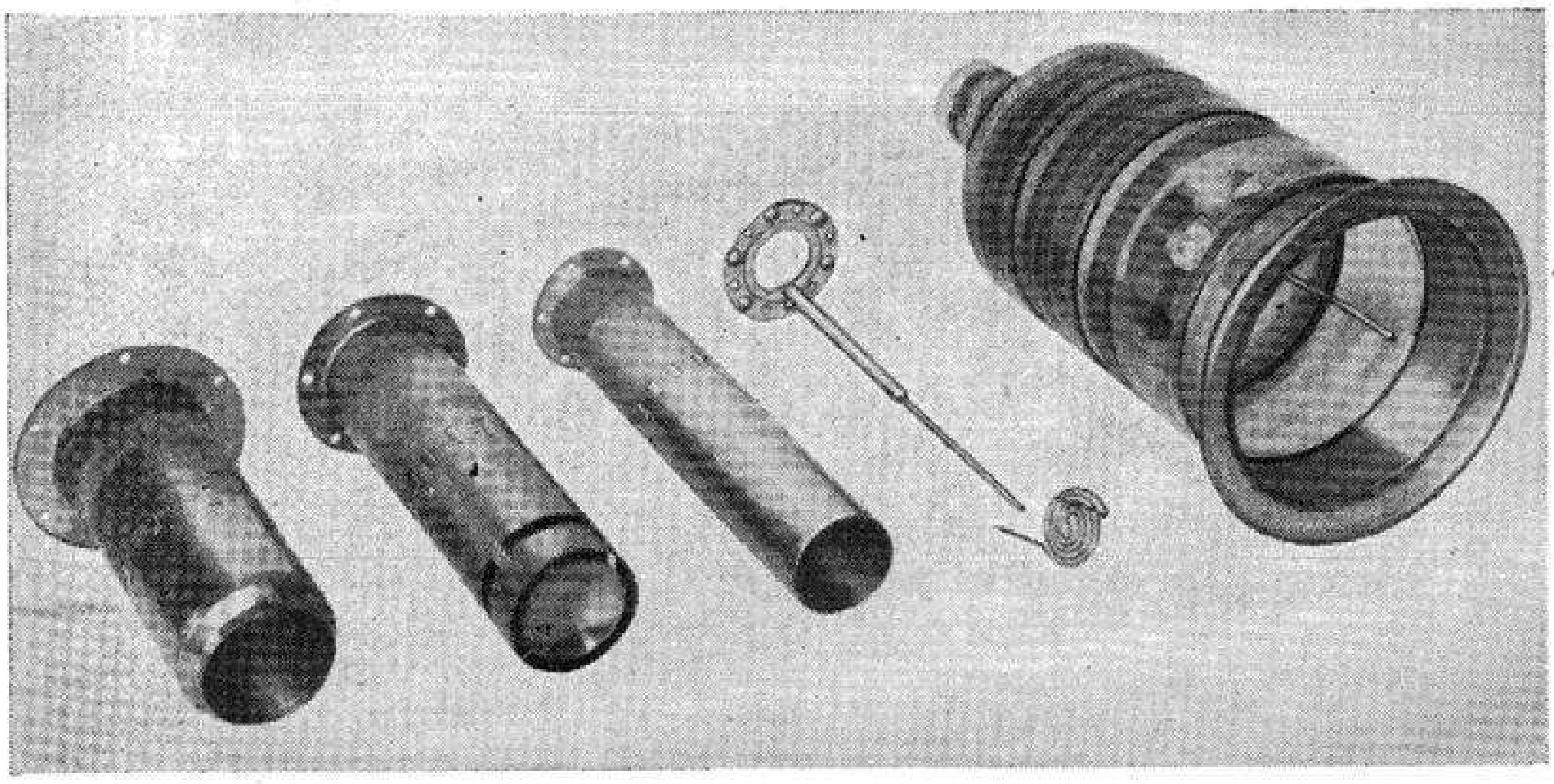
FIG. 1—Schematic of triple-cavity (two-stage) klystron amplifier shows inherent simplicity and straightforward arrangement of elements

In the triple-cavity or cascade klystron, the first stage, as shown in Fig. 1, can be likened to a voltage amplifier and the stage between the second and third cavities acts as a power amplifier. The efficiency of the cascade klystron is about the same as the conventional two-cavity (single-stage) klystron, but the gain is much higher, being approximately the product of the gains of two single-stage klystrons. The electrons are actually used twice to obtain a very high gain from a given expenditure of power.

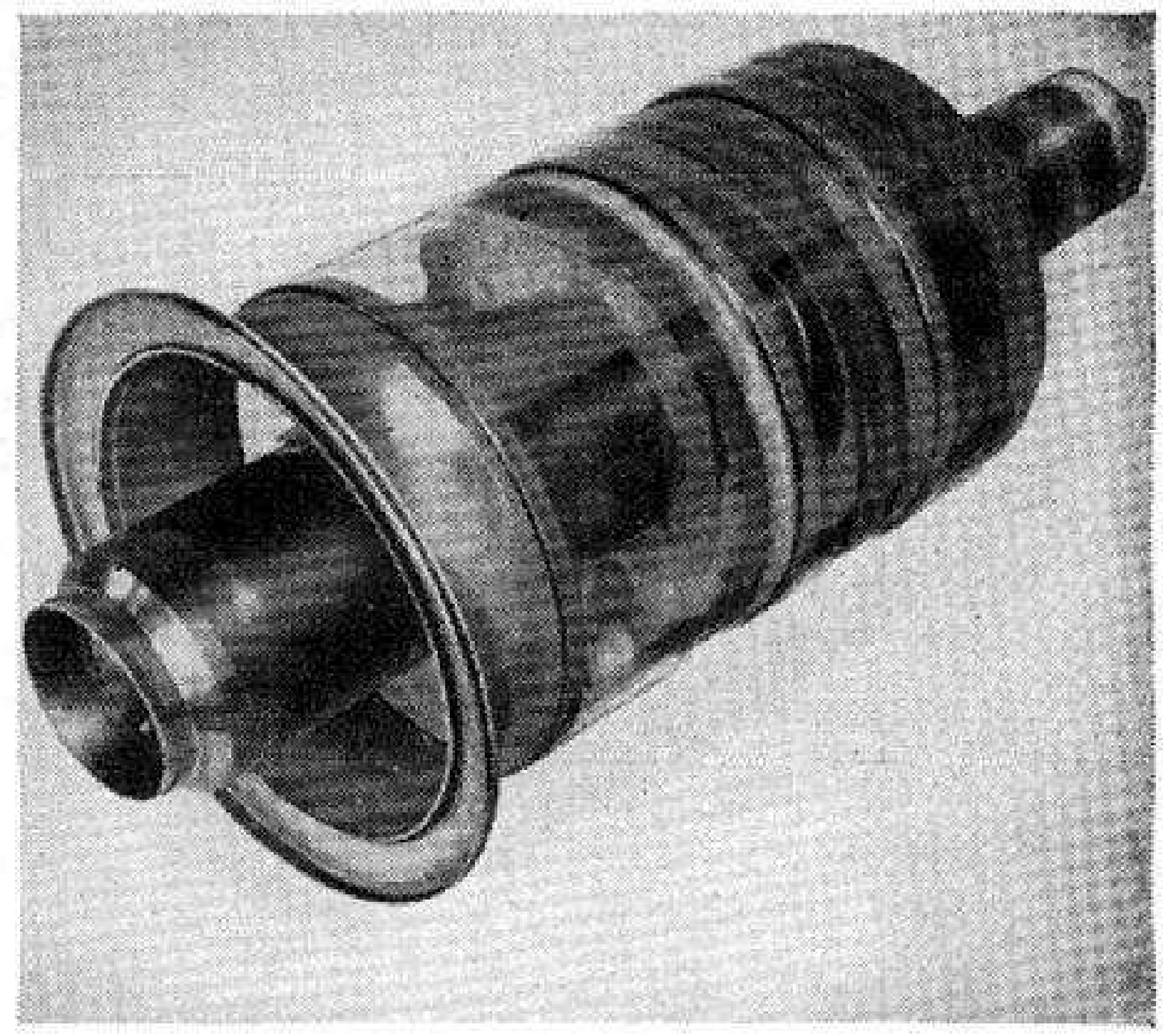
Cathode Structure

Expected efficiency, r-f considerations and physical convenience determine the diameter and length of the drift tube as well as the voltage and current of the beam. For this tube, the figures came out to be 2 amperes and 10,000 volts to pass through a tube 1 inch in diameter and 24 inches long. A cathode design to produce such a beam is straightforward, using the so-called Pierce gun techniques. A magnetic field of approximately 200 gauss, produced by coils outside the resonators, is used to keep the beam from spreading to the walls of the drift tube.

The physical design of the cathode is interesting, in that it departs from the usual oxide emitting surface. One of the prime requirements of the amplifier is long life, and since practically everything else except the cathode consists of



Disassembled view shows components of cathode structure



Complete cathode assembly

heavy copper machined parts with essentially infinite life, the limiting factor on tube life is the cathode itself. To eliminate the troubles associated with oxide cathodes, our engineers developed a form of what is called a bombarded cathode. The schematic diagram of Fig. 2 illustrates such a cathode.

The emitting surface of the cathode is a piece of tantalum sheet 0.1 inch thick, supported by tabs from the end of a molybdenum tube. The moly tube, is supported in a kovar-to-glass ring seal. A focussing electrode is similarly supported at this point on another cylinder. Behind the tantalum cathode button is mounted a heater of tungsten wire. Radiation from the heater is insufficient to heat the tantalum to an emitting temperature, so a direct voltage is applied between the heater and the cathode. This causes a current to flow, as in a diode, and the electron bombardment of the back of the cathode button heats it to an emitting temperature.

Bombarded cathodes have been used in several klystrons, and they give long, trouble-free life. The limiting factor on life seems to be the evaporation of the tungsten heater, but if the heater is operated somewhat temperature limited (in the bombarding diode) life approaching 10,000 hours can be achieved. An advantage of this type of cathode is that it does not poison. The tube can be let down to air for repairs and repumped without damage to the cathode.

The usefulness of this tube is not limited to the 10,000-hour life of the cathode. Even though all possible care has been taken in designing both cathode and filament, failure in one or the other must occur eventually. When this happens, it is not necessary to scrap the entire tube structure since the cathode mount has been so arranged that it can be easily removed and replaced with a new assembly. This operation costs approximately one-sixth the original value of the tube. A tube which has been fitted with a new cathode is literally as good as new. The operation can be repeated, and there is no apparent limit to the number of times the cathode can be replaced.

In connection with cost considerations, it is important to realize that the klystron reaches the user completely fitted with its tank circuits. The klystron is actually a complete final amplifier requiring only the connection of power supply voltages and cooling water to put it into operation.

Collector

The collector is cooled by a stream of water flowing at approximately 5 gallons per minute. It is insulated from the body of the tube by a glass seal for the purpose of metering the relative currents lost to the drift tube and reaching the collector. Both the body of the tube and the collector are at ground potential (both d-c and r-f) since the cathode is operated below ground. This provides the maximum safety to operating personnel and avoids the usual troubles of electrolysis and of insulation for d-c and r-f potentials in the water hoses.

The bandwidth of a cascade klystron is approximately the same as that of a single-stage klystron. It can be increased beyond that corresponding to the Q's of the cavities either by loading the cavities to reduce their Q's or by stagger tuning. Stagger tuning is generally a preferable way of trading gain for bandwidth. The three cavities are tuned to different frequencies in such a manner that the band over which gain is obtained is increased, but gain is reduced.

Test results for the tube have shown that satisfactory performance can be obtained by an appropriate stagger tuning scheme in which there is no external loading on the center cavity. This permits an appreciable simplification of construction of the tube since the need for a coaxial line coupled to the center cavity is eliminated. In addition, the radio-frequency power which inevitably would have been lost in the band-widening load on the center cavity is conserved.

An actual measurement of the response curve shows a bandwidth of 5.6 mc between 1-db points. This curve is plotted in Fig. 3. The power gain corresponding to this curve was about 24 db or 250 times. This can be considered a typical performance for a cascade amplifier klystron in the uhf television band. The adequacy of this performance for television purposes was demonstrated by the General Electric Company when they actually used the klystron to amplify a television picture. The quality of the picture was essentially unchanged by its passage through the klystron amplifier.