A Tunable, Low-Voltage Reflex Klystron for Operation in the 50 to 60-kmc Band

By E. D. REED

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Electrical and mechanical techniques are described which have been successfully applied to the design of a reflex klystron operating in the 50,000 to 60,000-mc band. Not only have these techniques resulted in a practical tube operating at the highest frequency yet achieved with a gridded, low voltage reflex klystron, but they point the way to future work at still higher frequencies.

The M1805 reflex klystron has a mechanical tuning range of over 10,000 mc and at a beam voltage of 600 volts delivers a maximum CW power of 15–30 milliwatts. Its electron-optical system resulted in a repeller mode exhibiting good symmetry and almost complete absence of electronic hysteresis.

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INTRODUCTION

The design of a low-voltage tunable reflex klystron for continuous operation in the millimeter waveband poses a number of difficult problems most of which stem either directly or indirectly from the small physical size of the resonant cavity. In addition, we must contend with the unpleasant yet inescapable facts that klystron cavities become inherently poorer with increasing frequency and that both smoothness and freedom from stresses in cavity walls assume increasing importance.

Finally, if a long-life, oxide coated cathode is desired, that is, one operating at moderate surface current density, a somewhat delicate gun design problem must then be faced.

Many techniques, both electrical and mechanical, successfully used in the centimeter region fail when applied to the design of a millimeter-wave reflex klystron so that we are forced to look for alternatives, i.e., specialized solutions which satisfy the requirements peculiar to this frequency range. Also, since many of the problems are mechanical in nature, it is obvious that the electrical design of a tube of this type cannot proceed without unusually close attention to structural feasibility. Another obstacle to tube development in a relatively new frequency band is the lack of broadband waveguide components normally available for the determination of important tube parameters.

The M1805* reflex klystron is the outgrowth of development effort which was aimed at exploring the possibility of millimeter-wave generation by means of a low voltage tunable reflex klystron. The ease of operation and general convenience afforded by such a tube not only were needed for the millimeter wave research in progress at Bell Laboratories and in the military establishment but, it was felt, would render practical and stimulate new investigations held in abeyance because of the lack of suitable primary signal generators.

As described in a recent paper by S. E. Miller,[1] the Bell System's interest in the millimeter wave region has been centered chiefly around the use of circular waveguide as a low-loss communication medium. This interest and, equally important, certain military needs led to an intensification of the millimeter klystron effort, an effort which, since the later part of the war, had been pursued at Bell Laboratories on a comparatively small scale and with several interruptions. As early as 1945, J. R. Pierce[2] succeeded in producing several milliwatts of continuous millimeter wave power. His tube, the 1464XQ, could be thermally tuned from about 45 to 48 kmc and with a resonator voltage of 400 volts, a value, which was determined by the power handling ability of the grids, would deliver some 2–5 milliwatts of RF power. A small number of these tubes was built but development was stopped short of completion. The experience gained in the course of that investigation and in later work of C. T. Goddard, however, has in no small way contributed to the success of the M1805.

The present development program, which was culminated in the highest frequency reflex klystron of the low voltage, gridded type ever

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* This tube was developed under Office of Naval Research Contract Nonr 687(00).

built, started out with two distinct aims. The first was to determine whether a low-voltage, tunable reflex klystron for CW operation in the 5–6 mm band could be built on a laboratory basis. There was no assurance that this could be done within the limitations imposed by such requirements as low voltage operation, tunability, moderate emission density and long life. Moreover, as the performance of Pierce's 1464XQ had been marginal, scaling to a still higher frequency appeared a somewhat risky endeavor. The second objective was contingent upon the success of the first. It called for a tube of reproducible characteristics and one which would lend itself to quantity production if and when required.

Results obtained to date with representative numbers of M1805's indicate that the original design objectives have in most instances been met and in some, such as power output and tuning range, exceeded. A typical tube will tune mechanically from 50 to 60 kmc, will deliver a maximum of 15 to 30 milliwatts of RF power* within this band and will exhibit a clean and symmetrical mode shape, almost free from electronic hysteresis. Optimum coupling to a matched waveguide has been achieved over most of the mechanical tuning range and, in general, the tube seems to be as well behaved and as easy to operate as lower frequency reflex klystrons of more conventional design.

In its present form, the M1805 reflex klystron combines results obtained in the course of a number of separate studies all of which had to be essentially completed before the final mechanical design of this tube could even be started. These studies pertained to the electron-optical system and, more particularly, to the design of a highly convergent electron gun; they pertained to the evolution of an efficient passive circuit consisting of the tunable resonant cavity and the broad-band output coupling system. Finally, they were directed at finding methods of handling the tolerances and the dimensions — some of which resemble "normal" tolerances — dictated by the operating frequency of this tube.

As a result of these studies we found that the minute dimensions and tight tolerances encountered in a millimeter wave klystron do not present undue difficulties if handled with appropriate techniques and we have, in fact, obtained a degree of reproducibility in such parameters as gun perveance and transmission efficiency considerably higher than has been customary with lower frequency tubes. The consistency of the RF performance has been satisfactory too, although capable of further improvement.

Of the mechanical techniques responsible for this unusual measure of

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* This spread includes a possible uncertainty in power measurement of about 1 db.

reproducibility and control in the face of minuteness both in the size of elements and their spacings, the more important ones are: (1) the extensive use of precision hubbing, (2) the reliance on optical rather than self-alignment to obtain the close degree of concentricity required, and (3) the use of individually selected ceramic spacers to determine spacings. Equally important, of course, has been an electrical design which permits the fullest utilization of these techniques.

GENERAL DESIGN CONSIDERATIONS

Suppose we now take a somewhat more detailed look at the major problems which confront the designer of a millimeter wave reflex klystron. Later in this paper we shall see what solutions were obtained to these problems and how they were applied to the design of the M1805.

Let us first examine the frequency determining resonant cavity. Its linear dimensions are directly proportional to wavelength or inversely proportional to frequency. Hence, a 4,000-mc cavity, for example, having an outer diameter of about one inch would shrink to one having a diameter of $1/15$ inch or 67 mils* if we wanted to go up in frequency by a factor of 15, that is, to 60,000 mc. Whereas a dimensional tolerance of ± 2 mil might be acceptable in the 4,000-mc cavity, this tolerance now becomes $\pm 2/15$ mil or ± 0.13 mil for the same relative accuracy in resonant frequency. Furthermore, Q is inversely proportional to the square root of frequency. Hence, the millimeter cavity would have at best an internal Q lower by a factor of $\sqrt{15}$ or roughly 4, provided its surface smoothness was relatively as good as that of the 4,000-mc cavity. In practice, this means that our millimeter cavity should have mirror smooth copper surfaces. This in turn, renders drawn and plated parts or, perhaps, machined cavities, which are perfectly acceptable at 4,000 mc, unsuitable for the millimeter band.

Next, consider the method of tuning which, in most internal cavity type tubes involves changing the grid separation in order to vary the effective shunt capacitance of the resonator. In a 4,000-mc tube this can be realized by making the top wall of the resonator a flexible membrane. Such a diaphragm, having a diameter of about one inch and containing properly dimensioned concentric corrugations and radial slots will withstand many thousands of tuning cycles. For practical reasons, such performance cannot be expected of a tuning diaphragm having a diameter of some 60 mils. This mechanical difficulty, then, forces us to look at modifications of the passive circuit which will permit the use of a sufficiently large tuning diaphragm.

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[*] Because of the small dimensions involved, it is convenient to express dimensions in mils, i.e., in thousands of an inch.

The ratio of megacycles of frequency shift per mil of change in gap spacing is about 500/30 for a typical 4,000-mc reflex klystron such as the Western Electric 431A. For a cavity scaled up in frequency by 15 this factor will become 225 times greater or 3750 mc/mil. One mil change in gap spacing would therefore detune this hypothetical cavity by close to 4,000 mc. This, incidentally, makes the millimeter wave reflex klystron so sensitive an indicator of dimensional changes, that special measures must be taken to provide a tuner of adequate dispersion be it of the mechanical or thermal type. Steps must also be taken to prevent the transmission to the tuning diaphragm of undesired motions which might easily result in the destruction of the grids. Such motions might be caused by differential thermal expansion during processing on the pump and would be difficult to predict.

The electron gun poses another problem which cannot be solved by simple scaling. Since the total effective beam current should be at least equal to and preferably greater than that required for lower frequency tubes of medium power output, scaling down of the cathode surface would result in prohibitive current densities so far, at least, as oxide coated cathodes are concerned. This, then, requires an electron gun of the highest possible convergence. At the same time it is necessary to: (a) arrange for a mechanical structure capable of the high degree of precision in spacings and concentricity required for such guns, yet provide adequate thermal isolation for the cathode, and (b) devise grids which will withstand bombardment by an electron beam having a current density many times greater than that encountered in lower frequency klystrons.

Or, let us examine the problem of heat dissipation. Essentially the entire beam power which may be of the order of 25 watts is dissipated on the central cavity post. If this cavity post and the grid contained therein are to withstand this concentrated electron bombardment, these elements must be surrounded by a very effective heat sink which, in turn, must carry the heat to the outside of the tube envelope where either natural or forced convection and conduction cooling may be applied.

The performance of a millimeter wave klystron cannot be predicted on paper with any certainty. Too many are the approximations contained in the small signal theory and too many are the assumptions and guesses involved in estimating such important tube parameters as effective beam current, beam coupling coefficient, resonator shunt conductance, etc. At best, theory predicts that the tube should oscillate if the cavity Q is not degraded to a value greatly below that caused by frequency scaling and if the reflector space geometry gives rise to efficient bunching. It may come as somewhat of a disappointment to many readers that the design of a millimeter wave reflex klystron in many respects is not a quantitative science. The philosophy, then, with which we approached this task was an essentially simple one. It called for an attack on the individual problems outlined earlier with a view to fitting the better solutions into the most promising overall pattern.

THE ELECTRON GUN

The design objectives for the electron gun were:

(a) high perveance,
(b) oxide coated, unipotential cathode,
(c) long life, which with (b) necessitates a highly convergent beam, and
(d) no accelerating grid.

The considerations leading to these objectives are readily discernible except, perhaps, (d); apart from mechanical complexity, the use of accelerating grids has, in the past, frequently given rise to instabilities associated with ion oscillations.

Two basic gun configurations, known to us at the time, seemed capable of further refinement and thereby of meeting the objectives listed above. One was the well known Pierce gun and the other one a gun developed by O. Heil[3] at Ohio State University.

Small guns of the Pierce type had been investigated during the war by E. M. Boone in connection with the 1464XQ. The best gun developed in the course of that study and the one used in the 1464XQ performed about as follows:

accelerating voltage	400 volts
cathode current	20 ma
cathode current density	425 ma/cm^2
perveance	2.5 $\text{microamps/volt}^{3/2}$
transmission efficiency through a 0.025″ dia. ungridded aperture	80 per cent
current density multiplication	12

The performance of the Heil gun as described in the literature looked so promising that a thorough study of its suitability for use in the M1805 seemed imperative. The published value of current density multiplication of 230 was almost 20 times greater than that of the Pierce gun described above and the perveance of 4.5 $\mu\text{A/V}^{3/2}$ almost twice as great. Accordingly, a number of sealed-off and gettered gun testers were built containing scaled-down Heil guns. In spite of careful scaling, however, and for reasons not entirely clear to us, these testers fell short of duplicating published performance. Their perveance came fairly close to the published value but their transmission ranged around the unusably low value of 50 per cent. These initial results strongly suggested the need for extensive changes from the Heil gun as published if it was to play its intended role in the millimeter wave reflex klystron.

The basic outlines of the Heil gun are shown in Fig. 1. Its cathode is a portion of a spheroid formed by the rotation of an ellipse about its minor axis. The ratio of the major to minor axis, b/a, equals 1.295 and the height of the spheroid measured along the minor axis is 0.423 a. If the missing area of the semi-spheroid is assumed to be cylindrical (which is a very close approximation) the expression for the cathode area simplifies to,

$$\text{Cathode area (in cm}^2) = 7.85\, b^2 \tag{1}$$

where

$$b = \text{major axis in inches}$$

This equation is plotted in Fig. 1 along with cathode current density for

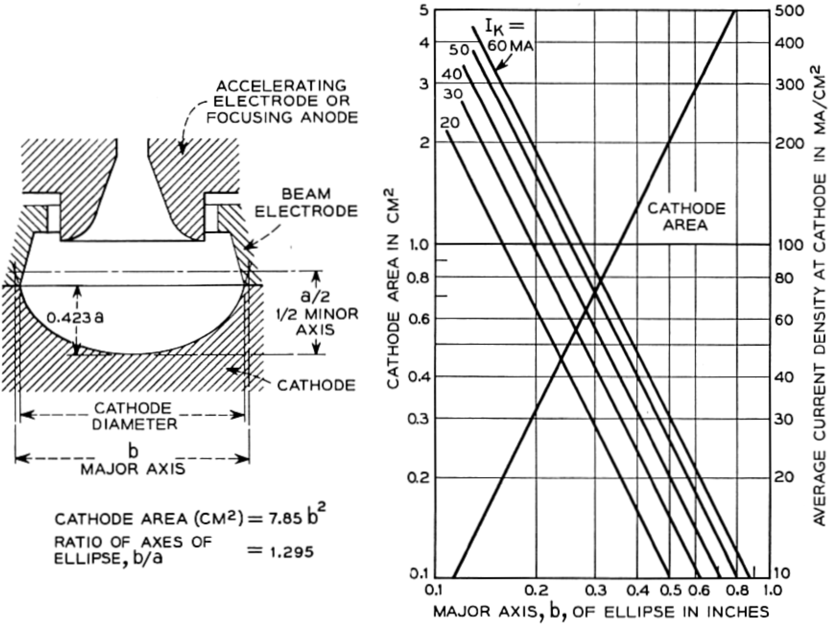


Fig. 1 — Design data for the Heil electron gun. The drawing to the left shows the basic configuration of the Heil gun and the plots on the right show the dependence of cathode area and average current density upon cathode size.

several values of current. The curves can be used to determine average current densities for proposed cathode diameters.

Closely adjacent to the cathode and joined to it electrically but isolated thermally is the beam forming electrode. Its shape as well as that of the accelerating electrode are also shown in Fig. 1. The angle subtended by the beam electrode and the tangent to the cathode at the point where it joins the beam electrode is 157.5°. This provides the well known 67.5° angle between the beam electrode and the trajectory of edge-electrons.

The program we undertook to explore the Heil gun for use in the millimeter wave klystron was a purely empirical one. It involved the systematic variation of the parameters *d* and *f* shown in Fig. 3. Dimension *d*, the spacing between cathode and focusing anode, controls the perveance of the gun and dimension *f* denotes the aperture diameter which in the final gun closely approximates the minimum beam diameter.

In order to provide for a vacuum environment closely resembling that typical of actual tubes, all gun testers were housed in sealed-off and gettered glass envelopes. Within these envelopes, however, the structures

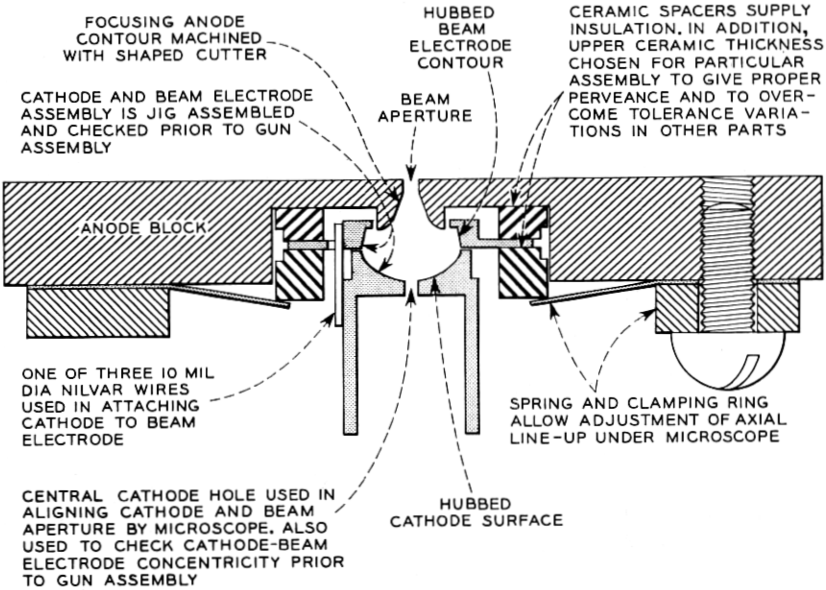


Fig. 2 — The demountable electron gun structure shown in this figure was originally used in an experimental study aimed at adapting the Heil gun for use in the M1805 millimeter wave reflex klystron. The reproducibility and mechanical stability, however, proved so satisfactory that this structure was incorporated in the final tube design essentially without change.

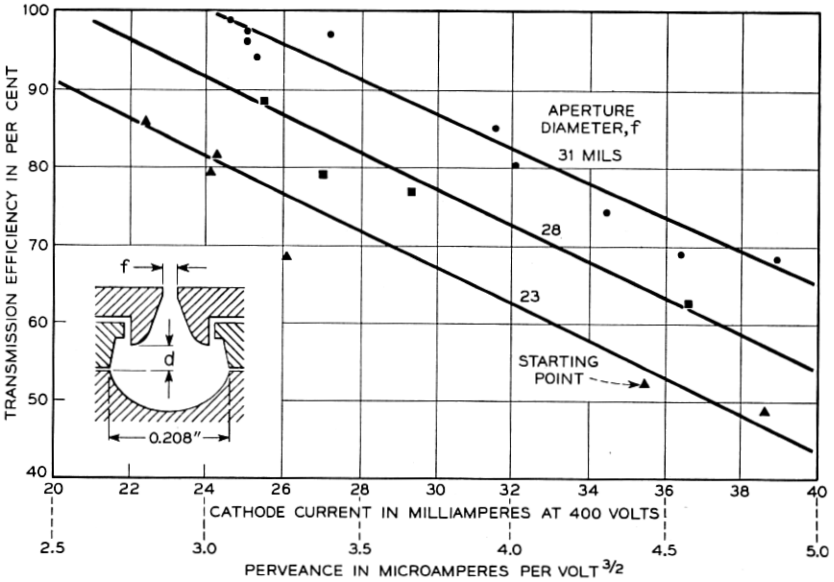


Fig. 3 — Experimental results obtained by varying the perveance and beam aperture of a Heil gun having a cathode scaled to 208-mil diameter. Each point represents the result obtained with a sealed-off and gettered gun tester. Perveance was changed by varying *d*. This, in turn, was achieved by the use of ceramic spacers (see Fig. 2) having different thicknesses thereby moving the cathode and beam-electrode as a unit. The diameter of the beam aperture, *f*, was enlarged in successive steps by cylindrical reaming.

were completely demountable as shown in Fig. 2. The gun testers consisted of three major elements: the collector assembly comprising the collector proper and secondary electron shield (not shown in Fig. 2), the cathode beam-electrode assembly and the anode block to which the first two assemblies were bolted. To achieve consistent and reproducible performance, it was found that dimensions had to be controlled to a degree which could not be achieved with self aligning parts. The following techniques were therefore adopted.

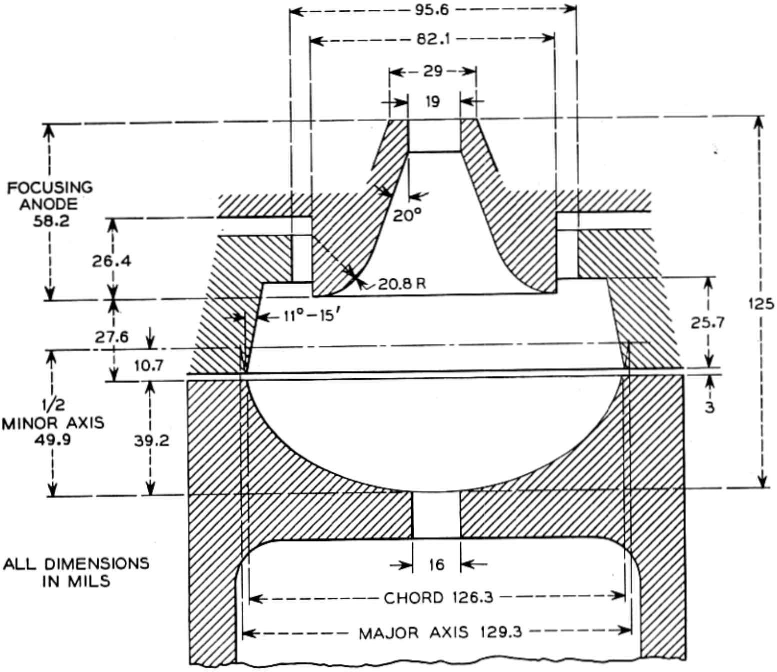
The emitting surface of the cathode was produced from a solid nickel blank with great accuracy by hubbing, a technique which will be described in greater detail in connection with the passive circuit. Other, less critical, cathode contours were machined. Three Nilvar wires, dimensioned for good thermal insulation consistent with adequate mechanical rigidity, were welded to both cathode and beam electrode, thereby yielding an assembly which could be carefully inspected both for concentricity and spacing. By means of two ceramic spacers and a combination of spring and clamping ring, this assembly was electrically insulated from and properly spaced with respect to the anode block. The lower ceramic served as insulator only and its dimensions were therefore quite uncritical. The upper ceramic determined the cathode-anode spacing and hence had to have a closely controlled thickness and truly parallel surfaces. Instead, however, of keeping its thickness to a fixed value we found it preferable to maintain a stockpile of spacers having known and graded thicknesses and to select one which gave the desired gun perveance thereby overcoming dimensional variations in other parts.

The spring and clamping ring combination, in conjunction with the microscopic alignment procedure to be described, made concentricities of the order of ¼ mil readily achievable. This procedure involved assembling the constituent gun parts as in Fig. 2 but with the clamping ring tightened just enough to hold them together yet permitting lateral motion of the cathode assembly with very light pressure. The assembly was then mounted on a monocular microscope equipped with a reticule consisting of concentric circles. By alternately focusing on the beam aperture and the central cathode hole — which, incidentally, was provided for this purpose only and has no electrical significance — the cathode assembly could be brought into essentially perfect alignment and the clamping ring tightened.

There are two simple yet effective means of controlling the transmission efficiency of an electron gun; variation of the spacing between cathode and focusing anode — and hence of perveance — and adjustment of the limiting aperture size. In the Heil gun of Fig. 3 this corresponds to varying dimensions *d* and *f* respectively. As mentioned earlier, the starting point for this study was a scaled down version of the original Heil gun, scaled down to a cathode diameter of 208 mils, with a corresponding beam aperture of 23 mils dia. and housed in the semi-demountable structure described earlier. The experimental result obtained with this tester after seal-off and under space charge limited conditions is represented by the point marked "starting point" in Fig. 3. We see that its perveance equalled about 4.4 $\mu a/V^{3/2}$ and was therefore approximately correct but that its transmission efficiency of about 50 per cent was too low to be useful. Keeping the diameter of the beam aperture fixed at 23 mils and varying the gun perveance by substituting upper ceramic spacers (see Fig. 2) of different thicknesses, F. P. Drechsler obtained the triangular points of Fig. 3 which define the lowest of the three straight lines shown. This particular series of experiments was stopped before the transmission efficiency had increased beyond 85 per cent since the perveance had then dropped below 2.8 $\mu a/V^{3/2}$. Drechsler then enlarged the diameter of the beam aperture (dimension, *f*, Fig. 3) by cylindrical reaming and traversed the same range of perveances, obtaining the experimental points which define the middle curve of Fig. 3. Finally, the experiment was repeated with a 31 mil diameter aperature. This yielded a group of gun testers with a transmission efficiency clustered around 95 per cent and a perveance slightly greater than 3 $\mu A/V^{3/2}$. As this performance was considered satisfactory, the configuration giving rise to it was selected as the prototype for the millimeter tube gun. It merely remained to scale this design down by a factor of about ⅔, that is, to a beam aperture of 19 mils, thereby making it compatible with the dimensions established in the course of the cavity study to be described later. The significant dimensions of this modified Heil gun of final size and its performance under various operating conditions are given in Fig. 4. It should be noted that the tabulated values of cathode current and cathode loading were obtained with a unidirectional electron beam such as is normally produced in gun testers. In an operating reflex klystron a certain fraction of electrons are returned to the cathode region and perveance will therefore be somewhat lower.

The mechanical gun structure described earlier was conceived originally as a convenient yet precise vehicle for gun studies. So favorable, however, has been our experience with this method of gun mounting, in ease of assembly, in reproducibility of results and in thermal stability, that it was incorporated in the M1805 essentially without change.

The cathode currents of more than 90 per cent of the tubes built fell within 10 per cent of the mean, that is, within 2 ma of 18.7 ma when operated at 400 volts. About 95 per cent of these same tubes had transmission efficiencies within 5 per cent of the mean value of 56 per cent. The value of cathode current at a given beam voltage is a sensitive measure of the spacing between cathode and focusing anode (dimension, *d*, in Fig. 3). If we assume that this is the only source of the variation in perveance, the experimental data indicate that this spacing is being held to within 1.5 mil for the great majority of tubes. The value of transmission efficiency as such has little significance since secondary electrons are not controllable in the tube structure. However, the spread in values of transmission efficiency is closely related to the reproducibility in gun alignment. To obtain the value of transmission efficiency experimentally, we must operate the repeller positively and measure the fraction of cathode current reaching it after having passed through two grids. In a normal reflex klystron, operation with a positive repeller would soon result in overheating and the consequent destruction of the tube. To overcome this difficulty a directly-reading transmission measuring set was developed by C. L. Nenninger in which the electron beam was pulsed at a sufficiently low duty cycle. The information was presented as an oscilloscope display consisting of two pulses with heights proportional to cathode current and transmitted current respectively as shown in Fig. 5.



TRANSMISSION EFFICIENCY	95%
PERVEANCE	3 MICROAMP/VOLT $^{3/2}$
CURRENT DENSITY MULTIPLICATION	75
HEATER POWER	3.9 WATTS

BEAM VOLTAGE (VOLTS)	400	500	600
CATHODE CURRENT (MA)	24	33	45
CURRENT DENSITY AT CATHODE (MA/CM^2)	180	250	340
CURRENT DENSITY AT BEAM MINIMUM (AMPS/CM^2)	14	19	25

Fig. 4 — Modified Heil electron gun as used in M1805 millimeter wave reflex klystron. The performance data tabulated above, only apply to a unidirectional electron beam as produced in gun testers. Both perveance and cathode loading will be somewhat lower in an operating reflex klystron due to electrons returned into cathode region.

THE PASSIVE CIRCUIT

Of the two most commonly used mechanical means of tuning a klystron cavity, namely, capacitive and inductive tuning, tubes of the internal cavity type almost exclusively employ capacitive tuning. Generally, this method of tuning involves changing the separation between the interaction gap grids; this changes the effective shunt capacitance and hence the resonant frequency of the cavity. For a given frequency change it requires a much smaller physical motion than inductive tuning and one which is more readily realized mechanically. Capacitive tuning, therefore, became the obvious choice for the M1805.

How did this decision affect the design of the passive circuit? Lower frequency reflex klystrons are usually tuned by distorting a metal diaphragm which might be the cavity wall containing one of the interaction gap grids. Such an elementary approach, when applied to a millimeter wave cavity, would lead to many practical difficulties. Fig. 6(a) shows the shape and size of the frequency-determining, resonant cavity. Its upper surface is seen to have a diameter of only 76 mils, clearly too small to afford the flexibility required of a tuning diaphragm; this problem is further aggravated by the difficulty of scaling such items as tuning links or the size of brazing fillets. The solution, here, was to surround the inner, frequency-determining cavity by a stepped, radial choke section which presents a good broadband short to the inner cavity. As shown in Fig. 6(b) the diaphragm now extends across both the cavity and choke section, the latter having a diameter of 284 mils, almost four times that of

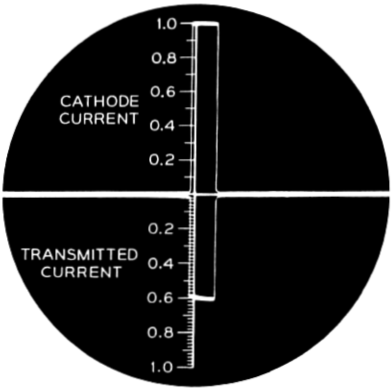
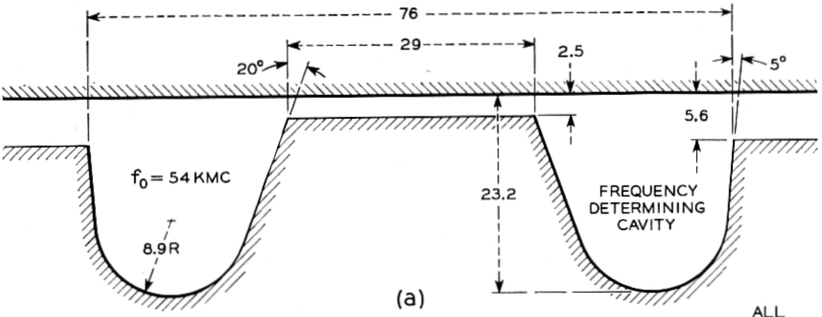
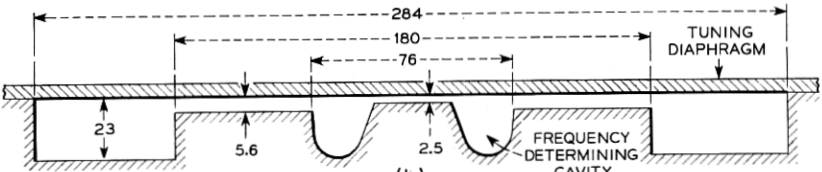


Fig. 5 — Oscilloscope display obtained with electron-gun-transmission test set. The special reticule permits the cathode current pulse to be adjusted for unit height; thus the height of the transmitted current pulse gives transmission efficiency directly.



(a)
FREQUENCY–DETERMINING, BASIC CAVITY



(b)
CAVITY OF (a) PLUS STEPPED RADIAL CHOKE

Fig. 6 — Resonant cavity of M1805 millimeter wave reflex klystron — (a) the shape and size of the inner, frequency-determining cavity and (b) the same cavity surrounded by a stepped, radial choke section. The choke section presents a broadband short to cavity proper, yet permits the use of a tuning diaphragm sufficiently large for flexibility. The resonant frequency of the cavity with the gap spacing as shown is about 54 kmc. This frequency is not appreciably affected by the addition of the choke section.

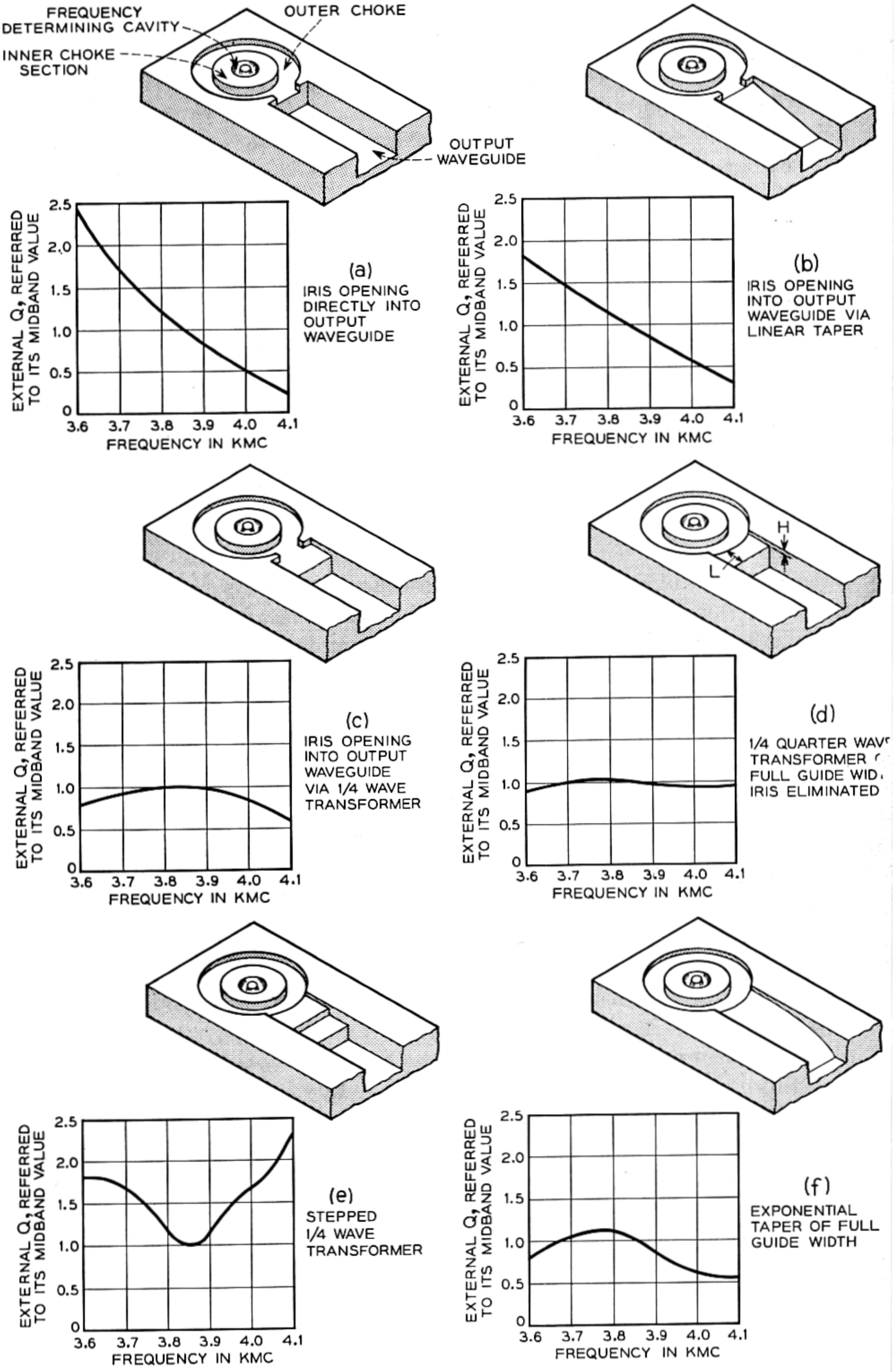
the primary cavity. The exact configuration was established experimentally with the aid of machined brass models scaled for operation in the 4,000-mc band, a frequency range in which broadband waveguide components and adequate measurement techniques were available. The addition of the radial choke section was found to have a negligible effect on either the internal Q or the resonant frequency of the inner cavity. It did, however, complicate the design of a broadband output transformer which forms the connecting link between the resonator and the output waveguide.

For the operating reflex klystron to deliver maximum power to a matched waveguide without an external susceptance transformer, the external load must be coupled to the resonator with sensibly uniform tighness over the projected mechanical tuning range. In other words, the output transformer must give rise to an external Q, Q_E, which does not change appreciably with frequency. In the case of the resonator and choke system of Fig. 6(b), this must be achieved in the presence of variations in height of the inner choke section. These variations of height and consequently of the characteristic impedance of the radial transmission line adjacent to the inner cavity are caused by the tuning motion of the diaphragm.

Some of the output coupling configurations investigated in the process of evolving a design which would have the required electrical properties yet be amenable to fabrication are shown in Fig. 7. Shown beside each configuration is an experimental plot giving the variation in external Q, normalized with respect to the midband value, over the frequency range of interest. Like the cavity study proper, this work too was performed in the 4,000-mc band using large scale brass models. It is seen, for instance, that the electrically simplest case, namely that of an iris opening directly into the output waveguide, Fig. 7(a), gives rise to a variation in external Q greater than 10:1, an obviously undesirable condition. The steep slope of this curve is primarily due to variations in height of the inner choke section. Thus, at the high frequency end where the external Q has its lowest value and the tube is consequently most strongly coupled to the external load, the inner choke section has its maximum height. As we tune to lower frequencies by closing the interaction gap, the inner choke height decreases and along with it the tightness of coupling; Q_E, therefore, increases. Proceeding to Fig. 7(b) it is seen that the interposition of a linear taper between iris and waveguide has reduced the variation in external Q from a value exceeding 10:1 to about 6:1. The use of a quarter-wave transformer as in Fig. 7(c) reduces the variation to less than 2:1.

It is conceivable that the frequency sensitivity of the quarter-wave transformer of Fig. 7(c) could have been adjusted to yield an essentially uniform external Q. It was deemed desirable, however, to eliminate the thin iris required for this design because of the serious structural difficulties it would have presented when scaled down by a factor of about 15. This consideration led to the output transformer of Fig. 7(d) in which the iris has been replaced by a quarter-wave transformer of full guide width brought right up to the outer choke section. This configuration not only is the mechanically simplest one and therefore well suited for scaling, but gave rise to the best electrical performance. It became the obvious choice for the final design of the M1805. The electrical performance of this transformer is determined by the length, L, and the height, H, (see Fig. 7d). Basically, the height controls the tightness of coupling and the length the frequency sensitivity.

The effect of the length, L, of the quarter-wave transformer on the frequency sensitivity of external Q is shown in the experimental curves



(a) IRIS OPENING DIRECTLY INTO OUTPUT WAVEGUIDE

(b) IRIS OPENING INTO OUTPUT WAVEGUIDE VIA LINEAR TAPER

(c) IRIS OPENING INTO OUTPUT WAVEGUIDE VIA 1/4 WAVE TRANSFORMER

(d) 1/4 QUARTER WAV
TRANSFORMER
FULL GUIDE WID
IRIS ELIMINATED

(e) STEPPED 1/4 WAVE TRANSFORMER

(f) EXPONENTIAL TAPER OF FULL GUIDE WIDTH

Fig. 7

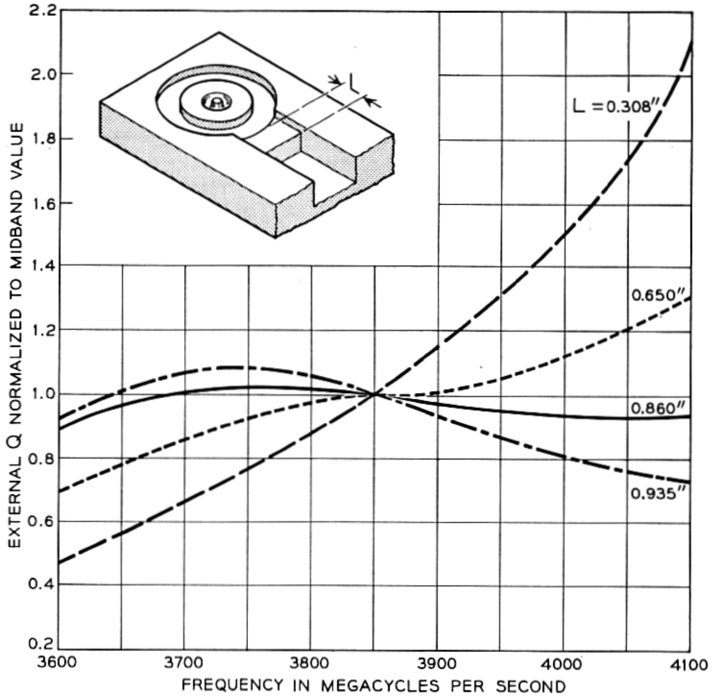


Fig. 8 — Variation in cavity loading (i.e., external Q) for various lengths, L, of the output transformer. The curve for $L = 0.860''$ shows the least variation and was chosen for M1805 design. The above curves were obtained experimentally using scaled-up, 4,000-mc brass models.

of Fig. 8. As shown by the solid curve in this figure it is possible, by a proper choice of L, to limit the variation in external Q to less than ±3 per cent. We further see that not only can L be adjusted for maximum uniformity in loading but that its value might be chosen to produce controlled variations in external Q. These, in turn, could compensate for such variations in internal cavity losses as are shown in the curves of Fig. 9. The first two of these curves, namely, the ones relating internal Q and equivalent gap capacitance with frequency, were obtained by independent experiments using scaled-up brass models of the passive circuit and the third curve was calculated from the relation, $R = Q_0/\omega C$.

Fig. 7 — Various output coupling configurations and corresponding variations in external Q with frequency. The values of external Q have been normalized with respect to the midband value. The output circuit, (*d*), shows the least variation in external Q, only ± 3 per cent, and is the simplest mechanically. It was chosen for the final design of the M1805. Dimension "*L*" controls the frequency sensitivity of coupling and "*H*" its tightness. This work was performed in the 4,000-mc band using scaled-up brass models.

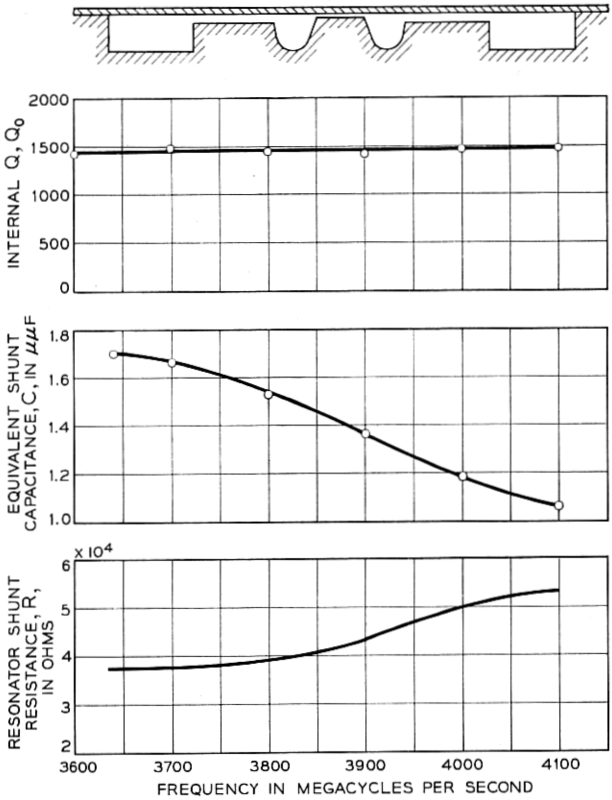


Fig. 9 — Variation of internal cavity parameters over the mechanical tuning range. Using a scaled-up brass model of the cavity shown in Fig. 6 (b), the curves for internal Q, Q_0, and for the equivalent gap capacitance, C, were determined experimentally by independent methods and the third curve calculated from the first two using the relation, $R = Q_0/\omega C$.

Disregarding the absolute values of shunt resistance because of the uncertainty of the applicable scaling factor but considering only its relative variation over the mechanical tuning range, we may well argue that a constant external Q will not extract the maximum available power at all frequencies.[4] Instead, the curve of external Q should be shaped such that the tube is more heavily loaded towards the high frequency end. This argument is further complicated by the fact that the beam coupling coefficient and consequently the electronic admittance also change as the grid separation is varied and that this change occurs in a direction tending to counteract the variation of resonator shunt resistance shown in Fig. 9. On the whole, then, the requirement of constant external Q seems to be a reasonable initial assumption and one that can only be improved upon by experimental equalization with the aid of operating millimeter tubes of near final design. At the same time, being able to change the loading characteristics in a controlled manner appears to be a definite advantage, although one which has not as yet been exploited in the M1805. Performance data to be given later indicate that this tube delivers maximum, or near maximum, power into a matched waveguide with an output transformer scaled from the one corresponding to the solid curve in Fig. 8.

The objective of the model studies just described was a design which not only would have the desired electrical properties but would make possible a one-piece, hubbed cavity block. Accordingly, we have arranged that all the elements constituting the passive circuit extend *into* the cavity block from a common and plane surface and, in addition, we have eliminated the thin-walled iris which would normally connect the resonator with the output waveguide. This one-piece, hubbed structure has given rise to excellent reproducibility despite the minute sizes.

The method of fabrication of the cavity block as evolved by L. B. Luckner, proceeds as indicated in Fig. 10. The starting point is a simple cylindrical blank as in Fig. 10(a) made of vacuum melted, OFHC copper and having a polished top surface. A hardened and highly polished steel die, the inverse in shape of the impression to be hubbed, is forced into the cold blank by means of a hydraulic press with a thrust of about 16 tons. The resulting impression of the resonant cavity and output circuit has a very dense and essentially mirror smooth surface. To prevent any accidental marring or scratching of this surface and to preserve the finish during subsequent machining operations, the impression is filled with resin immediately after it has been hubbed as shown in Fig. 10(b). By means of three reference holes impressed into the blank during the original hubbing, the cavity block is accurately chucked in the lathe where the focusing anode and the adjacent contours are machined. All that remains now is the relatively straight-forward machining of the common flat surface to give the finished block as shown in Fig. 10(c).

The finished cavity block may be seen more clearly in the cutaway drawing of Fig. 11. Contained in this single unit are the following essential tube elements:

1. Inner, frequency determining cavity
2. Stepped radial choke section
3. Broadband output transformer
4. Output waveguide
5. Focusing anode for Heil gun

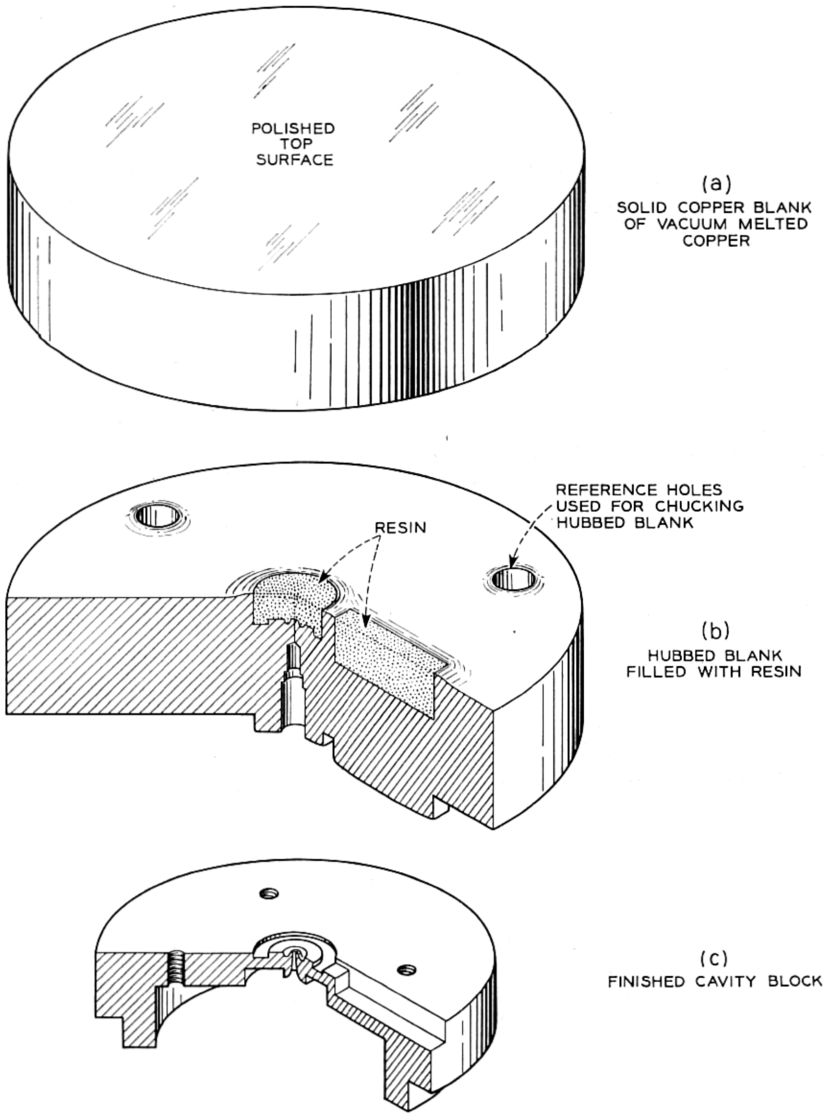


Fig. 10 — Principal steps in preparation of cavity block. (a) Starting point is a cylindrical blank made of vacuum melted, OFHC copper. (b) Copper blank into which has been hubbed the passive circuit and three reference holes used for precise chucking in subsequent machining. Resin filler prevents marring of mirror smooth surfaces. (c) Finished cavity block.

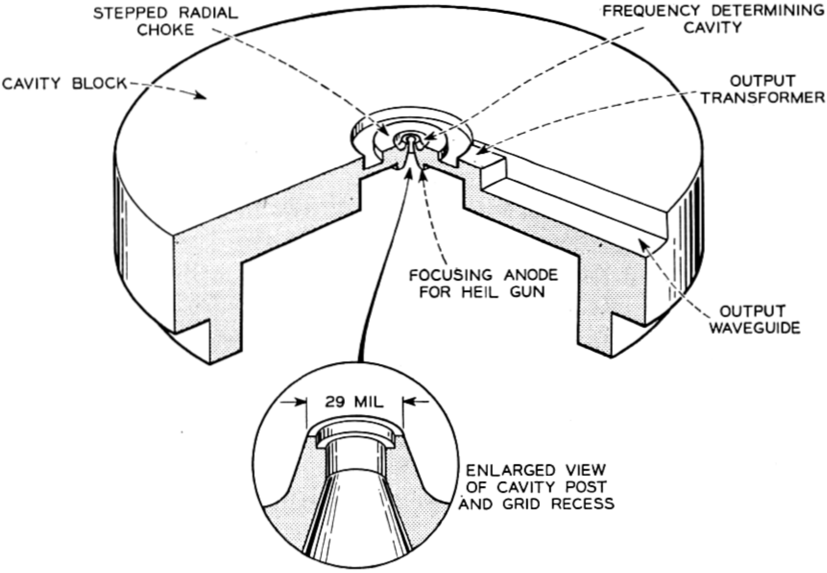


Fig. 11 — Cutaway view of completed cavity block. Made from a solid copper blank by the process outlined in Fig. 10, this unit really constitutes the heart of the tube.

In addition, we have hubbed a recess into the cavity post (see enlargement in Fig. 11) to serve as a nest for one of the interaction-gap grids.

By this design of the passive circuit, a number of significant electromechanical advantages have been achieved. These are:

1. All surfaces carrying high frequency currents are produced solely by hubbing. They require no further machining or handling so that their mirror like surface finish may be readily retained.
2. The hubbing process and the one-piece construction have eliminated the normal build up tolerances and thereby given rise to excellent reproducibility.
3. By rounding the contour of the inner frequency-determining cavity a favorable shape factor has been achieved.
4. The lossy braze joint between diaphragm and cavity is located in the outer choke section where it does not appreciably degrade the internal Q.
5. Since the copper block extends to the outside of the tube envelope, forced air cooling may be applied effectively and a comparatively cool heat sink presented to the central cavity post and the grid it contains.

Since at 60,000 mc the skin depth in copper equals about $\frac{1}{100}$ mil, surface layers of low conductivity have a very pronounced effect on cavity *Q*. Such lowered conductivity may be due not only to chemical impurities or surface roughness but may be the result of worked surface layers.

In a recent British study,[5, 6] the RF conductivities of hubbed copper surfaces at 8 mm wavelength were reported to be from 30 to 50 per cent lower than the dc conductivity. The same study also describes a number of surface treatments which, when applied to 8-mm hubbed cavities, yielded values of internal *Q* very close to the theoretical value. In general, these processes involved the relief of residual strain by annealing and the removal or coverage of surface layers by chemical means. Only the first of these techniques, namely annealing, has been applied to the M1805 cavity block to date. The application of the chemical surface treatments suggested in the British report is planned but will have to wait upon a refinement of *Q*-measuring techniques in the 5–6 mm range. Rough *Q*-measurements made on M1805 cavities indicate that the hubbing process followed by annealing gives rise to a value of *Q* close to that extrapolated from measurements on brass models operating in the 4,000-mc band.

GRIDS

The need for a gridded interaction gap arose as a direct consequence of our decision to aim at low voltage operation. Apart from considerations of general convenience, it was felt that a low voltage tube would afford economies in the cost of power supplies and in the maintenance of future systems such as to more than outweigh the difficulty of providing grids. This difficulty was due not only to the exceedingly small size of the grids, 20- and 30-mil internal diameter for G1* and G2* respectively, but also to the very intensive electron bombardment to which they would be subjected. Thus, for an accelerating voltage of 600 and a unidirectional beam, the current density at the plane of G1 would be about 25 amps/cm^2 and the corresponding power density 15 kilowatts/cm^2.

Early millimeter wave tubes were equipped with grids of the type shown in the micro-photographs of Fig. 12. Comparatively simple in construction, these grids consisted of a number of parallel tungsten wires, 0.8 mil in diameter, embedded and gold brazed into the surrounding copper. When used as G1, this type of grid was found to withstand continuous bombardment by a 600-volt beam. When used as G2, however,

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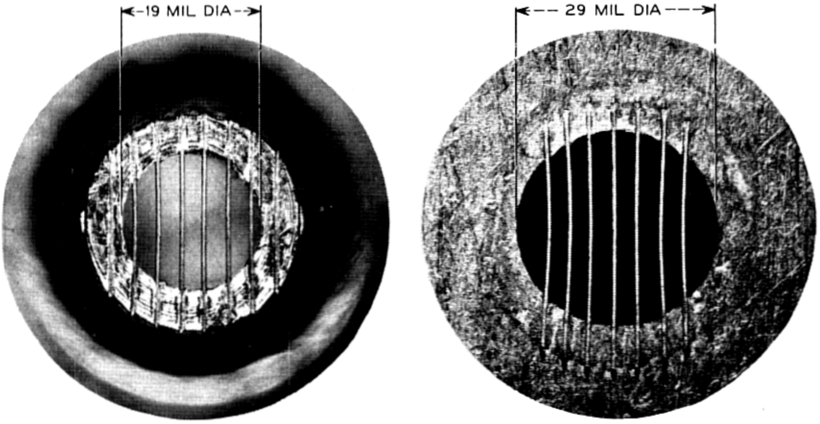
* G1 denotes the interaction-gap-grid closer to the cathode and G2 the grid closer to repeller.

the central portion was invariably eroded away. The heating conditions for G2 are, of course, much more severe than those for G1. The latter is smaller in diameter, connected to a more effective heat sink, namely the copper cavity, and, presumably, is bombarded by the outgoing stream only. G2, on the other hand, has a diameter of 30 mils (as against 20 mils for G1), it is bombarded by both the outgoing and returning stream and is connected to a relatively poorer heat sink, a rather thin copper diaphragm. This type of grid, then, limited the maximum beam voltage for continuous operation to about 400 volts. It was therefore necessary to operate early tubes having round wire grids under pulsed conditions if the beam voltage was increased beyond that value.

Since grids of the size used in the M1805 are cooled mainly by conduction, their dissipative capacity can best be raised by increasing the cross sectional area of the laterals, provided this does not result in increased electron interception. A grid consisting of fine ribbons or vanes rather than wires of circular cross section would, therefore, be of great advantage. The electron interception of such a grid would be determined primarily by the thickness of the ribbons perpendicular to the electron flow whereas the cross sectional area available for heat conduction would be proportional also to its depth parallel to the electron flow. A grid of this type was indeed suggested by R. L. Vance[7] of Bell Telephone Labo-



0.8 MIL DIA TUNGSTEN WIRE GRID
BRAZED TO CAVITY POST

0.8 MIL DIA TUNGSTEN WIRE GRID
BRAZED TO DIAPHRAGM

Fig. 12 — Round-wire tungsten grids used in early M1805 millimeter-wave klystrons. Consisting of several 0.8 mil diameter, gold plated tungsten wires embedded and brazed into the cavity post or diaphragm, these grids limited the beam voltage for continuous operation to about 400 volts. Higher beam voltages required pulsed operation.

ratories several years ago. Its basic configuration is shown in Fig. 13. Consisting of a number of tungsten vanes brazed individually into an outer cylindrical rim, this grid not only offers the increased heat dissipation capacity inherent in the use of vanes instead of wires, but the additional important advantage of well controlled and predictable thermal motions. These are results both of the cross sectional shape and the initial curvature which, in the presence of electron bombardment, will cause the "growing" grid laterals to continue in the direction of the initial curvature, i.e., without appreciably changing the gap spacing.

The special problem which confronted us was that of scaling this ribbon grid down to a size where Vance's suggested method of fabrication could no longer be used. We were greatly aided in the solution of this problem by engineers of the Sperry Gyroscope Corporation who very kindly disclosed to us the basic steps of an ingenious process by which ribbon grids with the basic configuration of Fig. 13 could be fabricated in very minute sizes. Important contributions to the detailed processing of these grids were subsequently made by W. Gronros, D. E. Koontz and F. P. Drechsler of the Laboratories.

The principal steps in the preparation of the ribbon grid are illustrated in Fig. 14. Copper plated ribbons of tungsten and iron — the tungsten 0.3-mil thick and the iron 3-mil thick — are wound and brazed into a tight spiral as shown in Fig. 14(a). Upon removal of the mandrel, the

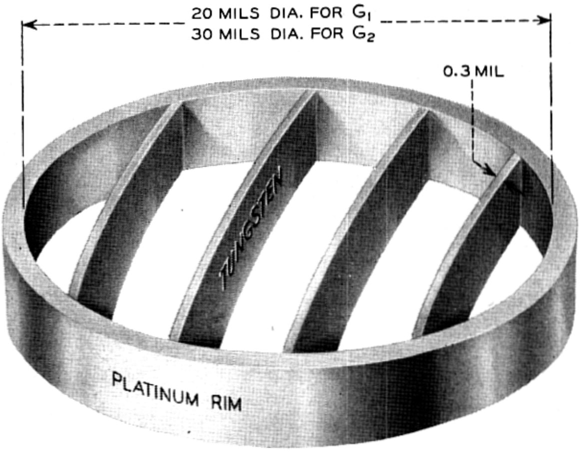


Fig. 13 — Sketch showing basic configuration of grid used in final version of M1805. The tungsten vanes, which present a thickness of 0.3 mil to the electron stream but are 3 to 4 mil deep parallel to the electron flow, are butt-brazed into the outer platinum rim. Their initial curvature serves to define the direction of expansion during operation at elevated temperatures.

brazed spiral is face ground on both sides to a thickness of perhaps 10 mil and chromium plated, the chromium serving as a thin barrier layer against subsequent brazes. The ground and plated spiral is then parted into several segments as shown in Fig. 14(b). Each segment is edge-ground to form a small, solid "pill" with a diameter corresponding to the inside diameter of the desired grid as indicated in Fig. 14(c). The grid pill is inserted and brazed into a short length of tightly fitting, thin walled platinum tubing which, for ease of handling, has previously been brazed into an iron disc; this is shown in Fig. 14(d). This entire assembly is then machine-lapped on both sides as in Fig. 13(e) to a thickness of 3 to 4 mils, i.e., to a thickness equal to the desired depth of the final grid. It merely remains to remove the iron both from outside and inside the platinum by etching. In the early stages of development, the etchant used was hot concentrated hydrochloric acid. Grids made in this manner, however, were not satisfactory because the acid did not completely remove the metallic deposits from the laterals. In addition to excessive electron interception, there was danger of these etching residues vaporizing at the high operating temperature. Deposition on the smooth cavity walls would cause increased RF losses while deposition on the insulation would cause electrical leakage. Moreover, hydrochloric acid also tended to attack the brazing fillets and thereby often gave rise to loose laterals.

A much more elegant process of iron removal was evolved by D. E. Koontz of the Chemical Department of the Laboratories. This process has consistently resulted in a high yield of ribbon grids of excellent quality. Briefly, it operates as follows: if iron is placed in a solution of aqueous copper chloride, the surface layer of iron goes into solution and is replaced by metallic copper. Ordinarily this reaction stops when the surface has been completely covered. The only way of maintaining this reaction is to continuously remove the deposited copper in order to expose the underlying metal to further attack. In Koontz's process, this is achieved by immersing the specimen of Fig. 14(c) in an ultrasonically agitated copper-chloride solution to which has been added a quantity of carborundum powder. The action of the suspended carborundum powder is twofold. It grinds off the surface layer of copper, as it is being formed, thereby providing the necessary condition for the complete dissolution of iron and it is quite effective in freeing the ribbon grid from any burrs which may have been raised in preceding lapping and grinding operations.

Since grids of the size used in the M1805 are cooled primarily by conduction, we may wonder whether the substitution of copper for tungsten would lead to a ribbon grid having adqeuate power handling capacity

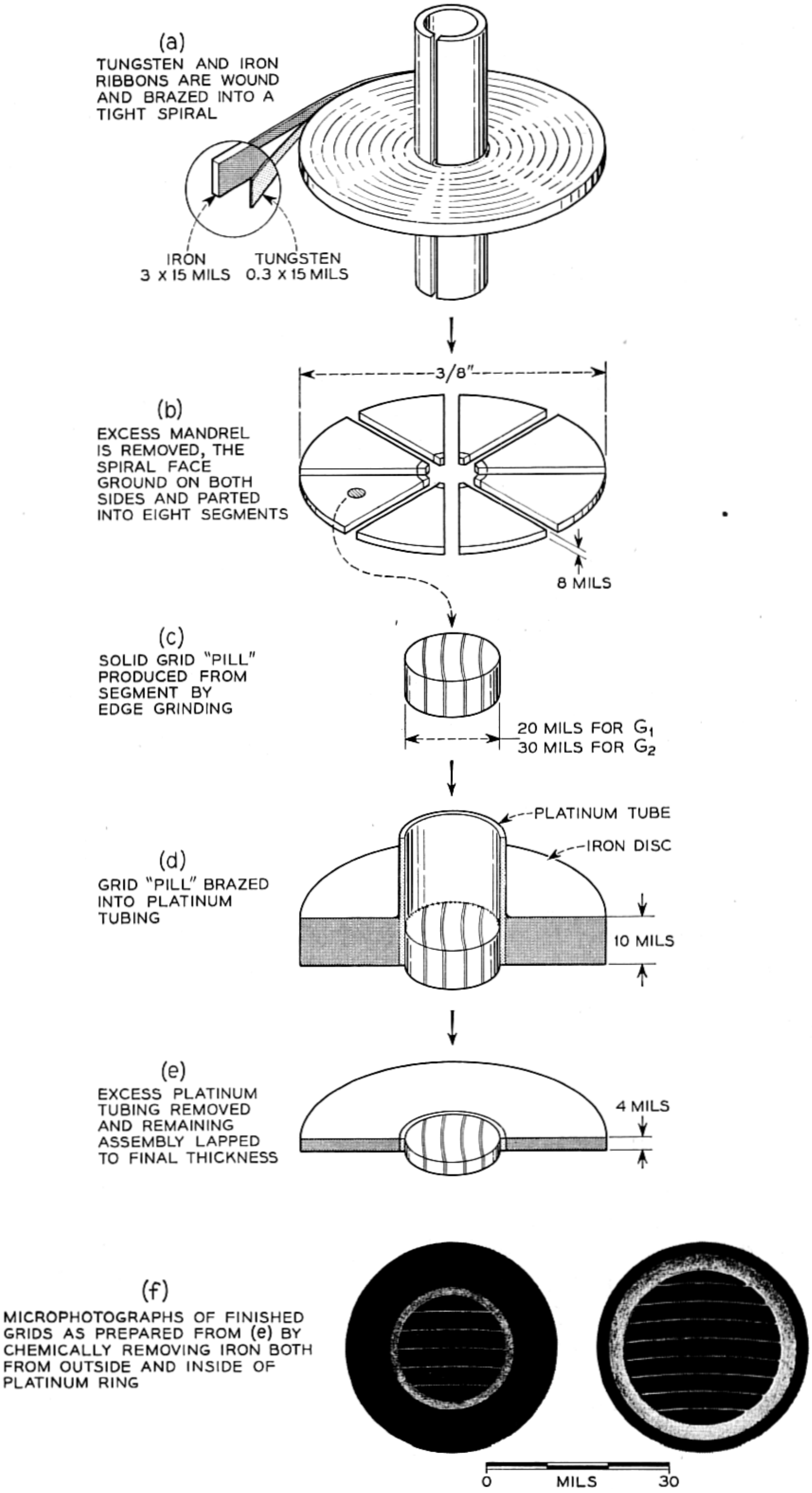


Fig. 14 — Basic steps in fabrication of ribbon grid.

yet with greatly reduced RF losses. The superior heat conductivity of copper might be thought to more than offset the lower melting point. This problem as well as others aimed at better understanding the nature of grid heating in millimeter wave klystrons were investigated in the course of a theoretical study by R. L. Wigington. He was able to show that a copper ribbon grid should operate much cooler than the equivalent tungsten ribbon grid but — for the case of G2 and a 600-volt beam — at a temperature too close to its own boiling point* to be useful.

Since the boiling point of tungsten is less than its melting temperature at normal tube pressures, overheating will first result in the erosion rather than the melting of the grid. Also, for the reasons already stated, the greatest possibility of burnout occurs at the center of G2. Fig. 15 shows theoretical plots of the maximum grid temperature, i.e., of the temperature at the center of the central G2-lateral, as a function of beam power for three types of grids. The first one of these grids, namely, the round wire tungsten grid, seems to leave the region of safe operation at about 400 volts and this agrees fairly well with experimental evidence. The second type of grid shown in Fig. 15, the tungsten ribbon grid, operates much cooler, staying well within the safe region at a beam voltage of 600 volts. Here, however, experiment indicates theory to be somewhat optimistic. This disagreement is, perhaps, not too surprising since we assumed parallel electron flow in calculating temperature distribution; thus the fractional electron interception depended on the projected grid area whereas the effective area is probably considerably greater. The expected performance of a copper ribbon grid is shown in the third plot of Fig. 15. Its calculated maximum temperature with a 600-volt beam is seen to come dangerously close to its boiling point. Since, for the reasons given earlier, the calculated temperatures are believed to be somewhat optimistic, this grid has not been constructed.

THE REFLECTOR

The last remaining tube element of electrical significance, namely, the reflector is shown in Fig. 16. Scaled down from an empirically derived design which had been found satisfactory in a 4,000-mc reflex klystron with a comparable electron-optical system, this repeller is the first and only one used to date. We are by no means certain that it constitutes an optimum design although there are indications that this first choice was a rather fortunate one. Experimental work aimed at optimizing a re-

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* The "boiling point" is taken as the temperature at which the vapor pressure of the metal equals that of its environment. At normal tube pressure the boiling of copper will be near 1000°K and that of tungsten about 2500°K.

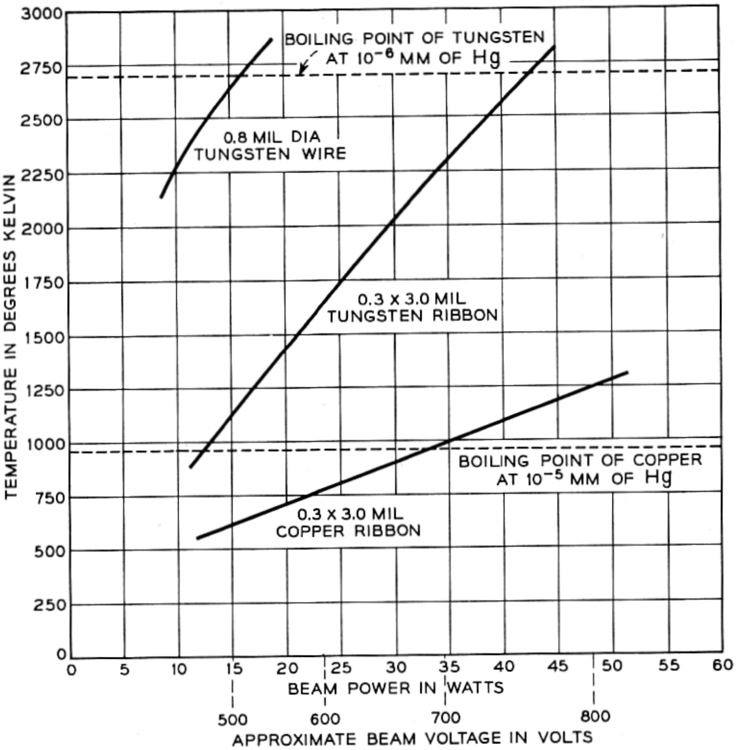

Fig. 15 — Calculated dependence of maximum grid temperature on the bombarding beam power for three types of grids. These curves have been computed for the specific geometry of the M1805. The maximum temperature occurs at the center of the central G2-lateral.

peller shape in our own laboratory and by other workers in this field have so far failed to disclose any sharp optima. There remains the important task, however, of demonstrating that the M1805 reflector design at least finds itself on a broad maximum.

Like the cathode, the electrically significant repeller contour is produced by hubbing and it too is aligned optically, with the help of a central aperture provided for this purpose only.

THE ELECTRICALLY SIGNIFICANT TUBE CONTOURS

Having covered all the essential tube components, individually, we may now proceed to show their interrelationship and their combination into a single overall pattern. Fig. 17 shows a scale drawing of the electrically significant contours of the M1805 millimeter wave reflex klystron. It is interesting to note the large size of the cathode relative to the resonator and reflector regions. Note also that the centerline of the tube passes through four successive apertures, two of which, the cathode and reflector apertures, have been provided only to facilitate optical alignment.

One electrically significant component which has not been described in detail is the output window; it is a conventional choke-type glass window scaled into the millimeter band. The insertion loss of this window, the structure of which is shown in Fig. 19, ranges around 0.7 db and is fairly uniform over the band of interest.

CONSIDERATIONS IN CHOICE OF TUNER

It was stated earlier that this tube is tuned mechanically by changing the separation between the interaction gap grids. The total amount of motion required for tuning the tube from 50 to 60 kmc is less than four mils which corresponds to an average tuning rate of 0.4 micro-inch per megacycle. Fig. 18 shows the spread in tuning curves for seven tubes. Shown also (as the dashed curve) is the tuning curve which was predicted from the results obtained with large scale cavity models. In the

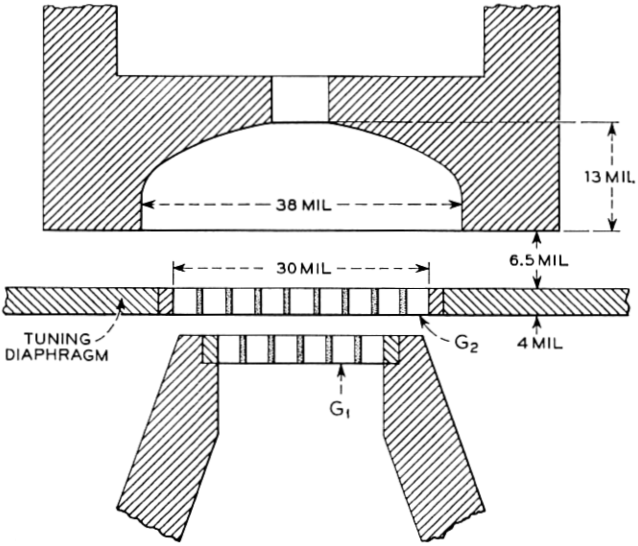

Fig. 16 — M1805, reflector space geometry. The central aperture in the reflector facilitates optical alignment.

face of the scaling factor of 15, such close agreement between model and actual tubes was rather gratifying.

Since the total tuning motion required in the M1805 is so small, we may wonder whether it would best be transmitted by mechanical or thermal means. Mechanical tuning would involve some type of linkage capable of producing very small motions in a controlled manner. In thermal tuning, we utilize motions induced by the thermal expansion of some member of a mechanical linkage, with the heating effect derived either from electron bombardment or from the passage of comparatively heavy electric currents. It is probably true that thermal tuning is inherently better suited to producing the delicate motions required in a millimeter wave tube. It must be remembered, however, that thermal tuning greatly complicates the structure inside the vacuum envelope and — external to the tube — invariably requires a feedback system to maintain frequency stability. Fortunately, though, the initial choice of tuner does not greatly affect the basic electrical design of the tube. For these reasons, we decided in favor of a mechanical tuner, a somewhat refined version of the tuner used in the 4,000-mc Western Electric 431A reflex klystron. The experience with this tuner has, on the whole, been

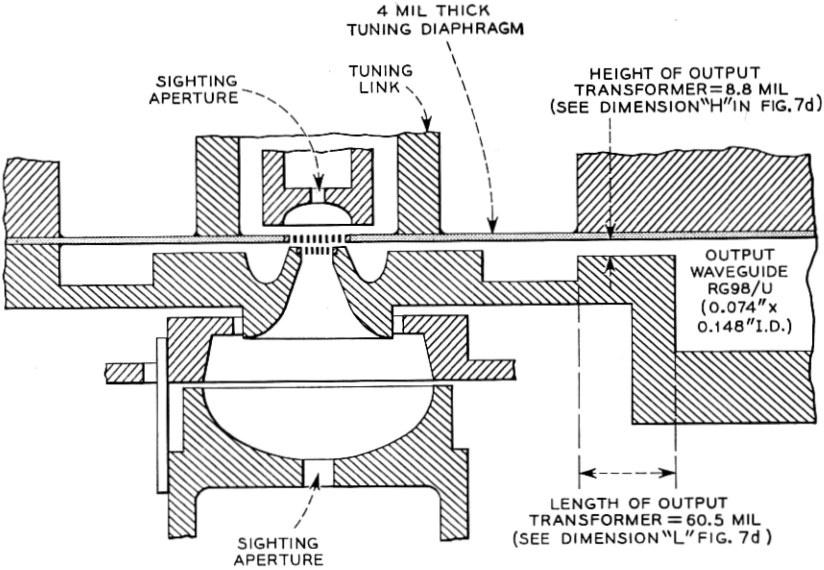

Fig. 17 — M1805, electrically significant contours. This drawing shows the interrelationship and the combination of the essential tube elements. More detailed data on these elements were contained in Fig. 4 for the gun, Fig. 6 for the passive circuit and Fig. 16 for the repeller.

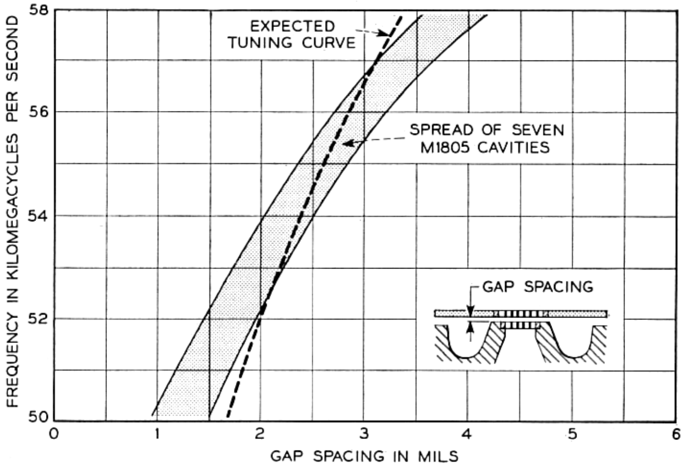

Fig. 18 — Cold tuning data for seven M1805 cavities. The dashed curve represents the tuning characteristic predicted for the millimeter wave tube on the basis of a 4000-mc cavity model. The difference in slope is probably the result of the lack of grids and, hence, the relatively greater gap capacitance of the low frequency model.

satisfactory. Just like the gun mounting structure described earlier it started out as a temporary expedient but, because of its satisfactory performance, was selected as our final solution. It is entirely possible, however, that future system applications may generate the need for a thermal tuner. Such a substitution could then be effected without the exploration of new techniques.

THE MECHANICAL STRUCTURE

The mechanical structure of the M1805 millimeter wave reflex klystron for which L. B. Luckner is largely responsible, is shown in the drawing of the completed tube of Fig. 19. In essence, it consists of three separate units which are combined by high-frequency brazes to form the finished tube. Proceeding from top to bottom, the first is the top bulb and tuner assembly. The second contains the entire passive circuit including the output window, the electron-optical system and — mounted on the cavity block by three struts — the stem and heater. The third element is a simple sleeve which slides over the stem and is brazed to it as well as to the cavity block to complete the vacuum envelope.

Referring to Fig. 19, we see that the mechanical tuner consists of a horizontal tuning arm pivoted approximately at its center on a vacuum

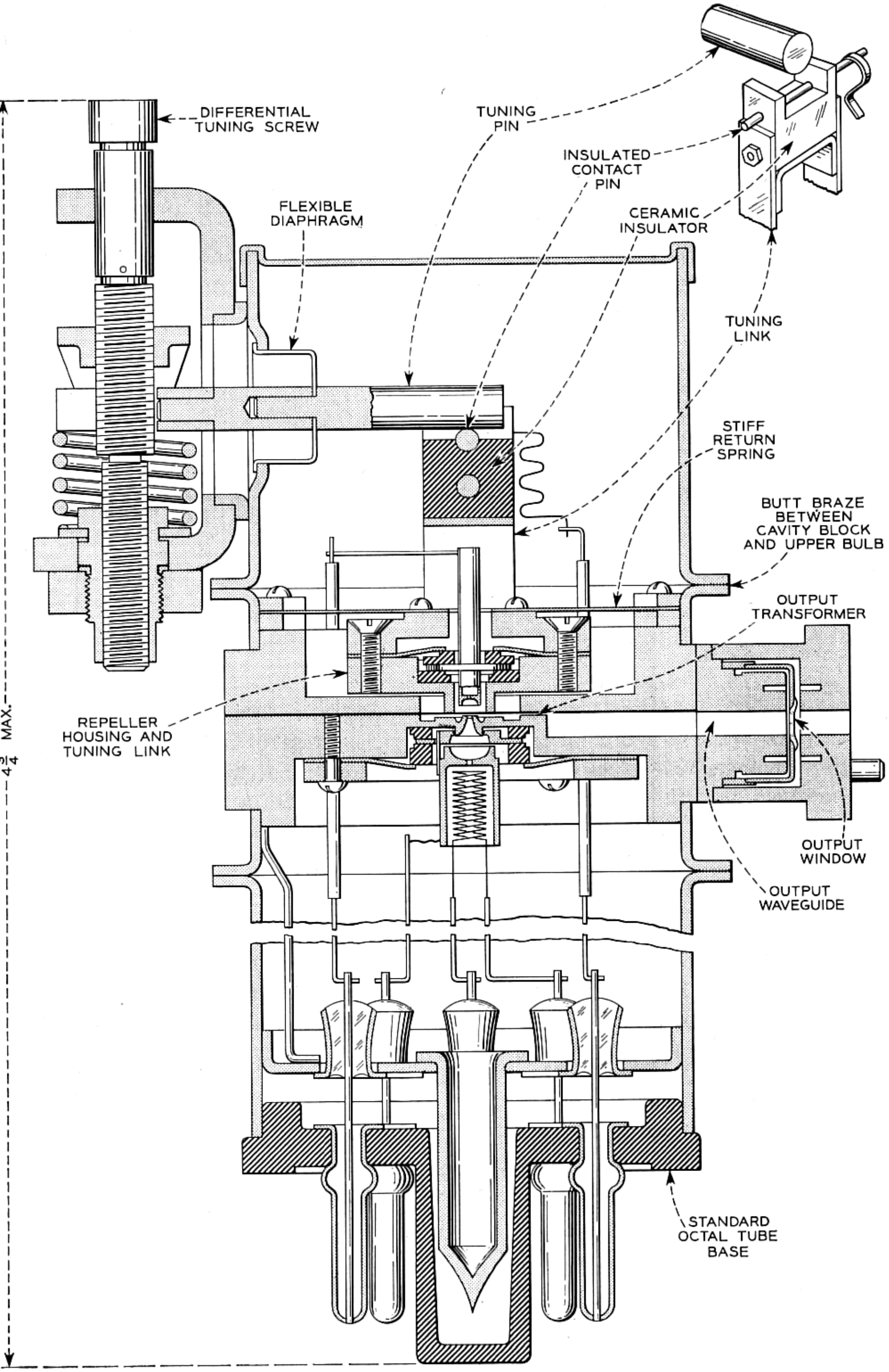

Fig. 19 — Layout of M1805, millimeter reflex klystron. The enlarged insert shows details of insulated contact pin which forms part of the alarm circuit.

tight diaphragm. Outside the vacuum, the tuning arm is acutated by a differential screw chosen such that one revolution moves the tuning arm some 0.3 mil along the center line of the tube.

The tuning arm is not rigidly connected to the tuning link but simply bears down on an insulated steel pin forming part of the tuning link. This tuning link is attached to the repeller housing which, in turn, is brazed to the tuning diaphragm. Hence, any motion of the insulated pin causes the equivalent motion of the G2-grid. The repeller housing and tuning link are firmly positioned by an Inconel-X return spring, the stiffness of which greatly exceeds that of the 4-mil copper tuning diaphragm. During pumping, this stiff return spring maintains an interaction gap spacing which corresponds to a resonant frequency somewhat higher than the upper limit of the mechanical tuning range. In the process of tuning, the tuning arm must simply exert sufficient downward pressure to overcome the restoring force of the return spring.

During bake-out and pumping, a spacing of several mils is maintained between the tuning arm and the insulated pin so as not to transmit undesired motion to the diaphragm. When the tube is ready for test, the tuning arm is brought down slowly until it contacts the insulated pin. The instant of contact is indicated by an external alarm circuit which may be connected between tube envelope and insulated pin; for this purpose a connection to the insulated pin is brought out to the base. From here on, any further motion of the tuning arm produces the corresponding motion of the G2-grid.

Another advantage of the external contact indication is that it makes possible an absolute frequency calibration such as is shown in Fig. 20(d). The tuning characteristic has been found sufficiently stable with time so that millimeter tubes can be rough-tuned to the desired frequency without the need for tedious wavemeter-tracking.

Referring to Fig. 19, we see that the cavity block can be reclaimed simply by unbrazing the upper and lower bulb. Since most of the cost of the tube is contained in the cavity block, this is an important feature and one which has demonstrated its usefulness on several occasions.

M1805, ELECTRICAL PERFORMANCE

Typical performance data are given in the experimental plots of Fig. 20. From Fig. 20(a) it is seen that the tube tunes mechanically from about 48,000 mc to 60,000 mc, that is, over a 12,000-mc band. This tube delivers a maximum of about 20 milliwatts of millimeter-wave power when operated with a 600-volt beam. Being approximately optimally coupled to a matched waveguide, a standing wave introducer is not re-

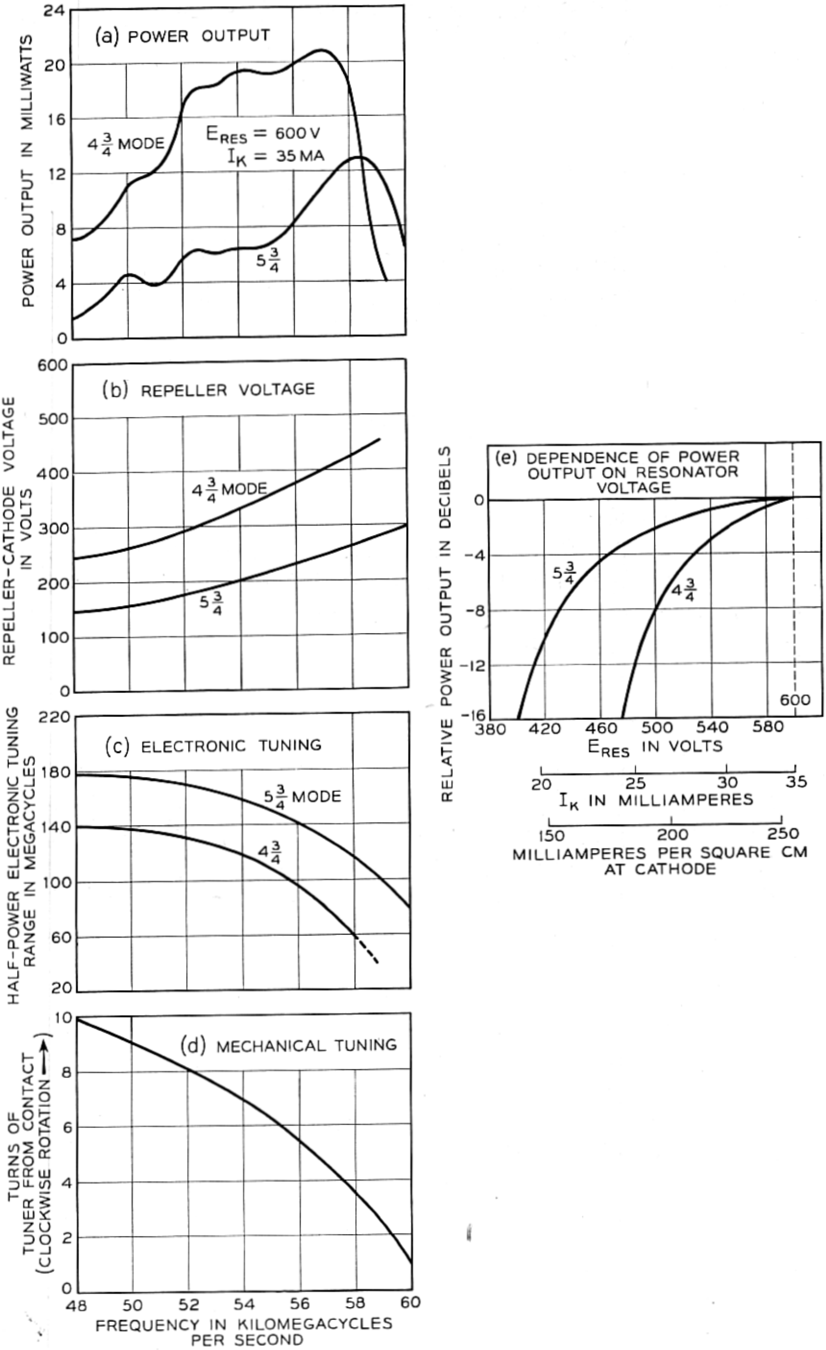

Fig. 20 — Typical M1805 performance characteristics.

quired for the extraction of maximum power. Individual tubes have delivered as much as 30 milliwatts of RF power, but the majority have ranged between 15 and 25 milliwatts. This spread in performance which includes data from early tubes has in part been traced to slight warpages in the diaphragm. Figures 20(b) and (c) relate the values of repeller voltage for maximum power output and the electronic tuning range with frequency for the 4¾ and 5¾ repeller modes.

The M1805 may be operated at beam voltages less than 600 volts, a typical dependence of power output on beam voltage being plotted in Fig. 20(e). If the beam voltage is decreased by 100 volts, that is, from 600 to 500 volts, the power output in the 4¾ mode drops about 8 db whereas it decreases by only 2 db in the 5¾ repeller mode.

The performance of the mechanical tuner is indicated by Fig. 20(d)

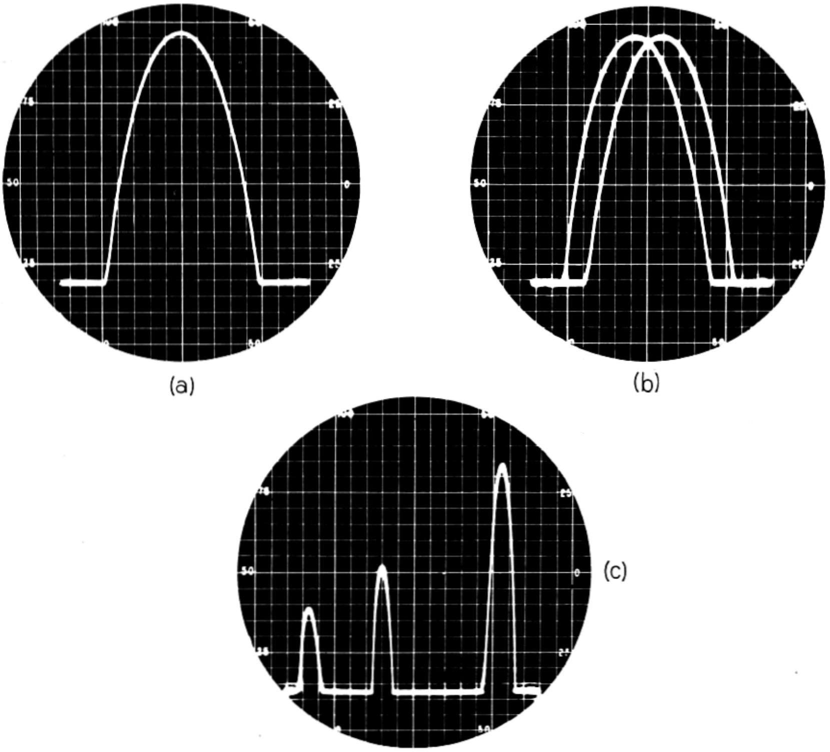
(a)
(b)
(c)

Fig. 21 — Oscillographs of typical repeller mode shapes obtained with sinusoidal sweep. In (a) and (c) the forward and reverse sweeps are coincident while they have been separated in (b) so as to facilitate examination of the individual traces. Oscillograph (c) shows the 4¾, 5¾ and 6¾ repeller modes.

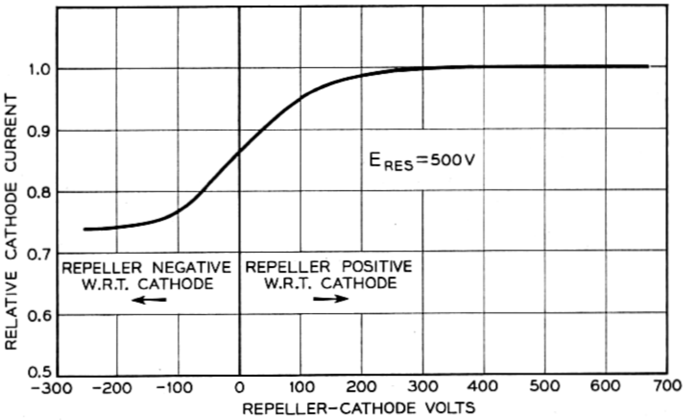

Fig. 22 — Variation of cathode current with repeller voltage. The values of cathode current have been normalized with respect to that obtained with a positive repeller. For the reflector space geometry of the M1805, operation with a negative repeller returns some electrons into the cathode region thereby causing a reduction in cathode current.

where the relation has been plotted between frequency and the rotational position of the tuning screw.

One noteworthy and quite consistent property in the performance of this tube has been the virtual absence of electronic hysteresis and the consequently very clean and symmetrical mode shapes. The oscillographs of Fig. 21 are typical. Oscillograph (a) shows a mode shape obtained with sinuosoidal repeller sweep and with both forward and reverse sweeps coincident. In oscillograph (b) the two sweeps are displaced in phase thereby permitting an examination of the individual traces; oscillograph (c) shows three adjacent repeller modes, again with the forward and reverse sweeps superimposed. This absence of multiple transit hysteresis is, perhaps, surprising in view of the reflector space geometry of Fig. 16. From this figure we might expect a considerable fraction of the returning electrons to re-enter the cathode region. This has, indeed, been verified in an experiment (see Fig. 22) in which cathode current was monitored as the repeller voltage was varied over a wide range. Because of the limited power handling capacity of the repeller, this experiment was performed with a pulsed beam. For values of repeller voltage negative with respect to the cathode, the cathode current and hence the apparent perveance was about 25 per cent lower than that corresponding to positive repeller voltages. The absence of hysteresis must therefore mean either that few electrons reach the interaction gap for a third transit or that those which do are no longer bunched.

ACKNOWLEDGMENTS

The M1805 millimeter wave reflex klystron is the outcome of an intensive team effort which has required and received the cooperation of numerous persons working in highly diversified fields. In presenting this paper, therefore, the author wishes to be considered as the spokesman for this group. Of the people most closely associated with this project from its inception, L. B. Luckner has been in large measure responsible for the mechanical design and its reduction to practice, while F. P. Drechsler has contributed importantly to other phases of this work, notably the design of the electron gun, the fabrication of the ribbon grid and the electrical testing. The feasibility of hubbing as applied to the cavity block was first established by L. B. Luckner working in close cooperation with H. O. Schroder, subsequent refinements and simplifications being due to W. Patterson and K. E. Schukraft of the Precision Room at Murray Hill. The group of skilled technicians responsible for the assembly of the M1805 was under the direction of H. W. Schwarz. Other contributors to this project — but by no means all — have been named in the body of the text. In addition, the success of this project is in no small measure due to the encouragement received from J. O. McNally, J. R. Wilson and H. T. Friis. Finally, the author would like to thank D. A. Chisholm for his constructive criticism of the manuscript.

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