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C.W. X-BAND VOLTAGE TUNABLE OSCILLATOR

Report Number 9

Contract Number DA-36-039 AMC-03270 (E)

Department of the Army Task No. 1P6-22001-A-055-04

Final Report

1 July 1963 to 31 October 1965

U. S. ARMY ELECTRONICS COMMAND

FORT MONMOUTH, NEW JERSEY

Mictron Inc.

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Object: To conduct an investigation of a C.W. X-Band Voltage Tunable Oscillator in accordance with Electronics Command Technical Requirement Number SCL-7001/86 and deliver six experimental models that are representative of work accomplished during the investigation.

Report prepared by

Dr. M. R. Boyd

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PURPOSE

The purpose of this contract is to conduct an investigation of a C.W. X-Band Voltage Tunable Oscillator in accordance with Electronics Command Technical Requirement Number SCL-7001/86 and to deliver six experimental models that are representative of work accomplished during the investigation.

This research and development program will be conducted in two phases.

Phase I	Research Phase
Phase II	Development Phase - Delivery of six development samples

ABSTRACT

The design objectives for a 10 watt X-Band VTM are discussed and the prior art is reviewed. The general approach is evolved from considerations of the problem of mode stability and coupling. Two basic designs are presented, one interdigital and one consisting of a novel approach with the cavities integral to the vacuum device.

Detailed information on the theory of each of the basic designs is given as well as information on the fabrication of the units. Circuit configurations are discussed and a suitable circuit for each of the designs is evolved. A chronological review of all results of operating tubes is given with discussions of important design changes and the reasons for them.

Units were developed which exceeded the objective specifications, the most significant performance being 14 watts at 33% efficiency over the 7.0 to 8.0 GHz band. The principal problem area, a lack of consistency in results obtained, is discussed in detail. The composite results are analyzed in terms of the objectives and recommendations are made for further development.

FACTUAL DATA

I INTRODUCTION

The principal objective of the subject program was to conduct a research and development effort leading to a Voltage Tunable Magnetron for the low X-Band frequency range. The objective specifications are contained in Signal Corps Technical Requirements SCL-7001/86 dated 21 November 1962. For reference, this document has been included as Appendix I of this report.

Although the mechanism of voltage tuning of magnetrons had been demonstrated some fifteen years prior to this contract, most of the subsequent effort was devoted to development in the lower frequency ranges. (For a more comprehensive discussion of prior developments, the reader is referred to Quarterly Progress Report Number 1 issued during the subject program.) The feasibility of operation at X-Band had been demonstrated, but little information of a design nature could be derived from previous programs. The performance of lower frequency VTM's must still provide the basis for X-Band designs.

The general philosophy of the approach which was undertaken merits some discussion insofar as it affected the nature of the subsequent program. The approach was to be primarily experimental and based upon the study of operating units. There would be both theoretical analysis and cold-test experimental work, but major emphasis would be analysis of experimental tubes. There were several reasons for pursuing this type of effort. As an oscillator, the VTM is a non-linear device with a nebulous theory of operation and, as such, is not amenable to meaningful analysis. Since the objectives were primarily experimental, so was the approach. Unlike many other microwave tubes, the basic VTM unit is relatively inexpensive and can be fabricated quickly. This characteristic of the device was responsible for the concentration of effort on operating devices rather than on cold test experiments. Of course, a further consideration is that the end product itself must be an operating device.

PUBLICATIONS, LECTURES REPORTS AND CONFERENCES

Conferences:

Conference Number	Date	Location	Personnel Attending
1	July 24, 1963	Mictron Inc. 265 Osborne Rd. Albany, New York	M. R. Boyd M. Weinstein A. Marfut N. Wilson W. Carbaugh
2	Sept. 11, 1963	Mictron Inc. 265 Osborne Rd. Albany, New York	M. R. Boyd M. Weinstein A. Marfut N. Wilson
3	Nov. 26, 1963	Mictron Inc. 265 Osborne Road Albany, New York	M. R. Boyd M. Weinstein A. Marfut R. Jourdain W. Carbaugh
4	Jan. 24, 1964	U. S. Army Electronics Lab. Belmar, New Jersey	M. Weinstein N. Wilson W. Carbaugh
5	March 18, 1964	Mictron Inc. 265 Osborne Rd. Albany, New York	M. R. Boyd M. Weinstein A. Marfut N. Wilson J. Pritchett
6	June 26, 1964	Mictron Inc. 265 Osborne Rd. Albany, New York	M. R. Boyd M. Weinstein A. Marfut N. Wilson J. Pritchett
7	Oct. 1, 1964	Mictron Inc. 265 Osborne Rd. Albany, New York	M. R. Boyd A. Marfut R. Jourdain J. Pritchett
8	Jan. 28,29, 1965	Mictron Inc. 265 Osborne Rd. Albany, New York	M. R. Boyd A. Marfut J. Pritchett
9	March 23, 1965	Americana Hotel Room 4908 New York City	M. R. Boyd A. Marfut J. Pritchett
10	March 30, 1965	Mictron Inc. 265 Osborne Rd. Albany, New York	M. Weinstein M. R. Boyd J. Pritchett
11	April 30, 1965	Mictron Inc. 265 Osborne Rd. Albany, New York	M. R. Boyd M. Weinstein J. Pritchett
12	June 11, 1965	Mictron Inc. 265 Osborne Rd. Albany, New York	M. R. Boyd M. Weinstein J. Pritchett
13	Sept. 1, 1965	Mictron Inc. 265 Osborne Road Albany, New York	M. R. Boyd M. Weinstein N. Wilson
14	Oct. 1, 1965	Mictron Inc. 265 Osborne Road Albany, New York	M. R. Boyd M. Weinstein J. Pritchett

Quarterly Progress Reports issued beginning September, 1963 - October, 1965.

After considering previous experience in both low frequency and X-Band areas, the decision was made to pursue a program which would evaluate three approaches simultaneously. These were:

1.) Interdigital structure operated in pi-mode (Design I)

2.) Vane-type anode circuit operated in pi-mode (Design II)

3.) "θ-mode" operation

Design I and Design II programs were activated at the outset and conducted simultaneously. A few special tubes were designed to enhance θ-mode operation but this program consisted mainly of evaluating θ-mode oscillations in the Designs I and II types. These results will be discussed further in a later section.

The design of the interaction space is common to both Designs I and II and is based on conventional magnetron design equations[1]:

$$(1)\quad V_a = \frac{3040\,B\,(d_a^2 - d_c^2)}{N\lambda}$$

$$(2)\quad V_c = 0.0356B^2\,\frac{(d_a^2 - d_c^2)^2}{d_a^2}$$

$$(3)\quad \eta = 1 - k = 1 - \frac{V_a}{V_c}$$

where

V_a = anode to cathode voltage in volts

B = magnetic field in gauss

d_a = anode diameter in inches

d_c = cathode diameter in inches

N = number of vanes

λ = wavelength in cm. of π-mode freq.

V_c = Hull cutoff voltage

η = theoretical efficiency

[1] See, for example, Vacuum Tubes by Spangenberg. McGraw-Hill 1948 Chapter 18.

The parameters specified initially are:

V_a = 2250 volts (center voltage)

N = 18 vanes

λ = 4 cm (f_n = 7500 Mc)

d_a = 0.160 inches

d_c = 0.110 inches

The remaining parameters may be computed using Equations (1), (2) and (3)

These are:

B = 3950 gauss

V_c = 3950 volts

η = 43% (theoretical)

Based on previous experience, the interaction length was chosen as:

1 = 0.170 inches

The choice of the interaction length of 0.170 inches merits some comment. Some limited experimental evidence at lower frequencies had indicated that performance would degrade if the interaction length was reduced below a "critical" value. To avoid this possibility the aspect ratio, i.e., the ratio of anode diameter to interaction length, was made to be consistent with lower frequency designs of proven capability. The interaction length later proved to be a critical parameter as will be seen.

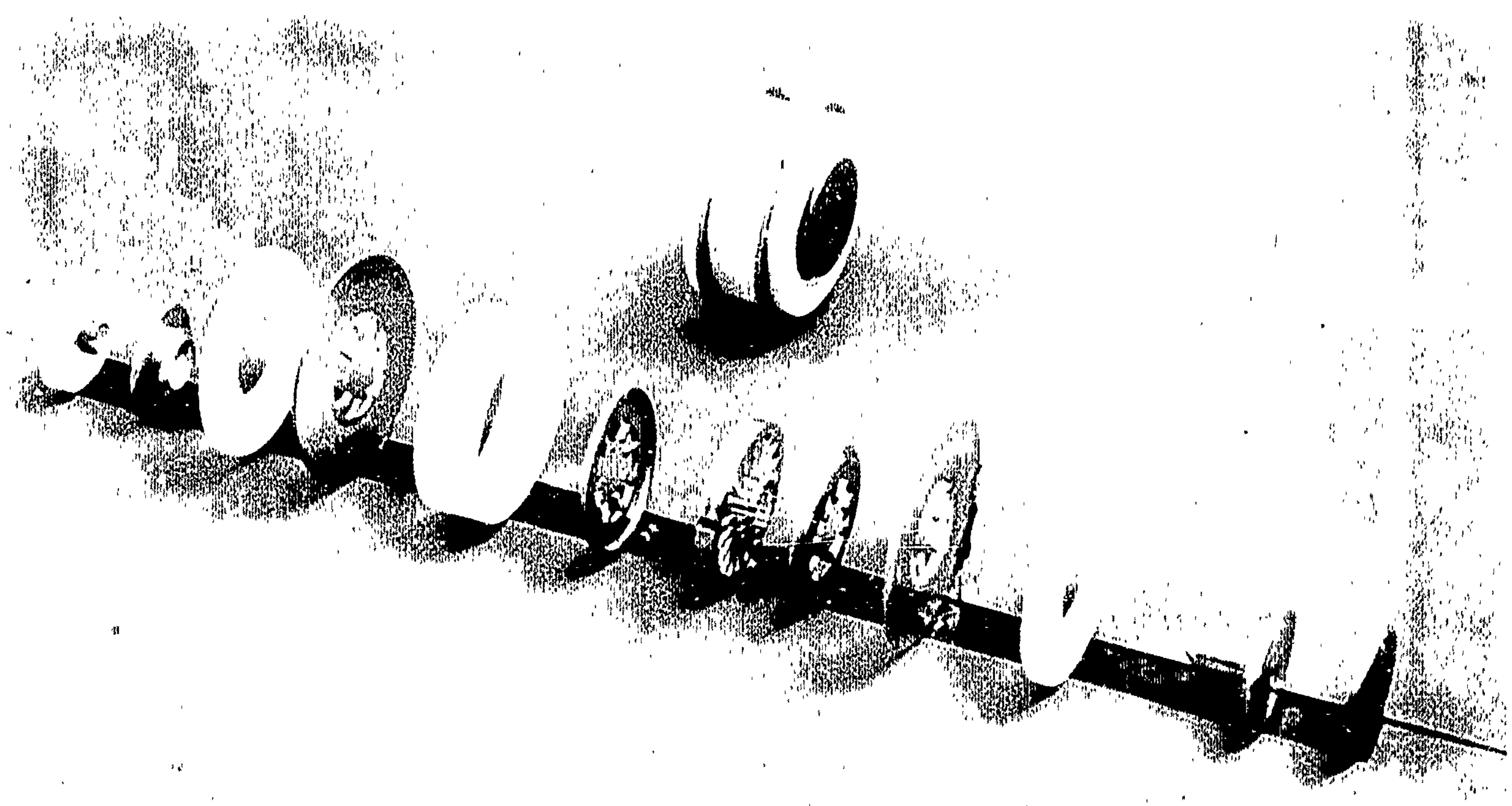


FIGURE 2

Design II Showing Component Parts

II DESIGN II PROGRAM

A discussion of the modes in multicavity magnetron structures is given in Quarterly Report #1, Page 7-14. This material is included as Appendix V of this report. The concept of Design II evolved from these considerations of modes as well as the problems of heavily loading cavity magnetrons. A cross section of the Design II model is shown in Figure 1.

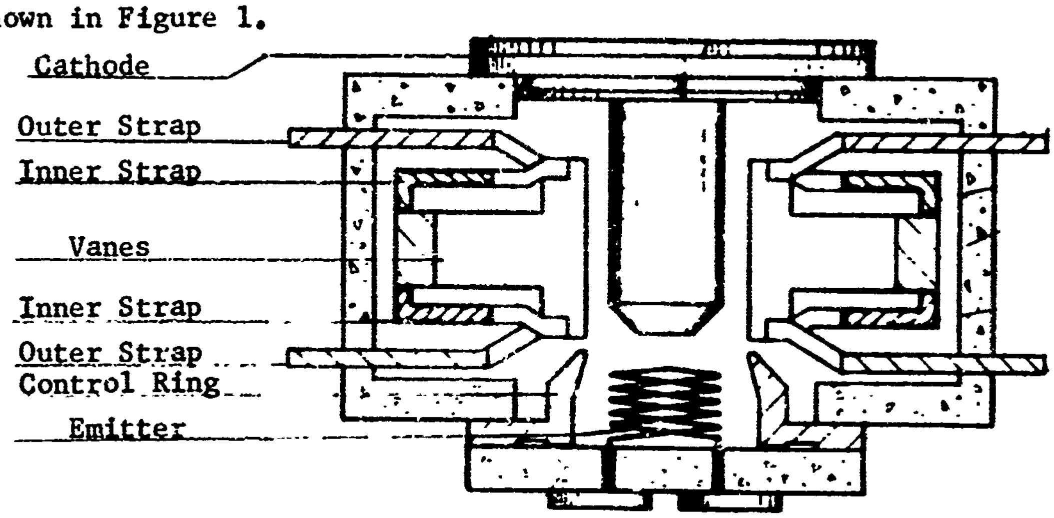


FIGURE 1
DESIGN II CROSS SECTION

A photograph of the assembled unit is shown in Figure 2 with the component parts. The strapping and coupling are the unique features of this particular design. The heavy disc strapping was utilized to separate modes and also provide a symmetrical means by which to couple power out.

In Appendix II the technology of tube fabrication is outlined as it applies to both Design I and Design II. The particular feature of Design II which merits comment in this section is the anode sub-assembly. The anode block itself is made by Electro-Discharge-Machining a blank slug which has been machined to dimension. The unit is then chemically processed and fired prior to assembly. The inner (small diameter) straps are brazed to alternate sets of vanes on the anode block. This unit is then sub-assembled with the outer (large diameter) straps and the ceramic window. Brazing material is required between each vane and each tab to the disc straps - a total of 36 braze points in addition to the ceramic seals of the sub-assembly.

The anode window sub-assembly is then combined with a filament assembly and a control electrode and brazed (with an alignment jig) into a body which is complete except for the cold cathode. The cold cathode is brazed at a lower temperature into the structure after the alignment jig has been removed.

The vane-to-vane spacing of the anode blocks could be held to close (0.001") tolerance by the EDM process, but a technology problem which caused radial staggering of the vanes arose during the fabrication of Design II tubes. This was due to the fact that alternate vanes were brazed to the outer strap which was then sealed to the ceramic window in a subsequent braze. Since this braze occurs at approximately 1000°C., the copper parts have expanded more than the ceramic window. Upon cooling, the ceramic-to-metal braze then held these alternate vanes at a greater radius causing staggering. An attempt to improve this situation was made by prefabricating the anode sub-structure with niobium (columbium) inner straps. The idea here was to cause the set of vanes not tied to the outer strap to be set radially outward by a similar process. This improved the situation but the problem remained in a lesser degree. The exact effect of this radial staggering could not be fully determined because units without some degree of staggering could not be built. The best results were obtained with units where the vanes were formed around a mandrel after the sub-assemblies had been brazed.

The circuit development incorporating the Design II tubes consisted mainly of a waveguide configuration. A cross section of a Design II tube in the waveguide circuit is shown in Figure 3.

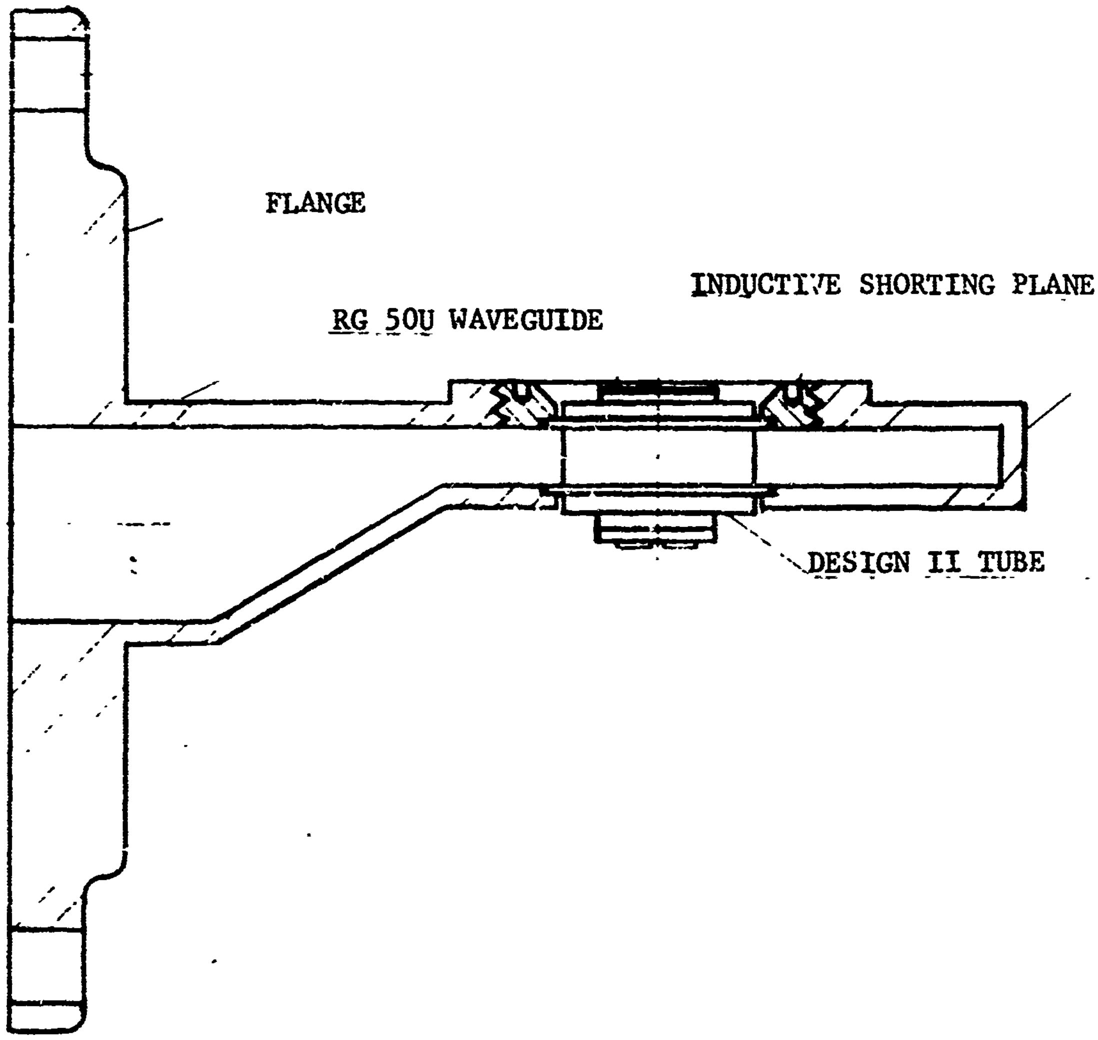


FIGURE 3
CROSS SECTION DESIGN II MOUNTED IN WAVEGUIDE CIRCUIT

A sliding short having finger contacts provided the inductive circuit by which the tube capacity was tuned to the frequency of interest. In general, operation in the 7.0 to 8.0 Gc band was obtained by pushing the short in close proximity to the window ceramic. Similar operation could be obtained by the short being placed a half wavelength (approximately 2 cm.) from the window, but there was a tendency for the VTM to operate at a lower frequency more effectively than the oscillation at X-Band.

Several circuit configurations were tried in an attempt to match the device over the band of interest. These consisted of inductive and/or capacitative irises inserted between the tube and the waveguide output. All of these matching circuits, however, had the effect of restricting the band of oscillation. Progress in this area was limited because of two reasons. The behavior of the tubes in the circuitry indicated that the thickness of the window ceramic and its diameter prevented access of the coupling network to the fields.

In other words, it appeared that in order to be effective, the coupling network should be incorporated in the vacuum device. Because of the empirical design of these components and the difficulty of fabricating vacuum devices this approach was not seriously pursued. Another difficulty in the development of wideband waveguide circuitry was the limited number of waveguide configurations which could be tried and the inaccessibility of the waveguide fields during testing. The tube alignment in the magnet would have to be disturbed for each position of an iris that was being investigated.

In spite of inherent problems of tube fabrication and circuit development, sufficient data were obtained to encourage the continuation of the Design II approach. Some of the more significant results are shown in Figures 4, 5.

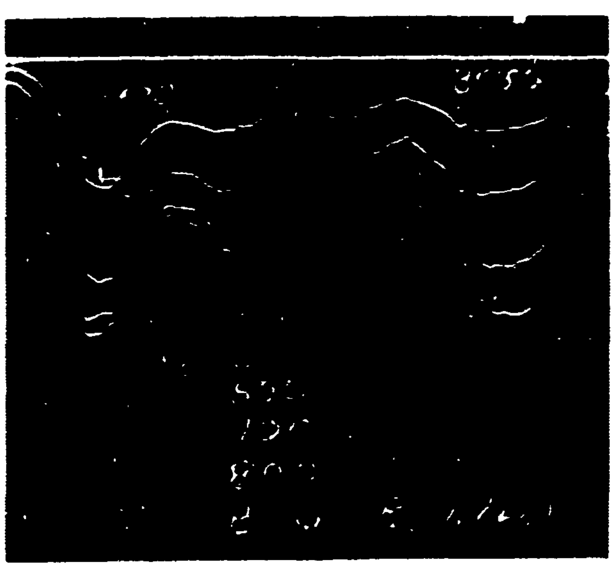


FIGURE 4
FREQUENCY-POWER RESPONSE DESIGN II UNIT

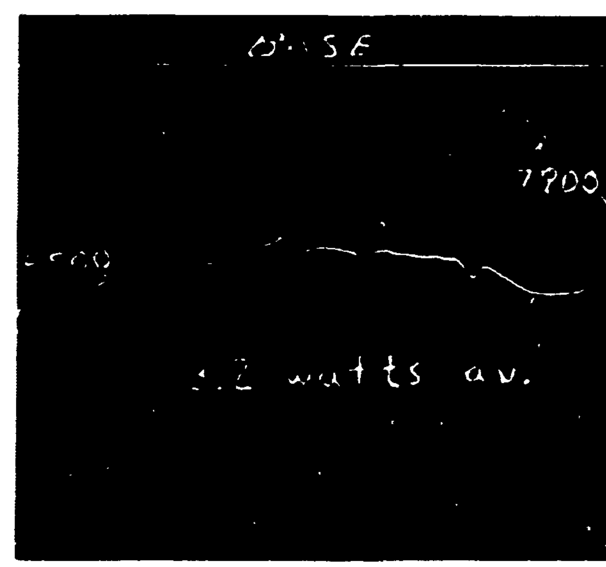


FIGURE 5
FREQUENCY-POWER RESPONSE DESIGN II UNIT

The first units employing Design II tubes which oscillated over a wide band were assembled during the fifth quarter. These were generally low power units (1-3 watts) which operated best in a wider band and at a lower frequency than was desired. The design change which resulted in this performance was a reduction of strapping capacitance by cutting back the diameter of the inner strap. Figure 6 shows this modification.

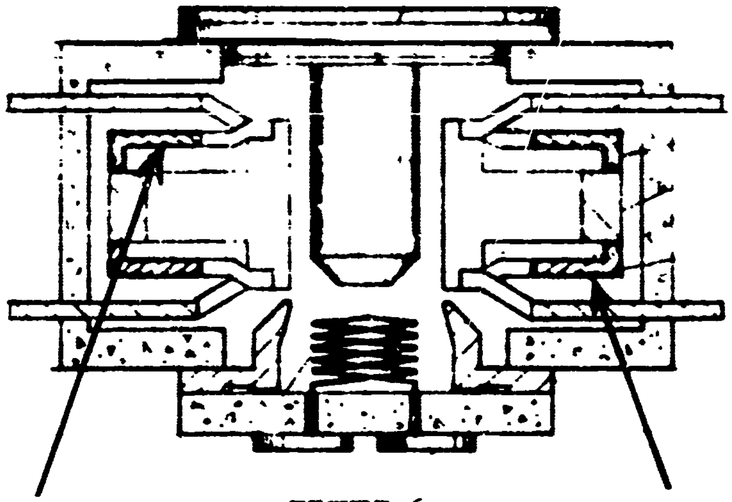


FIGURE 6
DESIGN II CROSS SECTION

A reduction in the cavity size led to some significant improvements in the performance. The anode cavity outer diameter was decreased from 0.460" to 0.428". This change was designed to increase the intrinsic resonance of the block from 6.5 GHz to 7.5 GHz. The first unit built using this block oscillated most effectively in the 7.9 to 8.9 GHz range. (See Figure 7)

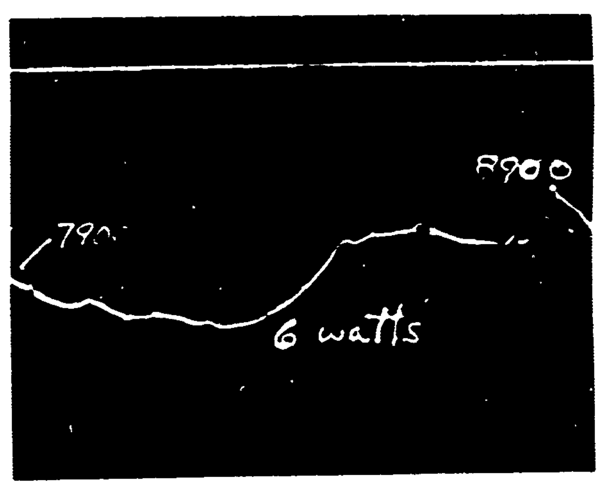


FIGURE 7
FREQUENCY-POWER RESPONSE DESIGN II UNIT

This unit was packaged and shipped to the contractor. Since the oscillation band was somewhat higher than the desired band a design modification was made to reduce the frequency. This change consisted in reducing the length of the strap tabs which were brazed to the vanes. This modification unintentionally introduced a close spacing between straps and a consequent inconsistency in the results obtained.

However, experimental data were obtained from two tubes which provided a further insight into the design and operation of the units.

One of the purposes of Design II was to avoid the cathode coupling which is inherent in interdigital type circuits. However, the operation of the two tubes described above indicated that cathode coupling was a significant factor. This became apparent as the performance was quite sensitive to vertical position in the magnet. By probing the fields in the vicinity of the cold cathode lead the performance could be changed considerably. By covering the cathode with a shield, the leakage could be minimized and the performance enhanced considerably.

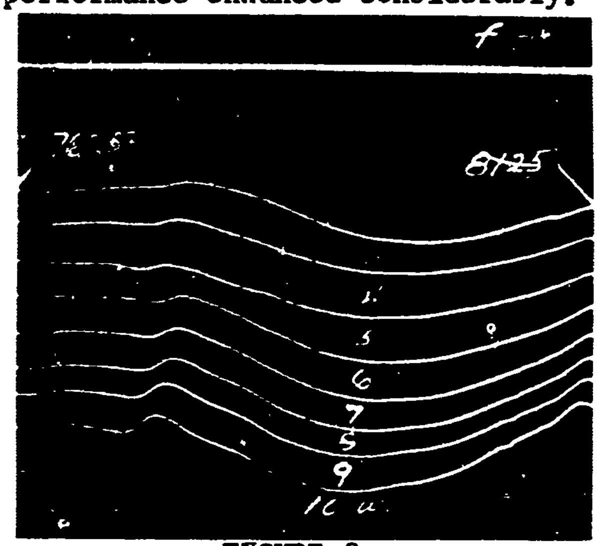


FIGURE 8

FREQUENCY-POWER RESPONSE DESIGN II UNIT

In Figure 8 the Power vs Frequency characteristics of tube 96 x 995 are shown with control electrode voltage as a parameter. Although the band was narrowed when cathode coupling was minimized, the stability and efficiency improved. Previous units tended to operate stably over a very narrow range of control and with efficiency in the 10-12% range. Tube 96 x 995 operated without break from 3 watts to 10 watts with an efficiency of 25%.

Perhaps the most discouraging aspect of the Design II approach was the lack of consistency in results obtained from tubes which should have been identical.

During the seventh quarter a total of 21 operable Design II tubes were tested. Some of these tubes incorporated deliberate modifications to improve performance but many were supposedly identical. It was only possible to speculate why this design was beset with inconsistency whereas lower frequency VTM's exhibited results which were quite reproducible. The difficulty could well have arisen from the fact that the tube is large compared with a wavelength - a presumed advantage, incidentally, at the beginning of the program. As discussed in the Seventh Quarterly Report, the field configurations and interactions may be much more sensitive to abberations in the tube structure. Also, the large diameter which isolates external circuitry from the interaction may lead to extreme sensitivity in the coupling schemes. X-ray data and examination of a number of tubes which had been destroyed for study indicated that the difficulty in reproducing results was due to a very subtle and undetermined cause.

In Table I the composite data for all Design II tubes is presented. Of the total of 43 tubes built 41 were operable. Of the operable tubes a total of 9 tubes exhibited wide band performance which could be considered interesting. Although these isolated results illustrated that the basic design was feasible, the yield of satisfactory packages was distressingly low.

In view of results being obtained with a modified Design I approach, to be described below, the effort on Design II was terminated at the end of the seventh quarter. It is quite possible that the approach of Design II would be superior if further development were continued. This is particularly true if frequency bands above 8 Gc were of interest. At least two of the concepts which evolved during the subsequent Design I program could be applied beneficially to the Design II approach, a reduction in the axial vane length and a cavity enclosure for the cathode button. Also, modifications of the control electrode and cathode geometries would likely improve performance.

The significant results of this phase of the program can be summarized by the following observations:

1.) Wide band, stable performance was demonstrated indicating that the method of disc strapping and coupling is practical.

2.) Mode stability of the disc strapped structures was found to be excellent. At no time was the limiting factor mode stability.

3.) Operating efficiency of 25% over a wide band was observed indicating that the disc coupling scheme was capable of providing effective loading of the interaction.

4.) Several watts were obtained in a stable oscillation in the 8 to 9 Gc band indicating promise of this approach at higher frequencies.

The problem areas which remain in any further development of the Design II approach may be summarized as follows:

1.) Inconsistency of results from "identical" tubes. The solution here must lie in extreme care in both tube fabrication, parts and procedures as well as in precise control of external circuitry.

2.) Cathode coupling. This condition may be minimized by a combination of internal geometry changes and external circuitry to choke the cathode circuit and prevent external coupling.

3.) Back heating of the emitter. This characteristic was common to all of the operating Design II units. No extensive development was undertaken to minimize the effect. It was noted, however, that as cathode coupling effects were minimized, back heating characteristics improved. A similar study of control ring coupling should provide further improvement in this area.

4.) External Circuit Design. Much work remains to be done to optimize the circuitry associated with Design II units. It is likely that more progress could be made in a coaxial configuration with a later transition to waveguide.

III DESIGN I PROGRAM

The performance of wide band lower frequency VTM's has given an insight into the problem of mode interference. (See Appendix V for discussion.) The mode problem would be avoided if it were possible to frequency-scale a satisfactory lower frequency unit. This, however, is not practical if the same tolerances prevail and if anode voltage is to be held to a reasonable value. Two concepts were applied to the Design I in order to insure an effective interaction area and mode stability. The first was to maintain the extended vane length in order to avoid power limitations which had been indicated during previous experience. The second was a unique strapping arrangement which would insure mode stability in spite of the extended vanes.

A cross section view of Design I is shown in Figure 11.

As discussed in Quarterly Progress Report Number 1 the advent of θ-modes is a function of the length of the interdigital vanes. Although the flanges act as effective straps, there may be variation of the fields along the vanes which permit θ-directed fields to exist at the vane ends in the interaction space. A diagram may help to clarify this concept. In Figure 10 (a) the cross section of an interdigital flange and vane is shown with the intensity of θ-directed fields plotted along the axis.

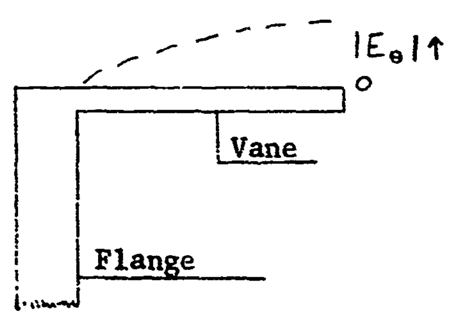


FIGURE 10 (a)

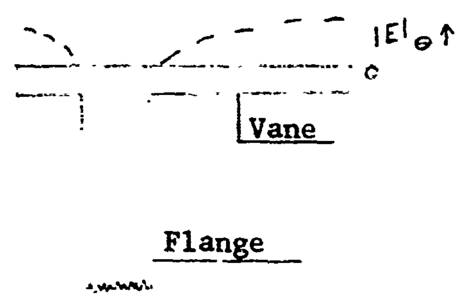


FIGURE 10 (b)

FIELD DISTRIBUTION ALONG VANES

In Figure 10 (b) the distribution of field along a vane of the Design I type is shown. The important distinction between Figures 10 (a) and (b) is the difference in field intensity at the vane end for a given frequency, or more significantly, the difference in frequency for a given intensity at the vane end.

The θ-mode will interfere at the frequency where the intensity at the vane end can sustain the oscillation. Since the determining length in Figure 10 (b) is less than that of 10 (a), the θ-mode will occur at a higher frequency. The pi-mode will not be affected since the distribution is uniform along the entire vane length, which is made the same in both Figures 10 (a) and 10 (b).

The geometry of the interaction space in Design I is identical to that of Design II. One of the principal concerns was the ability to provide external circuitry in close proximity to the interaction. A thin (0.030" wall) window was utilized in the design for this purpose. Since the window height (0.056") was small, the mechanical strength of the unit was not impaired. This choice of a thin wall window did lead to a slight reduction in the yield of vacuum tight bodies, but it was not a significant drop. The design of the filament and control electrode assembly did introduce a serious technology problem, however. Referring to Figure 11,

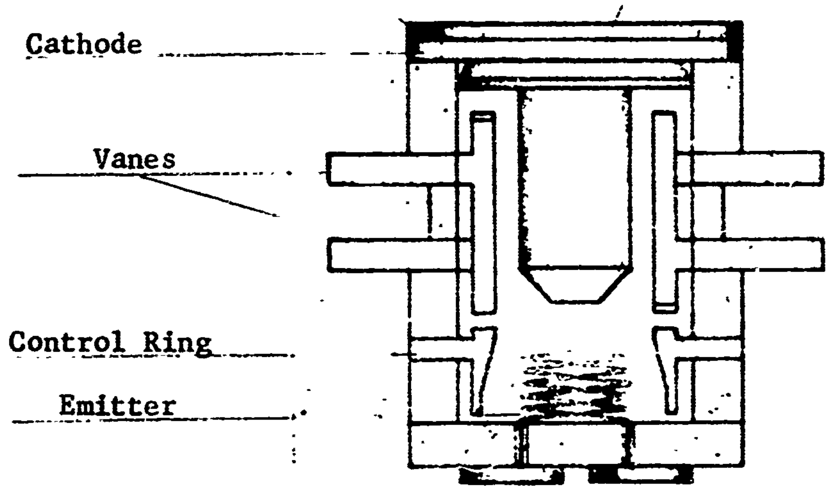


FIGURE 11
CROSS SECTION DESIGN I

the cross section of the Design I model, it can be seen that there is a ceramic-to-ceramic seal involved between the filament ceramic and the control ring ceramic on the emitter side of the control electrode. The tube was made this way in order to use a simple filament ceramic and two identical control ring ceramics yet still provide effective shielding from film build up. As the tube operates, material is evaporated from the emitter onto the filament ceramic, this providing a conducting film on the surface.

However, the design provided excellent shielding behind the projection of the control ring and thus a continuous film between emitter and control electrode could not exist. The difficulty arose when a metallic ring was used to facilitate the ceramic-to-ceramic seal. When the external connection was made between the control electrode and the button on the filament ceramic, the shielded path was shorted and conducting film became a problem. This connection is usually made by painting a conducting stripe from the control electrode to the button. Attempts were made to by-pass the metal ring between ceramics with a tantalum tab, but this was difficult to attach to the control electrode. Also, the tab projected outward and introduced voltage break-down problems. The solutions to the problems introduced by the ceramic-to-ceramic seal in the design were not solved until the two ceramics were replaced by a single ceramic. This will be described in more detail during the discussion of the modified (short) Design I tubes.

A total of 17 Design I tubes was built. These are tabulated in Chart II with indications of the geometrical distinctions and the performance characteristics. Almost without exception, the performance of these units yielded no significant positive results. One unit (93-782) was operated over a 900 Mc band around 7.5 Gc and produced about 8 watts in a stable oscillation. It was determined, however, that the tube was oscillating in a θ-mode. This determination was made by observing the voltage and frequency characteristics of other modes which were present. Tube 93-782 was, incidentally, a 16 vane tube. The efficiency of the oscillation was less than 10%. Consequently, no attempt was made to pursue this type of performance.

The progress of the Design I approach was limited by several factors, some of which were later found to be of a fundamental origin and inherent in the design approach. At the end of the seventh quarter, the results of this approach were negligible and the entire effort was to be directed to Design II approach. The problem areas of the Design I approach can be summarized as follows:

1.) Tubes which generated film due to the design of the filament ceramic assembly had very limited life because heat generated with the film current cracked the ceramic.

2.) Tubes which did oscillate for brief periods could not be loaded effectively. The heater characteristics indicated severe back heating even though no external evidence of oscillation was present. It was suspected that the tubes were oscillating in a θ-mode and in a circuit contained within the vacuum envelope. This type of behavior always led to the destruction of the tube because of the heat generated internally.

The Design I approach would have been abandoned as unsatisfactory if it had not been for some significant results obtained from other programs which were being conducted at the time. These results will be discussed in detail in the following section. However, the conclusion of the results, was that the basic concept of Design I was faulty. In view of this the lack of performance became more understandable.

IV MODIFIED DESIGN I (Short Tube)

During the seventh quarter of the investigation some experiments were performed which indicated that the principal interaction occurred over a very limited portion of the axial vane length. Because of the profound significance of these results on the subject program as well as on VTM design in general, it would be well to describe the experiments in detail and discuss the implications thereof.

During the course of a supplemental program at Mictron an L-band tube was built in which all components were conventional with the exception of the cold cathode. The cold cathode in the standard L-band tube consisted of a cylindrical section which was tapered at the emitter end to a blunt point. Such a cathode is shown in Figure 12 (a).

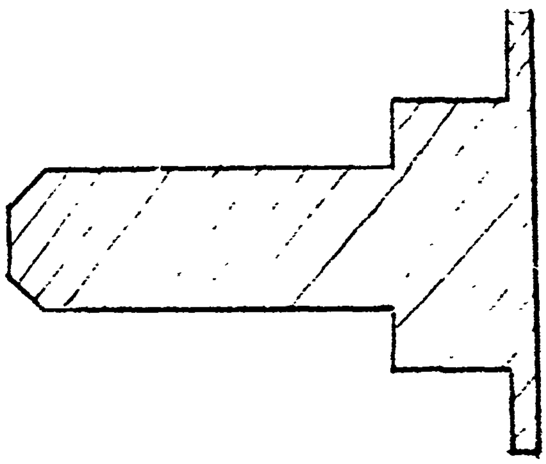


FIGURE 12 (a)
COLD-CATHODE

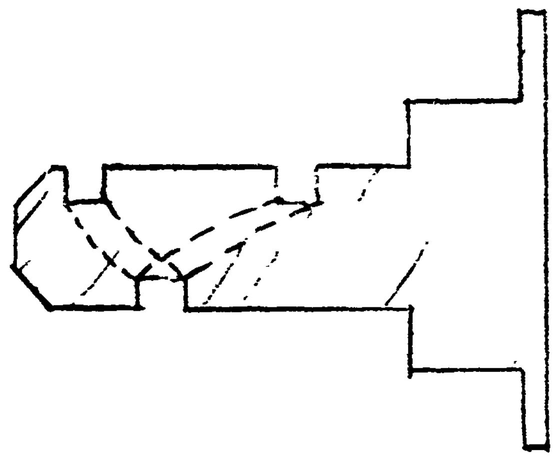


FIGURE 12 (b)
SPIRAL GROOVE COLD CATHODE

The special tube which was fabricated contained a cathode of the type shown in Figure 12 (b). This cathode at the tapered end was identical to the standard, 12 (a). However, the cylindrical portion of the cathode contained a deep spiral groove extending from the taper to the end hat at the opposite end. The performance of this tube was identical to that of a standard L-band tube. If the interaction extended axially along the vanes and cathode beyond the taper, the geometry of the space would surely have modified the performance characteristics.

A second experiment which substantiated the above-described results involved tubes having different angles on the tapered sections of the cathodes. The anode voltage for a given frequency was directly related to the taper and essentially independent of the principal cathode diameter, the inference again being that the interaction occurs in the region of the vanes closest to the emitter. There are, of course, effects of the cathode post geometry on the composite electromagnetic fields in the interaction space, and these will indirectly affect the interaction. An example of this would be the cathode-anode capacitance itself.

A third experiment which was significant was the evaluation of a tube in which one set of vanes (on the flange nearest the emitter) was deliberately removed, leaving only a small projection for interaction. The sketch of this vane structure is shown in Figure 13.

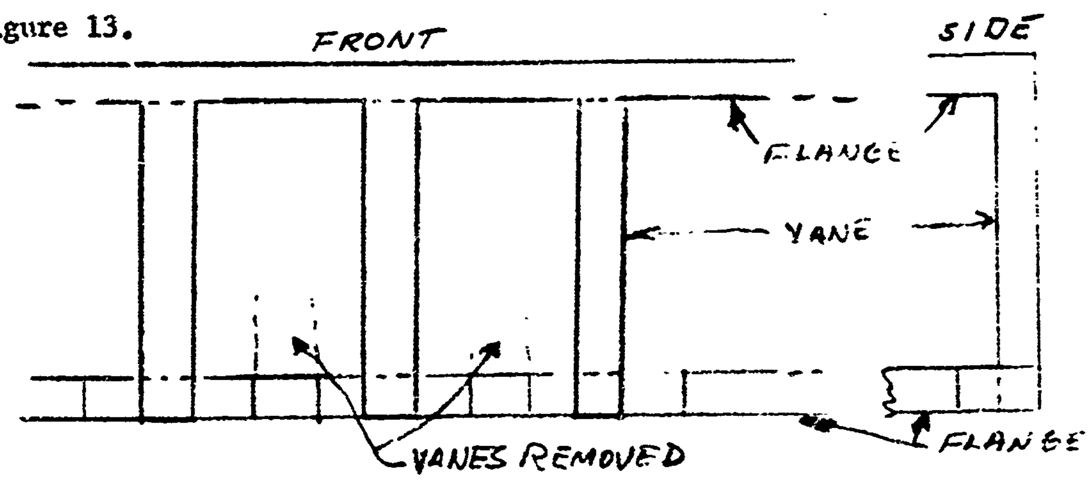


FIGURE 13
EXPERIMENTAL VANE STRUCTURE

This tube oscillated effectively as a VTM over a wide band but at a higher voltage than the standard tube with two complete vane structures. The removal of one entire set of vanes was a drastic modification of the cathode-anode region and the composite fields.

A few qualitative remarks may serve to clarify the concept of the vane tip interaction. Figure 14,

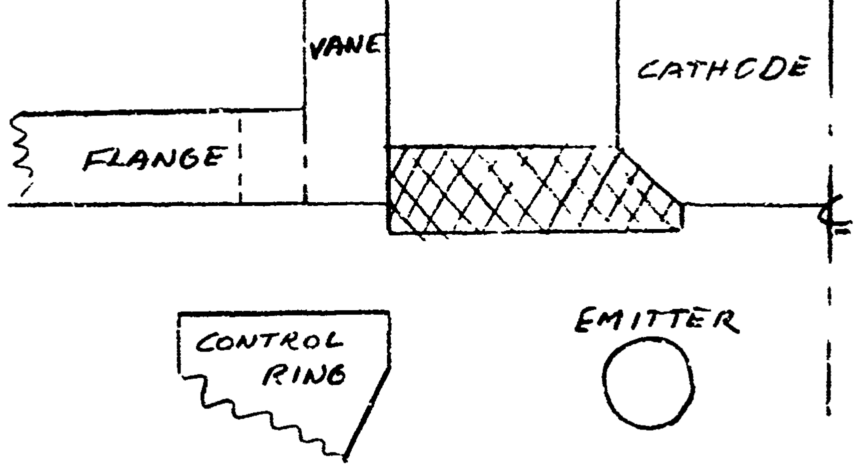


FIGURE 14 CROSS SECTION INTERACTION AREA

is an elarged section of the region comprised of the injection space and the lower portion of the interaction area. The shaded region designates the area wherein the principal interaction is believed to occur. It is difficult to estimate the extent of the region except that it is presumably influenced by the strength of the oscillating electric field which the electrons encounter. These electrons enter the interaction space with an axial drift velocity as well as a circumferential (rotational) velocity, both of which are a consequence of the d.c. electrode voltages and the magnetic field. The oscillating fields "phase-focus" the d.c. beam into a bunched beam having an r.f. content. The bunched beam further enhances the oscillating fields and, also, drives the load coupled to the magnetron. The phase focusing is simply the bunching mechanism of crossed field devices; i.e., the electrons which derive energy from the d.c. fields are driven into the cathode and those electrons which give up their potential energy to the fields are propelled radially toward the anode. The transit time for these anode electrons is, of course, influenced by many factors, one of which is the strength of the oscillating electromagnetic field. The depth of penetration into the interaction region will depend on this field as well as the axial drift (injection) velocity.

It would be difficult without an extensive computer program to determine the trajectories of the electrons in the VTM interactions. However, the numbers at which one arrives using simple concepts do not readily support the "vane tip" theory in any quantitative measure. The modulation index (ratio of oscillating field to d.c. field), based on experimental power and impedance measurements, indicates that the oscillating voltage is the order of 5% or less of the d.c. voltage at the power levels and frequencies under consideration. The unknown quantity is the magnitude of the axial drift velocity. No experimental or analytical program was undertaken to determine these trajectories.

It has been stated that the concept of Design I was faulty in view of the experimental evidence cited above. It is important to note that excess vane length is not only unnecessary but extremely deleterious to the VTM performance. The effect of vane length on mode stability has been discussed previously in this report and will not be repeated here. A further degradation in performance arises from a fundamental relationship involving a figure of merit for all microwave tubes, klystrons, traveling wave tubes, triodes, as well as magnetrons. Mathematically, the relation is stated as:

$$\int_0^{\infty} R \, dw \leq \frac{\pi}{2C}$$

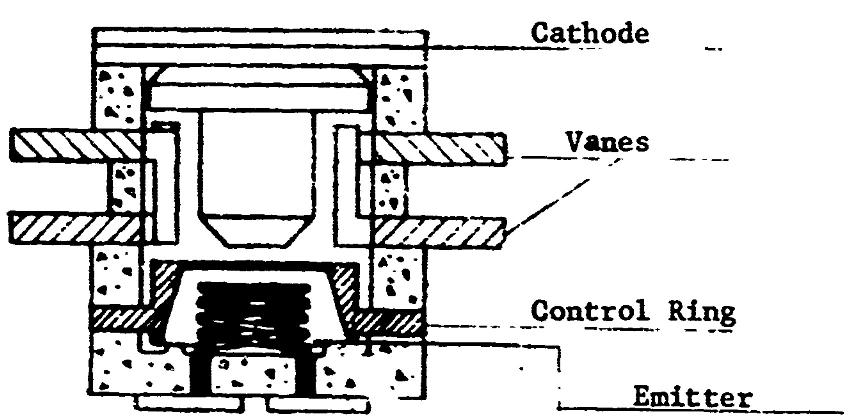
This expression states that the impedence (or real part thereof) integrated over the bandwidth is inversely proportional to the capacitance which is associated with the interaction. Although this theorem has general implications in the areas of network analysis and synthesis, it is most significant in the design of electronic devices. The relation is often expressed implicity in stating that well designed microwave tubes minimize the energy storage in electric fields which do not have access to the electron beam. For example, consider two segments of a tunnel forming an interaction gap for a linear beam klystron or traveling wave tube. The theorem above would dictate a higher intrinsic impedance-bandwidth product for a thin-walled tunnel than for a thick wall tunnel.

H. W. Bode Network Analysis and Feedback Amplifier Design. Van Wostrand, New York, (1945) Page 282.

Or, for the case in point, the interdigital magnetron VTM performance would degrade if the radial thickness of the vanes were increased. Excess capacity has been introduced but the fringing fields which interact with electrons would remain unchanged. Some capacity is obviously necessary to sustain the interaction fields and the minimum limit is usually set by thermal considerations. In conventional magnetrons in which the entire cathode emits, excess length introduces extra capacity but extra electrons are also introduced and the impedance-bandwidth product reduction will be compensated by a lower electronic impedance.

In the original Design I tubes the extra vane length, considered in the design concept to be necessary, presented excess capacity which actually degraded the impedance-bandwidth capabilities of the device. In view of the foregoing considerations, these tubes were redesigned to investigate the behavior of tubes having a shortened interaction length. The vanes were shortened by the amount that the vane tips projected beyond the flange. This resulted in a conventional interdigital type structure having a short interaction length. The length of the vanes was reduced from 0.170" to 0.116", a 32% reduction. Reducing the height of the tube resulted in a bonus advantage which was not a consideration in the design. The overall height of the tube was reduced from 0.468" to 0.376" permitting a corresponding decrease in the magnet gap. This is more than a marginal improvement since it leads to approximately a 50% reduction in weight for the same field strength.

A cross section view of the Modified Design I tube (Tube Type 98) is shown in Figure 15.



CROSS SECTION MODIFIED DESIGN I

FIGURE 15

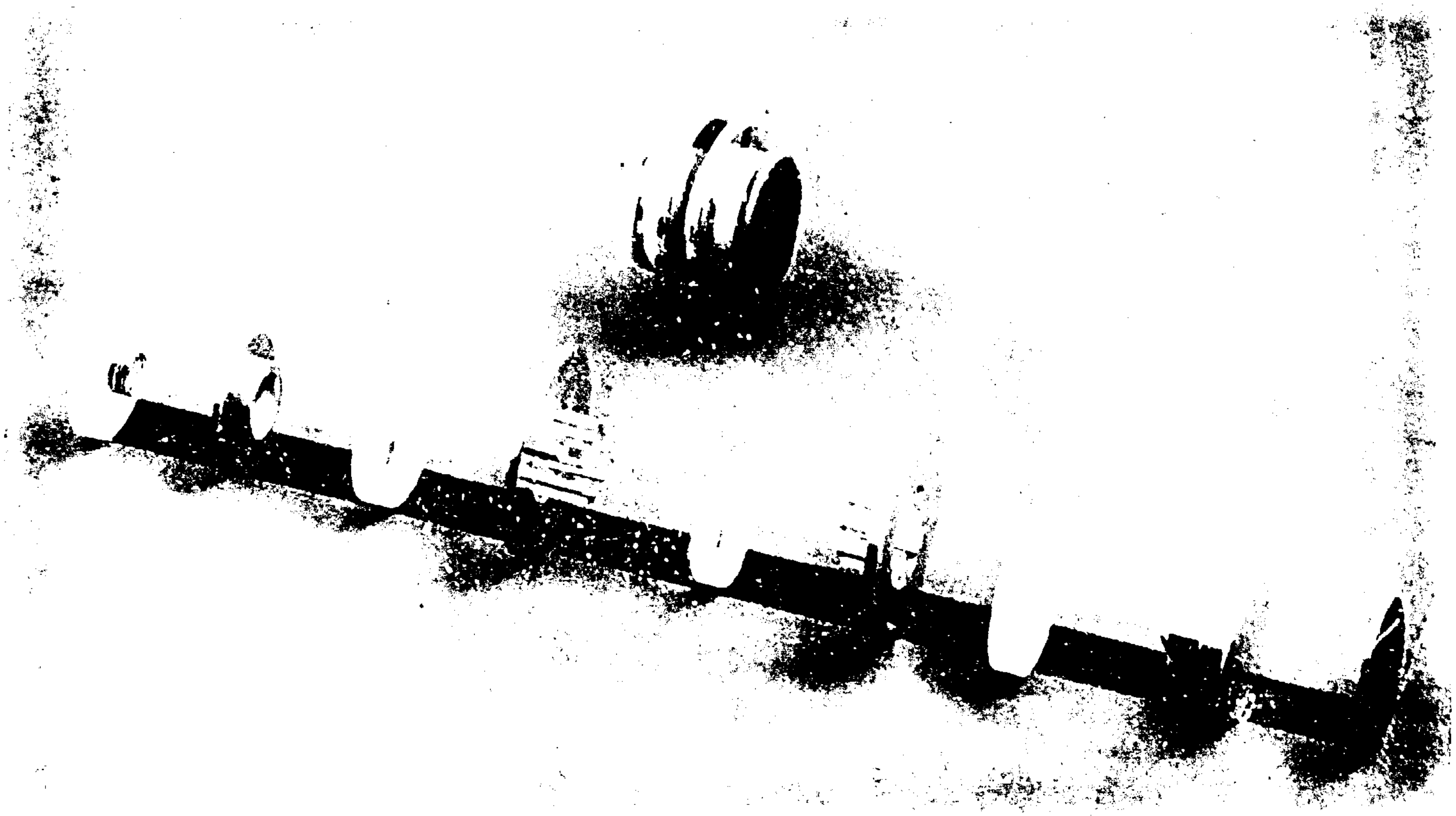


FIGURE 15(a)

Design I Showing Component Parts

An additional improvement was incorporated in the design as Type 98 tubes were being assembled. A new filament ceramic had been procured which permitted excellent shielding from products emanating from the emitter. Figure 15 (a) is a photograph of an assembled tube with a layout of components parts.

In order to facilitate the circuit development, the Type 98 units were installed in coaxial-type circuits rather than in waveguides. The initial test results were the most promising of any obtained to that point in the program. During the eighth quarter, a total of twenty three type 98 tubes were built. (Before the design was standardized, this type was designated as 93x.) Seventeen of the units were operable and five of these exhibited excellent performance. Some of the more significant results are tabulated below.

Tube 93x1213

Swept 6600-8150 MHz
Anode Voltage 2204 volts
" Current 17 Ma
Control Voltage 500 volts
Average Power out 8.7 watts
" Efficiency 23%

Tube 93x1302

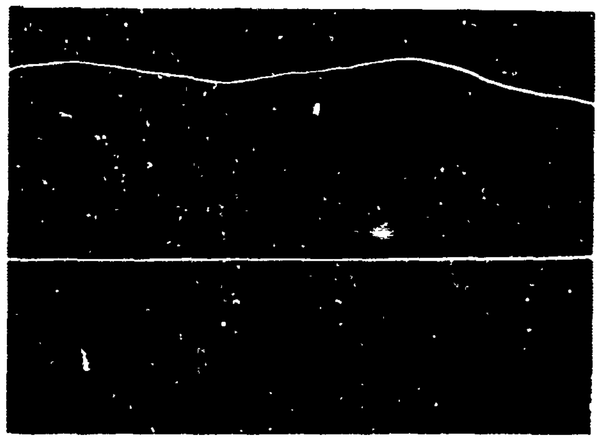
Swept 6675-8325 MHz
Anode Volts 2400 volts
" Current 14.5 Ma
Control Volts 600 V_c
Average Power out 10 watts
" Efficiency 29%

Tube 93x1310

Swept 7000-8000 MHz
Anode Voltage 2300 volts
" Current 18.2 Ma
Control Volts 550 volts
Average Power output 14.4 watts
" Efficiency 34%

An oscilloscope trace of the power frequency curve for 93x-1310 is shown in Figure 16, 14

watts



Frequency

7.0 Gc 8.0 Gc

FIGURE 16
POWER-FREQUENCY DATA (Tube 93x1310)

to illustrate the flatness of the response. This performance represented the best of any that was achieved in the program.

In Chart III a tabulation of the tubes of the modified Design I type is presented. The area of most concern was again the lack of consistent results which could be obtained from supposedly identical tubes. One potential source of difficulty was traced to the cathode ceramic. In the original design the same ceramic was to be used for both the control ring and cathode. This was a ceramic in which the inside diameter was not ground to close tolerances as is the case in the lower frequency units. With the parts tolerances specified, it was possible for the cathode to be quite eccentric.

Since the best results had been obtained in a coaxial circuit this approach was continued during the later phase of development. The Type 98 tubes were sensitive to vertical position in the magnet gap.

As was found in the case of Design II units, this phenomenon was a circuit effect rather than an electronic effect. Energy was being coupled out via the cathode making the magnet an effective part of the circuit. A solution to this problem was achieved by creating a cavity around the cathode button. A section of the circuit assembly is shown in Figure 17. The lower flange of the tube is soldered to the circuit base and the cathode electrode is recessed in the lower cavity. Beryllium copper tuning shorts are positioned around the tube window and soldered into place after adjustment. The top tube flange is coupled directly to a matching slug which has been soldered to the center conductor of the screw-in TNC connector. A photograph of a tube, circuit, and output connector is shown in Figure 18. Figure 19 shows the tube-circuitry assembly mounted with the test equipment and the magnet alignment jig.

There were problems of instrumentation associated with the coaxial circuitry at the frequencies of interest. Furthermore, the objective specifications called for RG 51/U waveguide output. None of the coaxial attenuators which were available would handle the power above 5.0 Gc. When a directional coupler and matched termination were used, the mismatch (1.3 VSWR) affected the performance of the VTM. During the eighth quarter, a 10 watt isolator, which also served as a TNC to RG 51/U adapter, was obtained. This facilitated the instrumentation and also improved the performance of the VTM because of the improvement in the termination input VSWR. A photograph of a packaged unit showing the isolator is shown in Figure 20. Figure 21 is a photograph of a packaged unit without the isolator adapter.

The effort during the final phase of the program was devoted to the following areas:

1.) Standardization of tube design.

2.) Consistency of results.

3.) Improvement of back heating ratio.

4.) Potting and packaging.

5.) Delivery of units required by contract.

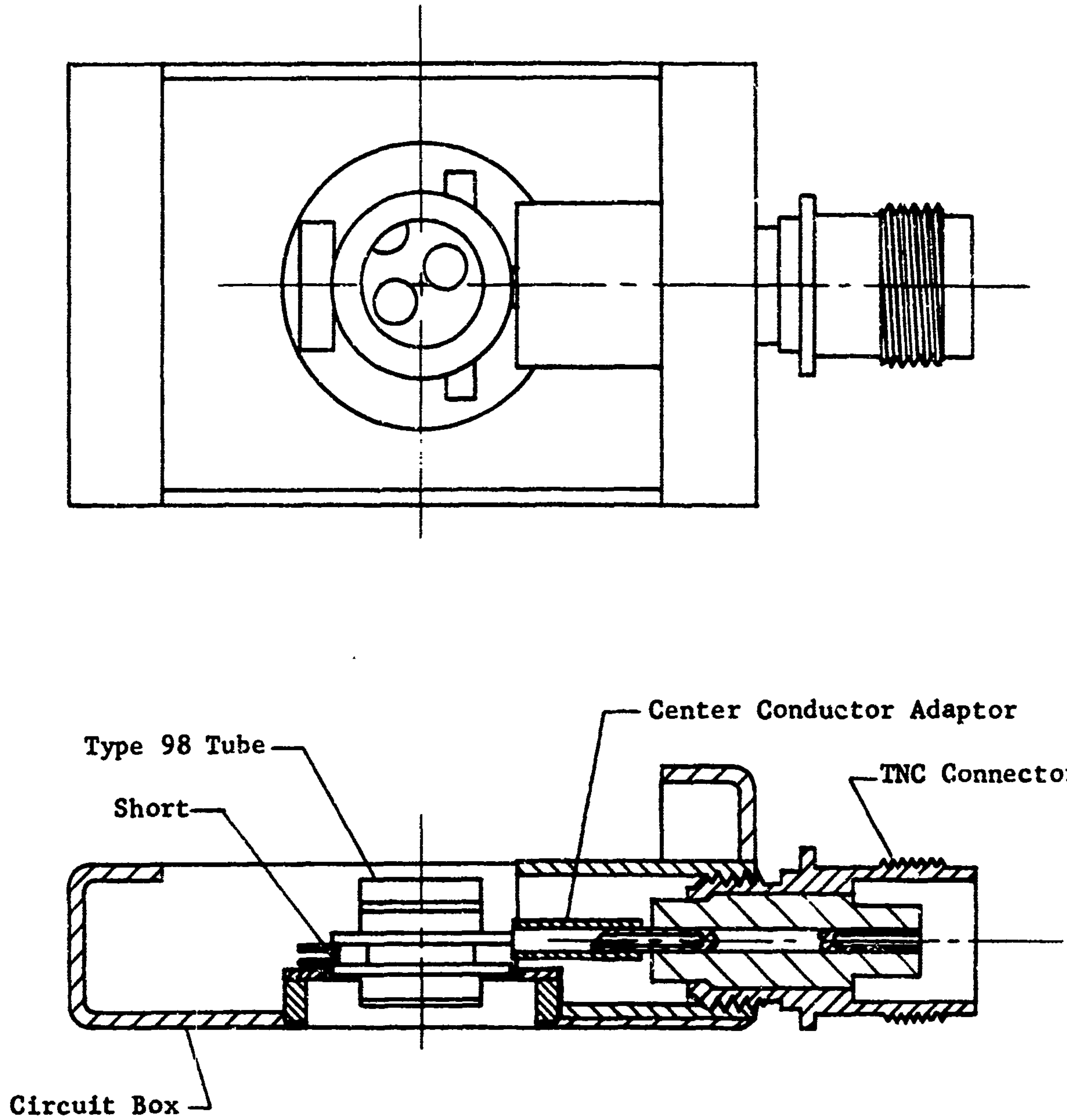


FIGURE 17

X-BAND VTM
Circuit Assembly

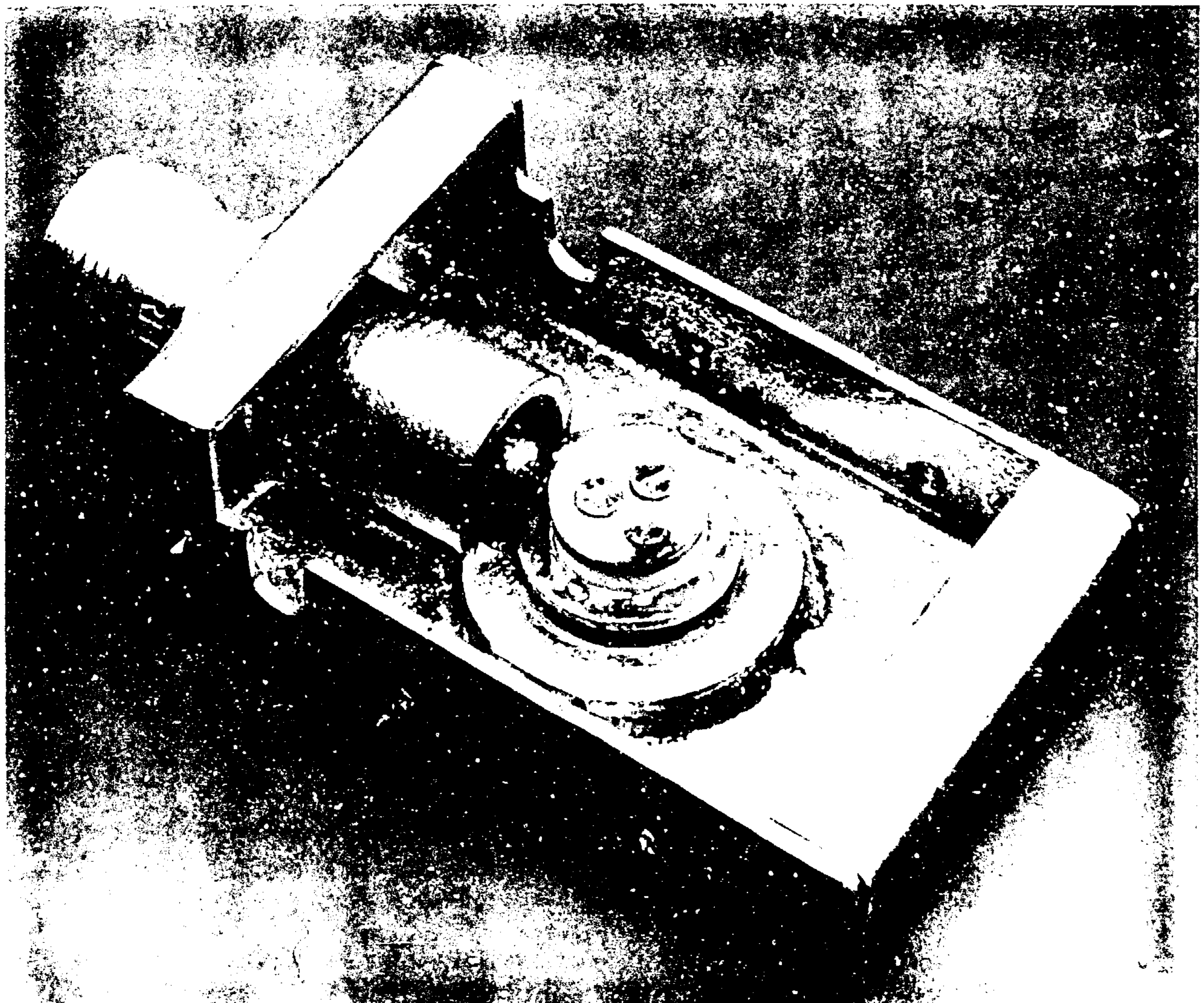


FIGURE 18

Circuit Tube Assembly

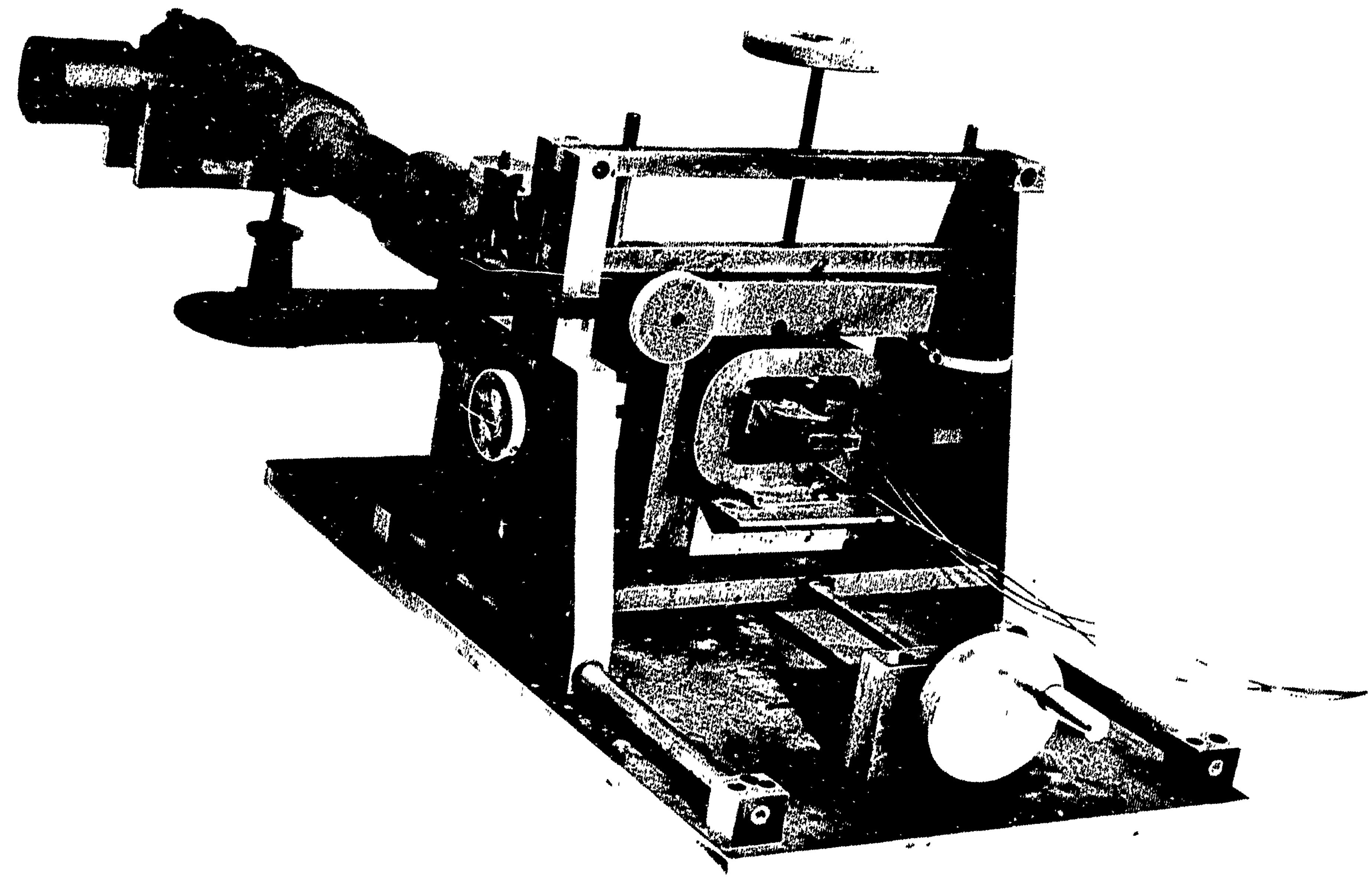


FIGURE 19

Circuit in Test Set-up

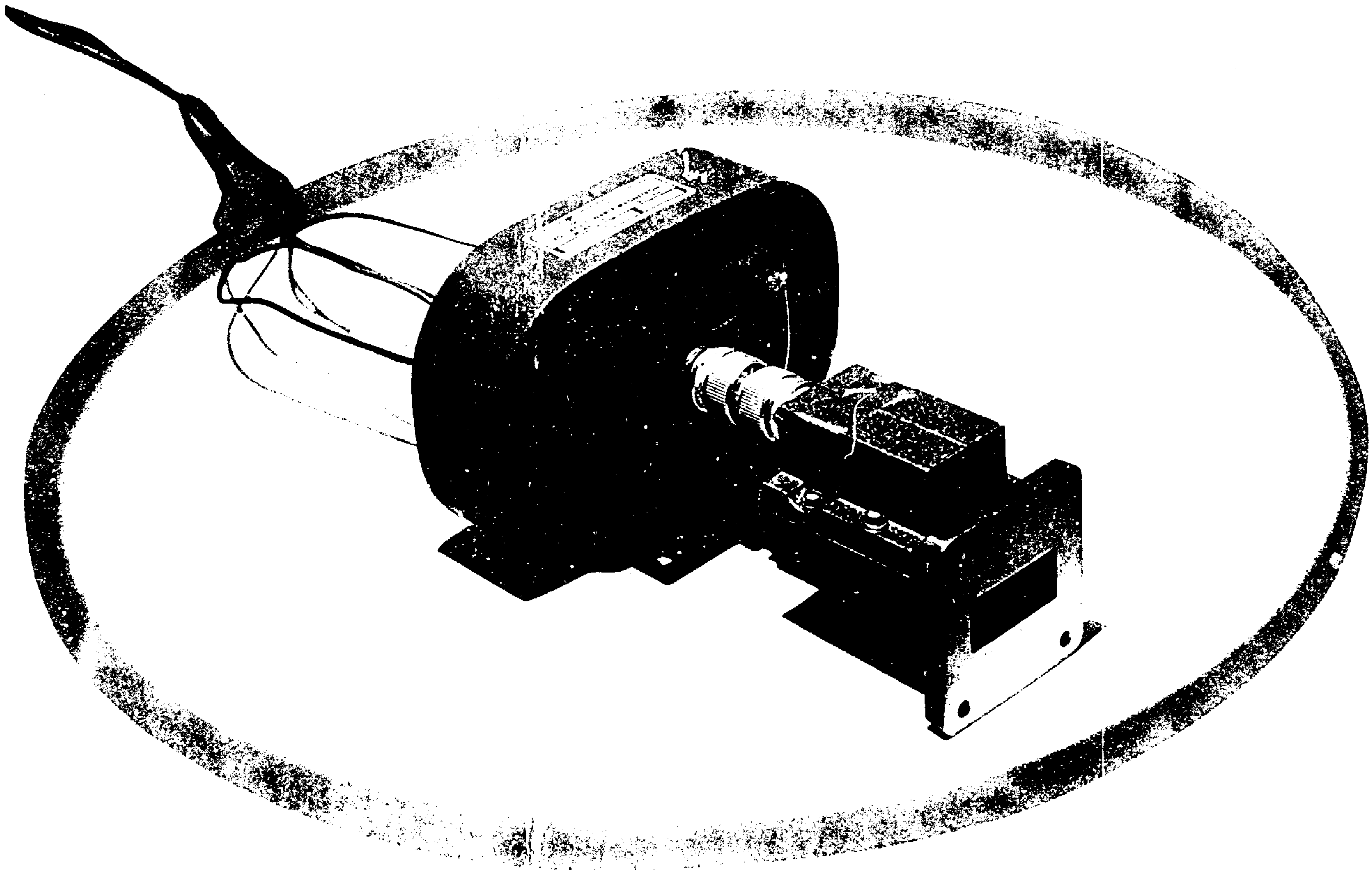


FIGURE 20

Packaged Unit with Isolator-Adapter

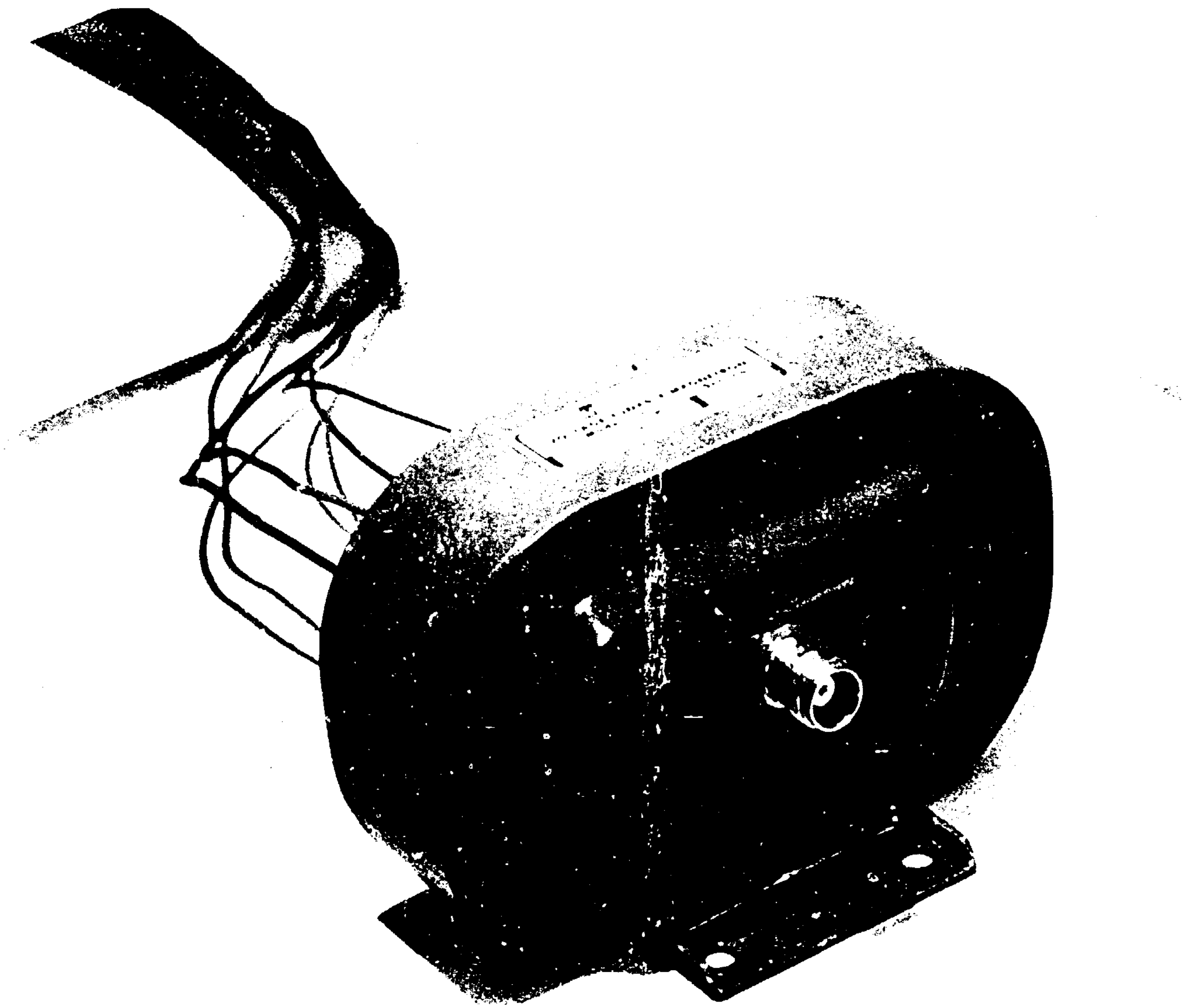


FIGURE 21

Packaged Unit with TNC Output

Many modifications of the tube geometry had been made during the course of the program. These were primarily in the cathode and control electrode shapes. The power, stability, noise and backheating characteristics were observed as various combinations were evaluated. The geometry was finally standardized with the dimensions of the units which had yielded the best overall performance. The significant feature of the cathode design was a very short taper section as can be seen from the Modified Design I (Type 98) section of Figure 15. Best results were obtained from tubes which had a 0.160" diameter control electrode with a slight taper. The anode structures were interdigital units having 9 vanes on each flange. The emitter was a thoriated tungsten filament with an O.D. of 0.110".

The problem of inconsistent results from "identical" tubes was approached from both the tube and the circuit aspects. A rigorous quality control was initiated to follow the tube components through fabrication, processing, and assembly. The anode blanks were carefully measured prior to EDM and the vane structures were checked after their return. All metal parts and ceramics were carefully measured and those not meeting specified tolerances were rejected. All tubes were assembled and brazed using the same fixtures in order to eliminate this as a variable. The sub-assemblies were checked under a microscope for any abberations which could be observed. The fabrication of these units represented what was considered the best practical procedure which could be used.

A standard circuit (as shown in Figures 17 and 18) was used to evaluate the tubes. There were still variations possible in the exact geometry of the coupling slug and the exact placement of shorting tabs around the periphery of the window. These variables, however, were adjusted for optimum performance with each tube. The results of testing tubes during this phase of the program will be discussed below.

Back-heating caused by electrons driven from the oscillating fields into the emitter is a major factor in the life of a VTM. The problem is particularly severe in wide band VTM's where back heating may depend on the frequency (voltage). If the emitter temperature is adjusted to accomodate the back heating at one end of the band where it is most severe, the emission may be inadequate at the frequencies where back heating may be less of a factor.

Two significant observations were made concerning back heating in the tubes of the subject program. First, there appeared to be a direct correlation between the degree of back heating and the diameter of the control electrode. Tubes were built which were identical except for this parameter and the back heating was most severe in those having the smallest diameter. The second observation was that the degree of back heating was inversely dependent on the general tube performance. The units in which the lowest back heating characteristics were observed also exhibited the best frequency, power and efficiency characteristics.

A possible explanation of this correlation concerns the amount of r.f. which couples into the control electrode circuit. The effect of the potting compound on performance, to be discussed below, also substantiates the evidence that r.f. is prevalent in this area. An oscillating field superimposed on the d.c. fields at the emission surface would result in severe back heating of the emitter as well as in a general degradation of performance. A solution to this problem will be suggested in the portion of the report containing conclusions and recommendations for further development.

As the electrical performance was achieved more effort was devoted to packaging the units in a manner which would be compatible with environmental requirements of the specifications. Since the basic approach did not differ from that of the standard Mictron lower frequency units, no extensive modifications were considered necessary. Units had been built which had been qualified for military systems with rigorous vibration, shock, altitude, temperature and humidity requirements. A discussion of this procedure may be found in Appendix VI.

One problem, unique to the X-Band development, did arise, however, during the potting operation. Tubes are frequently tested with a layer of insulating tape as a temporary measure to prevent breakdown. Before the tube-circuit is packaged, this tape is removed and a liquid silicone rubber potting compound is applied to cover the external tube electrodes and connecting leads. This procedure insures that voltage breakdown does not occur between the electrodes even at the reduced pressures of high altitude. There are many varieties of silicone rubber compound which may be generally suitable for potting, but many of these were not satisfactory for the X-Band units.

The effect of the potting compound on performance was most pronounced at the high frequency end of the spectrum. The effect on a typical power-frequency spectrum is illustrated in Figure 22.

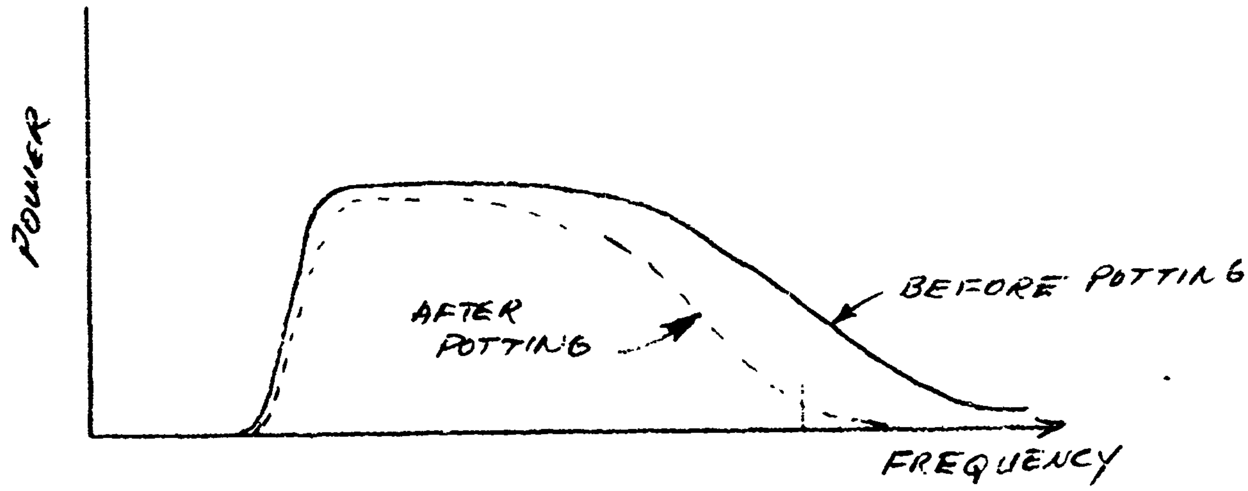


FIGURE 22
EFFECT OF POTTING ON FREQUENCY CHARACTERISTICS

Since other factors appeared to be limiting the high frequency response, the effect of the potting was even more severe. The time available did not permit an extensive program to investigate this phenomenon but an interim solution was obtained by selecting the best of the available compounds and applying it sparingly. Even at best, however, the high frequency was significantly degraded. The preferred potting compound was found to be General Electric Clear Silicone Potting Compound RTV-602.

The VTM test data sheets for the six experimental models which were delivered are contained in Appendix III. The tubes used in these packages were all Type 98 tubes mounted in the same basic circuit. There were, however, minor differences in the coupling circuitry. A few comments regarding the performance data are in order. The best performance data was achieved with Model 10X7-8 Serial Number 2 which incorporated Tube Number 98x-1660. This tube oscillated from 6800 MHz to 8050 MHz with an average power of 10.8 watts and an efficiency of 33.3%. The anode voltage ranged from 2170 to 2515 volts. The back heating on this tube was minimal and the control range and stability were also good. The tube itself would be considered as the basic design unit from which to proceed with any further development.

It can be seen from the experimental data that most of the units were deficient at the high frequency end of the spectrum. Suggestions will be made in a later section to improve this situation and extend the frequency range and bandwidth capability.

Also, it will be noted that units 3, 4, and 6 indicate that performance is sensitive to heater current. These are units which suffer from a combination of back heating effect and limited control range.

Although the noise characteristics were of interest no intensive effort was made to improve the performance in this respect. The noise response of 10X7-8 #3 is shown in Figure 23. This oscilloscope picture is typical of the response of the units. During the interim development, however, units were tested which were significantly better, indicating that improvement in this area could be expected. The noise was measured by means of a wide band crystal mixer and an amplifier with a band of 100 KHz to 100 MHz. The tube was swept over its operating range as noise was measured. Since the oscilloscope had an amplifier with a 10 MHz response, the noise presented was that which occurred in a band from 100 Kc to 10 MHz around the carrier as it was swept. The trace at the bottom of the photograph of Figure 23 illustrates the relative magnitude of the system noise in the absence of the VTM signal. The VTM level is adjusted until the reference noise level is doubled. Under these conditions the noise level measured was the order of 80 db below the carrier over the 7 to 8 GHz band.

During the final phase of the program some effort was devoted to investigating tubes designed to extend the frequency range. Although the development did not produce any positive results, some comments may be pertinent. A few tubes of the Modified Design I type having 10 vane anodes were constructed from the blanks for 9 vane anodes. These units, operated in a coaxial circuit, did not oscillate well in the specified band but did produce several watts in a narrow band around 9.4 GHz. In view of the foregoing discussion on the effects of capacity on performance it would be expected that these units would be inferior. Furthermore, the difficulty in assembling these units with this corresponding close vane spacings precluded any extensive effort to continue with 20 vane tubes.

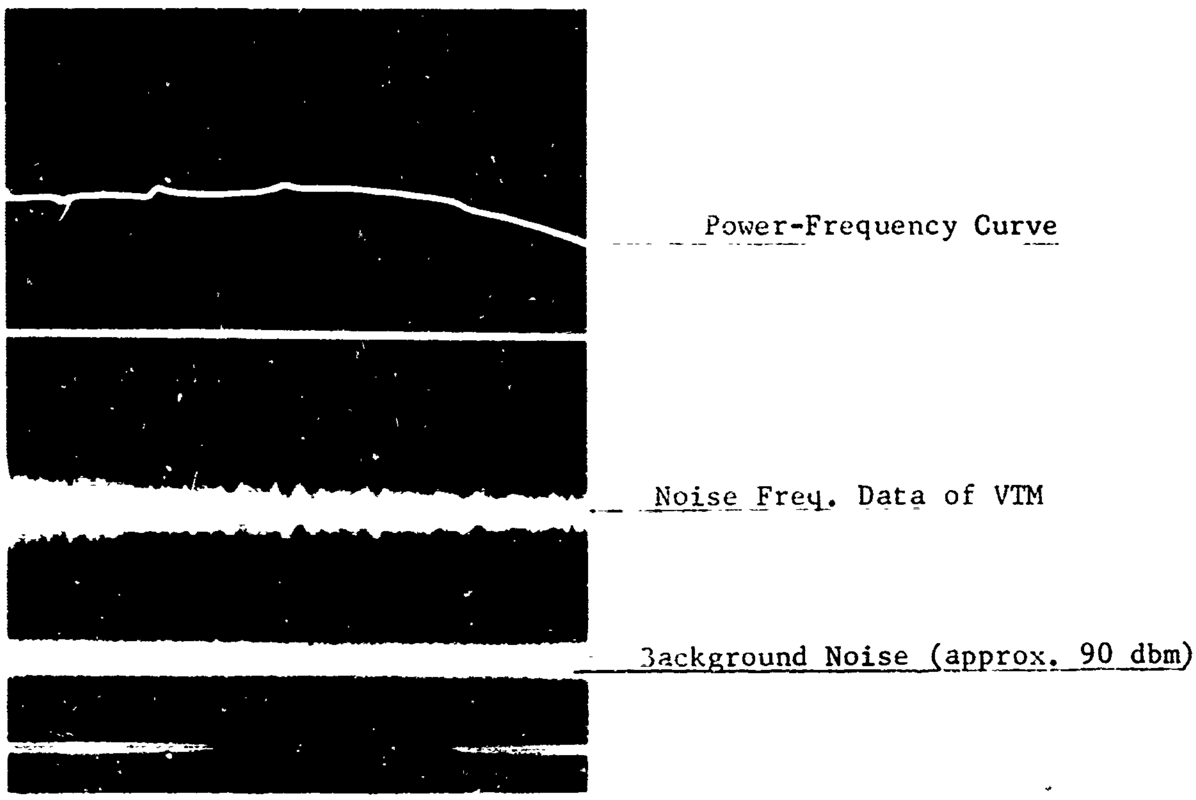


FIGURE 23
NOISE CHARACTERISTICS

The second tube type which was investigated during the late phase of the program contained an emitter and cathode of 0.075" diameter and anodes of 0.140" diameter. The choice of these dimensions was dictated primarily by the availability of the 0.075"emitter and a filament ceramic which would accommodate it. The anode diameter was chosen to give an operating voltage of the proper magnitude. Several units of this type were built and none oscillated at any frequency. It became apparent that the anode-cathode diameter ratio was too large to permit the start of oscillations. This investigation was discontinued as the effort was concentrated in the areas where positive results had been demonstrated.

OVERALL SUMMARY AND RECOMMENDATIONS

During the course of the program a total of 136 tubes of all types were fabricated. Of these tubes, 118 were operable to the extent that they were tested in r.f. circuits. Of the operable tubes, 41 were of Design II type, 15 were Design I, 37 were Modified Design I (short tubes) and the remaining 25 were miscellaneous types having 6, 7, 8 and 10 vane anodes. This latter group of tubes was used in preliminary development work and for evaluation of higher frequency designs.

Although many promising results were obtained with the Design II approach, the lack of consistent results defeated the attempt to achieve contract specifications. This characteristic was ascribed to the sensitivity of the performance to slight abberations in the internal tube geometry and the external circuitry, being a consequence of the relatively large electrical size of the unit. Other problem areas associated with the Design II approach were concerned with the relative complexity of the unit as compared with the interdigital design, the consistently low efficiency which was observed in operating units, and the excessive back heating of these units. The Design II approach would warrant further investigation in any program to achieve performance in higher frequency bands. In this case, a more sophisticated approach to coupling and external circuitry would be suggested. The positive aspects of this phase of the program include the demonstration of a unique method to achieve mode stability and symmetrical coupling over a wide band of frequencies.

The original Design I approach did not yield any meaningful results of a positive nature. However, as the course of the investigation revealed that the concept of the extended interaction length was detrimental, this vehicle served as a basis for designing shorter tubes which did perform effectively. Also, technology problems, common to both interdigital types, were solved using the components of the original Design I units. No further investigation of this particular approach is suggested.

Although the Θ-mode approach was designated at the outset of the program to merit careful consideration, the performance which was observed never warranted more than a cursory investigation. (See Appendix VII for a discussion of Θ-mode operation.) During the early phase of the program several tubes were built in an attempt to enhance Θ-mode performance. Although these units could be made to oscillate over substantial bands, the stability and efficiency in all cases were found to be marginal. This effort was discontinued as Design I and Design II units became available and exhibited more interesting performance oscillating in pi-mode. No recommendations regarding further effort on the Θ-mode approach will be made because of the limited experience in this area during the program.

A modified Design I approach in which the anode length was reduced by 32% provided the best results during the program and the best promise for further VTM activity in the X-Band frequency range. Although the effort was plagued by an inability to achieve consistent results, units were obtained which exceeded portions of the electrical specifications deliniated by SCL-7001/86 (Appendix I). An average power of 11 watts was achieved over the 6850-8050 MHz band with a variation of less than 2db. and an average efficiency of 33%. This performance was achieved in a unit which exhibited good stability with changes in control electrode voltage and was not impaired by severe back heating. Many of the units which were shipped in accordance with contract requirements did not exhibit these features and also were limited in performance at the high frequency end of the spectrum. However, the causes of these deficiencies are understood and remedies will be suggested for further development.

Since the performance of the units was found to be marginal in the vicinity of 8 GHz and above, a new design should be modified accordingly. In view of the discussion of the effect of intrinsic capacitance on impedance-bandwidth characteristics, steps should be taken to reduce this parameter.

Perhaps the most straightforward approach would be to redesign the unit to have slightly reduced cathode and anode diameters, e.g., a 0.100" diameter cathode with 0.150" anodes This modification should extend the frequency range appreciably. A slight improvement could be achieved by thinning the radial dimension of the anode vanes. This would reduce the vane-to-vane capacity but not the vane-to-cathode capacity, both of which limit the impedance-bandwidth product.

A second development suggested to improve performance would be in the area of reducing r.f. in the region between the emitter and the control electrode. Following the improvement noted when the cathode electrode was enclosed in a cavity, a similar arrangement could be provided for the emitter and control electrodes. Also, modifications of the internal control electrode geometry should be investigated as a means to eliminate the oscillating fields from the emitter surface. Advances in this area could be expected to result in a reduction of back heating as well as a general improvement in performance.

An extended development should, of course, include refinement of the external circuitry. The characteristics of coaxial plumbing, particularly TNC, at X-Band are, at best, questionable. From a system standpoint the VTM units should be designed in waveguide circuits. The incorporation of an isolator is strongly recommended in any event.

As a final recommendation for further development of high frequency VTM units the importance of precision parts with close tolerances should be emphasized as well as extreme care in the fabrication of tubes and circuits.

APPENDIX I

SIGNAL CORPS
TECHNICAL
REQUIREMENTS

SCL-7001/86
21 November 1962
Specifications Amended 3 April 1963
Amendments on page 49

CW X-BAND VOLTAGE-TUNABLE OSCILLATOR

1. SCOPE

1.1 This specification covers firm and objective requirementf for the development of a voltage-tunable oscillator capable of operation over the frequency range of 7.0 to 8.0 gigacycles (Gc) at a CW power output level of 10 watts. The following types of oscillators are some suggested approaches to this development, but should not be considered as limiting.

(a) Voltage-tunable magnetron

(b) M-type backward wave oscillator

(c) TWT and feedback device

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on date of invitation for bids, form a part of this specification to the extend specified herein.

SPECIFICATION

SIGNAL CORPS

SCL-7001/86	Electron Tubes

MILITARY

MIL-E-5400	Electronic Equipment, Aircraft General Specification for

(Copies of documents required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer. Both the title and identifying number or symbol should be stipulated when requesting copies.)

3. REQUIREMENTS

3.1 Description, general. The CW X-band voltage-tunable oscillator to be developed under this specification shall meet the applicable requirements of Specification MIL-E-1 referenced in SCL-7001, and in addition, the device shall have the following electrical and mechanical characteristics.

3.2 Electrical.

3.2.1 Frequency. The tube shall be capable of linear voltage tuning while meeting the power output requirements over any 60 megacycle band in the frequency range from 7.0 to 8.0 Gc. (See Note 3)

3.2.2	Power output.	10 watts (min) (Note 5)
3.2.3	Efficiency.	35% (obj); 25% (min)
3.2.4	Anode voltage.	
	(a) Relative to cathode	2500 V (abs. max)
	(b) At center frequency (fo)	2000 V (max)
3.2.5	Anode input power.	40 watts (max)
3.2.6	Auxiliary electrode voltage.	1000 V (max), (Note 1)
3.2.7	Auxiliary electrode current.	1.0 ma (max)
3.2.8	Tuning sensitivity.	1.0 Mc/V (min); 4.0 Mc/V (max)

3.2.9 Tuning linearity. Variations of tuning sensitivity shall not be more than 2 percent (objective) across any 60 megacycle band within the specified tuning range.

3.2.10 Power output variation. $\pm\frac{1}{2}$ db (max) over any 60 Mc band within the specified tuning range of 7.0 to 8.0 Gc. (Note 5)

3.2.11 AM noise.

(a) At lease 90 db below carrier in any 1 Mc band at least 5 Mc away from carrier frequency (obj).

(b) 70 db below the carrier in any 1 Mc band at least 5 Mc away from carrier frequency (min).

3.2.12 FM noise. 0.1 Mc/Sec (mas) during non-modulated operation.

3.2.13 Heater.

(a) Voltage. To be specified. ( ) Vdc (max)

(b) Power. 4 watts (max)

3.2.14 Frequency tuning power.

(a) 1 watt for ± 30 Mc (obj)

(B) 2 watts for ± 30 Mc (acceptable)

3.2.15 FM rate. 30 Mc/sec/sec (min)

3.2.16 Pulling. VSWR 1.3:1 15 Mc (max) (Note 2)

3.2.17 Pushing. For a change in anode current resulting in a 10 percent change in Po 2 Mc (max)

3.2.18 Interlectrode capacitance. 30uuf (max) between cathode and all other electrodes connected to ground (obj).

3.2.19 Magnet. A permanent magnet of minimum size and weight consistent with tube performance shall form an integral part of the device.

3.2.20 Life. (Note 4) 500 hours (min)

3.2.21 Warm-up time. Within 5 minutes after application of input voltages, the tube shall oscillate to within ± 1.0 Mc of its preset frequency.

3.3 <u>Mechanical</u>.

3.3.1 Size, overall. 30 cubic inches (obj)

3.3.2 Weight. 4 pounds (max)

3.3.3 Output connector. Waveguide UG-51/U

3.3.4 High temperature operation (with forced air) +165°F

3.3.5 Low temperature operation. -65°F

3.3.6 Shock. 5g's at 10 milliseconds; 2 shocks in each of three perpendicular directions; heater power only. After this test, the tube must meet the specified performance limits.

3.3.7 Vibration (1). 10 to 55 cps; 10 g's or 0.080 inch peak to peak displacement, whichever is limiting. The heater current (If) shall not vary more than ±10 percent.

Vibration (2). 40 to 2000 cps at 15 g's (refer to MIL-E-5400). Center frequency must not vary more than ±½ Mc.

3.3.8 Shelf life. 5 years (obj)

NOTES:

1. The polarity of the auxiliary electrode voltage shall be specified with respect to the cathode by the contractor. Additional electrode voltages, if required, will be specified by the contractor.

2. The tube shall be operated into a load having a VSWR of 1.3:1. Although the use of an isolator is not desirable, the use of one is not to be excluded.

3. The frequency tuning voltage shall be applied to the electrode as required for the type of device listed in 1.1.

4. The tube shall be cycle tested to achieve a minimum of 1500 cycles. A cycle shall consist of a 2-minute preheat interval, a 20-minute operate interval, and 8-minute off period. The center frequency will be changed 100 Mc for each cycle so that the entire frequency range will be traversed every 11 cycles.

5. The minimum power output at any frequency within the 7.0 to 8.0 Gc range shall be 10 watts. The power variation across the entire frequency range shall not exceed 3 db.

4. QUALITY ASSURANCE PROVISIONS

4.1 <u>Testing and inspection.</u> The tubes developed under this specification will be tested and inspected by authorized personnel of the U. S. Army Electronics Research and Development Laboratory, Fort Monmouth, New Jersey to determine compliance with the requirements of this specification.

4.2 <u>Preliminary inspection.</u> Preliminary inspection of the tubes may be made at the contractor's plant. Inspection and tests may be witnessed by representatives of the contractor.

5. PREPARATION FOR DELIVERY

5.1 The tube shall be packaged, packed, and marked for shipment as specified in the bid request and contract.

6. NOTES

None.

NOTICE: When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished or in any way supplied to said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

SIGNAL CORPS
TECHNICAL
REQUIREMENT

SCL-7001/86
21 November 1962
Amendment Nr. 1
3 April 1963

CW X-BAND VOLTAGE-TUNABLE OSCILLATOR

1. Paragraph 1.1 In third line, change "7.0 to 8.0 gigacycles (Gc)" to read "7.125 to 8.125 gigacycles (Gc)".

2. Paragraph 2.1 Add the following Applicable Document:

   "MIL-STD-446 — Environments for Electron Parts, Tubes and Solid State Devices"

3. Paragraph 3.2.1 Frequency. In third line, change "7.0 to 8.0 Gc" to read "7.125 to 8.125 Gc".

4. Paragraph 3.2.10 Power output variation. In second line, change "7.0 to 8.0 Gc" to read "7.125 to 8.125 Gc".

5. Sheet 4. In Note 5 change "7.0 to 8.0 Gc" to read "7.125 to 8.125 Gc".

6. Paragraph 4.1 Testing and inspection. Replace with:

   "4.1" Contractor responsibility. The supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own or any other inspection facilities and services acceptable to the Government. Inspection records of the examination and tests shall be kept complete and available to the Government as specified in the contract or order. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

7. Paragraph 4.2 Preliminary inspection. Replace with:

   "4.2" Test procedures. The applicable test procedures covered in Specifications MIL-F-1, MIL-STD-446, and MIL-E-5400 shall apply.

APPENDIX II TECHNOLOGY OF TUBE FABRICATION

The assembly and material practices used in the fabrication of the vacuum units are the best known procedures for insuring ultra clean and ultra-high vacuum devices. All metallic components are chemically and ultrasonically cleaned and vacuum fired before assembly begins. (Cleaning procedures may be obtained from Rosebury's "Handbook of Electron Tube and Vacuum Techniques" Addison-Wesley Publishing Company.) All ceramics without metallizing are air fired and metallized ceramics are ultrasonically cleaned in a solvent or hydrogen fired. Clean room procedures are observed strictly during the assembly and brazing of the units.

The first sub-assembly is the filament unit. A filament, ceramic, and buttons are assembled and brazed with an alignment jig at a temperature higher than subsequent brazes will occur. The actual temperature will depend on the brazing material which is used. A variety of alloys are available which are suitable for this assembly. After the unit has been brazed, the filament is flashed in an atmosphere of Benzene. This procedure is standard practice for carbonizing the emitter. (A discussion of this procedure is given in Kohls "Materials and Techniques for Electron Tubes" Reinhold Publishing Corporation.)

The filament sub-assembly is then combined with the remaining tube components (with the exception of the cold cathode) on a precision alignment jig. Brazing material is inserted at each metal to ceramic junction and pressure is applied to the assembly during brazing.

The body sub-assembly is then removed from the alignment jig and the cold cathode is then brazed at a lower temperature. The tube is checked for vacuum tightness and conducting film then aged for a period of twenty four hours.

APPENDIX III

CHART I

Design II Tube Data

Tube Number	Distinctive Features	Comments
X2-1	Original Design	Brok. Heater
X2-2	" "	Cracked Cathode Ceramic
X2-3	" "	6.0-7.2 GHz Intermittent
584	" "	No Data
92-649	0.450" Inner Strap	1.2w.,7.1-8.0 GHz
92-655	" "	No Data
92-665	" "	" "
92-680	Original Design	" "
92-703	0.153" Control Ring	" "
92-709	" "	" "
94-718	" "	" "
94x-747	0.115" Diameter Cathode	" "
94x-776	0.114" " "	3.2w.,6.5-7.9 GHz
94x-784	" " "	1.7w.,6.7-8.05 GHz
94x-791	0.115" Diameter Cathode, Full Strap	Low Power
94x-803	0.110" " " " "	Low Power
94x-816	0.115" " " " "	Conducting Film
94x-840	0.148" Control Ring	3w.,7.4-8.2 GHz
94x-841	" " "	Narrow Band
94x-854	" " "	6w.,7.9-8.9 GHz
94x-862	" " "	Poor Alignment
94x-893	0.148" Control Ring	Leaker
94x-896	0.112" Cathode	Soft
94x-950	501 Anodes (Large Diameter)	L.P.,7.4-8.2 GHz
94x-970	" " " "	Conducting Film
96x-995	584 " (Small Diameter)	10w.,7.6-8.1 GHz

Tube Number	Distinctive Features	Comments
96x-999	584 Anodes (Small Diameter)	Leaker
96x-1012	0.110" Cathode	Broken Heater
96x-1013	" "	Low Power
96x-1021	0.115" "	No Data
96x-1034	No Data	Conducting Film
96 -1043	" "	Conducting Film
96 -1045	" "	" "
96x-1057	501 Anodes (Large Diameter)	Poor Alignment
96x-1059	Straightened vanes	4w., 6.8-8.1 GHz
96-1071	No Data	Poor Performance
96x-1085	0.065 Filament Ceramic	Shorted Strap
96x-1086	501 Anodes (Large Diameter)	Narrow Band
96x-1087	" "	Misaligned
96x-1097	0.055" Filament	Narrow Band
96x-1102	Copper Internal Strap	No Data
96x-1106	No Straps	Multiple Modes
96x-1158	No Data	Leaker
96x-1176	501 Anodes Copper Strap (Large Diam)	10w., 6.9-7.9 GHz
96x-1185	0.075" Filament	Good Performance
96x-1200	584 Anodes (Small Diameter)	Low Frequency
96x-1211	" 0.110" Diameter Cathode	Poor Performance
96x-1217	No Data	No Data
96x-1221	501 Anode (Large Diameter)	" "
96x-1228	" " " "	" "

CHART II

Design I Tube Data

Tube Number	Distinctive Features	Comments
X-380	Original Design	Conducting Film
X-409	" "	Leaker
93-651	" "	Conducting Film
93-656	Internal Short	" "
93x-745	0.115" Cathode	Unstable
93-762	Original Design	Conducting Film
93x-851	0.115" Cathode	No Data
93x-852	" "	" "
93x-1213	" "	8.7w., 6.6-8.1 GHz
93x-1280	Special Cathode	Leaker
93x-1302	Short Taper on Cathode	20w., 6.75-8.0 GHz
93x-1307	" " " "	No Data
93x-1310	" " " "	20w., 6.9-7.4 GHz
93x-1312	" " " "	No Data
93x-1318	Coaxial Circuit	2.5w., 8-9.4 GHz
93x-1332	No Data	No Data
93x-1338	" "	Narrow Band
93x-1357	" "	" "
93x-1358	.052" Heater	6.9-8.2 GHz

CHART III

Modified Design I (Short) Tube Data

Tube Number	Distinctive Features	Comments
98-1361	Filed Down (Design I) Anodes	Gassy
98-1369	" " " "	"
98-1372	" " " "	"
98-1423	" " " "	Narrow [illegible]
98-1424	" " " "	No Data
98-1431	" " " "	12w., 7.2-8.1 GHz
98-1462	" " " "	Gassy
98-1463	Short Tube Parts	Narrow Band
98-1570	Staggered Vanes	Leaker
98-1571	" "	No Data
98-1577	No Data	" "
98-1578	" "	Narrow Band
98-1589	0.160" Diameter Control Ring	" "
98x-1590	" "	" "
98x-1599	" "	" "
98-1600	Vanes Staggered	" "
98-1601	No Data	" "
98-1612	Flat Cathode	No Data
98-1613	" "	Leaker
98x-1659	No Data	No Data
98x-1660	Tapered Cathode	Excellent
98x-1672	" "	Leaker
98x-1725	Flat Cathode	No Data
98x-1752	0.153" Control Ring	" "
98x-1760	" "	" "

Tube Number	Distinctive Features	Comments
98x-1761	0.153" Control Ring	No Data
98x-1762	Tapered K. 0.153" C.R.	" "
98x-1763	Flat Cathode "	Low Power
98x-1765	" " "	Poor
98x-1769	Tube .010" Shorter	Narrow Band
98x-1770	" "	" "
98x-1775	Flat Cathode	Gassy
98x-1776	Flat Cathode 0.160" C.R.	9wpk, 6.75-8.55 GHz
98x-1777	Tapered Cathode "	No Data
98x-1782	Flat Cathode "	" "
98x-1783	" " "	Narrow Band
98x-1844	" " "	No Data
98x-1868	" " "	Low Power Good C.R. Range
98x-1893	Tapered Cathode 0.153" C.R., .0085" Heater	Narrow Band 6000 C.R.
98x-1894	Flat Cathode " "	No Data

CHART IV

Miscellaneous Tube Data

Tube Number	Distinctive Features	Comments
8-594	8 Vane Design I	No Data
82-721	" "	" "
82x-724	" "	" "
82x-725	" "	" "
82-732	.070'Window (θ-mode)	" "
7-730	Reg. 7 Vane Anodes	" "
93x-742	7 Vane Design I	4-6 GHz TNC
93x-757	8 Vane Design I	No Data
93x-758	" "	" "
93x-782	" " 0.115"Cathode	θ-mode 8w., 7.0-8.0 GHz
93x-783	" " "	" 7.5w., 7.0-8.0 GHz
93x-802	" "	Film
93x-801	" "	No Data
93x-853	" " 0.115 Diameter Cathode	" "
82x-919	Internal Shorts (θ-mode)	" "
83x-MRB	8 Vane Design I	" "
93x-1170	" "	" "
83x-1212	" "	" "
83x-1241	" "	Shorted
83x-1256	" "	Leaker
66-1540	6 Vane Design I	No Data
66-1541	" "	" "
100-1620	20 V., .075"Diam Cath, Htr 0.140"Anode	No Start
100-1637	" " "	" "
100-1638	" " "	Shorted Heater

Tube Number	Distinctive Features			Comments	
100-1639	20 V., .075"Diam Cath, Htr 0.140"Anode			N.B. 9.4 GHz	
99-1644	"	"	18 Vanes	No Start	
99-1645	"	"	"	"	"
99-1888	"	"	"	"	"

Iz

GHz

APPENDIX IV

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MICTRON INC.

VOLTAGE TUNABLE MAGNETRON TEST REPORT

Model X-BAND Ser. No. 1

Condition 1 - swept from 7000 to 8000 Mc.

P_o average 12.0 w. V_{cr} 460 V I_f 1.65 a
V_a 2300 V. I_{cr} 0 V_f 2.2 V [illegible] stability

I_a 16.0

Maximum frequency coverage 7000 to 8000 Mc at 4[illegible] V_{cr}.

Control ring variation: 15.0 watts at 500 V_{cr}.
10.0 watts at 430 V_{cr}.

Condition 2 - point by point.

V_{cr} 460

Frequency Mc	V_a - volts	I_a - ma	P_{out} - watts
7000	2140	15.5	10.0
7200	2210	17.5	11.0
7400	2280	17.2	15.4
7600	2360	20.6	15.0
7800	2410	17.8	9.0
7900	2450	15.5	6.4

Date 5/7/65

By MRB

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MICTRON INC.

VOLTAGE TUNABLE MAGNETRON TEST REPORT

98X-1560

Model 10X7-8 Ser. No. 2

Condition 1 - swept from 6800 to 8050 Mc.

P_o average 10.8 w V_{cr} 440 I_f 2.0a.

V_a 2360 v I_{cr} 0 V_f 2.7 v.

I_a 13.8 ma

Maximum frequency coverage 6770 to 8350 Mc at 440 V_{cr}.

Control ring variation: 6.6 watts at 400 V_{cr}.

11.0 watts at 480 V_{cr}.

Condition 2 - point by point.

V_{cr} 480

Frequency Mc	V_a - volts	I_a - ma	P_{out} - watts
6850	2170	15.0	14.0
7000	2230	15.0	12.6
7200	2280	14.6	10.0
7400	2330	14.2	10.0
7600	2390	16.8	13.6
7800	2440	15.6	10.4
8000	2490	18.5	13.0
8050	2515	17.0	9.4

Date 9/7/65

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P.O. DA-36-039 AMC 03270 (E)

Job. ______ P.S. 2506

MICTRON INC.

VOLTAGE TUNABLE MAGNETRON TEST REPORT

Model 10X7-8 Ser. No. 3

Condition 1 - swept from 7.1 to 7.95 ~~Mc.~~ Gc.

P_o average 14.0W. V_{cr} 560V I_f 2.0a → 1.9a for CW

V_a 2370V. I_{cr} 0 V_f 2.6a

I_a 24ma

Maximum frequency coverage 7100 to 7950 Mc at 560 V_{cr}.

Control ring variation; 10.6 watts at 520 V_{cr}. [BREAK AT 7100]

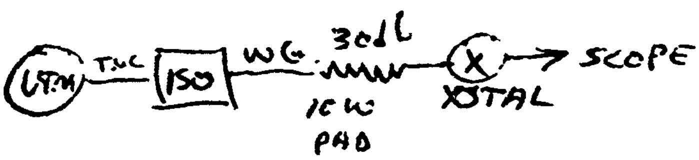
19.0 watts at 670 V_{cr}.

Condition 2 - point by point.

V_{cr} 560

Frequency Mc	V_a - volts	I_a - ma	P_{out} - watts *
7100	2270	26.0	14.4
7300	2350	23.0	16.6
7500	2400	22.0	15.8
7700	2450	22.0	14.0
7900	2500	20.0	10.0

* AT OUTPUT OF ISOLATOR



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Customer Fort Monmouth

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Job. — P.S. 255V

MICTRON INC.

VOLTAGE TUNABLE MAGNETRON TEST REPORT

Model 10X7-8 Ser. No. 4

Condition 1 - swept from 7100 to 8100 Mc.

P_o average 11.4 w V_{cr} 450 V I_f 1.65a (adjust stabil)

V_a 2400 V I_{cr} 0 V_f 2.1 V

I_a 20.8 ma

Maximum frequency coverage 7100 to 8100 Mc at 450 V_{cr}.

Control ring variation: 9.2 watts at 400 V_{cr}.

11.0 watts at 460 V_{cr}.

Condition 2 - point by point.

V_{cr} 450

Frequency Mc	V_a - volts	I_a - ma	P_{out} - watts
7100	~~48.6~~ 2280	18.6	10.8
7300	2330	20.4	12.0
7500	2400	21.4	12.2
7700	2460	22.4	13.4
7900	2520	21.4	10.8
8100	2590	20.0	8.2

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MICTRON INC.

VOLTAGE TUNABLE MAGNETRON TEST REPORT

Model ~~10X7-8~~ Ser. No. ~~5~~

Condition 1 - swept from ~~7170~~ to ~~7920~~ Mc.

P_o average ~~10 w.~~ V_{cr} ~~490 v.~~ I_f ~~2.0 a~~

V_a ~~2250 v~~ I_{cr} ~~0~~ V_f ~~2.9 v~~

I_a ~~21.6 ma~~

Maximum frequency coverage ~~7170~~ to ~~7920~~ Mc at ~~490~~ V_{cr}.

Control ring variation: ~~12.4~~ watts at ~~550~~ V_{cr}.

~~5.4~~ watts at ~~370~~ V_{cr}.

Condition 2 - point by point.

V_{cr} ~~490~~

Frequency Mc	V_a - volts	I_a - ma	P_{out} - watts
~~7200~~	~~2130~~	~~21.0~~	~~10.0~~
~~7400~~	~~2220~~	~~30.0~~	~~16.0~~
~~7600~~	~~2290~~	~~30.0~~	~~15.0~~
~~7800~~	~~2360~~	~~22.4~~	~~8.0~~
~~7850~~	~~2380~~	~~16.6~~	~~5.0~~

Date ~~11/17/65~~

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Customer Fort Monmouth

P. O.

Job. P.S. 2578

MICTRON INC.

VOLTAGE TUNABLE MAGNETRON TEST REPORT

Model 10X7-8 Ser. No. 6

Condition 1 - swept from 7100 to 7650 Mc.

P_o average 8.4 w V_{cr} 500 V I_f 1.65 a

V_a 2270 I_{cr} 0 V_f 2.2 V

I_a 22 ma

Maximum frequency coverage 7050 to 7900 Mc at 530 V_{cr}.

Control ring variation: 7.6 watts at 490 V_{cr}.

11.2 watts at 570 V_{cr}.

Condition 2 - point by point.

V_{cr} 500

Frequency Mc	V_a - volts	I_a - ma	P_{out} - watts
7100	2160	7.0	2.7
7200	2190	230	7.8
7300	2230	22.8	8.2
7400	2260	24.4	9.8
7500	2300	26.3	11.2
7600	2340	23.6	7.7
7750	2370	15.4	1.7

Date 11/22/63

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5. AUTHOR(S) (Last name, first name, initial)

Boyd M. R. Dr.

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13. ABSTRACT

The design objectives for a 10 watt X-Band VTM are discussed and the prior art is reviewed. The general approach is evolved from considerations of the problem of mode stability and coupling. Two basic designs are presented, one interdigital and one consisting of a novel approach with the cavities integral to the vacuum device.

Detailed information on the theory of each of the basic designs is given as well as information on the fabrication of the units. Circuit configurations are discussed and a suitable circuit for each of the designs is evolved. A chronological review of all results of operating tubes is given with discussions of important design changes and the reasons for them.

Units were developed which exceeded the objective specifications, the most significant performance being 14 watts at 33% efficiency over the 7.0 to 8.0 Gc band. The principal problem area, a lack of consistency in results obtained, is discussed in detail. The composite results are analyzed in terms of the objectives and recommendations are made for further development.

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
CW, X-Band Voltage Tunable Oscillator						
Electron Tubes						
Microwave Oscillators						
Magnetrons						
Voltage Tunable Magnetrons						

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