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R-F TUNING STRUCTURES FOR USE WITH THE INSERTION MAGNETRON

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Electronic Defense Group
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ABSTRACT

The design and performance of several cavities for use with the multianode, external cavity, "Insertion Magnetron" is considered in this report. The "Insertion Magnetron" is a sealed-off system of anodes and magnetron interaction space which is used to excite an external microwave circuit. The microwave circuit which surrounds this tube may therefore be altered without disturbing the sealed-off magnetron interaction space. The external circuits investigated were of three types: coaxial, "ground plane resonator", and waveguide. They are examined in terms of their adaptability to mechanical and voltage tuning when used with this tube. Methods of rapidly scanning certain of the structures are proposed. The contemplated range of operation for these geometries is between 1500 and 3000 megacycles with power levels of the order of one half watt or more.

R-F TUNING STRUCTURES
FOR USE WITH THE INSERTION MAGNETRON

1. INTRODUCTION

The lack of adequate sources of continuously tunable microwave frequency power has been one of the most serious obstacles encountered in the development of microwave receiving systems and microwave measurement techniques. The objective of the investigation described in this report was to attempt to alleviate this deficiency especially in the range of frequencies between 1500 and 3000 megacycles per second and power levels of the order of one-half watt or more. It was felt desirable to pursue tuning methods utilizing either mechanical or electrical (voltage-tunable) methods. The vehicle chosen for this investigation was the "Insertion Magnetron"; a magnetron designed for low power operation in conjunction with an external circuit.* The Insertion Magnetron was developed at the University of Michigan Electron Tube Laboratory with the express purpose of investigating both the voltage-tunable and mechanical tuning capabilities of an external-cavity magnetron oscillator. Emphasis was on the properties of the magnetron. In the present study the emphasis is on properties of the external circuitry which might render the magnetron more suitable for applications such as panoramic receivers.

A number of circuit structures are presented and are discussed in terms of their mechanical and voltage-tunable capabilities when used with the

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* Needle, J. S., "The Insertion Magnetron", Technical Report No. 11, Electron Tube Laboratory, University of Michigan, August, 1951. The characteristics of the Insertion Magnetron are described in detail in this report. The present report describes only the external circuitry investigated and the results of this investigation.

Insertion Magnetron. It would, at this time, be premature to come to any final conclusions with regard to the different types of microwave circuitry employed in view of the limitations of operation imposed by the characteristics of the Insertion Magnetron itself. However, the results described here should be of value in future work of this nature.

Figure 1.1 is an assembly drawing of the Model 9B Insertion Magnetron used in this investigation. This magnetron consists of a short hermetically-sealed section of coaxial transmission line which contains a multi-anode structure formed by six equally-spaced vane anodes extending radially from the inner wall of an outer coaxial cylinder into six longitudinal slots in an inner coaxial cylinder. The cathode is located symmetrically within the inner coaxial cylinder at the position of the multi-anode structure. This sealed-off tube is used to excite a TEM mode in an external coaxial circuit.

During the course of the present circuit study with the Insertion Magnetron the Electron Tube Laboratory continued its investigation of voltage-tunable operation with a new external-cavity interdigital magnetron designed by Mr. J. A. Boyd. The results achieved by Mr. Boyd with his new tube are significant to the development of higher power voltage-tunable generators and will be discussed in a report which will be issued by the Electron Tube Laboratory at a later date.

2. THE COAXIAL-T RESONATOR (HIGH Q)

In the initial experiments with the Insertion Magnetron a coaxial resonator was employed which was mechanically tuned in a direction coincident with the axis of the magnetron cathode. This coaxial configuration was severely

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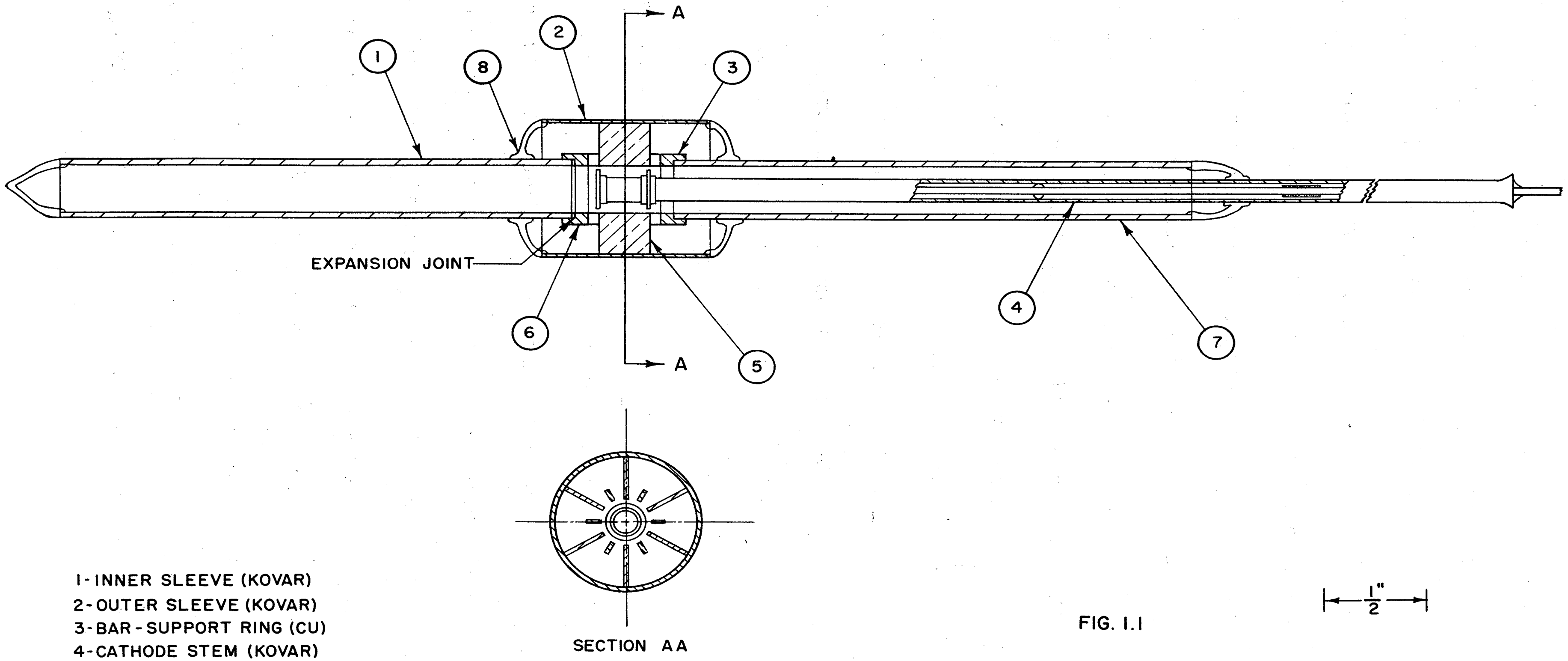

FIG. 1.1

1-INNER SLEEVE (KOVAR)
2-OUTER SLEEVE (KOVAR)
3-BAR-SUPPORT RING (CU)
4-CATHODE STEM (KOVAR)
5-VANE (CU)
6-BAR-SUPPORT RING (CU)
7-INNER SLEEVE (KOVAR)
8-GLASS SEAL

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Figure 1.1

limited in frequency range in view of the mechanical limitations imposed by magnetic circuit requirements. The Coaxial-T resonator shown in Fig. 2.1 was designed primarily to overcome these mechanical and magnetic circuit deficiencies. The magnetron operating in conjunction with this high Q coaxial-T resonator was capable of being tuned from 375 to 2140 megacycles per second. Tuning curves for this oscillator configuration are given in Fig. 2.2. The upper wave length limits shown by the tuning curves in this figure are not considered boundaries for the operating range of this type of resonator system. The upper wave length limits may easily be increased beyond those shown in Fig. 2.2 by increasing the tuner stub length. The power output from the oscillator varied within wide limits over the frequency range, because the position of the output loop was fixed. The maximum CW power output from this oscillator system is estimated to be of the order of one to three watts. Magnetic fields of the order of 1200 gauss were supplied by means of an electromagnet.

A packaged version of this oscillator built with two type QK59-62 magnetron permanent magnets in parallel also gave satisfactory, mechanically tunable operation. The problems which arose in connection with the coaxial-T oscillator were (a) cathode back heating, which eventually caused instability of operation, and (b) the restriction of tuning speed by the mechanical structure of the tuning stub. Neither of these points was investigated fully enough to provide final solutions; however, attempts were made to attain faster tuning by employing a butterfly tuner in the tube cavity portion of the resonator. The results of the butterfly tuning method were negative and indicated that if faster mechanical tuning was to be obtained, the tuning stub portion of the resonator would have to be designed for rapid mechanical scanning.

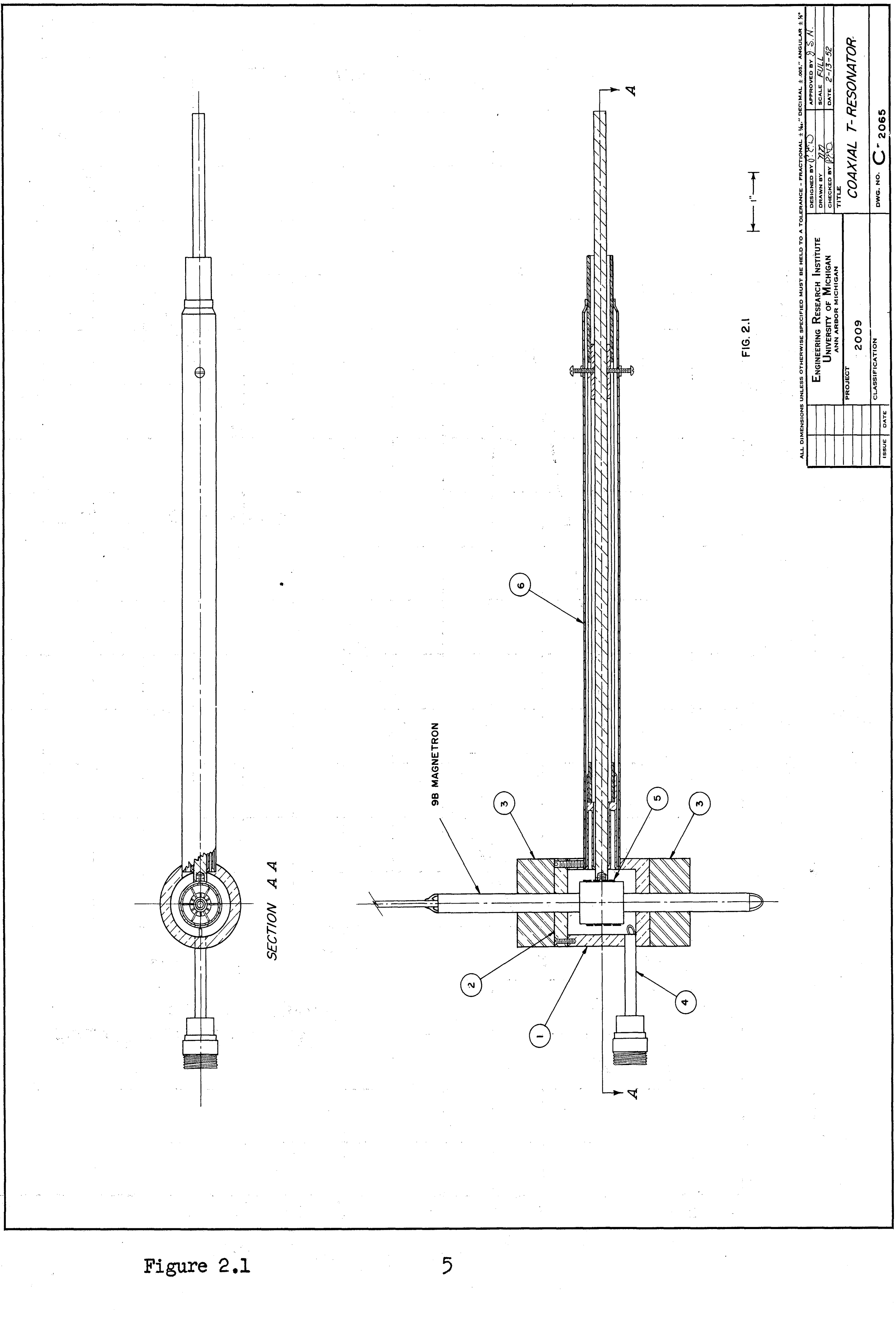
SECTION A A
9B MAGNETRON
①
②
③
④
⑤
⑥
A
A
1"
FIG. 2.1
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Figure 2.1

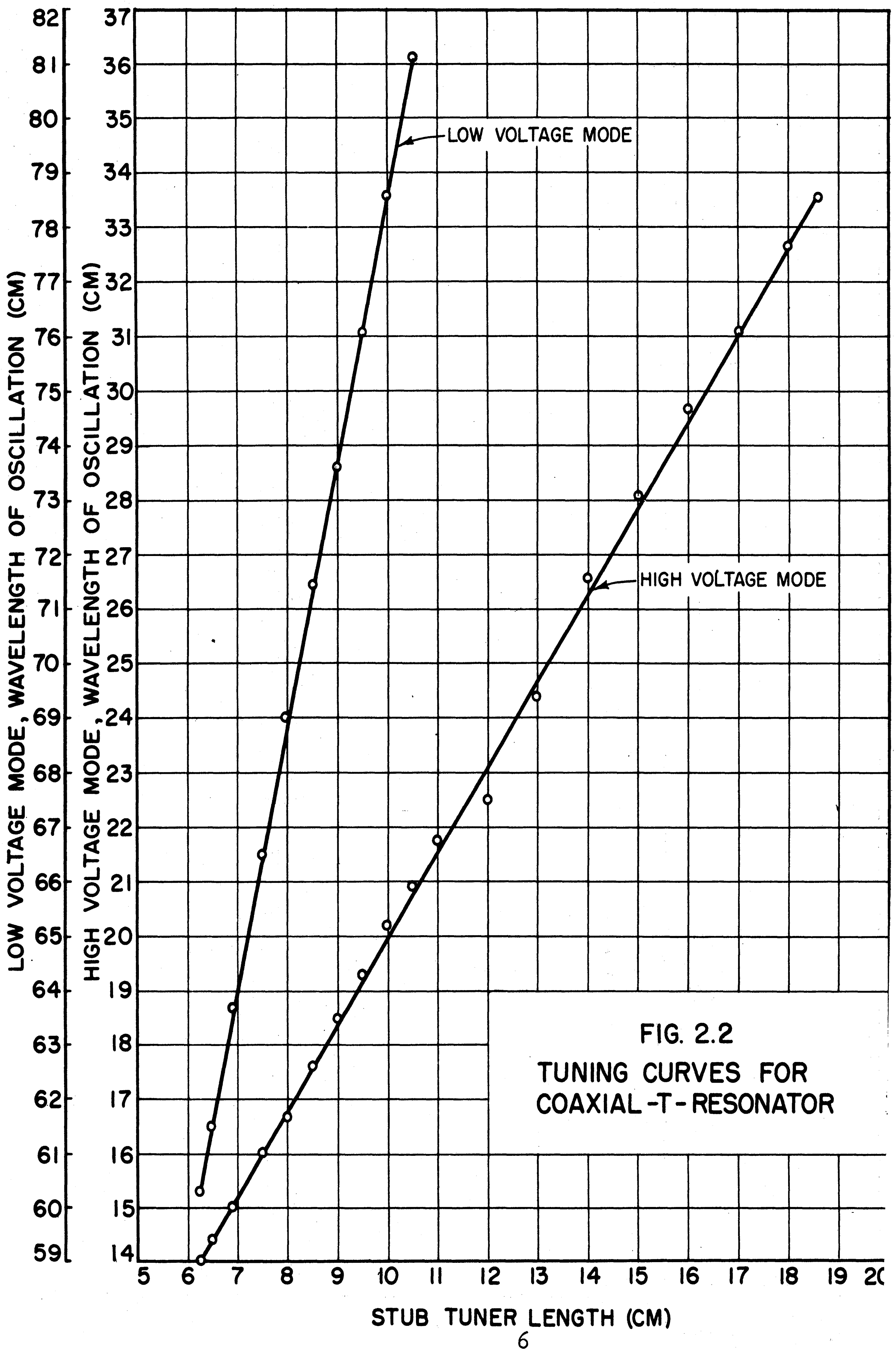

FIG. 2.2
TUNING CURVES FOR
COAXIAL-T-RESONATOR

3. COAXIAL-T CIRCUIT (LOW Q)

A second type of coaxial-T circuit shown in Fig. 3.1 was built primarily to determine the character of low Q voltage tunable operation attainable with this design. The structure differs from the coaxial-T high Q oscillator only to the extent that it is much more heavily loaded. One side of this low Q circuit feeds directly into a 50 ohm coaxial output terminal through a tapered coaxial line. This oscillator arrangement was found to be mechanically tunable from 375 to 3750 megacycles per second with a maximum output of approximately one watt CW over the tuning range. This direct dependence of frequency on tuner length indicates that the Q of the structure cannot be reduced to a low enough level for satisfactory voltage tunable operation. In addition, the magnetic circuit requirements are more difficult to satisfy than in the case of the high Q oscillator design described above. The conclusions reached with regard to this structure are that (a) it does not satisfy the low Q conditions for voltage tunable operation, and (b) it is not as good as the high Q structure if mechanical tuning is desired.

4. GROUND PLANE RESONATOR

The initial Electron Tube Laboratory investigation of the Insertion Magnetron resulted in the conclusion that, for voltage tunable operation, it would be desirable to operate the tube into as high an impedance as possible and still maintain the low Q properties of the external circuit. This conclusion was based on the concept that the electrons in the low Q magnetron oscillator are bunched, mainly because of the electric field between adjacent anodes and that the R-F amplitude is, to a great extent, a function of the impedance

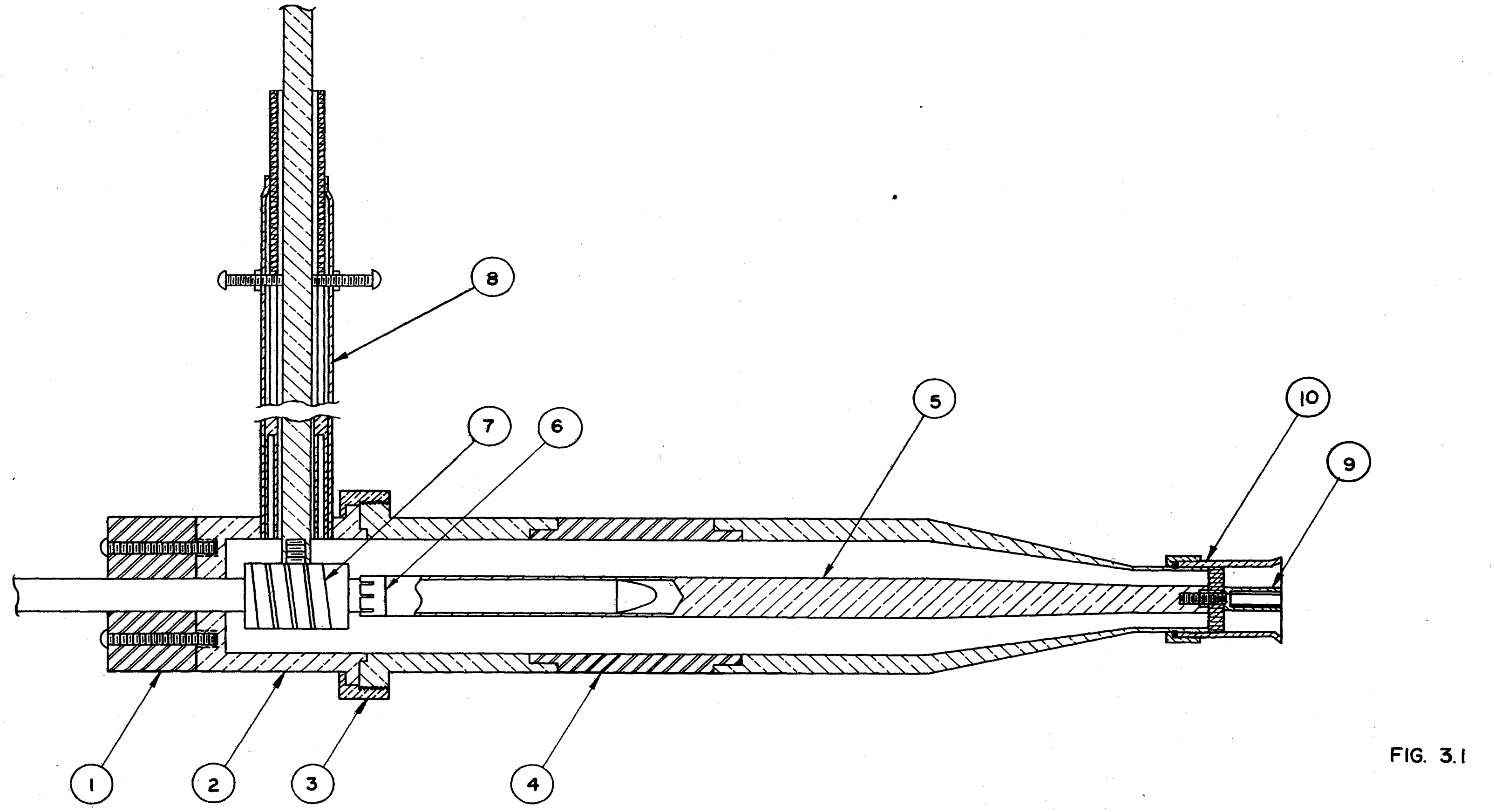

FIG. 3.I

ALL DIMENSIONS UNLESS OTHERWISE SPECIFIED MUST BE HELD TO A TOLERANCE - FRACTIONAL ± 1/64," DECIMAL ± .005," ANGULAR ± 1/2°

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Figure 3.1

between the magnetron anodes.* The circuits described below were designed with this concept in mind and represent a departure from the "usual" coaxial transmission line, whose practical upper limit of characteristic impedance is of the order of 75 ohms.

One of the structures investigated as an external cavity for the Insertion Magnetron was a "slab line" or "ground plane resonator". (The development of this resonator was based on an article appearing in the March, 1950, Proceedings of the IRE entitled "A New Type of Slotted Line Section," by W. Bruce Wholey and W. Noel Eldred, p. 244. See also "Etched Sheets Serve as Microwave Components," by R. M. Barrett, June, 1952, Electronics, pp. 114-118.) The problem was one of obtaining a resonator system with a given characteristic impedance whose physical configuration would be compatible with the tube and would also be capable of being easily swept. A transmission line consisting of parallel planes seemed to have certain advantages and a conformal transformation was available for this development. The transformation used for mapping the coaxial line into the parallel plane line was $w = \tan Z$.

If we consider a cross section of a cylindrical coaxial line to be in the "w" plane and the transformed section to be in the "Z" plane, then the application of the transformation can be considered as a systematic warping of the conductors of the coaxial line. Cutting the outer conductor of the coaxial line at two diametrically opposite points and then pulling the points upward and outward causes the outer conductor to degenerate into two semi-infinite planes. As a result of the warping of the outer conductor the inner conductor

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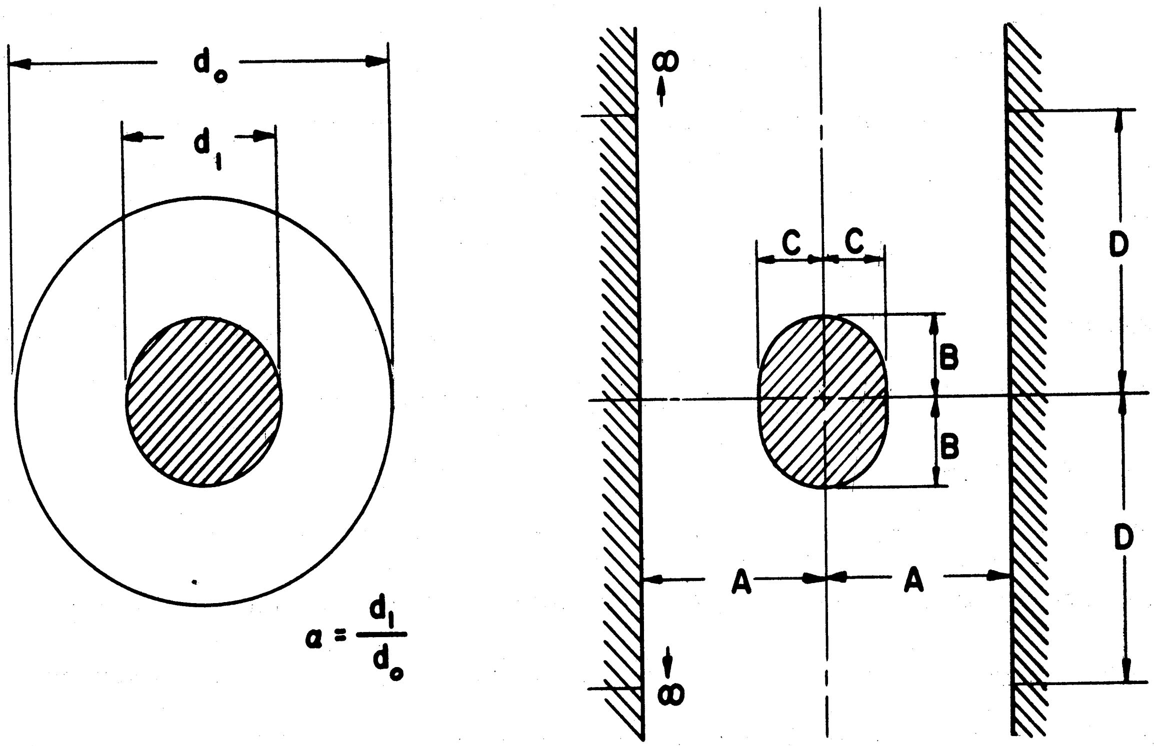
* Welch, H. W., Jr., "Dynamic Frequency Characteristics of the Magnetron Space Charge; Frequency Pushing and Voltage Tuning", Technical Report No. 12, Electron Tube Laboratory, University of Michigan, November, 1951.

is also warped, and the inner conductor has a slightly elliptically-shaped cross section located symmetrically between these planes. The resultant transformed line is shown below.



The dimensions A, B, and C are related to the coaxial section as follows:

$$\frac{A}{B} = \frac{\pi}{4 \text{ arc tanh } \alpha}$$

$$\frac{A}{C} = \frac{\pi}{4 \arctan \alpha}$$

$$\alpha = \frac{\text{outer diameter of inner conductor of coaxial line}}{\text{inner diameter of outer conductor of coaxial line}}$$

Fig. 4.1
Transformation of Coaxial Line to Parallel Plane Geometry

Because of the need for semi-infinite planes and a slightly elliptically shaped center conductor it would appear that this line would be difficult to construct. However, it is possible to modify this configuration so as to permit practical construction without appreciably changing the electrical characteristics.

First the semi-infinite planes are modified into planes of finite extent. This modification is possible because the fields are rapidly attenuated with vertical distance from the center conductor. The second modification is applied to the center conductor to provide a convenient fabricated shape. The basic requirement in making this modification is to keep the characteristic impedance of the modified conductor the same as the elliptical conductor. The center conductor may be of any shape, but a circular one was chosen for its ease of fabrication. The method which was used to make this modification was to consider that, for small changes in the center conductor, one can write $Z_o = k/C$ where Z_o = char. impedance; k = a constant; C = capacitance per unit length of line. Hence in changing the shape of the center conductor, if the capacitance C remains constant, the Z_o will remain approximately the same. In this approach the field associated with the circular center conductor was matched to that of the original center conductor at 4 points. This gave a match which was adequate.

Using this transformation, and applying the resulting equations, one structure was made and tested. This structure is shown in Fig. 4.2. In this figure it is apparent that the model 9B tube is centered in the parallel plane structure by means of parts (20) and (21). The kovar anode support ring is located in the cylindrical hole of the brass center spacer (9). The two shorting slugs (7) and (8) are free to move and are used to tune the cavity. Power is coupled out through the loop (26).

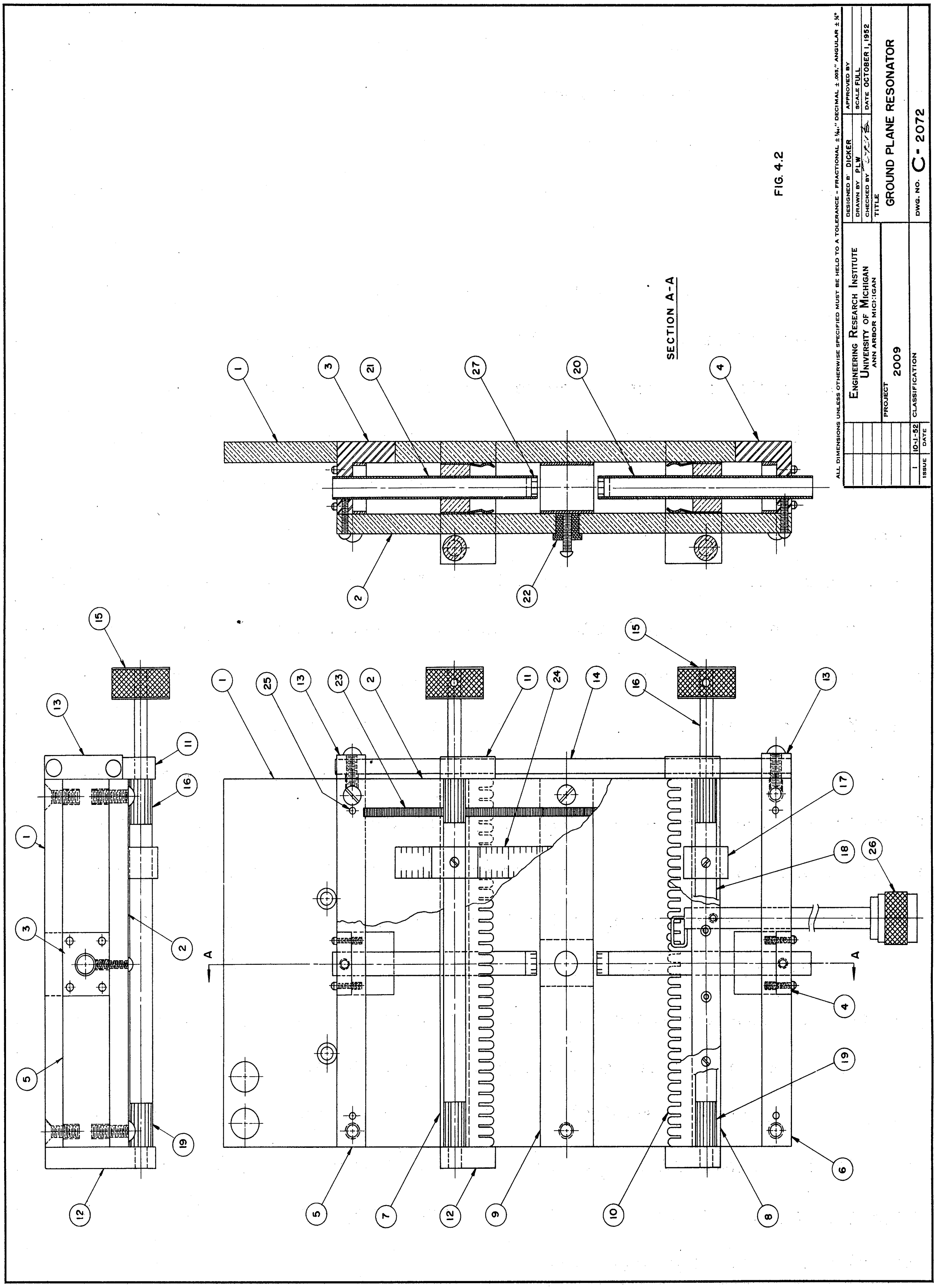


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Figure 4.2

Tests on the "Ground-Plane Resonator" indicated that both mechanical and voltage tuning were feasible. The tube-and-cavity was operated both CW and pulsed. The pulse was one of 15 microseconds duration and a repetition rate of 60 pulses per second. The observed wave lengths of oscillation were at low voltages (order of 190-300 volts), and the wave lengths themselves were in the 60-80 cm range. This cavity may be swept over a narrow range by the insertion of a rotating member between the parallel plane side-walls in close proximity to the center conductor. The length of the transmission line between the insertion tube and the rotating disk "short" would then be a function of time.

This structure is bulky and heavy in its present form. It can be reduced in weight and somewhat in size. The magnetic field path can be shortened, thereby affording a reduction in the size and weight of the magnet used. However the limitations are believed to outweigh the advantages for any application other than laboratory use.

5. WAVEGUIDE CIRCUITS

It was felt desirable to attempt to operate the Insertion Magnetron into a waveguide transmission system. One of the waveguide circuits employed in this connection is shown in Fig. 5.1. The magnetron is used to excite the TE_{01} mode in a section of S-band waveguide. Here the axis of the tube is in the same direction as the TE_{01} electric field in the guide. An L-shaped loop which is joined to the vane anode ring of the magnetron at one end and to the larger guide wall at its other end is oriented so as to excite the TE_{01} mode in the waveguide. Operation as a mechanically tunable oscillator was obtained by terminating one end of the waveguide in a matched load and tuning the opposite end with a not-contacting shorting plunger. It was possible in this way to

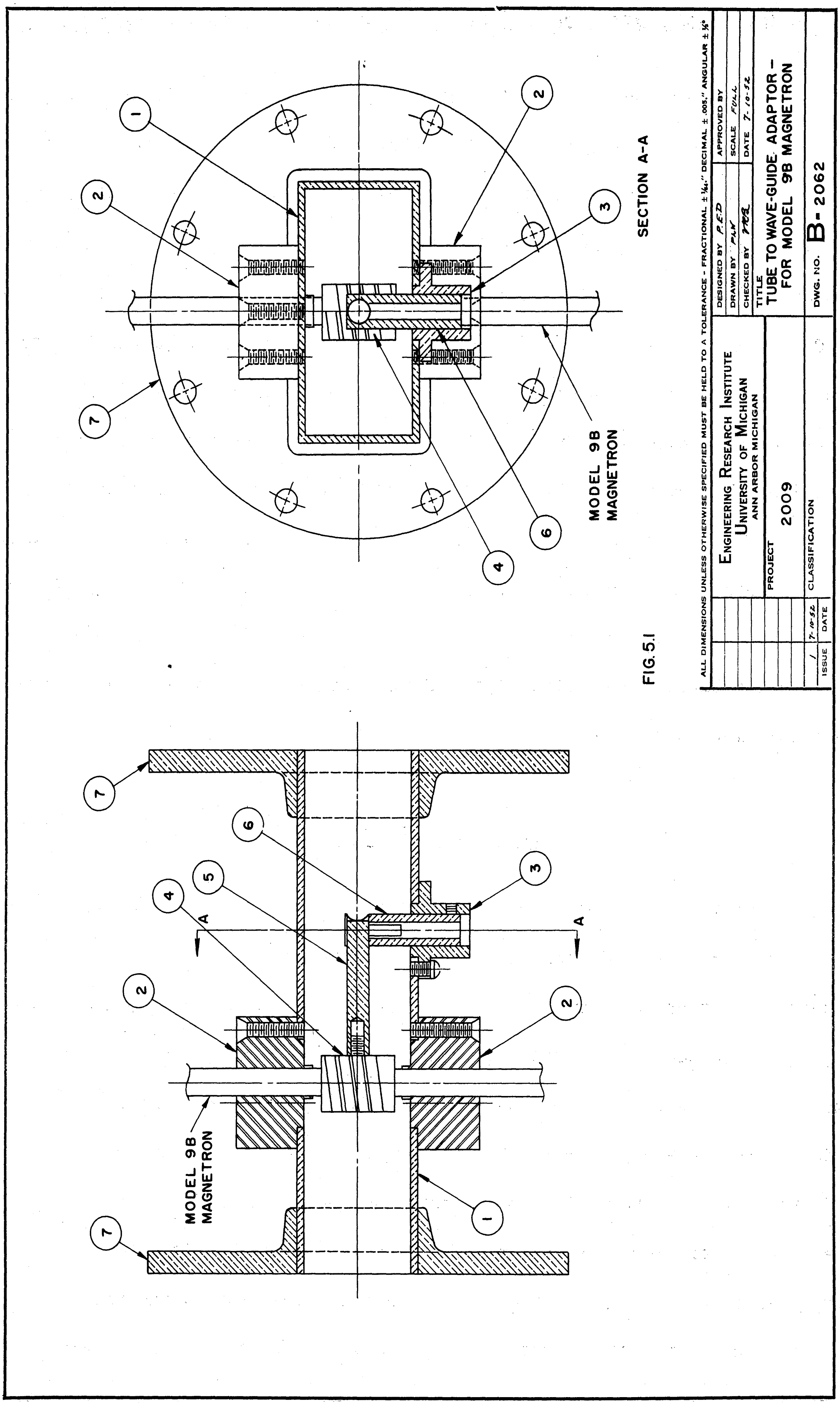
SECTION A-A
MODEL 9B MAGNETRON
FIG. 5.1
1
2
3
4
5
6
7
A
A
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Figure 5.1

tune the structure mechanically over a frequency range from 3000 to 4800 megacycles per second. The size of the L-shaped loop to a great extent determines both the coupling into the waveguide and the upper frequency limit of operation. This type of transmission system is definitely better than any mechanically tuned coaxial system, especially at high frequencies. It can be packaged easily and has possibilities insofar as both low Q and rapid mechanical scanning are concerned.

Another waveguide circuit structure for operation with the Model 9 Insertion Magnetron is shown in Fig. 5.2. This circuit consists of a section of S-band waveguide and a cylindrical rod which is located on the longitudinal axis of the waveguide. It should be apparent from this figure that the magnetron will be coupled to a load through this modified ground-plane coaxial transmission line. The center conductor of the transmission line is attached to the vane anodes of magnetron and the bar anodes are connected to the waveguide. The characteristic impedance of this ground-plane type of coaxial transmission line can conveniently be made as high as 150 ohms. In addition to providing a higher characteristic impedance than is practical with a concentric cylinder line, higher magnetic fields are more easily obtainable with this circuit arrangement.

A limited amount of testing was carried out with this circuit and tube arrangement. The results of these limited tests indicate that higher power output can be attained with this structure than with a coaxial system of practical dimensions; however, the band width of this structure is smaller than the low Q coaxial circuits used to date.

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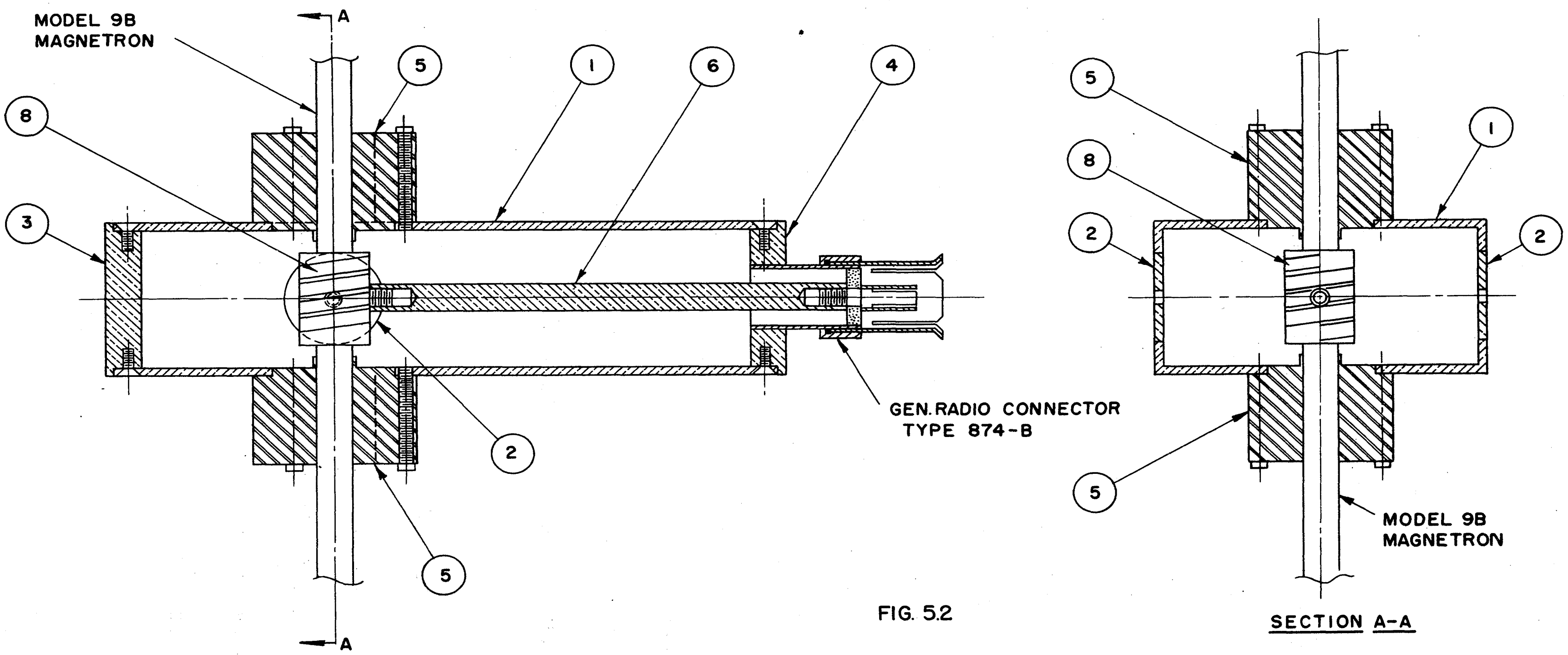

FIG. 5.2

SECTION A-A

NOTE -
PARTS -6 AND -7 ARE USED ALTERNATELY
-3 AND-4 ARE THEN REVERSED

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Figure 5.2

6. CONCLUSIONS

It has been shown that the Insertion Magnetron can be operated in conjunction with a number of different external circuits. Furthermore, in high Q mechanically tunable operation power output of the order of one watt can be attained over a wide frequency range in the 10 cm region.

The limitations in low Q voltage tunable operation are attributed to the Insertion Magnetron itself. The limitations in the Insertion Magnetron result from the interference of the "vane mode" and the restriction to low magnetic fields. This conclusion has been confirmed by more recent tube studies at the Electron Tube Laboratory of the University of Michigan. An extension of circuit studies should, in our opinion, be carried on on the basis of the more recent tube developments.

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