RESEARCH AND DEVELOPMENT PROGRAM FOR X-BAND CROSSED-FIELD AMPLIFIER

QUARTERLY ENGINEERING REPORT
28 JUNE 1964 TO 12 SEPTEMBER 1964

Contract Number NObsr 89504
Project Serial Number SF 0100201, Task 9294

Bureau of Ships
Department of the Navy
Washington 25, D. C.

(Prepared by Warnecke Electron Tubes, Inc., Des Plaines, Illinois)

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PREPARED BY

WARNECKE ELECTRON TUBES, INC.
175 West Oakton Street
Des Plaines, Illinois

FOR

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ABSTRACT

At the end of the first year's work it was demonstrated that an X-band line can be made by photo-forming on the surface of an insulator. The fenced line (a dissymmetric multiple meander with edges closed) was found to have many advantages, but (1) the r-f fields were concentrated at the center, (2) dispersion was excessive for the broad band required here, and (3) transmission losses were too high. A multiple meander open at the edges is therefore to be used in further studies. A saphire support was chosen for the line; the principal disadvantage of ceramics was surface roughness. Work with beryllia ceramics is continuing because the thermal conductivity is important. Studies on other parts of the tube design have been undertaken: (1) support of the delay line in a niobium frame; (2) a stepped ridge to couple the delay line to the waveguide and avoidance of coupling to possible fast wave in the interaction space; (3) a high current density gun with a grid and other design features to reduce excess noise, and with a shield to keep r-f energy out of the cathode region.

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SECTION I

INTRODUCTION

The purpose of the program is the development of a crossed-field amplifier in the 7 to 11 gc range capable of 2 kilowatts c-w output. It was the purpose of the first year's work to investigate the electrical design and the technology of fabricating delay line circuits suitable for use in such an amplifier. The second year's work is to design, construct and evaluate amplifier tubes based on the results of the first year's work.

SECTION II

GENERAL FACTUAL DATA

2.1 IDENTIFICATION OF TECHNICAL PERSONNEL

The technical personnel who have been directly connected with the project and the time worked on the project between June 30 and August 30, 1964 are listed below. Accounting periods correspond to calendar months, so that hours cannot be made to coincide exactly with the period of the report. The rate of expenditure on the program was reduced in August by vacation shut-downs.

Warnecke Electron Tubes, Inc.

Name	Man Hours
B. Giltner	35.0
R. R. Moats	109.0

CSF

Name	Man Hours
J. Arnaud	40.0
M. Daspet	89.7
O. Doehler	40.0
M. Grauleau	55.6
C. Lyon	108.1

2.2 REFERENCES

No general references are cited in this report. Specific references have been included as footnotes in the text where pertinent to this report.

2.3 MATHEMATICAL DERIVATIONS AND FORMULAS

The mathematical derivations made during the period of this report represent an essential part of the research and development work in this program. Consequently they are included in the text of Section III, DETAILED FACTUAL DATA.

SECTION III

DETAILED FACTUAL DATA

3.1 FENCED LINE ON SAPPHIRE SUPPORT

During the course of the preceding year, a technology for making delay lines by photo-engraving has been established. It consists of making a layer of copper adherent upon a carefully polished piece of sapphire with an intermediate layer of titanium, the thickness of which does not exceed 0.1 microns. This layer of copper with titanium is engraved by a photo-chemical procedure and thickened electrolytically.

The "fenced line" has been studied, principally in the S-band, that is, with a scale factor of 2.67. This structure is composed of six meander lines in parallel short-circuited at the sides. The six lines are not all identical, so that the frequency of degeneracy of the second order transverse mode is raised, (the first order transverse mode is the one desired), and to eliminate waves with reverse dispersion.

On a dissymmetric multiple meander line deposited on sapphire at full scale (X-band), cold measurements of attenuation and transmission have been made (figure 1) and measurements of delay ratio have also been made (figure 2). For that the line is interposed in the cold measurement assembly described in the Final Engineering Report

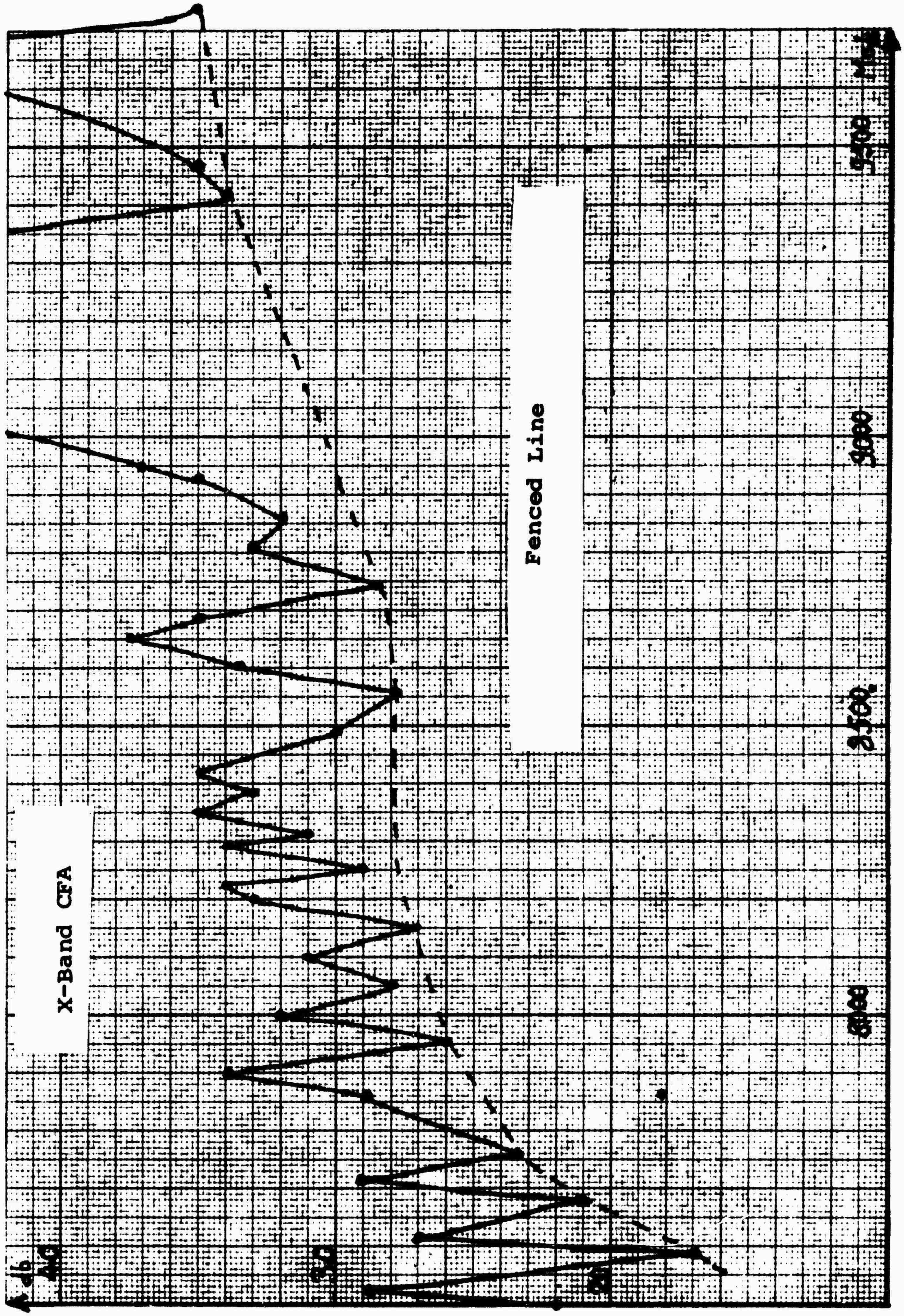


FIGURE 1. INSERTION LOSS OF DISSYMMETRIC MULTIPLE MEANDER OR "FENCED" LINE

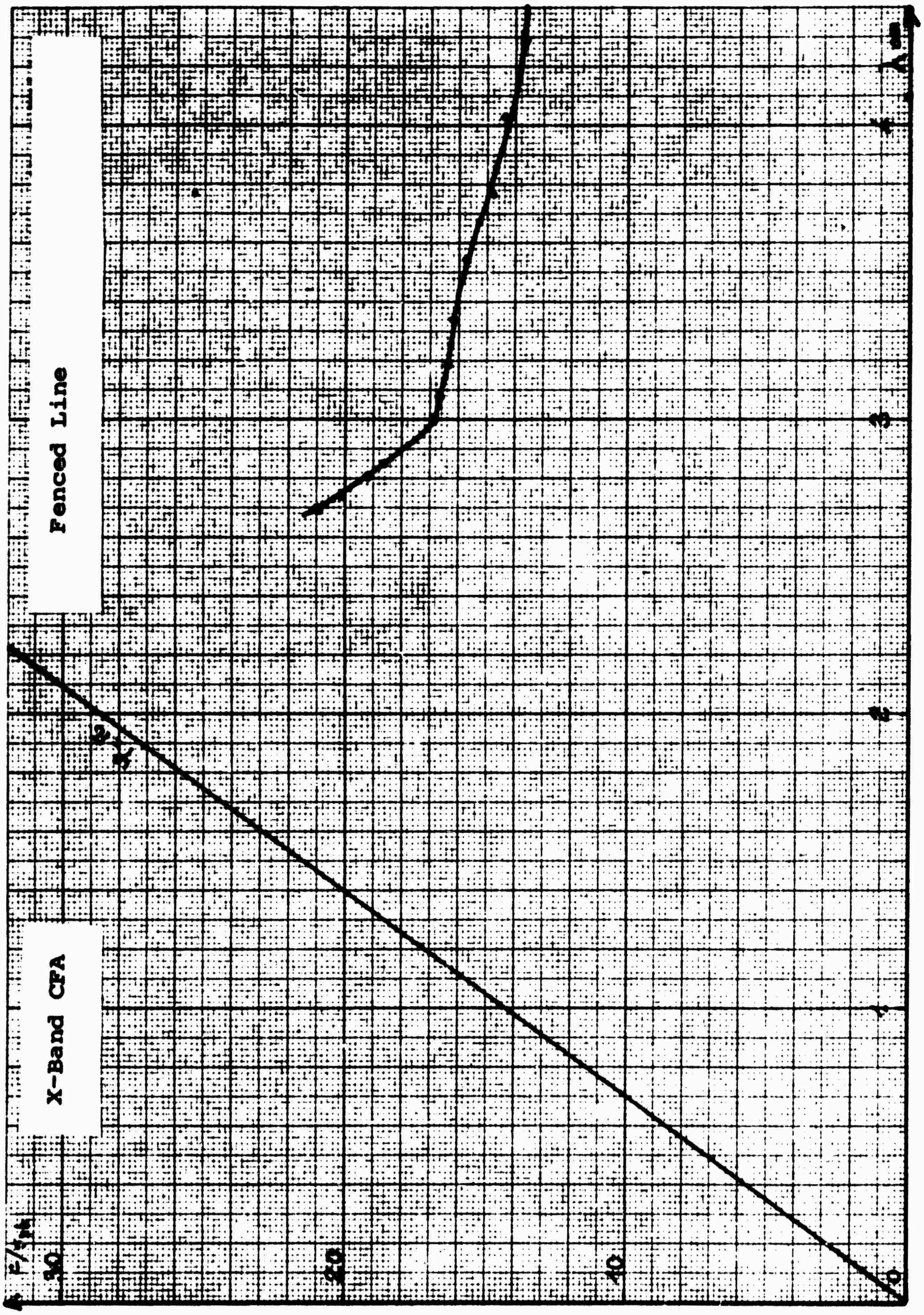


FIGURE 2. DELAY RATIO OF "FENCED" LINE AS A FUNCTION OF WAVELENGTH

of the first year's work in figure 2.10. No special precaution has been taken in the matching of the guide to the line. It undertakes merely to examine the propagation of this line at a scale of unity. The assembly is shown in figure 3.

The experimental work has essentially been completed. Satisfactory values of coupling impedance were measured. However, this structure is not entirely satisfactory for the following reasons:

1. The field varies laterally and the useful region of interaction is limited to 7 millimeters.

2. The dispersion is also too high to cover the band because v_ϕ/v_g = 1.8 to 3.5 instead of the desired value of 1.4.

3. The insertion losses are excessive: 1.2 db per delayed wavelength.

For these reasons a different multiple meander line has been considered, a double meander with the circuit open on the edges to give a field more nearly uniform. By operating between $\phi = \pi$ and $\phi = 2\pi$ this solution leads to a smaller value of dispersion and to smaller insertion loss. The problem of higher order modes, which initially was put aside, will be able to be resolved.

During this year the problem of losses of structures deposited on the surface of ceramics has been studied by an analog method of field analysis.

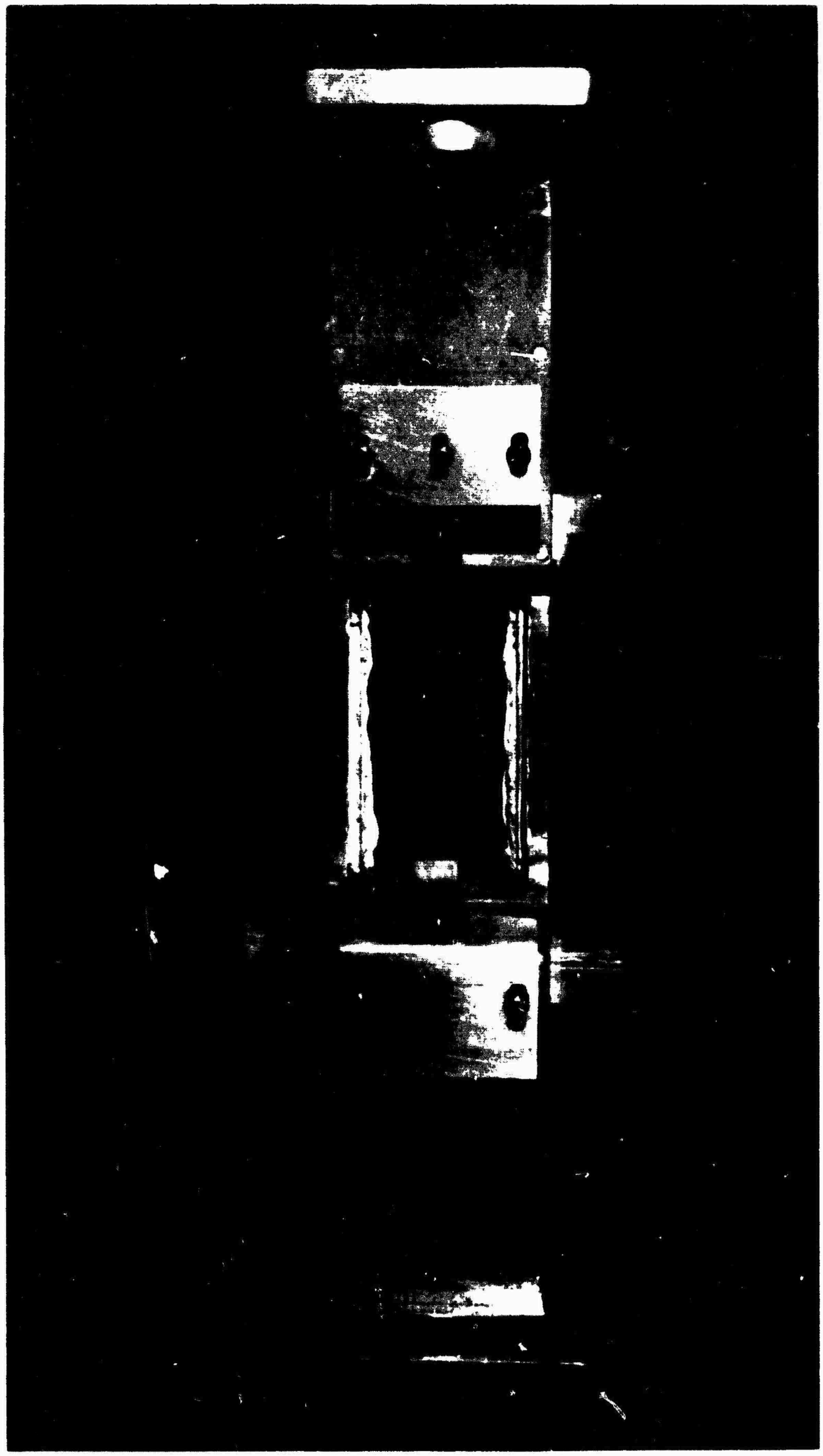


FIGURE 3. COLD-TEST ASSEMBLY FOR MEASUREMENT OF THE DISSYMMETRICAL MEANDER LINE

The problem of support of the sapphire has been made the object of numerous tests. One positive result is that a tight braze between a piece of sapphire of 0.3 mm thickness to a frame of niobium is possible. Under the force of vacuum on one side a deformation of 0.1 mm is produced. It remains then to improve the mechanical strength.

It was shown that a power of 1.6 kilowatts could be dissipated through the sapphire.

The problem of sputtering from the sole has been studied. This effect can be significantly reduced by coating the sole.

3.2 DESIGN OF THE TUBE

A preliminary design of the tube has been presented in the Final Engineering Report of the first year's work (figure 7.2). This design would be fully acceptable in its principle and in its technology. At the same time we have studied in more detail during the course of this quarter different parts of the tube which would be the object of separate tests (figure 4):

(1) Design of double meander line.

(2) Coupling to the guide by a ridge transition and windows.

(3) Design of the sapphire support with improvement of its mechanical rigidity.

(4) Study of gridded gun and shielding.

(5) Study of collector designed to dissipate 4 kw.

3.2.1 Design of Double Meander Line - Theoretical Calculations

All of the calculations have been carried out for one of the two meanders of the proposed double meander lire. It is known that when one does not take account of a backplate with respect to this line (that is to say, with an infinite thickness of dielectric) the dispersion of line is given by the relation:

$$\tan^2 \frac{kL}{2} \sqrt{\frac{1+\epsilon}{2}} = \left| \tan \frac{\phi}{4} \right|$$

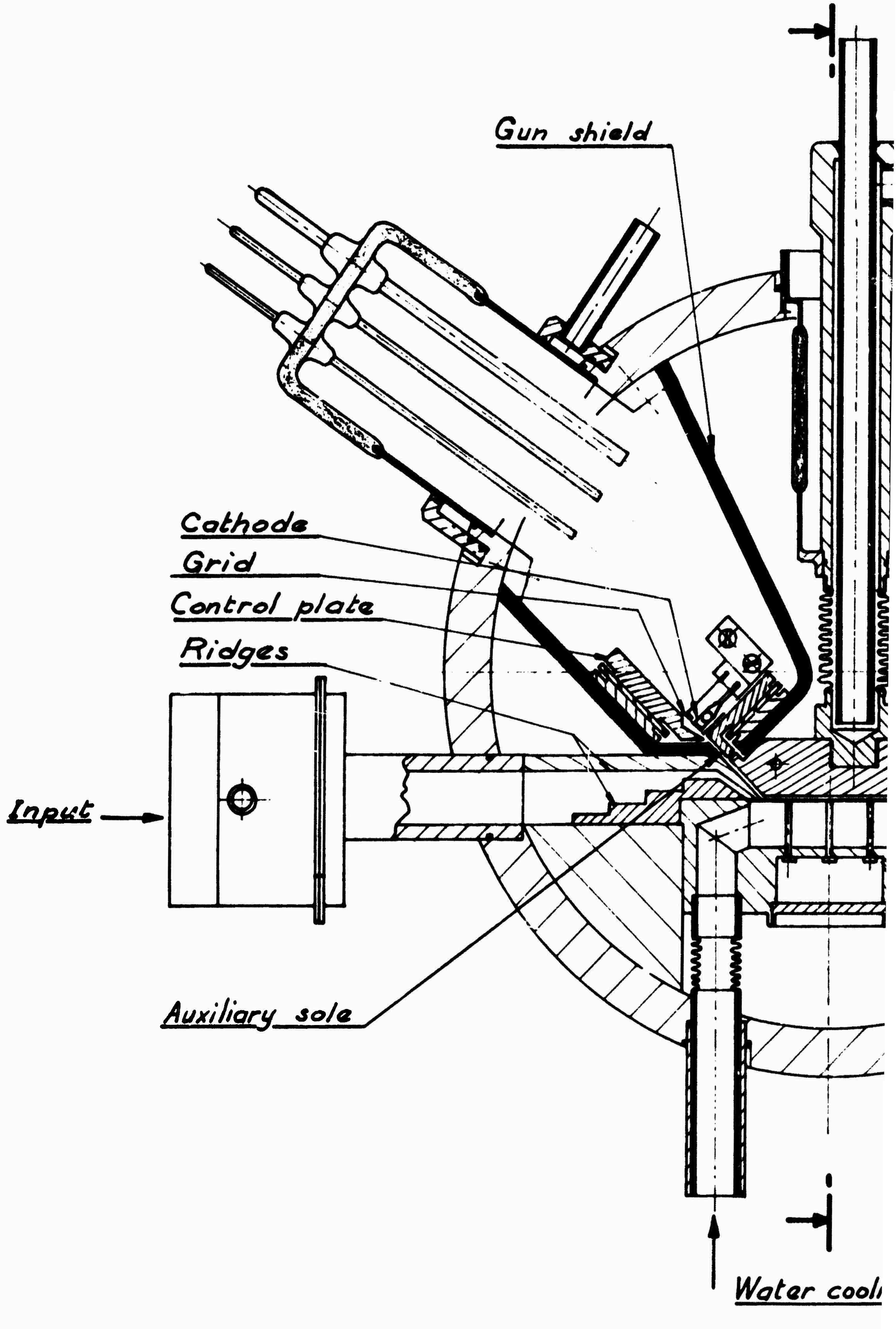
where k is the constant of propagation in vacuum, L is the length of a finger (where the length of the alternate connections between fingers of the lines are negligible in length as compared with the width of the line) and ϕ is the phase difference between one cell to the next over a complete pitch p.

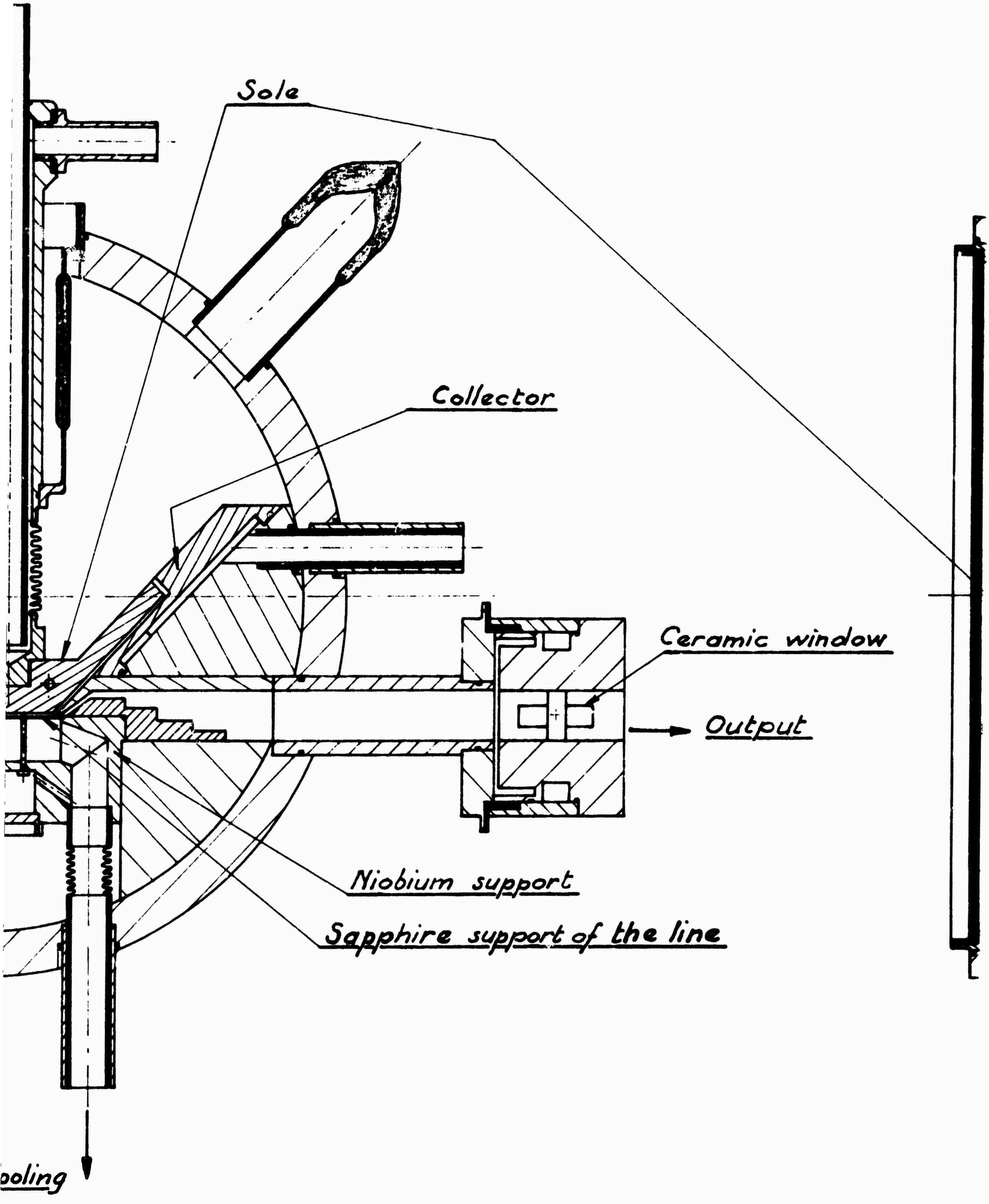
The expression $\sqrt{(1+\epsilon)/2}$ is a factor taking into account the dielectric material of the support. Knowing furthermore that $\tau = \lambda\phi/2\pi p$, one can trace a theoretical curve as a function of wavelength .

Leblond and Mourier(1) have demonstrated a method of calculation for the meander line in which a base plate is introduced

---

(1) A. Leblond, G. Mourier, Annales de Radioelectricitie, v. 9, pp. 311-328, 1954. Also see J. Arnaud, "Circuits for Crossed-Field Tubes," Crossed-Field Microwave Devices (E. Okress, ed.) Vol. 1, Sec. 2.3, Academic Press, 1961.


Gun shield
Cathode
Grid
Control plate
Ridges
Input
Auxiliary sole
Water cool


Sole
Collector
Ceramic window
Output
Niobium support
Sapphire support of the line
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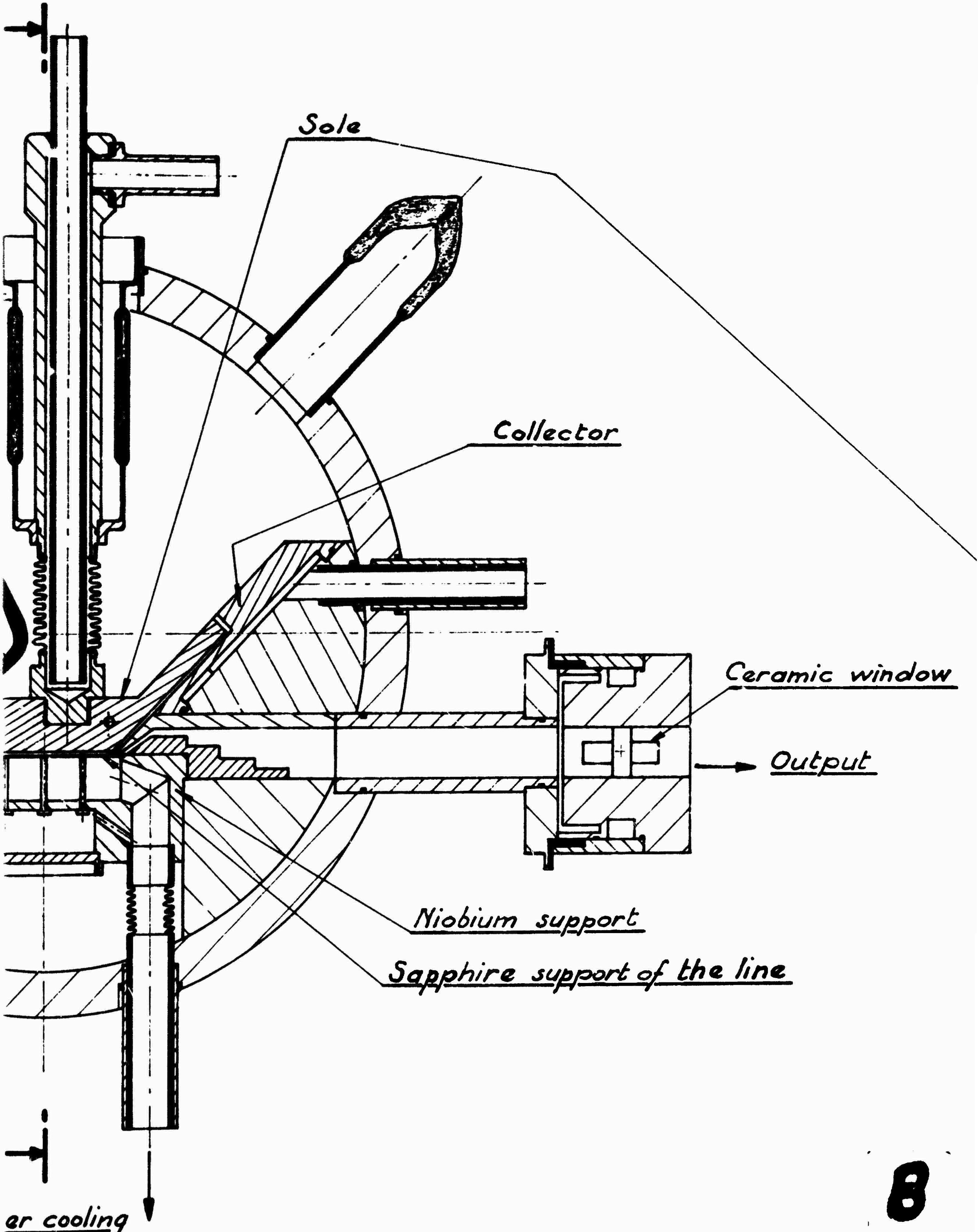
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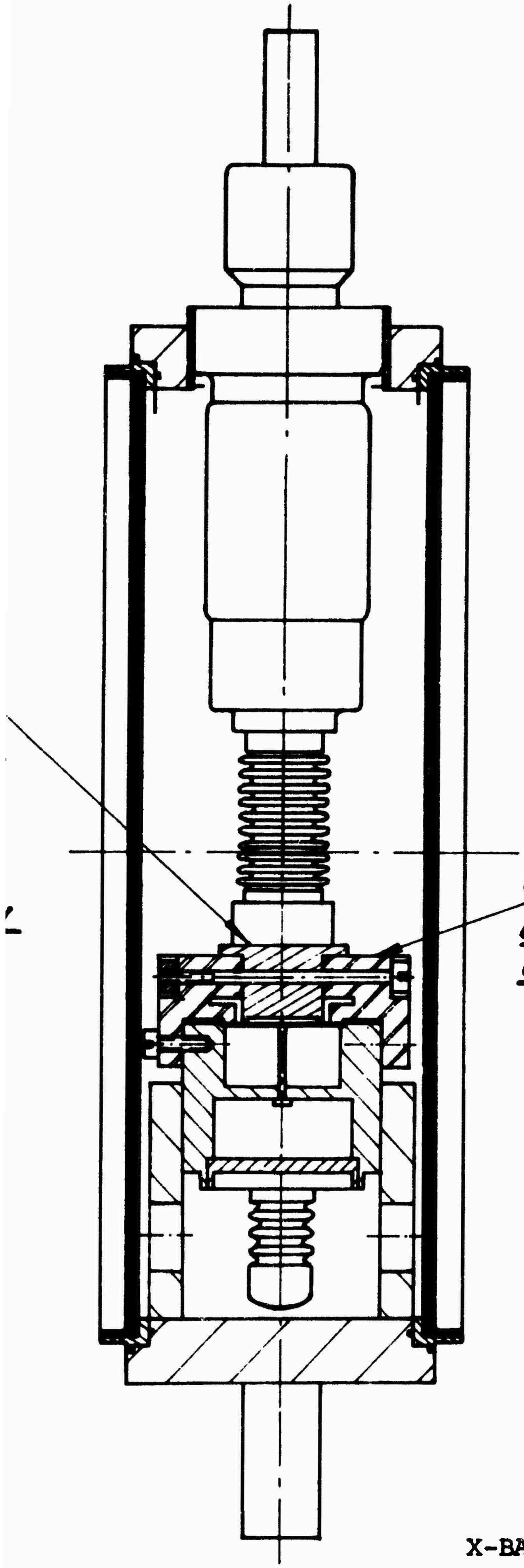

Ceramic positionning the sole with respect to the line

X-BAND CROSSED-FIELD AMPLIFIER (Scale:1)

FIG. 4

to reduce the dispersion; but it only has taken into account the two following capacities:

γ_o: capacity between finger and base plate.

γ_1: capacity between two adjacent fingers.

All the other capacities are neglected. The dispersion of the line is then given by the formula:

$$\tan^2\left(\frac{kL}{2}\sqrt{\frac{1+\epsilon}{2}}\right) = \tan^2\left(\frac{\phi}{4}\;\frac{1+4\,\frac{\gamma_1}{\gamma_o}\cos^2\frac{\phi}{4}}{1+4\,\frac{\gamma_1}{\gamma_o}\sin^2\frac{\phi}{4}}\right)$$

The capacities are calculated from the dimensions of the line: L = 5.33 mm, h = 0.3 mm, e = 0.05 mm, p = 1.2 mm (see figure 5). This gives theoretically:

$$\gamma_1 = \varepsilon_o\left(\frac{4e}{p} + 2\,F_e\right)$$

where F_e is a correction factor taking into account the fringing field; here $F_e = 0.5$ for the width of the finger with respect to the interval between fingers.(2) Actually F_e is evaluated only in air. The lines of electric flux are deformed by the presence of the sapphire support, and the capacity evaluated as F_e is only approached. The other capacities γ_2, γ_3, etc. have been neglected.

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(2) R. R. Moats, Sect. 2.4, Vol. 1, Crossed Field Microwave Devices (E. Okress, ed.) Academic Press, 1961.

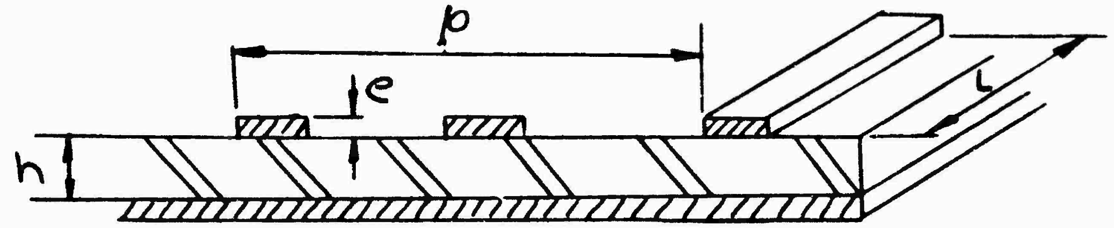

FIGURE 5. DELAY LINE DIMENSIONS

At the same time:

$$\gamma_o = \epsilon_o \epsilon_r \frac{p}{2h}$$

where p/2 has been substituted for p/4 to take into account the fringing field. A comparison has been made between the two theoretical formulas. The curves of delay ratio are plotted as functions of wavelength in figure 6. But there are actually two meanders of the preceding type in parallel. They are coupled and for the first symmetrical mode the transverse electric field will be symmetrical and approximately constant. However, an antisymmetrical mode is introduced by the assembly of meanders. For this mode the r-f voltage is zero at the center and maximum at the outside extremeties (figure 7a).

In this case the plane of symmetry can become a ground plane so that we consider only one meander, according to the configuration of figure 7b. In writing the conditions of propagation of such a structure, without taking account of the capacities of the ends of the meander, it is shown that:

$$\tan^2\left(kL\sqrt{\frac{1+\epsilon}{2}}\right) \sim \infty$$

leading to:

$$\lambda = 4L\sqrt{\frac{1+\epsilon}{2}}$$

Therefore there is a vertical line in the plot of τ versus λ. By introducing the capacities of the ends of the meander,

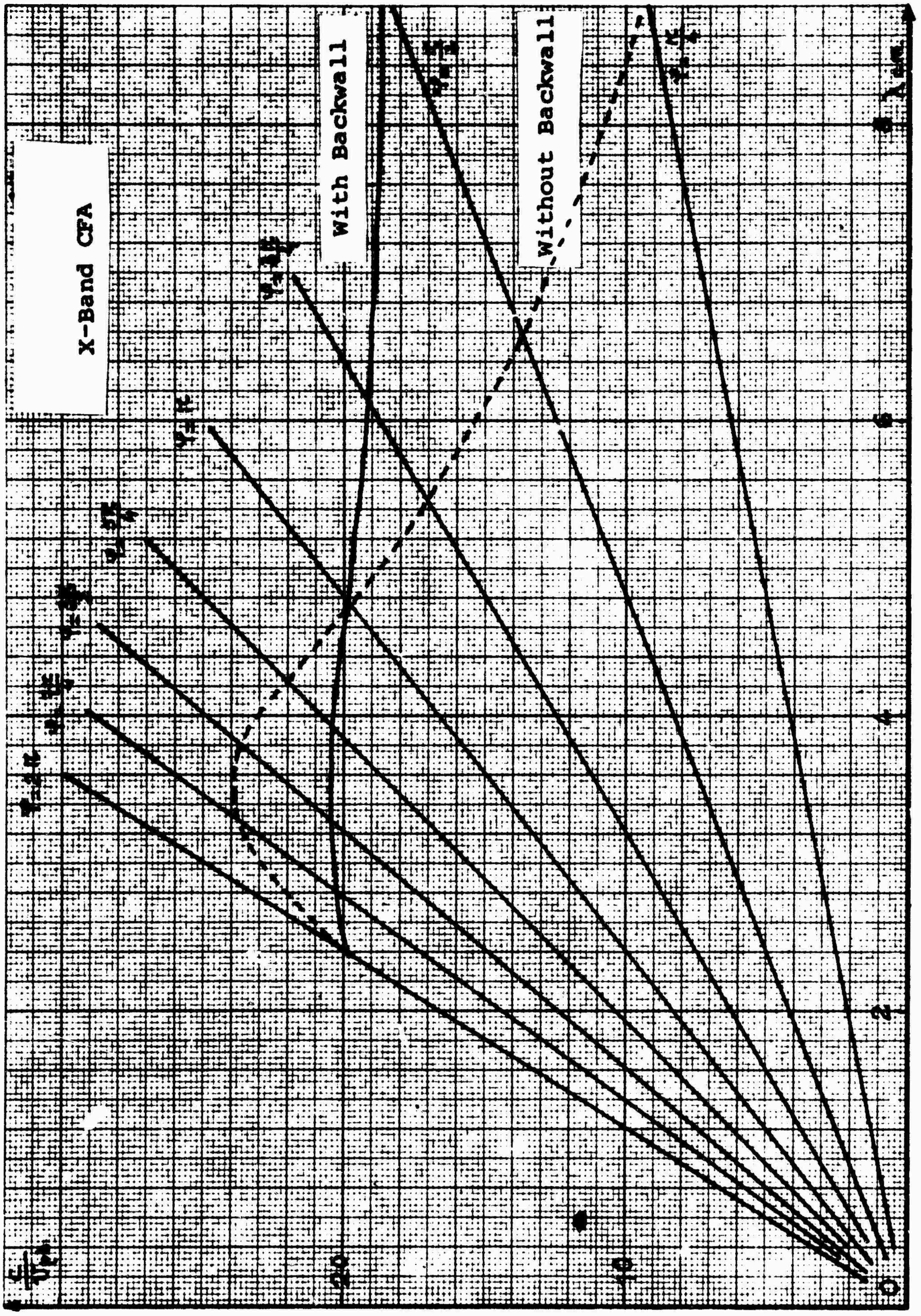

FIGURE 6. THEORETICAL DISPERSION CURVES FOR MEANDER LINES WITH AND WITHOUT BACKWALL

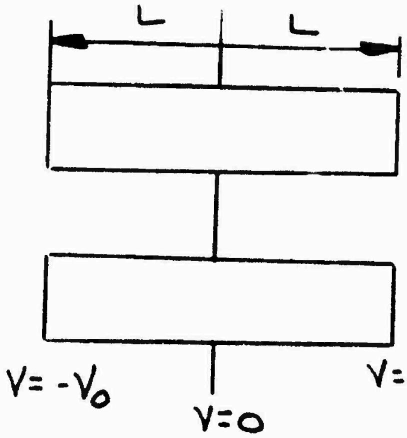

Figure 7a. Double meander line. Voltages are for the first antisymmetric mode.

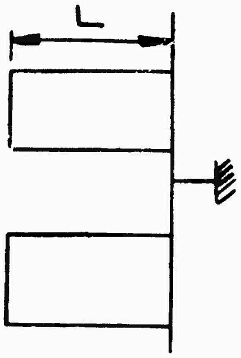

Figure 7b. Conducting plane and one meander shown as electrical equivalent of figure 7a.

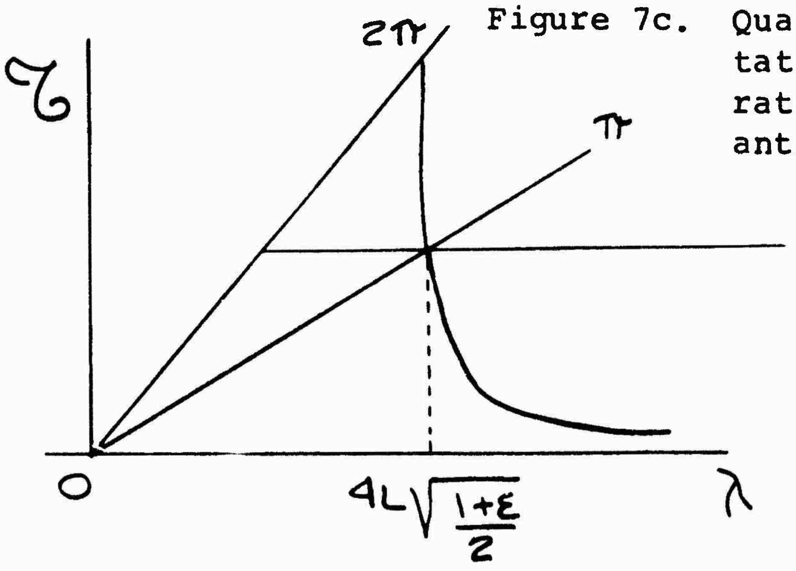

Figure 7c. Qualitative representation of delay ratio of first order antisymmetric mode.

FIGURE 7. DESIGN CONSIDERATIONS IN A DOUBLE MEANDER LINE

this line curves inward asymptotically with respect to the low frequencies. The resulting dispersion is shown qualitatively in figure 7c.

3.3 DESIGN OF LINES AND OF MEASUREMENT

The X-band line at unity scale with two meanders in parallel has been designed. The mock-up at large scale is going to be made with the view of making the negative for the engraving of the line. It will be deposited on the same supports of sapphire as the line with six meanders.

3.4 COUPLING BETWEEN LINE AND GUIDE

Several problems present themselves relative to the attachment and to the output of the line for an X-band guide (7 to 11 gcs).

3.4.1 Matching from Guide to Line with the Help of a Stepped Ridge

The guide presents an effective impedance in the vicinity of 500 ohms, and the input to the line several tens of ohms. With that low impedance the r-f power coupled into the line would be very small. Because of this discontinuity of impedance it is necessary to introduce between the guide and the input of the line a stepped ridge, for which the calculation is well known. Furthermore to assure the continuity of fields on the walls of the guide, another ridge connected to the first finger of the line and having an actual length of 2 millimeters is attached to the upper wall of the input guide. The same arrangement is found at the output of the line. The optimum width of the second ridge will be determined by cold measurements.

3.4.2 R-F Coupling Between the Guide and the Upper Ridge at the Input of the Line

As has been described above the r-f power can be coupled to the input of the line; it would be lost for the interaction and could introduce parasitic phenomena by modulation of the beam before it reaches the interaction space opposite the line.

A large scale cold test mock-up is foreseen to study this phenomenon. For this, the delay line is replaced by a continuous layer of copper not capable of r-f transmission. By lengthening the sole to constitute a sort of guide, it is then possible to measure the r-f energy. The problem may possibly be resolved by connecting a ridge to the line which will be all of the width of the large side of the guide and which would be terminated by a smaller part attached to the beginning of the line.

3.4.3 R-F Coupling Between Line and Sole

R-F energy can also be transmitted in the free space between the line and the sole normally occupied by the beam. A large scale mock-up is foreseen for the study: the extremeties of the sole will be extended to constitute a sort of guide capable of collecting the stray transmitted energy. It is assumed that all the r-f matches are good.

3.4.4 Propagation of a Fast Wave in the Sapphire Support of the Line

The sapphire metallized on all its faces other than those of the input and output ends of the line constitutes a guide filled with dielectric ($\epsilon_r = 9$) capable of propagating a wave not retarded by the line. One manipulation will consist of verifying that this propagation can or cannot take place depending on different types of metallization.

3.4.5 Output and Input Windows

The support for the line and its inputs by the guides will be part of the tube and will therefore be in the vacuum. It is necessary to foresee a ceramic window well matched to the guide and able to transmit the specified power without excess heating (dielectric losses and conduction losses in the braze) and capable of adequate mechanical strength in the presence of vacuum on one side (approximately 1 atmosphere). Such windows have now been realized for other tubes and have been made the object of theoretical studies. They have allowed the transmission of 1,000 watts of r-f power and a wide frequency band.

Cooling of the output window is foreseen to remove the heat generated by the r-f losses in the titanium part.

3.5 TECHNOLOGY OF THE LINE

3.5.1 Support of the Line and Brazing to a Frame

The study of the support of the line has been resolved into the following problems:

a. Rigid mounting of the sapphire.

b. Easy cooling by circulation of water.

c. Stability of the shape of the sapphire under the action of vacuum, of the pressure of water, of the heating of the delay line.

d. Stability of the delay line.

e. Stability of the sole-to-line spacing.

To satisfy these conditions several studies of brazing of sapphire onto a piece of niobium have been made. This assembly would have its support brazed to posts and to a water jacket made of copper. Six tests have been made:

a. The first four have been negative: the sapphire was split, it seems, from the constraint imposed upon it by the differential expansion between the niobium and the copper (materials with different thermal expansions).

b. A fifth test, following the same technique but with posts were intentionally weakened to yield more freely with respect to the sapphire for cooling, was equally negative: the sapphire was split.

c. A sixth test has not yet given results: the number of posts has been reduced; only the two central rows have been preserved with one post out of two. The brazing of the niobium frame has not taken place everywhere.

The problem is thus back at the beginning.

The sapphire support is brazed on the niobium frame only. This mounting was verified to be good by a helium leak test. The sapphire has excellent flatness and shows no fractures. Two tests have been made in this way. One of the preceding methods of assembly is repeated in an effort to resolve the problem of the strength with respect to vacuum and the water pressure in another manner.

On the longitudinal axis of the sapphire there is brazed a U-shaped groove of niobium to increase the longitudinal rigidity. The test is negative: the sapphire was split. This test will be repeated.

In parallel with these studies, another method of mounting is foreseen (figure 8), with the water jacket of niobium and three free copper posts with convexity opposite to that of the sapphire, held transversely in holes pierced in a mesh separating the water jacket into two parts. The sapphire is brazed on the first part of

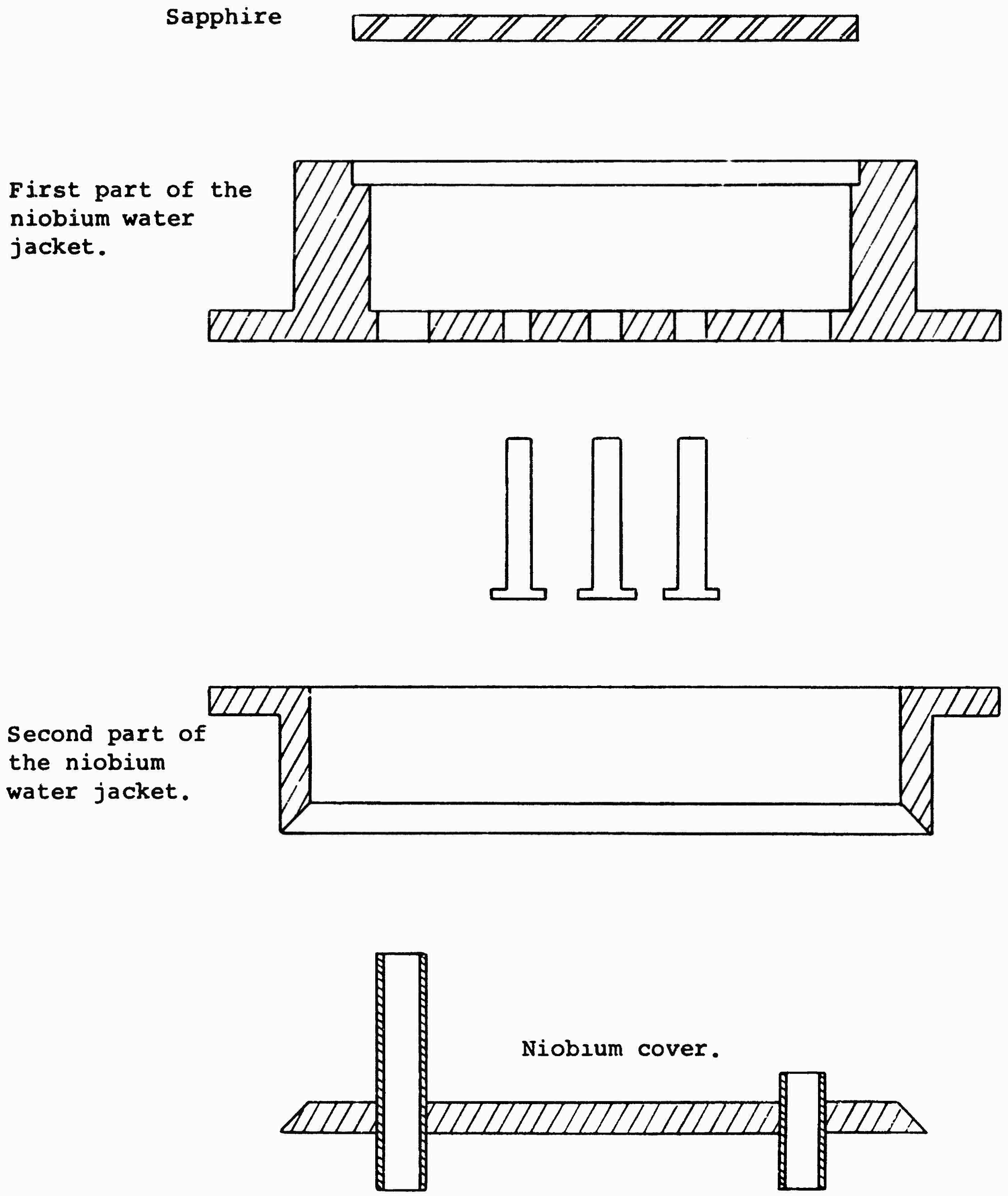

FIGURE 8. DESIGN FOR BRAZING SAPPHIRE DELAY LINE SUPPORT TO NIOBIUM ASSEMBLY

the water jacket at the same time as the three posts. The second part of the water jacket with the pipes for circulation of water is brought in by an argon-arc weld or by another procedure of localized brazing.

3.5.2 Beryllia Support of the Delay Line

The use of a beryllia support for the delay line will make possible a great improvement in power output capability. Its much greater thermal conductivity allows correspondingly greater power dissipation. Its lower dielectric constant will increase the possible width of the double meander line, reducing the beam power density needed for a given power level; the lower dielectric constant will also lead to lower conduction losses on the delay line. The physical properties of beryllia are not so different from those of alumina (or sapphire) as to cause serious obstacles. Some of the physical and electrical properties of these various materials are compared in Table I.

The availability of beryllia of 99.5% purity, with a minimum of glass phase present, makes possible a surface finish much improved over what was previously available. The disadvantages of using glazes on the surface were discussed at length in the Final Engineering Report covering the first year's work on this contract.

TABLE I

	Dielectric Constant (10 gc)	Thermal Expansion (Linear Coefficient, per °C, Average from Room Temperature to 900°C)
Sapphire[3]	11.0*	8.23×10^{-6} * 8.86×10^{-6} **
Alumina Ceramic[4] AlSiMag 748 98% Al_2O_3	9.0	8.0×10^{-6}
Beryllia Ceramic[4] AlSiMag 754 99.5% BeO	6.3	8.5×10^{-6}
Niobium[5]	-	8.37×10^{-6}

---

[3] W.H. Kohl, Materials and Techniques for Electron Tubes, Reinhold Publishing Corp., New York, 1960.

[4] American Lava Corp.

[5] Metals Handbook, 8th Edition, American Society for Metals, 1961.

* Perpendicular to c-axis.

**Parallel to c-axis.

3.6 STUDY OF THE GUN

A tube with low impedance requires a gun capable of delivering a sufficiently high current without presenting an excessive level of "abnormal" noise. Without seeking to obtain a low noise figure, it is still necessary to avoid a noise level high enough to affect the efficiency of coherent amplification. Furthermore, the contract specifies that the current should be able to be controlled by a grid presenting a coefficient of amplification, μ, as high as possible and a capacity as low as possible. This grid presents an additional advantage in the reduction of noise.

3.6.1 Calculation of Dimensions

The calculations for the tube lead to the following values: it is necessary to inject a current of 1.3 amperes in a space of 0.8 mm (distance from sole to line) by 10.66 mm (width of beam); the cathode to ground voltage is 3,095, the sole to cathode voltage is 1,000 volts. The magnetic field is 3,412 gauss.

The first element of the calculation is the density of the current to cathode. By utilizing an impregnated cathode (10 amperes per square centimeter) and by supposing uniform emission and a width of 10.66 mm (equal to that of the beam), one is led to a height h of 1.2 mm.

Choosing a distance from plate to cathode equal to the distance from sole to line, D one sees that the cathode is large:

$$h \gg D$$

The density of emission will not then be uniform if the plate is parallel to the cathode.

The use of an inclined plate allows, as numerous authors have indicated by a rigorous theory, by theories based on the limiting Brillouin current, or by experiment, the obtaining of uniform emission.

The impedance of the beam is 2,300 ohms. This impedance is low for a c-w tube but it is clearly much higher than that of crossed-field amplifiers functioning under pulsed condtions. Actually the width of the beam is 10.6 mm, which corresponds to a width for L-band of 80 mm, but a TPOM-I (pulsed crossed-field amplifier) having this width uses an impedance beam of 500 ohms (CSF tube type TPOM-I 425).

Abnormal noise would appear if the plate is parallel to the cathode, when height h has the value:

$$h > 0.6h'$$

h' being the height of a cycloid calculated in absence of space charge. It would thus be desirable to use a narrow cathode, if this were possible. The maximum current which could be supplied by an M-type gun (current limited to the Brillouin value) is given by:

$$Z = \left(\frac{B_c'}{B'}\right)^2 \left\{ 1 - \left[1 - \left(\frac{B_c'}{B'}\right)^2 \right]^{1/2} \right\}^{-2}$$

where Z is the reduced impedance of the beam, defined by:

$$Z = \frac{V' \eta B' \ell' \epsilon_o}{I}$$

with V' the voltage between cathode and plate, ℓ' the width of the cathode, and η is the ratio of charge to mass of an electron. (See figure 9 for dimensions of gun and interaction space.) B_c' is the critical field in the gun, the only component of which is parallel to the cathode, and is defined by:

$$B_c'^2 = \frac{2}{\eta} \frac{V'}{D'^2}$$

D' being the distance between the plate and cathode. When the plate is far enough away from the beam, the only quantity which determines the current is the electric field. In the absence of the beam, $E_o = V'/D'$ as one can see from the above expression when B_c'/B' approaches zero. It is shown that:

$$I_{max} = \frac{\epsilon_o \ell' E_o^2}{2B'}$$

Then the abnormal noise would appear when:

$$h > 0.6h' = 0.6 \frac{2}{\eta} \frac{E_o}{B'^2}$$

The total current emitted is a fraction of the current I_{max} indicated above; to establish an order of magnetude we set:

$$I = 0.5\ I_{max} = \frac{\epsilon_o \ell' E_o^2}{4B'}$$

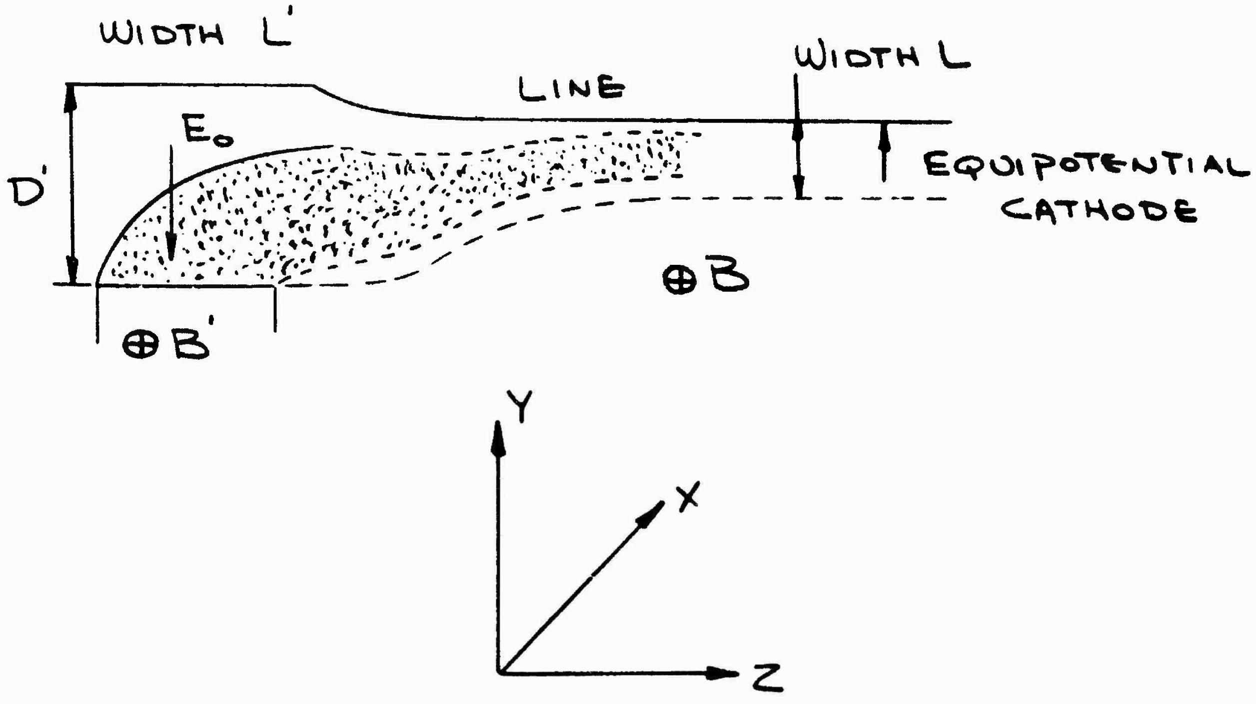

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FIGURE 9. CROSS-SECTION OF CROSSED FIELD GUN

One can then obtain a current as high as one wishes without abnormal noise by increasing the field at the cathode; the difficulty appears when it is necessary to inject this beam into the interaction space which has a fixed spacing D, and a voltage between cathode and line V fixed by the conditions of interaction with the slow wave circuit and by the input power.

Some further understanding of electron motion is gained from the fact that the electrons tend to follow approximately the equipotentials. This follows from the equations of motion when one neglects the terms of acceleration, that is to say when B is large and the radius of rotation about the average trajectory is small. The equations of motion may be written:

$$\ddot{y} + \omega_c \dot{z} = -\eta E_y$$

$$\ddot{z} - \omega_c \dot{y} = -\eta E_z$$

where a dot above a coordinate represents differentiation with respect to time, and where $\omega_c = \eta B$. Coordinates are those in figure 9. By neglecting $\ddot{y}$ and $\ddot{z}$, the velocity components $\dot{y}$ and $\dot{z}$ are perpendicular to the respective field components E_y and E_z. The beam will only be able to penetrate the interaction space if the potential of the upper part of the beam is less than the potential between cathode and line:

$$V > h' E_o = \frac{2}{\eta} \frac{E_o^2}{B'^2}$$

where:

$$\frac{I}{V} < \frac{\epsilon_0 \eta B' \ell'}{8}$$

or,

$$Z = 8$$

In the case considered this corresponds to:

$$\frac{V}{I} = 4{,}800 \text{ ohms}$$

for B' = B = 3,400 gauss (assuming the field in the gun equal to the field in the interaction space). This impedance of 4,800 ohms is greater than the desired impedance; thus there is a problem.

Another limitation can be imposed by the maximum density of emission from the cathode. The calculations based on the use of an impregnated cathode have shown that the minimum required value of h is 1.2 mm. But h' is written with the preceding relationships:

$$h'? = \frac{2V}{\eta B'^2}$$

If again B = B':

$$h < 0.6 \frac{B_c}{B} d$$

The value of B/B_c has been chosen as 1.1, and d is 0.8 mm.

Then:

$$h < 0.44 \text{ mm}$$

This value is not compatible with the value of 1.2 mm imposed by the allowable density of current.

To avoid abnormal noise there are several possible solutions:

(1) To use an inclined plate, a space charge gun, or "Kino" gun.

(2) To use a grid which F. Diamand has shown to be effective for the reduction of noise and the stability of the tube in a crossed-field amplifier (200 watts in L-band).[6]

(3) To use $\ell' \gg \ell$ in the gun to permit the reduction of h, the current being as a result concentrated close to the side of the sole. This concentration in width is evidently limited to the maximum Brillouin current. The sloping of the sides of the sole leads to a component of velocity toward the line and thus to the interception of electrons.

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(6) F. Diamand "Research on Noise in Crossed-Field Tubes," CSF-U.S. Army Contract, European Research Office Contract No. DA 91-591 EUC 312U. Also see J. Arnaud, O. Doehler, "Study of Noise in Crossed-Field Gun," J.A.P. v. 33, p. 234, January 1962.

(4) To use $B' \ll B$. The density being proportional to B^2, this results in convergence in thickness of the beam (the third and fourth can be combined to give a constant magnetic potential, $B'\ell'$).

(5) Under-heat the cathode to obtain temperature limitation.

These five solutions can moreover be used simultaneously.

In the case where ℓ', B' and V' are varied it is necessary to maintain the Brillouin current constant, that is to say:

$$\frac{E_o^2\ell'}{B'} = \text{constant}$$

For practical reasons, the magnetic potential B' ' and also V' are maintained constant, one is led to:

$$D' \sim \ell' \sim \frac{1}{B}$$

In practice, a non-convergent gun will be used to begin with for reasons of simplicity of the magnetic system, but it will incorporate a grid and inclined plate; the conditions of temperature under which the noise is minimum will be studied.

3.6.2 Shielding of the Cathode

If the abnormal noise remains present in some degree in the gun, the r-f signal can modulate the beam very strongly and initiate parasitic oscillations. Further, when the r-f power is of the order of kilowatts it can cause additional heating of the cathode through the leads. It is for that reason that it is important to surround part of the gun by a shield at ground potential up to the output connections. This will make it easy to study the gun independently of the beam. Measurements have shown that the shielding (with a window for the beam to pass through) causes a reduction of field in the gun of at least 20 db.

The gun incorporates five connections:

(1) Filament-cathode.

(2) Filament.

(3) Wehnelt and grid.

(4) Auxiliary sole.

(5) Plate.

The plate and the auxiliary sole will be cooled by conduction across an alumina plate brazed to the shield, which is cooled by circulation of water.

The principal sole, opposite the delay line, will have an external connection independent of the gun; it will be cooled by circulation of water.

3.7 STUDY OF THE COLLECTOR

To obtain efficient collection of the electrons without leading to excessively small distances between sole and collector, it is preferable to make use of the tendency which the electrons have to follow lines of the magnetic field when the sides of the sole focus them less effectively. This is the technique of the collector surrounding the sole. The collector will be beveled to better distribute the heat.

SECTION IV

STATUS SUMMARY

4.1 COLD TEST CHARACTERISTICS OF THE FENCED LINE

a. Attenuation: in progress.

b. Propagation Constant: already completed.

4.2 COLD TEST CHARACTERISTICS OF THE DOUBLE MEANDER LINE

The following tests are to be made:

a. Dispersion of both symmetric and antisymmetric mode.

b. Attenuation.

c. Input impedance.

4.3 TEST OF WINDOWS

Windows are to be made and tested for the following characteristics:

a. VSWR.

b. Losses.

c. Power handling capability.

4.4 PILOT TEST: M-CARCINOTRON

Tests to be made.

4.5 TESTS OF RIDGES FOR OUTPUT AND INPUT MATCHING WITH A STRIP ON THE SAPPHIRE DELAY LINE SUPPORT

A cold test model is to be made for measuring:

a. Matching, coupling from ends of the guide.

b. Power handling capability.

4.6 TEST OF COMPLETE SLOW-WAVE CIRCUIT WITH WINDOWS

This must follow item 4.5.

a. Matching.

b. Transmission and reflection.

c. Power handling capability.

4.7 TEST OF SHIELDED GUN

Gun tester is being designed to measure:

a. Current emitted.

b. Abnormal noise.

c. Thermal dissipation.

d. Life test.

4.8 TEST OF OPTICS WITH THE DELAY LINE REPLACED BY A PLATE OF COPPER

This is to follow item 4.7 for measurement of:

a. DC power capability.

b. Beam transmission; collector current as a function of cathode current.

4.9 TESTS OF OPTICS WITH THE SAPPHIRE ENTIRELY METALLIZED; POWER HANDLING CAPABILITY

This may parallel item 4.8.

4.10 TECHNOLOGY

a. Brazing frame, water jacket, and supporting posts to sapphire delay line support: in progress.

b. Beryllium oxide delay line support: parts designed, parts procurement in progress.

4.11 DESIGN AND CONSTRUCT A TUBE

Design work in progress.

SECTION V

CONCLUSIONS

5.1 DELAY LINES

The most crucial part of the entire program was considered to be the achievement of a satisfactory delay line. To this end, the principal part of the first year's work and the continuing work to date has been the study of different types of delay line structures.

It has been demonstrated that it is possible to build a delay line structure suitable for crossed-field amplifiers for c-w operation in X-band by the technique of photo-engraved lines.

After extensive studies it has been concluded that the "fenced line," the multiple dissymmetric meander line closed on both edges, is unsatisfactory because of its high dispersion, its high attenuation and because it concentrates the r-f fields in the middle to the extent that only about half of the total width is useful. The double meander open on each side has been chosen instead.

Early in the program it was concluded that it was necessary to use a polished sapphire surface instead of the ceramics then available in order to deposit a delay line with enough uniformity. Efforts to improve the surface of the ceramic by means of a glaze were unsuccessful in that the glazed surface could not be metallized satisfactorily. A delay line in X-band in the form of a double meander deposited on sapphire is estimated to have a power output capability of about 500 watts c-w, limited by the thermal conductivity of the sapphire. Such a tube would have less size and weight and better mechanical ruggedness as compared with other X-band crossed-field amplifiers.

It is essential then to use beryllium oxide as the support for the delay line because of its greater heat conductivity if the goal of 2 kilowatts c-w output power is to be achieved. Higher quality beryliium oxide ceramics are now available and are believed to be suitable for a very good surface finish. The use of the double meander instead of fenced line relieved somewhat the requirements of the quality of the finish since the pitch of the double meander is somewhat larger than that of the fenced line.

5.2 COUPLING FROM GUIDE TO DELAY LINE

The impedance difference between guide and delay line can be matched by means of a ridge with multiple steps. Stray radiation must be avoided, such as could excite a fast wave between delay line and sole or propagate r-f energy into the gun region. Output window requirements are rather stringent in terms of avoiding heating either through dielectric losses or conduction losses at the edge of the window, in terms of mechanical strength, and in terms of a broad band match. A ceramic window meeting all these requirements is considered possible.

5.3 SUPPORT OF THE DELAY LINE

The sapphire support for the delay line can be brazed to a niobium frame but the presence of a copper water jacket has evidently led to failure because of the differential expansion between niobium and copper. (Niobium and sapphire have approximately the same thermal expansion.) Brazing to a niobium frame has been more successful.

5.4 GUN STUDIES

It will be necessary to achieve a very high beam density and at the same time keep the excess noise within reasonable limits. Scaling from lower frequency tubes of the same power level is only partly valid because it is not practical to raise the magnetic field in direct proportion to frequency, and in addition the limitation of available electron emission per unit area is encountered. A number of ways of reducing excess noise are being proposed to be used separately or in combination.

SECTION VI

PROGRAM FOR NEXT INTERVAL

6.1 DELAY LINE STUDIES

Tests of attenuation of the fenced line will be completed. A photo-formed X-band double meander line will be made and tests for delay ratio and attenuation will be undertaken.

6.2 DESIGN OF A STEPPED-RIDGE OUTPUT AND INPUT

The design of a stepped-ridge output and input matching section will be completed and models for cold testing will be made.

6.3 TESTS OF BRAZING SAPPHIRE TO A NIOBIUM FRAME

Further tests of brazing sapphire to the niobium frame and the water jacket, along with the posts which have been introduced to maintain flatness of the sapphire, will be continued.

6.4 ELECTRON GUN

Appropriate beam testers will be designed and built to evaluate the following properties of the beam:

(1) Available current.

(2) Beam transmission.

(3) Noise.

6.5 COLLECTOR

A collector capable of dissipating 4 kilowatts c-w will be designed. It may be tested in the beam testers.

6.6 DESIGN OF THE TUBE

Additional work will continue on the overall designing of the operating tube.