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**Trip to Radiation Laboratory, M.I.T.; Bell Telephone Laboratories, and
Naval Research Laboratories: July 30th to August 7th, 1945**
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NATIONAL RESEARCH COUNCIL OF CANADA

RADIO BRANCH

S E C R E T

TRIP TO RADIATION LABORATORY, M.I.T.; BELL TELEPHONE
LABORATORIES, AND NAVAL RESEARCH LABORATORIES
JULY 30th to AUGUST 7th, 1945

I. I. F. AMPLIFIERS

(1) Discussion of Stagger-Tuned Receivers (Yardley Beers, M.I.T.)

Beers is writing a report on his conclusions regarding the Miller effect in stagger tuned amplifiers. In general the effect is to drop the response in the high frequency region. If the capacity is large enough, it may cause instability.

Some trouble with harmonics from sweep oscillators which utilize a limiter was reported. Beers recommends that this type should not be used. A convenient way to observe the output from an amplifier when fed by a sweep oscillator, is to connect a detector to one of the cathodes.

(2) Low-Noise I.F. Input Circuits (Wallman, M.I.T.)

A circuit diagram was obtained for the Wallman low-noise I.F. input circuit which has been indexed among the vault documents (Radio #14895). The noise figure for this circuit is approximately 1.5 db. The bandwidth could not be specified exactly, but was assumed to be very wide.

The transient response computed for a number of linear phase circuits was obtained. These illustrate the lack of overshoot which may be expected from such circuits.

(3) I.F. Amplifiers (A. L. Hopper, B.T.L.)

A double-tuned, symmetrically loaded I.F. amplifier on 60 mc. employing 6AK5 tubes, has been developed for the B.T.L. K-band head. The units were fixed-tuned, and had a bandwidth of 10 mc. at 3 db. down. A theoretical analysis indicated that this type was much less susceptible to variations of tube capacity than a number of others (feed-back amplifiers were not included). The analysis consisted of evaluating the first and second derivatives of the response curve at the mid-band frequency for some specified difference of capacity. It was observed that the first derivative for the symmetrically-loaded double-tuned type was smaller than for any of the others, but that the second derivative was somewhat larger than for any of the others.

The general lay-out of the receiver did not seem to be particularly good. Separate screen and plate by-pass condensers were used which resulted in a greater number of parts than is customary. The coils were pre-tuned by varying spacing of the end turns in such a way that the mutual coupling was not affected.

(4) Transient Response (H.N.Beveridge, N.R.L.)

An interesting point in connection with the transient response of I.F. amplifiers was observed. As is to be expected theoretically, a pulse well off the mid-band frequency can excite a transient which is considerably greater than the response obtained under steady state conditions. This was observed very nicely using a pulse I.F. signal generator, and one of the receivers which has been built at N.R.L. At a point 40 db. down on the steady state response, the transient response is down by only 20 db. This response manifested itself by a short transient at the beginning of the pulse, and another identical one at the end of it.

II. OSCILLATORS

(1) C.W. Magnetrons (Clogston, M.I.T.)

Clogston reports cathode lives of 100 hours or better. After 100 hours the emission drops until the tube cannot be modulated. The normal operating current is 125 milliamperes at anode voltages of 1000 to 1200 volts. The magnetrons must be anode-modulated, a series pentode being recommended. These tubes have been considered for noise jamming purposes. The frequency swing is not very serious at currents above 50 milliamperes. The figures are:

<u>CURRENT</u>	<u>FREQUENCY SWING</u>
0-50 ma.	5 mc.
50-150 ma.	1 mc.

Raytheon manufactures the following C.W. magnetrons (with tuning head):

QK59 - 2700-2870 megacycles	
QK60 - 2840-3005	"
QK61 - 2973-3170	"
QK62 - 3135-3330	"

C. V. Lytton, Lytton Manufacturing Labs., P.O. Box 79, Redwood California, is manufacturing a 3-5 kv., 500-ma., 500-watt tube.

(2) K-Band Local Oscillator 2K50 (Kuper, M.I.T.)

The 2K50 is being manufactured by Model Shop production at E.T.L. M.I.T. is attempting to maintain the specifications of 10 milliwatts output

over the band 1.225 to 1.275 cm. in the designed mode. The Bell Laboratories want this eased as the shrinkage in production is about 65%. Kuper states that somewhat higher powers may be obtained in other modes, and that the reject tubes are usually satisfactory for laboratory work. The rejects are known as 1462's.

The tuning is done thermally in these tubes by means of an element heated by electron bombardment, the bombarding current being controlled by means of a grid. A 500-megacycle swing may be obtained with this element without a readjustment of the tube potentials. The band can be swept in two seconds, with a velocity of 800 Mc/sec^2 at centre band.

III. CRYSTALS

(1) Balanced K-Band Mixers (Whitford, M.I.T.)

The balanced K-band mixer manufactured by Yale & Towne was inspected. These may be ordered from them, attention Mr. A. D. Dalton (Radiation Lab. Dwg. No. 11226) (Cost \$175.00).

The crystal holder is not very satisfactory in these mixers; it allows R.F. to couple directly into the crystal. The remedy for this is to sharpen the end of the crystal capsule into a knife edge which is forced against the lower retaining flange. An important feature is that local oscillator power can be varied independently of the tuning, by moving a tapered attenuator.

(2) Crystals (Dicke, M.I.T.)

The germanium crystals have been found no better in signal-to-noise than the silicon crystals, although the gain may become greater than 1. The d-c current VS d-c voltage curve has regions of negative slope when the crystal is excited with K-band local oscillator power.

Germanium crystals processed with antimony have very high back impedance and make excellent second detectors. Manufactured by the Western Electric Company under the number D-171612, they can be mounted as circuit elements.

IV. T/R's AND DUPLEXING

(1) Broad Band T/R's - X-Band (M.I.T.)

M.I.T. has been developing broad band T/R switches for the S and X bands. The switches appear to be part of a general programme of developing broad band components. These switches have the following advantages over the resonant cavity type:

- (i) Such broad band systems lend themselves to the construction

of radar-radio sets that can operate with transmitters on any portion of the band in question so they may be used with tunable magnetrons and balanced mixers for anti-jamming purposes.

- (ii) The new T/R taken in conjunction with additional decoupling between magnetrons and crystal by means of magic Tees seems to represent a considerable improvement in the art of crystal protection. The essentials of a broad-band T/R are shown in Fig. 1.

At each end there is a low Q ($Q \approx 1$) resonant window, covered with glass. At $\lambda_g/4$ intervals inside the T/R there are two or three windows with $Q \approx 3$ which are not glazed. One or more keep-alive spikes is inserted perpendicular to the field close to the $Q \approx 3$ window. The low Q window blocks transmission of harmonics. (The Q 's mentioned here refer to the Q of one of the window elements when it is terminated by a flat load.)

DATA: Receiving Loss - Out of five tubes checked at three frequencies, only one measurement showed loss higher than 1 db. Transmission is chiefly better than 0.6 db.

Transmitting Loss - Less than 0.2 db.

Keep-Alive Current - 150 μ A.

Leakage Power - Spike 0.1 ergs/pulse
Flat 50 to 100 mw.

Gas Filling - Argon-10 mm. H_2O -4 mm., (sometimes includes a hydroscopic salt to maintain water vapour).

The General Electric Co. are making some of these Z-658 tubes for X-band with three $Q \approx 3$ windows. Meanwhile M.I.T. have done further work, and the final design will be a two-gap tube with the internal windows shaped as in Fig. 2. The flaring of the conical posts reduces the Q and allows a smaller gap.

The G.E. Co. and Sylvania are going to change their production to a model involving two conical gaps. In this model the end windows have Q 's of 2.5 and 1.2, the lower Q window being placed nearer the magnetron. The spike on this tube is 0.08 ergs/pulse.

(2) Broad Band T/R's - S-Band (Smullin,) (M.I.T.)

There is an S-band T/R, similar to the type described above, in production for S_w , S_a and S_g , bands. This is used with an untuned R/T and a mixer of the type shown in Fig. 3. The performance of this mixer was said to be not quite as good as that of the coaxial mixers, but it is matched from 10.2 to 11.1 cm. There are, of course, no image reflections in such a T/R mixer system.

(3) Broad Band T/R's - K-Band (Zabel, M.I.T.)

The K-band T/R shown in Fig. 1 is still in development. It is for use in circular waveguide to permit passage of T-E waves of any polarization. The gas envelope is sealed by two low-Q circular glass windows. The resonant element is composed of two perpendicular slits. The Q is approximately 20. No keep-alive is used.

(4) Duplexing

The crystal in a radar set could theoretically be protected without the use of a T/R cavity switch by using a balanced R.F. network of the Magic-Tee type. Such a network would involve at least a 6 db. loss. However, good protection with only fair T/R switches can be obtained by combining T/R switches with magic-Tee networks. Dicke has shown that the theory of such devices can be developed by considerations of symmetry and the use of scattering matrices. Some different forms of magic-Tee are shown in Fig. 4.

Fig. 5 shows a form used at X-band known as the "Rat Race". Here the electric field is radial in the curved guides. Matching is achieved by making the characteristic impedance of the circular guide segments $1/\sqrt{2}$ that of the straight branches.

In all these magic-Tee's inputs 1 and 2 are decoupled, and inputs 3 and 4 are decoupled. In the types involving circular guide, 3 and 4 refer to waves polarized 90° apart.

Proper matching adjustments, made with certain degrees of symmetry insure that when power is sent into one inlet, and all the other outlets are terminated in flat loads, there is no reflection at that inlet.

The system shown in Figure 6 is used in an X-band radar set. The pulse of R.F. power from the magnetron enters branches 3 and 4 of the first rat race, and after breaking down the T/R switches S_1 and S_2 , is reflected back to the rat race. The total time to outlet 2 is the same, so that the waves reinforce there and are transmitted out 2 to the antenna. The returning echo is split in the first magic-Tee, and the path lengths via A or B are equal to outlet 2 of the second rat race, but differ by $\lambda/2$ to outlet 1. Thus all the received signal is handed to the mixer. However, any leakage of magnetron power past the T/R's arrives at the second rat race with a path difference of $\lambda/2$ and hence is sent into the flat load at outlet 1. This equipment uses the multiple window broad-band type of T/R.

Figure 7 shows another possible type of duplexing system which was experimental only, and not used in practise on account of its bulk. C. and D. are phase shifters which increase the path length to one polarization by $\frac{1}{2}\lambda$ over that of the other.

A more compact arrangement is possible with the type of magic Tee shown in the lower right of Fig. 4. This is shown as Fig. 8.

The K-band T/R, as described by Zabel of M.I.T., is of the type sketched in Fig. 1. Considering the transmitting pulse, the fact that the side stubs differ in length by $\frac{1}{4}\lambda_g$ means that almost all the magnetron power is transmitted to the antenna during the transmitter pulse.

The received power does not go to the magnetron, but is transmitted up the round guide through the T/R switch to the crystal. Magnetron power leaking through the T/R switch is carried instead to a flat load. By using a T/R switch that permits the passage of two modes,--only one T/R is required in this system.

V. SYSTEMS

(1) K-Band Heads (X-66388) (S. E. Miller, B.T.L.)

These units looked extremely neat and compact, and incorporated most of the latest improvements;--i.e. balanced mixer and an improved magnetron. Two packages are available of almost the same size: $13\frac{1}{4}$ " x 9" x $13\text{-}3/16$ " and 12" x 9" x $13\text{-}3/16$ ". The electrical characteristics are:

Bandwidth	-	10 megacycles at 3 db down
Video Output	-	1.5 volts (following limiter)
	(115 volts A.C., 380-2400cycles/sec.
	(24 volts D.C.
Power Input---	(+150 volts D.C.
	(-150 volts D.C.
	(+300 volts D.C. (regulated)
Peak Output	-	40-60 kilowatts
Duty Cycle	-	0.001
Weight	-	34 lbs.

The present specifications for the magnetron call for a duty cycle of 0.0006, but the engineers are confident that 0.001 can be used safely.

Full-scale production of these units is supposed to start at Western Electric in August 1945. They are at present in pre-production at B.T.L. with 250 units projected.

An interesting comparison between single mixers and balanced mixers for two different I.F. frequencies has been made by Miller. In the table below are listed the noise figures in decibels for K-band receivers using balanced and single mixers and I.F. frequencies of 60 megacycles and 100 megacycles:

	Single Mixer	Balanced Mixer
60 megacycles	15.71	13.42
100 megacycles	14.19	13.59

As will be seen, there is a considerable advantage for the balanced mixer at 60 megacycles. The balanced mixers were the Yale & Towne type.

(2) K-Band Heads (M.I.T.)

A new model of the old Sylvania head using the same components, will be produced by Philco. The Radiation Laboratory design of head for APQ-34 uses all new components, including a package magnetron and a QK50 and balanced mixer. This is hand-made at M.I.T.

(3) Variable Frequency Set (M.I.T.)

M.I.T. have developed an X-band transmitter-receiver involving the following components:

Tunable magnetron 2J51
Low voltage, electrically tuned local oscillator, 2K45
Two rat-race, two T/R duplexing system
Balanced mixer

This system can be tuned rapidly to avoid jamming. The balanced mixer is useful to avoid the type of jamming arising from the simultaneous transmission of a noise-modulated signal and a "local oscillator" signal. The set has two alternative AFC systems for beacon or radar use.

(4) U.H.F. Communications (Ridenour) (M.I.T.)

M.I.T. have developed an idea for a communications system where the oscillator is stabilized by means of two magic Tee's. The second magic Tee is terminated at arm 3 (See Fig.9) by a resonant cavity, and at arm 4 by a short circuit $\lambda_g/8$ beyond the zero phase position. Arm 3 of the first magic Tee feeds arm 1 of the second. Two crystals placed at arms 2 of these two magic Tee's feed into a balanced push-pull d-c amplifier.

Zero phase position would be found, for example, by detuning the cavity completely to the higher frequency side, and locating the plunger in 4 for a flat input.

VI. TEST EQUIPMENT

(1) Test Set (M.I.T.)

M.I.T. are at present manufacturing two F-M test sets. One, a sample of which is at N.R.C., is the TS-259. This is manufactured for the U.S. Army by Browning Laboratories at Winchester, Mass., and uses a 2K33 as a signal generator. The U.S. Army demand is fairly heavy, procurement being through the Munitions Board. The other set, the TS-223, will be manufactured for the U.S. Navy. Five pre-production sets are being made by Aircraft Radio Corp., Boonton, N.J. These will use the 2K50 as a signal generator. The plumbing lay-out is shown in Fig. 10. It is milled out of two pieces of aluminum which fit together like a waffle iron. To prevent rusting of the poly-iron attenuators, they are coated with rust-proof oil or lacquer.

The wavemeter of the type we have been purchasing from Kannenstine Laboratories has an interfering mode between 23600 and 23650 megacycles. This shows up as a reduction in the dip. Dr. Howard is producing a new design of a longer resonant cavity to avoid this difficulty.

(2) Thermistor Mounts (M.I.T.)

M.I.T. claim their thermistor mounts are reproducible and stable in operation, giving results within 1 db. of those obtained with a water load. There is a certain amount of leakage and loss at the plane where the back plate is fastened onto the mounting block.

(3) Standard Attenuator (M.I.T.)

A secondary standard attenuator, TPK-35PB40, is in production by F. R. Machine Works, Long Island City, N.Y. (Should be ordered through Dr. Howard, M.I.T.)

(4) Test Equipment (B.T.L.)

The B.T.L. are not manufacturing or designing a complete test set for K-band receivers. However, the Western Electric Co. will have certain directional coupler and power meter units for sale. The directional coupler is unit X-66401A. Their standing wave detector is based on the directional coupler and is known as unit X-66402A.

Two of their compensated thermistor bridges are described in "Laboratory Models of a Compensated Thermistor Circuit for Microwave Power Measurements - Case 24662" and "Temporary Instruction Book for X66399-A Power Meter" (both of which are on file in the Radio Document Vault). The B.T.L. thermistor block is unit X66823C shown in photograph 124331 of the first reference above.

VII. MISCELLANEOUS (Naval Research Laboratories)

(1) General N.R.L. Projects

Very little radar work is being done at N.R.L. The Mk.V. I.F.F. constitutes the greatest effort of this nature. The following is a brief list of other projects:

S-Band Communications System
K-Band Propagation
An S-Band High Power Modulator
S-Band Jamming (Noise)

(2) Aircraft Antennas for Mk.V. I.F.F. (Rumsey)

All of the antennas developed at N.R.L. have been flush with the surface of the aircraft in order to reduce drag. They have been devised by

cutting slots and holes in the skin, following the lines originated by the T.R.E. group.

One interesting type is illustrated in Figure 11. This is merely a coaxial line which has been expanded out to a diameter of about $3\lambda/4$. This antenna, of course, produces a null along the axis which, in this instance, is the kind of pattern which is sought.

Another type is illustrated in Figure 12. This consists of slots in the skin, one slot acting as an excited element, and the other a parasitic. In order to avoid losses, the backs of the slots are covered by means of a box, the size of which affects very materially the impedance of the system.

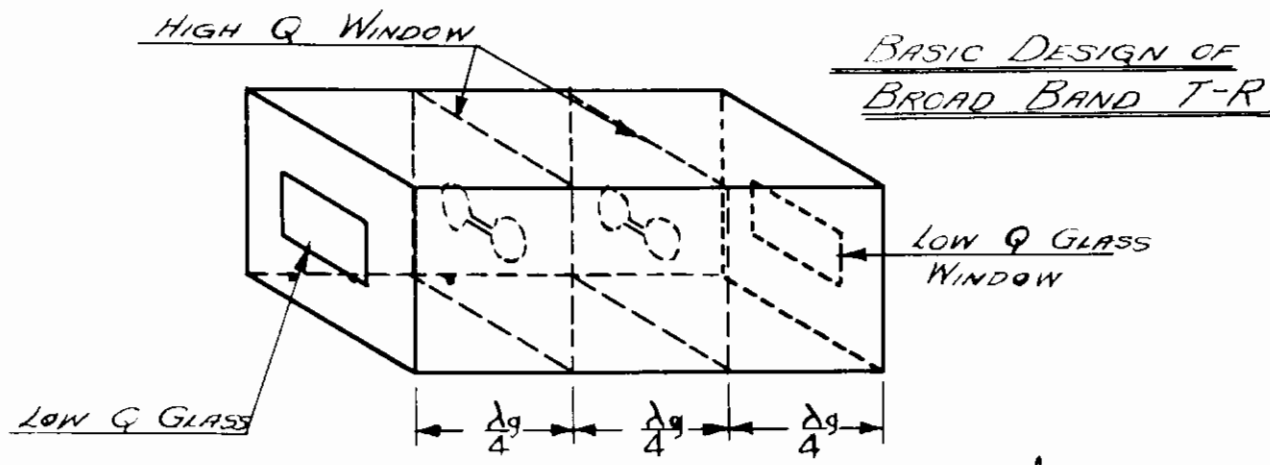
(3) Computer.

N.R.L. possesses an electrical computer which is being used to analyze the results of tests of radar accuracy. With this machine the laborious calculations which formerly required months can be performed in a week or so.

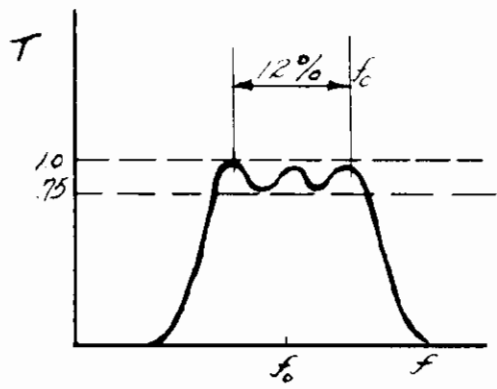
A. J. Ferguson

P. D. P. Smith

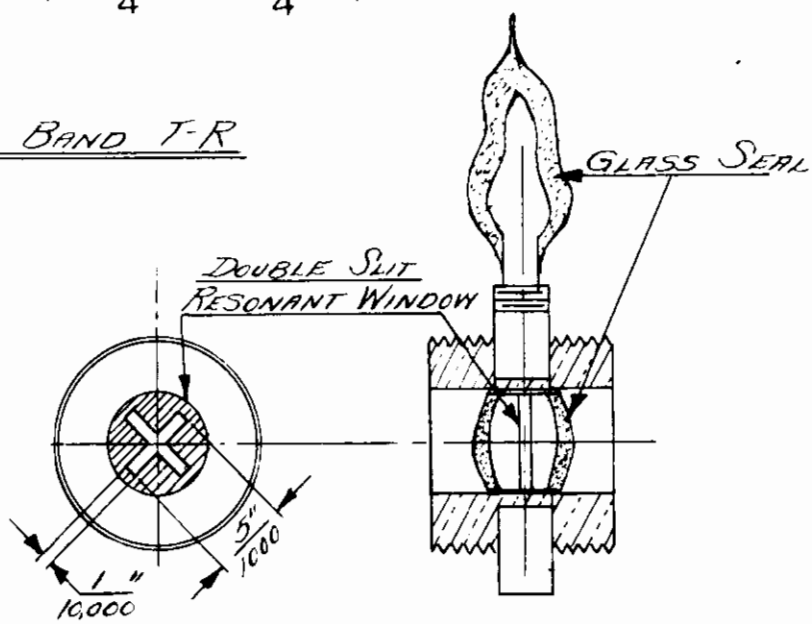
National Research Council,
Ottawa, October 8, 1945.



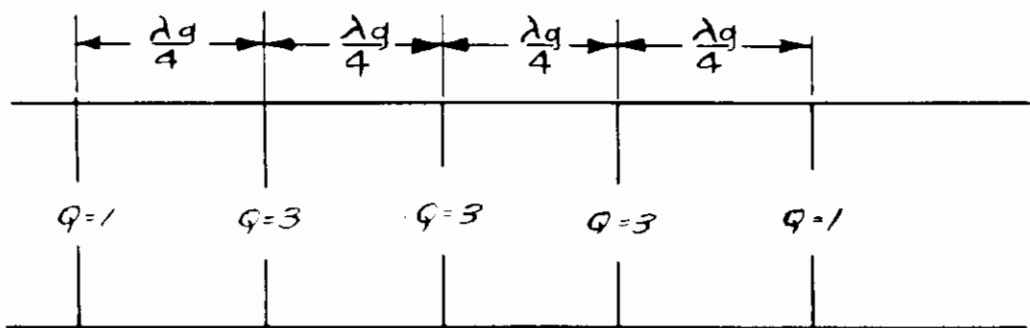
BROAD BAND T-R



TRANSMISSION CHARACTERISTIC

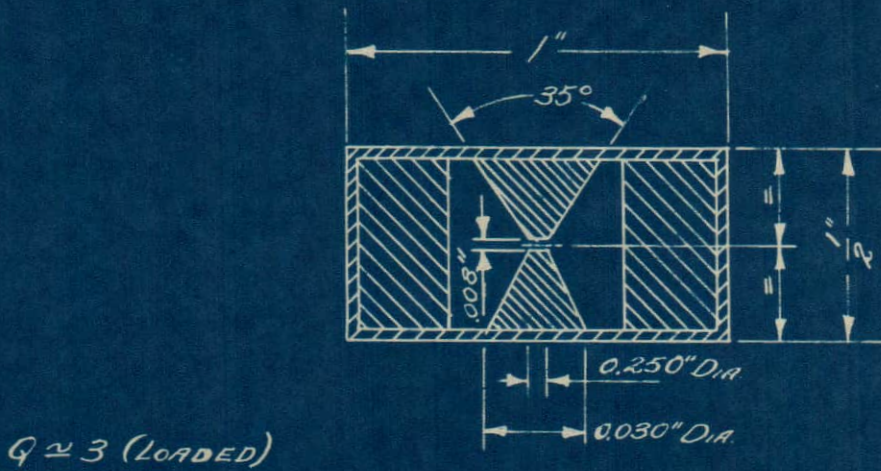


K-BAND T-R



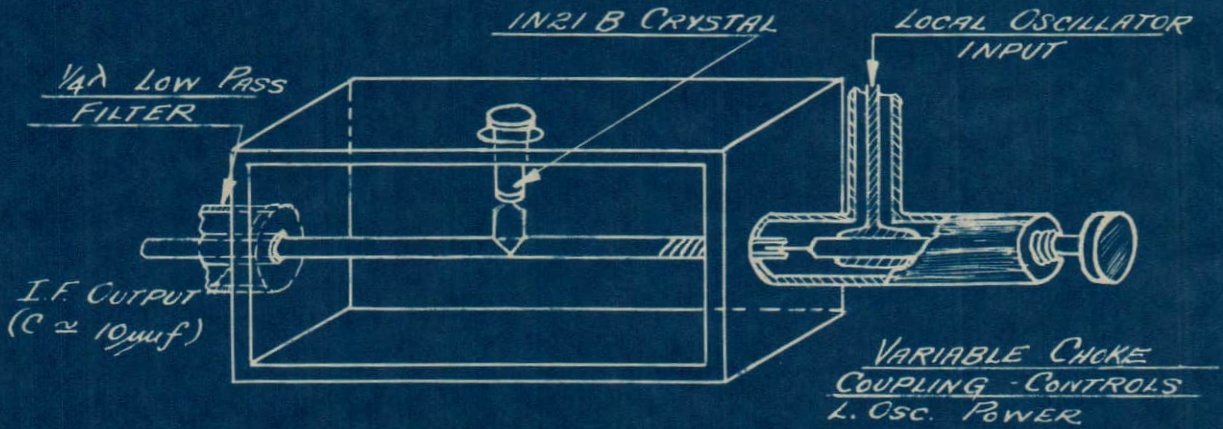
NOTE: LOADED Q'S OF WINDOWS.
IE Q'S WITH 20 TERMINATION.

FIGURE 1



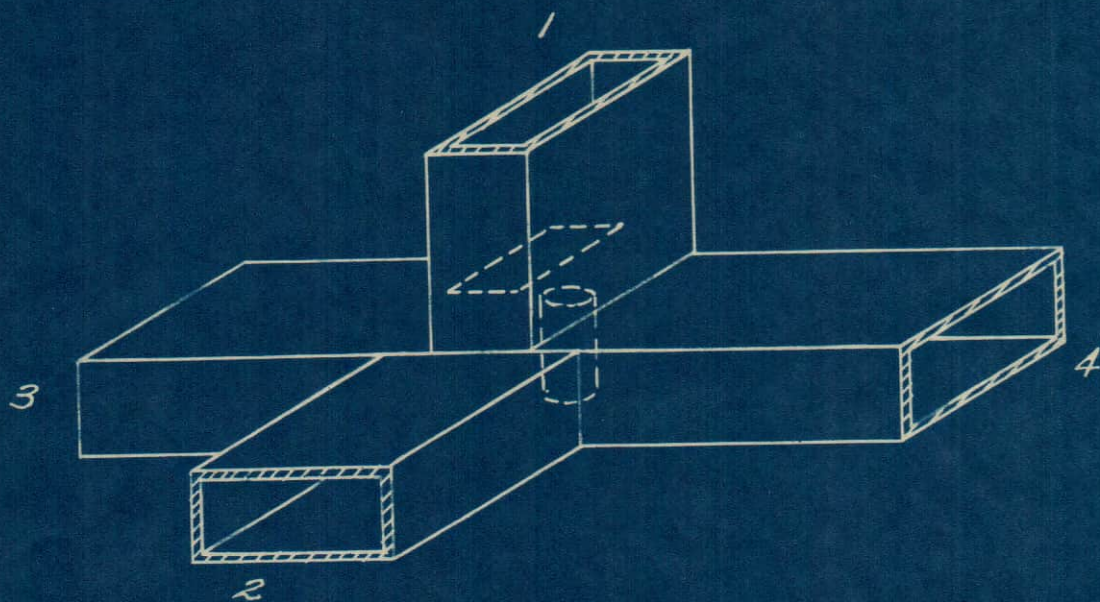
RESONANT WINDOW FOR X-BAND T-R

FIGURE 2

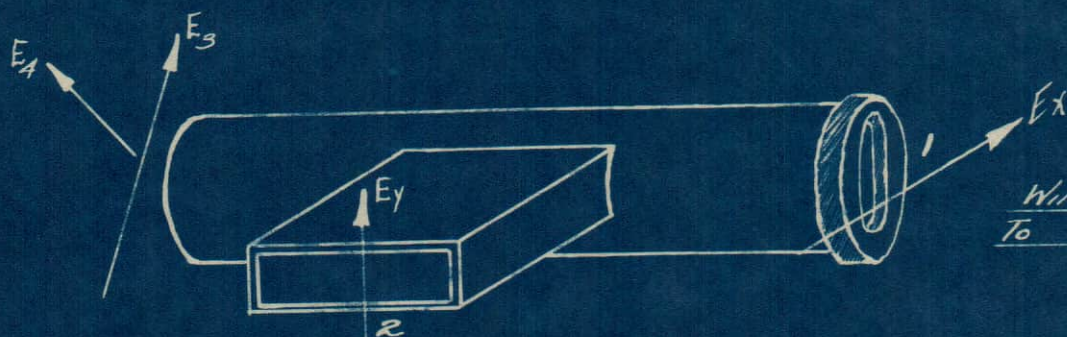


SKETCH OF S-BAND MIXER FOR BROAD BAND T-R.

FIGURE 3

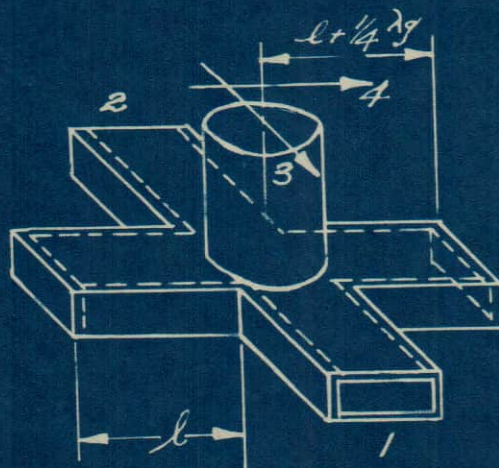
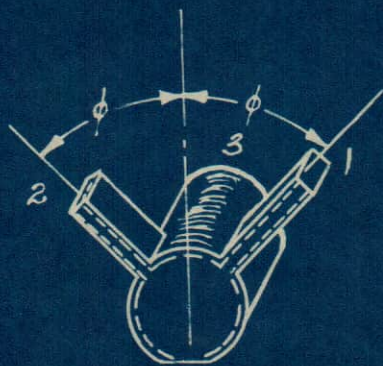


CLASSICAL MAGIC T



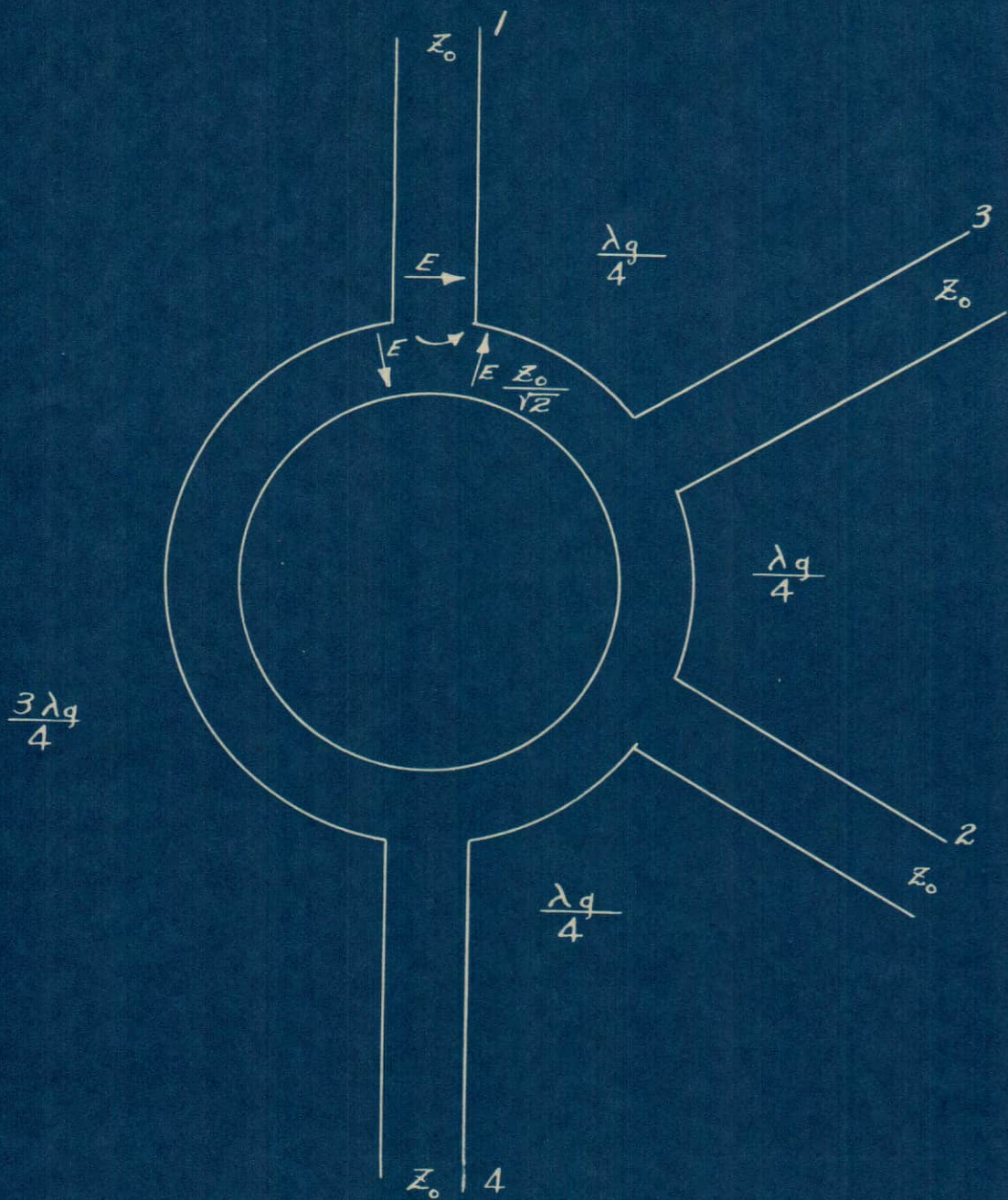
WINDOW MATCHES E_x
TO ROUND GUIDE

ROUND GUIDE FORM OF MAGIC T



OTHER FORMS OF MAGIC T

FIGURE 4



THE RAT RACE
(WAVE-GUIDE - SERIES BRANCH TYPE)

FIGURE 5

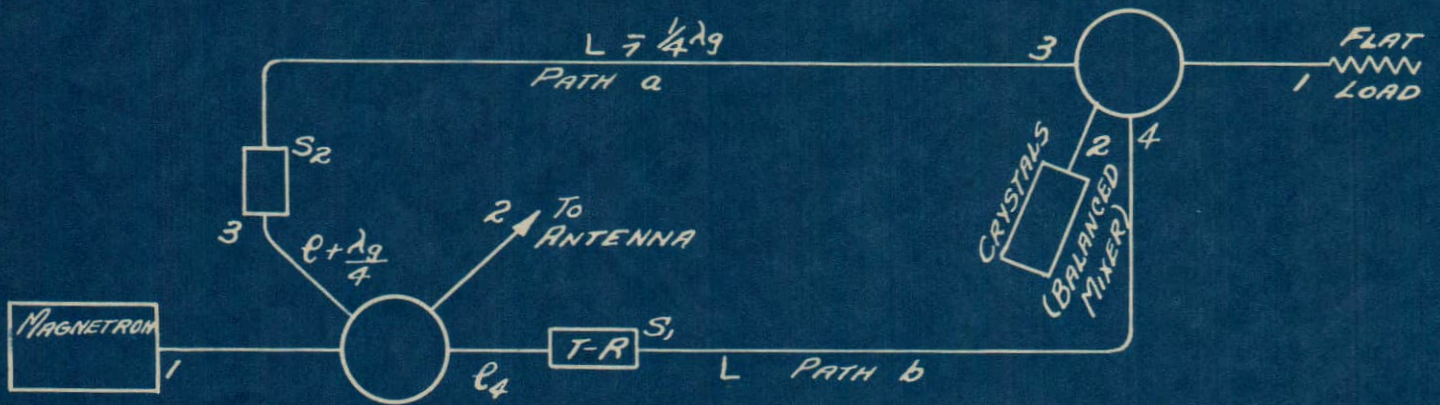


FIG. A. TWO RAT RACE DUPLEXING SYSTEM.

FIGURE 6

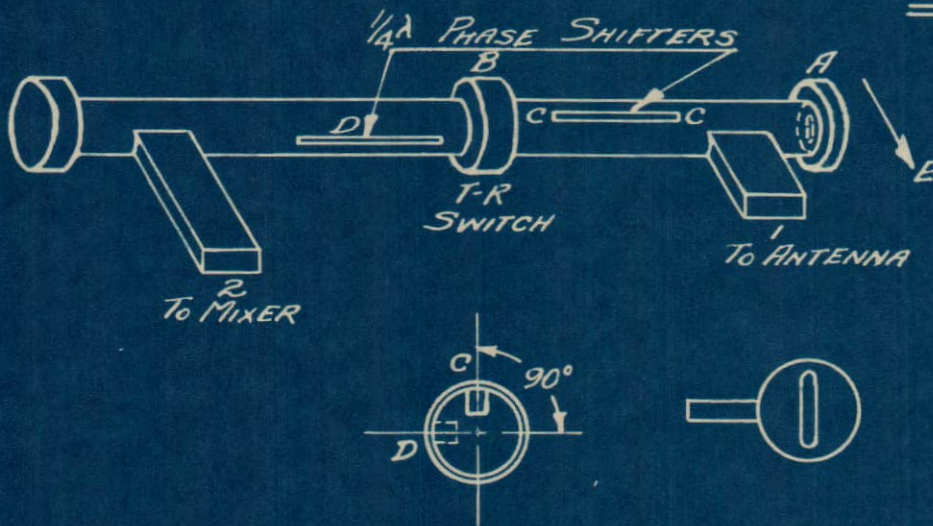


FIGURE 7

FIG. B. EXPERIMENTAL DUPLEXING SYSTEM

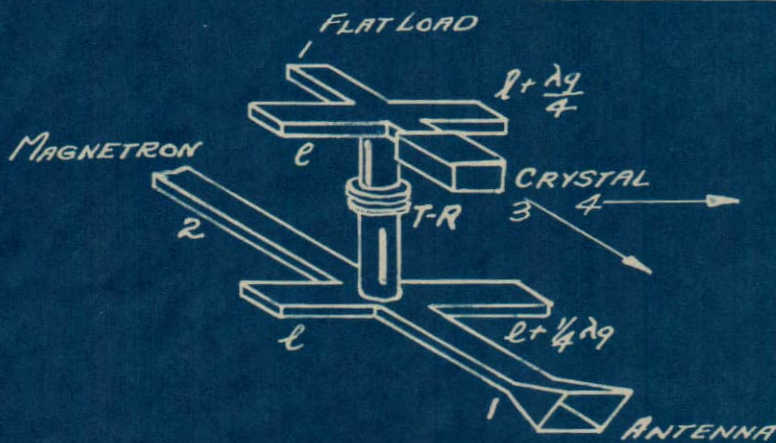
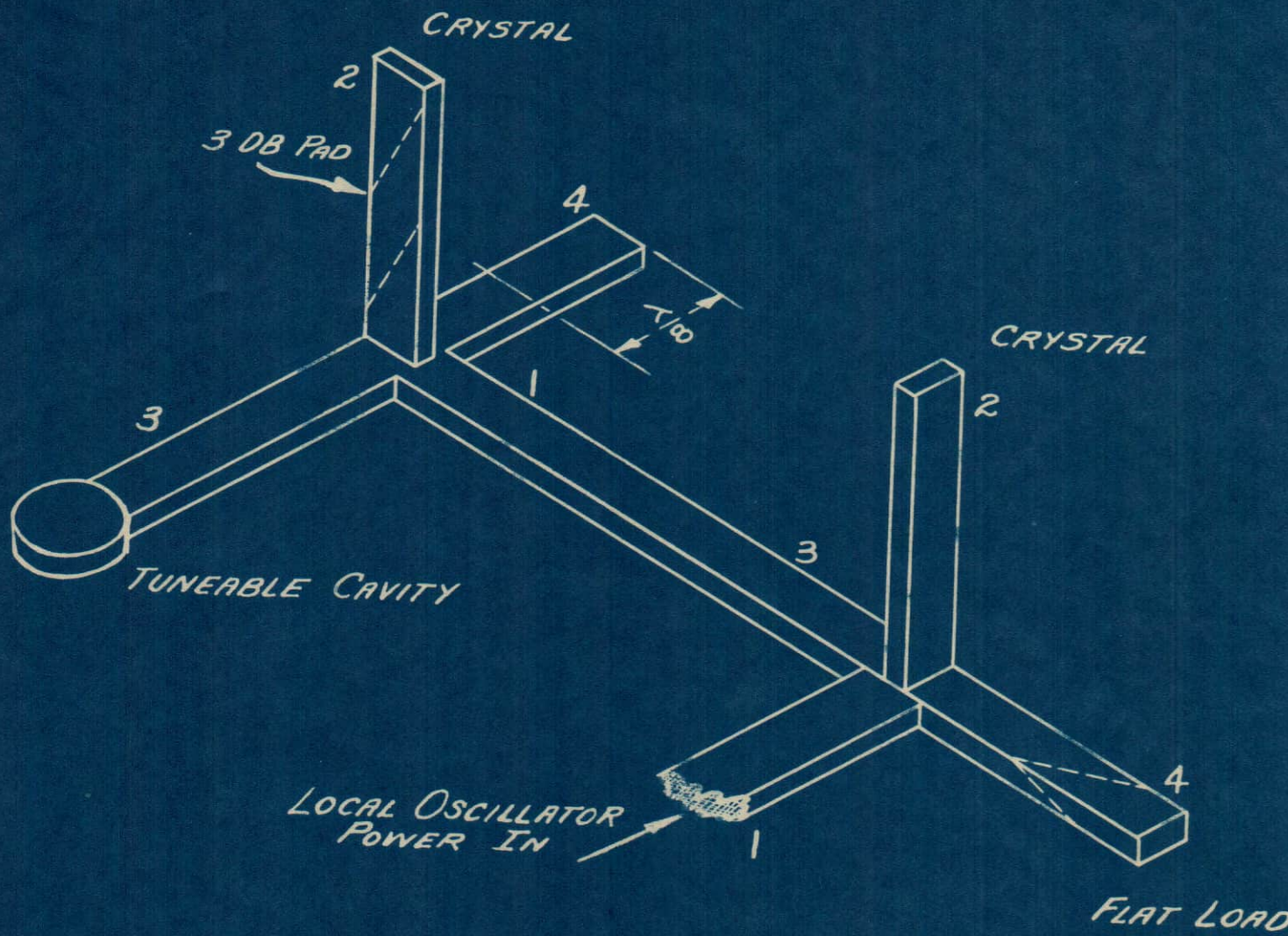


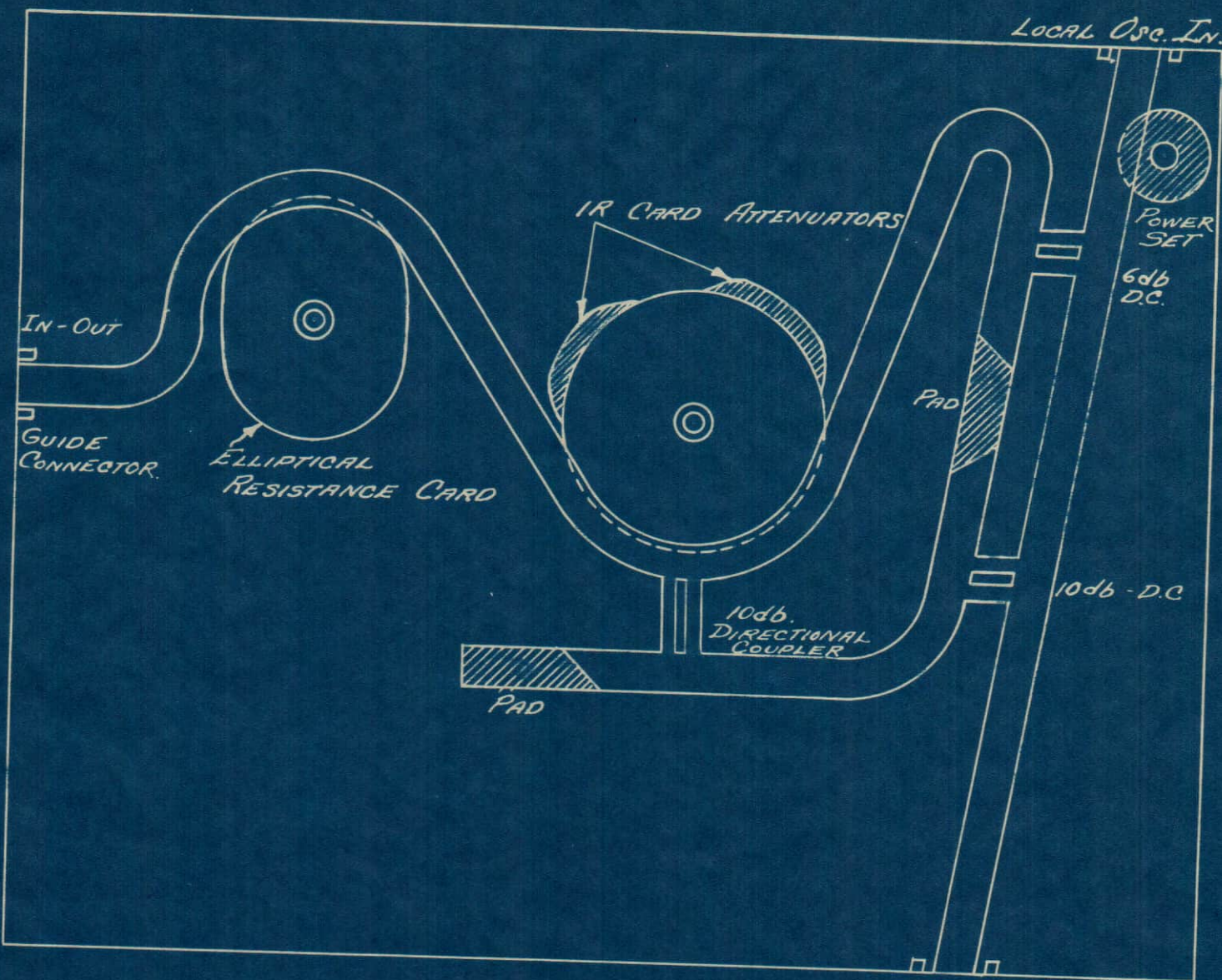
FIGURE 8

FIG. C. K-BAND DUPLEXING SYSTEM



R.F. FREQUENCY STABILISER

FIGURE 9



NOTE: MACHINE LIKE WAFFLE
IRON OUT OF ALUMINUM.

PLUMBING FOR MIT TEST SET

FIGURE 10

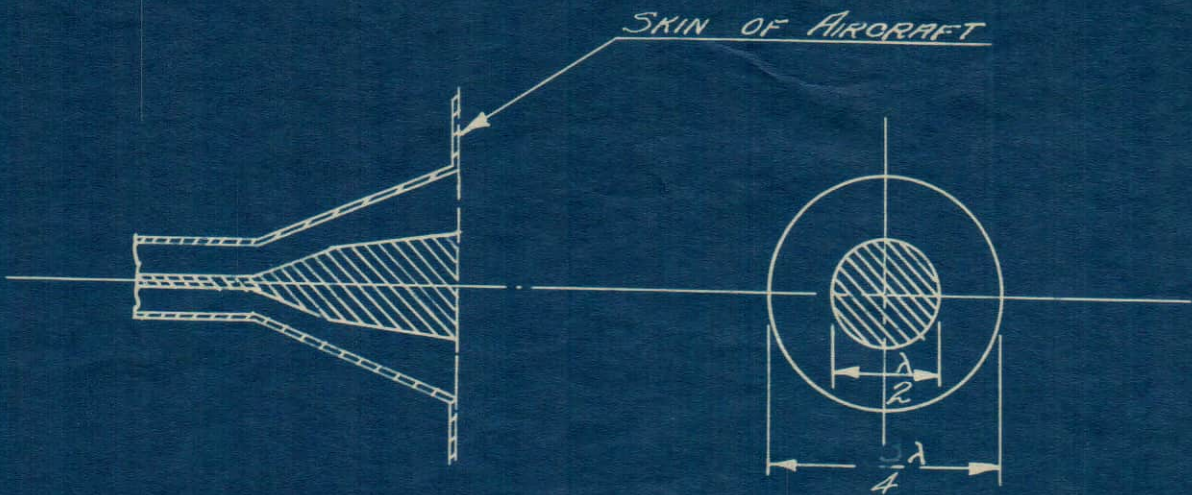


FIGURE 11

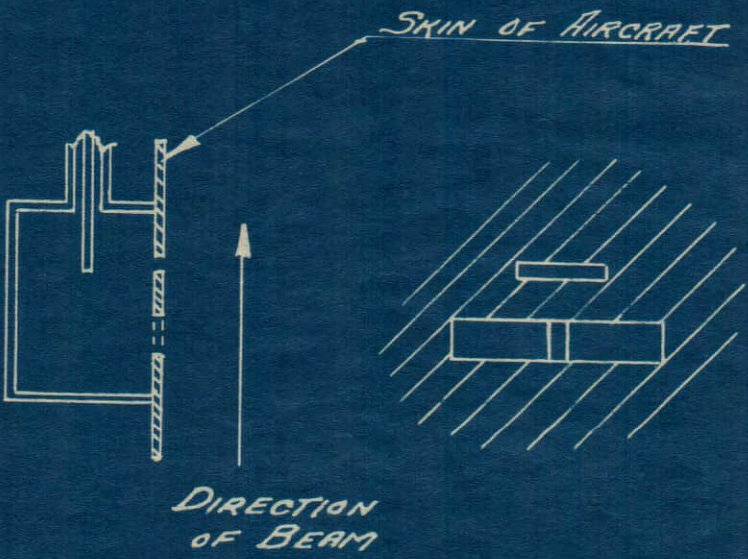


FIGURE 12