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TO PHASE SHIFTER
AND THE CALIBRATION OF BOTH**

JOHN REED

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**RESEARCH LABORATORY OF ELECTRONICS
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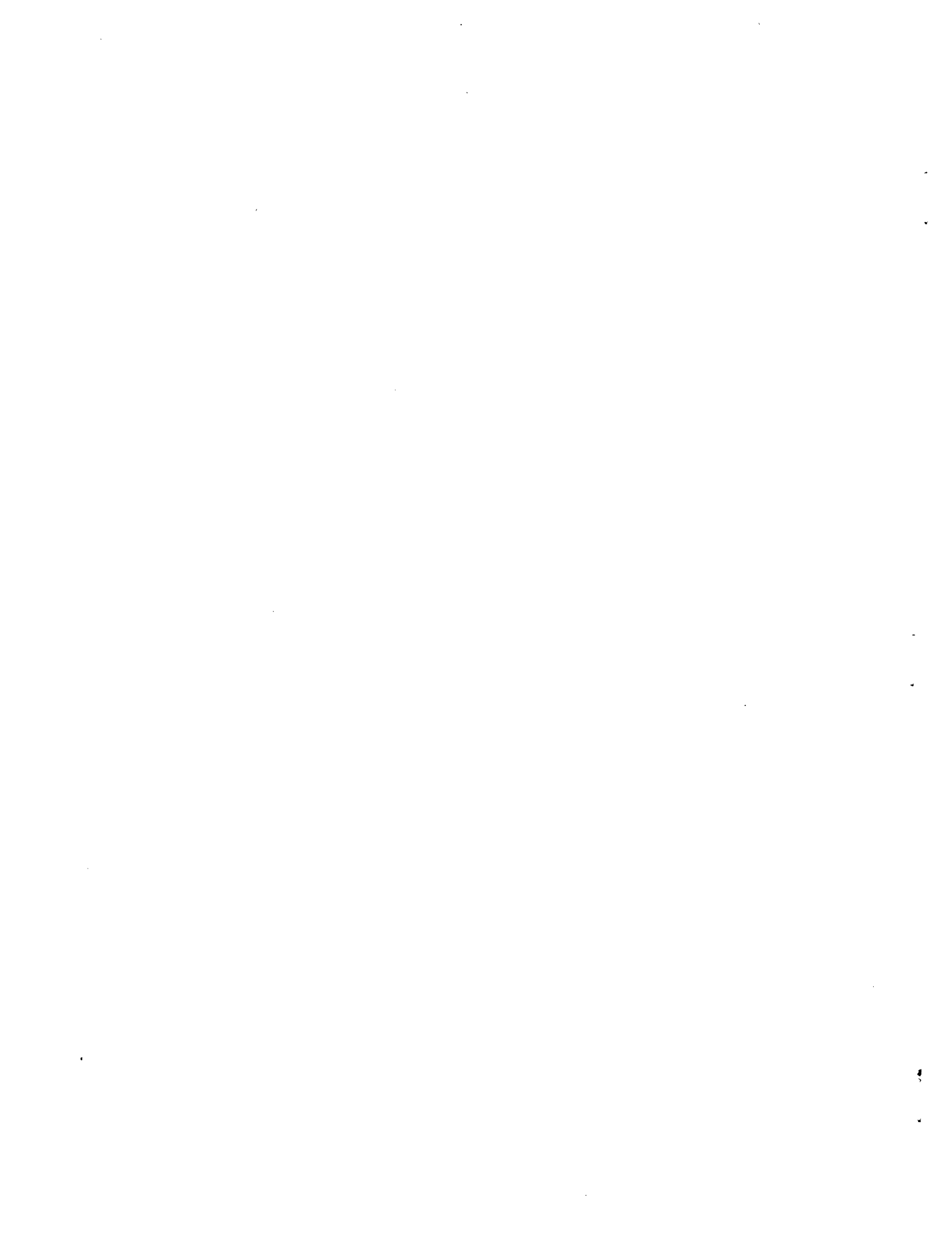
THE CONVERSION OF AN ATTENUATOR TO PHASE SHIFTER
AND THE CALIBRATION OF BOTH

by

John Reed

Abstract

X-band phase shifters and attenuators suitable for use in the guided-missiles project are obtained by modifying Attenuator TPX-27GM/25. The necessary changes are described as well as the procedure for calibrating these instruments. With the phase shifters as originally designed, extraneous resonances were introduced. These were studied and the means of eliminating them are discussed.



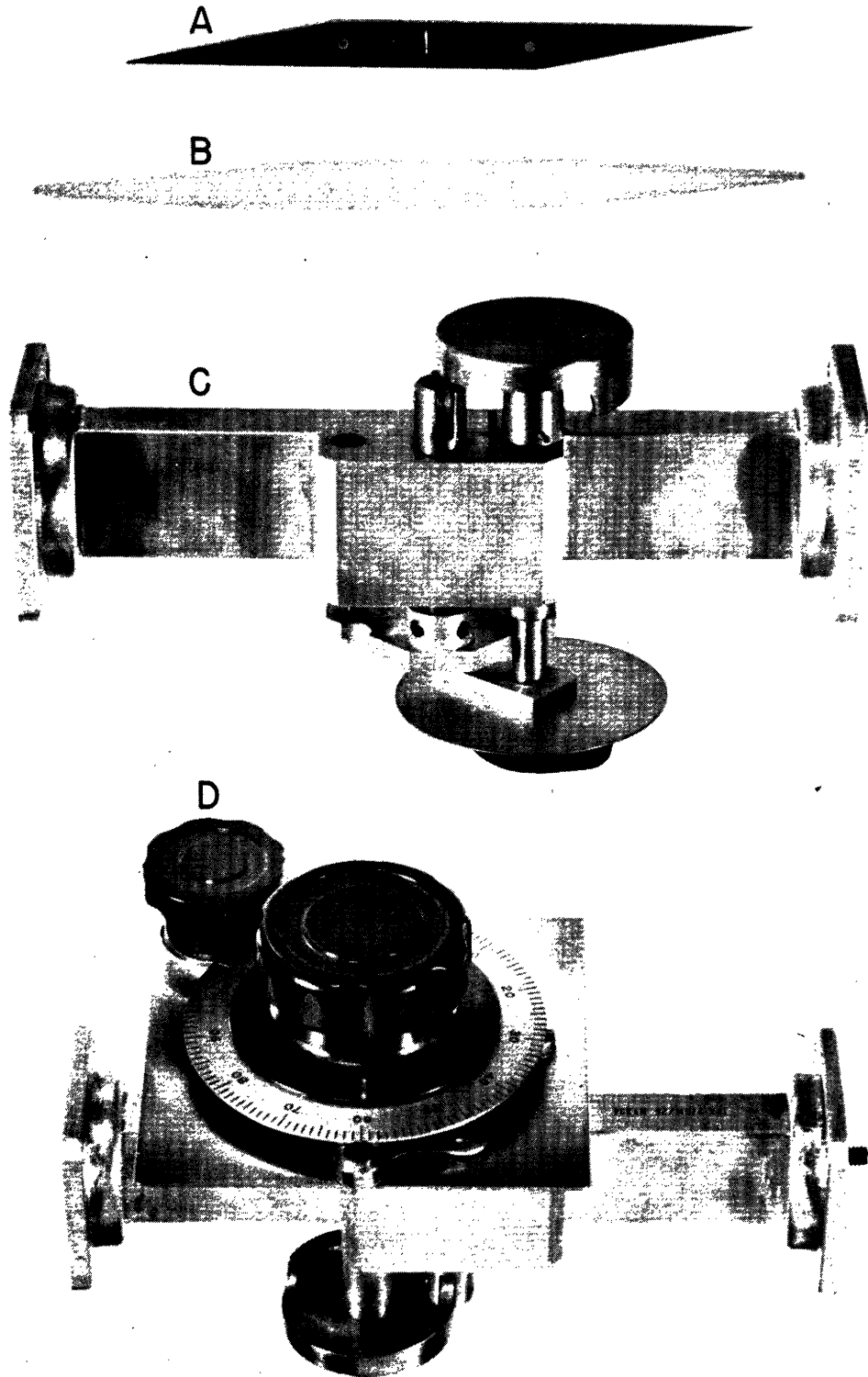
THE CONVERSION OF AN ATTENUATOR TO PHASE SHIFTER AND THE CALIBRATION OF BOTH

X-Band phase shifters and attenuators that can be calibrated are required for the guided-missiles project. At the present time, the device that appears to be the most promising and that is, in addition, the most easily available is Attenuator TPX-27GM/25 (see RL Drawing 11888-A) which may be modified to permit accurate calibration and to serve as both phase shifter and attenuator. A photograph of the attenuator before and after the alteration (described in the next section) is shown in Fig. 1. The substitution of a large dial (GR Type 702B) for the original small and inaccurate pointer and dial is noted. When the instrument is used as an attenuator, variation in attenuation is achieved by the motion of a metallized glass plate inside the guide. If the glass plate is replaced by a polystyrene slug (to be described in Sec. 2.1), the device can be used as a phase shifter of the type described in RL Report 788 by F. Worrell. Both the glass plate and the polystyrene slug are also shown in the photograph.

1. The Attenuator

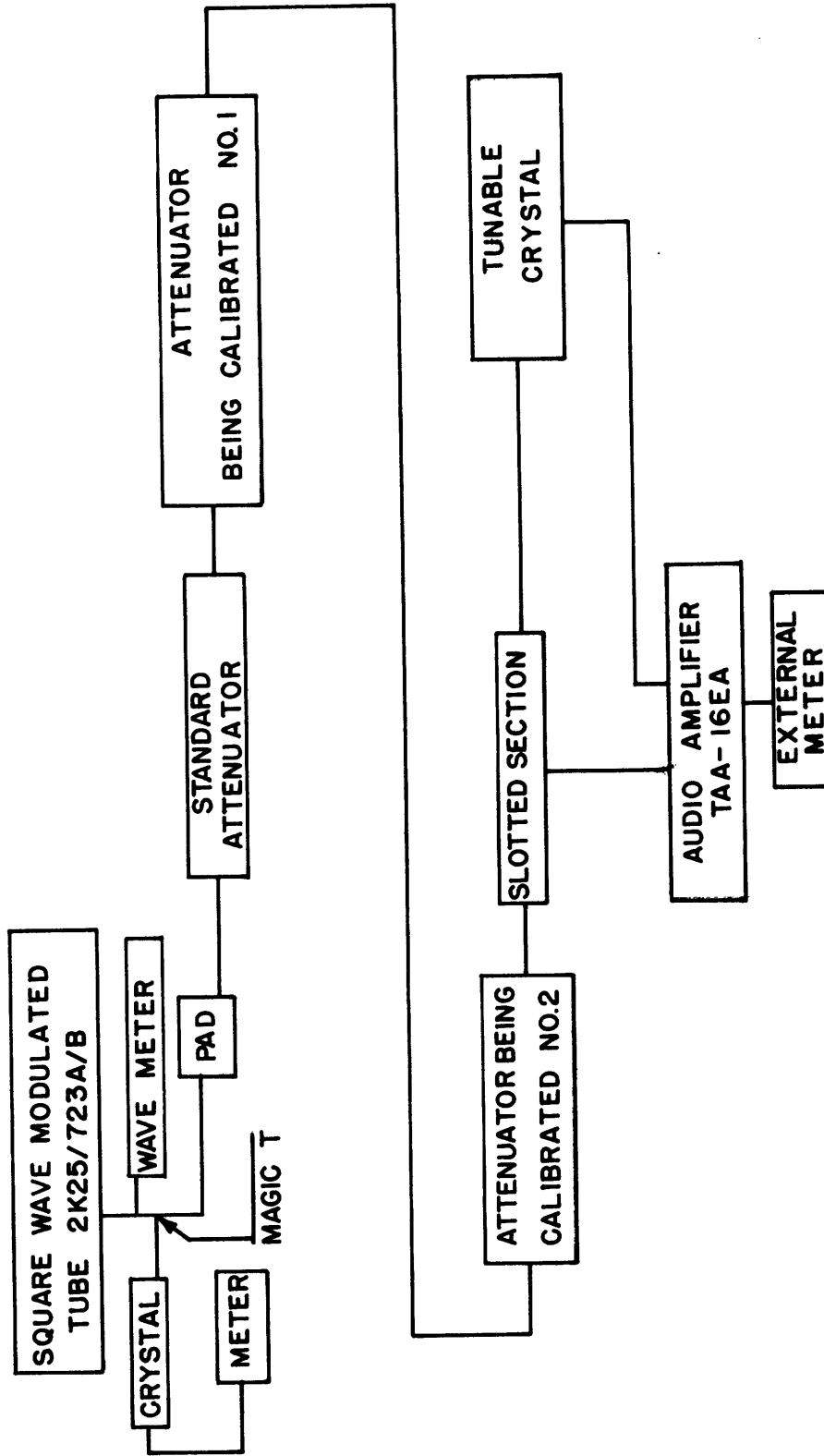
1.1 Modification. In order that the attenuator may be calibrated accurately, several simple changes are necessary. Already mentioned is the substitution of the large dial to permit more precise settings and readings. This dial rotates with the main shaft of the attenuator to which is connected a cam. Rotation of the cam drives a yoke to which the supporting pins of the glass plate mentioned above are attached. A strong spring always keeps the bearing against the cam so that there is little backlash. The changes include the fabrication of a new shaft for the cam, a brass plate on which to mount the dial unit, and a brass post to steady the mounting plate, as well as the substitution of some Allen-head screws for the slotted screws in the main knob so that these screws may be more securely tightened on the shaft. Additional markings can be made extending the scale from 100 to 120 to permit readings to be made over a larger portion of the dial. For a more complete description of these changes, see RLE Drawing D-64-A.

1.2 Calibration. The arrangement illustrated in Fig. 2 was used to calibrate the attenuator. The attenuation of the standard was set at 22 db. The crystal was matched to the line until the voltage standing-wave ratio in the standing-wave detector was less than 1.02. Care was taken to use the crystal at the same power level for which it was matched so that the r-f impedance would not be changed. The crystal was run at such a low power level that, when it was short-circuited, there was no noticeable change in the r-f match from the open-circuit value. Then the attenuator to be calibrated and the standard could be varied if the setting of the extra attenuator and the current through the crystal were always kept constant. The calibration of the unknown against the standard could thus be easily effected. Two or three unknown attenuators could be calibrated in the same setup by keeping the readings of those not in use at any particular instant at some fixed value.



(A) Metallized glass plate for attenuator, (B) polystyrene slug for phase shifter, (C) attenuator before alteration, (D) attenuator after alteration.

Figure 1



Block diagram for calibrating attenuator
Figure 2

CALIBRATION OF VARIABLE ATTENUATOR
TPX-27 GM/25 #42

○ = 8490 Mc/sec
X = 9000 Mc/sec
△ = 9575 Mc/sec

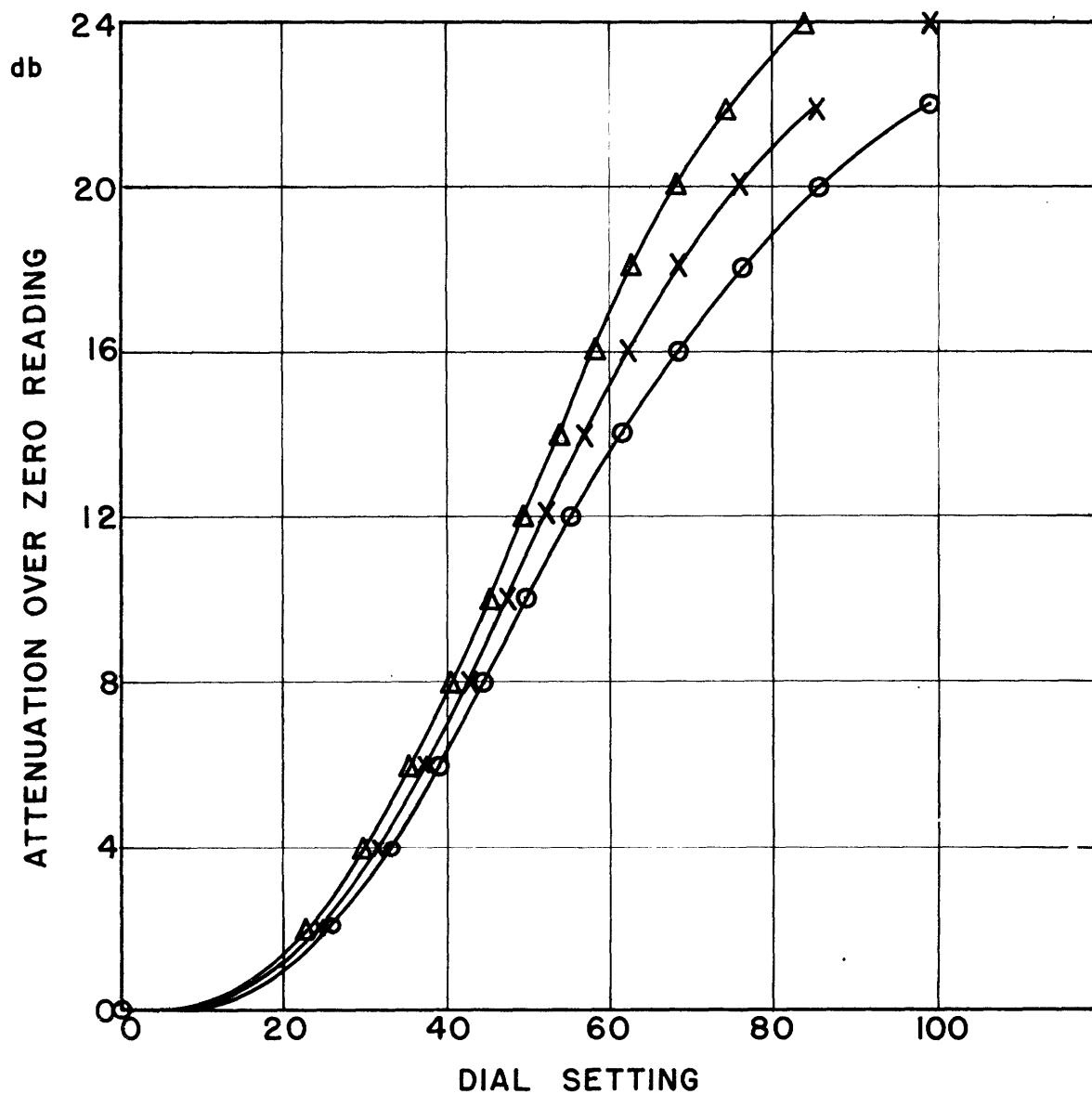


Figure 3

In a calibration procedure of this type the power into the crystal does not change, and the "law" of the crystal does not, therefore, affect the calibration. An external meter with a large scale was used to increase accuracy. Figure 3 shows a typical curve of attenuation vs. dial setting.

1.3 Test. The reflection due to the attenuator was determined by measuring the voltage standing-wave ratio when the attenuator was terminated by a matched load. With the attenuators tested, this ratio was less than 1.07 over the band for all positions of the glass plate.

2. Phase Shifter

2.1 Conversion of Attenuator to Phase Shifter. If the metallized glass plate of the attenuator is replaced by a polystyrene slug of the correct dimensions, the attenuator is converted into a phase shifter of the type described in RL Report 788. A few additional refinements and changes, however, should be made. A full-wavelength taper of the polystyrene may be used instead of the half-wavelength taper previously employed. A sketch of the polystyrene slug is shown below. The voltage standing-wave ratio introduced by a phase shifter of this type is found to be less than 1.15 over

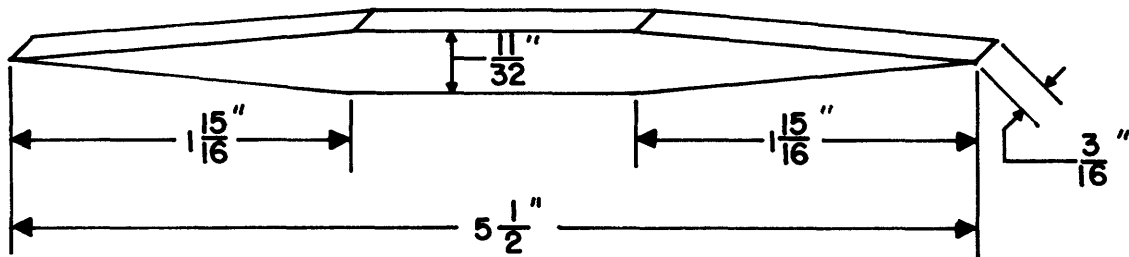


Figure 4

the frequency band, 8490 to 9575 Mc/sec. If the dial reading is kept at less than 100, however, the voltage standing-wave ratio will be less than 1.13. A half-wavelength phase shift is still possible. The taper is made symmetrical instead of with a single slope to reduce the possibility of contact between the end of the polystyrene and the top or bottom of the waveguide when the slug is moved back and forth. In the phase shifter described in RL Report 788, the metal pins that support the polystyrene slug go all the way across the waveguide, but for this type of phase shifter the pins should go only part way across the waveguide.

2.2 Study of Extraneous Resonances: When the first phase shifters were made as described, sharp dips occurred in the power transmitted as the polystyrene was moved back and forth. These dips were assumed to be due to resonances and further investigations of their nature were made.

In one study of the resonance, the polystyrene slug was removed and only one pin was used. It was thus determined that the resonance may occur when the top half of the waveguide is not symmetrical with the bottom half at or near the place where the metal pin is inserted in the side of the guide. In this case there may be excited

in the waveguide a mode with one component of the E-vector parallel to the pin. A resonance then occurs for two positions of the pin, one when the pin is about a quarter-wavelength long and the other when the pin is three quarter-wavelengths long. The lost power is not all reflected but a great deal of it is absorbed. On one measurement of the resonance a 21 per cent loss in transmitted power was found, whereas the loss due to reflected power was measured as only 1 per cent (VSWR = 1.2). This resonance was caused by a brass rod, 4 in. long, 1/16 in. in diameter, lying along the inside corner of the waveguide (and therefore causing asymmetry) and a pin sticking in the side of the waveguide. No resonance would occur if the rod were not there. A rough sketch showing the arrangement is given in Fig. 5.

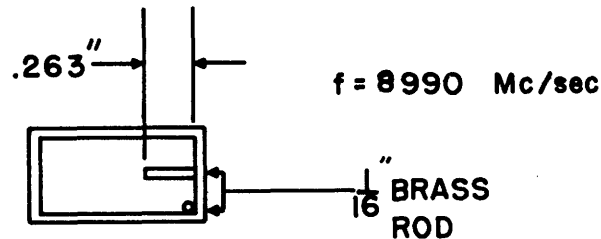


Figure 5

Resonance may also be caused by the asymmetry that is present when a polystyrene slug does not have the holes drilled in the exact center of its face. If dielectric instead of metal supporting pins are used, the trouble with the resonance does not occur. Resonance can also be caused by a single metal pin. If two pins of slightly different lengths are used (as in a phase shifter of the early design), there will be two resonances close to each other as the two are moved back and forth together and as each assumes the proper length. If one metal pin is inserted to a different length and the other is unchanged, the dial setting for one of the resonances will change but that for the other will remain the same; from this observation, one would conclude that the resonance is not an inter-pin effect.

For the purpose of determining the positions of the pins, the linear motion of the yoke was calibrated against rotation of the dial. The displacement was found to be nearly linear with angle, a change of one division on the dial corresponding to about .0021 in. of movement of the yoke. A calibration curve of the motion of the yoke of a special test piece with a standard cam as a function of the dial setting is shown in Fig. 6. In this graph the best straight line is drawn through the points so that the departure from linearity can be easily perceived. For computational purposes, however, the best smooth curve through the points was drawn and used.

The following procedure was used to determine the properties of the resonance. A metal pin was threaded for about an inch of its length and screwed into the polystyrene slug so that it could be adjusted for various penetrations through the slug. The slug was then put into the waveguide and the pin threaded into the polystyrene for various distances. When the polystyrene slug touched the wall, the dial was set at a fixed value and the pin clamped in the yoke. Then the dial was turned until resonance was obtained. This action moved the slug and the pin together, and from the amount that the dial was turned, the distance which the slug was moved away from the wall was easily found. When this distance, together with the length of the pin

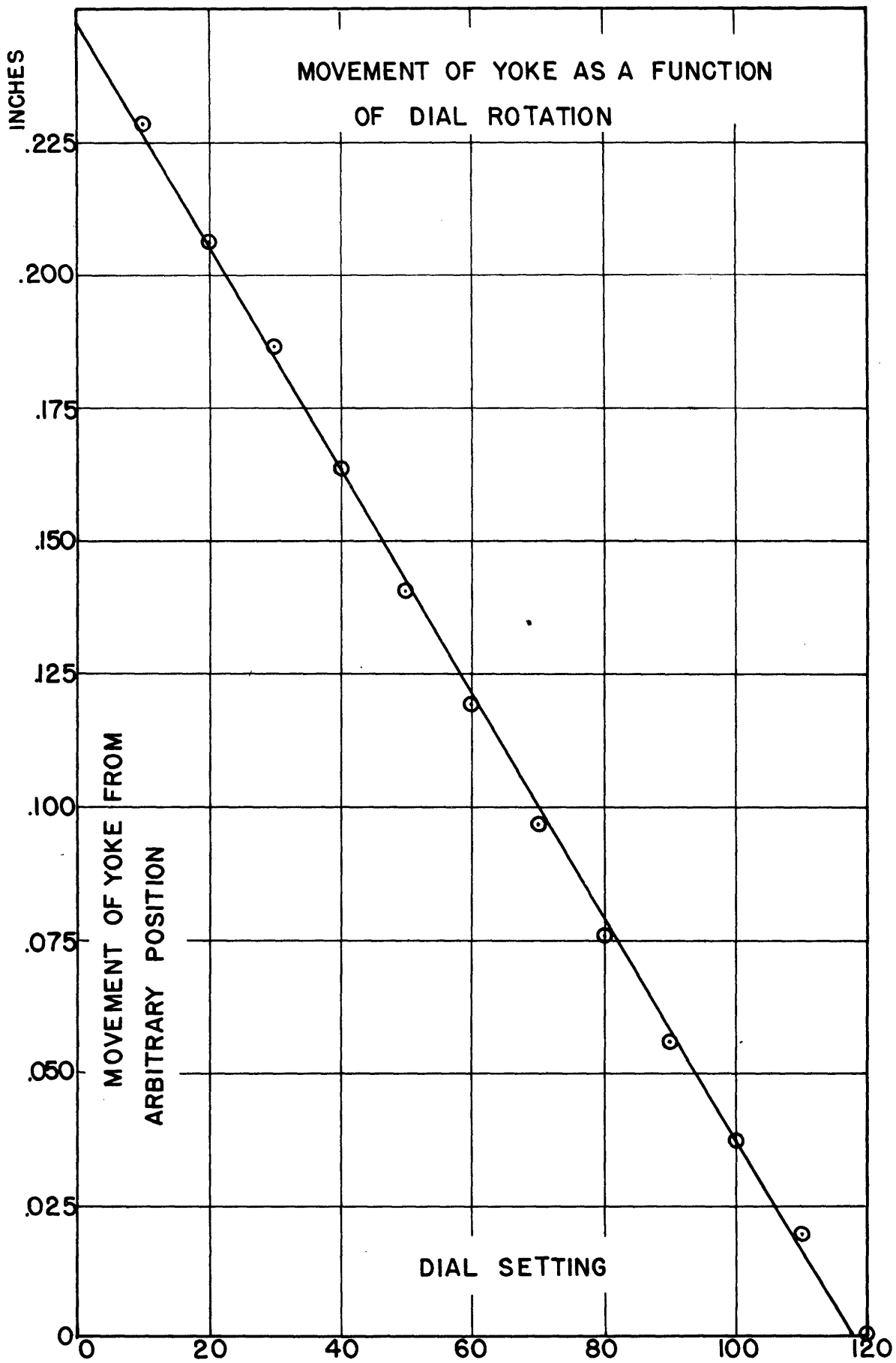


Figure 6

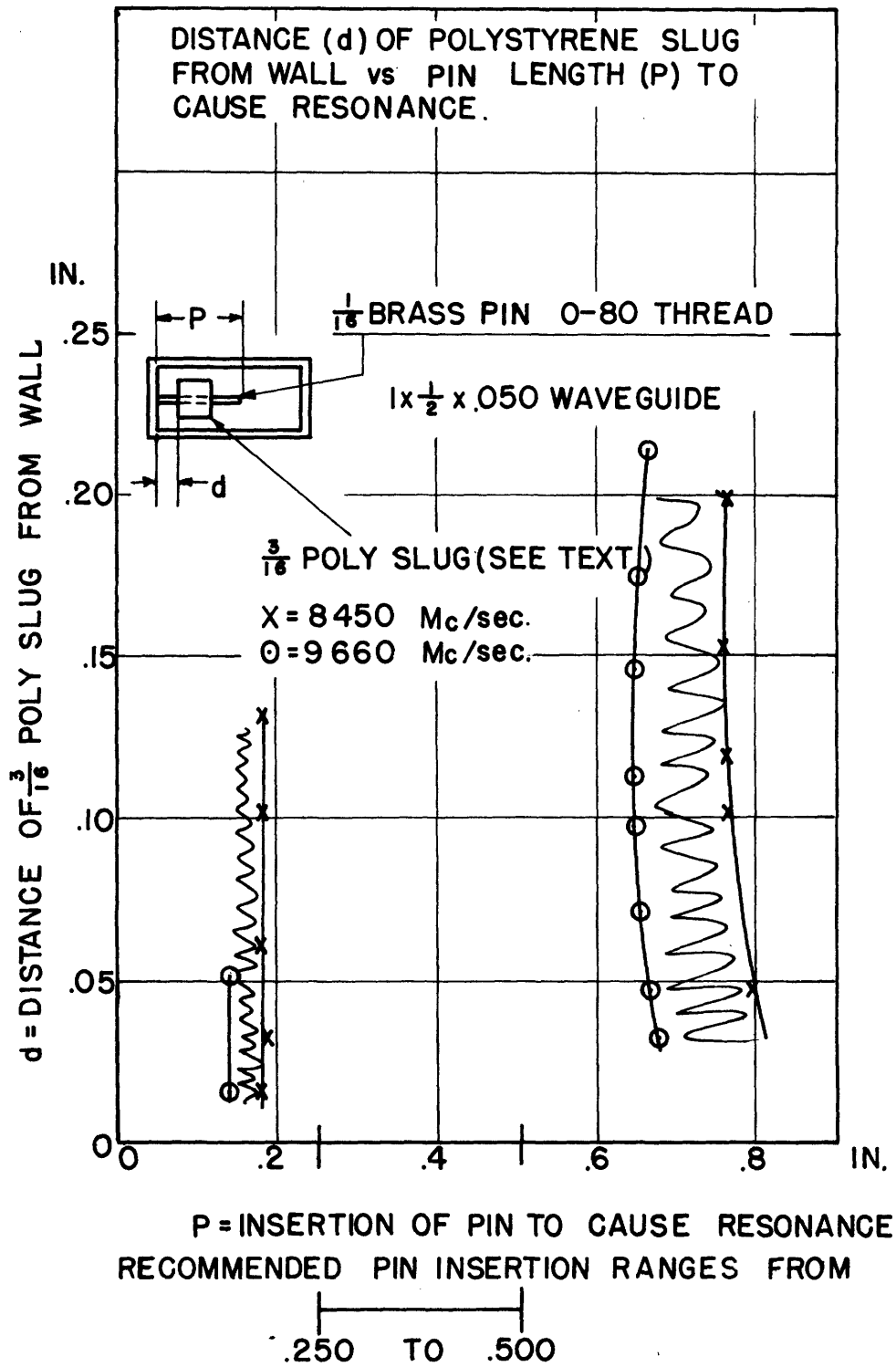


Figure 7

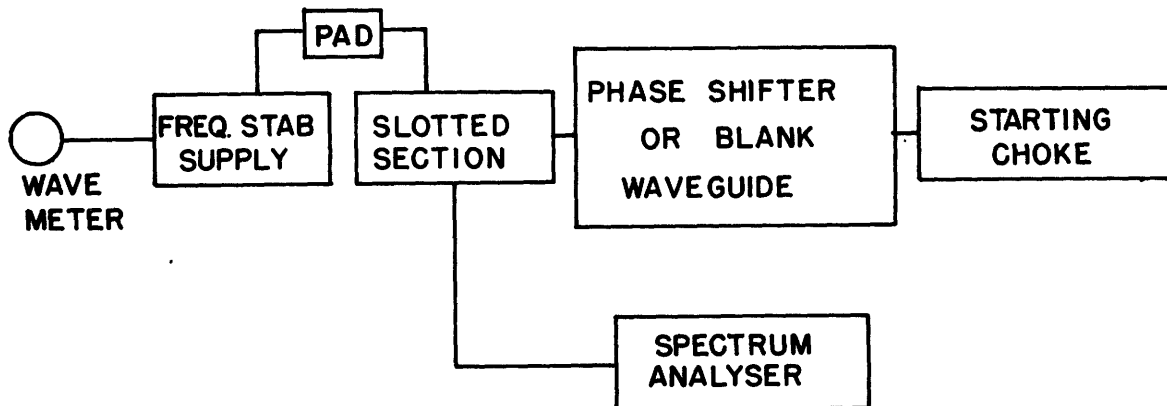
protruding from the yoke was known, the distance that the pin stuck into the guide at resonance could be determined. The latter measurement was found as a function of the slug position for frequencies at the ends of the frequency band, 8490 to 9575 Mc/sec.

In Fig. 7 are plotted the results of these investigations. Shown is a plot of the distance of the polystyrene slug from the wall as a function of the length of the pin sticking into the guide when resonance occurs. If the pin stuck into the guide for 0.900 in., it would, of course, go all the way across the guide. The curves for a given frequency are very nearly vertical straight lines. If they were exactly vertical lines, the position of the polystyrene slug would not affect the length of the pin necessary for resonance. As can be seen from the graph, this is nearly the case. The areas between the curves shown represent the regions in which the curves would lie for frequencies between those for which the observed curves were taken. A rough sketch of the cross section of the phase-shifter test piece is also shown in the figure. It is to be noted that for each frequency and position of the slug, there are two lengths of insertion of the brass pin which may cause resonance. A first mode occurs when the metal pin is essentially a quarter-wavelength long and a second mode occurs when the metal pin is essentially three-quarters of a wavelength long.

The total excursion possible when the cam is used is 0.250 in., and the phase shifters are fixed so that the polystyrene slug is next to the side wall nearest the yoke at one end of its run. Therefore, if the brass pin is threaded into the polystyrene a distance of 0.100 in., for instance, the insertion of the metal pin will vary from 0.100 in. to 0.350 in. and the device will almost certainly resonate in the second mode.

The recommended method of avoiding the resonance is to thread the brass pin for 1/4 in. of its length and to screw it all the way into the polystyrene. Since the polystyrene is 3/16 in. thick, 1/16 in. of the pin will protrude from the other side of the polystyrene. The range of values of insertion of the metal pins will then vary from 1/4 to 1/2 in. For all frequencies used and for all the positions of the polystyrene slug, these values are greater than those that will cause the first mode to occur and less than those that will cause the second mode to occur. Several phase shifters have been made with these precautions observed and they are all free from resonance. Dielectric pins can be used, but, if they are made strong enough, they are of such large diameter that they introduce too much reflection.

2.3 Calibration of the Phase Shifters. The phase shifters were calibrated at three different frequencies; namely, 8490, 9000, and 9575 Mc/sec. Figure 8 shows a block diagram of the calibration setup. If a frequency-stabilized oscillator were not used, the change of impedance seen by the tube and caused by the variation of the phase shifter would pull the operating frequency by as much as 2 or 3 Mc/sec., and the calibration would therefore be inaccurate. The frequency of the oscillator was set at the proper value and the slotted-section probe adjusted so that the power picked up by the probe was shown on the spectrum analyser.



Block diagram for calibrating phase shifter

Figure 8

The following procedure was used for the calibration:

- a. A piece of empty waveguide of the same physical length as a phase shifter and with the same end fittings was connected to the slotted section with a short-circuiting choke on the far end. From two positions of the minimum in the slotted section, the guide wavelength in the slotted section was found for these conditions.
- b. A computation was then made of the new positions at which the minimum would be observed when the blank waveguide would be replaced by a phase shifter with the polystyrene slug in such a position as to give the chosen angles of phase shift.
- c. Next, one of the phase shifters was used in place of the blank waveguide. The probe in the standing-wave detector was set at each of the computed values, the position of the slug to give this value of phase shift was found, and the corresponding dial reading recorded.

This procedure was performed at a single frequency. The process was then repeated for two other frequencies, and curves were drawn of the phase shift as a function of the dial setting for the various frequencies. A sample curve is given in Fig. 9. Individual curves are made for each phase shifter to a more accurate scale. In order to avoid crowding the graph, the curve for 9000 Mc/sec. was not included, but it lies between the other two.

The setting for the zero reading of the phase shifter was found and the phase shift from that of the blank waveguide was computed as previously indicated.

CALIBRATION CURVE FOR PHASE SHIFTER # 443

○ = 8490 Mc/sec

△ = 9575 Mc/sec

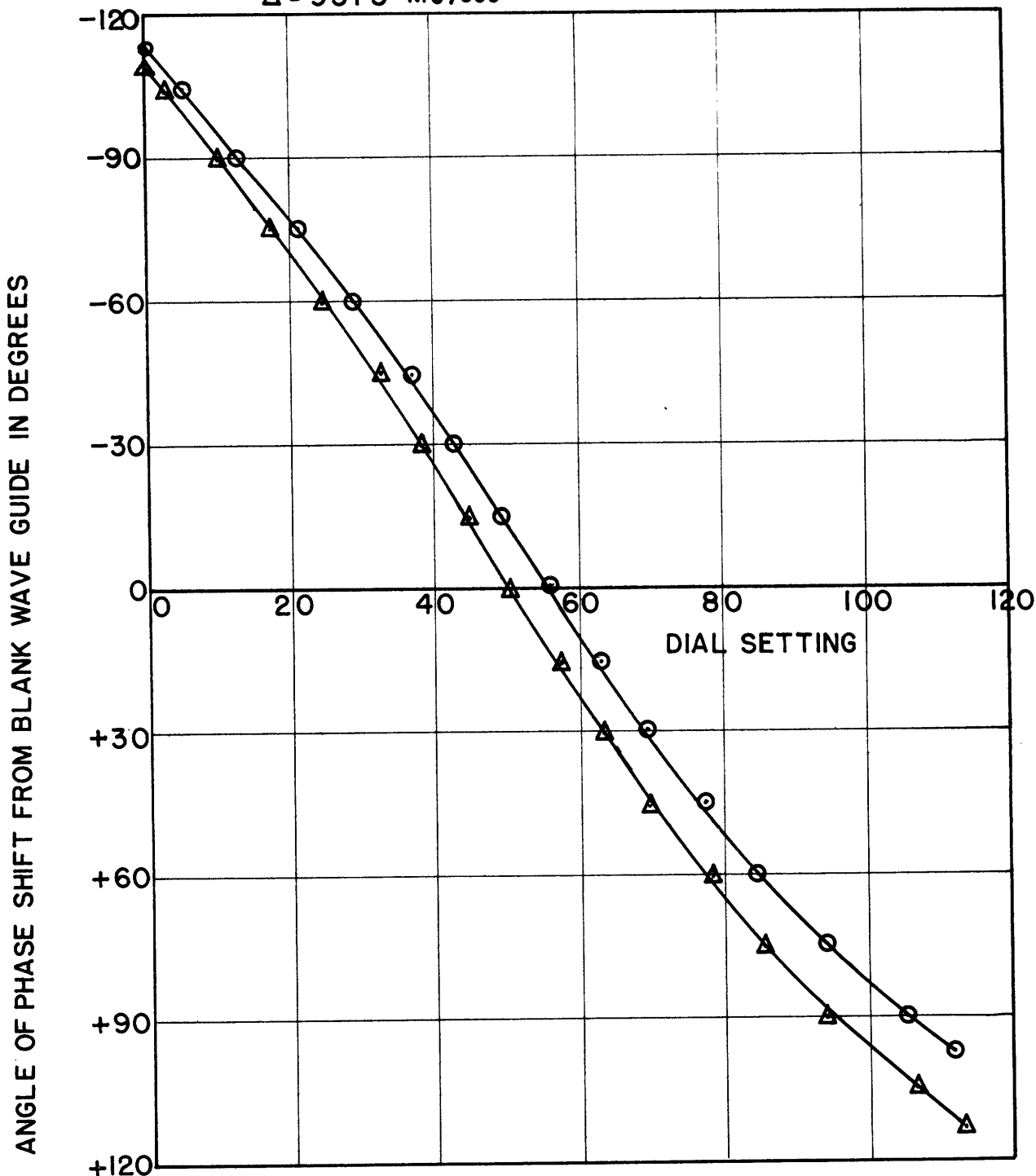


Figure 9

A typical calibration tabulation follows.

$f = 8490 \text{ Mc/sec.}, \lambda_0 = 3.53 \text{ cm}$

Blank waveguide

minimum at 15.22 cm

9.65 cm

$5.57 \text{ cm} = \lambda_g = 360^\circ$

$15^\circ = 0.23 \text{ cm}$

$30^\circ = 0.46 \text{ cm}$

$45^\circ = 0.70 \text{ cm}$

etc.

Phase shifters in place

Angle of phase shift from blank waveguide	Position of minimum (cm)	<u>Dial Settings to give this minimum</u>		
		<u>P. S. 392</u>	<u>P. S. 443</u>	<u>P. S. 447</u>
		0.0 = dial 11.54 = minimum 122° = phase shift	0.0 = dial 11.41 = minimum 114° = phase shift	0.0 = dial 11.48 = minimum 118° = phase shift
120°	11.51	2.1		
105°	11.27	9.8	5.1	8.8
90°	11.04	17.6	13.0	17.1
75°	10.81	26.2	21.2	25.2
60°	10.58	33.4	28.3	32.8
45°	10.35	41.1	37.1	40.0
30°	10.11	47.7	43.0	46.8
15°	9.88	55.0	49.3	53.7
0°	9.65	61.9	56.2	60.1
15°	9.42	69.3	62.7	67.3

The dials could usually be reset to within at least 0.3 division or about 0.6° .

