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T.R.E. REPORT

No. T 1473

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Unit T.R.3539, using the Power Klystron CV.150.

LIST OF FIGURES

1. SUMMARY

This report describes some of the experimental work carried out at TRE in connection with the Unit - TR3539, operating on 9.2 to 9.6 cm, and designed for use in Oboe Mark IIB. The new components used in the box are also described, viz. The Pulse Klystron CV.150, The Soft Gas Switch CV.157, and a modified crystal mixer.

The performance under experimental conditions has been measured. About 15-20 KW peak power are obtained with 4 μsec. pulses at a maximum repetition rate of 133 per second, or the equivalent mean power. An effort has been made to estimate the effect of aerial mismatch upon the performance, from which it is apparent that very careful aerial design is necessary if the system is to function efficiently.

2. INTRODUCTION

No new principles are used in the design of this circuit, but owing to the difficulty of coupling out of a power klystron by means of a loop, especially at high altitudes, it was decided to use a wave-guide feed out of the klystron. It then became convenient to substitute for the convential concentric line a wave-guide T.R. switching unit, using soft gas switches of the type which have been developed for higher powers on magnetron equipments, and to transform to cable only on leaving the box.

The work was carried out under pressure for service reasons, and the experiments are incomplete in some respects. It should be emphasised that the box was not designed as a Universal Unit, although where possible it has been made interchangeable with the projected Universal Klystron Box.

The klystron with its resonator circuit was developed by Messrs. E.M.I. The layout and engineering of the box were the responsibility of the Gramophone Co.

The same R.F. circuit has been adopted by the General Electric Company for their ground station, except that they have used their own mixer. It is described in G.E.C. Report No.8253, which also gives a procedure for setting up the circuit.

3. GENERAL DESCRIPTION OF THE CIRCUIT

A simplified circuit diagram is given in Fig.1, while Fig.2 shows the special arrangement of the most important components.

The klystron feeds directly into the end of the wave-guide with no matching device other than the special resonator window.

The gas switches V2 and V3, one quarter wave apart, are the familiar "T.R." and "anti-T.R." switches. Switch V2 (anti-T.R) is closely coupled to the guide by a window in the guide wall $1\frac{1}{2}$" long by $\frac{5}{8}$" wide and exists to prevent the received signal dissipating itself in the klystron resonator. The valve V3 is more loosely coupled by a window 1" x $\frac{5}{8}$" and protects the crystal from injury during transmission.

The mixer is adapted from the fixed 9.1 cm mixer, but one tuning adjustment has been restored to deal with the very wide impedance variations which have been found in yellow spot crystals (CV.101).

The local oscillator, CV.158, is tunable by remote control by means of an Admiralty motor pattern 9298 Mk.X. All other tuning controls must be set up on the ground.

The pulse transformer has a step up ratio of 1.5:1, and is adapted to 4 μsec. pulses. The box must be driven by a 7.8 KV. pulse.

The head amplifier has one stage on $14\frac{1}{2}$ Mc/s and a band-width of 10 Mc/s.

4. THE PULSE KLYSTRON CV.150

(a) The CV.150, which is described in E.M.I. Report No.RF/137 is of the double gap single beam transit type.

Fig. 3(a) and (b) show a cross-section through the catcher, and the plate by which the klystron is bolted to the guide. This type of window gives almost maximum power into a $2\frac{1}{2}$" x 1" rectangular wave-guide without pulling the resonator frequency seriously. The small amount of pulling is taken up by channelling the buncher resonator as shown in Fig.3(c).

Each resonator is tuned by five spring-loaded plungers. The tuning is flat, and it is not difficult to put the valve into oscillation.

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The results described in sub-paragraphs (d) and (e) were obtained with a type 64 modulator on 1 μsec. pulses and with a special pulse transformer because the Oboe modulator was not available. They cannot therefore be regarded as final.

(b) Rating

Peak Power Input	150 KW.
Peak Power Output	18 KW.
Heater Voltage	13
Heater Current (max)	2.2 amps.
Cathode Voltage	-12.5 KV pulsed.
Resonator Current	6 amps.
Collector Current	6 amps.
Wave-length coverage	± $2\frac{1}{2}$ mm. centred on 9.4 cms.
Maximum mean input power	80 watts

(c) Frequency stability

The frequency changes about 6 mc/sec. for a voltage change of 1 KV., at 12.5 KV. On warming up the frequency changes by about 3 mc/sec. during the first 15 minutes, and thereafter remains steady. The frequency is also seriously affected by the load presented by the aerial. This point is referred to under paragraph 3(b) below.

(d) Matching

For maximum power output the klystron requires a standing wave of about 1.5:1 in volts with a voltage minimum at the resonator opening. Into a matched guide it delivers about 90% of its maximum power.

(e) Power Output

On the type 64 modulator with about $12\frac{1}{2}$ KV on the cathode and a pulse recurrence frequency of 490 the following powers were measured in a correctly matched water calorimeter. Owing to the low temperature difference observed the mean power may be in error by 10%. This valve was rated by the makers at 17 KW, and considering the difference in conditions these results agree well enough at the lower wave-lengths:-

λ = 9.16 cm	Peak Power = 15.2 KW
λ = 9.30 cm	" " = 15.2 KW
λ = 9.55 cm	" " = 12.3 KW

(f) Cold Resonance

Some measurements have been made on this with the experimental arrangement shown in Fig.4. A signal of variable frequency is fed into the klystron, and the standing wave and minimum position in the guide are noted. From these figures the normalised impedance (in terms of the guide impedance) presented by the klystron are calculated, the point of reference being the surface of the plate.

A typical set of results is shown in Fig.4. The peak at 3230 Mc/s is due to the catcher, and that at 3322 Mc/s to the buncher.

The two peaks are not quite independent of each other in position or height. The exact relative positions of the centre of the catcher peak and the transmitted frequency are liable to vary, and it is this which makes the second gas-gap necessary.

5. THE MIXER

(a) Necessity for Modification

It was found, on removing the loop from the present fixed mixer use on 9.1 cm equipment (see TRE Drg. B100/7974), that very large variations impedance were measured when different crystals were inserted in the mixe This effect was traced chiefly to the large variation in the reactive par of the crystal impedance. Rough calculations show that, after allowing for the inductance of the loop, the coupling into the rhumbatron will be greatest when a crystal of low or negative reactance is used, and will fa off by a factor of about five when a high reactance crystal is used. We should therefore expect that, on an average, low reactance crystals would give a good apparent sensitivity but be liable to burn-out, while high reactance crystals would appear to be several db. below the best possible figure.

It was therefore decided to redesign the mixer so as to match out the reactive part of the crystal impedance, and make use of the fact that the resistive part is usually within ± 20% of the mean. There are several methods of doing this: the one adopted involved a minimum of experimentat and used a large number of machined parts from the old mixer, but it has the disadvantage of adding a tuning control in the mixer itself.

(b) R.F. Impedances of Yellow Spot Crystals, CV.101

The crystal impedances were measured in the head of the mixer, which was not modified in any way. The crystal arm was removed from the mixer and attached directly to a 75 ohm impedance meter. In all cases the outpu from the signal generator was adjusted until the crystal current was 0.3 mA This procedure involves the assumption that the impedance measured when the signal is sufficiently strong to cause a crystal current of 0.3 mA is the same as when the signal is small and the crystal current is drawn from the local oscillator.

The impedance is calculated at a point level with the spot on the crystal, when as shown in Fig. 5(b) the resistive part is found to be nearly constant.

(c) The Modified Mixer

The essential features of the modified mixer are shown in Fig. 5(a). For details, the drawings of Gramophone Co., should be referred to.

The distances from the crystal spot and from the loop to the centre of the block are both one quarter wave-length. It is thus possible for the st to tune out the reactances of both the crystal and the loop, and for an impedance equal to the real part of the crystal impedance to be presented to the gas switch. This mixer has shorter arms and a smaller loop than the old The loop is made by bending a portion of the outer wall round a jig and soldering to a projection on the inner. All dielectric spacers have been eliminated from the inside of the mixer. The tuning stub makes use of a moveable polythene slug in a 120 ohm line. This is free from contact troubles but is only just able to take up the variations in crystal impedance

The loop size, in the absence of special measuring gear, was arrived at by trial and error. Protection was tested directly by running a number of crystals under operating conditions. The length of the tuning stub could then be calculated, and a final adjustment made by experiment.

It is worth noting that if the crystal impedance rises under pulse conditions theprotection increases, an effect noted in the Radiation Laboratory Report 53-11, and also that detuning the mixer can only increase the protection to the crystal. (See Appendix (e)).

6. THE GAS SWITCH CV.157

(a) Description

The CV.157 is a soft gas switch designed to be coupled directly to a wave-guide and thus closely resembles the Admiralty valves CV.106 and 107.

It differs from CV.106 in three important respects.

(i) The frequency which is tunable from 3140 Mc/s to 3250 Mc/s.

(ii) The size of the aperture connecting it to the guide. This is as large as is mechanically possible, ($1\frac{1}{2}$" long by $\frac{5}{8}$" across) and the coupling to the guide is reduced where necessary by having a smaller window in the guide wall.

(iii) The diameter of the resonator which is 46 mm. instead of 43 mm. in CV.106. This increase in size is not an advantage.

The CV.157 is designed for small scale production only, and it is hoped to replace it by a die-cast version which will have parts in common with other gas switches. The resonator of the valve is shown in TRE drawings CRT.19112, ATR.19108-9-10-11. The four 2 B.A. holes in the base plate correspond with those in CV.106, in order that the valve may be used in Admiralty Equipment if desired.

(b) The Admittances of CV.157 when attached to the edge of the Wave-guide.

For purely mechanical reasons it was decided to couple the CV.157 to the edge of the guide. In this position the coupled admittance of the rhumbatron acts in parallel with that of the guide. The normalised admittances can be measured either by matching the guide or by terminating it with a stub of known (preferably zero) susceptance as shown on Fig.6. If the frequency of the signal is kept constant and the tuning plungers are moved, the measured admittances lie on a circle similar to that shown on Fig.6. The plotting of these circles is often of use, since it enables a number of observations, each one of which may be inaccurate, to be correlated. The results given here were all taken using a crystal standing wave detector and assuming the square law. As very large standing waves are sometimes measured there may be considerable systematic errors.

Size of Aperture.	Diameter of Circle.	Approx. height of Centre above Real Axis
$1\frac{1}{2}$" x $\frac{5}{8}$"	15-20	0.7
1" x $\frac{5}{8}$"	5-6	0.1

See Appendix (c)

(c) The Use of CV.157 as "Anti-T.R." Switch

The "Anti-T.R." switch, when properly tuned, is almost equivalent to a short circuit across the guide, and the klystron impedance in parallel with it can only increase the effectiveness of the short circuit. One quarter wave away, therefore, where the "T.R." switch and mixer are matched into the guide, we have the equivalent of a resistance > 15 in parallel with unit resistance, and the theoretical loss will be < 0.3 db.

(d) Use of CV.157 as "T.R." Switch

(i) Matching. The coupling between mixer and rhumbatron is fixed by considerations of protection (see para. 5c). It remains therefore to choose the size of the coupling hole so as to give the best match into the guide under conditions of reception. This cannot be done accurately for all crystals because their impedances vary but neither is it very important, a mis-match of less than 2:1 be acceptable. The best size of hole was found to be 1" x $\frac{5}{8}$". In one experiment with this arrangement when thirteen crystals were tried, whose reactances varied from -0.4 to +1.1, the standing wa ratio in the guide varied from 1.4 to 1.6 in volts.

(ii) Signal Dissipated in Rhumbatron. The loss in the T.R. switch is not easy to measure directly with any accuracy but it may be obtained by a simple calculation from results given in paras. 6(b) and (d). The maximum resistive impedance of the gas switch when loaded by the mixer and coupled by a hole 1" x $\frac{5}{8}$" is nearly unity, while without the mixer it is $5\frac{1}{2}$. It follows that the ratio

$$\frac{\text{Power lost in Rhumbatron}}{\text{Total Power}} = \frac{1}{5.5}$$

corresponding to a loss of 0.9 db. (see Appendix (d))

(e) Distance Apart of the Two Switches

Although the two switches are so close together that the apertures actually overlap, it was not possible to detect any direct coupling between them. The distance apart is not critical, and the arrangement is not frequency sensitive over the tuning range of the klystron.

7. THE WAVE-GUIDE TO CABLE TRANSFORMER

A special moulded probe transformer ending in a standard high power plug and matching into 63 ohms was developed. This is shown in TRE drawing CRT.17329. The matching necessitates the exact determination both of the length of the probe and the position of the plate, but once these are fixed a probe of this type is useful over quite a large frequency band. Six models of this have been tested between 8.9 and 9.6 cms, and they produce standing waves better than 1.2:1 in volts over this band.

8. PERFORMANCE OF THE COMPLETE R.F. CIRCUIT

(a) Power Output into a matched load

The switch system under transmitting conditions produces a small standing wave (1.2 in volts), because although the switches are a quarter-wave apart their apertures are not the same. The klystron was placed at the voltage minimum of this standing wave system, 7.5 cms from the centre of the "anti-T.R." switch. The output power was then measured at the same frequencies as those of para. 4(c). The power was never decreased by more than 0.4 db. by the failure of the switch system to meet exactly the conditions of para. 4(d).

(b) Altitude Test The whole box has been tested by the Gramophone Co., at low pressure, and found to withstand the equivalent of about 40,000 ft. Breakdown first occurs between the cathode and resonator of the CV.150.

(c) Effect of Aerial Mismatch on Transmitted frequency and Power

To test the effect of badly matched aerials on the transmitter performance the output probe was removed and a matched guide substituted. A trolitul slug was then moved to and fro in the guide, producing a standing wave of variable phase. The results are summarised below.

	Slug A Standing wave 2.15:1 in volts	Slug B Standing wave 1.47:1 in volts
Maximum frequency pulling from frequency delivered into Matched Load.	+ 7 Mc/s - 5 Mc/s	± 3 Mc/s
Maximum drop in output power.	32%	22%.

These figures show that a really badly matched aerial may easily halve the output power, while if as the aerial scans the phase of the standing wave changes, the transmitter frequency may be pulled right out of the receiver band-width. It should be stated that measurements on magnetrons reveal effects of the same order, and the figures above do not imply a defect peculiar to the CV.150.

It cannot however be too strongly emphasised that careful aerial matching is essential if T.R.3539 is to give its best output.

AH/WJW/WAS
15th August 1943

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APPENDIX

Equivalent Circuit of Gas Switches and Mixer. Formulae.

(a) Figure 7(a) shows a proposed equivalent circuit for the whole R.F. system and mixer on reception. Most of it is self-explanatory but the following points require comment.

(i) L_3 and L_4 represent the windows coupling the switches to the guide. There is some theoretical justification for regarding a window on the edge as equivalent to a purely inductive coupling.

(ii) The presence of the quarter-wave transformers joining L_3 and L_4 to the guide is best understood, at any rate qualitatively, by considering the currents flowing in the walls of the guide. A diagram of these is reproduced in figure 7(b). It will be noticed that the current maximum on the edge of the guide is opposite the current minimum at the top, i.e. the currents on edge and top are 90° out of phase. If we regard the coupling between the guide and the cavity as due to the sharing of current between them, we see that a window-coupled cavity at B is roughly equivalent to a similar one on the top at A. Now the cavity at A would produce some impedance Z_c which would be in series with the guide impedance Z_g, i.e. the impedance measured at A would be $(Z_c + Z_g)$ and also would the admittance measured at C. Z_g is of course equal to the guide admittance measured at C, if the window is removed from A to B. Thus the admittances of a window on the edge would follow similar laws to the impedances of a window on the top. Its admittance must be added to the guide admittance as measured at a point opposite the window. It therefore, appears to be in parallel with the guide.

(iii) Part of the system is composed of 75 ohm concentric line and part of wave-guide whose characteristic impedance is unknown. We define all impedances in terms of the guide impedance. As a result, while we can measure the ratio of K_2 to the rhumbatron or mixer impedances, we cannot find the absolute value of either.

(iv) All elements in Figure 7(a) are regarded as lumped impedances unless marked with a length.

(b) Z_1 is the mixer impedance measured across AB.

$Z_2 = R_2(1 + 2jQ\delta)$ is the impedance of the rhumbatron.

(where Q refers to the cavity)

$\delta = \dfrac{\omega - \omega_0}{\omega_0}$ being a measure of the difference between the resonant frequency of the cavity and the actual frequency.

Z_3 is the impedance measured across CD looking into the gas switch. This is of course equal to the admittance measured at EF.

$X_1 = \omega L_1$

$X_2 = \omega L_2$

K_1 and K_2 are the coupling impedances, taken as purely imaginary.

Then

$$Z_3 = jX_3 + \frac{K_2^2}{Z_2 + \left(\dfrac{K_1^2}{Z_1 + jX_1}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

But as explained in paragraph 5(c), the mixer can be tuned until $Z_1 + jX_1$ becomes resistive, and can be written as R_1.

Hence (1) becomes

$$Z_3 = jX_3 + \frac{K_2^2}{R_2 + \dfrac{K_1^2}{R_1} + 2jQ\delta R_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

(c)/

(c) If δ is varied the locus of Z_3 on the Argand diagram is a circle of the type shown in Figure 6, with its centre a distance X_3 above the real axis and a diameter given by

$$D = \frac{K_2^2}{R_2 + \frac{K_1^2}{R_1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Evidently if the mixer is not present the diameter is

$$D_1 = \frac{K_2^2}{R_2}$$

(d) The ratio of the power lost in the rhumbatron (p) to the total power (P) fed into the rhumbatron

$$\frac{p}{P} = \frac{R_2}{R_2 + \frac{K_1^2}{R_1}} = \frac{D}{D_1}$$

(see para. 6(d))

(e) If the mixer is not correctly tuned the term $\frac{K_1^2}{R_1}$ in (2) must have a reactive term added to it. This can only decrease the power absorbed by the mixer and hence increase the protection to the crystal. (see para. 5(c)).

We are greatly indebted to Dr. Starr for help in preparing the matter of this appendix.

WJW/WS
23.8.43

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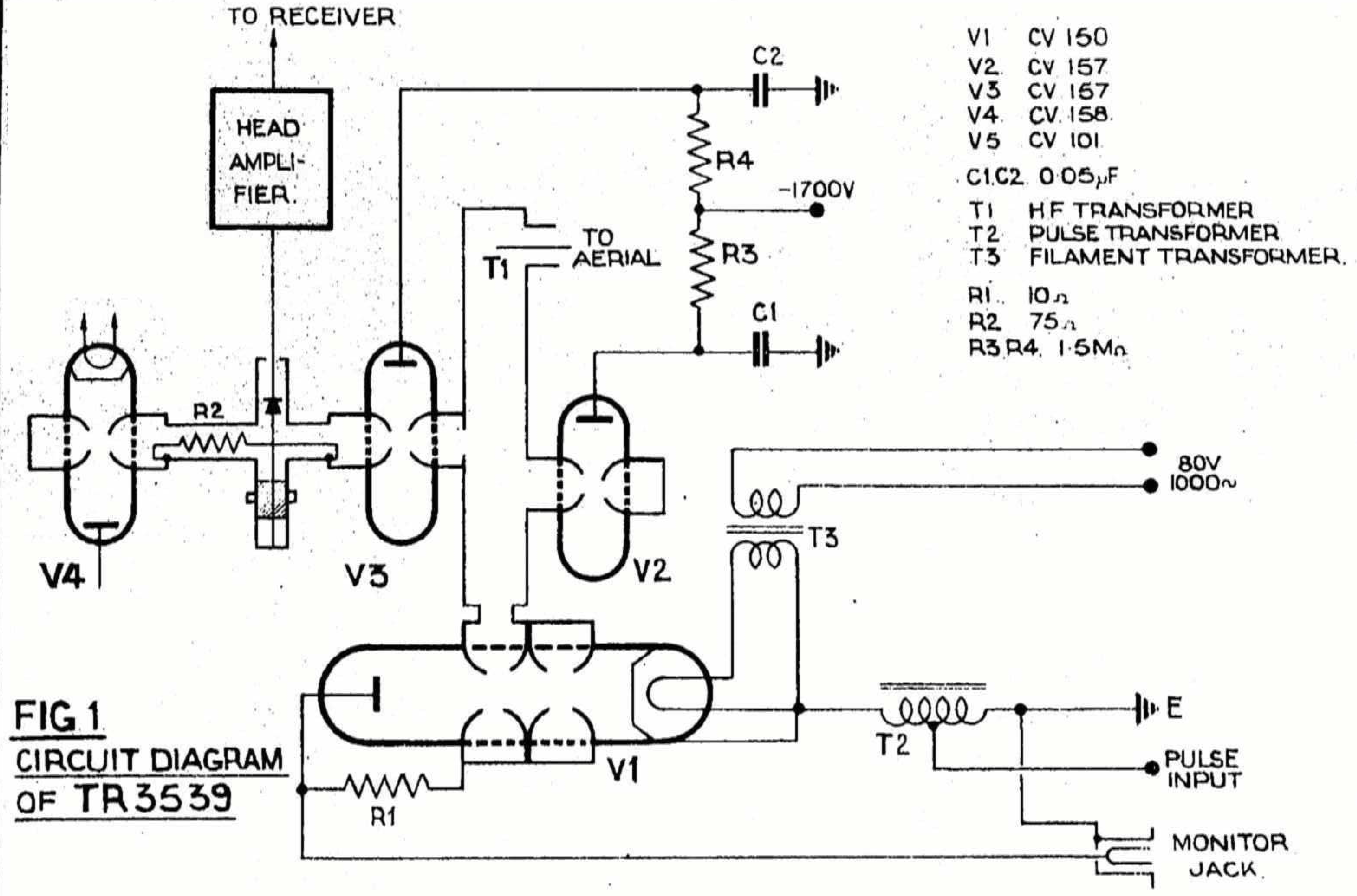

FIG 1
CIRCUIT DIAGRAM
OF TR3539

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TITLE:
FIG.1 CIRCUIT DIAGRAM OF TR3539

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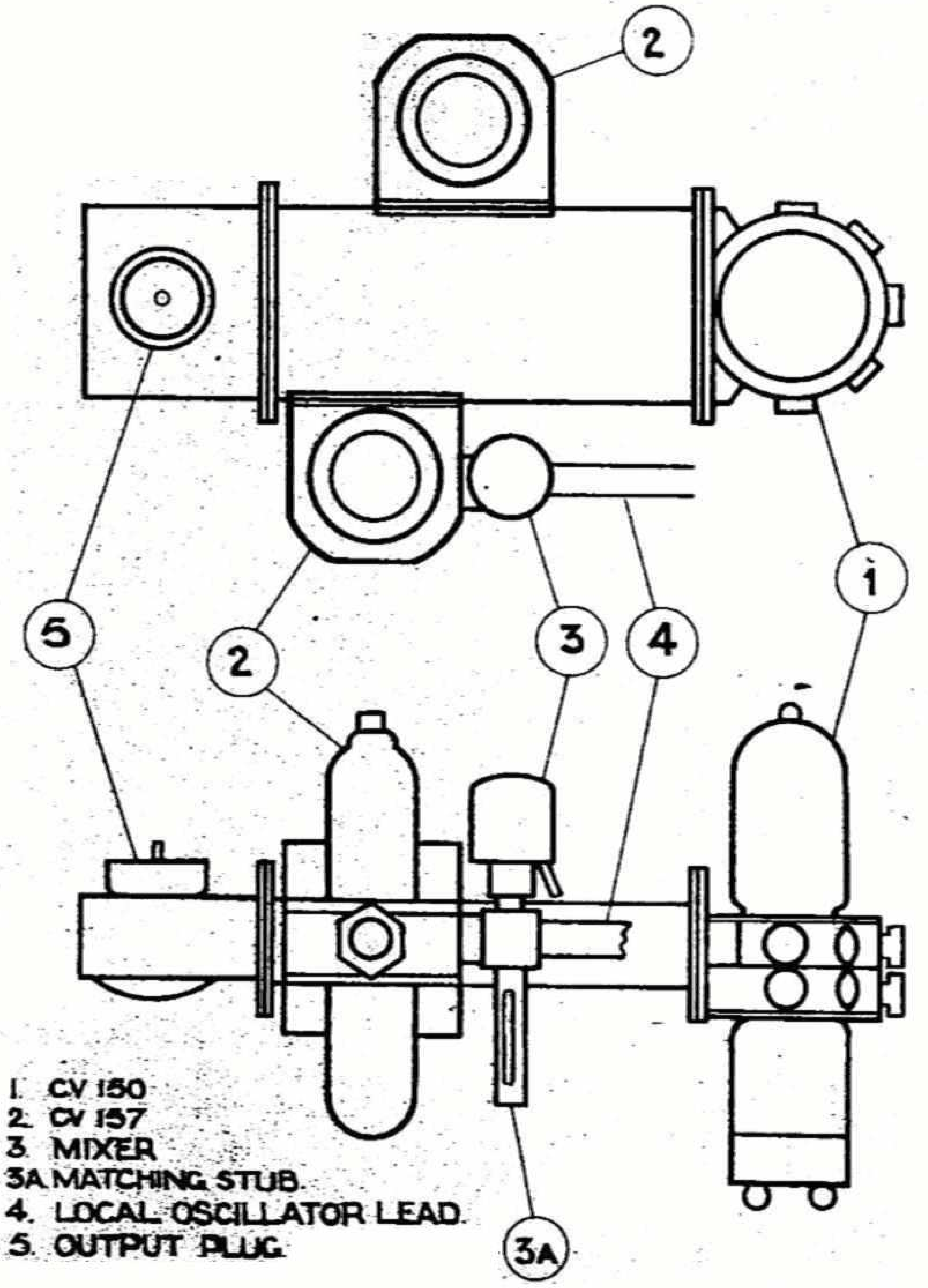

FIG.2. SKETCH OF OUTPUT CIRCUIT.

(AMERICAN PROJECTION)

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TITLE:
FIG.2. SKETCH OF OUTPUT CIRCUIT

T.R.E. MAP

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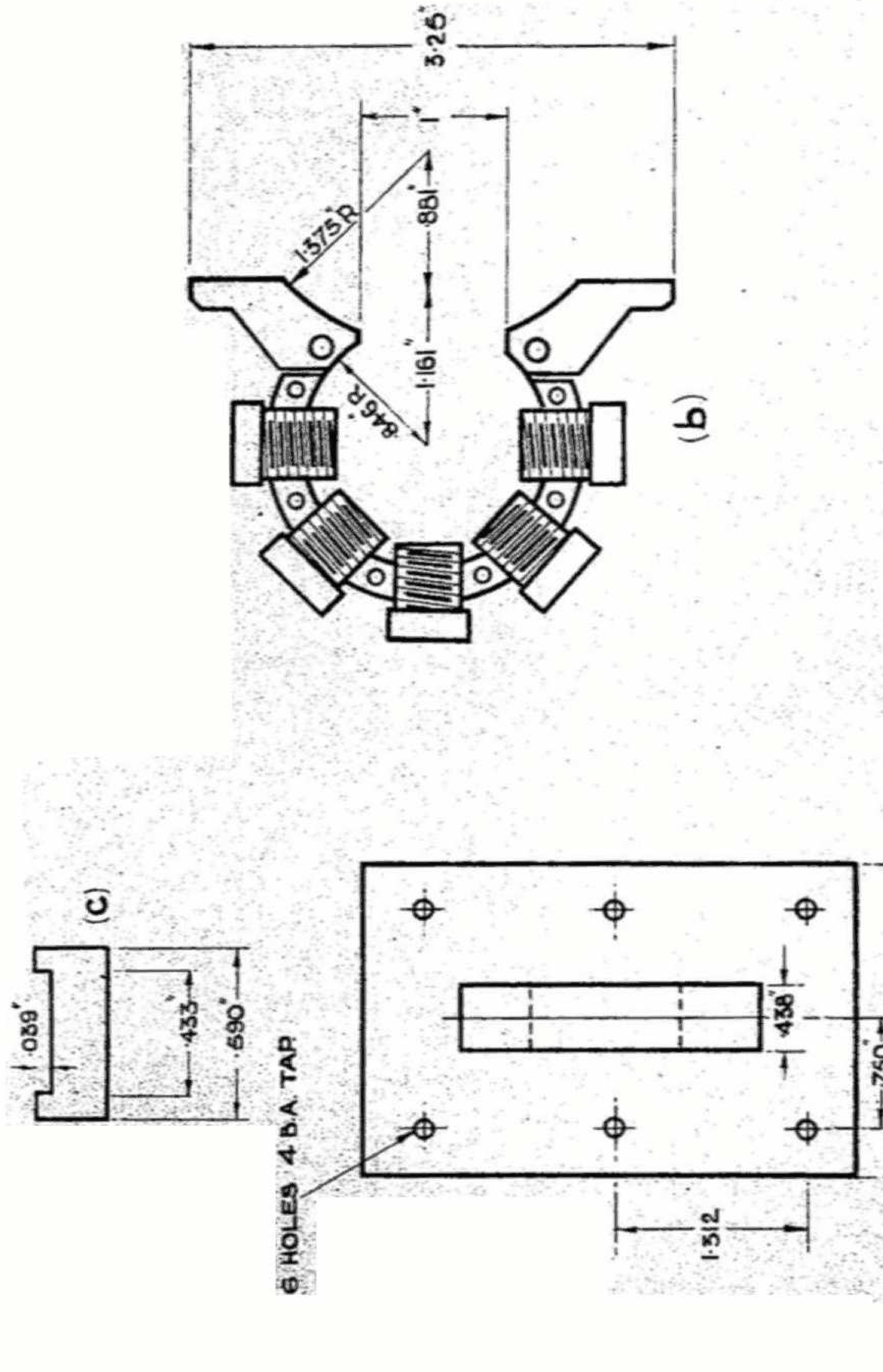

FIG.3. RESONATOR OF CV150.

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FIG.3. RESONATOR OF CV150

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T.R.E. MAP

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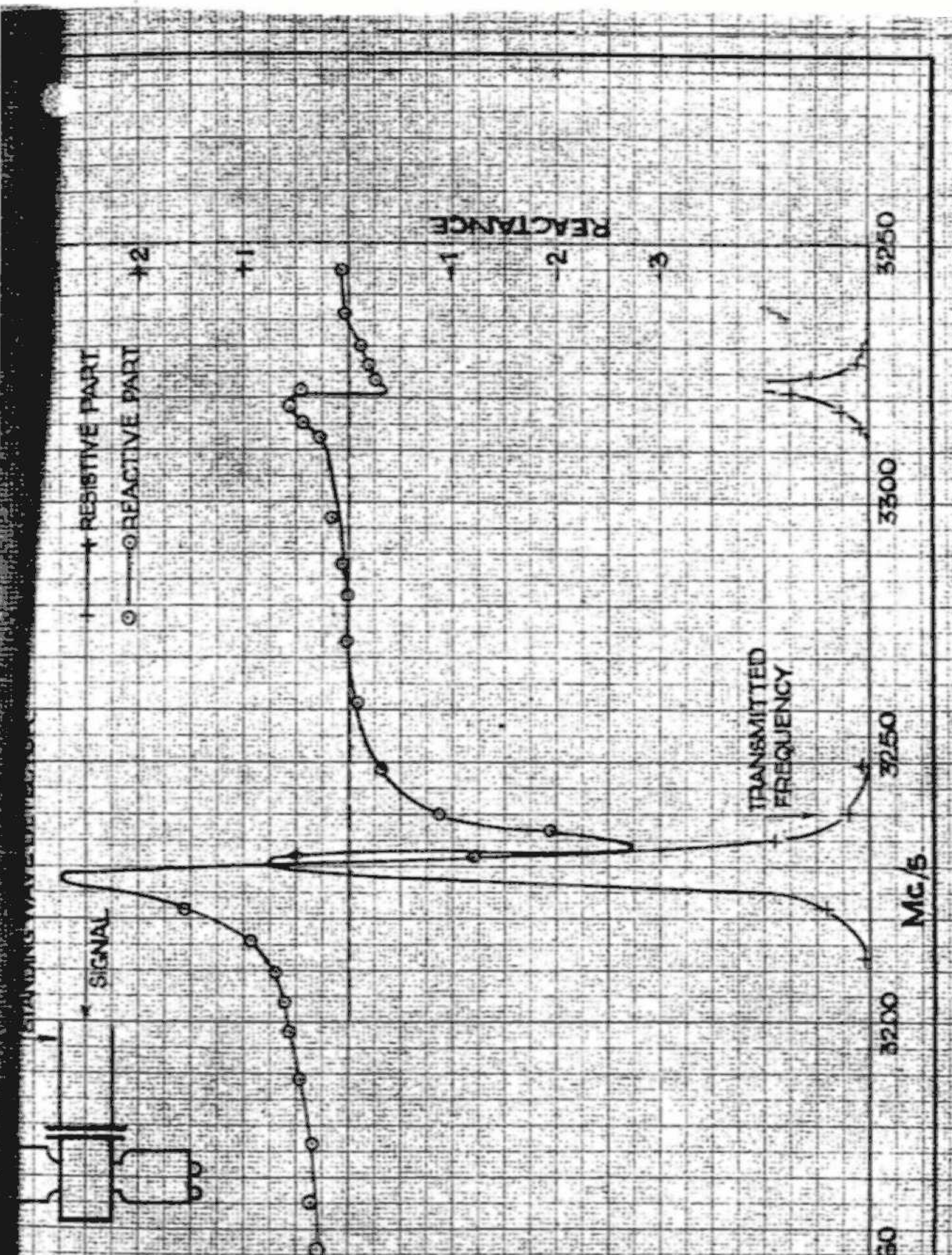

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LE:

G.4 COLD IMPEDANCE OF CV150.

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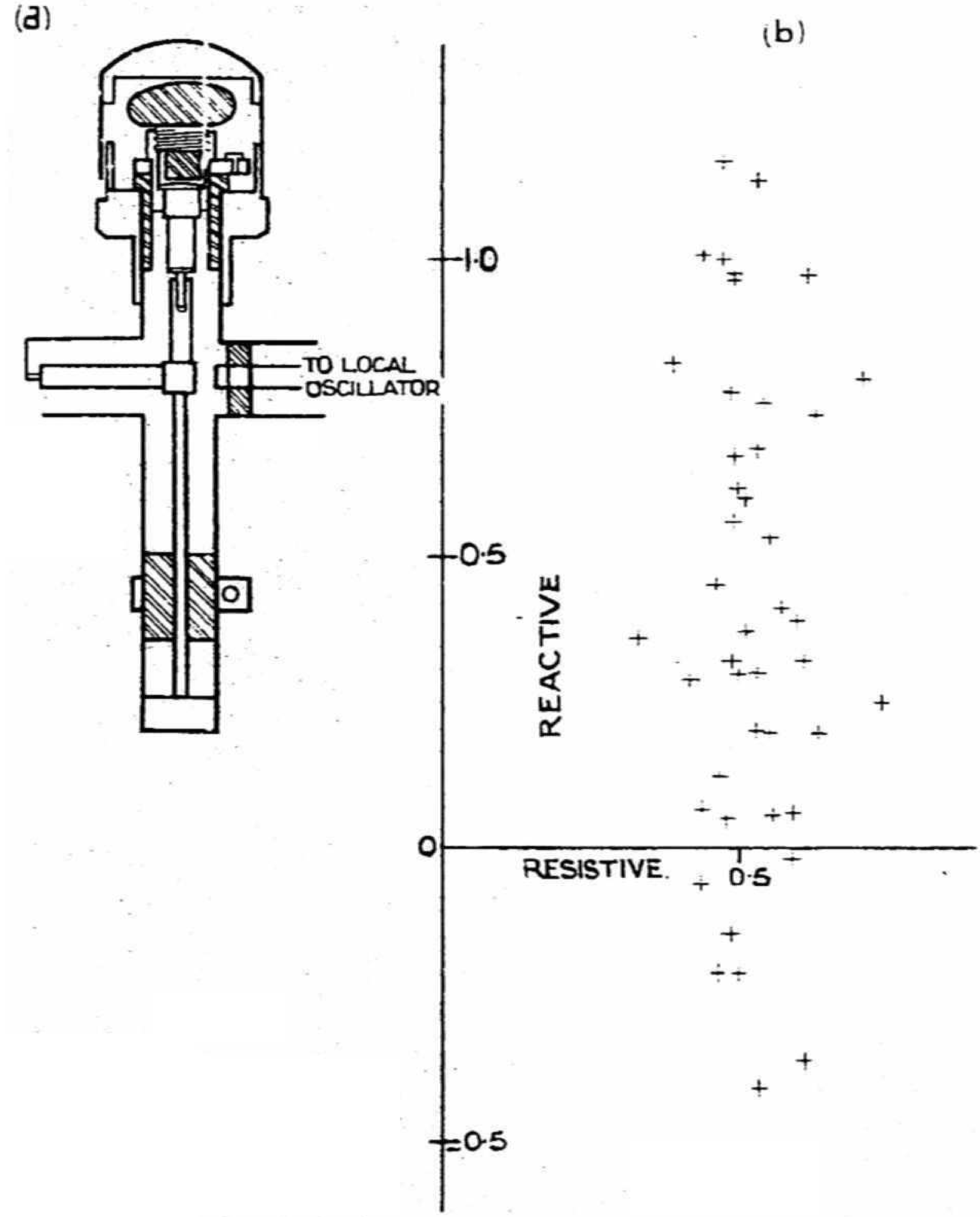

FIG.5 (a) MIXER.
(b) IMPEDANCES OF CV101 CRYSTALS, MEASURED IN 75Ω LINE.

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TITLE: FIG.5 (a) MIXER. (b) IMPEDANCES OF CV101 CRYSTALS MEASURED IN 75Ω LINE.							T.R.E. MAP.
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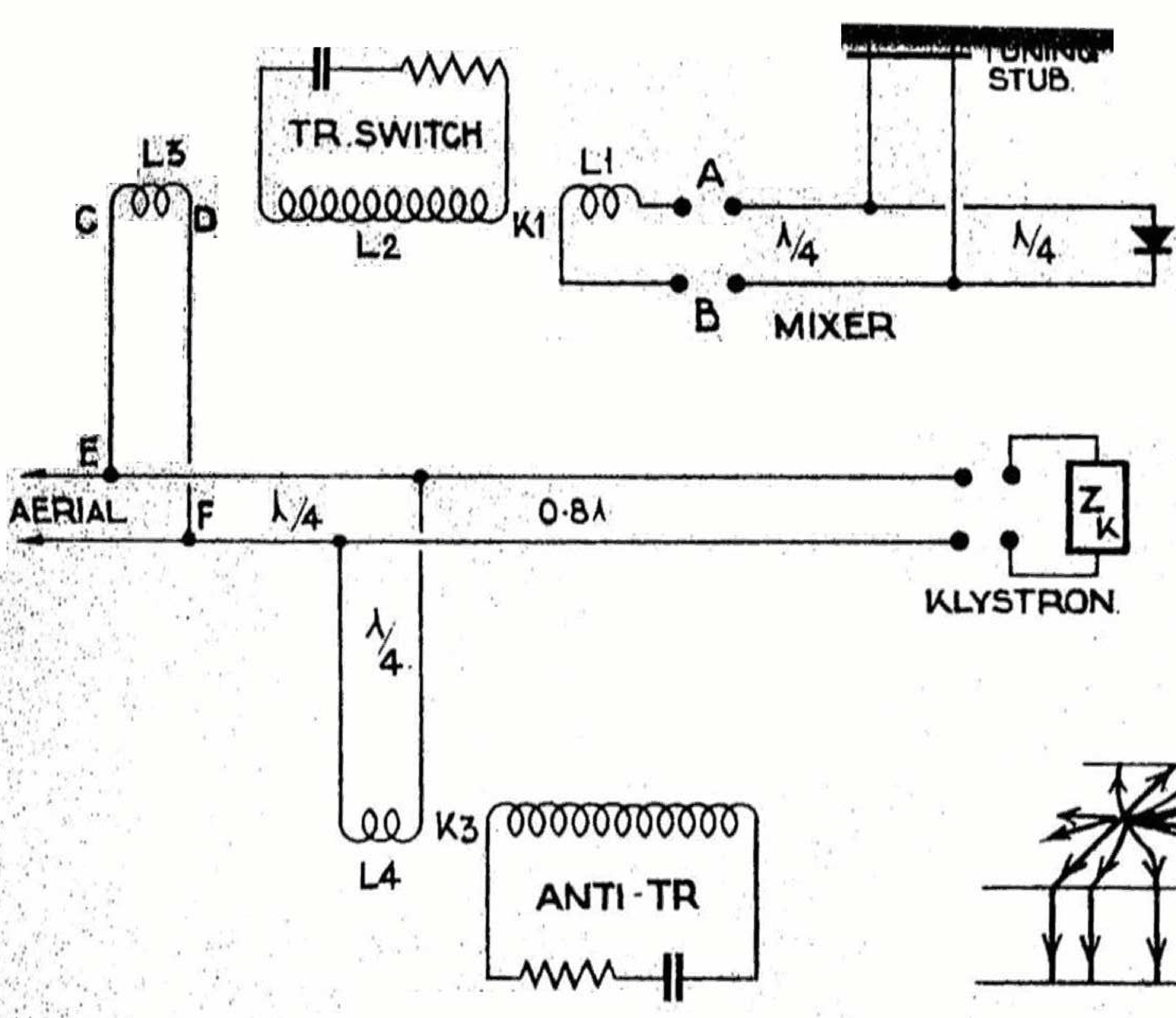

FIG. 7(a) EQUIVALENT CIRCUIT

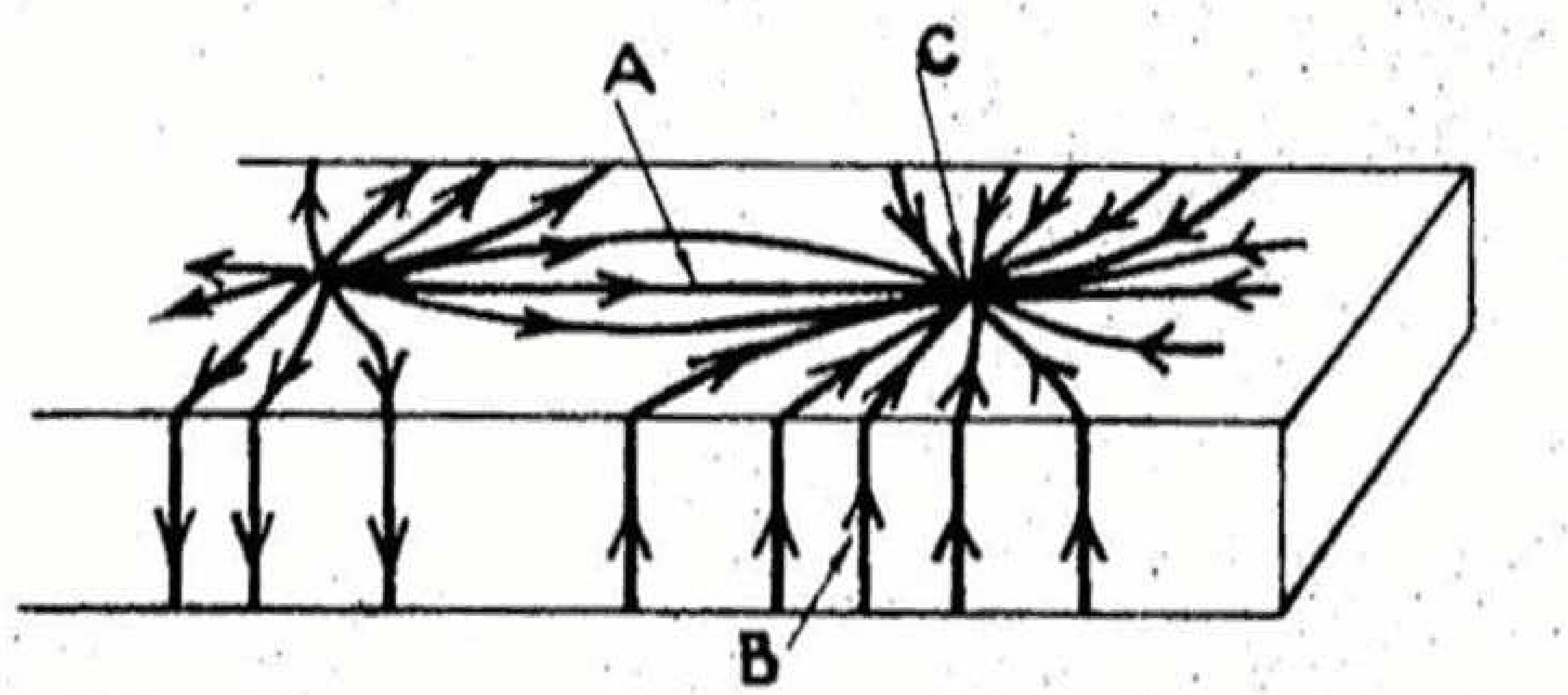

FIG. 7(b)

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TITLE: FIG. 7a EQUIVALENT CIRCUIT. FIG. 7(b)

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T.R.E. MAP

DIAGRAM. Nº

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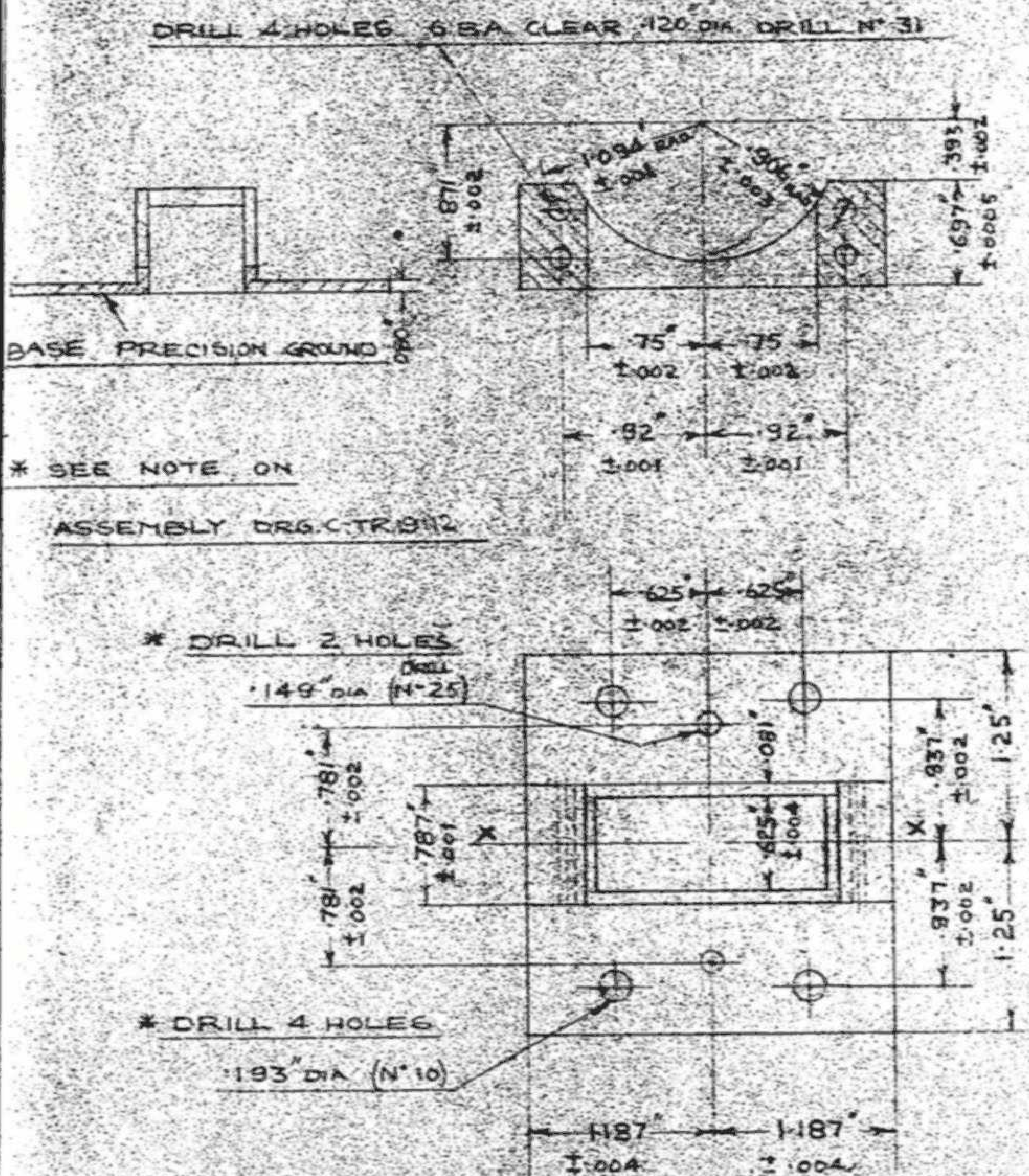
HOLES MARKED * MUST BE JIG DRILLED AFTER ASSEMBLY SO THAT THEIR POSITION WITH RELATION TO THE ℄ X-X DOES NOT VARY MORE THAN 14' OF ANGLE.



BASE PLATE
BRASS
FIN. SILVER PLATE

NOTE! ALL DIMENSIONS ARE OVER PLATING

THIS DRAWING IS TO BE READ IN CONJUNCTION WITH SPECN O.C.D. W.T.1000.

TITLE: CASING FOR VALVES CV157 & CV179 PLATE DET.

T.R.E. MAP

DRG. No. A-TR 19108

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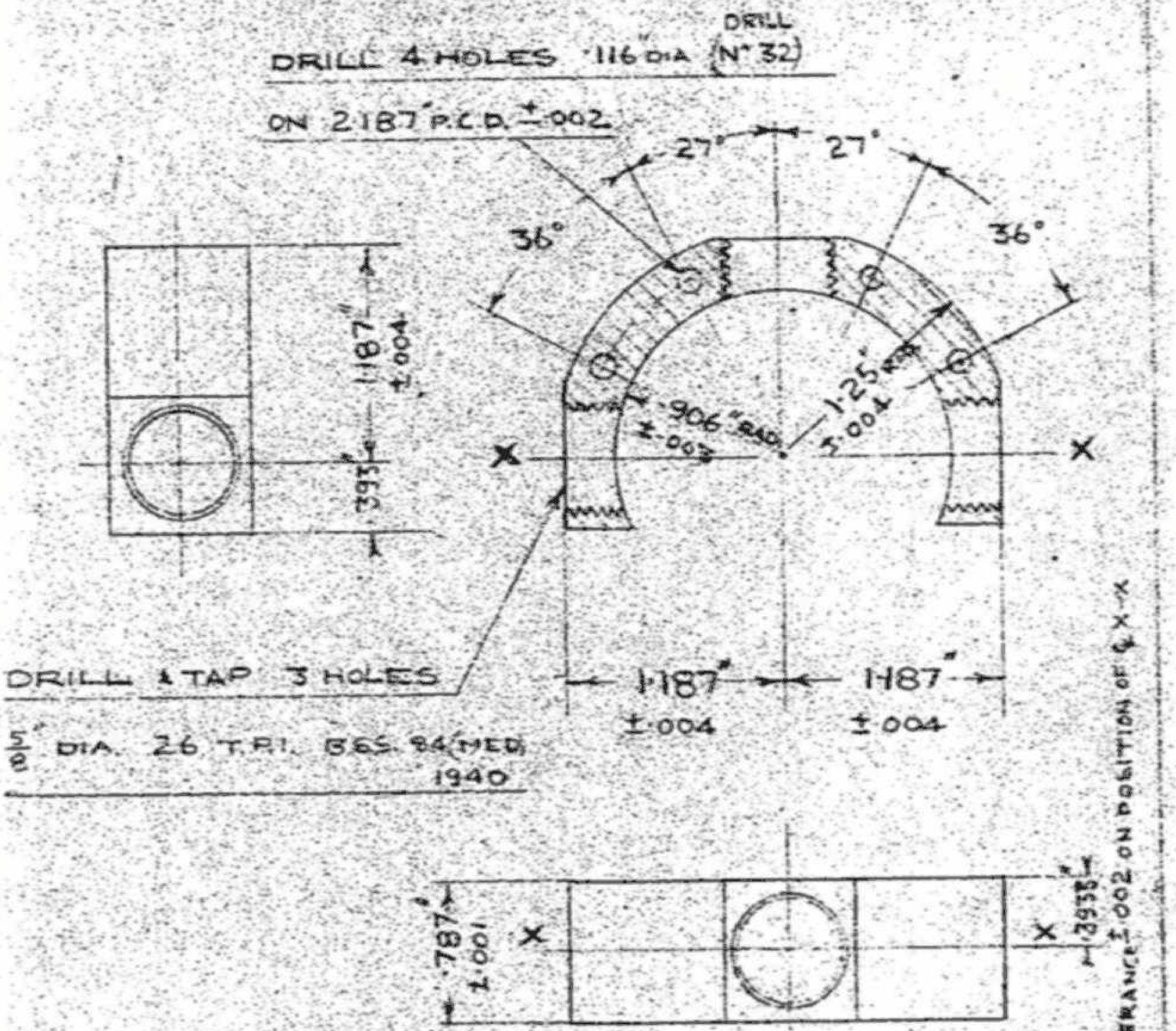

WHEN THIS PART IS ASSEMBLED WITH BASE PLATE A-TR 19108 THE HOLES ON AXES X-X MUST BE PARALLEL TO THE UNDER-SURFACE OF THE BASE PLATE & SIDE FACES TO WITHIN 4' OF ANGLE.

LUG HOLDER
BRASS
FIN. SILVER PLATE

NOTE! ALL DIMENSIONS ARE OVER PLATING

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TITLE: CASING FOR VALVES CV 157 & CV 179. HOLDER DET.

T.R.E. MAP

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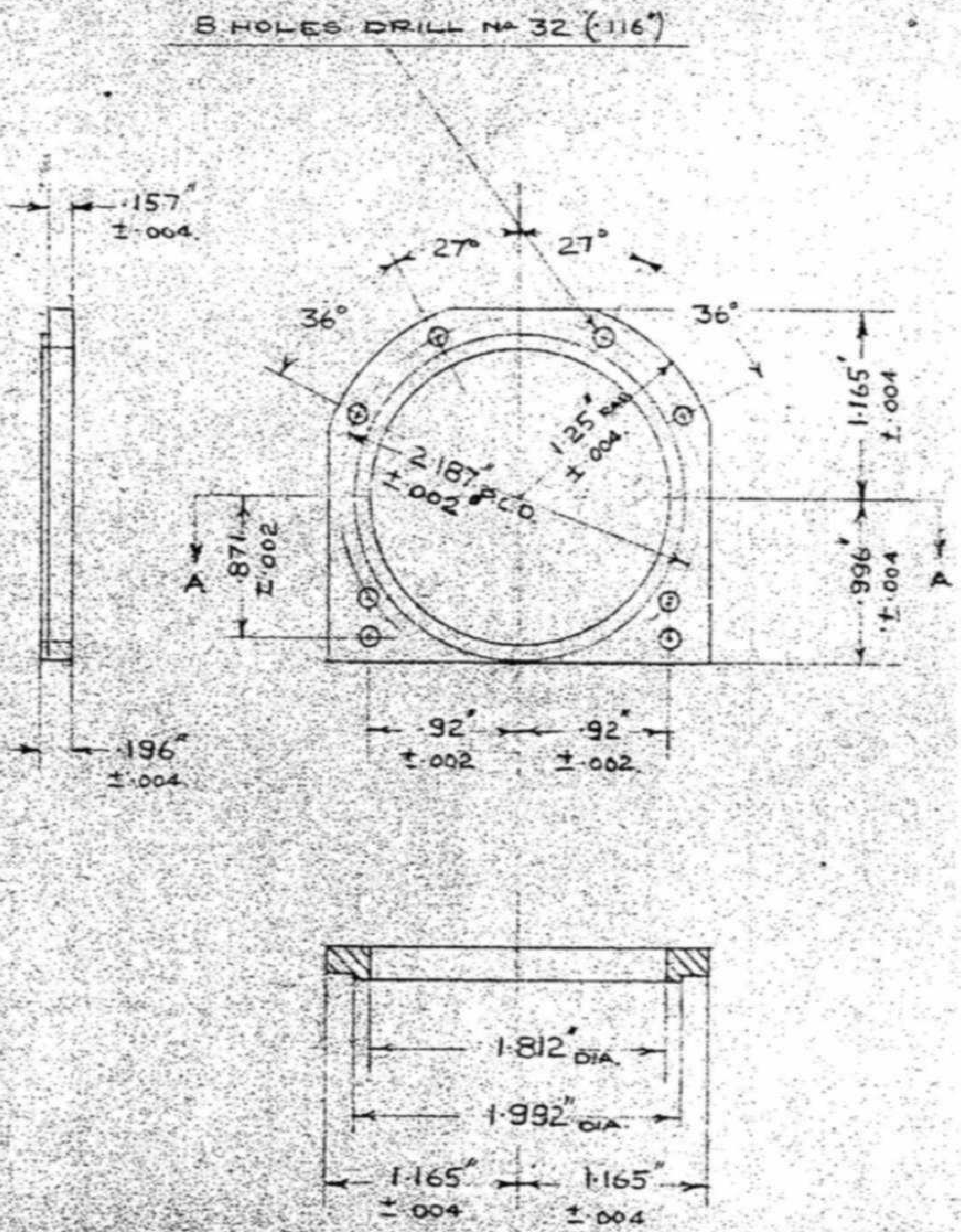
DRG. NO. A-TR 19109



CURING RING.

ASS.

. SILVER PLATE

SECTION THROUGH A-A

NOTE: ALL DIMENSIONS ARE OVER PLATING

DRAWING IS TO BE READ IN CONJUNCTION WITH SPECn D.C.D. W.T. 1000

LE: CASING FOR VALVES
V. 157 & C.V. 179. RING DET.

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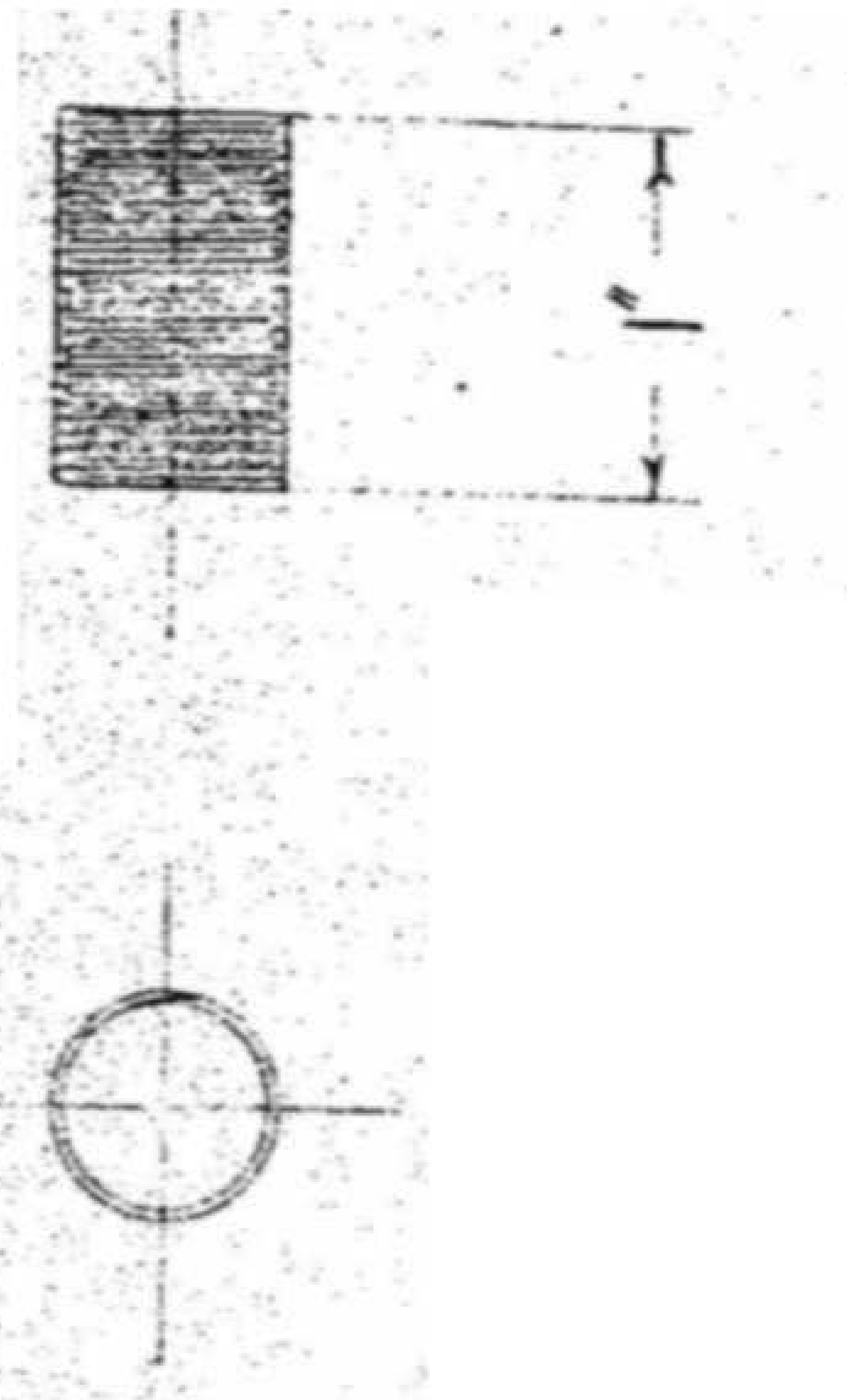
					CHECKED: HALEY	A-TR 19110
					APPRD:	



SCREWED 26 T.P.I.

ON $\frac{5}{8}''$ DIA.

B.S.S. 84 (MED) 1940

NOTE! ALL DIMENSIONS ARE OVER PLATING.

...NING PLUG

...ASS

... SILVER PLATE

...RAWING ... TO BE READ IN CONJUNCTION WITH SPECⁿ D.C.D. W.T. ...

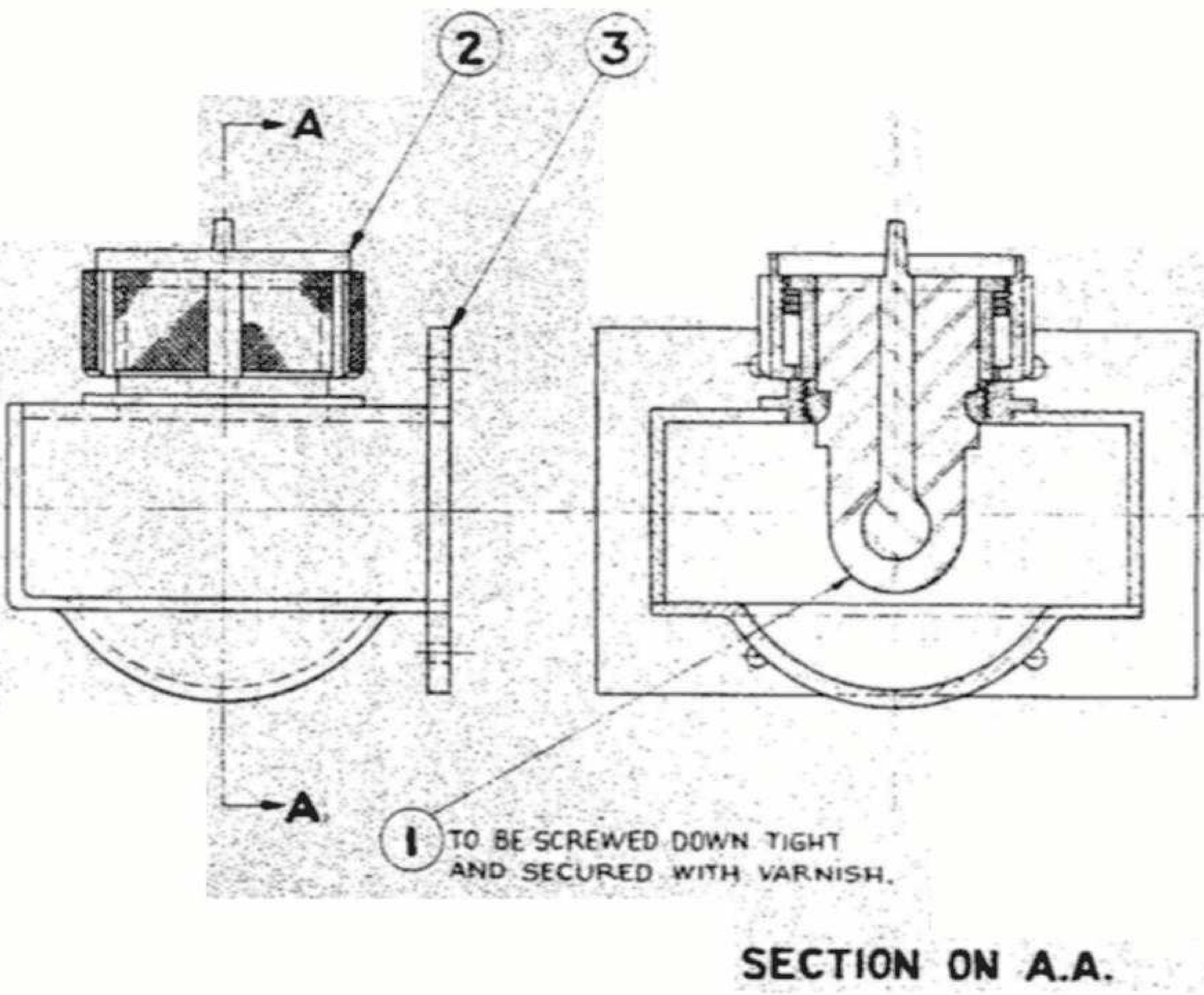
...E: CASING FOR VALVES ...157 & CV 179 . PLUG DET.

T.R.E. MAP

DRG Nº A-TR 19111

DATE	MOD Nº				
					DRAWN: GRAY
					TRACED:
					CHECKED: HALEY
					APPR'D:

ITEM	DRG.Nº	DESCRIPTION	Nº OFF	REMARKS. REF. Nº, ETC.
1	ATR.19616	PROBE, MOULDING ASSY.	1	
2	ATR.19618/3	NUT, KNURLED.	1	
3	ATR.19611	FEEDER, TUBULAR.	1	
		BAKELITE VARNISH.	AS REQ'D	



SCALE: 1/1.

BASED ON THE GRAMOPHONE CO. DRG. Nº 119110 B.

THIS DRAWING IS TO BE READ IN CONJUNCTION WITH SPECN. D.C.D. W.T.1000.

TITLE: PROBE ASSEMBLY. REF. Nº 10H/6810.

T.R.E. M.A.P.

ISSUE	DATE	MOD. Nº				
1	16-8-43	—				DRAWN
						TRACED JOHNSON
						CHECKED
						APPR'D

DRAWING Nº **A.T.R. 19612.**