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SUPERSONIC COMPONENTS FOR USE IN RADAR TRAINERS

REPORT
1050

RADIATION LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE - MASSACHUSETTS

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RADIATION LABORATORY

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SUPERSONIC COMPONENTS FOR USE IN RADAR TRAINERS

ABSTRACT

The principles governing the simulation of radar signals for a supersonic trainer are presented. The crystal, crystal cartridge, reflectors and reflecting maps are described and lines for future investigations are indicated.

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Title Page
26 numbered pages

SUPERSONIC COMPONENTS FOR USE IN RADAR TRAINERS

I. INTRODUCTION

The purpose of this report is to describe the principles governing the simulation of radar signals in the supersonic trainer, and to briefly describe the components developed for this purpose at the Radiation Laboratory.

In a supersonic echo simulating system a piezoelectric crystal submerged in a tank of water is excited with a high power pulse of intermediate frequency energy. The compressional waves produced in the liquid are shaped with a suitably chosen reflecting surface and spread out over the surface of a reflecting map located at the bottom of the tank. Waves reflected from the map impinge on the quartz crystal and the voltage produced by the piezoelectric action is amplified, detected, and displayed on the usual radar indicator.

The simulation of radar signals in a supersonic trainer will be achieved if the following conditions are met:

1. The intensity distribution of the supersonic beam is identical with that of the electromagnetic beam of the radar set.
2. The bandwidth of the supersonic system is identical with the bandwidth of the radar system.
3. The width and shape of the supersonic pulse are identical with the width and shape of the radar pulse.
4. The supersonic map reflects supersonic energy in a manner analagous to the reflection of electromagnetic waves by cities, lakes, etc.
5. The slant range of targets in a supersonic system is proportional to the cosecant of the angle of elevation at a given altitude, as is true in a radar system.
6. The minimum altitude of the crystal is equal to the minimum operational altitude of the radar set.

None of these conditions has been fully met in any supersonic trainer designed to date, but in general the simulation has been surprisingly good.*

II. THE PIEZOELECTRIC CRYSTAL

The operating frequency of a supersonic echo simulating system is determined by the range requirements. It has been shown both theoretically and experimentally that in the range of frequencies utilized in supersonic trainers, the absorption of supersonic energy in water varies as the square of the frequency. In order to obtain ranges of not less than 50 miles on ground signals it has been found inadvisable to exceed 15 mc. as the operating frequency.

The specifications for the standard 15 mc. crystal** require that the plated crystal, unmounted, resonate to a frequency of 15.00 mc. ± 0.15 mc. The resonant frequency is determined in manufacture by measuring the frequency of oscillation of an oscillator employing the crystal as the frequency determining element. This test requires that the crystal oscillate in an oscillatory circuit and, in general, tests of crystal "activity" are performed with this circuit. This test requires that the grid current of the oscillator exceed a specified value. This activity test is somewhat arbitrary, however, for "inactive" crystals perform satisfactorily in the supersonic simulation system. The frequency of the mounted crystal in water will differ from the resonant frequency as determined above. The resonant frequency in the standard 7B mount drops to 14.75 ± 0.15 mc. The resonant frequency of the mounted crystal immersed in a liquid is defined as the frequency at which the conductance of the crystal is a maximum. The conductance may be readily measured with the General Radio 821-A Twin-T Impedance Measuring Circuit.

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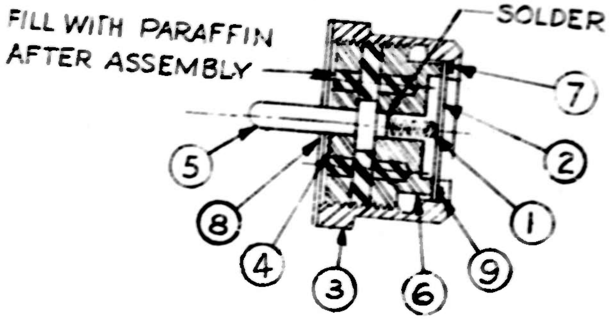
* See Radiation Laboratory Report S-45, "Ultrasonic Radar Trainer PPI Photographs of a Simulated Bombing Mission over Tokyo" by P. Rosenberg.

** Radiation Laboratory Report S-35, "Specifications for 15 mc Supersonic Crystals for Crystal Cartridges Types 3 and 7B" by P. Rosenberg.



PART NO.	FIG. NO.	
1	15, 22	CAT-WHISKER
2	NONE	CRYSTAL
3	16	BODY
4	17	SMALL INSULATING BEAD
5	18	CONNECTOR PLUG
6	19	LARGE INSULATING BEAD
7	20	CRYSTAL GASKET
8	21	ADAPTOR GASKET
9	NONE	LEDGE

FIG. 1 ASSEMBLY DRAWING OF CRYSTAL CARTRIDGE

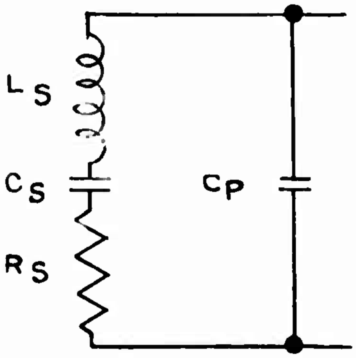
The crystal is made of quartz cut so that the crystallographic x axis is perpendicular to the faces of the quartz plate to within 1° as determined by x-ray measurement. No tests have been performed to determine how great an angle may be tolerated. After the two plane surfaces of the crystal are ground to approximate thickness (for at least 100 KC) they are etched to the desired thickness. The plating is sputtered on and is baked for at least one hour at 500° C. The plating is gold rather than any other metal higher in the electrochemical series, for in trainer applications the crystal must be submerged in water for long periods of time.

The electrical characteristics of the crystal are obtained for the crystal mounted in the crystal cartridge of Fig. 1. In general the Q of a crystal in air is quite high. This is no longer true when one face of the crystal vibrates directly into a liquid medium, such as water, where the acoustic impedance of the medium is of the order of magnitude of the acoustic impedance of the crystal.

An adequate equivalent electrical circuit of the crystal in the cartridge of Fig. 1 is given in Fig. 2. C_p is the capacity between the plated areas of the crystal plus the capacity between the "high" side of the crystal (back plating, catwhisker, and connector plug) and the cartridge itself. L_s and C_s are respectively the equivalent inductance and equivalent capacity of the crystal and are related to the resonant frequency, ω_o, of the crystal by the relation,

$$\omega_o L_s - \frac{1}{\omega_o C_s} = 0.$$

For piezoelectric crystals the ratio of the capacity between the plates of the crystal and the equivalent capacity, C_s, is constant. This constant, α, is approximately 140 for quartz. R_s represents the "radiation resistance" of the crystal and is a function of the medium surrounding the crystal. For the crystal (in the mount of Fig. 1), radiating into water, $R_s = 4500$ ohms, $C_p = 20$ $\mu\mu$f and $C_s = 0.14$ $\mu\mu$f. From these constants it is apparent that the Q of the crystal defined as $1/\omega_o C_s R_s$ is approximately equal to 15.



R_S = "RADIATION RESISTANCE" OF CRYSTAL
C_P = CAPACITY BETWEEN BOTH FACES OF CRYSTAL
L_S = EQUIVALENT ELECTRICAL INDUCTANCE
C_S = EQUIVALENT ELECTRICAL CAPACITY

FIG. 2 EQUIVALENT CIRCUIT OF PIEZOELECTRIC QUARTZ CRYSTAL

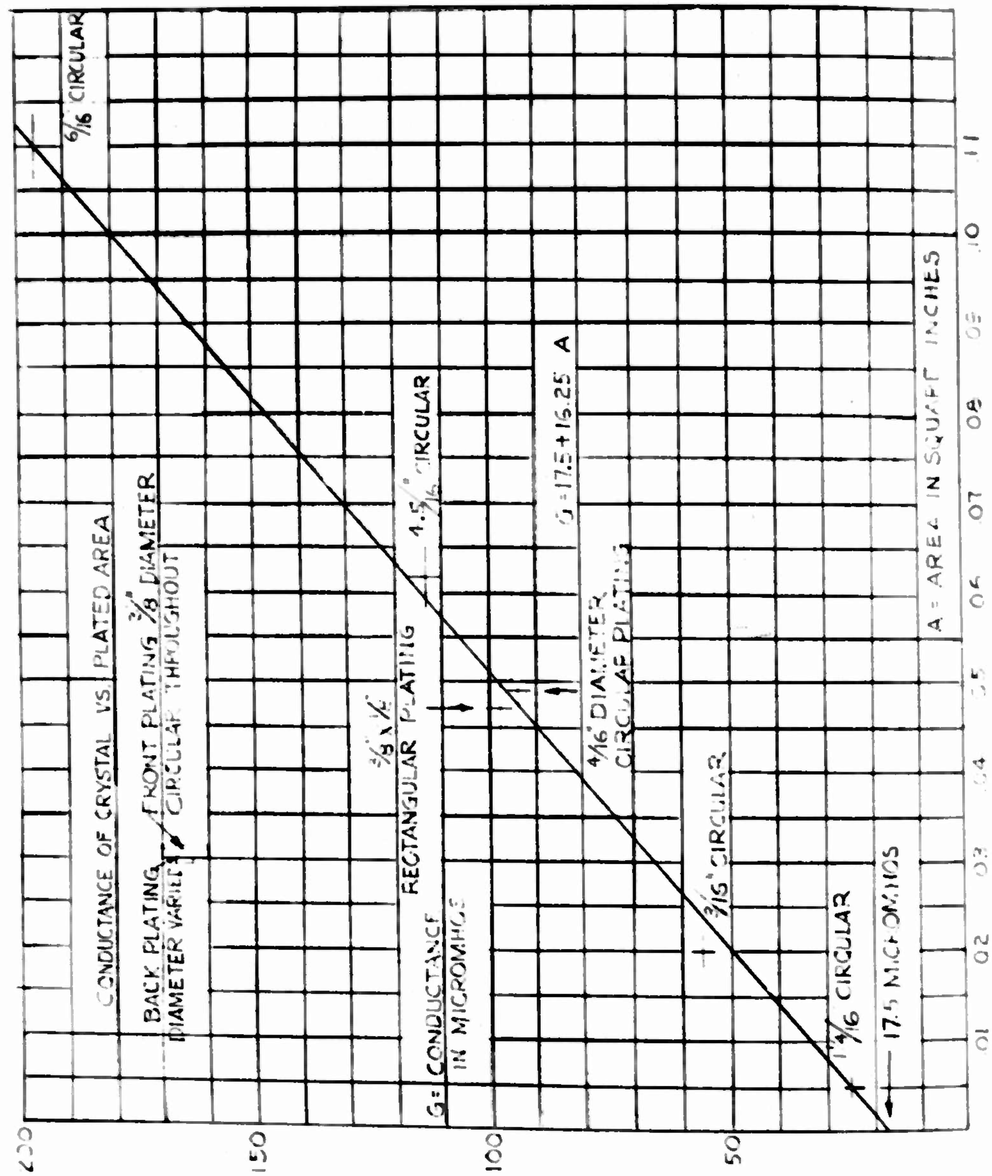
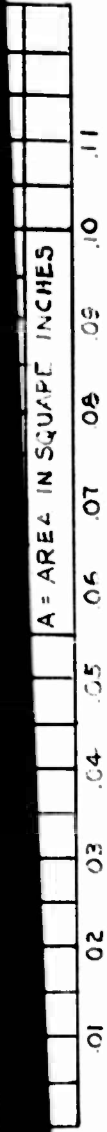


FIG. 3 CONDUCTANCE OF 15 MC CRYSTAL AS FUNCTION OF PLATED AREA



The radiation resistance, R_s, is also a function of the plated area of the piezoelectric crystal. The crystals employed in trainers at the Radiation Laboratory were fully plated on the "front" face. This face was grounded to the system ground by contact with the grounded body of the crystal cartridge. The "back" plating has a smaller diameter than that of the front face; the plot of conductance vs. back plating area of Fig. 3 shows that it is the smallest plated area that controls the area of the crystal that actually vibrates.

The presence of 17.5 micromhos conductance at zero area may be attributed to the edge effect present because of the large (1½") diameter plating on the front face. The empirical relation between back plating area, A, (in square inches) and conductance, G, (in micromhos) is given by:

$$G = 17.5 + 1625A \qquad (1)$$

The effective parallel resistance of the equivalent circuit of Fig. 2 can be shown to be given by:

$$R' = R_s\,(1 + Q_s^2\,\gamma^2) \qquad (2)$$

Thus the validity of this equivalent circuit may be determined by plotting the experimentally determined values of R′ vs. γ^2 where

$$\gamma = \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right).$$

A representative plot is given in Fig. 4. If the equivalent circuit is valid, the slope of this curve should be $R_s\,Q_s^2$. It appears that the value $Q_s = 15.3$ is constant in a 2.5 mc band about the center frequency (15 mc). At frequencies remote from the center frequency the effective Q_s increases and the equivalent circuit breaks down.

In applications where the bandwidth of the crystal and associated networks is of importance (as it is in a supersonic echo simulating system) the crystal capacity, C_p, is usually tuned to resonance at the crystal frequency. In addition the parallel tuned circuit that results is usually damped with a resistor, R_p. The equivalent circuit of crystal and tuning network for a received signal is given in Fig. 5. If E_0 represents a small voltage induced in the crystal by a supersonic wave striking the crystal then the bandwidth of the system is given by a plot of expression (3) as a function of γ.

$$\left(\frac{E}{E_0}\right)^2 = \frac{1}{\left[1+\frac{\alpha}{Q_pQ_s} - \alpha\gamma^2\right]^2 + \left[\alpha\left(\frac{Q_p+Q_s}{Q_p\,Q_s}\right)\gamma\right]^2}$$

$$Q_p = R_p\,\omega_0\,C_p \qquad (3)$$

$$Q_s = \frac{1}{R_s\,\omega_0\,C_s}$$

A plot of this expression for $\alpha = 140$ for various values of Q_p is given in Fig. 6.

It can be shown that the bandwidth of this system may be improved by reducing the Q of the crystal. This may be done by substituting various liquids in place of air in the space behind the crystal in the crystal cartridge. (See Fig. 1.) Although acoustically damping the crystal in this manner does produce systems of wider bandwidth, it results in a sacrifice of some of the power that would normally radiate out into the water. It is possible, however, to increase the bandwidth without loss in power. This may be done by interposing between the crystal and medium a quarter wave length layer of material of acoustic impedance, $(\rho c)_m$, such that:

$$(\rho c)_m^2 = (\rho c)_{warter} \cdot (\rho c)_{quartz} \qquad (4)$$

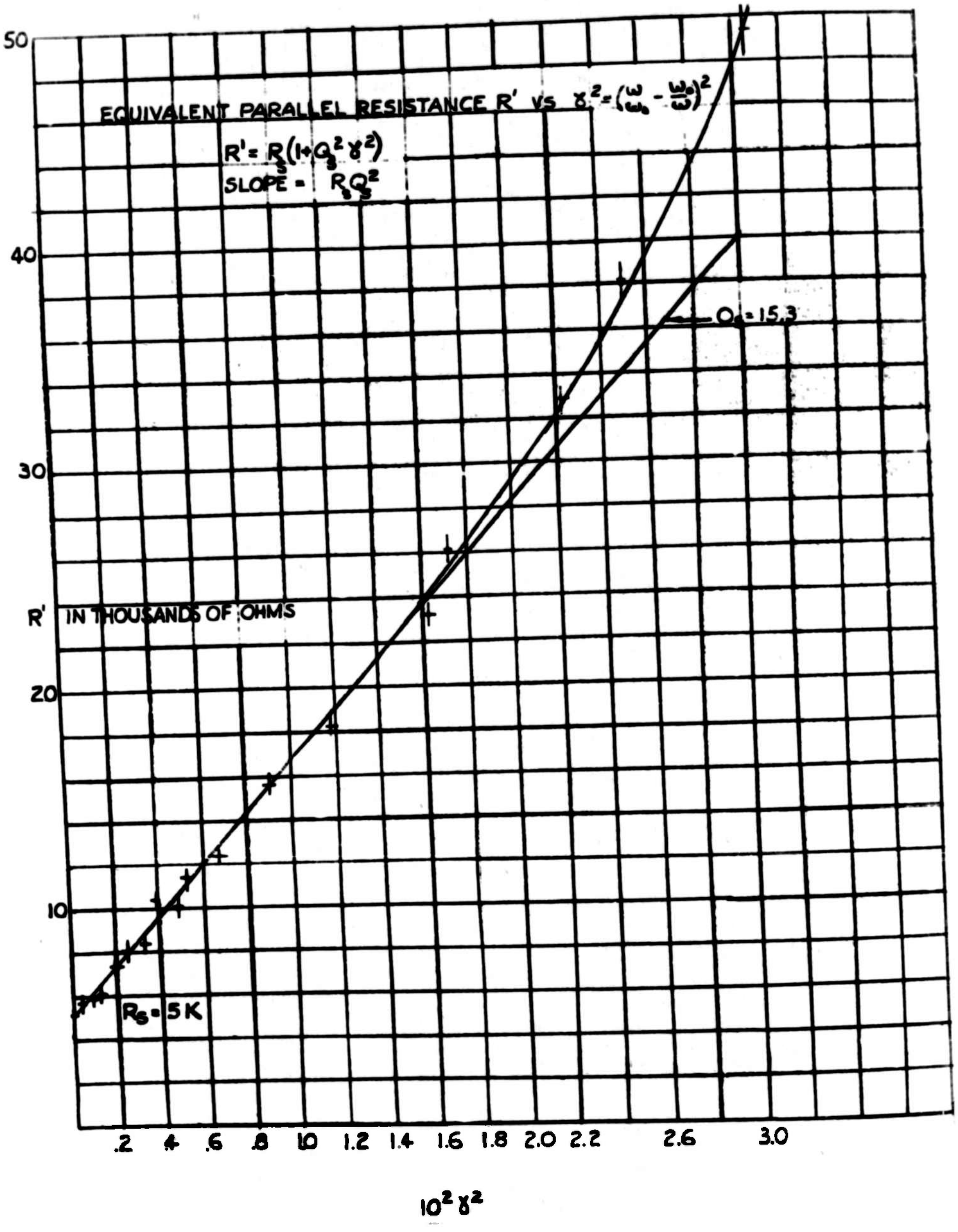


FIG. 4 VALIDITY OF EQUIVALENT CIRCUIT OF FIG. 2.

(Dr. H. Grayson of the T.R.E. indicated in discussions with the authors that successful work along these lines had been carried out at T.R.E. but that as yet (6-45) no practical damping material had been obtained for underwater use.)

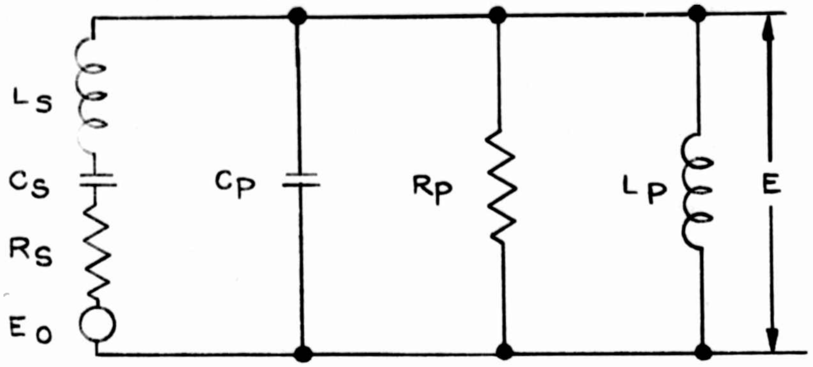


FIG. 5 EQUIVALENT CIRCUIT OF CRYSTAL AND TUNING NETWORK

It is also possible that the bandwidth of the crystal may be increased by proper design of the crystal itself. The properties of wedge shaped crystals have not been investigated, but it is the opinion of the authors that continued work on broadbanding should not overlook this line of investigation. When the crystal is used in conjunction with an i-f amplifier it is possible to compensate for the narrow band of the crystal by proper design of the band pass of the amplifier.*

III. THE CRYSTAL CARTRIDGE

The assembly drawing of the type 7B crystal cartridge is given in Fig. 1. Detailed prints may be found at the end of the report. The body of the cartridge (3) is made of brass. Brass has been chosen because it is easily tooled and can stand the deleterious effects of continued underwater use. Stainless steel, aluminum, and plastic bodies have been used, but show no advantages over brass. The crystal (2) is kept in place with a large threaded insulating bead (6), which screws down into the cartridge body and forces the crystal against the ledge (9) of the front face of the cartridge body. A thin rubber gasket (7) is placed between the crystal and the ledge so that the pressure of the large insulating bear will provide a watertight seal. Leakage of water through the crystal-ledge interface to the back of the crystal has three harmful effects:

1. The small spacing between crystal plating and cartridge body and the conductivity of tap water combine to provide a low resistance shunt across the crystal.

2. Water in place of air behind the crystal results in an increase in crystal resistance, R_s.

3. Half the power delivered to the crystal will be dissipated in the water behind the crystal.

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* This scheme is discussed in detail in Radiation Laboratory Report 1055, "A Supersonic Echo Simulation System for AN/APQ-T1" by S. Frankel and D. C. Grahame.

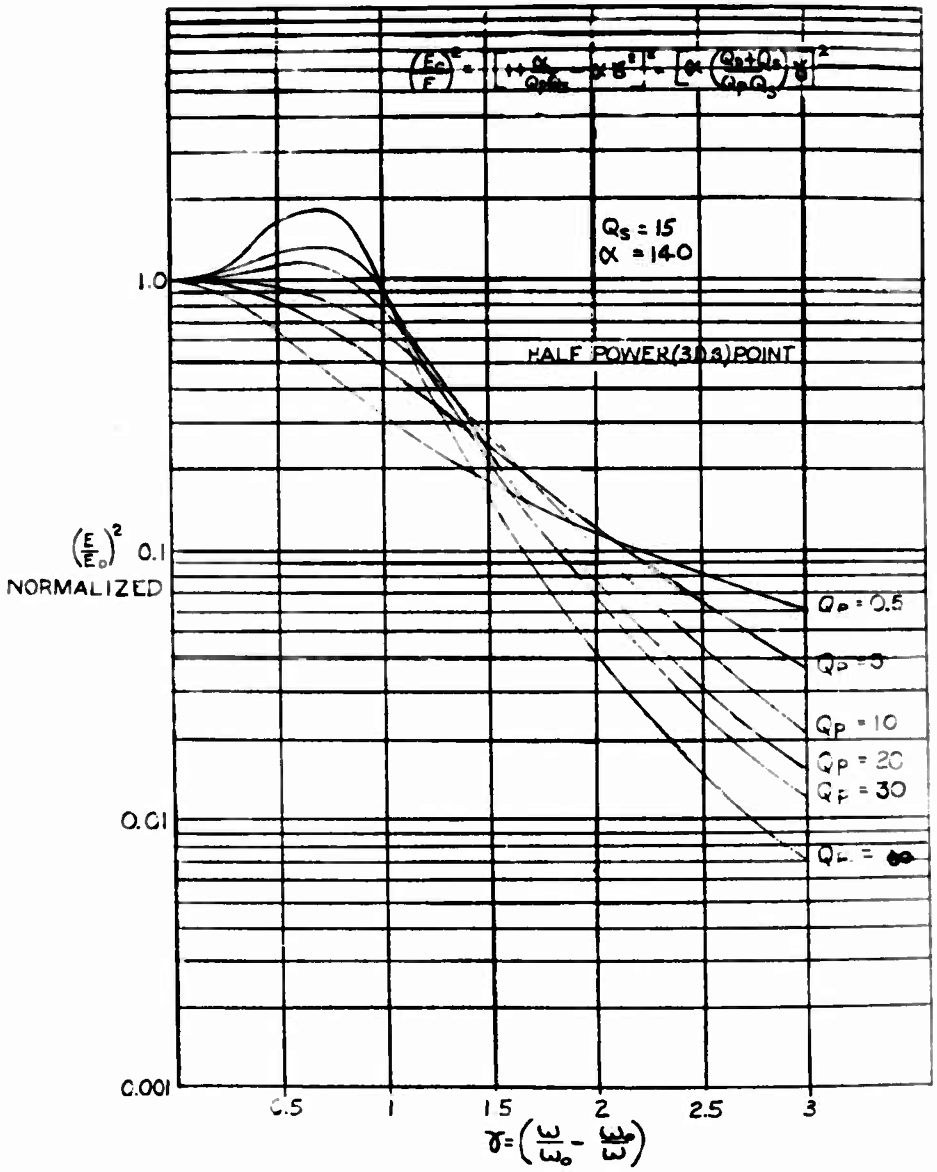


FIG. 6 FREQUENCY RESPONSE OF CRYSTAL IN CIRCUIT OF FIG. 5

These factors not only add lossy elements to the crystal, but serve to change the impedance of the crystal and hence detune the matching networks that deliver power to the crystal.

One end of a fine silver catwhisker (1) touches lightly on the gold plating of the crystal. The other end is soft soldered to the connector plug (5) that leads the 15 mc. voltage to the crystal. Another small insulating bead (4) supports the connector plug in place. Holes are provided in the upper and lower beads to allow insertion of a tool to facilitate assembly. To make the crystal cartridge watertight at the connector plug end, melted paraffin is usually poured through these holes into the space between the beads. To further reduce the possibility of leakage through the upper bead, a rubber adapter gasket (8) may be employed which fits over the connector plug. The space between the large insulating bead and the crystal is normally filled with air. This space may be filled with suitable liquids for the purpose of acoustically damping the crystal. A table of values of crystal Q under various loading conditions is given in Fig. 7.

Back Loading Medium	*Propagation Medium*	*Radiation Resistance*	Q_s
air	water	4.5K	15.3
methylene iodide	water	16.5K	4.2
mineral oil	water	10.0K	6.9
castor oil	water	10.2K	6.8
air	carbon tetrachloride	4.7K	14.5
air	acetone	2.85K	24.1
air	methyl alcohol	3.0K	22.9
air	chloroform	4.4K	15.6
air	ethyl acetate	3.9K	17.3
air	trimethyl bromide	6.8K	10.3
air	glycerine	6.3K	10.9
air	ethyl alcohol	3.2K	21.5

Frequency—14.75 mc
Back Plating Diameter—26/64"
Front Plating Diameter—½"

Fig. 7 Q of Quartz Crystal Under Various Loading Conditions

Certain problems in transducer design have arisen that are not met by the transducer described. When high intermediate frequency voltages are applied to the crystal the contact between the whisker and gold plating often open circuits. This is due to a "burning" at the gold plating at the point of contact. The cause of this "whisker burnout" had not been determined at the close of the war. The burnout may be due to arcing between the whisker and plating when the piezoelectric crystal contracts. The burnout may be reduced by shaping the whisker contact as shown in Fig. 22. In this way the area of contact is increased and "burnout" is rarely observed. The old type whisker design is given in Fig. 15.

The use of the thin rubber gasket to render the crystal-ledge interface watertight requires careful assembly and, in general, this scheme has not been wholly satisfactory. Further work, perhaps along the line of special adhesives, should be done on the crystal-ledge bond.

One of the most serious drawbacks of the transducer is the presence of the phenomenon of "ringing". When a high powered pulse excites the crystal, the crystal appears to vibrate after the pulse for a period at times as great as 150 microseconds. This "ringing" is not directly observable on a synchroscope, but if a high gain amplifier is connected across the crystal (as must be done in a supersonic trainer) the ringing appears as a block of saturated signals. The "ringing" time increases as the power to the crystal is increased. These spurious signals are objectionable in the trainer for they mask return signals at short ranges.

No adequate solution to this problem has been found. It is believed that the "ringing" cannot be accounted for by the natural decrement of the crystal.

IV. THE REFLECTOR

The supersonic beam from the crystal must be properly shaped to simulate the electromagnetic beam of the radar. Certain fundamental limitations, however, render perfect simulation impossible. To retain the geometrical correspondence between a radar and a supersonic system, it would be necessary to operate the supersonic system at radar frequencies. Both our inability to generate supersonic energy in liquids at radar frequencies, and the high absorption of supersonics in liquids rule out such a system. Even were such operation possible, we would be forced to adhere rigidly to a change in scale and a 30 cm radar antenna would have to be replaced by a crystal only 0.00015 cm. in plated area!

Because of the frequency limitation imposed by the range requirements for supersonic trainers, 15 mc. has been the maximum frequency of operation. Thus it is not impossible to retain the radar ratio of wave length to antenna diameter. A ten-wave length antenna would be 0.1 cm in diameter on the supersonic scale. The diffraction pattern of a 0.1 cm crystal, however, would have objectionable side lobes and therefore it is necessary to use larger crystal platings. Employing a 1.0 cm crystal, however, results in a diffraction pattern where the Fresnel region extends out to 100 miles and hence we are no longer reproducing the radar case. In addition our antenna would now be approximately one mile high.

In practice a circular crystal plating approximately 0.9 cm in diameter was employed in the supersonic trainers. The above plating shape and plating dimension is not considered the optimum in design, but was chosen for reasons intimately connected with the "crash program" for which the crystal and crystal cartridge were designed.

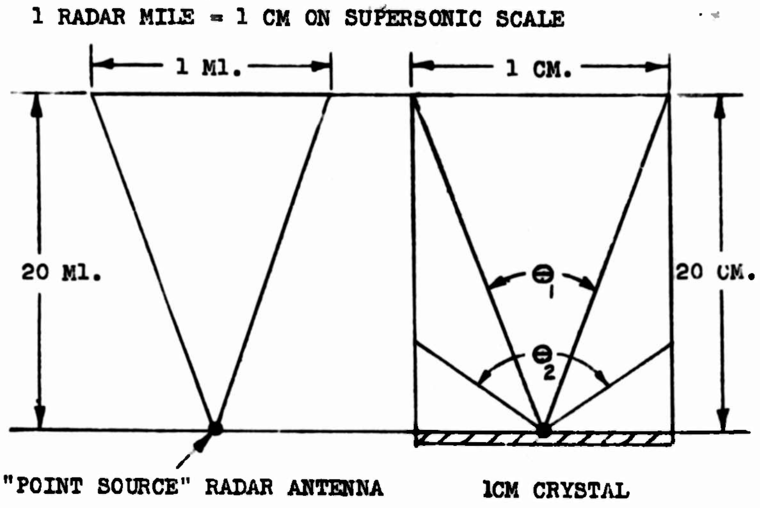


FIG. 8 COMPARISON OF RADAR AND SUPERSONIC BEAMS

Fig. 8 compares a radar beam and the idealized supersonic beam of a 1.0 cm crystal. The outlines of the beam represent the half power points in the patterns. If we define the beam width as the angle subtended by lines from the half power points to the center of the antenna or crystal, then it appears that the radar beam width is independent of range and is approximately 3 degrees. The supersonic beam width is however identical with the radar beam width at only one range and in general varies contangentially with range. It is obvious that at a range of five miles the beam width would be 11.4 degrees while at a range of 57 miles it would be one degree. In order to simulate the radar beam a crystal plating varying in width range would be required. Since the supersonic beam is not truly a colinear beam as shown in Fig. 8, such a shape plating would be difficult to calculate.

The above remarks are particularly related to the beam width of a crystal for a beam of conical, ellipsoidal, or rectangular cross section. However, it is often necessary to provide other beam shapes. The major burden of beam simulation in designing trainer systems has fallen on the simulation of the "$\csc^2\theta$", antenna employed in the AN/APS-15 and AN/APQ-13 radar sets. The function of this antenna is to provide essentially constant returned signal power independent of range.

We will digress a moment, to examine the characteristics required of such an antenna. The power at x, (Figure 9), due to an antenna at point P at altitude h, is given by:

$$P(x) = \frac{P(\theta)}{r^2} \tag{5}$$

where $P(\theta)$ is the distribution of the antenna. If the reflecting particle at x has a scattering cross section k_1, then the return intensity P is given by:

$$P = \frac{P(\theta)}{r^2} \cdot k_1 \cdot \frac{P(\theta)}{r^2} = k_1 \frac{P^2(\theta)}{r^4} \tag{6}$$

From Figure 9 we have $r = h \csc\theta$, and if P is to be constant (equal to k_2) and independent of range we have:

$$P(\theta) = h^2 \frac{\sqrt{k_2}}{\sqrt{k_1}} \csc^2\theta = K_1 \csc^2\theta \tag{7}$$

where K_1 is not a function of θ. Thus the requirement on an antenna that is to provide constant return signal for objects of equal scattering coefficient at any range is given by equation 7. It can be shown that the requirement of constant illumination along the ground is identical with the requirement of constant

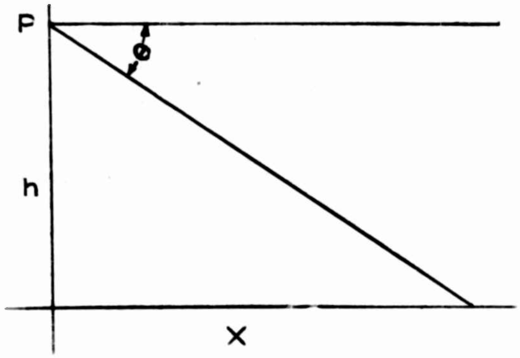


FIG. 9 COORDINATES FOR REFLECTOR DERIVATION

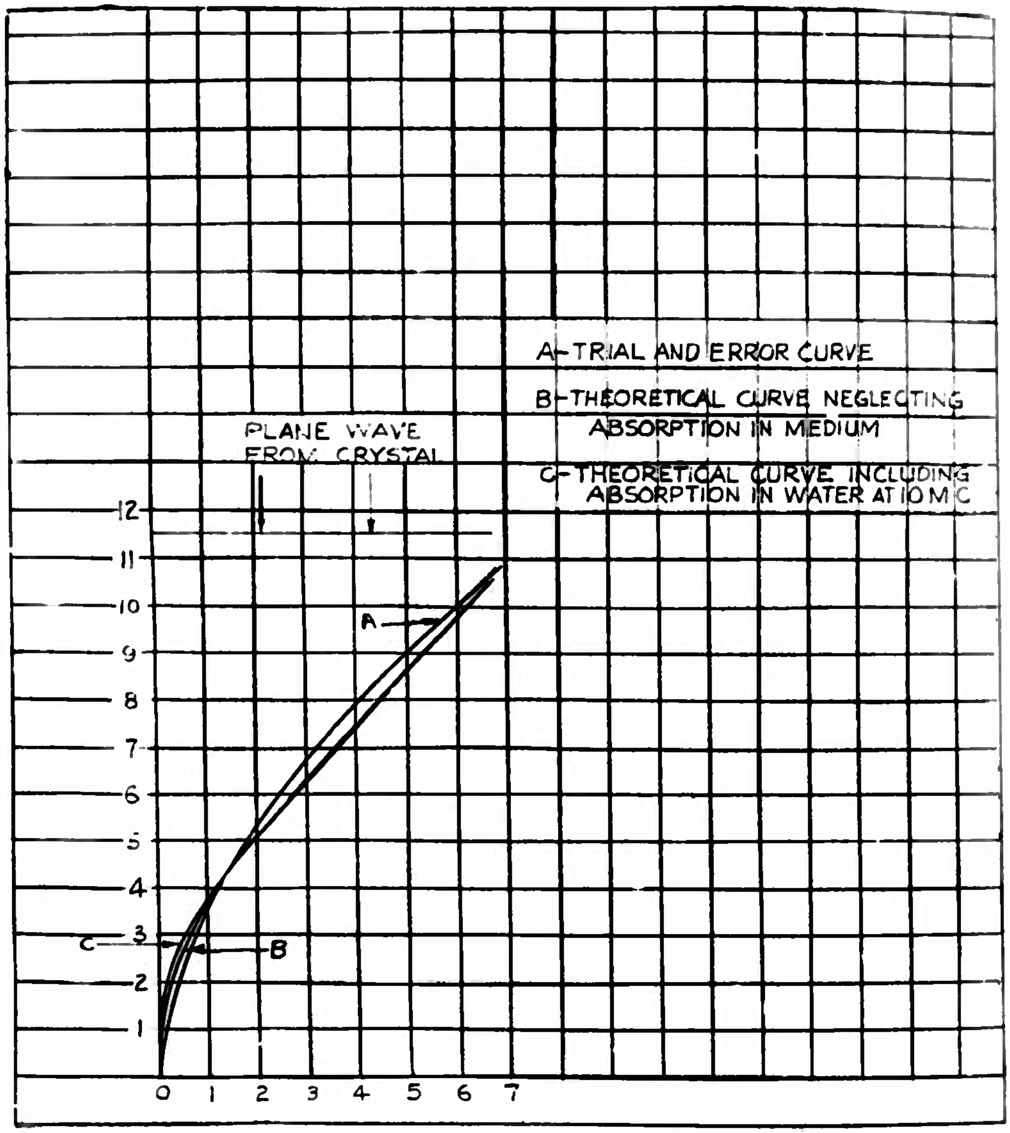
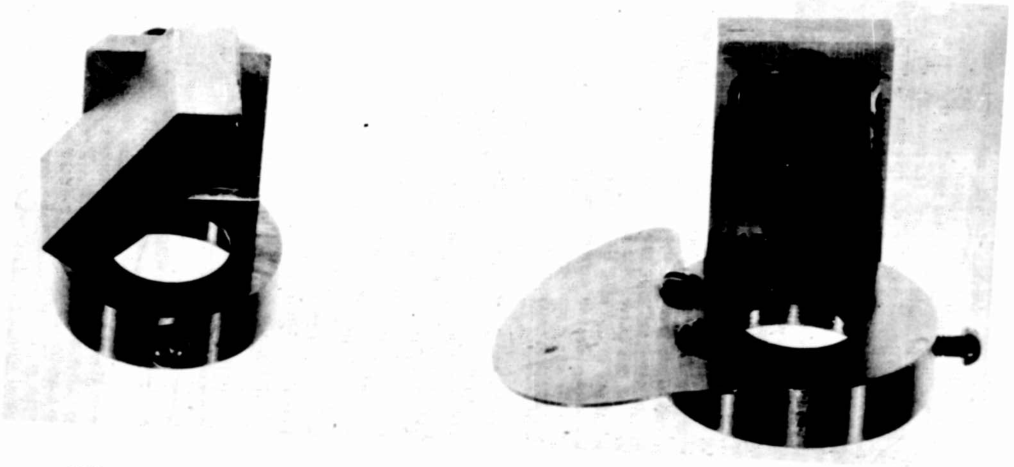


FIG. 10A VARIOUS "CSC^2" REFLECTOR CURVES



MOUNTED BELL AND HOWELL REFLECTOR MOUNTED SPHERICAL REFLECTOR

FIG. 10B REFLECTOR MODELS

returned signal. In order to simulate this radar beam, a reflecting surface that would spread the direct beam from the crystal over the specified range was required.

The first reflectors were hand made of "dural" and gave satisfactory distribution as determined from the appearance of a supersonic map on a PPI. They were made by trial and error methods with a rough theoretical curve as a guide.* They could not however be duplicated by an industrial process. The desired illumination could be approximated, however, by the use of sections of glass lenses that could be readily manufactured. The urgent need for some sort of reflector resulted in the use of these "spherical" glass reflectors that were usually convex in the plane of elevation and slightly concave (to provide some focusing action) in the azimuth plane. A photograph of this reflector is given in Figure 10B.

These reflectors were not satisfatcory, but at that time no method for grinding glass surfaces to more complicated shapes had been developed. During this period the theoretical shape of a reflecting surface that would provide a $\csc^2 \theta$ pattern had been determined. This curve was designed for a crystal of rectangular plating; it was only an approximation, for the analysis did not include the absorption in the medium or the finite dimensions of the crystal. The equation for the surface is given by $y = \ln\left(1 + \frac{\sqrt{1+x^2}}{x^2}\right) - \sqrt{1+x^2}$

The development at the Bell and Howell Co., Lincolnwood, Ill., of a pantograph cutting process made possible the production of specially shaped glass reflectors. The first reflector made by this process followed the theoretical curve, but the inadequacy of this curve, especially for circular crystal platings, resulted in slight modifications in the final production model. The production curve gave satisfactory coverage, but in general the return at short ranges was too intense. By the end of the war, a pantograph grinding and polishing machine had been set up at the Radiation Laboratory and curves of various types were being made.

The pantograph grinding and polishing machine set up at Radiation Laboratory was constructed by modifying a Gorton three dimensional pantographic miller. The milling cutter was replaced by a grinding or polishing wheel. The guide arm of the pantograph is made to follow a metal cam cut by hand to correspond to a predetermined reflector curve. A special slow speed drive was installed for final polishing. It was found advisable to modify the guiding mechanism of the pantograph by the installation of a motor driven reciprocator to eliminate the striations that appeared in the glass reflector. The reciprocating motion was parallel to the axis of rotation of the grinding wheel. One could dispense with this reciprocating motion only by careful choice of grinding mixture and skillful manipulation of the guiding arm. For production purposes at the Bell and Howell Co. and at the Radiation Laboratory the reciprocator was always employed.

It could be shown that if the absorption of the medium were taken into account in designing a constant return system, the required distribution would be given by:

$$P(\theta) = K_2 \csc^2 \theta \, \varepsilon^{2h \csc \theta} \qquad (8)$$

where 2 was a measure of the absorption of the medium. In this case the distribution would not be independent of altitude, h. To determine the reflector curve for a 10 mc. system a graphical integration was carried out. A glass reflector was made from this curve at the Radiation Laboratory. It gave very uniform ground coverage when used with a ⅜" x ⅛" rectangular crystal plating. It was designed to throw energy out to 100 miles at an altitude of 22,000 feet. The signal to noise ratio with this reflector was not completely satisfactory, for de-

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* These early experimental reflectors were made by Sgt. R. P. Blanchard who was stationed at the Radiation Laboratory.

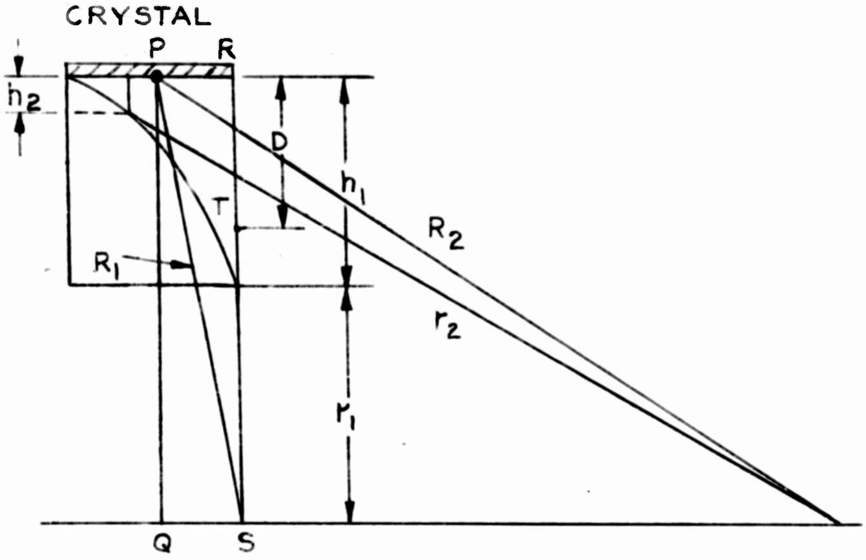

FIG. 11 GEOMETRY OF REFLECTING SYSTEM

signing the curve for 100 mile coverage reduced the overall signal level. It is believed that a redesign of this reflector on a more conservative basis (say 85 miles) would improve the signal intensity. The reflector curves are given in Fig. 10A. Curve A is the hand tooled reflector of R. P. Blanchard. Curve B is the theoretical curve neglecting the absorption in the medium. Curve C includes absorption at 10 mc in water. All curves are indicated for 50 mile coverage; curves B and C are identical at long ranges within the precision of the plot. A photograph of the Bell and Howell reflector is given in Fig. 10B.

Range distortion is introduced by the large physical size of the crystal and by the shape of the reflector. From Fig. 11 it appears that the effective slant range is given by $r_1 + h_1$ whereas the true slant range is R_1 if the center of the optical system is located at P, the center of the crystal. Similarly for zero ground range, the true slant range is R_2 rather than $r_2 + h_2$. The range error $\Delta = R - (r+h)$ is not constant for all ranges and therefore no simple correction can be made to reduce the range error to zero. In order for the reflector to cover targets at zero ground range it becomes necessary to move the axis of rotation from PQ to RS. In this way the true slant range equals the effective slant range at zero ground range. The geometry of the "offset" situation is given in Fig. 12, where R' is the true slant range with point P as the effective origin. The minimization of range error is most important at short ranges if the trainer is to be used effectively for radar bombing training as well as for radar navigation training. From Fig. 12 it is apparent that the range error $\Delta' = R' - (r'+h')$ is negative for all ground ranges greater than zero. It has been found possible to reduce the error at short ranges by introducing an electrical delay into the range sweep of the radar set. If the sweeps are started after the crystal is pulsed by a time equal to the time of traversal of the supersonic pulse from P to T, then the effective height of the crystal is placed at T. The range error expression now becomes:

$$\Delta' = R' - (r' - h') - D.$$

If D were made equal to H, the distance from the crystal to the toe of the reflector, then the range error would be zero at zero ground and positive for all ranges greater than zero. The magnitude of the range error at short ranges is less if the electrical delay is introduced. The errors at short ranges may be averaged if D is made slightly less than H. Fig. 13 shows a plot of range error vs. range for various amounts of electrical delay.*

The introduction of an electrical delay does by no means eliminate the range error completely. The only solution to the range error problem involves the generation of a very small source of supersonic energy. One would expect the range error of the $K_2\csc^2\theta\,\varepsilon^{2h\csc a}$ reflector to be less than that of the Bell and Howell reflector, for the energy spread over short ranges originates from a smaller area at the toe of the reflector.

Work on the development of a concave reflector that would decrease range errors was halted at the end of the war. In this type of reflector (Fig. 13), the rays from the crystal cross through a small area about P. If PQ is made the axis of rotation of the system, and if an electrical delay approximately equal to AB + BP is introduced into the system, the origin of the energy appears at P and both the magnitude and spread of range errors should be reduced.

In designing a reflector mount, certain practical difficulties are encountered. Most of these difficulties were eliminated in the final reflector mount used in the Eagle Trainer. The mount must be designed so that it does not get in the path of the supersonic beam. If this is not done energy reverberates between the crystal and mount and although the fraction of the total energy reflected may be small it is usually greater than signal energy returned from small targets at close range. The reflector mount must also be designed to allow tilting the reflector so that adjustment may be made to obtain best reflector coverage. In addition, an adjustment must be provided so that the position of the toe of the reflector may be accurately located. If the toe of the reflector protrudes beyond the supersonic beam, the range of coverage will not extend in to zero ground range. If the toe of the reflector does not cut off the major fraction of the beam, a high powered altitude signal (direct signal from the map) will be received. If the

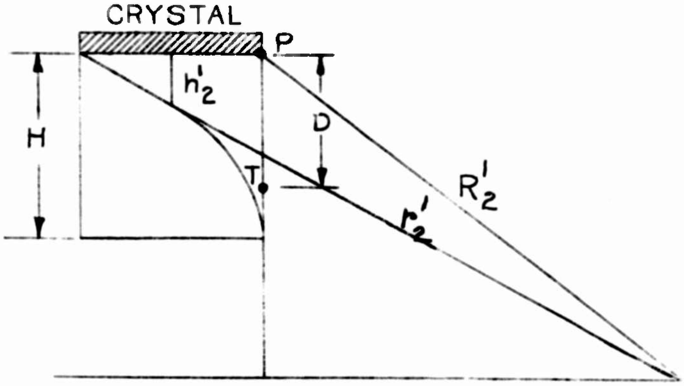

FIG. 12 GEOMETRY OF REFLECTOR SYSTEM WITH OFFSET

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* This data was taken on an Eagle Supersonic trainer equipped with a Bell and Howell reflector. Measurements were made under the direction of Lt. J. B. Higley with an A & R scope and are representative of the type of range error curve obtained.

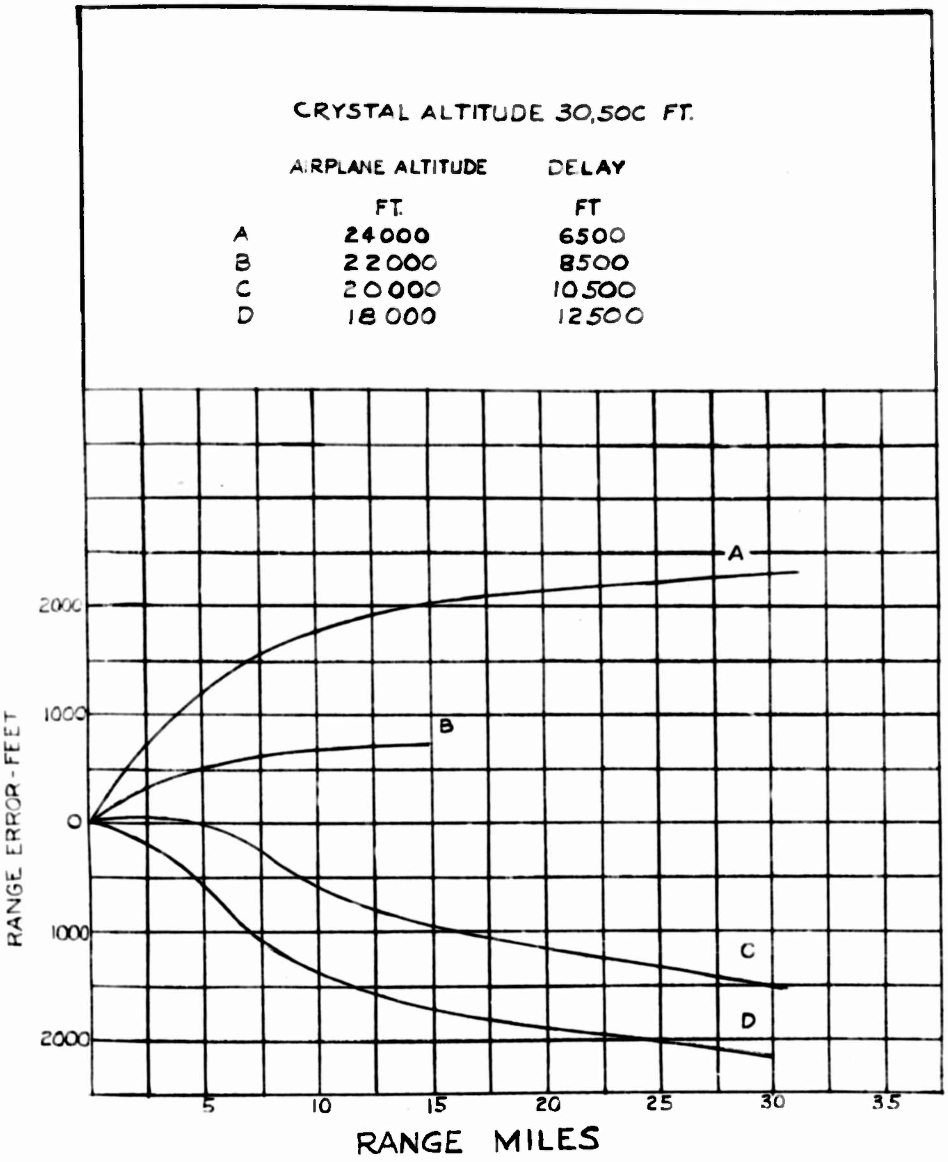

FIG. 13 RANGE ERROR OF BELL AND HOWELL REFLECTOR FOR VARIOUS AMOUNTS OF ELECTRICAL DELAY

energy received in this way is not reduced to a minimum, there will be sufficient energy passing by the toe to travel back and forth between the crystal or crystal cartridge and the "ground" directly below the crystal. Thus a series of equally spaced reflections will appear and will show up as consecutive "altitude rings" on the PPI. To eliminate reflections from the surface of the water, a "visor" (see Fig. 10B) is employed. The Bell and Howell reflector is shown in Fig. 10B. An old style reflector mount is shown in these photographs.

V. THE REFLECTING MAP

A properly designed reflecting map should simulate radar signals and radar dimensions. Since it is not desirable to change the sweep speeds and timing circuits in the radar indicator, the scale of the map must be determined by the ratio of velocity of electromagnetic waves in air to the velocity of supersonic waves in the liquid employed as the propagation medium. Although it is not difficult to adhere to this scale factor in the ground plane, it is most difficult to construct a map that will truly represent the height of cities, mountains, river banks, etc. For example, a group of 100 foot factory buildings would have to be represented by a layer of reflecting material only .006" high. It has been found that various levels of signal return from cities, mountains, ground, and bodies of water, cannot be obtained merely by choosing reflecting materials with different acoustic impedance, for the spread in values of acoustic impedance for solids is not very great. In addition, at a wave length of .01 cm, small particles the size of factories do not reflect in a directional manner but act as scatterers. For these reasons the size of cities on the map must be greatly exaggerated if we are to receive signals from them at a great distance or if we are to distinguish them readily from the lower level ground return signals.

The earliest maps used in supersonic trainers were made of plate glass.[*] The simulation of ground return was obtained by sprinkling fine sand over a coating of varnish on the glass. Cities were built of small glass beads and carborundum. The glass itself served to simulate water areas. The main faults in these maps were:

1. The maps were not desirable for continuous underwater use; the varnish bond between sand and glass would loosen after long immersion.
2. The exaggerated size of cities resulted in the production of undesirable "shadows".
3. Mountain areas could not be efficiently simulated.
4. Glass maps were naturally fragile and difficult to ship.

Another type of map[**] especially suited for the simulation of mountain areas, was the flexible plastic "waffle" relief map. A short description of the construction of this map will serve to indicate its properties.

A sheet of aluminum is fashioned into a relief model of the geographic area by means of a "reliefograph" machine. The "reliefograph" which was developed at Aero Service Corporation, Philadelphia, specifically for this purpose consists of a small motor-driven trip-hammer which reciprocates vertically and rapidly, and which hammers the aluminum sheet into the desired shape. The effective depth of the stroke of the small hammer is accurately determined by a hand control which can be set to correspond to the altitude of any desired contour line. The contour lines of the desired map, drawn to the supersonic scale, are printed directly upon the aluminum sheet. The hammer mechanism enables the hammer to be guided by hand along any given contour line. The aluminum sheet is thus

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[*] See Radiation Laboratory Reports: M-181, "Handbook of Instructions for the Preparation of Maps for the H_2X Supersonic Trainer," by W. R. Carmody; M-205, "Handbook of Instructions for the Preparation of Mountain Maps for the H_2X Supersonic Trainer," by W. R. Carmody.

[**] A report on the latest waffle map developments is that of the Aero Service Corp. submitted Oct. 1, 1945, entitled "12' x 16' Ultrasonic Relief Model".

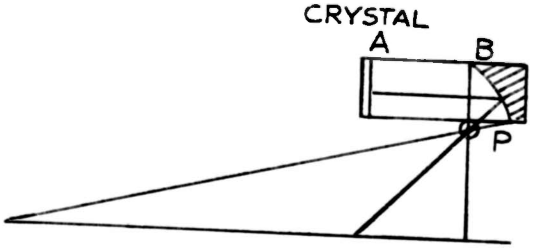
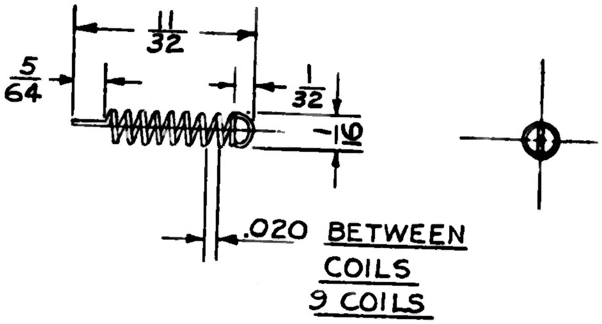


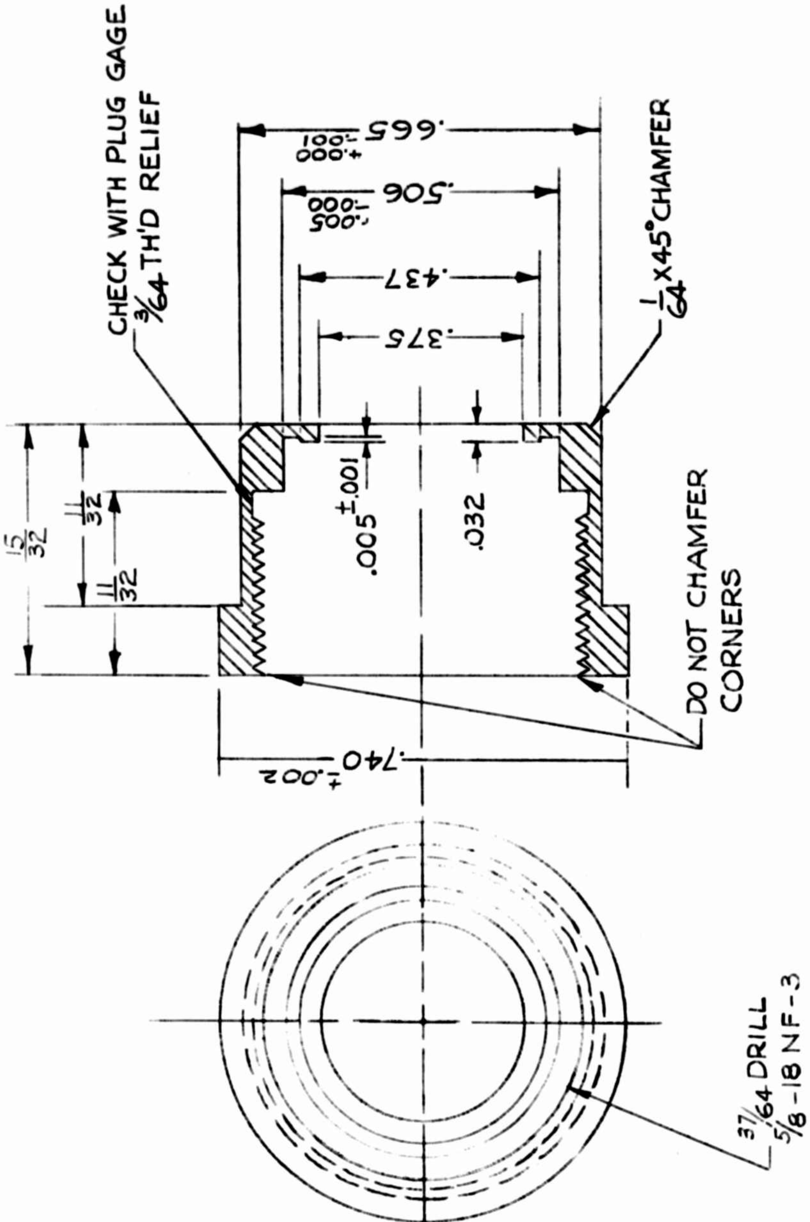
FIG. 14 CONCAVE REFLECTOR FOR MINIMIZING RANGE ERROR



NOTE: SPRING WOUND ON .040 MANDRELL

MATERIAL - .006 STERLING SILVER WIRE-SPRING TEMPERED

FIG. 15 CAT WHISKER (OLD TYPE)



MATERIAL - H. H. BRASS

FIG. 16 CARTRIDGE BODY

hammered into a three dimensional relief model of the terrain represented by the contour line.

From the aluminum master, a master mold of plaster-of-Paris-like material is cast in one 4' x 6' piece. This master mold serves to form the plastic sheets into the finished relief model. The plastic is a hard opaque vinylite in the form of a sheet .010 inch thick. The plastic sheet is heated either by hot water or by infra-red lamps, and simultaneously pressed into the plaster-of-Paris mold. The edges of the vinylite sheet are clamped air-tight all around, and the air is evacuated between the plastic sheet and the plaster-of-paris.

The resulting three dimensional map is treated as are the glass maps to obtain sanded ground areas, cities, lakes, etc.

The advantages of the waffle maps are:

1. They provide better simulation of mountain areas.

2. They are flexible and light and therefore easily shipped and less subject to breakage than the glass map.

The disadvantages of this map are:

1. The return from the water areas is greater than in the case of the plate glass map and thus the range of signal level is reduced.

2. The density of the plastic is not sufficiently greater than the density of water to allow for stable positioning in the tank.

3. While the dimensional stability of a flat vinylite sheet is almost as good as the stability of a glass plate, this is no longer true of the stability of the cast waffle map in the vertical plane. No tests have been made on the stability of the waffle map in the ground plane.

4. The size and shape of the "reliefograph" trip hammer and the "pulling" of the aluminum sheet limit the fineness of detail that can be built directly into the map.

The latest map development* is that of the Sullivan-Meade Co. of Chicago. It is cast from Thiokol, a synthetic rubber.

The finished map is one-quarter inch thick at sea level, with the relief areas cast solid. It is mounted on a canvas back which is equipped with handles and hang-up loops. A six- by four-foot map weighs about sixty-three pounds, and rolls into a tight bundle for shipping. This material can be stretched out of shape and when laid flat will resume its previous contours.

Its dimensional stability, although not as yet tested with instruments, seems to be good, both horizontally and vertically. The specific gravity of the material is considerably higher than water, so it hugs the bottom of the tank.

The supersonic ground return is cast into the surface of the Thiokol by means of a roughened mold. Cities are made up on wire mesh or nylon, generally by sewing beads to the fabric, which is in turn sewed to the map. To alter the appearance of cities, headed pins can be stuck into the map.

The process includes the making of the original relief map, preferably by hand, with wax on a glass plate. A negative is then cast in plaster or dental stone. The roughened surface is provided by sprinkling the original with Farina, which can then be washed out of the hardened plaster, leaving pits. The Thiokol is puddled into the plaster negative, and no pressure is required. Heat speeds up the curing process, but is not necessary.

S. FRANKEL
P. ROSENBERG
Dec. 1, 1945

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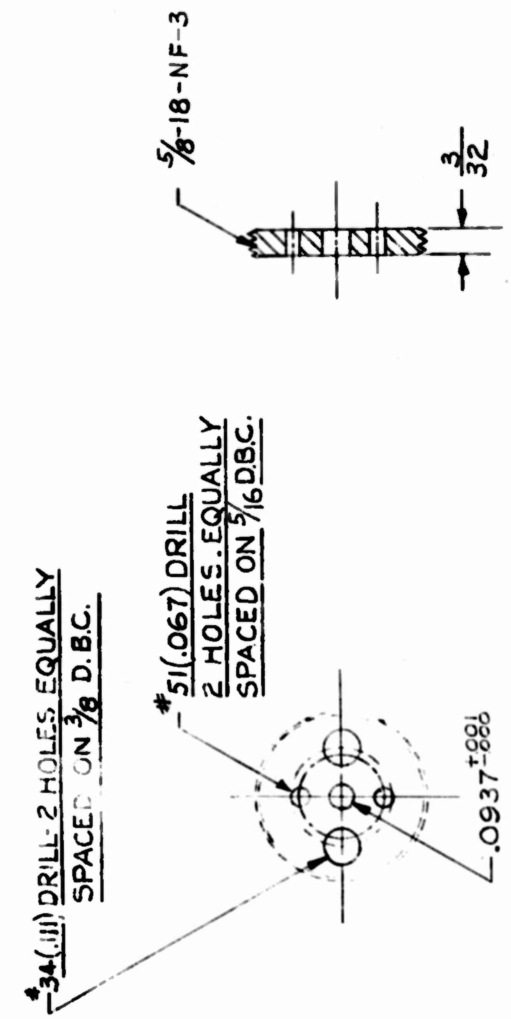
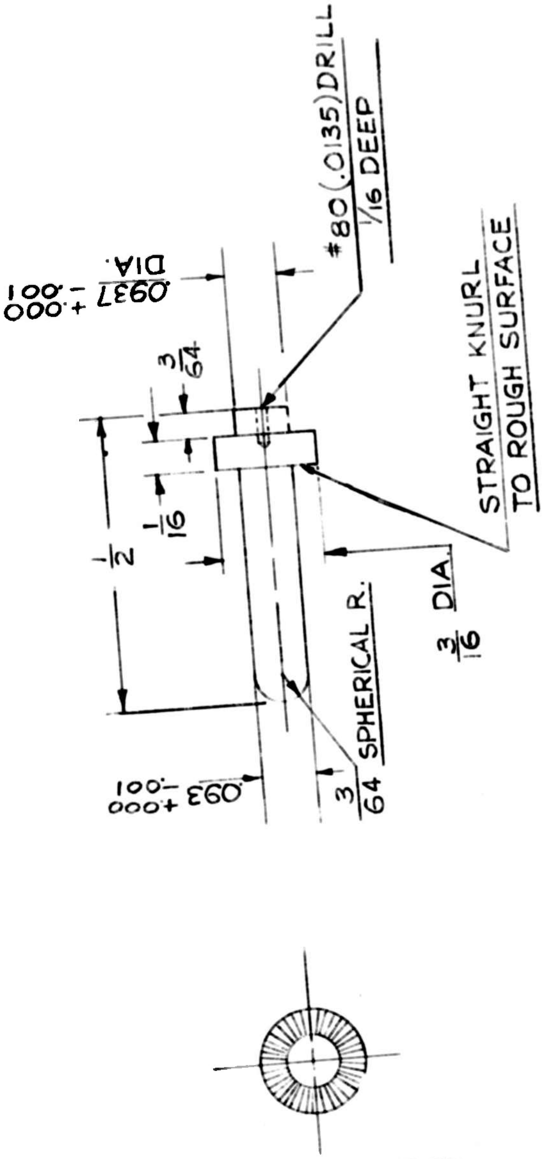
* This material is abstracted from information furnished by R. A. Roberts.



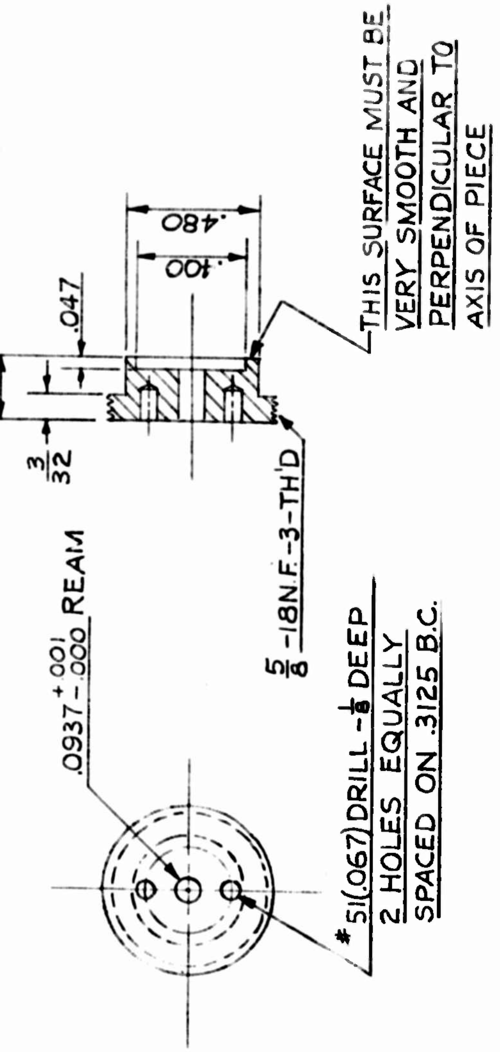
MATERIAL - POLYSTYRENE

FIG. 17 SMALL INSULATING BEAD



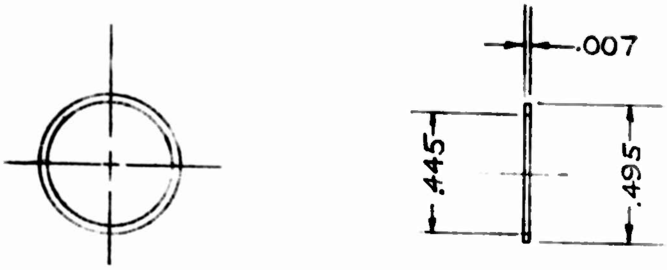
MATERIAL - COIN SILVER

FIG. 18 CONNECTOR PLUG



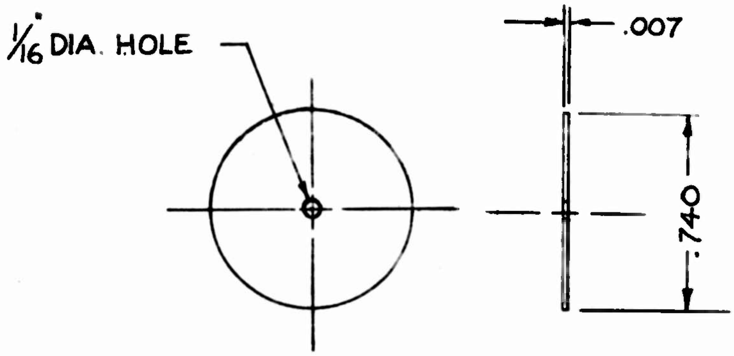
MATERIAL - POLYSTYRENE

FIG. 19 LARGE INSULATING BEAD



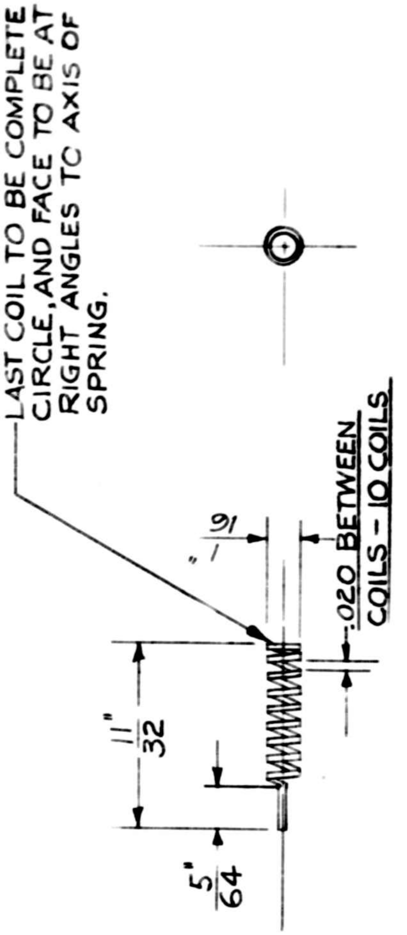
MATERIAL - DENTAL RUBBER

FIG. 20 CRYSTAL GASKET



MATERIAL - DENTAL RUBBER

FIG. 21 ADAPTOR GASKET



MATERIAL - .006 STERLING SILVER
WIRE-SPRING TEMPERED
SPRING WOUND ON .040
MANDRILL

FIG. 22 CATWHISKER (NEW TYPE)

REEL – C

485

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ABSTRACT

The principles governing the simulation of radar signals in a supersonic trainer are presented along with brief description of the piezoelectric crystal and other components developed for this purpose. It is shown that the simulation requirements include the following condition: that the intensity distribution of the supersonic beam is identical with that of the electromagnetic beam of the radar set. None of the requirements has been fully met in any supersonic trainer designed to date.

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