

NRL MEMORANDUM REPORT

No. 83

A NEW METHOD OF CALIBRATING
FIELD STRENGTH MEASURING EQUIPMENT

Harold E. Dinger
William E. Garner

RADIO DIVISION II

14 November 1952



13 LA

NAVAL RESEARCH LABORATORY, WASHINGTON, D.C.

PLEASE RETURN THIS COPY TO:

**NAVAL RESEARCH LABORATORY
WASHINGTON, D.C. 20375
ATTN: CODE 2628**

Because of our limited supply you are requested to return this copy as soon as it has served your purposes so that it may be made available to others for reference use. Your cooperation will be appreciated.

NDW-NRL-5070/2035 (Rev. 3-73)

DISTRIBUTION STATEMENT A APPLIES.
Further distribution authorized by _____
UNLIMITED only.

TEXT

FOR

NRL MEMORANDUM REPORT NO. 83

UNCLASSIFIED

A NEW METHOD OF CALIBRATING
FIELD STRENGTH MEASURING EQUIPMENT

14 NOVEMBER 1952

SYSTEMS UTILIZATION BRANCH

RADIO DIVISION II

NAVAL RESEARCH LABORATORY

WASHINGTON 25, D. C.

UNCLASSIFIED

CONTENTS

ABSTRACT	iv
AUTHORIZATION	iv
INTRODUCTION	1
THEORY	1
DETAILED PROCEDURE	3
SIMPLIFIED PROCEDURE	7
TABLE I	10

ABSTRACT

A new method of calibrating radio interference and field strength measuring equipment employing shielded loop antennas has been developed. It is based on the concept of the shielded loop antenna acting as a unity coupled transformer; the shield being the primary and the inner conductor the secondary. It is assumed that the loop dimensions are small compared to the wavelength, that the shield is made of a highly conductive non-ferrous material, and that the inner turns do not approach resonance when open circuited. The calibrating signal is injected into the loop shield across the shield gap. This signal voltage is equal to the voltage that would be induced in the shield of the loop by an electromagnetic field of the intensity at which it is desired to calibrate the equipment. The principal advantages of this method are: simplicity, wide range of calibration levels, and adaptability to field use.

PROBLEM STATUS

This is an interim report on one phase of these problems; work is continuing on this and other phases of the problems.

AUTHORIZATION

Problems No. 39R07-41 and No. 39R07-26

Subj: A New Method of Calibrating Field Strength Measuring Equipment

- Ref: (a) Terman, F. E., "Radio Engineer's Handbook", McGraw-Hill Book Company, 1943, pp 813-815.
(b) Libby, L. L., "Special Aspects of Balanced Shielded Loops", Proceedings of I.R.E., Vol. 34, p 643, September, 1946.

INTRODUCTION

1. Most of the modern radio interference and field strength measuring equipments operating below 25 megacycles employ shielded loop antennas either as the primary pickup device or as an accessory. These equipments frequently require recalibration and it is common practice in many instances for the user to return the equipment to the manufacturer or a standardizing agency for this purpose, or simply to continue to use the equipment and assume it to be calibrated correctly. The calibration methods now in general use require rather precise and critical installations, or are subject to error, and the more accurate methods are practically impossible to use out in the field.

2. While making a study of the calibration methods now in general use, a new method was developed which has a very high degree of accuracy and is very simple to apply, even in the field. Some phases of the investigation of this method are still being carried on; however, the application of this method for the calibration of the Stoddart Aircraft Radio Company Radio Interference-Field Intensity Meters NM-10A (Navy Model AN/URM-6) and NM-20A (Navy Model AN/PRM-1) has been completed. This report will therefore include the procedure for applying this method to these instruments along with a discussion of the general theory of the method.

THEORY

3. The shield-injection method of calibrating radio interference and field strength measuring equipment is applicable only to equipments employing shielded loop antennas, the dimensions of which are small compared to the wavelength. It is assumed that the loop shield is made of a highly conductive, nonferrous material such as copper, aluminum, or brass, and that the inner conductor does not approach resonance when open-circuited. It is based on the concept of the shielded loop antenna acting as a closely coupled transformer; the shield being the primary and the inner conductor the secondary. When such an antenna is placed in an electromagnetic field, the magnetic component of the field induces a voltage in the shield and the total induced voltage appears across the shield gap. The coefficient of coupling between the shield and the inner conductor is unity, and therefore, the open-circuit output voltage of the loop is equal to the product of the shield gap voltage and the number of turns of the inner conductor, provided that the inner conductor does not approach resonance when open-circuited.

4. If the shield of a loop without any inner conductor were placed in an electromagnetic field in free space, a voltage (E_s) would be induced in the shield and the total voltage could be calculated from the equation, reference (a),

$$E_s = 2\pi E N \frac{A}{\lambda} \cos \theta \quad (1)$$

where

- E_s = the voltage induced in the shield in microvolts,
- E = the field strength of the field in microvolts per meter,
- N = the number of turns (shield),
- A = the mean area of the loop in square meters,
- λ = the wavelength in meters,
- θ = the direction of travel of wave with respect to plane of loop.

For the ordinary loop shield N equals one. If there were an open-circuited conductor inside this shield, and it did not approach resonance in this condition, then there would be negligible reaction between the shield and the inner conductor, and the induced voltage would be the same as that without an inner conductor present.

5. In most methods of calibrating radio interference and field strength measuring equipment employing shielded loop antennas, a radio-frequency field, the strength of which is calculated, is produced, and the antenna is placed in this field. The shield-injection method is a direct signal insertion type of calibration. The voltage that a known field would induce into the shield (E_s) is injected across the shield gap.

6. Up until now, all the discussion has been concerning the open-circuited loop. When a load, such as the input circuit of a radio interference or field strength meter and the connecting cable, if any, is connected to the output of the shielded loop antenna, in an electromagnetic field, the shield gap voltage and the loop output voltage change by some amount depending upon the impedance of the load. These voltages may further change as the meter is tuned. Since it is rather difficult to calculate these changes in the loop voltages, the shield-injection method is based on open-circuit voltage calculations. If the shield gap voltage induced by a particular field, with the loop output open-circuited, is replaced by a voltage of the same frequency and magnitude from a constant-current (high-impedance) source connected across the shield gap, and some impedance is then connected across the loop output, the shield gap voltage and the loop output voltage will change by the same amount as they would if the loop were in an electromagnetic field. In the application of the shield injection method, a current is caused to flow in the loop shield. Although the shield gap voltage and the loop output voltages change depending upon the load impedance, the shield current must remain constant. Therefore, a constant-current (high-impedance) signal source must be used. The calibration of a radio interference or field strength meter by the shield-injection method is done by first calculating the shield gap voltage (E_s) from equation (1) for a field strength level at

which it is desired to calibrate the meter. This voltage is then injected across the shield gap from a constant-current (high-impedance) source with the loop output open-circuited. The meter is then connected to the loop in the normal manner and adjusted to indicate a field strength equal to that used in equation (1) to calculate E_s .

DETAILED PROCEDURE

7. The shield-injection method of calibration is probably applicable to all field strength measuring equipments employing shielded loop antennas; however, the techniques in applying it may vary with the particular equipment. The application of this method to the AN/URM-6 and the AN/PRM-1 has been completed and the techniques will be discussed in detail here. Later a simplified procedure will be outlined. Its application for the calibration of the RCA Model 308-A Field Intensity Meter provides an interesting study which is now being investigated and will be discussed in a later report. It has been found that this method is applicable to the 308-A but because of the large number of turns of the inner conductor of some of its loops some special techniques are required, and a more thorough investigation is being made. Most authorities in the field of electromagnetic field-strength measurements at the present time consider the loop-separation method of calibration to be the most accurate of the methods now in general use. The shield-injection method has been compared with the loop-separation method in the calibration of the AN/URM-6 and the AN/PRM-1 over their entire frequency ranges and it has been found that the two methods agree within five percent.

8. The shielded loop antennas used with the AN/URM-6 and the AN/PRM-1 all have their shields balanced to ground. In the discussion of the theory of the shield-injection method, it was stated that the signal generator output that was connected across the shield gap had to be of high impedance. Theoretically therefore, the signal generator output should be a balanced, high impedance and such a signal generator is not readily available. The loop shield impedance as measured across the gap is twice the impedance from either side to the base of the antenna. Assuming that the shield is made of a highly conductive, nonferrous material, the inductance of the entire shield can be calculated from the approximate relation, reference (b),

$$L_s = 0.01595 D (2.303 \log_{10} \frac{8D}{d} - 2) \tag{2}$$

where

- L_s = the inductance in microhenrys,
- D = the mean diameter of the loop in inches,
- d = the shield diameter in inches.

The radiation resistance (R_r) of the shield is given by the approximate expression, reference (b),

$$R_r = 31000 \frac{A^2}{\lambda^4} \text{ ohms} \tag{3}$$

where

- A = the mean area of the loop in square meters,
- λ = the wavelength in meters.

Using equation (3) the radiation resistance of the AN/PRM-1 loop and most loops would be of the order of 0.002 ohms or less and of the two AN/URM-6 loops is less than 10^{-8} ohms. The inductive reactance of the shields of most loops is also very low but it is very high compared with the radiation resistance. With the loop output open-circuited, the inductive reactance of the shields of the loops used with the AN/URM-6 and the AN/PRM-1 was measured at 200 kilocycles to be

AN/URM-6 thirty-inch loop,	$X_L = 2.11$ ohms
AN/URM-6 five-inch loop,	$X_L = 0.176$ ohms
AN/PRM-1 loop,	$X_L = 0.522$ ohms

Therefore, since the radiation resistance is small enough to be neglected, the impedance of either side of the shield gap above ground would be just half this value, assuming ground to be at the base of the antenna, and the impedance varies directly with frequency. The action of the loop as an antenna depends upon the impedance of either side of the shield gap to the base and not necessarily to the true electrical ground. In most instances the base of the shielded loop antenna is not at zero potential with respect to other parts of the ground system. In order for connections made to either side of the shield gap to have negligible effect on the loop action, the impedance of the added circuitry between the gap and the base of the loop must be very high compared with the shield impedance between the gap and the base. It has been found, that if certain precautions are taken, an unbalanced signal generator connected as shown in Figure 1 can be used for the calibration of most radio interference and field strength measuring equipments.

9. When calibrating the AN/URM-6 and the AN/PRM-1 by the shield-injection method the following precautions should be taken in order to use an unbalanced signal generator connected as shown in Figure 1. The series resistor (R) serves to keep the impedance connected across the gap high compared with the shield impedance, and to keep the load impedance essentially constant and high compared with the internal impedance of the signal generator. The equipment being calibrated should not be grounded or connected to the signal generator in any way other than by the signal generator output cable. There may be a ground connection through the power line but the impedance of this ground lead would be high enough so as not to have any effect on the calibration. The coaxial cable connecting the signal generator output to the shield gap should be at least three feet long.

10. The first step in the calibration procedure is to calculate the gap voltage that would be induced into the shield by a field of some particular intensity. The gap voltage is calculated from equation (1). The mean effective areas of the loops under discussion are given in Table I. For the particular loop in question, equation (1) can be reduced to the following form using the frequency (f) in megacycles, and $\cos \theta$ equals one.

AN/URM-6 thirty-inch loop:

$$E_s = 9710 \times 10^{-6} \text{ } \xi f \quad (4)$$

AN/URM-6 five-inch loop:

$$E_s = 302 \times 10^{-6} \text{ } \xi f \quad (5)$$

AN/PRM-1 loop:

$$E_s = 676 \times 10^{-6} \text{ } \xi f \quad (6)$$

The loop of the equipment to be calibrated should be mounted in the same relative position as used in making measurements but with the loop output open-circuited. That is, if the loop is normally mounted on the meter for measurement purposes, it should be so mounted for calibration. In the case of the AN/URM-6, the five inch loop should be mounted on the meter in its normal way but the cable used to connect the loop to the meter should be disconnected at the loop output connector. The thirty-inch loop should be mounted on its tripod with its accompanying cable disconnected at the loop output. For the AN/PRM-1, a special adaptor must be made to permit mounting of the loop in its normal position but disconnected at its output. If the adaptor increases the height of the loop above the meter case by an inch or so, the effect is negligible. The shielded output cable of a standard signal generator is then connected across the gap in the loop shield as shown in Figure 1. The series resistor (R) should be of the order of a thousand ohms or more to raise the impedance connected across the gap and to prevent loading of the signal generator. More will be said in the simplified procedure concerning the exact value of this resistance. The connections to the shield should be made immediately at the edges of the gap and the open lead lengths from the end of the signal generator output cable to the shield should be as short as possible including the length of the series resistor (R). It is necessary to keep these open leads short because their length may increase the effective area of the loop. There should not be any other large metallic objects near the loop. The signal generator should be about three feet or more from the loop. Figure 2 shows the calibration installation for the AN/PRM-1. The figure shows the loop rather close to the signal generator; however, this was only for the purpose of grouping for the picture.

11. Because of the series resistor (R), the applied gap voltage is not equal to the output voltage of the signal generator. Therefore, the applied gap voltage must be measured. This can be done very satisfactorily by using the meter being calibrated as a transfer device. Since there is no input to the meter when the gap voltage is first applied, the Antenna Input of the meter can be used to measure this gap voltage. To do this, a signal of the desired frequency and equal to the calculated gap voltage (E_s) should first be fed into the Antenna Input of the meter through the proper impedance matching network (CU-186/URM-6 or CU-195/PRM-1 as the case may be). This is done by connecting the signal generator output cable to a four or five foot length of fifty-ohm coaxial cable

which is connected to the meter through the impedance matching network. The meter is then tuned and adjusted to indicate some convenient value. The signal generator output is again connected to the shield gap through the series resistor. The four to five foot length of coaxial cable is then connected directly across the shield gap with "ground" to the same side as the signal generator "ground" lead. The other end of the cable is left connected to the meter as before without disturbing the settings of any of the meter controls. The signal generator output is then adjusted so that the meter indicates the same value as before. The voltage into the meter cable, which is the voltage applied across the gap, is the desired gap voltage. The signal generator output voltage (E_g) should be noted. The cable connected between the shield gap and the meter Antenna Input should be disconnected. The loop output is then connected to the meter input in the normal manner. The meter should then be tuned and adjusted to indicate a field strength equal to that used in the calculation of the gap voltage (E_s). Any loop factors that are normally used in field strength measurements with the particular loop and meter should also be used in determining the field strength indication for the shield-injection calibration. For example; if the AN/URM-6 is being calibrated using the thirty-inch loop the factor of 10 must be applied to the field strength indication. If the meter was being calibrated at a field strength of 1000 microvolts per meter, the meter should read 100 microvolts if the X1 step of the Attenuator is used or 10 microvolts if the X10 step is used. Gap voltage measurements made in the manner outlined above should, in general, be made at some frequency below about 500 kilocycles. There may be considerable error in this method of measurement for the AN/PRM-1 loop at frequencies above 800 kilocycles because of gap loading. This, however, does not limit the calibration of the equipment to frequencies below 500 kilocycles.

NOTE: The gap voltage is rather low for some loops at the lower frequencies even for rather large field strengths. It may be found convenient to use the gap voltage calculated for a field strength of one volt per meter. After the signal generator output voltage (E_g), required to produce this gap voltage, has been determined, the signal generator output voltage can be reduced proportionally to produce the gap voltage and field strength indication desired. The gap voltage and field strength indication is directly proportional to the signal generator output voltage.

12. It is necessary to measure the gap voltage at only one frequency, and for any particular loop this measurement has to be made only once, since information obtained from this one measurement can be used for future calibration of the equipment without repeating the gap voltage measurement. In the application of the shield-injection method, a current (I_s) is caused to flow in the shield of the loop. This current is constant whether the loop is open-circuited or loaded. The field strength indication of the equipment being calibrated is directly proportional to this current. If the magnitude of this current (I_s) to produce a certain field strength indication could be calculated then it would not be necessary to measure the gap voltage. Thus far, an equation

for the accurate calculation of this current has not been derived. However, the shield current can be determined experimentally for any particular loop and equipment. As mentioned before, the impedance of the shield is very low. If the series resistance (R) shown in Figure 1 is very large compared with the shield impedance, then the shield current (I_S) for practical purposes can be calculated from the expression

$$I_S = \frac{E_g}{R} \quad (7)$$

where E_g is the signal generator output voltage required to give the necessary gap voltage and R is the resistance of the series resistor. It has already been shown that the resistive component of the shield impedance, when the loop is open-circuited, is negligible. Hence, the open-circuited shield impedance can be considered to vary directly with frequency. The shield gap voltage is equal to the product of the shield impedance and shield current. Assuming a constant field strength, the open-circuit gap voltage varies directly with frequency, and the shield current (I_S) is constant with frequency. Therefore, once the shield current necessary to produce a certain field strength indication has been determined, the gap voltage need not be calculated or measured again for the particular loop and equipment. The shield current necessary to produce a certain field strength has been determined experimentally for the AN/URM-6 and the AN/PRM-1. This greatly simplifies the procedure for the calibration of these equipments.

NOTE: Throughout this report the term "signal generator output voltage (E_g)" is the voltage that appears at the output end of the signal generator output cable. In some signal generators, such as the Model LP-5 shown in Figure 2, the voltage output of the signal generator as read on the output calibration dials is not necessarily the voltage that appears at the output end of the cable. This, of course, is especially true at the higher frequencies where the error can be very large. In such a case the voltage at the output end of the cable can be calculated from the signal generator output setting, the frequency, and the impedance and length of the output cable. The use of a signal generator which employs a properly terminated output cable eliminates this difficulty.

SIMPLIFIED PROCEDURE

13. In the application of the shield-injection method, the shield gap voltage and the loop output voltage may change depending upon whether the loop output is open-circuited or loaded and with changes in the load impedance. However, the current (I_S) flowing in the shield must remain constant during these changes in voltage. If the series resistance (R) is very large compared to the impedance of the shield under these various conditions, the signal generator will see a practically constant load impedance and therefore its output current, which is the same as the shield current, will remain constant. This principle of constant current, and the fact that the field strength indication is proportional to this current, makes the shield-injection method very simple to apply once the value of this current per unit of field strength has been determined.

14. If the shield current per unit of field strength is known, it is not necessary to first inject the calibrating signal with the loop output open-circuited. The equipment to be calibrated should be set up in the same manner as for making field strength measurements with the loop antenna. The desired loop should be mounted and connected to the meter input in its normal manner. There should not be any metallic masses near the loop other than what is required for the calibration. The signal generator output should be connected to the shield gap as shown in Figure 1 and previously discussed, and the loop should be about three feet from the generator. The signal generator is then set to the desired frequency and its output voltage (E_g) is adjusted so that

$$E_g = I_s R \quad (8)$$

This output voltage (E_g) is the voltage appearing at the output end of the signal generator output cable as noted previously. The meter being calibrated is then adjusted to indicate a field strength proportional to the value of current used. The shield currents (I_s) required for the three loops under discussion are listed in Table I. These currents are listed for the particular loop as so many microamperes per volt per meter. For example, if the AN/URM-6 was being calibrated using the thirty-inch loop, and a shield current of 920 microamperes were used, the meter should indicate a field strength of one volt per meter. If 0.92 microamperes were used then the field strength indication would be 1000 microvolts per meter since the field strength is directly proportional to the shield current. The same antenna factors must always be applied to the field strength indications for the shield-injection calibration as when making field strength measurements.

15. It will be found very convenient to make the value of the series resistor (R) such that the field strength indication in microvolts per meter is equal to the signal generator output (E_g) in microvolts. The correct value of series resistance to do this for the loops and meters discussed is given in Table I. If these values of resistance given in the table are used for R in Figure 1, and it is desired to calibrate the meter at 1000 microvolts per meter, simply set the signal generator to the desired frequency and the output voltage (E_g) to 1000 microvolts and adjust the equipment being calibrated to indicate a field strength of 1000 microvolts per meter. It may be found that the value of the series resistances listed in Table I is not high enough to avoid loading of some signal generators. A load resistance of 1000 ohms decreases the output of the LP-5 by about 4.5 percent when the X10,000 step of the attenuator is used. However, if the lower attenuator steps of the attenuator are used, a load resistance of 1000 ohms causes negligible loading of the output. This loading effect must be taken into account in the determination of the true signal generator output voltage (E_g) or a higher series resistor should be used. If a resistance of ten times the value quoted were used, it would probably be high enough to avoid loading in most signal generators and the field strength indication in microvolts per meter would be one-tenth the signal generator output voltage in microvolts.

NOTE: The series resistor (R) should have a good frequency characteristic so that its resistance does not change over the range of frequencies used for calibration.

16. Figures 2 through 6 show the three loops used with the AN/URM-6 and the AN/PRM-1 and their respective coupling devices used to calibrate the equipment by the shield-injection method. The original coupling devices that were made for the investigation of this calibration method had two mounted coaxial connectors. One was for the connection of the signal generator output and the other was for the connection of the cable to measure the gap voltage. If the shield current technique is used the second connector is unnecessary. The coupling devices shown in the photographs have been found to be very convenient. The ones used for the AN/URM-6 loops are mounted permanently and do not affect the normal operation of the loops provided nothing is connected to the coupling device when radio interference or field strength measurements are made. The coupling device used for the AN/PRM-1 loop snaps into place for calibration or can be left mounted permanently.

17. Most signal generators have an upper limit of output voltage at about one volt. Since, in most instances in calibrating with the shield injection method, the field strength indication in microvolts per meter is equal to the signal generator output voltage in microvolts, the equipment can be calibrated at practically any level desired including very high levels of field strength. In most other methods of calibration this is not easily accomplished, and calibration must be done at the lower levels of field strength. It is advantageous to be able to calibrate at the higher field strength levels especially if it is necessary to calibrate the equipment in the presence of high ambient radio interference. Under such conditions it may be possible to calibrate the equipment at a level much higher than the ambient interference and thereby not introduce an error in the calibration. Also, for accurate field strength measurements it is generally possible to make the measurements by the direct substitution method and eliminate any error in the scale tracking, attenuator, or internal calibration of the meter. To make measurements by the direct substitution method, the meter is tuned to the signal to be measured and the antenna is oriented for maximum pickup. The gain of the meter is adjusted for some convenient indication. The loop is then oriented to a null or the signal may be turned off, if possible, and the controls on the meter are not disturbed. The shield-injection method of calibration is then applied in the normal manner except that the meter controls are not disturbed and the signal generator is tuned to the meter frequency and its output voltage is adjusted so that the meter again indicates the same as it did when receiving the radiated signal. The field strength can then be calculated in the normal way for the shield-injection method.

Harold E. Dinger
Harold E. Dinger

William E. Garner
William E. Garner

TABLE I
SHIELD-INJECTION CALIBRATION DATA FOR AN/URM-6 AND AN/PRM-1

Loop	A ⁽¹⁾ Sq. Meters	I _S ⁽²⁾ $\mu\text{a/V/m}$	R ⁽³⁾ ohms
AN/URM-6:			
Thirty-inch loop	0.464	920	1090
Five-inch loop	0.0144	340	2940
AN/PRM-1 loop	0.0323	260	3850

- (1) The mean effective area (A) of the loops in square meters.
 (2) The shield-injection shield current (I_S) expressed in microamperes per volt per meter. (See Text)
 (3) The series resistance (R) necessary to make the field strength indication in microvolts per meter equal the signal generator output voltage in microvolts.

ILLUSTRATIONS

FOR

NRL MEMORANDUM REPORT NO. 83

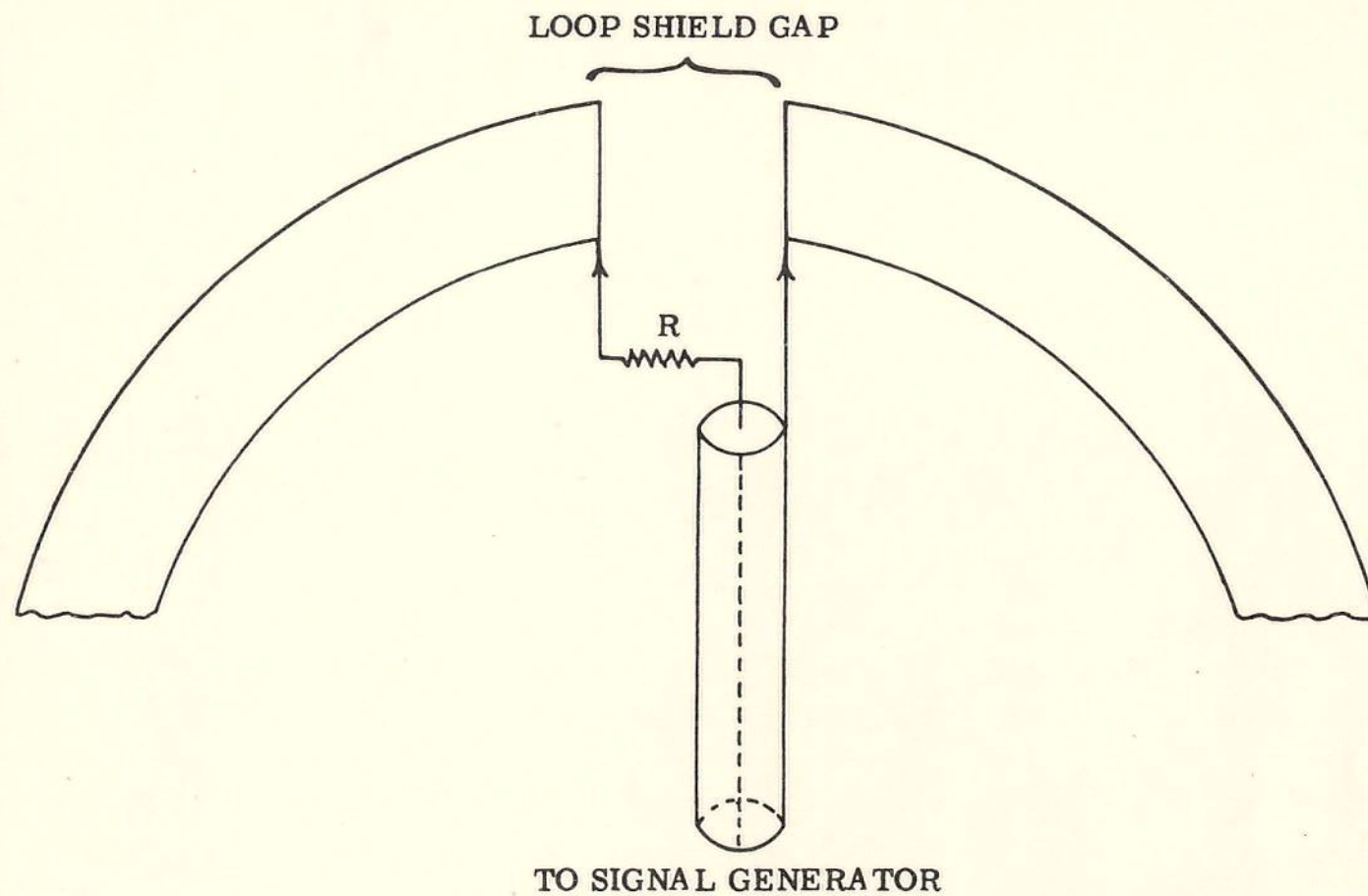


Figure 1 - Schematic Drawing Showing Connections for Calibrating the AN/URM-6 and the AN/PRM-1 by the Shield Injection Method.

6100 EN 3 111111

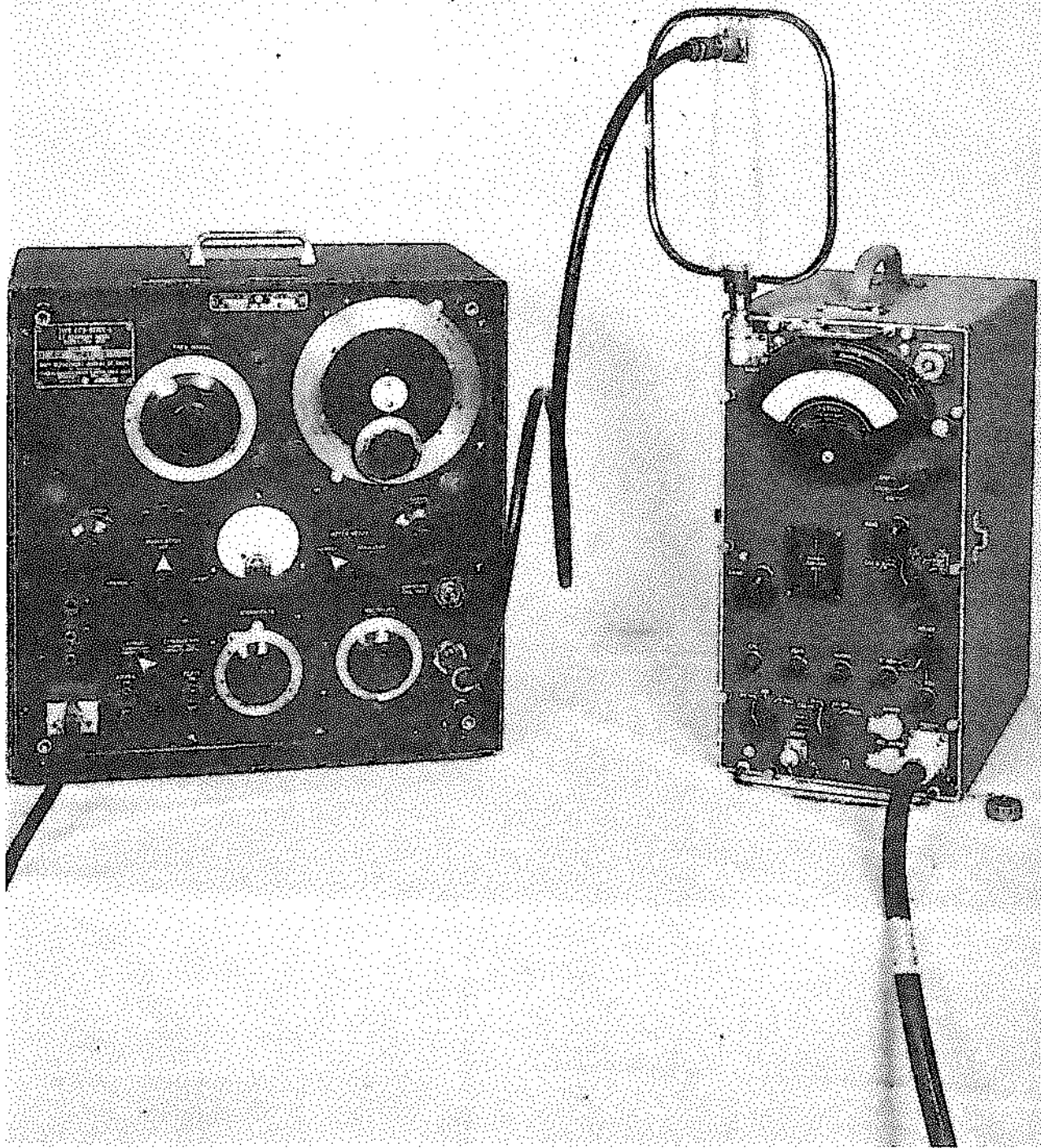


Figure 2 Shield Injection Calibration Installation for the AN/PRM-1

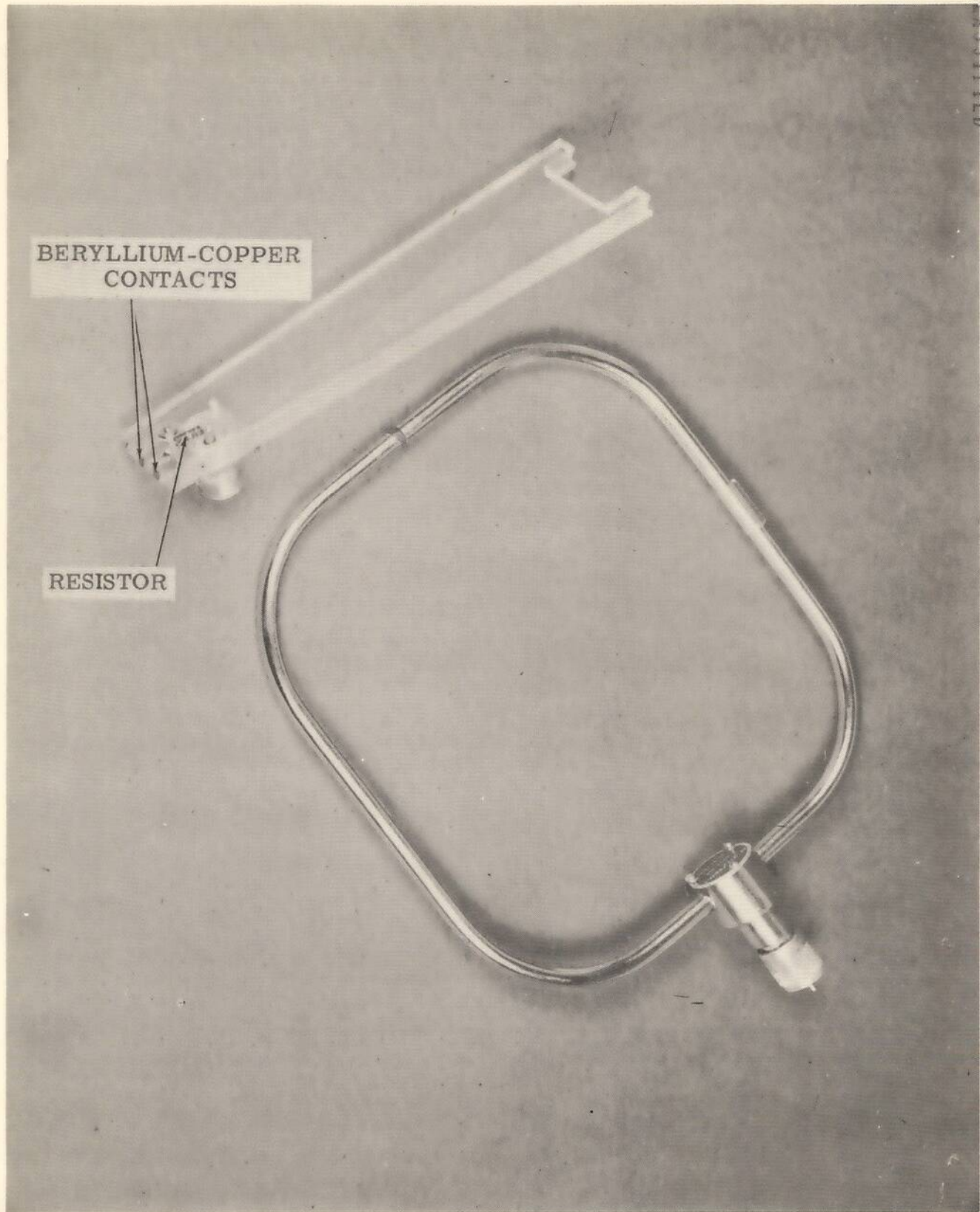


Figure 3 The AN/PRM-1 Loop With Shield Injection Coupling Device

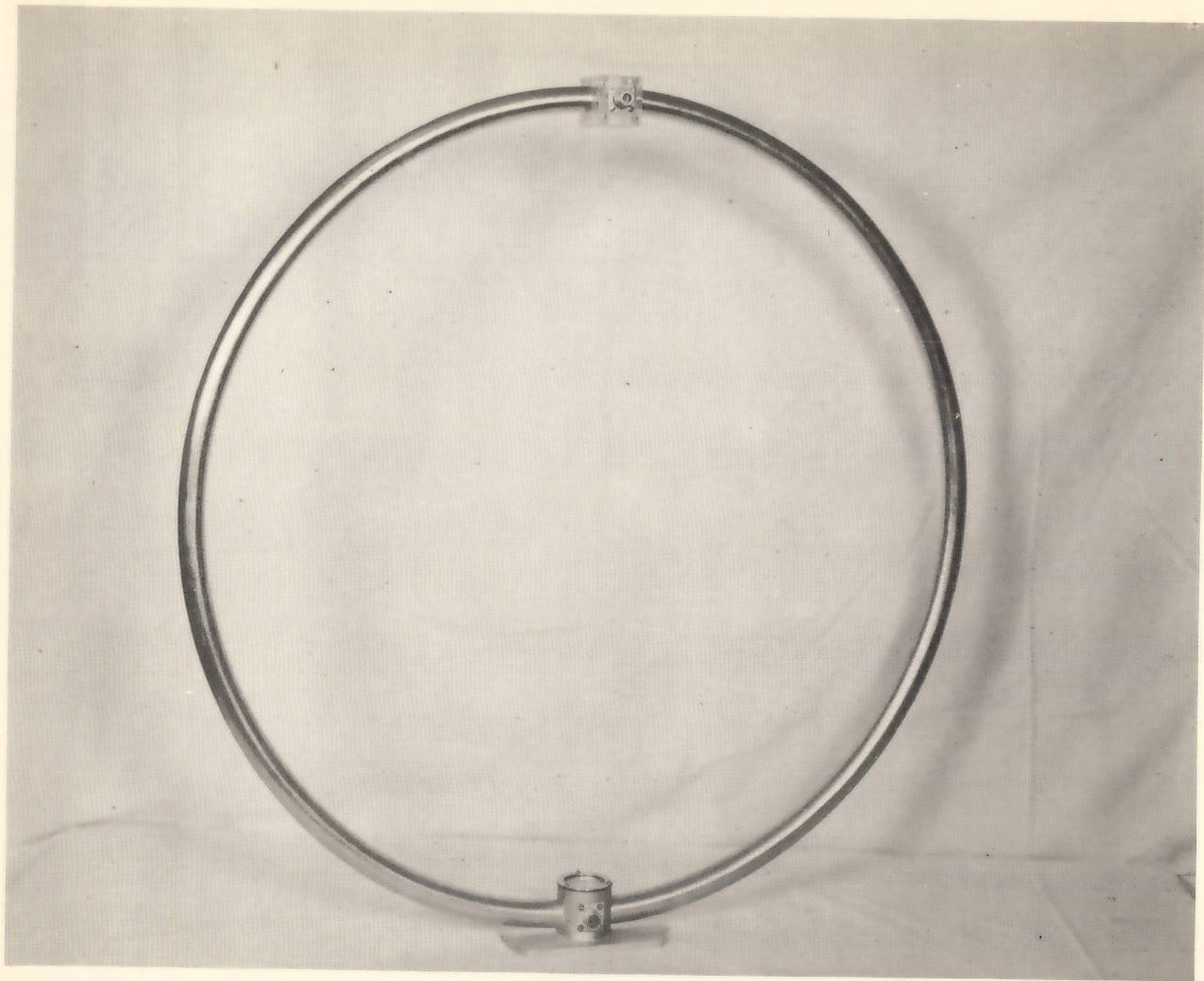


Figure 4 The AN/URM-6, 30 Inch Loop, With Shield Injection Coupling
Device Connected

UNCLASSIFIED

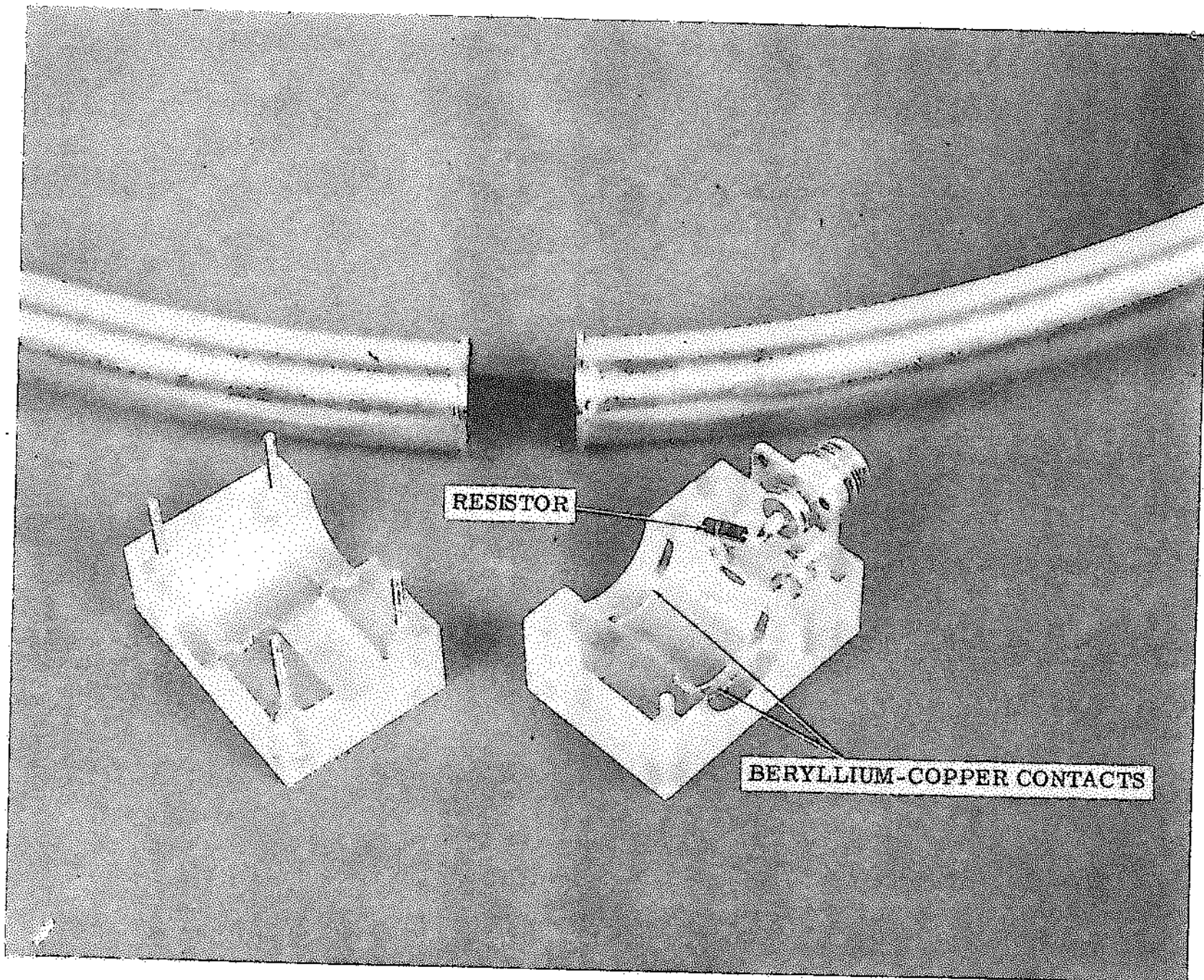


Figure 5 The AN/URM-6, 30 Inch Loop, Shield Injection Coupling
Device Opened to Show Connections

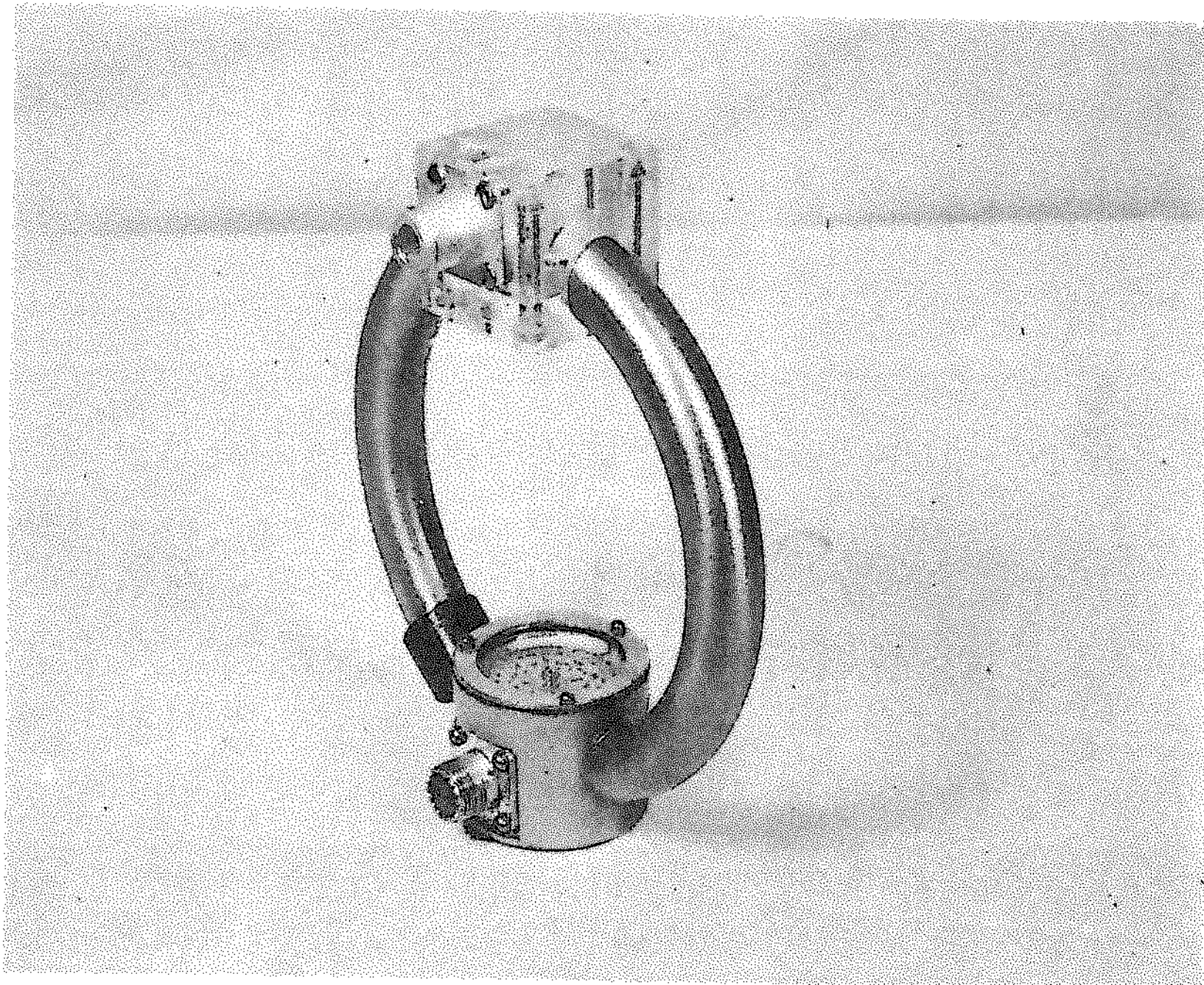


Figure 6 The AN/URM-6, 5 Inch Loop With Shield Injection Coupling Device Connected

081110013080