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THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

Radiation Laboratory

STUDY OF MEASUREMENT TECHNIQUES APPLICABLE
TO AUTOMOBILE IGNITION RADIATION

FINAL REPORT

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by

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I INTRODUCTION

This report describes the work performed under Purchase Order 47-R-323480 with the Ford Motor Company. The objective of the study was to develop a means of measuring the radiated RF energy adjacent to an engine, the data to be obtained in a form such that the effect of the radiation on the FM radio system could be measured. Specifically we were to:

1. develop test standards,
2. develop near field probes,
3. specify techniques of operation and suitable equipment, and
4. demonstrate and report results.

These objectives have been achieved, the approach taken and the results obtained are described herein.

A considerable amount of work has been done by other workers to determine the characteristics of the RF radiation from automobile engines and to measure the intensity levels involved. Most workers have been interested in determining the radiation level at distances several feet from the source. For example, the SAE standard J-551a specifies a spearation distance of 33 feet between the antenna and the near side of the car while the IEEE Standard number 263 specifies a distance of 4 feet. The interest in this study was in more detailed information on source location and in the radiation level of individual components. Hence, many of the measurements in this study were made adjacent to the source; others were made within a foot of the source. This, of course, necessitated the use of sensing antennas much smaller than those used in earlier measurements.

Two types of probes, one electric and the other magnetic, were developed and tested. These probes are described in Chapter II and information on fabrication techniques and impedance behavior is given. In Chapter III, far field calibration procedures are described and curves showing probe sensitivity relative to that of a $\lambda/2$ dipole are presented over the 50 to 200 MHz band. Theoretical data for the magnetic loop is also presented. In Chapter IV various RFI measurement techniques are discussed. Two techniques, the quasi-conductive and the near field radiation methods are described. Data showing the radiation level from a 1973 Lincoln Continental using both techniques are presented. The data is the form of curves showing probe output level in dB above one $\mu v/MHz$ versus frequency for several locations in and about the test car. The frequency range studied included the FM radio band and extended from 50 to 200 MHz. The effect of polarization on the near field data is also shown.

A summary is presented in Chapter V and in Appendix A detailed instructions on measurement procedures are given.

II PROBE CONFIGURATION

Two probe configurations were evaluated for use as Radio Frequency Interference (RFI) field probes. The first was an electric probe and the second was an electrostatic shielded loop.

A photograph of the electric probe is shown in Figure 1. This probe is basically an electrically short dipole (0.03λ at 100 MHz). Since the RFI meter (Singer NF 205) is equipped with an unbalanced input (coaxial) and the dipole is inherently a balanced device, it was necessary to employ a balanced-to-unbalanced (balun) transformer. The balun device employed was a high frequency (100 MHz) conventionally wound transformer chosen because of its small physical size. The probe was fabricated from a copper clad dielectric material.

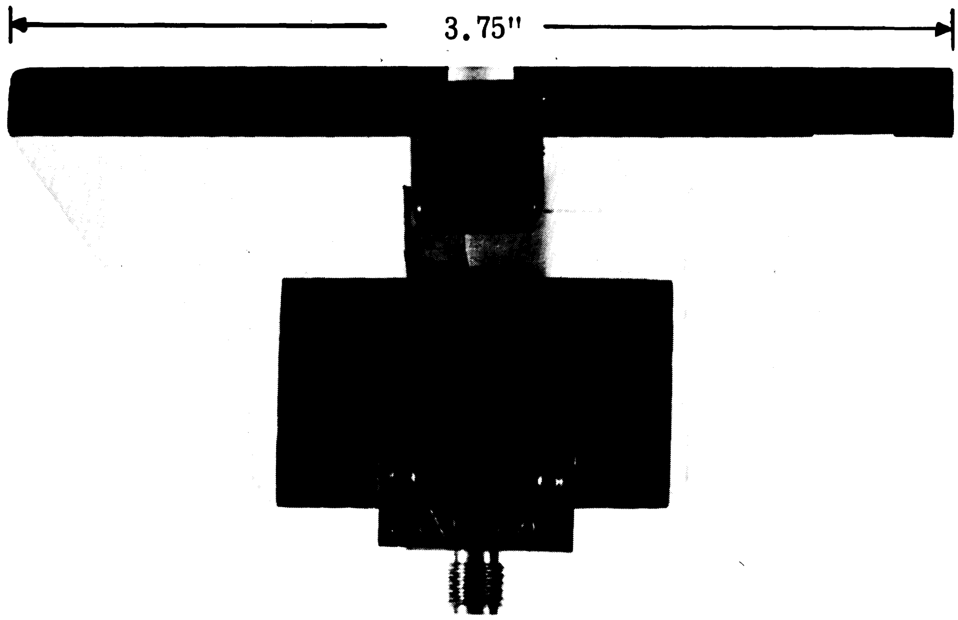


Figure 1: Electric Dipole Probe.

The electrostatically shielded loop is made from a length of coaxial line formed into a loop of the desired diameter. This diameter is generally chosen to be less than 0.0625λ to obtain a near uniform current distribution along the loop circumference. Figure 2 illustrates the fabrication process.

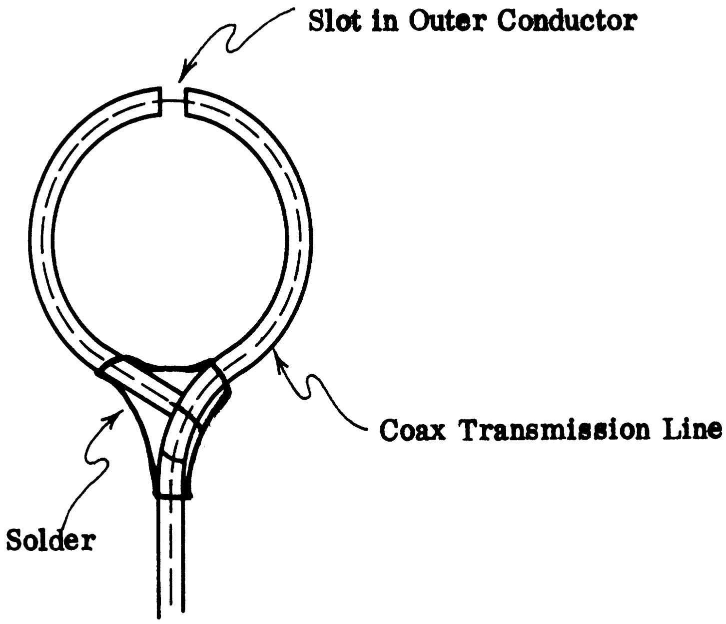


Figure 2: Loop Construction.

The coaxial transmission line employed was fabricated by Uniform Tube Inc., and is designated as UT-141 P. Loop configurations having loop diameters of 3.75 inches (0.03λ at 100 MHz) and 0.75 inches (0.006λ at 100 MHz) were constructed and evaluated. Photographs of the loop probes are shown in Figures 3 and 4. Probe impedance performance was first studied. Measurements were made over the 70 to 200 MHz range and the results are shown in Figures 5, 6 and 7 for the electric dipole probe, the small loop and the large loop respectively. As is seen in these plots, the electric dipole presents a better match to the $50\,\Omega$ line than either of the loops. Far field calibration tests, which were made later,

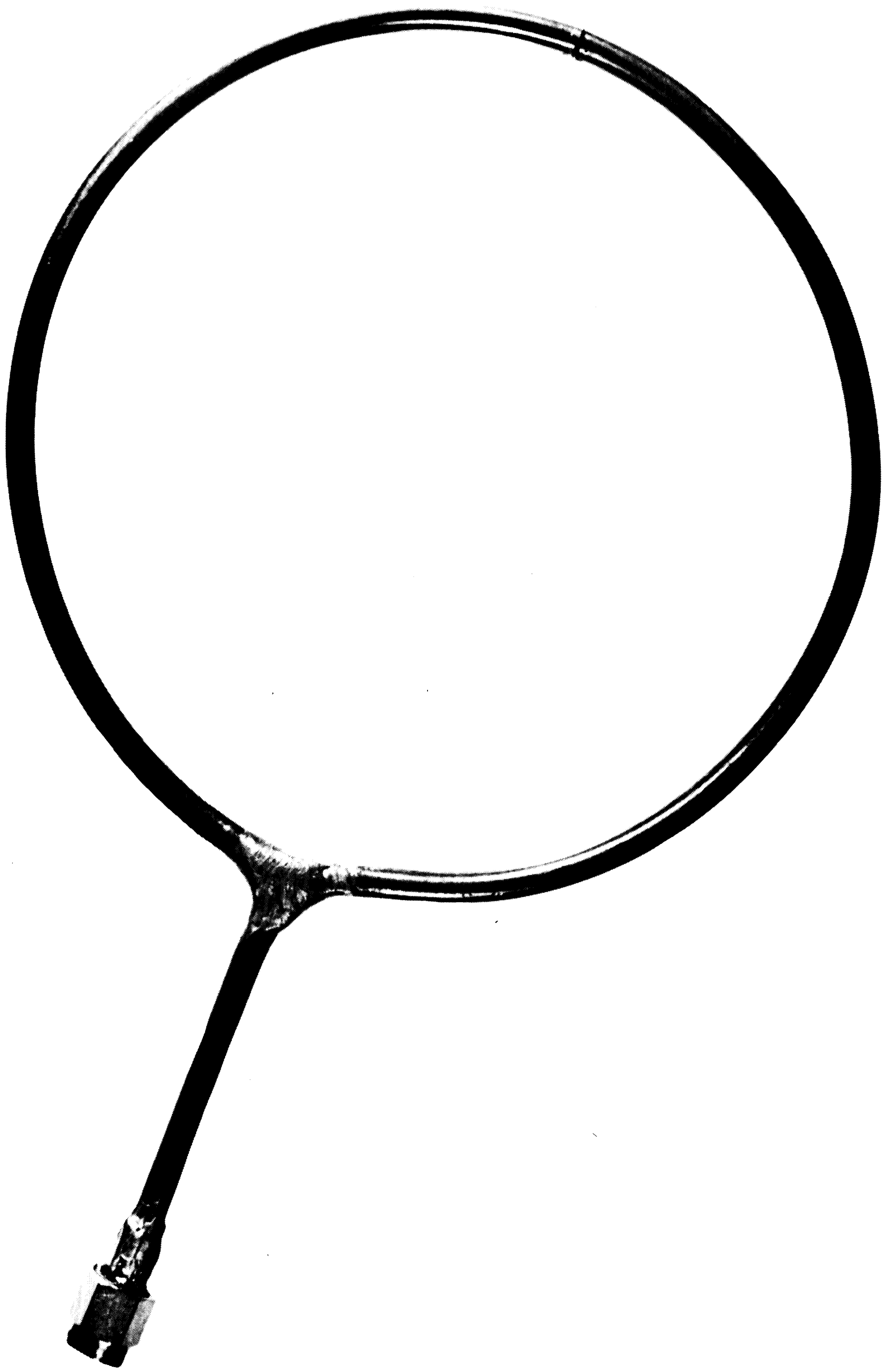


Figure 3: 3.75 Inch Diameter Loop Probe.

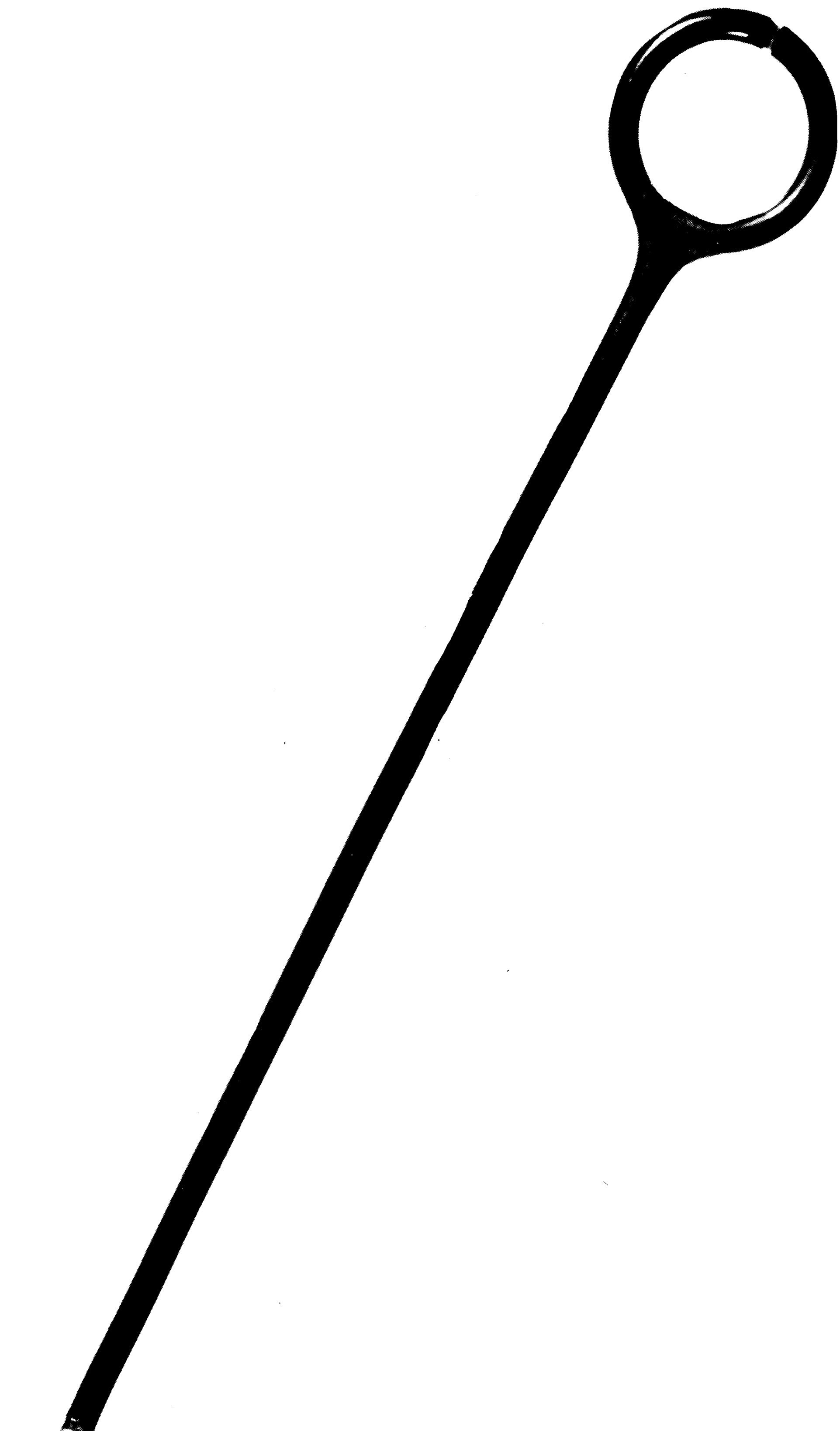


Figure 4: 0.75 Inch Diameter Loop Probe.

showed, however, that the sensitivity of the electric dipole was significantly less than that of a loop of corresponding dimension. This was due, we believe, to the loss in the electric dipole balun. As a result of this loss and the physical disadvantages of the dipole, we decided that the loop probes were more suitable for RFI measurements on automobiles. The loops were considered to be more sturdy and less easily damaged than the dipole.

To evaluate the effect of the width of the slot in the loops, a numer of quasi-conductive measurements were made with different slot widths. In these measurements, the 3/4 inch diameter loop was in contact with the insulation on one of the spark plug wires. Data was obtained with probes having slot widths of 0.003", 0.017" and 0.045", and the results obtained (Figure 8) showed negligible difference as a function of slot width. It was decided, therefore, that the 0.017" slot should be used in both of the loop configurations.

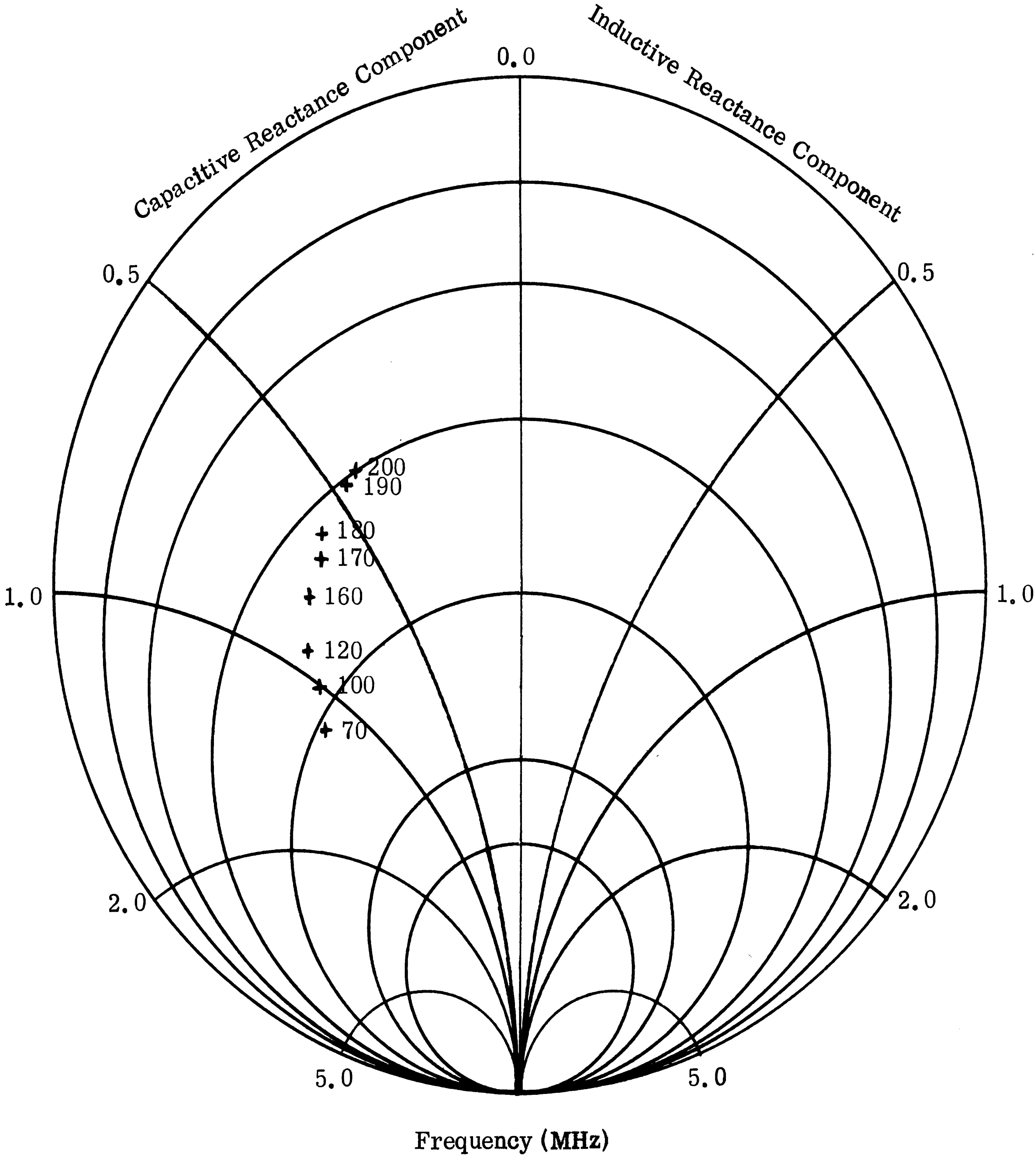


Figure 5: Impedance of the Electric Dipole Probe.

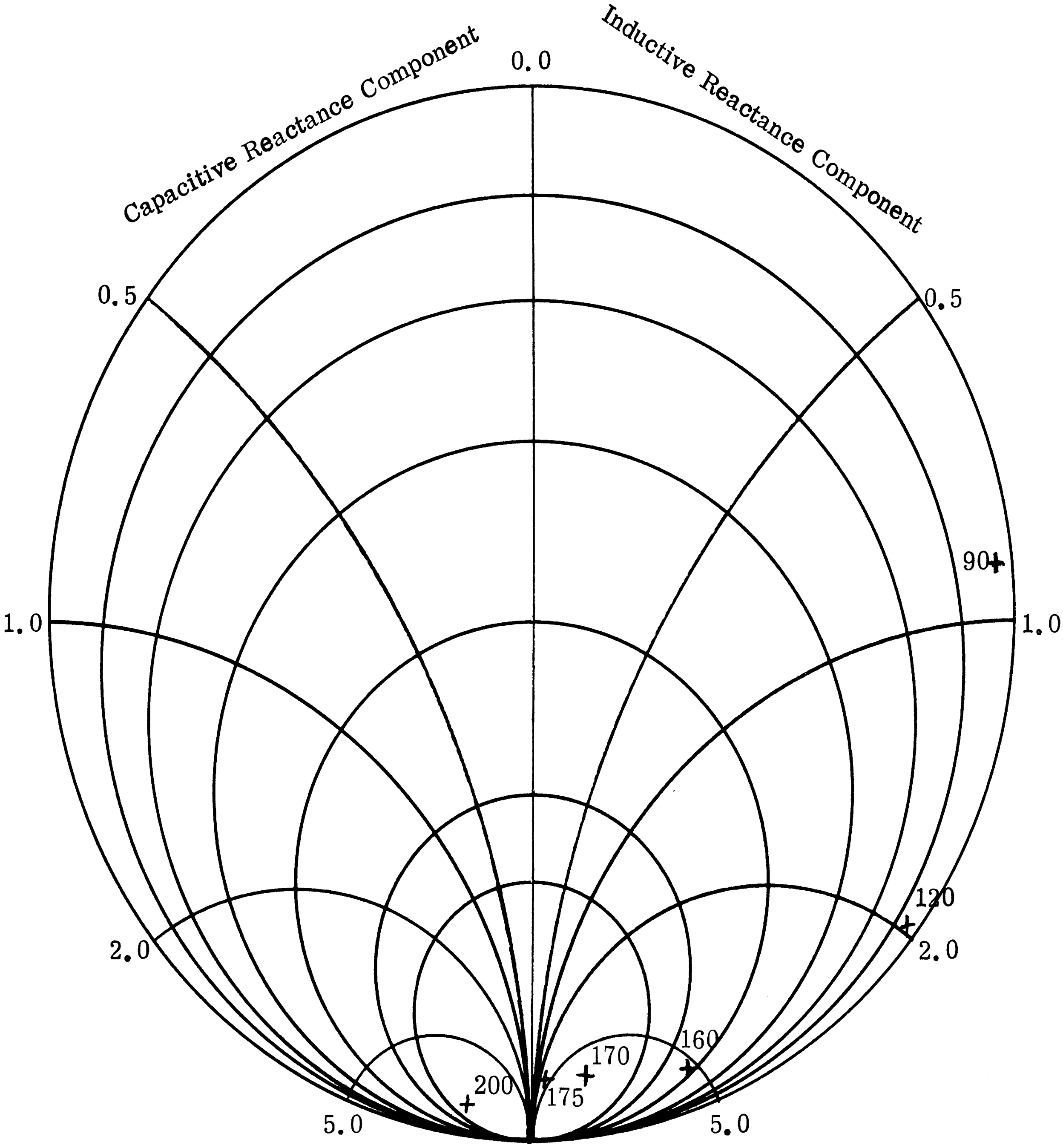


Figure 6: Impedance of the 0.075 Inch Loop Probe

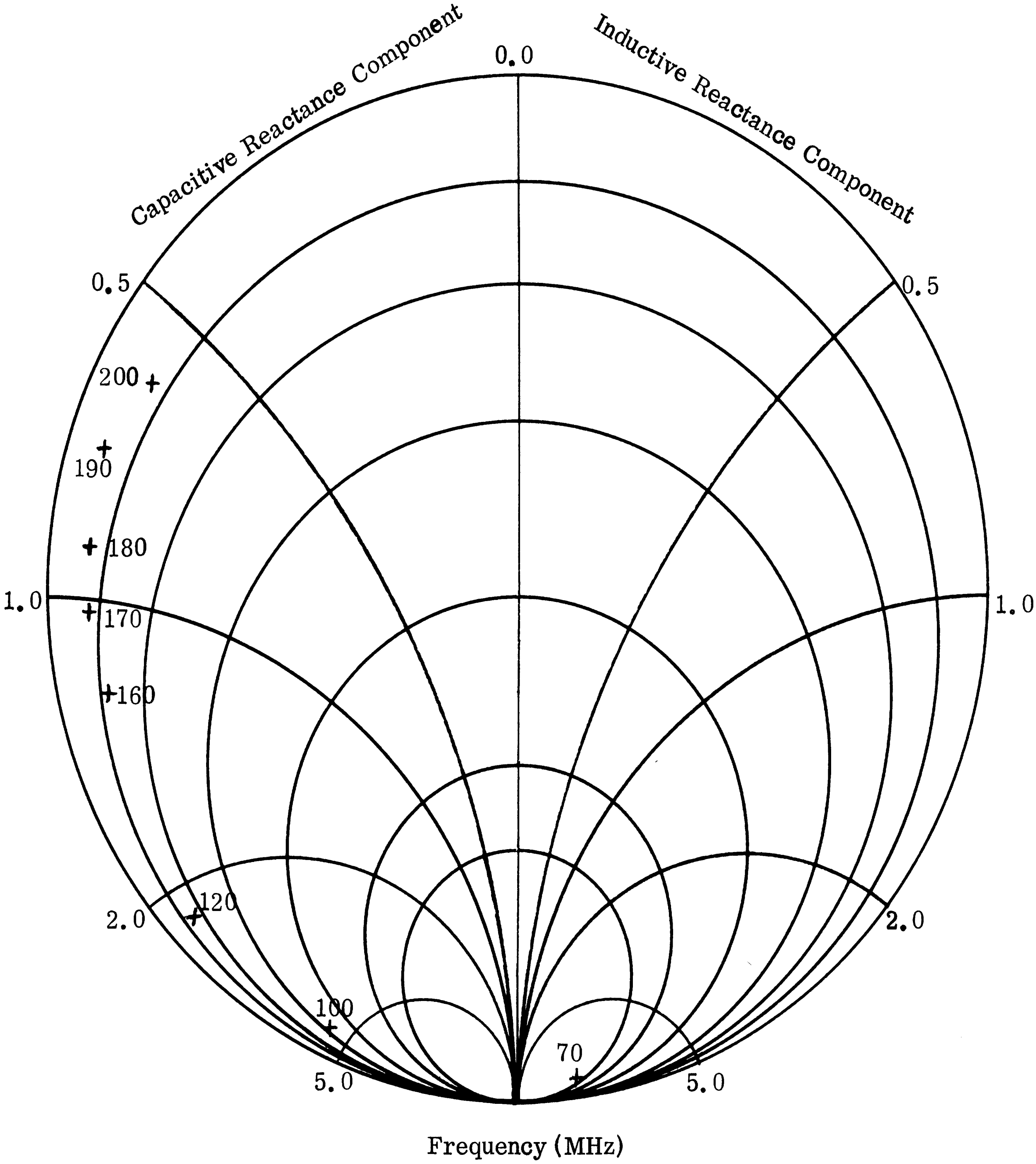
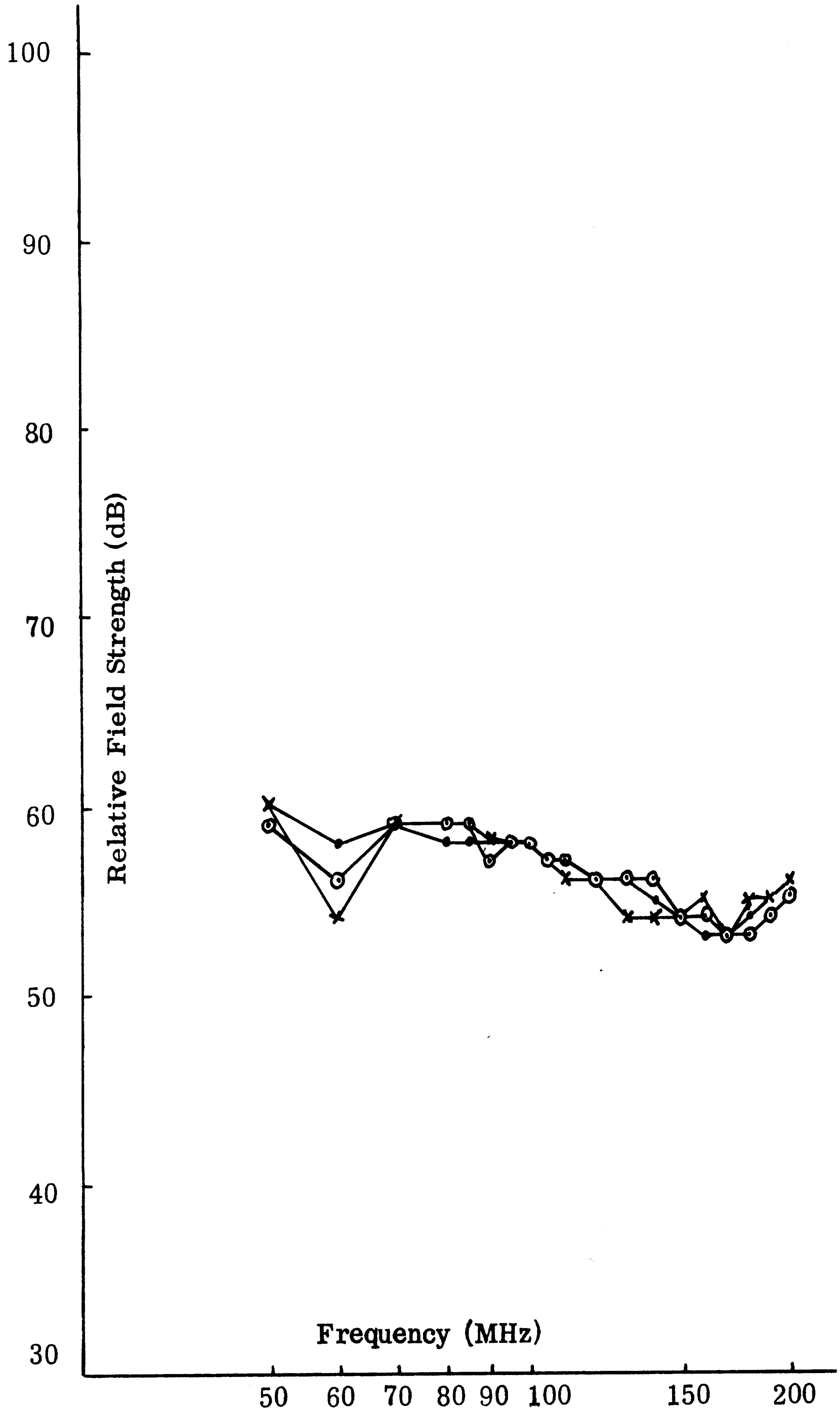


Figure 7: Impedance of the 3.375 Inch Loop Probe.



■ Figure 8: Quasi-Conductive RFI Measurements with 0.75" Loop Probes Having Gap-Widths of 0.003" (x — x), 0.017" (· —— ·), and 0.045" (o —— o). Probes were Adjacent to the Right Front Spark Plug Wire in 1973 Lincoln Automobile.

III FAR FIELD PROBE CALIBRATION

To provide information on the relative sensitivity of the probes, far field measurements were made. This was accomplished on the University of Michigan low frequency (50 to 500 MHz) ground plane range. This range employs a fixed distance (80 feet) between the transmitting and receiving antennas. The height of the receiving antenna was fixed at 8 feet and the height of the transmitting antenna varied between 12.5 and 50 feet depending on the frequency of operation. The transmitting antenna is set at a height that will cause the energy arriving at the receiver via the ground bounce to be in phase with the direct rays. The relationship between the parameters involved is shown by the equation for the ground plane antenna range.

$$h_r = \lambda R / 4 h_t$$

where h_r and h_t are the antenna heights above the ground, R is the distance between the two antennas and λ is the wavelength. The ground plane geometry is shown in Figure 9.

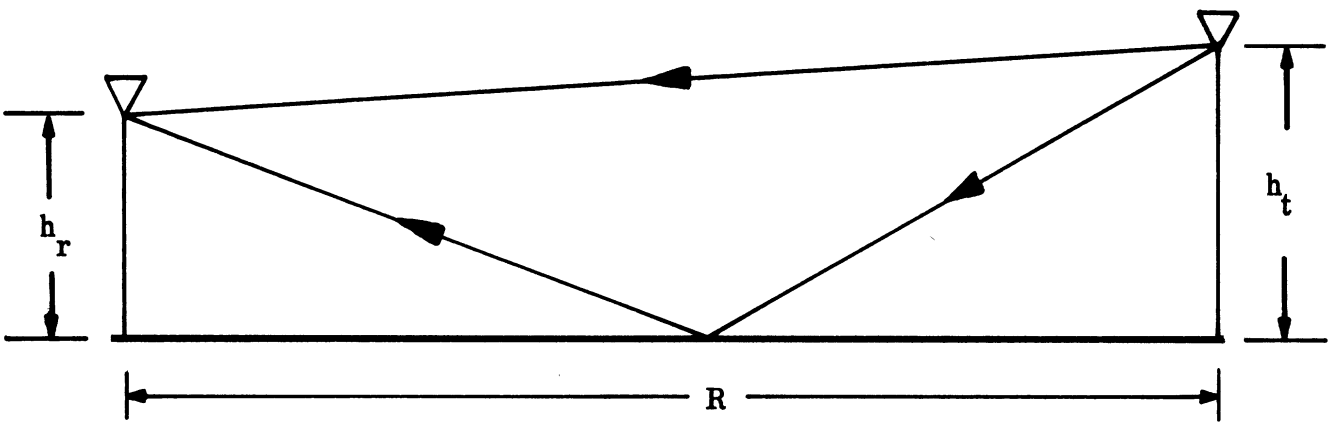


Figure 9: Ground Plane Geometry.

It is obvious from the equation that h_r can be fixed if h_t is adjusted at each frequency so that λ / h_t is a constant. Following this procedure the illumination pattern of the transmitting source is essentially independent of the transmitting antenna aperture and the operating frequency.

The experimental setup used for the probe calibration is shown in Figure 10. The signal to be transmitted was obtained by driving a General Radio unit oscillator with a regulated power supply. The strength of the signal fed to the transmitting antenna and also the level of the reflected signal in the line leading to the transmitting antenna was monitored using a 20 dB dual directional coupler and two power meters. A log-periodic antenna designed to operate from 50 to 500 MHz was used as the transmitting antenna. The probes which were being calibrated served as the receiving antennas. The received signal was fed to a model 1600 Scientific-Atlanta receiver and its output went to a Hewlett-Packard standing wave indicator from which the received power level was read.

Some difficulty is experienced in working in the 50 to 200 MHz band due to the presence of interfering signals from FM radio and TV stations and the 108 to 140 MHz air traffic communications signals. The selectivity of the Scientific-Atlanta microwave receiver made it possible in general to avoid the undesirable signals. It also provides a visual display of all signals received at or near the frequency of interest. Prior to taking data the frequency band was scanned and the spot frequencies free from interference were selected and used in the calibration measurements.

The probes were calibrated using cw signals at about 10 MHz intervals between 50 and 200 MHz. At each of these frequencies, the transmitting antenna was positioned to give the desired radiation pattern maximum at height h_r. Horizontal polarization was used. With this arrangement, the received signal

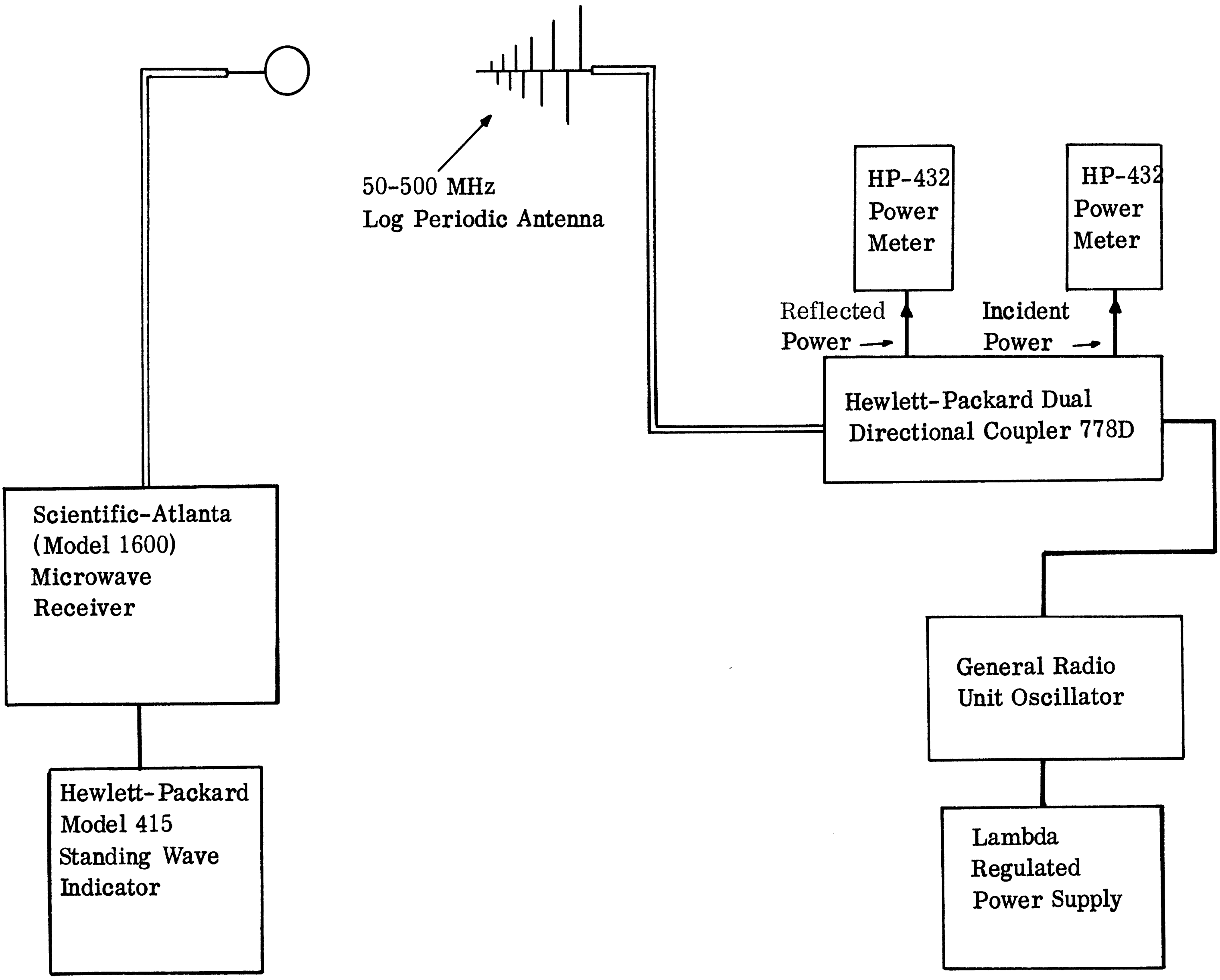


Figure 10: Far Field Calibration Test Setup.

was measured first with a $\lambda/2$ dipole and then with the small electric dipole probe and the 0.75 inch and 3.75 inch loops. The results of the latter three measurements are shown in Figure 11 where the signal received by each relative to the dipole signal is plotted as a function of frequency. It is noted that the curves are smooth and well behaved. A curve showing the theoretically predicted response versus frequency is also plotted in Figure 11. For this curve, values were determined for a 3-3/4 inch loop probe based on the work of King et al (1968). The experimental and theoretical curves were arbitrarily matched at the 200 MHz frequency point and it is seen that their frequency response is in close agreement. Based on these and other tests, it was decided that the 0.75 inch loop probe would be used for the quasi-conductive measurements. Less sensitivity was needed for these measurements since the loop was placed adjacent to the source. Moreover, its small size made it more suitable for placement in confined areas. It was decided also that the 3.75 inch loop probe would be used for the near field measurements since more sensitivity was needed for those measurements and since its size was not a problem. The small electric dipole probe appeared to have no particular advantage over the loops so no further tests were made with it.

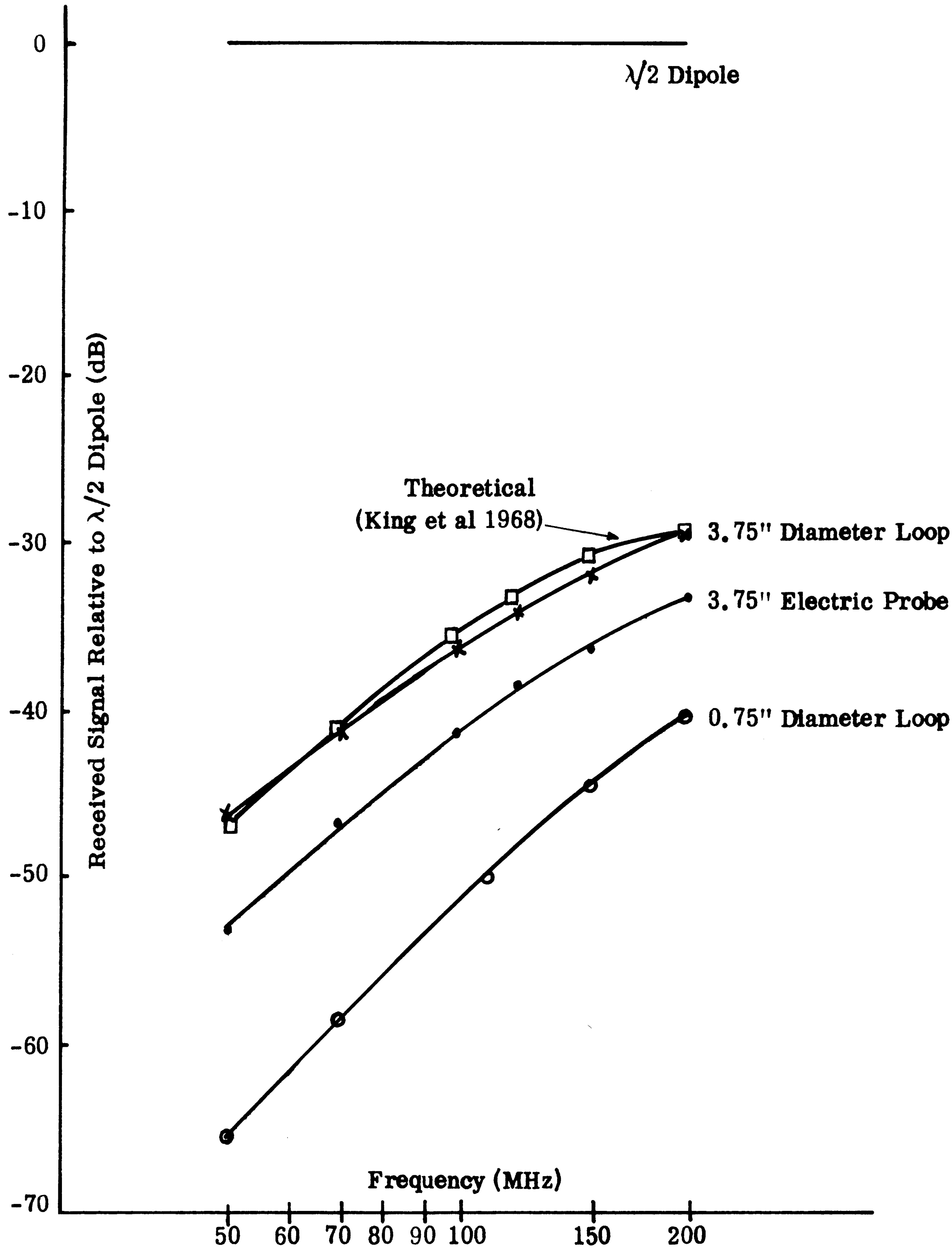


Figure 11: Probe Calibration Curves Relative to a $\lambda/2$ Dipole.

IV RFI MEASUREMENT TECHNIQUES

All RFI measurements were conducted using a 1973 Lincoln Continental. The Singer NF 205 RFI meter was employed as a receiver and the slideback method was used to obtain all data (for details on slideback method refer to Appendix A). A fifteen foot double shielded coaxial cable (RG-223/U) was used to connect the probes to the receiver and the receiver was placed approximately twelve feet away from the engine compartment of the car.

Three schemes for monitoring the received signals via the slideback method were investigated. First, in the meter needle deflection procedure, the received signal was monitored by following the deflections of the receiver's meter needle. Second, in the aural method, a set of earphones was used to monitor the received interference signal. In the third or visual method, the received RFI signal was monitored on an oscilloscope screen. Repeated tests proved that the first method was unsatisfactory as the data obtained showed poor repeatability. Tests showed that the aural method was quite acceptable both in data repeatability and ease of performance. Although the visual method produced acceptable data it was found necessary to use the aural method as an additional aid to give the operator an idea of the intensity of the RFI signal appearing on the screen and thus give him a reference point by which to adjust the scope sensitivity. Also, noise on the scope not related to the RFI signal source under investigation is in general un-distinguishable from the signal itself. Although reliable data can, in general, be obtained by the aural method, the simultaneous use of aural and visual methods is recommended since the two methods supplement each other.

Because of the difficulty involved in obtaining valid data in RF noise measurements, some precaution is necessary to insure data integrity. The operator should experiment extensively with the receiver using the slideback method to develop a feeling for the actual validity of the data being obtained. Care should be taken to assure that the engine under test has reached a steady state before measurements are performed to avoid erratic results. It is believed also that the randomness of the RFI signals will be less and a certain degree of periodicity will be introduced by increasing the engine's revolutions per minute above the idling point.

4.1 Quasi-Conductive Measurements

Quasi-conductive measurements are performed with physical contact between the sensitive area of the probe (surface around the gap) and the wire or cable or other surface whose RFI emissions are to be measured. The loop is actually in contact with the insulation on the wires; physical contact is not intended to imply electrical contact. Note that the plane of the loop probe should be parallel to the wire or cable, i.e., parallel to the direction of electric current, to assure maximum signal pickup by the probe.

The main purpose of quasi-conductive measurements is to obtain data on the isolated effects of various engine components; for this reason particular care should be taken to shield or move away other sources of RFI radiation to isolate the components under measurement.

The 0.75 inch diameter loop probe was employed in all quasi-conductive measurements as its size lends itself to easy positioning adjacent to the source of interest. Also, it is less sensitive than the 3.75 inch diameter loop probe to radiation from signal sources slightly removed from the component under test.

Figures 12, 13 and 14 give samples of quasi-conductive data which were collected using the 1973 Lincoln Continental. The ordinate in these plots is the loop output in dB above a microvolt per MHz (μV/MHz). The realibility of these absolute values is dependent on the accuracy of the variable attenuators in the

RFI meter used and also on the accuracy of the output calibration of the impulse generator in the instrument. The accuracy is perhaps not a critical issue since the major objective is to develop test probes and techniques. The data in Figure 12 shows the variation of signal strength versus frequency along one of the alternator wires. The variation with frequency is much greater and more erratic than most sources investigated. Figure 13 shows the radiated field adjacent to the left rear spark plug wire. Two curves are presented to show the difference between an open and a closed hood over the automobile engine. We found the effect of the hood to be almost negligible. Figure 14 shows that there is little difference between the data obtained using the visual monitor and that using the aural monitor of Figure 13.

4.2 Near Field Radiation Measurements

Near field radiation measurements are obtained by placing the probe in the near field of the radiation source. We consider as near field any point in space within a distance of two wavelengths from the source. In the frequency band 50 - 200 MHz the near field extends several feet from the car body. When measurements are performed on a car one finds that currents may be induced on the entire car body and as a result any or all metal parts may radiate depending on the strength of the currents involved.

To assure maximum probe response the plane of the probe should be parallel to the direction of electric currents. This presents some difficulty since radiation is received from several sources with electric currents and the resulting polarization vector in various directions. This being the case the recommended procedure is to position the plane of the probe so as to receive the maximum signal.

A series of near field measurements were made on the 1973 Lincoln to perfect the measurement technique and to provide typical data. The 3.75 inch probe was used in all of these measurements to take advantage of its greater

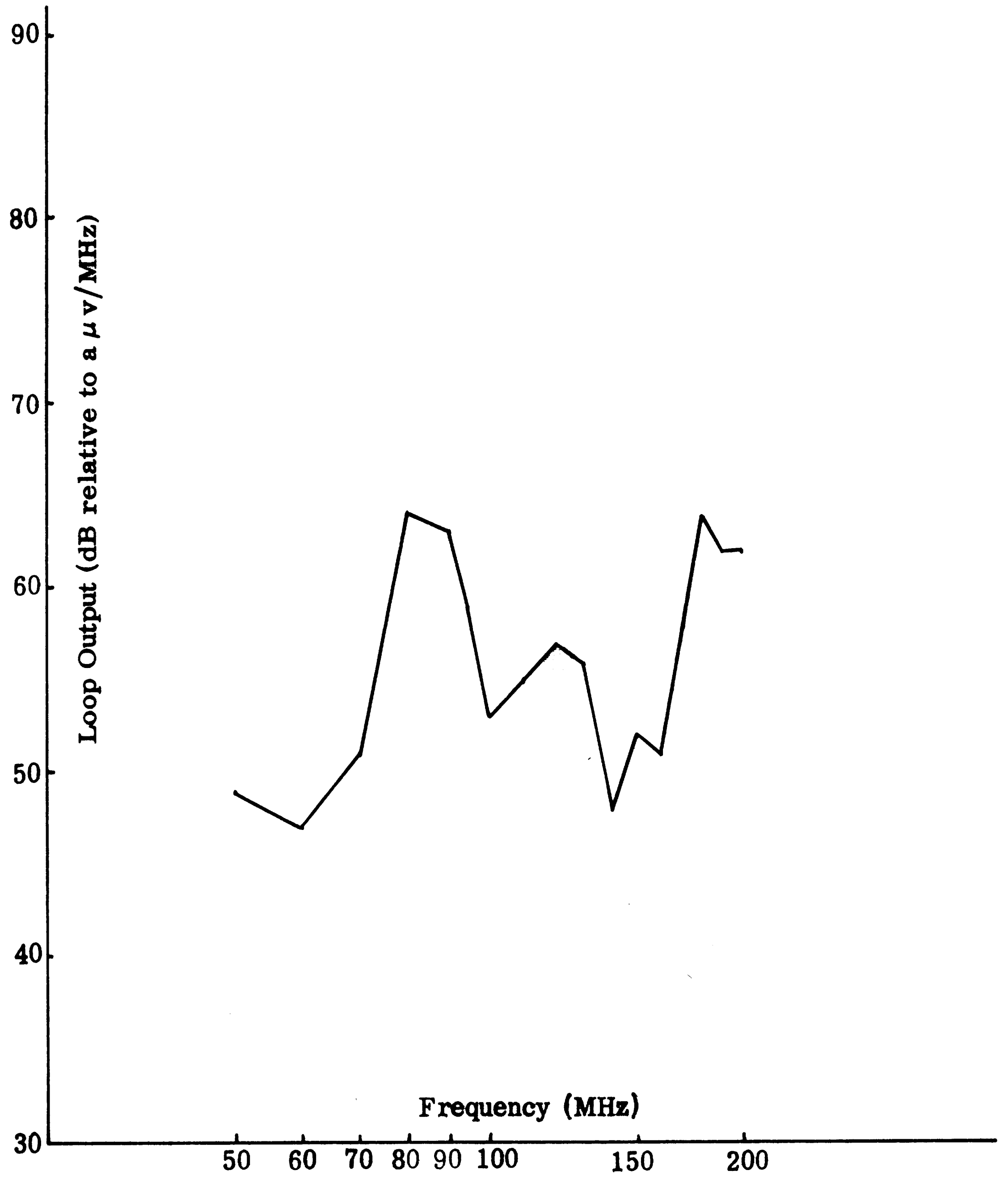


Figure 12: 1973 Lincoln RFI Quasi-Conductive Measurements with 0.75 Inch Loop Probe Adjacent to Alternator Wire. Gap Width: 0.017".

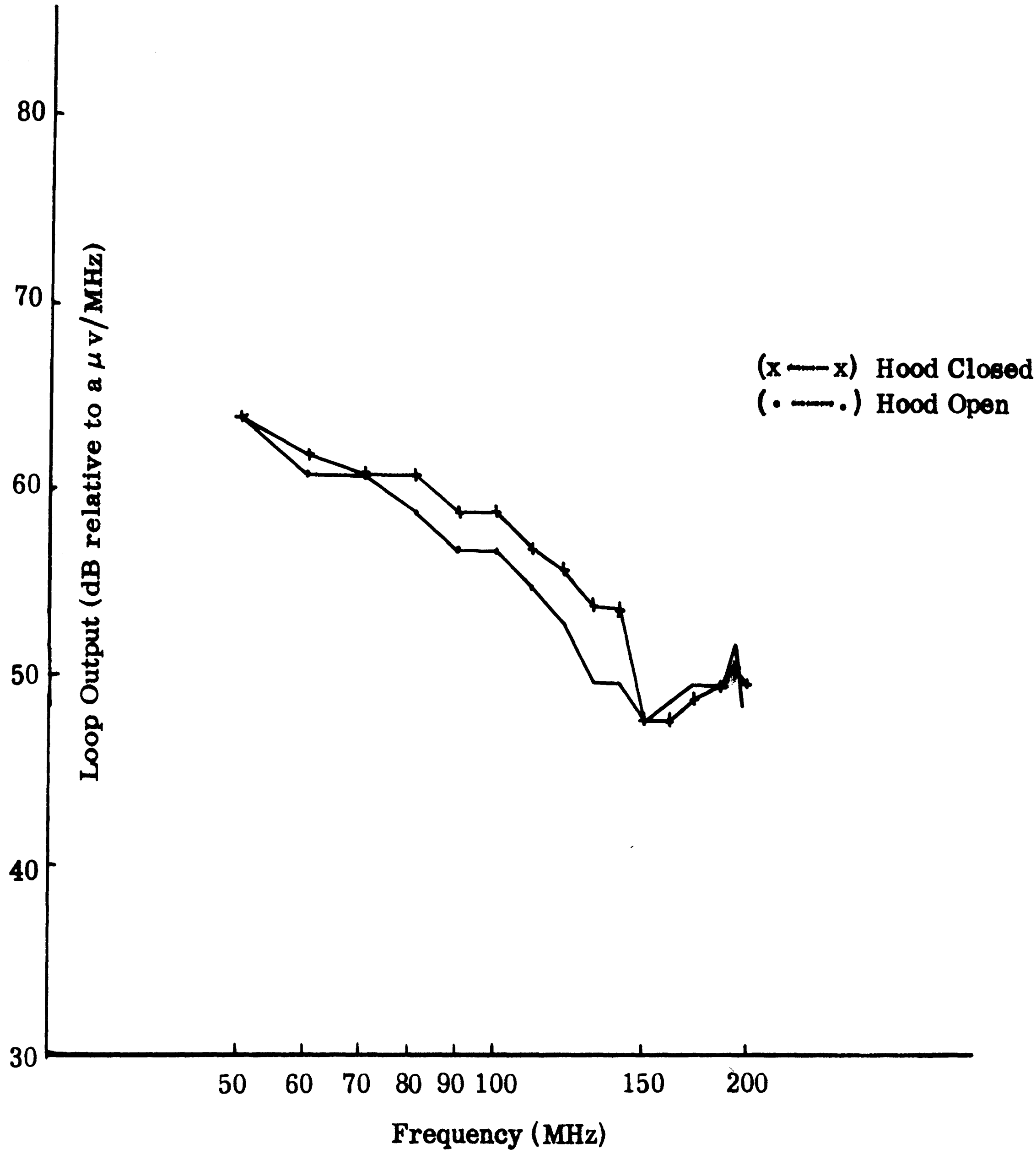


Figure 13: 1973 Lincoln Quasi-Conductive Measurements With 0.75 Inch Loop Probe Adjacent to the Left Rear Spark Plug Wire with Car Hood Closed and Open.

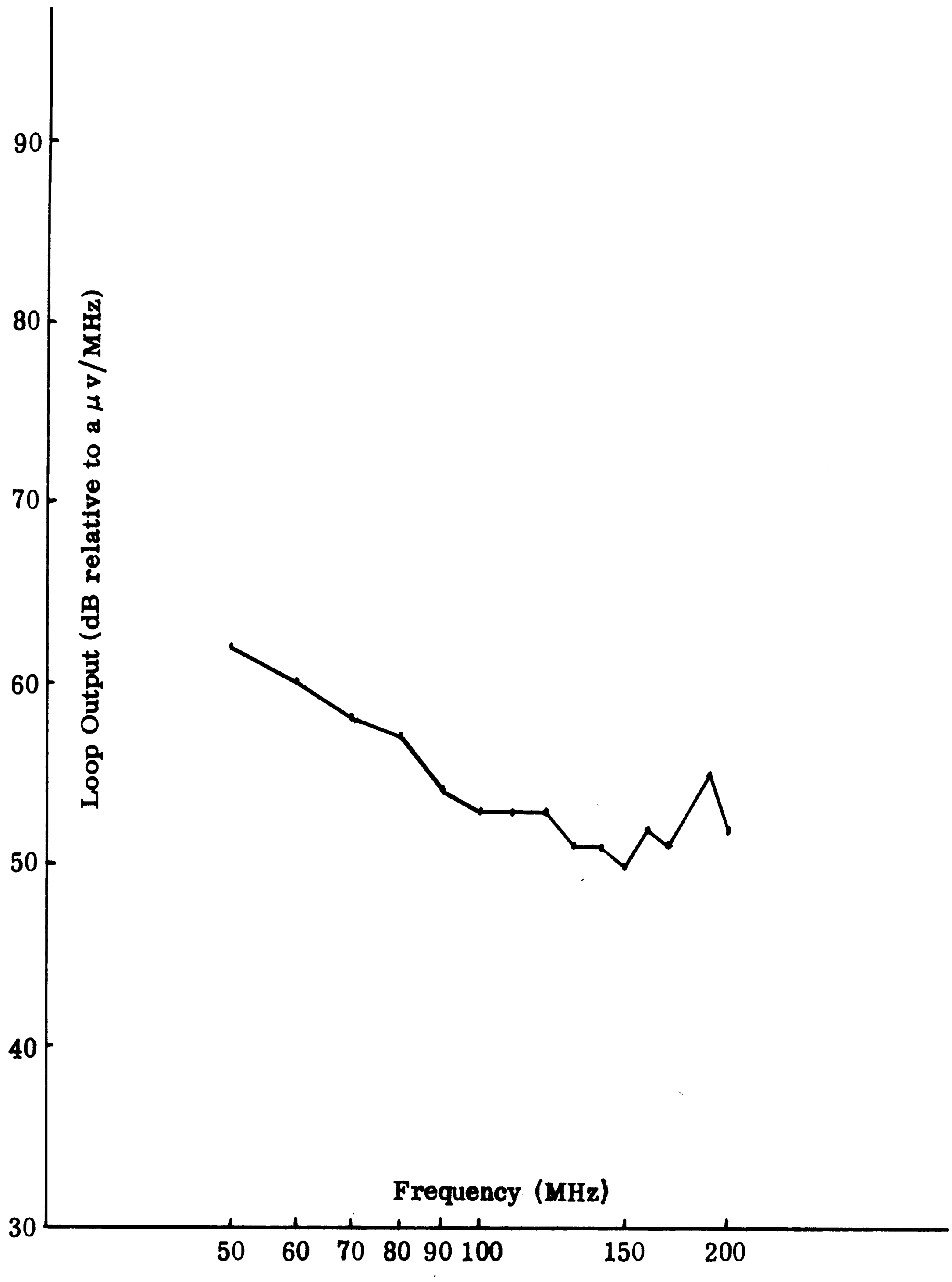


Figure 14: 1973 Lincoln RFI Measurements with 0.75 Inch Loop Probe Adjacent to the Left Rear Spark Plug Wire with the Hood Open. The Visual Method of Monitoring is Used.

sensitivity. Data was obtained over the 50 to 200 MHz band with the probe positioned at several selected locations near the car. For most locations data was taken for two polarizations, i.e., with the plane of the loop parallel and perpendicular to a radiating slot or parallel and perpendicular to the earth.

The data obtained is presented in the next seven figures (15 through 21); as in the three previous figures the ordinate in these curves is the value of the loop probe output in dB relative to a microvolt per MHz as indicated on the Singer NF 205.

Figure 15 shows the results with the loop near the slot between the hood and the car body and just above the right front tire. The radiation polarized perpendicular to the slot is generally more intense. This is expected as the E field tends to be across radiating slots in waveguides or cavities.

In Figure 16, similar data is presented but with the probe over the center of the front hood area. The same observation with respect to polarization can be made as was given for Figure 15. Note that in these two and in most subsequent figures, the radiation intensity for both polarizations tends to be lower in the middle of the frequency band, that part covering the FM frequency band.

In Figures 17 and 18 data is shown for radiation in the vicinity of the right and left front tires at a level 2 feet above the ground. Note that the ordinate axis is discontinuous. In both cases the level of the vertically polarized radiation is slightly higher than the horizontally polarized signal. The reason for the higher level vertically polarized signal is not obvious.

In Figures 19 and 20 the probe is positioned 12 inches in front of the radiator grill. Figure 19 shows the different response for the two polarizations at 2 feet above the ground. Figure 20 shows the effect of varying probe height; the effect of height change from 4 inches to 30 inches is less than was expected.

Figure 21 shows the radiation level with the hood open and with the probe 20 inches above the car air filter. As would be expected, the average level is several dB higher than in any of the measurement positions of the previous six figures.

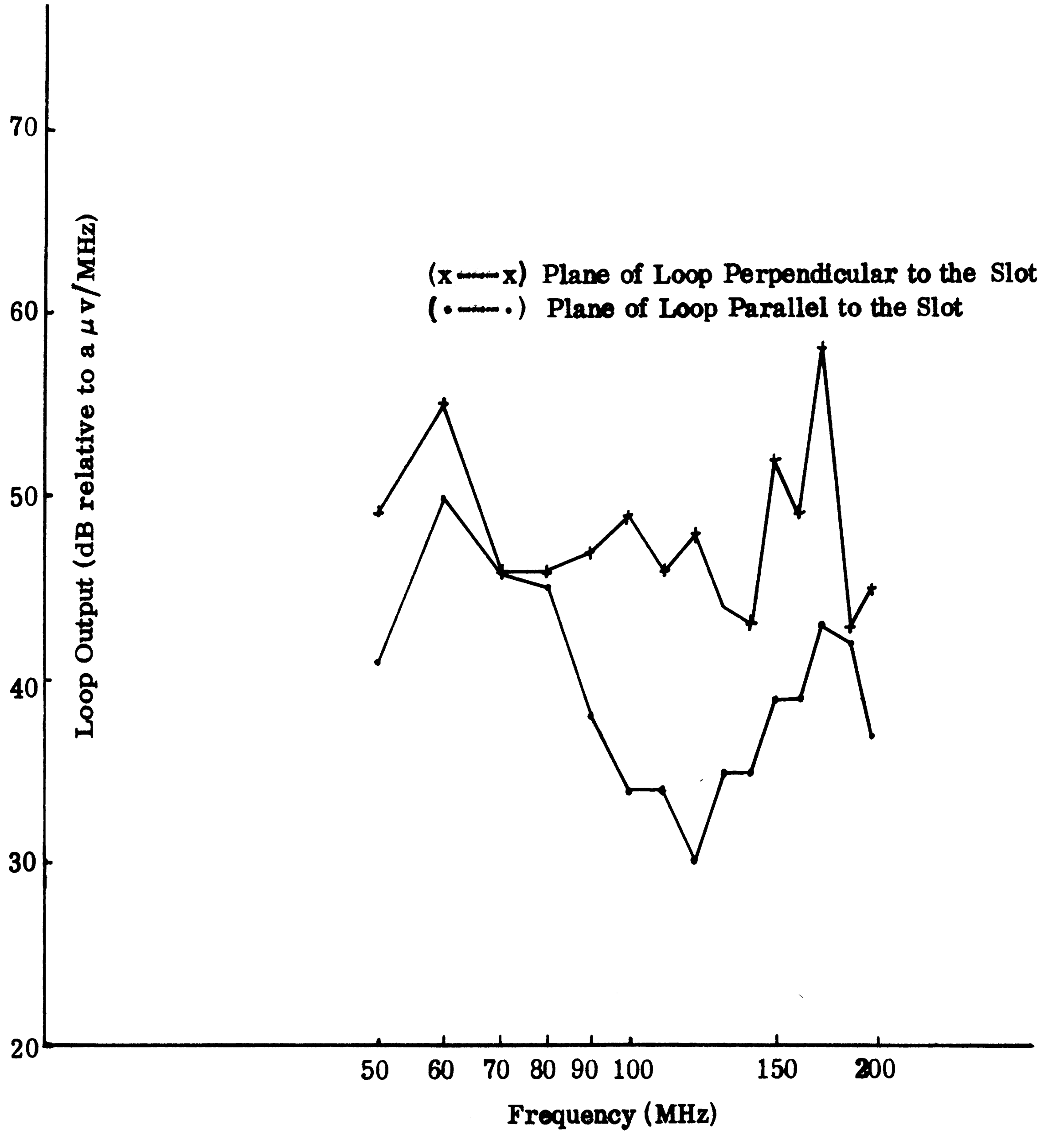


Figure 15: 1973 Lincoln Near Field Radiation Measurements. 3.75 Inch Loop Probe 3 Inch Above Slot Between Hood and Car Body Above Right Tire.

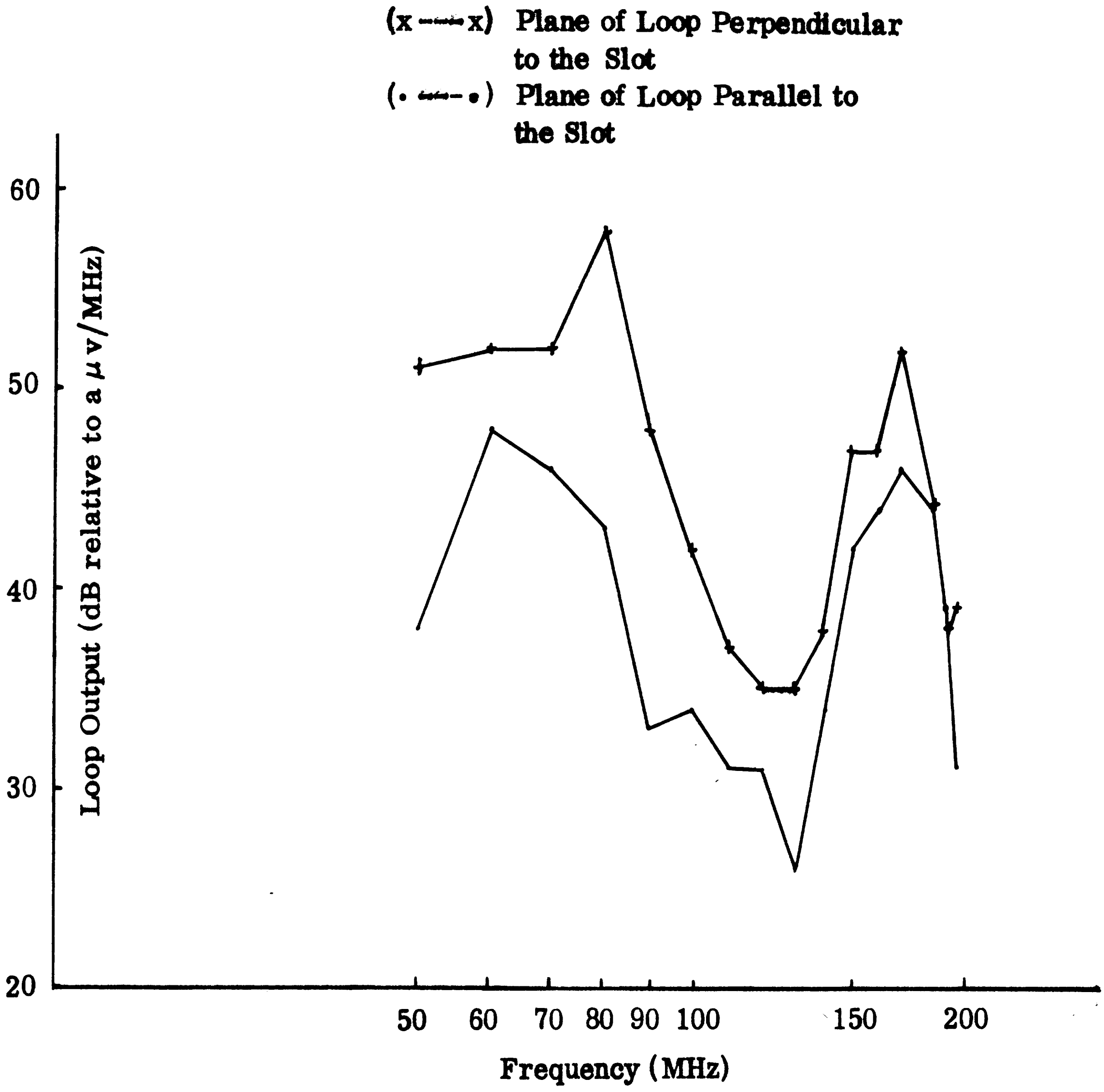


Figure 16: 1973 Lincoln Near Field Radiation Measurements. 3.75 Inch Loop Probe 3 Inches Above Slot Between Front Hood and Car Body Next to the Radiator.

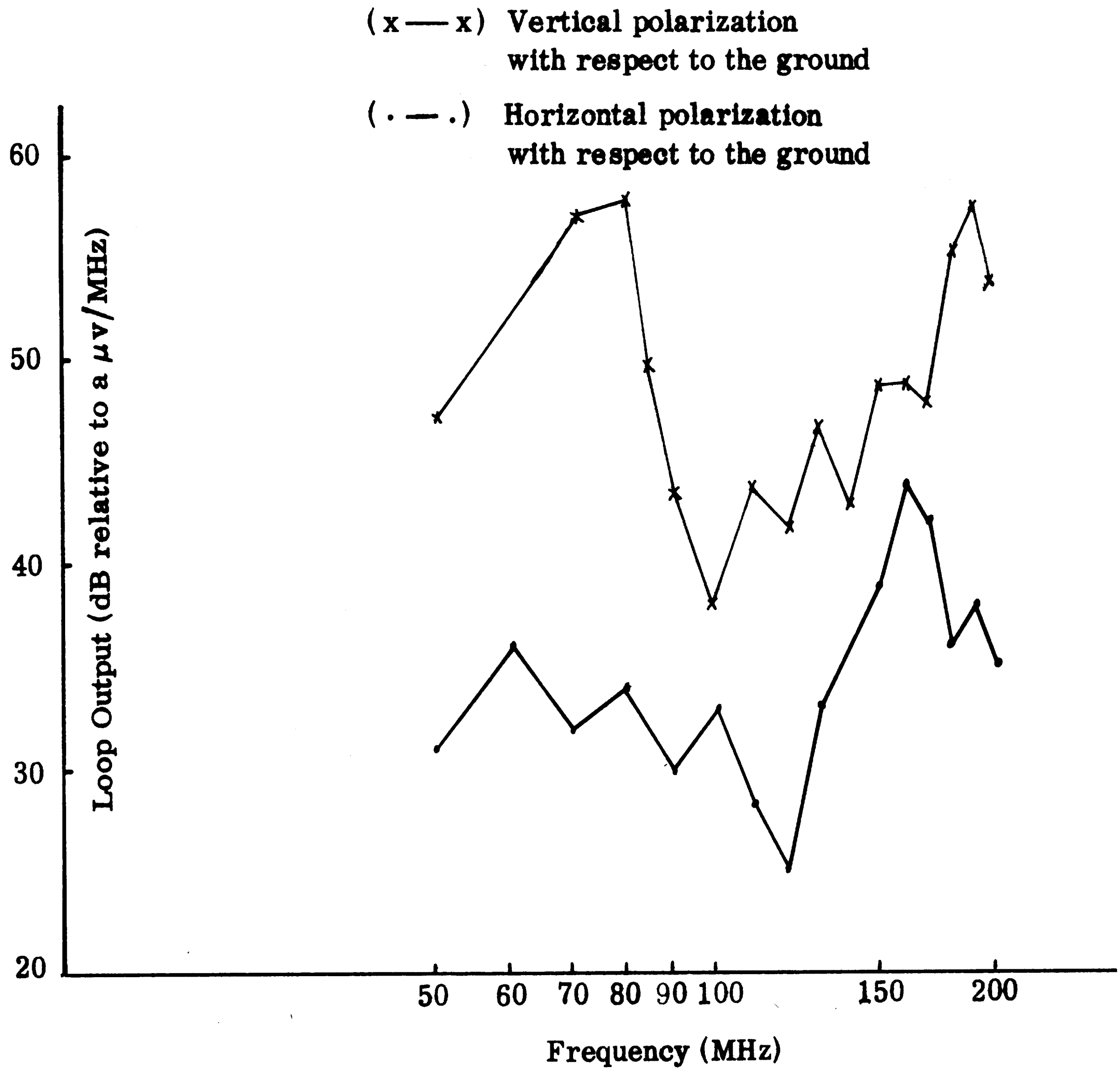


Figure 17: 1973 Lincoln Near Field Radiation Measurements. 3.75 Inch Loop Probe 4 Inches Away from Right Front Tire, 2 Feet Above Ground.

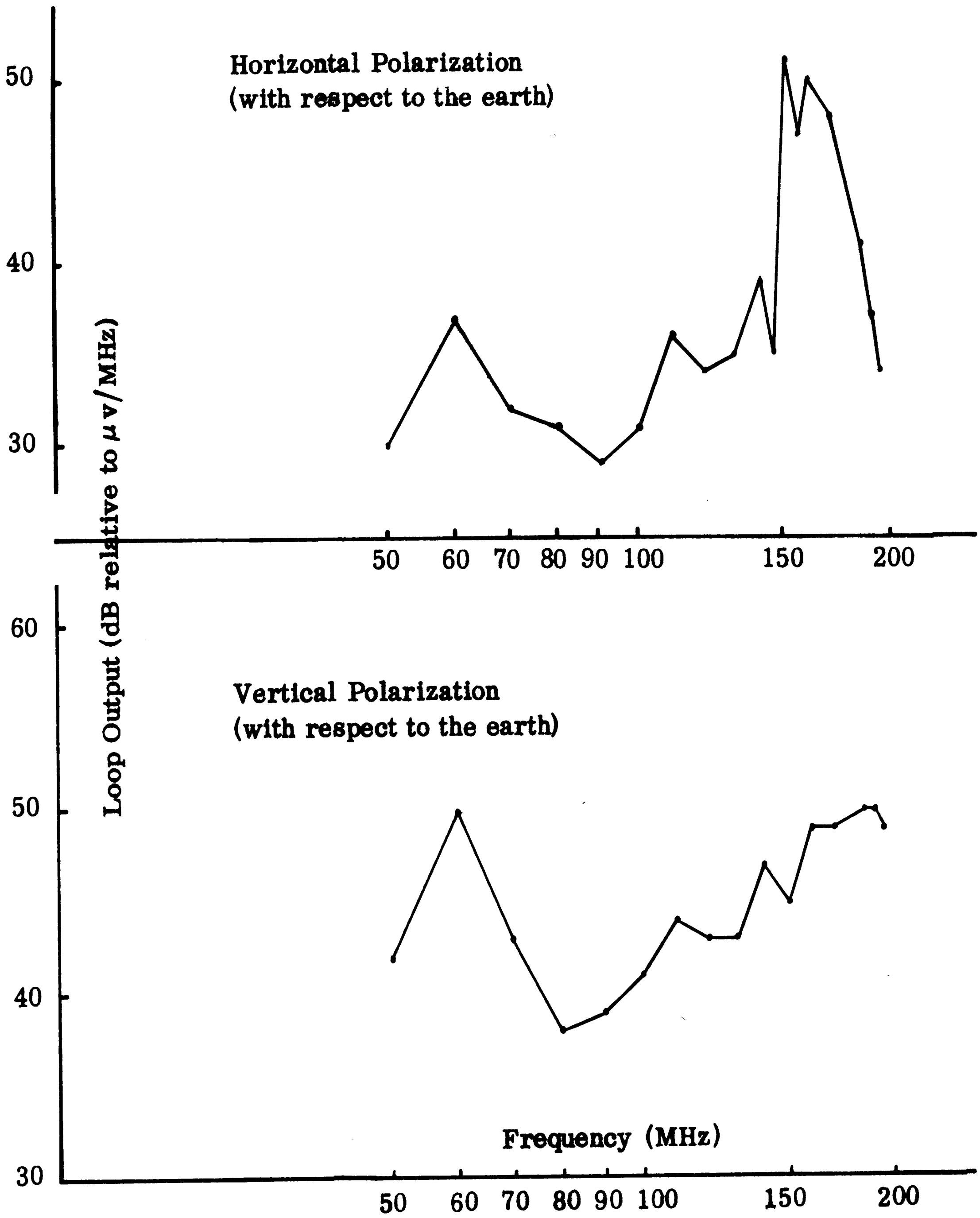


Figure 18: 1973 Lincoln Near Field Radiation Measurements. 3.75 Inch Loop Probe 4 Inches away from Left Front Tire 2 Feet Above Ground.

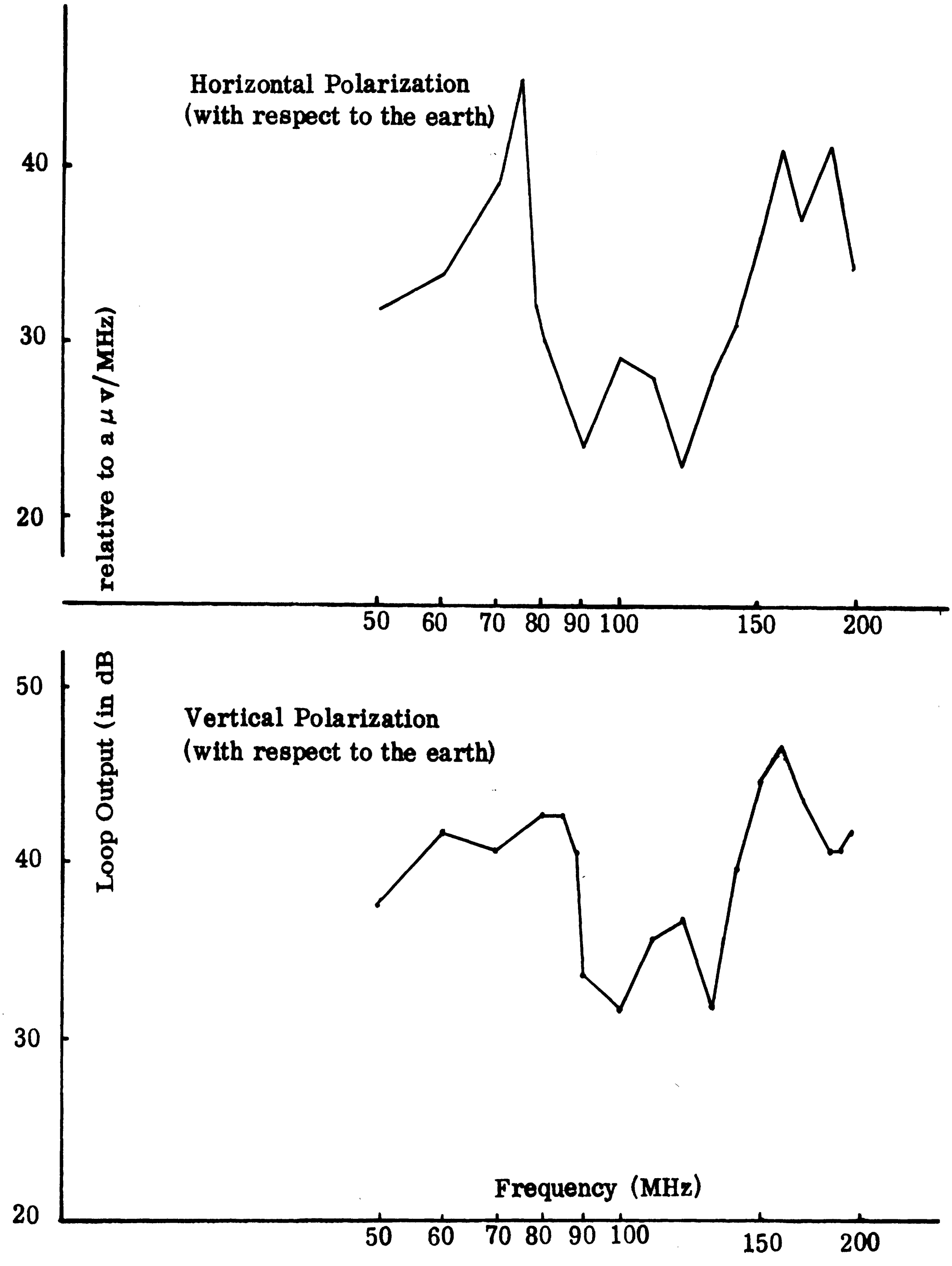


Figure 19: 1973 Lincoln Near Field Radiation Measurements. 3.75 Inches Loop Probe 12 Inches Away from Center of Front Grill 2 Feet Above Ground.

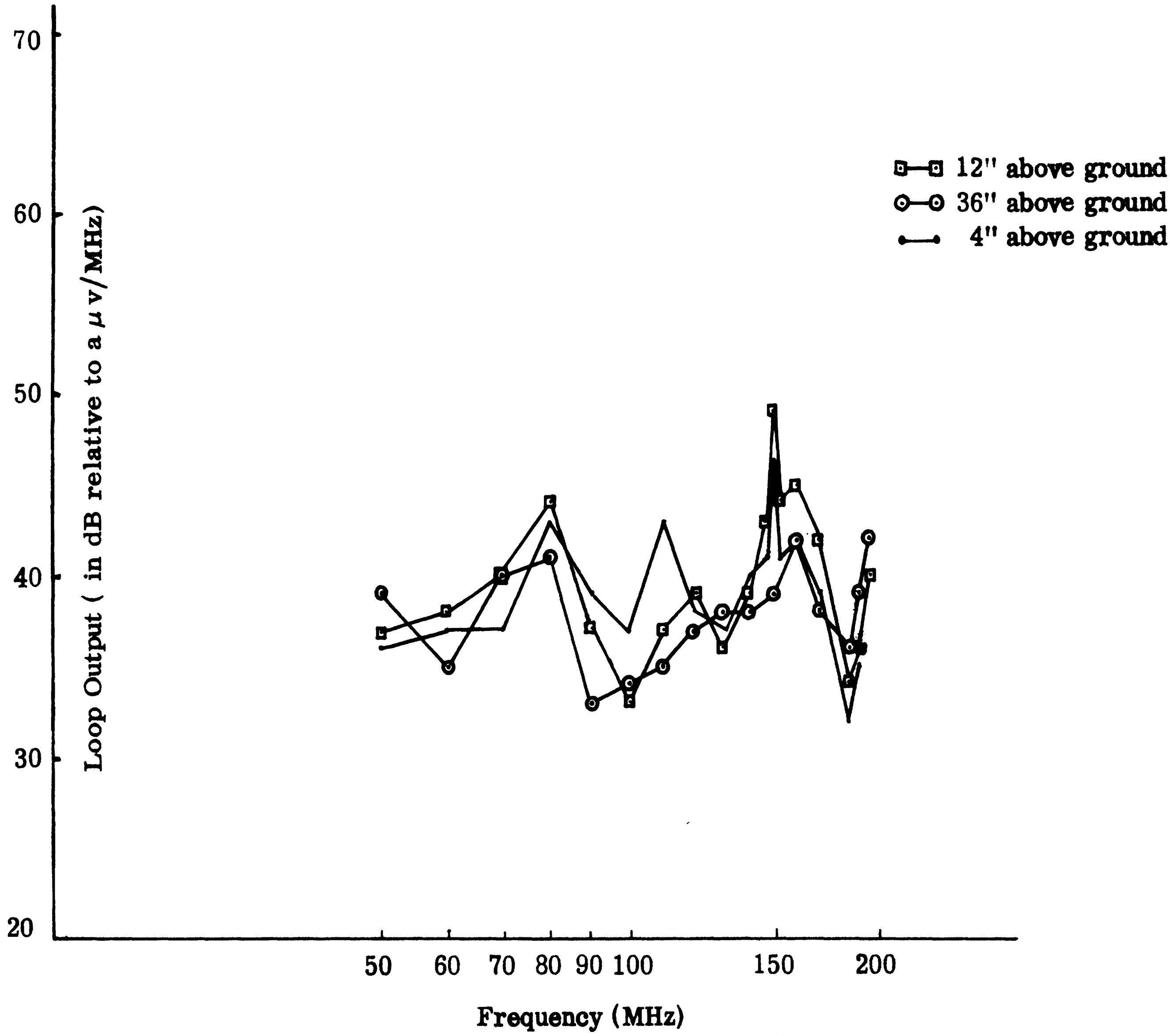


Figure 20: 1973 Lincoln Near Field Radiation Measurements. 3.75 Inch Loop Probe Positioned at Various Heights Above Ground 12 Inches Away from Center of Front Grill. Vertical Polarization.

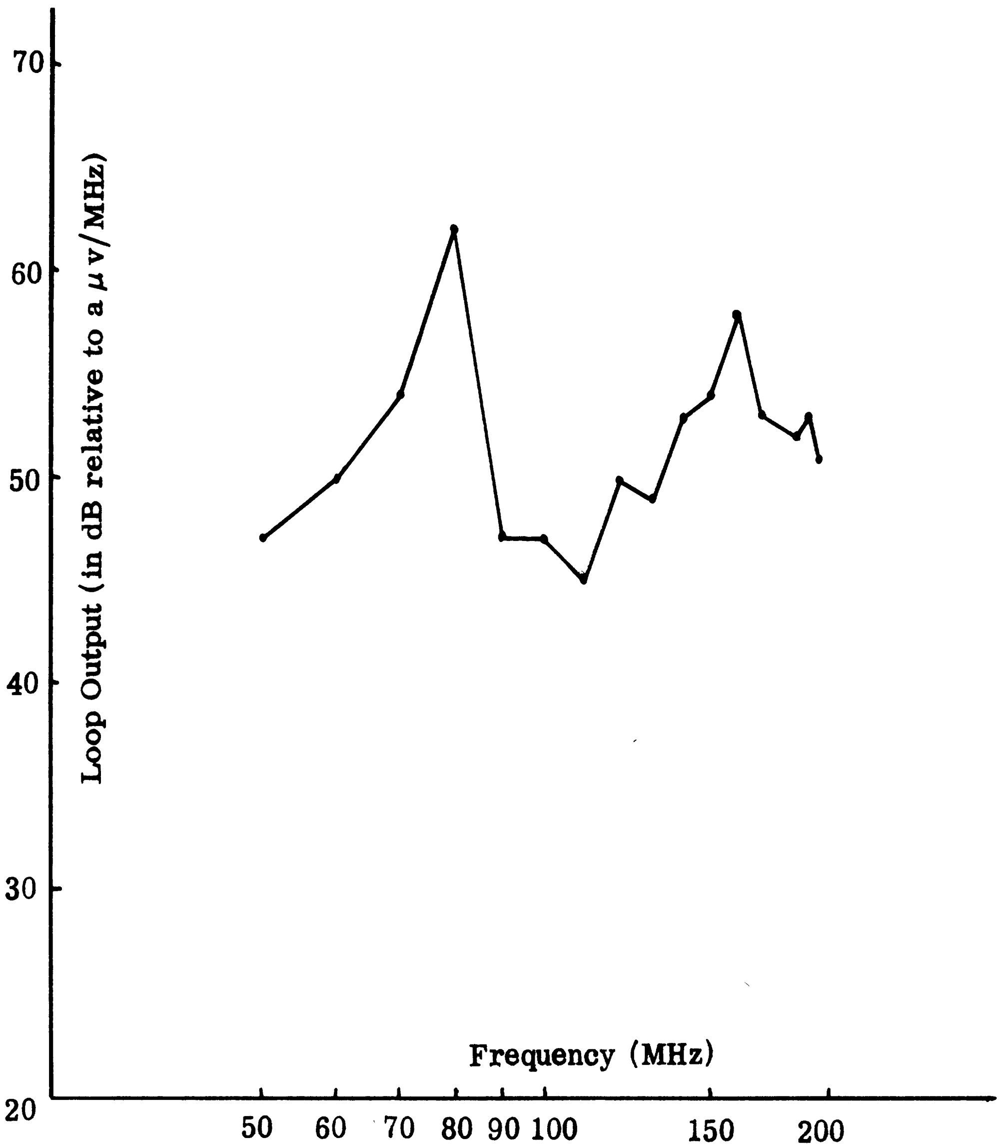


Figure 21: 1973 Lincoln Near Field Radiation Measurements. 3.75 Inch Loop Probe 20 Inches Above Car Air Filter. Hood Open. Loop Polarization Vertical and Oriented in Azimuth for Maximum Signal.

V SUMMARY

Two types of probes, the short electric dipole and the magnetic loop were fabricated and tested. Based on their use, performance and physical characteristics, the loop type probe was selected for use in the development of measurement techniques. Loop probes 3/4 inch and 3-3/4 inch in diameter were calibrated against a half-wavelength dipole over a 50 to 200 MHz band.

Two measurement techniques were investigated in detail and are recommended for use in further tests. The 3/4 inch loop was used in measurements to pin point and assess radiation intensity adjacent to a selected source — the probe being in physical but not electrical contact with the source. We termed these quasi-conductive measurements. The large loop, 3-3/4 inches in diameter, was used in that which was called near field measurements. These are measurements several inches removed from the source but still in its near field. Such measurements are more appropriate for determining intensity levels in selected areas or volumes of space.

Quasi conductive measurements were made adjacent to several sources in a 1973 Lincoln Continental. In addition near field measurements for two polarizations were made at several locations near the same car. Numerous curves showing radiation level over the 50 to 200 MHz band were presented.

Both of the above type measurements were made using the Singer NF 105 RFI meter. It was found necessary or at least desirable to modify and refine the procedures to be followed in using the Singer instrument. The procedure developed is described in detail in Appendix A.

It has been demonstrated that repeatable and meaningful data can be obtained using the probes and techniques developed in this study. To obtain probe output levels in absolute units, a properly calibrated RFI instrument is required. In these measurements, it has been assumed that the bandwidth of the RFI meter used was sufficient to accomodate the wideband RF radiation emanating from the engine under test. The reliability of this assumption has not been verified.

Reference

King, W. P., R. B. Mack, S. S. Sandler, Arrays of Cylindrical Dipoles, Cambridge University Press, pp. 372 (1968).

APPENDIX A

MEASUREMENT OF BROADBAND QUASI-CONDUCTED OR NEAR-FIELD RADIATED SIGNALS BY THE METERED SLIDEBACK METHOD

The directions in the Singer NF 205 RFI manual that apply to the quasi-conductive and near-field measurements of the radiation from automobiles are sometimes difficult to follow. This is partly because some appear in one place and others in another place in the manual. In addition they seem imcomplete and unclear when applied to these particular measurements. For these reasons we have prepared a revised set of instructions describing the procedures which we found to be satisfactory.

It may be well to restate the principle on which the operation of the Singer NF 205 RFI meter is based. Briefly, it is as follows. The signal to be measured is detected and amplified and its intensity is indicated on the meter or by the sound level in the earphones. Dial settings give information on the frequency. Attenuation is introduced by means of calibrated attenuators to reduce the indicated signal to the threshold of audibility (or to some other suitable indication, e.g., visual). At this stage, the unknown signal is switched off and the output of the calibrated impulse generator which is a part of the RFI unit is fed through the same circuits used in the detection, amplification and attenuation of the unknown signal. The output level of the impulse generator is adjusted until its aural indication is just barely at the threshold of audibility. Assuming no change in the attenuator setting and assuming a reliable calibration on the impulse generator, the level of the unknown signal is that which is indicated on the dial of the impulse generator in dB above 1 μv/MHz.

RF energy radiated from an internal combustion engine tends to be erratic and non-repetitive causing the response of the metering circuitry of the output meter pointer to fluctuate, thereby making measurement difficult. To measure such signals accurately, the metered slideback technique provided with the Singer NF 205 RFI meter should be employed. To make the measurements in the 50 - 200 MHz frequency range the T-1/NF-205 tuning unit is used. Aural monitoring of applied signals is highly desirable and earphones should be plugged into the PHONES receptable. The loudness of the aural indication can be adjusted to a comfortable level by means of the VOLUME control.

Many of the instructions, a through q, which follow have been lifted verbatim from the Instruction Manual of the NF-205 RFI meter.

a. Apply power and perform the preliminary adjustments as noted below.

1. Initial Control Settings. Set the controls as listed in Table 1 prior to application of line power. Controls not specifically referenced in the table may be set set to any arbitrary position.

2. Power Application and Preliminary Adjustments. To prepare the NF-205 for operation, proceed as follows.

With the POWER Switch set to OFF, check the indication of the output meter pointer; it should indicate 0 on the MICROVOLTS scale. If this indication is not obtained, carefully adjust the output meter mechanical zero set screwdriver control until the pointer deflects to a MICROVOLTS scale indication of 0.

CAUTION

PULL OUT THE SIGNAL ATTENUATOR DB SWITCH BEFORE PLACING IN A NEW SETTING. TURNING THE

SWITCH KNOB WITHOUT FIRST PULLING IT FORWARD WILL DAMAGE THE SWITCH. AFTER THE DOT ON THE SWITCH KNOB IS LINED UP FOR THE DESIRED SETTING, PUSH THE KNOB ALL THE WAY IN.

TABLE 1: INITIAL CONTROL SETTINGS

Control	Setting
POWER switch	OFF
METER switch	INT
CAL switch	SHUNT
SIGNAL ATTENUATOR DB switch	20
IMPULSE GENERATOR switch	OFF
IMPULSE GENERATOR DB ABOVE $1\mu V/MHz$ switches	70 and 0
GAIN control	Mid-range
VOLUME control	Mid-range
Function Selector switch	ZERO ADJ
METER DAMP switch	OFF
SLIDEBACK control	Fully clockwise
ZERO ADJ control	Mid-range

After the preliminary adjustments have been performed, determine the type of measurement to be made (quasi-conductive or near-field radiation). Connect the appropriate pickup device (3/4" loop for conductive measurement and 3-3/4" loop for near field radiation measurement) and auxiliary equipment to the basic unit and/or tuning unit as illustrated in Figure A-1.

Interconnect the equipment as illustrated in Figure A-2. Set the POWER switch to ON and, if an inverter or autotransformer is employed, set its "power" switch to "on". If an autotransformer is employed, adjust its output for 115 volts after it stabilizes. The POWER pilot lamp will illuminate upon application of the line power. Allow the equipment to warm up for at least 15 minutes.

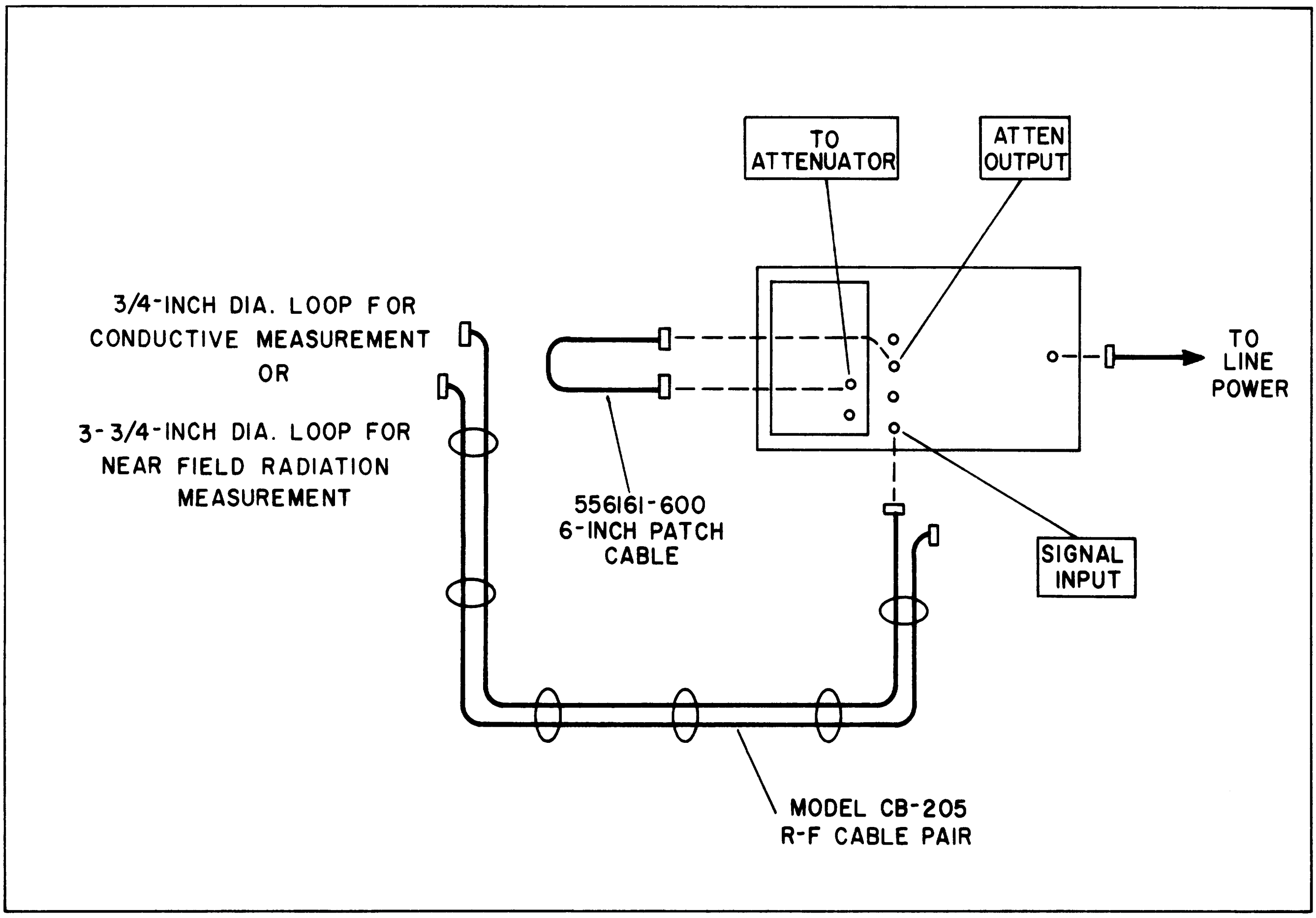


FIGURE A-1: BASIC INTERCONNECTION DIAGRAM

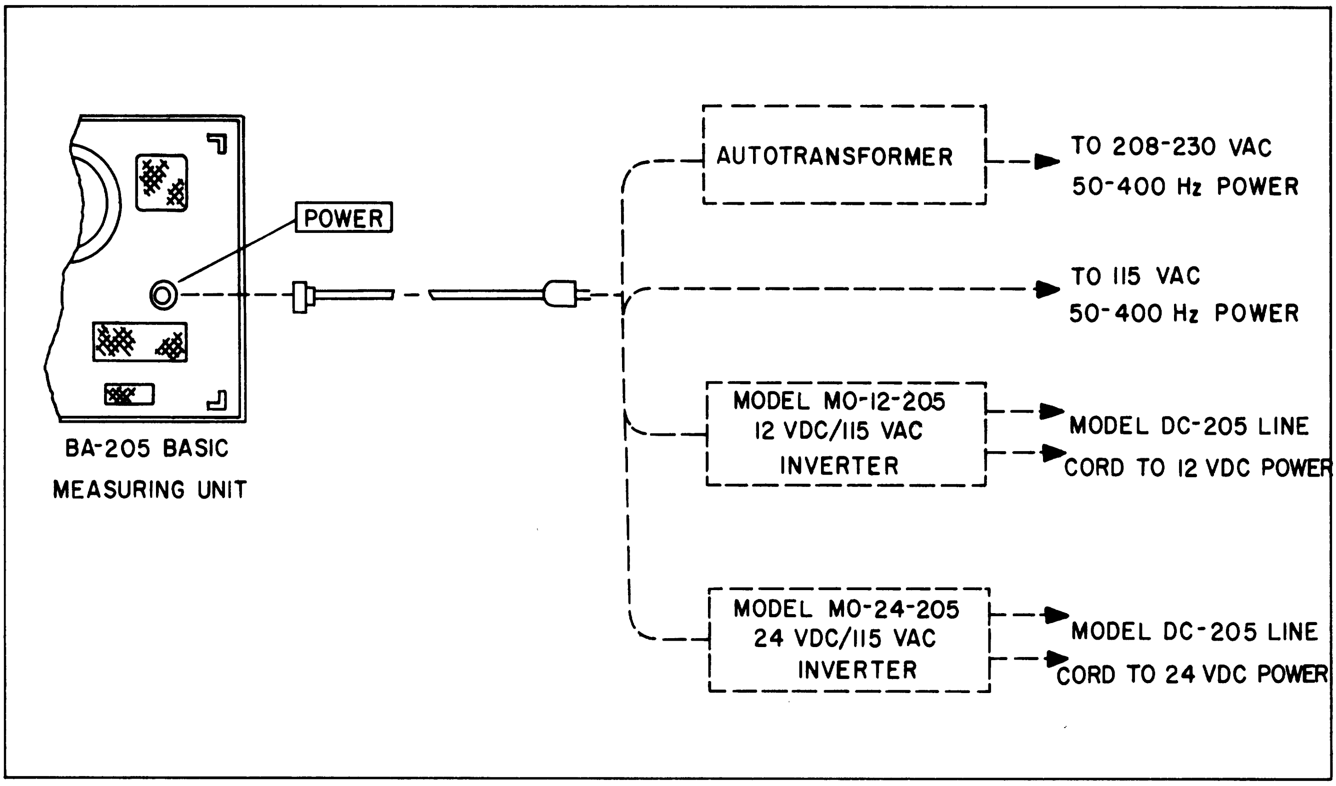


FIGURE A-2: POWER CONNECTION DIAGRAM

3. Quasi-Conductive Measurements. To make quasi-conductive measurements attach the 3/4" loop to the surface of the wire of interest (ignition wire or auxiliary electrical wire). The plane of the loop should be parallel to the wire at the point of contact to ensure maximum response from the loop. To ensure that only interference from one wire is being detected all other wires should be displaced at least 6 inches or so from the wire-loop contact point if possible. The cable that interconnects the loop probe and the NF-205 may be dressed, either down under the car if the hood is to be closed or out over the fender. Placement did not appear to be critical.

4. Near-Field Radiation Measurements. To make near-field radiation measurements attach the 3-3/4" loop to a non-conductive tripod at the desired location of the vehicle under test. In the measurements the loop was positioned within a foot or so from the vehicle body. These measurements may also be made within the engine compartment with the loop placed in the area of interest.

When making near-field radiation measurements the plane of the loop should be oriented for maximum response or for the polarization of interest.

b. Set the SIGNAL ATTENUATOR DB switch to 0 SUBST ONLY.

c. Set the BAND SELECTOR switch to the lowest frequency band and rotate the TUNING control counterclockwise to obtain a MHz dial indication corresponding to the low-frequency end of the selected band or to the frequency of interest.

d. Set the Function Selector switch to PULSE PEAK and adjust the GAIN control to obtain an output meter pointer noise indication of 4 on the DECIBELS scale.

e. Set the CAL switch to SERIES. (If the signal frequency is known continue at step k.)

f. Slowly rotate the TUNING control clockwise to scan the band in search of the presence of a broadband signal. Signal interception will cause the output meter pointer to rise upscale above noise as the signal enters the equipment passband.

g. Continue rotating the TUNING control clockwise until a maximum output meter pointer deflection is obtained. Should the output meter pointer deflect to an off-scale indication before reaching a maximum set the SIGNAL ATTENUATOR DB switch to 20.

h. Continue rotating the TUNING control clockwise (inserting r-f attenuation as necessary by means of the SIGNAL ATTENUATOR DB switch) until a maximum output meter pointer deflection is obtained. Note the frequency at which this maximum occurs and the setting of the SIGNAL ATTENUATOR DB switch.

i. Continue rotating the TUNING control clockwise. The output meter pointer will start to drop downscale after the maximum intensity point of the broadband signal leaves the equipment bandpass. Remove r-f attenuation by means of the SIGNAL ATTENUATOR DB switch, while simultaneously rotating the TUNING control, until the output meter pointer again indicates noise when in its most sensitive condition or the pointer once again rises upscale to indicate the interception of another broadband signal.

j. Repeat steps g through i until all broadband signal components within the frequency range of the installed tuning unit have been noted.

k. Tune the equipment to the frequency of interest. Set the attenuator as noted in h (or to a position where the signal is detectable) and set the function switch to METERED SLIDEBACK.

l. Set the SLIDEBACK control fully clockwise.

m. Adjust the VOLUME control to obtain a comfortable aural indication of the signal repetition rate.

n. Carefully rotate the SLIDEBACK control counterclockwise. The intensity of the aural indication will decrease as the control is adjusted. Alternately adjust both the SLIDEBACK and VOLUME controls until the aural indication is just at the threshold of audibility when the VOLUME control is set fully clockwise.

Note

Do not reset the SLIDEBACK control for the remainder of the procedure at the frequency of measurement.

o. Set the CAL switch to SHUNT, set the IMPULSE GENERATOR switch to ON and adjust the IMPULSE GENERATOR DB ABOVE $1\mu V/MHz$ switches until the aural indication of the impulse generator repetition rate is just barely at the threshold of audibility. (Note that it may be necessary to reset the position of the SIGNAL ATTENUATOR DB switch. If this is required, note the new setting.)

The intensity of the broadband signal relative to that which it would have been if the loop had a sensitivity equal to that of a $\lambda/2$ dipole, is equal to the sum of: 1) the output level of the impulse generator, 2) the difference between the settings of the SIGNAL ATTENUATOR DB switch for when the broadband signal under measurement is applied and that for whcn the impulse generator signal is applied, 3) the probe calibration factor (from Figure A-3), and 4) the attenuation due to the length of rf cable used (see manufactures specifications).

Note

If the total insertion loss of the r-f attenuators was reduced to permit the impulse generator output level to reach the threshold of audibility, this difference must be added to the impulse generator output level and cable attenuation. Conversely, if the total insertion loss of the r-f attenuators was increased to permit the impulse generator output level to reach the threshold of audibility, this difference must be subtracted from the sum of the impulse generator output level and the cable of attenuation.

p. De-energize the impulse generator.

q. Repeat steps b through p for the remainder of the frequencies within the range of the tuning unit.

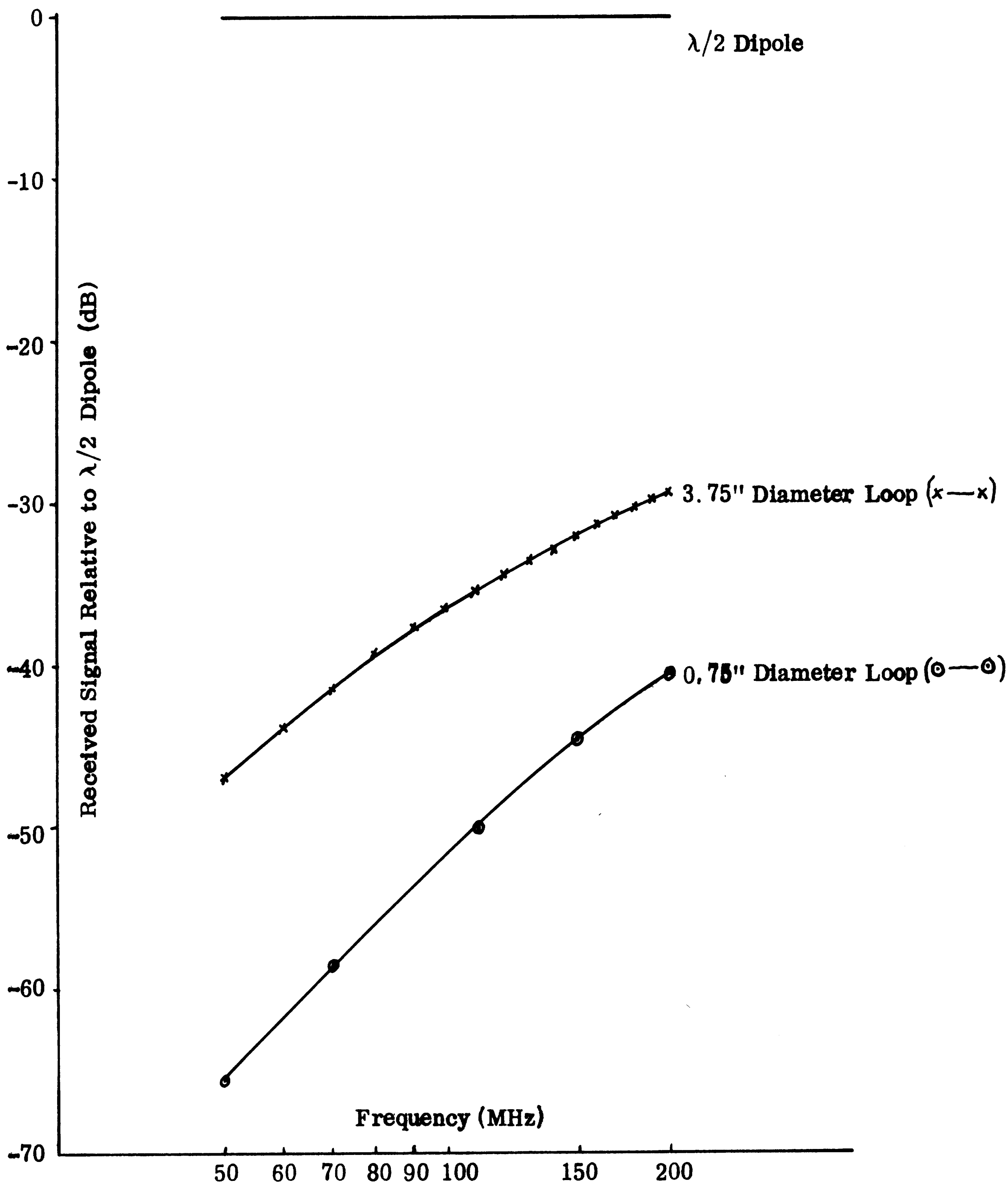


Figure A-3: Probe Calibration Curves Relative to a λ/2 Dipole - Experimental Data.