Technical

Report

Final Report
F-C3102

EVALUATION AND DETERMINATION OF SENSITIVITY AND ELECTROMAGNETIC INTERACTIONS OF COMMERCIAL BLASTING CAPS

by

R. H. Thompson

August 1973

Prepared for

U.S. Bureau of Mines
Department of Interior

Contract No. H0210068

THE FRANKLIN INSTITUTE RESEARCH LABORATORIES
THE BENJAMIN FRANKLIN PARKWAY • PHILADELPHIA, PENNSYLVANIA 19103

USBM Contract No. H0210068

EVALUATION AND DETERMINATION OF SENSITIVITY AND ELECTROMAGNETIC INTERACTIONS OF COMMERCIAL BLASTING CAPS

By

R. H. Thompson

The Franklin Institute Research Laboratories

USBM Contract Final Report (Contract No. H0210068)

Department of the Interior
Bureau of Mines
Washington, D. C.

ADDENDUM

The six types of caps tested in this report are referred to by the capital letters A, B, C, D, E and F. Types E and F are those of foreign manufacture underground coal mining operations. The caps tested are described below:

A. DuPont Instantaneous Electric Blasting Cap

The DuPont instantaneous cap is mechanically assembled with plastic leg wire insulation, rubber plug closure, and shielded shunts. This particular cap has copper leg wires and is not normally used in coal mining operations. This cap was selected for testing on the advice of the Bureau of Mines.

B. Atlas Kolmaster Delay Blasting Cap

The Kolmaster delay cap is provided with iron leg wires for coal mining operation. The leg wires are plastic insulated and shunted against stray currents. This cap is a delay cap with an average delay time of 25 ms. Delays up to 450 ms are available, but the lowest delay time was tested as being representative of the lot.

C. DuPont Coal Mine Delay Blasting Cap

This DuPont delay cap is similar in construction to the instantaneous cap. It is available in delays ranging from 25 ms up to 1000 ms. Color coding is used to differentiate the various delay caps. They are designed to conform to all United States Bureau of Mines recommendations on delay blasting. The delay time chosen for this cap was 25 ms.

D. Hercules "Coaldet" Coal Mining Delay Blasting Cap

The Hercules delay caps have iron leg wires which are shunted to provide protection against stray currents. This particular shunt forms an envelope around the exposed leads which provides corrosion protection. Delay times are available from 25 ms to 500 ms and are color coded. A delay of 25 ms was also chosen for this cap in the testing program.

E. Austin Delay Blasting Cap

The Austin Powder Company delay blasting cap is a coal mining cap made in Great Britain. It has iron leg wires and is similar in construction to the other delay caps. Its delay, however, is 30 ms.

F. Austin Instantaneous Blasting Cap

The Austin Powder Company instantaneous cap is a coal mining cap and is similar in construction to the DuPont instantaneous cap. It has iron leg wires and is shunted to protect against stray currents.

FOREWORD

This report was prepared by the Franklin Institute Research Laboratories under USBM Contract No. H0210068. The contract was initiated under the Coal Mine Health and Safety Research Program. It was administered under the technical direction of the Pittsburgh Mining and Safety Research Center with Mr. Richard W. Watson acting as the technical project officer. Mr. Dean Priddy was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period July 1971 to July 1973. This report was submitted by the author on October 9, 1973.

ABSTRACT

Six different types of blasting caps, mainly of the type used in coal mines, were evaluated to determine both their RF and DC characteristics. Two of the caps were of foreign manufacture. All the American made caps had "no-fire" (0.1% firing probability with 95% confidence, as determined by the Bruceton test) levels above 0.04 watts. One of the caps of foreign manufacture had a "no-fire" level of 0.023 watts.

A worst case analysis of blasting cap pick up of RF power in coal mines was performed and safe distance curves were generated.

ACKNOWLEDGEMENTS

This report was prepared by the Applied Physics Laboratory of FIRL under the administrative supervision of Mr. P. F. Mohrbach, Principal Physicist. The experimental effort was physically carried out by Messrs. A. W. Cipkins and H. T. Tucker. Mr. W. J. Dunning, Research Engineer and Mr. D. J. Mullen, Senior Research Engineer, evaluated the experimental data and contributed to the writing of this report. Mr. Jeffrey Tecosky assisted in some of the computer programming and data plotting and Mr. R. C. Thompson compiled the data of Appendix G.

We would like to thank Mr. R. W. Watson of the Bureau of Mines for his advice and assistance in the planning and execution of the work.

SUBJECT INVENTIONS

There were no inventions made or patents issued as a result of the work performed on this report.

CONTENTS

CONTENTS (CONT'D.)

FIGURES

FIGURE (CONT'D.)

TABLES

1. INTRODUCTION

The specific object of this program was to provide a means of evaluating the potential hazards to blasting caps caused by equipment producing electromagnetic fields, particularly communication systems.

In many underground coal mining operations the use of electromagnetic field producing equipment, particularly communication systems, not only increases the overall efficiency of the mining operation but can be directly linked with mine safety considerations. The use of electromagnetic field producing equipment in underground coal mining operations can only be expected to grow. Several new communication systems have already been proposed. In addition, high-frequency producing equipments for many diverse uses in mining operations are under study.

The use of this equipment in underground mining operations is hampered by the possibility of their electromagnetic fields interacting with the electric blasting cap operations commonly carried out in the mines. Such interactions can have at least two results bearing directly on mine safety:

- Premature initiation of the cap, either in its normal shot location or during hookup or transportation
- Dudding of the cap so that normal firing operations do not cause initiation, thereby leaving unexploded high explosives after normal firing

The general problem of predicting possible RF hazards for any electro-explosive device (EED) is best treated by reference to Appendix A[1] of this report. Appendix A considers the general problem from a military/space agency viewpoint but blasting caps are the primitive models for most EEDs so the material is directly applicable to blasting cap problems.

[1]Superscripts refer to the numbered references of Section 8. Appendix A is an excerpt from reference 1.

In brief, the specific problem of analytically predicting possible RF hazards to blasting caps can be reduced to finding answers to the following three questions:

(1) How much power, at the frequency of concern, is necessary to function the caps?

(2) How much power is coupled to the cap by a given field existing in the vicinity of the cap and its associated wiring?

(3) What fields will exist in the vicinity of the blasting cap and its wiring for a given source, physical environment, frequency and separation?

A considerable body of work[2,3,4] exists that deals with questions (2) and (3) for aboveground blasting operations and sources. Although some of the results of this work are directly applicable to underground mining operations, the factors of minimum distance between transmitting sources and caps, tunnel geometry, unknown electrical properties of the surrounding minerals, etc., that are inherent in underground operations limit complete application of these methods and results. Some limited theoretical investigations[5,6], tailored to a specific underground communication system, have been performed. In the end, electromagnetic hazard evaluation of the system was forced to rely on experimental data taken in a tunnel of the mine in which the communication system was to be installed.

The overall program described here can be broken down into the following tasks:

(1) The experimental determination of the dc sensitivity, RF sensitivity, static sensitivity, and dc and RF dudding susceptibility for commercial blasting caps used in coal mines.

(2) The determination, in sufficient detail to allow conservative estimation, of the electromagnetic properties of the mine environments.

(3) The development of propagation models for underground mine environments considering typical source antenna characteristics, the mineral electromagnetic parameters, and the tunnel geometry, mine equipment, etc.

(4) The correlation of previous analyses on aboveground operations to underground blasting wiring configurations.

(5) Determination of the possible power that can be delivered to caps used in various underground operations from various electromagnetic sources.

Sections 2, 3, 4 and 5 of this report describe the overall experimental effort and Sections 6, 7 and 8 present the analytical portion of the work.

2. THE BLASTING CAPS TESTED

Underground coal mining operations using electric blasting techniques generally use blasting caps that incorporate a time delay. The delays commonly available from commercial sources run from a minimum of approximately 25 milliseconds to about 500 milliseconds in steps of approximately 75 milliseconds. The advantages gained by use of caps having various delays in coal mining operation are both economically and safety oriented[7] and are not our concern here; however, the sheer number of different delay caps available seemed to require an enormous amount of testing to characterize the RF behavior of the caps. Visits to the manufacturing facilities of the various cap producers in the United States, examination of assembly drawings, and discussions with the manufacturers' production and design personnel showed that the ignition producing subsystem (the header, bridge-wire and primer mix) of almost all of each manufacturers' delay caps was of the same construction. Since this is the only portion of the cap that can be expected to influence the RF behavior of the cap we can, with small risk, characterize all of a manufacturers coal mine delay caps by testing a single delay from each manufacturer.

The caps selected for testing were:

(1) Three 25 millisecond delay caps from different United States manufacturers. All of these caps had iron leg wires.

(2) A 30 millisecond delay cap of foreign manufacture. (iron leg wires)

(3) An instantaneous cap of U.S. manufacture for control purposes. (copper leg wires)

(4) An instantaneous cap of foreign manufacture for control purposes. (iron leg wires)

Iron leg wires caps are the type most usually encountered in underground coal mining operations. Our methods of determining cap sensitivity require that the cap leads be reduced to less than one-quarter inch in length, so we do not believe that copper leg wire caps will differ seriously in RF sensitivity from the results determined for the iron leg wire caps.

The six types of caps tested in this report are referred to by the capital letters A, B, C, D, E and F. Types E and F are those of foreign manufacture.

3. THE TESTS PERFORMED

Blasting caps can be initiated with RF energy in two different ways. The blasting cap is designed to initiate by bridgewire heating and this mode of initiation can be utilized by RF currents as well as the normal firing currents. Since a potential difference must exist between the blasting cap leads (or "pins") for this mode of initiation it is referred to as the pin-to-pin firing mode. Blasting caps can also be initiated by application of an RF potential between one of the pins and the metallic case. In this firing mode it makes little or no difference whether the pins are shorted together or not. This firing mode is usually referred to as the pins-to-case mode.

The most common statistical method of determining the sensitivity of any electroexplosive device is the "Bruceton" test. This method of testing is described in a report submitted by the Statistical Research Group, Princeton University, to the Applied Mathematics Panel of the National Defense Research Committee in July, 1944. The report details the methods for statistical analysis of the test data obtained by the new procedure at the Explosives Research Laboratory at Bruceton, Pa. Hence, the designation "Bruceton" test. Much of our evaluation work here uses the Bruceton procedure. Reference 8 is the original "Bruceton" report.

Tests conducted on electroexplosive devices (EEDs) over the last ten years have indicated that, rather than conduct a full Bruceton-type statistical test at each frequency and firing mode (pin-to-pin or pins-to-case) combination, a set of probing tests can be conducted across the frequency band of interest using the dc sensitivity as a reference level. Bruceton type RF sensitivity tests are generally conducted only at those conditions which indicate the greatest sensitivity. If the blasting cap has some unusual sensitivity to RF at a specific condition this approach should detect it and define it. This approach eliminates a large portion of the otherwise required testing and hence provides a means of economically determining EED RF characteristics.

In brief, the general test plan is as follows:

(1) The dc response of the cap to constant current pulses is determined as a control. Additional supporting data obtained includes thermal time constant, rate of change of resistance of the bridgewire with application of electric stimulus (dR/dt), and time to rupture of the bridgewire.

(2) The approximate RF response of the cap in all modes of initiation, as determined from the probing tests, is compared with the dc response.

(3) The RF condition which indicates the greatest sensitivity is explored with a Bruceton or Probit-type test.

(4) The static sensitivity of the cap is determined.

(5) The dudding characteristics of the cap are determined.

The equipment used in the testing is all special purpose instrumentation and evaluation equipment. The measurement techniques are also special purpose and have been developed particularly for the evaluation of electroexplosives. A full description of the equipment and techniques is given in References 9, 10 and 11. Reference 9 deals with the dc instrumentation, 10 with the static tests and 11 with the RF equipment and techniques. Reference 12 gives more information on the RF firing systems. The RF firing systems require a precise mounting arrangement for the blasting caps. Figure 3-1 shows, from right to left, a blasting cap in the "as received" condition, a cap with the leg wires cut and stripped, a stripped cap mounted in a collet type mounting fixture and the actual firing mount in which the collet type mounting fixture is inserted to provide a precise mounting arrangement for the cap. The actual firing mount provides a precisely known location for the transition from the coaxial line that connects to the firing system and the input to the blasting cap.

The following paragraphs give a brief description of the specific tests that were conducted on each different type of cap.

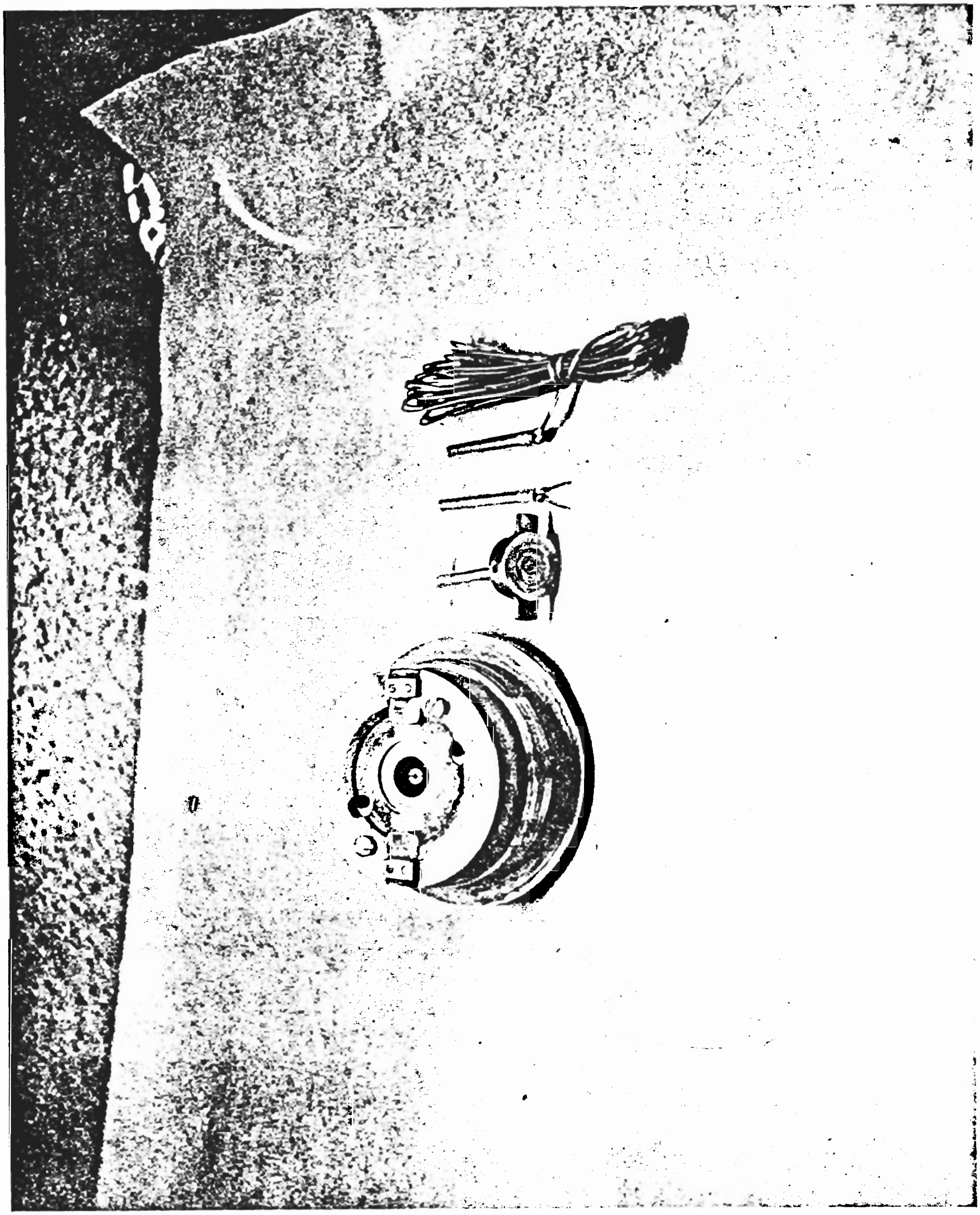


Figure 3-1. Cap Mounting for RF Sensitivity Determination

3.1 DC CONSTANT CURRENT SENSITIVITY

This test determines the mean current sensitivity of the cap to long dc pulses. The resulting information forms the basis for evaluating relative sensitivity with other stimuli such as short pulses or RF. The testing procedure uses the Franklin Institue Laboratories Universal Pulser (FILUP)[9] which determines the resistance and funtioning time for each item during the constant current test. Using this equipment and the Bruceton procedure each item is subjected to a constant current pulse for 10 seconds. If the item fires, the next item is tested at the next lower level. If it does not fire, the next item is fired at the next higher level. From this "fire; no-fire" information at the various fixed firing levels the mean and standard deviation of the firing current can be determined as well as the "no-fire" (0.1%) level and the "all-fire", (99.9%) level. In addition, various confidence intervals may be attached to these levels.

3.2 DYNAMIC RESISTANCE

The dynamic resistance of a blasting cap is a necessary parameter for calculation of the input power for a given constant current stimuli. This calculation is required since the RF data is obtained in terms of power. Furthermore, a knowledge of the changing resistance characteristics of an EED under electrical stimuli aids in anticipating problems resulting from impedance mismatching between RF generator and blasting caps. The bridgewire resistance varies due to the heating effect of the applied stimulus, immediate environment of the bridgewire and the bridgewire material. The dynamic resistance of the blasting cap is obtained by passing a known current through the bridgewire and recording the voltage across the bridge as a function of time.

3.3 BRIDGEWIRE BREAK TIME

It is often of interest to know at what time a bridgewire breaks after application of a particular firing stimulus; for example, if a number of devices are to be connected in series for firing, it may be of considerable importance to know when the circuit may be interrupted. Even for an instantaneous cap this break time can differ considerably from the functioning time, defined as the time of stimulus application to rupture of the case.

The dynamic resistance measurements discussed in Section 3.2 are conducted at reasonably large stimulus levels and the bridgewire electrical parameters are monitored by an oscilloscope. As a result, useful bridgewire break times can be obtained as an extra dividend from the dynamic resistance data.

3.4 THERMAL TIME CONSTANT

It is possible that the blasting cap may be subjected to repetitive, pulse-type stimulus such as that produced by the modulation of a common search radar signal. Each pulse alone has insufficient energy to fire the blasting cap or effect its performance, but the combined effect may produce thermal stacking and fire the cap. Thermal stacking occurs when the bridgewire has not had sufficient time to cool off before the next pulse arrives, thus the bridgewire temperature increases until it reaches the ignition temperature of the explosive mix. Thermal time constant is measured by passing a small, constant current through the blasting cap and measuring the voltage across it. A high amplitude, short duration pulse is separately applied and the bridgewire resistance is recorded as a function of the time. The thermal time constant is defined as the time required for the bridgewire temperature to decay to 36.8% (1/e) of the maximum temperature excursion. Since temperature change is proportional to resistance change, the thermal time constant may be obtained directly from the monitoring voltage recording which is proportional to bridgewire resistance.

3.5 DC CONSTANT-CURRENT DUDDING

The dudding tests measure the change in sensitivity of a blasting cap due to application of stimuli not sufficient to fire the blasting cap. A blasting cap that misfires in use could produce a hazardous situation, so any reduction in senstivity caused by previous exposure could be dangerous. In addition, an occasional device shows an increase in sensitivity when subjected to prior exposure. The dc dudding test is performed by passing the 0.1% firing current of interest through a number of caps for 5 minutes and then determining the sensitivity to the standard stimulus used in 3.1 using the Bruceton technique. The results are then compared with the control Bruceton. The 0.1% level used in the dudding tests is computed without a confidence level.

3.6 STATIC SENSITIVITY

The test measures the effects of human generated static electricity on the blasting cap as well as the effects of electromagnetic fields induced by nearby lightning discharges. Very high voltages can be generated by persons handling caps, especially if they are wearing synthetic clothing and/or rubber soled shoes. The test potential is applied across the bridgewire (pin-to-pin) as well as pins-to-case. A 500 pF capacitor is charged to the test potential (25,000 volts) and discharged into the cap through a 5,000 ohm resistor. These values of resistance and capacitance are typical of those of a person handling the cap. See Reference 13 for a detailed description of personnel-borne static charge hazard.

3.7 RF COMPARISON

RF testing is conducted in a slightly different manner than the dc tests. Both the pin-to-pin (normal dc firing mode) and pins-to-case mode are investigated. This is necessary since some caps may be more sensitive to RF excitation in the pin-to-case mode than they are to RF pin-to-pin excitation. Using the results of the dc Bruceton test (Section 3.1) and the dynamic resistance test (Section 3.2), the approximate mean firing power is calculated. This information is then used as the starting point in the RF sensitivity determination. At each test frequency, a series of items is fired to determine the approximate mean firing level at that frequency in both the pin-to-pin and pins-to-case modes. Many frequencies throughout the RF spectrum are employed in the probing tests. They are chosen to match the frequency bands which contain high radiated powers. Broadcast band, HF communications, business radio, telemetry, microwave heating, and various radar and microwave frequencies are used. In addition to continuous wave (cw), pulse modulation is used in the microwave region where this type of modulation is frequently encountered.

Before a test is begun, the item is placed in a mount compatible with the firing system and frequency involved as well as the type of test (pin-to-pin or pins-to-case). The firing system is then matched to the item to be tested and the system efficiency is determined. Thus, the actual power delivered to the EED may be accurately determined.

3.8 RF COOK-OFF OR DUDDING

This test is conducted to determine the effects of applied RF power not sufficient to fire the EED. Such an exposure might alter the sensitivity of a device so that it will not fire when intended, or fire prematurely while being handled or tested. The device is subjected to RF energy at its most sensitive frequency at the approximate no fire (0.1% firing) level for 5 minutes. The items are then subjected to a dc Bruceton using the standard conditions stated in Section 3.1. Any changes in sensitivity will then be detected as deviations from the original (control) dc Bruceton.

3.9 RF BRUCETON

Bruceton tests are performed at the most sensitive frequency/modulation stimuli of the comparison tests for both the pin-to-pin and pins-to-case modes. The Bruceton procedure is the same as that used for the dc Bruceton control test.

4. TEST RESULTS

The planned tests for each cap type and the number of caps to be used in each test are given in Table 4-1. Appendix B contains the computer output sheets for all of the Bruceton test data evaluations. Appendix C gives the data obtained from the RF probing tests.

The dc test results, including the "means" for both the dc and RF dudding Bruceton tests are summarized for all caps in Table 4-2. While functioning times are recorded during tests and we have included average functioning time in the data summary, it is of little practical value since it was determined at the firing levels which are used in the Bruceton tests. Currents used during the test would not compare with the large currents used to fire the items in the field and the current level materially effects the functioning time. Exact thermal time constants were not obtained on any of the caps tested because it was found that all caps had comparatively rapid cooling rates (thermal time constants less than 7 microseconds) and that thermal stacking thus should not occur. Exact determination of thermal time constant less than 7 microseconds was impossible with our present equipment. It should also be noted that none of the caps tested indicated any significant sensitivity to personnel-borne static charges.

The results of the RF tests are summarized in Table 4-3 along with the data from the dc control Bruceton tests converted to power values. The conditions at which the RF Bruceton tests were conducted were chosen on the basis of the RF probing tests which in general were conducted on ten caps each in both the pin-to-pin and pins-to-case mode at the following frequencies: Continuous Wave 0.088, 1.5, 10, 150, 450, 2700, 5400 and 9000 MHz; Pulsed: 2700, 5400, and 9000 MHz.

Table 4-1. Blasting Cap Test Plan

pp = stimuli pin to pin

pc = stimuli pin to case

DC Tests	Number of Caps and Firing Mode
D. C. Control Bruceton	50 pp
Dynamic Res.	10 pp
Static	15 pp
D.C. Dudding	50 pp at 0.1% of D.C. Control for 5 minutes, then Bruceton
Thermal Time Constant	10 pp

RF Tests

R.F. Probes Frequency (MHz)	Exposures pp	Exposures pc
0.088	10	10
1.5	10	10
10	10	10
150	10	10
450	10	10
2700 cw	10	10
pulsed	10	10
5400 cw	10	10
pulsed	10	10
8900 cw	10	10
pulsed	10	10
RF Bruceton	50	50
RF Dudding	50 at 0.1%	then D.C. Bruceton

Table 4-2. Summary of dc Results

			Firing Levels (Amps)							
Cap Designation	Cap Type	Average Bridgewire Resistance (ohms)	DC Control Test 0.1%	DC Control Test 50%	DC Control Test 99.9%	DC Dudding 50%	RF Dudding 50%	dR/dt (ohms/s)	Average Bridgewire Break Time (ms)	Static Sensitivity
A	Inst.	1.2	.254	.286	.321	.315	.302	126	1.028	None Indicated
B	Delay	1.3	.303	.339	.381	.473	.398	596	.353	None Indicated
C	Delay	1.2	.466	.526	.594	.550	.429	805	.762	None Indicated
D	Delay	1.6	.228	.275	.331	.305	.286	309	.527	None Indicated
E	Delay	2.9	.173	.299	.517	.301	.290	1400	.148	None Indicated
F	Inst.	2.1	.266	.314	.369	.312	.294	1200	.183	None Indicated

Table 4-3. Summary of RF Results for Most Sensitive Conditions Tested

	Firing Levels (watts)													
	dc Control			RF Pin-to-Pin					RF Pins-to-Case					
Cap	0.1%	50%	99.9%	Frequency (MHz)	Modulation Mode	0.1%	50%	99.9%	Frequency (MHz)	Modulation Mode	0.1%	50%	99.9%
A	.078	.098	.124	1.5	cw	.077	.110	.157	9000	P	.580	3.312	18.919
B	.119	.149	.189	1.5	cw	.164	.253	.389	5400	cw	.770	2.611	8.851
C	.260	.332	.423	1.5	cw	.275	.331	.399		Not	Fired		
D	.083	.121	.175	1.5	cw	.089	.125	.176	1.5	cw	.059	.085	.123
E	.087	.259	.775	10	cw	.098	.146	.219	2700	P	.388	1.764	8.024
F	.148	.207	.286	10	cw	.023	.156	1.069	5400	P	.043	.251	1.475

Discussions of the results for the individual caps follow. It should be noted that all 0.1% and 99.9% firing levels mentioned in this report have been determined with 95% confidence.

4.1 CAP A

DC Test Results. The dc control produced a mean firing level of 0.286 amperes and a 0.1% firing level of 0.254 amperes. While these values marked this cap as one of the more sentitive caps it also appeared to have one of the tightest spreads between 0.1% and 99.9% firing levels. Its dR/dt of 126 ohms/second was the lowest recorded and its average bridgewire break time of 1.028 ms was the longest determined time. The results of both the dc and RF dudding tests indicated a slight shift toward decreased sensitivity. The RF dudding stimulus was 0.086 watts at 1.5 MHz cw, p-p. The dc dudding stimulus was 0.269 amperes.

RF Test Results. All probing tests were conducted as previously indicated except that no firings were obtained at 0.088 MHz, pins-to-case at the firing levels we were able to generate. The most sensitive condition for pin-to-pin firing occurred at 1.5 MHz, cw where a 0.1% firing level of 0.077 watts was obtained. Furthermore, as in the case of the dc control Bruceton, the spread between 0.1% and 99.9% firing values was small. Comparison with the dc Bruceton indicates that the RF and dc levels are really quite comparable to each other as one would expect at 1.5 MHz in the bridgewire mode. The most sensitive condition in the pins-to-case mode occurred at 9000 MHz and the Bruceton test produced a 0.1% firing level of 0.580 watts. The spread between 0.1% and 99.9% levels was large. In summary this cap indicated no marked pins-to-case sensitivity and its pin-to-pin sensitivity was in line with what one would expect from its dc sensitivity.

4.2 CAP B

DC Test Results. The dc control Bruceton test produced a mean firing level of 0.339 amperes and a 0.1% firing level of 0.303 amperes. This made it one of the least sensitive caps tested. The spread between 0.1% and 99.9% was acceptably small. dR/dt was 596 ohms/sec, an intermediate change rate, and average bridgewire break time was 0.353 ms which was on the short side. The results of the dudding tests indicated some decrease of sensitivity was caused by preexposure although the effect was much more marked in the case of the dc exposures than it was in the case of the RF exposures. The shift produced by the dc exposure of 318 mA for 5 minutes was the largest produced on any cap in the evaluation. The RF dudding stimulus was 0.192 watts at 1.5MHz cw, p-p.

RF Test Results. All probing tests were conducted as previously indicated except no tests were conducted at 0.088 MHz, pins-to-case. The most sensitive pin-to-pin condition was determined to be at 1.5 MHz, cw where the mean was 0.253 watts and the 0.1% firing level was 0.164 watts. This was somewhat less sensitive than the dc sensitivity and probably indicates some RF loss in the base even at this low frequency. The most sensitive pins-to-case condition was determined to be at 5400 MHz cw, where 0.1% firing level of 0.770 watts was produced which was the highest (least sensitive) value obtained in these tests. In summary, this cap demonstrated no unexpected RF sensitivity.

4.3 CAP C

DC Test Results. The dc control test produced a mean firing level of 0.526 amperes and a 0.1% firing level of 0.466 amperes. This was the least sensitivity of any of the caps tested. Bridgewire break time was 0.762 ms, one of the longer ones recorded and the dR/dt recorded was 805 ohms/sec, an intermediate rate. The results of the dudding tests were somewhat confusing. The caps exposed to a dc preexposure showed practically no significant shift in sensitivity from the dc control Bruceton. In the case of the RF preexposure, however, the caps showed a marked *increase* in sensitivity. While this increase in sensitivity did not make the cap unusually sensitive in comparison to all of the caps tested, it is an unusual result and indicates a possible need for further study. The RF dudding stimulus was 0.0293 watts at 1.5 MHz cw, p-p. The dc dudding stimulus was 0.496 amperes.

RF Test Results. There were no exceptions to the probing test schedule for this cap. The most sensitive frequency for the pin-to-pin firing mode occurred at 1.5 MHz, cw where the mean firing level was determined to be 0.331 watts and the 0.1% firing level was 0.275. This compares very favorably with the dc control Bruceton results. There was no determination of pins-to-case sensitivity by Bruceton testing for this item. The RF probing tests showed that this item is relatively insensitive in pins-to-case exposure and in consequence a Bruceton test would have been impossible to perform with available equipment. We feel that it is safe to assume, on the basis of the RF probing data, that this cap is less sensitive pins-to-case than pin-to-pin at its most sensitive point so that the pin-to-pin RF Bruceton data can be used as an upper limit on the pins-to-case sensitivity.

4.4 CAP D

DC Test Results. The dc control Bruceton test produced a mean firing level of 0.275 amperes and a 0.1% firing level of 0.228 amperes. These levels indicate it is one of the more sensitive caps tested.

A bridgewire break time of 0.527 ms was recorded along with a dR/dt of 309 ohms/second, both intermediate. Both dudding tests, dc and RF preexposure, indicated no significant shift in sensitivity. The RF dudding stimulus was 0.105 watts at 1.5 MHz cw, p-p. The dc dudding stimulus was 0.252 amperes.

RF Test Results. There were no exceptions to the probing test schedule on these caps. The most sensitive condition in the pin-to-pin mode was determined to be at 1.5 MHz, cw where the mean firing level was found to be 0.125 watts and the 0.1% firing level was computed at 0.089 watts. This coincided almost exactly with the dc control Bruceton test results. For this device the most sensitive pins-to-case sensitivity was at 1.5 MHz, cw where the mean firing level was 0.085 watts and the 0.1% firing level was 0.059 watts. This was the most sensitive pins-to-case mean value recorded on any of the caps tested.

4.5 CAP E

DC Test Results. The dc control Bruceton produced a mean firing level of 0.299 amperes and a 0.1% firing level of 0.173 amperes. This was the lowest 0.1% firing level computed from the dc control tests. In addition the bridgewire break time of 0.148 ms was the shortest time recorded for any of the caps tested and the dR/dt of 1400 ohms/second was the largest rate of increase recorded. Neither the dc or RF dudding response test indicated any significant effect due to the preexposure of the cap to the dudding stimulus. The RF dudding stimulus was 0.114 watts at 10 MHz cw, p-p. The dc dudding stimulus was 0.239 amperes.

RF Test Results. There were no exceptions for this device in the RF probing test schedule. The most sensitive RF pin-to-pin condition was found to occur at 10 MHz, cw where the mean firing level was found to be 0.146 watts and the 0.1% firing level was calculated to be 0.098 watts. Comparing the mean firing levels of this test and the dc control test indicates that the RF sensitivity has shifted to somewhat more sensitive condition. However, the spread of data on the RF test was even tighter than on the dc control test this resulted in comparable 0.1% firing levels for both tests. We, therefore, concluded that the dc levels and the most sensitive pin-to-pin RF levels are substantially the same. The most sensitive pins-to-case RF sensitivity occurred at 2.7 GHz, pulsed where the mean firing level was found to be 1.764 watts and the 0.1% firing level was computed as 0.388 watts. This is a relatively insensitive response.

4.6 CAP F

DC Test Results. The dc control Bruceton test produced a mean firing level of 0.314 amps and a 0.1% firing level of 0.266 amps. This is a medium sensitivity for the set of caps considered in this study. The bridgewire breaktime was 0.183 ms, a relatively short time, and the dR/dt was 1200 ohms/second, a relatively large rate of change. The results of the dc and RF dudding preexposure tests indicated no significant effect from the dudding stimulus. The RF dudding stimulus was 0.053 watts at 10 MHz, cw, p-p. The dc dudding stimulus was 0.290 amperes.

RF Test Results. No exceptions to the RF probing tests schedule were made with this cap. The most sensitive condition was judged to occur at 10 MHz, cw where the mean firing level was determined to be 0.156 watts and the 0.1% firing level was computed as 0.023 watts. This cap, as in the case of Cap E, indicated an increased sensitivity for the RF mean over the dc control mean. At this relatively low RF frequency and in the pin-to-pin or bridgewire mode this is an unusual occurrence. However, this cap also had a relatively wide spread of response and as a result produced the lowest 0.1 firing level of any cap in this study, 0.023 watts. The most sensitive pin-to-case response occurred at 5400 MHz, pulsed where the mean firing level was determined to be 0.251 watts and the 0.1% firing level was computed as 0.043 watts. This is the lowest 0.1% pin-to-case level determined in this evaluation.

5. TEST CONCLUSIONS

It must be noted when considering the data in this report that the data was gathered to evaluate the performance of the overall group of caps, not any individual cap. With this understanding certain overall conclusions may be considered.

The dc sensitivity firing characteristics of all the caps are similar. The 0.1% firing levels range from 173 ma to 466 ma and the 99.9% firing levels range from 321 ma to 594 ma. No particularly unusual sensitivity is indicated nor any particular difficulty in producing fires. Furthermore, for the most part, there seems to be little chance of producing duds or dangerously sensitive caps by preexposure to either low level RF or dc. Of course, every measure should be taken to eliminate the possibility of such preexposure, but the data indicates that while some changes occurred, these changes did not alter the sensitivity of the caps to unacceptable levels.

The dR/dt data, while of interest for many special calculations probably has a minimal effect on performance since the changes occur in such a short time and just before firing.

Bridgewire break time is meaningful only when used with other information as indicated earlier. All of the manufacturers of these caps seem to have taken adequate steps to minimize personnel borne static sensitivity since no indication of static sensitivity was observed in the tests. It must be remembered, however, that electrostatic sources other than that used in the personnel borne static tests can produce much worse conditions both in terms of capacitance and voltage so one must not construe the results to lower the need for proper handling.

In the case of the RF tests, the pin-to-pin tests indicated that the most sensitive condition for all caps occurred at the low frequency end of the frequency range listed and paralleled the dc sensitivity. This indicates that functioning for pin-to-pin RF exposure of these caps is by bridgewire heating as in the case of the dc exposure. Cap F is a possible exception to this statement and no explanation is offered for the pin-to-pin results on that cap at this time. It should be noted that even though the pin-to-pin response of the rest of the caps is straightforward and exactly as one would predict from normal cap behavior, the potential RF firing levels are low enough to be of concern. Even if we ignore the 23 mw, 0.1% firing level of Cap F, we still have levels as low as 77 mw with which to contend. With this low level a user should be aware of his RF environment in any firing set-up and be prepared to take steps to minimize resulting problems.

The majority of these caps show no significant sensitivity to pins-to-case applied RF. Caps D and F are the exceptions. Cap D has a 0.059 watt 0.1% firing level at 1.5 MHz cw. The 0.043 watt 0.1% level of Cap F, at 5400 MHz p, is more in keeping with the type of behavior we have observed in other electroexplosives investigations. The same comments about user awareness of the RF environment made in the last paragraph are reinforced by these relatively low RF pins-to-case sensitivities.

6. PREDICTING THE RF POWER PICKUP OF BLASTING CAPS

6.1 INTRODUCTION

The use of electrically initiated blasting caps in blasting operations creates the possibility of the initiation of explosives by electrical energy sources not directly under the user's control. The most commonly recognized of these sources are: lightning; static electricity; electromagnetic communication; navigation or search systems; galvanic potentials and ground currents.

The electroexplosive devices used in blasting are designed to be initiated by the rapid heating of a low resistance (about 1 ohm) wire in contact with a fairly sensitive explosive. Premature initiation will occur whenever an uncontrolled source of energy can sufficiently heat the wire or when sufficient electrical energy can be delivered directly to the sensitive explosive. The latter may occur whenever the electrical potential between the initiating wire and the case of the electroexplosive device is high enough. Figure 6-1 is a crude schematic of a typical blasting cap. Normally, a voltage is applied between points A and B to cause initiation. We refer to this mode as the pin-to-pin firing mode. If the energy source voltage is applied between points A and C, or B and C, the mode is pin-to-case.

We are concerned, in this report, specifically with the pickup from electromagnetic communication equipment and other unspecified radiating equipment that might be in use in underground mining operations. Our final object is to predict distances from these sources at which blasting caps can be used safely.

A strict analytical solution to the general problem of determining aboveground safe distance from a source of radio frequency power requires complete knowledge of the power output of the source, the effect of

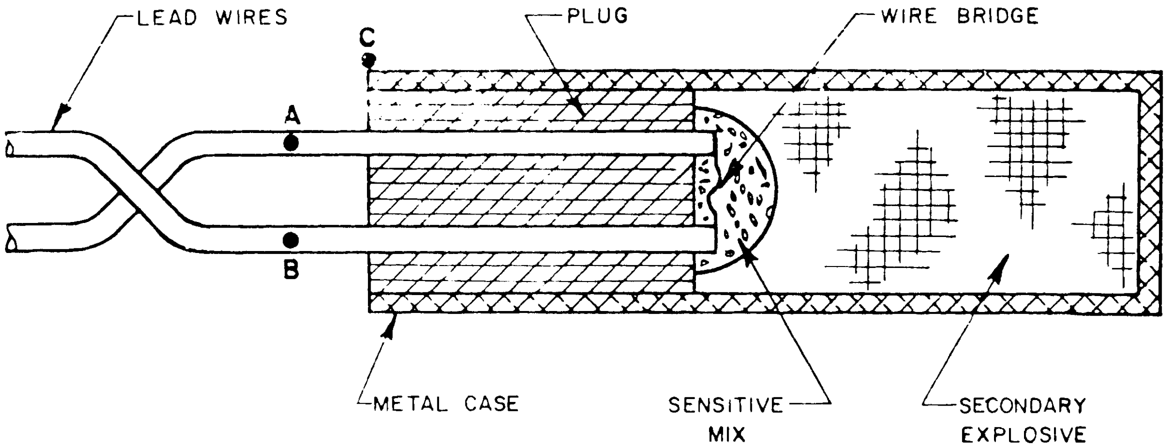


Figure 6-1. Schematic of a Typical Blasting Cap

distance, the ability of wiring in the blasting circuit to pick up energy, and the amount of power necessary for initiation of a blasting cap. This would be a formidable problem even in an ideal case; in practice the difficulties become unsurmountable. The presence of objects, terrain features, and soil moisture, which may absorb or reflect power; the fact that the wiring of the blasting circuit is randomly laid out and is not usually divisible into neat geometric segments which can be analyzed and related to the plane of polarization of the offending field - all these are complications which make a strict analytical solution virtually impossible even for aboveground operations. The underground problem is further complicated. Figure 6-2 is a rough sketch of a section of underground tunnel that exemplifies some of these further complicating features. The sketch tries to illustrate the possibilities of tunnel geometry irregularity, and the presence of field perturbing objects such as vehicles and power lines. In sum, even for the simplest well defined geometry and source/blasting wiring configuration the hope of an exact analytical solution to the pickup problem is hopeless. We must make some simplifying assumptions and, since we are concerned with personnel/explosive safety situations, they must be selected so that any resulting error due to the assumptions will occur on the side of caution.

An analysis using such assumptions is called "worst-case". The result of a worst case analysis indicating safety may be taken as quite safe indeed; the lack of such a result should be interpreted as indicating that safety cannot be proved, not necessarily that a hazard exists.

As mentioned in the introduction to this report, the specific problem of analytically predicting possible RF hazards to blasting caps can be reduced to finding answers to the following three questions:

(1) How much power, at the frequency of concern, is necessary to function the caps?

(2) How much power, at the frequency of concern, is coupled to the cap by a unit amplitude field existing in the vicinity of the cap and its associated wiring?

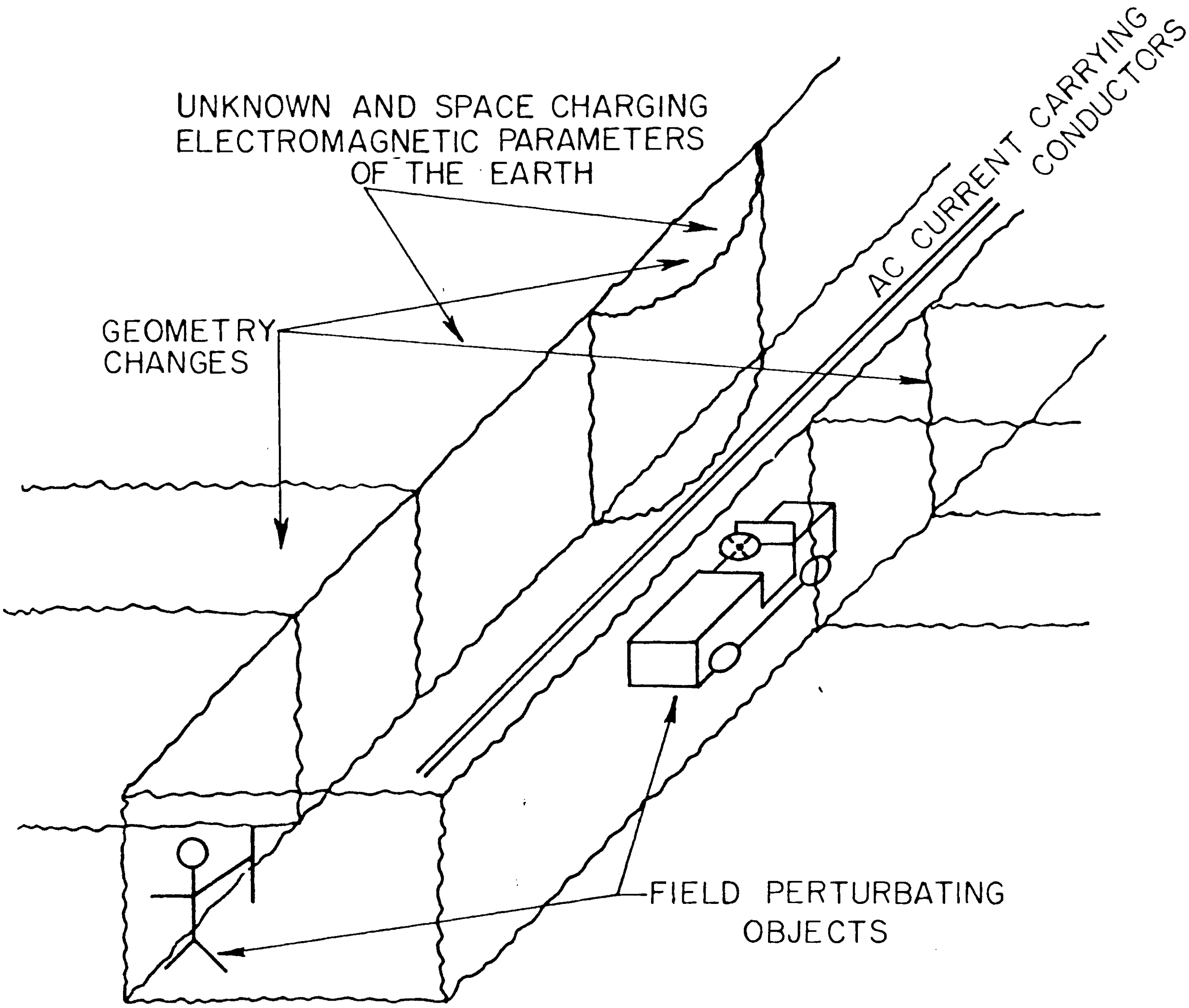


Figure 6-2. Underground Complications

(3) What fields will exist, at the frequency of concern, in the vicinity of the blasting cap and its wiring for a given source, physical environment and separation?

The following sections present worst case answers to the above questions.

6.2 FUNCTIONING POWER

The amount of power necessary to function the caps can be determined, from a worstcase viewpoint, by consideration of Figure 6-3 which summarizes the RF Bruceton test results of Sections 3 and 4. The large arrows of Figure 6-3 indicate the frequencies at which the RF probing tests were performed. These frequencies were selected as those most likely to be used in any high RF power equipment with which underground blasting operations might interact. Note also that these frequencies provide a fairly even sampling of the overall frequency interval of concern. The circles connected by solid vertical lines indicate the mean and 0.1% firing level (95% confidence) for the pin-to-pin Bruceton tests. The squares connected by dashed lines indicate the same levels for the pin-to-case Brucetons. Since the frequencies at which the Bruceton tests were fired were selected as the most sensitive of the frequencies probed, the Bruceton test results can be used as a good frequency independent approximation to the most sensitive firing levels for the caps. Roughly, the top of each vertical line in Figure 6-3 represents a power level at which one-half of the caps fired during a Bruceton test. The power level at the bottom of the line (0.1% level, 95% confidence) is the predicted level at which no more than one in a thousand of the caps would fire. The 0.1% level (with 95% confidence) has been used, for about the past fifteen years, as a general level at which exposures of electroexplosives could be tolerated without undue risk. This level has not been determined for blasting caps in general but a level of 0.04 watts (for any frequency and firing mode) has been used as an approximation for American made caps for many years. The data of Figure 6-3 would seem to contradict

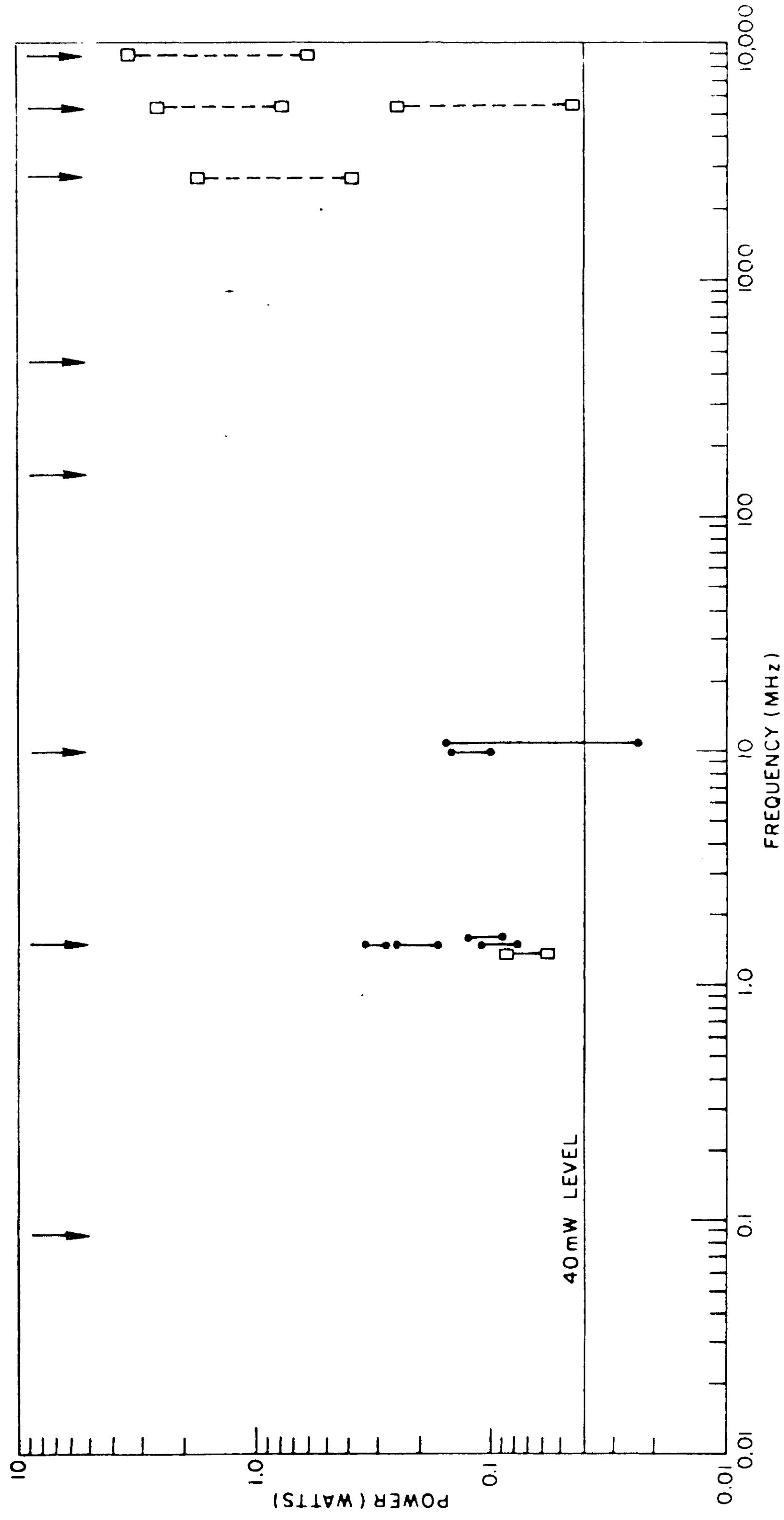


Figure 6-3. Summary of Bruceton Results

this assumption since a 0.1% level of 0.023 watts at 10 MHz is indicated. However, this level, as well as the 0.043 watt pin-to-case 0.1% level at 5400 MHz, is associated with Cap F, a cap of foreign manufacture. So we see that the use of a 0.04 watt level as a tolerable exposure level for caps of American manufacture is in keeping with the data determined by the experiments. In particular the data shows that the use of a 0.04 watt level as an approximation to the 0.1% firing level is conservative for the American made caps that would be encountered in underground blasting operations.

6.3 COUPLING TO THE CAP

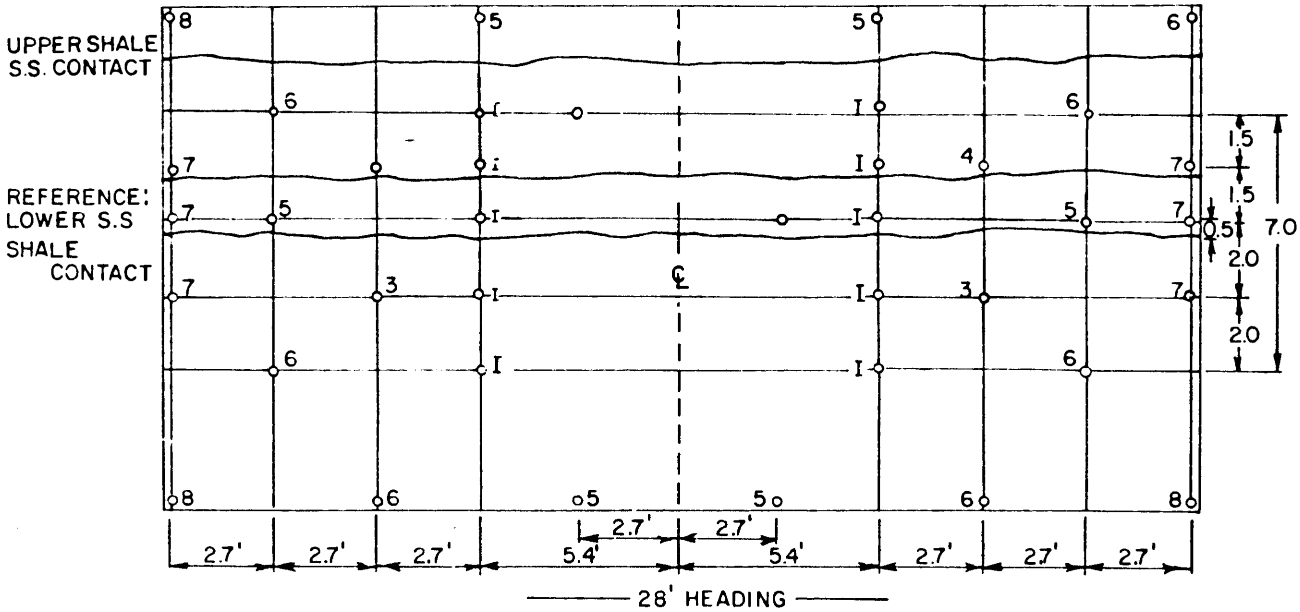
The determination of the power coupled to the cap, at the frequency of concern, by a unit amplitude field in the vicinity of the cap and its wiring is essentially a determination of a pickup model for the cap and its wiring. In line with our worst case approach to the overall problem we must choose a pickup model which maximizes the total power picked up by the cap at all frequencies and yet is in accord with the physical aspects of the cap and its wiring.

Figure 6-4 is a layout sketch for the boring of a 38 hole blast of a 28' wide heading in a copper mine. Figure 6-5 shows how the blasting cap leg wires (which will extend from each hole after hole loading) will be connected together for connections to the shot line. Figure 6-6 is a sketch of how the wired face and shot line might appear after connection. During the loading and connection of the face, the caps and their attached wires assume several distinct configurations. These configurations are identical from a worst case viewpoint, to those formed in almost any underground blasting operation. The configurations of concern are:

1) Caps in their original packing configuration.

2) Caps with leg wires extended, but leg wires still shorted, both in the bore hole and before insertion in the hole.

38 HOLE ROUND FOR 28' WIDE HEADING
WITH 0–2.0' OF BASAL MASSIVE S.S



DELAY NO.	CAPS REQ'D
I (0)	10
1	2
3	2
4	2
5	6
6	6
7	6
8	4
ALL	TOTAL 38 CAPS

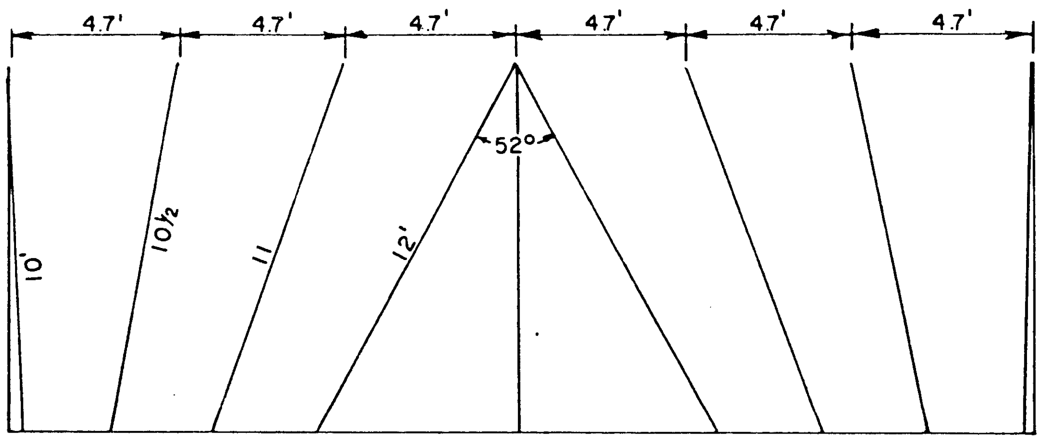


Figure 6-4. Layout for Face Boring

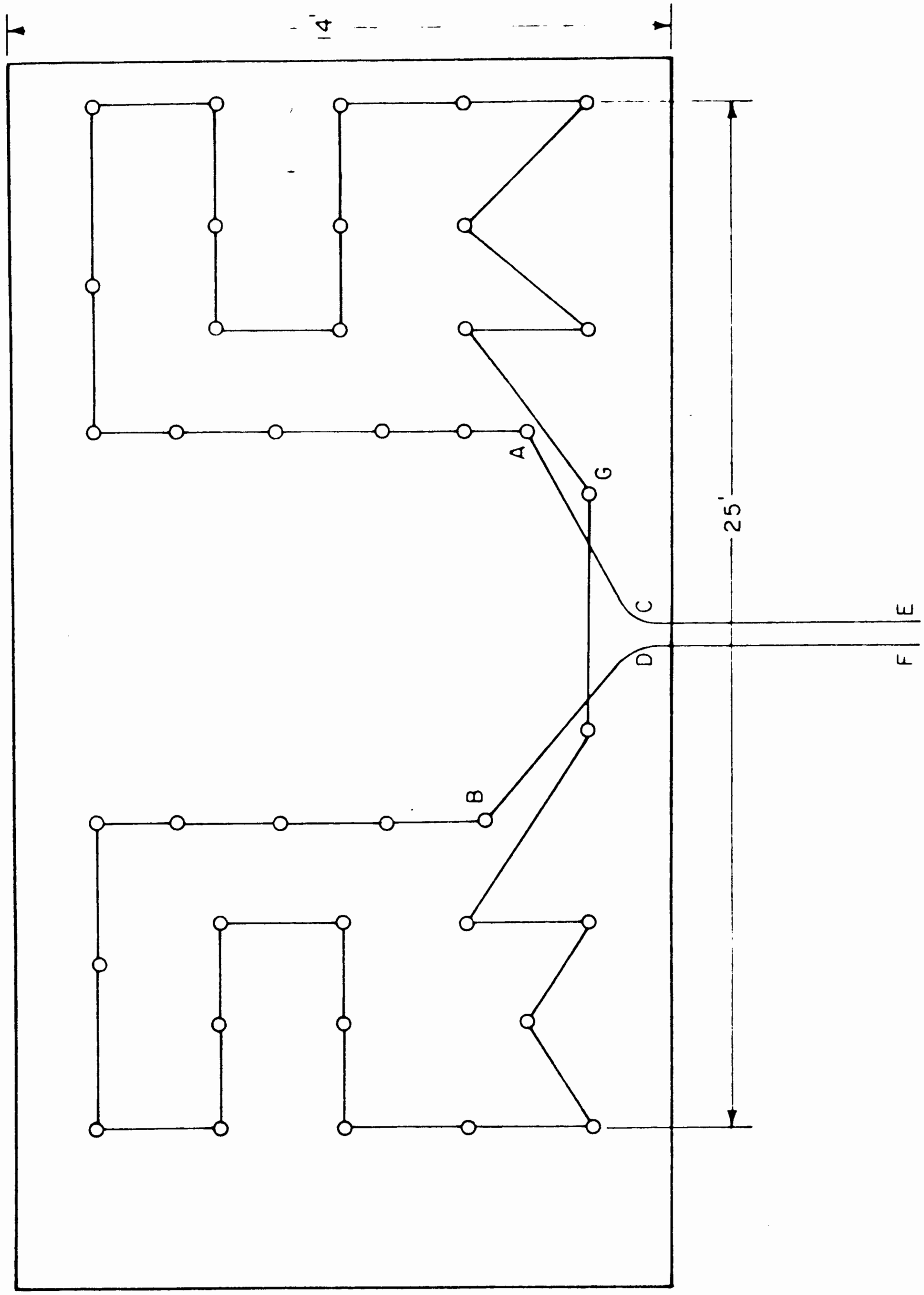


Figure 6-5. Cap Connection Layout

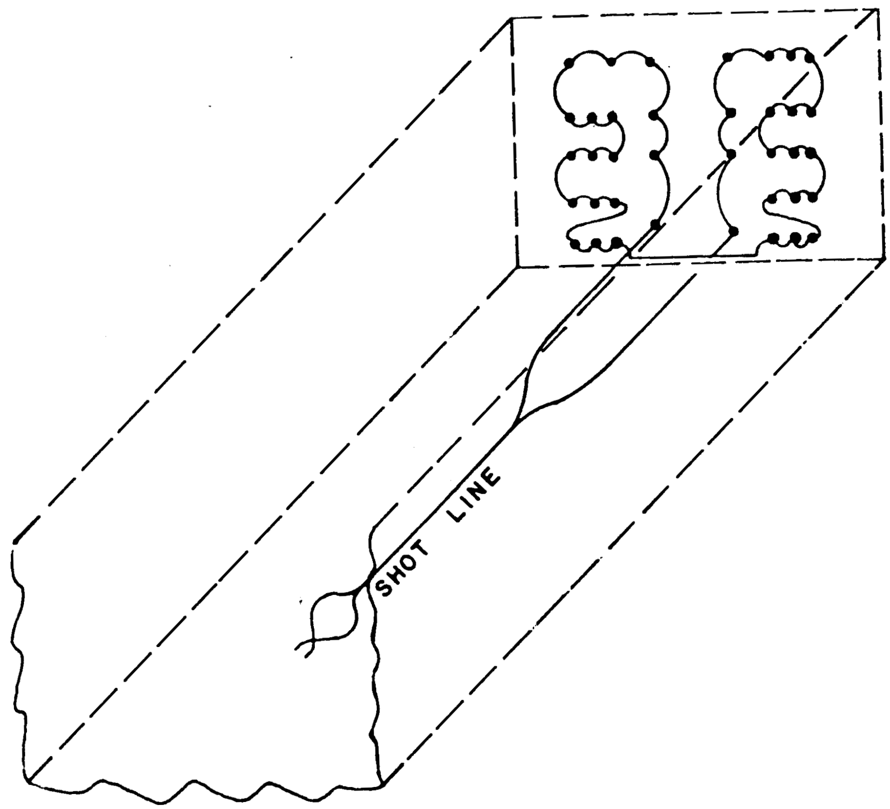


Figure 6-6. Shot Line and Wired Face

3) Cap in bore hole with the short removed from leg wires.

4) Caps connected leg to leg and final legs shorted. [Wired, shorted face].

5) Wired face connected to either a shorted or an open shot line.

Figures 6-7, 6-8 and 6-9 are sketches of aboveground blasting wiring layouts that have been considered as antennas. Reference 2 treats the models for these configurations in detail and concludes that the best overall antenna model for aboveground layouts is that of the vertical loop antenna of Figures 6-8 and 6-9. The sketches of Figures 6-10 and 6-11 show that the vertical loop antenna configurations can also be formed in underground blasting layouts. The half-wavelength dipole configuration of Figure 6-7 can also be formed in underground layouts for RF sources with wavelengths equal to twice the length of cap lead wire extending from a loaded bored hole. Many other antenna configurations can also be identified in underground layouts but they do not differ significantly from those of aboveground layouts. The arguments presented by Reference 2 for the use of the vertical loop antenna as a worst case antenna for aboveground blasting layouts are still valid for underground blasting wiring configurations. There are no configurations formed underground that are significantly different, in an RF pickup point of view, from those formed aboveground. We will, therefore, use the vertical loop for our underground pickup determination.

Reference 2 derives the worst case aperture for the vertical loop antenna as

$$A_e = \frac{0.95\ f_{Mc}^2}{(1 + .616\sqrt{f_{Mc}})^2} \text{ square meters, } f_{Mc} \leq 20$$

$$A_e = \frac{1.07 \times 10^4}{f_{Mc}^2} + \frac{62}{f_{Mc}},\ 20 \leq f_{Mc} \leq 70$$

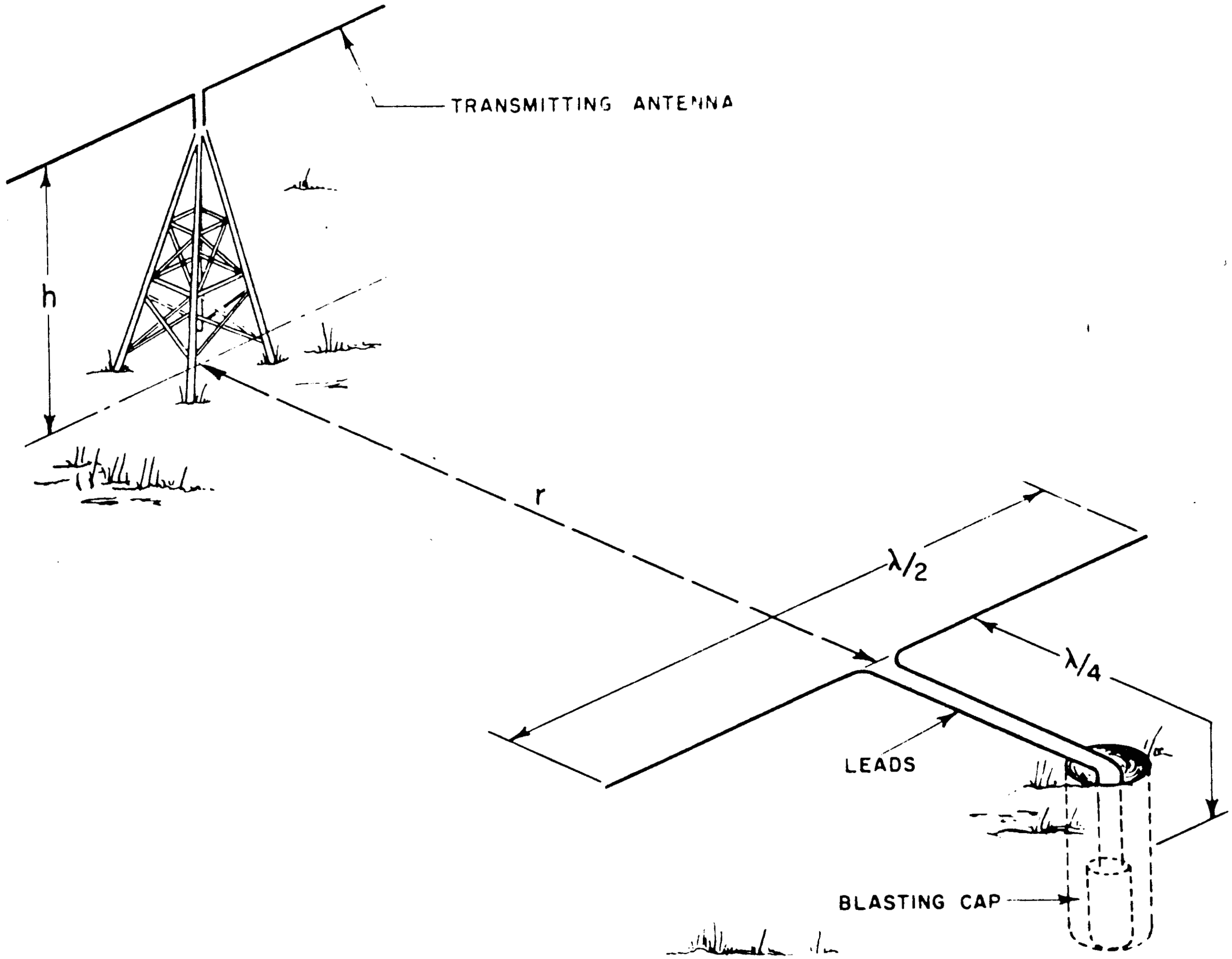


Figure 6-7. Possible Blasting Configuration and Transmitting Antenna Which Illustrate the Horizontal Half-Wavelength Dipole Antenna Model.

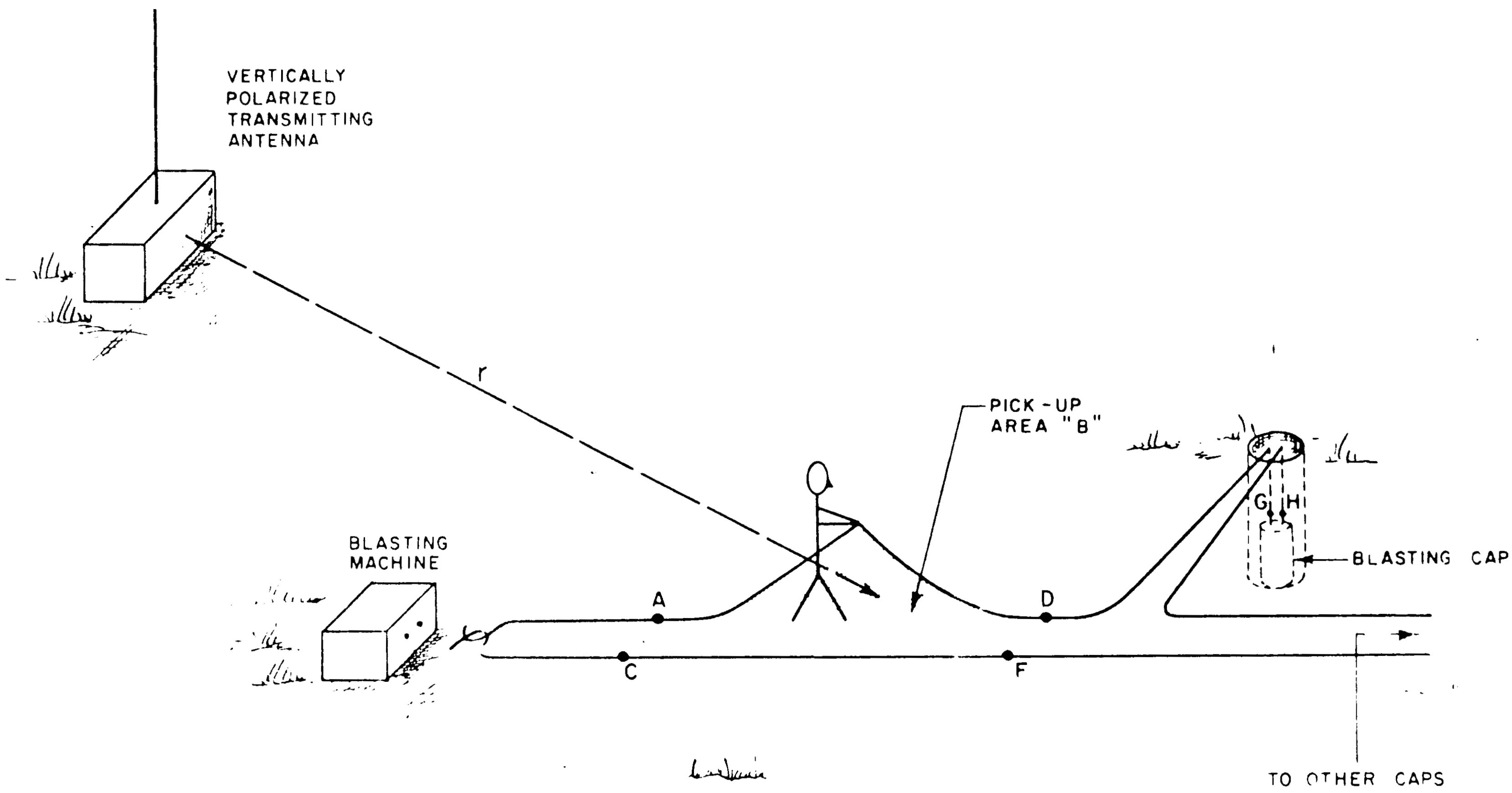


Figure 6-8. Possible Blasting Configuration and Transmitting Antenna Orientation, Which Illustrates with Vertical Loop Antenna Model.

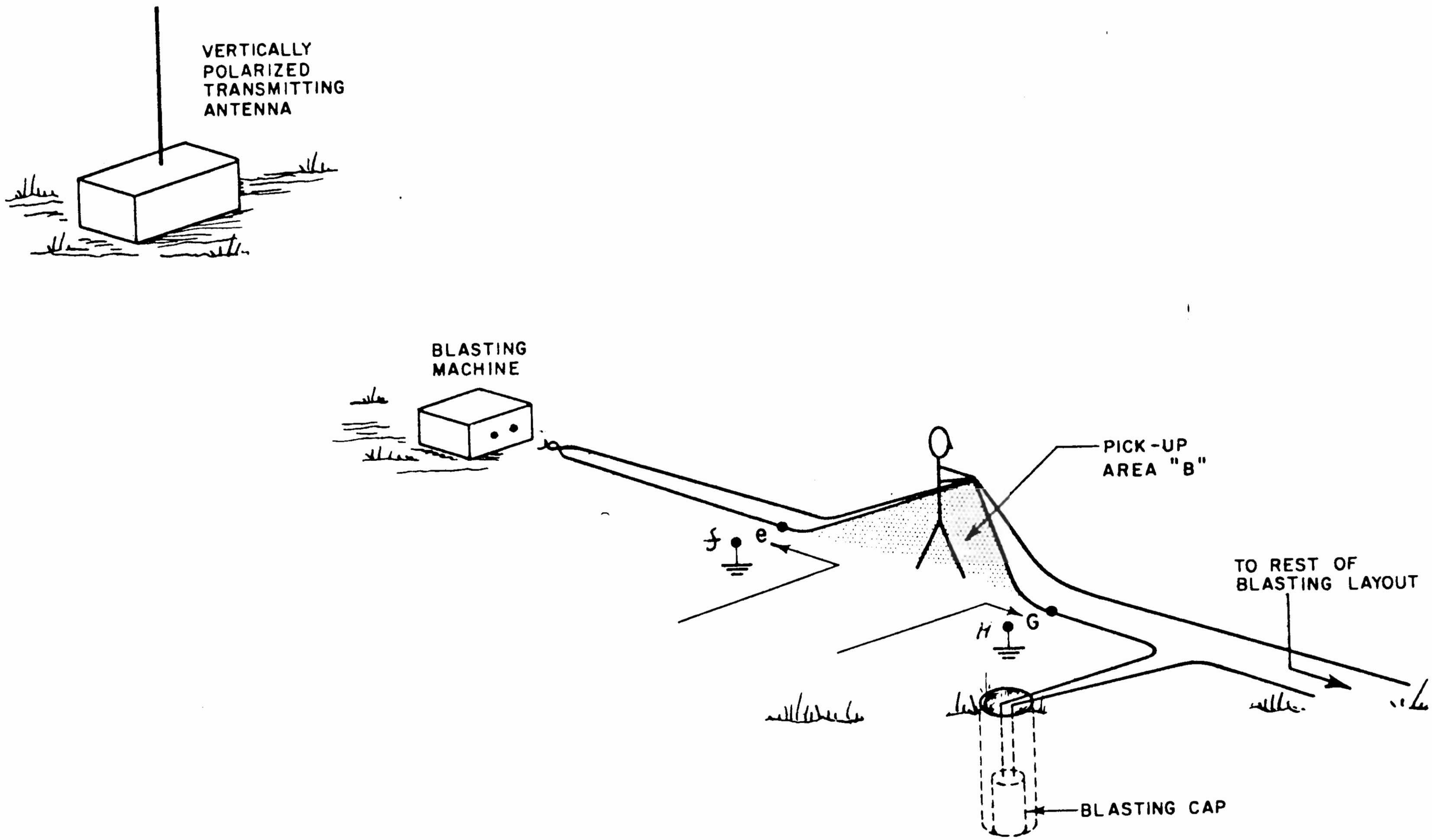


Figure 6-9. Pin-to-Case Sensitive Blasting Configuration and Its Antenna Model

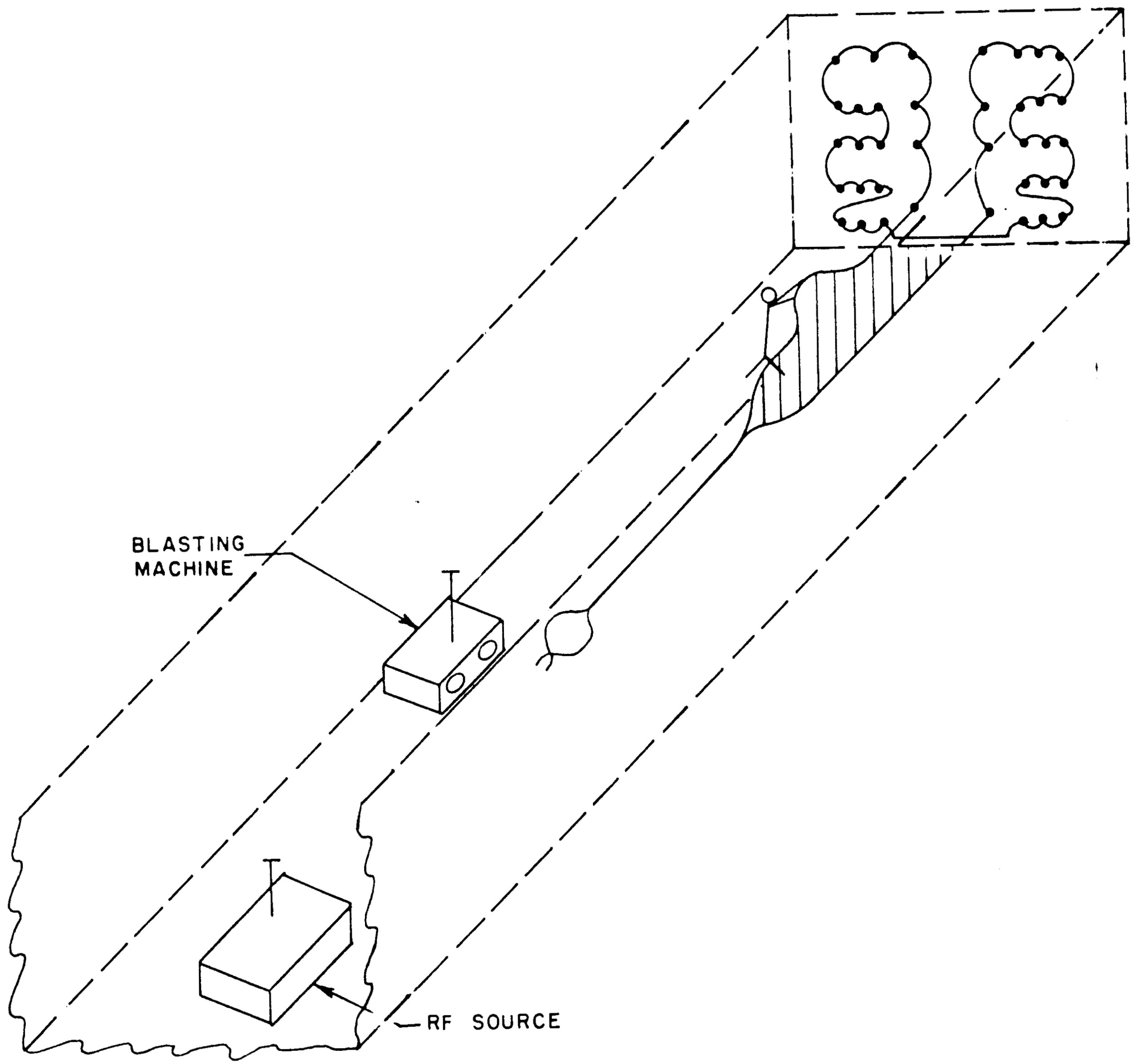


Figure 6-10. Pin-to-Pin Vertical Loop Underground Configuration.

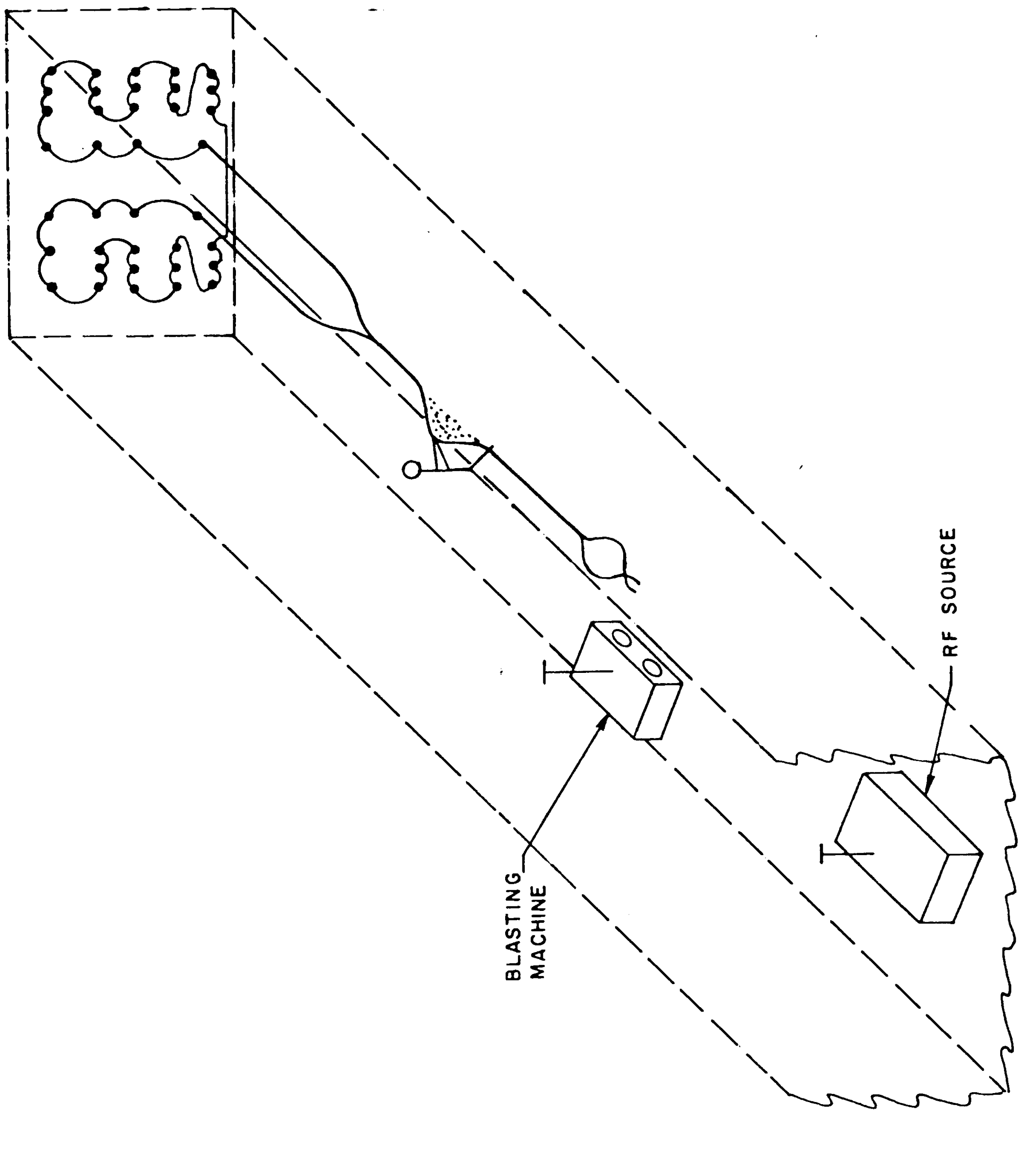


Figure 6-11. Pin-to-Case Vertical Loop Underground Configuration.

$$A_e = \frac{219}{f_{Mc}}, f_{Mc}, f_{Mc} > 70$$

where

A_e is the worst case aperture in square meters and f_{Mc} is the frequency in Megahertz.

Figure 6-12 plots A_e as a function of frequency.

The power delivered to the electrical load connected to an antenna can be computed, with certain limitations, by multiplying the aperture of the antenna/load combination by the incident power density. If P_d (watts/meter^2) is the power density incident on the antenna and A_e (square meters) is the effective aperture of the antenna/blasting cap combination, than the power delivered to the blasting cap load is W_R (watts) where

$$W_R = P_d A_e$$

Appendix D is an excerpt from Reference 2 that contains most of the detailed derivation of the worst case nature of the vertical loop antenna aperture. The interested reader is referred to Reference 2 in its entirety for a complete understanding of the method of derivation. Reference 1 is also helpful. We would like to note here, however, that the vertical loop aperture as given above is an upper limit on any linear antenna having the same ratio between area and perimeter and the same electrical loading conditions as those used to derive the vertical loop aperture. In effect the aperture of the vertical loop as given by Figure 6-12 is an upper bound (at any frequency) for any vertical loop in the blasting wiring of a smaller linear dimension than that used to generate Figure 6-12.

In addition it can be shown that for frequencies higher than the peak of the aperture curve of Figure 6-12, the curve is an upper limit on any linear antenna of total length less than or equal to the perimeter of the loop on which Figure 6-12 is based [7.35 meters].

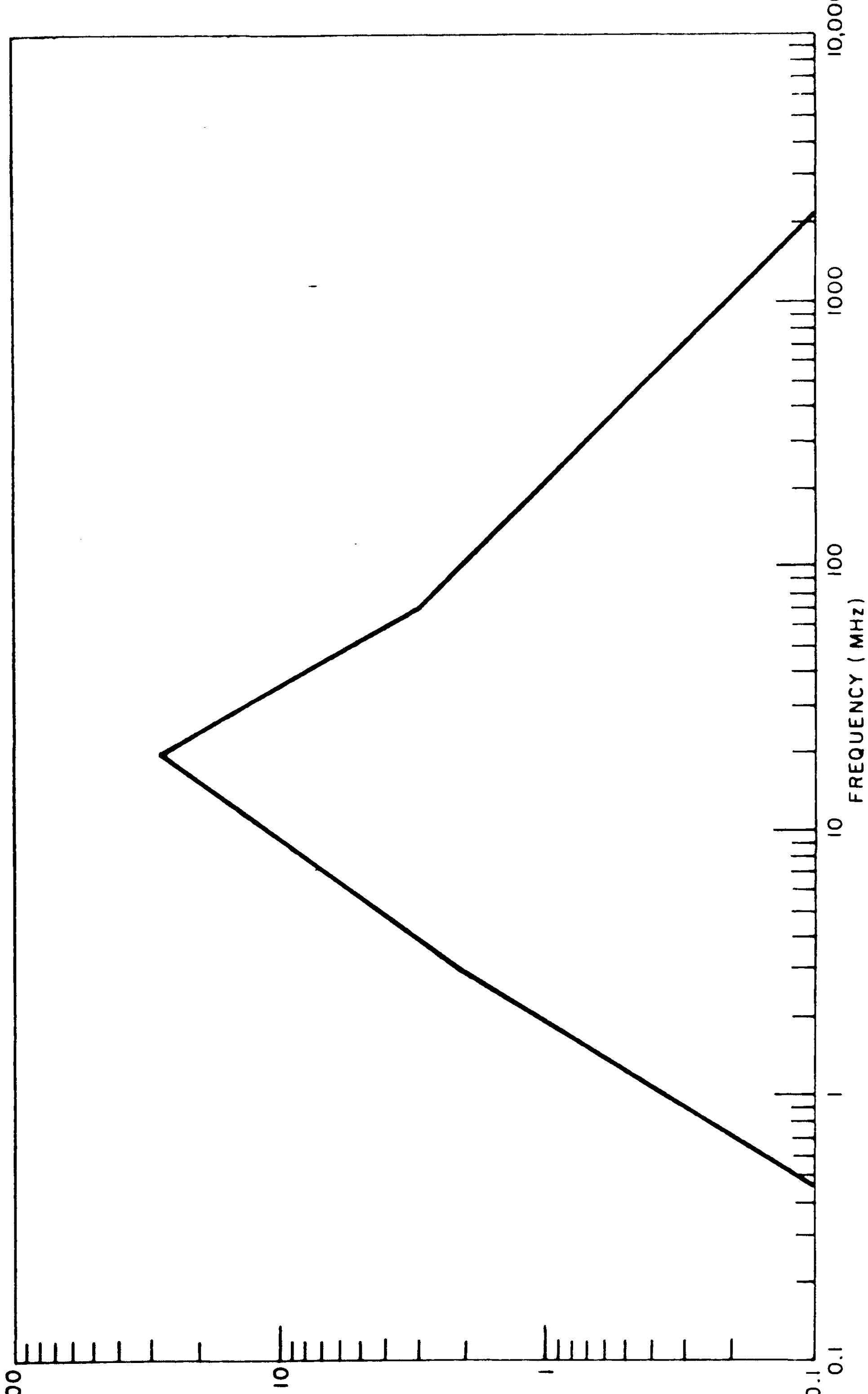


Figure 6-12. Vertical Loop Aperature.

6.4 THE FIELD IN THE VICINITY OF THE BLASTING CAP AND ITS ASSOCIATED WIRING

The fields in the vicinity of the blasting wiring are primarily dependent on the source characteristics (output power, antenna configuration, frequency and modulation type), the geometry of the mine tunnels, the locations of the source and the blasting wiring, and the electromagnetic charcteristics of the geological strata in which the mine is located.

Distances between possible sources and the blasting wiring can be controlled and source characteristics, at least those known, can also be controlled by limiting the types of equipment that can be used in underground mining. The parameters of interest are, therefore, the uncontrollable parameters: mine geometry and the electromagnetic parameters of the geological strata. Appendix E lists a number of papers and articles that deal with underground propagation of electromagnetic waves. Some of these, particularly those dealing with the electromagnetic properties of minerals, were quite useful and are referenced in the following discussion.

6.4.1 Electromagnetic Parameters

Many basic electromagnetic field texts[14, 15] point out that for media that are homogeneous, isotropic and linear the electromagnetic behavior of the medium is completely defined if the complex permittivity and complex permeability are known as functions of frequency. Although the minerals usually encountered in coal mining may be inhomogeneous, anisotropic and non-linear we expect these characteristics to be confined to localized small volumes so that the overall behavior of the mineral can be specified by some complex macroscopic permeability and permittivity. The real parts of these complex quantities are simply the familiar magnetic permeability and dielectric constant of the medium. The imaginary parts of the complex parameters determine the loss (power dissipating) characteristics of the medium. The losses associated with magnetic phenomena, and magnetic phenomena in general, are usually associated with relatively pure materials with magnetic permeability considerably greater than that of free space. In the geologic strata of coal mine workings such materials are not to be expected in large enough amounts to seriously change the results of an analysis based on a magnetically lossless media of the same magnetic permeability as that of free space.

The dielectric and conduction losses associated with the complex permittivity are another matter, however. We will assume, in this report, that all losses are associated with the resistivity of the media. Actually the division of the total loss between dielectric loss and conduction loss mechanisms depends on frequency but since the only data available on mineral electromagnetic parameters has been gathered in such a way as to lump all losses into resistivity losses, we have no other choice. This procedure does us no harm since we are only interested in macroscopic behavior of the media. With the above considerations we need only the dielectric constant and resistivity of a medium to completely characterize it electromagneticly.

Study of the papers and articles listed in Appendix E, plus searches of the open literature, indicate that good detailed data on the electromagnetic parameters of the minerals likely to be encountered in coal mining operations are not available. References 16, 17 and 18 indicate, however, that relative dielectric constant values varying between 2 and 10 seem to cover almost all coal mine encounterable minerals. This holds for all frequencies greater than 10 KHz. The resistivities of minerals vary rapidly with water content. The data of Reference 16 shows resistivities of about 180 ohm meters for the wet rocks investigated. Study of the Reference 17 data indicates that resistivities of 10 to 1000 ohm meters might to expected as normal for wet rock. In any event the bibliographic entries and the pertinent references above agree that the resistivity of the rocks likely to be encountered in coal mining operations will vary widely depending on the water content. The water content in turn varies with the rock porosity and local geographical features. About the only reasonably reliable deduction we can make for purposes of our analysis is that the resistivity of the wet rocks likely to be encountered in mining operations should be somewhere between 100 and 1000 ohm meters.

In sum, the result of our reference search is that the relative dielectric constant of the minerals likely to be encountered will be between 2 and 10 and the resistivity between 100 and 1000 ohm meters. The relative permeability of the minerals can be assumed to be that of free space. The above conclusions hold for wet rock. The resistivity of dry rock should be considerably greater than 1000 ohm meters ranging to 10^{10} ohm meters under ideal conditions.

6.4.2 TEM Propagation

With the electromagnetic parameters of the minerals known, the propagation constant for transverse electromagnetic (TEM) waves may be calculated for the minerals. In truth, such waves can never exist exactly and probably the fields propagating along a mine drift will not be even approximately TEM; nevertheless, the TEM propagation constant will provide a useful reference point for the rest of our calculations.

Reference 14 derives expressions for the TEM propagation constant. We will, by the way, adhere strictly to the notation of Reference 14 in all of our electromagnetic calculations unless otherwise noted. The reader who is unfamiliar with electromagnetic propagation problems and wishes to follow our reasoning in detail should consult References 14 and 15 or other similar texts. In general the propagation constant

$$\gamma = \alpha + j\beta \tag{6-1}$$

defines the variation of the total electromagnetic field solution with distance. Thus, for propagation in the z direction,

$$\varphi = \text{Re}\left\{A_o\, e^{-\gamma z}\right\} = \text{Re}\left\{A_o e^{-\alpha z} \cdot e^{-j\beta z}\right\} \tag{6-2}$$

where $A_o = A\, e^{j\omega t}$; A is a complex constant,

$j=\sqrt{-1}$, ω is the angular frequency, φ is the real instantaneous value of one of the electric or magnetic field components and the Re operation extracts the real part of the complex quanity to which it is applied. The significance of α, the attenuation constant, is easily seen if we rewrite (6-2) as

$$\wp = e^{-\alpha z} \left\{ Re \left\{ A_o \; e^{-j\beta z} \right\}\right\} \qquad (6\text{-}3)$$

Since $\wp$ of (6-3) represents all or any of the solutions field components, the power density of the solution varies as the square of the magnitude of $\wp$. Thus the power density of the solution P_d varies as

$$P_d = c \; e^{-2\alpha z} \qquad (6\text{-}4)$$

where

P_d is the power density in convenient units,

C is a constant,

α is the attenuation constant (nepers/meter), and

z is the distance parameter in the direction of propagation (meters).

Since the power density is the parameter of major concern in the calculation of pickup by the blasting wiring our interest in a parameter of the type of the attenuation constant is obvious. Reference 14 gives, after simple manipulation of some of the units,

$$\alpha = 1.4809 \times 10^{-2} \times f_{MHz} \times \sqrt{\varepsilon_R} \sqrt{\sqrt{1 + \left(\frac{18 \times 10^3}{\rho \; \varepsilon_R \; f_{MHz}}\right)^2} - 1}, \text{ nepers/meter} \qquad (6\text{-}5)$$

β, the phase constant is given by the same expression as (6-5) but the minus sign under the radical must be charged to plus. In (6-5),

f_{MHz} is frequency in megahertz,

ε_R is the relative dielectric constant (unitless) and

ρ is the resistivity in ohm-meters.

Figure 6-13 plots α for various values of ρ and ε_R and Figure 6-14 plots β for the same values.

Study of Figure 6-13 shows that the very low frequency TEM attenuation is dependent primarily on resistivity whereas the high frequency attenuation depends on both the dielectric constant and the resistivity. The high frequency asympotic values for TEM α are

$$\alpha \xrightarrow[f_{MHz} \to \infty]{} \frac{188.5}{\rho\sqrt{\varepsilon_R}} \quad \text{nepers/meter}$$

Figure 6-14 shows that while the low frequency phase constant behavior is primarily dependent on resistivity, the high frequency behavior is wholly determined by the dielectric constant (for the resistivity range of 1 to 1000). Thus at high frequencies

$$\beta \xrightarrow[f_{MHz} \to \infty]{} \sqrt{\varepsilon_R} \cdot \frac{2\pi}{300} \cdot f_{MHz}, \text{ radians}$$

We are interested, however, not only in the high and low frequency limits. Our concern is also directed to the middle frequencies where, we have seen, the aperture of the blasting wiring can have a maximum.

6.4.3 A General Approach to the Propagation Problem

Our objective in the study of the possible propagation in coal mines is to determine a reasonably good estimate of the minimum attenuation that will occur between two points in the mine. Now even if the mine drift were a perfectly regular rectangular or cylindrical hole in an almost perfect conductor we would have great difficulty in determining the actual propagation exactly. The main problems in this case would be determining how much of the transmitted energy was in each of an infinite number of "modes" permitted by the geometry. We could calculate the attenuation for each mode to a very good approximation since this problem has been completely solved for certain regular geometries. If we desired a worst case

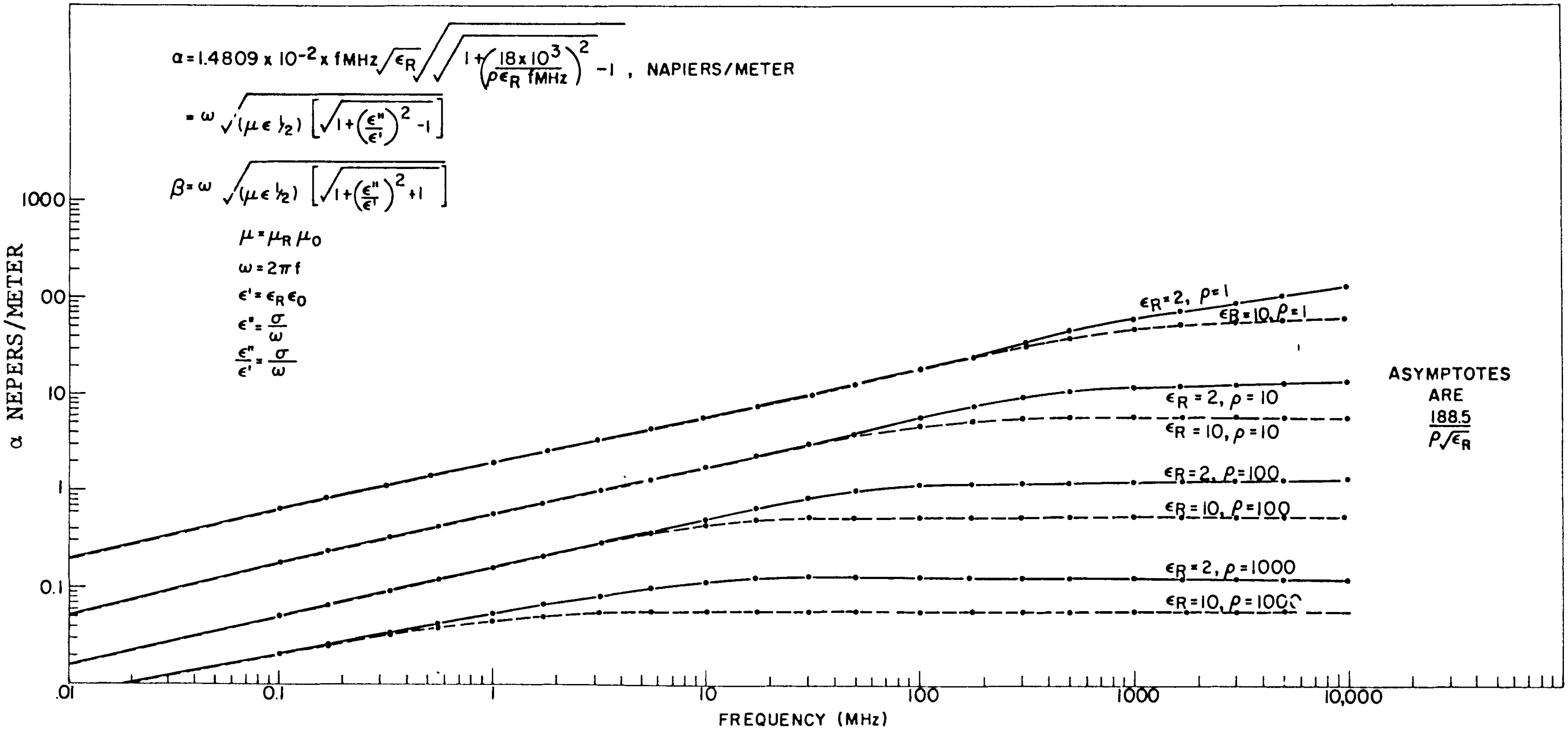


Figure 6-13. TEM Attenuation Constant versus Frequency

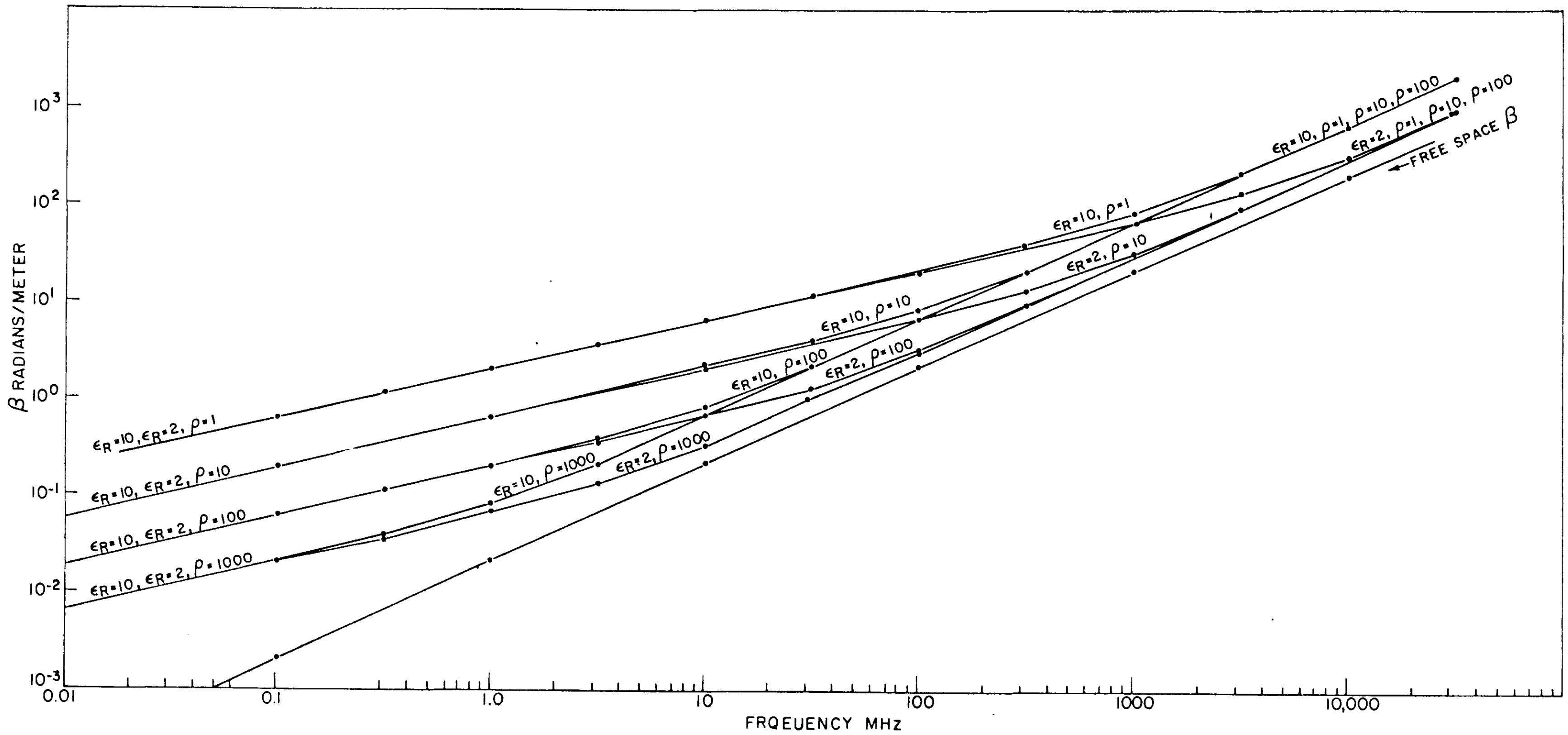


Figure 6-14. TEM Phase Constant versus Frequency

estimate of propagation in this case we could use the value of the smallest attenuation constant for any of the modes and be sure that our estimate was good.

One of our first approaches to the overall problem was to try to determine the equations that define the propagation constants for a smooth walled rectangular hole in the medium described by the electromagnetic parameters (i.e. $2 \leq \varepsilon_R \leq 10$, $10 \leq \rho \leq 1000$) that describe the minerals in which the drift is located. Figure 6-15 is a sketch of the geometry for this case. The classical approach to the solution of a problem of this type is to assume a separable solution for the fields such that all the boundry conditions are satisfied. If this assumed solution satisfies Maxwell's equations then it is "the" solution since a general theoreom of "uniqueness of solution" applies. What it amounts to is "cut and try" but the "cut" can, for simple problems, be a well-guided guess; not some random choice. The successful result of such a procedure in a complicated problem such as we face is not the final answer, however. What is usually obtained is a set of complex transcendental equations involving the propagation constant, γ, the dimensions related to the geometry and the electromagnetic parameters of the media. If all the values of γ that simultaneously satisfy the equations can be found, then the overall propagation problem would be solved and we would be in the same position for our problem of very lossy material as we are for the slightly lossy conductor problem of normal waveguide theory.

We realized early in our attempt to obtain the α defining equation for the very lossy material that the equations would be extremely difficult to solve for the αs, but we hoped to be able to take limits for resistivity and demonstrate that the equations were indeed compatible with the slightly lossy waveguide solutions which are well known. There was also the hope that perhaps the equations would not be "all that" difficult to solve. In any event we couldn't even determine the defining equations. The classical approach of assuring a separable solution of exponential functions leads to overspecification of the propagation

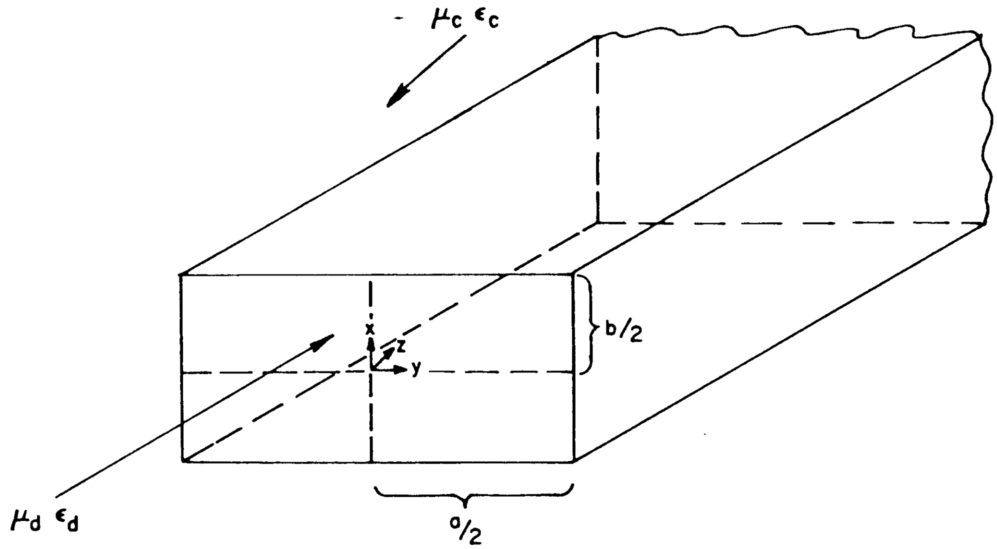


Figure 6-15. Geometry for the General Rectangular Waveguide Problem

constants and so we conclude that no simple separable solution exists. This is good reason to suspect that no separable solution exists in rectangular coordinates. The problem in cylindrical coordinates for a round mine tunnel does appear to be simpler but it was not investigated.

While considering our next step we observed that even a complete solution for a rectangular drift in the minerals would not provide us with the sort of worst case information we desired. Many, if not most, mines have metal pipes, metal rails, electrical power cables or telephone wires that run along the drifts. Certainly the presence of the conductor in the drift would be expected to provide a "guiding" aspect to any electromagnetic propagation along the drift and thus allow propagation with a considerably lower attenuation than would be expected (or calculated) for the drift alone.

We can thus see that a general solution that does not include the possible presence of conductors along the drift will not give a worst case estimate.

6.4.4 Propagation With a Conductor in the Drift

We would expect that, for a single conductor in the drift, the larger the surface area of the conductor the lower the attenuation. Thus a mine drift having rails for ore cars would provide lower attenuation than the same drift with only a telephone line present. We also speculate that a drift with a layer of highly conducting water on the floor would represent a practical limit in this respect. A possible geometry for this case is shown in Figure 6-16. We estimate that the solution for the propagation constants for the geometry of Figure 6-16 would be considerably more difficult to determine than the general solution for a smooth rectangular hole.

A simplification of the estimation problem can be expected, however, if the drift is very wide in relation to its height. Figure 6-17 suggests this condition. For this geometry the electromagnetic field configuration in the portion of the drift between the dotted lines AA' and BB' of

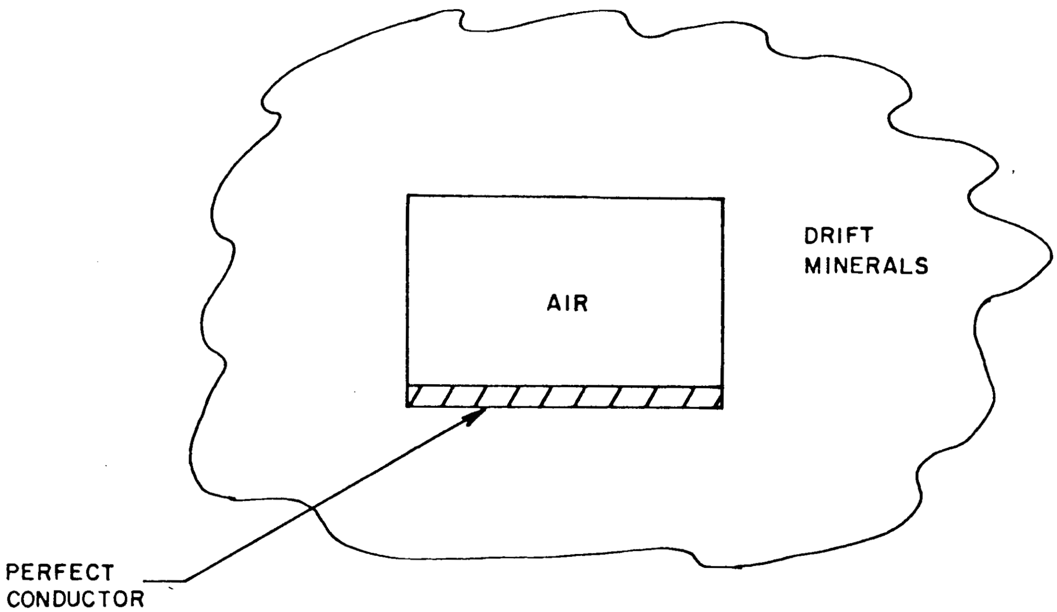


Figure 6-16. Section of a Drift with a Good Conductor on the Floor

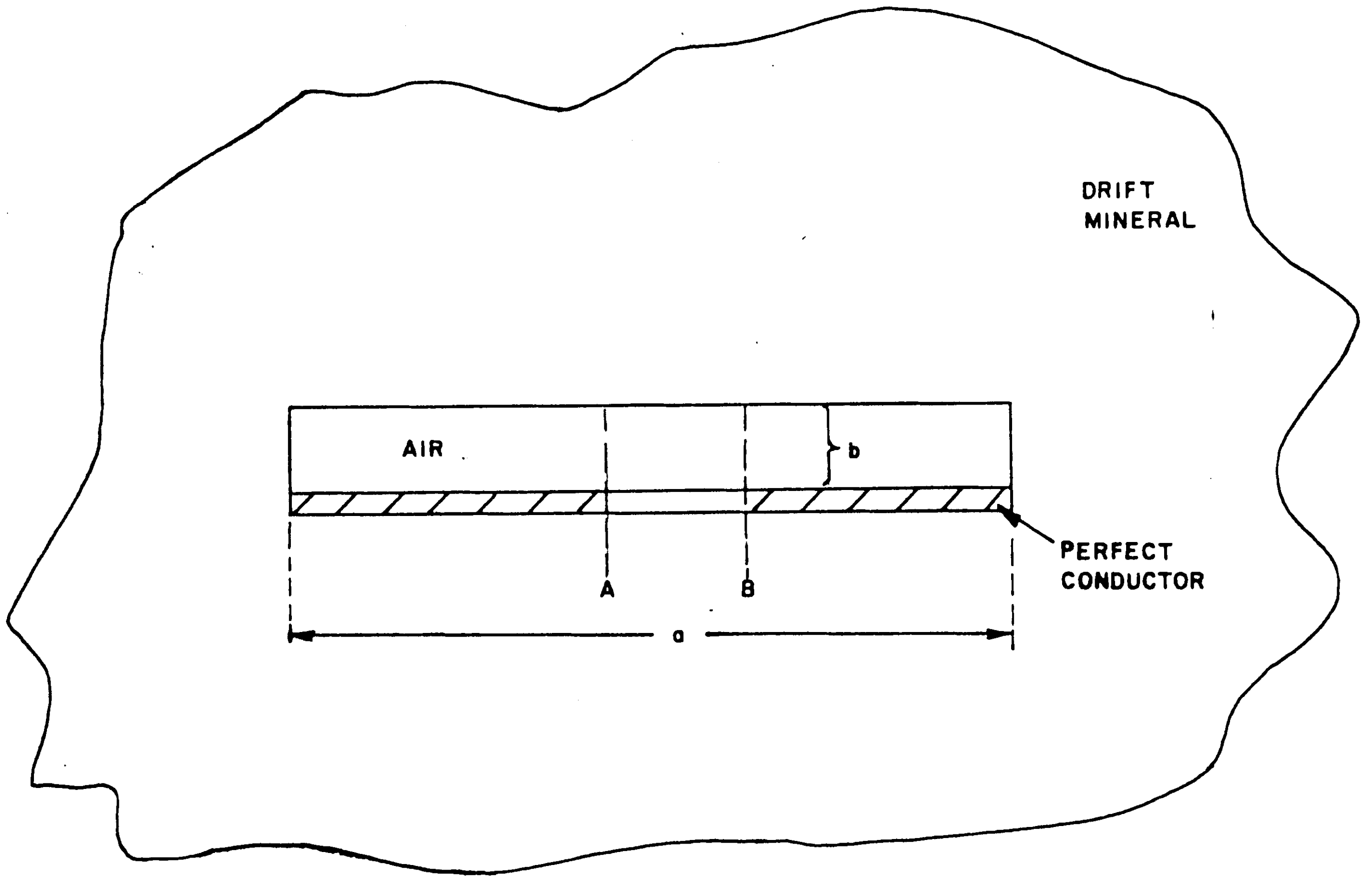


Figure 6-17. Section of A Wide Drift with a Conducting Floor.

Figure 6-17 could be calculated, at least for a portion of the frequency bands of interest, as if the dimension "a" of Figure 6-17 were infinite. Further, we would expect such a determination to give attenuation values lower than those determined by a procedure that considers "a" as finite. This is due, in the main, to the fact that less of the field will be required to be in the lossy material and hence we will have lower attenuation. We thus reason that the attenuation constants for a infinitely wide drift with a perfectly conducting floor will provide us with a worst case estimate of propagation in coal mines. This geometry is shown in Figure 6-18.

6.4.5 The Worst Case Propagation Constants

The propagation constants for the geometry of Figure 6-18 are the same as those for the geometry of Figure 6-19. Figure 6-19 illustrates that our geometry of Figure 6-18 can be imaged in the perfect conductor to obtain a new geometry. The constraint imposed for solutions in Figure 6-19 is that all electric fields are zero half way between the planes. This problem, with this odd symmetry constraint, is addressed by Reference 14. The problem yields to the classical approach and since there is only one dimension of variation, other than the direction of propagation, we obtain only one complex transcendental equation. The equation is

$$\tan (K_d b) = j \frac{K_c}{K_d \, \varepsilon^*_{RC}} \qquad (6\text{-}6)$$

where

b is the dimension shown in Figure 6-18, meters

$K_d = \sqrt{\gamma^2 + \omega^2 \mu_o \varepsilon_o}$, meters^{-1}

$K_c = \sqrt{\gamma^2 + \omega^2 \mu_o \varepsilon_o \, \varepsilon_{RC}^*}$, meters^{-1}

$j = \sqrt{-1}$

$\omega = 2\pi f$, Hertz

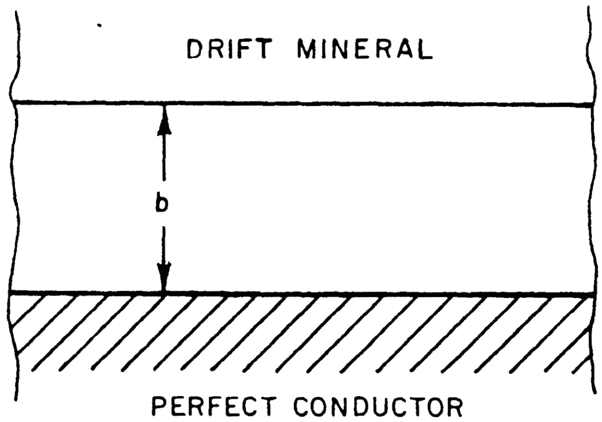


Figure 6-18. Section of the Infinitely Wide Drift with a Conducting Flow

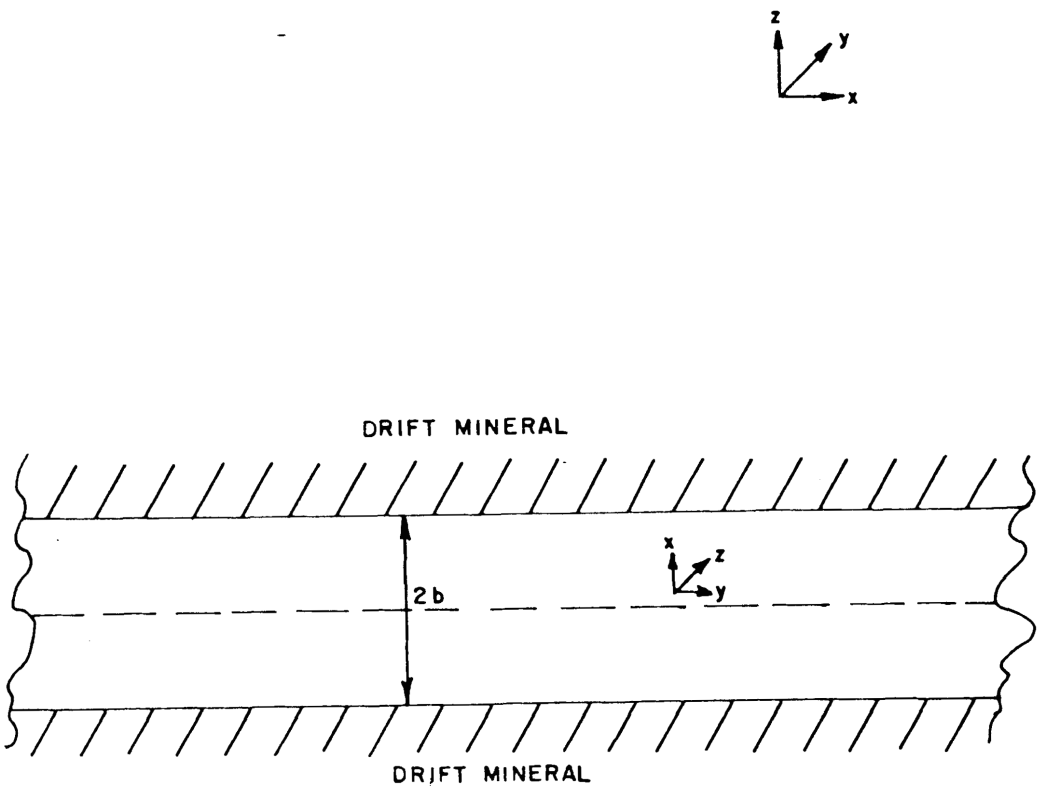


Figure 6-19. Image Geometry

f = frequency, Hertz

μ_o = permeability of air, henries/meter

ε_o = permittivity of air, farads/meter

$\varepsilon^*_{RC} = \varepsilon_{RC} + \frac{1}{j\omega\rho\varepsilon_o}$, unitless, the relative complex dielectric constant of the drift mineral

ε_{RC} = the relative real dielectric constant of the drift mineral

ρ = resistivity of the drift mineral, ohm meters

$\gamma = \alpha + j\beta$, the propagation constant, meters^{-1}

α = the attenuation constant, nepers/meter

β = the phase constant, radians/meter

Note that if we assume that we know ρ, ε_{RC}, b and frequency the only unknowns in equation 6-6 are α and β. Thus values of $\gamma = \alpha + j\beta$ that satisfy equation 6-6 are the propagation constants we desire to find. For our worst case estimate we further require, for each set of values of ρ, ε_{RC}, b and frequency assumed, the γ that has the smallest real part, α.

Analytical solution of 606 for general values of the parameters is impossible; however, if ρ is very small, the equation approximates a non-transcendental equation that can be solved. This aspect is the one that promoted the derivation of this equation in Reference 14. We will use this limiting case later as a check for our general non-analytic solution.

In order to formulate a non-analytic solution we can define a new real quantity q such that

$$q \equiv \left| j \frac{K_c}{K_d \varepsilon^*_{RC}} - \tan (K_d b) \right| \qquad (6\text{-}7)$$

where the vertical bands denote magnitude. Now, values of γ that satisfy equation 6-6 force q of equation 6-7 to be zero; thus our desired γs are the roots of equation 6-7. The overall situation can be visualized as a three dimensional function. For a certain set of frequency, ρ, ε_{RC} and b values, α, β and q can be related by equation 6-7 and plotted in the coordinates of Figure 6-20. For every set of parameter (ρ, f, ε_{RC} and b) values, q will be a surface over the α, β plane. The roots of the function will be those values of α and β for which $q = 0$. Equation 6-7 shows that q is non-negative so we can imagine each q surface as a surface over the α, β plane.

The roots of equation 6-7 can be determined in various ways. Our first approach was to obtain a set of tabular values of q versus a region in the α, β plane for a given ε_{RC}, ρ, f and b. The tabular data were studied and locations of roots could be found for some cases. In general, however, the effects of the roots were relatively local and they were hard to find. Figure 6-21 is a photograph of a "q" surface plotted for a discrete set of α, β values. The surface is that for a frequency of 150 MHz, a mineral relative dielectric constant (ε_{RC}) of 2, a resistivity (ρ) of 1000 ohm meters and a spacing (b) of 2 meters. The pencil locations in the photograph are close to the locations of two roots. These roots were not found by observation of the data that made up the three dimensional plot. Indeed, Figure 6-21 shows that the surface is quite irregular and that plotting is not, in general, an effective method of root location.

The tabular data used for the plotting approach were, of course, computer generated. It required about fifty minutes of hand calculation with an HP-35 calculator to evaluate one value of equation 6-7. This hand calculated value was used to check the computer program that was written to calculate q.

Since plotting was not effective in finding the roots we decided to use a "hill climbing", or in our case "hill descending", computer approach. In this scheme a value of q is calculated by equation 6-7 for the parameter set of interest. The values of α and β used for this first computation are specified, call them α_o and β_o. Next a set of values of q for several points in the neighborhood of (α_o, β_o) are calculated and examined. The α and β values associated with the lowest value of q of this set of qs is then used as a new (α_o, β_o) point and the iteration is repeated.

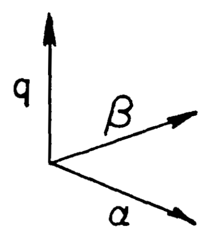


Figure 6-20. Three Dimentional Rectangular Coordinates

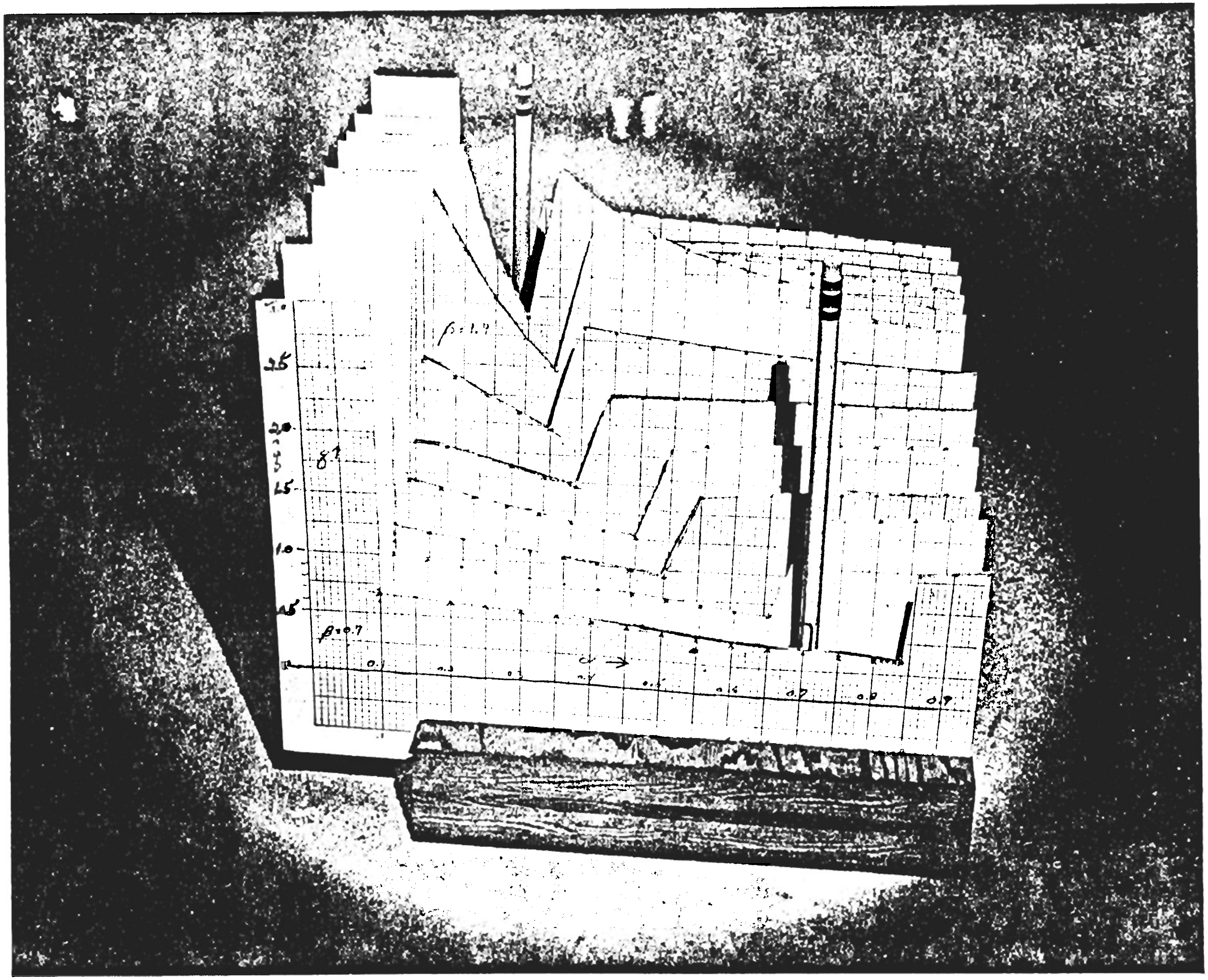


Figure 6-21. "q" Surface (150 MHz, $\varepsilon_R=2$, $\rho=1000$ and b=2 meters)

Thus the computer program will always be dealing with a point that is "downhill" of the previous point. If this continues long enough the program will always arrive at a zero of the q function or a local minimum. A more exact approach can be taken in this scheme by evaluating the gradient of the q function in terms of α and β at (α_o, β_o) and stepping in the direction of the gradient. This method theoretically converges faster since the direction of the gradient is the direction of steepest descent. Actual convergence time depends however on the scheme used to choose the size of the step. We used only the first described scheme that evaluates points close to (α_o, β_o).

6.4.6 Determination of the Propagation Constants

A computer program using the hill descending technique and the previously checked out q calculation program was written in FORTRAN V.

Appendix E shows the program and some sample output. The program evaluated the q function at 8 points evenly spaced about (α_o, β_o), the program starting point. One thousand iterations are performed. The first set of sample output is for the parameter set of a frequency of 150 MHz, a dielectric constant of 2, a resistivity of 1000 and a spacing of 2. The (α_o, β_o) point chosen to start the program was (0.01, 14.627). After 1000 iterations the value of q was found to be about 7.9×10^{-6} at a (α, β) location of (0.0265, 14.47). The sample output also shows the intermediate values of q, α and β for each iteration evenly divisable by 10. The overall running time on a UNIVAC 1108 is about 10 seconds for the 1000 iterations.

The second set of sample output is a check of the entire computation scheme. It shows a value of q of 2.32×10^{-5} for an α of 6.693×10^{-6} and a β of 3.1415996. The parameters are a frequency of 150 MHz, a dielectric constant of 2, a resistivity of 1.73×10^{-7} ohm meters and a spacing of 2 meters. We mentioned earlier that Reference 14 derived equation 6-6 and then took limits to use the resulting equation for a slab waveguide loss evaluation. The parameter set above agrees with the limiting operations performed in Reference 14. Using their results, p.382 of Reference 14, and our parameter set we obtain an α of 6.6925 x 10^{-6} and a β of 3.1415994. The close agreement between the results of our program and those of Reference 14 shows that our root evaluation program gives correct answers.

Appendix G gives all the roots found by the computer program. Figures 6-22 and 6-23 plot roots for three different parameter sets. Note that the legends on the figures give values for ϵ_R. ϵ_R is exactly equivalent to ϵ_{RC} used previously. These symbols are used interchangeably from here on in the test and on the figure leg ends. Figure 6-22 is concerned only with sets containing ϵ_R = 2. Roots associated with ϵ_R = 2, ρ = 1000, and b = 2 meters are plotted as crosses (X), with ϵ_R = 2, ρ = 100 and b = 2 as circles with dots (⊙) and with ϵ_R = 2, ρ = 1000 and b = 1 as triangles with dots ▲. Figure 6-23 uses the same legend but is only concerned with ϵ_R = 10.

Study of Figures 6-22 and 6-23 shows that at the low frequencies the infinitely wide drift is behaving as a waveguide and that its attenuation would be predictable from the slab line equations. At intermediate frequencies (∿ 50 MHz) the attenuation peaks and then the mineral behavior begins to be dominated by the dielectric properties and we obtain a sort of surface wave phenomena with more and more of the wave being bound tightly to the conductor and the lossless air space. Note the numerous higher order α values shown on Figures 6-22 and 6-23. Each of these corresponds to a higher order mode. It is of considerable interest to observe that some of these modes show very high attenuations at only moderate frequencies so that any energy in these modes is likely to be quickly dissipated.

Figures 6-22 and 6-23 also plot the TEM α values for reference. Figure 6-24 plots some values of the phase constant (β) for ϵ_R = 10. At the higher frequencies [f_{MHz} > 50] the lowest α values were associated with β values very close to the free space propagation constant for the same frequency.

Figure 6-25 shows an approximation of the α curves of Figures 6-22 and 6-23 that is no larger than any of the determined attenutation

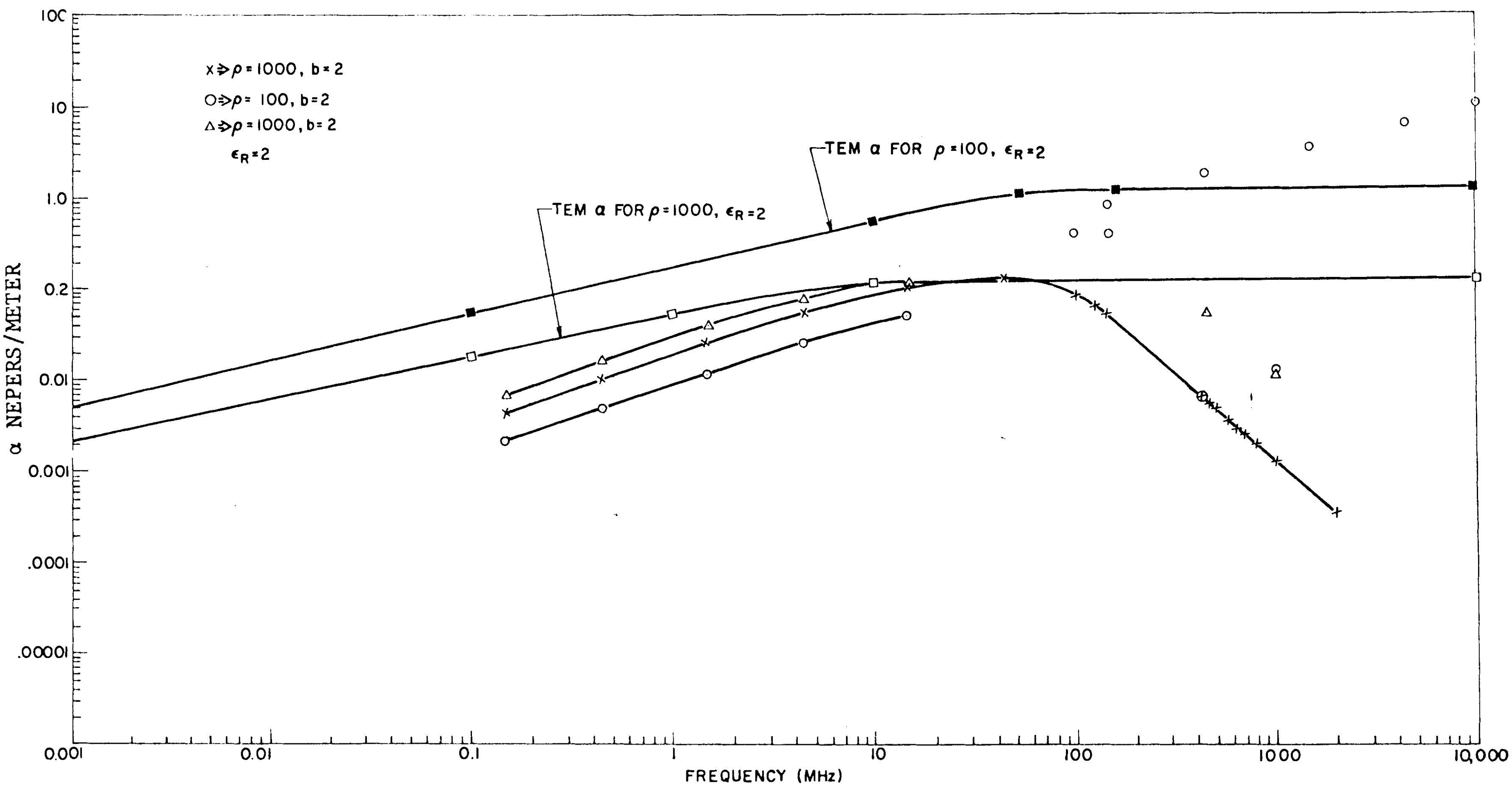


Figure 6-22. Attenuation Constant for $\epsilon_R = 2$

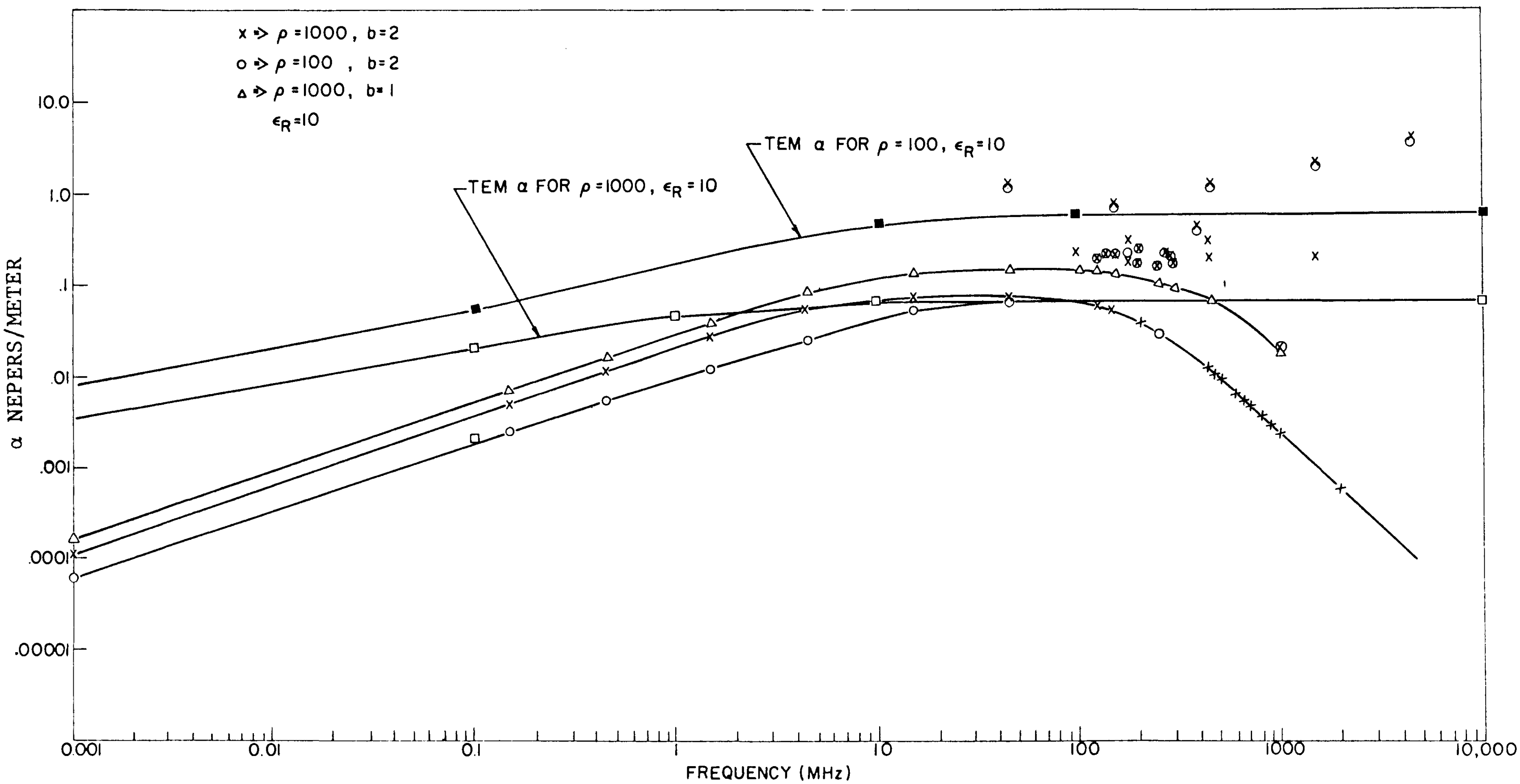


Figure 6-23. Attenuation Constant for $\varepsilon_R = 10$

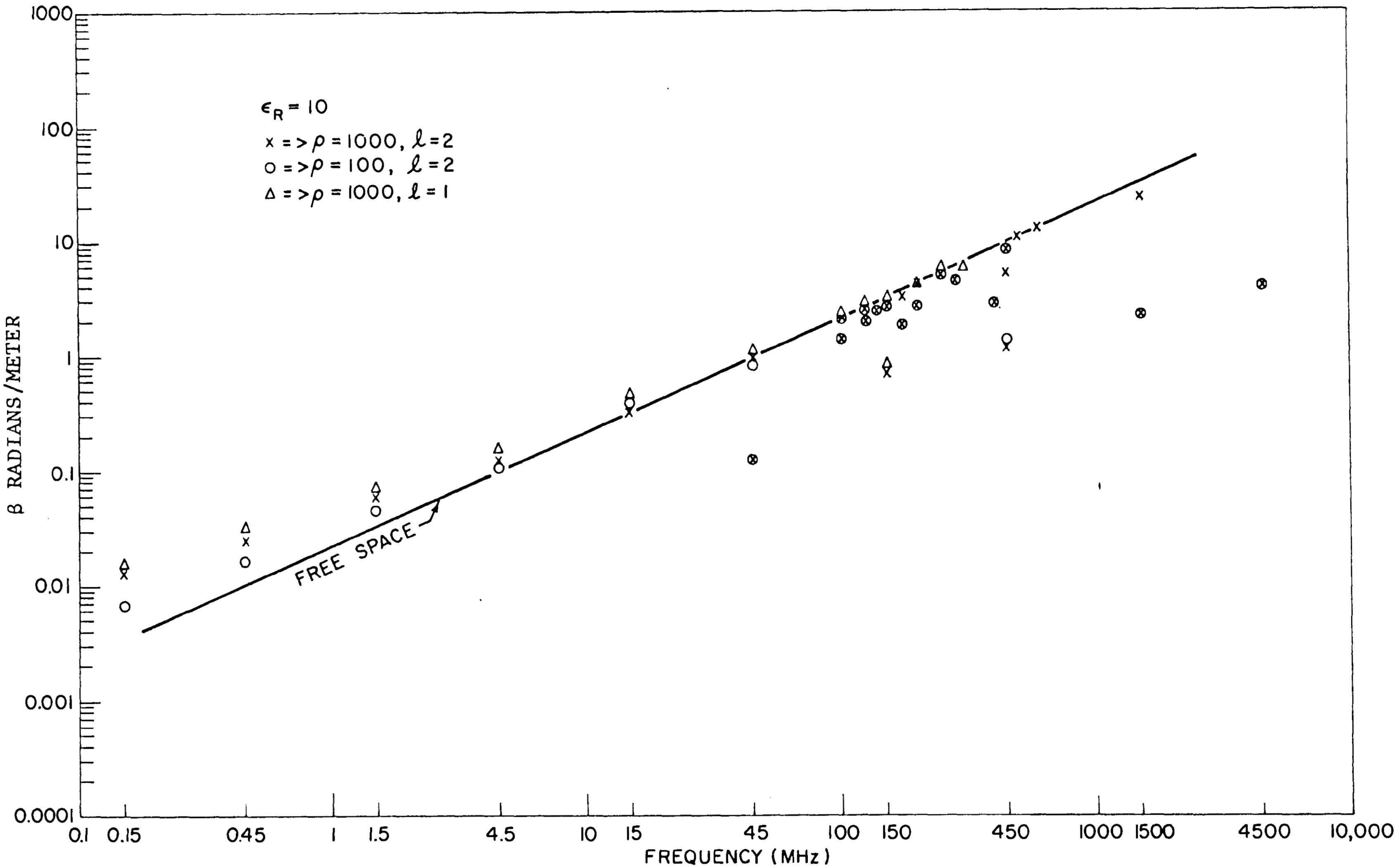


Figure 6-24. Phase Constant for ϵ_R = 10

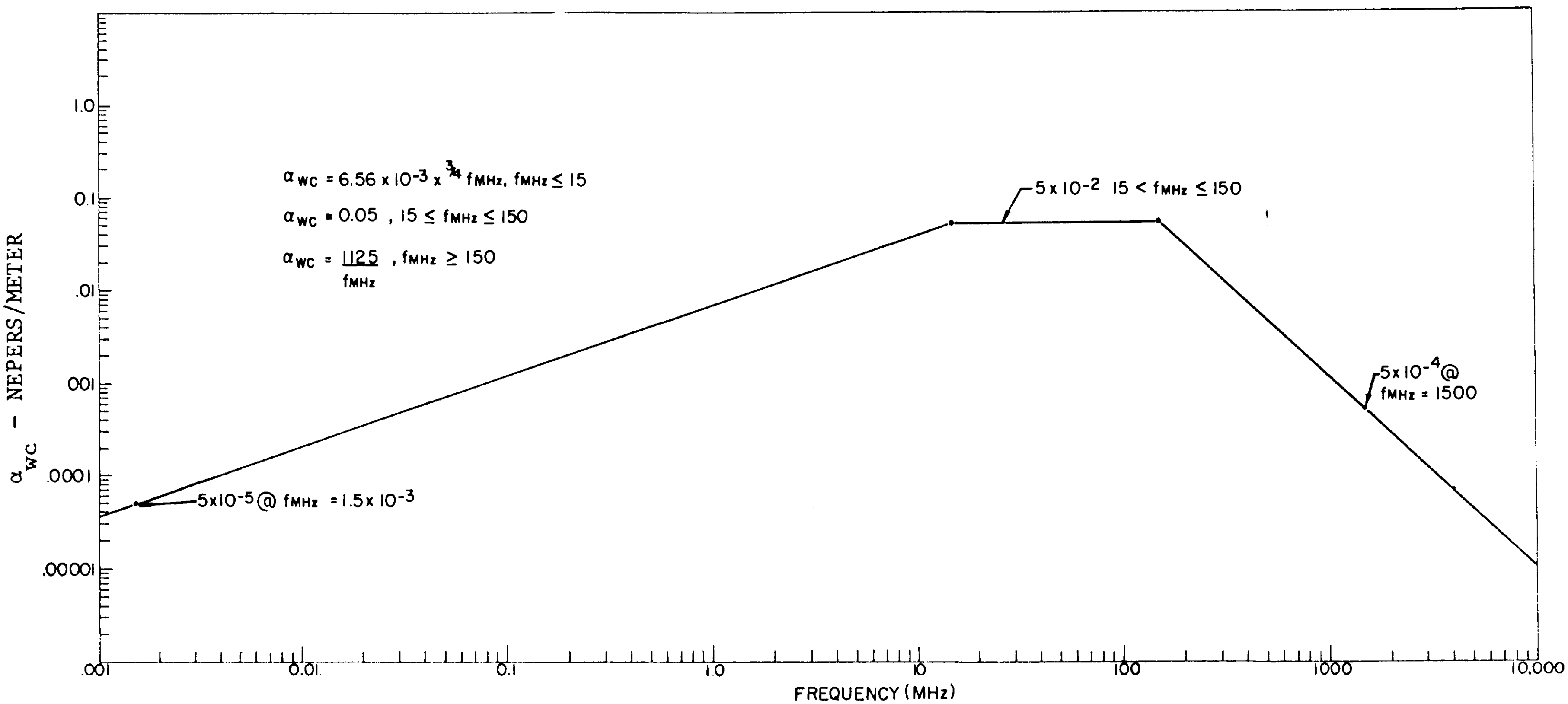


Figure 6-25. Worst Case Attenuation Constant

constants. We will use this approximation as the worst case attenuation constant (α_{WC}) for coal mines. The approximation was chosen so we could easily obtain an analytic expression for α_{WC}. We obtain

$$\left.\begin{aligned} \alpha_{WC} &= 6.56 \times 10^{-3}\ f_{MHz}^{3/4}, \quad f_{MHz} < 15 \\ \alpha_{WC} &= 0.05, \quad 15 \le f_{MHz} \le 150 \\ \alpha_{WC} &= \frac{1125}{f_{MHz}{}^2}, \quad f_{MHz} > 150 \end{aligned}\right\} \qquad (6-8)$$

where α_{WC} is given in nepers per meter and f_{MHz} is frequency in megahertz. In dB we obtain

$$\left.\begin{aligned} dB_{WC} &= 0.057 \times f_{MHz}^{3/4}, \quad f_{MHz} \le 15 \\ dB_{WC} &= 0.434, \quad 15 \le f_{MHz} \le 150 \\ dB_{WC} &= \frac{9770}{f^2_{MHz}}, \quad f_{MHz} \ge 150 \end{aligned}\right\} \qquad (6-9)$$

where dB_{WC} is the minimum number of dB per meter of attenuation.

In making the approximation of Figure 6-25 we note that the actual data of Figure 6-22 and 6-23 are extremely close to a $1/f_{MHz}{}^2$ variation at high frequency but that the low frequency data are really a bit slower varying than the $f_{MHz}^{3/4}$ variation we have assumed.

6.5 AN OVERALL COUPLING EXPRESSION

An overall coupling expression can now be written for the worst case coupling of a transmitter in a drift to a blasting cap wiring set-up some x meters away. Thus

$$W_R = W_T \cdot A_e \cdot T_T \cdot e^{-2\alpha_{WC}} \qquad (6-10)$$

where

W_R is the power delivered to the blasting cap, watts,

T_T is a transforming parameter of the transmitting antenna, meters^{-2}.

α_{WC} is the worst case propagation constant determined in the last section (eq. 6-8), meters^{-1}.

x is the separation between the transmitter and the blasting cap wiring, meters, and

A_e is the worst case aperture of the blasting cap wiring as given in Section 6-3, meters squared.

If we are to relate safe distances to transmitted power we must still provide a worst case estimate of the transmitting antenna T_T parameter. All other parameters of equation 6-10 have been treated.

The power gain of a transmitting antenna is essentially a measure of the efficiency of the antenna in converting input power to power density at the point at which the gain is to be measured. In our application where the antenna is to be used underground and we are interested primarily in the power density in the lowest order, minimum attenuation propagation mode, some analogous parameter can be considered a measure of the efficiency of conversion of input power to power density in the lowest order propagation mode. We call this parameter T_T. At the lower frequencies we estimate that no more than one-quarter of the power input to the antenna could be converted to lowest order propagation mode power density. For a drift of minimum dimensions of 1.5 x 3 meters this would give a T_T value of 0.056 meters^{-2}. At higher frequencies where highly directional antennas could be used we estimate that 1/2 of the transmitted power could be converted so that above 1000 MHz we will assume T_T to be 0.11 meters^{-2}.

With all the factors of equation 6-10 accounted for we can rearrange 6-10 and solve for x, thus

$$\frac{1}{2\alpha_{WC}} \ln \left\{ \frac{A_e T_T}{W_R} \cdot W_T \right\} = x \qquad (6\text{-}11)$$

Equation 6-11 is the final coupling equation that we will use for the estimation of safe distances in coal mines. The worst case approximations to be used in its evaluation are, in review,

$$\left.\begin{array}{ll} T_T = \dfrac{0.056}{\text{meters}^2} , & f_{MHz} \leq 1000 \\[2ex] T_T = \dfrac{0.11}{\text{meters}^2} , & f_{MHz} \geq 1000 \end{array}\right\} \text{meters}^{-2} \qquad (6\text{-}12)$$

$$W_R = 0.040 \text{ watts}, \qquad (6\text{-}13)$$

$$\left.\begin{array}{ll} A_e = \dfrac{0.95\, f_{MHz}^{\,2}}{(1 + 0.616 \sqrt{f_{MHz}})^2} , & f_{MHz} \leq 20 \\[3ex] A_e = \dfrac{1.07 \times 10^{+4}}{f_{MHz}^{\,2}} + \dfrac{62}{f_{MHz}} , & 20 \leq f_{MHz} \leq 70 \\[3ex] A_e = \dfrac{219}{f_{MHz}} , & f_{MHz} > 70 \end{array}\right\} \text{meters}^2 \qquad (6\text{-}14)$$

and

$$\left.\begin{array}{ll} \alpha_{WC} = 6.56 \times 10^{-3}\, f_{MHz}^{\,3/4} , & f_{MHz} \leq 15 \\[2ex] \alpha_{WC} = 0.05 , & 15 \leq f_{MHz} \leq 150 \\[2ex] \alpha_{WC} = \dfrac{1125}{f_{MHz}^{\,2}} & f_{MHz} \geq 150 \end{array}\right\} \text{meters}^{-1} \qquad (6\text{-}15)$$

6.6 SAFE DISTANCES

Equation (6-11), with the substitutions given in equations 6-12 through 6-15, defines the safe distances for coal mine blasting cap/transmitter separations. Figure 6-26 plots 6-11 for several values of transmitted power (W_T). The use of the curves in Figure 6-26 is straightforward.

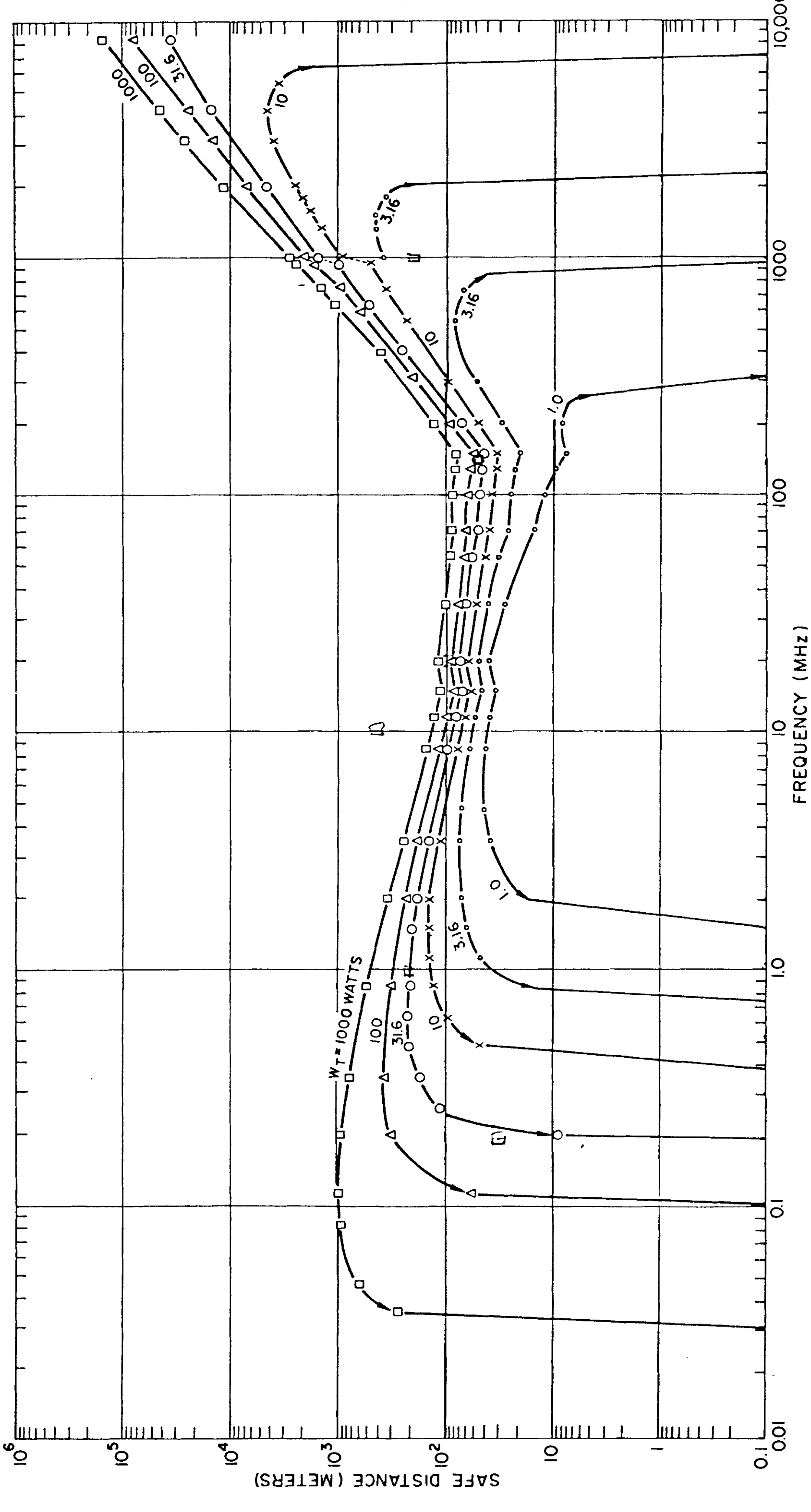


Figure 6-26. Safe Distances

Suppose we have a transmitter with an output of 100 watts of average power at 160 MHz driving a transmission line in a coal mine drift. Figure 6-26 indicates that if blasting wiring is kept 60 meters from any portion of the transmission line and transmitter we have no interaction problem even in the event the transmission line is attached to an antenna. The reader, having come this far and noted all our worst case approximations, will realize that we will probably have no problem if the wiring is much closer than the safe distance recommended by Figure 6-26. The important word in the last sentence is probably. The safe distances predicted by Figure 6-26 are the only reliable distances we can use without more information about a particular interaction and its environment.

Figure 6-26 may seem odd in the fact that the curves predict safe distances of essentially zero for certain transmitted power/frequency combinations. This behavior is due to the way we have formulated the general coupling equation, (6-11). We repeat it here:

$$\frac{1}{2\alpha_{WC}} \ln \left\{ \frac{A_e T_T \quad W_T}{W_R} \right\} \tag{6-11}$$

As long as the expression in brackets is greater than one, x is greater than zero. At the point where the bracketed expression equals 1, x goes to zero. Remember that we assumed the parameter T_T to convert (or spread out) the transmitted power to a power density in the lowest order propagating mode. In essence we allowed T_T to perform this function in no distance at all, so that the transmitters location is really a location of some "equivalent" power density. In the bracketed term of equation 6-11, the $T_T W_T$ product produced is power density, if this density is multiplied by the aperture we obtain the amount of power extracted from the field at the transmitter location by the blasting wiring. This term is in the numerator of equation (6-11). If it is less than the 0.04 watts assumed to be W_R then the bracket is less than one and a separation distance is trivial. We can't extract enough power to equal 0.04 watts even at the transmitter location. The overall problem arises because we allow

T_T to its work in essentially no distance at all. This points out that the curves should not be applied for any distances of, say 5 meters or less. The sharp drop-off of the safe distances for the various transmitting powers shows that the bracketed term varies quickly with frequency about the drop-off point. We have calculated the frequencies at which the brackets equal one and plotted there points as if the safe distance equalled 0.1 meters instead of zero meters at these frequencies. The zero would be difficult to locate on the log-log plot.

6.7 ON USE OF THE SAFE DISTANCE CURVES

The safe distance curves of Figure 6-26 have been derived as worst case safe distances and, as such, they provide positive limits outside of which we can assume that no significant transmitter/blasting cap interactions occur. By their worst case nature they are conservative and hence operation inside the safe distances will probably not result in premature cap initiations; HOWEVER, there is no way we can evaluate the possibility so such operation must be considered unsafe unless a more detailed analysis can be made of the actual operation site or measurements can be performed using the equipment of concern.

7. CONCLUSIONS

Section 5 gives the detailed conclusions for the blasting cap tests and Section 6.2 comments in detail about a general sensitvity level useful for hazard evaluation. In sum the blasting cap tests performed indicated that the use of a 0.040 watt level as a "no-fire" level for American made blasting caps for coal mine use is reasonable. It is applicable for both pin-to-pin and pin-to-case excitation of the caps for all the frequencies tested.

The safe distance curves of Figure 6-26 have been derived as worst case safe distances and, as such, they provide positive limits outside of which we can assume that no significant transmitter/blasting cap interactions occur. By their worst case nature they are conservative and hence operation inside the safe distances will probably not result in premature cap initiations; HOWEVER, there is no way we can evaluate the possibility so such operation must be considered unsafe unless a more detailed analysis can be made of the actual operation site or measurements can be performed using the equipment of concern.

8. REFERENCES

1. Monograph on *Computation of RF Hazards* - M-C2210 P. F. Mohrbach, R. H. Thompson, et al - prepared for NASA, Goddard Space Flight Center, Greenbelt, Maryland, 1968.

2. *Investigations of the RF Hazards to Electric Blasting Caps* - F-B2256, R. H. Thompson, P. F. Mohrbach, et al - prepared for the Institute of Makers of Explosives, 1965.

3. *RF Pickup of Antennas Simulating Blasting Wiring Configurations, Measurement Results* - F-B2256-2, R. H. Thompson - prepared for the Institute of Makers of Explosives, 1966.

4. *Measurements of the RF Coupling Between an Antenna Simulating a Blasting Wiring Configuration and Nearly Mobile Transmitting Antenna*, E-C1951, R. H. Thompson, K. Fertner - prepared for the Institute of Makers of Explosives, 1967.

5. *The Possible RF Hazard to Blasting Caps Caused by a Lossy Communication System* - F-C2399, R. H. Thompson, P. F. Mohrbach - prepared for Motorola, Inc., 1969.

6. *RF Pickup of Blasting Face Wiring* - F-C2942, R. H. Thompson - prepared for Motorola Incorporated, 1970.

7. *Blasters Handbook*, 14th Ed., E. I. duPont, Wilmington, Delaware, p. 340.

8. Bruceton Report, *Statistical Analysis for a New Procedure in Sensitivity Experiments*, National Defense Research Committee Report No. 101.1R, July 1944.

9. *Operation and Maintenance Manual for the FIRL Universal Pulser* - FILUP 3, C. T. Davey, prepared by FIRL for NASA, Langely Research Center, 1965.

10. *Instruction Manual for Initiator Static Tester Model III* - FM-C1981, C. T. Davey, prepared by FIRL for NASA, Marshall Space Flight Center, 1967.

11. *Systems and Technicians Employed at The Franklin Institute to Determine Responses of EEDs to R. F. Power*, APL-69-1, P. F. Mohrbach, R. F. Wood, prepared by FIRL, revised 1970.

12. *RF Susceptibility Evaluation of Minuteman Ordnance Systems*, The Franklin Institute, Report No. P-B2198-6, August 1964.

13. *Electrostatic Hazard to Electroexplosive Devices From Personnel-Borne Charges*, APL 65-1, R. Amicone, C. T. Davey and J. B. Campbell, prepared by FIRL, February 1965.

14. *Fields and Waves in Communication Electronics*, Ramo, Whinnery and Van Duzer, John Wiley and Sons, N.Y., N.Y., 1965.

15. *Time Harmonic Electromagnetic Fields*, R. F. Harrington, McGraw-Hill Book Company, Inc., N.Y., N.Y., 1961.

16. *Dielectric Constants and Dissipation Factors for Six Rock Types Between 20 and 100 Megahertz*, Russel E. Griffin and Robert L. Marovelli, U.S. Dept. of the Interior - report of Invest. 6913 - July 1963.

17. *Dielectric Behavior of Rocks and Minerals*, B. F. Howell, Jr. and P. H. Licastro, The American Mineralogist V46, Mar.-Apr. 1961, p. 269-88.

18. *Electrical Properties of Rocks and Mineral*, George V. Keller, Handbook of Physical Constants (Rev. Ed.) - The Geological Soc. of Amer. Memoir 97, 1966, p. 553-77.

Appendix

A

EXCERPT FROM FRANKLIN INSTITUTE
RESEARCH LABORATORIES REPORT
M-C2210-1

THE FRANKLIN INSTITUTE RESEARCH LABORATORIES
THE BENJAMIN FRANKLIN PARKWAY · PHILADELPHIA, PENNSYLVANIA

M-C2210-1

MONOGRAPH

ON

COMPUTATION OF RF HAZARDS

(Excerpt)

by

Paul F. Mohrbach
Ramie Thompson
Robert F. Wood
Daniel J. Mullen

July, 1968

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

Monograph M-C2210-1
"Computation of RF Hazards"
Paul F. Mohrbach, Ramie H. Thompson,
Robert F. Wood, Daniel J. Mullen
The Franklin Institute Research Laboratories
July, 1968
for National Aeronautics and Space
Administration/Goddard Space Flight Center

J. R. Feldmeier
Director of Laboratories

ABSTRACT

This monograph presents a method for analyzing the potential RF susceptibility to electrical components and systems used in typical space vehicles. It presents the philosophy, applicability and limitations of this approach. While not exhaustive, enough mathematics is presented to permit analysis of a very large percentage of the types of problems which normally occur. Where the actual development of equations is not given in detail, suitable references are provided. Familiarization with the text and the cited references should provide the reader with the necessary information to analyze most systems and the general procedures to handle those situations which are beyond the scope of this monograph.

ACKNOWLEDGEMENTS

This monograph is based on work performed and techniques and ideas developed by the Applied Physics Laboratory, E. E. Hannum, Manager. Inquiries concerning this work should be referred to him or to the sponsoring agency.

1. INTRODUCTION

The determination of the potential radio frequency (RF) hazard to any system exposed to an incident RF field is a very complex problem. Consider, for example, a typical electroexplosive device (EED) and its associated firing circuit mounted in a missile. To begin with, the missile may be transported to the launch site with some or all of its circuits installed and could conceivably be exposed to a wide variety of RF signals along the way. At the launch site it may be necessary to install some of the EEDs or electronic components while in an RF environment. This would permit the possibility of the individual components being irradiated during handling and, subsequently, after installation in its circuit. In addition check out procedures often result in altering the circuits, connecting temporary new circuits to the potentially vulnerable component and such actions as the opening and closing of vents and ports in the missile skin. Furthermore, there would probably be constant movement of vehicles and personnel in the area and this movement would cause continual fluctuation in local RF field intensities. All of these factors would contribute to a constantly changing and very difficult to define set of conditions with respect to RF hazards. It should be noted that localized field intensity conditions can exceed the overall field intensity that would be determined by measuring the field produced at a given point by a radiating transmitter. Unless one can measure the field at the exact point of interest, under the actual conditions and with all equipment that will be in the area and without serious perturbation of the field by the measuring equipment one can be certain only of an approximation of the actual field conditions.

Even if one could accomplish a testing program which would cover all of the conditions, the inherent variation from missile to missile would introduce another large variable. Slight changes in the arrangement of the wiring or in the orientation of the missile with respect to the RF field might well produce large variations in the amount of RF energy delivered to the device under investigation, identical electrical impedance conditions cannot be maintained from missile to missile and on board transmitters may directly interact with the vulnerable circuits.

Of course, if the circuit designer were free to design his circuits with nothing else in mind but to make them insensitive to RF, the RF problem could be essentially eliminated. Complete continuous shielding of the entire systems would in general reduce RF levels at the components to safe values. However, this is often almost impossible, for in our modern complex electric circuits it is usually necessary to break branch circuits out of the shield, to terminate on circuit boards open to RF signals or to follow other procedures which compromise RF safety. In addition, other design groups may argue for and obtain different concepts for wiring to accomplish their ends, and in so doing may also seriously compromise the RF protection.

On the other hand it is often suggested that even with circuits poorly designed from the RF viewpoint, there have been relatively few accidents directly attributed to RF and therefore the problem must be negligible. This could be a very dangerous viewpoint. First of all, information on accidents of any nature is usually very poorly disseminated so that it is difficult to know what accidents have occurred and what situations surrounded such accidents. This is particularly true of accidents which do not result in severe injury to personnel or very large property damage. Second, the determination of the cause of an accident after it has happened is a very difficult business. This is particularly true when trying to evaluate the after-the-fact influence of anything as variable as the potential RF hazard. Furthermore if the investigators do not fully understand how RF energy can be transferred they will easily miss many possibilities. Third, at the present time most RF fields in proximity of vulnerable systems are of reasonably low intensity or are turned off during possibly critical periods. Every year, however, the RF environmental levels are increasing, and RF silence may not always be possible. Systems which are now marginal may eventually become quite vulnerable.

With all of these complicating and generally uncontrollable factors, how can one even evaluate the potential RF hazard to any critical system? Unfortunately, the answer at the present state-of-the-art is that it cannot be done with great precision for anything but a very specifically defined case; however, the hazard can sometimes be evaluated in such a manner that it can be conclusively stated that no hazard exists if this should be the case.

Two methods are now in general use. Both of these require that the RF sensitivity of the device in question be known. There are laboratory techniques for determining this with reasonable precision; unfortunately, the RF sensitivity is of the device is not always so determined and this in general will negate the effectiveness of either method unless suitable precautions are taken.

The first method, stated briefly, is to directly radiate the system in question with a variety of high powered transmitters and to observe the RF levels that arrive at the device under test. The method is appealing, if expensive, since it is a direct approach which superficially appears to simulate the actual conditions that will occur. But, while such tests are much used, and have a definite place in the scheme of things, there are many pitfalls that generally make them unsatisfactory for a really valid hazard determination. The chief weaknesses of the method include inadequacy of present RF detectors, inability to determine field strengths accurately, the very large expense of suitably powerful transmitters, the risk of assuming that tests on one or two systems can be extended to all such systems and the lack of complete understanding by most field testers of the mechanisms of RF damage on the vulnerable devices.

To minimize the effect of these various problems, irradiation tests are often conducted with an arbitrary safety factor added to the acceptable RF pick up at the detector. Many times this factor is not large enough for all conditions. In addition it should be recognized that the only positive result of a field irradiation is to demonstrate that a hazard exists for certain frequencies, irradiation angles, polarizations and orientations of the irradiating antenna and the system being irradiated. Specifically a field irradiation test can never assure complete RF safety since only a finite number of frequencies, polarizations, etc., can be tested from the literally infinite number of situations that can develop in the actual use of the system. However, properly conducted, field tests can give considerable reassurance regarding RF safety.

The second method is the application of analytical techniques to the systems to determine the extent of RF hazard. This approach in its present form has two distinct advantages: first, properly conducted the results are always on the safe side, and should it be demonstrated by this approach that a system is safe in a given field and at a specific frequency, its safety can practically be guaranteed; second, the actual analysis is reasonably inexpensive. The main expense comes from the fact that to perform the analysis properly the RF sensitivity of the device in question must be determined, but as was pointed out earlier, this should also be done in the case of the direct radiation method. The one exception to this occurs when the circuits are so well designed from an RF standpoint that it can be demonstrated analytically that protection levels are so large that the sensitivity of the device is not a factor after installation in these circuits. The main objection to the analytic method in its present form is that it can put unusually stringent restrictions on the circuits so that only the very well designed systems can be shown to be safe; in other words, the safety factor afforded thereby can be unreasonably large. In contrast to the irradiation method, it should be noted that the only positive result of the analytical approach is to show that a given system is safe. Specifically, the analysis can not show that a system is hazardous since the worst case assumptions implicit in the analysis can never be guaranteed to exist.

-1.1 General Approach

The procedure for establishing the extent of the RF hazard to any system by means of the analytic method is as follows:

a. The RF sensitivity of the particular device or devices in each of the circuits in the system is determined over the entire frequency range of interest, for both continuous wave (CW) and pulsed RF signals and for all possible modes of damage such as through the regular leads or between the leads and the case or any other potential damage mode which exists.

b. Using circuit diagrams, wiring diagrams, observation of the actual systems, observations and discussions of the handling, installation and checkout procedures and discussions with the engineers directly concerned the details of the actual physical systems are established. These details include such things as length of cables, locations of wiring breakouts, and separation of distance between firing leads and between the firing leads and the ground plane.

c. Mathematical models are constructed which closely resemble the actual wiring systems, and which can be handled with analytic techniques. These models are constructed for all phases of the problem; i.e., handling, installation, check out and installed; and treat circuits, in the case of EED's for example, for pin-to-pin, pins-to-case and bridgewire-to-bridgewire effects, as applicable. All known parameters of the circuits are used such as the length of unshielded portions, and the physical shape; but wherever a parameter cannot be properly defined a worst case assumption is made. For example it is normally assumed that a given circuit is oriented with respect to the

RF field for maximum pick-up of energy, that the entire circuit is in a single plane and that all impedances in the circuit are matched for optimum pick-up and transfer of energy.

d. The mathematical model is analyzed to establish the amount of RF energy that can be extracted from any incident RF field and subsequently transferred to the device under consideration, for example, the EED terminating the circuit. The analysis gives, for a particular circuit, a quantity known as "aperture" a measure of ability to pick up energy. The aperture as a function of frequency plot can be applied to any assumed field intensity.

e. For any assumed field intensity and frequency the amount of RF energy that could be delivered to the test item is obtained by the product of the incident power density and the aperture and this value compared with its RF sensitivity. The degree of potential hazard is thereby established. Under the assumptions which are made, an indicated safe condition should be quite safe; an indicated hazardous condition may or may not be hazardous.

These data are usually presented graphically and in such a manner that as long as the same circuits and test items are employed, the analysis can be immediately applied to any change, present or future, in the incident field desnities. Only those circuits which are completely different need be analyzed; for example, in the case of redundant circuits only one analysis need be conducted if the two circuits are very similar. In a few rare cases the evaluation of the RF sensitivity of the device under test can be eliminated. The usual case occurs when preliminary investigations of the circuits indicates that they are so well designed from an RF standpoint that only a small amount of energy can be extracted from even a very strong incident field; then the sensitivity of the test device may be of secondary importance. However, RF sensitive EEDs should always be avoided if possible.

This approach is often designated a "worst case" analysis, however, it should be noted that this is a mild misnomer. In actual fact, all of the known or reasonably obtained data bearing upon any circuit is used. For example, such details as actual sizes of loops, length of unshielded wire runs, separation distance of cable from frame, pin configuration of test device, RF sensitivity of test device, impedance of test device, quality of shielding material used and attenuation provided by switches and arming devices used in the circuit are carefully determined and actual values are used in the calculations wherever possible. On the other hand, those characteristics which could be variable from test vehicle to test vehicle or very expensive to determine are assumed to be at their worst. For example; orientation of all circuits is assumed to be optimized in the incident field, impedances throughtout the circuit are generally assumed to be matched in such a manner as to give maximum transfer of RF energy to the test device, RF pickup from all loops is assumed to be in phase and missile skins, except under unusual circumstances, are assumed to offer no attenuation. Experience has shown this last assumption to be quite valid.

As a result, the analysis produces values of RF power delivered to the test device which are always on the conservative side, occasionally by rather large amounts. This leads to the statement made earlier that if under the worst case approach a system is found to be safe, it is most likely quite safe; if on the other hand a hazard is indicated, the system may still be safe.

Three additional points should be noted, however. First, experience has shown that if the missile system is considered across a wide frequency band there is a good probability that at some point in the frequency spectrum the worst case assumptions will come close to being satisfied and the analysis and the real conditions will come close to coinciding. Second, attempts to assign probability values to

2. DETAILED ANALYSIS PROCEDURES

It is the purpose of this section to describe in detail most of the mathematical procedures necessary to conduct an RF analysis on a component. From the start it should be carefully noted that when analyzing the potential hazard to a component such as an EED every pertinent aspect of its history must be carefully considered in its own specific situation. For example, the circuit attached to an EED when it is installed in a space vehicle may have very different RF pickup characteristics than the circuit which might be temporarily attached to check the resistance or some other parameter of the EED. If the EED is installed in a vehicle with the shorting cap attached and the shorting cap is removed to attach the functioning circuit while an RF field is present, possible RF hazard must be considered for the EED with shorting cap, without shorting cap and installed in circuit. Should a monitoring circuit be included in the EED, the RF pickup associated with this circuit must be considered along with its possible coupling to the EED functioning circuit. In short, the engineer performing the analysis must become intimately familar with all aspects of the device, its associated circuits usually back to the power source and its history insofar as handling, installation, checkout and final installed condition are concerned.

In addition the engineer must consider all of the possible functioning modes of a device. For a wire bridge EED this would include the following: through the bridgewire, between the bridgewire and the case and between the bridgewires, if applicable.

For each condition, the engineer must characterize the system as to its most likely manner of acting as a receiving antenna. In its simplest form one might consider a wire lead EED with its leads twisted together at the end. This system could probably be most directly characterized as a small loop antenna terminated in the bridgewire impedance. The same EED installed in a complex missile circuit may be much more elusive to characterize, however. A typical configuration would result in shielding of the cables leading to the EED but no attachment of the shield to the case of the EED. If single point grounding of the shield philosophy is also followed, the engineer may find that a large loop is formed and attached to the pins-to-case mode of the EED.

In summary, and it cannot be said too strongly, when applying the analytical techniques discussed here, it is most important to consider all possible configurations and hazard modes and to characterize the systems being considered into their proper patterns. This step is the single most important and time consuming element of the analysis.

Appendix

B

BRUCETON TEST RESULTS

The computer output sheets give the results of the Bruceton tests. The program computer conforms to the Bruceton procedure as given in reference 8. All Bruceton test results for the same item are grouped together, first those for cap A, then cap B, etc.

* * * B R U C E T O N   A N A L Y S I S * * *

DATA, DC TEST, 10 SEC, CAP A, PROJECT C3102,   TEST 2199

SER. RES. NO. (OHMS) | FUNCT. TIMES. (SEC)

L E V E L S

Trial	1	2	3	4	5	6	7	8	9	10
1			X							
2		O								
3			O							
4				X						
5			X							
6		X								
7	O									
8		O								
9			X							
10		O								
11			O							
12				X						
13			X							
14		O								
15			X							
16		O								
17			O							
18				X						
19			X							
20		O								
21			O							
22				X						
23			O							
24				X						
25			O							
26				X						
27			O							
28				O						
29					X					
30				O						
31					X					
32				X						
33			X							
34		O								
35			O							
36				X						
37			X							
38		O								
39			X							
40		O								
41			X							
42		O								
43			X							
44		X								
45	O									
46		X								
47	O									
48		O								
49			X							

LEVEL NO.	STIMULUS (AMPS)	I	I*I	NO	NX
1	.2736+00	0	0	3	0
2	.2800+00	1	1	12	3
3	.2865+00	2	4	8	12
4	.2932+00	3	9	2	8
5	.3000+00	4	16	0	2
6	.0000	5	25	0	0
7	.0000	6	36	0	0
8	.0000	7	49	0	0
9	.0000	8	64	0	0
10	.0000	9	81	0	0

NO=25 NX=25

LOG OF FIRST LEVEL= -.56288 D= .010

AO= 34 AX= 59

BO= 62 BX= 155

MO= .63040 MX= .63040

MEANO= -.54428 MEANX= -.54428

SIGMO= .01090 SIGMX= .01090 SIGMA= .01090

S= 1.09026 G= .998 G*G= .995492

H= 1.422 H*H= 2.022010

CONFIDENCE INTERVAL= .01681

LOG OF 99.9%(95%CONF)= -.49378 99.9%(95%CONF)= .321 AMPS

LOG OF MEAN(50%)LEVEL= -.54428 MEAN(50%)= .286 AMPS

LOG OF 0.1%(95%CONF) = -.59478 0.1%(95%CONF)= .254 AMPS

V A L I D I T Y   T E S T S

EQUALITY OF OCCURRENCE -OK

NO. OF RUNS- 34

LENGTH OF RUNS- 3

* . . B R U C E T O N   A N A L Y S I S . * *

DATA, DC TEST, 10 SEC, CAP A, PROJECT C3102 DUDDED 264MA 5M TEST 2202

SER. NO.	RES. (OHMS)	FUNCT. TIMES. (SEC)	LEVELS 1	2	3	4	5	6	7	8	9	10
1				O								
2					O							
3						X						
4					X							
5				O								
6					O							
7						X						
8					X							
9				O								
10					O							
11						X						
12					O							
13						X						
14					O							
15						X						
16					X							
17				O								
18					O							
19						X						
20					O							
21						X						
22					O							
23						X						
24					X							
25				O								
26					O							
27						X						
28					X							
29				X								
30			O									
31				O								
32					O							
33						X						
34					O							
35						X						
36					O							
37						O						
38							X					
39						X						
40					O							
41						X						
42					X							
43				O								
44					O							
45						X						
46					O							
47						X						

LEVEL NO.	STIMULUS (AMPS)	I	I*I	NO	NX
1	.3000+00	0	0	1	0
2	.3070+00	1	1	7	1
3	.3141+00	2	4	15	6
4	.3215+00	3	9	1	15
5	.3289+00	4	16	0	1
6	.0000	5	25	0	0
7	.0000	6	36	0	0
8	.0000	7	49	0	0
9	.0000	8	64	0	0
10	.0000	9	81	0	0
				NO=24	NX=23

LOG OF FIRST LEVEL= -.52288 D= .010

AO= 40		AX= 62			
BO= 76		BX= 176			
MO= .38889		MX= .38563			
MEANO= -.50121		MEANX= -.50092			
SIGMO= .00692		SIGMX= .00687		SIGMA= .00689	
S= .68923		G= 1.056		G*G= 1.116078	
H= 1.269		H*H= 1.611427			

CONFIDENCE INTERVAL= .00991

LOG OF 99.9%(95%CONF)=	-.46987	99.9%(95%CONF)=	.339 AMPS
LOG OF MEAN(50%)LEVEL=	-.50107	MEAN(50%)=	.315 AMPS
LOG OF 0.1%(95%CONF) =	-.53228	0.1%(95%CONF)=	.294 AMPS

V A L I D I T Y   T E S T S

EQUALITY OF OCCURRENCE -OK

NO. OF RUNS- 30

LENGTH OF RUNS- 3

```
                          * * * B R U C E T O N     A N A L Y S I S * * *

              DATA,DC TEST RF DUDDED CAP A PROJECT C5102 TEST 2354

          FUNCT.       L E V E L S           LEVEL  STIMULUS                                           V A L I D I T Y   T E S T S
SER. RES. TIMES.
NO. (OHMS) ( SEC)      1 2 3 4 5 6 7 8 9 10  NO.    (AMPS )     I   I*I    NO     NX
            1              X
            2            X                    1      .2880+00   0    0      2      0          EQUALITY OF
            3          O
            4            X                    2      .2947+00   1    1     10      2          OCCURRENCE -OK
            5          O
            6            O                    3      .3016+00   2    4      9     10
            7              X
            8            O                    4      .3086+00   3    9      3      9          N.O. OF RUNS- 30
            9              O
           10                X                5      .3158+00   4   16      0      3
           11              O
           12                O                6      .0000      5   25      0      0          LENGTH OF
           13                  X
           14                O                7      .0000      6   36      0      0                RUNS-  3
           15                  X
           16                X                8      .0000      7   49      0      0
           17              X
           18            O                    9      .0000      8   64      0      0
           19              X
           20            O                   10      .0000      9   81      0      0
           21              O
           22                X                                        NO=24  NX=24
           23              X
           24            O                   LOG OF FIRST LEVEL= -.54061  D=  .010
           25              O
           26                X               AO=   37           AX=   61
           27              O
           28                X               BO=   73           BX=  171
           29              X
           30            O                   MO=  .66493        MX=  .66493
           31              O
           32                X               MEANO= -.52019  MEANX= -.52019
           33              X
           34            O                   SIGMO=  .01148  SIGMX=  .01148  SIGMA=  .01148
           35              O
           36                X               S= 1.14835          G=  .996      G*G=   .992596
           37              O
           38                X               H= 1.444         H*H=  2.084035
           39              X
           40            O                   CONFIDENCE   INTERVAL=  .01637
           41              X
           42            O                   LOG OF 99.9%(95%CONF)= -.46634   99.9%(95%CONF)=     .342 AMPS
           43              O
           44                O               LOG OF MEAN(50%)LEVEL= -.52019          MEAN(50%)=     .302 AMPS
           45                  X
           46                X               LOG OF 0.1%(95%CONF) = -.57404    0.1%(95%CONF)=     .267 AMPS
           47              X
           48            O
```

* * * B R U C E T O N   A N A L Y S I S * * *

DATA,RF TEST,PP,1.5MHZ,CAP A, PROJECT C3102 2/3/72 TEST 2241

```
            FUNCT.        L E V E L S          LEVEL  STIMULUS                                   V A L I D I T Y   T E S T S
SER. RES.   TIMES.
NO. (OHMS)  ( SEC)       1 2 3 4 5 6 7 8 9 10  NO.    (WATTS)     I    I*I    NO    NX
                   1           X
                   2         X                  1    .9600-01    0     0      2     0       EQUALITY OF
                   3       O
                   4         X                  2    .1029+00    1     1     13     2       OCCURRENCE -OK
                   5       O
                   6         X                  3    .1102+00    2     4      6    14
                   7       O
                   8         X                  4    .1181+00    3     9      3     7       NO. OF RUNS- 35
                   9       O
                  10         O                  5    .1266+00    4    16      0     3
                  11           X
                  12         X                  6    .0000       5    25      0     0       LENGTH OF
                  13       O
                  14         X                  7    .0000       6    36      0     0             RUNS-  4
                  15       X
                  16     O                      8    .0000       7    49      0     0
                  17       O
                  18         X                  9    .0000       8    64      0     0
                  19       O
                  20         X                 10    .0000       9    81      0     0
                  21       O
                  22         O                                         NO=24  NX=26
                  23           X
                  24         X                 LOG OF FIRST LEVEL=-1.01773  D=  .030
                  25       O
                  26         O                 AO=   34          AX=   63
                  27           X
                  28         O                 BO=   64          BX=  169
                  29           X
                  30         X                 MO=  .65972       MX=  .62870
                  31       X
                  32     O                     MEANO= -.96023  MEANX= -.96004
                  33       O
                  34         O                 SIGMO=  .03419  SIGMX=  .03260  SIGMA=  .03337
                  35           O
                  36             X             S= 1.11240           G=  .997     G*G=   .994388
                  37           O
                  38             X             H= 1.430          H*H=  2.045586
                  39           O
                  40             X             CONFIDENCE   INTERVAL=  .05175
                  41           X
                  42         O                 LOG OF 99.9%(95%CONF)= -.80526   99.9%(95%CONF)=    .157 WATTS
                  43           X
                  44         X                 LOG OF MEAN(50%)LEVEL= -.96013        MEAN(50%)=    .110 WATTS
                  45       O
                  46         X                 LOG OF 0.1%(95%CONF) =-1.11500    0.1%(95%CONF)=    .077 WATTS
                  47       O
                  48         X
                  49       O
```

```
                          * * * B R U C E T O N     A N A L Y S I S * * *

                 DATA,RF TEST NUMBER 2248 9.0 GC PIN TO CASE CAP A PROJECT C3102

            FUNCT.      L E V E L S           LEVEL  STIMULUS                                         V A L I D I T Y   T E S T S
SER. RES.   TIMES.
NO. (OHMS)  ( SEC)     1 2 3 4 5 6 7 8 9 10   NO.    (WATTS)    I   I*I     NO     NX
                    1          O
                    2            X             1     .2540+01   0    0       3      0          EQUALITY OF
                    3          O
                    4            X             2     .2850+01   1    1       9      3          OCCURRENCE -OK
                    5          X
                    6        X                 3     .3198+01   2    4       4      9
                    7      O
                    8        X                 4     .3588+01   3    9       2      5          NO. OF RUNS- 27
                    9      X
                   10    O                     5     .4026+01   4   16       4      3
                   11      X
                   12    X                     6     .4517+01   5   25       0      4          LENGTH OF,
                   13  O
                   14    O                     7     .0000      6   36       0      0                 RUNS-  4
                   15      X
                   16    O                     8     .0000      7   49       0      0
                   17      X
                   18    O                     9     .0000      8   64       0      0
                   19      X
                   20    X                    10     .0000      9   81       0      0
                   21  O
                   22    O                                            NO=22  NX=24
                   23      O
                   24        X                 LOG OF FIRST LEVEL=  .40483  D=  .050
                   25      O
                   26        O                 AO=   39           AX=   68
                   27          O
                   28            X             BO=  107           BX=  232
                   29          O
                   30            X             MO= 1.72107        MX= 1.63889
                   31          X
                   32        X                 MEANO=  .51847  MEANX=  .52150
                   33      X
                   34    O                     SIGMO=  .14509  SIGMX=  .13800  SIGMA=  .14144
                   35      X
                   36    X                     S= 2.82877           G=  .954     G*G=   .910652
                   37  O
                   38    O                     H= 2.020           H*H=  4.080804
                   39      X
                   40    O                     CONFIDENCE   INTERVAL=  .31980
                   41      O
                   42        O                 LOG OF 99.9%(95%CONF)= 1.27690   99.9%(95%CONF)=  18.919 WATTS
                   43          X
                   44        X                 LOG OF MEAN(50%)LEVEL=  .52005        MEAN(50%)=   3.312 WATTS
                   45      X
                   46    O                     LOG OF 0.1%(95%CONF) = -.23680    0.1%(95%CONF)=    .580 WATTS
```

```
                          * * * B R U C L E T O N    A N A L Y S I S * * *

                   DATA,DC TEST,10 SEC,CAP B,PROJECT C3102        TEST 2238

                 FUNCT.        L E V E L S        LEVEL  STIMULUS                                 V A L I D I T Y   T E S T S
SER.  RES.       TIMES.
NO.  (OHMS)      ( SEC)        1 2 3 4 5 6 7 8 9 10  NO.   (AMPS )     I   I*I    NO    NX
                          1      O
                          2        X                  1    .3310+00    0    0      3     0         EQUALITY OF
                          3      O
                          4        X                  2    .3348+00    1    1      8     3         OCCURRENCE -OK
                          5      O
                          6        O                  3    .3387+00    2    4      6     8
                          7          O
                          8            X              4    .3426+00    3    9      5     6         NO. OF RUNS- 2
                          9          O
                         10            X              5    .3466+00    4   16      1     5
                         11          X
                         12        X                  6    .3506+00    5   25      0     1         LENGTH OF
                         13      O
                         14        X                  7    .0000       6   36      0     0                 RUNS-  4
                         15      O
                         16        O                  8    .0000       7   49      0     0
                         17          X
                         18        X                  9    .0000       8   64      0     0
                         19      X
                         20    O                     10    .0000       9   81      0     0
                         21      O
                         22        O                                         NO=23  NX=23
                         23          X
                         24        X              LOG OF FIRST LEVEL= -.48017  D=  .005
                         25      O
                         26        O              AO=   39          AX=   62
                         27          O
                         28            X          BO=   93          BX=  194
                         29          X
                         30        O              MO= 1.16824       MX= 1.16824
                         31          O
                         32            O          MEANO= -.46919  MEANX= -.46919
                         33              X
                         34            X          SIGMO=  .00992  SIGMX=  .00992  SIGMA=  .00992
                         35          X
                         36        O              S= 1.98312          G=  .975     G*G=   .951448
                         37          O
                         38            X          H= 1.742          H*H=  3.034535
                         39          X
                         40        X              CONFIDENCE   INTERVAL=  .01942
                         41      X
                         42    O                  LOG OF 99.9%(95%CONF)= -.41913   99.9%(95%CONF)=     .381 AMPS
                         43      X
                         44    O                  LOG OF MEAN(50%)LEVEL= -.46919         MEAN(50%)=     .339 AMPS
                         45      O
                         46        X              LOG OF 0.1%(95%CONF) = -.51925    0.1%(95%CONF)=     .303 AMPS
```

```
                                   * * * B R U C E T O N     A N A L Y S I S * * .

                    DATA,DC TEST,10 SEC,CAP B,PROJECT C3102 DUDDED 316MA 5M TEST 2239

          FUNCT.      L E V E L S          LEVEL  STIMULUS                                        V A L I D I T Y   T E S T S
SER. RES. TIMES.
NO. (OHMS) ( SEC)     1 2 3 4 5 6 7 8 9 10  NO.    (AMPS )     I    I*I    NO     NX
            1               X
            2             O                  1      .4460+00   0     0      2      0          EQUALITY OF
            3               O
            4                 X              2      .4564+00   1     1      4      2          OCCURRENCE -OK
            5               X
            6             O                  3      .4670+00   2     4     10      4
            7               X
            8             O                  4      .4779+00   3     9      7     10          NO. OF RUNS- 26
            9               X
           10             X                  5      .4890+00   4    16      1      7
           11           O
           12             O                  6      .5004+00   5    25      0      1          LENGTH OF
           13               X
           14             O                  7      .0000      6    36      0      0              RUNS-  4
           15               O
           16                 X              8      .0000      7    49      0      0
           17               O
           18                 X              9      .0000      8    64      0      0
           19               X
           20             X                 10      .0000      9    81      0      0
           21           X
           22         O                                                 NO=24  NX=24
           23           O
           24             O                 LOG OF FIRST LEVEL= -.35067  D=  .010
           25               X
           26             O                 AO=   49            AX=   73
           27               O
           28                 O             BO=  123            BX=  245
           29                   X
           30                 X             MO=  .95660         MX=  .95660
           31               X
           32             O                 MEANO= -.32525  MEANX= -.32525
           33               O
           34                 X             SIGMO=  .01631  SIGMX=  .01631  SIGMA=  .01631
           35               X
           36             X                 S= 1.63101           G=  .984     G*G=   .968698
           37           X
           38         O                     H= 1.619           H*H=  2.621240
           39           O
           40             X                 CONFIDENCE   INTERVAL=  .02910
           41           O
           42             O                 LOG OF 99.9%(95%CONF)= -.24576   99.9%(95%CONF)=    .568 AMPS
           43               O
           44                 X             LOG OF MEAN(50%)LEVEL= -.32525        MEAN(50%)=    .473 AMPS
           45               O
           46                 X             LOG OF 0.1%(95%CONF) = -.40475    0.1%(95%CONF)=    .394 AMPS
           47               X
           48             O
```

```
                              * * * B R U C E T O N     A N A L Y S I S * * *

                    DATA,DC TEST RF BUDDED CAP B PROJECT C3102 TEST 2056

           FUNCT.     L E V E L S       LEVEL  STIMULUS                                           V A L I D I T Y   T E S T S
SER. RES.  TIMES.
NO. (OHMS) ( SEC)     1 2 3 4 5 6 7 8 9 10  NO.   (AMPS )      I    I*I     NO     NX
              1             X
              2           O                  1     .3800+00    0     0      3      0          EQUALITY OF
              3             X
              4           X                  2     .3888+00    1     1      9      3          OCCURRENCE -OK
              5         O
              6           O                  3     .3979+00    2     4      8      9
              7             X
              8           X                  4     .4072+00    3     9      3      9          NO. OF RUNS- 29
              9         X
             10       O                      5     .4167+00    4    16      0      3
             11         O
             12           X                  6     .0000       5    25      0      0          LENGTH OF
             13         O
             14           X                  7     .0000       6    36      0      0                 RUNS-  4
             15         O
             16           X                  8     .0000       7    49      0      0
             17         X
             18       O                      9     .0000       8    64      0      0
             19         O
             20           O                 10     .0000       9    81      0      0
             21             O
             22               X                                       NO=23  NX=24
             23             O
             24               X              LOG OF FIRST LEVEL= -.42022  D=  .010
             25             O
             26               X              AO=   54          AX=   60
             27             X
             28           X                  BO=   68          BX=  166
             29         O
             30           O                  MO=  .77127       MX=  .75000
             31             X
             32           X                  MEANO= -.40044  MEANX= -.40022
             33         O
             34           O                  SIGMO=  .01326  SIGMX=  .01289  SIGMA=  .01307
             35             X
             36           O                  S= 1.30708         G=  .992     G*G=   .984705
             37             X
             38           O                  H= 1.502         H*H=  2.256546
             39             X
             40           X                  CONFIDENCE   INTERVAL=  .02196
             41         O
             42           X                  LOG OF 99.9%(95%CONF)= -.33796   99.9%(95%CONF)=    .459 AMPS
             43         X
             44       O                      LOG OF MEAN(50%)LEVEL= -.40033       MEAN(50%)=    .396 AMPS
             45         O
             46           O                  LOG OF 0.1%(95%CONF) = -.46267    0.1%(95%CONF)=    .345 AMPS
             47             X
```

```
                              * * * B R U C E T O N    A N A L I S I S * * *

                        DATA,RF-TEST 2246,P-P CAP B,1.5MHZ CW,PROJECT C3102-01

          FUNCT.        L E V E L S           LEVEL  STIMULUS                                   V A L I D I T Y   T E S T S
SER. RES. TIMES.
NO. (OHMS) ( SEC)    1 2 3 4 5 6 7 8 9 10    NO.    (WATTS)    I   I*I    NO     NX
                  1            X
                  2          O                1     .2310+00    0    0     4      0           EQUALITY OF
                  3            X
                  4          X                2     .2419+00    1    1    11      4           OCCURRENCE -OK
                  5        X
                  6      X                    3     .2533+00    2    4     5     12
                  7    O
                  8      X                    4     .2652+00    3    9     2      6           NO. OF RUNS- 35
                  9    O
                 10      X                    5     .2777+00    4   16     1      3
                 11    O
                 12      X                    6     .2908+00    5   25     0      2           LENGTH OF
                 13    X
                 14  O                        7     .0000       6   36     0      0                  RUNS-  4
                 15    O
                 16      X                    8     .0000       7   49     0      0
                 17    X
                 18  O                        9     .0000       8   64     0      0
                 19    X
                 20  O                       10     .0000       9   81     0      0
                 21    X
                 22  O                                                NO=23  NX=27
                 23    O
                 24      O                     LOG OF FIRST LEVEL= -.63639  D=  .020
                 25        X
                 26      O                     AO=   31          AX=   68
                 27        X
                 28      X                     BO=   65          BX=  204
                 29    O
                 30      O                     MO= 1.00945       MX= 1.21262
                 31        X
                 32      O                     MEANO= -.59943  MEANX= -.59602
                 33        X
                 34      X                     SIGMO=  .03440  SIGMX=  .04099  SIGMA=  .03810
                 35    O
                 36      X                     S= 1.90520          G=  .977     G*G=   .955252
                 37    O
                 38      X                     H= 1.715          H*H=  2.941717
                 39    O
                 40      X                     CONFIDENCE   INTERVAL=  .07029
                 41    O
                 42      O                     LOG OF 99.9%(95%CONF)= -.40956   99.9%(95%CONF)=    .389 WATTS
                 43        O
                 44          X                 LOG OF MEAN(50%)LEVEL= -.59759        MEAN(50%)=    .253 WATTS
                 45        O
                 46          X                 LOG OF 0.1%(95%CONF) = -.78562    0.1%(95%CONF)=    .164 WATTS
                 47        X
                 48      X
                 49    O
                 50      X
```

* * * B R U C E T O N   A N A L Y S I S * * *

DATA,RF TEST NUMBER 2247 5.4 GC P-CASE CAP B PROJECT C3102

SER. NO.	RES. (OHMS)	FUNCT. TIMES. (SEC)	1	2	3	4	5	6	7	8	9	10
1							X					
2						O						
3							O					
4								X				
5							X					
6						X						
7					O							
8						O						
9							O					
10								X				
11							O					
12								X				
13							O					
14								O				
15									X			
16								O				
17									X			
18								X				
19							X					
20						X						
21					X							
22				O								
23					X							
24				O								
25					X							
26				X								
27			O									
28				O								
29					O							
30						X						
31					X							
32				X								
33			O									
34				O								
35					X							
36				X								
37			O									
38				X								
39			O									
40				O								
41					O							
42						X						
43					X							
44				X								
45			O									
46				O								
47					X							
48				X								
49			O									

LEVEL NO.	STIMULUS (WATTS)	I	I*I	NO	NX
1	.2340+01	0	0	6	0
2	.2450+01	1	1	6	7
3	.2566+01	2	4	3	7
4	.2687+01	3	9	2	4
5	.2813+01	4	16	4	3
6	.2946+01	5	25	2	4
7	.3085+01	6	36	0	2
8	.0000	7	49	0	0
9	.0000	8	64	0	0
10	.0000	9	81	0	0

NO=23 NX=27

LOG OF FIRST LEVEL= .36922 D= .020

AO= 44 AX= 77

BO= 150 BX= 291

MO= 2.86200 MX= 2.64472

MEANO= .41748 MEANX= .41626

SIGMO= .09577 SIGMX= .08828 SIGMA= .09180

S= 4.59012 G= .910 G*G= .828550

H= 2.521 H*H= 6.357038

CONFIDENCE INTERVAL= .24648

LOG OF 99.9%(95%CONF)= .94697 99.9%(95%CONF)= 8.851 WATTS

LOG OF MEAN(50%)LEVEL= .41682 MEAN(50%)= 2.611 WATTS

LOG OF 0.1%(95%CONF) = -.11333 0.1%(95%CONF)= .770 WATTS

V A L I D I T Y   T E S T S

EQUALITY OF OCCURRENCE -OK

NO. OF RUNS- 27

LENGTH OF RUNS- 5

```
                         * * * B R U C E T O N   A N A L Y S I S * * *

                DATA,DC TEST 10 SEC CAP C PROJECT C3102 TEST 2261

            FUNCT.       L E V E L S          LEVEL  STIMULUS                                 V A L I D I T Y  T E S T S
SER. RES.   TIMES.
NO. (OHMS)  ( SEC)    1 2 3 4 5 6 7 8 9 10   NO.    (AMPS )     I   I*1     NO     NX
                  1         O
                  2           X               1     .5010+00    0    0       1      0         EQUALITY OF
                  3         X
                  4       X                   2     .5127+00    1    1       8      1         OCCURRENCE -OK
                  5     O
                  6       X                   3     .5246+00    2    4       8      8
                  7     O
                  8       X                   4     .5368+00    3    9       3      8         NO. OF RUNS- 26
                  9     X
                 10   O                       5     .5493+00    4   16       0      3
                 11     O
                 12       X                   6     .0000       5   25       0      0         LENGTH OF
                 13     O
                 14       X                   7     .0000       6   36       0      0             RUNS-  3
                 15     O
                 16       O                   8     .0000       7   49       0      0
                 17         X
                 18       O                   9     .0000       8   64       0      0
                 19         X
                 20       O                  10     .0000       9   81       0      0
                 21         X
                 22       X                                            NO=20  NX=20
                 23     O
                 24       O                  LOG OF FIRST LEVEL= -.30016  D= .010
                 25         X
                 26       X                  AO=   33          AX=   53
                 27     O
                 28       O                  BO=   67          BX=  153
                 29         X
                 30       O                  MO=  .62750       MX=  .62750
                 31         O
                 32           X              MEANO= -.27866  MEANX= -.27866
                 33         X
                 34       X                  SIGMO=  .01091  SIGMX=  .01091  SIGMA=  .01091
                 35     O
                 36       O                  S= 1.09116           G=  .996     G*G=   .995447
                 37         X
                 38       O                  H= 1.422           H*H=  2.022970
                 39         O
                 40           X              CONFIDENCE   INTERVAL=  .01900

                                             LOG OF 99.9%(95%CONF)= -.22594   99.9%(95%CONF)=    .594 AMPS

                                             LOG OF MEAN(50%)LEVEL= -.27866         MEAN(50%)=    .526 AMPS

                                             LOG OF 0.1%(95%CONF) = -.33138    0.1%(95%CONF)=    .466 AMPS
```

* * * B R U C E T O N   A N A L Y S I S * * *

DATA.DC TEST DC DUDDED CAP C PROJECT C 3102 TEST 2365

LEVELS (trial record)

SER. NO.	RES. (OHMS)	FUNCT. TIMES. (SEC)		1	2	3	4	5	6	7	8	9	10
			1	O									
			2		O								
			3			O							
			4				X						
			5			O							
			6				X						
			7			O							
			8				O						
			9					X					
			10				X						
			11			X							
			12		O								
			13			X							
			14		X								
			15	O									
			16		O								
			17			O							
			18				X						
			19			X							
			20		O								
			21			O							
			22				X						
			23			O							
			24				X						
			25			O							
			26				X						
			27			X							
			28		O								
			29			X							
			30		O								
			31			O							
			32				X						
			33			X							
			34		O								
			35			O							
			36				X						
			37			X							
			38		O								
			39			X							
			40		O								
			41			O							
			42				X						
			43			O							
			44				O						
			45					X					
			46				X						
			47			X							
			48		X								
			49	O									
			50		O								

LEVEL NO.	STIMULUS (AMPS)	I	I*I	NO	NX
1	.5250+00	0	0	3	0
2	.5372+00	1	1	10	2
3	.5497+00	2	4	11	9
4	.5625+00	3	9	2	11
5	.5757+00	4	16	0	2
6	.0000	5	25	0	0
7	.0000	6	36	0	0
8	.0000	7	49	0	0
9	.0000	8	64	0	0
10	.0000	9	81	0	0

NO=26 NX=24

LOG OF FIRST LEVEL= -.27984 D= .010

AO= 38 AX= 61

BO= 72 BX= 169

MO= .63314 MX= .58160

MEANO= -.26022 MEANX= -.25942

SIGMO= .01094 SIGMX= .01010 SIGMA= .01055

S= 1.05467 G= .999 G*G= .997269

H= 1.409 H*H= 1.984314

CONFIDENCE INTERVAL= .01612

LOG OF 99.9%(95%CONF)= -.21113 99.9%(95%CONF)= .615 AMPS

LOG OF MEAN(50%)LEVEL= -.25984 MEAN(50%)= .550 AMPS

LOG OF 0.1%(95%CONF) = -.30855 0.1%(95%CONF)= .491 AMPS

V A L I D I T Y T E S T S

EQUALITY OF OCCURRENCE -OK

NO. OF RUNS- 29

LENGTH OF RUNS- 4

* * * B R U C E T O N   A N A L Y S I S * * *

DATA,JC TEST RF DUDDED CAP C PROJECT C3102 TEST 2548

SER. NO.	RES. (OHMS)	FUNCT. TIMES. (SEC)	1	2	3	4	5	6	7	8	9	10
1						X						
2					X							
3				X								
4			O									
5				X								
6			O									
7				O								
8					O							
9						X						
10					O							
11						X						
12					X							
13				O								
14					O							
15						O						
16							X					
17						X						
18					O							
19						O						
20							X					
21						O						
22							O					
23								X				
24							X					
25						X						
26					O							
27						X						
28					O							
29						O						
30							O					
31								X				
32							O					
33								X				
34							X					
35						O						
36							O					
37								X				
38							O					
39								O				
40									X			
41								O				
42									X			
43								O				
44									X			
45								X				
46							X					
47						X						
48					O							

LEVEL NO.	STIMULUS (AMPS)	I	I*I	NO	NX
1	.3980+00	0	0	2	0
2	.4073+00	1	1	2	2
3	.4168+00	2	4	7	2
4	.4265+00	3	9	5	7
5	.4364+00	4	16	5	5
6	.4466+00	5	25	3	5
7	.4570+00	6	36	0	3
8	.0000	7	49	0	0
9	.0000	8	64	0	0
10	.0000	9	81	0	0
				NO=24	NX=24

LOG OF FIRST LEVEL= -.40012 D= .010

AO= 66 AX= 90

BO= 230 BX= 380

MO= 2.02083 MX= 2.02083

MEANO= -.36762 MEANX= -.36762

SIGMO= .03392 SIGMX= .03392 SIGMA= .03392

S= 7.39215 G= .940 G*G= .883969

H= 2.192 H*H= 4.804373

CONFIDENCE INTERVAL= .08116

LOG OF 99.9%(95%CONF)= -.18164 99.9%(95%CONF)= .658 AMPS

LOG OF MEAN(50%)LEVEL= -.36762 MEAN(50%)= .429 AMPS

LOG OF 0.1%(95%CONF) = -.55360 0.1%(95%CONF)= .280 AMPS

V A L I D I T Y T E S T S

EQUALITY OF OCCURRENCE -OK

NO. OF RUNS- 28

LENGTH OF RUNS- 4

* * * B R U C E T O N   A N A L Y S I S * * *

DATA,RF2308,1.5MHZ,P-P,10SEC.BLAS.CAP NO.C,C3102-01, 4-13-72

SER. NO.	RES. (OHMS)	FUNCT. TIMES. (SEC)		LEVELS 1	2	3	4	5	6	7	8	9	10
			1			X							
			2		X								
			3	O									
			4		O								
			5			X							
			6		X								
			7	O									
			8		O								
			9			X							
			10		O								
			11			O							
			12				O						
			13					X					
			14				O						
			15					X					
			16				X						
			17			O							
			18				X						
			19			O							
			20				O						
			21					X					
			22				X						
			23			X							
			24		O								
			25			X							
			26		O								
			27			O							
			28				O						
			29					X					
			30				X						
			31			O							
			32				O						
			33					X					
			34				O						
			35					X					
			36				X						
			37			O							
			38				X						
			39			X							
			40		O								
			41			O							
			42				X						
			43			X							
			44		O								
			45			O							
			46				X						
			47			X							
			48		X								
			49	O									
			50		X								

LEVEL NO.	STIMULUS (WATTS)	I	I*I	NO	NX
1	.3150+00	0	0	3	0
2	.3223+00	1	1	7	4
3	.3298+00	2	4	8	8
4	.3375+00	3	9	6	8
5	.3454+00	4	16	0	6
6	.0000	5	25	0	0
7	.0000	6	36	0	0
8	.0000	7	49	0	0
9	.0000	8	64	0	0
10	.0000	9	81	0	0
				NO=24	NX=26

LOG OF FIRST LEVEL= -.50169 D= .010

AO= 41 AX= 68

BO= 93 BX= 204

MO= .95660 MX= 1.00592

MEANO= -.47961 MEANX= -.48054

SIGMO= .01631 SIGMX= .01710 SIGMA= .01672

S= 1.67?43 G= .983 G*G= .966661

H= 1.634 H*H= 2.669000

CONFIDENCE INTERVAL= .02944

LOG OF 99.9%(95%CONF)= -.39897 99.9%(95%CONF)= .399 WATTS

LOG OF MEAN(50%)LEVEL= -.48009 MEAN(50%)= .331 WATTS

LOG OF 0.1%(95%CONF) = -.56121 0.1%(95%CONF)= .275 WATTS

V A L I D I T Y   T E S T S

EQUALITY OF OCCURRENCE -OK

NO. OF RUNS- 29

LENGTH OF RUNS- 3

* * * B R U C E T O N   A N A L Y S I S * * *

DATA, DC TEST, 10 SEC CAP D PROJECT C3102 TEST 2200

SER. RES. NO. (OHMS) — FUNCT. TIMES. (SEC)

L E V E L S

Trial	1	2	3	4	5	6	7	8	9	10
1		O								
2			X							
3		X								
4	O									
5		X								
6	O									
7		X								
8	O									
9		O								
10			X							
11		O								
12			X							
13		O								
14			O							
15				X						
16			X							
17		O								
18			X							
19		O								
20			O							
21				X						
22			X							
23		O								
24			O							
25				O						
26					X					
27				X						
28			O							
29				X						
30			O							
31				X						
32			X							
33		X								
34	O									
35		O								
36			O							
37				O						
38					X					
39				O						
40					X					

LEVEL NO.	STIMULUS (AMPS)	I	I*I	NO	NX
1	.2630+00	0	0	4	0
2	.2691+00	1	1	8	4
3	.2754+00	2	4	6	7
4	.2818+00	3	9	3	5
5	.2884+00	4	16	0	3
6	.0000	5	25	0	0
7	.0000	6	36	0	0
8	.0000	7	49	0	0
9	.0000	8	64	0	0
10	.0000	9	81	0	0

NO=21 NX=19

LOG OF FIRST LEVEL= -.58004 D= .010

AO= 29 AX= 45

BO= 59 BX= 125

MO= .90249 MX= .96953

MEANO= -.56123 MEANX= -.56136

SIGMO= .01546 SIGMX= .01662 SIGMA= .01602

S= 1.60226 G= .965 G*G= .970113

H= 1.609 H*H= 2.588239

CONFIDENCE INTERVAL= .03136

LOG OF 99.9%(95%CONF)= -.46040 99.9%(95%CONF)= .331 AMPS

LOG OF MEAN(50%)LEVEL= -.56129 MEAN(50%)= .275 AMPS

LOG OF 0.1%(95%CONF) = -.64218 0.1%(95%CONF)= .228 AMPS

V A L I D I T Y T E S T S

EQUALITY OF OCCURRENCE -OK

NO. OF RUNS- 26

LENGTH OF RUNS- 4

```
                                      * * * B R U C E T O N     A N A L Y S I S * * *

                DATA-DC TEST DC DUDDED CAP D PROJECT C3102 TEST 2352

          FUNCT.         L E V E L S           LEVEL  STIMULUS                                          V A L I D I T Y   T E S T S
SER. RES. TIMES.
NO. (OHMS) ( SEC)        1 2 3 4 5 6 7 8 9 10   NO.    (AMPS )      I    I*I     NO      NX
                    1          X
                    2        O                   1      .2880+00     0     0      2       0          EQUALITY OF
                    3          O
                    4            X               2      .2947+00     1     1      3       2          OCCURRENCE -OK
                    5          X
                    6        O                   3      .3016+00     2     4      8       4
                    7          X
                    8        O                   4      .3086+00     3     9      5       9          NO. OF RUNS- 21
                    9          X
                   10        X                   5      .3158+00     4    16      1       5
                   11      O
                   12        O                   6      .3231+00     5    25      0       1          LENGTH OF
                   13          X
                   14        O                   7      .0000        6    36      0       0                RUNS-  4
                   15          O
                   16            X               8      .0000        7    49      0       0
                   17          O
                   18            X               9      .0000        8    64      0       0
                   19          X
                   20        X                  10      .0000        9    81      0       0
                   21      X
                   22    O                                                   NO=19  NX=21
                   23      O
                   24        O                    LOG OF FIRST LEVEL= -.54061  D=  .010
                   25          X
                   26        O                    AO=    58          AX=   62
                   27          O
                   28            O                BO=    96          BX=  204
                   29              X
                   30            X                MO= 1.05263        MX=  .99773
                   31          X
                   32        O                    MEANO= -.51561  MEANX= -.51609
                   33          O
                   34            X                SIGMO=  .01800  SIGMX=  .01704  SIGMA=  .01751
                   35          X
                   36        X                    S= 1.75058          G=  .961     G*G=   .962823
                   37      X
                   38    O                        H= 1.661          H*H=  2.759764
                   39      O
                   40        X                    CONFIDENCE   INTERVAL=  .03535

                                                  LOG OF 99.9%(95%CONF)= -.42642   99.9%(95%CONF)=     .375 AMPS

                                                  LOG OF MEAN(50%)LEVEL= -.51586          MEAN(50%)=     .305 AMPS

                                                  LOG OF 0.1%(95%CONF) = -.60531   0.1%(95%CONF)=     .248 AMPS
```

```
                        * * * B R U C E T O N    A N A L Y S I S * * *

                 DATA.DC TEST RF DUDDED CAP D PROJECT C3102 TEST 2555

            FUNCT.     L E V E L S          LEVEL  STIMULUS                                  V A L I D I T Y   T E S T S
SEN. RES.   TIMES.
NO. (OHMS)  ( SEC)     1 2 3 4 5 6 7 8 9 10  NO.   (AMPS )      I   I*I    NO     NX
                  1    O
                  2      X                    1     .2750+00    0    0      7      0           EQUALITY OF
                  3    O
                  4      X                    2     .2814+00    1    1      5      6           OCCURRENCE -OK
                  5    O
                  6      O                    3     .2860+00    2    4      6      5
                  7        X
                  8      X                    4     .2947+00    3    9      2      6           NO. OF RUNS- 23
                  9    O
                 10      X                    5     .3015+00    4   16      0      2
                 11    O
                 12      O                    6     .0000       5   25      0      0           LENGTH OF
                 13        X
                 14      O                    7     .0000       6   36      0      0              RUNS-  4
                 15        O
                 16          X                8     .0000       7   49      0      0
                 17        X
                 18      X                    9     .0000       8   64      0      0
                 19    O
                 20      O                   10     .0000       9   81      0      0
                 21        O
                 22          O                                        NO=20  NX=19
                 23            X
                 24          X                LOG OF FIRST LEVEL= -.56067  D=  .010
                 25        X
                 26      O                    AO=   23            AX=   42
                 27        O
                 28          X                BO=   47            BX=  112
                 29        O
                 30          O                MO= 1.02750         MX= 1.00831
                 31            X
                 32          X                MEANO= -.54417  MEANX= -.54356
                 33        O
                 34          X                SIGMO=  .01755  SIGMX=  .01726  SIGMA=  .01742
                 35        O
                 36          X                S= 1.74168          G=  .981     G*G=   .963260
                 37        X
                 38      X                    H= 1.658          H*H=  2.749391
                 39    O
                                              CONFIDENCE   INTERVAL=  .02560

                                              LOG OF 99.9%(95%CONF)= -.45446   99.9%(95%CONF)=    .351 AMPS

                                              LOG OF MEAN(50%)LEVEL= -.54386        MEAN(50%)=    .286 AMPS

                                              LOG OF 0.1%(95%CONF) = -.63329    0.1%(95%CONF)=    .233 AMPS
```

*** * * B R U C E T O N   A N A L Y S I S * * ***

DATA,RF-2309,1.57HZ,P-P,10SEC.BLAS.CAP NO.D.C3102-01,4-17-72

SER. NO.	RES. (OHMS)	FUNCT. TIMES. (SEC)	1	2	3	4	5	6	7	8	9	10
1								X				
2							O					
3								O				
4									X			
5								X				
6							O					
7								X				
8							X					
9						X						
10					X							
11				O								
12					X							
13				O								
14					X							
15				O								
16					O							
17						O						
18							X					
19						X						
20					X							
21				O								
22					O							
23						O						
24							O					
25								X				
26							X					
27						X						
28					O							
29						X						
30					O							
31						O						
32							X					
33						X						
34					X							
35				X								
36			O									
37				X								
38			O									
39				O								
40					O							
41						X						
42					X							
43				O								
44					O							
45						X						
46					O							
47						X						
48					X							
49				O								
50					X							

LEVEL NO.	STIMULUS (WATTS)	I	I*I	NO	NX
1	.1180+00	0	0	2	0
2	.1207+00	1	1	7	2
3	.1236+00	2	4	7	8
4	.1264+00	3	9	3	8
5	.1294+00	4	16	3	4
6	.1324+00	5	25	1	4
7	.1355+00	6	36	0	1
8	.0000	7	49	0	0
9	.0000	8	64	0	0
10	.0000	9	81	0	0
				NO=23	NX=27

LOG OF FIRST LEVEL= -.92812 D= .010

AO= 47 AX= 84

BO= 135 BX= 306

MO= 1.69376 MX= 1.65432

MEANO= -.90269 MEANX= -.90201

SIGMO= .02854 SIGMX= .02779 SIGMA= .02814

S= 2.81352 G= .955 G*G= .911379

H= 2.015 H*H= 4.061435

CONFIDENCE INTERVAL= .06067

LOG OF 99.9%(95%CONF)= -.75471 99.9%(95%CONF)= .176 WATTS

LOG OF MEAN(50%)LEVEL= -.90232 MEAN(50%)= .125 WATTS

LOG OF 0.1%(95%CONF) =-1.04993 0.1%(95%CONF)= .089 WATTS

V A L I D I T Y   T E S T S

EQUALITY OF OCCURRENCE -OK

NO. OF RUNS- 27

LENGTH OF RUNS- 4

```
                                  * * * B R U C E T O N    A N A L Y S I S * * *

                        DATA,RF2310,1.5MHZ,P-C,10SEC.BLAS.CAP NO D C3102-01,4-18-72

             FUNCT.      L E V E L S          LEVEL  STIMULUS                                         V A L I D I T Y   T E S T S
SER. RES.    TIMES.
NO. (OHMS)   ( SEC)      1 2 3 4 5 6 7 8 9 10  NO.    (WATTS)     I   I*I    NO     NX
                    1          X
                    2        X                  1      .7800-01   0    0      5      0             EQUALITY OF
                    3      O
                    4        X                  2      .8168-01   1    1      9      5             OCCURRENCE -OK
                    5      X
                    6    O                      3      .8552-01   2    4      7      9
                    7      O
                    8        X                  4      .8956-01   3    9      4      7             NO. OF RUNS- 31
                    9      X
                   10    O                      5      .9378-01   4   16      0      4
                   11      O
                   12        O                  6      .0000      5   25      0      0             LENGTH OF
                   13          O
                   14            X              7      .0000      6   36      0      0                   RUNS-  4
                   15          O
                   16            X              8      .0000      7   49      0      0
                   17          X
                   18        O                  9      .0000      8   64      0      0
                   19          X
                   20        X                 10      .0000      9   81      0      0
                   21      X
                   22    O                                                NO=25  NX=25
                   23      X
                   24    O                     LOG OF FIRST LEVEL=-1.10791  D=  .020
                   25      O
                   26        X                 AO=   35            AX=   60
                   27      X
                   28    O                     BO=   73            BX=  168
                   29      O
                   30        O                 MO=  .96000         MX=  .96000
                   31          X
                   32        O                 MEANO=-1.06991  MEANX=-1.06991
                   33          X
                   34        X                 SIGMO=  .03270  SIGMX=  .03270  SIGMA=  .03270
                   35      O
                   36        X                 S= 1.63522           G=  .984     G*G=   .968491
                   37      O
                   38        X                 H= 1.621          H*H=  2.626083
                   39      O
                   40        X                 CONFIDENCE   INTERVAL=  .05713
                   41      O
                   42        O                 LOG OF 99.9%(95%CONF)= -.91173   99.9%(95%CONF)=     .123 WATTS
                   43          O
                   44            X             LOG OF MEAN(50%)LEVEL=-1.06991         MEAN(50%)=     .085 WATTS
                   45          X
                   46        O                 LOG OF 0.1%(95%CONF) =-1.22809    0.1%(95%CONF)=     .059 WATTS
                   47          X
                   48        O
                   49          O
                   50            X
```

```
                              * * * B R U C E T O N     A N A L Y S I S * * *

                  DATA.DC TEST.10 SEC.CAP E,PROJECT C3102 TEST 2557

         FUNCT.       L E V E L S        LEVEL  STIMULUS                                  V A L I D I T Y   T E S T S
SER. RES. TIMES.
NO. (OHMS) (.SEC)     1 2 3 4 5 6 7 8 9 10  NO.   (AMPS )    I   I*I    NO    NX
              1                     X
              2                   O          1   .2690+00   0    0     1     0          EQUALITY OF
              3                     X
              4                   X          2   .2753+00   1    1     1     1          OCCURRENCE -OK
              5                 O
              6                   X          3   .2817+00   2    4     1     1
              7                 O
              8                   O          4   .2882+00   3    9     5     1          NO. OF RUNS- 29
              9                     X
             10                   O          5   .2950+00   4   16     5     5
             11                     X
             12                   O          6   .3018+00   5   25     5     6          LENGTH OF
             13                     X
             14                   X          7   .3089+00   6   36     5     6             RUNS-  4
             15                 X
             16               O              8   .3160+00   7   49     0     6
             17                 X
             18               O              9   .0000      8   64     0     6
             19                 X
             20               X             10   .0000      9   81     0     0
             21             O
             22               O                                     NO=23  NX=26
             23                 X
             24               X              LOG OF FIRST LEVEL= -.57025  D=  .010
             25             O
             26               X              AO=   93          AX=  134
             27             X
             28           X                  BO=  435          BX=  754
             29         X
             30       O                      MO= 2.56333       MX= 2.43787
             31         O
             32           O                  MEANO= -.52482  MEANX= -.52371
             33             O
             34               X              SIGMO=  .04294  SIGMX=  .04075  SIGMA=  .04179
             35             O
             36               O              S= 4.17945         G=  .921     G*G=   .847346
             37                 X
             38               X              H= 2.414         H*H=  5.826820
             39             O
             40               O              CONFIDENCE   INTERVAL=  .10669
             41                 O
             42                   X          LOG OF 99.9%(95%CONF)= -.28639   99.9%(95%CONF)=     .517 AMPS
             43                 O
             44                   X          LOG OF MEAN(50%)LEVEL= -.52423         MEAN(50%)=     .299 AMPS
             45                 O
             46                   O          LOG OF 0.1%(95%CONF) = -.76207    0.1%(95%CONF)=     .173 AMPS
             47                     X
             48                   X
             49                 X
```

* * * BRUCETON ANALYSIS * * *

DATA.DC TEST DC DUDDED CAP E PROJECT C3102 TEST 2369

SER. NO.	RES. (OHMS)	FUNCT. TIMES. (SEC)		LEVELS 1	2	3	4	5	6	7	8	9	10
			1		O								
			2			X							
			3		O								
			4			X							
			5		O								
			6			O							
			7				X						
			8			X							
			9		X								
			10	O									
			11		O								
			12			O							
			13				O						
			14					O					
			15						X				
			16					X					
			17				O						
			18					O					
			19						O				
			20							X			
			21						X				
			22					X					
			23				O						
			24					X					
			25				O						
			26					X					
			27				X						
			28			O							
			29				O						
			30					X					
			31				O						
			32					X					
			33				X						
			34			O							
			35				X						
			36			X							
			37		O								
			38			O							
			39				O						
			40					X					
			41				X						
			42			X							
			43		O								
			44			O							

LEVEL NO.	STIMULUS (AMPS)	I	I*I	NO.	NX
1	.2820+00	0	0	1	0
2	.2886+00	1	1	6	1
3	.2953+00	2	4	6	5
4	.3022+00	3	9	7	5
5	.3092+00	4	16	2	7
6	.3164+00	5	25	1	2
7	.3238+00	6	36	0	1
8	.0000	7	49	0	0
9	.0000	8	64	0	0
10	.0000	9	81	0	0

NO=23 NX=21

LOG OF FIRST LEVEL= -.54975 D= .010

AO= 52 AX= 70

BO= 150 BX= 264

MO= 1.41021 MX= 1.46032

MEANO= -.52214 MEANX= -.52142

SIGMO= .02384 SIGMX= .02472 SIGMA= .02426

S= [illegible]2649 G= .964 G*G= .929947

H= 1.891 H*H= 3.575250

CONFIDENCE INTERVAL= .05271

LOG OF 99.9%(95%CONF)= -.39411 99.9%(95%CONF)= .404 AMPS

LOG OF MEAN(50%)LEVEL= -.52180 MEAN(50%)= .301 AMPS

LOG OF 0.1%(95%CONF) = -.64948 0.1%(95%CONF)= .224 AMPS

VALIDITY TESTS

EQUALITY OF OCCURRENCE -OK

NO. OF RUNS- 23

LENGTH OF RUNS- 5

```
                         * * * B R U C E T O N   A N A L Y S I S * * *

                   DATA.DC TEST RF DUDDED CAP 5 PROJECT C3102 TEST 2339

           FUNCT.        L E V E L S        LEVEL  STIMULUS                                   V A L I D I T Y   T E S T S
SER. RES.  TIMES.
NO. (OHMS) ( SEC)     1 2 3 4 5 6 7 8 9 10  NO.    (AMPS )     I   I*I    NO     NY
              1           X
              2         O                    1     .2754+00    0    0     4      0          EQUALITY OF
              3           O
              4             O                2     .2818+00    1    1     8      4          OCCURRENCE -OK
              5               X
              6             O                3     .2884+00    2    4     4      8
              7               X
              8             O                4     .2951+00    3    9     7      4          NO. OF RUNS- 25
              9               X
             10             X                5     .3020+00    4   16     1      7
             11           O
             12             O                6     .3090+00    5   25     0      1          LENGTH OF
             13               X
             14             X                7     .0000       6   36     0      0                RUNS-  5
             15           X
             16         O                    8     .0000       7   49     0      0
             17           X
             18         X                    9     .0000       8   64     0      0
             19       O
             20         O                   10     .0000       9   81     0      0
             21           O
             22             O                                         NO=24  NX=24
             23               X
             24             O               LOG OF FIRST LEVEL= -.56004  D=  .010
             25               O
             26                 X           AO=   41          AX=   65
             27               X
             28             X               BO=  103          BX=  209
             29           X
             30         X                   MO= 1.37326       MX= 1.37326
             31       O
             32         O                   MEANO= -.53796  MEANX= -.53796
             33           X
             34         X                   SIGMO=  .02321  SIGMX=  .02321  SIGMA=  .02321
             35       O
             36         O                   S= 2.32053          G=  .967     G*G=    .935064
             37           X
             38         O                   H= 1.856          H*H=  3.444246
             39           X
             40         X                   CONFIDENCE   INTERVAL=  .04722
             41       O
             42         O                   LOG OF 99.9%(95%CONF)= -.41993   99.9%(95%CONF)=    .381 AMPS
             43           X
             44         O                   LOG OF MEAN(50%)LEVEL= -.53796          MEAN(50%)=    .290 AMPS
             45           O
             46             O               LOG OF 0.1%(95%CONF) = -.65698   0.1%(95%CONF)=    .220 AMPS
             47               X
             48             X
```

* * * BRUCETON ANALYSIS * * *

DATA,RF2381 10 MHZ P-P 10 SEC. BIAS CAP. E C3102-01 7-21-72

SER. RES. NO. (OHMS) | FUNCT. TIMES. (SEC)

LEVELS	1	2	3	4	5	6	7	8	9	10
1					X					
2				X						
3			O							
4				O						
5					X					
6				O						
7					X					
8				X						
9			O							
10				O						
11					O					
12						X				
13					X					
14				O						
15					X					
16				X						
17			O							
18				X						
19			X							
20		O								
21			X							
22		O								
23			X							
24		X								
25	O									
26		O								
27			X							
28		O								
29			X							
30		O								
31			O							
32				X						
33			X							
34		X								
35	O									
36		O								
37			O							
38				X						
39			X							
40		O								
41			O							
42				X						
43			X							
44		X								
45	O									
46		O								
47			O							
48				X						
49			O							
50				X						

LEVEL NO.	STIMULUS (WATTS)	I	I*I	NO	NX
1	.1322+00	0	0	3	0
2	.1384+00	1	1	8	3
3	.1450+00	2	4	8	8
4	.1518+00	3	9	4	9
5	.1589+00	4	16	1	5
6	.1664+00	5	25	0	1
7	.0000	6	36	0	0
8	.0000	7	49	0	0
9	.0000	8	64	0	0
10	.0000	9	81	0	0

NO=24 NX=26

LOG OF FIRST LEVEL= -.87877 D= .020

AO= 40 AX= 71

BO= 92 BX= 221

MO= 1.05556 MX= 1.04290

MEANO= -.83544 MEANX= -.83415

SIGMO= .03590 SIGMX= .03542 SIGMA= .03565

S= 1.78238 G= .960 G*G= .961264

H= 1.672 H*H= 2.796933

CONFIDENCE INTERVAL= .06418

LOG OF 99.9%(95%CONF)= -.66044 99.9%(95%CONF)= .219 WATTS

LOG OF MEAN(50%)LEVEL= -.83477 MEAN(50%)= .146 WATTS

LOG OF 0.1%(95%CONF) =-1.00910 0.1%(95%CONF)= .098 WATTS

VALIDITY TESTS

EQUALITY OF OCCURRENCE -OK

NO. OF RUNS- 29

LENGTH OF RUNS- 3

```
                          * * * U P U C E T O N   A N A L Y S I S * * *

                DATA,RF23BL 2.76C PL I-C 10SEC DUAL.CAP  E  C3102-01 7-27-72

              FUNCT.      L E V E L S          LEVEL  STIMULUS                                   V A L I D I T Y   T E S T S
  SER. RES.   TIMES.
  NO. (OHMS)  ( SEC)      1 2 3 4 5 6 7 8 9 10  NO.    (WATTS)     I   I*I    NO    NX
                    1         O
                    2           X               1     .1335+01     0    0      4     0          EQUALITY OF
                    3         O
                    4           O               2     .1498+01     1    1      5     4          OCCURRENCE -OK
                    5             O
                    6               X           3     .1681+01     2    4      8     5
                    7             X
                    8           X               4     .1886+01     3    9      5     6          NO. OF RUNS- 26
                    9         X
                   10       X                   5     .2116+01     4   16      3     5
                   11     O
                   12       O                   6     .2374+01     5   25      0     3          LENGTH OF
                   13         O
                   14           O               7     .0000        6   36      0     0              RUNS-  5
                   15             X
                   16           X               8     .0000        7   49      0     0
                   17         O
                   18           X               9     .0000        8   64      0     0
                   19         X
                   20       X                  10     .0000        9   81      0     0
                   21     O
                   22       O                                              NO=25  NX=25
                   23         O
                   24           O               LOG OF FIRST LEVEL=  .12548  D=  .050
                   25             O
                   26               X           AO=   48          AX=   73
                   27             O
                   28               X           BO=  130          BX=  251
                   29             X
                   30           O               MO= 1.51360       MX= 1.51360
                   31             X
                   32           X               MEANO=  .24648  MEANX=  .24648
                   33         X
                   34       O                   SIGMO=  .12753  SIGMX=  .12753  SIGMA=  .12753
                   35         X
                   36       X                   S= 2.55054          G=  .961     G*G=   .923975
                   37     O
                   38       X                   H= 1.931          H*H=  3.729852
                   39     O
                   40       O                   CONFIDENCE   INTERVAL=  .26385
                   41         X
                   42       O                   LOG OF 99.9%(95%CONF)=  .90439   99.9%(95%CONF)=   8.024 WATTS
                   43         O
                   44           X               LOG OF MEAN(50%)LEVEL=  .24648          MEAN(50%)=   1.764 WATTS
                   45         O
                   46           O               LOG OF 0.1%(95%CONF) = -.41143   0.1%(95%CONF)=    .388 WATTS
                   47             X
                   48           X
                   49         O
                   50           X
```

* * * B R U C E T O N   A N A L Y S I S * * *

DATA,DC TEST,10 SEC,CAP F,PROJECT C3102 TEST 2558

SER. NO.	RES. (OHMS)	FUNCT. TIMES (SEC)	TRIAL	1	2	3	4	5	6	7	8	9	10
			1					O					
			2						X				
			3					O					
			4						X				
			5					X					
			6				O						
			7					X					
			8				O						
			9					X					
			10				X						
			11			O							
			12				O						
			13					O					
			14						X				
			15					X					
			16				O						
			17					X					
			18				X						
			19			O							
			20				X						
			21			X							
			22		O								
			23			O							
			24				X						
			25			X							
			26		O								
			27			X							
			28		O								
			29			X							
			30		O								
			31			O							
			32				X						
			33			O							
			34				X						
			35			X							
			36		O								
			37			O							
			38				O						
			39					O					
			40						X				
			41					X					
			42				X						
			43			O							
			44				X						
			45			O							
			46				X						
			47			X							
			48		O								
			49			O							

LEVEL NO.	STIMULUS (AMPS)	I	I*I	NO	NX
1	.2950+00	0	0	0	0
2	.3019+00	1	1	6	0
3	.3089+00	2	4	9	6
4	.3161+00	3	9	5	9
5	.3235+00	4	16	4	6
6	.0000	5	25	0	0
7	.0000	6	36	0	0
8	.0000	7	49	0	0
9	.0000	8	64	0	0
10	.0000	9	81	0	0

NO=24   NX=21

LOG OF FIRST LEVEL= -.53016   D= .010

AO= 55   AX= 63

BO= 151   BX= 201

MO= 1.03993   MX= .57143

MEANO= -.50226   MEANX= -.50516

SIGMO= .01769   SIGMX= .00997   SIGMA= .01460

S= 1.46028   G= .986   G*G= .977116

T= 1.558   H*H= 2.427010

CONFIDENCE INTERVAL= .02600

LOG OF 99.9%(95%CONF)= -.46250   99.9%(95%CONF)= .369 AMPS

LOG OF MEAN(50%)LEVEL= -.50562   MEAN(50%)= .314 AMPS

LOG OF 0.1%(95%CONF) = -.57475   0.1%(95%CONF)= .266 AMPS

V A L I D I T Y   T E S T S

EQUALITY OF OCCURRENCE -OK

NO. OF RUNS- 31

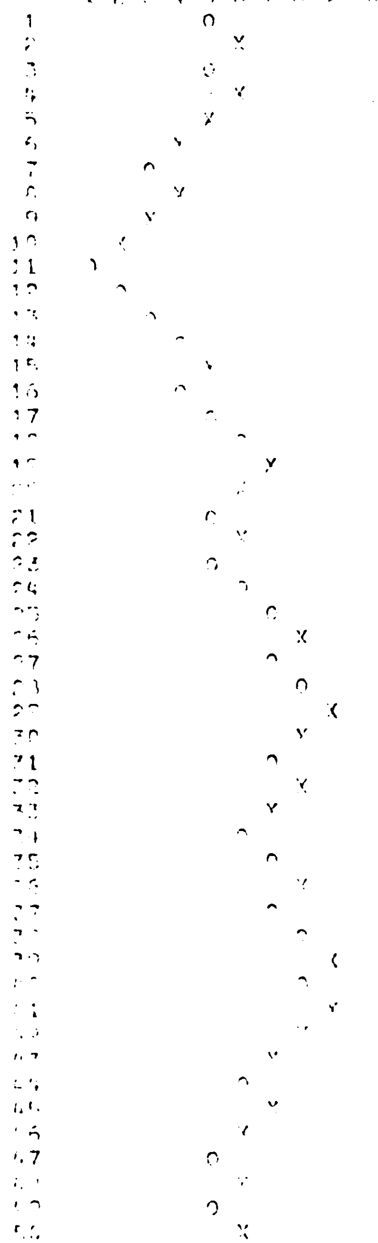
LENGTH OF RUNS- 4

```
                              * * * B R U C E T O N     A N A L Y S I S * * *

                   DATA,DC TEST DC DUDDED CAP F PROJECT C 3102 TEST 2371

            FUNCT.        L E V E L S            LEVEL  STIMULUS                                        V A L I D I T Y   T E S T S
SER. RES.   TIMES.
NO. (OHMS)  ( SEC)      1 2 3 4 5 6 7 8 9 10    NO.     (AMPS )     I    I*I     NO      NX
                    1           X
                    2         O                  1      .2950+00    0     0      2       0          EQUALITY OF
                    3           O
                    4             X              2      .3019+00    1     1      4       3          OCCURRENCE -OK
                    5           O
                    6             X              3      .3089+00    2     4      7       5
                    7           X
                    8         O                  4      .3161+00    3     9      3       8          NO. OF RUNS- 23
                    9           O
                   10             X              5      .3235+00    4    16      3       4
                   11           X
                   12         X                  6      .3310+00    5    25      0       3          LENGTH OF
                   13       X
                   14     O                      7      .0000       6    36      0       0                RUNS-  4
                   15       O
                   16         X                  8      .0000       7    49      0       0
                   17       X
                   18     X                      9      .0000       8    64      0       0
                   19   O
                   20     O                     10      .0000       9    81      0       0
                   21       X
                   22     X                                                  NO=19  NX=23
                   23   O
                   24     O                      LOG OF FIRST LEVEL= -.53018  D=  .010
                   25       O
                   26         X                  AO=   39            AX=   66
                   27       O
                   28         X                  BO=  107            BX=  234
                   29       X
                   30     O                      MO= 1.41828         MX= 1.43289
                   31       O
                   32         X                  MEANO= -.50465  MEANX= -.50561
                   33       O
                   34         O                  SIGMO=  .02409  SIGMX=  .02421  SIGMA=  .02416
                   35           X
                   36         X                  S= 2.41578             G=  .965     G*G=   .930464
                   37       O
                   38         X                  H= 1.887            H*H=  3.561962
                   39       O
                   40         X                  CONFIDENCE   INTERVAL=  .05573
                   41       X
                   42     X                      LOG OF 99.9%(95%CONF)= -.37681   99.9%(95%CONF)=    .420 AMPS

                                                 LOG OF MEAN(50%)LEVEL= -.50518         MEAN(50%)=    .312 AMPS

                                                 LOG OF 0.1%(95%CONF) = -.63355    0.1%(95%CONF)=    .233 AMPS
```

* * * B R U C E T O N   A N A L Y S I S * * *

DATA,DC TEST OF BUDDED CABLE PROJECT C3102 TEST 2390

SER. RES. NO. (OHMS) | FU ST. TI TS. (SEC) | LEVELS 1 2 3 4 5 6 7 8 9 10



LEVEL Q.	STIMULUS (AMPS)	I	I*I	NO	NX
1	.2630+00	0	0	1	0
2	.2591+00	1	1	1	1
3	.2754+00	2	4	2	1
4	.2912+00	3	9	2	2
5	.2888+00	4	16	7	2
6	.2951+00	5	25	4	7
7	.3020+00	6	36	5	4
8	.3090+00	7	49	3	5
9	.3162+00	8	64	0	7
10	.0000	9	81	0	0

NO=25 NX=25

LOG OF FIRST LEVEL= -.59004 D= .010

AO= 110   AX= 135

BO= 566   BX= 811

MO= 3.28000   MX= 3.28000

MEANO= -.53104 MEANX= -.53104

SIGMO= .05471 SIGMX= .05471 SIGMA= .05471

S= 5.47112   G= .900   G*C= .810000

H= 2.732   H*H= 7.465306

CONFIDENCE INTERVAL= .15091

LOG OF 99.9%(95%CONF)= -.20297   99.9%(95%CONF)= .627 AMPS

LOG OF MEAN(50%)LEVEL= -.53104   MEAN(50%)= .294 AMPS

LOG OF 0.1%(95%CONF) = -.85911   0.1%(95%CONF)= .139 AMPS

V A L I D I T Y   T E S T S

EQUALITY OF OCCURRENCE -OK

NO. OF RUNS- 30

LENGTH OF RUNS- 4

```
                       * * * B R U C E T O N    A N A L Y S I S * * *

          DATA.RF2380 10 MHZ P-P 10 SEC. BLAS.CAP.  F  C3102-01 7-20-72

           FUNCT.      L E V E L S           LEVEL  STIMULUS                                  V A L I D I T Y   T E S T S
SER. RES.  TIMES.
NO. (OHMS) ( SEC)      1 2 3 4 5 6 7 8 9 10  NO.    (WATTS)    I   I*I   NO    NX
  1           X
  2         O                                  1    .1188+00   0    0     3     0          EQUALITY OF
  3           O
  4             X                              2    .1303+00   1    1     6     3          OCCURRENCE -OK
  5           O
  6             X                              3    .1428+00   2    4     1     6
  7           O
  8             X                              4    .1566+00   3    9     6     2          NO. OF RUNS- 30
  9           X
 10         O                                  5    .1717+00   4   16     7     7
 11           O
 12             X                              6    .1883+00   5   25     1     7          LENGTH OF
 13           X
 14         X                                  7    .2065+00   6   36     0     1               RUNS-  4
 15       X
 16     O                                      8    .0000      7   49     0     0
 17       X
 18     O                                      9    .0000      8   64     0     0
 19       X
 20     O                                     10    .0000      9   81     0     0
 21       O
 22         O                                                          NO=24  NX=26
 23           O
 24             X                            LOG OF FIRST LEVEL= -.92518  D=  .040
 25           O
 26             X                            AO=   59           AX=   90
 27           X
 28         O                                BO=  201           BX=  368
 29           X
 30         O                                MO= 2.33160        MX= 2.17160
 31           O
 32             O                            MEANO= -.80685  MEANX= -.80672
 33               X
 34             X                            SIGMO=  .15626  SIGMX=  .14542  SIGMA=  .15072
 35           X
 36         O                                S= ..75601           G=  .931     G*G=   .866388
 37           X
 38         X                                H= 2.300           H*H=  5.292279
 39       X
 40     O                                    CONFIDENCE   INTERVAL=  .36986
 41       X
 42     X                                    LOG OF 99.9%(95%CONF)=  .02881   99.9%(95%CONF)=   1.069 WATTS
 43   O
 44     O                                    LOG OF MEAN(50%)LEVEL= -.80678         MEAN(50%)=    .156 WATTS
 45       X
 46     X                                    LOG OF 0.1%(95%CONF) =-1.64237    0.1%(95%CONF)=    .023 WATTS
 47   O
 48     X
 49   O
 50     O
```

* * * B R U C E T O N   A N A L Y S I S * * *

DATA,RE,2366,C3102,CAP F P-C,5.4GL P,1000PPS,PW=1 ,11-17-72

```
              FUNCT.     L E V E L S            LEVEL  STIMULUS                                V A L I D I T Y   T E S T S
SER. RES.     TIMES.
NO. (OHMS)    ( SEC)     1 2 3 4 5 6 7 8 9 10   NO.    (WATTS)     I   I*I    NO    NX
                    1          X
                    2        X                   1    .1813+00     0    0      1     0      EQUALITY OF
                    3      O
                    4        O                   2    .1993+00     1    1      3     1      OCCURRENCE -OK
                    5          O
                    6            X               3    .2186+00     2    4      4     4
                    7          X
                    8        X                   4    .2397+00     3    9      6     5      NO. OF RUNS- 22
                    9      O
                   10        O                   5    .2628+00     4   16      5     6
                   11          O
                   12            X               6    .2881+00     5   25      5     5      LENGTH OF
                   13          X
                   14        O                   7    .3159+00     6   36      0     5               RUNS-  5
                   15          O
                   16            O               8    .0000        7   49      0     0
                   17              O
                   18                X           9    .0000        8   64      0     0
                   19              X
                   20            X              10    .0000        9   81      0     0
                   21          O
                   22            O                                        NO=24  NX=26
                   23              X
                   24            X               LOG OF FIRST LEVEL= -.74041   D=  .040
                   25          O
                   26            X               AO=  74            AX=  103
                   27          X
                   28        X                   BO=  278           BX=  463
                   29      O
                   30        O                   MO= 2.07639        MX= 2.11391
                   31          O
                   32            O               MEANO= -.59708   MEANX= -.60195
                   33              O
                   34                X           SIGMO=  .13936   SIGMX=  .14161   SIGMA=  .14054
                   35              X
                   36            O               S= 3.51341           G=  .937      G*G=   .878278
                   37              O
                   38                X           H= 2.227           H*H=  4.961537
                   39              O
                   40                X           CONFIDENCE   INTERVAL=  .33415
                   41              O
                   42                X           LOG OF 99.9%(95%CONF)=  .16880    99.9%(95%CONF)=   1.475 WATTS
                   43              X
                   44            O               LOG OF MEAN(50%)LEVEL= -.59961         MEAN(50%)=    .251 WATTS
                   45              X
                   46            X               LOG OF 0.1%(95%CONF) =-1.36802    0.1%(95%CONF)=    .043 WATTS
                   47          X
                   48        X
                   49      X
                   50    O
```

Appendix

C

RF PROBING TEST RESULTS

This appendix presents the results of the RF probing tests. Exposures were commonly made for 10 seconds unless otherwise noted. The tests were not performed in any particular order. The test numbers indicate the order in which the tests were performed. For example, PROP TEST #2204 (which is real probing test #2204) occurred before any test of higher number.

The RF Probing Test Results are given for each cap tested in the following tables. The test results for each cap are grouped together. Each table is headed by our laboratory record book RF Probing Test Number. An X (or fire) result is to be interpreted as the result of the application of the associated RF power. An 0 indicates a no-fire response. In many cases a cap that fired had been exposed to lower powers of the same modulation and frequency type so that the tables really record the maximum power applied to each cap. Each probing test used virgin caps.

PROB. TEST # 2372
CAP # F
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
2.5	X
3.0	X
3.0	X
3.0	X
3.5	X
4.0	X
4.0	X
4.0	X
5.0	X
5.0	X

COMMENTS:

PROB. TEST # 2377
CAP # F
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Pin
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
1.5	X
1.75	X
1.75	X
2.5	X
3.0	X
3.0	X
3.0	X
3.0	X
3.0	X
10.0	X

COMMENTS: Arcing

PROB. TEST #
CAP #
FREQUENCY - MHz
FIRING MODE -
MODULATION -

AVE. POWER WATTS	RESULT X = FIRE 0=NO

COMMENTS:

PROB. TEST # 2375
CAP # F
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
8.0	X
10.0	X
10.0	X
13.0	X
13.0	X
15.0	X
19.0	X
19.0	X

COMMENTS:

PROB. TEST # 2378
CAP # F
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Case
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
1.5	X
2.0	X
2.0	X
3.0	X
10.0	0
10.0	0
15.0	0
15.0	0
15.0	0
15.0	0

COMMENTS: Arcing

PROB. TEST #
CAP #
FREQUENCY - MHz
FIRING MODE -
MODULATION -

AVE. POWER WATTS	RESULTS X = FIRE 0=NO

COMMENTS:

PROB. TEST # 2322
CAP # F
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.600	X
0.600	X
0.700	X
0.750	X
0.800	X
0.800	X
1.0	X
1.0	X
1.0	X
4.0	X

COMMENTS:

PROB. TEST # 2326
CAP # F
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Pin
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.600	X
0.650	X
0.650	X
0.700	X
0.700	X
0.700	X
0.800	X
0.900	X
0.900	0
0.900	X

COMMENTS: Arcing

PROB. TEST # 2314
CAP # F
FREQUENCY - 1.5 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.275	X
0.300	X
0.300	X
0.300	X
0.350	X
0.350	X
0.350	X
0.350	X
0.500	X
0.500	X

COMMENTS:

PROB. TEST # 2325
CAP # F
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
10.0	X
10.0	X
12.0	X
20.0	X
20.0	0
20.0	0
20.0	0
30.0	X

COMMENTS:

PROB. TEST # 2329
CAP # F
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Case
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0

COMMENTS: Arcing

PROB. TEST # 2316
CAP # F
FREQUENCY - 1.5 MH
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULTS X = FIRE 0=NO
2.0	0
3.2	0
3.2	0
4.0	0
4.0	X
4.0	0
4.0	0
4.0	X
4.0	X
4.0	0

COMMENTS: All misfires had a short

PROB. TEST # 2323
CAP # E
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE O=NO
0.600	X
0.700	X
0.700	X
0.750	X
0.800	X
0.800	X
0.800	X
0.800	X
0.850	X
0.900	X

COMMENTS:

PROB. TEST # 2327
CAP # E
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Pin
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE O=NO
0.550	X
0.550	X
0.550	X
0.600	X
0.650	X
0.800	X
0.900	X
0.900	X
0.900	X
0.900	X

COMMENTS:

PROB. TEST # 2319
CAP # E
FREQUENCY - 10 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE O=NO
0.175	X
0.175	X
0.175	X
0.175	X
0.175	X
0.200	X
0.200	X

COMMENTS:

PROB. TEST # 2324
CAP # E
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE O=NO
5.0	X
6.0	X
7.0	X
8.5	X
10.0	X
15.0	X
15.0	X
15.0	O
15.0	O
15.0	O

COMMENTS:

PROB. TEST # 2328
CAP # E
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Case
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE O=NO
1.75	X
1.75	X
2.0	X
2.0	X
3.0	X
3.0	X
4.0	X
4.0	X
4.0	X
4.0	X

COMMENTS: Arcing

PROB. TEST # 2320
CAP # E
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULTS X = FIRE O=NO
6.0	O
6.0	O
6.0	O
6.0	O
6.0	O
6.0	O
6.0	O
6.0	O

COMMENTS:

PROB. TEST # 2339
CAP # F
FREQUENCY - 150 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.200	X
0.200	X
0.250	X
0.250	X
0.275	X
0.300	X
0.300	X
0.325	X
0.400	X
0.400	X

COMMENTS:

PROB. TEST # 2347
CAP # F
FREQUENCY - 0.088 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.140	X
0.140	X
0.140	X
0.140	X
0.150	X
0.150	X
0.190	X
0.190	X

COMMENTS:

PROB. TEST # 2318
CAP # F
FREQUENCY - 10 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.150	X
0.150	X
0.175	X
0.175	X
0.175	X
0.175	X
0.200	X
0.200	X
0.200	X
0.300	X

COMMENTS:

PROB. TEST # 2340
CAP # F
FREQUENCY - 150 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
5.0	0
5.0	0
5.0	0
5.0	0
5.0	0
5.0	0
5.0	0
5.0	0
5.0	0
5.0	0

COMMENTS:

PROB. TEST #
CAP # F
FREQUENCY - 0.088 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO

COMMENTS: Could not fire but it was above other low fires

PROB. TEST # 2321
CAP # F
FREQUENCY - 10 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULTS X = FIRE 0=NO
3.5	0 *
5.0	0
5.0	0
5.0	0
5.0	0
5.0	0
5.0	0
5.0	0

COMMENTS: * Shorted

PROB. TEST # 2331
CAP # E
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
1.5	X
1.5	X
1.5	X
1.5	X
2.0	X
2.0	X
2.0	X
2.0	X

COMMENTS:

PROB. TEST # 2335
CAP # E
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Pin
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
1.0	X
1.0	X
1.25	X
1.25	X
1.25	X
1.5	X
1.5	X
1.5	X
2.0	X
2.0	X

COMMENTS: Some Arcing

PROB. TEST # 2342
CAP # E
FREQUENCY - 450 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.350	X
0.375	X
0.400	X
0.400	X
0.400	X
0.400	X
0.500	X
0.500	X

COMMENTS:

PROB. TEST # 2333
CAP # E
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
15.0	X
17.5	X
17.5	X
20.0	X
20.0	X
25.0	X
25.0	X
25.0	X

COMMENTS:

PROB. TEST # 2336
CAP # E
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Case
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
3.5	X
4.0	X
5.0	X
5.0	X
5.0	X
7.0	X
10.0	X
10.0	X
10.0	X
10.0	X

COMMENTS: Arcing

PROB. TEST # 2344
CAP # E
FREQUENCY - 450 MH
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULTS X = FIRE 0=N(
2.0	0
2.0	0
2.0	0
2.0	0
2.0	0
2.0	0
2.0	0
2.0	0
2.0	0
2.0	0

COMMENTS:

PROB. TEST # 2330
CAP # F
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
1.0	X
1.0	X
1.0	X
1.0	X
1.0	X
1.5	X
1.5	X
1.5	X

COMMENTS:

PROB. TEST # 2334
CAP # F
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Pin
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
1.0	X
1.25	X
1.25	X
1.25	X
1.5	X
1.5	X
1.5	X
1.5	X
2.0	X
2.0	X

COMMENTS: Arcing

PROB. TEST # 2343
CAP # F
FREQUENCY - 450 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.350	X
0.350	X
0.350	X
0.350	X
0.400	X
0.450	X
0.450	X
0.500	X
0.500	X
0.500	X

COMMENTS:

PROB. TEST # 2332
CAP # F
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
15.0	X
15.0	X
15.0	X
15.0	X
20.0	X
20.0	X
20.0	0
20.0	0

COMMENTS:

PROB. TEST # 2337
CAP # F
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Case
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
4.0	X
4.0	X
4.0	X
4.0	X
5.0	X
5.0	X
5.0	X
10.0	0
10.0	0
10.0	0

COMMENTS: Arcing

PROB. TEST # 2345
CAP # F
FREQUENCY - 450 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULTS X = FIRE 0=NO
2.0	0
2.0	0
2.0	0
2.0	0
2.0	0
2.0	0
2.0	0
2.0	0
2.0	0

COMMENTS:

PROB. TEST # 2338
CAP # E
FREQUENCY - 150 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.250	X
0.250	X
0.300	X
0.300	X
0.300	X
0.350	X
0.550	X
0.550	X
1.0	X
1.0	O

COMMENTS:

PROB. TEST # 2346
CAP # E
FREQUENCY - 0.088 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.130	X
0.140	X
0.140	X
0.140	X
0.146	X
0.150	X
0.190	X
0.190	X
0.190	X
0.190	X

COMMENTS:

PROB. TEST #
CAP #
FREQUENCY - MHz
FIRING MODE -
MODULATION -

AVE. POWER WATTS	RESULT X = FIRE 0=NO

COMMENTS:

PROB. TEST # 2341
CAP # E
FREQUENCY - 150 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
4.5	O
4.5	O
4.5	O
4.5	O
4.5	O
4.5	O
4.5	O
4.5	O
4.5	O
4.5	O

COMMENTS:

PROB. TEST #
CAP # E
FREQUENCY - 0.088 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO

COMMENTS: Could not fire but it was above other low fires

PROB. TEST #
CAP #
FREQUENCY - MHz
FIRING MODE -
MODULATION -

AVE. POWER WATTS	RESULTS X = FIRE 0=NC

COMMENTS:

PROB. TEST # 2204
CAP # A
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE O=NO
10.0	X
10.0	X
13.0	X
14.0	X
14.0	X
18.0	X
18.0	X
18.0	X
18.0	X
18.0	X

COMMENTS:

PROB. TEST # 2205A
CAP # A
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Pin
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE O=NO
1.5	X
2.0	X
2.0	X
3.0	X
3.0	X
4.0	X
4.0	X
4.0	X
5.0	X
6.0	X

COMMENTS: Arcing

PROB. TEST # 2209
CAP # A
FREQUENCY - 450 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE O=NO
0.275	X
0.275	X
0.300	X
0.300	X
0.300	X
0.300	X
0.350	X
0.350	X
0.400	X
0.400	X

COMMENTS:

PROB. TEST # 2205B
CAP # A
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE O=NO
20.0	X
25.0	X
25.0	X
25.0	X
25.0	X
25.0	X
25.0	X
25.0	X
25.0	X
25.0	X

COMMENTS:

PROB. TEST # 2206
CAP # A
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Case
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE O=NO
3.5	X
4.0	X
5.0	X
5.0	X
5.0	X
5.0	X
5.0	X
7.0	X
7.0	X
7.0	X

COMMENTS: Some arcing

PROB. TEST # 2230
CAP # A
FREQUENCY - 450 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULTS X = FIRE O=NO
22.0	O
22.0	O
22.0	O
22.0	O
22.0	O
22.0	O
22.0	O
22.0	O
22.0	O
22.0	O

COMMENTS:

PROB. TEST # 2242
CAP # B
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
20.0	X
25.0	O
25.0	X
25.0	X
25.0	X
25.0	X

COMMENTS:

PROB. TEST # 2245
CAP # B
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Pin
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
15.0	O
15.0	O
15.0	O
15.0	O
15.0	O
15.0	O
15.0	O
15.0	O

COMMENTS: Arcing

PROB. TEST # 2228
CAP # B
FREQUENCY - 450 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.400	X
0.400	X
0.450	X
0.475	X
0.500	X
0.500	X
0.600	X
1.2	X
1.2	X
1.2	X

COMMENTS:

PROB. TEST # 2243
CAP # B
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
20.0	X
20.0	X
25.0	X
25.0	X
25.0	X
25.0	X

COMMENTS:

PROB. TEST # 2244
CAP # B
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Case
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
5.0	X
5.0	X
5.0	X
7.5	X
7.5	X
10.0	X
10.0	X
15.0	O
15.0	X
15.0	O

COMMENTS: Arcing

PROB. TEST # 2231
CAP # B
FREQUENCY - 450 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULTS X = FIRE 0=NO
1.1	X
1.1	X
1.1	X
1.1	X
1.5	O
1.5	O
1.5	O
1.5	O
1.5	O
1.5	O

COMMENTS:

PROB. TEST # 2212
CAP # B
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
3.0	X
5.0	X
5.0	X
5.0	X
8.0	X
10.0	X
12.5	X
15.0	X
15.0	X
18.0	X
18.0	X
3= 20.0	X
24.0	X

COMMENTS:

PROB. TEST # 2210
CAP # B
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Pin
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0

COMMENTS: Arcing

PROB. TEST # 2223B
CAP # B
FREQUENCY - 10.0 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.550	X
0.550	X
0.600	X
0.600	X
0.600	X
0.600	X
0.650	X
0.700	X
0.700	X
0.950	X

COMMENTS:

PROB. TEST # 2213
CAP # B
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
9.0	X
9.0	X
10.0	X
10.0	X
10.0	X
10.0	X
10.0	X
10.0	X

COMMENTS:

PROB. TEST # 2211
CAP # B
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Case
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
5.0	X
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0

COMMENTS: Arcing

PROB. TEST # 2225
CAP # B
FREQUENCY - 10 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULTS X = FIRE 0=NO
0.500	0
0.500	0
0.500	0
0.500	0
0.500	0
0.500	0
0.500	0
0.500	0
0.500	0
0.500	0

COMMENTS:

PROB. TEST # 2232
CAP # A
FREQUENCY - 150 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.850	X
0.850	X
1.0	X
1.0	X
1.0	X
1.0	X
1.0	X
1.0	X
1.2	X
1.2	X

COMMENTS:

PROB. TEST # 2236
CAP # A
FREQUENCY - 0.088 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.123	X
0.123	X
0.123	X
0.123	X
0.123	X
0.134	X
0.155	X
0.192	X
0.192	X
0.192	X

COMMENTS:

PROB. TEST #
CAP #
FREQUENCY - MHz
FIRING MODE -
MODULATION -

AVE. POWER WATTS	RESULT X = FIRE 0=NO

COMMENTS:

PROB. TEST # 2234
CAP # A
FREQUENCY - 150 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
1.6	O
1.6	O
1.6	O
1.6	O
1.6	O
1.6	O
1.6	O
1.6	O
1.6	O
1.6	O

COMMENTS:

PROB. TEST #
CAP # A
FREQUENCY - 0.088 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
*	

COMMENTS: * Could not fire but it was above other low fires

PROB. TEST #
CAP #
FREQUENCY - MHz
FIRING MODE -
MODULATION -

AVE. POWER WATTS	RESULTS X = FIRE 0=NO

COMMENTS:

PROB. TEST # 2214
CAP # A
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
5.0	X
6.5	X
8.0	X
8.0	X
8.0	X
10.0	X
15.0	X
18.0	X
20.0	X
20.0	X
30.0	X

COMMENTS:

PROB. TEST # 2220
CAP # A
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Pin
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
5.0	X
5.0	X
5.0	X
9.0	X
9.0	X
9.0	X
9.0	X
9.0	X
9.0	X
9.0	X

COMMENTS: Some arcing

PROB. TEST # 2222
CAP # A
FREQUENCY - 1.5 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.135	X
0.135	X
0.135	X
0.162	X
0.162	X
0.162	X
0.162	X
0.162	X
0.216	X
0.302	X

COMMENTS:

PROB. TEST # 2215
CAP # A
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
15.0	X
15.0	X
15.0	X
18.0	X
20.0	X
20.0	X
25.0	X
25.0	X
25.0	X

COMMENTS:

PROB. TEST # 2221
CAP # A
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Case
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
4.0	X
4.5	X
4.5	X
5.0	X
5.0	X
9.0	X
9.0	X
9.0	X
9.0	X
9.0	X

COMMENTS: Some arcing

PROB. TEST # 2227
CAP # A
FREQUENCY - 1.5 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULTS X = FIRE 0=NO
4.0	X
4.5	X
4.5	X
4.5	0*
5.6	X*
5.6	X
5.6	X*
5.6	0
5.6	0
5.6	0*

COMMENTS: * Some shorted

PROB. TEST # 2207
CAP # A
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.975	X
1.0	X
1.0	X
1.0	X
1.0	X
1.0	X
1.0	X
1.2	X
1.2	X
1.2	X

COMMENTS:

PROB. TEST # 2209
CAP # A
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Pin
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.800	X
0.800	X
0.800	X
0.800	X
1.0	X
1.0	X
1.0	X
1.0	X
1.0	X
1.0	X

COMMENTS:

PROB. TEST # 2224A
CAP # A
FREQUENCY - 10 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.325	X
0.350	X
0.350	X
0.350	X
0.350	X
0.375	X
0.375	X
0.375	X
0.375	X
0.375	X

COMMENTS:

PROB. TEST # 2208
CAP # A
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
8.0	X
9.0	X
9.0	X
9.0	X
11.0	X
11.0	X
20.0	X
20.0	X
20.0	X
20.0	X

COMMENTS:

PROB. TEST # 2210
CAP # A
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Case
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
4.0	X
5.0	X
6.0	X
8.0	X
8.0	X
8.0	X
8.0	0
15.0	0
15.0	0
15.0	0

COMMENTS: Arcing

PROB. TEST # 2224B
CAP # A
FREQUENCY - 10 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULTS X = FIRE 0=NO
1.0	0
1.0	0
1.0	0
1.0	0
1.0	0
1.0	0
1.0	0
1.0	0
1.0	0
1.0	0

COMMENTS:

PROB. TEST # 2304
CAP # C
FREQUENCY - 150 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.650	X
0.700	X
0.700	X
0.700	X
0.750	X
0.750	X
0.750	X
0.800	X
0.800	X
0.800	X

COMMENTS:

PROB. TEST # 2305
CAP # C
FREQUENCY - 0.088 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.276	X
0.276	X
0.276	X
0.3025	X
0.3025	X
0.3025	X
0.3025	X
0.360	X
0.490	X
0.640	X

COMMENTS:

PROB. TEST #
CAP #
FREQUENCY - MHz
FIRING MODE -
MODULATION -

AVE. POWER WATTS	RESULT X = FIRE 0=NO

COMMENTS:

PROB. TEST # 2301
CAP # C
FREQUENCY - 150 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
2.0	0
2.0	0
6.0	0
6.0	0*
6.0	0*
6.0	0*
6.0	0*
6.0	0*

COMMENTS: * Shorted

PROB. TEST #
CAP # C
FREQUENCY - 0.088 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO

COMMENTS: Could not fire but it was above the other low fires

PROB. TEST #
CAP #
FREQUENCY - MHz
FIRING MODE -
MODULATION -

AVE. POWER WATTS	RESULTS X = FIRE 0=NO

COMMENTS:

PROB. TEST # 2287
CAP # C
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
15.0	X
15.0	X
15.0	X
15.0	X
20.0	X
20.0	X
20.0	X
20.0	O

COMMENTS:

PROB. TEST # 2268A
CAP # C
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Pin
MODULATION -

AVE. POWER WATTS	RESULT X = FIRE 0=NO
3.0	X
3.0	X
4.0	X
5.0	X
5.0	X
10.0	O
10.0	O
10.0	O

COMMENTS: Arcing

PROB. TEST # 2297
CAP # C
FREQUENCY - 450 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
1.25	X
1.25	X
1.25	X
1.25	X
1.25	X
1.5	X
1.5	X
2.0	X
3.0	X

COMMENTS:

PROB. TEST # 2288
CAP # C
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
30.0	O
30.0	O
30.0	X
30.0	X
30.0	X
30.0	X

COMMENTS:

PROB. TEST # 2268B
CAP # C
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Case
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
10.0	O
10.0	O
10.0	O
10.0	O
10.0	O
10.0	O
10.0	O

COMMENTS: Arcing

PROB. TEST # 2300
CAP # C
FREQUENCY - 450 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULTS X = FIRE 0=NO
0.240	O
0.270	O
0.270	O
0.270	O
0.270	O
0.270	O
0.270	O
0.270	O

COMMENTS:

PROB. TEST # 2256
CAP # C
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
4.0	X
4.0	X
5.0	X
5.0	X
5.0	X
5.0	X
5.0	X
5.0	X
6.0	X
10.0	X

COMMENTS:

PROB. TEST # 2262
CAP # C
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Pin
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
4.0	X
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0

COMMENTS: Arcing

PROB. TEST # 2294
CAP # C
FREQUENCY - 10 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.450	X
0.450	X
0.500	X
0.500	X
0.500	X
0.500	X
0.750	X
1.0	X
1.5	X
3.0	X

COMMENTS:

PROB. TEST # 2257
CAP # C
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
38.0	0
38.0	0
38.0	X
38.0	0
38.0	0
38.0	X
38.0	0
38.0	0

COMMENTS:

PROB. TEST # 2263
CAP # C
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Case
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0

COMMENTS: Arcing

PROB. TEST # 2296
CAP # C
FREQUENCY - 10 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULTS X = FIRE 0=NO
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0

COMMENTS:

PROB. TEST # 2233
CAP # B
FREQUENCY - 150 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE O=NO
0.800	X
0.900	X
1.0	X
1.0	X
1.2	X
1.5	X
1.5	X
1.5	X
1.5	X
1.9	X

COMMENTS:

PROB. TEST # 2237
CAP # B
FREQUENCY - 0.088 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE O=NO
0.173	X
0.173	X
0.173	X
0.173	X
0.173	X
0.204	X
0.204	X
0.204	X
0.204	X
0.204	X

COMMENTS:

PROB. TEST #
CAP #
FREQUENCY - MHz
FIRING MODE -
MODULATION -

AVE. POWER WATTS	RESULT X = FIRE O=NO

COMMENTS:

PROB. TEST # 2235
CAP # B
FREQUENCY - 150 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE O=NO
0.900	O
0.900	O
0.900	O
0.900	O
0.900	O
0.900	O
0.900	O
0.900	O
0.900	O
0.900	O

COMMENTS:

PROB. TEST #
CAP # B
FREQUENCY - 0.088 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE O=NO
*	

COMMENTS: * Could not fire but it was above other low fires

PROB. TEST #
CAP #
FREQUENCY - MHz
FIRING MODE -
MODULATION -

AVE. POWER WATTS	RESULTS X = FIRE O=NO

COMMENTS:

PROB. TEST # 2216
CAP # B
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
3.0	X
3.0	X
6.0	X
6.0	X
8.0	X
8.0	X
10.0	X
10.0	X
10.0	X
10.0	X

COMMENTS:

PROB. TEST # 2218
CAP # B
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Pin
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
1.75	X
1.75	X
2.0	X
2.0	X
2.0	X
3.0	X
5.0	X
10.0	0
10.0	0
10.0	0

COMMENTS: Arcing

PROB. TEST # 2223A
CAP # B
FREQUENCY - 1.5 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.325	X
0.325	X
0.350	X
0.350	X
0.350	X
0.400	X
0.400	X
0.400	X
0.400	X
0.400	X

COMMENTS:

PROB. TEST # 2217
CAP # B
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
6.5	X
8.0	X
8.0	X
10.0	X
10.0	X
10.0	X
10.0	X
10.0	X
10.0	X
15.0	X
15.0	X

COMMENTS:

PROB. TEST # 2219
CAP # B
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Case
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
3.0	X
5.0	X
5.0	X
5.0	X
5.0	X
10.0	X
10.0	0
10.0	0
10.0	0
10.0	X

COMMENTS: Arcing

PROB. TEST # 2226
CAP # B
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULTS X = FIRE 0=NO
2.5	X
2.5	X
3.3	X
3.3	0
3.3	X
8.5	0
8.5	0
8.5	0
8.5	0
8.5	0

COMMENTS:

PROB. TEST # 2258
CAP # D
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.750	X
0.850	X
1.0	X
1.0	X
1.0	X
1.0	X
1.0	X
1.5	X
3.0	X
5.0	X

COMMENTS:

PROB. TEST # 2264
CAP # D
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.850	X
0.850	X
0.850	X
0.900	X
0.950	X
0.950	X
0.950	X
1.0	X
1.0	X
1.2	X

COMMENTS: Some arcing

PROB. TEST # 2295
CAP # D
FREQUENCY - 10.0 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.200	X
0.200	X
0.200	X
0.200	X
0.250	X
0.250	X
0.250	X
0.300	X
0.300	X

COMMENTS:

PROB. TEST # 2259
CAP # D
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
12.0	X
12.0	X
15.0	0
15.0	X
20.0	0
20.0	X
20.0	X
20.0	X

COMMENTS:

PROB. TEST # 2265
CAP # D
FREQUENCY - 2700 MHz
FIRING MODE - Pin-Case
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
1.25	X
1.25	X
1.25	X
1.5	X
1.5	X
2.0	X
2.0	X
2.0	X
2.0	X
3.5	X

COMMENTS:

PROB. TEST # 2293
CAP # D
FREQUENCY - 10 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULTS X = FIRE 0=NO
1.25	X
1.5	X
1.5	X
1.5	X
1.8	X
1.8	X
1.8	X
1.8	X
2.4	X
2.4	X

COMMENTS:

PROB. TEST # 2285
CAP # D
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.450	X
0.500	X
0.500	X
0.500	X
0.550	X
0.550	X
0.600	X
0.600	X
0.700	X
5.0	X

COMMENTS:

PROB. TEST # 2266
CAP # D
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Pin
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.500	X
0.600	X
0.600	X
0.600	X
0.600	X
0.750	X
0.750	X
0.750	X
1.5	X
3.0	X

COMMENTS: Some arcing

PROB. TEST # 2298
CAP # D
FREQUENCY - 450 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.450	X
0.450	X
0.450	X
0.450	X
0.450	X
0.450	X
0.500	X
0.500	X
0.500	X
0.600	X

COMMENTS:

PROB. TEST # 2286
CAP # D
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
6.0	X
8.0	X
8.0	X
8.0	X
8.0	X
10.0	X
10.0	X
10.0	X
15.0	X

COMMENTS:

PROB. TEST # 2267
CAP # D
FREQUENCY - 5400 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.500	X
0.500	X
0.500	X
0.600	X
1.0	X
1.0	X
1.0	X
1.0	X
3.0	X

COMMENTS:

PROB. TEST # 2299
CAP # D
FREQUENCY - 450 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULTS X = FIRE 0=NO
0.150	X
0.175	X
0.175	X
0.200	X
0.200	X
0.225	X
0.250	X
0.250	X
0.250	X

COMMENTS:

PROB. TEST # 2253
CAP # D
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE O=NO
2.0	X
2.0	X
2.5	X
2.5	X
2.5	X
3.0	X
3.0	X
4.0	X

COMMENTS:

PROB. TEST # 2251
CAP # D
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Pin
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE O=NO
0.500	X
0.650	X
0.750	X
0.750	X
1.0	X
1.0	X
1.0	X
1.0	X
2.0	X
4.0	X

COMMENTS:

PROB. TEST # 2290
CAP # D
FREQUENCY - 1.5 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE O=NO
0.143	X
0.143	X
0.143	X
0.143	X
0.143	X
0.163	X
0.163	X
0.163	X
0.163	X
0.242	X

COMMENTS:

PROB. TEST # 2254
CAP # D
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE O=NO
6.0	X
7.0	X
8.0	X
8.0	X
8.0	X
8.0	X

COMMENTS:

PROB. TEST # 2252
CAP # D
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Case
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE O=NO
1.0	X
1.0	X
1.25	X
1.25	X
1.25	X
1.5	X
1.5	X
3.0	X

COMMENTS:

PROB. TEST # 2291
CAP # D
FREQUENCY - 1.5 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULTS X = FIRE O=NO
0.091	X
0.091	X
0.104	X
0.104	X
0.104	X
0.104	X
0.130	X
0.130	X
0.130	X
0.390	X

COMMENTS:

PROB. TEST # 2303
CAP # D
FREQUENCY - 150 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.250	X
0.275	X
0.300	X
0.300	X
0.300	X
0.300	X
0.300	X
0.500	X
1.0	X

COMMENTS:

PROB. TEST # 2306
CAP # D
FREQUENCY - 0.088 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.119	X
0.130	X
0.130	X
0.147	X
0.147	X
0.147	X
0.179	X
0.179	X
0.211	X
0.211	X

COMMENTS:

PROB. TEST #
CAP #
FREQUENCY - MHz
FIRING MODE -
MODULATION -

AVE. POWER WATTS	RESULT X = FIRE 0=NO

COMMENTS:

PROB. TEST # 2302
CAP # D
FREQUENCY - 150 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
4.0	X
5.0	X
5.0	X
6.0	X
7.0	X
10.0	X
10.0	X
10.0	O
10.0	O
10.0	O

COMMENTS:

PROB. TEST #
CAP # D
FREQUENCY - 0.088 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO

COMMENTS: Could not fire but it was above other low fires

PROB. TEST #
CAP #
FREQUENCY - MHz
FIRING MODE -
MODULATION -

AVE. POWER WATTS	RESULTS X = FIRE 0=NO

COMMENTS:

PROB. TEST # 2254
CAP # C
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
4.0	X
5.0	X
8.0	X
8.0	X
10.0	X
10.0	X

COMMENTS:

PROB. TEST # 2249
CAP # C
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Pin
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
4.0	X
5.0	X
6.0	X
10.0	X
10.0	0
10.0	0
10.0	0
10.0	0

COMMENTS:

PROB. TEST # 2289
CAP # C
FREQUENCY - 1.5 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
0.360	X
0.360	X
0.420	X
0.420	X
0.420	X
0.420	X
0.420	X
0.420	X
0.600	X
0.900	X

COMMENTS:

PROB. TEST # 2255
CAP # C
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
20.0	0
30.0	X
30.0	0
30.0	0
30.0	0
30.0	0

COMMENTS:

PROB. TEST # 2250
CAP # C
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Case
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
3.0	X
6.0	X
8.0	X
10.0	0
10.0	0
10.0	0
10.0	0
10.0	0

COMMENTS:

PROB. TEST # 2292
CAP # C
FREQUENCY - 1.5 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULTS X = FIRE 0=NO
0.850	0
0.850	0
0.850	0
1.04	0
1.19	0
1.36	0
1.36	0
1.53	0

COMMENTS: All shorted p-c after exposure

PROB. TEST # 2373
CAP # E
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Pin
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
1.5	X
1.5	X
2.0	X
2.0	X
2.0	X
2.0	X
2.5	X
2.5	X
10.0	X

COMMENTS:

PROB. TEST # 2376
CAP # E
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Pin
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
1.0	X
1.0	X
1.25	X
1.25	X
1.25	X
1.5	X
2.0	X
2.0	X
5.0	X
5.0	X

COMMENTS:

PROB. TEST #
CAP #
FREQUENCY - MHz
FIRING MODE -
MODULATION -

AVE. POWER WATTS	RESULT X = FIRE 0=NO

COMMENTS:

PROB. TEST # 2374
CAP # E
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Case
MODULATION - CW

AVE. POWER WATTS	RESULT X = FIRE 0=NO
6.0	X
7.0	X
7.0	X
7.0	X
10.0	X
10.0	X
15.0	X
15.0	X
15.0	X

COMMENTS:

PROB. TEST # 2379
CAP # E
FREQUENCY - 8900 MHz
FIRING MODE - Pin-Case
MODULATION - Pulsed

AVE. POWER WATTS	RESULT X = FIRE 0=NO
6.0	X
15.0	X
15.0	X
15.0	X
15.0	X
15.0	X
15.0	X

COMMENTS: Arcing

PROB. TEST #
CAP #
FREQUENCY - MHz
FIRING MODE -
MODULATION -

AVE. POWER WATTS	RESULTS X = FIRE 0=NO

COMMENTS:

Appendix

D

EXCERPT FROM FIRL REPORT
F-B2256

(which is evaluated when the terminating resistance equals the radiation resistance, and when the reactances cancel), we can obtain for the induced voltage

$$\left(\frac{V}{2}\right)^2 \frac{1}{R_R} = W_{max} = \frac{P\ D\lambda^2}{4\pi} \qquad (2\text{-}22)$$

Replacing R_R and D by the values given above, we get

$$V^2 = \frac{P \times 4.67 \times 10^4\ A^2}{\pi\lambda^2} \qquad (2\text{-}23)$$

Substituting this expression and $X_A = -X_T$, in Equation 2-20 we obtain

$$A_e = \frac{4.67 \times 10^4\ A^2}{\pi\lambda^2} \cdot \frac{R_T}{(R_T + R_L + R_R)^2} \qquad (2\text{-}24)$$

For large λ the λ^4 term in the expression of the radiation resistance dominates and the radiation resistance becomes very small (for reasonable areas, say $<10\ m^2$), in relation to the other resistance in the circuits; therefore we may assume $R_R = 0$.

Using this approximation we obtain

$$A_e = \frac{4.67 \times 10^4\ A^2}{\pi\ \lambda^2} \cdot \frac{R_T}{(R_T + R_L)^2} \qquad (2\text{-}25)$$

The same expression for the aperture as given by Equation 2-25 can be derived by calculating the maximum open circuit voltage that would be induced in the loop. The expression therefore implies that the power reradiated by the loop is small.

To obtain an expression for the voltage induced in the small loop, assume that the magnetic flux density is uniform over the loop. The total voltage around the loop is then given by

$$|V| = - \oint \frac{\partial \bar{B}}{\partial t} \cdot ds = A\mu_o \, \omega |H| \qquad (2\text{-}26)$$

where A = area of the loop

$\omega = 6\pi \times 10^8/\lambda = 2\pi f$

f = frequency, λ = wave length in meters

μ_o = permeability of free space

$\bar{B}$ = magnetic flux density

If we express $|H|^2$ in terms of P and Z_o from Equation 2-2 and frequency in terms of wavelength and substitute these into the square of Equation 2-26 we obtain

$$|V|^2 = \frac{A^2 \, 4\pi^2 \, P\mu_o \, c^2}{Z_o \, \lambda^2} \qquad (2\text{-}27)$$

where

$$c = f\lambda = 3 \times 10^8 \text{ m/sec}$$

If we now make use of the physical relations

$$c = \frac{1}{\sqrt{\mu_o \epsilon_o}} = 300 \times 10^6 \text{ meters/sec and } Z_o = \sqrt{\frac{\mu_o}{\epsilon_o}} = 377 \text{ ohms}$$

where ϵ_o is the permittivity of free space, we can write Equation 2-27 in the form

$$|V|^2 = \frac{A^2 \, 4\pi^2 \, P \, Z_o}{\lambda^2} = \frac{1.48 \times 10^4 \times A^2 \, P}{\lambda^2} \qquad (2\text{-}28)$$

Substitution of Equation 2-28 in 2-20 with $R_R = 0$, $X_R = -X_T$ again results in Equation 2-25.

Equation 2-25 represents the aperture of a small loop, assuming reactive match between antenna and load, no dissipation of power by means of reradiation (we have seen that the radiation resistance is very low for small loops), and orientation of the loop for maximum pickup.

The analysis holds for frequencies up to $\lambda = 2\ell$ where ℓ is the perimeter of the loop. At higher frequencies it breaks down due to the non-uniform current distribution of the leads; the maximum effecitve aperture (A_{em}) at these higher frequencies can, however be calcualted from Equation (2-5) repeated here:

$$A_{em} = \frac{D\lambda^2}{4\pi}$$

which holds for any lossless antenna.

In this formula A_{em} is the maximum possible aperture, assuming a complete impedance match, and D is the directivity of the antenna.

The directivity of the configuration under consideration as a function of frequency is not known; but if we assume that it can be no more than that of an antenna of known directivity we can calculate A_{em}.

Reference 5, page 16, gives curves of directivity for three types of antennas: the unterminated rhombic, the long wire, and the circular loop. It is reasonable to assume that our configuration will be no more directive than these, since these are among the most directional linear antennas known.

Figure 2-9 is a composite plot of the greatest directivity of these antennas types as a function of overall lead length. The plot was made directly from the above reference. Using Figure 2-9 and Equation 3-29 the maximum effective aperture of our antenna configuration can be calculated. The maximum effective aperture (A_{em}) is calculated under the assumption that the lead configuration will be no more directive than an unterminated rhombic, a long wire or a circular loop antenna of equal linear dimension. The effective aperture (A_e) is calculated with

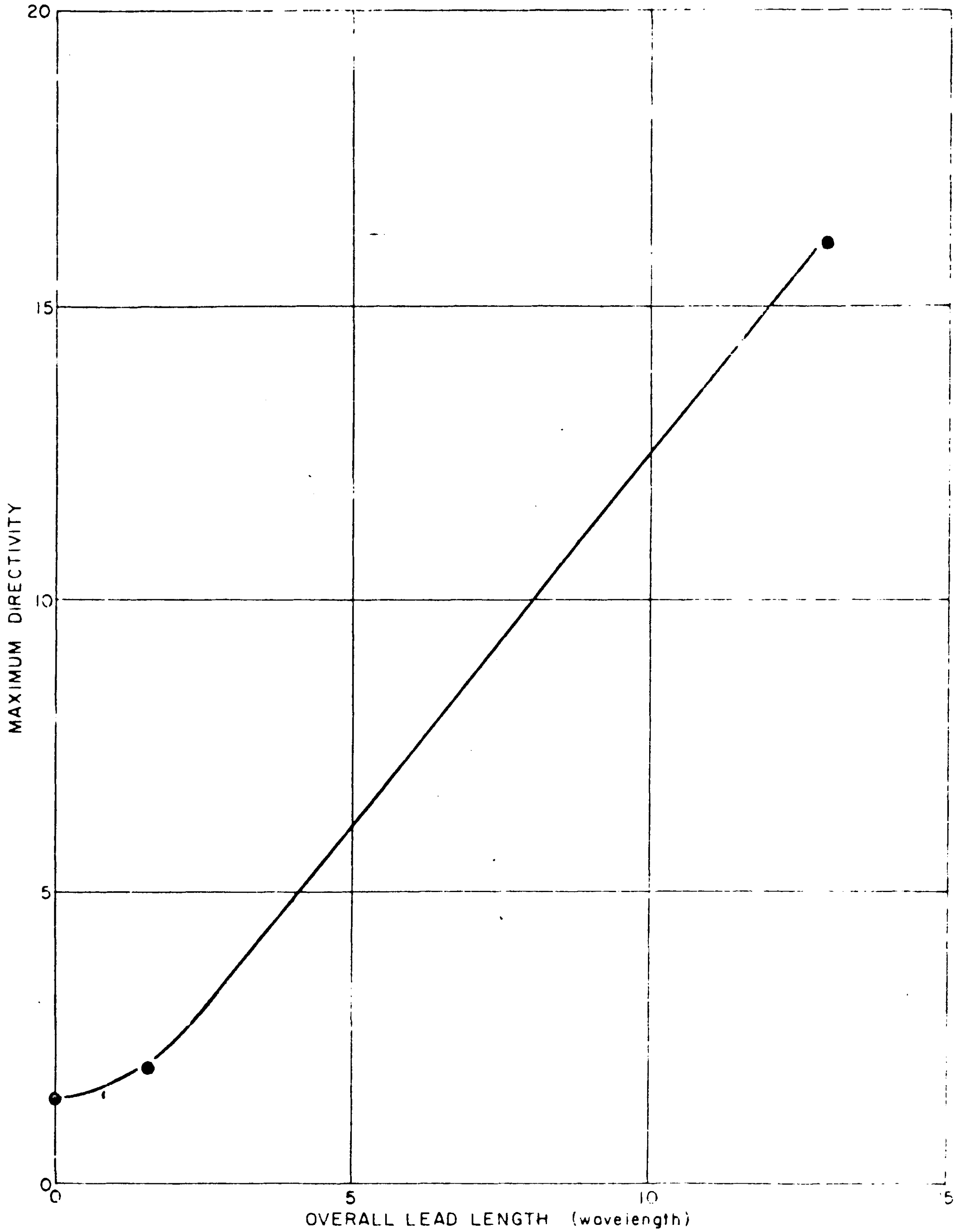


FIG. 2-9. MAXIMUM DIRECTIVITY OF THREE KNOWN ANTENNA CONFIGUATIONS

the following assumptions: the terminating bridgewire resistance is no less than the dc resistance, the antenna is reactively matched, loss resistance is zero, and the radiation resistance is zero. Note that the last three assumptions effectively maximize the A_e expression (see Equation 2-20 where V^2 is considered constant). These calculations contain a seeming anomaly, since the effective aperture curve rises above the maximum effective aperture curve. This is the result of considering the radiation resistance as equal to zero in our maximizing procedure of the effective aperture. If the radiation resistances were taken into consideration, the curves would not intersect.

The blasting wiring layouts that correspond to the loop model are shown in Figures 2-10 and 2-11. Figure 2-10 shows a pickup having its effect chiefly pin-to-pin; Figure 2-11 is similar, except pin-to-case.

The model for the situation shown in Figure 2-10 is a loop of wire of the same planar area as the pickup area (A) shown in the figure. The loop will be loaded with two impedances: that seen between points A and B looking toward the blasting machine and that seen between points C and D looking towards the cap or caps.

The configuration shown in Figure 2-11 is similar except now the loading impedances of the wire loop are those measured between one of the blasting wires and ground, and in addition the loop is loaded with the impedance appearing between the measurement ground points (Z_e)

In both of the antenna models the loading impedances are almost completely unknown. We know only that the cap impedance (either pin-to-pin or pin-to-case) influences the value of the impedance seen looking toward the cap.

The impedances looking away from the cap can be expected to be mainly reactive but we will treat them as completely unspecified. For maximum power to the cap the sum of the reactive portions of the loading impedances is assumed to be zero thus providing a reactively matched antenna. The cap impedance is actually separated from the measurement point by a length of transmission line of farily high characteristic impedance.

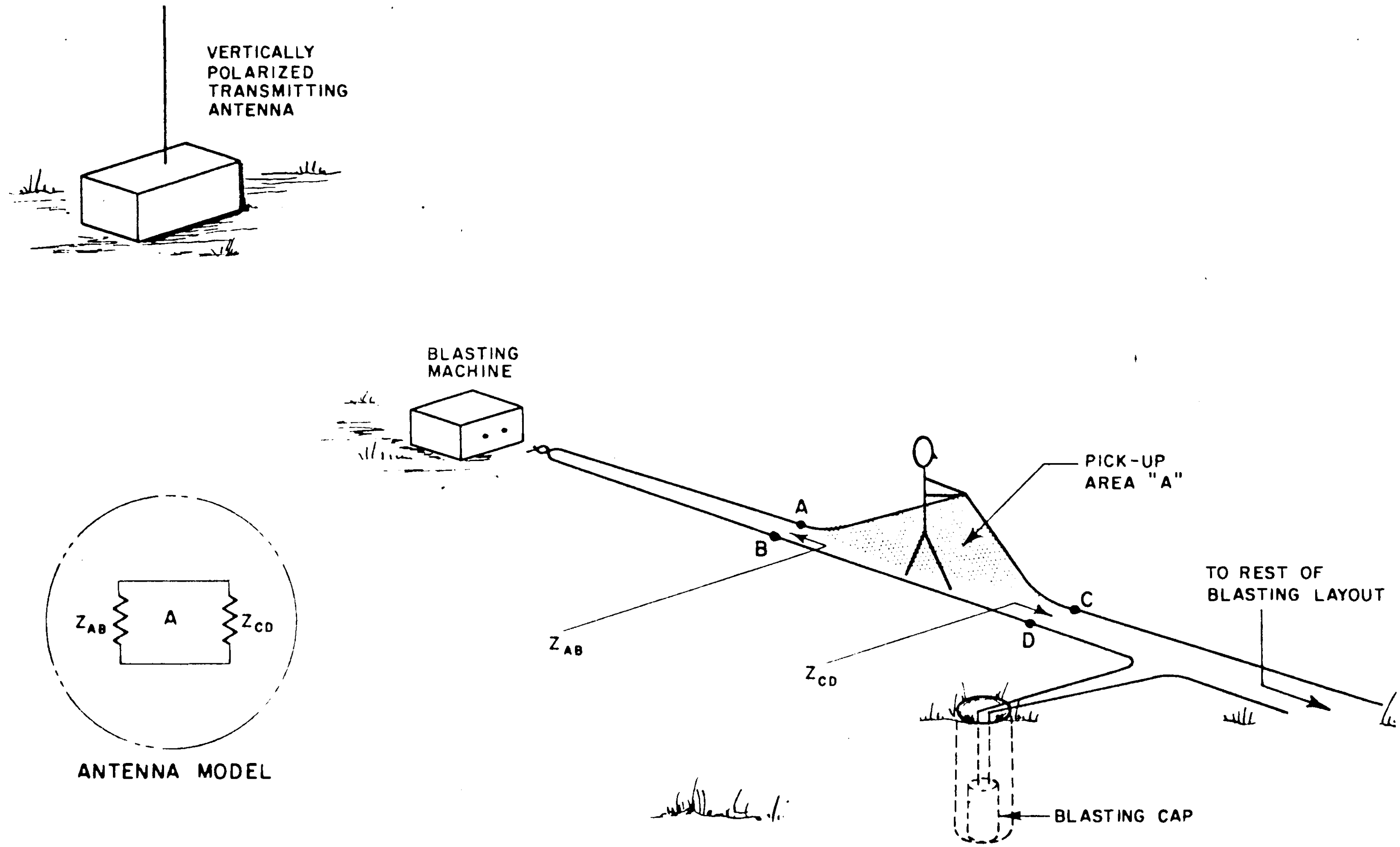


FIG. 2-10. PIN-TO-PIN SENSITIVE BLASTING CONFIGURATION AND ITS ANTENNA MODEL

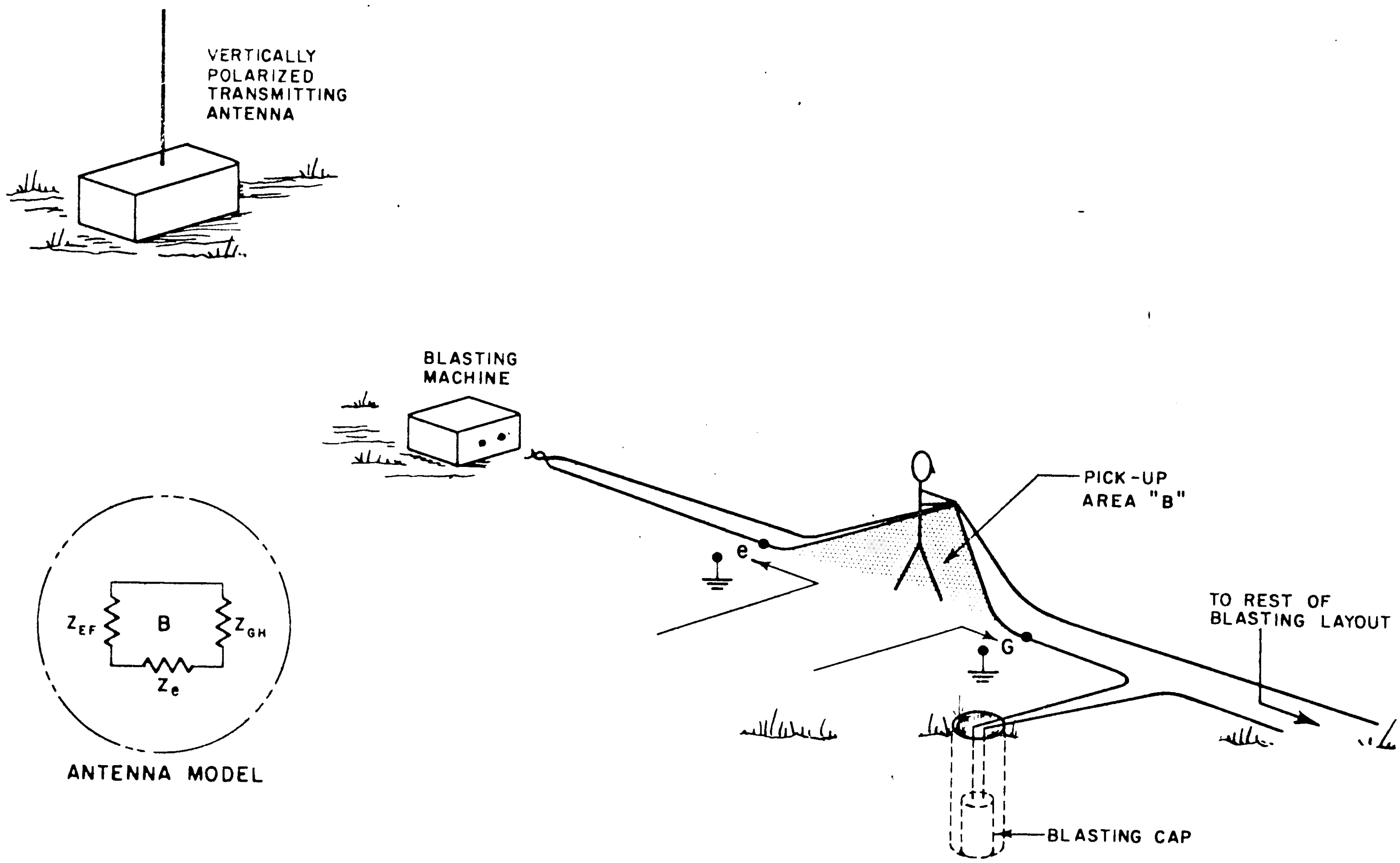


FIG. 2-11. PIN-TO-CASE SENSITIVE BLASTING CONFIGURATION AND ITS ANTENNA MODEL

Expressing λ in terms of frequency in megacycles (f_{Mc}) and using the above approximations we can rewrite Equation 2-25 to give the low frequency aperture of our model, thus

$$A_e = \frac{0.95\ f_{Mc}^2}{(1 + .616\sqrt{f_{Mc}})^2}\text{, in square meters} \qquad (2\text{-}31)$$

where we have substituted in Equation 2-25.

$$R_T = 1 \text{ ohm}$$

$$R_L = 0.616\sqrt{f_{Mc}} \text{ ohms}$$

$$A^2 = 5.75 \text{ meters}^2$$

$$\lambda = \frac{300}{f_{Mc}}$$

In the Fraunhofer region of the transmitting antenna

$$P_d = \frac{G_T W_T}{4\pi\ r^2} \qquad (2\text{-}32)$$

where

P_d is the power density in (watts/meter^2)
G_T is the transmitting antenna gain (unitless)
W_T is the power into the antenna (watts)
r is the distance from the antenna (meters)

Substituting Equation (2-32) in Equation 2-4 and solving for r^2 we obtain

$$r^2 = \frac{A_e\ G_T\ W_T}{4\pi\ W_R} \qquad (2\text{-}33)$$

where W_R is watts dissipated in the antenna load (the cap), and A_e is given by Equation 2-31.

Now $G_T\ W_T$ is Effective Radiated Power (ERP); making this substitution along with W_R = 10 mw as an estimate of the minimum sensitivity of the cap, and substituting Equation 2-31 into 2-33, we get

$$r^2 = \frac{7.56\, f_{Mc}^2\, ERP}{(1 + 0.616\sqrt{f_{Mc}})^2}$$

and

$$r = 2.74\sqrt{ERP}\left(\frac{f_{Mc}}{1 + 0.616\sqrt{f_{Mc}}}\right), \text{ in meters} \qquad (2\text{-}34)$$

or

$$r = 1.71 \times 10^{-3}\sqrt{ERP} \cdot K_{fv}, \text{ in miles} \qquad (2\text{-}35)$$

where

$$K_{fv} = \frac{f_{Mc}}{1 + 0.616\sqrt{f_{Mc}}}$$

K_{fv} is plotted in Figure 2-12 with a plot of $K = f_{Mc}$ as a comparison. This comparison line illustrates the value of K_{fv} if the losses in the wire loop are ignored. Plots of Equation 2-35 as a function of frequency, with ERP as a parameter, yield the low frequency safe distances for the loop model we are considering. The higher frequency distance can be computed from Equation 2-29 and Figure 2- 9. Taking 7.35 meters as the total perimeter of loop and making a straight line approximation to Figure 2-9 we obtain for the maximum possible aperture

$$A_{em} = \frac{1.07 \times 10^4}{f_{Mc}^2} + \frac{62}{f_{Mc}}, \quad f_{Mc} < 70$$

$$A_{em} = \frac{219}{f_{Mc}}, \; f_{Mc} \qquad f_{Mc} > 70 \qquad (2\text{-}36)$$

Using the same development that led to Equation (2-33) we obtain

$$r^2 = \frac{A_{em} \cdot ERP \cdot 100}{4\pi} \quad \text{meters} \qquad (2\text{-}37)$$

or

$$r = 1.75 \times 10^{-3}\sqrt{ERP \cdot A_{em}} \quad \text{miles}$$

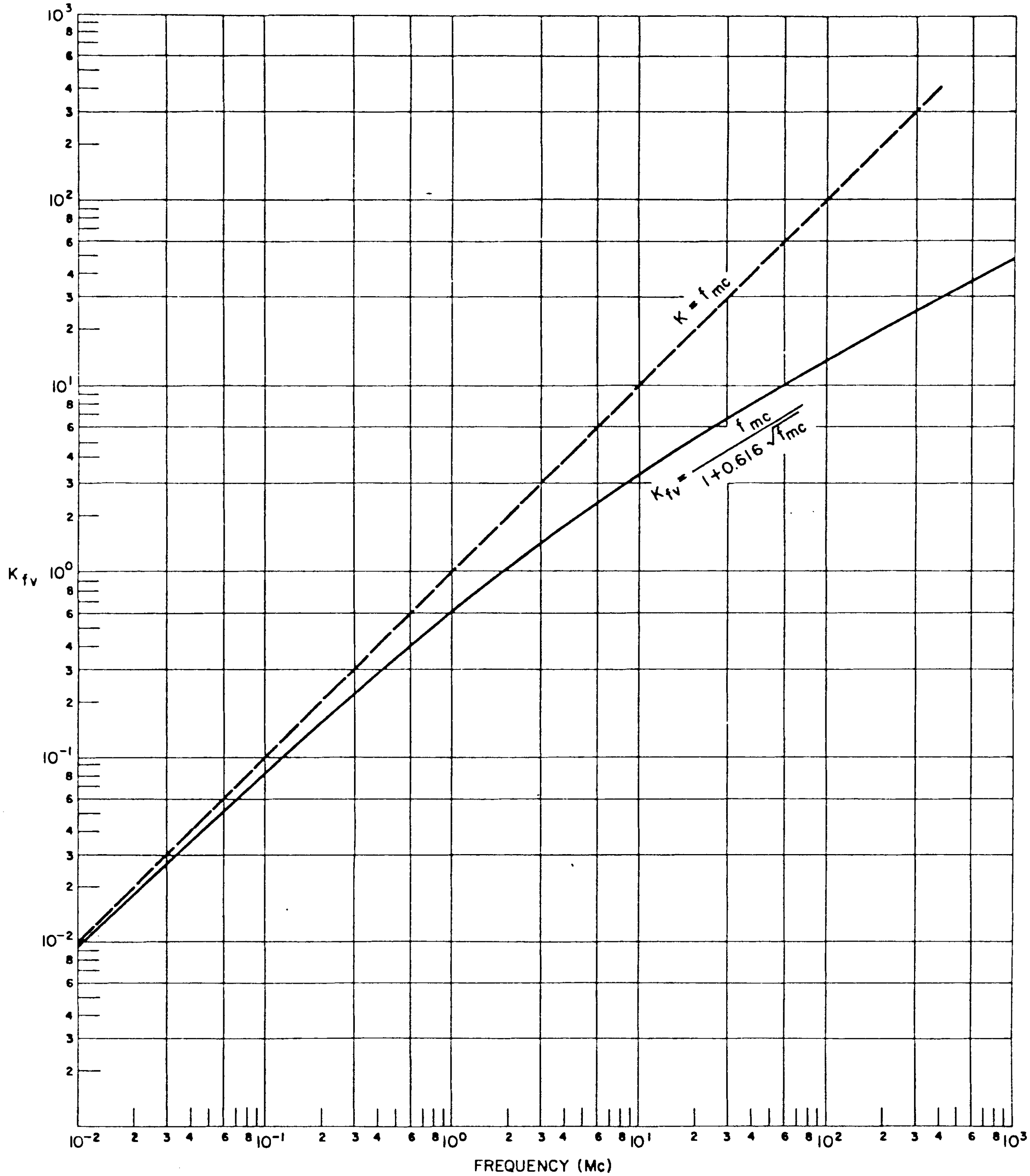


FIG. 2-12. FREQUENCY FACTOR (K_{fv}) FOR THE VERTICAL LOOP MODEL VS. FREQUENCY

Appendix

E

BIBLIOGRAPHY FOR UNDERGROUND PROPAGATION OF ELECTROMAGNETIC WAVES

1. Electrical Properties of Rocks and Minerals, George V. Keller, Handbook of Physical Constants (Rev. Ed.) - The Geological Soc. of Amer. Memoir 97, 1966, p. 553-77.

2. Magnetic Properties of Rocks and Minerals, D. H. Lindsay, G. E. Andreasen, and J. R. Balsley, Handbook of Physical Constants - The Geological Soc. of Amer. Memoir 97, 1966, p. 543-52.

3. Dielectric Constants and Dissipation Factors for Six Rock Types Between 20 and 100 Megahertz, Russel E. Griffin and Robert L. Marovelli, U.S. Dept. of the Interior - report of Invest. 6913.

4. Dielectric Behavior of Rocks and Minerals, B. F. Howell, Jr. and P. H. Licastro, The American Mineralogist V46, Mar.-Apr. 1961, p. 269-88.

5. Electrical Properties in the Deep Crust, G. V. Keller, IEEE Transactions on Antennas and Propagation, May 1963, p. 344-57.

6. Rock Electrical Characteristics Deduced from Depth Attenuation Rates (in Drill Holes), J. T. de Bettencourt and J. W. Frazier, IEEE Transactions on Antennas and Propagation, May 1963, p. 358-63.

7. The Diffraction of a Plane Wave Through Two or More Slits in a Plane Screen, Erik B. Hansen, App. Sci. Res. (Sec. B) V8, 1960, p. 73-83.

8. Generalized Scattering Matrix Equations for Waveguide Structures of Varying Surface Impedance Boundaries, E. Bahar, Radio Sci. V2 (New Series), n. 3, Mar. 1967, p. 287-97.

9. A Reciprocity Theorem for the Electromagnetic Field Scattered by an Obstacle, A. T. DeHoop, App. Sci. Res. (Sec. B) V8, 1960, p. 135-40.

10. Electromagnetic Fields of a Small Loop Antenna on the Surface of a Polarizable Medium, B. K. Bhattacharyya, Geophysics V29, n. 5, Oct. 1964, p. 814-31.

11. Electromagnetic Absorption by Rocks With Some Experimental Observations Taken at the Mammoth Cave of Kentucky, J. Wallace Joyce, U.S. Dep. of Commerce - Technical Paper 497, January 11, 1952.

12. Radio Propagation in Coal Mines, L. Finklestein and U. Erdem, Mining and Minerals Engineering, Mar. 1969, p. 48-55.

13. Propagation of Electromagnetic Pulses in a Homogeneous Conducting Earth, James R. Waif, App. Sci. Res. V8 (Sec. B), 1960, p. 213-53.

14. Waveguide Survey, H. E. M. Barlow, Electronics and Power, Oct. 1964, p. 332-8.

15. An Approximate Wave Equation for an Axially Symmetric Periodic Waveguide, C. R. James and G. B. Walker, IEEE Transactions on Microwave Theory and Tech. V MTT-14, n. 9, Sept. 1966, p. 428-30.

16. Cutoff Frequencies of Eccentric Waveguides, H. Y. Yee and N. F. Audeh, IEEE Transactions on Microwave Theory and Tech. V MTT-14, n. 10, Oct. 1966, p. 487-93.

17. Propagation in Nonuniform Waveguides with Impedance Walls, Robert L. Gallawa, Radio Sci. J. V68D, n. 11, Nov. 1964, p. 1201-213.

18. Radio Waves in Rock Near Overburden-Rock Interface, J. Carolan, Jr. and J. T. de Bettencourt, IEEE Transactions on Antennas and Propagation, May 1963, p. 336-8.

19. A General Power Loss Method for Attenuation of Cavities and Waveguides, J. J. Gustincic, IEE Transactions on Microwave Theory and Tech., Jan. 1963, p. 83-7.

20. The Propagation of an Electromagnetic Wave Along an Infinite Corrugated Surface, R. A. Hurd, Canadian Journal of Physics V32, n. 12, Dec. 1954, p. 727-34.

21. Telecommunication Equipment for Hazardous Areas, J. R. H. Stevens, Communications and Electronics (Lond.) V2, n. 4, April 1955, p. 50-4.

22. Electrical Properties of Coals and Carbonized Materials, K. Ouchi, Fuel V46, n. 2, March 1967, p. 71-85.

23. How Radio Locates Drill Holes Underground, R. P. Corbett, Eng. and Mining,J. V156, n. 9, Sept. 1955, p. 90-1.

24. A Power Main's Firing Circuit, Australian Mining V58, n. 1, Jan. 15, 1966, p. 17.

25. Continuation of Electromagnetic Fields - II, Amalendu Roy, Geophysics V34, n. 4, Aug. 1969, p. 572-83.

Appendix

F

HILL DESCENDING PROGRAM AND SAMPLE OUTPUT

```
@FOR,IS
FOR S61-09/06-10:03

   MAIN PROGRAM

   STORAGE USED: CODE(1) 006447; DATA(0) 004711; BLANK COMMON(2) 000000

   EXTERNAL REFERENCES (BLOCK, NAME)

    0003   NINTR$
    0004   NRDC$
    0005   NI02$
    0006   NEXP6$
    0007   CDV$
    0010   NEXPD$
    0011   CSQRT
    0012   CTAN
    0013   NPRT$
    0014   NI01$
    0015   NSTOP$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0000    004555 100F      0001    000475 1000L     0001    000004 105G      0001    000454 108L      0001    000473 111L
    0001    000041 124G      0001    000070 133G      0001    000072 136G      0001    000077 141G      0001    000140 150G
    0001    000437 222G      0001    000640 3002L     0000    004650 3004F     0000    004625 3008F     0000    004644 3009F
    0001    000622 335G      0000    004647 3421F     0001    000002 4002L     0001    000530 4641L     0000    004603 5001F
    0000    004621 5002F     0000    004570 5003F     0000    004606 5004F     0000    004557 5005F     0001    000222 641L
    0001    000231 644L      0001    000255 649L      0001    000335 8510L     0000 C 000144 CP      0000 C 000620 CP1
    0000 C 003100 CP2     0000 R 004541 DD      0000 I 004553 I       0000 I 004540 L       0000 I 004543 L1
    0000 I 004545 M       0000 I 004546 M1      0000 I 004550 M2      0000 I 004547 M3      0000 I 004551 M4
    0000 I 004544 N       0000 I 004554 NA      0000 R 000454 R       0000 R 004552 RH1     0000 R 002424 RQ
    0000 R 001750 RR      0000 R 004230 RRV     0000 R 004542 VV      0000 R 000000 X

 00100      1*     C ********************************************
 00100      2*     C
 00100      3*     C   TM PROPAGATION CONSTANT DETERMINATION
 00100      4*     C
 00100      5*     C ********************************************
 00100      6*     C
 00100      7*     C ********************************************
 00100      8*     C *                                          *
 00100      9*     C *            REVISION NUMBER 1             *
 00100     10*     C *                                          *
 00100     11*     C ********************************************
 00100     12*     C
 00101     13*           DIMENSION   X(100) ,CP(100),R(100),CP1(300) ,
 00101     14*          1RR(300),RQ(300) ,CP2(300) ,RRV(200)
 00103     15*           COMPLEX   CP,CP1,CP2
 00104     16*       4002 DO 101 L=1,8
 00107     17*           READ 100, X(L)
```

```
00112         100 FORMAT( E20.9)
00113         101 CONTINUE
00115             DD=0.0
00116             R(1)=X(5)
00117             R(2)=X(6)
00120                     R(91)=X(7)
00121                 VV=X(1)*0.1
00122             CP(11)=(CMPLX(1.0,1.0) )/( (2.0)**0.5)
00123             DO 99 L=1,7
00126             L1=11+L
00127          99 CP( L1 )  =  CP(11)**(1+L)
00131             CP(20) = CMPLX( X(1), X(2))
00132             DO 2000 N=1,100
00135             DO 1000 M=1,10
00140             DO 105 M1=1,8
00143             M3=10+M1
00144             M2=20+M1
00145         105 CP(M2) =  CP(20)+(CP(M3)* X(7))
00147             DO 106 M4=20,28
00152             CP(1) = CP(M4)
00153             R(3) = (1.8E4 /( R(1)*X(4))) *(-1.0)
00154             R(4) = ((2.0*355.0/113.0)*R(1)/30J.")**2.0
00155             CP(2) = CMPLX ( X(3) , R(3)  )
00156             CP(3) =  CMPLX ( 0.0  , 1.0)
00157             CP(4) = (CP(1)*CP(1)+R(4))
00160             CP(5) = CSQRT (CP(4))
00161              CP2(500)=CP(5)
00162               RH1=AIMAG(CP(5))
00163                 IF(RH1-80.0) 641,641,642
00166         642  CP(8)=CMPLX(0.0,1.0)
00167                 GO TO 649
00170         641   IF(RH1+80.0) 643,644,644
00173         643  CP(8)=CMPLX(0.0,-1.0)
00174                 GO TO 649
00175         644 CP(8) = CTAN  (R(2)*CP(5))
00176         649   CONTINUE
00177             CP(6) = CP(I)*CP(I)+R(4)*CP(2)
00200             CP(7) = CSQRT  (CP(6))
00201             R(5) = AIMAG (CP(7))
00202             IF(R(5)) 8510,8510,8511
00205        8511 CP(7) = CP(7)*(-1.0)
00206        8510     CONTINUE
00207             CP(9) = ((CP(3)*CP(7))/(CP(5)*CP(2)))  - CP(8)
00210             R(6) = AIMAG(CP(9))
00211             R(7) = REAL (CP(9))
00212             R(8) = (( P(6)**2.0) + ( R(7)**2.0))
00213             R(9)=R(8)**0.5
00214         106 R(M4) = R(9)
00216             R(29) = R(20) -R(21)
00217                 R(39)=R(21)
00220             CP(29) = CP(21)
00221             DO 108 I=22,28
00224             R(30) = R(20)-R(I)
00225             R(31) = R(30) -R(29)
00226             IF(R(31)) 108,108,109
00231         109 R(29)=R(30)
00232             CP(29)=CP(I)
```

```
00233                R(39)=R(I)
00234        108 CONTINUE
00236            IF(R(29))110,110,111
00241        110 X(7)=X(7)/1.02
00242            DD=DD+1.0
00243                R(39)=R(20)
00244            GO TO 1000
00245        111 CP(20)=CP(29)
00246       1000 CONTINUE
00250            RQ(N) = R(39)
00251            CP1(N)=CP(20)
00252            RR(N)=X(7)
00253                  CP2(N)=CP2(300)
00254              RRV(N)=R(5)
00255                N8=N-1
00257                R(92)=RQ(N8)-RQ(N)
00257              IF(R(92))    4641,4642,4641
00262       4642   CP(20)=CP(20)+X(7)
00263                X(7)=X(7)*1.3
00264       4641     CONTINUE
00265       2000 CONTINUE
00267              PRINT 5005
00271       5005   FORMAT(1H1,23X,'TM PROPAGATION CONSTANT DETERMINATION ' )
00272                PRINT 5003
00274       5003   FORMAT(////,8X,'FREQ(MHZ)',5X,'EPSILON',10X,'RHO',12X,'D'/)
00275             PRINT 5001,X(5),X(3),X(4),X(6)
00303       5001  FORMAT(6X,4(1PE14.7),//)
00304            PRINT 5004
00306       5004   FORMAT(9X,'ALPHA',10X,'BETA',10X,'INC',11X,'SEN',12X,'DD',/)
00307            PRINT 5002, X(1),X(2),R(91),X(8),DD
00316       5002   FORMAT( 6X,5(1PE14.7) ,//////)
00317             PRINT 3008
00321       3008     FORMAT(////,12X,'Q',24X,'GAMMA',19X,'INCREMENT',
00321            1  17X,'K SUB D',15X,'IN K SUB C',//)
00322                 I=100
00323            PRINT 3009 , RQ(I),CP1(I),RR(I)
00330       3009 FORMAT (6X, 4(1PE14.7,3X) )
00331                 PRINT 3421
00333       3421   FORMAT(///)
00334            DO 3000 I=1,100
00337            PRINT 3004 , RQ(I),CP1(I),RR(I) ,CP2(I),RHV(I)
00346       3004 FORMAT (6X, 7(1PE14.7,3X) )
00347       3000 CONTINUE
00351            IF(X(8)) 3001,3001,3002
00354       3001 GO TO 4002
00355       3002 STOP
00356            END

     END OF COMPILATION:        NO  DIAGNOSTICS.
```

TM PROPAGATION CONSTANT DETERMINATION

FREQ(MHZ)	EPSILON	RHO	B
7.0000000+02	2.0000000+00	1.0000000+03	2.0000000+00

ALPHA	BETA	INC	SFN	DD
9.9999999-03	1.4627000+01	3.0000000-03	0.0000000	5.2700000+02

Q	GAMMA		INCREMENT	K SUP D		TM K SUB C
7.9223963-06	2.6471657-02	1.4473065+01	1.9349058-07			
4.8303222+00	3.1213200-02	1.4605778+01	3.0000000-03	1.2957602+00	3.6179167-01	-1.5594999-01
3.7692002+00	5.2426400-02	1.4584576+01	3.0000000-03	1.5553483+00	4.9991699-01	-1.3477575-01
3.0327411+00	7.3639600-02	1.4563364+01	3.0000000-03	1.7784172+00	6.1031509-01	-1.1372241-01
2.5257493+00	9.4852800-02	1.4542152+01	3.0000000-03	1.9767402+00	7.0436405-01	-9.2789475-02
2.1614455+00	1.0121676-01	1.4514789+01	3.0000000-03	2.1616343+00	6.9993192-01	-8.4475789-02
1.9277242+00	1.0121676-01	1.4484790+01	3.0000000-03	2.3387360+00	6.4559251-01	-8.4519345-02
1.7600697+00	8.0367520-02	1.4466941+01	3.0000000-03	2.4324880+00	5.1360083-01	-1.0193564-01
1.3591019+00	5.0367525-02	1.4466941+01	3.0000000-03	2.4008816+00	3.3965259-01	-1.3115579-01
5.9512271-02	2.6003567-02	1.4473305+01	2.9411765-03	2.3440220+00	1.7908427-01	-1.5786050-01
5.9512271-02	2.6003567-02	1.4473305+01	2.4127890-03	2.3437646+00	1.7577576-01	-1.5838585-01
1.4158418-01	2.5279730-02	1.4473305+01	2.6245880-03	2.3435267+00	1.7265748-01	-1.5888084-01
1.3024334-01	2.5374836-02	1.4473305+01	2.3305590-03	2.3445271+00	1.8541884-01	-1.5685417-01
1.1988129-01	2.5462698-02	1.4473305+01	2.0694696-03	2.3433500+00	1.7030341-01	-1.5925441-01
1.0814830-01	2.7454148-02	1.4473305+01	1.8743823-03	2.3441975+00	1.8130867-01	-1.5750720-01
9.8156014-02	2.5650430-02	1.4473305+01	1.6976858-03	2.3432628+00	1.6912701-01	-1.5944107-01
8.8107412-02	2.7253360-02	1.4473305+01	1.5376463-03	2.3432042+00	1.6833624-01	-1.5956653-01
8.1041991-02	2.5802696-02	1.4473305+01	1.3926936-03	2.3438232+00	1.7653381-01	-1.5826550-01
7.4535708-02	2.7116606-02	1.4473305+01	1.2614055-03	2.3431423+00	1.6749597-01	-1.5969983-01
6.7565533-02	2.5920557-02	1.4473305+01	1.1424938-03	2.3436458+00	1.7422184-01	-1.5863253-01
6.1583374-02	2.6272342-02	1.4473578+01	1.0347918-03	2.3479037+00	1.6832192-01	-1.5950754-01
5.5769926-02	2.6670515-02	1.4473528+01	9.3724277-04	2.3477512+00	1.7022357-01	-1.5920909-01
5.0675168-02	2.6303121-02	1.4473486+01	8.4888964-04	2.3472594+00	1.6741277-01	-1.5965954-01
4.5743[illegible]-02	2.60[illegible]-02	1.[illegible]73222+01	7.6886549-04	2.3471191+00	1.6901517-01	-1.5940827-01
4.13210[illegible]-02	2.6[illegible]1295-02	1.[illegible]3206+01	6.9638515-04	2.3467295+00	1.6666977-01	-1.5978374-01
3.751212[illegible]-02	2.6737680-02	1.447[illegible]934+01	6.3073747-04	2.3452719+00	1.6530976-01	-1.6001723-01
3.4016646-02	2.6591952-02	1.4472782+01	5.7127835-04	2.3437164+00	1.6524693-01	-1.6004710-01

3.0737519-02	2.6560820-02	1.4472809+01	5.1742430-04	2.3429063+00	1.6609003-01	-1.5992466-01
2.7780591-02	2.6570917-02	1.4472834+01	4.6864720-04	2.3431211+00	1.6702159-01	-1.5977491-01
2.5253912-02	2.6684355-02	1.4472960+01	4.2446820-04	2.3431597+00	1.6559242-01	-1.5999976-01
2.2930317-02	2.6551262-02	1.4472874+01	3.8445392-04	2.3439201+00	1.6464298-01	-1.6013975-01
2.0780491-02	2.6401100-02	1.4472892+01	3.4821175-04	2.3433752+00	1.6521008-01	-1.6005729-01
1.8701603-02	2.6316815-02	1.4473000+01	3.1538610-04	2.3435285+00	1.6585310-01	-1.5995391-01
1.6927402-02	2.6414684-02	1.4472924+01	2.8565490-04	2.3441469+00	1.6609913-01	-1.5990714-01
1.5331250-02	2.6420604-02	1.4473193+01	2.5872644-04	2.3448417+00	1.6580138-01	-1.5994517-01
1.3947002-02	2.6519676-02	1.4473181+01	2.3433650-04	2.3446853+00	1.6412140-01	-1.6021226-01
1.2642603-02	2.6428148-02	1.4473170+01	2.1224578-04	2.3450638+00	1.6441569-01	-1.6016099-01
1.1454016-02	2.6376774-02	1.4473104+01	1.9223754-04	2.3450277+00	1.6481672-01	-1.6009817-01
1.0355201-02	2.6380053-02	1.4473029+01	1.7411546-04	2.3446673+00	1.6502386-01	-1.6007009-01
9.3635643-03	2.6440084-02	1.4472987+01	1.5770174-04	2.3442303+00	1.6490115-01	-1.6009505-01
8.5011547-03	2.6501680-02	1.4472994+01	1.4283532-04	2.3439627+00	1.6452041-01	-1.6015854-01
7.7209644-03	2.6536253-02	1.4473038+01	1.2937035-04	2.3439758+00	1.6408891-01	-1.6022707-01
6.9915822-03	2.6530009-02	1.4473089+01	1.1717471-04	2.3442082+00	1.6379568-01	-1.6026973-01
6.3126334-03	2.6495648-02	1.4473117+01	1.0612874-04	2.3444921+00	1.6374274-01	-1.6027467-01
5.7124491-03	2.6452196-02	1.4473112+01	9.6124072-05	2.3446629+00	1.6387612-01	-1.6025125-01
5.1803442-03	2.6489740-02	1.4473108+01	8.7062532-05	2.3446476+00	1.6405306-01	-1.6022352-01
4.6817548-03	2.6510814-02	1.4473081+01	7.8855216-05	2.3446025+00	1.6379149-01	-1.6026537-01
4.2449973-03	2.6507007-02	1.4473050+01	7.1421597-05	2.3444375+00	1.6363722-01	-1.6029181-01
3.8331762-03	2.6484844-02	1.4473037+01	6.4683739-05	2.3442609+00	1.6363001-01	-1.6029519-01
3.4752547-03	2.6460073-02	1.4473036+01	5.8590583-05	2.3442935+00	1.6397532-01	-1.6024030-01
3.1601718-03	2.6462509-02	1.4473038+01	5.3067296-05	2.3442746+00	1.6359360-01	-1.6030077-01
2.8739595-03	2.6461782-02	1.4473041+01	4.8064684-05	2.3441991+00	1.6367183-01	-1.6028978-01
2.5699716-03	2.6462798-02	1.4473086+01	4.3533664-05	2.3444809+00	1.6362994-01	-1.6029240-01
2.3396407-03	2.6452261-02	1.4473073+01	3.9429780-05	2.3444737+00	1.6371220-01	-1.6027952-01
2.1192082-03	2.6454164-02	1.4473057+01	3.5712766-05	2.3444001+00	1.6375463-01	-1.6027376-01
1.9210356-03	2.6465246-02	1.4473049+01	3.2346152-05	2.3443105+00	1.6372941-01	-1.6027888-01
1.7308233-03	2.6477632-02	1.4473050+01	2.9296906-05	2.3442991+00	1.6351874-01	-1.6031226-01
1.5751063-03	2.6456642-02	1.4473070+01	2.6535110-05	2.3443149+00	1.6367505-01	-1.6028740-01
1.4274649-03	2.6470690-02	1.4473053+01	2.4033666-05	2.3442693+00	1.6361047-01	-1.6029817-01
1.3132506-03	2.6467115-02	1.4473054+01	2.1768032-05	2.3444052+00	1.6353032-01	-1.6030909-01
1.1927469-03	2.6461811-02	1.4473061+01	1.9715976-05	2.3443604+00	1.6348786-01	-1.6031636-01
1.0641591-03	2.6462717-02	1.4473060+01	1.7857367-05	2.3443118+00	1.6348522-01	-1.6031739-01
9.8172999-04	2.6475111-02	1.4473057+01	1.6173967-05	2.3443896+00	1.6354557-01	-1.6030688-01
8.8635075-04	2.6474762-02	1.4473072+01	1.4649260-05	2.3442933+00	1.6354071-01	-1.6030887-01
8.0966437-04	2.6474563-02	1.4473058+01	1.3268286-05	2.3443792+00	1.6352463-01	-1.6031031-01
7.2068745-04	2.6469271-02	1.4473059+01	1.2017495-05	2.3443719+00	1.6348460-01	-1.6031672-01
6.5837218-04	2.6469428-02	1.4473070+01	1.0884615-05	2.3443011+00	1.6348351-01	-1.6031779-01
5.8215071-04	2.6469663-02	1.4473060+01	9.8585310-06	2.3443039+00	1.6347708-01	-1.6031877-01
5.2216755-04	2.6470111-02	1.4473063+01	8.7540932-06	2.3443471+00	1.6350806-01	-1.6031333-01
4.7758287-04	2.6467735-02	1.4473065+01	7.9288517-06	2.3443424+00	1.6345149-01	-1.6032232-01
4.3441541-04	2.6466100-02	1.4473063+01	7.3250332-06	2.3443120+00	1.6348318-01	-1.6031771-01
3.9088081-04	2.6474994-02	1.4473063+01	6.6345081-06	2.3443129+00	1.6346048-01	-1.6032128-01
3.5406669-04	2.6470532-02	1.4473068+01	6.0090783-06	2.3443425+00	1.6348215-01	-1.6031748-01
3.2319573-04	2.6469015-02	1.4473066+01	5.4426072-06	2.3443280+00	1.6347769-01	-1.6031837-01
2.9327365-04	2.6472746-02	1.4473062+01	4.9295368-06	2.3443185+00	1.6346464-01	-1.6032055-01
2.6201706-04	2.6470819-02	1.4473063+01	4.4648333-06	2.3443281+00	1.6346867-01	-1.6031979-01
2.3034256-04	2.6472528-02	1.4473063+01	4.0439369-06	2.3443269+00	1.6343957-01	-1.6032440-01
2.0765354-04	2.6472476-02	1.4473063+01	3.5909002-06	2.3443433+00	1.6345337-01	-1.6032201-01
1.9102130-04	2.6472400-02	1.4473063+01	3.1806165-06	2.3443423+00	1.6345044-01	-1.6032249-01
1.7246305-04	2.6473164-02	1.4473065+01	2.8314001-06	2.3443291+00	1.6345385-01	-1.6032212-01
1.4409111-04	2.6471197-02	1.4473066+01	2.5142022-06	2.3443358+00	1.6344990-01	-1.6032265-01
1.3375603-04	2.6472841-02	1.4473065+01	2.2325396-06	2.3443295+00	1.6344806-01	-1.6032303-01
1.1291173-04	2.6471293-02	1.4473066+01	1.9054510-06	2.3443259+00	1.6343670-01	-1.6032486-01
9.9100604-05	2.6470896-02	1.4473065+01	1.6588097-06	2.3443293+00	1.6343245-01	-1.6032549-01

8.1297630-05	2.6471048-02	1.4473064+01	1.4440936-06	2.3443276+00	1.6343828-01	-1.60[illegible]9-01
7.2813922-05	2.6472011-02	1.4473065+01	1.2571704-06	2.3443280+00	1.6343690-01	-1.60[illegible]481-01
6.3889183-05	2.6471188-02	1.4473065+01	1.1163313-06	2.3443348+00	1.6343518-01	-1.6032409-01
4.9784636-05	2.6471525-02	1.4473064+01	9.9127021-07	2.3443337+00	1.6343182-01	-1.6032553-01
4.8977000-05	2.6472123-02	1.4473065+01	8.2945654-07	2.3443302+00	1.6343474-01	-1.6032512-01
3.6452899-05	2.6471537-02	1.4473064+01	6.9404710-07	2.3443328+00	1.6343008-01	-1.6032582-01
3.1625575-05	2.6472008-02	1.4473065+01	5.8074753-07	2.3443309+00	1.6343242-01	-1.6032508-01
2.9501108-05	2.6471987-02	1.4473065+01	5.1568717-07	2.3443308+00	1.6343188-01	-1.6032556-01
1.8614360-05	2.6471829-02	1.4473065+01	4.4013402-07	2.3443319+00	1.6343034-01	-1.6032579-01
1.8614360-05	2.6471829-02	1.4473065+01	3.6106310-07	2.3443319+00	1.6342985-01	-1.6032587-01
1.4759887-05	2.6471720-02	1.4473065+01	3.9275796-07	2.3443319+00	1.6342938-01	-1.6032594-01
6.8848042-06	2.6471720-02	1.4473065+01	3.2864228-07	2.3443306+00	1.6342907-01	-1.6032601-01
6.8848042-06	2.6471720-02	1.4473065+01	2.6960112-07	2.3443306+00	1.6342870-01	-1.6032607-01
1.2299427-05	2.6471639-02	1.4473065+01	2.9326719-07	2.3443306+00	1.6342835-01	-1.6032612-01
1.1621185-05	2.6471647-02	1.4473065+01	2.6041286-07	2.3443306+00	1.6342819-01	-1.6032615-01
7.9223963-06	2.6471657-02	1.4473065+01	2.3586395-07	2.3443306+00	1.6342807-01	-1.6032616-01
7.9223963-06	2.6471657-02	1.4473065+01	1.9349058-07	2.3443310+00	1.6342780-01	-1.6032620-01

TM PROPAGATION CONSTANT DETERMINATION

FREQ(MHZ)	EPSILON	RHO	d	
1.5000000+02	2.0000000+00	1.7200000-07	2.0000000+00	
ALPHA	BETA	INC	SEN	DD
6.6900000-06	3.1415990+00	9.9999949-05	1.0000000+00	7.4000000+02

Q	GAMMA		INCREMENT
2.5250377-05	6.6931401-06	3.1415996+00	6.3211367-09
9.7165659-04	6.6900000-06	3.1415990+00	8.2034826-05
9.7165659-04	6.6900000-06	3.1415990+00	6.7297127-05
2.6306485-02	-1.3499135-05	3.1415990+00	7.3204589-05
2.6306485-02	-1.3499135-05	3.1415990+00	6.0053257-05
2.8737182-02	-1.8770715-05	3.1415990+00	6.5324839-05
2.7556205-02	4.2858761-05	3.1415990+00	5.9166719-05
2.6038858-02	-1.2960963-05	3.1415990+00	5.3589119-05
2.5006270-02	-1.0980254-05	3.1415990+00	4.7585604-05
2.3713582-02	3.4811353-05	3.1415990+00	4.3099747-05
2.2289752-02	-6.6635221-06	3.1415990+00	3.9036767-05
2.1066331-02	-5.1916269-06	3.14159[illegible]	3.4063531-05
1.9673007-02	2.7524149-05	3.1415990+00	3.1395827-05
1.8221129-02	-2.6759753-06	3.1415990+00	2.7331956-05
1.6641665-02	-1.6350459-06	3.1415990+00	2.4269994-05
1.5028500-02	-7.1952309-07	3.1415990+00	2.1551059-05
1.3468986-02	7.7494178-08	3.1415990+00	1.9136724-05
1.2542426-02	1.7431014-05	3.1415990+00	1.6659669-05
1.1185199-02	1.5873629-05	3.1415990+00	1.4793300-05
1.0119676-02	1.6487202-06	3.1415990+00	1.2878465-05
9.0463010-03	2.1391927-06	3.1415990+00	1.1435709-05
8.0984505-03	2.5747182-06	3.1415990+00	1.0154582-05
7.2746665-03	2.9577736-06	3.1415990+00	9.0169775-06
6.5475617-03	3.3011826-06	3.1415990+00	8.0068177-06
5.9131591-03	3.6061199-06	3.1415[illegible]90+00	7.1098247-06
5.3126119-03	1.0310482-[illegible]	3.1[illegible]5[illegible]0+00	6.4395872-06
4.8594259-03	9.9545772-[illegible]	3.1415990+00	5.7181690-06

4.3060750-03	9.5233968-06	3.1415990+00	5.0775703-06
3.8720395-03	4.6354128-06	3.1415990+00	4.5989117-06
3.5466877-03	4.8087929-06	3.1415990+00	4.0837019-06
3.1647860-03	8.6645629-06	3.1415990+00	3.6987345-06
2.8815447-03	5.1750617-06	3.1415990+00	3.3500577-06
2.6231864-03	8.2980184-06	3.1415991+00	3.0342505-06
2.4205572-03	8.1602110-06	3.1415991+00	2.8031784-06
2.1921106-03	8.0122212-06	3.1415991+00	2.4891421-06
1.9468677-03	6.2840532-06	3.1416007+00	2.2544926-06
1.7538534-03	5.7389472-06	3.1416000+00	2.0419634-06
1.5862826-03	7.1011541-06	3.1415987+00	1.8494691-06
1.4443183-03	5.8920177-06	3.1415999+00	1.6751211-06
1.3127971-03	7.0403900-06	3.1415989+00	1.5172088-06
1.1572834-03	7.0003327-06	3.1416003+00	1.3741827-06
1.0595561-03	6.1019267-06	3.1415998+00	1.2202349-06
9.1980046-04	7.2350779-06	3.1415994+00	1.0835336-06
8.1417183-04	6.5068309-06	3.1415991+00	9.6214683-07
7.5536608-04	6.2715295-06	3.1415994+00	8.7144601-07
6.5885103-04	6.3179080-06	3.1415994+00	7.7381910-07
6.0175276-04	6.5564674-06	3.1415999+00	6.8712919-07
5.1421182-04	6.8315587-06	3.1415999+00	6.2235407-07
4.4265852-04	6.5863946-06	3.1415998+00	5.4179665-07
4.0511919-04	6.9265836-06	3.1415995+00	4.7166657-07
3.4632826-04	6.6054115-06	3.1415998+00	4.1061413-07
3.1476391-04	6.8738606-06	3.1415995+00	3.7190586-07
2.4168989-04	6.6208036-06	3.1415994+00	3.3024175-07
2.2680158-04	6.8281593-06	3.1415996+00	2.7633151-07
1.6918208-04	6.7446399-06	3.1415995+00	2.4537447-07
1.6287759-04	6.5965543-06	3.1415996+00	2.0531837-07
1.3536790-04	6.7360987-06	3.1415995+00	1.7874199-07
1.2713840-04	6.6191995-06	3.1415996+00	1.5560566-07
8.6237344-05	6.7249567-06	3.1415996+00	1.3280793-07
7.4668775-05	6.7249567-06	3.1415995+00	1.1112773-07
7.3155265-05	6.7235885-06	3.1415995+00	9.4846445-08
5.7113882-05	6.6614311-06	3.1415996+00	8.4220927-08
5.3851278-05	6.6636322-06	3.1415996+00	7.4785771-08
5.0596615-05	6.7135426-06	3.1415996+00	6.7735776-08
4.7884135-05	6.7108516-06	3.1415996+00	6.0147429-08
3.4672802-05	6.7092001-06	3.1415996+00	5.2361956-08
3.4672802-05	6.7092001-06	3.1415996+00	4.2955040-08
2.3709136-05	6.6963136-06	3.1415996+00	4.6725711-08
2.3709136-05	6.6963136-06	3.1415996+00	3.8331356-08
2.7126346-05	6.6848142-06	3.1415996+00	4.1696152-08
2.7126346-05	6.6848142-06	3.1415996+00	3.4205366-08
2.9122888-05	6.7041819-06	3.1415996+00	3.7952133-08
2.9122888-05	6.7041819-06	3.1415996+00	3.1133967-08
2.3347582-05	6.6948417-06	3.1415996+00	3.3866962-08
2.3347582-05	6.6948417-06	3.1415996+00	2.7782704-08
2.3995705-05	6.6970855-06	3.1415996+00	3.0221519-08
2.3995705-05	6.6970855-06	3.1415996+00	2.4792171-08
2.4024227-05	6.6896478-06	3.1415996+00	2.6968473-08
2.4024227-05	6.6896478-06	3.1415996+00	2.2123540-08
2.3450474-05	6.6914345-06	3.1415996+00	2.4065584-08
2.3450474-05	6.6914345-06	3.1415996+00	1.9742161-08
2.3237888-05	6.6930239-06	3.1415996+00	2.1475163-08
2.3237883-05	6.6930239-06	3.1415996+00	1.7617113-08
2.3292969-05	6.6944517-06	3.1415996+00	1.9163575-08

2.3292969-05	6.6944517-06	3.1415996+00	1.5720805-08
2.3534220-05	6.6957214-06	3.1415996+00	1.7100805-08
2.3534220-05	6.6957214-06	3.1415996+00	1.4028616-08
2.3434637-05	6.6915128-06	3.1415996+00	1.5260073-08
2.3434637-05	6.6915128-06	3.1415996+00	1.2518575-08
2.3277058-05	6.6925238-06	3.1415996+00	1.3617477-08
2.3277058-05	6.6925238-06	3.1415996+00	1.1171074-08
2.3231199-05	6.6934260-06	3.1415996+00	1.2151691-08
2.3231199-05	6.6934260-06	3.1415996+00	9.9086186-09
2.3269384-05	6.6942310-06	3.1415996+00	1.0843682-08
2.3269384-05	6.6942310-06	3.1415996+00	8.8955956-09
2.3368382-05	6.6949494-06	3.1415996+00	9.6764670-09
2.3368382-05	6.6949494-06	3.1415996+00	7.9380729-09
2.3271404-05	6.6925680-06	3.1415996+00	8.6348911-09
2.3271404-05	6.6925680-06	3.1415996+00	7.0836179-09
2.3230377-05	6.6931401-06	3.1415996+00	7.7054306-09
2.3230377-05	6.6931401-06	3.1415996+00	6.3211367-09

@FIN

Appendix

G

ROOTS OBTAINED FROM THE COMPUTER PROGRAM

APPENDIX G

ROOTS OBTAINED FROM THE COMPUTER PROGRAM

The following tables contain the approximate roots obtained for equation 6-7. The tables are given in order of increasing frequency. Each table lists the dielectric constant (ϵ_R), the resistivity (ρ) [in hm meters], the dimension (b) [in meters] and the value of α_R and β_R, the real and imaginary parts of the root. The value of q at the root value is also given.

All data is presented in the same notation as the computer printout. The number is followed by a signed exponent. Thus 1.23-02 is read as 1.23×10^{-2}.

0.15 MHz

	ε_R	ρ	b	α_R	β_R	q_P
CO	10	100	2	2.35-03	6.87-03	4.44-05
CO	10	1000	2	4.73-03	1.29-02	5.18-05
CO	10	1000	1	6.91-03	1.47-02	1.27-05
CO	2	1000	1	6.79-03	1.49-02	1.18-05
CO	2	1000	2	4.62-03	1.10-02	4.56-05
CO	2	100	2	2.34-03	6.87-03	4.38-05

	ε_R	ρ	b	α_R	β_R	q_P
CO	10	100	2	5.07-03	1.66-02	3.16-05
CO	10	1000	2	1.12-02	2.44-02	5.29-05
CO	10	1000	1	-1.61-02	-3.17-02	1.76-05
CO	2	1000	2	1.06-02	2.51-02	3.66-05
CO	2	100	2	5.00-03	1.67-02	3.87-05
CO	2	1000	1	1.59-02	3.27-02	1.84-05

	ε_R	ρ	b	α_R	β_R	q_P
CO	10	100	2	1.16-02	4.55-02	5.93-05
CO	10	1000	2	-2.74-02	-5.65-02	3.80-05
CO	10	1000	1	-3.76-02	-7.16-02	2.02-05
CO	2	1000	2	-2.66-02	-6.10-02	4.30-05
CO	2	100	2	1.12-02	4.58-02	9.18-05
CO	2	1000	1	3.95-02	7.39-02	3.29-05

4.5 MHz

	ε_R	ρ	b	α_R	β_R	$q_R \times 10^{+5}$
CO	10	100	2	-2.48-02	-1.17-01	2.63
CO	10	1000	2	5.33-02	1.20-01	2.69
CO	10	1000	1	8.02-02	1.50-01	9.96-01
CO	2	1000	2	5.62-02	1.34-01	3.29
CO	2	100	2	-2.30-02	-1.19-01	3.68
CO	2	1000	1	7.68-02	1.51-01	2.02

	ε_R	ρ	b	α_R	β_R	$q_R \times 10^{+5}$
CO	10	100	2	5.37-02	3.40-01	2.81
CO	10	1000	2	7.26-02	3.23-01	3.30
CO	10	1000	1	1.32-01	3.51-01	1.74
CO	2	1000	1	1.28-01	3.92-01	1.34
CO	2	1000	2	9.76-02	3.47-01	6.61-01
CO	2	100	2	5.26-02	3.56-01	5.36

15 MHz

F-C3102

	[illegible]R	[illegible]	b	[illegible]R	[illegible]R	$q_R \times 10^{+5}$
CO	10	100	2	5.37-02	3.40-01	2.81
CO	10	1000	2	7.26-02	3.23-01	3.30
CO	10	1000	1	1.32-01	3.51-01	1.74
CO	2	1000	1	1.28-01	3.92-01	1.34
CO	2	1000	2	9.76-02	3.47-01	6.61-01
CO	2	100	2	5.26-02	3.56-01	5.36

45 MHZ

	ε_R	ρ	b	α_R	β_R	$q_R \times 10^{+5}$
CO	10	1000	1.750	8.53-02	.934	4.202×10^{-2}
CO	10	100	2	1.23	.123	2.66-01
CO	10	1000	2	1.26	1.29-01	2.94-06
CO	10	1000	1	1.49-01	9.45	1.85
CO	10	1000	2	7.43-02	9.33-01	3.59-02
CO	10	100	1.75	1.50	1.18-01	5.04-01
CO	10	1000	1.65	9.06-02	9.35-01	7.04-01
CO	10	100	1.5	9.74-02	9.51-01	5.46-01
CO	10	1000	1.5	9.98-02	9.36-01	4.98-01
CO	10	100	2.0	7.41-02	9.45-01	4.409-01
	.2	100	1.5	1.44-01	9.91-01	4.64-01
CO	2	1000	1.75	.1458	.935	2.20×10^{-2}
CO	2	100	2	1.13	1.65-01	1.53-01
CO	2	1000	2	1.27-01	9.27-01	3.16-02
	2	1000	1.75	.1458	.935	2.20×10^{-2}
CO	2	100	1.75	1.40	1.52-01	4.68-01
CO	2	1000	1.5	1.68-01	9.47-01	3.24-01

100 MHz

	ε_R	ρ	b	α_R	β_R	$q_R \times 10^5$
CO	10	100	2	2.38-01	1.41	8.43-01
CO	10	1000	2	2.42-01	1.39	1.03
CO	10	1000	2	6.63-02	2.0669	.85
CO	10	100	2	6.96-02	2.07	8.60-01
CO	10	100	1	1.49-01	2.08	.0512
CO	10	1000	1	2.35	1.67-01	9.81+03
	2	1000	2	8.95-02	2.02	1.25-01
CO	2	100	2	4.31-01	1.558	6.37-01
CO	2	100	1	2.095	6.20-01	2.79-01

125 MHz

	ε_R	ρ	b	α_R	β_R	$q_R \times 10^5$
CO	10	1000	2	2.03-01	2.08	.068
CO	10	100	2	2.03-01	2.093	.052
CO	10	1000	1	1.44-01	2.58	.236
CO	10	1000	2	6.07-02	2.58	.43
CO	10	100	2	6.39-02	2.58	.49
CO	2	1000	2	6.88-02	2.54	1.29-01

140 MHz

	ε_R	ρ	b	α_R	β_R	$q_R \times 10^5$
CO	10	1000	2	.193	2.46	.0589
	10					
CO	10	100	2	.195	2.47	.021 x 8

150 MHz

	ε_R	ρ	b	α_R	β_R	$q_R \times 10^5$
CO	10	1000	2	1.90-01	2.70	1.23-02
CO	10	10	2	4.84-01	7.59-01	2.25-01
CO	10	100	2	7.00-01	7.29-01	6.92-06
CO	10	100 -	2	5.73-02	3.10	4.44-01
CO	10	100	1	9.99-01	1.016	2.10-01
	10	1000	2	2.24-01	6.99-01	5.98-03
CO	10	1000	2	.75	.5	1.41+03
CO	10	1	2	2.16-01	4.90-01	1.75-01
CO	10	.1	2	1.16-01	2.78-01	2.69-01
CO	10	1000	2	1.90-01	2.70	1.23-02
CO	10	1000	2	7.22-01	7.10-01	2.76
CO	10	1000	2	5.45-02	3.10	5.07-01
CO	10	100	2	1.91-01	2.71	1.45-01
CO	10	1000	1	1.41-01	3.10	7.34-01
CO	10	1000	1	7.22-01	8.19-01	1.30-01
CO	10	100	2	5.73-02	3.10	4.44-01
CO	2	1	2	2.08-01	4.94-01	1.80-01
CO	2	100	2	3.99-01	9.70-01	2.29-01
CO	2	100	2	9.24-01	1.32	5.84+03
CO	2	100	1	1.27	1.67	1.02
CO	2	100	2	8.90-01	1.23	3.05+01
CO	2	100	2	5.26-02	3.07	4.25-01
CO	2	.1	2	1.15-01	2.78-01	1.04-01

175 MHz

	ε_R	ρ	b	α_R	μ_R	$q_R \times 10^5$
CO	10	1000	2	1.84-01	3.28	.629
	10	1000	1			
CO	10	100	2	3.10-01	1.92	.233
CO	10	1000	2	.313	1.90	.236

200 MHz

	ε_R	ρ	b	α_R	β_R	$q_R \times 10^5$
CO	10	1000	2	.2468	2.77	.00802
	10	1000	1			
CO	10	100	2	.245	2.78	.0549
	10	1000	2	.180	3.84	.09
CO	10	100	2	.184	3.84	.093
CO	10	1000	1	.132	4.133	1.8
CO	10	1000	2	.0417	4.14	.63
	10	100	2			

250 MHz

	ε_R	ρ	b	α_R	β_R	$q_R \times 10^5$
CO	10	1000	2	3.10-02	5.19	1.09
CO	10	1000	1	1.21-01	5.169	.13
CO	10	100	2	3.19-02	5.19	.80
CO	10	1000	2	.173	4.9	.89
CO	10	100	2	.1779	4.44	1.29
CO	10	1000	1	.121	5.16	2.5

275 MHz

	ε_R	ρ	b	α_R	β_R	$q_R \times 10^5$
CO	10	1000	2	.202	4.81	.060
CO	10	100	2	.202	4.82	.074

300 MHz

	ε_R	ρ	b	α_R	β_R	$q_R \times 10^5$
CO	10	1000	2	1.989-01	5.433	.022
CO	10	1000	2	1.998-01	5.435	7.40
CO	10	100	2	.199	5.43	.013
CO	10	1000	1	.108	6.20	.45
CO	10	100	2	.167	6.01	.32
	10	1000	2	.167	6.007	.137
CO	10	100	2	1.67-01	6.01	1.13-01
	10	1000	2	1.98-01	5.42	3.58-02
	10	100	2	1.99-01	5.43	6.28-02

400 MHz

ε_R	ρ	b	α_R	β_R	$q_R \times 10^5$
10	1000	2	.4642	2.94	.030
10	1000	1			
10	100	2	.4625	2.95	.0298

450 MHz

	ϵ_R	ρ	b	α_R	β_R	$q_R \times 10^5$
CO	10	1000	2	.2014	8.15	1.63-02
	10	1000	2	.01102	9.395	3.3
	10	100	2	1.23	1.25	1.68-01
	10	100	2	2.41-01	1.39	8.40-01
CO	10	1000	2	1.245	1.23	1.81-01
	10	1000	2	2.95-01	5.214	9.90-02
	10	1000	1			
	10	1000	1	.07189	9.3409	.397
	10	100	2	.2019	8.15	
	10	100	2	.0112	9.3949	1.86
CO	10	100	2	.206	8.84	.045
CO	2	1000	2	.00684	9.3931	2.24
	2	100	2	1.86	2.14	2.37-01
	2	100	2	.006754	9.393	5.8
	2	1000	1	.0520	9.3108	.0796
CO	2	1000	2	6.61-02	9.13	3.28+01

475 MHz

	ε_R	ρ	b	α_R	β_R	$q_R \times 10^5$
CO	2	1000	2	6.15-03	7.91	1.05+01
CO	10	1000	2	1.00-02	9.91	2.28

500 MHz

	ε_R	ρ	b	α_R	β_R	$q_R \times 10^5$
CO	2	1000	2	5.56-03	10.44	7.25
CO	10	1000	2	9.07-03	10.44	3.09

	ε_R	[illegible]	b	α_R	β_R	$q_R \times 10^5$
CO	2	1000	2	3.87-03	12.542	9.13
CO	10	1000	2	6.37-03	12.543	2.65

650 MHz

	ε_R	σ	b	α_R	β_R	$q_R \times 10^5$
CO	2	1000	2	3.30-03	13.59	16.3
CO	10	1000	2	5.45-03	13.59	6.94

700 MHz

	ε_R	ρ	b	α_R	β_R	$q_R \times 10^5$
CO	2	1000	2	2.85-03	14.6	5.10
CO	10	1000	2	4.71-03	14.6	3.37
CO	2	1000	2	2.64-02	1.44+01	7.92-01
CO	10	1000	2	4.62-02	1.44+01	3.22-01

800 MHz

	ϵ_R	ρ	b	α_R	β_R	$q_R \times 10^5$
CO	2	1000	2	2.18-03	16.7	8.19
CO	10	1000	2	3.62-03	16.7	1.29

900 MHz

	ε_R	ρ	b	α_R	β_R	$q_R \times 10^5$
CO	10	1000	2	1.73-03	18.8	4.19+01
CO	10	1000	2	2.86-03	18.8	3.22+01

	ϵ_R	σ	b	α_R	β_R	$q_R \times 10^5$
CO	2	1000	2	1.40-03	20.9	7.67+01
CO	10	1000	2	2.32-03	20.9	6.56
CO	2	1000	2	1.06-04	2.58-04	1.16-04
CO	2	100	2	5.95-05	1.46-04	2.42-04
CO	2	1000	1	1.51-04	3.63-04	1.13-04
CO	10	1000	2	1.06-04	2.58-04	1.37-04
CO	10	100	2	5.96-05	1.46-04	3.41-04
CO	10	1000	1	1.57-04	3.63-04	2.66-04
CO	10	1000	2	2.19-02	2.08+01	1.60
CO	10	100	2	2.19-02	2.08+01	1.16
CO	10	1000	1	1.81-02	2.08+01	2.04
CO	2	1000	2	1.28-02	2.08+01	4.09
CO	10	1000	2	2.19-02	2.08+01	1.54
CO	10	100	2	2.19-02	2.08+01	1.26
CO	10	1000	1	1.81-02	2.08+01	2.93
CO	2	1000	2	1.28-02	2.08+01	4.03
CO	2	100	2	1.27-02	2.08+01	3.87
CO	2	1000	1	1.11-02	2.08+01	5.19
CO	2	1000	2	1.28-02	2.08+01	3.75

1500 MHz

	ε_R	ρ	b	α_R	β_R	$q_R \times 10^5$
CO	10	1000	2	2.193-01	23.87	3.75-02
CO	10	100	2	2.26	2.27	6.09-02
CO	10	1000	2	2.26	2.26	4.67-02
	2	100	2	3.63	3.79	7.59-02
	2	100	2	3.63	3.79	7.59-02

2000 MHz

	ε_R	ρ	b	α_R	β_R	$q_R \times 10^5$
CO	2	1000	2	3.51-04	41.8	1.68+03
CO	10	1000	2	5.84-04	41.8	6.47+01

2500 MHz

	ε_R	ρ	b	α_R	β_R	$q_R \times 10^5$
CO	2	1000	2	1.34-02	1.56+02	3.09+01
CO	2	100	2	1.34-02	1.56+02	2.28+01

	ε_R	ρ	b	α_R	β_R	$q_R \times 10^5$
CO	10	100	2	3.92	3.93	6.52-02
CO	10	1000	2	3.92	3.92	1.59-02
	2	100	2	6.39	6.49	4.75-02
	2	100	2	6.39	6.49	4.15-02

7500 MHz

	ϵ_R	[illegible]	b	α_R	β_R	$q_R \times 10^5$
CO	2	1000	2	1.34-02	1.56+02	2.79+01
CO	2	1000	2	9.90-02	1.50+02	5.80+01
CO	2	100[illegible]	2	9.34-01	1.28+02	2.00-01
CO	2	1000	2	1.34-02	1.56-02	2.18+01
CO	2	100	2	6.95-01	1.30+02	8.14-01
CO	10	100	2	3.55-01	1.49+02	8.78-01
CO	2	1000	2	1.34-02	1.56+02	2.79+01
CO	2	100	2	2.16-02	1.55+02	2.30
CO	2	100	2	2.16-02	1.55+02	1.40