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EARTH GROUND SYSTEM DESIGN AND EVALUATION.(U)

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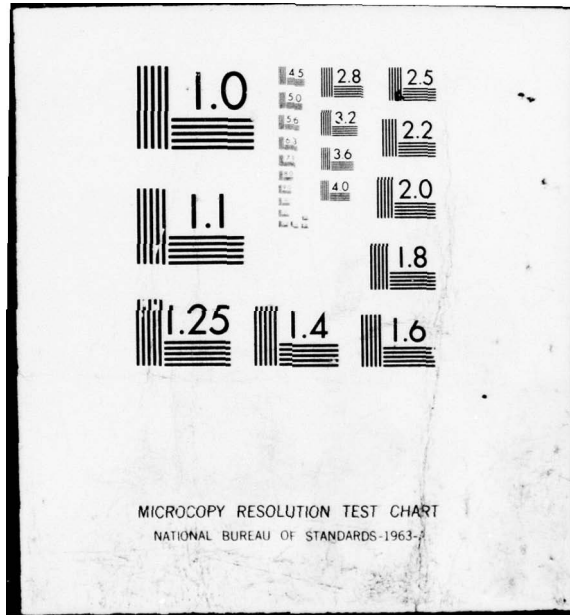
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EARTH GROUND SYSTEM DESIGN AND EVALUATION

JOHN D. RILEY



JANUARY 1979

FINAL REPORT

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NOTICE

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16. Abstract Model K2-10 ground rods were installed, tested, and evaluated with copper-clad steel (CCS) and CCS salt-enhanced (CCSS) rods at field sites and the National Aviation Facilities Experimental Center (NAFEC) for comparison and determination if they meet the manufacturer's specifications in high-, medium-, and low-resistivity soils under arid and wet conditions through a year of seasonal change. It was determined at most sites that the XIT-rod-to-earth impedance remained lower than the CCS and CCSS rods under the above conditions, although seasonal impedance variations did exist. XIT rod earth impedance remained well above 4 ohms at most sites. XIT rod installation costs were greater, and unit costs were much greater than CCS and CCSS rods. The engineering approach used herein may be a useful guide for engineering ground systems at field facilities.			
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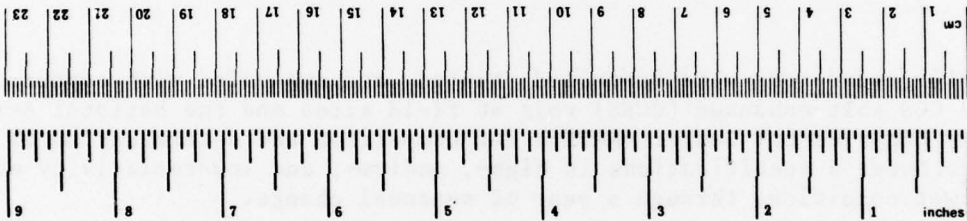
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
in ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha
MASS (weight)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
VOLUME				
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.96	liters	l
gal	gallons	3.8	liters	l
ft ³	cubic feet	0.03	cubic meters	m ³
yd ³	cubic yards	0.76	cubic meters	m ³
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
AREA				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000 m ²)	2.5	acres	acres
MASS (weight)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	short tons
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	35	cubic feet	ft ³
m ³	cubic meters	1.3	cubic yards	yd ³
TEMPERATURE (exact)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$2.25. SD Catalog No. C13.10.286.

PREFACE

Acknowledgement is given XIT Company for permission to use company-provided technical specifications in this report.

Acknowledgement is also expressed to personnel at each of the test site locations for their cooperation in collecting data for this report.

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
Purpose	1
Background	1
DISCUSSION	1
Description	1
Installation	1
Test Design	1
Certification	3
Theory	3
RESULTS	7
Jefferson County Airport, Beaumont, Texas	7
El Paso Airport, El Paso, Texas	10
Wildwood RCAG Site, Wildwood, New Jersey	10
Phoenix H Marker Site, Phoenix, Arizona	12
NAFEC, Atlantic City, New Jersey	12
Chesterfield VOR Site, Chesterfield, South Carolina	13
Cost Analysis	14
CONCLUSIONS	16
RECOMMENDATIONS	17
REFERENCES	17
APPENDIX	

LIST OF ILLUSTRATIONS

Figure		Page
1	XIT Ground Rod	19
2	Estimated Average Earth Resistivity in U.S.	20
3	Biddle Earth Tester Kit	21
4	Earth Resistivity Measurement Setup	22
5	XIT Rod Technical Specification (2 Sheets)	23
6	Jefferson County Airport, Beaumont, Texas, Ground Rod Resistance versus Time Plot	25
7	El Paso Airport, El Paso, Texas, Ground Rod Resistance versus Time Plot	26
8	Wildwood RCAG Site, Wildwood, New Jersey, Ground Rod Resistance versus Time Plot	27
9	Phoenix H Marker Site, Phoenix, Arizona, Ground Rod Resistance versus Time Plot	28
10	Chesterfield VOR Site, Chesterfield, South Carolina, Ground Rod Resistance versus Time Plot	29
11	NAFEC, Atlantic City, New Jersey, Ground Rod Resistance versus Time Plot	30
12	Earth Resistance Shells Surrounding a Vertical Earth Electrode	31
13	Typical Variations in Soil Resistivity as a Function of Moisture, Temperature, and Salt Content	32
14	Effect of Rod Length upon Resistance	33
15	Effect of Rod Diameter upon Resistance	33
16	Ratio of the Actual Resistance of a Rod Array to the Ideal Resistance of N Rods in Parallel	34

LIST OF TABLES

Table		Page
1	Relative Conductivity of Common Metals	4
2	Resistivity Values of Earthing Mediums (2 Sheets)	5
3	Approximate Soil Resistivity	6
4	Earth Resistivity and Ground Rod Calculations for Copper-Clad Steel Ground Rods 5/8-Inch Diameter	8
5	Monthly Ground Rod Resistance Measurements in Ohms	9
6	Ground Rod Resistance Comparisons	11
7	Resistance in Ohms and Cost of XIT Rod versus CCS Ground Grid	15

INTRODUCTION

PURPOSE.

This report describes the installation, test, and analysis of results of model K2-10 XIT ground rod, procured from the XIT Rod Company and installed at the following six sites: the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey; Wildwood, New Jersey, remote center air-ground facility (RCAG); Chesterfield, South Carolina, very high frequency omnirange (VOR); Beaumont, Texas, airport surveillance radar (ASR); El Paso, Texas, ASR; and Phoenix, Arizona, H Marker, between October 28, 1975, and January 20, 1978.

BACKGROUND.

Prior to solid state electronics, a ground rod impedance to earth of 25 ohms was sufficient protection for personnel and high-current vacuum tube electronic equipment. Since the introduction of solid state electronics, it has been realized that ground rod impedance to earth of 5 ohms or less is required for electronic equipment protection. This requirement is due to the low voltage and current capacity of solid state electronic equipment.

Early in 1974, several Federal Aviation Administration (FAA) facilities began installation of XIT rods and have since attained a measure of success with them. Late in 1975, FAA Headquarters Research and Development requested that NAFEC conduct tests to validate the manufacturer's specification.

DISCUSSION

DESCRIPTION.

The model K2-10 XIT rod in figure 1 is a type K copper tube, 10 feet long, 2 1/8 inches outer diameter, and a wall thickness of 0.083 inch. It contains metallic salts with spun glass inside each end where holes have been provided behind the capped ends. The materials within the tube absorb the external atmospheric moisture through the top entry holes where it is chemically converted to an electrolytic and by gravity enters the soil. The XIT Rod Company manufactures four different patented rods all of the same material, diameter, and wall thickness. The difference in these rods are their 8-, 10-, and 20-foot lengths or the L shaped rod which is used in areas where bedrock is close to the earth's surface.

INSTALLATION.

The installation procedure for the XIT rod is to auger a hole to the XIT rod length, insert the rod into the hole (insure that the shipping tape has been removed from over the XIT rod holes), pour in sufficient salt to cover the bottom holes, pour several gallons of water into the hole to cover the bottom rod holes, back fill the hole with earth, and tamp. It should be noted that the rod's upper holes are to be exposed to the outside air in order that it may function properly.

TEST DESIGN.

The established procedure was to compare the XIT-rod-to-earth impedance

with those of a copper-clad steel (CCS) rod and a CCS rod centered in a salt ring (CCSS) for at least a 15-month period. The tests were performed in various soil resistivities under predominately moist or dry conditions. Six sites were selected under the following conditions:

1. Low soil resistivity (up to 300 meter-ohms) with relatively high rainfall.
2. Medium soil resistivity (300 to 600 meter-ohms) with relatively high rainfall.
3. High soil resistivity (greater than 600 meter-ohms) with relatively high rainfall.
4. Low soil resistivity with relatively low rainfall.
5. Medium soil resistivity with relatively low rainfall.
6. High soil resistivity with relatively low rainfall.

Weather data were obtained from the Atlantic City Weather Service concerning average yearly temperature and rainfall throughout the nation. In addition, a Federal Communications Commission (FCC) estimated conductivity (reciprocal of resistivity) map (figure 2) was obtained for the purpose of determining prospective FAA test locations. Soil resistivity data on specific soils within the areas of possible interest were obtained from each of the local county agriculture departments. It should be noted that the resistivities at each of these locations were to depths less than 10 feet. To further insure success in site

selection, earth resistivity measurements were made at each of the potential sites with a hand-cranked Biddle Megger Null Balance Earth Tester model 63220 (figure 3). Unfortunately, these measurements were not conducted at identical temperature and moisture conditions at all locations due to travel difficulties.

These measurements, as shown in figure 4, were made at 10-foot depths (length of each test ground rod) in three or more different locations, in an equilateral triangular fashion 30 feet apart. The purpose of the 30-foot triangular spread between ground rods was to avoid interaction between rods, and to attempt to attain equal and uniform resistivity for each ground rod.

A 15-month data collection period was established to verify and compare the XIT Rod Company's specification impedance-time curve with those of the CCS and CCSS rods. It can be seen in figure 5, that several months of this period were required for the XIT rod to chemically react with the earth before the impedance to earth averages 4.5 ohms. The 12 remaining months were established to determine the effects of seasonal temperature changes on the test ground rod impedance to earth (figures 6 through 11).

During the above-mentioned tests, a modified XIT rod test was conducted at NAFEC. This effort was made to determine if the XIT-rod-to-earth impedance could be further reduced and remain so during the 15-month test period. This XIT rod was modified with additional 1/4-inch holes 1 foot apart along the length of the rod. It was installed and tested in the same fashion and test area as the standard XIT rod. Figure 11 gives data results.

CERTIFICATION.

The XIT rod had undergone corrosion tests by Underwriters Laboratories and granted a listing under UL467J. These tests show that the XIT rod is less susceptible to corrosion effects than the standard CCS rods with direct current (d.c.) voltage applied for periods of 6 months and 1 year.

THEORY.

Because of the distributed nature of the earth volume into which electrical energy flows, the resistance to earth is defined as the resistance in ohms between the point of connection and a very distant point on the earth. Resistance to current flow through a ground rod depends on (a) resistance of the ground rod and connections to it, (b) ground rod and earth contact resistance, and (c) resistance of the surrounding earth (figure 12).

In table 1, the resistivity of the various metallic compounds may be determined by obtaining the reciprocal of their relative conductivities. If the size and cross-sectional areas of these materials are large, their resistances will be negligible. It should be noted that copper and silver are the two highest conductivity materials.

The contact resistance of a ground rod to earth depends on the rod surface area contact with the soil. Corrosion has little effect on contact resistance, providing it has not corroded to the extent of reducing the length of the rod.

The resistivities of various soils may be seen in table 2. Soil resistivities also vary according to moisture and temperature, as shown in

table 3 and figure 13. Soil resistivity can be further reduced when salt is added as shown in figure 13.

The resistance of a rod is directly affected by changes in the length of the rod and by the logarithm of the length. Changes in the diameter only show up as slight changes in the logarithm of the length. Figures 14 and 15 show the measured changes in resistance that occur with rod length and rod diameter. It is evident that effects of rod length do predominate over the effects of rod diameter.

Soil resistivities may be obtained from (1) the FCC Conductivity Charts, (2) United States (U.S.) Department of Agriculture Soil Survey Reports of counties of interest, and (3) field measurements. The FCC Conductivity Charts are appropriate for locating general soil conductivity data in a region, but are not accurate for a specific area.

The U.S. Department of Agriculture (USDA) Soil Survey Report contains aerial photograph maps and tables of all the soil types within a specific county. A location can be pinpointed on the aerial photograph map, and the soil type outlined on it. The tables reveal all the soil particulars including conductivity and/or resistivity at various depths. These measurements, however, do not necessarily reflect the specific point that may be of interest.

Field measurements with a Megger Earth Tester provide the most accurate method of determining earth resistivity of a specific point. The other two above-mentioned methods are of value in the attempt to locate a low-resistivity area.

Soil resistivity can be expressed as $\rho = 2\pi AR$, where ρ is the average

TABLE 1. RELATIVE CONDUCTIVITY OF COMMON METALS

<u>Metal</u>	<u>Relative Conductivity</u> (g _r)	<u>Comments</u>	<u>Metal</u>	<u>Relative Conductivity</u> (g _r)	<u>Comments</u>
Alfenol	.011		Nickel-silver	.062	64% Cu, 18% Zn, 18% Ni
Beryllium	.377		Palladium	.160	
Brass	.442	66% Cu, 34% Zn	Permalloy	.038	45% Ni, 55% Fe
Cadmium	.230		Permendure	.066	50% Co, 1-2% V, bal. Fe
Chromax	.017	15% Cr, 35% Ni, 50% Fe	Platinum	.164	
Chromium	.663		Rodium	.338	
Cobalt	.177		Rhometal	.019	36% Ni, 64% Fe
Constantan	.039	55% Cu, 45% Ni	Sendust	.022 -.029	10% Si, 5% Al, 85% Fe (cast)
Copper	1.000	Commercial annealed	Silver	1.064	
Gold	.707		Steel	.078 -.133	0.4%-0.5% C, bal. Fe
HyMu80	.030	80% Ni, 20% Fe	Steel, manganese	.025	13% Mn, 1% C, 86% Fe
Iron, Pure	.178	Annealed	Steel, silicon	.034	4% Si, 96% Fe (hot rolled)
Iron, Swedish	.172		Steel, stainless	.019	0.1% C, 18% Cr, 8% Ni, 73.9% Fe
Iron, cast	.057		Supermalloy	.029	79% Ni, 5% Mo, 16% Fe
Kovar A	.006	29% Ni, 17% Co, 0.3% Mn, 53.7% Fe	Tin	.151	
Lead	.079		Titanium	.036	
Magnesium	.387		Tungsten	.315	
Manganin	.039	84% Cu, 12% Mn, 4% Ni	Zinc	.287	
Monel Metal	.041	67% Ni, 30% Cu, 1.4% Fe, 1% Mn			
Mumetal	.034 -.069	71-78% Ni, 4.3-6% Cu, 0-2% Cr, bal. Fe			
Nickel	.250				

TABLE 2. RESISTIVITY VALUES OF EARTHING MEDIUMS

Medium	Resistivity		
	Minimum (ohm-cm)	Average (ohm-cm)	Maximum (ohm-cm)
Surface soils, loam, etc.	10^2		5×10^3
Clay	2×10^2		10^4
Sand and gravel	5×10^3		10^5
Surface limestone	10^4		10^6
Limestones	5×10^2		4×10^5
Shales	5×10^2		10^4
Sandstone	2×10^3		2×10^5
Granites, basalts, etc.		10^6	
Decomposed gneisses	5×10^3		5×10^4
Slates, etc.	10^3		10^4
Fresh Water Lakes		2×10^4	2×10^7
Tap Water	10^3		5×10^3
Sea Water	20	10^2	2×10^2
Pastoral, low hills, rich soil, typical of Dallas, Texas; Lincoln, Nebraska areas		3×10^3	
Flat country, marshy densely wooded typical of Louisiana near Mississippi River	2×10^2	10^4	
Pastoral, medium hills and forestation, typical of Maryland, Pennsylvania, New York, exclusive of mountainous territory and seacoasts		2×10^4	

TABLE 2. RESISTIVITY VALUES OF EARTHING MEDIUMS (Continued)

Medium	Resistivity		
	Minimum (ohm-cm)	Average (ohm-cm)	Maximum (ohm-cm)
Rocky soil, steep hills, typical of New England	10^3	5×10^4	10^5
Sandy, dry, flat, typical of coastal country	3×10^4	5×10^4	5×10^5
City, industrial areas		10^5	10^6
Fills, ashes, cinders, brine, waste	6×10^2	2.5×10^3	7×10^3
Clay, shale, gumbo, loam	3×10^2	4×10^3	2×10^4
Same--with varying proportion of sand and gravel	10^3	1.5×10^4	10^5
Gravel, sandstones, with little clay or loam, granite	5×10^4	10^5	10^6

TABLE 3. APPROXIMATE SOIL RESISTIVITY

Type of Soil	Resistivity		
	(ohm-m)	(ohm-cm)	(ohm-ft)
Wet Organic Soil	10	10^3	33
Moist Soil	10^2	10^4	330
Dry Soil	10^3	10^5	3,300
Bedrock	10^4	10^6	33,000

soil resistivity to depth A in centimeter-ohms, and R is the Megger earth tester reading in ohms. In table 4, each test site name appears in the far left column. To the right of this column are the meter readings taken at each of these sites at 2-foot and 10-foot depths. It should be noted that at Beaumont an additional 3-foot depth reading was made to see if the soil resistivity progressively reduced between 2 and 10 feet. Additional readings were not made due to limited time. At Chesterfield, South Carolina, 30-foot readings were made after 10-foot readings appeared too high. It was discovered that the resistivity remained approximately the same at 30 feet as it was at 10 feet.

Ground rod resistance to earth can be expressed as $R = \left(\frac{\rho}{2\pi L} \right) \left(\ln \frac{4L}{a} - 1 \right)$,

where ρ is the soil resistivity in centimeter-ohms, L is the length of the ground rod in centimeters, and a is the diameter of the ground rod in centimeters. In table 4 it may be seen that ground rod resistances to earth were computed by using the earth measurements at various depths at all sites. The dimensions of the ground rods used in these computations were standard 10-foot length, 5/8-inch-diameter CCS rods. It should be noticed in table 4 that the average computed ground-rod-to-earth resistance is compared with the average actual measurement for each test location. It should also be noted that the average measured resistivity is compared with the FCC chart and the USDA resistivities for each test site.

Monthly ground-rod-to-earth resistance measurements with temperature and moisture can be seen in table 5. Unfortunately, the test

team had difficulty in obtaining more data from Chesterfield, South Carolina, due to the lack of an earth tester for these monthly measurements. It should also be noticed that the measurements for Phoenix, Arizona, dropped to zero through the later half of this study. This condition is totally unexplainable, since several calibrated instruments were used to insure confidence in these measurements. The average measurement for Phoenix CCS rod would certainly have been higher than 49 ohms had this condition not appeared.

A plot of the measurements in table 5 may be seen in figures 6 through 10 for each test site. These plots compare each type of ground rod resistance to earth over a time period.

RESULTS

JEFFERSON COUNTY AIRPORT, BEAUMONT, TEXAS.

In table 5 and figure 6, it can be seen that the average CCSS rod resistance of 2.2 ohms to earth was twice as high as the XIT rod resistance of 1.1. In fact, the standard CCS rod average resistance of 6.9 was approximately six times the XIT rod resistance. The Morey-type soil is of a gumbo texture where a CCS rod can be pushed into the earth but next to impossible to remove due to a vacuum created. The ground rod bond to the earth was excellent. The XIT rod was hand augered into the earth by FAA employees. The average rainfall is 55.21 inches, and the average temperature is between 22° Fahrenheit (F) and 98° F. The soil resistivity is 9 to 19 meter-ohms at 9- to 12-foot

TABLE 4. EARTH RESISTIVITY AND GROUND
COPPER-CLAD STEEL GROUND

	Meter Readings in Ohms at 2- Foot Depth Except Where Indicated	Meter Readings in Ohms at 10- Foot Depth	Resistivity Meter-Ohms at 2-Foot Depth Except Where indicated	Resistivity Meter-Ohms at 10-Foot Depth	Average 2-Foot Depth Resistivity Meter-Ohms Except Where Indicated	Average 10-Foot Depth Resistivity Meter-Ohms	FCC Chart Resistivity Meter-Ohms
BEAUMONT TX.	2.63 (3)	0.45	15.11 (3)	8.62	15.11 (3)	9.19	33.33
Earth resistivity	5.09	0.48	19.5	9.19	18.68		
between 0-300	5.0	0.43	19.15	8.23			
meter-ohms and	5.4	0.52	20.68	9.96			
high rainfall	4.4	0.49	16.85	9.38			
	4.5	0.51	17.24	9.77			
EL PASO, TX.	20.3	3.21	77.75	61.98	70.99	61.91	125.0
Earth resistivity	19.8	3.4	75.84	65.11			
between 300-600	19.5	3.08	74.69	58.99			
meter-ohms and	20.3	3.15	77.75	60.33			
low rainfall	13.9	3.6	53.24	68.94			
	17.4	2.93	66.65	56.11			
WILDWOOD, N.J.	470	20	1,800.21	383.02	1,445.19	316.95	250.0
Earth resistivity	680	17	2,604.56	224.07			
between 300-600	270	13	1,034.16	248.96			
meter-ohms and	295	23	1,129.92	440.48			
high rainfall	310	20	1,187.37	383.02			
	240	11.6	919.26	222.15			
PHEONIX, AZ.	233	50.8	892.44	972.88	888.61	773.11	66.67
Earth resistivity	231	56.3	884.78	1,078.21			
between 600-1100		34.5		660.71			
meter-ohms and		32.4		620.5			
Low rainfall		30.2		578.36			
		37.7		722.0			
NAFEC, N.J.	463	184	1,773.4	3,523.81	1,886.39	3,590.84	250.0
Earth resistivity	522	191	1,999.38	3,657.87			
above 600 meter-							
ohms and high							
rainfall							
CHESTERFIELD, S.C	437 (30)	1,430	25,107.16 (30)	27,386.0	29,645.98 (30)	29,971.5	500.0
Earth resistivity	595 (30)	1,700	34,184.8 (30)	32,557.0			
above 600 meter-							
ohms and high							
rainfall							

GROUND ROD CALCULATIONS FOR
 5/8-INCH DIAMETER

Chart Activity m-Ohms	Computed Ground Rod Resistance in Ohms	Average Measured 10-Foot Ground Rod Resistance in Ohms	U.S. Department of Agriculture Soil Survey Data For Each Locality
3.33	19.68 (2) 11.68 (3) 2.71 (10)	6.9	Morey soil, clay and silty or gumbo texture. Average rainfall 55.21 inches. Average temperature 22°F-98°F. Resistivity is 9-19 meter-ohms at 9 to 12 feet depth.
3.0	74.77 (2) 18.24 (10)	20.7	Hueco-wink soil which is a fine loam sand and moist 80 inches below surface. Average rainfall 7.89 inches. Average temperature 49.9°F-77.2°F. Conductivity is less than 2 mmhos/cm or 5 meter-ohms down to 80 inches depth.
3.0	1522.97 (2) 93.4 (10)	146.0	Hammonton sandy loam soil with water table 5 feet below surface. Average rainfall 43 inches, average temperature 10°F-94°F. Resistivity is 10 to 50 meter-ohms to 80 inches depth.
3.67	935.97 (2) 227.83 (10)	49.0	Alluvial soil which is a very sandy loam and dry below 10 feet. This soil prevails along riverbeds in this region. Average rainfall 6-8 inches. Rain is excessive at times. Average temperature 40°F-100°F. No Resistivity or conductivity measurements given.
3.0	1986.92 (2) 1058.21 (10)	450.0	Quartzipsamments soil which is coarse sand with quartzose gravel. Resistivity is greater than 50 meter-ohms down to 60 inch depth.
3.0	8832.52 (10) 3479.08 (30)	> 10000.0	Typic quartzipsamments lakeland soil which is coarse grain sand 100-200 feet to rockbed. Average rainfall 55 inches. Average temperature 66°F. No resistivity or conductivity measurements given.

2

TABLE 5. MONTHLY GROUND ROD RESISTANCE MEASUREMENT

	OCT.	NOV.	1975 DEC.	1976 JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	1976 DEC.	1977 JAN.	FEB.	MAR.	APR.	MAY	JUN.
BEAUMONT, TX																					
XIT Rod											16	14	7	5	22	24	29		6	9	
CCS Rod											1.75	1.2	1.3	1.1	0.2	0.7	1.0		1.2	1.6	
CCSS Rod											3.08	3.0	3.7	6.1	7.6	6.4	6.7	10.0		6.9	7.8
Temperature (*F)											3.37	2.6	2.6	2.3	2.0	2.0	1.8	2.2		2.3	2.0
Soil Moisture											89*	90*	65*	65*	42*	51*	60*	73*		80*	84*
EL PASO, TX.																					
XIT Rod											17		1	1	2	4	9	2	11	2	1
CCS Rod											9.04		8.1	8.4	9.07	9.4	9.4	9.4	9.6	9.4	9.9
CCSS Rod											9.01		17.5	19.0	18.5	21.0	22.5	21.0	21.0	20.0	22.0
Temperature (*F)											21.9		21.4	23.0	23.0	36.0	16.0	13.0	12.0	12.0	14.0
Soil Moisture											95*		69*	64*	39*	56*	48*	50*	58*	68*	91*
WILDWOOD, N.J.																					
XIT Rod											9	17	7	9	10	12	10	10	15	16	14
CCS Rod											42.0	41.5	38.0	45.0	50.0	58.0	76.0	60.5	65.0	64.2	59.0
CCSS Rod											150.0	140.0	135.0	153.0	180.0	360.0	135.0	130.0	130.0	130.0	113.0
Temperature (*F)											183.0	50.5	45.0	45.0	50.0	67.0	78.0	81.0	87.0	90.0	82.0
Soil Moisture											73*	86*	76*	40*	48*	17*	46*	50*	60*	80*	70*
PHOENIX, AZ.																					
XIT Rod											19	21		18	20	13	17	15	12	26	
CCS Rod											22.0	28.0	22.0	22.0	21.0	28.0	31.0	31.0	31.0	22.0	
CCSS Rod											69.0	68.0	63.0	64.0	80.0	78.0	88.0	88.0	93.0	93.0	
Temperature (*F)											50.3	43.5	42.0	44.0	64.0	56.0	64.0	64.0	66.0	66.0	
Soil Moisture											103*	98*	90*	86*	67*	50*	86*	72*	86*	71*	
ATLANTIC CITY, N.J.																					
XIT Rod	28	1	6	6	8	22	6	21	24		3	14	5	29	3	4	10	10	14	3	3
CCS Rod	408.0	297.0	213.0	110.0	172.0	221.0	210.0	212.0	187.0		222.0	210.0	210.0	210.0	260.0	390.0	400.0	410.0	400.0	410.0	422.0
CCSS Rod		425.0	442.0	640.0	540.0	541.0	495.0	426.0	394.0		413.0	350.0	350.0	390.0	445.0	520.0	670.0	510.0	460.0	430.0	437.0
Modified XIT Rod											313.0	215.0	270.0	270.0	400.0	430.0	685.0	570.0	570.0	620.0	600.0
Temperature (*F)	80*	35*	30*	28*	23*	70*	61*	80*	78*		125.0	110.0	101.0	100.0	100.0	104.0	115.0	120.0	110.0	110.0	108.0
Soil Moisture	dry	moist	moist	moist	ice	wet	dry	moist	dry		73*	86*	68*	55*	30*	37*	46*	50*	60*	69*	61*
CHESTERFIELD, S.C.																					
XIT Rod						24	30	26						7	7						
CCS Rod						2740.0	2500.0	2700.0							2200.0	2100.0					
CCSS Rod						4380.0	>10k	>10k							>3k						
Temperature (*F)						>10k	2700.0	1900.0							1050.0	950.0					
Soil Moisture						61*	75*	62*							78*	77*					
						dry	dry	wet							dry	moist					

MENTS IN OHMS

		1977					1978					REMARKS
JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	JAN.	HIGH	LOW	AVG.		
9	7	8			14	16						
1.6	1.1	1.2			1.2	1.2		1.75	0.2	1.1		February 1977 readings were made March 1, 1977, and March 29, 1977.
7.8	7.2	10.0			10.2	8.2		10.2	3.0	6.9		
2.0	2.0	1.8			1.8	2.0		3.37	1.8	2.2		
84*	84*	94*			72*	52*						
dry	dry	moist			dry	wet						
1	1	1	4	1	12	6						
9.9	13.0	12.0	12.0	12.0	12.0	14.0	16.0	16.0	8.1	10.7		Additional salt enhancement was made to the GCSS rod to drop resistance below the CCS rod on February 9, 1977.
22.0	22.0	20.0	20.0	20.0	20.0	23.0	24.0	24.0	17.5	20.7		
14.0	15.0	11.0	10.0	12.0	12.0	12.0	12.0	36.0	10.0	16.5		
91*	94*	91*	67*	63*	63*	53*						
dry	dry	dry	wet	dry	dry	wet						
14	11	11	12	5	16							
59.0	60.0	77.0	71.0	71.0	62.0		77.0	38.0	59.0			
13.0	96.0	105.0	113.0	130.0	132.0		360.0	96.0	146.0			
82.0	50.0	90.0	93.0	99.0	122.0		183.0	45.0	82.0			
70*	75*	89*	75*	72*	64*							
moist	dry	moist	dry	dry	moist							
20	19	6	13	21	13							
0.0	0.0	0.0	0.0	0.0	0.0		31.0	0.0	16.1			October 1976 readings were made November 2, 1976, and November 18, 1976.
0.0	0.0	0.0	0.0	0.0	0.0		93.0	0.0	49.0			
0.0	0.0	0.0	0.0	0.0	0.0		66.0	0.0	35.0			
98*	109*	101*	86*	74*	69*							
dry	dry	dry	dry	dry	dry							
3	22	6	15	4								
22.0	428.0	383.0	375.0	377.0			428.0	110.0	297.0			October 1976 readings were made on the 5th and 28th. No readings were made on November 1976.
37.0	396.0	361.0	368.0	358.0			670.0	350.0	450.0			
90.0	540.0	486.0	539.0	552.0			685.0	195.0	411.0			
88.0	92.0	90.0	86.4	87.9			240.0	86.4	114.0			
61*	81*	84*	70*	66*								
dry	dry	wet	dry	moist								
							2740.0	2100.0	2348.0			The last two readings were made with a Vibroground earth tester which has a 3k-ohm maximum scale. The first three readings were made with a NAFEC Biddle earth tester ohm maximum scale.
							>10k	4300.0	>10k			
							>10k	950.0	3320.0			

depths. Our resistivity measurement for this site averaged 2.71 meter-ohms at 10-foot depth. During the 15-month period of varying temperature and precipitation, the resistance to earth change of the CCSS rod was only 0.02 ohms higher than the XIT rod's 1.55 ohms. In fact, the CCS rod resistance change was only 7.2 ohms for the same period.

In table 6, it can be seen that the average ground-rod-to-earth resistance of the XIT rod (1.1 ohms) was half that of the CCSS rod (2.2 ohms) and a sixth of that of the CCS rod (6.9 ohms). The resistance variation during the entire test period for the XIT rod (1.55 ohms) was almost the same as that of the CCSS rod (1.57 ohms) and about a fifth of that of the CCS rod (7.2 ohms).

EL PASO AIRPORT, EL PASO, TEXAS.

As indicated in table 5 and figure 7, it was discovered that an insufficient amount of salt was placed around the CCSS rod. Additional salt was added around this rod on February 9, 1977. If the CCSS rod measurements were considered beginning at this date, the average ground-rod-to-earth resistance would be 12.63 ohms, and the resistance variation would be 6 ohms instead of 26 ohms. The XIT rod average ground-rod-to-earth resistance was 10.7 ohms, and the resistance variation was 7.9 ohms. The standard CCS rod average ground-rod-to-earth resistance was 20.7 ohms, and the resistance variation was 6.5 ohms.

It can be seen that if the revised CCSS rod measurement readings were considered, then the CCSS and the CCS rods resistance variations were less than the XIT rod. The CCSS rod and the XIT rod average resistance to

earth would be only 2-ohms difference, while the CCS rod is twice the resistance of the XIT rod.

The Hueco-Wink soil is a fine loam sand, and a CCS rod can be easily hammered into the soil. The XIT rod installation cost was \$45.00 and required heavy equipment for installation in this soil. The average rainfall is 7.89 inches, and the average temperature is between 49.9° F and 77.2° F. The soil resistivity is greater than 5 meter-ohms to a 6.67-foot depth.

In table 6, it can be seen that the average ground-rod-to-earth resistance of the XIT rod (10.7 ohms) was four-fifths of the CCSS rod (12.6 ohms) and half of the CCS rod (20.7 ohms). The resistance variation during the entire test period for the XIT rod (7.9 ohms) was 1.9 ohms more than the CCSS rod (6.0 ohms) and 1.4 ohms more than the CCS rod (6.5 ohms).

WILDWOOD RCAG SITE, WILDWOOD, NEW JERSEY.

In table 5 and figure 8, it can be seen that the XIT rod average ground-rod-to-earth resistance was 59 ohms, and the resistance variation was 39 ohms. The CCS rod average ground-rod-to-earth resistance was 146 ohms, and the resistance variation was 264 ohms. The CCSS rod average ground-rod-to-earth resistance was 82 ohms, and the resistance variation was 138 ohms. Although the CCSS rod average ground-rod-to-earth resistance was only 28 percent higher than the XIT rod, the resistance variation was 3.5 times the XIT rod resistance variation. The CCS rod average ground-rod-to-earth resistance was 146 ohms, and the resistance variation was 264 ohms. These readings were approximately twice the readings on the CCSS rod,

TABLE 6. GROUND ROD RESISTANCE COMPARISONS

<u>SITE</u>	<u>RESISTANCE</u>	<u>MOD. XIT</u>	<u>XIT</u>	<u>CCSS</u>	<u>CCS</u>
Beaumont TX.	Average		1.1	2.2	6.9
	Variation		1.55	1.57	7.2
	Ratio to XIT			2:1	6.3:1
El Paso TX.	Average		10.7	12.6	20.7
	Variation		7.9	6.0	6.5
	Ratio to XIT			1.2:1	1.9:1
Wildwood N.J.	Average		59.0	82.0	146.0
	Variation		39.0	138.0	264.0
	Ratio to XIT			1.5:1	2.5:1
Phoenix AZ.	Average		16.1	35.0	49.0
	Variation		31.0	66.0	93.0
	Ratio to XIT			2.2:1	3:1
NAFEC N.J.	Average	114.0	297.0	411.0	450.0
	Variation	153.6	318.0	490.0	320.0
	Ratio to XIT	0.4:1		1.4:1	1.5:1
Chesterfield S.C.	Average		2348.0	3320.0	>3k
	Variation		640.0	9050.0	
	Ratio to XIT			1.4:1	

approximately eight times the XIT rod resistance variation, and twice the XIT rod average resistance. The Hammonton soil is a sandy loam with a water table approximately 5 feet below the earth surface. The average rainfall is 43 inches, and the average temperature is between 10° F and 94° F. The soil resistivity is between 10 and 50 meter-ohms to a 6.67-foot depth. The extremely high ground-rod-to-earth resistance for the CCS rod of 360 ohms was due to a severely cold winter in 1976 and 1977. The XIT rod was hand augered into the earth by NAFEC employees.

With all three ground rods about 3,000 feet from the bay and encountering ground water 5 feet below the earth surface, it can be seen in table 6 that the average ground-rod-to-earth resistance of the XIT rod (59 ohms) was three-fourths of the CCSS rod (82 ohms) and a fourth of the CCS rod (146 ohms). The resistance variation during the entire test period for the XIT rod (39 ohms) was 99 ohms less than the CCSS rod (138 ohms) and 225 ohms less than the CCS rod (264 ohms).

PHOENIX H MARKER SITE, PHOENIX,
ARIZONA.

In table 5 and figure 9, it will be noticed that the average XIT rod earth-to-ground resistance is half the value of the CCSS rod and a third of the CCS rod. It is further noticed that the same is true of the resistance variations. During the eleventh month of testing, all ground rod readings dropped to zero. This phenomenon cannot be explained. This test bed is located in Alluvial soil that is very sandy loam. The average rainfall is between 6 and 8 inches but can be excessive at times. The

average temperature is between 40° F and 100° F. The USDA made no resistivity or conductivity readings in this soil. The XIT rod installation cost was \$60.00, and a backhoe was required instead of an auger due to the fine sandy texture of the soil.

In table 6, it can be seen that the average ground-rod-to-earth resistance of the XIT rod (16.1 ohms) was about half of the CCSS rod (35 ohms) and a third of the CCS rod (49 ohms). The resistance variation during the entire test period for the XIT rod (31 ohms) was half the CCSS rod (66 ohms) and a third of the CCS rod (93 ohms).

The last 6 months of data collection results showed zero ohms for all three test ground rods. These results are totally unexplainable, since field sector personnel calibrated three different type earth testers and got the same measurement from each instrument in the test site. One possibility for these zero readings for the last 6 months is that the water table rose due to the above-normal rainfall in the area and the location of site in a former salt riverbed area.

NAFEC, ATLANTIC CITY, NEW JERSEY.

In table 5 and figure 10, it can be seen that the modified XIT ground-rod-to-earth average resistance was 114 ohms, and the variation of resistance was 154 ohms. The standard XIT ground rod average resistance was 297 ohms, and the variation of resistance 318 ohms. The CCS rod average resistance was 450 ohms, and the variation of resistance 320 ohms. The CCSS rod average resistance was 411 ohms, and the variation of resistance 490 ohms.

It should first be noted that the modified XIT rod's average resistance and variation of resistance were less than half the resistances of the standard XIT rod. The CCSS ground rod's poor resistive performance relative to the CCS ground rod in the last 5 months of the 2-year test appears to be due to the loss of salt enhancement. All ground rods except for the modified XIT rod appear to have increase in resistance during the very cold winter of 1976-1977. It further appears that these ground rod resistances never returned to their original low summer values. It should be further noted that the modified XIT rod resistance to earth versus time plot more closely resembles the XIT rod company's standard XIT rod plot in figure 5. NAFEC's quartzipsamments soil is a coarse sand with quartzose gravel mix. The average rainfall is 43 inches, and the average temperature is between 10° F and 94° F. The soil resistivity is greater than 50 meter-ohms to a 5-foot depth. The XIT rods were machine augered into the earth by NAFEC employees.

In table 6, it can be seen that the average ground-rod-to-earth resistance of the XIT rod (297 ohms) was 2 1/2 times the NAFEC-modified XIT rod (114 ohms), three-fourths of the CCSS rod (411 ohms), and two-thirds of the CCS rod (450 ohms). The resistance variation during the entire test period for the XIT rod (318 ohms) was twice that of the modified XIT rod (153.6 ohms), three-fifths of the CCSS rod (490 ohms), and about equal to the CCS rod (320 ohms).

In figure 11, it should be noted that the CCSS rod lost its salt enhancement during the January-February 1976 period and remained higher in resistance than the CCS rod. It

should also be noted that the XIT rod resistance increased above the CCS rod during the June-July 1977 period and remained so thereafter. The modified XIT rod remained substantially lower and at steady resistance value during the entire test period. In fact, it was continuing a slightly downward resistance trend. The modified XIT rod, CCSS rod, and CCS rod resistance ratios to the XIT rod were 0.4 to 1, 1.4 to 1, and 1.5 to 1, respectively. Testing of the modified XIT rod should be continued to determine if the same favorable results can be obtained in soils in other regions of the country.

CHESTERFIELD VOR SITE, CHESTERFIELD, SOUTH CAROLINA.

Despite the poor data return, it was believed that these few data were of significant importance. Unfortunately, these data were obtained from two different earth testers with different maximum scales. The first three measurements were made with a NAFEC Biddle tester with 10,000-ohms maximum scale, and the last two measurements were made with a Southern Region's Vibroground tester with 3,000-ohms maximum scale. Assuming that the Vibroground tester's maximum scale was the same as the Biddle tester's maximum 10,000-ohm scale, the CCS rod average ground resistance would than approximate 10,000 ohms as shown in table 5 and figure 10. The XIT rod earth-to-ground average resistance was 2,348 ohms, and the variation of resistance was 640 ohms. The CCSS rod earth-to-ground average resistance was 3,320 ohms, and the variation of resistance was approximately 9,050 ohms. This test bed is located in typical quartzipsamments (Lakeland Series) soil that is of a coarse-grain sand texture down to between 100 and 200 feet to bedrock.

The average rainfall is 55 inches, and the average temperature is 66° F. The USDA made no resistivity or conductivity measurements of this soil. The XIT rod was installed by Southern Region personnel with a hand auger.

Due to the lack of funds for this project and available earth testers in the Florence, South Carolina, AFS, data collection was sparse. This was unfortunate, since the Lakeland series soil extends from Texas to Virginia and covers bedrock and has rapid permeability in the Chesterfield area. The average resistivity measurements at a 2-foot depth was 29,646 meter-ohms and 29,971 meter-ohms at a 10-foot depth.

With the small amount of data collected, it can be seen in table 6 that the average ground-rod-to-earth resistance of the XIT rod (2,348 ohms) was two-thirds of the CCSS rod (3,320 ohms). The CCS rod resistance was off the meter scale resulting in an unknown figure. The resistance variation for the entire test period for the XIT rod, 640 ohms, was much less than the CCSS rod, 9,050 ohms.

A ground grid of 20-foot XIT rods may prove a beneficial test for this type of facility ground environment, since longer ground rods further reduce ground-grid-to-earth resistance.

COST ANALYSIS.

Since XIT rods cost \$141.75 each and require contractor augering equipment with labor cost up to \$65, a single XIT rod installation amounts to a total cost of \$206.75. By comparison, installation of 12 CCS rods at \$72 interconnected with 360 feet

of 3/8-inch-diameter bare copper wire at \$14.40 using government labor without special installation equipment amounts to a total cost of \$110.40.

In table 7, a comparison has been made of the resistance and cost of a single XIT rod for each test site versus various CCS ground grid systems. It should be noted, however, that a ground grid of XIT rods would be an excellent means of attaining a low resistance ground at sites like NAFEC and Chesterfield.

Although the XIT-rod-measured resistance appeared lower than the CCS ground grids for Phoenix, it should be noted that the earth resistivity continued decreasing to zero during the test period. The CCS ground grid computations were based on the original 773.11 meter-ohms resistivity.

The method used in deriving these computations, utilized the following formulas for a square or rectangular ground grid.

- (1) The total resistance of N CCS rods.

$$R_R = \frac{.366 \rho K \log \frac{3L_R}{d_R}}{NL_R}$$

- (2) The total resistance of connecting wire to the ground rods.

$$R_W = \frac{\rho}{2\sqrt{4A/\pi}} + \frac{\rho}{L_W}$$

- (3) The total mutual resistance of wire and rods.

$$R_{WR} = \frac{.73\rho}{L_W} \log \frac{2 L_W}{L_R}$$

TABLE 7. RESISTANCE IN OHMS AND COST OF XIT ROD VERSUS CCS GROUND GRID

Site	Resistivity	XIT Rod Measured Resistance	R _T Rods 20 Feet		R _T Rods 10 Feet		R _T Rods 40 Feet		R _T Rods 20 Feet		R _T Rods 20 Feet		R _T Rods 20 Feet	
			Apart	Apert	Apart	Apert	Apart	Apert	Apart	Apert	Apart	Apert	Apart	Apert
Beaumont	9.19	1.1	0.5	0.3	0.5	0.3	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1
El Paso	61.91	10.7	3.4	1.8	3.2	1.7	1.7	1.2	1.0	0.7	0.7	0.7	0.7	
Wildwood	316.95	59.0	17.6	9.4	16.6	8.9	8.9	6.4	5.1	3.6	3.6	3.6	3.6	
Phoenix	773.11	16.1	42.8	23.0	40.4	21.7	15.6	12.4	8.8	8.8	8.8	8.8	8.8	
NAFEC	3,590.85	297.0	198.9	106.8	187.8	100.9	72.4	40.9	57.5	40.9	40.9	40.9	40.9	
Chesterfield	29,971.5	2,348.0	1,660.3	891.4	1,567.7	842.6	604.3	480.2	341.6	341.6	341.6	341.6	341.6	
Parameters														
A grid area			400 ft.	1,600 ft.	400 ft.	1,600 ft.	1,600 ft.	1,600 ft.	3,600 ft.	3,600 ft.	3,600 ft.	3,600 ft.	3,600 ft.	3,600 ft.
L _w wire length			80 ft.	160 ft.	80 ft.	160 ft.	160 ft.	320 ft.	360 ft.	720 ft.	720 ft.	720 ft.	720 ft.	720 ft.
L _r rod length			10 ft.	10 ft.	10 ft.	20 ft.	20 ft.	10 ft.	10 ft.	10 ft.	10 ft.	10 ft.	10 ft.	10 ft.
D _r rod diameter			0.625 in.	0.625 in.	0.625 in.	0.625 in.	0.625 in.	0.625 in.	0.625 in.	0.625 in.	0.625 in.	0.625 in.	0.625 in.	0.625 in.
K resistance ratio			1.25	1.4	1.85	1.25	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.7
N number rods			4	8	8	4	4	8	12	12	12	12	12	16
Installation Costs		\$206.75	\$35.20	\$70.40	\$67.20	\$70.40	\$70.40	\$76.80	\$110.40	\$124.80	\$176.80	\$176.80	\$176.80	\$176.80

(4) The total resistance of the ground grid.

$$R_T = \frac{R_w R_R - R_{wR}^2}{R_w + R_R - 2 R_{wR}}$$

Where ρ is the soil resistivity in meter-ohms,
A is the ground grid area in square meters,
 L_w is the total length of connecting wire,
 L_R is the length of each rod,
 d_R is the diameter of each rod,
K is the resistance ratio (see figure 16).

See appendix for programing procedures for these computations in a TI58 or TI59 pocket calculator.

CONCLUSIONS

From the results, it is concluded that:

1. At sites where soil resistivity is low and under humid conditions, a single CCS rod would be sufficient to maintain a low earth resistance during seasonal weather changes. If the replenishment of salt is cumbersome, then a CCS ground grid of four rods should maintain seasonal resistance changes below 5 ohms. Either method would be cheaper than an XIT rod.
2. At sites where soil resistivity is low and under dry conditions, a CCS ground grid of eight rods should maintain seasonal resistance changes below 5 ohms. The area encompassed

by such a ground grid would accommodate most FAA facilities. See column 5 of table 7.

3. At sites where soil resistivity is medium and under humid conditions, a CCS ground grid of 12 rods should maintain seasonal resistance changes near 5 ohms. If a 90-square-foot area is too large, a ground grid of four XIT rods would be needed to reduce the area to a 20-square-foot area. It should be noted that the cost of the CCS ground grid would be \$124.80 (see column 7 of table 7), while the XIT rod ground grid would be \$570.20 excluding installation costs.

4. Since the Phoenix, Arizona, soil resistivity became reduced to some value below 773.11 meter-ohms, where even the CCS rod-to-earth resistance was zero, the average measured XIT rod-to-earth resistance value of 16.1 ohms is rather meaningless. The CCS ground grid calculations in table 7 are based on the maximum 773.11 meter-ohm resistivity. If it could be assumed that the data were meaningful, then the same conclusion could be made for sites with medium soil resistivity under humid conditions, with exception that a larger CCS ground grid would be required.

5. At sites where soil resistivities are high and under humid conditions, a ground grid of XIT rods would be more practicable, especially where area is limited.

6. In view of the excellent results obtained with the modified XIT rod (see figure 15), this type XIT rod in a ground grid would require fewer ground rods, thus reducing ground grid area and cost while still obtaining a low ground grid resistance.

RECOMMENDATIONS

From the conclusions, it is recommended that:

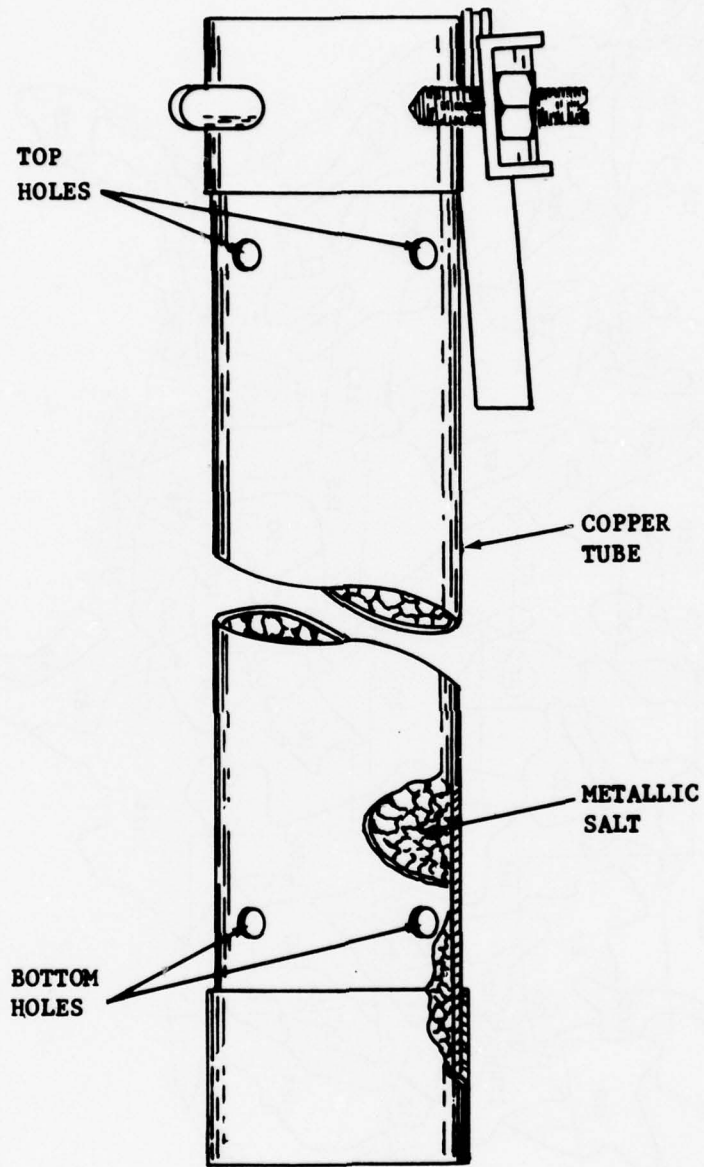
1. Earth resistivity measurements should be made prior to installation of facility electronic equipment.
2. Local county agriculture departments should be consulted to determine soil salinity and/or resistivity, depth of bedrock, permeability, water table, etc.
3. Computations should be made to determine whether an XIT rod, CCS rod, or CCSS rod ground grid would attain the desired earth-ground rod resistance and if the cheaper CCS rod grid system would suffice in lieu of the XIT rod grid system.
4. Consideration should be made for the use of the modified XIT rod, especially in high soil resistivity areas. Twenty-foot XIT rods should also be considered for these areas.
5. The use of XIT rods in low earth resistivity areas with high or low rainfall is questionable, since an increased number of CCS rods in a grid could do the job at lower cost.
6. The use of XIT rods in medium earth resistivity areas is worth considering if a ground grid size is limited by the facility area.
7. The XIT rod resistance at all sites except one averaged well above the company's low claim. Its resistance variation over the test period was as large as the CCS rod at NAFEC. See table 6 and figures 10 through 15.

8. At sites with high soil resistivity, a ground grid of 20-foot-long modified XIT rods may be the solution to the ground resistance problem.

REFERENCES

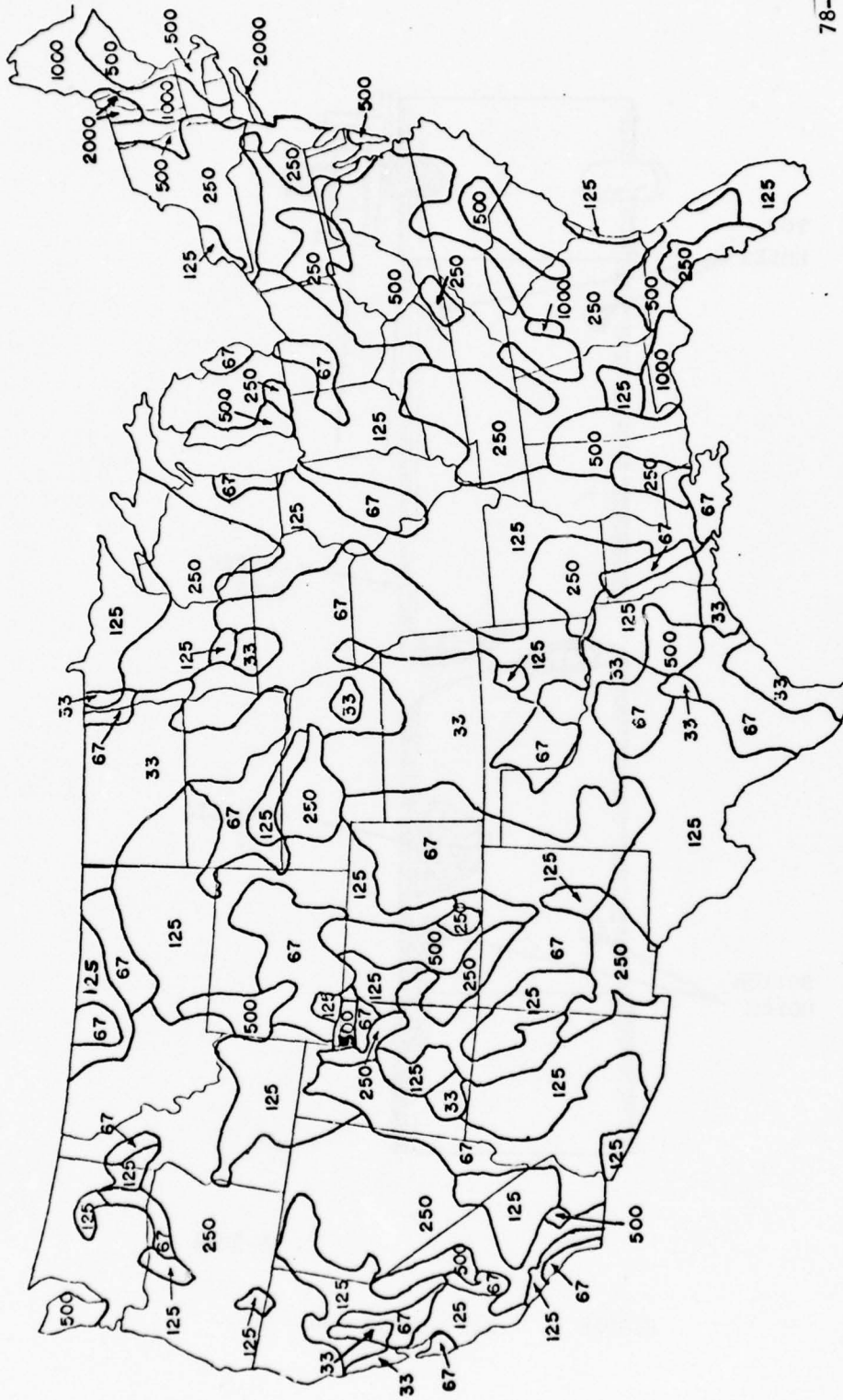
1. "Electrical Protection Grounding Fundamentals," Rural Electrification Administration, Telephone Engineering and Construction Manual, Section 802 Issue No. 1, June 1975.
2. "Corrosion Considerations in Outside Plant," Rural Electrification Administration, Telephone Engineering and Construction Manual, Section 670 Issue No. 1, December 1970.
3. FAA/Georgia Institute of Technology Grounding Workshop and Lightning Protection Seminar, Report No. FAA-RD-75-106, May 1975.
4. Grounding, Bonding, and Shielding Practices and Procedures for Electronic Equipments and Facilities, Report No. FAA-RD-75-215, June 1975.
5. Federal Aviation Administration -- Georgia Institute of Technology Workshop on Grounding, Bonding and Shielding, Report No. FAA-RD-76-104, May 1976.
6. FAA/Georgia Institute of Technology Workshop on the Grounding of Electronic Systems, Report No. FAA-RD-74-147 March 1974.
7. Technical Specifications, XIT Rod Company.
8. XIT Rod Low Impedance Electrical Grounding System, XIT Rod Company.

9. An Effective Ground Conductivity in the Eastern United States, FCC Office of Chief Engineer Technical Research Division TRR Report No. 2.1.4 (Revised).
10. Estimated Effective Ground Conductivity in the Eastern United States, Chart 004-000-00279-2.
11. Estimated Effective Ground Conductivity in the Western United States, Chart 004-000-00280-6.
12. Interim Soil Survey Report Atlantic County, New Jersey National Cooperative Soil Survey, U.S. Department of Agriculture (USDA).
13. Interim Soil Survey Report Cumberland County, New Jersey National Cooperative Soil Survey, USDA.
14. Soil Survey of Charlston County, South Carolina, USDA.
15. Soil Survey of Salem County, New Jersey, USDA.
16. Soil Survey--Jefferson County, Texas, USDA.
17. Soil Survey of El Paso County, Texas, USDA.
18. Soil Survey of Hidago County, New Mexico, USDA.
19. Soil Survey of Yellowstone County, Montana, USDA.
20. Soil Survey of Apache County, Arizona, Central Part, USDA.
21. Soil Survey of Tucson-Area Valley Area, Arizona, USDA.
22. Soil Survey of Eastern Moricapa and Northern Pinal Counties Area, Arizona, USDA.
23. Soil Survey of Palo Verde Area, California, USDA.
24. Soil Survey of Lexington County, South Carolina, USDA.
25. Interim Soil Survey of Jim Hogg, Storr, Webb, and Zapata Counties, Texas, USDA.
26. Soil Survey of Oklahoma County, Oklahoma, USDA.
27. Soil Survey of the Gallatin Valley Area, Montana, Series 1931 Number 16, USDA.
28. Interim Soil Survey--Tas Animas County, Colorado, USDA.
29. Guide for Interpreting Engineering Uses of Soils, USDA.
30. Soil Survey Laboratory Methods and Procedures for Collecting Soil Samples, USDA.
31. Getting Down-To-Earth, James G. Biddle Company.



78-50-1

FIGURE 1. XIT GROUND ROD



78-50-2

FIGURE 2. ESTIMATED AVERAGE EARTH RESISTIVITY IN U.S.



FIGURE 3. BIDDLE EARTH TESTER KIT

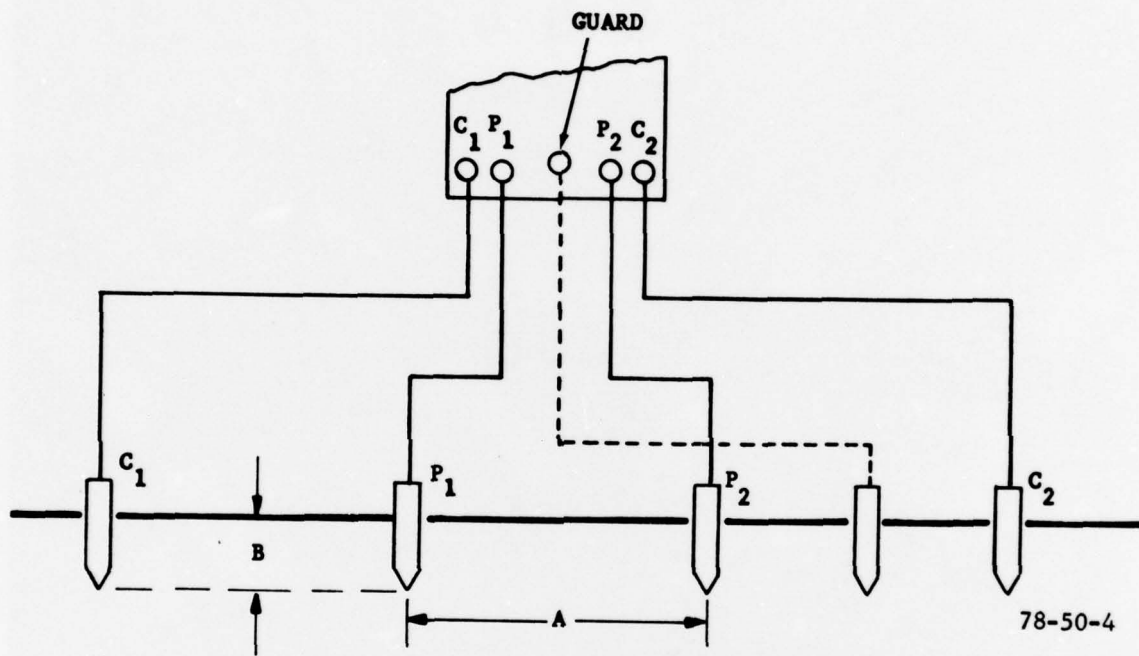
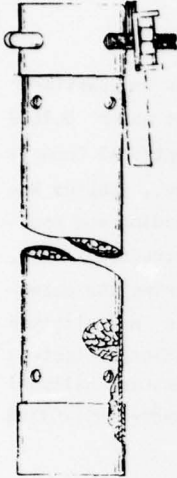


FIGURE 4. EARTH RESISTIVITY MEASUREMENT SETUP

TECHNICAL SPECIFICATIONS

Xit-Rods are used in any electric, communication, or process system, in arid or wet conditions, and their impedance to ground averages 4 ohms or less. They cost less to use than any other made or investment system because only one Xit Rod is necessary as compared to the plurality of other rods usually required. No periodic checking or adjustments are necessary.

Diameter of all models is 2-1/8" O.D.
 Wall thickness = .083"
 Material = Type K Copper

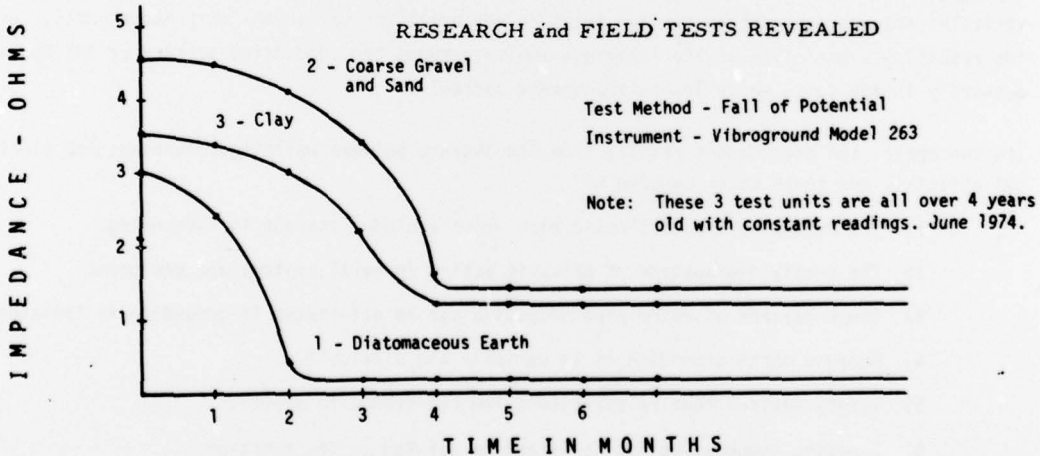


- .K2-8 Standard model for general use 8' lengths.
- .K2-10 Is recommended for installations in jurisdictions where 10' depth is minimum requirement, and in areas where a high resistivity factor is known.
- .K2-H Where bedrock is encountered too impervious for drilling with auger bit. Use this L shape horizontal model. Specify vertical depth requirement.
- .K2-20 Is available in 20' length for power stations, microwave and communication towers, where there exists known earth resistance variables too great for good consistent communication. Also in areas where installations are vulnerable to lightning.

Note Resonant lengths for RF frequencies on special order.

Ground Clamp Tested For

#8 AWG Brass Cable Fastener
 To
 #3/0 AWG U-Bolt and Pressure Plate



Patented U.S. #3,582,531, U.K. #1,343,182, Pending in Canada, Europe, and Asia.



ROD



78-50-5
 P.O. Box 1314
 Covina, California 91722
 (714) 845-3986

Printed USA 745

FIGURE 5. XIT ROD TECHNICAL SPECIFICATION (SHEET 1 OF 2)



It
ROD



Listed
467J

A HOLLOW-TUBE, CHEMICALLY-CHARGED-ROD ELECTRODE



On October 6, 1972 acceptance for Underwriters' Laboratories Listing was granted under UL467J and on January 30, 1974 the Electrical Council of Underwriters' Laboratories Inc., adopted Revisions of the Standard for Grounding and Bonding Equipment, in Appendix A, paragraphs 6.7L, 6.7M, and 6.7N exclusively covering the patented Xit Rod system, and which is now eligible for inclusion in the Revised National Electrical Code. Approval as an American National Standard has been established under ANSI-C33.8 effective April 24, 1974

SPECIAL FEATURES

Grounding in earth is variable by (1) soil type, (2) chemical content, (3) moisture, and since the size and depth of Xit Rod is compatible for good grounding, it also overcomes the three variables above by generating its own moisture and metallic salts and, most importantly, uses the resulting electrolyte as the interface medium between the conducting surface of Xit Rod and outwardly in the soil, which lowers resistance markedly.

Its conception and development results from the impasse between building, plumbing, and electrical officials and their codes because of:

- 1) The expanding use of plastic pipe which excludes its use for grounding.
- 2) The costly degradation of galvanic action in metal systems and equipment.
- 3) Shock hazards of water pipe grounding can be eliminated if grounding is isolated.
- 4) Because earth grounding is so variable and difficult.
- 5) Safety devices require consistent low resistance to ground.
- 6) Freezing temperature has no effect on Xit-Rod or its function.
- 7) Xit-Rod functions indoors or out.
- 8) Brazing directly to Xit-Rod is not harmful, although it may dry out and cause a short delay in electrolyte formation in that portion of rod heated.

AS THE FINEST MADE SYSTEM AVAILABLE. IT IS TRULY THE MOST NEGATIVE APPROACH TO GROUNDING 78-50-5

FIGURE 5. XIT ROD TECHNICAL SPECIFICATION (SHEET 2 OF 2)

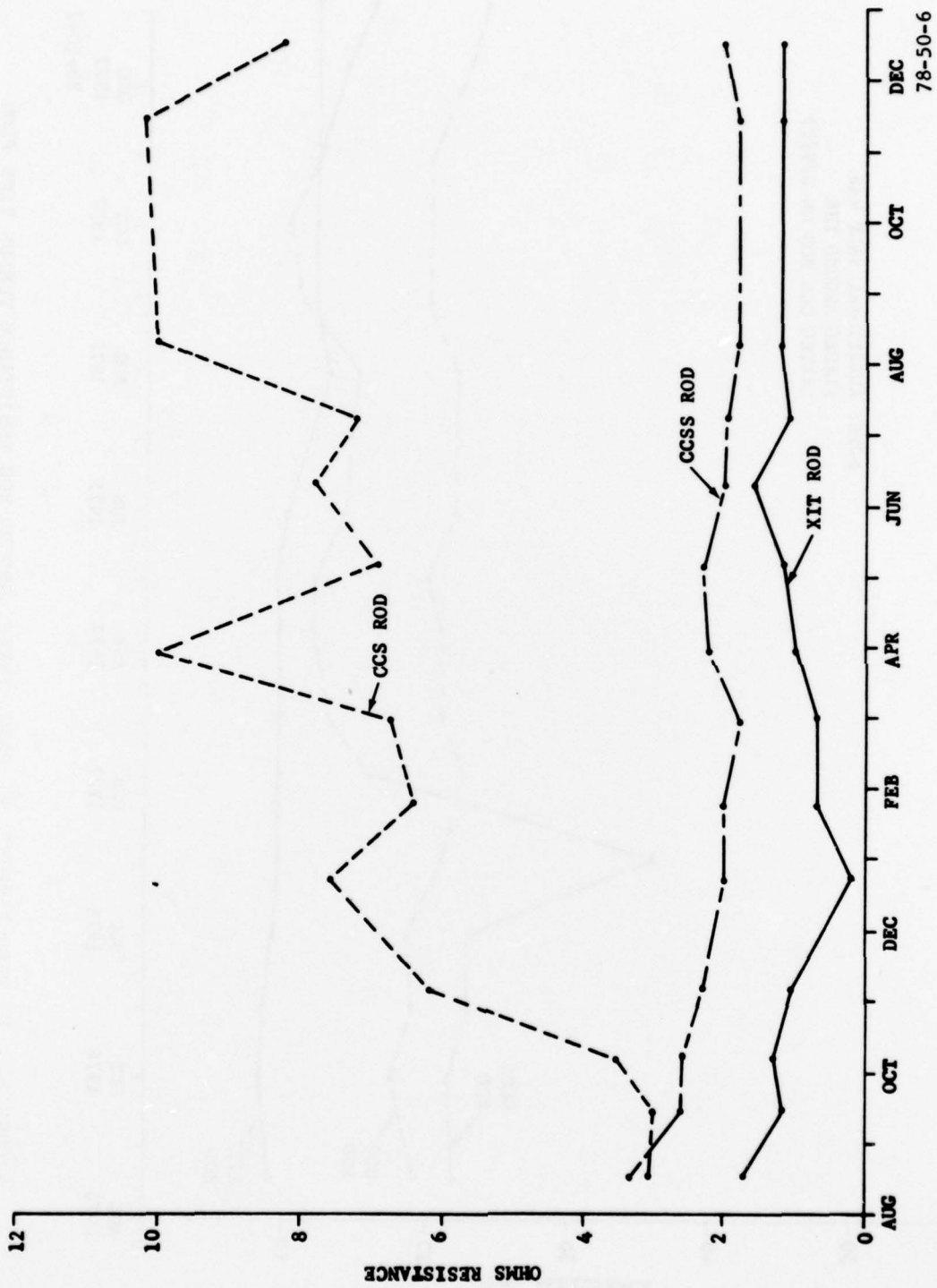


FIGURE 6. JEFFERSON COUNTY AIRPORT, BEAUMONT, TEXAS, GROUND ROD RESISTANCE VERSUS TIME PLOT

78-50-6

NOTE: ADDITIONAL SALT WAS
 PLACED AROUND THE
 SALTED CCS ROD ON 2/9/77

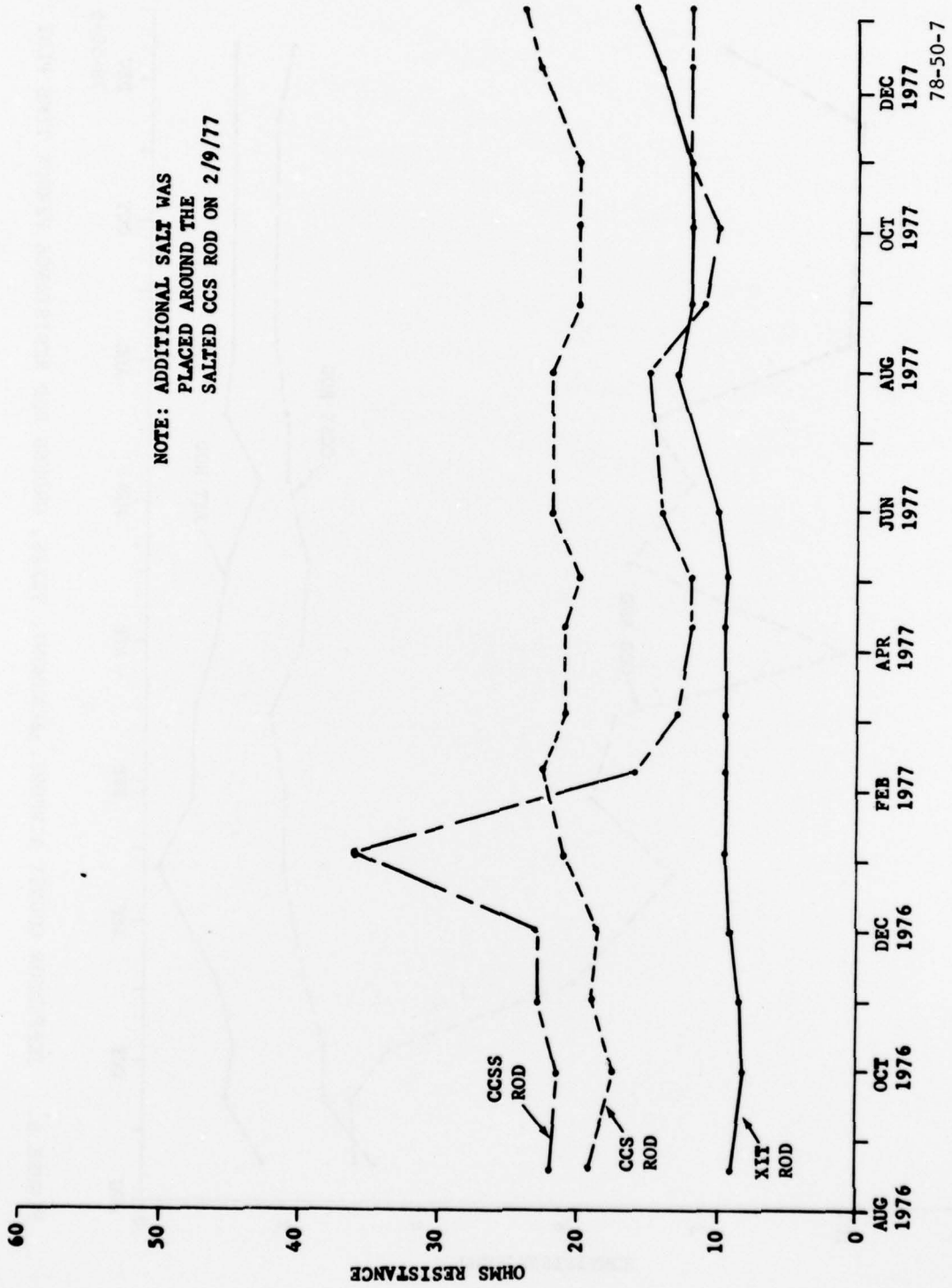


FIGURE 7. EL PASO AIRPORT, EL PASO, TEXAS, GROUND ROD RESISTANCE VERSUS TIME PLOT

78-50-7

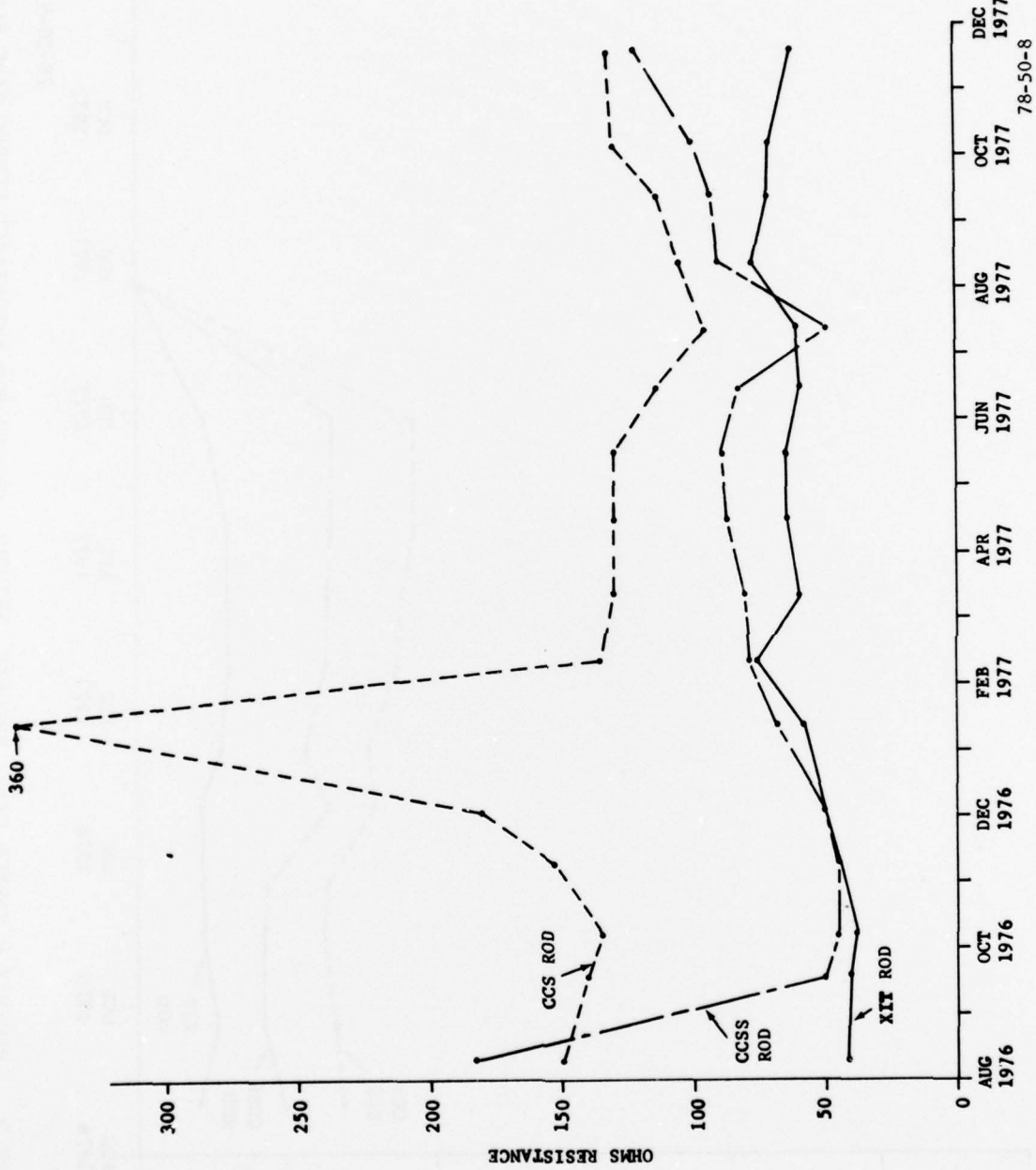


FIGURE 8. WILDWOOD RCAG SITE, WILDWOOD, NEW JERSEY, GROUND ROD RESISTANCE VERSUS TIME PLOT

78-50-8

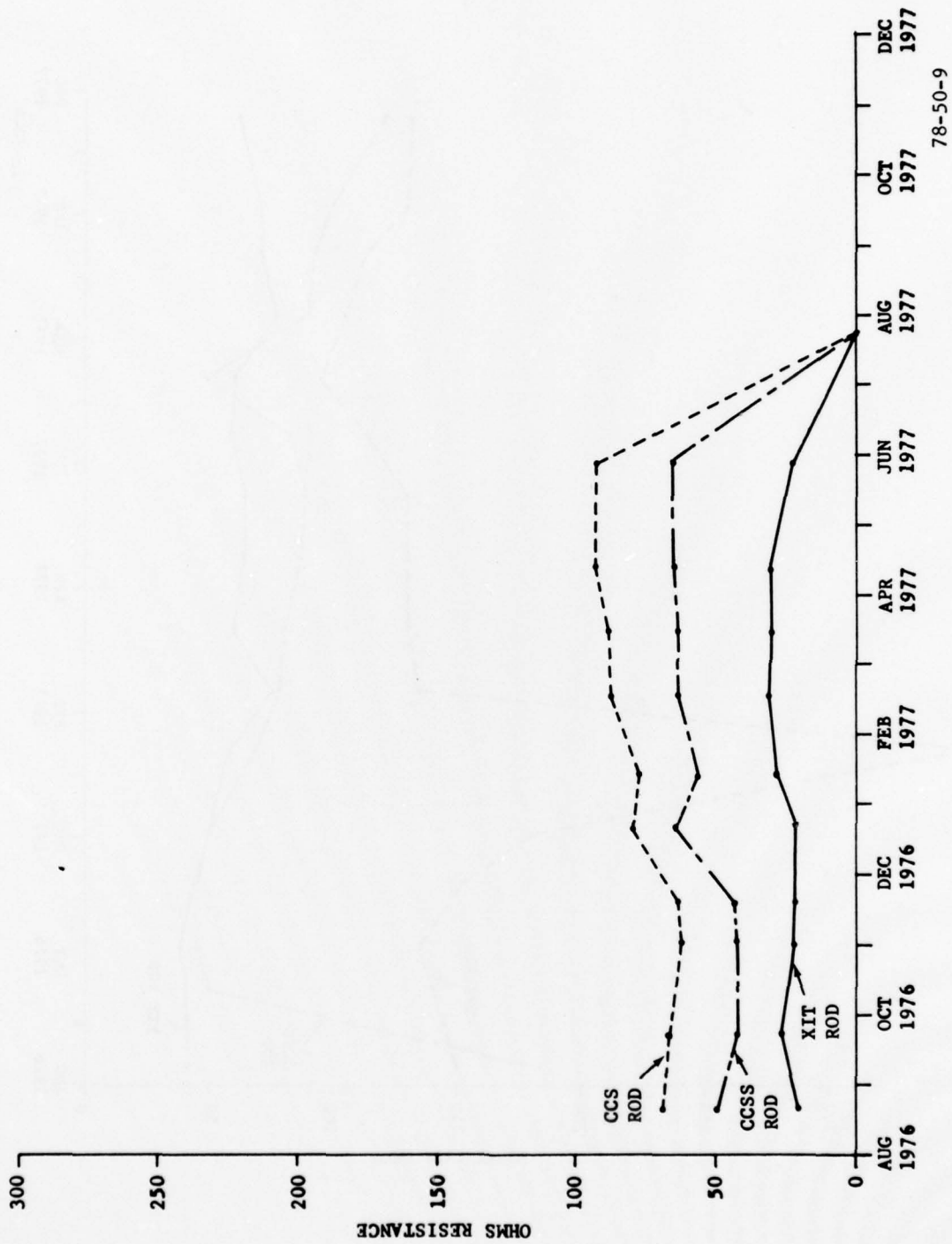
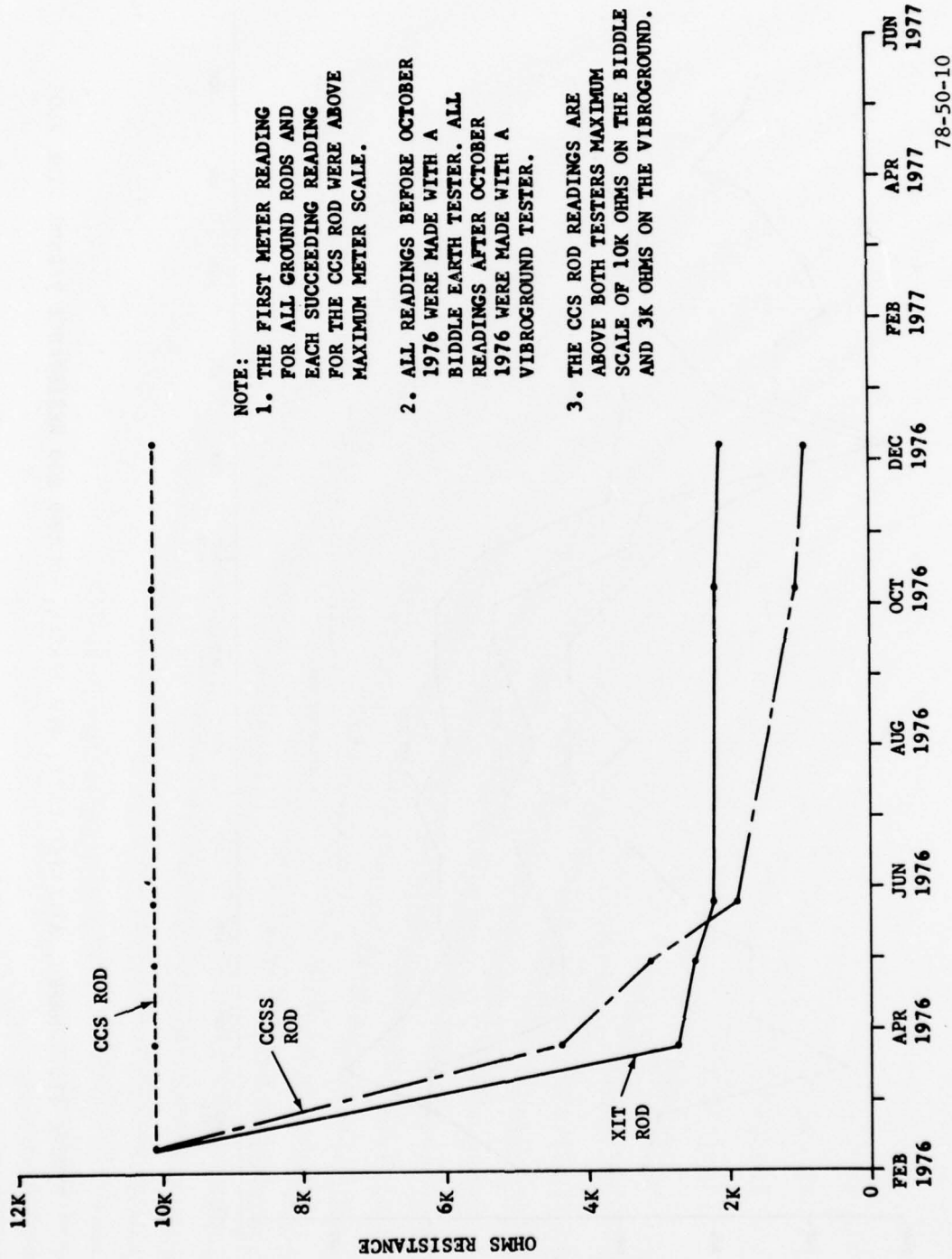


FIGURE 9. PHOENIX H MARKER SITE, PHEONIX, ARIZONA, GROUND ROD RESISTANCE VERSUS TIME PLOT

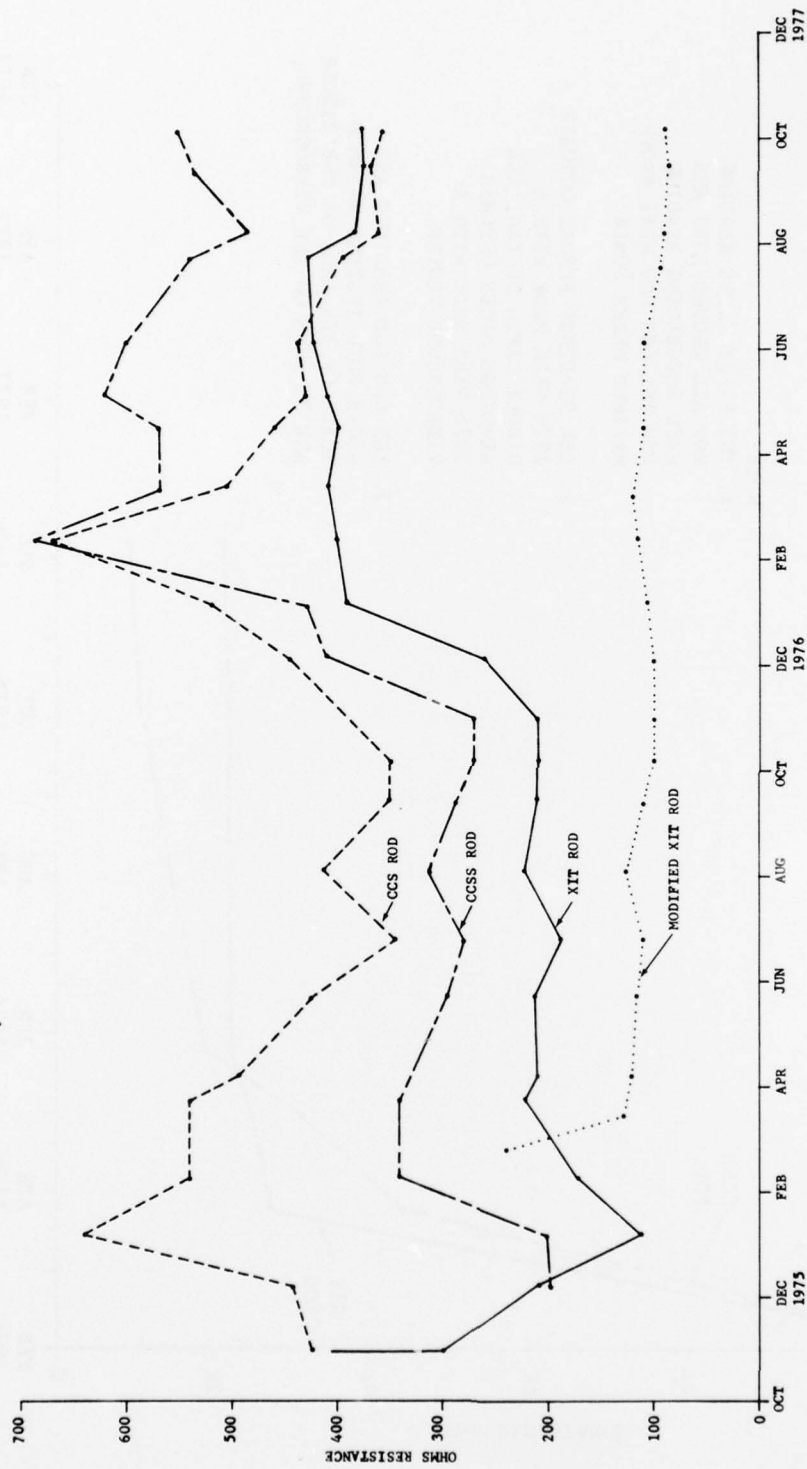
78-50-9



NOTE:

1. THE FIRST METER READING FOR ALL GROUND RODS AND EACH SUCCEEDING READING FOR THE CCS ROD WERE ABOVE MAXIMUM METER SCALE.
2. ALL READINGS BEFORE OCTOBER 1976 WERE MADE WITH A BIDDLE EARTH TESTER. ALL READINGS AFTER OCTOBER 1976 WERE MADE WITH A VIBROGROUND TESTER.
3. THE CCS ROD READINGS ARE ABOVE BOTH TESTERS MAXIMUM SCALE OF 10K OHMS ON THE BIDDLE AND 3K OHMS ON THE VIBROGROUND.

FIGURE 10. CHESTERFIELD VOR SITE, CHESTERFIELD, SOUTH CAROLINA, GROUND ROD RESISTANCE VERSUS TIME PLOT 78-50-10



78-50-11

FIGURE 11. NAFEC, ATLANTIC CITY, NEW JERSEY, GROUND ROD RESISTANCE VERSUS TIME PLOT

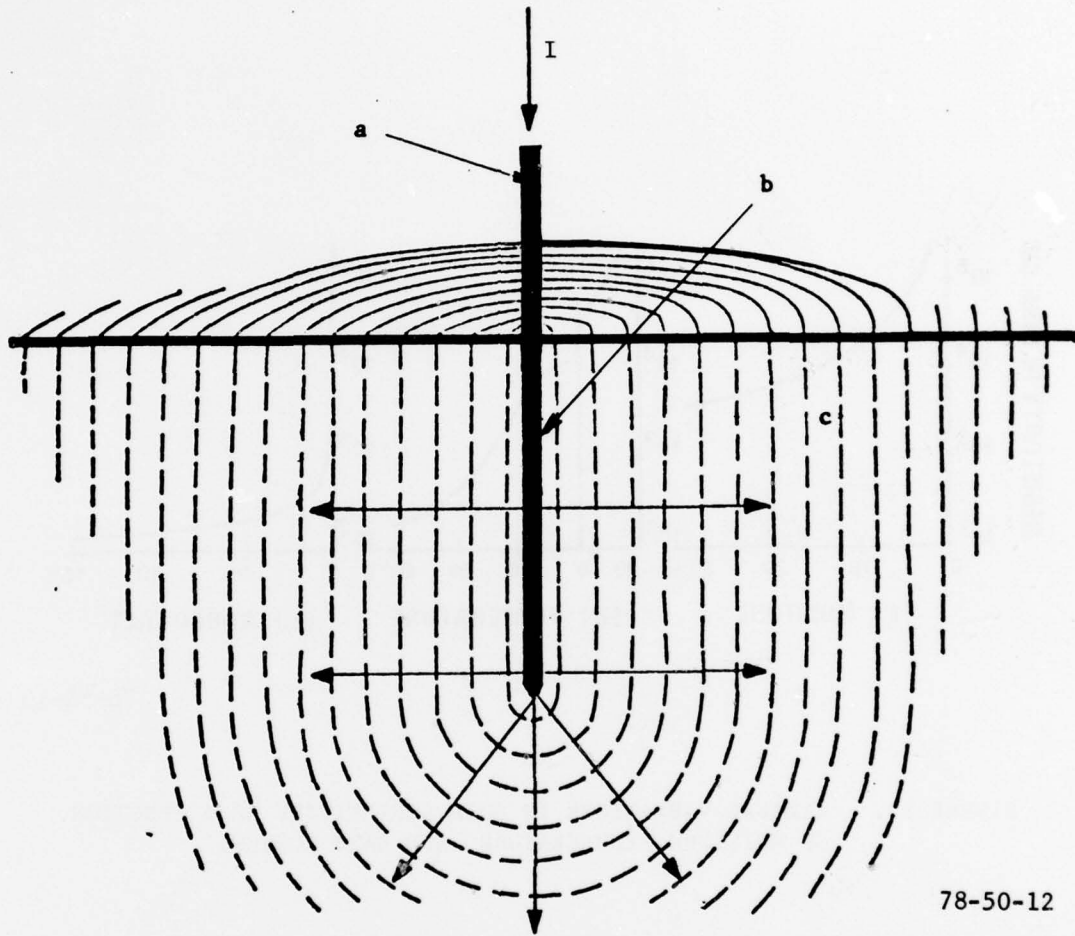
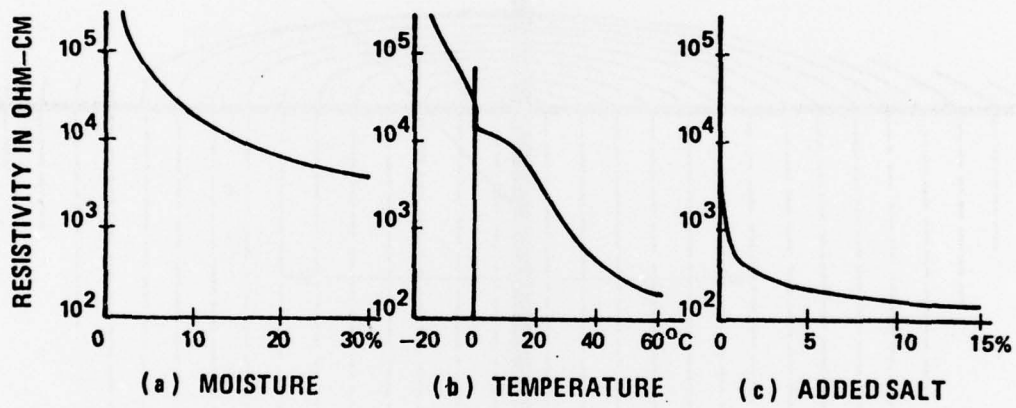


FIGURE 12. EARTH RESISTANCE SHELLS SURROUNDING A VERTICAL EARTH ELECTRODE



78-50-13

FIGURE 13. TYPICAL VARIATIONS IN SOIL RESISTIVITY AS A FUNCTION OF MOISTURE, TEMPERATURE, AND SALT CONTENT

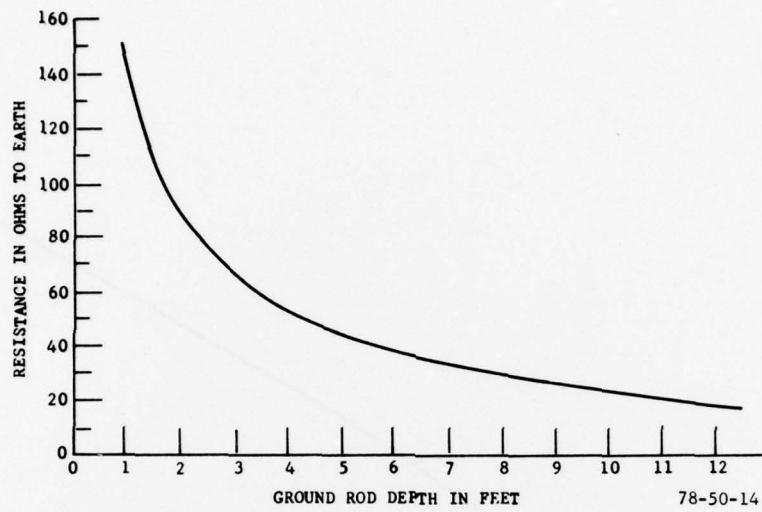


FIGURE 14. EFFECT OF ROD LENGTH UPON RESISTANCE

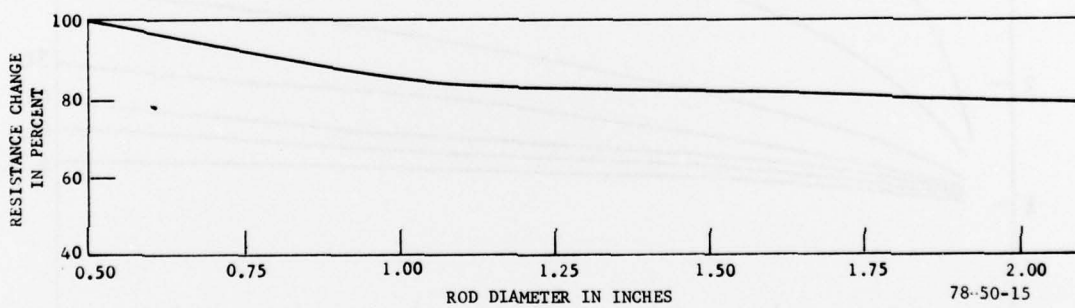


FIGURE 15. EFFECT OF ROD DIAMETER UPON RESISTANCE

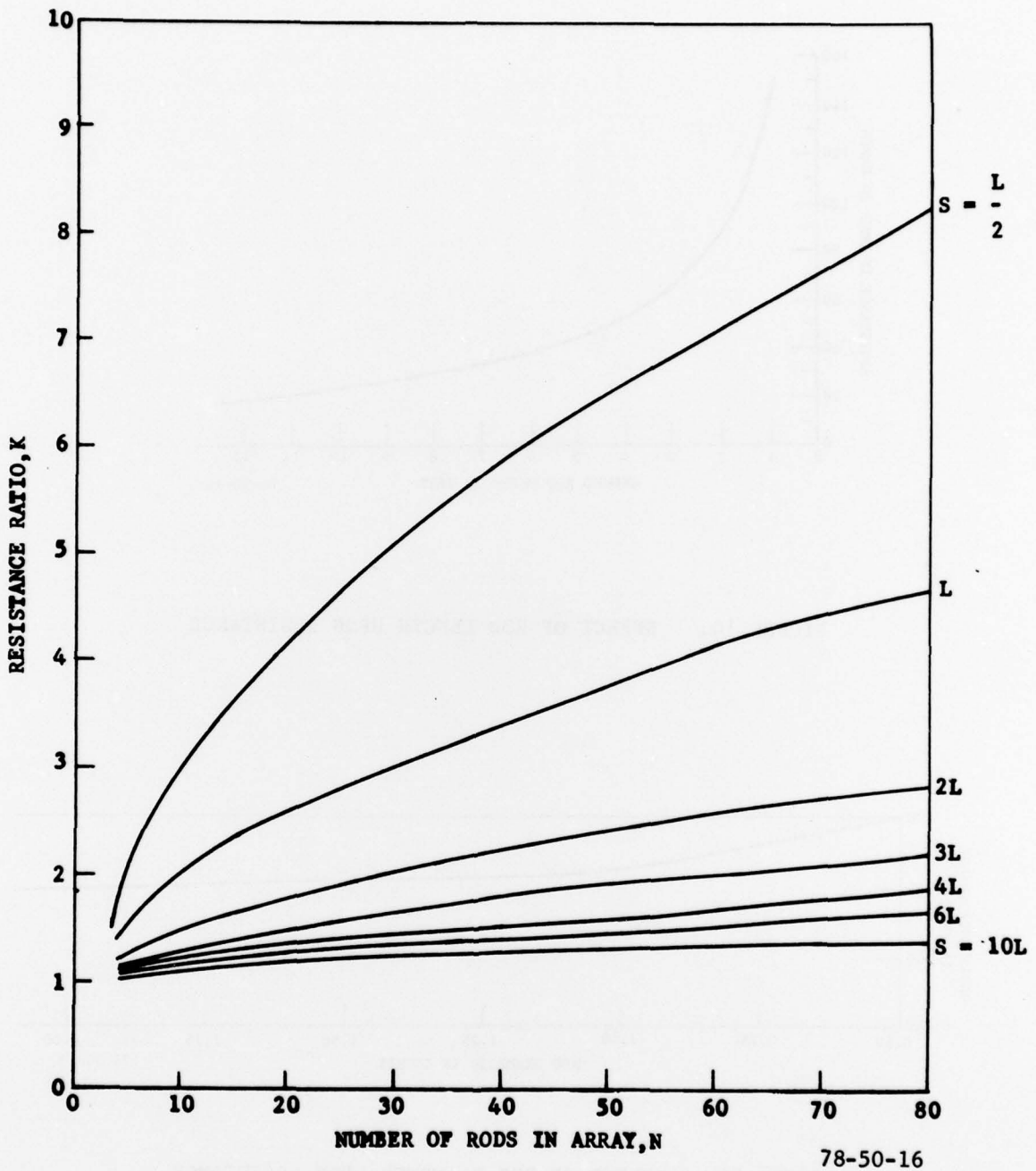


FIGURE 16. RATIO OF THE ACTUAL RESISTANCE OF A ROD ARRAY TO THE IDEAL RESISTANCE OF N RODS IN PARALLEL

TABLE A-1. PROGRAMMING PROCEDURE

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
0	76	LRL		110	43	RCL		165	07	7		166	03	3		167	54		
1	11	A	p	111	04	04		166	03	3		167	54			168	55	+	
2	42	STO		112	65	X		167	54			168	55	+		169	43	RCL	L _w
3	01	01	SBR	113	01	1		168	55	+		169	43	RCL		170	03	03	
4	92	RTN	TAN	114	02	2		169	43	RCL		170	03	03		171	55	+	
5	76	LRL		115	55	+		170	03	03		171	55	+		172	93	*	
6	12	B	A	116	43	RCL		171	55	+		172	93	*		173	03	3	
7	42	STO		117	05	05		172	93	*		173	03	3		174	0	0	
8	02	OZ	RTN	118	54	)		173	03	3		174	0	0		175	04	4	
9	92	RTN	MOP	119	28	LOC		174	0	0		175	04	4		176	08	8	
10	76	LRL		120	65	X		175	04	4		176	08	8		177	65	X	
11	13	C	L _w	121	93	*		176	08	8		177	65	X		178	43	RCL	p
12	42	STO		122	03	3		177	65	X		178	43	RCL		179	01	01	
13	03	03		123	06	6		178	43	RCL		179	01	01		180	54)	
14	92	RTN		124	06	6		179	01	01		180	54	)		181	42	STO	
15	76	LRL		125	65	X		180	54	)		181	42	STO		182	10	10	
16	14	D	L _r	126	43	RCL		181	42	STO		182	10	10		183	92	RTN	
17	42	STO		127	06	06		182	10	10		183	92	RTN					
18	04	04		128	54	+													
19	92	RTN		129	55	+													
20	76	LRL		130	43	RCL													
21	15	E	d _r	131	04	04													
22	42	STO		132	55	+													
23	05	05		133	43	RCL													
24	92	RTN		134	07	07													
25	76	LRL		135	55	+													
26	16	A'	K	136	93	*													
27	42	STO		137	03	3													
28	06	06		138	00	0													
29	92	RTN		139	04	4													
30	76	LRL		140	08	8													
31	17	B'	N	141	65	X													
32	42	STO		142	43	RCL													
33	07	07		143	01	01													
34	92	RTN		144	54)													
35	76	LRL		145	42	STO													
36	26	CE		146	09	09													
37	53	(		147	92	RTN													
38	71	SBR		148	68	MOP													
39	38	SIN		149	76	LRL													
40	65	X		150	30	TAN													
41	71	SBR		151	53	(
42	39	COS		152	53	(
43	75	SBR		153	53	(
44	71	SBR		154	02	2													
45	30	TAN		155	65	X													
46	33	X ²		156	63	RCL													
47	34	)		157	03	03													
48	55	(		158	55	+													
49	53	(		159	43	RCL													
50	71	SBR		160	04	04													
51	38	SIN		161	54)													
52	85	+		162	28	LOC													
53	71	SBR		163	65	X													
54	39	COS		164	93	*													

PROGRAM DESCRIPTION

$R_p = (\rho_w R_{wg} - R_{wg}^2) / (R_{wg} 2 R_{wg})$ Total Ground Grid Resistance
 $R_{wg} = (\rho_w / 2\pi \sqrt{A} \sqrt{M}) \rho / L_w$ Total Connecting Wire Resistance
 $R_{rg} = (.366 \rho K / L_{rg}) \log(2L_w/d_g)$ Total Rods Resistance
 $R_{mg} = (.73 \rho / L_w) \log(2L_w/L_r)$ Mutual Wire and Rods Resistance

USER INSTRUCTIONS

Step	Procedure	Enter	Press	Display
1	ρ = Soil Resistivity in meter-ohms	ρ value	A	ρ
2	A = Area of ground grid in feet	A value	B	A
3	L _w = Total length of wire used in feet	L _w value	C	L _w
4	L _r = Rod length in feet	L _r value	D	L _r
5	d _r = Rod diameter in inches	d _r value	E	d _r
6	K = Resistance ratio	K value	2nd A'	K
7	N = Number of ground rods	N value	2nd B'	N
8	R _w = Total connecting wire resistance	SBR 2nd	SBR	R _w
9	R _g = Total Rods resistance	SBR 2nd	SBR	R _g
10	R _{mg} = Mutual wire and rods resistance	SBR 2nd	SBR	R _{mg}
11	R _{pt} = Total ground grid resistance	SBR CE	SBR	R _{pt}

USER DEFINED KEYS

USER DEFINED KEYS	DATA REGISTERS
A	0
B	1
C	2
D	3
E	4
A'	5
B'	6
K	7
R _w	8
R _g	9
R _{mg}	10