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FAA LIGHTNING PROTECTION STUDY: LIGHTNING SIMULATION TESTS OF COMMUNICATION CABLES

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16. Abstract

The purpose of the Lightning Protection Study is to determine the degree of susceptibility of the Federal Aviation Administration electronic systems to induced electromagnetic pulse effects due to lightning, and to propose protective devices adequate for low voltage electronic systems. This report covers one phase of the study; the measurement of inducted electromagnetic effects in typical FAA electronic cables under simulated lightning tests. The other study phases are reported in separate reports, namely analytical cable coupling, cable terminal equipment susceptibility levels, and low voltage lightning protection devices.

This report consists of four brief chapters on the description of the cables tested, the cable test list plan, the measurements performed, and the results of the testing. Appendices include a brief description of lightning effects and related data, description of the lightning simulation test equipment, a detailed bibliography of simulated lightning cable testing, and the FAA specifications for the cables tested.

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FOREWORD

The Post-Doctoral Program at Rome Air Development Center is pursued via Project 9567 under the direction of Dr. W.W. Everett, Jr. The Post-Doctoral Program is a cooperative venture between RADC and the participating universities: Syracuse University (Department of Electrical and Computer Engineering, the U.S. Air Force Academy (Department of Electrical Engineering), Cornell University (School of Electrical Engineering), Purdue University (School of Electrical Engineering), University of Kentucky (Department of Electrical Engineering), Georgia Institute of Technology (School of Electrical Engineering), Clarkson College of Technology (Department of Electrical Engineering), State University of New York at Buffalo (Department of Electrical Engineering), Florida Technological University (Department of Electrical Engineering), Florida Institute of Technology (College of Engineering), Air Force Institute of Technology (Department of Electrical Engineering), and the University of Adelaide (Department of Electrical Engineering) in South Australia. The Post-Doctoral Program provides, via contract, the opportunity for faculty and visiting faculty at the participating universities to spend a year full time on exploratory development and operational problem-solving efforts with the post-doctorals splitting their time between RADC (or the ultimate customer) and the educational institutions.

This effort was conducted via RADC Job Order No. 9567 0006 for the Federal Aviation Administration. Mr. Fred Sakate was the F.A.A. focal point and he participated closely in the technical coordination meetings and cable testing sessions.

The authors wish to acknowledge: the assistance of W.B. Rucker, Chief of Airways Facilities Division for the F.A.A., and George Elmore of the F.A.A. Southern Region Office, Atlanta, in obtaining the electrical communication and control cables used in the cable testing; the contributions of Mr. Fred Sakate throughout the study period; members of the Post Doctoral Program team on the overall F.A.A. Lightning Protection Study, for their contribution to the cable testing phase; especially Mr. Warren Peele (Purdue University), who served as Project Leader, Mr. Keith Huddleston (Georgia Tech), Dr. John Norgaard (Georgia Tech), and Dr. Chin- Lin Chen (Purdue University); the very capable and timely assistance of Mr. John Hill (F.I.T. student) and Mr. John Herring (LTRI), for preparing the lightning simulation tests; Mrs. Jo Kapus and Mrs. Mary Farson of F.I.T. for final draft preparation.

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Richard M. Cosel is a former Director of Research and Development for the United States Air Force. He received his Bachelor of Science in Business Administration with High Distinction from Indiana University in 1957 and has also attended Cornell University (E.E.), Modern Engineering at University of California, Los Angeles and several related service schools. Memberships include Beta Gamma Sigma, Sigma Iota Epsilon and he is a Fellow of the American Association for Advancement of Science.

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ABSTRACT

The purpose of the Lightning Protection Study is to determine the degree of susceptibility of the Federal Aviation Administration electronic systems to induced electromagnetic pulse effects due to lightning, and to propose protective devices adequate for low voltage electronic systems. This report covers one phase of the study: the measurement of inducted electromagnetic effects in typical F.A.A. electronic cables under simulated lightning tests. The other study phases are reported in separate reports, namely analytical cable coupling, cable terminal equipment susceptibility levels, and low voltage lightning protection devices.

This report consists of four brief chapters on the description of the cables tested, the cable test list plan, the measurements performed, and the results of the testing. Appendices include a brief description of lightning effects and related data, description of the lightning simulation test equipment, a detailed bibliography of simulated lightning cable testing, and the F.A.A. specifications for the cables tested.

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CHAPTER 1
Introduction

The high voltage, lightning simulation testing of electrical communication cables described in this report is part of a larger study program to provide protection for communication electronics equipment against transient electromagnetic disturbances. Current pulses are induced in cables running between buildings or equipment enclosures. These currents are then conductively coupled into the terminal equipment.

The electromagnetic disturbances may be the result of nearby lightning activity or man-made electromagnetic pulse. This larger study, known as the F.A.A. Lightning Protection Study, has been performed by the Post Doctoral Program through several of its member Universities for the Federal Aviation Administration. The schools include Air Force Institute of Technology, Florida Institute of Technology, Georgia Institute of Technology, and Purdue University. The individual participants in the F.A.A. Lightning Protection Study are listed in Appendix A.

1.1. F.A.A. Lightning Protection Study

Increasing use of solid state, integrated circuit electronics in the F.A.A. communication and control equipment, means that reliance on the over voltage protection adequate for higher voltage electron tube and discrete transistor circuitry would be inadequate. The overvoltage protection of carbon blocks, in the several hundred volt range, and neon bulbs, with long, relatively high inductance leads in the 60 - 100 volt range, is not adequate for the solid state circuits which operate at lower voltage levels (presently down to 5 volts).

The overall study has three technical tasks: (1) determination of voltage and current levels likely to be conducted to F.A.A. equipment; (2) the determination of the susceptibility levels of F.A.A. solid state equipment, and (3) determination of lightning protective devices that are available to reduce the levels of (1) to those permitted by (2). These three tasks have been performed in parallel with close interaction. Task one has been accomplished by two means: (1) computer analysis and (2) high voltage pulse testing of representative F.A.A. cable. Appendix A lists the schools having primary responsibility for each of the tasks. All participants contributed to each task through frequent meetings and informative exchanges.

1.2. Lightning Simulation Tests

This report discusses lightning simulation tests performed as part of Task 1. The tests were conducted on five communication cables representative of classes of cables used at F.A.A. facilities to inter-connect equipment located in different buildings or equipment shelters. Because the F.A.A. conditions are typical for many non-F.A.A. facilities, the results of this report may be applicable to a much wider audience. This report is written so that the results may be useful to a wide range of situations within the F.A.A. and to others as well. Since the cables are usually buried, the chances of direct lightning stroke are not high. However, induced effects due to strokes nearby may be significant as has been experienced in the field. Appendix B has a brief description of lightning phenomena and includes data on the frequency of lightning storms and the expected magnitude (current amperage) of lightning strokes. Appendix C contains an annotated bibliography of high voltage pulse testing and associated areas.

The lightning simulation tests performed and reported herein can be scaled to predict the induced effects due to the larger natural strokes. The report gives the scaling factors. The tests were performed under subcontract by the Lightning and Transients Research Institute, L.T.R.I., using their high voltage test facilities aboard the RV THUNDERBOLT docked at Miami, Florida.

CHAPTER 2
Cable Test Plan

Much effort went into the planning of the cable tests to assure the results would be as valid as possible for the F.A.A. scenario. The choices of possible testing situations range from in-situ tests at one or more F.A.A. facilities to laboratory bench tests. In-situ tests have many disadvantages, including uncertainty of the actual cable location and lack of control of test parameters, the inconvenience of moving the high voltage impulse generators and instrumentation vans to the site, the high cost of field operations, the potential disturbance of a vital operating systems, and the question of "how typical is the site chosen". At the other extreme, laboratory bench tests cannot duplicate the induced effects due to nearby lightning strokes of large magnitude, and do not permit sufficient cable length to simulate pick up conditions found in the field.

In this study, it was decided to conduct simulated lightning tests on test cables of sufficient length and with a test configuration which would approximate the essential features of the F.A.A. installations. The familiarity of the study participants with F.A.A. facilities gained from previous studies * and from site visits conducted during this study was extremely helpful in choosing the appropriate test cables and test configuration.

2.1. Cable Selection

Three types of electrical cables are in frequent use at F.A.A. airport facilities and Air Route Traffic Control Centers for exterior, buried use. The exterior cable runs are more exposed to lightning than are cables within buildings or equipment enclosures. The cables chosen are used for communication and control of communciation-electronics and navigation-electronics systems. The three types are: coaxial cable; exterior electrical control cable; and exterior telephone cable. For the testing phase of the F.A.A. Lightning Protection Study covered in this report, five cables were tested: one speciman of

* W.D. Peele, A.W. Revay, Jr., V. Eveleigh, "F.A.A. Electromagnetic Pulse (EMP) Protection Study", Final Report, June 1972, Report No. FAA-RD-72-68.

coaxial cable, RG-11/U; two specimens of Type 1B exterior electrical control cable, namely six pair and twelve pair, each pair individually shielded with an overall flat metallic armor sheath; and two specimens of Type II exterior telephone cable, namely, 50 pair and 100 pair telephone cable with an overall metallic sheath. The F.A.A. specifications for these cables are given in Appendix C, "F.A.A. Cable Specifications". The RG-11/U coaxial cable used in the tests was not furnished by F.A.A. and is not armored. The other four cables furnished by the F.A.A. are shown in Figure 2.1-1. The six inch scale provides a ready reference of the cable size. The largest diameter cable, the 100 pair telephone cable is approximately 1 3/4 inches in diameter. From left to right in Figure 2.1-1.are: The 12 pair shielded, armored control cable; the 100 pair sheathed telephone cable; the 50 pair sheathed telephone cable; and the 6 pair, shielded, armored control cable. All of the cables have #19AWG signal conductors, except for the RG-11/U, whose center conductor is #18AWG.

Coaxial cable is chosen not only because it is used in the field but also because it is small enough to permit it to be readily handled during test set up and check out of the test facilities. Another reason was that replacement coaxial cable was readily available in case tests would cause permanent cable damage. Damage could have occurred during the early tests when the magnitude of the induced effects due to lightning probe location and strength of the lightning stroke were not known with very much certainty.

Two cables of the same type were selected to determine the affect of increased size and number of conductors on the induced voltages and currents.

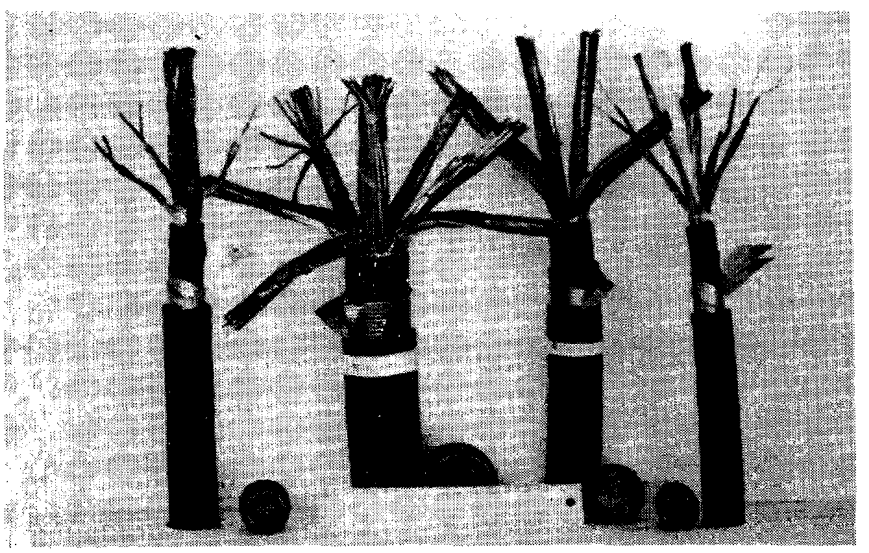


Figure 2.1-1. Four Cables Furnished by F.A.A.

CHAPTER 3
Cable Testing

Each of the communication and control cables described in Chapter 2 has been tested under lightning simulation conditions. Prior to assembling each cable into its test configuration with terminal junction boxes at both ends, measurements were made of the cable electrical parameters.

3.1. Measurement of Cable Properties

The electrical parameters, most important in determining lightning induced effects, were measured for each of the F.A.A. cables. The tests include d.c. resistance measurements and time domain pulse reflectometry. Measurements were made with the cables rolled on the cable spools. The tests were performed at the Florida Institute of Technology, Melbourne campus.

3.1.1. D.C. Resistance Measurements

The d.c. resistance of the signal conductors, braided shield, and outer metallic sheath (or armor) was measured. Because the cable was rolled on a drum, both ends of the cable were accessible with normal ohmmeter leads. The measured resistance was corrected for lead resistance. Measurements were made with the HP Model 3470A/34740A Digital Readout Multimeter having an accuracy of .05 per cent on the ranges used. Measured values are given in section 3.1.3.

3.1.2. Time Domain Pulse Reflectometry

The pulse reflectometry test configuration is shown in Figure 3.1.2 -1, where measurement of the signal line to sheath characteristic impedance of a telephone cable is indicated. Typical waveforms for various values of far end terminating resistances are shown in Figure 3.1.2 -2. The pulse reflectometry tests are used to measure characteristic impedance, the pulse propagation delay time, and the pulse attenuation of the cable. By measuring the delay time of a reflected pulse and dividing by the round trip distance (2 times the cable length) the propagation delay constant may be calculated. In the present case the round trip delay time for the lightning simulation test specimen (180 feet) is of interest.

The measured results and calculated values are given in section 3.1.3. When the far end termination resistance is equal to the characteristic impedance of the cable, no reflection takes place. In the tests performed on the F.A.A. cables, the value of the far end terminating resistor was varied until the no reflection condition was obtained. The far end terminating resistance value resulting in no reflection is therefore recorded as the characteristic impedance of the cable. The following characteristic impedances was measured for each cable: Signal line to signal line of pairs, signal line to braided shield, signal line to outer sheath (armor). Several signal pairs were tested to assure that the values did not differ significantly from pair to pair. The values did not differ (within the one or two ohms of measurement precision).

During the lightning simulation tests several values of far end terminating resistances are used to simulate the various conditions found in F.A.A. terminal equipment. Figure 3.1.2.-2 shows the reflected waveforms for open circuit (infinite impedance) and short circuit (zero impedance) terminations. For terminating impedance higher than the cable characteristic impedance value, a positive reflected voltage pulse is observed. For a line with no attenuation, the ratio of the reflected pulse height to the transmitted pulse height is given by the expression:

$$p = \frac{Z_T - Z_C}{Z_T + Z_C} ,$$

where Z_T is the terminating impedance
Z_C is the cable characteristic impedance.

As the equation shows, for $Z_T = Z_C$ the ratio is zero. For Z_T greater than Z_C the ratio is positive. For an open circuit condition, $Z_T \rightarrow \infty$, the ratio is positive unity. However in a real cable, attenuation occurs. The attenuation is measured, under open circuit conditions and may be expressed in attenuation per foot of cable by dividing by the cable round trip distance (two times cable length). As the equation shows, for Z_T less than Z_C the ratio is negative so that the polarity of the reflected pulse is opposite the transmitted pulse. For Z_T equal to zero (short circuit), the ratio is negative unity, so that the cable attenuation can also be measured under this condition.

As is seen in Figure 3.1.2.-2. the reflected wave form is not an exact replica of the transmitted waveform. In addition to attenuation, filtering effects of high frequencies due to cable capacitance result in a rounding-off of the reflected waveform.

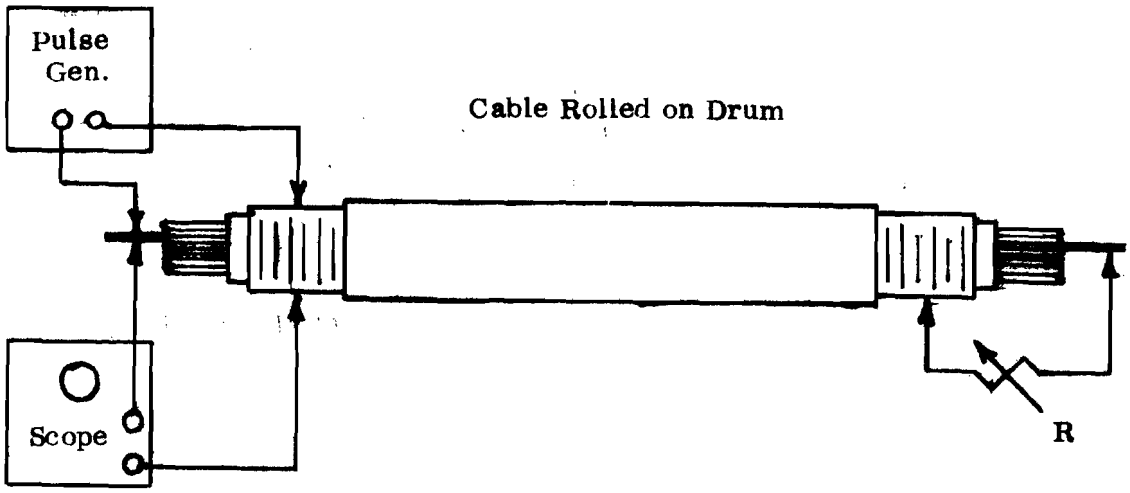


Figure 3.1.2-1. Pulse Reflectometry Test Configuration

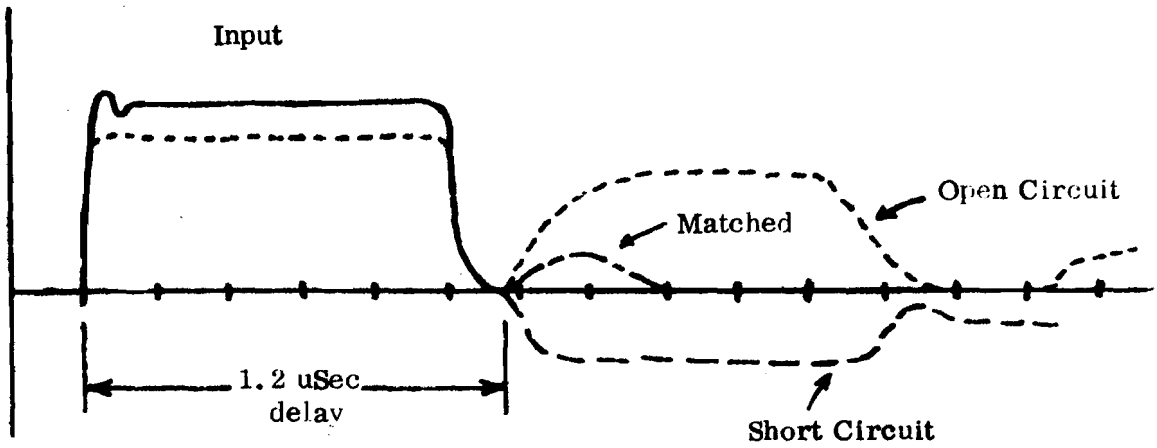


Figure 3.1.2-2. Typical Waveforms, Far End Terminations

3.1.3. Measurement Results and Comparison

The results of the cable d.c. resistance measurements and the pulse reflectometry tests are shown in Table 3.1.3 -1., D.C. Resistance Measurements, and Table 3.1.3.-2, Pulse Reflectometry Measurements. The actual measurements for each cable sample is shown without parenthesis. For these measurements the length of the cable was not standardized. The parenthetical entries show the calculated data per foot (100 feet) and per 180 feet, the final standardized length which was used in the lightning simulation tests. The data per foot (100 feet) is listed to permit comparison with hand book or specification data to assure the accuracy of the data.

Armored RG/11 coaxial cable was not available, so standard, unarmored cable was used. It was not available for the series of tests described in this section 3.1., but was used for the lightning simulation tests described in section 3.2. Measurements on a different 85 foot sample of RG-11/U are given in Table 3.1.3-1. Reported manufacturer's data are given in Table 3.1.3-2.

Not shown are tests conducted on RG 58/U cable which were made previous to the listed measurements to check out the measurement scheme. Comparison of the measured data with reference data showed good agreement.

The values for d.c. resistance of the signal conductor range from 7.48 to 8.33 milliohms per foot for the 12 pair shielded, and the 50 pair and 100 pair telephone cables. The hand book value for #19 wire is given as 8 milliohms per foot. The value of the d.c. resistance of the signal conductors for the 6 pair shielded cable is calculated to be 10 milliohms per foot, based upon a cable length of 180 feet. Since the cable lengths were measured at a later time it is reasonable to believe that either the length was improperly measured or that the cable was cut to the standard 180 foot before its length was measured. The cable shipping voucher (Project Material Requisition/Transfer) lists the length as 200 feet. Based upon 200 feet the calculated value would be 9 milliohms per foot, a value closer to that predicted for #19AWG.

The d.c. resistance of the sheath is important in predicting induced cable voltages for a given induced sheath current. Past measurements have shown that a simple multiplication of sheath current times sheath d.c. resistance gives a good approximation of the voltages induced between sheath and cable signal conductors. For the cables tested, the d.c. resistance of the sheath falls within the

ranges from 0.26 ohms to 0.03 ohms per 180 feet. The value decreases with increasing diameter of cable sheath, as is expected.

Table 3.1.3-1.

Cable	D.C. Resistance		
	Signal Conductor ohms	Braided Shield ohms	Sheath or Armor ohms
RG -11/U Coaxial	*6mΩ/ft	*1.35mΩ/ft	×
6 TwP Shielded, Armored	1.8Ω/180' (10mΩ/ft)	.19Ω/180' (1.055mΩ/ft)	.26Ω/180' (1.444mΩ/ft)
12 TwP Shielded, Armored	1.6Ω/214' (7.48mΩ/ft) (1.346Ω/180')	.08Ω/214' (.37mΩ/ft) (66.6mΩ/180')	.23Ω/214' (1.075mΩ/ft) (193.45mΩ/180')
50 Pair, Sheathed	3.0Ω/380' (7.9mΩ/ft) (1.42Ω/180')	×	.090Ω/380' (.23mΩ/ft) (.042Ω/180')
100 Pair, Sheathed	1.5Ω/180' (8.33mΩ/ft)	×	.03/180' (.166mΩ/ft)

*Measured on a different sample of RG-11/U (*18 AWG center conductor)
Parenthetical entries are calculated.

× condition doesn't exist.

Table 3.1.3-2.

Cable	Pulse Reflectometry					
	Signal Conductor to Signal Conductor (Pair)		Signal Conductor to Shield		Signal Conductor to Sheath	
	Charac. Imped. ohms	Pulse Delay usec	Z ohms	Delay usec	Z ohms	Delay usec
RG-11/U Coaxial			75Ω			
6 TwP Shielded, Armored	75Ω	.6/180ft rnd try	46Ω	.6/180 ft	56Ω	.6/180 ft
12 TwP Shielded, Armored	85Ω	-.6/214	50Ω	.6/214 ft	50Ω	.6/214 ft
50 Pair, Sheathed	85Ω	1.2usec/380 ft (.57usec/180ft)	✕		103Ω	
100 Pair, Sheathed	103Ω	.5/180 ft	✕		103Ω	.5/180 ft

✕ condition doesn't exist.

The delay time is essentially the same for all terminations, independent of the points of pulse application, i.e., signal conductor to signal conductor of a pair, signal conductor to shield, or signal conductor to sheath. The value measured fell in the range 0.5 to 0.6 microseconds for the round trip delay on the cables. For the cable lengths involved, this gives a signal propagation time of approximately 0.8 times the speed of light; a value which is very reasonable for electrical cable of this type.

The characteristic impedance of the different cables and terminations varies from approximately 50 ohms to 100 ohms. Several measurements on different signal lines within each cable gave consistent results indicating that the signal lines are well transposed over the length of cable tested

3.2. Test Configuration

3.2.1. Facilities

The test facilities of L.T.R.I. in Miami, Florida consist of shipboard and dock side facilities. The 165 foot RV THUNDERBOLT houses high voltage MARX generator and the instrumentation facilities. The RV THUNDERBOLT is docked at the Florida Power and Light substation on MacArthur Causeway. The dock side facilities include a cleared area and certain high voltage test structures. The lightning simulation tests of this study were performed with the test cables oriented perpendicularly to the ship running from the ship and terminating 150 feet away. A diagram of the layout is shown in Figure 3.2.1-1. Figure 3.2.1-2 is a photograph of the RV THUNDERBOLT taken from the shore. Figure 3.2.1-3. is a photograph of the shore taken from the RV THUNDERBOLT. This figure shows the far end termination of the cable, a portion of the far end cable and the sand box. The sand box was used to obtain a burial medium of a known consistancy.

Figure 3.2.1-4 shows a close up of the far end terminal box including 6 pair, shielded test cables.

Figure 3.2.1-5. shows the ship cable terminal box looking towards the instrumentation room enclosure.

Figure 3.2.1-6 shows a portion of the instrumentation room interior.

The high voltage MARX generator is located on the after deck of the ship with the high voltage lead running from the ship to the shore where it is placed near and to one side of the test cable. The use of foundary sand permitted the investigation of the effective buried cable while permitting relatively easy change of the various 5 cables. The cables were not buried the entire length but were buried for a length of approximately 30 feet with the lightning probe at approximately the center and to one edge of the sand area. For the rest of the test cable run on land, the cable lies on the surface of the ground. The portion of the cable between the dock side and the ship terminal is located in a 3" flexible conduit. The leads from the shipboard termination junction box to the instrument room junction box pass through approximately 10 feet of "Greenfield" flexible conduit. The far end junction box was configured with several types of terminal strips in common usage at F.A.A. facilities. The types chosen were obtained from first hand observation and through discussion

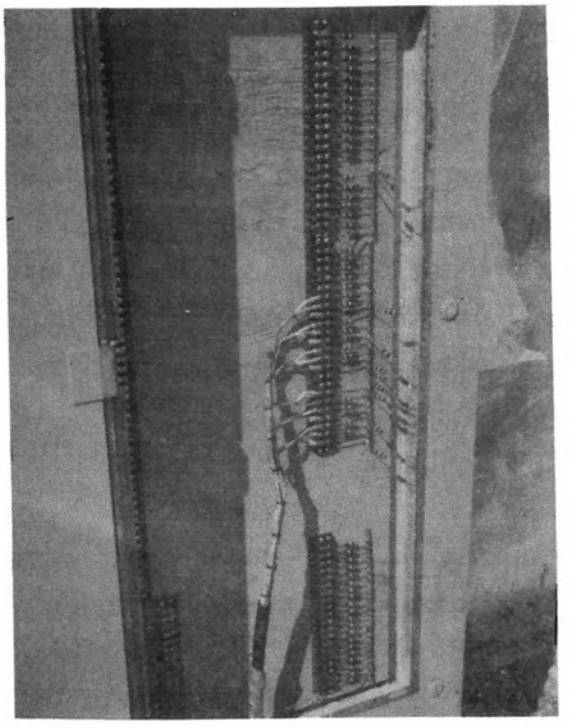


Figure 3.2.1-4.
Far End Terminal Box - With 6
Pair Shielded Armored Cable

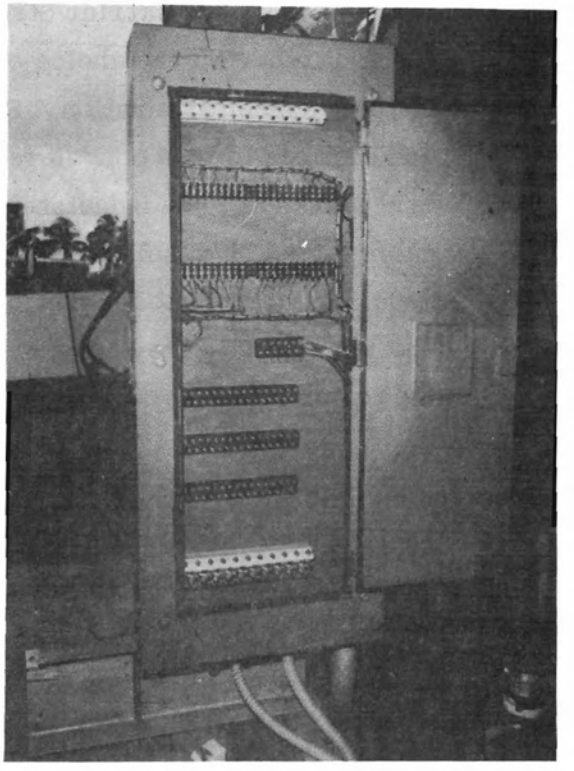
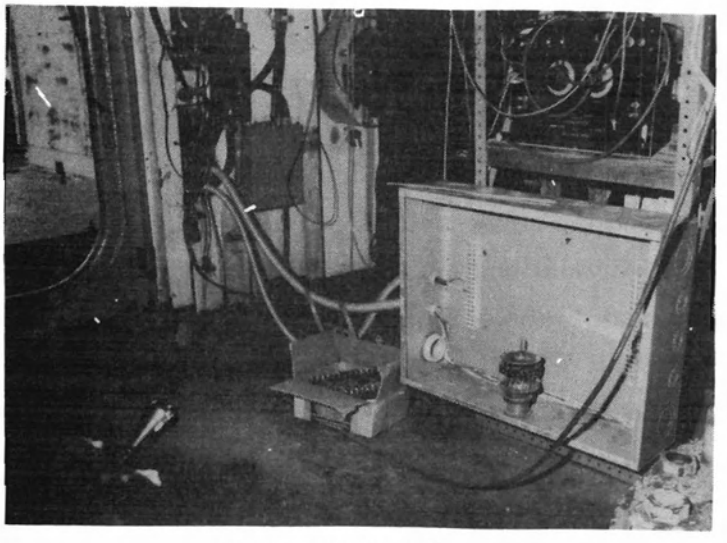


Figure 3.2.1-5. (a)
Near End Terminal Box
(2 Views)

(b)



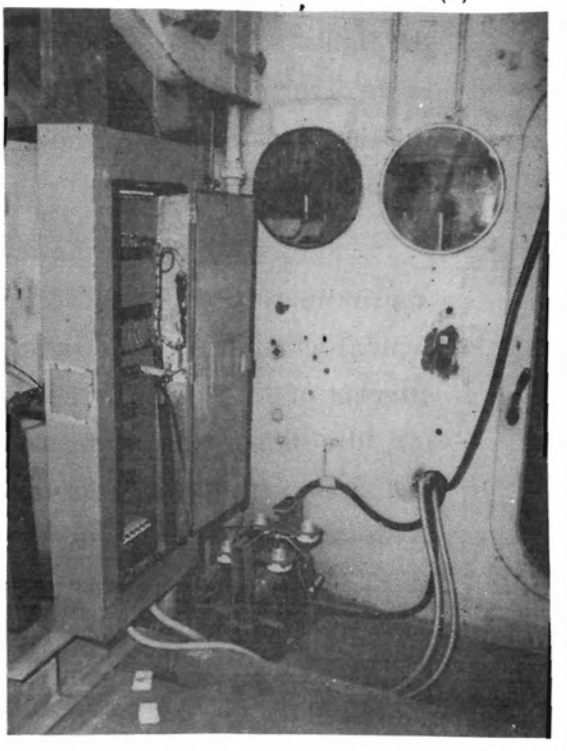


Figure 3.2.1-6.
Portion of the Instrumentation Bay
(Note Sheath Current Shunt)

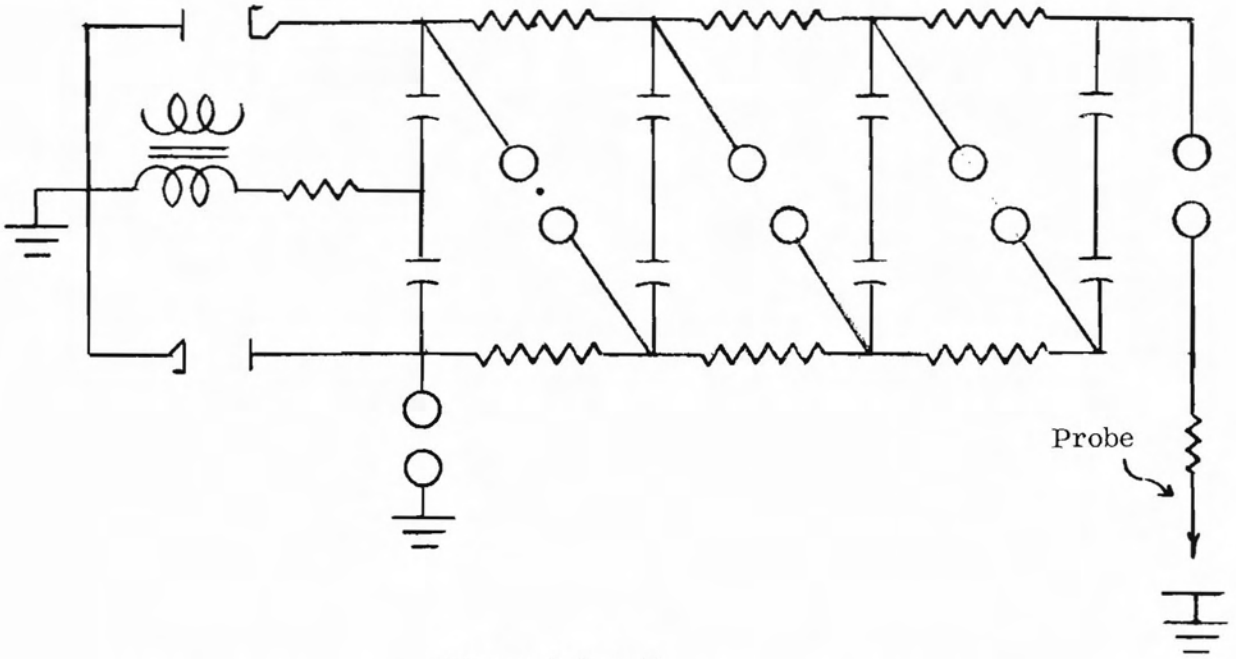


Figure 3.2.1-7.
Lightning Simulator (MARX) Generator Schematic Diagram
(4 Stages Shown)

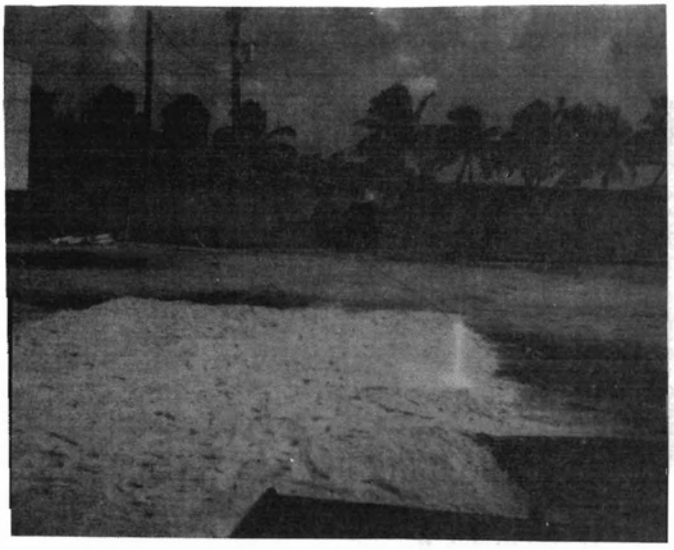


Figure 3.2.1-8.
Typical Simulated Lightning Stroke

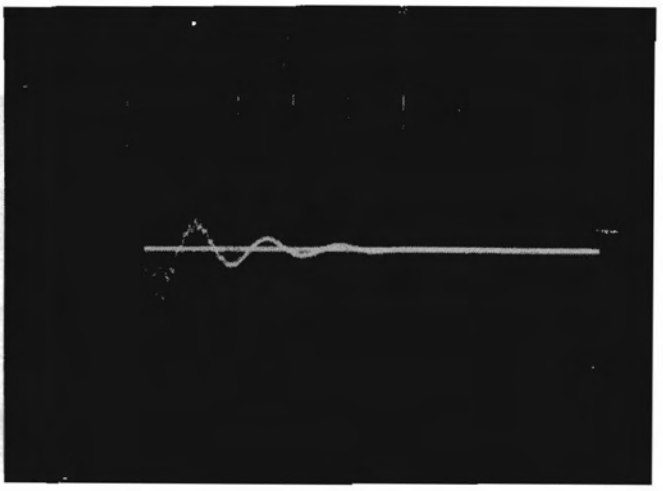


Figure 3.2.1-9.
Simulated Lightning Discharge Waveform
(11,000 Amperes Peak Current, 5 Microseconds per Major Division)

3.2.2. Lightning Simulation Test Results

The results of 47 simulated lightning tests are given in Tables 3.2.2-1. through 3.2.2-7. The tests are grouped by type of cable and are listed in the order in which the tests were performed.

The test data tables give for each test the cable type, shield current, voltage or current measurement test points, the measured peak value of voltage or current, and the test conditions. The test conditions list the location of the lightning probe with respect to the cable, and the signal conductor terminations both at the far-end and near-end.

For Test 1 through 4 the lightning probe position is varied. The magnitude of the induced sheath current is relatively insensitive to distances from the cable except for Test 4. In Test 4, the stroke penetrated the outer insulating cover and conducted directly to the copper sheath.

For Tests 6 through 47, the lightning probe position is fixed so that the point directly below the probe is 2.5 feet from the cable. The cable itself is buried one foot below the surface of the sand.

In this section, photographs of the far-end and near-end terminal boxes, and oscilloscope pictures of typical waveform measured at the near-end termination are shown for each cable tested (Except the RG11/U terminations, which were not photographed).

Test data for RG11/Ucoaxial cable are given in Tests 1 through 8 listed in Table 3.2.2-1. Figure 3.2.2-1. shows the waveform of the voltage induced in Test 1 at the near-end between the center conductor and the coaxial braided sheath. The horizontal time scale is 5 microseconds per major division (centimeter on the oscilloscope). The remaining waveforms shown in this section have the same time scale. The vertical scale is 20 volts per major division. The largest induced voltage for a 11,000 ampere stroke is reported in Test 7 as 48 volts for both ends open-circuited. The open circuit condition would be the limit reached for high impedance circuits terminating the cable.

Test data for the 6 pair shielded, armored cable are given in Tests 9 through 14 listed in Table 3.2.2-2. Figure 3.2.2-2. shows the near-end termination. The coaxial cable of Figure 3.2.2-2. is the instrumentation probe which goes to the instrument room. The reader is cautioned not to interpret shadows as additional leads. Figure 3.2.1-4. of the previous Section shows the far-end termination. Figures

far-end and near-end terminations, respectively. Note that some of the terminations are open-circuits, some short circuit to ground, and some terminated in the cable's 100 ohm characteristic impedance. The sheath current for these tests had a peak value of 200 amperes. Figures 3.2.2-16. and -17. show the induced voltage between signal conductor and sheath at the near-end for both ends terminated (Test 33), and for far-end terminated and near-end open (Test 34), respectively. The highest peak value for both ends terminated was 39 volts, and the highest value for the far-end only terminated was 38 volts. For both ends open circuited, the highest induced voltage was 54 volts. The highest voltage between conductor of a signal pair was 44 volts. The short circuit currents were 4.8 amperes for signal conductor to shield, and 6 amperes for signal pair.

3.2.3. Discussion of Lightning Simulation Test Results

Table 3.2.3. shows a summary of the worst case (highest values) data chosen from the many tests conducted for the five communication and control cables. The data are for a lightning stroke of nominally 11,000 amperes striking at a nominal distance of 2.5 feet from the cable. Variations about nominal values occur during the tests for several reasons discussed below. These variations would be typical of those associated with an actual F.A.A. site.

The results point up the fact that the voltages induced in the cables by a lightning stroke depend on the current flow paths under the ground. "Grounds" are almost never homogeneous and have a wide range of conductivities which are variable due primarily to rainfall (moisture content). The current flow is also strongly influenced by other buried conductors such as pipes and power lines. The earth near the simulated lightning test site did contain buried metal and piping. In dry earth most of the current could find its way to a water pipe and then follow it. Cable induced voltages would then be primarily dependent on the distance between the pipe and cable and pipe orientation relative to the cable, showing little dependence on the exact stroke entry point on the surface of the ground. Also, as has been shown, the stroke usually is forked and enters the ground at several points. It also may retain its plasma branching form in the dry earth, following many paths, or it may diffuse into a ground of high conductivity. Therefore, a knowledge of the ground conductivity and of buried conductors in the vicinity of the cable is essential to estimating the expected cable induced voltages. Such effects help explain the lack of

F.I.T. DATA SHEET

Table 3.2.2-1

Test No.	Cable	Shield Current	Test points	Voltage or Current	Test Conditions
1	RG-11	136 Amp.	Center Cond. To Shield	20 volts	Probe 8 feet from cable.
2	"	144 Amp.	"	26 volts	Probe 5 feet from cable.
3	"	160 Amp.	"	36 volts	Probe 2.5 feet from cable.
4	"	1600 Amp.	"	300 volts	Probe 8 inches from cable. (Cable punctured) (Probe at 2.5' selected as standard)
5	"	136 Amp.	"	36 volts	Terminated both ends in 47 ohms. Ground wet.
6	"		"	38 volts	A 2 foot earth ground was added to far cabinet.
7	"		"	48 volts	Both ends open circuited.
8	"		"	11 amps.	Both ends short circuited.

F.I.T. DATA SHEET

Table 3.2.2 - 3

Test No.	Cable	Shield Current	Test points	Voltage or Current	Test Conditions
17	12 pair shielded & armored	Cu Shield 19.2 Amp.	White - Gray pair		Shorted at far end (White - Gray connected to shield).
18	"	20 Amp.	White - Gray		Shorted at both ends.
19	"		(Red - Gray) Red - Cu Shield	40 volts	Both ends terminated in 47 ohms.
20	"		Gray to Cu	40 volts	Far end short circuited.
21	"		White - Gray	4 amps.	" " " "
22	"		White to Cu of White - Blue pair	4 volts	Open circuit on both ends.
23	50 pair	200 Amp	Yellow to Shield	40 volts	Terminated both ends in 100 ohms.

F.I.T. DATA SHEET

Table 3.2.2 - 5

Bundles: Outer, 12, 13, 12, 13, 12, 13 = 75 pair Inner 25 (Solid copper outer shield)

Test No.	Cable	Shield Current	Test points	Voltage or Current	Test Conditions
32	50 pair		Blue to White	4 amps.	Short circuit current.
33	100 pair	200 Amp.	Blue to Shield	36 volts	Terminated both ends in 100 ohms.
34	"		Purple to Shield (Outside Bundle)	34 volts	Terminated far end only, 100 ohms.
35	"		Brown to Shield (Same pair, #34)	34 volts	" " " " , 100 ohms.
36	"		Red to Shield (Center Bundle)	38 volts	" " " " , 100 ohms.
37	"		Brown to Shield	39 volts	Terminated both ends, 100 ohms.
38	"		Gray to Shield (Outside Bundle)	41 volts	Open circuit both ends.

F.I.T. DATA SHEET

Table 3.2.2 - 7

Test No.	Cable	Shield Current	Test points	Voltage or Current	Test Conditions
46	100 pair	200 Amp.	Black - Gray (Outer bundle)	44 volts	Open circuit on both ends.
47	"		Gray - Red (Inner bundle)	44 volts	" " " " "

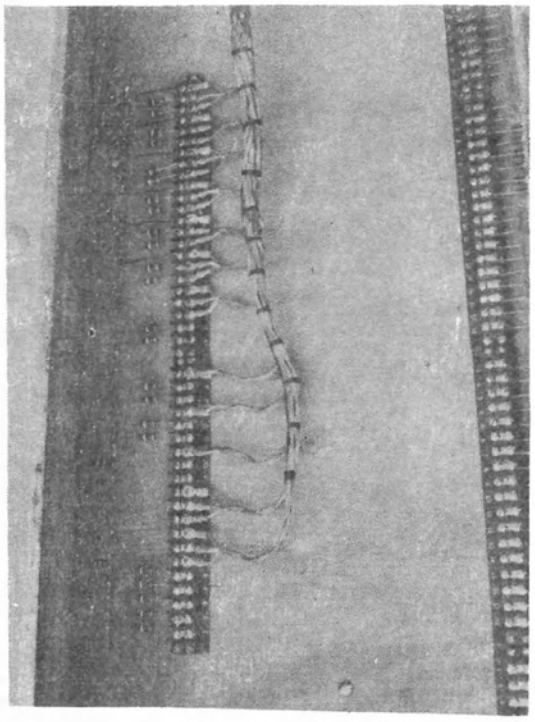


Figure 3.2.2-6.
Far End Termination For 12 Pair Shielded Armored Cable

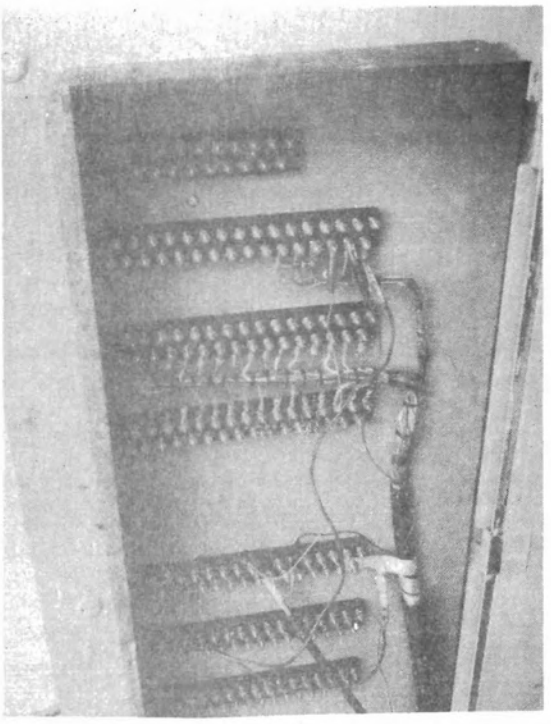


Figure 3.2.2-7.
Near End Termination For 12 Pair Shielded Armored Cable

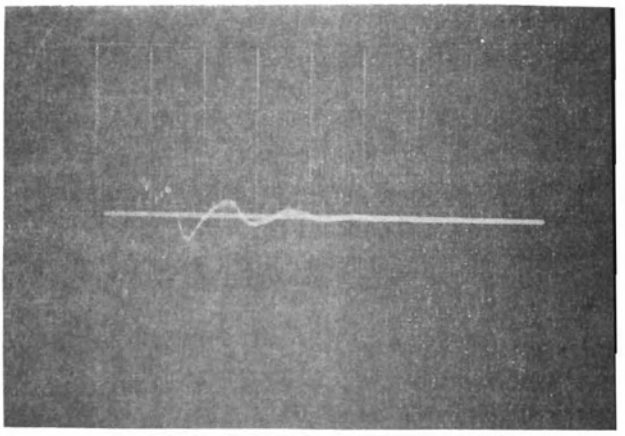


Figure 3.2.2-8.
Armor (Sheath) Current on 12 Pair Shielded Armored Cable (Test 15)
120 Amperes Peak

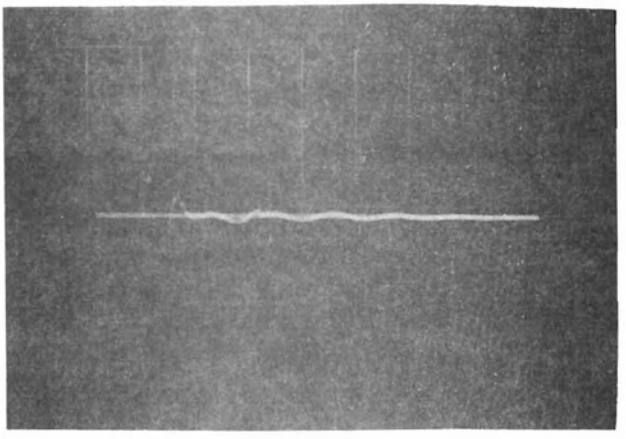


Figure 3.2.2-9.
Copper Shield Current on 12 Pair Shielded Armored Cable (Test 17)
19.2 Amperes Peak

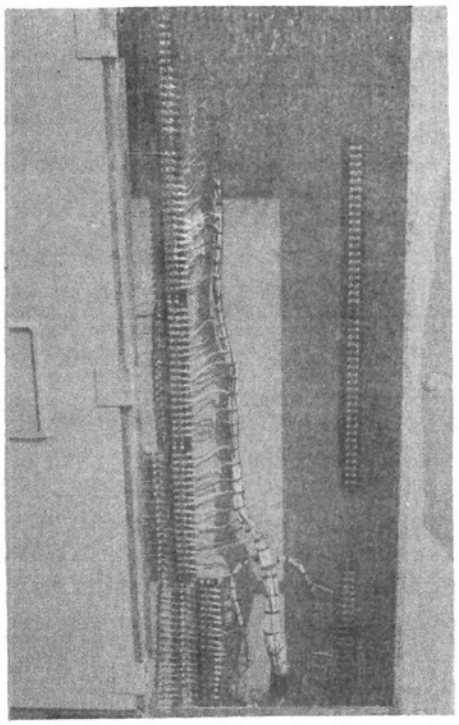


Figure 3.2.2-14.
Far End Termination For 100 Pair Telephone Cable

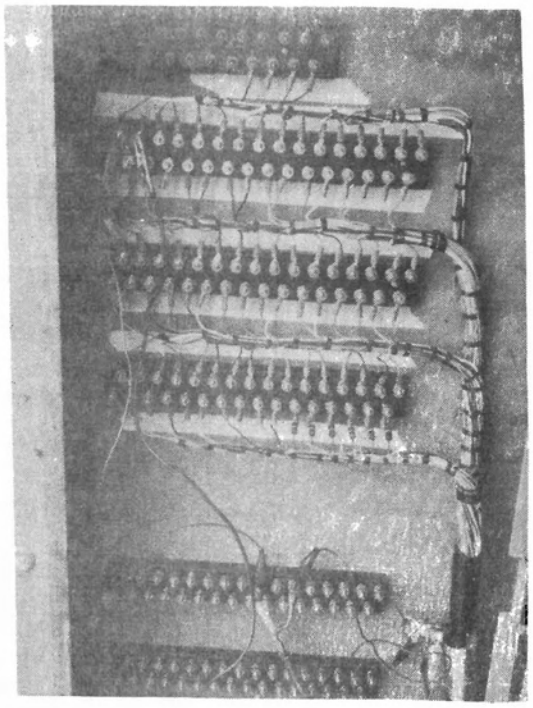


Figure 3.2.2-15.
Near End Termination For 100 Pair Telephone Cable

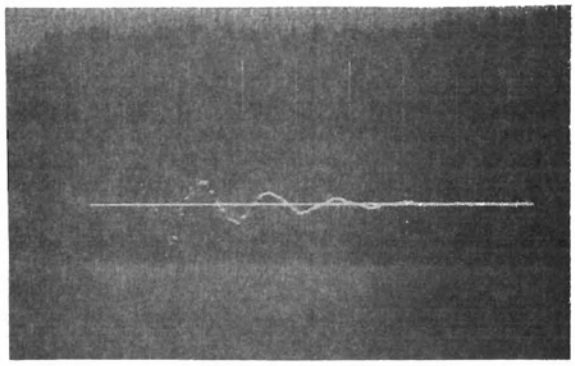


Figure 3.2.2-16.
Induced Voltage Between Signal Conductor and Sheath of 100 Pair Telephone Cable With Both Ends Terminated in Characteristic Impedance

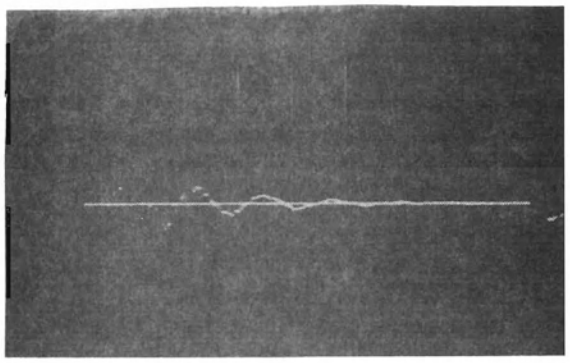


Figure 3.2.2-17.
Induced Voltage Between Signal Conductor and Sheath of 100 Pair Telephone Cable With Far End Terminated

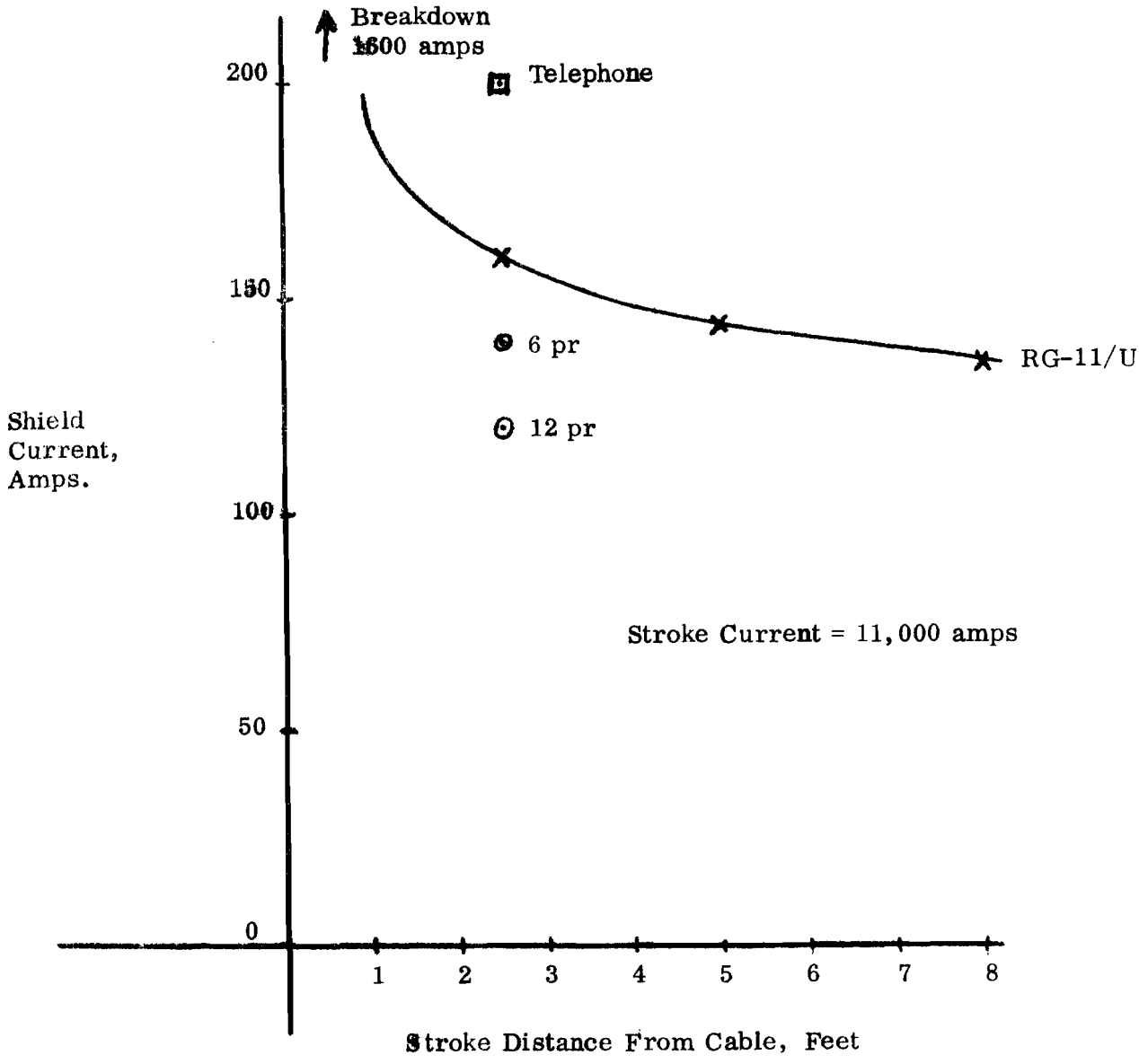


Figure 3.2.3. Shield Current as a Function of Stroke Distance

APPENDIX B

Brief Description of Lightning

The paper by E. L. Hill entitled, "Electromagnetic Radiation from Lightning Strokes", is attached for the convenience of the reader who may be unfamiliar with the electrical characteristics of lightning. The reader may wish to consult other references listed at the end of Hill's paper, or listed in Appendix C, "Cable Testing Bibliography". The recent book by Martin Uman (Lightning, McGraw-Hill 1969) is an especially readable, yet definitive work on natural lightning.

Figure B-1 shows the average number of thunderstorm days per year as indicated by data from the U.S. Weather Bureau* . Figure B-2 shows the distribution of peak initial stroke currents (Io) for lightning flashes to buried cables**.

*From Lightning Protection of Buried Cable - Bibliography reference 6, page 279.

**From Bell Laboratory article - Bibliography reference 1, page 48.

ELECTROMAGNETIC RADIATION FROM LIGHTNING STROKES *

BY

E. L. HILL [1]

SUMMARY

A theory is given of the spectral distribution and the absolute amount of low frequency electromagnetic radiation emitted from a vertical lightning stroke from cloud to ground. The calculation depends on an assumed physical mechanism for the flow of charge on the discharge channel, but the model corresponds closely to the empirical observations of Schonland, Pierce, and others. The radiated energy has a maximum intensity at about 11 kc/sec and a total width at half-maximum of 12 kc/sec. The predicted radiation in the megacycle region agrees reasonably well with that reported by Chandrashekhar Aiya, although the present theory was developed primarily for the low frequency region. The total energy radiated in one leader and return stroke is estimated to be about 220,000 joules.

I. INTRODUCTION

The erratic occurrence of natural lightning makes it very difficult to obtain absolute measurements of the electromagnetic energy which is radiated. The total radiation and its spectral distribution also may vary widely from stroke to stroke. Laby and his co-workers (1)[2] have made measurements of waveforms of atmospherics in Australia from which they estimate the mean radiated energy per stroke to be of the order of 2×10^5 joules. This figure may be different in other regions, depending on the prevalent type of storm.

Extensive statistical studies have been made on the noise power spectrum. The low frequency noise has been discussed recently by Barlow, Frey, and Newman (2), while the high frequency region (1 Mc to 20 Mc) has been studied by Chandrashekhar Aiya (3). These papers give references to other important recent work.

Much of our knowledge of the mechanism of natural lightning is derived from measurements in the visual optical region, from quasi-static changes in the field of a thundercloud during a storm, and from the analysis of waveforms of atmospherics. Most of the theoretical work has been based on the approximation of the field of a thundercloud by a variable electrical dipole, with dependence on measured waveforms to provide a spectrum analysis of the radiation (4).

The work reported in this paper has been prompted by a desire to

* This study is part of an atmospherics research program at the Lightning and Transients Research Institute under joint sponsorship of the USAF, Wright Air Development Center, Communication and Navigation Laboratories and the Navy Department, Bureau of Aeronautics.

[1] School of Physics, University of Minnesota, Minneapolis, Minn.; Consultant to Lightning and Transients Research Institute, Foshay Tower, Minneapolis, Minn.

[2] The [illegible] numbers in parentheses refer to the references appended to this paper.

itself somewhat indefinite in meaning and its use emphasizes our present ignorance of the details of the motions of the electrical charges within the body of a thundercloud during a stroke. This is possibly a serious point since we have no way at present of determining the magnitude of the contribution of the distributed currents in and above the cloud to the radiated energy. The best compromise which can be made is to consider the length of the discharge channel as an adjustable parameter.

In order to calculate the radiation in the long wavelength part of the spectrum, in which the wavelength of the radiation is large compared with the length of the channel, one must have some picture of the coherent flow of current over the channel as a whole. We idealize the cloud base and the earth as parallel conducting planes having a separation h, the former being negatively charged to a potential $V_c = -Eh$

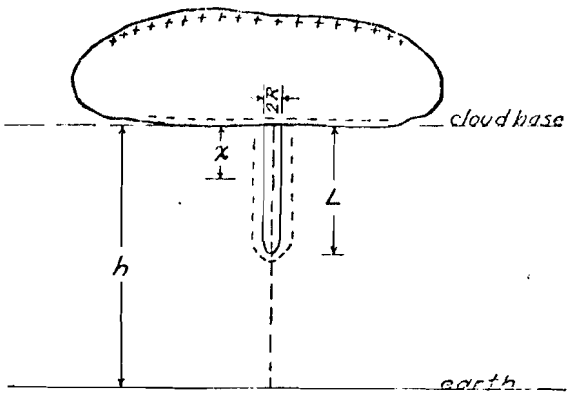


FIG. 1. Schematic diagram of the development of the ionized channel by the leader stroke.

with respect to the ground. The electric field is then directed from the ground to the cloud and is of magnitude E (volts/meter). The ionized channel of the stroke at any stage of its development will be idealized as a thin elongated spheroidal surface of base $2R$ on the cloud base, and of length L. These geometrical conditions are indicated schematically in Fig. 1.

Since the ionized channel of the developing stroke will be partially conducting, and since it is subject to the general electric field between the cloud and the earth, there must be a flow of charge from the cloud tending to make the channel an equipotential region. We think of this as leading to a quasi-static charge distribution on the surface of the channel.

When the leader stroke reaches the ground the ionized channel becomes a short-circuiting path between cloud and ground. It is difficult to decide on *a priori* grounds what physical processes will be [illegible] stroke. But in any case these should seem

from which the current flow at the base of the channel is found to be

$$|I(L,t)| = |dQ/dt| = 6\pi\alpha\epsilon_v EL \cdot dL/dt. \tag{6}$$

Here we can interpret $v_l = dL/dt$ as the mean speed of the leader stroke.

These formulas are expected to hold from time $t = 0$, when the leader starts from the cloud base, until $t_l = h/v_l$ when it reaches the ground. At the instant t_l the current along the whole channel has the maximum value which it attains during the leader stroke

$$|I(h,t_l)| = 6\pi\alpha\epsilon_v Ehv_l. \tag{7}$$

The characteristics of the return stroke are much more difficult to assess. For lack of better evidence we assume that the inertia of the magnetic field associated with the leader stroke current maintains the current given in Eq. 7 at any point on the channel until the arrival

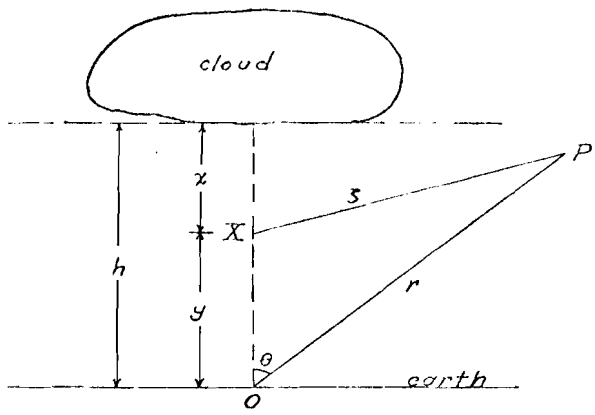


FIG. 2. Geometrical coordinates for the calculation of the radiation at the distant point P.

of the return stroke at that point. The following assumptions concerning the current in the return stroke do not seem to be unreasonable on physical grounds. When the return stroke reaches a point on the channel it is just such as, (*a*) to annihilate the current remaining from the leader stroke, (*b*) to remove the charge on the channel at the rate of progress of the return stroke, and (*c*) to provide a residual current I_f which continues to flow in the channel for some time after the return stroke has passed. The last contribution is inserted because it is known that after the return stroke is over there remains a low residual current which may last for a relatively long time and which is responsible for transporting the bulk of the electrical charge which passes in the stroke. The contribution of this residual current to the radiated energy is expected to be negligible. The radiation process is considered to be over when the return stroke reaches the cloud base.

the second member gives that from the associated earth currents as represented by the image channel.

The magnetic induction vector can be found from the usual formula, $\mathbf{B} = \text{curl } \mathbf{A}$. Making use of the unit vector system for spherical polar coordinates with origin at the point O in Fig. 2, it is found that

$$\mathbf{B}(P,t) = -\phi_1 \left[\sin\theta \left(\frac{\partial}{\partial r} + \frac{2}{r} \right) \right] A(P,t). \tag{15}$$

Only the leading term which diminishes as $1/r$ is required for the calculation of the radiation field. The function $A(P,t)$ has a leading term which diminishes as $1/r$ and only terms of this type need be retained in the calculation of Eq. 15. To this approximation we find

$$A(P,t) = \frac{\mu_v}{4\pi r} \left\{ \int_0^h \left[I\left(y,t - \frac{r}{c} + y\frac{\cos\theta}{c} \right) + I\left(y,t - \frac{r}{c} - y\frac{\cos\theta}{c} \right) \right] dy \right\}. \tag{16}$$

It is convenient to introduce a Fourier integral representation for the channel current in the form

$$\frac{\mu_v}{4\pi} I(y,t) = \int_0^\infty [\varphi(y,\omega)\cos\omega t + \psi(y,\omega)\sin\omega t]\, d\omega, \tag{17}$$

with

$$\begin{Bmatrix} \varphi(y,\omega) \\ \psi(y,\omega) \end{Bmatrix} = \frac{\mu_v}{4\pi^2} \int_{-\infty}^{+\infty} I(y,t) \begin{Bmatrix} \cos\omega t \\ \sin\omega t \end{Bmatrix} dt. \tag{18}$$

On insertion of these quantities into Eqs. 15 and 16 one finds the following expression for the magnetic induction vector of the radiation field:

$$\mathrm{B}(P,t) = \phi_1 \frac{\sin\theta}{r} \left\{ \int_0^\infty \frac{\omega}{c} \left[-M(\omega,\theta)\sin\omega\left(t - \frac{r}{c}\right) + N(\omega,\theta)\cos\omega\left(t - \frac{r}{c}\right) \right] d\omega \right\}, \tag{19}$$

with the definitions

$$\begin{Bmatrix} M(\omega,\theta) \\ N(\omega,\theta) \end{Bmatrix} = 2\int_0^h \begin{Bmatrix} \varphi(y,\omega) \\ \psi(y,\omega) \end{Bmatrix} \cos\left(\frac{\omega y \cos\theta}{c} \right) dy. \tag{20}$$

The radiative part of the electrical field can be found from the general formula

$$\mathrm{E}(P,t) = -\mathbf{r}_1 \times \mathrm{B}(P,t), \tag{21}$$

$$+\frac{\omega h}{v_l}\frac{iv_l^2h+\omega v_lh^2}{b_+b_-}+\frac{\omega h}{v_r}\frac{iv_r^2h+\omega(v_l-v_r)h^2}{a_+a_-}$$

$$-\frac{iv_l^2h}{2}\left[\frac{e^{-ib_+}}{b_+}+\frac{e^{-ib_-}}{b_-}\right]-\left(\frac{iv_r^2h+\omega v_lh^2}{2}\right)\left[\frac{e^{ia_+}}{a_+}+\frac{e^{ia_-}}{a_-}\right]$$

$$-\frac{i\omega v_lh^2}{2}\left[\frac{e^{-ib_+}-1}{b_+^2}+\frac{e^{-ib_-}-1}{b_-^2}\right]$$

$$-\frac{i\omega v_rh^2}{2}\left[\frac{e^{ia_+}-1}{a_+^2}+\frac{e^{ia_-}-1}{a_-^2}\right]\Bigg\}. \quad (26)$$

When one proceeds to the calculation of the spectral function from Eq. 24 by use of 26, the resulting expressions become very cumbersome. Fortunately many of the terms can be seen to be of small numerical significance. The apparent strong dependence on the angle θ arises from Doppler effects and is not important since we know that $v_l \ll v_r \ll c$. It is sufficiently accurate for present purposes to treat the angular distribution of the radiation as that of a dipole with its axis along the channel. All effects of the residual current have been ignored in Eq. 26 as giving a negligible contribution to the radiation.

It has been judged unprofitable to make a complete numerical analysis of the radiation with use of Eq. 26 at the present time. An analytical approximation of sufficient accuracy to show the most important features of the calculation has been developed on the basis of the radiation from the return stroke alone. If we write

$$|M+iN|^2=\beta^2h^6\gamma^{-2}F(\gamma), \quad (27)$$

the following expression has been found for $F(\gamma)$:

$$F(\gamma)=|j_1(\gamma)|^2=\gamma^{-4}(\sin\gamma-\gamma\cos\gamma)^2, \quad (28)$$

where j_1 is the spherical Bessel function of first kind of order unity.

This formula can be used to complete the evaluation of the total electromagnetic energy emitted in the stroke. One has only to integrate the Poynting vector over the hemisphere into which the radiation flows. If R is the radiated energy in joules per unit (angular) frequency interval, one finds that

$$R=\frac{16\pi^2\beta^2v_r^2h^4}{3\mu_vc}F(\gamma). \quad (29)$$

It is useful to introduce the total charge on the channel at the instant contact is made with the ground as a parameter. Equation 5 shows that this charge is

$$Q(h)=-3\pi\epsilon_vEh^2. \quad (30)$$

somewhat smaller value of 2×10^7 m/sec for the mean speed of the return stroke. It seems reasonable to adopt the round number

$$v_r = 3 \times 10^7 \text{ m/sec.} \tag{35}$$

There is some uncertainty at present in the estimation of the mean speed of the leader stroke. According to the work of Pierce and Wormell (9) it is appreciably lower than the figure given by Schonland and others. A recent review by Pierce (8) gives the value $v_l \cong 6 \times 10^4$ m/sec. This is not a critical point here since our approximate formula 31 for the total radiation does not involve this constant at all, and it is quoted only for purposes of comparison.

6. THE SPECTRAL DISTRIBUTION OF THE RADIATED ENERGY

When the numerical values adopted in Sec. 5 are inserted into formula 31 the following explicit expression results:

$$R = 8 \times 10^4 \, F(\gamma) \, \frac{\text{joules}}{\text{kc/sec}}. \tag{36}$$

A plot of the function $F(\gamma)$ is shown in Fig. 3. Using the numerical

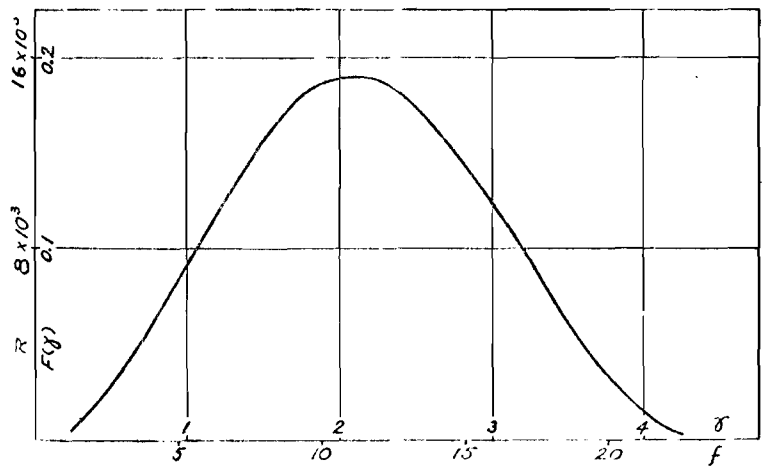


FIG. 3. Plot of the function $F(\gamma) = \gamma^{-4} (\sin\gamma - \gamma\cos\gamma)^2$ giving the spectral distribution of the emitted radiation. The scales for the frequency, f, in kc/sec, and for the emitted radiation, R, in joules/(kc/sec), are fixed by the choice of constants discussed in the text.

values given one finds that the frequency at the maximum point is $f_m = 11.2$ kc/sec, while the total width at half-maximum is about 12 kc/sec. Integration over the spectral distribution yields a total energy emitted of about 220,000 joules.

The [illegible] of our formula at the extreme ends of the spectrum

12 kc/sec, although no definitive measurements are known to the writer. Such a result may be explained by the consideration that often an unobserved part of the discharge channel may lie inside the cloud, so that the visual position of the cloud bank would not be a direct measure of the channel length. Furthermore, from the point of view of the model considered in this paper, the quantity which determines the spectral distribution of the radiation is the time of travel of the return stroke. Since the longer discharge channels can be expected to be associated with larger amounts of charge deposited on the channel by the leader stroke, it may be that the mean speed of the return stroke is then also increased. Thus there may arise a correlation between channel length and stroke speed such that their ratio is more nearly constant for all types of discharge than is either of these quantities separately.

REFERENCES

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(2) J. S. BARLOW, G. W. FREY AND J. B. NEWMAN, "Very Low Frequency Noise Power from the Lightning Discharge," JOUR. FRANKLIN INST., Vol. 258, pp. 187–203 (1954).

(3) S. V. CHANDRASHEKHAR AIYA, "Noise Power Radiated by Tropical Thunderstorms," *Proc. I.R.E.*, Vol. 43, pp. 966–974 (1955).

(4) P. W. A. BOWE, "The Waveforms of Atmospherics and the Propagation of Very Low Frequency Radio Waves," *Phil. Mag.*, Vol. 42, pp. 121–138 (1951);
K. G. BUDDEN, "The Propagation of a Radio Atmospheric—II," *Ibid.*, Vol. 43, pp. 1179–1200 (1952).

(5) H. NORINDER, "Some Aspects and Recent Results of Electromagnetic Effects of Thunderstorms," JOUR. FRANKLIN INST., Vol. 244, pp. 109–130 and 167–207 (1947);
H. NORINDER, "Experimental Lightning Research," *Ibid.*, Vol. 253, pp. 471–504 (1952).

(6) B. F. J. SCHONLAND, "Atmospheric Electricity," New York, John Wiley & Sons, Inc., 1953, Second edition, chapter 4.

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(8) E. T. PIERCE, "Electrostatic Field-Changes due to Lightning Discharges," *Quart. J. Roy. Meteorological Soc.*, Vol. 81, pp. 211–228 (1955);
E. T. PIERCE, "The Development of Lightning Discharges," *Ibid.*, pp. 229–240.

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9. Vance, E. F. "Shielding Effectiveness of the Liquid Tight Flexible Conduit from Transient Tests", Stanford Research Institute, Production Engineering and Management Note PEM-3, May 1972.

10. Uman, Martin A., "Lightning", McGraw-Hill. Advanced Physics Monograph Series, 1969.

11. Chalmers, J. Alan, Atmospheric Electricity, 2nd Edition, Pergamon Press, Copyright 1967.

In addition to the above, DDC Sources were checked, Bibliography Search Control Number 8001 and Report No. CW80075. Directly applicable abstracts are attached. The abstracts include the search key words used.

DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. 008001

AD-676 501 17/2 9/1
RURAL ELECTRIFICATION ADMINISTRATION WASHINGTON D C
TELEPHONE STANDARDS DIV

LIGHTNING SHIELDING OF PLASTIC TELEPHONE CABLE, (U)

68 17P FISHER,EARL L. ;BISHOP,
WAYNE F. ;ROBINSON,EVERETT A. , JR;

UNCLASSIFIED REPORT

SUPPLEMENTARY NOTE: PREPARED FOR PRESENTATION AT THE INTERNATIONAL WIRE AND CABLE SYMPOSIUM (17TH), ATLANTIC CITY, N. J., 5 DEC 68.

DESCRIPTORS: (*ELECTRIC CABLES, LIGHTNING), (*TELEPHONE LINES, SHIELDING), LIGHTNING, UNDERGROUND, COMMUNICATION SYSTEMS, PLASTICS, COPPER, ALUMINUM, STAINLESS STEEL, CARBON ALLOYS, STEEL, CORROSION, DESIGN (U)

DATA IS PRESENTED ON THE SURGE CHARACTERISTICS OF VARIOUS TYPES AND COMBINATIONS OF METALS WHEN APPLIED AS A SHIELD FOR BURIED TELEPHONE CABLES. SURGE CURRENTS WERE APPLIED TO THE SHIELD OF 500 FOOT LENGTHS OF CABLE AND THE POTENTIALS DEVELOPED BETWEEN THE SHIELD AND CONDUCTORS WERE MEASURED AT SELECTED POINTS ALONG THE CABLE LENGTH IN ORDER TO DETERMINE RELATIVE SUSCEPTIBILITY TO LIGHTNING INFLUENCE. THE SHIELD METALS INCLUDED COPPER, ALUMINUM, STAINLESS STEEL AND LOW CARBON STEEL, AND COMBINATIONS OF THESE METALS. THIS PROGRAM WAS BEGUN AND COMPLETED IN THE CALENDAR YEAR 1968. THIS PROGRAM MAY HAVE A SUBSTANTIAL IMPACT IN THE FUTURE DESIGNS OF CABLE USED IN THE REA SYSTEMS. (AUTHOR) (U)

DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. 008001

AD-869 851 9/1 17/9
NAVAL TRAINING DEVICE CENTER ORLANDO FLA

LIGHTNING PROTECTION FOR NAVY DEVICE 2D2
SITE, ASTOR, FLORIDA. (U)

DESCRIPTIVE NOTE: FINAL REPT.,
MAY 70 31P JOHNSON,CARL B. ;
REPT. NO. NAVTRADEVCEN-IH-175
PROJ: NAVTRADEVCEN-8083-P39, NAVTRADEVCEN-8083-P40

UNCLASSIFIED REPORT

DESCRIPTORS: (*GUIDED MISSILES(SURFACE-TO-AIR),
RADAR EQUIPMENT), (*RADAR EQUIPMENT,
ELECTROMAGNETIC SHIELDING), (*ELECTROMAGNETIC
SHIELDING, *LIGHTNING ARRESTERS), RELAYS,
COAXIAL CABLES, GROUND(ELECTRICAL), VOLTAGE,
POWER SUPPLIES, VERY HIGH FREQUENCY, COMPUTERS,
COMMUNICATION EQUIPMENT, GUIDED MISSILE RANGES,
ELECTROMAGNETIC WAR RE (U)
IDENTIFIERS: DEVICE D2 ELECTRONIC EQUIPMENT,
NIKE, AN/MPQ-47 (U)

THE PROTECTIVE SYSTEM INCLUDED A SYMMETRICAL SHIELD
WHICH PROVIDES A CANOPY OVER THE NIKE RADARS, THE
AN/MPQ-47 RADAR AND ALL MOBILE VANS WHICH HOUSE
COMPUTERS, CONTROL EQUIPMENT AND COMMUNICATION
EQUIPMENT. THE CANOPY REDUCES THE PROBABILITY OF
DIRECT-LIGHTNING-STRIKE DAMAGE TO EQUIPMENT AND
REDUCES THE CURRENTS INDUCED IN CABLES
INTERCONNECTING BETWEEN DEVICE 2D2 SUBSYSTEMS.
(AUTHOR) (U)

DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. 008001

AD-826 447L 16/1 10/2 9/3
GENERAL ELECTRIC CO PITTSFIELD MASS

OCE NEMP PROGRAM. DEVELOPMENT OF CRITERIA FOR PROTECTION OF NIKE-X POWER PLANT AND FACILITIES ELECTRICAL SYSTEMS AGAINST NUCLEAR ELECTROMAGNETIC PULSE EFFECTS. PROTECTIVE MEASURES. (U)

DESCRIPTIVE NOTE: REPT. FOR 1 APR-1 DEC 67.
DEC 67 412P UHLIG,E. R. I
REPT. NO. 67U11
CONTRACT: DA-49-129-ENG-543

UNCLASSIFIED REPORT
DISTRIBUTION: DOD ONLY: OTHERS TO OFFICE OF THE CHIEF OF ENGINEERS (ARMY), ATTN: MILITARY CONSTRUCTION. WASHINGTON, D. C. 20315.

DESCRIPTORS: (*POWER PLANTS(ESTABLISHMENTS), ELECTROMAGNETIC SHIELDING), GUIDED MISSILES(SURFACE-TO-AIR), LAUNCHING SITES, ELECTROMAGNETIC PULSES, ELECTRICAL EQUIPMENT, GUIDED MISSILE COMPONENTS, PENETRATION, POWER SUPPLIES, GROUND SUPPORT EQUIPMENT, ELECTRIC WIRE, SOILS, RESISTANCE(ELECTRICAL), GROUND(ELECTRICAL), PIPES, BUILDINGS, WAVEGUIDES, ATTENUATION, SHIELDING, LIGHTNING, DUCTS, TRANSIENTS, QUALITY CONTROL (U)
IDENTIFIERS: NIKE-X, CONDUITS (U)

THIS DOCUMENT REPRESENTS THE LATEST AND MOST ACCURATE INFORMATION AVAILABLE FOR USE IN PROTECTING NIKE-X POWER PLANTS AND FACILITIES ELECTRICAL SYSTEMS AGAINST THE EFFECTS OF NUCLEAR ELECTROMAGNETIC PULSES. THE INFORMATION PROVIDES THE CURRENT RESULTS OF THE OCE NEMP PROGRAM FOR DEVELOPMENT OF CRITERIA. THE INFORMATION IS WRITTEN IN CRITERIA FORMAT, SO THAT ALL OR PART OF IT MAY BE EXTRACTED FOR USE BY AGENCIES WORKING WITH THE NIKE-X PROJECT OFFICE IN PREPARATION OF FORMAL DESIGN CRITERIA FOR THE VARIOUS MAJOR SYSTEM COMPONENTS OR CATEGORIES SUCH AS POWER PLANT, TECHNICAL FACILITIES, MISSILE FARM, ETC. (AUTHOR) (U)

DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. 008001

AD-813 356L 9/5
SYLVANIA ELECTRONIC SYSTEMS-EAST WALTHAM MASS

LIGHTNING PROTECTION OF AN ANTENNA SYSTEM. (U)

JAN 63 35P TOWNE,H. M. !
CONTRACT: AF 04(694)-261

UNCLASSIFIED REPORT
DISTRIBUTION: USGO: OTHERS TO BALLISTIC SYSTEMS DIV., ATTN: BSQT. NORTON AFB, CALIF. 92409.
SUPPLEMENTARY NOTE: MICROFICHE ONLY AFTER ORIGINAL COPIES EXHAUSTED.

DESCRIPTORS: (*UNDERGROUND ANTENNAS, LIGHTNING), (*LIGHTNING ARRESTERS, UNDERGROUND ANTENNAS), LAUNCHING SITES, SOILS, ELECTRICAL CONDUCTANCE, PROBABILITY, THUNDERSTORMS, TRANSMISSION LINES, ELECTRIC CABLES, GROUND(ELECTRICAL), COAXIAL CABLES, POLYETHYLENE PLASTICS, ELECTRIC INSULATION (U)

THIS ANTENNA SYSTEM AND ITS DIRECTLY ASSOCIATED EQUIPMENT, FOR USE AT LAUNCH FACILITY (LF) AND LAUNCH CONTROL FACILITY (LCF) SITES SEPARATED THROUGHOUT THE MISSILE SQUADRON AREA, PRESENTS EXCEPTIONALLY LOW DEGREE OF DIRECT EXPOSURE TO LIGHTNING DAMAGE DUE TO ITS OWN COMPLETE UNDERGROUND INSTALLATION WITH VIRTUALLY NO PROJECTING ELEMENTS EXTENDING ABOVE GRADE LEVEL. THIS DOCUMENT DISCUSSES THE LIGHTNING PROTECTION PROBLEM OF THE ANTENNA SYSTEM. (U)

DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. 008001

AD-440 274
GENERAL ELECTRIC CO SYRACUSE N Y

LIGHTNING PHENOMENA INVESTIGATION. (U)

DESCRIPTIVE NOTE: FINAL REPT.
MAR 64 90P
CONTRACT: AF29 601 5402
PROJ: AF-8809
MONITOR: AFWL TDR-64-21

UNCLASSIFIED REPORT
NOFORN
SUPPLEMENTARY NOTE:

DESCRIPTORS: (*LIGHTNING, ELECTRIC CABLES), (*ELECTRIC CABLES, LIGHTNING), (*LAUNCHING SITES, LIGHTNING), TESTS, VOLTAGE, ELECTRIC CURRENTS, MEASUREMENT, INSTRUMENTATION, METEOROLOGICAL PARAMETERS, THUNDERSTORMS, ATMOSPHERIC ELECTRICITY, DAMAGE, TEST EQUIPMENT (ELECTRONICS) (U)

THE LIGHTNING-PHENOMENA INVESTIGATION PROGRAM WAS DESIGNED TO DETERMINE INDUCED VOLTAGE AND CURRENTS IN CERTAIN SELECTED MISSILE-SITE CABLES AS A RESULT OF A LIGHTNING DISCHARGE ON OR NEAR THE INSTRUMENTED SM-78 SITE. THE CHARACTERISTICS OF THE LIGHTNING DISCHARGE, WHICH PRODUCED THE INDUCED SIGNALS, WERE MEASURED; IN ADDITION, BACKGROUND METEOROLOGICAL MEASUREMENTS WERE MADE TO FACILITATE THE ANALYSIS OF THE STORM EVENT AND THE RESULTING DATA. LIMITED OSCILLO GRAPHIC SURGE DATA ARE PRESENTED ON THE ONLY THREE STORMS WHICH OCCURRED IN THE VICINITY OF THE INSTRUMENTED SITE. DATA ARE ALSO PRESENTED ON THE 6-MONTH CONTINUOUS MONITORING PERIOD ON THE METEOROLOGICAL PARAMETERS, POINT DISCHARGE CURRENT, AND THE ATMOSPHERIC ELECTRIC GRADIENT. THE EXTENT OR TYPE OF DAMAGE TO THE SM-78 SYSTEM THAT WOULD RESULT FROM A DIRECT OR NEAR LIGHTNING STRIKE CANNOT BE CONCLUDED FROM THE LIMITED DATA PRESENTED FOR THE THREE STORMS, SINCE THE ONLY LIGHTNING DISCHARGES DURING THE INSTRUMENTATION PERIOD OCCURRED SEVERAL MILES FROM THE INSTRUMENTED SITE. (AUTHOR) (U)

DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. 008001

AD-297 816
SPERRY RAND CORP ST PAUL MINN UNIVAC DEFENSE SYSTEMS DIV

PROJECT LIGHTNING (U)

NOV 61 1V

UNCLASSIFIED REPORT

DESCRIPTORS: *COMPUTER STORAGE DEVICES, *COMPUTERS, *INFORMATION RETRIEVAL, CIRCUITS, CONTAINERS, DESIGN, OPERATION, TEST METHODS (U)
IDENTIFIERS: LIGHTNING PROJECT (U)

JUNE DEMONSTRATION UNIT (JDU) AND LIGHTNING TEST MACHINE (LTM) WERE SUBJECTED TO TEST DURING SERVICE OPERATION. THE LTM WAS CHECKED TO DETERMINE RELIABILITY OF ESTIMATED SPEED OF LTM MEMORIES AND SHIFT MATRIX, HIGH SPEED MEMORY, SEARCH MEMORY, EXPLORATORY WORK, PACKAGING, AND TO PHASE CLOCK.

DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. 008001

AD-479 569 17/2
NORTHERN ELECTRIC CO LTD MONTREAL (QUEBEC)

LIGHTNING PROTECTION OF BURIED CABLE BY SEMI-CONDUCTING JACKETS. (U)

DEC 65 19P CAMPBELL,H. D. ;

UNCLASSIFIED REPORT

SUPPLEMENTARY NOTE: PRESENTED AT THE FOURTEENTH ANNUAL WIRE AND CABLE SYMPOSIUM, 1-3 DEC 65, ATLANTIC CITY, N. J.

DESCRIPTORS: (*TELEPHONE LINES, *PROTECTIVE COVERINGS), (*SEMICONDUCTORS, PROTECTIVE COVERINGS), LIGHTNING, UNDERGROUND, DAMAGE, WATER, CORROSION, MOISTUREPROOFING, ELECTRIC CURRENTS, VOLTAGE, POLYETHYLENE PLASTICS, TEMPERATURE, FAILURE(ELECTRONICS), SOILS, RESISTANCE(ELECTRICAL) (U)
IDENTIFIERS: ALPETH, STALPETH (U)

SEMI-CONDUCTING JACKETS ON BURIED TELEPHONE CABLE WILL BE SUBJECTED TO HEAVY SURGE CURRENTS CAUSED BY LOCAL LIGHTNING STROKES TO GROUND. THE IMPULSE CURRENT STRENGTH OF A SEMI-CONDUCTING POLYETHYLENE COMPOUND, HAVING A NOMINAL RESISTIVITY OF 20 OHM-CM, IS MEASURED AND THE EFFECTS OF SOME ENVIRONMENTAL FACTORS ASSESSED. IT IS CONCLUDED THAT THE PROBABILITY OF SURGE CURRENT RUPTURE OF THE CABLE JACKET IN SERVICE IS VERY SMALL EXCEPT WHEN DIRECT STROKES TO THE CABLE OCCUR. (AUTHOR) (U)

DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. 008001

AD-750 642 9/1
FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OHIO

PROTECTION OF COMMUNICATION CABLES IN PLASTIC SHEATHS FROM LIGHTNING STRIKES. (U)

AUG 72 16P SOKOLOV,S. A. ;ORLOV,V. K. ;GORYUNOV,B. K. ;
REPT. NO. FTD-MT-24-41-72

UNCLASSIFIED REPORT

SUPPLEMENTARY NOTE: EDITED MACHINE TRANS. OF ELEKTRICHESTVO (USSR) N4 P80-83 1969, BY CHARLES T. OSTERTAG, JR.

DESCRIPTORS: (*TRANSMISSION LINES, SHIELDING), ELECTRIC INSULATION, PLASTIC COATINGS, METAL COATINGS, EFFECTIVENESS, LIGHTNING, USSR (U)
IDENTIFIERS: *SHEATHING, *SHEATHS, TRANSLATIONS (U)

FROM IMPULSE GENERATOR TESTS ON A CABLE 4 KM IN LENGTH (A ONE-QUARTER CABLE WITH POLYTHENE-INSULATED CORES, AN ALUMINUM FOIL SCREEN IN THE FORM OF A TWO-LAYER WINDING OF STEEL WIRES EACH 0.25 MM IN DIAMETER; ENCLOSED IN P.V.C. COVER; OUTSIDE DIAMETER OF CABLE OF THE ORDER 15 MM), IT WAS FOUND THAT PROTECTION BY EARTHING THE CABLE SCREEN ALONG THE LINE IS GENERALLY LESS EFFECTIVE THAN PROTECTION BY LAYING A LIGHTING CONDUCTOR OF BIMETAL 0.25-0.35 M DEEP, ALTHOUGH COST CONSIDERATIONS AND LOCAL CONDITIONS MAY INFLUENCE THE CHOICE IN PARTICULAR CASES. (U)

DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. 008001

AD-525 207 4/1 19/5 13/12
KAMAN SCIENCES CORP COLORADO SPRINGS COLO

LIGHTNING STUDY FOR THE XM-50 FIRING SYSTEM. (U)

DESCRIPTIVE NOTE: FINAL REPT.,
MAR 73 125P CURRY,J. REGNALD ;
REPT. NO. K-73-226(FR)
CONTRACT: DAAA21-73-C-0095

GDS CONFIDENTIAL REPORT

DESCRIPTORS: (*LIGHTNING, FIRING CIRCUITS), FIRING MECHANISMS(WEAPON), LIGHTNING ARRESTERS, ELECTROMAGNETIC FIELDS, ELECTRIC CABLES, SAFETY, CLOUDS, TRANSIENTS, COUPLING CIRCUITS, VOLTAGE, ELECTRIC CURRENTS, SOILS, ELECTRIC FIELDS, ELECTRICAL CONDUCTANCE (U)
IDENTIFIERS: M-50 FIRING CIRCUITS (U)

THE WORK REPORTED CONSIDERS THE CALCULATION OF LIGHTNING INDUCED TRANSIENTS ON THE THREE MAIN CABLES OF THE XM-50 FIRING SYSTEM. THE LIGHTNING COUPLING MECHANISM IS DIVIDED INTO THREE MAIN CATEGORIES: (1) DIRECT STRIKE, (2) FIELD ILLUMINATION FROM NEARBY CLOUD-TO-GROUND STROKES, AND (3) FIELD ILLUMINATION FROM OVERHEAD CLOUD-TO-CLOUD STROKES. FOR THE SIX SEPARATE SYSTEM CONFIGURATIONS CONSIDERED IN THE STUDY, INDUCED CABLE TRANSIENTS ARE CALCULATED FOR THE THREE COUPLING MECHANISMS. SHEATH CURRENTS AND VOLTAGES AS WELL AS INTERNAL OPEN CIRCUIT VOLTAGES AT THE CABLE ENDS ARE CALCULATED. THE CALCULATIONS ARE PERFORMED WITH PARAMETRIC VARIATIONS OF LIGHTNING ENVIRONMENT AND SOIL PARAMETERS IN ORDER TO DETERMINE WORST CASE COUPLING CONDITIONS. THE LIGHTNING ENVIRONMENTS AND COUPLED CABLE TRANSIENTS ARE PRESENTED AS TIME WAVEFORM PLOTS. (AUTHOR) (U)

APPENDIX D

F. A. A. Electrical Cable Specifications

This appendix contains three specifications for electrical communication and control tables used by the Federal Aviation Administration. The specifications and the nomenclature and Federal Stock numbers of the F. A. A. cables used in this report are as follows:

D. 1 Armoured Coaxial Cable RG-11/U, Specification Number FAA-E-2171a, dated November 10, 1965

D. 2 Exterior Electrical Control Cable, Specification Number FAA-E-2042, dated November 6, 1963

- D. 2. 1 Type 1B, 6 shielded pair, #19AWG, Federal Stock No. 6145-867-2026
- D. 2. 2 Type 1B, 12 shielded pair, #19AWG, Federal Stock No. 6145-910-66391

D. 3 Exterior Telephone Cable, Specification Number FAA-E-2072, Dated January 8, 1970

- D. 3. 1 Type II, 50 pair #19AWG, Federal Stock No. 6145-767-79201
- D. 3. 1 Type II, 100 pair #19AWG, Federal Stock No. 6145-765-67061

2.2.1 American Society for Testing Materials

ASTM D1248 Polyethylene Moulding and Extrusion Materials

2.2.2 Insulated Power Cable Engineers Association

S-19-81 (Fourth Ed.) Rubber Insulated Wire and Cable

2.2.3 National Electrical Manufacturers Association

WC-21 Non-returnable Reels for Wire and Cable

(Single copies of Military specifications may be obtained from the Federal Aviation Agency, Washington, D. C. 20553, ATTN: Contracting Officer. Requests should cite the invitation for bids, request for proposals, or contract for which the material is needed. Mail requests, if found acceptable, will be forwarded to a Military supply depot for filling; hence, ample time should be allowed.)

(Information on obtaining copies of ASTM Standards may be obtained from American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pennsylvania.)

(Information on obtaining copies of IPCEA Standards may be obtained from Insulated Power Cable Engineers Association, 155 East 44th Street, New York, New York 10017.)

(Information on obtaining copies of NEMA Standards may be obtained from National Electrical Manufacturers Association, 155 East 44th Street, New York, New York 10017.)

(Copies of this specification may be obtained from the Contracting Officer in the Federal Aviation Agency Office issuing the invitation for bids or request for proposals. Requests should fully identify material desired, i.e., specification, standard, amendment, and drawing numbers and dates. Requests should cite the invitation for bids, request for proposals, or the contract involved or other use to be made of the requested material.)

3. REQUIREMENTS

3.1 Armored coaxial cable.- The armored coaxial cable shall consist of a basic cable, an armor and an overall jacket.

3.2 Basic cable.- The basic cable shall be an RG-11A/U cable conforming to specification MIL-C-17 and specification sheet MIL-C-17/6 except for the jacket.

4.3.3 Bend test.- The length of cable used for the tests in 4.3.1 and 4.3.2 shall be reused for the bend test. A length of cable shall be bent a minimum of one complete turn at room temperature around a mandrel whose diameter is thirty times the finished cable's diameter. After being re-straightened the outer jacket shall be removed and the armor inspected for retention of all the protective characteristics specified elsewhere in this specification. Upon completion of this bend test, the tests required in paragraphs 4.3.1 and 4.3.2 shall be repeated. There shall be no degradation in the attenuation and impedance characteristics of the cable from those observed before the bend test.

5. PREPARATION FOR DELIVERY

5.1 General.- Cable shall be delivered wound on reels conforming to paragraph 5.1.2.

5.1.1 Cable length per reel.- Cable shall be delivered in one continuous 5,000 foot length per reel, except that fifteen per cent of the quantity on order may be in lengths between 2,000 feet and 5,000 feet per reel.

5.1.2 Reel construction.- Reels shall be new and comply with NEMA Standard No. WC-21, Table I for Wood Reels. All reels shall be lagged with nominal two inch by four inch No. 2 common lumber, lagging pieces to be edge-to-edge around circumference and shall be strapped with two or more steel straps outside of lagging. The cable ends shall be hermetically sealed to prevent the entrance of moisture. The exposed cable end shall be protected by covering with sheet metal of 18 gauge minimum.

5.1.3 Reel marking.- The contractor's name, contract number under which the cable was purchased, reel serial number, quantity and type of cable, and the name and address of the consignee shall be applied plainly on both reel flanges with permanent type ink or paint The type of cable shall be designated as "Armored RG-11A/U."

6. NOTES

6.1 Notes on information items.- The contents of the subparagraph below are only for the information of the Contracting Officer. They are not contract requirements, nor binding on either the Government or the contractor, except to the extent that they may be specified elsewhere in the contract as such. Any reliance placed by the contractor on the information in these subparagraphs is wholly at the contractor's own risk.

SPECIFICATION ANALYSIS SHEET

This sheet is provided for obtaining information on the use of this specification by either Contractor or Government personnel. Recommendations should be based on actual or potential savings and advantages to the Government or users. Return of this form will be appreciated. Fold on lines on reverse side, staple closed, and mail.

SPECIFICATION NUMBER AND TITLE	CONTRACT NUMBER

SUBMITTING ORGANIZATION	ADDRESS

SPECIFICATION USED IN:

- ☐ Direct Government Contract - No: _____
- ☐ Government Subcontract - No: _____
- ☐ Other - _____

1. Has any part of the specification created problems or required interpretation?

   A. Give paragraph number and wording.

   B. Recommendations for correcting the deficiencies.

2. Comments on any specification requirement considered too rigid?

3. Is the specification restrictive? ☐ Yes; ☐ No

   If "yes", in what way?

4. REMARKS. "Attach to this form any additional pertinent data which may be of use in improving this specification. Form with attachments should be mailed together in an envelope addressed as shown on reverse side".

SUBMITTED BY	DATE

FAA Form 3705 (1-63)

(4310)

A 90 - Weight of Zinc Coating
B 3 - Soft or Annealed Copper Wire
B 8 - Concentric Copper Stranding
B 209 - Specification for Aluminum
D 470 - Method of Testing
D 1248 - Polyethylene Molding and Extrusion Materials

2.2 The Insulated Power Cable Engineers Association standards.- The following IPCEA standards form a part of this specification:

S-61-402 - Thermoplastic Insulated Wire and Cable
S-56-434 - Polyethylene Insulated, Thermoplastic Jacketed Communication Cables

2.3 National Electrical Manufacturers Association.- The following NEMA standard forms a part of this specification:

WC-21 - Nonreturnable Reels

2.4 In the event of conflict between the above-mentioned standards and this specification, this specification shall govern. Standards are referred to by basic number and title; the issue in effect on date of invitation for bids shall apply.

(Copies of this specification may be obtained from Federal Aviation Agency, Washington, D. C. 20553, ATTN: Contracting Officer. Requests should fully identify material desired, i.e., specification numbers, dates, amendment numbers, complete drawing numbers; also requests should state the contract involved or other use to be made of the requested material.)

3. REQUIREMENTS

3.1 Materials.- Materials shall be as specified herein. When materials are used for a purpose for which no material is specified herein, they shall be entirely suitable for the purpose. The manufacturer shall be prepared to show proof that insulation and jacket were made from virgin compounds.

3.2 Workmanship.- Workmanship shall be in accordance with high grade commercial manufacturing practices.

3.3 Design and construction.- The finished cable shall be substantially circular in cross section except where noted otherwise herein.

3.3.1 Conductors.- Conductors shall be bare, soft drawn solid copper in accordance with ASTM B 3 except conductors No. 14 and larger shall be stranded in accordance with ASTM B 8, Class B.

3.3.5 Cable identification.- All cable shall be provided with a marker tape laid under the jacket, the shield or the core covering. It shall be a non-hygroscopic material not less than 1/8 inch wide and contain on one side the following printed information at intervals of one foot.

Name of manufacturer and year of manufacture

FAA Contract No.

Consecutive numbered footage markings at one foot intervals. This marker tape will be used to check footage of cable as desired but will not be used for test or payment purposes.

3.3.6 Jacket

3.3.6.1 General.- A jacket shall be applied over the cable core. For Type 1A, 2A, and 3A cables and for the outer jacket in Type 1B, 2B, and 3B cables, the jacket material shall be black high molecular weight polyethylene conforming, before application, to requirements of ASTM D 1248, for Type 1, Class C, Grade 5. Melt index shall be between 0.2 and 0.4.

3.3.6.1.1 Inner jackets for armored cables, Type 1B, 2B, and 3B, shall conform to the above requirements except that the material may be natural polyethylene without the addition of carbon black.

3.3.6.1.2 Opening of cable jacket for repair or for any other purpose will not be permitted. Minor jacket defects not in excess of 0.25 inch in size in any direction may be repaired by using heat fusing and jacket grade compound.

3.3.6.2 Jacket thickness.- Jacket thickness shall be as indicated below:

Diameter Under Jacket	Nominal Thickness of Jacket
0.5 inch and under	0.065 inch
0.51 inch to 0.75 inch	0.075 inch
0.75 inch to 1.00 inch	0.090 inch
1.01 inch and larger	0.100 inch

The minimum thickness at any point shall not be less than 75 per cent of the nominal thickness specified. Where flat oval construction is employed (paragraph 3.3.4.3) the average of the major and minor core diameters shall be used to determine diameter under jacket and jacket thickness.

3.3.7 Armor

3.3.7.1 Steel tape.- Unless otherwise specified, where armor is required, it shall consist of two overlaid spiral metal tapes of galvanized steel. The application and galvanizing of the tape shall comply with IPCEA S-61-402 except no jute bedding or flooding compound is required. Dimensions of armor shall be as follows:

4.1.3 Shield continuity.- Discontinuity of the shield will be cause for rejection of the length of cable involved. This test shall be performed on all shields.

4.1.4 Conductor resistance.- Measurement of conductor resistance shall be made on ten per cent, but not less than three pair (or three unpaired conductors) in each cable. The method used and direct current resistance shall comply with the requirements of IPCEA Standard S-61-402.

4.1.5 Insulation resistance.- Sampling tests of insulation resistance shall be performed on one length of cable from each 10,000 feet of cable being inspected. A minimum of three pair or three unpaired conductors shall be tested. They shall be measured with all other conductors and shield grounded. Test procedures and resistance values shall comply with IPCEA S-61-402.

4.1.6 High potential.- One conductor in each pair in all lengths of cable shall be tested against the other conductor of the pair grounded to the shield with 4,500 volts dc applied for a minimum of three seconds. The equivalent test shall be applied to unpaired conductors. Group testing of all pairs or all conductors at one time is permitted.

4.1.7 Jacket integrity.- Cable without armor shall be tested for defects in jacket with a test of 10,000 volts ac or 30,000 volts dc. Testing by means of a water trough or immersion in a water tank is required.

Sections of cable with repairable faults (paragraph 3.3.6.1.2) in excess of five per 2,000 feet will not be acceptable. All cable with repaired faults shall be retested for jacket integrity and for compliance with high potential test.

4.1.8 Jacket and insulation thickness.- Samples of jacket and insulation shall be measured for specified thickness.

4.1.9 Tensile test.- The tensile and elongation tests shall be performed in accordance with ASTM D 1248.

4.1.10 Shield test.- A suitable length of finished cable (before armoring) shall be bent, at room temperature, in a 180° arc around a cylinder of a diameter twenty times the outside diameter of the cable, then bent 180° in the reverse direction, completing one cycle. The speciman shall then be straightened and rotated 90° and a second cycle of bending performed. For cables having an outside diameter of one and one half inches or less, the shield shall not have fractures visible to the unaided eye. For cables having an outside diameter greater than one and one half inches, the shield shall show no individual fractures greater than one third the width of the shielding tape.

4.1.11 Armor galvanizing test.- The armor zinc coating shall comply with ASTM A 90 in accordance with requirements for Class C galvanizing.

4.2 Materials certification.- Certification covering the following requirements will be accepted in lieu of tests unless directed otherwise

5.2 Marking.- The contractor's name, contract number under which the cable was purchased, and the reel serial number shall be embossed, engraved, or indented, on non-ferrous plates securely attached to both reel flanges. The quantity, size, and type of cable on the reel, and the name and address of the consignee shall be applied plainly on both reel flanges with permanent type ink or paint.

6. NOTES

6.1 Notes to Government Contracting Officer

6.1.1 Cable lengths.- Suitable tolerances in the specified cable length per reel are allowable at the discretion of the Contracting Officer. An acceptable tolerance is plus or minus 5 per cent per reel with a total contract variation not to exceed plus or minus 1 per cent.

6.1.2 Materials certification.- Contract provisions should include a requirement for total cost of tests listed in paragraph 4.2 to be shown separately in invitation for bids.

* * * * *

Page 7, paragraph 4.1.10: Delete first paragraph and substitute: "A suitable length of cable shall be bent 180°, at room temperature, around a cylinder, then bent around the same cylinder 180° in the reverse direction, completing one cycle. The specimen shall then be straightened and rotated 90° and a second cycle of bending performed.

Type I cable shall be bent around a cylinder having a diameter 20 times that of the overall diameter of the cable. Type II cable shall be bent around a cylinder having a diameter 30 times that of the overall diameter of the cable."

Page 8, paragraph 5.1.1: Delete paragraph and substitute:

"5.1.1 Cable length per reel.- Each reel shall contain one continuous cable, the length as specified in the invitation for bid or contract."

* * * * *

2.3 Insulated Power Cable Engineers Association.- The following IPCEA standards form a part of this specification:

S-56-434 Polyethylene-Insulated, Thermoplastic-Jacketed, Communication Cables

S-61-402 Thermoplastic Insulated Wire and Cable

(Copies of this specification may be obtained from Federal Aviation Agency, Washington, D. C. 20553, ATTN: Contracting Officer. Requests should fully identify material desired; i.e., specification numbers, dates, amendment numbers, complete drawing numbers; also requests should state the contract involved or other use to be made of the requested material.)

2.4 In the event of a conflict between the above-mentioned standards and this specification, this specification shall govern. Specifications are referred to by basic number and title; the issue in effect on the date of invitation for bids shall apply.

3. REQUIREMENTS

3.1 Materials.- Materials shall be as specified herein. When materials are used for which no material is specified herein, they shall be entirely suitable for the purpose.

3.2 Cable shall be manufactured and processed in accordance with good design and high grade manufacturing practices. The cable shall be free of any imperfections which may affect its serviceability.

3.3 Design and construction.- The finished cable shall be substantially circular in cross section.

3.3.1 Conductors

3.3.1.1 Size.- Each conductor in the cable shall consist of a solid round copper wire, No. 19 AWG.

3.3.1.2 Materials.- The conductors shall be soft or annealed copper and meet the requirements of ASTM B 3.

3.3.1.3 Conductor joints.- Joints made in conductors during the manufacturing process may be brazed, using a silver alloy and a non-acid flux; or they may be welded. Conductor joints shall be free from lumps and sharp projections. The tensile strength of any section of a conductor, including a factory joint, shall be not less than 85 per cent of the tensile strength of an adjacent section of the solid conductor without a joint.

3.3.2 Insulation.- Each conductor shall be insulated throughout its length with a high molecular weight polyethylene compound, meeting the requirements of ASTM D 1248. Uncolored polyethylene for use with color concentrates shall

3.3.3.3 Forming of cable.- In cables having 25 pairs or less, the twisted pairs shall be assembled to form a snug, well-rounded core. Fillers, if used, shall be polyethylene.

In cable having more than 25 pairs, the twisted pairs shall be grouped, each group being bound by moisture resistant threads or tape. Groups shall not contain more than 25 pairs. When desired for manufacturing reasons, the basic 25 pair groups may be divided into two or more subgroups. Each subgroup shall have a binding of the colors or imprinting indicated for its particular 25 pair count; i.e., binder colors of the subgroups of the first 25 pairs shall be white-blue, of the second 25 pair, white-orange, etc.

Colored binders made of threads shall not have less than three ends of each color arranged as color bands. When tapes are used, they may be colored or they may be imprinted with the unit number and the names of the colors. Binders shall be applied with a lay of not more than four inches.

3.3.4 Core covering.- The stranded core shall be covered with one or more layers of non-hygroscopic dielectric material of thickness necessary to assure compliance with paragraph 4.1.1. All parts of the core shall be completely covered.

3.3.5 Shield

3.3.5.1 Type I cable.- An aluminum shield shall be applied over the core of Type I cable in such a manner that the core will be completely covered. The shield may be applied either helically or longitudinally provided it meets the bending test specified in paragraph 4.1.10.

Aluminum used for the shield shall conform to ASTM B 209, Alloy No. 990A and shall be 0.005 ± 0.001 inch in thickness.

Copper or bronze may be substituted for the aluminum shield provided the thickness is no less than 0.003 ± 0.0005 inch.

3.3.5.2 Type II cable.- Shield and armor shall be integral on Type II cable and shall comply with paragraph 3.3.8.

3.3.6 Cable identification.- All cables shall be provided with a marker tape laid under the jacket, under the shield or under the core covering. The tape shall be of a non-hygroscopic, non-wicking material, not less than 1/8 inch wide and containing on one side the following printed information at intervals of one foot:

Name of manufacturer and year of manufacture.
FAA Contract No.
Consecutive numbered footage markings at one foot intervals.

This marker tape will be used to check footage of cable as desired, but it will not be used for test or payment purposes.

The minimum average jacket thickness shall not be less than 90 per cent, and the minimum spot thickness not less than 70 per cent of the specified thickness.

3.3.8 Armor.- On Type II cable, an armor shall be applied over the inner jacket and it shall also serve as the shield. Armor material shall be copper or bronze with a nominal thickness of 10 mils. It may be applied either helically or longitudinally with an overlap. If applied longitudinally, the armor shall be corrugated.

4. SAMPLING, INSPECTION AND TEST PROCEDURES

4.1 General.- Unless otherwise specified, all tests shall be made by the contractor and shall be witnessed by an FAA inspector; however, the Government reserves the right to waive Government inspection. If Government inspection is waived, the contractor shall furnish two copies of certified test data showing completion of all required tests. The cable will not be accepted by the Government until the test data, certified to be true and correct by a properly authorized official of the contractor's company, and notarized, has been submitted to and approved by the Government. Only one inspection will be required and will be performed after the cable is completely manufactured and will consist of the following:

Electrical Tests	Paragraph
High potential	4.1.1
Insulation resistance	4.1.2
Shield continuity	4.1.3
Conductor faults	4.1.4
Conductor resistance	4.1.5
Capacitance	4.1.6

Physical Tests	Paragraph
Tensile test	4.1.7
Jacket thickness	4.1.8
Jacket integrity	4.1.9
Cable bend test	4.1.10

4.1.1 High potential test.- In each length of cable, the insulation between conductors shall withstand for a minimum of two seconds, 4,500 volts dc or 3,000 volts ac. Also, in each length of cable the insulation between conductors and shield shall withstand for a minimum of two seconds, 10,000 volts dc or 7,000 volts ac. Group testing of conductor insulation is permitted.

4.2 Certification of compliance of the following with ASTM D 1248 will be accepted in lieu of factory inspection unless otherwise directed by the Contracting Officer.

Insulation	Jacket
Brittle temperature	Brittle temperature
Dissipation factor and dielectric constant	Environmental stress
Melt index	Melt index
Density	Density
	Light absorptivity (outer jacket only)

4.3 Sampling

4.3.1 Inspector's samples.- Samples of cable shall be selected by the inspector in such lengths and quantities as he deems necessary for testing at the contractor's testing laboratory. The number of samples shall, in no case, be less than specified in ASTM D 470.

4.3.2 Referee samples.- When so stated in the invitation for bids or when later requested by the Contracting Officer, samples of the completed cable shall be supplied to a testing laboratory selected by the Contracting Officer. Such samples shall be not less than 10 feet long and shall be selected on the basis of one sample for the first 25,000 feet or fraction thereof of completed cable, one for the next 25,000 feet or fraction thereof, and one for each additional 50,000 feet or fraction thereof.

4.3.3 Shipment of samples.- Where the shipment of samples for inspection or referee tests is required, such shipment will be at Government expense on a Government bill of lading. Packing of samples and delivery to common carrier will be at the expense of the contractor.

5. PREPARATION FOR DELIVERY

5.1 General.- Cable shall be delivered, wound on reels conforming with paragraph 5.1.2.

5.1.1 Cable length per reel.- Each reel shall contain one continuous 2,000 foot length of cable. (See paragraph 6.1.2.)

5.1.2 Reel construction.- Reels shall be new and comply with NEMA WC-21, Wood Reels. Plywood reels are not acceptable. Capacity of reels shall be sufficient to allow a spacing of a minimum of two cable diameters between