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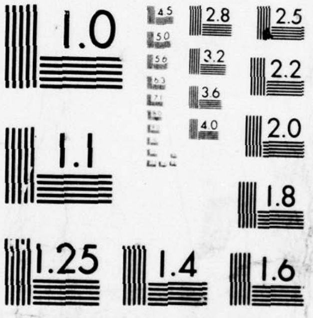

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LOW INDUCTANCE METHODS FOR GROUNDING CABLE SHIELDS TO SHIP STRUCTURES FOR EMP PROTECTION

BY B. ZENDLE and M. PETREE

ELECTRONICS SYSTEMS DEPARTMENT

2 APRIL 1979

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EMP coupling measurements at EMPRESS on DD and DLG classes of ships have shown that an efficient low-inductance method of grounding cable shields is needed. High frequency currents up to 150 amperes can be expected on cable shields in interior ship compartments where sensitive and sophisticated electronic systems are located.

A testing program encouraged by NAVSEC has demonstrated that attenuation of cable shield currents by 60 dB and better over a frequency range from

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0.5 MHz to 100 MHz can be achieved by grounding cable shields to stuffing tubes through 360° low-inductance grounding devices. Grounding collars external to the stuffing tubes were as efficient as RF gaskets located internally; were easier to install and inspect; and are less exposed to the sea environment.

SUMMARY

EMP coupling measurements at EMPRESS on DD and DLG classes of ships have shown that an efficient low inductance method of grounding cable shields is needed. High frequency currents up to 150 amperes can be expected on cable shields in interior ship compartments where sensitive and sophisticated electronic systems are located. Accordingly, NAVSEC 6174E has encouraged an effort to establish a method for attenuating EMP induced cable shield currents by at least 60 dB at points of entry of exterior cables into the interior of ships. MIL-STD-1310D (proposed) contains a requirement that metallic hull surface ships, which have EMP protection specified, shall have each exterior cable shield grounded 360 degrees to the hull.

The work carried out demonstrated that EMP induced cable shield currents can be attenuated by 60 dB to >73 dB (instrumentation noise level) over a frequency range from 0.5 MHz to 100 MHz. Effectiveness of various grounding methods was determined by measuring the current transfer function of candidate grounding devices in a specialized coaxial test fixture. Two current probes were used to detect the incident current and the current transmitted by the device under test. A network analyzer and a swept frequency generator were used to measure the transfer function (ratio of transmitted to incident current versus frequency). Figure 4a is a simplified diagram of the measurement scheme and Figure 4b shows a cross section of the coaxial test fixture and block diagram of the test instruments. This work was performed in two parts. Part I involved tests on grounding devices located inside stuffing tubes through which the cables pass from the ship's exterior to the interior. Part II dealt with grounding techniques located outside stuffing tubes and connected to them and the ship's hull on the interior non-weather side of the deck or bulkhead.

In Part I testing and evaluation were performed on low inductance grounding rings (RF gaskets) located inside the stuffing tube and making 360 degree circumferential ground contact between the cable shield and the interior wall of a metal stuffing tube that is welded to a ship's hull. Three types of gasket materials were investigated in a test program consisting of:

grounding effectiveness measurements in the frequency domain from 0.5 MHz to 100 MHz (transfer functions)

high amplitude pulsed current tests

saltwater environment tests

A machined aluminum split ring gasket gave best electrical (grounding effectiveness) performance but posed a potential corrosion problem. A conductive elastomer gave acceptable electrical performance but posed potential chemical and mechanical setting problems. A metal fiber RF gasket did not give acceptable electrical performance. Figure 11(a) summarizes the electrical performance of the Part I techniques at 1 MHz and 30 MHz. Figure 11(b) does the same for grounding techniques of Part II. Table 1 summarizes the data in Figures 11(a) and 11(b).

In Part II testing and evaluation were performed on devices providing 360 degree circumferential grounding at the ends and outside of the stuffing tubes on the interior non-weather side of the deck or bulkhead. For retrofit on ships in which the stuffing tube is flush-welded to the deck or bulkhead with no extension into the interior compartment, a self-clamping, flush-mounted device was designed by NSWC. Grounding effectiveness tests were performed on this device and three other devices, the latter being suitable for grounding cable shields to stuffing tube kick pipes protruding into the interior compartment. The devices tested in Part II can be installed more readily than the gaskets inside the stuffing tubes; they can be inspected and maintained more easily and they would have better protection from the sea environment. The best electrical grounding performance was found in the NSWC flush-mounted self-clamping device. With this device the cable shield current attenuation was greater than 73 dB (instrumentation noise level) from 0.5 MHz to 100 MHz. Of the devices intended for grounding to kick pipes, the most effective was a short section of tubular braid, slit and clamped around the kick pipe and bared cable shield. Attenuation was better than 73 dB from 1.0 MHz to 100 MHz. Next best was a sheet copper (truncated) cone, wrapped around the kick pipe and cable shield, and clamped to both with small hose-clamps. Attenuation was 49 dB at 0.1 MHz, 60 dB at 0.5 MHz, and greater than 70 dB from 5 MHz to 100 MHz. The poorest electrical performance was found in the Kern connectors, which makes electrical contact between cable shield and kick pipe by means of a toroidal stainless steel spring "iris" - an inherently higher inductance geometrical configuration than in the other devices measured. The attenuation provided by the Kern connector was 30 to 35 dB at 0.1 MHz, 15 to 50 dB at 1.0 MHz, and 58 to 64 dB at 30 MHz to 100 MHz. The spread in values of attenuation was due to variation of tightness in screwing the back shell onto the connector, resulting in differing compressions of the iris spring inside the connector. Observation of this effect resulted in a suggested modification by NSWC for imprcving the Kern connector.

Recommendations

The external methods of grounding (Part II) have practical advantages over the grounding methods of Part I in that:

1. Installation, inspection, and maintenance are more easily accomplished.

2. Grounding effectiveness is as good or generally better.

3. Corrosion due to sea environment is inherently less for Part II devices due to their locations in interior non-weather compartments.

Kurt R. Enkenhus

KURT R. ENKENHUS
By direction

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ILLUSTRATIONS (Cont'd.)

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Part I

METHODS FOR CABLE SHIELD GROUNDING INSIDE STUFFING TUBE

INTRODUCTION

The main objectives of this report are:

a. To provide test data and recommendations on a new method for grounding cable shields at entry ports into ships' structures. The new method is to be included in MIL-STD-1310D (proposed)[1] and complies with the requirement in Section 5.2.2.2.7.2, Figure 7, of that document that each cable shield shall be grounded 360°. Section 5.2.2.7 states that the 360° grounding requirement applies only to metallic hull surface ships which have EMP protection specified.

b. To describe the test plan, experimental procedure, and test apparatus.

c. To compare the grounding efficiency of the new method (grounding ring internal to stuffing tube) with the efficiency of previous grounding methods (ground straps external to stuffing tube) specified in MIL-STD-1310C.[2]

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[1] MIL-STD-1310D (Proposed), "Shipboard Bonding, Grounding, and Other Techniques for Electromagnetic Compatibility and Safety"

[2] MIL-STD-1310C (Navy), 30 November 1973, "Shipboard Bonding, Grounding, and Other Techniques for Electromagnetic Compatibility and Safety"

d. To observe the effect of simulated sea environment on the grounding efficiency of the particular configurations of materials investigated in this report.

e. To discuss further tests that may be necessary to evaluate grounding efficiency under sea-going conditions.

Preliminary feasibility tests[3] showed that 360° grounding can be more effective than the bonding strap technique presently used by the US Navy. This report describes more accurate laboratory tests to measure grounding efficiencies of several techniques with an eye toward facilitating actual implementation during shipyard installation of cables.

The new method of grounding cable shields by means of low-inductance RF gaskets is of interest, since recent EMP coupling measurements performed at the NSWC EMPRESS Facility (Electromagnetic Pulse Radiation Environment Simulator for Ships) have shown that high frequency currents, up to 100 amperes or more in amplitude, can be expected to appear on cable shields in the interior compartments of ships where sensitive electronic systems are located. In addition, high frequency bulk cable currents up to 600 amperes in amplitude can be expected on exterior cables. NAVSEC, during its development of MIL-STD-1310D, has supported the work herein reported as a part of its effort to establish a method for attenuating EMP-induced cable shield currents by 60 dB at ports of entry into the interior of a ship.

GROUNDING TECHNIQUES INVESTIGATED

Figure 1 shows a specimen of stuffing tube welded into a circular plate in the same manner that stuffing tubes are welded

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[3] Notebook data of D. D. Tomayko on shipboard tests of cable grounding devices irradiated by NSWC/EMPRESS.

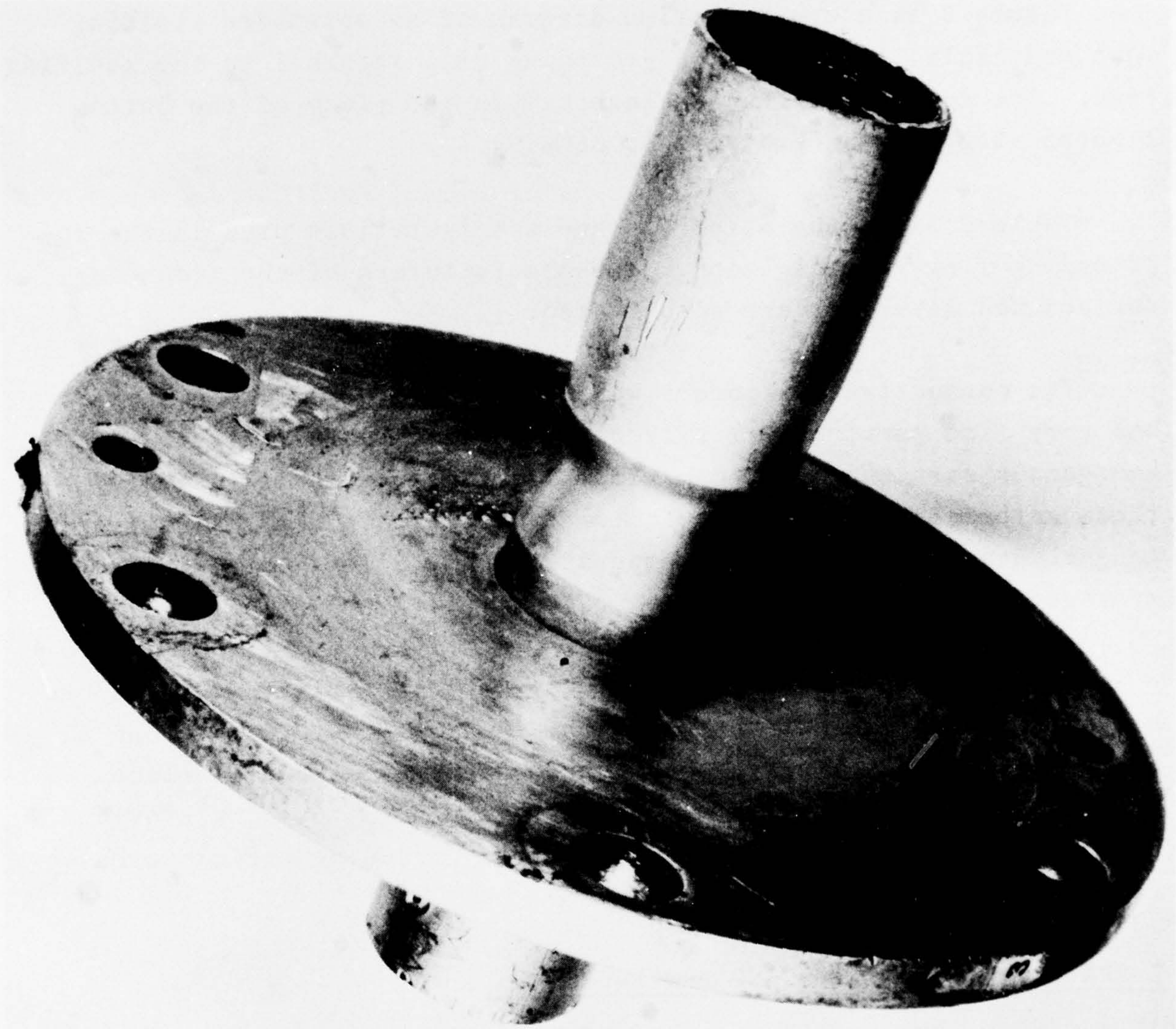

FIGURE 1 STUFFING TUBE WELDED INTO CIRCULAR PLATE FOR USE IN COAXIAL TEST FIXTURE USED IN THIS INVESTIGATION

into bulkheads, decks, or riser boxes on ships' decks. The plate represents a ship's bulkhead and forms part of the ground return path for current in laboratory test apparatus.

Figure 2 is a cross-section diagram of an assembled stuffing tube and cable, fitted with a grounding ring internal to the stuffing tube. The conductive ring is inserted in the place of the bottom tapered ring of standard weather packing.

Table 2 lists the materials and configurations used in the grounding ring investigation. The manufacturers of the grounding devices and materials are also listed.

The conductive elastomers were composites of silicone rubber and very fine particles of silver plated copper, formed into homogenous structures. The maximum use temperature is 125°C for these materials, and the manufacturer states that the shelf life is longer than 10 years if the temperature of 125°C is not exceeded in storage.

Copper grounding cages (Figure 3) were investigated, which can be installed to connect the cable sheath to the non-weather end of the stuffing tube after the cable and weather seal are in place. The cages were designed to be the best ground that can be provided by the method of ground straps, and their grounding efficiencies were measured for comparison purposes.

EXPERIMENTAL APPARATUS AND PROCEDURE

A coaxial fixture was constructed in which could be placed an assembly consisting of the cable, grounding ring (RF gasket), and stuffing tube. The cable was threaded through two current probes, one on either side of the grounding device. Current driven along the cable sheath in simulation of EMP pick-up current was largely diverted to the shell of the coaxial test chamber by the grounding device.

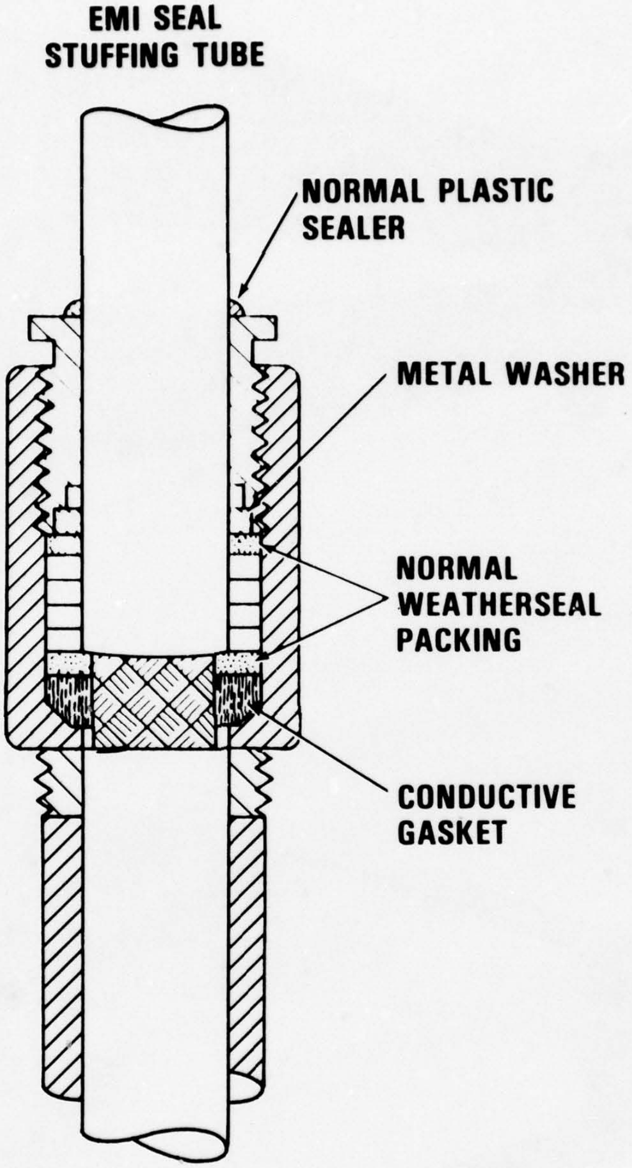

FIGURE 2 CROSS SECTION OF A STUFFING TUBE FITTED WITH A CONDUCTIVE GASKET, WHICH PROVIDES 360° GROUNDING FOR A COAXIAL CABLE SHIELD

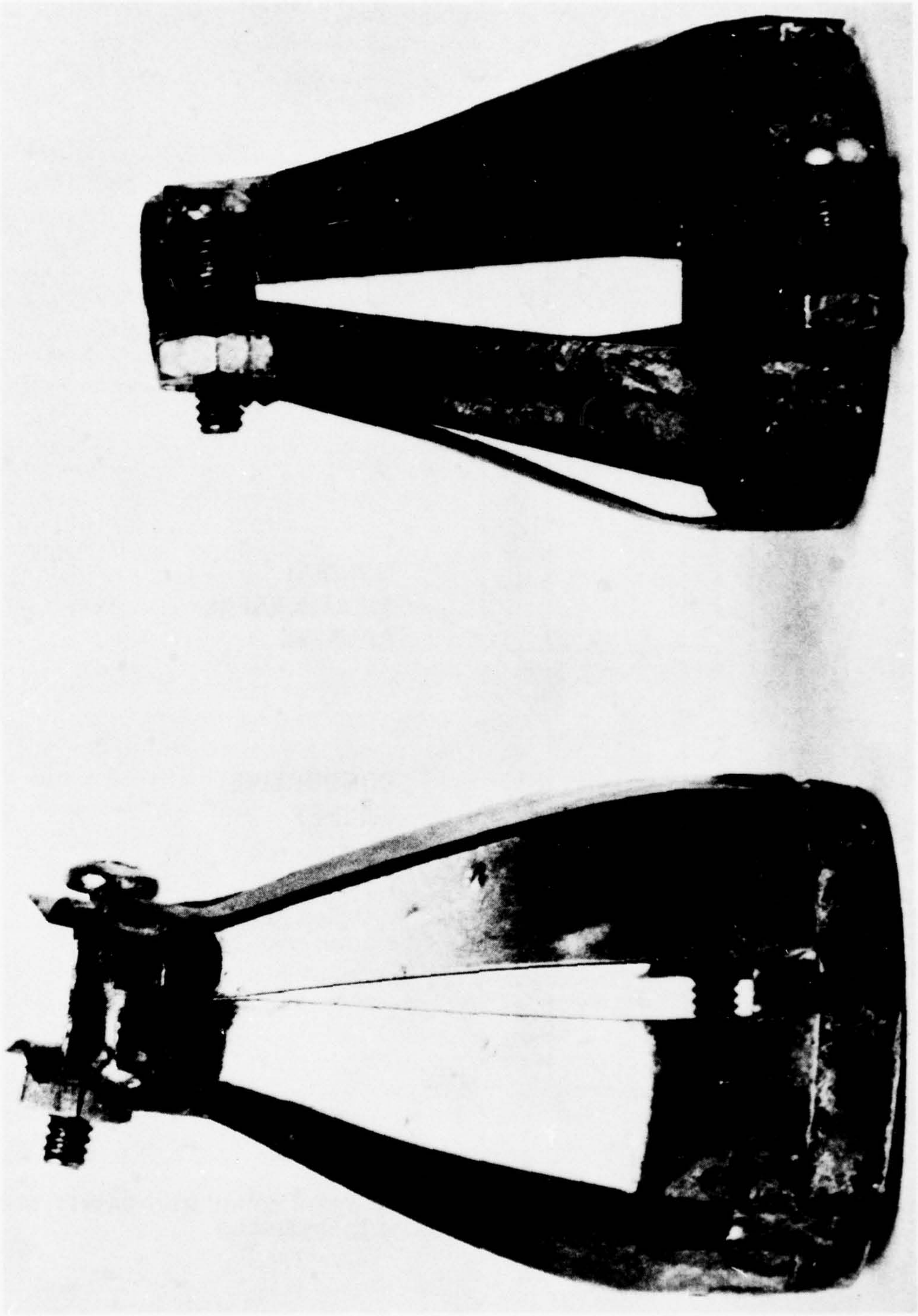

FIGURE 3 COPPER GROUNDING CAGES FOR GROUNDING CABLE SHIELDS TO STUFFING TUBES AFTER INSTALLATION OF CABLES

(HEIGHT ABOUT ONE INCH)

Table 1. Current Amplitude Transfer Functions, 20 log I/I_o, of Devices for Grounding Cable Shields to Ship Structures for EMP Protection

Part I Grounding Rings Located Inside Stuffing Tubes

Device	Transfer Function in dB at 1 MHz	Transfer Function in dB at 30 MHz
Copper Cage	-61	-56
Metex Steel Fiber Mesh	-57	-63
Chomerics Cho-Seal 1250	-66	-74
Aluminum Split Ring	-71	-72
Noise Level	-72	-74

Part II Grounding Collars Outside of Stuffing Tubes on the Non-Weather Side of Deck or Bulkhead

Device	Transfer Function in dB at 1 MHz	Transfer Function in dB at 30 MHz
Flush Mounted Phosphor Bronze Split Cone, Clamped	-72	-77
Slit Tubular Braid, 30 Gauge 9/16" ID, Wrapped and Clamped	-72	-76
Slit Tubular Brain, 36 Gauge 1/2" I.D., Wrapped and Clamped	-70	-70
Kern Connector, Iris Tightly Compressed	-50	-64
Noise Level	-72	-77

Table 2. Grounding Rings Tested

Material	Configuration	Manufacturer
Conductive Elastomer		
Cho-Seal 1215	Die cut washers 1/16" and 1/4" thick	Chomerics Woburn, Massachusetts
Cho-Seal 1250	Extruded rope 1/4" in diameter ("O" strip)	
Metal		
Aluminum	Machined split ring tapered to fit stuffing tube	Litton Ingalls Shipbuilding, Pascagoula, Mississippi
Steel Fibers	Compressible split ring	Metex Corporation, Edison, New Jersey

The current probes were used to measure the ratio of transmitted to incident current. The apparatus was used to measure the effectiveness of grounding rings as a function of frequency and in applying high current pulses to candidate RF gaskets.

Baseline electrical tests of grounding efficiency were made on conductive elastomer and Metex RF gaskets in steel and aluminum stuffing tubes; machined aluminum split rings in aluminum stuffing tubes; and copper grounding cages clamped onto aluminum stuffing tubes. RG/U 214 cable was used for all tests.

The baseline tests were CW diagnostic measurements, employing a network analyzer and swept-frequency signal generator to measure the current transfer functions over a frequency range of 0.1 to 100 MHz.*

Following the baseline tests and a rather extensive series of tests to validate proposed measurement methods, specimen stuffing tube assemblies were put through a test sequence consisting of simulated EMP-induced current pulses and an environmental test designed to accelerate saltwater corrosion. The stuffing tube assemblies were made up of RG/U 214 cable grounded to an aluminum stuffing tube by a conductive elastomer gasket (Chomerics Cho-Seal 1250 "O" strip, which is extruded elastomer rope 1/4" in diameter) and RG/U 214 cable grounded to an aluminum stuffing tube by a machined aluminum split ring (Litton-Ingalls design). Additional pulsed-current tests were made on assemblies consisting of RG/U 214 cable, conductive elastomer grounding ring, and steel stuffing tube.

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*The current transfer function as used in this report is the ratio versus frequency of transmitted current, I, to applied current I_o. The network analyzer displays this ratio in units of decibels, i.e., 20 log I/I_o, versus frequency.

In the pulsed current tests, the output pulses from a Pulsar Delta pulser system were applied to the cable and grounding device. Two pulse shapes were used, one having a decay time constant of 5 microseconds and a peak current of 560 amperes, the other having a decay time constant of 2.5 microseconds and a peak current of 1080 amperes. The current pulses used for simulating EMP were judged to be an adequate overtest, since the range of EMP-induced peak currents is within 600 amperes. This value was extrapolated to threat level from EMPRESS tests on ships of the DD and DLG classes. The pulse sequence was arranged to test for single-shot deterioration and cumulative deterioration. CW diagnostic measurements were made during the sequence of current pulses as a means of detecting any deterioration in grounding efficiency. (Low-level current pulses of 80 amperes from the Delta pulser were also used to monitor the effects of the high current pulses during a time interval when the network analyzer was in use for high priority field tests at Patuxent NATC). The distribution in amplitude of the pulses was as follows:

Simulated EMP Amplitude Distribution

Number of Pulses	Peak Current (Amperes)
24	75 to 80
4	640
3	750 to 800
31	1000 to 1080

The saltwater environmental test consisted of a daily 16-hour soak in hot water at 150°F (simulated seawater using Sea-Rite Salt) followed by eight hours of air drying. The formulation of simulated sea salt is given in Table 3. The purpose of cycling from hot seawater to air and back was to simulate more closely the real shipboard environment, which alternates between wet and dry. This can induce more corrosion than would occur in the saltwater alone over the same time span. The soak-and-air dry cycle continued for two weeks, except that the soak continued 24 hours per day over weekends. Two such two-week tests were run on each specimen, one with and one without the conductive anti-seize compound of Military Specification

Table 3. Formulation of Sea-Rite Salt*

Salt	Percent
NaCl	58.490
$MgCl_2$-$6H_2O$	26.460
Na_2SO_4	9.750
$CaCl_2$	2.765
Kcl	1.645
$NaHCO_3$	0.477
KBr	0.238
$HzBO_3$	0.071
$SrCl_2$-$6H_2O$	0.095
NaF	0.007

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*Sea-Rite Salt is a formulation of a simulated sea salt in qualities greater than 0.004% as found in natural seawater, it is formulated according to ASTM-D1141-52 method Formula A.

MIL-A-907D. This compound is a petroleum-based grease, filled with copper powder. It retards corrosion by minimizing galvanic effects, and its use in these tests was recommended by NAVSEC's RCA consultant. Measurements of grounding effectiveness were made periodically throughout the environmental tests, using network analyzers to measure current amplitude transfer functions, 20 log (I/I_0), in the frequency range of 0.1 to 500 MHz. While in the hot saltwater bath, each stuffing tube assembly (which included standard BACO weather-seal packing) was sealed into the lid of a water-tight aluminum chamber. The chamber simulated a shipboard riser box, in that it protected the nonweather side of the cable and stuffing tube from contact with the saltwater bath. The weather side of the stuffing tube was immersed in hot saltwater, as was most of the cable on the weather side, but the electrical connector on that end of the cable was not in contact with the saltwater bath. Aluminum stuffing tubes were used in the saltwater environment test.

TEST ARRANGEMENT FOR FREQUENCY DOMAIN RESPONSE. Figures 4a and 4b show the test arrangement for measuring the effectiveness of grounding methods as a function of frequency.

The coaxial test fixture, shown in cross section in Figure 4b, was constructed to accept an assembly consisting of cable, grounding ring (RF gasket), and stuffing tube with the cable being threaded through two current probes, one on either side of the grounding device. Current driven along the cable shield in simulation of EMP pick-up current is diverted to the shell of the coaxial test chamber by the grounding device, and the current probes are used to measure the ratio of transmitted to incident current. The shell of the coaxial test fixture provided shielding and simulated the metallic hull of a ship in providing a grounded return path for current.

The apparatus of Figure 4b was used for baseline measurements of candidate grounding devices and for diagnostic tests to detect

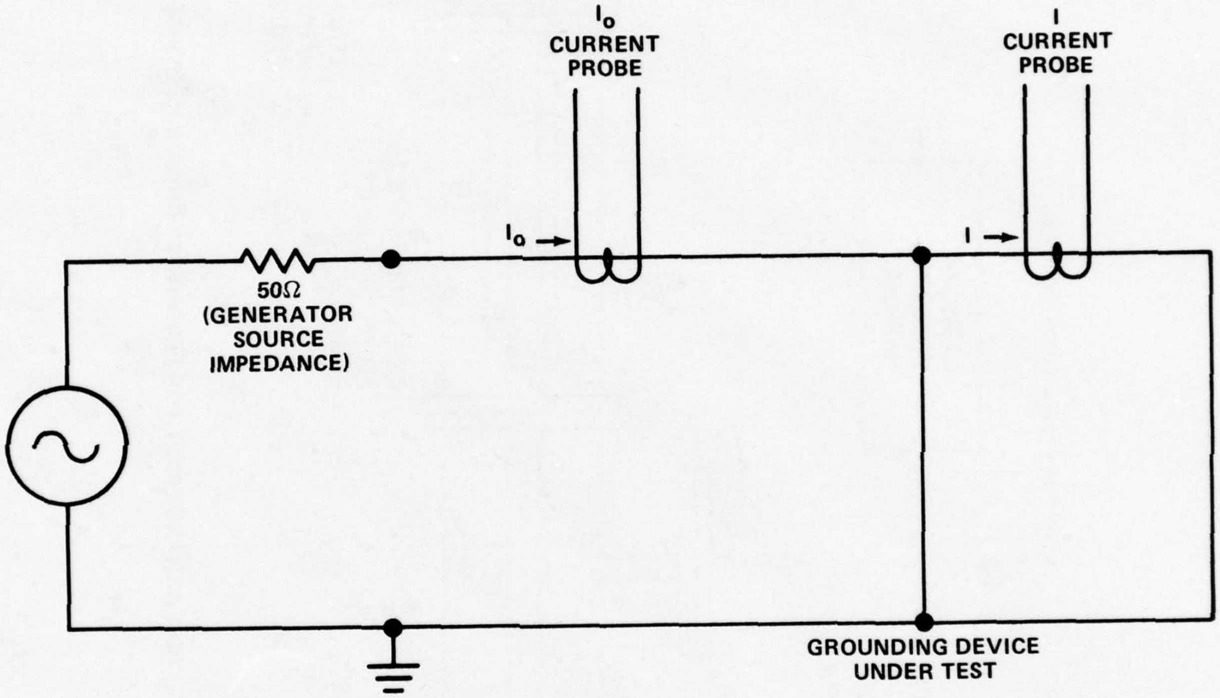
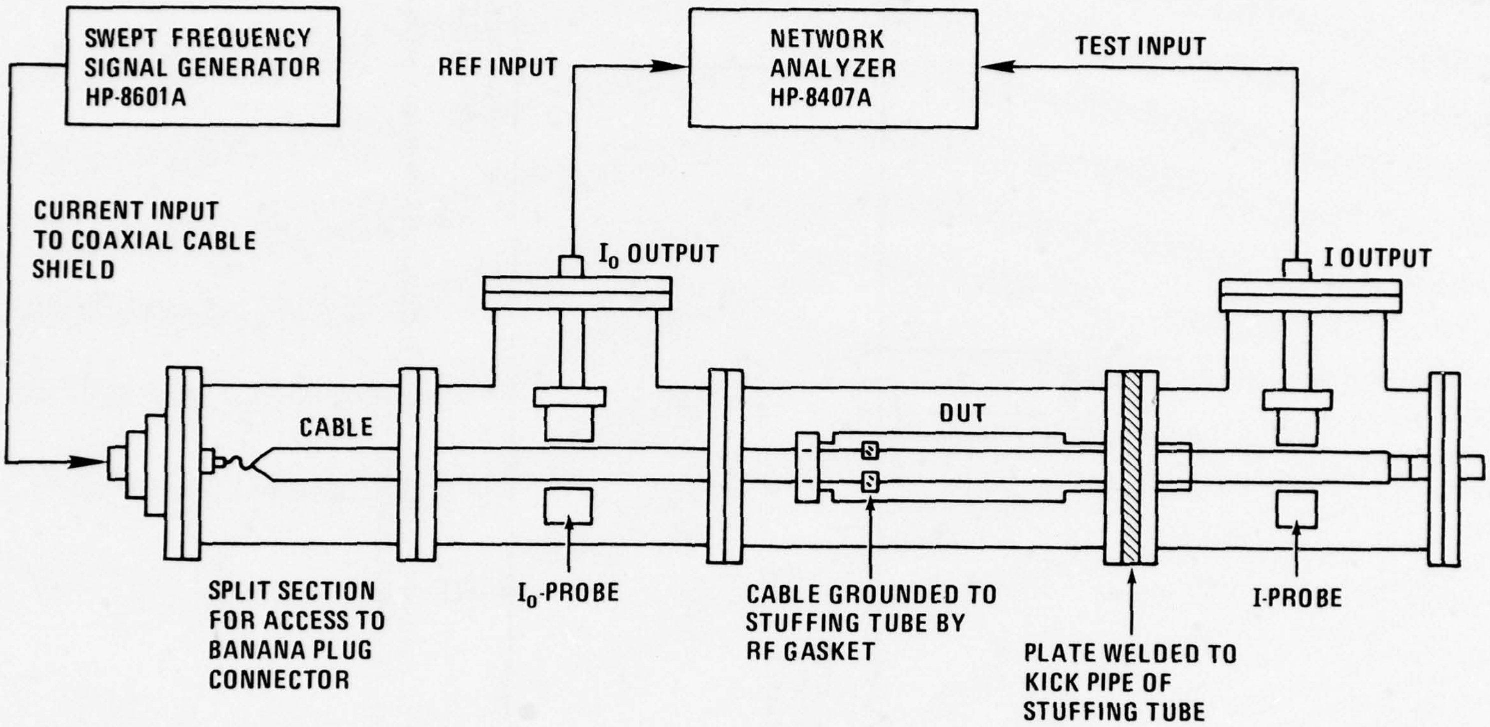


FIGURE 4a SIMPLIFIED DIAGRAM OF METHOD FOR MEASURING GROUNDING EFFECTIVENESS, 20 log I/I_o



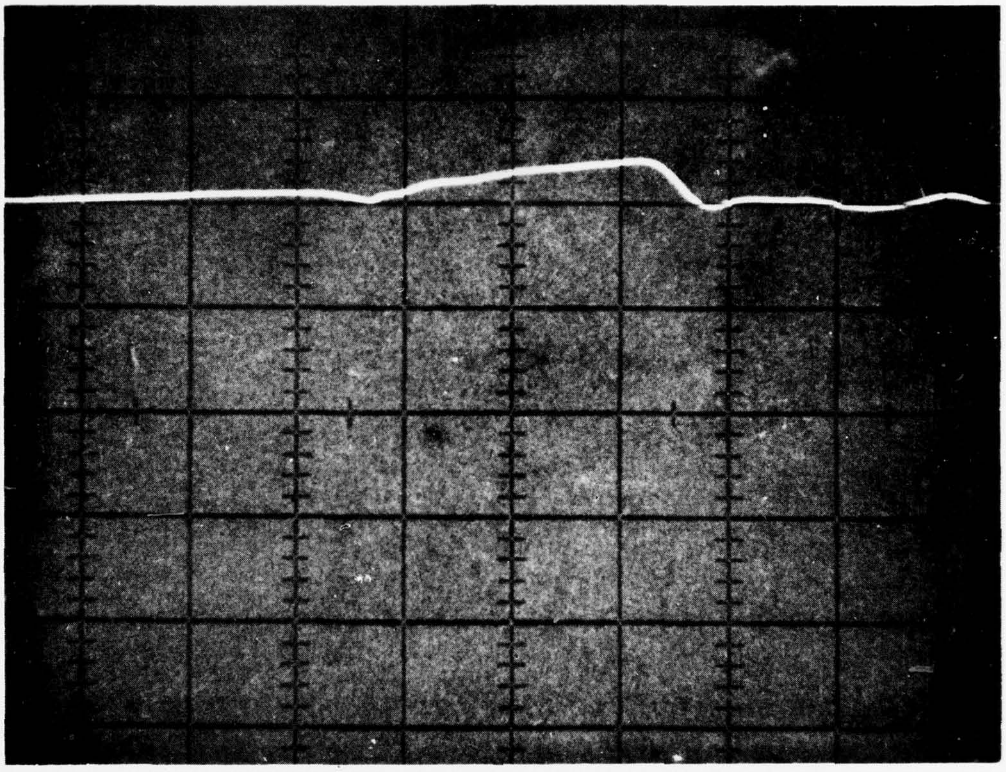
STUFFING TUBE TEST FIXTURE

FIGURE 4b TEST ARRANGEMENT FOR FREQUENCY DOMAIN RESPONSE deterioration caused by high-current pulses simulating EMP and to detect deterioration due to salt water environment.

When a measurement of current transmission ratio is being made, the HP-8601A Signal Generator applies a sinusoidal voltage to the left-hand end of the coaxial test chamber and sweeps the frequency of the applied sine wave through the range 0.1 to 100 MHz. The test fixture acts like a section of coaxial transmission line, which is shorted at the right-hand end, and which uses the shield of the RG/U 214 cable as its center conductor. The I_o current probe senses the input current on the cable shield and sends a voltage output to the REF input of the HP8407A Network Analyzer. The current that flows along the cable shield is diverted to the shell of the coaxial test chamber through the current path presented by the RF gasket (grounding ring), stuffing tube, and a circular plate that is welded to the stuffing tube and clamped between circular flanges at a joint between sections of the test fixture. The current that leaks past the RF gasket (grounding ring) in the stuffing tube is sensed by the I-probe, which sends a voltage output to the TEST input of the network analyzer. The right-hand end of the cable shield is short circuited to the shell of the coaxial test chamber. The HP 8407A Network Analyzer forms the ratio (TEST input)/(REF input) = I/I_o and displays the ratio as a graph of current transmission in units of decibels versus frequency (20 log I/I_o versus frequency).

Pearson Type 410 current probes were used for sensing I_o and I. These probes have a flat frequency response up to 35 MHz when used singly but were satisfactory up to 100 MHz when used to form the ratio I/I_o. Figure 5 shows that the current probes maintained the ratio I/I_o flat to within ±4dB in the frequency range of interest.

The frequency range of measurements of current transfer function was extended to 700 MHz by using a higher frequency network analyzer, HP-8410A, and a higher frequency sweep oscillator, HP-8690A. It was necessary to add to the test chamber a pair of high frequency current



0-100 MHz ⟶

VERT: AMPLITUDE
10 dB/DIV

HORZ: FREQUENCY
10 MHz/DIV

FIGURE 5 FREQUENCY RESPONSE OF PEARSON 410 CURRENT PROBES WHEN USED TO FORM THE RATIO $I/I_0=1$

probes, Tektronix CT-1, which have a flat frequency response up to 1000 MHz. The higher frequency range was used in order to observe the grounding efficiency of the RF gaskets (grounding rings) at the frequency of a shipboard radar transmitter. At frequencies in the UHF band, however, reflections within the test chamber were troublesome, causing peaks in the noise level curves and interfering with interpretation of the current transmission curves at the higher frequencies.

Figure 6 is a photograph of the coaxial test fixture sitting in front of both network analyzers. The two sweep generators and a camera are on the shelf above.

APPARATUS FOR PULSED CURRENT TESTS. In the pulsed current tests, the output pulses from a Pulsar Delta pulser system were applied to the cable and grounding device using the test arrangement shown in Figure 12. The coaxial test fixture shown in cross section was connected to instrumentation for recording incident and transmitted high-current pulses, simulating EMP. The Pulsar Delta pulse generator is a custom made pulse generator capable of sending fast-rise 50 kV pulses from an output capacitor switched by a high-voltage, triggered spark gap. The pulse width is adjusted by selecting the capacitor and the load resistor. Two pulse shapes were used in these tests. One had a 5 microsecond decay time constant, the other had a 2.5 μsec decay time constant; and both had a 10 nanosecond risetime. A Tektronix 556 dual beam oscilloscope was used to record the incident and transmitted currents, which were sensed by Pearson 410 current probes. The maximum peak current reached in the pulse tests was 1080 amperes.

DATA AND INTERPRETATION

BASELINE TESTS. In Figure 7 is shown the current transfer function of a Metex steel fiber gasket in an aluminum stuffing tube. The displayed frequency range on the horizontal scale is 0.1 to 10

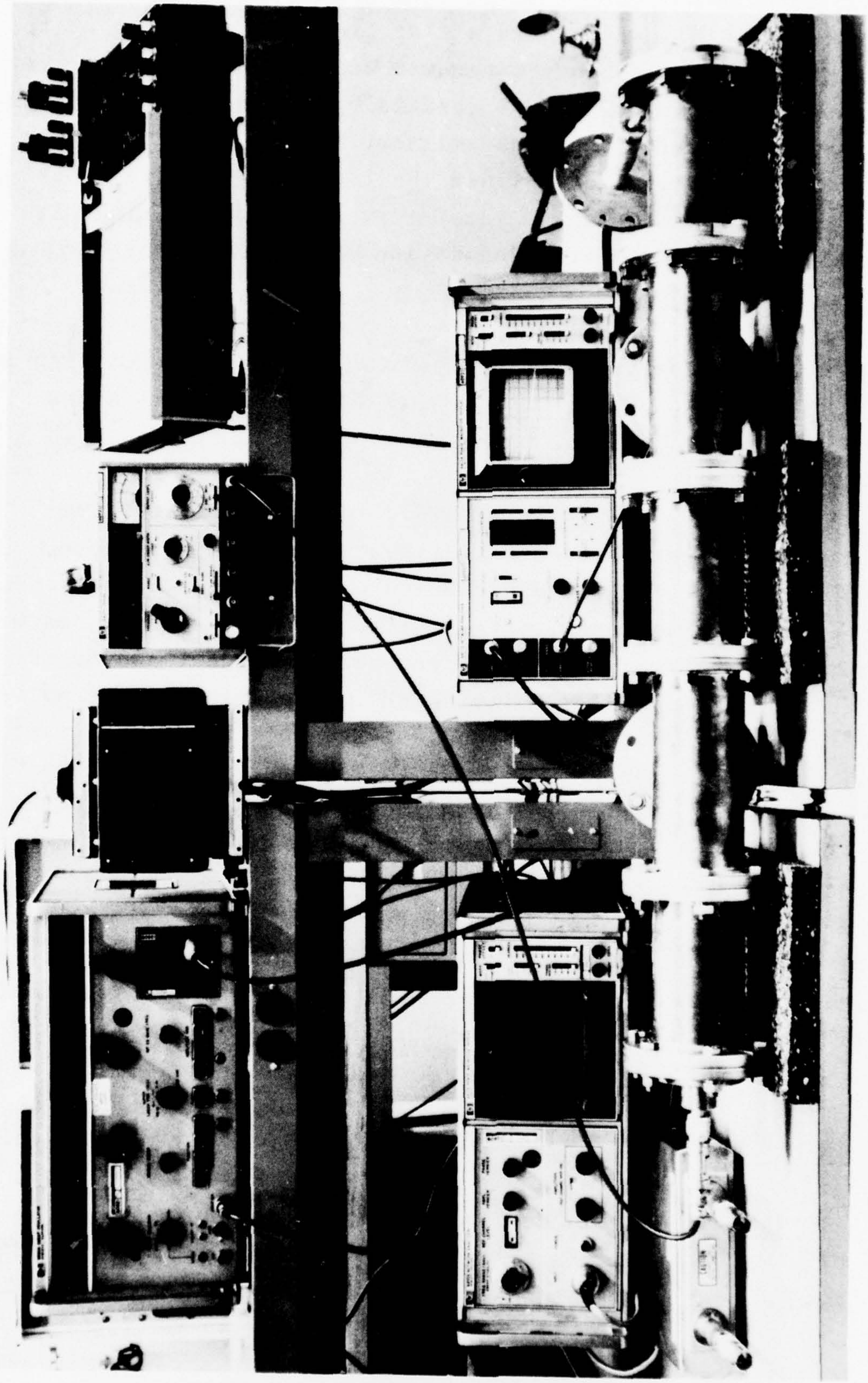


FIGURE 6 COAXIAL TEST FIXTURE AND INSTRUMENTATION FOR FREQUENCY DOMAIN RESPONSE

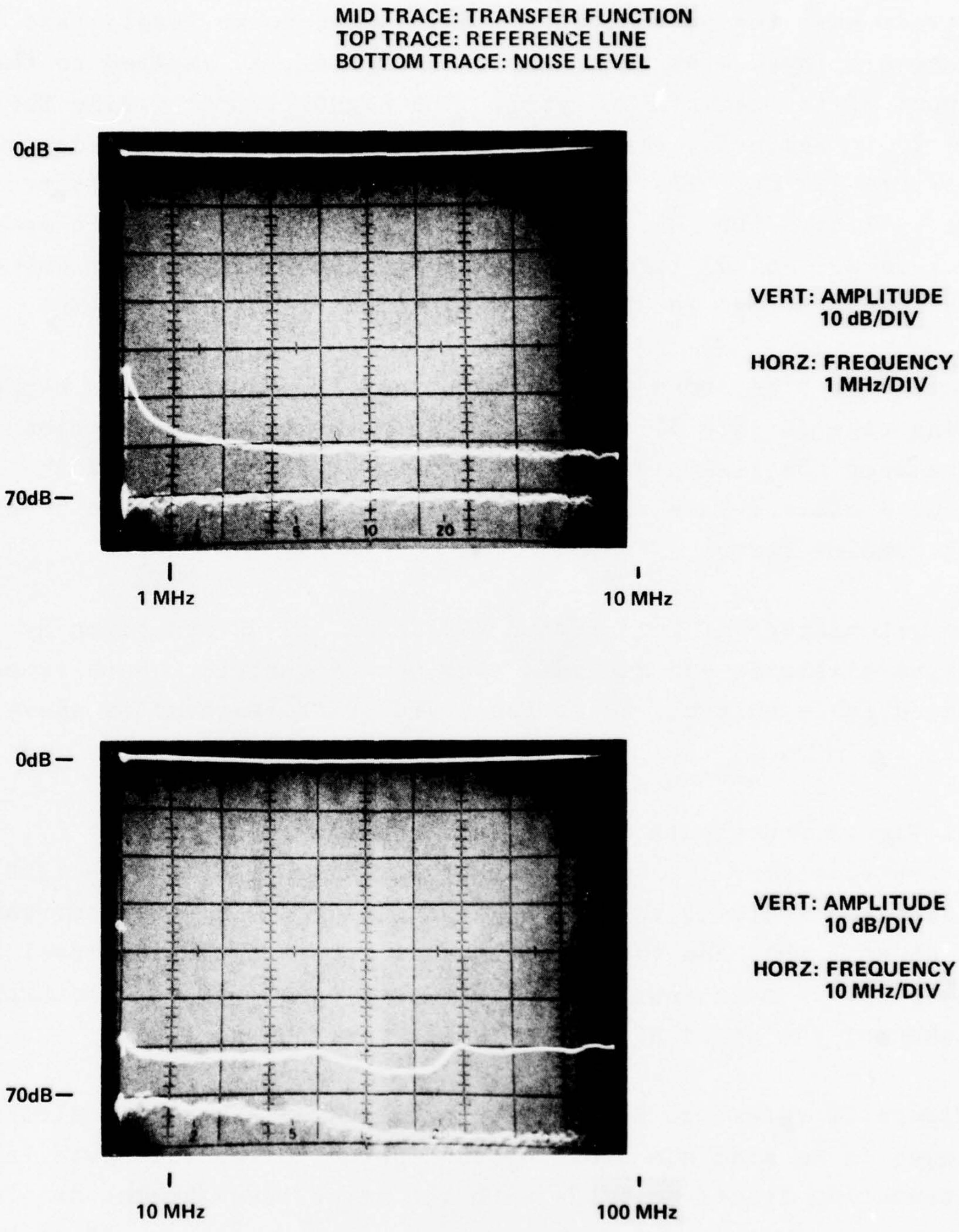


FIGURE 7 CURRENT TRANSFER FUNCTION OF METEX STEEL FIBER GASKET IN ALUMINUM STUFFING TUBE

MHz in the upper picture. The vertical scale is 10 dB per division. The zero dB reference line is at the top of the picture, and the fuzzy trace near the bottom, at -71 dB, is the noise level, that is, the trace displayed with no transmitted current, I, applied to the TEST input of the network analyzer. The signal trace, giving the ratio I/I_0 in decibels, starts at -44 dB on the left-hand side and falls off to -62 dB. The displayed frequency range in the lower picture is 1.0 to 100 MHz. The attenuation of current by the Metex gasket is about -62 dB throughout this frequency range. The curve shows attenuation of -50 dB to -60 dB between 1 MHz and 100 MHz.

In Figure 8 is shown the current transfer function of a copper grounding cage (Figure 3) that made a very short-path connection (1½") between the kick pipe of an aluminum stuffing tube and the shield of a cable. This represents the attenuation provided by an ideal grounding strap.

An attenuation of better than -55 dB or -62 dB was given by conductive elastomer and machined aluminum RF gaskets. Both types attenuated cable currents by at least -70 dB at frequencies above 5 MHz.

In Figure 9 presents the current transfer function of a conductive elastomer 1/4" diameter "O" strip (Chomerics Type 1250) in an aluminum stuffing tube. The attenuation of injected current is -65 dB at 1 MHz, and the signal traces are in the noise level of -70 dB to -80 dB over most of the frequency range. These pictures were taken at the start of the saltwater environment test.

Figure 10 shows the attenuation provided by a machined aluminum split ring in an aluminum stuffing tube prior to the salt bath test. The attenuation traces coincide with the noise level traces at -70 dB to -80 dB over most of the frequency range except for the 25-52 MHz band.

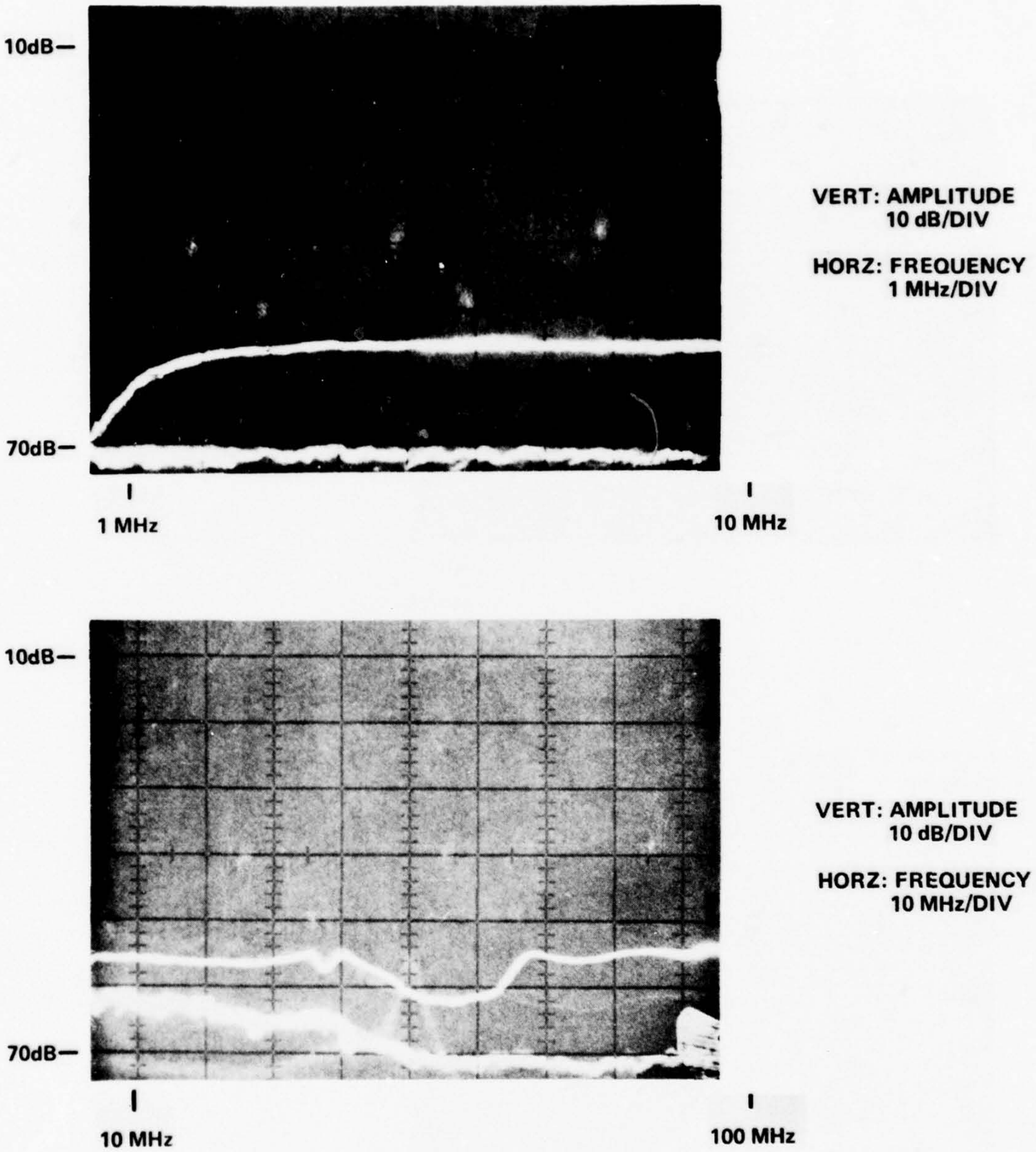


FIGURE 8 CURRENT TRANSFER FUNCTION OF 360° COPPER GROUNDING CAGE CLAMPED TO KICK PIPE OF AN ALUMINUM STUFFING TUBE

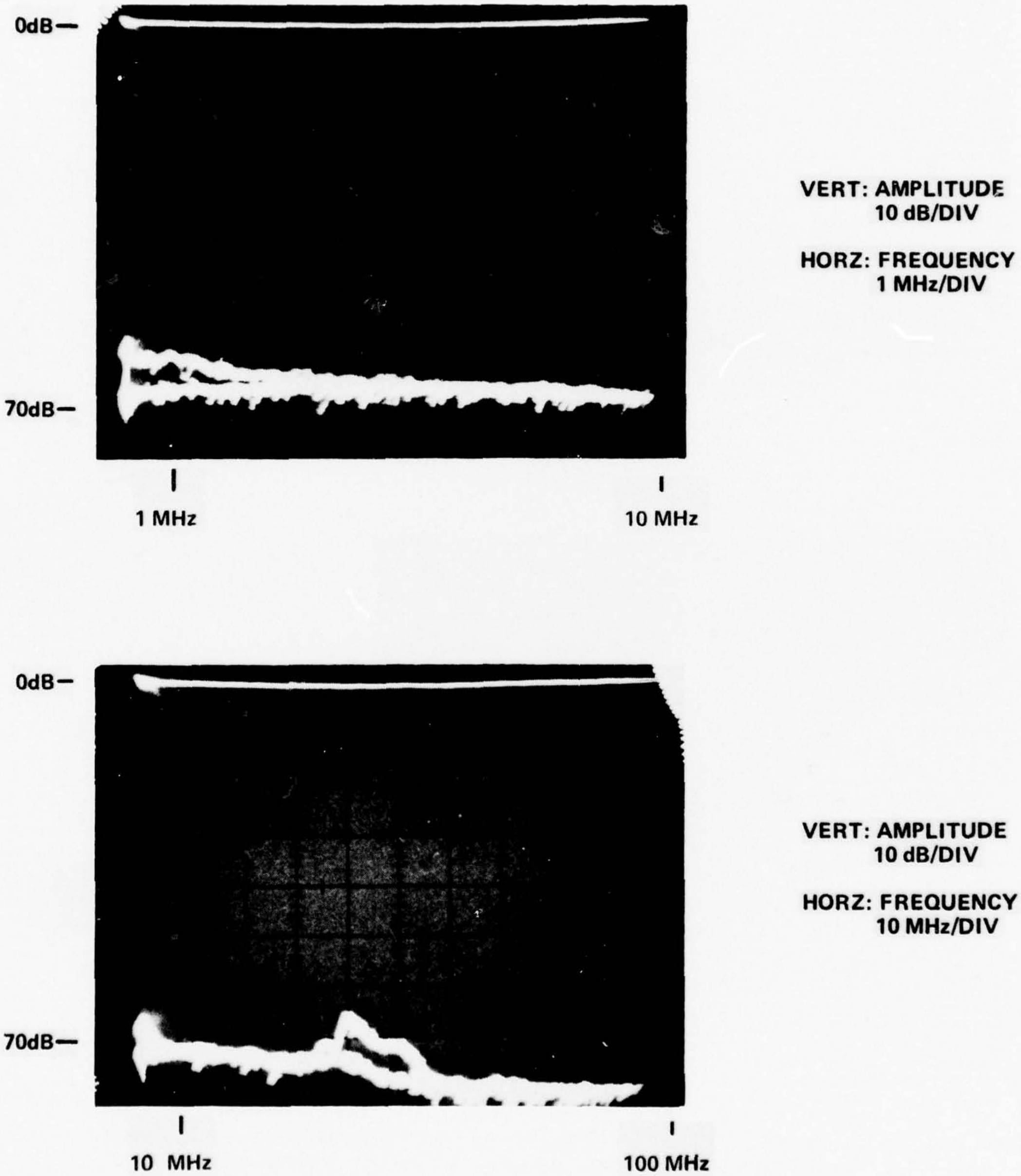


FIGURE 9 CURRENT TRANSFER FUNCTION OF CONDUCTIVE ELASTOMER GASKET (CHOMERICS TYPE 1250 "O" STRIP) IN ALUMINUM STUFFING TUBE AT START OF SALT BATH TEST

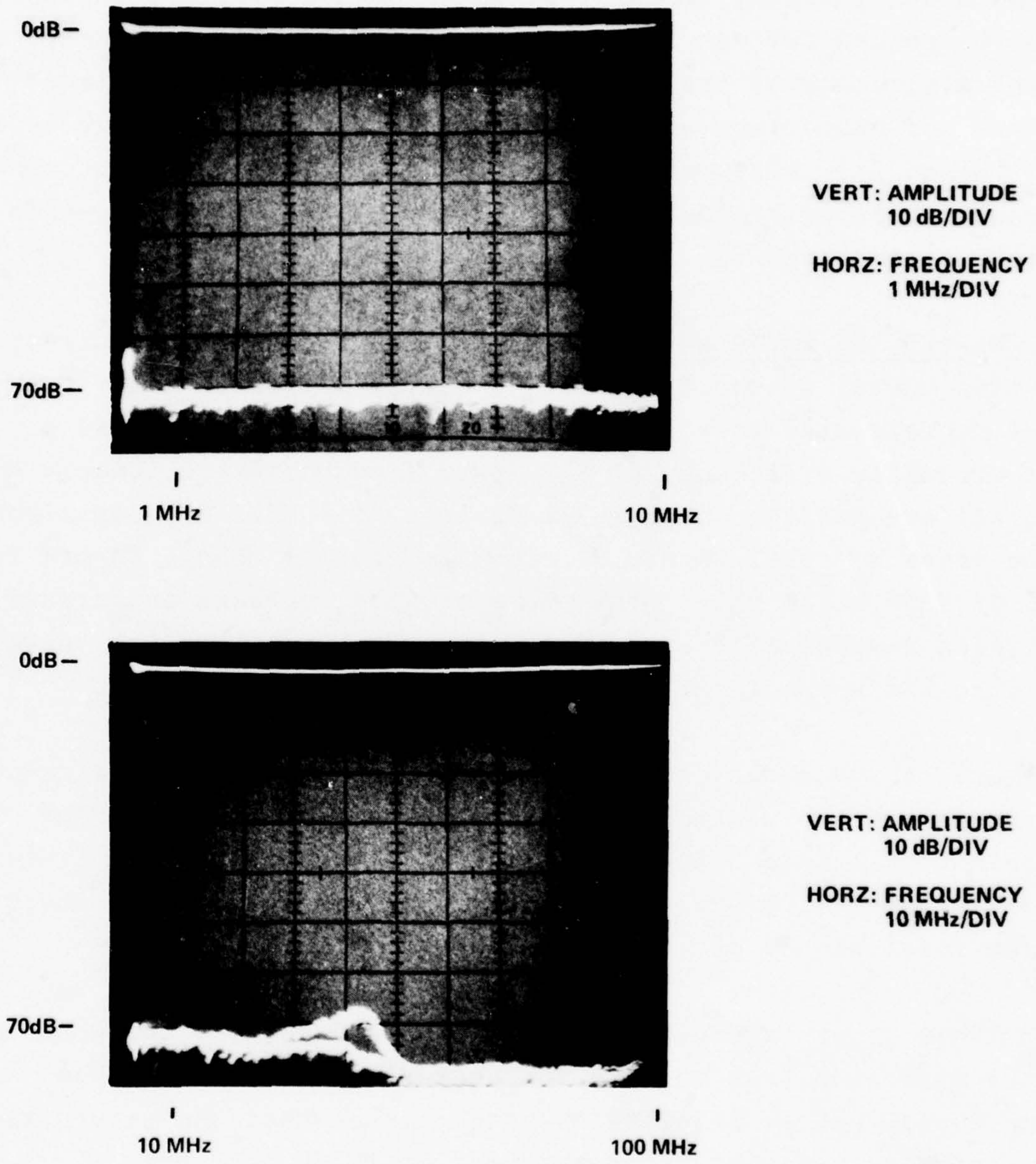


FIGURE 10 CURRENT TRANSFER FUNCTION OF MACHINED ALUMINUM SPLIT RING GASKET IN ALUMINUM STUFFING TUBE AT START OF SALT BATH TEST

PULSED CURRENT TESTS. No degradation of performance was observed in the conductive elastomer gaskets, and none was observed or expected in the aluminum gaskets. Both steel and aluminum stuffing tubes were used in the pulsed current tests. It was not possible to measure the grounding efficiency of the two types of RF gaskets under pulsed conditions for comparison with the CW method because the noise level for the pulsed I/I_0 measurement was too high. (This also was one of the fundamental limitations on the accuracy of the shipboard tests mentioned in reference 3).

SIMULATED SEA ENVIRONMENT TESTS. Figure 13 shows the current attenuation curves of the Chomerics "O" strip RF gasket after two weeks of the saltwater corrosion test. The principal change is a loss of grounding efficiency at the lower frequencies, 0.1 to 10 MHz. The overall attenuation curve is 10 dB less at 1 MHz, by comparison with the baseline test, Figure 9. The incremental change tapers to about 3 or 4 dB at 10 MHz. From there on, the increase in current transmission remains at 3 or 4 dB to about 70 MHz, where the curve blends into the noise level.

Figure 14 shows the attenuation curves of the machined aluminum split ring after two weeks of the saltwater corrosion test. The curves are very little changed from the initial curves. The transfer function in the 62-100 MHz range rises to approximately 8 dB above the noise level at -80 dB.

In Table 4 are readings of I/I_0 taken throughout a two-week saltwater corrosion test on both the Chomerics and the aluminum stuffing tubes. There was little change except that the attenuation of the Chomerics material becomes poorer by 10 dB at 1 MHz.

The frequency domain curves presented in Figures 9, 10, 13, and 14 and the single-frequency data in Table 4 show the effect of a two-week saltwater corrosion test on aluminum stuffing tube assemblies

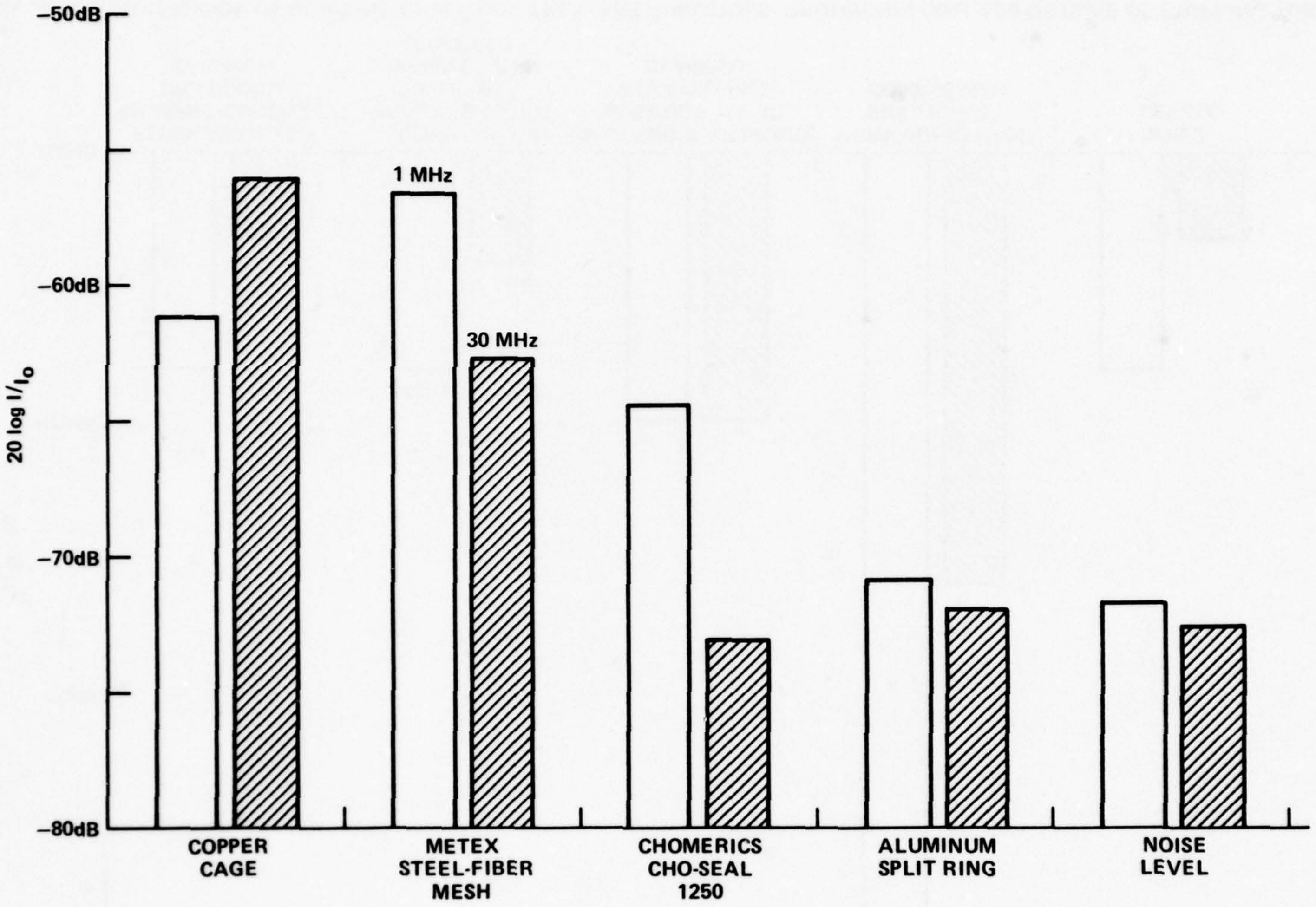


FIGURE 11a COMPARISON OF CURRENT AMPLITUDE TRANSFER FUNCTIONS: GROUNDING RINGS INSIDE STUFFING TUBES

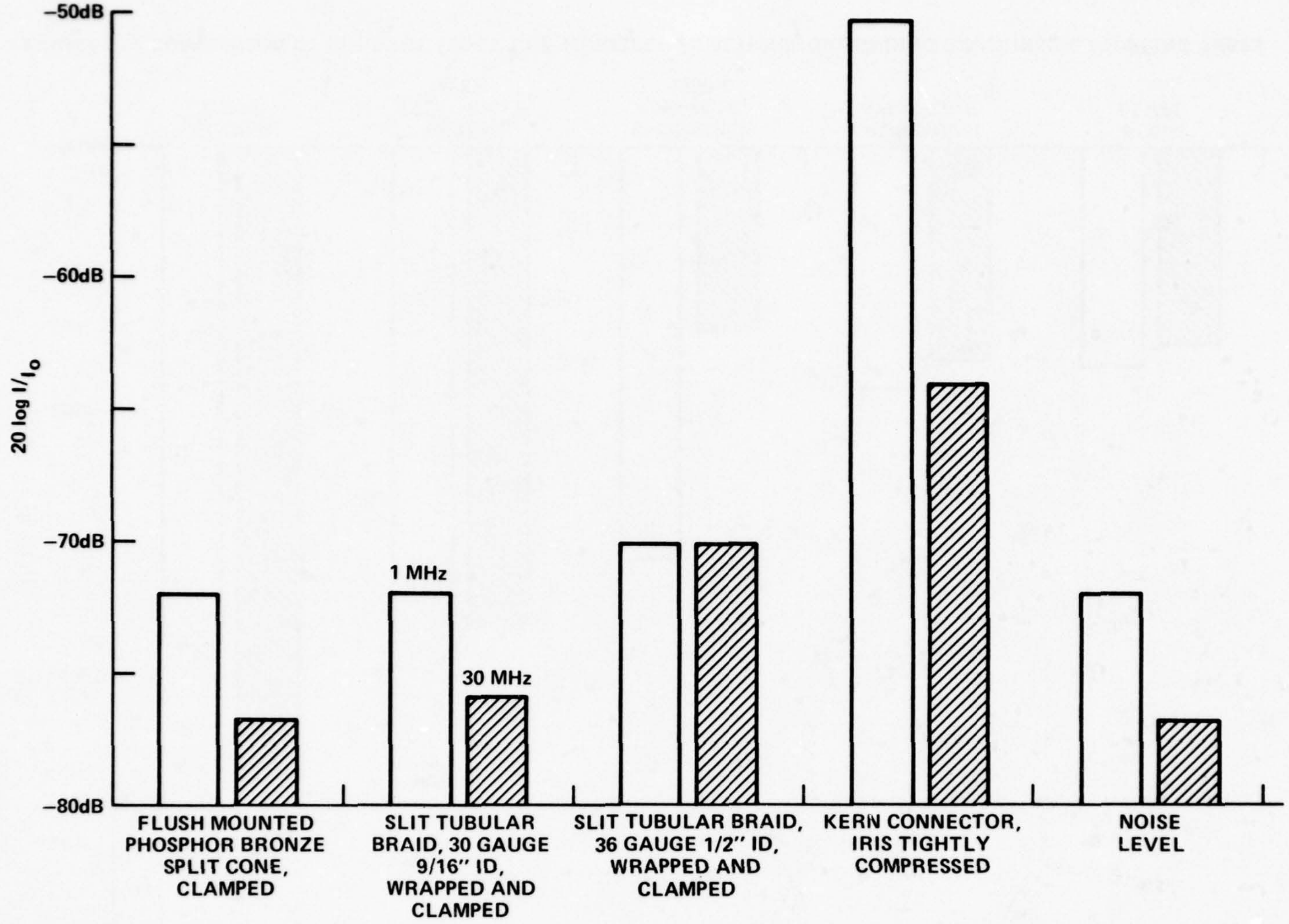


FIGURE 11b COMPARISON OF CURRENT AMPLITUDE TRANSFER FUNCTIONS: GROUNDING COLLARS OUTSIDE OF STUFFING TUBES

STUFFING TUBE TEST FIXTURE

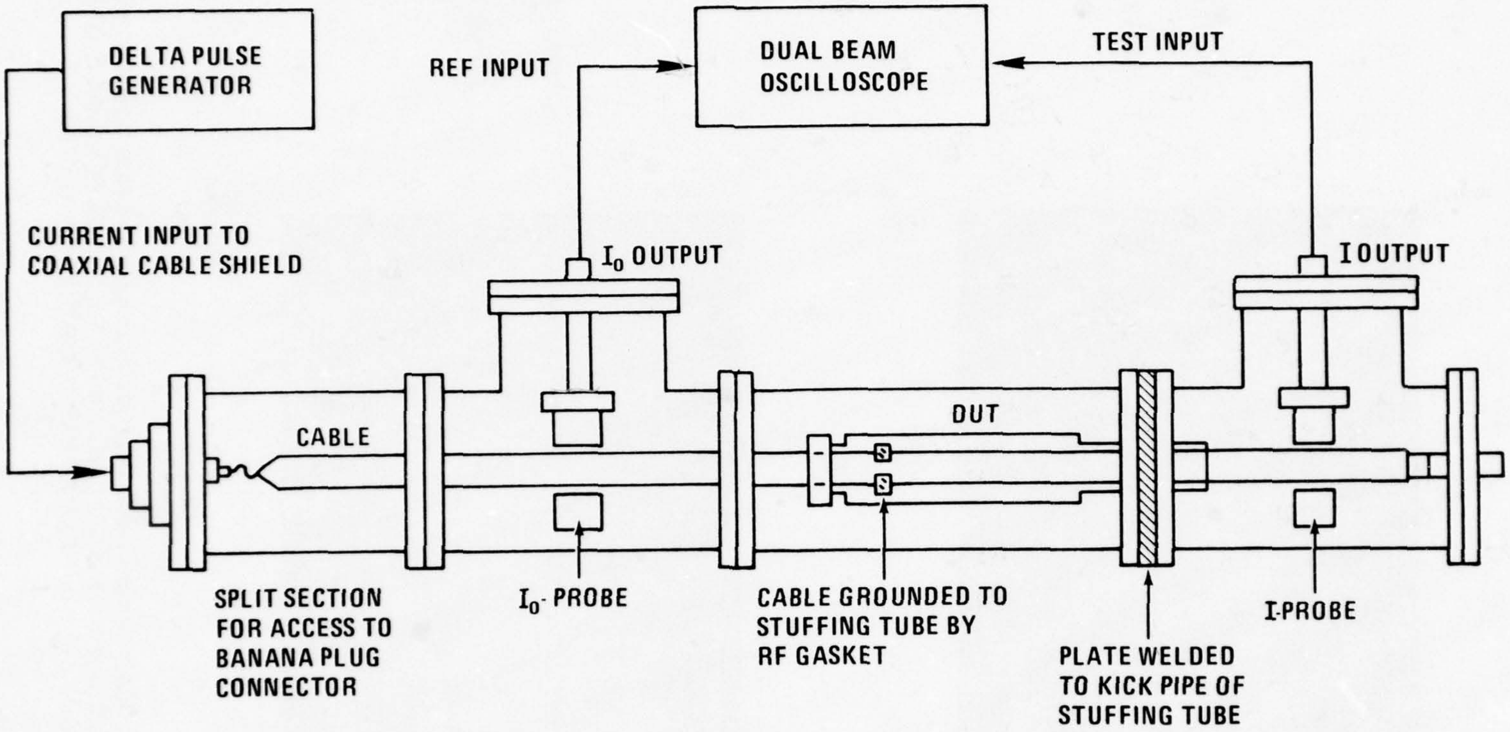
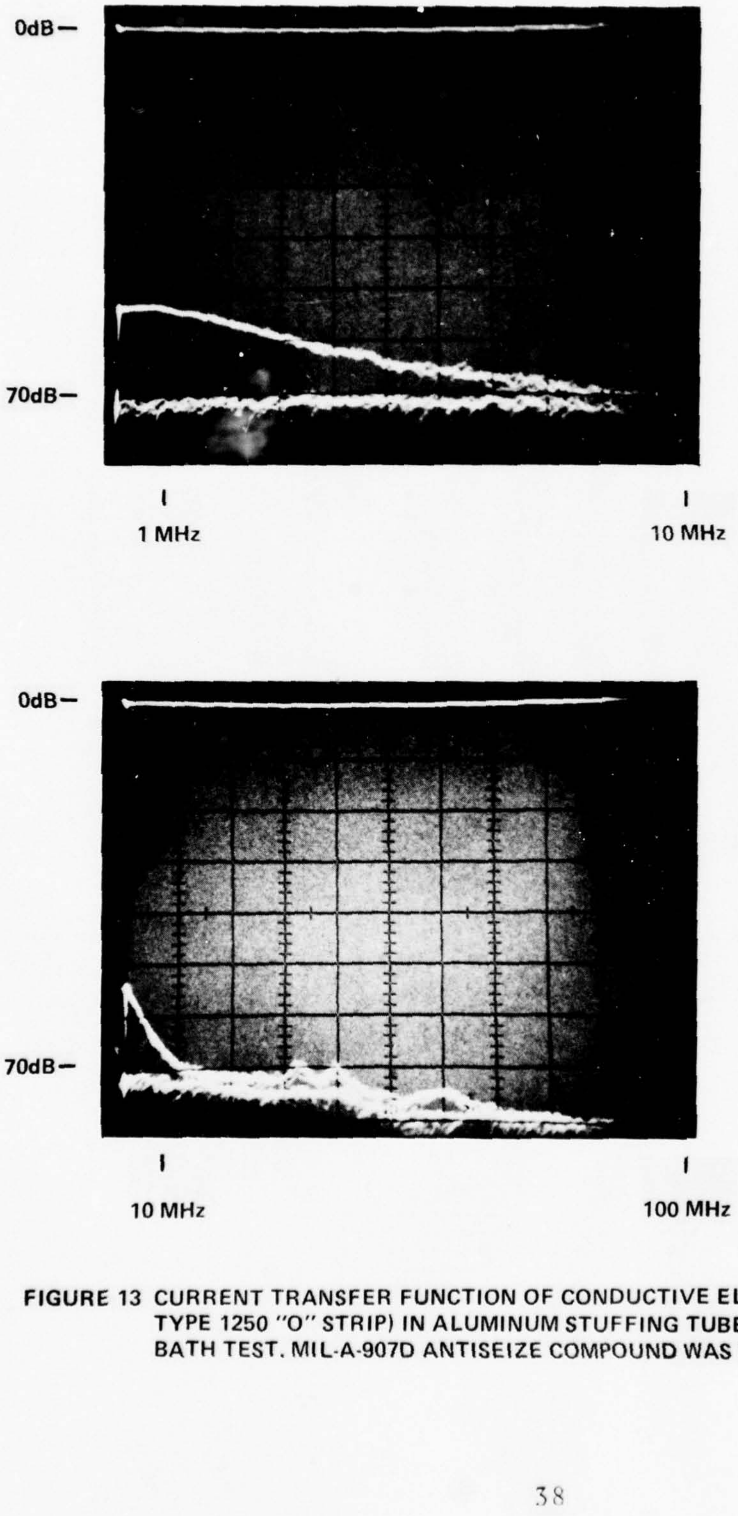


FIGURE 12 TEST ARRANGEMENT FOR TIME DOMAIN RESPONSE



VERT: AMPLITUDE
10 dB/DIV

HORZ: FREQUENCY
1 MHz/DIV

VERT: AMPLITUDE
10 dB/DIV

HORZ: FREQUENCY
10 MHz/DIV

FIGURE 13 CURRENT TRANSFER FUNCTION OF CONDUCTIVE ELASTOMER GASKET (CHOMERICS TYPE 1250 "O" STRIP) IN ALUMINUM STUFFING TUBE AFTER TWO WEEKS OF SALT BATH TEST. MIL-A-907D ANTISEIZE COMPOUND WAS USED

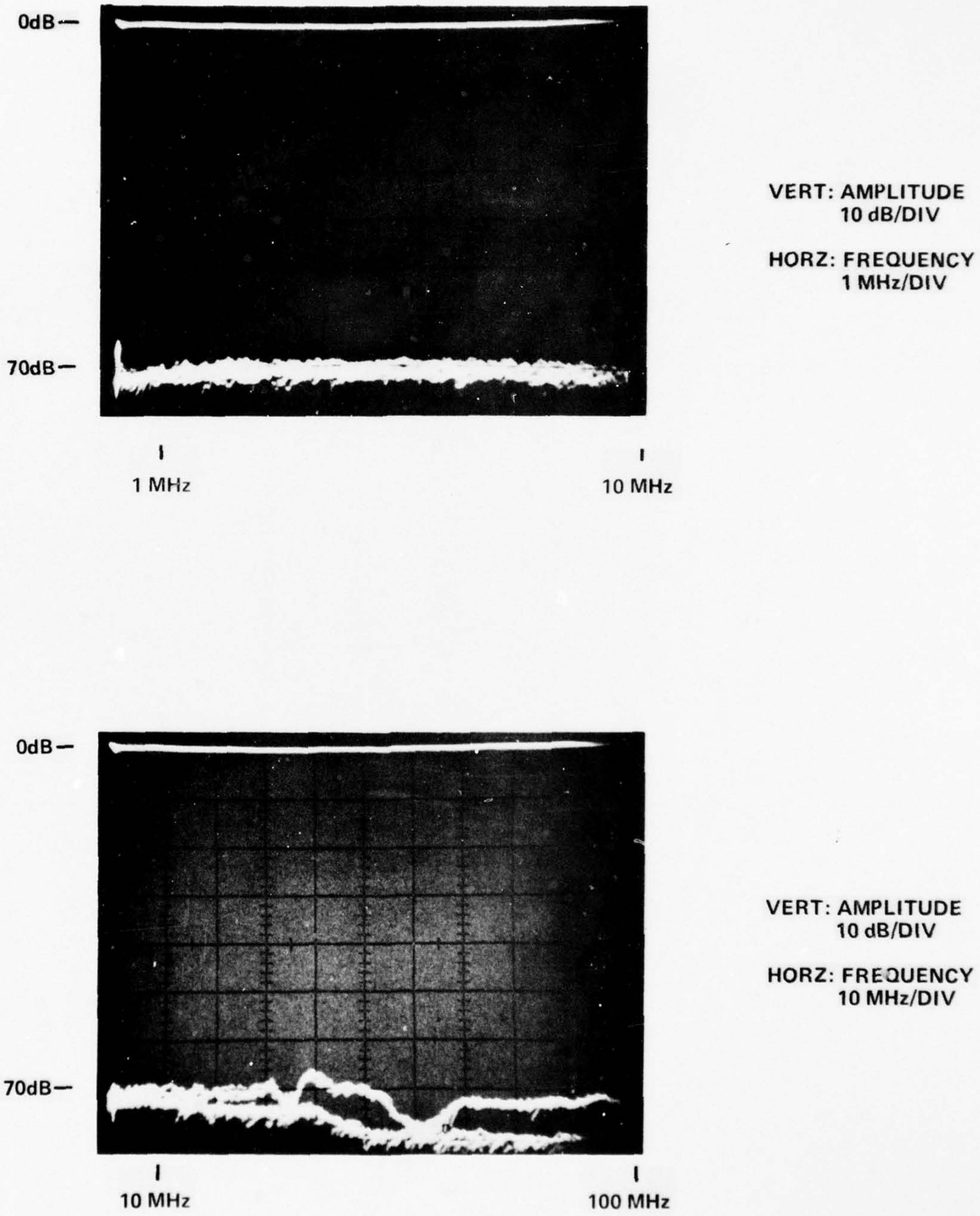


FIGURE 14 CURRENT TRANSFER FUNCTION OF MACHINED ALUMINUM SPLIT RING GASKET IN ALUMINUM STUFFING TUBE AFTER TWO WEEKS OF SALT BATH TEST. MIL-A-907D ANTISEIZE COMPOUND WAS USED

Table 4. Current Transfer Function, 20 log I/I_o, During Saltwater Corrosion Test: With Corrosion Retardant MIL-A-907D

No. of Days in Salt Bath	Chomerics 1250 "O" Strip			Aluminum Split Ring	
	dB at 1 MHz	dB at 30 MHz		dB at 1 MHz	dB at 30 MHz
0	-65	-74		-72	-72
2	-58	-68		-70	-72
4	-58	-72		-71	-71
7	-54	-73		-71	-74
9	-54	-73		-71	-74
11	-54	-72		-71	-70
15	-54	-72			
Average Noise Level	-71	-74		-71	-74

in which MIL-A907D conductive corrosion retardant was used to coat the grounding rings and the areas of electrical contact on the RG/U 214 cable shield and gasket seat inside the stuffing tube. There was no change in the grounding effectiveness of the aluminum split ring up to 20 MHz. At higher frequencies the signal rose above the noise level by about 10 dB, but the device still provided -70 dB attenuation or better. The grounding effectiveness of the conductive elastomer gasket did not change above 10 MHz but became poorer below that frequency. At 1 MHz it was poorer by 10 dB.

When the same environmental test was made on stuffing tube assemblies not protected by the corrosion deterrent, oxidation proceeded between the aluminum split-ring gasket and the gasket seat inside the aluminum stuffing tube. Figure 15 is an axial view of the interior of the stuffing tube, which shows the gasket seat after a two-week saltwater corrosion test in which no corrosion retardant was used. The white patch is the corroded area where the aluminum split ring was not in tight contact with the gasket seat. The corrosion product was either aluminum oxide or hydroxide. Both are insoluble in water. The corrosion reduced the area of electrical contact by a little more than 10%. No corrosion can be seen inside the stuffing tube shown in Figure 16, in which a Chomerics Cho-Seal 1250 "O" strip gasket was given a two week saltwater corrosion test, unprotected by MIL-A907D corrosion retardant. Evidently, the flexible conductive silicone gasket maintained good contact and prevented corrosion.

Results of electrical tests made during the two-week saltwater corrosion test of gaskets not protected by MIL-A-907D corrosion deterrent are summarized in Table 5. At 1 MHz and 30 MHz the aluminum RF gasket lost from 13 dB to 16 dB of attenuation due to corrosion. At 1 MHz the Chomerics gasket lost about 17 dB of attenuation, but suffered no loss at 30 MHz.

FIGURE 15 INTERIOR OF STUFFING TUBE SHOWING 360° GROUNDING REDUCED BY CORROSION DURING TWO WEEKS OF SALT BATH CYCLES. A MACHINED ALUMINUM GASKET WAS USED WITH NO MIL-A-907D COMPOUND

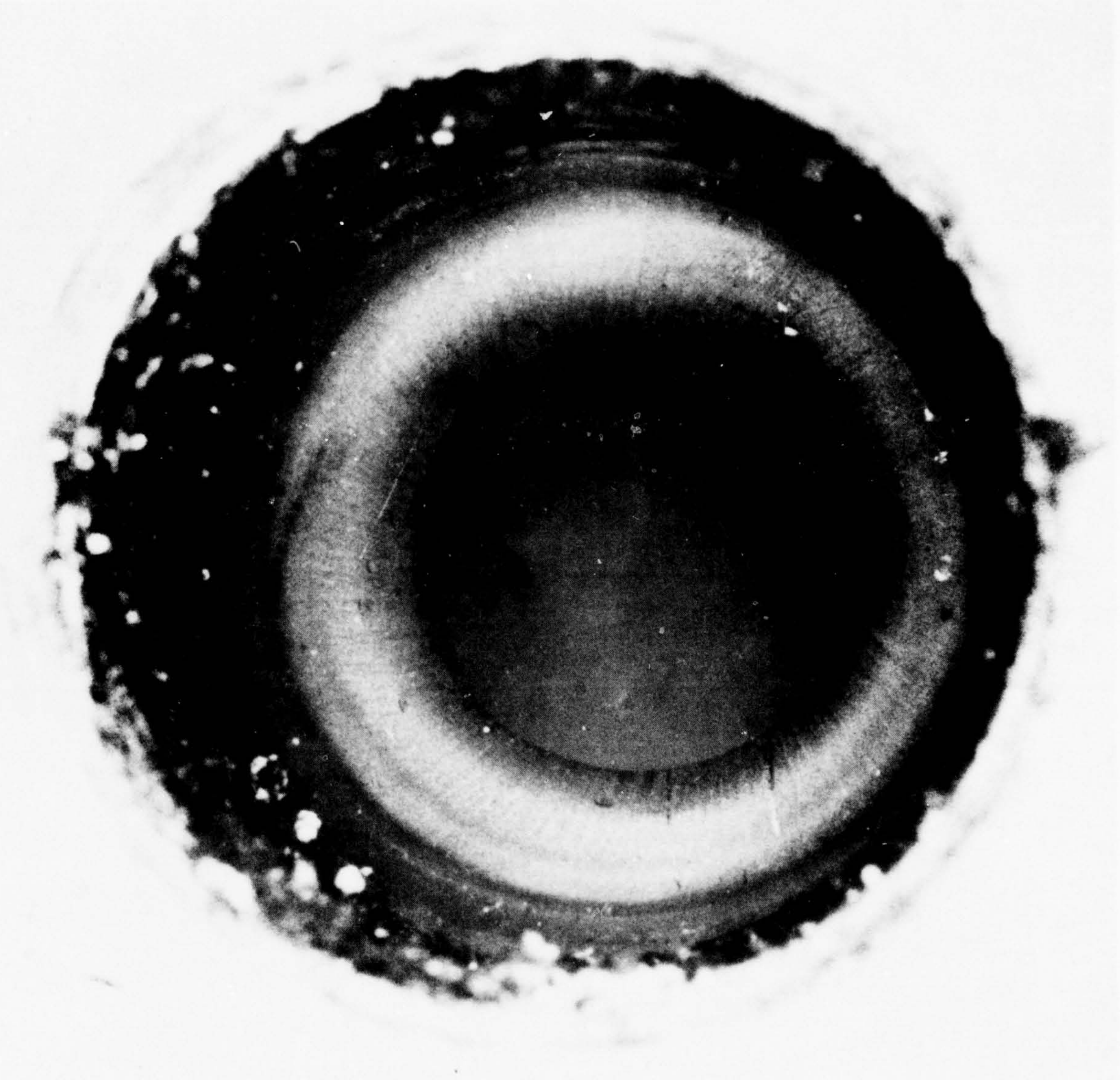


FIGURE 16 INTERIOR OF STUFFING TUBE SHOWING NO CORROSION AFTER TWO WEEKS OF SALT BATH CYCLING. A CONDUCTIVE ELASTOMER GASKET WAS USED WITH NO MIL-A-907D COMPOUND

Table 5. Current Transfer Function, $20 \log I/I_o$, During Saltwater Corrosion Test: With No Corrosion Retardant MIL-A-907D

No. of Days in Salt Bath	Chomerics 1250 "O" Strip		Aluminum Split Ring	
	dB at 1 MHz	dB at 30 MHz	dB at 1 MHz	dB at 30 MHz
0	-69	-75	-72	-75
2	-62	-72	-66	-66
4	-58	-75	-64	-68
7	-57	-75	-61	-69
9	-56	-74	-57	-71
Average Noise Level	-72	-75	-72	-75

Figure 17 and 18 are graphs of the current transfer function of the Chomerics conductive elastomer and the Litton-Ingalls aluminum split ring at 1 MHz throughout the two-week saltwater test, each type of gasket being tested with and without corrosion deterrent. The gaskets made of Chomerics Cho-Seal 1250 "O" strip lost from 11 to 17 dB of current attenuation at 1 MHz whether or not they were protected by the corrosion deterrent compound. No change was observed at 30 MHz. The network analyzer traces showed that the low frequency loss of attenuation by the conductive elastomer was noticeable only below 5 MHz. The graphs show that an aluminum split ring protected by corrosion deterrent suffered no change in grounding efficiency, whereas an unprotected aluminum gasket lost about 16 dB of attenuation at 1 MHz and 13 dB at 30 MHz, due to corrosion. The network analyzer curves showed a loss of about 15 dB in grounding efficiency over the frequency range of 0.1 to 100 MHz for the corroded aluminum gasket.

The network analyzer curves of current transmission versus frequency that were recorded periodically during the saltwater environment tests showed small random variations, particularly around 50 MHz where the curves came near the instrument noise level. It is estimated that differences less than 4 dB are not significant in tracking the course of environmental effects.

Electrical tests were continued for some weeks following the conclusion of the saltwater corrosion test, but no further changes in attenuation were observed.

No clear-cut explanation was found for the 10 dB loss of grounding efficiency suffered by the Chomerics gaskets in the low frequency range, 0.1 to 5 MHz. The volume resistivity of the conductive silicone increases somewhat with decreasing pressure, and a decrease in pressure could have been caused either by the gasket taking a mechanical set or by relaxation of the BACO weatherproof packing. The gaskets, when removed from the test assembly, did not appear to have taken a mechanical set; and calculations made

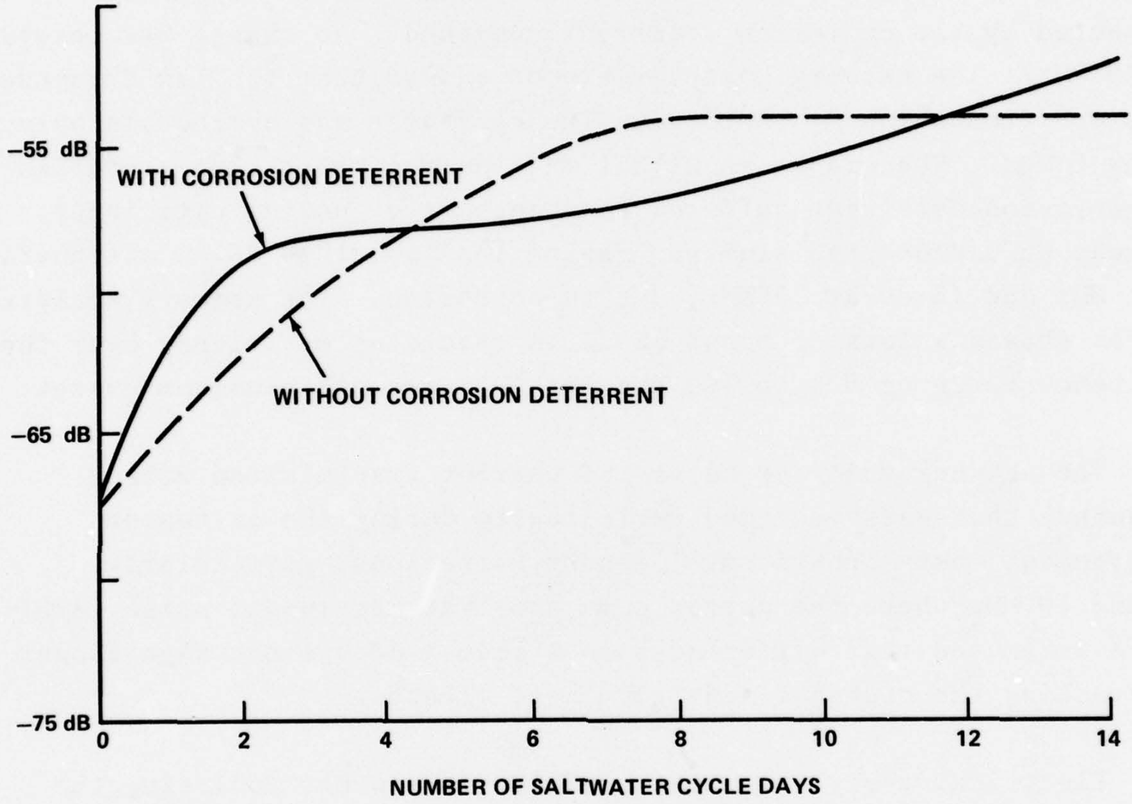


FIG. 17 - TRANSFER FUNCTION OF CHOMERICS CHO-SEAL 1250 AT 1 MHz

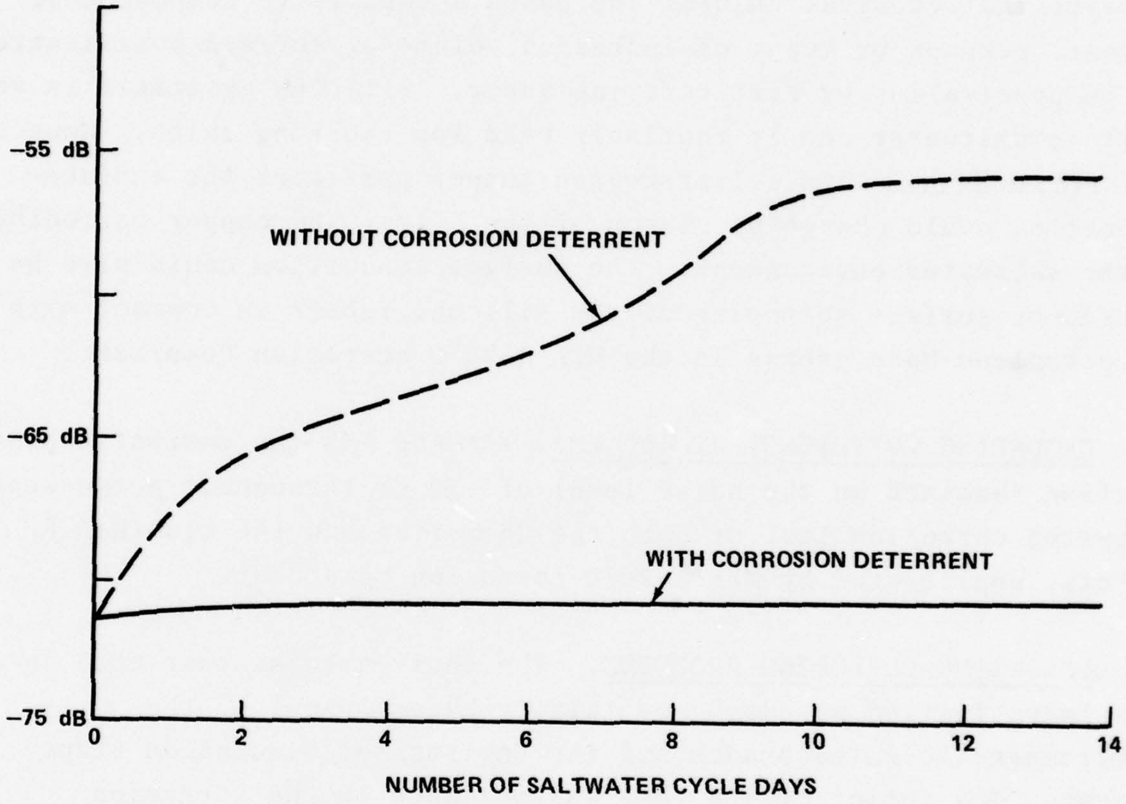


FIG. 18 - TRANSFER FUNCTION OF ALUMINUM SPLIT RING AT 1 MHz

from available data indicated, but not very convincingly, that the pressure effect was not large enough to account for the experimental results.[4,5] The frequency dependence of the effect was not observable throughout most of the frequency range, since the current transfer function was below the noise level at frequencies higher than 10 MHz. The low frequency rise in current transfer function suggests that chemical changes increased a capacitive component of current, perhaps by means of increased volume or surface polarization due to penetration by salt-carrying vapor. Silicone by itself is very inert to saltwater and is routinely used for caulking ships. However, in silicone filled with silver-coated copper particles the surface conduction could change by reason of the silver and copper corroding in the saltwater environment. The surface conduction could also be changed by surface softening of the silicone rubber in contact with the petroleum-base grease in the MIL-A-907D corrosion deterrent.

GROUNDING EFFICIENCY AT 400 MHz. At 400 MHz the current transfer function remained in the noise level of -70 dB throughout a two-week saltwater corrosion test of both the Chomerics and the aluminum RF gaskets, unprotected by MIL-A-907D corrosion retardant.

LONG-TIME CORROSION PROBLEMS. The environmental test used in this investigation was designed jointly by personnel of the Electromagnetic Pulse Branch and the Environment Simulation Branch of NSWC. The intent of the test was to check on the corrosion susceptibility of new types of RF gaskets for use in stuffing tubes that are subjected to ocean spray and occasional immersion during high sea states. Therefore, the designed test included cycles of immersion and drying time on the test hardware.

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[4] Maxam, G. L., and Solberg, J. E., Sandia Laboratories, "Degradation of EMP Hardening Devices," presented at DNA Seminar on EMP Environments and Protection Implementation Seminar, Eglin AFB, Florida, 4-6 Oct 1977.

[5] Chomerics, Inc., Woburn, Mass., EMI/RFI Gasket Design Manual.

It is judged that a two week test with high temperature immersion would certainly reveal any serious early corrosion problems; but it must be realized that no long-time corrosion effects can be foretold. In a memorandum of 8 June 1977, J. Jarus of the NSWC(WOL) Environmental Simulation Branch warns:

> "As mentioned during the design of the test, prediction of hardware life cannot be made from the lab test results unless some real time data is available for comparison. Without real time data, the lab tests can only be used to weed out gross incompatibilities between the various parts of the assembly. Failure or success after such a test may or may not be typical to those found in the real environment. Assigning a life limit would strictly be conjecture. Therefore, it is recommended that ... subject the RF gasket to some real service aboard a ship or ships around various locations to amass real time data for comparison with the lab tests."

Further, from his experience in corrosion testing, Jarus has become convinced that zinc-rich compounds are among the best corrosion regardants, whereas copper-rich compounds like that of MIL-A-907D have caused problems in the long run. He points to a finding that

> "...the presence of ... cupric ... ions in a saline solution increased the corrosion rate of aluminum and aluminum alloys ..."[6]

CONCLUSIONS

The ring contact between cable shield and inside wall of the stuffing tube is an excellent configuration of grounding device, because of its low-inductance geometry.

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[6] Becerra, Alcibiades and Darby, Ron, "The Influence of Copper and Bicarbonate Ions on the Corrosion of Aluminum Alloys in Saline Solutions," Corrosion 30, 153 (May 1974).

In the baseline tests two types of gasket materials, a flexible conductive elastomer and a rigid aluminum split ring, attenuated cable shield currents by 60 dB to 80 dB over a frequency range of 5 MHz to 100 MHz. Less efficient were a compressible ring of metal fibers and a copper grounding cage. The latter was designed to be the best ground that can be provided by the method of ground straps external to the stuffing tube and provides more effective grounding than the six to twelve inch grounding straps typically used.

Performance of the conductive elastomer and the aluminum split ring gaskets was satisfactory at 400 MHz and not degraded by pulsed current tests at 1080 amperes peak (the injected currents being an over-test for EMP-induced currents).

In an environmental test designed to accelerate saltwater corrosion in aluminum stuffing tubes fitted with RF gaskets, the performance of machined aluminum split ring gaskets was not degraded provided that MIL-A-907D compound was used as a protective coating on the gaskets. When the corrosion deterrent was not used, corrosion between the aluminum gasket and stuffing tube wall reduced by 10% the area of electrical contact, and the ratio of transmitted to incident current increased about 15 dB over the frequency range 0.1 to 100 MHz. In the same environmental test, conductive elastomer gaskets suffered a loss in grounding efficiency in the frequency range of 0.1 to 5 MHz, whether or not corrosion deterrent was used. The worst-case loss in current attenuation was about 15 dB at 1 MHz.

Either the conductive elastomer or the aluminum split ring can be used to achieve a shield current attenuation of 60 dB or better under adverse conditions, when protected from corrosion by MIL-A-907D compound. However, long-time corrosion effects cannot be predicted; and it has been suggested that a zinc-rich compound would be better than the copper-rich MIL-A-907D. In the tests herein reported, the aluminum split ring gaskets gave the best performance but pose a potential corrosion problem, while the conductive elastomer gaskets gave acceptable performance but pose a potential chemical or mechanical set problem.

Installation of the grounding ring inside the stuffing tube would not be an easy retrofit method and would considerably complicate the procedure for installing cables on ships under construction.

It would be impossible to detect by the customary visual inspection whether or not a grounding device had been installed.

PRECAUTIONS

If the method of grounding cable shields inside stuffing tubes is to be used, then further testing should be directed toward investigating: (a) nonlinear intermodulation effects (harmonic generation due to dissimilar metal junctions established by the grounding); (b) lifetime and chemical action of the conductive corrosion deterrent MIL-A-907D when used with Chomerics conductive silicone gaskets in cable and stuffing tube assemblies; (c) chemical compability of a zinc-rich silicone corrosion deterrent when used with Chomerics conductive silicone gaskets in cable and stuffing tube assemblies.

Part II

METHODS OF CABLE SHIELD GROUNDING AT NON-WEATHER END OF STUFFING TUBE

INTRODUCTION

The information in this Part II supplements that presented in a previous report[7], and in Part I of this report, which described the results of measurements on low inductance methods for grounding ship exterior cables inside stuffing tubes as they pass through the stuffing tubes into interior compartments. The data reported here pertain to low inductance methods for grounding cables, not inside the stuffing tubes but at the ends of the kick pipes of the stuffing tubes on the interior non-weather side of the deck or bulkhead through which the cables pass. Figure 19 shows three of the grounding methods investigated. Figure 20 shows the fourth method. The methods in Figure 19 are suitable when the kick pipe extends for a distance beyond the deck or bulkhead. The method in Figure 20 is suitable when the kick pipe does not extend beyond the deck or bulkhead. The grounding device shown in Figure 20 is a flush mounted metal cone[8] of phosphor-bronze cut in half along the cone axis. It is suitable for retrofit on existing ships where the kick pipe or stuffing tube itself is most often flush welded with no extension beyond the deck or bulkhead.

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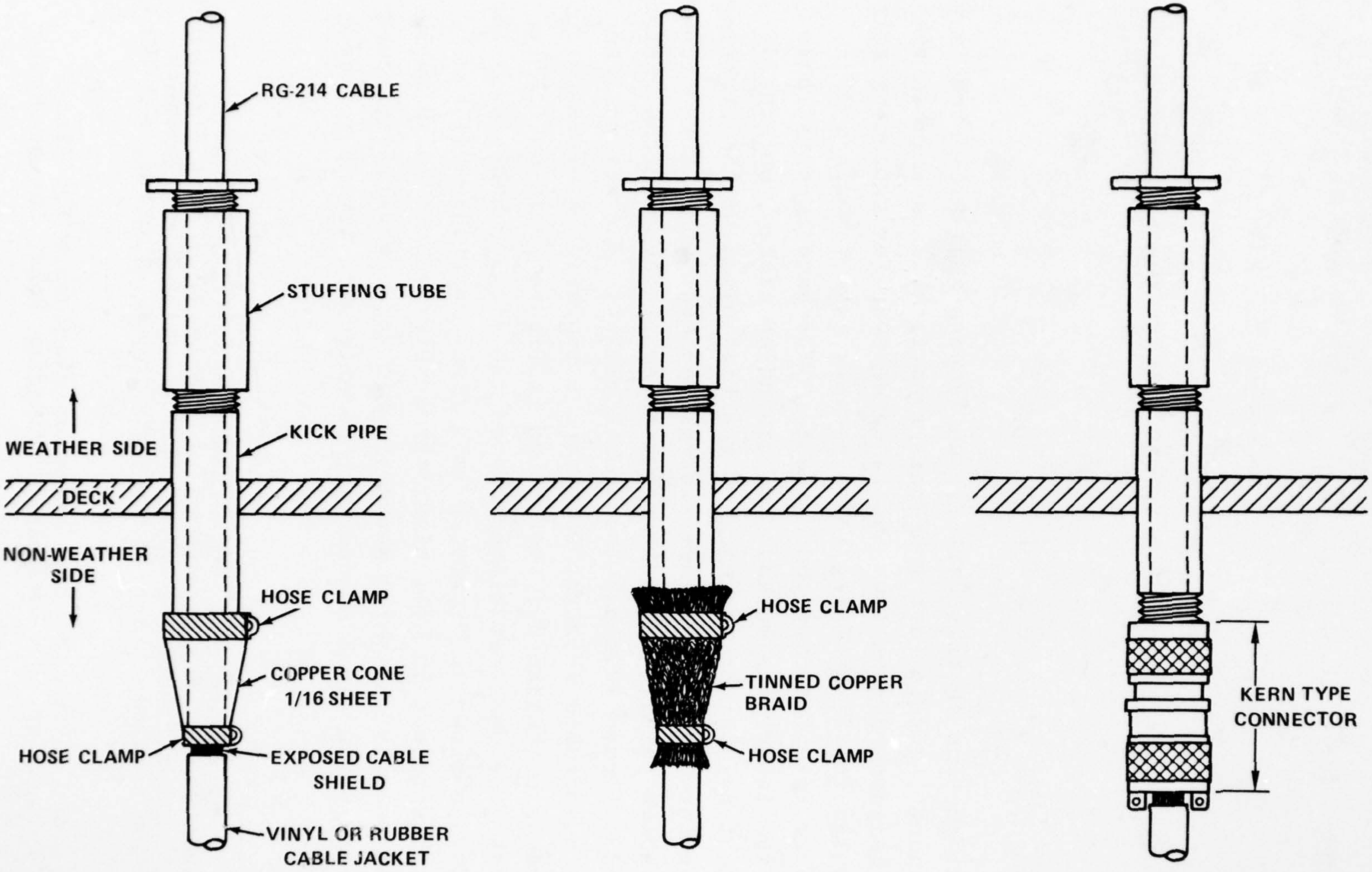
[7] Petree, M., and Zendle, B., "RF Gaskets in Stuffing Tubes: A Low Inductance Method for Grounding Cable Shields to Ship Structures for EMP Protection," NSWC/WOL, presented at DNA EMP Environments and Protection Implementation Seminar, Eglin AFB, Florida, 4-6 Oct 19 4-6 Oct 1977.

[8] Zendle, B., and Petree, M. C., Invention disclosure for Flush Mounted Self Clamping, Low Impedance Grounding Cone, Docket Number D-5735, NSWC/WOL.



A. COPPER CONE, 1/16 IN. SHEET

B. TINNED COPPER BAND

C. KERN TYPE CONNECTOR

FIG. 19 - LOW INDUCTANCE 360 DEGREE GROUNDING TECHNIQUES FOR SHIP EXTERIOR CABLES AT POINTS OF ENTRY INTO INTERIOR COMPARTMENTS. NEW SHIP CONSTRUCTION.

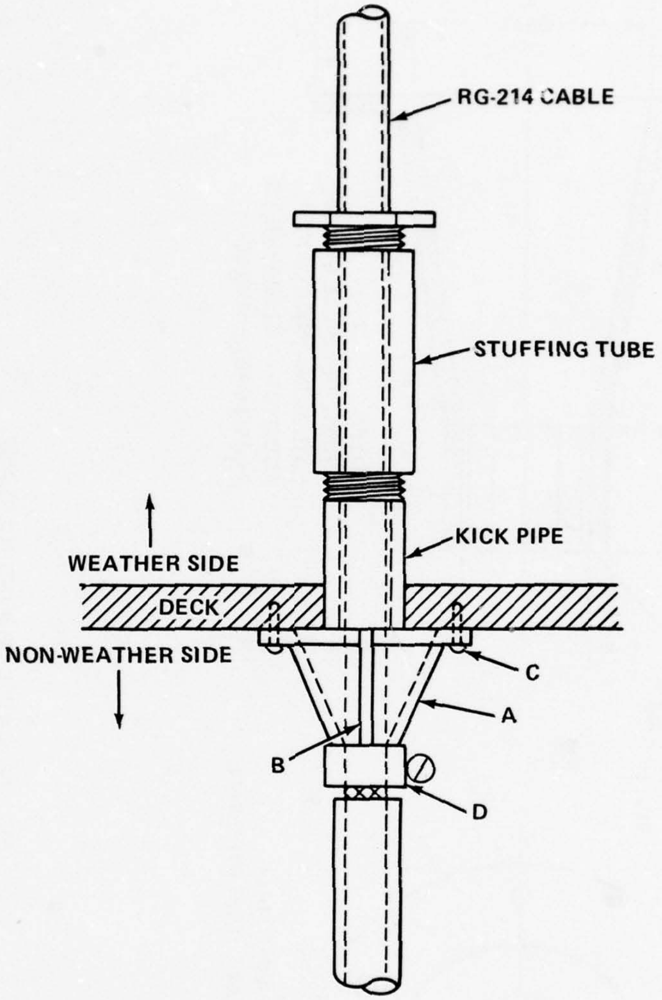


FIG. 20a - FLUSH MOUNTED 360 DEGREE GROUNDING CONE FOR SHIP CABLES ENTERING COMPARTMENTS. FORMER SHIP CONSTRUCTION.

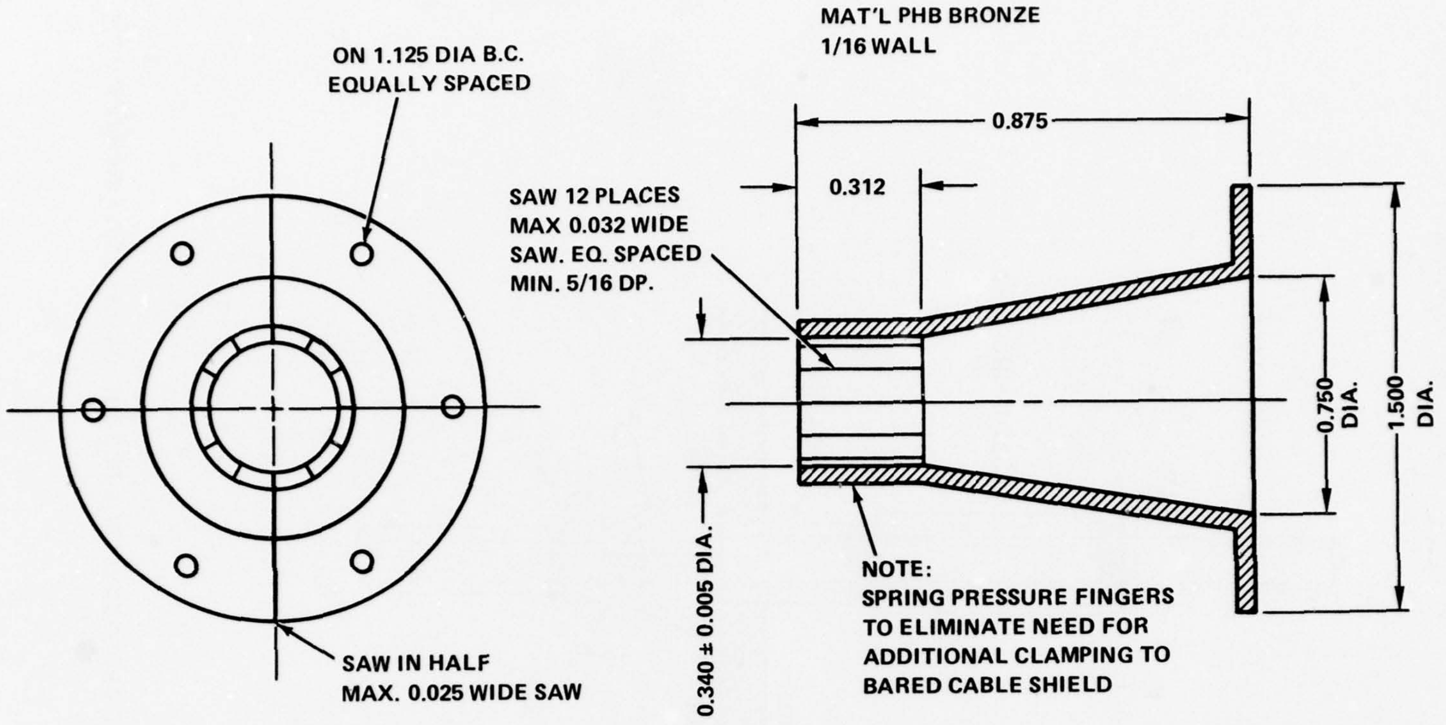


FIG. 20b - CABLE GROUNDING CLAMP

The objective in these investigations is to obtain information leading to improvement over present techniques as prescribed in MIL-STD-1310B or C for grounding ship exterior cables at points of entry into interior compartments. One technique prescribed in MIL-STD-1310B or C consists of a hose-type clamp around the bared cable shield on the interior side of the deck or bulkhead with a metal ground strap six to twelve inches long welded to the clamp at one end and bolted at the other end to a stud welded to the deck or bulkhead. Improvement over the presently prescribed grounding technique is desirable because of the relatively high inductive reactance for the dominant frequencies of the current transients induced on the shields of ship exterior cables by EMP and other shipboard sources of cable-shield current excitation.

During the performance of the Part I measurements, it became increasingly apparent to the authors that the technique of grounding inside stuffing tubes would complicate considerably the procedure for installing and inspecting cables grounded at the shipyard in this manner. In addition it is not known how well the cables grounded inside stuffing tubes would survive the sea environment. Part I described tests in simulated sea environments showing that sea water can leak past the weatherproof packing inside the stuffing tube. This can result in corrosion of the bared cable shield inside the stuffing tube unless special precautions are taken to apply a chemically-compatible conductive anti-corrosion compound to the bared cable shield and to the other grounding components inside the stuffing tube.

The grounding techniques to be described here call for exposing a short length of cable shield on the interior, non-weather side of the bulkhead. There is, therefore, no departure in this respect from the grounding method already practiced and prescribed in MIL-STD-1310B or C. The essential differences between the new techniques depicted in Figures 19 and 20 versus the six to twelve inch grounding strap method presently used are shorter length (approximately 1-1/2 inches) and the 360° configuration of the current conduction path to ground.

Both factors result in lower inductance than the ground strap prescribed in MIL-STD-1310B or C and, therefore, provide a better ground at higher frequencies.

APPARATUS

The test fixture and instrumentation for the present series of measurements are schematically shown in Figure 21. They are the same as those used in the previous series of measurements (Part I) in which cable grounding methods inside the stuffing tube were investigated. For the present series of measurements the only changes required were the cable grounding method and location. The new grounding location is labeled location "X" in Figure 21 and the four methods investigated here consisted of:

a. A 1/16 inch sheet copper cone wrapped and clamped around the kick pipe and the RG-214 cable shield exposed at location "X". See Figure 19a.

b. A tinned copper braid wrapped and clamped around the kick pipe and the RG-214 cable shield exposed at location "X". See Figure 19b.

c. A Kern connector screwed onto the threaded end of kick pipe and making ground contact by compression of a toroidal spring iris around the RG-214 cable shield exposed at location X. See Figure 19c. (The toroidal spring iris is inside the lower back shell of the connector and is not in view in Figure 19c).

d. A flush mounted metal cone, of phosphor bronze in these tests, cut in two halves along the cone axis, screwed into the deck or bulkhead through the cone base flange and clamped around the bared cable shield at the smaller flared end of the cone. See Figures 20a and 20b.

In all these tests there is no grounding inside the stuffing tube (as shown in Figure 21). The swept frequency signal generator applies current in two frequency ranges, 0.1 to 10 MHz and 1.0 to 100 MHz, to the RG-214 cable shield at the left end of the test fixture. The RG-214 cable shield and the cylindrical test fixture form a coaxial arrangement with the copper walls of the test fixture providing two current ground return paths, one through the plate shown cross-hatched in Figure 21 and welded to the kick pipe. A second ground return path is provided by the circular brass end plate at the right hand end of the cylindrical test fixture. One of the current probes measures the current I_0 applied to the cable shield by the swept frequency signal generator. The second probe measures the residual current I remaining on the cable shield beyond the location X of the grounding method under test. The network analyzer forms the ratio I/I_0 and displays this ratio in decibels versus frequency in two ranges, 0.1 to 10 MHz and 1.0 to 100 MHz.

RESULTS

The current amplitude transfer functions, 20 log (I/I_0) versus frequency, are shown in Figures 22 through 34 for the various grounding methods depicted in Figures 19 and 20.

BRAID. Figures 22 through 25 show the current amplitude transfer functions for grounding with 30 gauge by 9/16 inch I.D. tinned copper braid as per Federal Specification QQ-B-575a. The different results, ranging from very good performance to rather poor performance, are obtained for this type of braid depending upon the procedure used for connecting and wrapping the braid around the kick pipe and the RG-214 cable shield. The details are given in the legends of the Figures. Figure 26 shows the results obtained using a finer braid, 36 gauge by 1/2 inch I.D. specified in Federal Specifications QQ-B-575a. Figure 25 shows that relatively poor results can be obtained for the particular wrapping procedure

STUFFING TUBE TEST FIXTURE

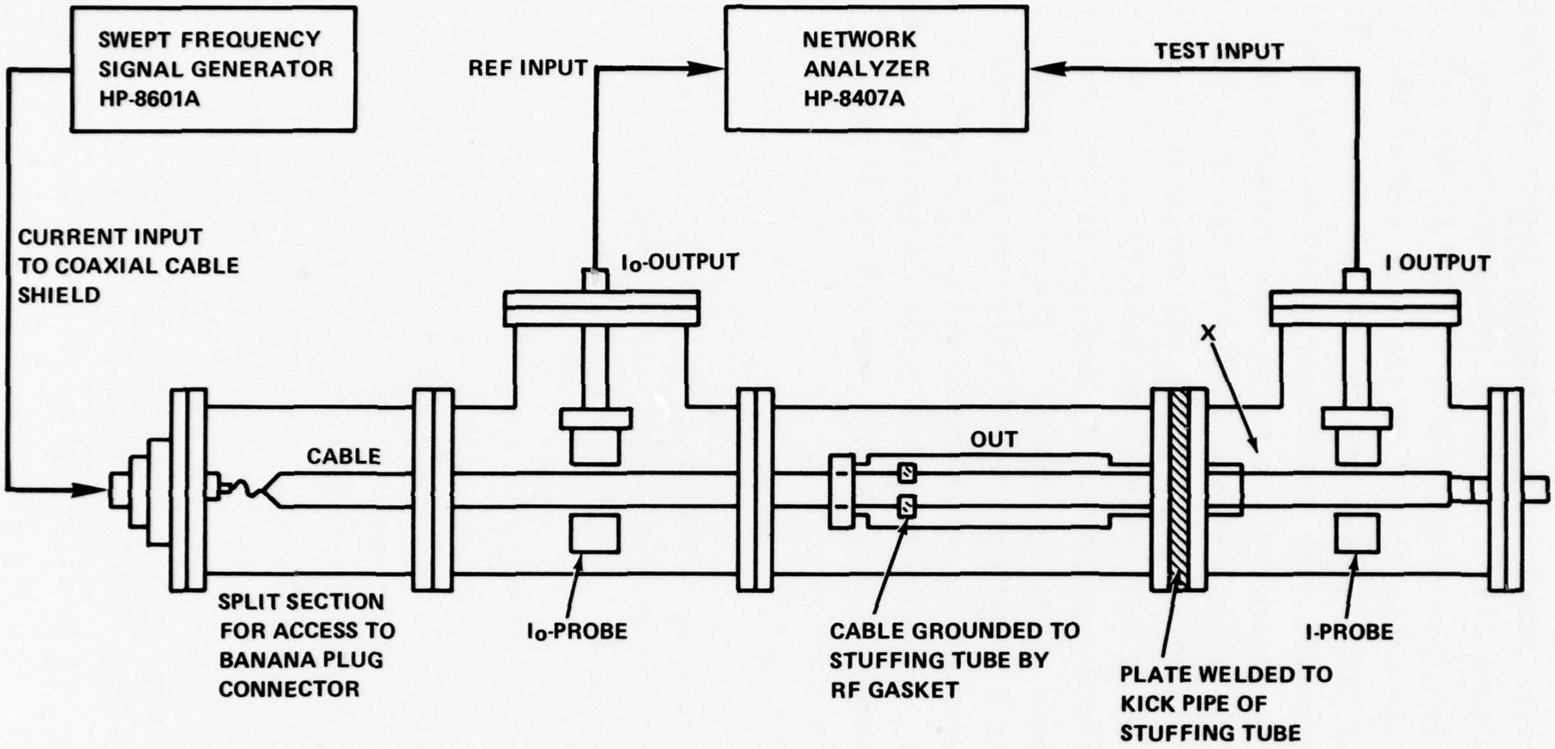


FIG. 21 - TEST ARRANGEMENT FOR FREQUENCY DOMAIN RESPONSE

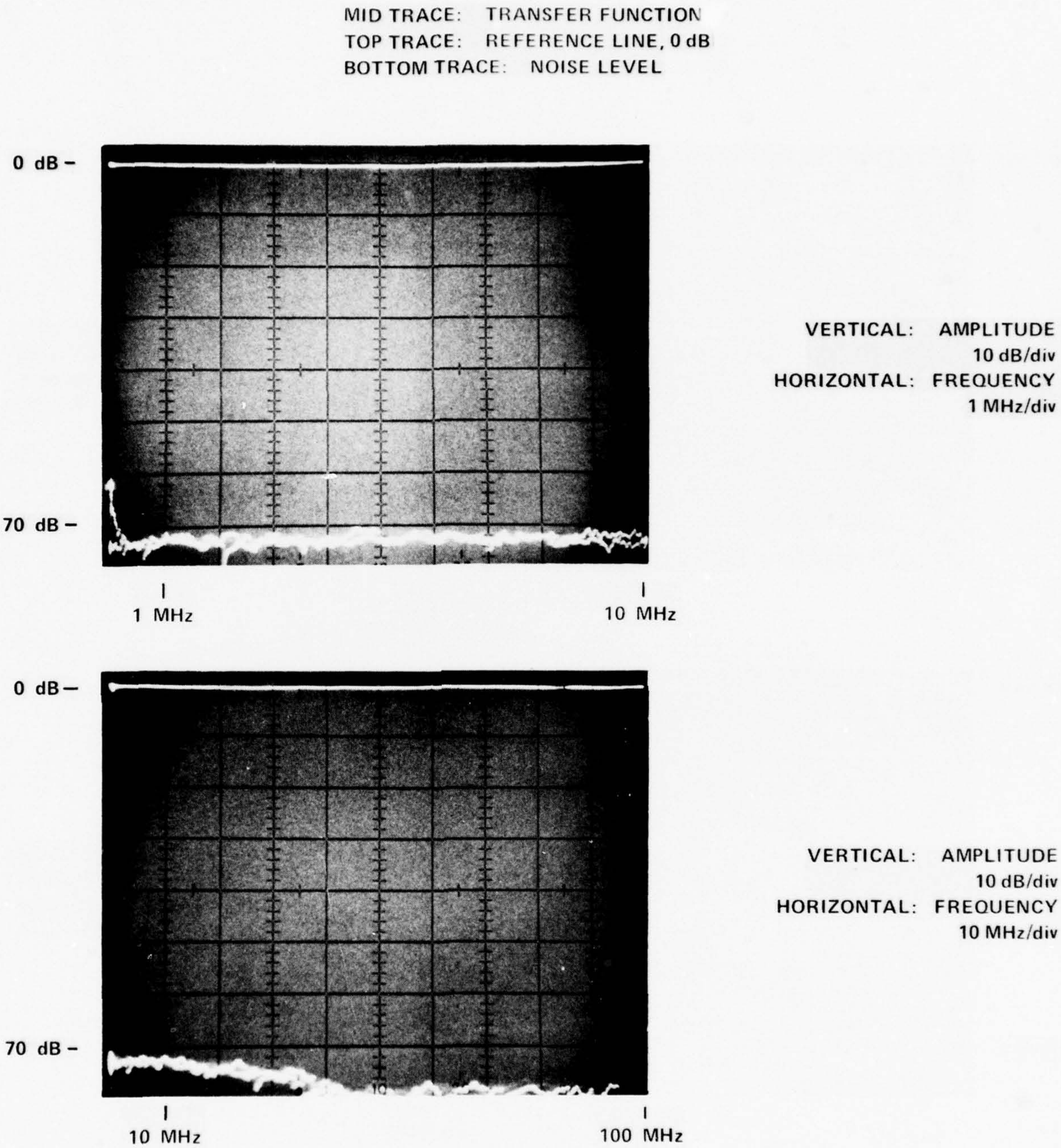


FIG. 22 - CURRENT AMPLITUDE TRANSFER FUNCTION. 360 DEGREE GROUNDING METHOD: SLIT TUBULAR BRAID WRAPPED AND CLAMPED AROUND STEEL KICK PIPE AND EXPOSED SHIELD OF RG-214 CABLE. BRAID SPECIFICATION; 30 GAUGE BY 9/16 INCH I.D. AS PER FED. SPEC. QQ-B-575a. DISTANCE BETWEEN CENTERS OF HOSE CLAMPS, ONE ON KICK PIPE AND ONE ON CABLE IS 1 5/8 INCHES.

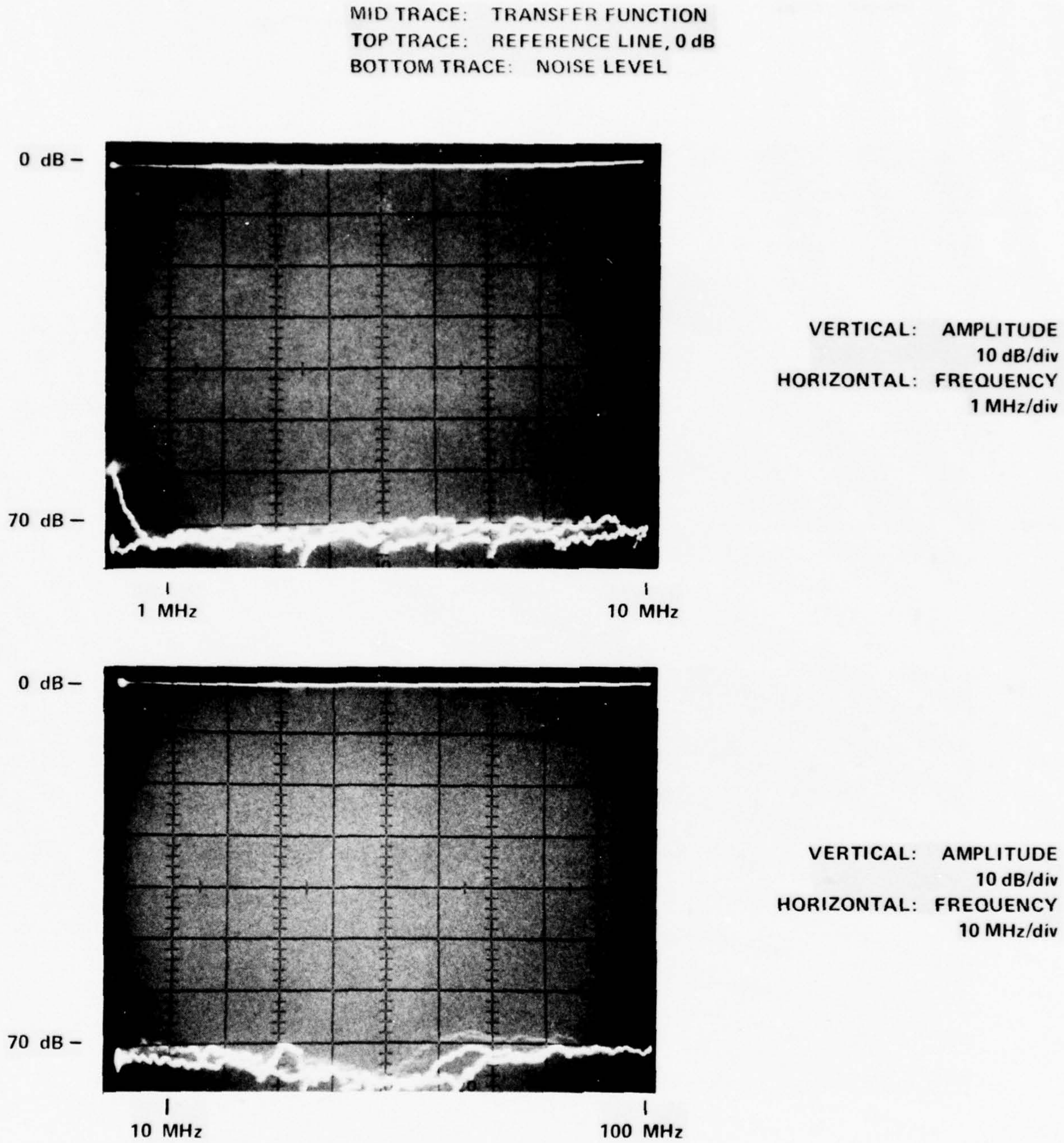
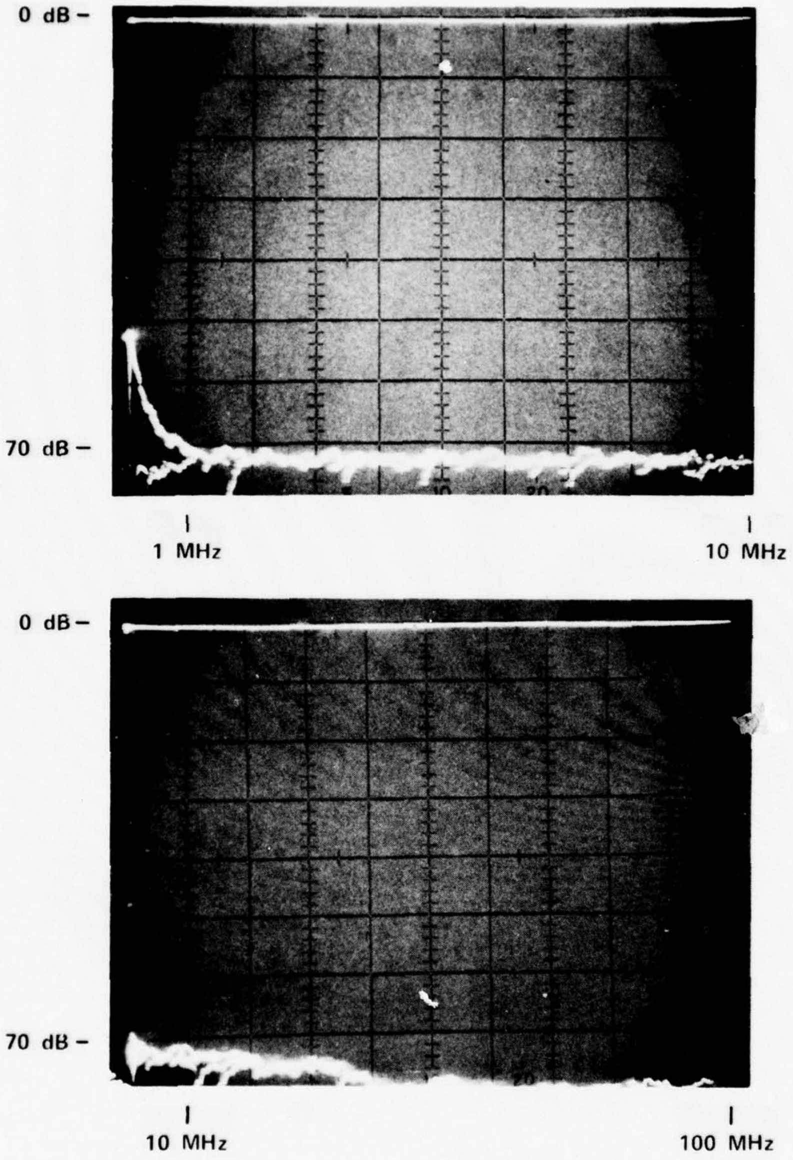


FIG. 23 - CURRENT AMPLITUDE TRANSFER FUNCTION. 360 DEGREE GROUND METHOD: SLIT TUBULAR BRAID WRAPPED AND CLAMPED AROUND ALUMINUM KICK PIPE AND EXPOSED SHIELD OF RG-214 CABLE. BRAID SPECIFICATION; 30 GAUGE BY 9/16 INCH I.D. AS PER FED. SPEC. QQ-B-575a.

MID TRACE: TRANSFER FUNCTION
TOP TRACE: REFERENCE LINE, 0 dB
BOTTOM TRACE: NOISE LEVEL

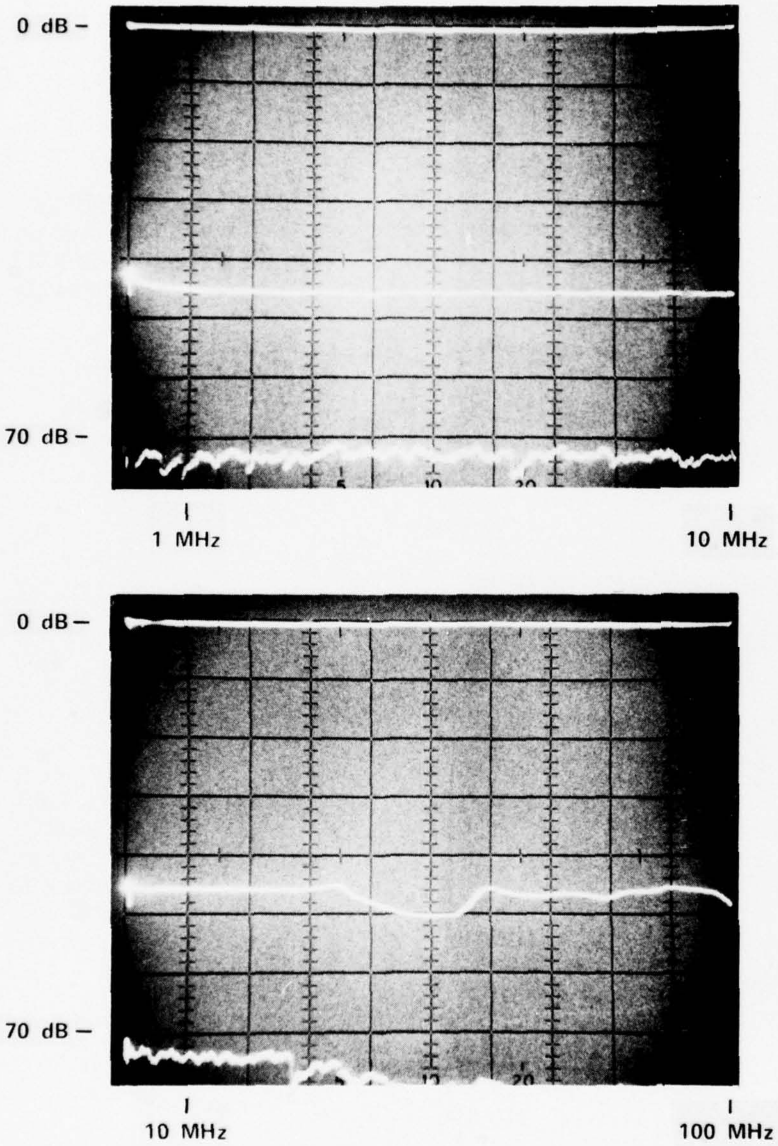


VERTICAL: AMPLITUDE
10 dB/div
HORIZONTAL: FREQUENCY
1 MHz/div

VERTICAL: AMPLITUDE
10 dB/div
HORIZONTAL: FREQUENCY
10 MHz/div

FIG. 24 - CURRENT AMPLITUDE TRANSFER FUNCTION. 360 DEGREE GROUNDING METHOD: TUBULAR BRAID HOSE CLAMPED AROUND STEEL KICK PIPE AND EXPOSED SHIELD OF RG-214 CABLE. BRAID SPECIFICATION; 30 GAUGE BY 9/16 INCH I.D. AS PER FED. SPEC. QQ-B-575a.

MID TRACE: TRANSFER FUNCTION
TOP TRACE: REFERENCE LINE, 0 dB
BOTTOM TRACE: NOISE LEVEL

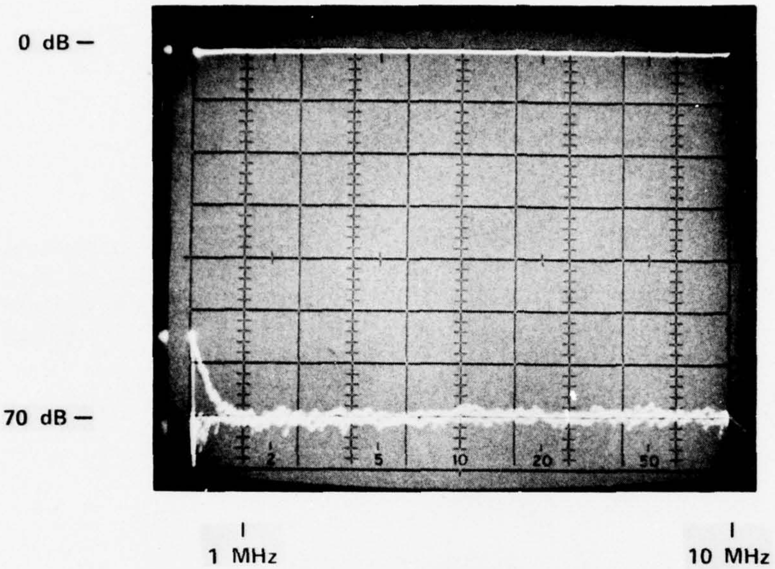


VERTICAL: AMPLITUDE
10 dB/div
HORIZONTAL: FREQUENCY
1 MHz/div

VERTICAL: AMPLITUDE
10 dB/div
HORIZONTAL: FREQUENCY
10 MHz/div

FIG. 25 - CURRENT AMPLITUDE TRANSFER FUNCTION. 360 DEGREE GROUNDING METHOD: FLATTENED TUBULAR BRAID SPIRALLY WRAPPED AND HOSE-CLAMPED AROUND STEEL KICK PIPE AND EXPOSED SHIELD OF RG-214 CABLE. BRAID SPECIFICATION; 30 GAUGE BY 9/16 INCH I.D. AS PER FED. SPEC. QQ-B-575a.

MID TRACE: TRANSFER FUNCTION
TOP TRACE: REFERENCE LINE, 0 dB
BOTTOM TRACE: NOISE LEVEL



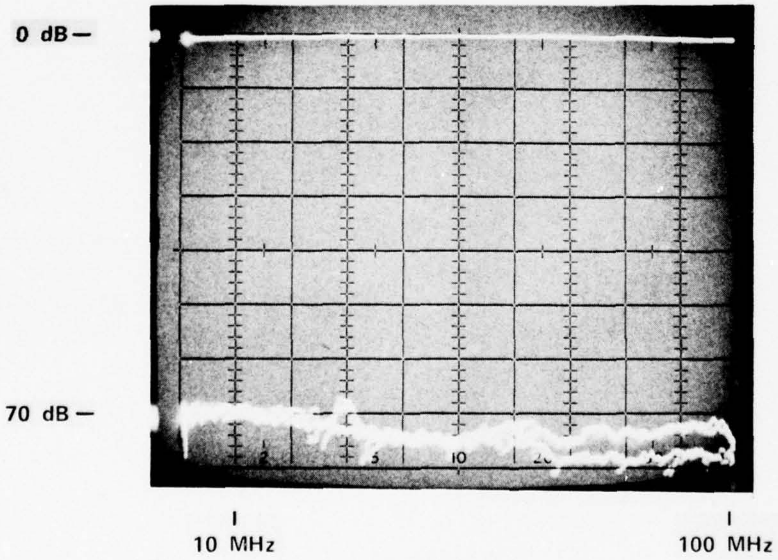
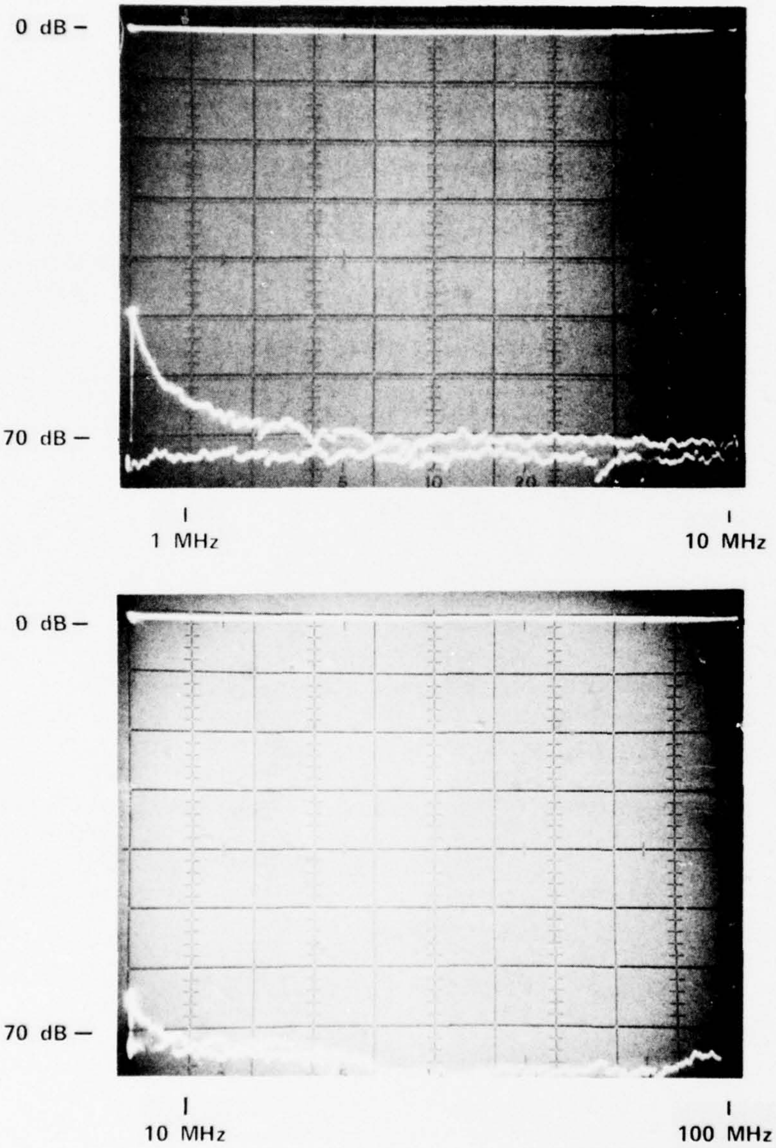


FIG. 26 - CURRENT AMPLITUDE TRANSFER FUNCTION. 360 DEGREE GROUNDING METHOD: SLIT TUBULAR BRAID, WRAPPED AND CLAMPED AROUND STEEL KICK PIPE AND EXPOSED SHIELD OF RG-214 CABLE. BRAID SPECIFICATION; 36 GAUGE, 1/2 INCH I.D. AS PER FED. SPEC. QQ-B-575a.

MID TRACE: TRANSFER FUNCTION
TOP TRACE: REFERENCE LINE, 0 dB
BOTTOM TRACE: NOISE LEVEL

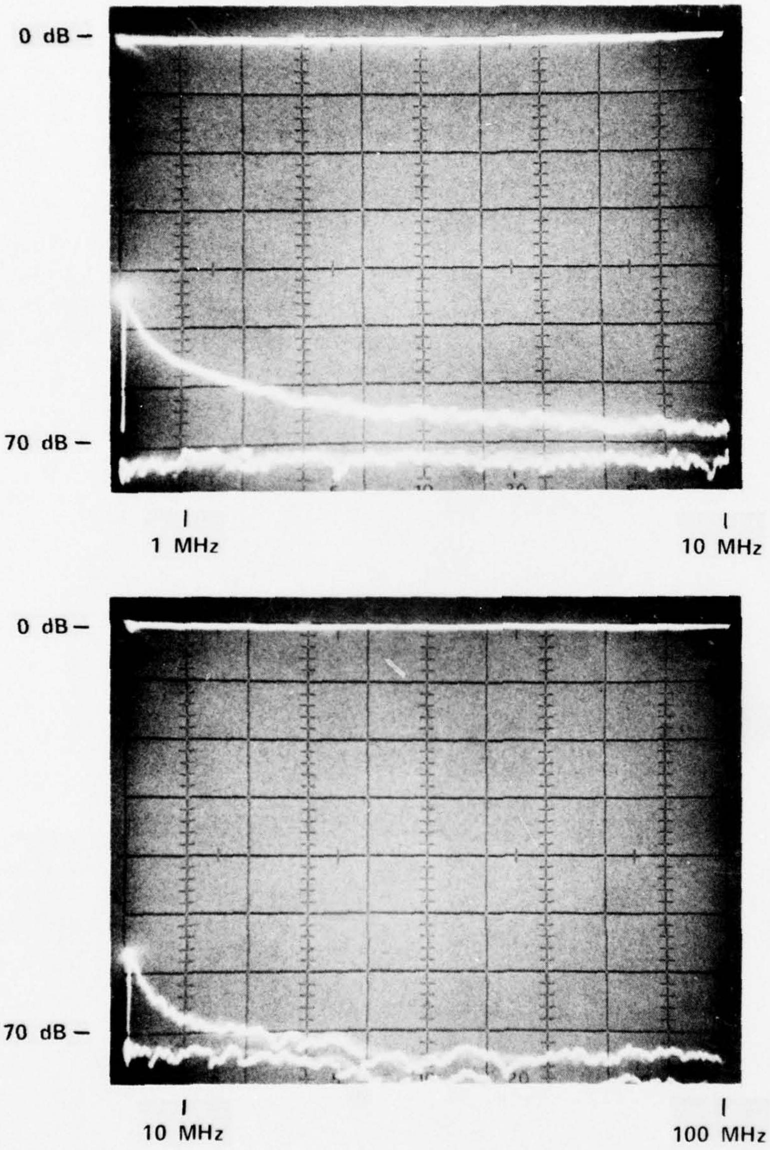


VERTICAL: AMPLITUDE
10 dB/div
HORIZONTAL: FREQUENCY
1 MHz/div

VERTICAL: AMPLITUDE
10 dB/div
HORIZONTAL: FREQUENCY
10 MHz/div

FIG. 27 - CURRENT AMPLITUDE TRANSFER FUNCTION. 360 DEGREE GROUNDING METHOD: SLIT COPPER CONE TAPED AROUND STEEL KICK PIPE AND EXPOSED SHIELD OF RG-214 CABLE. COPPER CONE FABRICATED FROM 1/16 INCH SHEET.

MID TRACE: TRANSFER FUNCTION
TOP TRACE: REFERENCE LINE, 0 dB
BOTTOM TRACE: NOISE LEVEL



VERTICAL: AMPLITUDE
10 dB/div
HORIZONTAL: FREQUENCY
1 MHz/div

VERTICAL: AMPLITUDE
10 dB/div
HORIZONTAL: FREQUENCY
10 MHz/div

FIG. 28 - CURRENT AMPLITUDE TRANSFER FUNCTION. 360 DEGREE GROUNDING METHOD: SLIT COPPER CONE WITH 1/8 INCH OVERLAPPED SLIT. COPPER CONE FABRICATED FROM 1/16 INCH SHEET AND TAPED AROUND STEEL KICK PIPE AND EXPOSE SHIELD OF RG-214 CABLE.

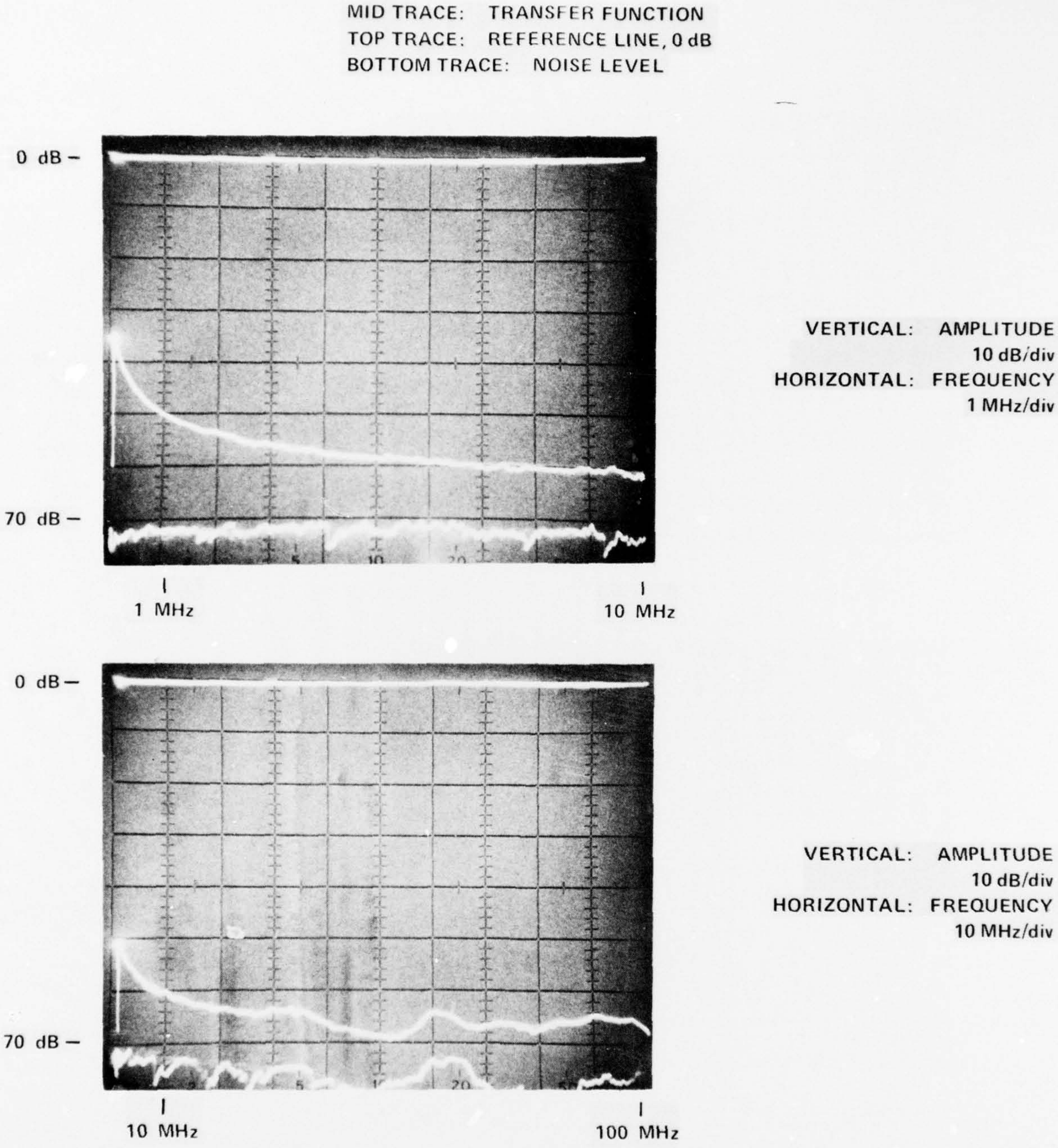
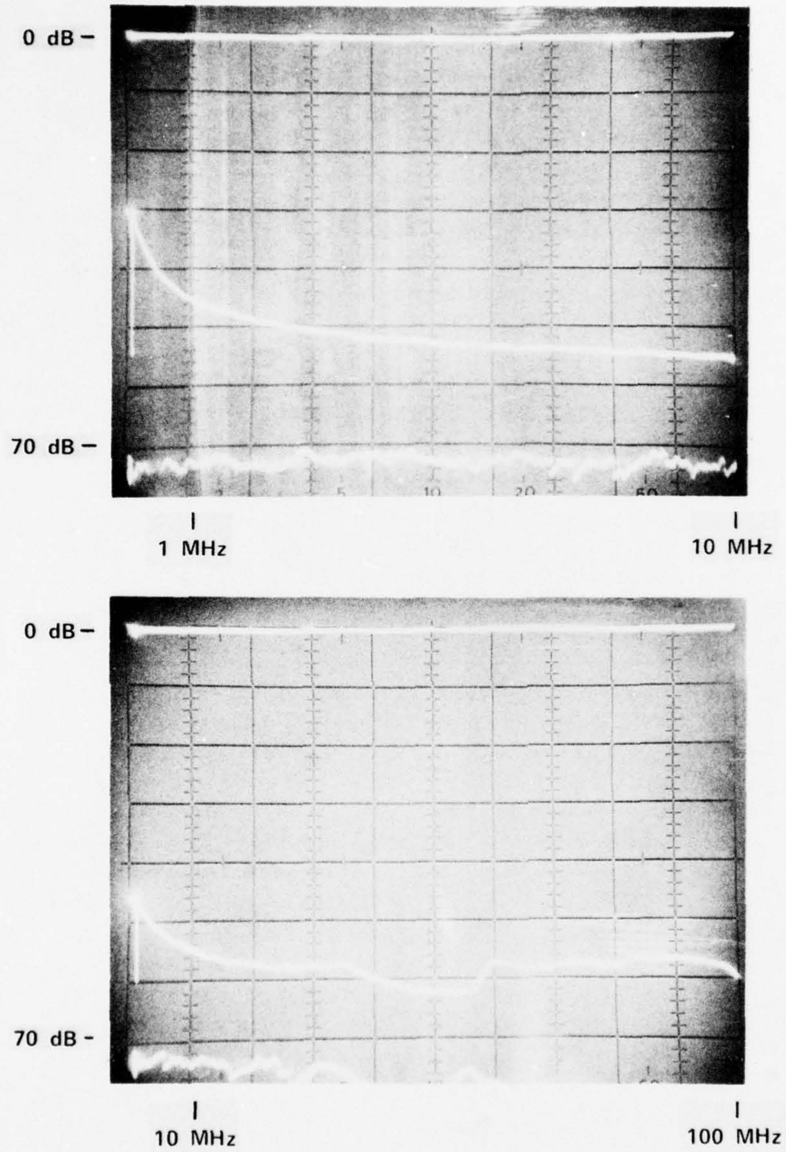


FIG. 29 - CURRENT AMPLITUDE TRANSFER FUNCTION. 360 DEGREE GROUNDING METHOD: KERN TYPE CONNECTOR THREADED INTO END OF STEEL KICK PIPE WITH GROUNDING SPRING VERY TIGHTLY COMPRESSED AROUND EXPOSED SHIELD OF RG-214 CABLE.

MID TRACE: TRANSFER FUNCTION
TOP TRACE: REFERENCE LINE, 0 dB
BOTTOM TRACE: NOISE LEVEL

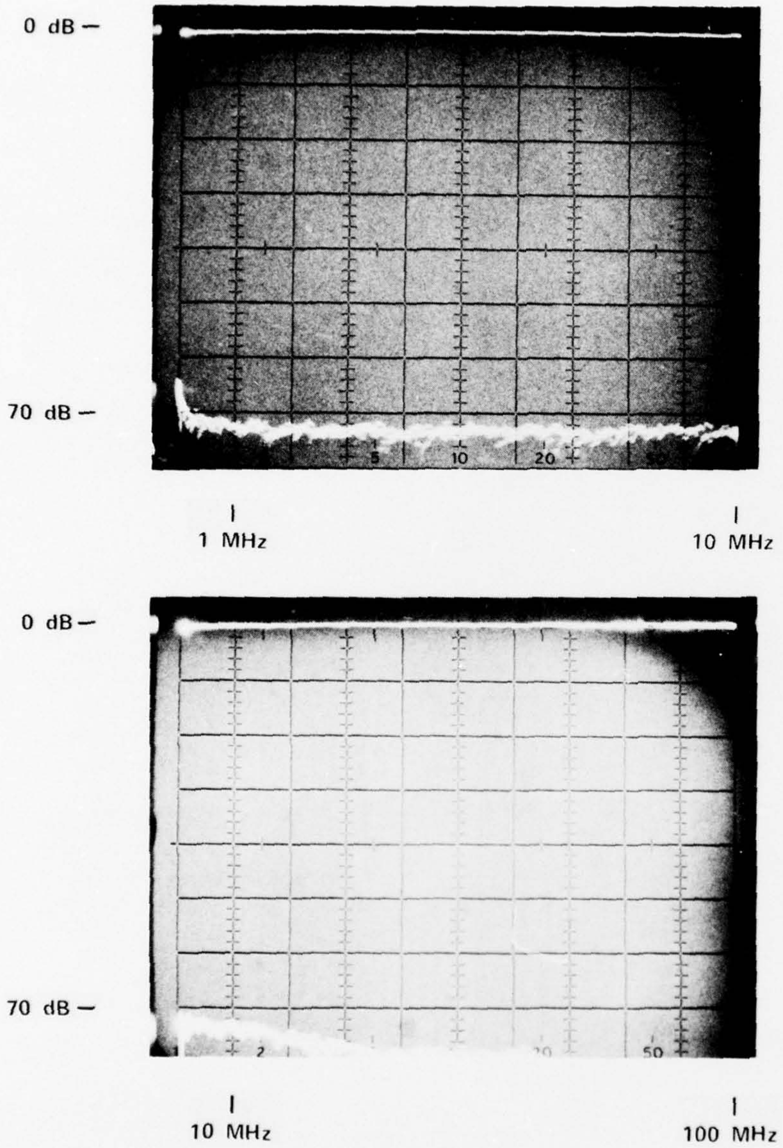


VERTICAL: AMPLITUDE
10 dB/div
HORIZONTAL: FREQUENCY
1 MHz/div

VERTICAL: AMPLITUDE
10 dB/div
HORIZONTAL: FREQUENCY
10 MHz/div

FIG.30 - CURRENT AMPLITUDE TRANSFER FUNCTION. 360 DEGREE GROUNDING METHOD: KERN TYPE CONNECTOR THREADED INTO END OF STEEL KICK PIPE WITH GROUNDING SPRING MODERATELY TIGHTLY COMPRESSED AROUND EXPOSED SHIELD OF RG-214 CABLE.

MID TRACE: TRANSFER FUNCTION
TOP TRACE: REFERENCE LINE, 0 dB
BOTTOM TRACE: NOISE LEVEL



VERTICAL: AMPLITUDE
10 dB/div
HORIZONTAL: FREQUENCY
1 MHz/div

VERTICAL: AMPLITUDE
10 dB/div
HORIZONTAL: FREQUENCY
10 MHz/div

FIG. 31 - CURRENT AMPLITUDE TRANSFER FUNCTION. 360 DEGREE GROUNDING METHOD: FLUSH MOUNTED, SPLIT CONE (PHOSPHOR-BRONZE). SIX (6) MOUNTING SCREWS INTO ALUMINUM DECK PLATE TO WHICH AN ALUMINUM STUFFING TUBE IS FLUSH WELDED. SMALLER FLARED ENDS OF SPLIT CONE HALVES ARE CLAMPED AROUND BARED RG-214 CABLE SHIELD WITH A SMALL HOSE-TYPE CLAMP.

MID TRACE: TRANSFER FUNCTION
TOP TRACE: REFERENCE LINE, 0 dB
BOTTOM TRACE: NOISE LEVEL

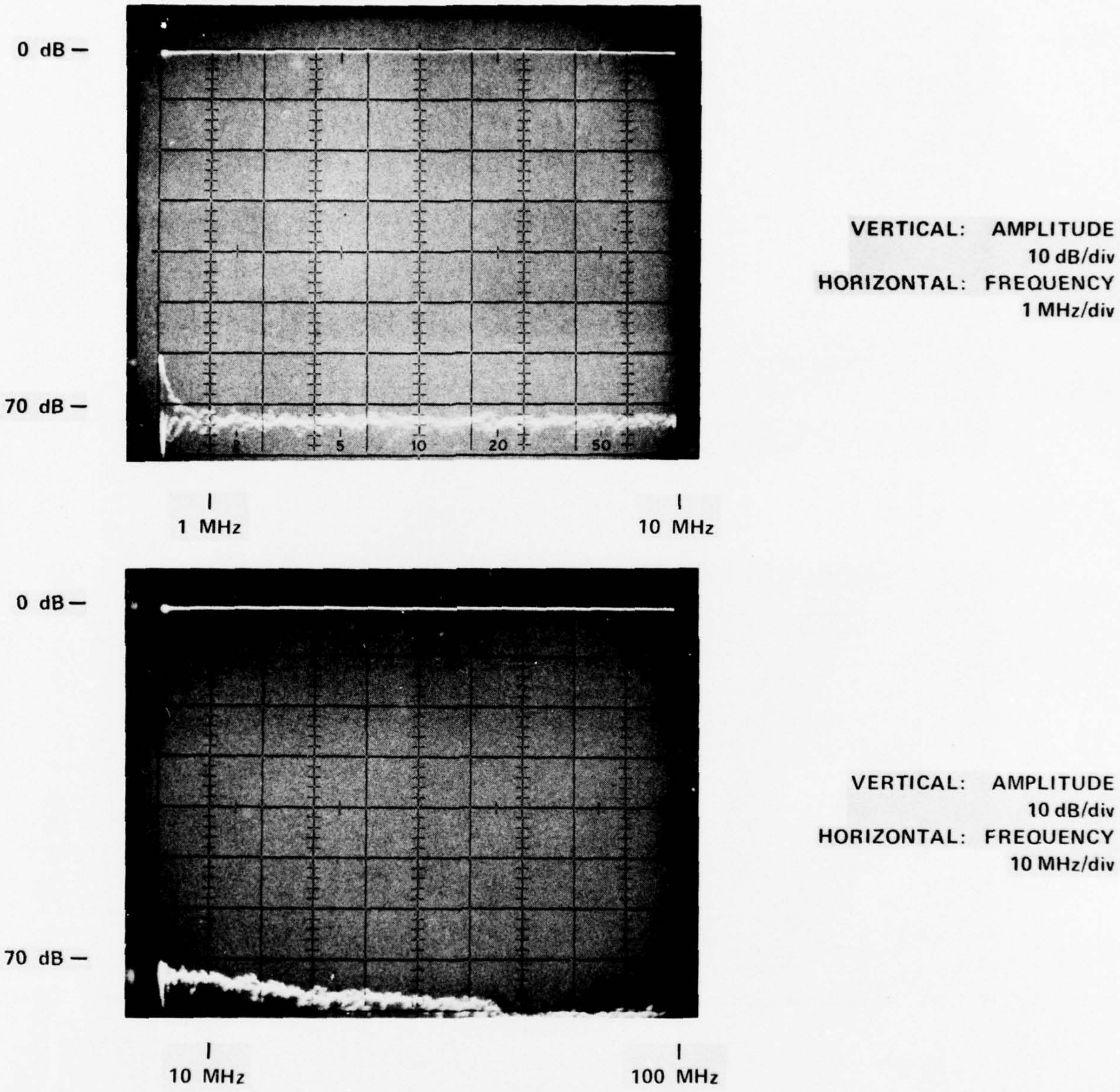
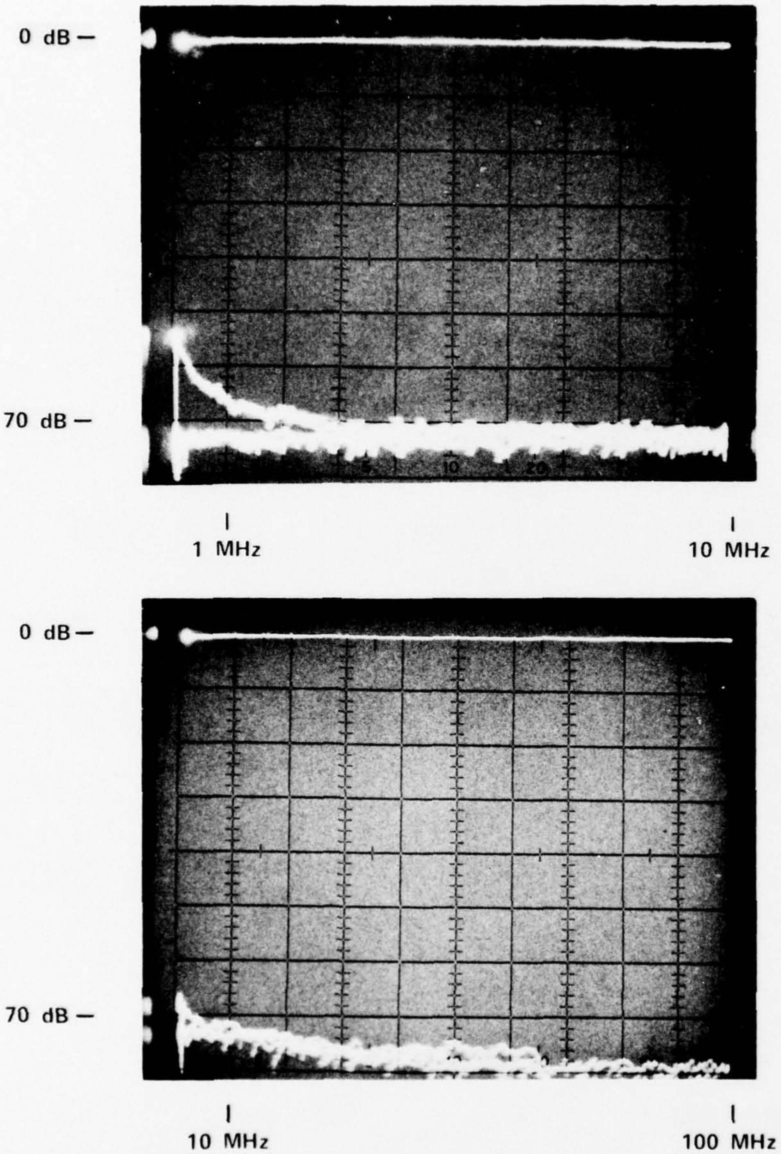


FIG. 32 - CURRENT AMPLITUDE TRANSFER FUNCTION. 360 DEGREE GROUNDING METHOD: FLUSH MOUNTED, SPLIT PHOSPHOR-BRONZE CONE, ALUMINUM DECK AND STUFFING TUBE. REMOVED HOSE-TYPE CLAMP AT SMALL END OF CONE. ELECTRICAL CONTACT TO BARED CABLE SHIELD BY PRESSURE ONLY OF 12 SPRING FINGERS CUT INTO FLARED ENDS OF CONE HALVES. TEST DEMONSTRATES SELF CLAMPING ACTION IS POSSIBLE WITH THIS METHOD.

MID TRACE: TRANSFER FUNCTION
TOP TRACE: REFERENCE LINE, 0 dB
BOTTOM TRACE: NOISE LEVEL

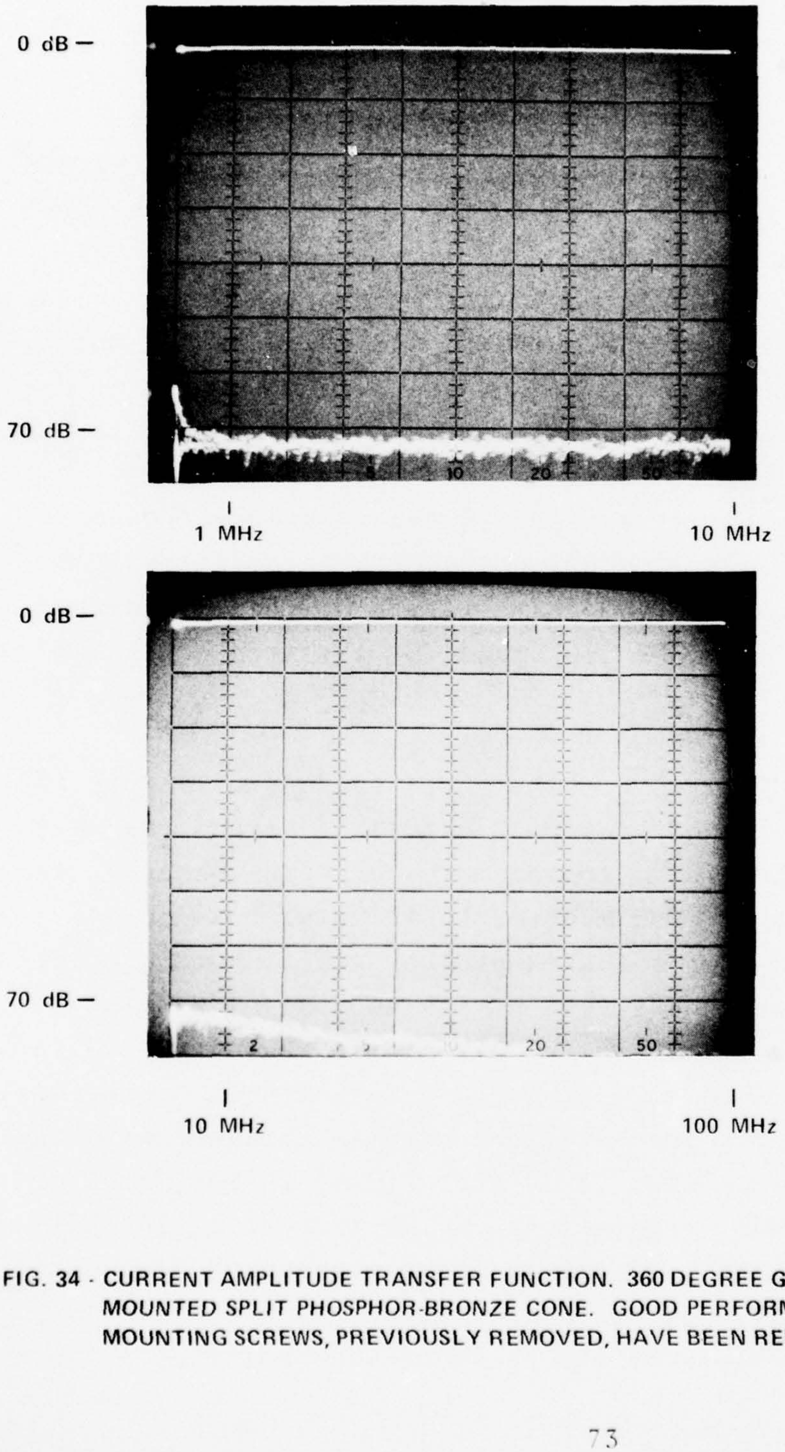


VERTICAL: AMPLITUDE
10 dB/div
HORIZONTAL: FREQUENCY
1 MHz/div

VERTICAL: AMPLITUDE
10 dB/div
HORIZONTAL: FREQUENCY
10 MHz/div

FIG. 33 - CURRENT AMPLITUDE TRANSFER FUNCTION. 360 DEGREE GROUNDING METHOD: FLUSH MOUNTED SPLIT PHOSPHOR-BRONZE CONE, SCREWED INTO ALUMINUM DECK PLATE AND FLUSH WELDED ALUMINUM STUFFING TUBE. HOSE CLAMP IN PLACE. TWO OF THE SIX MOUNTING SCREWS HAVE BEEN REMOVED. NOTE SLIGHT DETERIORATION OF PERFORMANCE AT THE LOWER FREQUENCIES, 0.1 MHz TO 3.5 MHz. IN ADDITION, THE SIGNAL BEGINS TO RISE OUT OF THE REMAINDER OF THE FREQUENCY RANGE TO 100 MHz.

MID TRACE: TRANSFER FUNCTION
TOP TRACE: REFERENCE LINE, 0 dB
BOTTOM TRACE: NOISE LEVEL



VERTICAL: AMPLITUDE
10 dB/div
HORIZONTAL: FREQUENCY
1 MHz/div

VERTICAL: AMPLITUDE
10 dB/div
HORIZONTAL: FREQUENCY
10 MHz/div

FIG. 34 - CURRENT AMPLITUDE TRANSFER FUNCTION. 360 DEGREE GROUNDING METHOD: FLUSH MOUNTED SPLIT PHOSPHOR-BRONZE CONE. GOOD PERFORMANCE IS RESTORED AFTER THE TWO MOUNTING SCREWS, PREVIOUSLY REMOVED, HAVE BEEN REPLACED.

described in the legend to Figure 25. The braid measurements in Figures 22, 23, 24, and 26 indicate that in the present experimental arrangement 70 dB or more of attenuation can be obtained over most of the frequency range from 0.1 to 100 MHz when using braid in the ways described in the legends of those figures.

COPPER CONE, 1/16 INCH SHEET. Figures 27 and 28 show that relatively good grounding performance can be obtained with the method indicated in Figure 19a. Curiously, the slit cone of 1/16 inch sheet copper gave better performance for the cone without overlap of the slit. Thus in Figure 27 we find better than 70 dB attenuation at all frequencies above 5 MHz, 60 dB at 0.5 MHz and 49 dB at 0.1 MHz.

KERN CONNECTOR. Figures 29 and 30 show the measured results obtained for the Kern connector. These results show that the grounding performance here is not as good as that for copper cone technique or most of the copper braid techniques. In addition it appears that the costs for parts and installation of the cone method and the slit braid method would be less than for the Kern connector method.

FLUSH-MOUNTED SPLIT METAL CONE. The three methods of Figure 19 rely on there being a section of kick pipe extending beyond the deck or bulkhead, onto which the braid, copper cone, or Kern connector can be clamped or threaded. The flush-mounted split metal cone method discussed here can be used when the kick pipe or stuffing tube itself is flush welded to the deck or bulkhead as is the case on most ships already built. The method discussed in this section and depicted in Figure 20 is suitable, therefore, for use as a retrofit on operational fleet ships. Figure 31 shows the excellent results obtained with this grounding technique: greater than 73 dB from 0.1 to 20 MHz, greater than 76 dB from 30 to 65 MHz, greater than 80 dB from 65 to 100 MHz. Figure 32 shows a very slight performance deterioration at frequencies below 0.5 MHz when the hose-type clamp is removed and electrical contact is made by the pressure of the phosphor-bronze spring fingers pressing against the bared cable braid. Figure 33 shows more deterioration of performance when two of the six deck mounting screws are removed. Figure 34 shows restoration of the excellent grounding performance after replacement of the two mounting screws removed for the test in Figure 33.

Stabilization of good electrical contact between the cone mounting flange and the deck or bulkhead might be achievable with fewer mounting screws by applying a conductive caulking (e.g., Emerson and Cuming, Inc. Eccoshield VY) to the cone-deck interface before mounting the cone to the deck with screws.

CONCLUSIONS

The tinned copper braid and the slit copper sheet cone, wrapped and clamped around the kick pipe and bared cable shield, showed better electrical grounding performance than the Kern connector over the frequency range from 0.1 MHz to 100 MHz. However, the braid wrapping procedure described in the legend of Figure 25 should be avoided.

The flush mounted, self clamping, split metal cone showed the best electrical grounding performance for all four grounding methods considered in this Part II series of tests. The latter method can also be used as a retrofit in situations where the kick pipe or stuffing tube has been flush welded to the deck or bulkhead leaving no extension beyond the deck for clamping.

The grounding devices of Part II can be readily inspected, are protected from salt-water spray and do not alter in any way the standardized method of weatherproofing entry points of cables.

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