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Leaky Coaxial Cable as a Transmitting Antenna for HEMP Shielding Effectiveness Testing

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MIL-STD-188-125 requires high-altitude electromagnetic pulse (HEMP)–shielded facilities to be tested at minimum 7-year intervals, or whenever a shield is modified in any way. This requires extensive measurements at many test points on all sides of a facility. The standard procedure is to position a transmitter and transmitting antenna at various points along the shield perimeter. This is labor intensive and repetitious. Further, in some cases it is extremely difficult to position transmitting antennas. Given the likelihood that these critical installations will have many decades of service life, these measurements will need to be repeated many times over the facility's life. The Army Research Laboratory, which has the mission to make such measurements at a variety of Department of Defense installations, is currently evaluating such a facility in which such measurements are unusually difficult. The military facility is underground and consists of several buildings placed in rock-walled tunnels. There is very little space between the tunnel walls and the building's walls, floor, and roof to maneuver transmitting antennas. A solution is being investigated in which the normal transmitting antennas, which are loops and bilogical arrays, may be replaced with leaky coaxial cables. These are coaxial cables with gaps in their shielding, which allows the center conductor to radiate. The cables therefore function as antennas, not transmission lines. They are broadband and normally used in wireless networking systems. Another common use is for communication systems in mining operations, an application not unlike the task in question. The cables are strung out longitudinally along the walls and floor of the facility, and testing is done by moving conventional receiving antennas inside the facility to the various test points along the cable, per the requirements of Appendix A, MIL-STD-188-125. Upon completion of testing, the cable antennas will be left in place for the next occasion of testing. They therefore have to be placed only once. We present the findings of the investigation of this new method for HEMP testing, as well as comparisons with more conventional testing also being done.

KEYWORDS: HEMP, Leaky coaxial cable, Testing

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1. Introduction

The HEMP Testing Team of the Directed Energy Branch of the Army Research Laboratory (ARL) has the Army mission of testing the shielding effectiveness of Army and other installations to ensure their ability to withstand a high-altitude electromagnetic pulse (HEMP). This is perhaps the most severe form of directed energy warfare, and protection against it is imperative to the national security. It is a broadband (10 kHz-1 GHz) radio frequency (RF) pulse generated by a nuclear device detonated at high altitudes (hundreds of miles) above the earth's surface for the sole purpose of disrupting electronic devices; blast and radiation effects on surface targets from a device at that altitude are negligible. Critical military installations must be protected from such effects. The hardening of such structures and the testing of them for compliance are covered by military handbook MIL-HNBK-423[2] and military standard MIL-STD-188-125.[3]

The standard calls for testing of a given facility every 7 years.[3] Modification to any portion of a facility shield requires that that portion be tested upon completion of the modification, in order to certify that the shield remains in compliance. Appendix A of this Military Standard describes the testing procedure in detail. ARL exceeds this standard, and our procedures are summarized as follows.

The Military Standard calls for the spacing of test frequencies to be logarithmic within each decade with a minimum sampling density as follows:

- 10–100 kHz: 20 test frequencies
- 100 kHz–1 MHz: 20 test frequencies
- 1–10 MHz: 40 test frequencies
- 10–100 MHz: 150 test frequencies
- 100 MHz–1 GHz: 150 test frequencies

The dynamic range at each test frequency is required to be at least 20 dB in excess of the shielding requirement at each test frequency, i.e., 100 dB for the 80-dB threshold being addressed.

Shielding is considered satisfactory when both of the following criteria are met:

a. No sequence of measurements occurs at three consecutive frequencies with the measured shielding effectiveness below the minimum requirements curve.
b. No more than 10% of the measurements in any decade are below the minimum requirements.

ARL performs this procedure not only on Army installations but often on facilities of other armed services and other government agencies.

Two sets of calibration data were collected: low-frequency (10 kHz–20 MHz) and high-frequency (20 MHz–1 GHz) RF calibration data. These low- and high-frequency calibration data were collected using RF network analyzers with appropriate frequency ranges. A total of 802 test frequencies were sampled for the 10-kHz–20-MHz and 20-MHz–1-GHz RF spectra. The sample frequencies are distributed logarithmically. Resolution bandwidth, set at 10 Hz, results in a sweep time of about 42 s for each data set. Data were averaged over a minimum three sweeps to reduce spurious noise spikes.

The testing apparatus consists of illumination and receiving components, shown in Fig. 1. Two antennas, one for illumination (transmitting) and one for receiving, are positioned on either side of the shield section to be tested, with a 10-ft separation between them. A network analyzer inside the shield sweeps through the test frequencies and outputs this

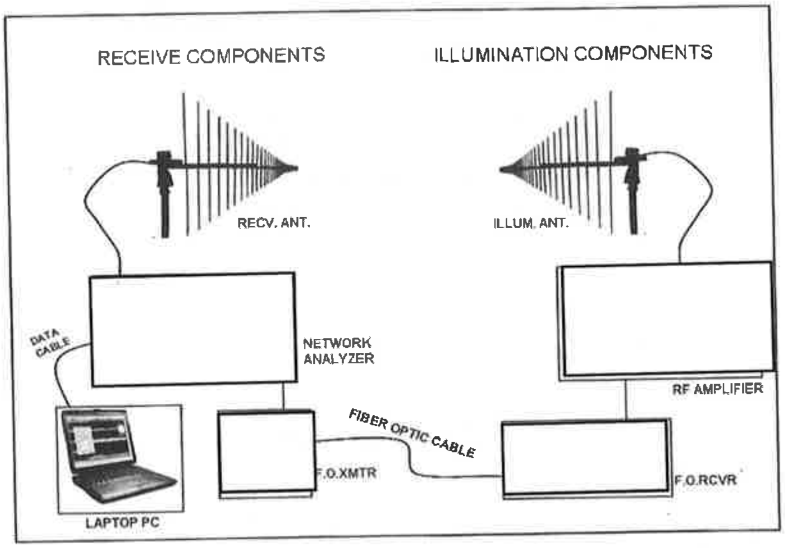


Fig. 1. Typical test setup, for high frequency. Low frequency is similar.

signal via fiber optics to an RF amplifier outside the shield, which amplifies the signal and feeds it to the illuminating antenna, which transmits it toward the shield. A receiving antenna inside the shield receives the attenuated signal and inputs it back to the network analyzer, which plots the signal as a function of the sweep frequency. We are currently unable to sweep the entire band of 10 kHz–1 GHz with one set of equipment. Normally, we sweep low frequencies (10 kHz–20 MHz) with a low-frequency network analyzer and loop antennas and the higher frequencies with a high-frequency network analyzer and bilogical antennas, with two orthogonal polarities tested for each frequency range at each test point. The latter antennas are a combination of a biconical loop and a log periodical antenna and cover a very high bandwidth. They do present a problem with regard to size, however.

2. The Problem

ARL has been called upon to test HEMP shielding effectiveness of a multiservice installation vital to the national defense. Because of the critical nature of this facility, the authors will not divulge its name, location, or function. It will be referred to subsequently as the Facility. The details are outside the scope of this work and do not directly relate to the technical discussion to follow.

The Facility is highly secure and is located deep underground. It consists of several multistory buildings in a series of rock tunnels. Between the building floor and the tunnel floor is a crawl space with a clearance of approximately 5 ft. Between the tunnel walls and the building walls, the clearance is even smaller, approximately 2 ft. This confined space is further exacerbated by the number of test points predicated by the building size, approximately 100. Because we test for two polarities for two sets of frequencies, this amounts to approximately 400 measurements. To survey the walls and floors of this facility would be difficult in some areas, impossible in others, and tedious overall. A solution was sought to replace relatively large antennas with compact antennas that would not need to be moved in a confined space once they were installed.

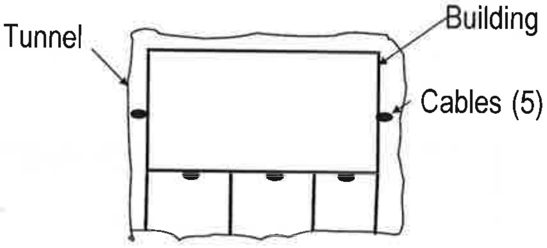


Fig. 2. Schematic of building in tunnel with leaky coaxial cables positioned along the floor and walls. Side wall cables are positioned at the vertical midpoint of the walls of the room under test. Floor cables are 10 ft apart.

3. The Solution

We solved this problem by replacing the standard loop and bilogical illuminating antennas with leaky coaxial cable. This is a coaxial cable with a slot or slots cut into the shield to allow RF to escape, thus turning the cable into an antenna. This type of cable is used extensively to provide communications in transportation tunnels and mines and has been extensively reported in the substantial literature.[4,7] This is the first application, to our knowledge, of this component as a transmitting antenna for this particular application. We are going to install a series of cables adjacent to the building at the Facility in a manner shown in Fig. 2. The cables will be on insulated standoffs mounted on the underside of the building floor and the sides of the first floor of the building. This will allow testing of the walls and floor of a room on the bottom floor of the building. The room's ceiling is easily accessible from the floor above, and conventional methods will be used to test the room's ceiling.

4. Testing Procedure

As previously stated, we will be testing over a low-frequency and a high-frequency band, with different receiving antennas and signal sources for each band. The only major difference in equipment configuration is the use of the leaky cable as an illumination antenna. The new system is shown in Fig. 3.

We have tested a sample cable in our Electromagnetic Research Facility at ARL. This large, mostly nonmetallic building was constructed for the purpose of testing sample systems for RF interactions. Our test setup is shown in Fig. 4. Calibration results are shown in Figs. 5–8, for both high and low frequencies, each at two orthogonal polarities. Signal strength is shown on the vertical axes as a function of frequency on the horizontal axes.

The test cable is approximately 30 ft long, with test points at the 5-, 15-, and 25-ft marks from the fed end. It has a 50 Ω impedance and is terminated at the free end with a 50 Ω termination. Performance is satisfactory above 1 MHz and acceptable below 1 MHz. Complete results of these tests are detailed in Ref. 1. The installed cable will be 150 ft long. Calibration will be done at each test point, to account for any attenuation due to cable length.

A key concern was the variability of the radiation pattern of the leaky cable at various points along its length. Intuitively, the radiation pattern from this type of cable should be unidirectional, in that the shield is open on only one side and the center conductor is shielded on the opposite side. Sinclair,[6] building on work by Schelkunoff,[5] shows that the radiation pattern is indeed omnidirectional, provided that the wavelengths of the operating

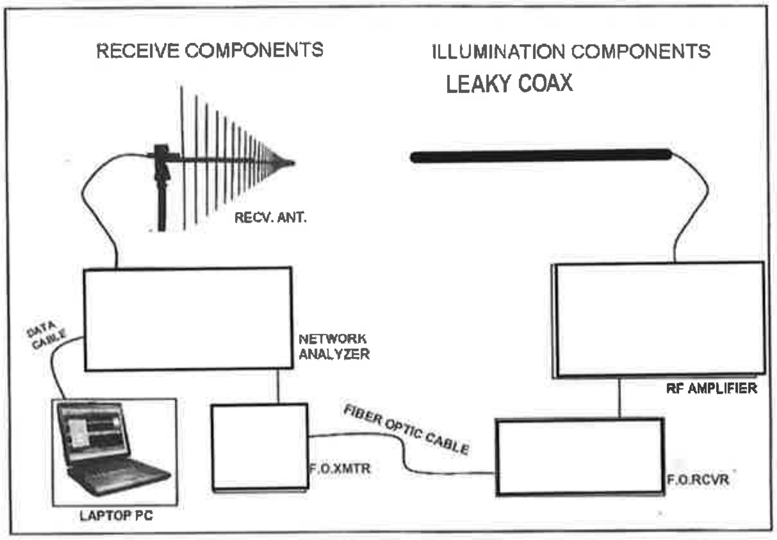


Fig. 3. Modified test setup showing the use of leaky coaxial cable as an illumination antenna. The high-frequency configuration is shown; low frequency is similar but uses the same leaky coaxial cable as an illumination antenna.

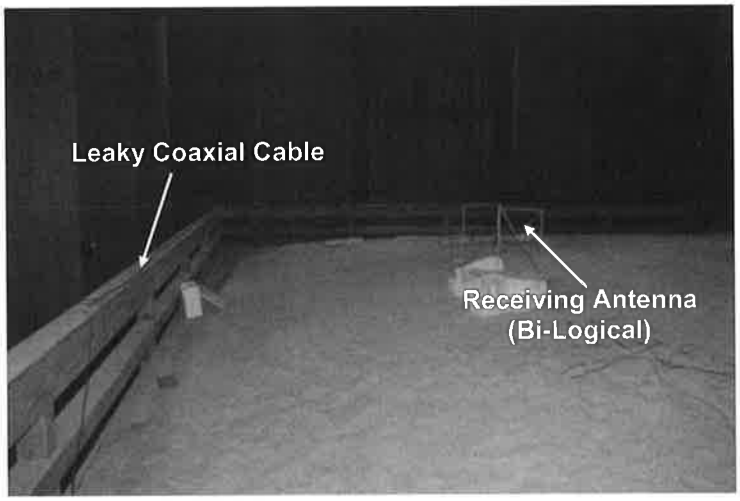


Fig. 4. Test setup in Electromagnetic Research Facility, high frequency, with bilogical antenna at right and leaky coaxial cable along railing at left. Low frequency is similar, utilizing a loop antenna instead of a bilogical.

frequencies are greater the wavelength of the cutoff frequency of the cable. The wavelength of the cutoff frequency in this case is twice the width of the shield gap. The shield gap is approximately 10 mm, so the cutoff wavelength is 20 mm. Our highest frequency was 1 GHz, so the minimum wavelength was 300 mm, an order of magnitude greater than the cutoff frequency. We did not see any significant variation in signal strength at various points along the cable. Because a cable of such a length would inevitably twist, a cable

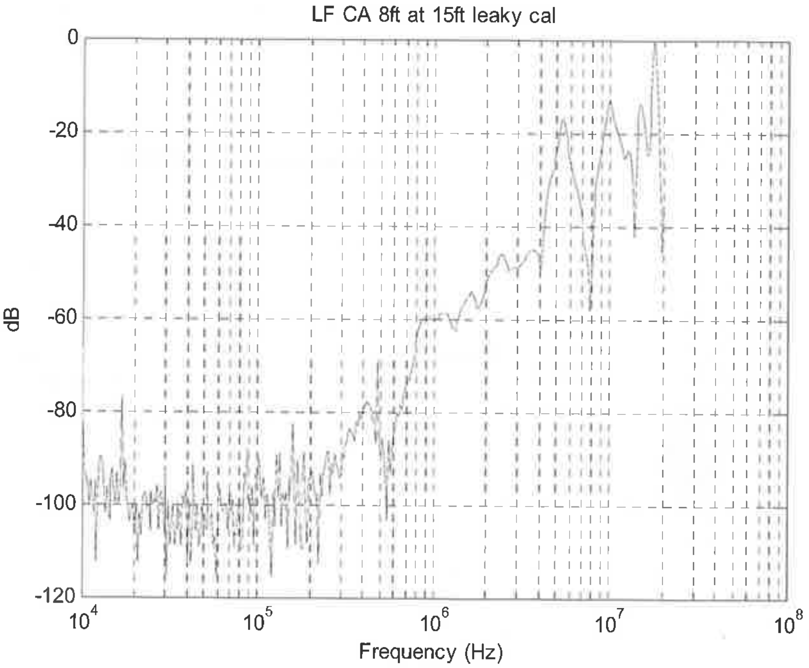


Fig. 5. Low frequency, 15 ft from fed end, coaxial (loop antenna axis perpendicular to cable).

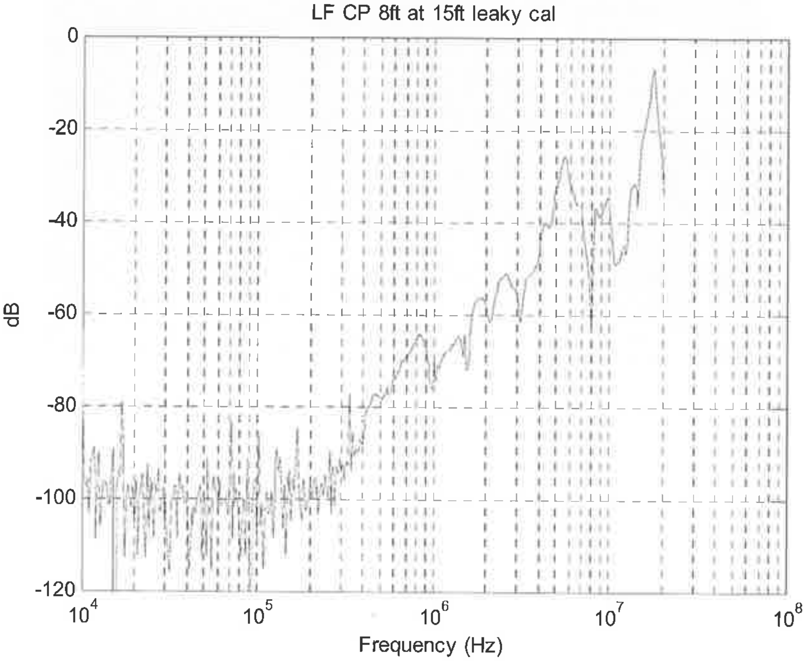


Fig. 6. Low frequency, 15 ft from fed end, coplanar (loop antenna axis parallel to cable).

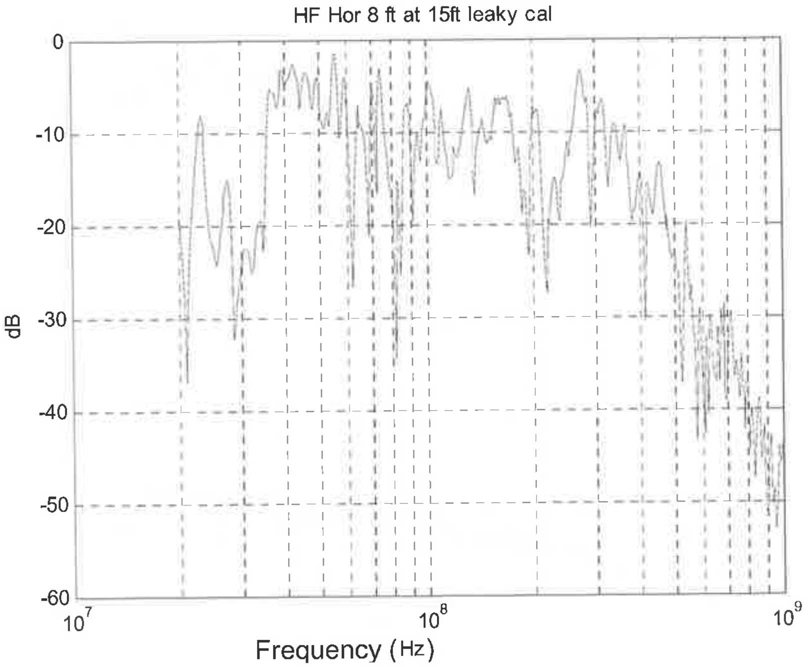


Fig. 7. High frequency, 15 ft from fed end, antenna elements parallel to cable. Characteristic bilogical "two hump" is clearly visible.

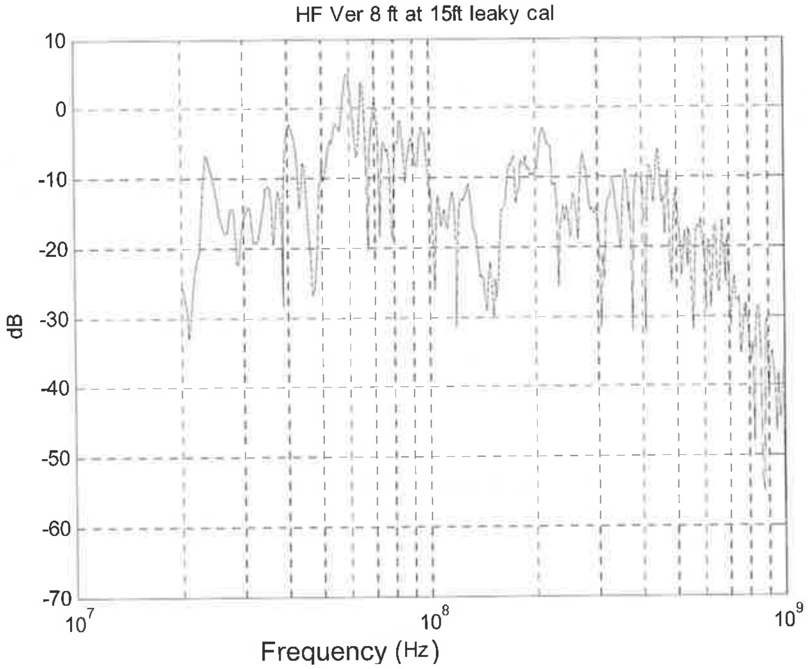


Fig. 8. High frequency, 15 ft from fed end, antenna elements perpendicular to cable. Characteristic bilogical "two hump" is clearly visible.

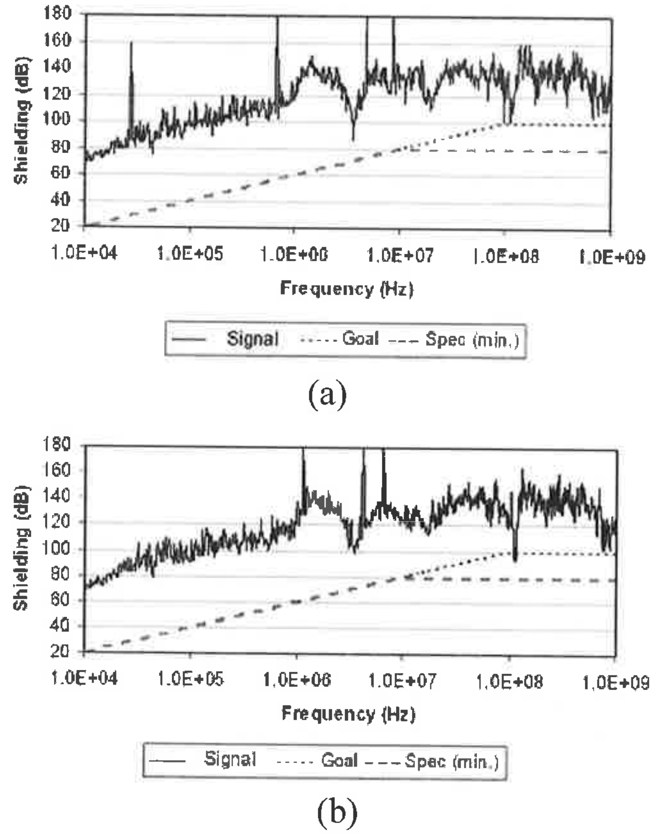
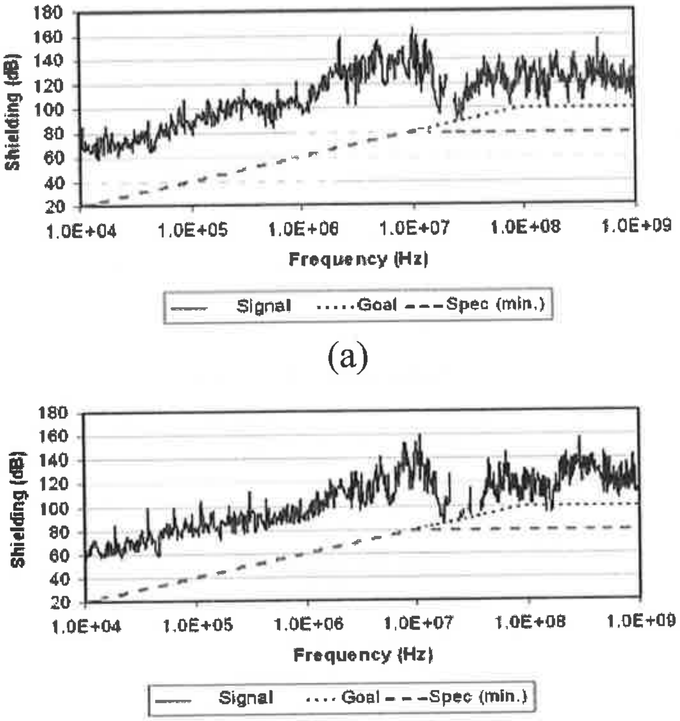


Fig. 9. (a) Facility floor results for the 15-ft mark from the fed end of the leaky cable. The low-frequency receiving antenna was coaxial (axis perpendicular to cable), and the high-frequency receiving antenna's elements were transverse to the cable. Spikes in the attenuation appear to be digitizing artifacts and have no effect on the overall merit of the measurement. (b) Facility wall results at a point adjacent to the previous floor measurements, using conventional antennas. Low-frequency loop antennas were arranged coaxially, and the high-frequency bilogical antennas' elements were in the horizontal plane.

not possessing an omnidirectional pattern would definitely exhibit large variations in signal strength at various points along the cable. We therefore concluded that the radiation pattern is indeed omnidirectional.

5. Facility Results

We then proceeded to perform measurements at the Facility using the same cable. We made measurements through the floor at the 5-, 15-, and 25-ft marks from the fed end of the cable, using a loop receiving antenna for low frequency and a bilogical receiving antenna for high frequency. Separations between the leaky coaxial antenna and the receiving antennas were each 8 ft, which exceeds the requirements of the standard, in that the illumination intensity is more intense over the shorter distance. We had the opportunity to test an adjacent wall of the facility near the point of the previous test. This was done using conventional



(a)

(b)

Fig. 10. (a) Facility floor results for the 15-ft mark from the fed end of the leaky cable. The low-frequency receiving antenna was coplanar (axis perpendicular to cable), and the high-frequency receiving antenna's elements were longitudinal to the cable. Note similar spikes as in Fig. 9. (b) Facility wall results at a point adjacent to the previous floor measurements, using conventional antennas. The low-frequency loop antennas were arranged coplanar, and the high-frequency bilogical antennas' elements were in the vertical plane.

methods. The shielding is the same for both the floor and the wall. Therefore, a valid comparison between the two methods is possible, even though different surfaces were tested. Comparative results for the 15-ft mark are shown in Figs. 9 and 10. Shielding attenuation is on the vertical axis. It is calculated by taking the difference between the measured signal through the shield and the higher intensity calibration signal. For a facility to pass testing as prescribed by MIL-STD-188-125, attenuation must exceed the level shown by the "Spec" line. At the higher frequencies, we hold to a higher standard in our testing, shown as the "Goal" line. In both cases, this particular floor point exceeded the requirements over the range of frequencies. Points corresponding to the 5- and 25-ft points showed similar results. Note the similarities between these results and those for the leaky coaxial cable.

6. Conclusion

We are confident that valid measurements may be made using leaky coaxial cable for an illuminating antenna for both high and low frequencies. This will result in easier measurements, both in the near term and especially in the far term. In the near term, the illuminating antennas will be placed once and left in place, as opposed to the present practice, which requires that illuminating antennas be moved to a different location for each set of measurements and different illumination antennas be used for low and high frequencies. In the far term, after the initial round of measurements, the leaky coaxial cable will be left in place for the next round of testing, eliminating entirely the necessity of placing illuminating antennas. Calibration will be necessary for each set of measurements. A duplicate cable will be left on site and used to calibrate the set of transmitting cables with the receiving antennas each time a set of measurements is made._In each case, a significant amount of labor and overall time will be saved.

7. Acknowledgment

The authors wish to express appreciation to David Conrad, recently retired lead technician for the Directed Energy Branch of the ARL, for suggesting the use of a leaky coaxial cable as a transmitting antenna for this type of testing.

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