TECHNIQUES FOR SHIELDING MEASUREMENTS FOR WIRE AND CABLE — AN OVERVIEW

INTRODUCTION

The effectiveness of a shield on an interconnecting cable has become an important consideration in understanding the total electromagnetic radiation from a computer system as well as the susceptibility of that system to electromagnetic radiation. Since most EMI specifications are total system specifications, the ability to predict shield effectiveness for a cable shield is important to the total system radiation and susceptibility.

Many measurement techniques exist to predict the radiation emitted from a cable. Each technique has its own strengths and weaknesses. This paper analyzes several methods of measurement in some detail and shows measurements with each method in order to determine if there exists correlations between the measurements of each.

The goal of any measurement technique is to make repeatable, useful measurements. EMI measurements have become more widely used in recent years to specify and correlate system behavior. Each EMI engineer has a preferred technique, and correlation of one measurement with another is seldom, if ever, attempted. Some of the popular techniques include open field test site measurements, shielded chamber measurements, transfer impedance measurements, SEED* measurements, and measurements of shield current.

In order for the measurements to be correlated we have taken all of the measurements using a single twisted shielded pair. The wires are #24 AWG (7 strands of #32 AWG tinned copper) insulated with .010″ polyvinyl chloride. The pair is twisted with a 2″ left hand lay, and wrapped with an aluminum/polyester tape in a "Z" fold configuration as shown in Figure 1. The drain is also #24 AWG (7 strands of #32 AWG tinned copper.)

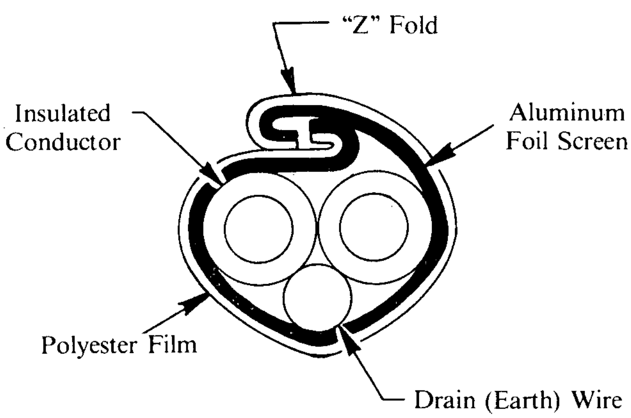

Figure 1. Test Pair.

*SEED = Shielding Effectiveness Evaluation Device — Belden Corporation.

The shielding effectiveness of a cable shield is made up of several terms, all of which contribute to the radiation through a cable shield. As a practical matter the effectiveness of every shield can be defined as;

$$SE(EMC) = 20 \log \frac{\text{Field Magnitude (without shield)}}{\text{Field Magnitude (with shield)}}$$

which is expressed in dB of effectiveness.

OPEN FIELD TEST SITE MEASUREMENTS

This technique, specified by the FCC as the method for qualifying systems to Part 15, Subpart J, is the scheme most commonly employed when systems are to be measured. Measurements made in an open field test site on the actual cable result in meaningful readings only if the test site has passed the FCC site attenuation specification. The FCC specifies an acceptable test site in terms of the attenuation that a known signal undergoes when being transmitted from one calibrated antenna and received by another calibrated antenna at a known distance. If the attenuation in a given test site is less than or equal to that specified by the FCC, then the site is considered to be appropriate for the required measurements. The open field test site specified by the FCC in Measurement Procedure 4 (MP-4) is shown in Figure 2.

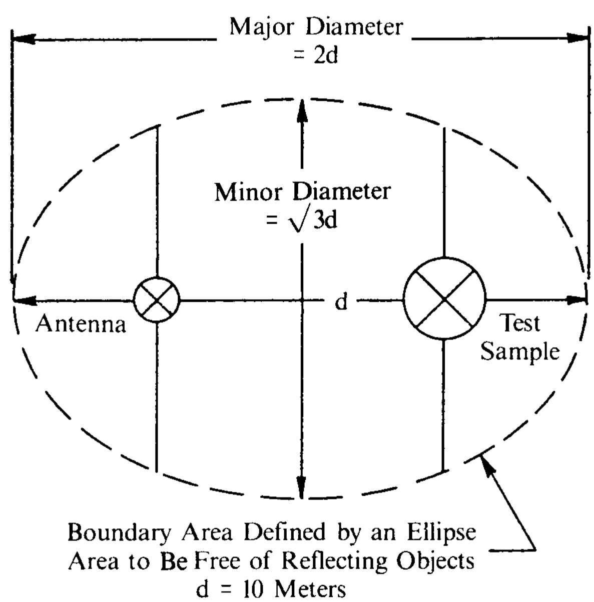

Figure 2. Open Field Test Site.

The site attenuation curves for the Mercury Wire Products' site are shown compared with the FCC requirements in Figure 3.

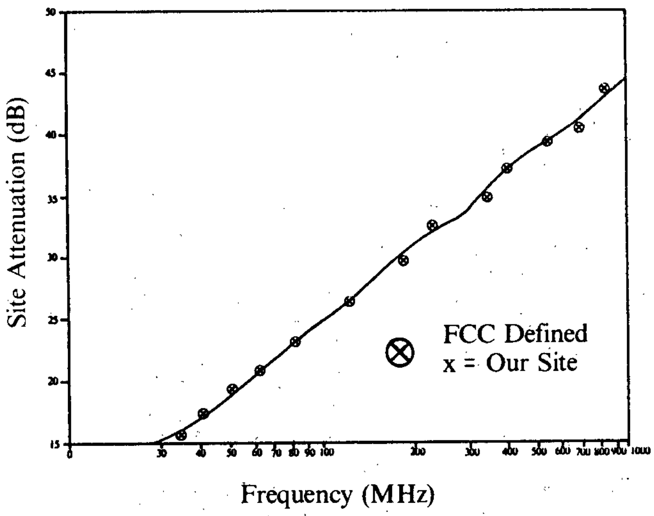

Figure 3. Site Attenuation Curve.

A point by point measurement of the test cable showing the shielding effectiveness of the aluminum/polyester shielded pair measured in the open field test site is shown in Table 1. Since open field measurements are those most commonly used at the present, these measurements will become our benchmark against which we will compare all of our other measurements.

Frequency (Hz)	Shielding Effectiveness (dB)
500 K	23
1 M	20
5 M	33
10 M	36
15 M	43
20 M	46
30 M	51
100 M	23

Table 1. Shielding Effectiveness of Aluminum Polyester Shielded Pair.

SHIELDED CHAMBER MEASUREMENTS

In order to have measurements in a shielded chamber be meaningful, measurements of an unshielded cable must first be made. When measurements of a shielded cable are subtracted point by point from those of an unshielded cable, the result will be the shielding effectiveness of the shielded cable.

One hazard that exists in all shielded chamber measurements is that of internal reflection within the test chamber. If internal reflections exist, then a distorted picture of the shielding of the cable will be presented. Figure 4 shows the test set-up for these measurements.

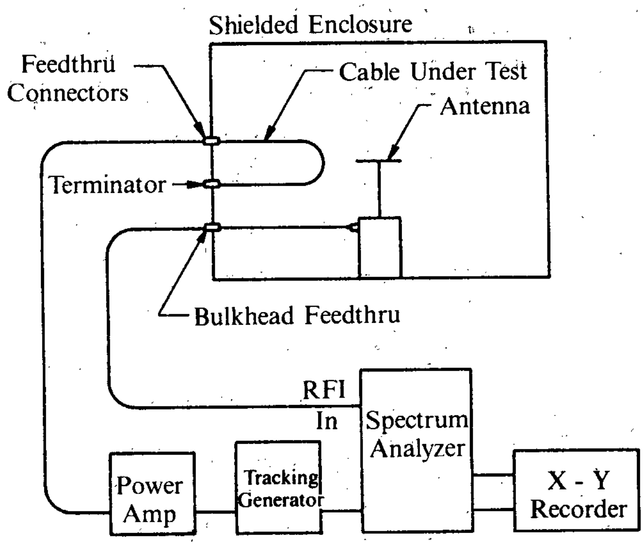

Figure 4. Test Set-Up.

Raw data for the shielded chamber measurements is shown in Figure 5.

A point by point tabulation of the results is shown in Table 2.

Frequency (Hz)	Measurements: Unshielded Cable (dB)	Measurements: Shielded Cable (dB)	Shielding Effectiveness (dB)
100 K	45	75	30
500 K	44	71	27
1 M	38	74	36
5 M	23	62	39
10 M	16	63	47
15 M	10	60	50
20 M	5	48	43
30 M	18	72	54
100 M	10	58	48

Table 2. Test Results.

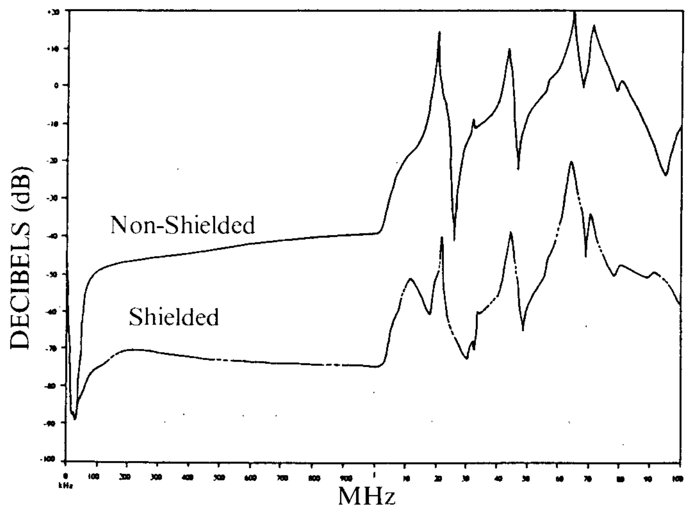

Figure 5. Shielded Chamber Measurements.

TRANSFER IMPEDANCE MEASUREMENTS

The concept of surface transfer impedance was first introduced by S. A. Schelkunoff[1] in 1931. In his work, the surface transfer impedance of a shield is defined as follows: "If a current is caused to flow along the conductor of a cable, with its return path on the surface of the shield, then the longitudinal voltage along an incremental length which results on the inside surface of the shield is related to that current by the surface transfer impedance, and has units of impedance per unit length." This can be expressed mathematically as follows:

$$Z_t = \frac{V \text{ shield}}{I \text{ shield}}$$

Although surface transfer impedance is an excellent way to measure shield performance, it does not mean much to the engineer who is attempting to specify a system in dB above or below a specification limit. In order for one to use surface transfer impedance to specify shields, the relationship between Z_t and dB must be known. The transfer impedance, Z_t, can be related to shielding effectiveness as follows:

let shielding effectiveness $\quad SE = \dfrac{P_{out}}{P_L}$

where $\quad P_{out} = I^2$

P_L = Power to end of line = $\dfrac{V_L{}^2}{Z_o}$

and $\quad F = \dfrac{4(1-\rho_{12}\rho_{22})(1-\rho_{21}\rho_{11})}{(1+\rho_{11})(1+\rho_{22})(1-\rho_{12})(1-\rho_{21})}$

where $\quad \rho_{11}$ = Reflection coefficient of the drive line at the source

ρ_{21} = Reflection coefficient of the drive line at the termination

ρ_{12} = Reflection coefficient of the pick-up line at the termination

ρ_{22} = Reflection coefficient of the pick-up line at the detector

The following equation for transfer impedance can be derived from known results:

$$Z_T = \sqrt{Z_{01}\ Z_{02}}\ \sqrt{\frac{1}{SE}}\ \left(\frac{F}{L}\right)$$

where $\quad Z_{01}$ = Characteristic impedance of the drive line

Z_{02} = Characteristic impedance of the pickup line

if we now solve for shielding effectiveness, then;

$$SE = \frac{Z_{01}\ Z_{02}}{Z_T}\ \left(\frac{F}{L}\right)^2$$

which rewritten in logarithimic form to express the results in dB gives;

$$SE = 10 \log_{10} Z_{01} + 10 \log_{10} Z_{02} + 20 \log_{10} F - 20 \log_{10} L - 20 \log_{10} Z_T \quad \text{dB}$$

The various terms of this formula are related to cable construction. The first term characterizes the relationship of the cable shield to all other conductors in the vicinity including the shield itself. The second characterizes the dependence of the shield's effectiveness on the internal construction of the cable. The third term characterizes the dependence of the shielding effectiveness of the way in which the conductors and the cable shield are terminated. The fourth term indicates that the shielding effectiveness for short cables (less than one-quarter of a wavelength) goes down as the square of the cable length decreases. The final term shows that shielding effectiveness increases as surface transfer impedance decreases.

Of the five terms characterizing shielding effectiveness, only the final term describes the shield leakage, so only that term is affected by the actual design of the shield. If it were possible to completely control all of the other terms, then the surface transfer impedance would be sufficient to totally specify shielding.

There have been many elaborate and expensive fixtures designed and utilized to measure surface transfer impedance. These include triaxial and quadriaxial fixtures (see Figures 6 & 7). However, this author has found that the very simple method described by Martin and Mendenhall[2] using their short-short method with a tracking generator and a spectrum analyzer is completely suitable. The ease of this method makes these measurements worthwhile.

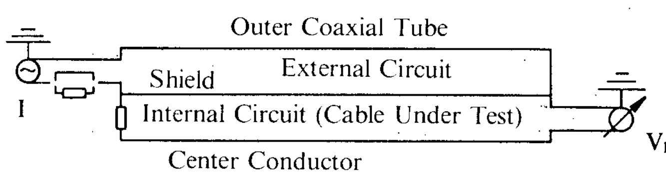

Figure 6. Triaxial Transfer Impedance Schematic.

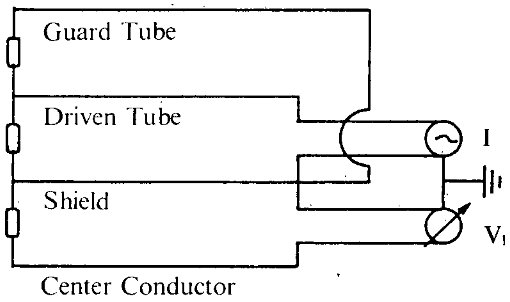

Figure 7. Quadriaxial Transfer Impedance Schematic.

Figure 8 shows the transfer impedance trace obtained with our test cable, while Table 3 shows the frequency — dB — transfer impedance relationship.

Frequency (Hz)	Attenuation (dB)	Transfer Impedance (Milliohms)
100 k	58	33.6
500 k	55	40.9
1 M	54	46.5
5 M	54	46.5
10 M	54	46.5
15 M	53	49.3
20 M	52	57.3
30 M	48	98.6
100 M	53	52.0

Table 3. Frequency — dB — Transfer Impedance Relationship.

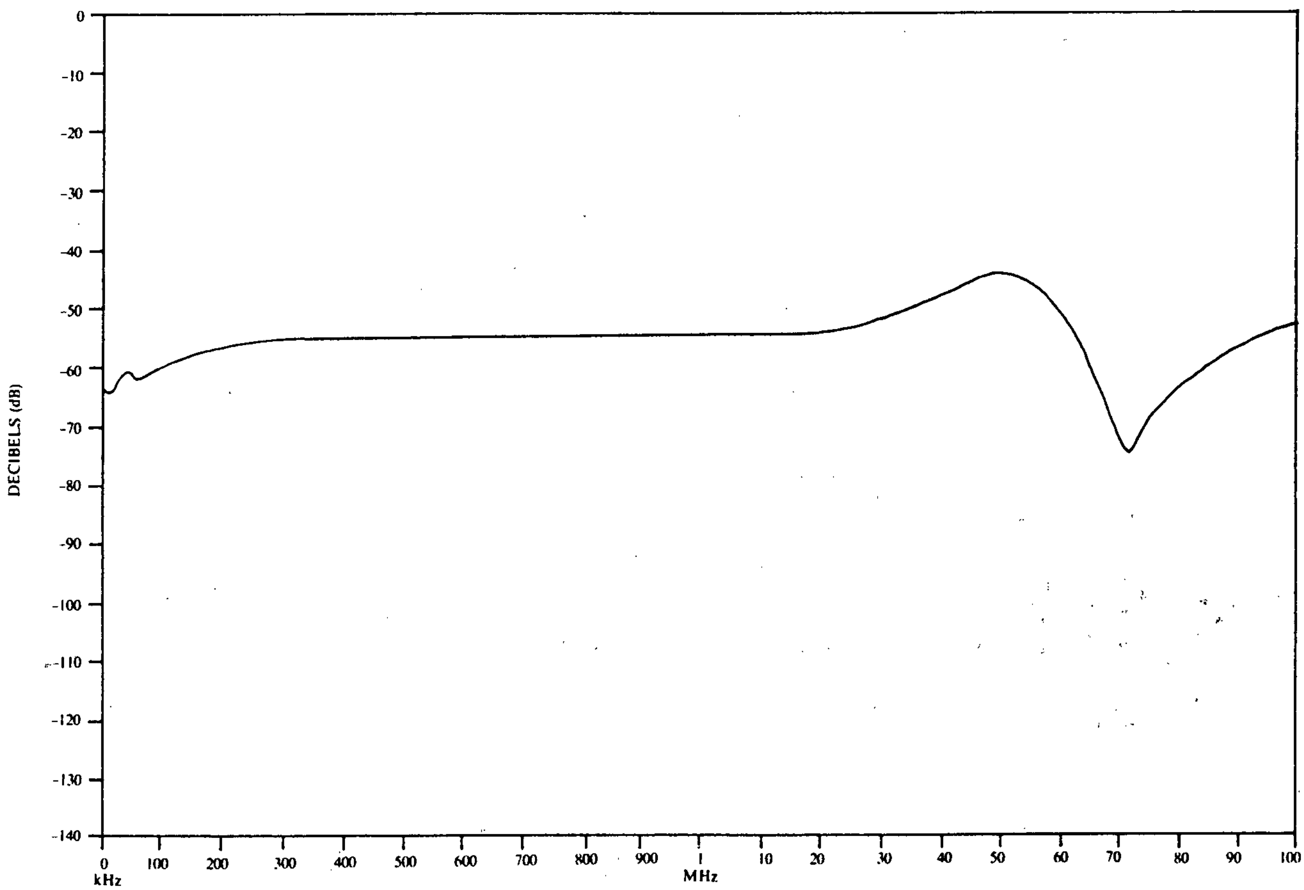

Figure 8. Transfer Impedance.

SEED (SHIELDING EFFECTIVENESS EVALUATION DEVICE) MEASUREMENTS

Developed by Belden Corporation of Geneva, Illinois as a method of measuring the shielding effectiveness of shielded pairs, this device allows measurement of shielding effectiveness to greater than 115 dB at 100 kHz.

Figure 9 shows a schematic view of the device in operation which is Belden's YR14017 SEED unit with a 3.125 inch O.D. tube.

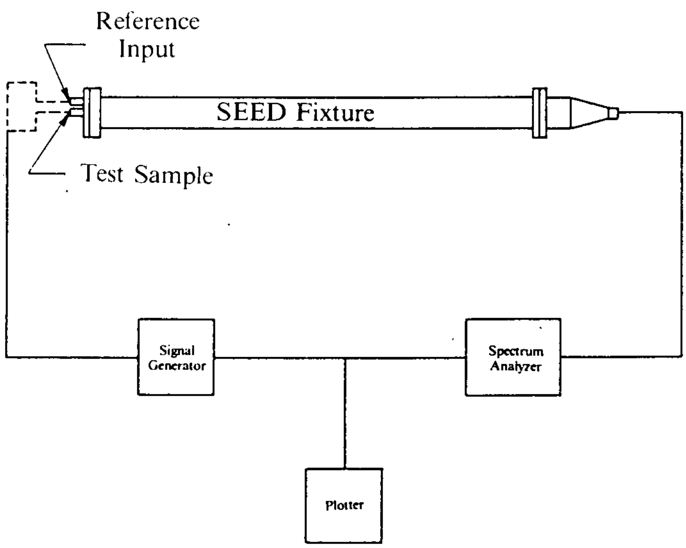

Figure 9. Measurement Device.

This device allows measurement of shield effectiveness from 100 kMz to 100 MHz with a useless area between 40 and 70 MHz due to resonance in the tube. This method features excellent repeatibility as well as excellent accuracy.

Figure 10 shows a plot of SEED measurements as a function of frequency, while Table 4 shows discrete frequency measurements taken with this same device.

Frequency (Hz)	Shielding Effectiveness (dB)
100 kV	104
500 kV	95
1 M	88
5 M	74
10 M	68
15 M	64
20 M	54
30 M	51
100 M	51

Table 4. Frequency Measurements.

SHIELD CURRENT MEASUREMENTS

Current waves in the form of standing waves are present on the surface of any shielded cable. The magnitude of the standing wave is a measure of leakage of the shield. Recently James Parker[3] introduced a method for predicting cable radiation that depends on the measurement of the surface current that travels on the outside of a cable shield.

Measurements are possible using this method at nearly any frequency of interest. However, for the purpose of this paper and for the sake of comparison they are only made from 5 MHz to 100 MHz, due to low frequency coil limitations. Since cable dress may play a large part in the actual measurement for this and all other techniques, the cable was laid straight. Since the effectiveness of the shield is being determined, Table 5 shows readings for both shielded and unshielded cables as well as the calculated shielding effectiveness.

Frequency (Hz)	Unshielded (dBM)	Shielded (dBM)	Shielding Effectiveness (dB)
5 M	55	104	51
10 M	32	87	55
15 M	51	104	53
20 M	42	104	62
30 M	27	88	61
100 M	53	82	29

Table 5. Comparison of Shielded and Unshielded Cables.

SUMMARY

Table 6 shows the comparison between each of the types of measurement that was made.

Frequency (Hz)	Shielding Effectiveness (dB)				
	Open Field	Chamber	Transfer Impedance	SEED	Current
100 kV	—	30	58	104	—
500 kV	23	27	55	95	—
1 M	20	36	54	88	—
5 M	33	39	54	74	51
10 M	36	47	54	68	55
15 M	43	50	53	64	53
20 M	46	43	52	59	62
30 M	51	54	48	51	61
100 M	23	48	53	51	29

Table 6. Comparison of Types of Measurement.

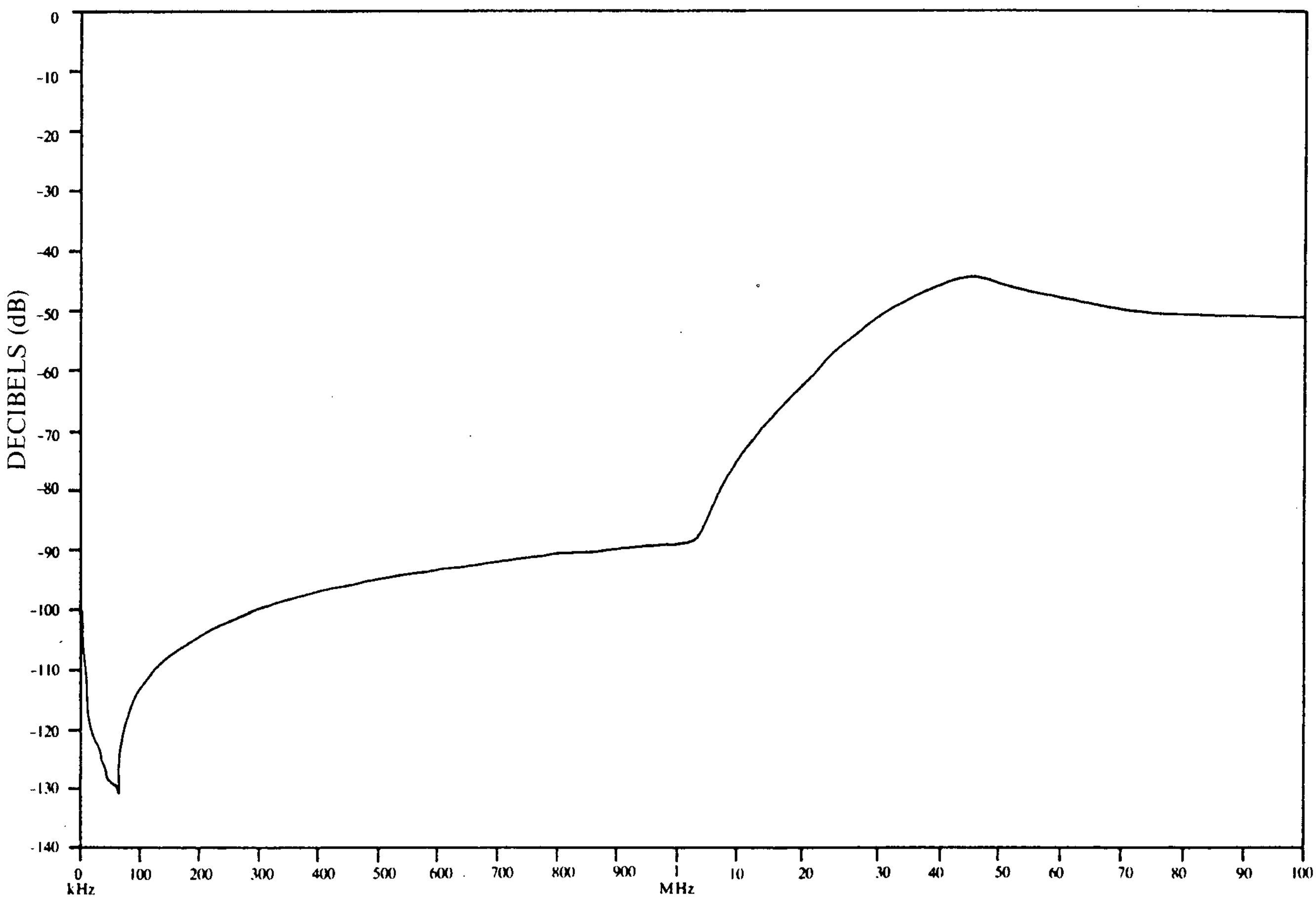

Figure 10. SEED Fixture.

At frequencies between 100 KHz and 30 MHz there is a reasonable correlation between shielded chamber results and open field results. The large difference at 100 MHz could be explained by standing wave phenomenon, as indicated by the correlation at 100 MHz between open field and shield current measurements.

Shield current and transfer impedance measurements correlate closely between 5 and 30 MHz. However, no two techniques show correlation at all frequencies.

Much of the reason for the lack of correlation is due to the fact that only the results from the open field measurements are due to far field effects. Chamber measurements are closest to open field since the receiving antenna is located a short distance from the cable under study and have some far field effects in the measurements. All of the other measurement techniques depend upon readings taken very close to the shielded cable and only display near field effects.

Only in the frequency range of 20 - 30 MHz is there any reasonable correlation between the various measurement methods where the differences between near and far field effects are not so pronounced.

REFERENCES

1. S.A. Schelkunoff, "The Electromagnetic Theory of Coaxial Transmission Lines and Cylindrical Shield," Bell Systems Technical Publication, Monograph B-816, 1939.
2. Albert R. Martin and Mark Mendenhall, "A Fast, Accurate, and Sensitive Method for Measuring Surface Transfer Impedance." IEEE Transactions on EMC, Vol. EMC-26, No. 2, May 1984.
3. James C. Parker, Jr., "A Useful Model For Evaluating Maximum Cable Radiation." 1984 IEEE national Symposium on Electromagnetic Compatibility, San Antonio, Texas, April 24-26, 1984.

This article was written for ITEM 85 *by Darrell Fernald, Manager, Sales and Product Development, Mercury Wire Products, Spencer, MA.*