Statistical Analysis of Coaxial Screening Attenuation

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Abstract
A statistical evaluation of a measurement system that is used to determine the screening attenuation performance of coaxial cable is presented. The measurement system, which is in accordance with IEC 61196 [1] guidelines, is defined to consist of the test equipment, appropriate personnel to operate the equipment, and samples of coaxial cable that are to be tested. The system measurement error is shown to depend primarily on the test fixture length, the frequency span of the test, and the design of the shield structure under test. The contributions of these components to the measurement error are identified through a series of five measurement system evaluations (MSE's). The MSE's were conducted with two shield designs used on standard 75-ohm coaxial cable. The first is a foil/braid shield design. The second is a single braid shield.

Keywords
Screening attenuation; coaxial cable; statistics; measurement system evaluation; MSE; capability; ANOVA.

1. Introduction
Shield effectiveness of coaxial cable can be measured by several methods such as transfer impedance, absorbing clamp, GTEM, anechoic chamber, and reverberation chamber. The costs involved with these methods can be considerably higher than screening attenuation. Higher costs are incurred for the equipment and for the skilled operator that uses the equipment. Absorbing clamp, anechoic chamber, and reverberation chamber may require a highly shielded enclosure. Transfer impedance and GTEM use specially made fixtures. In contrast, screening attenuation uses a low-cost fixture made from commercially available components.

Screening attenuation results of various shield designs of coaxial cable have been presented in past works using appropriate frequency ranges for the fixture length utilized [2,3]. A limited number of samples were tested in these cases and usually only a single typical result of each shield design was presented. Subsequent testing has been performed with multiple samples for each shield design in order to obtain a statistically valid picture of the cables and measurement system. The MSE quantifies the variation caused by the sample, by the gage, which consists of the measurement equipment and fixture, and by the operator. As a rule of thumb, transfer impedance has a generally accepted repeatability of ±6 dB. This paper presents the first known statistical analysis of screening attenuation to quantify its repeatability and reproducibility.

Measurement system evaluation will be described, followed by a brief discussion of capability as it refers to screening attenuation. The results of five MSE's will be presented along with a comparison of them. Suggested areas of further study will be presented along with conclusions drawn from the data presented.

2. Measurement System Evaluation
A measurement system evaluation (MSE) is a statistical tool used to determine the variations in a measurement system. The variation can be categorized as sample, gage, and operator.

Sample variation is the difference in screening attenuation among samples that have the same shield design. This variation can come from the materials, manufacturing process, or effects to the item after manufacture. A coaxial cable constructed with a solid tubular shield, such as a semi-rigid coaxial cable, would provide a very stable shield structure. This would permit greater accuracy in determining measurement system error.

Gage variation results from the equipment used to perform the measurement. A perfect gage would give the same result for each measurement of a sample, assuming the sample had not changed.

Actual gages always have some variation that must be considered when evaluating data obtained from the gage. Gage variation is not systematic such that the effects could be negated by normalization. The random nature only allows a statistical prediction of the range of variation.

Operator variation is caused by differences between operators in the manner of performing the test. Variations can result from subtle differences in operator technique. Typically, three operators test 10 items of a product three times each for a total of 90 measurements. If variations due to different operators are not an issue, one operator can test 16 samples twice for a total of 32 measurements.

Analysis of variance (ANOVA) [4] is applied to the data to determine the total variation and to separate the portions of variation caused by the sample, gage, and operator. Each source of variation is assigned a percentage and decibel value.

In an MSE it is assumed that the screening attenuation of each sample is stable. If it is not, an additional variability component will be added to the total variation. Instability can be a result of operator handling that causes changes in the shield. A coaxial cable constructed with a solid tubular shield provides a very stable shield structure. A semi-rigid coaxial cable fits this criterion. This allows a more accurate determination of the gage variation. The MSE is not capable of isolating instability variation from other causes. This became an issue, as will be shown in the test results.

3. Capability

Capability refers to the ability of the cable to meet a required specification. The amount of variation can be predicted through statistical analysis of samples taken from one, or preferably multiple, production runs. The maximum, minimum, mean, and standard deviation of screening attenuation characterize the product variation.

A minimum or typical value is usually advertised. Quite often only a single value is given for a broad frequency range. Sometimes no frequency is given.

4. Procedure

4.1 Cable Samples

Two coaxial cable shield designs were evaluated (Table 1). The first, a foil/braid design, was chosen as representative of a common shield design used in the CATV industry. The second, a braid-only design, was added because of the variations observed with the first. This will be explained later in this paper.

Table 1. Cable Shield Design

Cable Shield	Inner Foil (bonded to dielectric)	Braid/Angle
Foil/Braid	Al/polyester/Al	60% Al./27˚
Braid	N/A	95% b.c./23˚

4.2 Screening Attenuation Test Fixture

Two screening attenuation fixtures were used. Both were 76.5mm in diameter with 1.5m and 6.7m lengths. These have been discussed in detail in a previous publication [5]. The fixture length and the velocities of propagation in the sample and fixture determined the frequencies of the resonant responses. This produced a lower frequency limit of approximately 90 MHz for the 1.5m fixture and 20 MHz for the 6.7m fixture. In addition to providing a lower measurement frequency, the 6.7m fixture allowed a longer portion of cable to be under test. The test setup is shown in Figure 1.

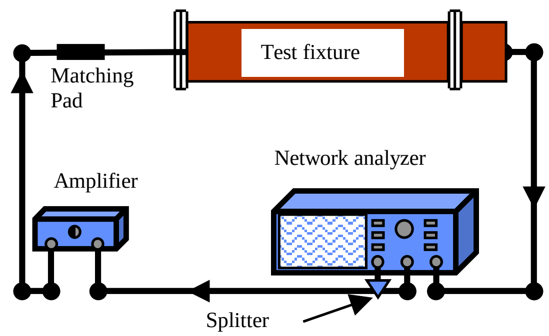

Figure 1. Test Equipment Setup

4.3 Measurement System Evaluations

Five measurement system evaluations were performed (Table 2). The 1.5m fixture was evaluated first followed by the 6.7m fixture. Both shield designs were evaluated in both fixtures.

Table 2. Measurement System Evaluations

MSE	Fixture Length (meters)	Cable Shield	Number of Samples	Number of Operators
1	1.5	Foil/Braid	10	3
2	1.5	Foil/Braid	10	1
3	1.5	Braid	16	1
4	6.7	Foil/Braid	16	1
5	6.7	Braid	16	1

4.3.1 MSE 1 (1.5m, foil/braid)

The initial MSE was performed on the 1.5m length screening attenuation fixture using ten samples of the foil/braid shield. The testing sequence was as shown in Table 3. These samples were rotated through the three operators such that each operator tested each sample three times. Nine measurements per sample and a total of 90 sets of data were produced. To preclude the possibility that the order of testing would influence the outcome, the order of testing was randomized during the second and third times each operator tested the ten samples. Figure 2 shows the first data set of screening attenuation for the ten samples.

Table 3. MSE 1 Testing Sequence

Operator	Samples	Sequence
1	1 through 10	In order
2		
3		
1	1 through 10	Random order
2		
3		
1	1 through 10	Random order
2		
3		

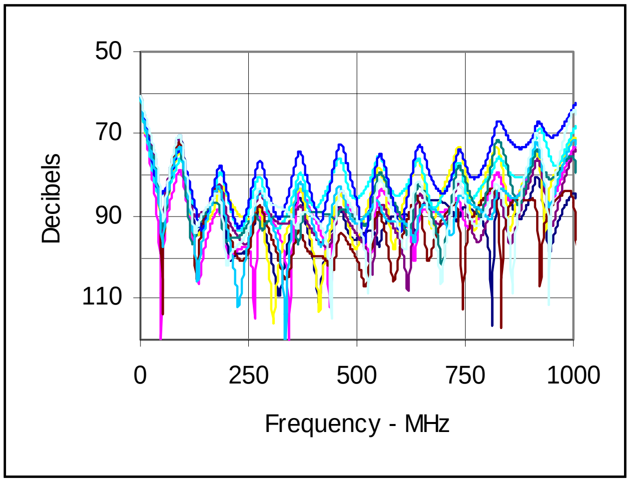

Figure 2. MSE 1 Foil/Braid Screening Attenuation Test Cycle 1, 10 Data Sets

The set of data derived from the measurements was divided into two frequency ranges for analysis purposes. The first range of 70-500 MHz was chosen to capture the resonance peaks from the first at the low frequency end to the one just below 500 MHz. The second range was 500-1000 MHz. The worst-case value was extracted for each sample from each frequency range. These worst-case values were tabulated and analyzed with commercially available statistics software [6].

The analysis revealed that the operator contributed only a small portion to the variation. The operator contribution was only 2.1% in the 70-500 MHz range and 3.3% in the 500-1000 MHz range. The greatest portion of variation was due to the gage and/or sample.

When performing an MSE it is desirable to have at least four distinct categories in the data analysis. The term distinct categories refers to the number of groups in the data that the measurement system can discern. The number of distinct categories is determined by comparing the sample variation to the gage variation. The smaller the gage variation is in relation to the sample variation, the greater the number of distinct categories. If the number of distinct categories is low, the gage variation is large in comparison to the sample variation. The number of distinct categories in MSE 1 was only one.

When the MSE 1 screening attenuation data was examined in its sequence of testing, it was discovered that the screening attenuation of four samples was degraded significantly for the fifth and following tests of those samples. This explained why the number of distinct categories was low. Although the cause was not determined, mishandling of the samples was suspected, because the screening attenuation remained at the degraded level for subsequent tests. This led to MSE 2 using new samples from the same reel of cable.

4.3.2 MSE 2 (1.5m, foil/braid)

Ten new samples of the foil/braid shield were used for a second MSE using the same fixture and setup as MSE 1. These samples came from the same spool of cable as the MSE 1 samples and were interspersed throughout the spool, as with the previous set. This second MSE used only one operator because MSE 1 indicated the operator contributed only a small portion to the total error. The testing sequence was as shown in Table 3 but with only a single operator.

MSE 2 has a greatly reduced measurement error compared to MSE 1. Measurement error decreased to 4.12 dB in the 70-500 MHz range and 6.41 dB in the 500-1000 MHz range (Table 4). The dramatic drop in measurement error confirmed the suspicion of samples degrading during the first MSE. The number of distinct categories increased, which is desirable. It must be emphasized that the same equipment and samples from the same spool were used in both MSE 1 and MSE 2.

4.3.3 MSE 3 (1.5m, braid)

The third MSE was also with the 1.5m fixture, but it used 16 samples of the braid shield and one operator. The single braid design was chosen because it was believed that it had a more stable screening attenuation than the foil/braid construction. Since the gage was the same, it would determine if the variation was from the gage or the sample. Table 4 is a comparison summary of MSE 2 and MSE 3.

Table 4. MSE 2 (foil/braid) vs. MSE 3 (braid)

	70-500 MHz		500-1000 MHz	
	MSE 2	MSE 3	MSE 2	MSE 3
Measurement Error (± dB)	4.12	0.26	6.41	0.53
Percent Contribution				
Total Gage (Repeatability)	35.81	14.33	11.97	7.53
Part to Part	64.19	85.67	88.03	92.47
Distinct Categories				
	2	3	4	5

Measurement system errors decreased from 4.12 dB to 0.26 dB in the 70 to 500 MHz range and from 6.41 dB to 0.53 dB in the 500 to 1000 MHz range. Contrasting this MSE 3 measurement error with MSE 2 clearly revealed that the gage introduces only a small amount of variation into the measurements. The large amount of error in MSE 2 is due mainly to the sample variation and not the gage variation.

4.3.4 MSE 4 (6.7m, foil/braid)

A measurement system evaluation was performed on the 6.7m fixture using 16 samples of the foil/braid and one operator. This was done to see how sample length effects measurement error. The data analysis was divided into frequency sub-bands of approximately 100 MHz because the longer fixture produced a greater number of resonant points for a given frequency range (Tables 5 and 6). Using the narrower sub-band gave approximately the same number of resonant peaks per sub-band as the 1.5m fixture.

Table 5. MSE 4 (6.7m, foil/braid)

	Frequency (MHz)				
	10-110	110-220	220-320	320-420	420-530
Measurement Error (± dB)	4.54	3.28	9.97	8.39	8.48
Percent Contribution					
Total Gage (Repeatability)	27.39	15.02	48.94	30.77	28.06
Part to Part	72.61	84.98	51.06	69.23	71.94
Distinct Categories					
	2	3	1	2	2

Table 6. MSE 4 (6.7m, foil/braid)

	Frequency (MHz)				
	530-630	630-730	730-850	850-950	950-1050
Measurement Error (± dB)	11.20	8.25	6.59	7.71	9.15
Percent Contribution					
Total Gage (Repeatability)	36.37	25.89	20.46	31.22	27.36
Part to Part	63.63	74.11	79.54	68.78	72.64
Distinct Categories					
	2	2	3	2	2

Measurement error with the 6.7m fixture and the foil/braid shield was similar to, but slightly higher than, the 1.5m fixture with the same cable shield type (MSE 1). In both cases the measurement error increased with frequency.

4.3.5 MSE 5 (6.7m, braid)

A second measurement system evaluation was performed on the 6.7m fixture using 16 samples of the braid shield and one operator. This was done to determine if the sample was causing most of the variation, which was the case with the 1.5m fixture. As with MSE 4, the data analysis was divided into frequency sub-bands of approximately 100 MHz (Tables 7 and 8).

Table 7. MSE 5 (6.7m, braid)

	Frequency (MHz)				
	10-110	110-220	220-320	320-430	430-530
Measurement Error (± dB)	0.33	0.74	1.43	1.16	0.85
Percent Contribution					
Total Gage (Repeatability)	31.56	6.74	14.37	7.58	5.23
Part to Part	68.44	93.26	85.63	92.42	94.77
Distinct Categories					
	2	5	3	5	6

Table 8. MSE 5 (6.7m, braid)

	Frequency (MHz)				
	530-630	630-750	750-850	850-950	950-1050
Measurement Error (± dB)	1.69	1.59	1.19	0.98	2.28
Percent Contribution					
Total Gage (Repeatability)	6.74	16.55	5.97	1.54	37.18
Part to Part	93.26	83.45	94.03	98.46	62.82
Distinct Categories					
	5	3	6	11	2

Comparing MSE 4 with MSE 5 shows again that the foid/braid shield design produced more variation than the single braid shield. Again, the variation increased with fixture length and frequency.

4.3.6 MSE 1-5 Comparison

The measurement errors of MSE's two through five are shown in Figure 3. MSE 2 and MSE 4 were performed with the foil/braid shield design. MSE 3 and MSE 5 used the single braid design. The general trend is increasing measurement error for increasing frequency and fixture length.

The significantly lower measurement error with single braid compared to the foil/braid designs shows that the gage actually has a small amount of variation. The variation with the foil/braid design is due to sample variation and is more indicative of capability than measurement system error. The variation in contact resistance between the foil and braid could be a cause of this greater variation. Wrinkling of the tape could also be a contribution factor.

5. Areas of Further Investigation

The differences in variation observed between different shield designs suggest that coaxial samples with shield designs other than foil/braid and braid could be evaluated. A coaxial cable constructed with a solid tubular shield would provide a very stable shield structure. A semi-rigid coaxial cable fits this criterion. A four-layer shield of foil/braid/foil/braid would possibly have the greatest variation.

The screening attenuation degradation due to flexing could be investigated in view of the observations of MSE 1. The quality of bonding of the tape to the dielectric is another area to consider. The wrinkling of the tape and changes in the overlap could change the screening attenuation.

Now that the measurement error has been quantified, capability studies could be performed on additional shield design.

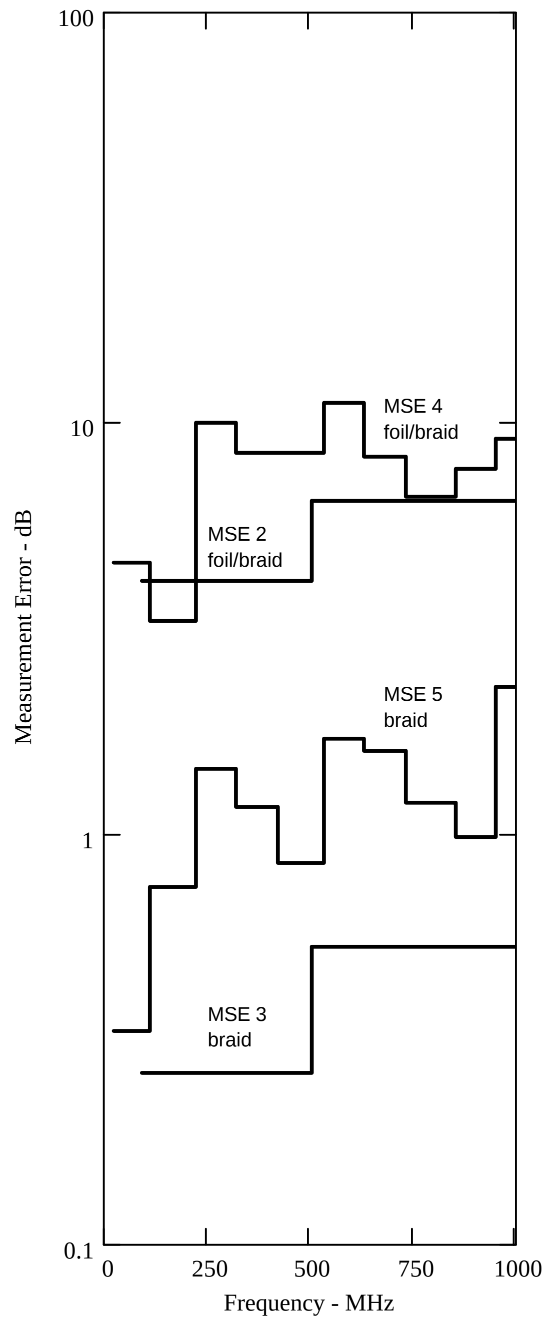

Figure 3 – Measurement Error Comparison

6. Conclusion

It was observed that screening attenuation variations can be a result of both sample variation and variation in the measurement system. Braid-only shield designs have less screening attenuation variation than foil/braid designs. This may be due to changes in contact resistance between the foil and braid. It could also be from wrinkling of the tape and changes in the overlap opening. Variation from the operator is a small percentage of total measurement error.

The screening attenuation test setups evaluated have less than the 6 dB rule-of-thumb measurement error often cited for transfer impedance. The braid only shield design in the 1.5m fixture has less than 1 dB of measurement error. Although the 6.7m fixture with the braid shield has greater than 1 dB measurement error at the higher frequencies, its measurement error at the lowest frequencies, where it extends below the 1.5m fixture, is still less than 1 dB. Measurement error increases as the frequency and fixture length increase.

Screening attenuation provides a cost-effective method for measuring shield effectiveness. It requires a level of skill typical of an electronics laboratory without an elaborate and expensive test setup. Screening attenuation is a tool that can be used for more MSE and capability studies of shield effectiveness.

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8. References

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