Investigation and Analysis of the Over-Braid Phenomena in Flexible Coaxial Cables

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Abstract
Shielding Effectiveness, or Screening Attenuation as it is often referred to, is probably the single-most important characteristic regarding the design of flexible coaxial cables. Technological developments in the CATV industry such as the return path, added bandwidth for system upgrades, VOIP and the eventual full transition to digital channels have even further enhanced the importance of the shielding characteristics of flexible coaxial cables, also known as Drop cables. Conventional wisdom assumes that the greater the optical braid coverage of a standard shield Drop cable, the better the shielding effectiveness. Recent studies contradict this logic. This paper will discuss the over-braid phenomena and examine the variables that affect the shielding effectiveness performance of standard shield Drop cables.

Keywords: Drop cable; shielding effectiveness; t-test; over-braid; CATV; coaxial cable; EMC

1. Introduction
A poorly designed Drop cable may be susceptible to noise (RF ingress) issues. This is the main reason why the return path modulation formats for cable modems are mainly limited to QPSK (Quadrature Phase Shift Keying) and 16-QAM (Quadrature Amplitude Modulation). QPSK and 16-QAM are robust transmission formats in noisy environments, but extremely inefficient in terms of data transfer. If Drop cables, Drop cable connections, and other in-home devices exhibited better shielding characteristics, higher data rates and improved system integrity could be achieved in regards to Internet, email, VoIP, and other subscriber services.

Most standard Drop cables are designed with a minimum of a laminated shielding tape (LST) and a single layer of braid. This outer conductor design is commonly referred to as a standard shield, or single braided cable. Other Drop cable designs include the tri-shield and quad-shield products. The tri-shield products consist of an LST, a layer of braid, and another LST. The quad-shield product consists of an LST, a layer of braid, a second LST, and a second layer of braid. Both the tri-shield and quad-shield products provide better EMI/RFI performance than the standard shield designs. The scope of this investigation is limited to the shielding performance of various single braided products and designs. The main difference between various standard shield designs is the percentage of braid coverage. Refer to Figure 1 for a description of typical design parameters in determining the overall optical braid coverage of the standard shield Drop cable.

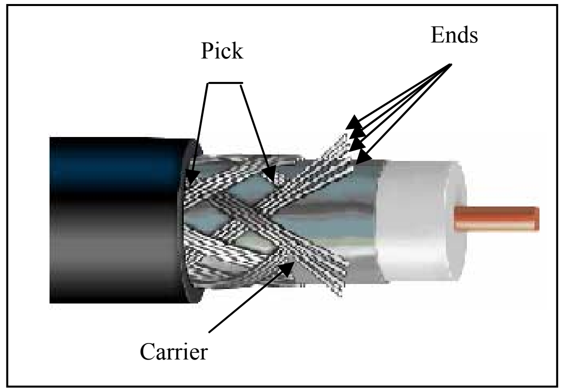

Figure 1 - Typical Braid Construction

Conventional logic surmises that the greater the optical braid coverage, the greater the shielding effectiveness. Recent studies indicate findings to the contrary on certain outer conductor designs for a number of Drop cable products. The term characterizing this attribute is known as the over-braid phenomena, where increased braid coverage degrades shielding effectiveness performance. Equations (1), (2), & (3) demonstrate how to calculate braid coverage of a Drop cable product[1].

$$\% Coverage = (2F - F^2) \times 100 \tag{1}$$

$$F = \frac{(N \bullet P \bullet d)}{\sin \alpha} \tag{2}$$

$$\alpha = \tan^{-1}[2\pi(D + 2d)(\frac{P}{C})] \tag{3}$$

Where:

α = Braid angle (radians)

D = Diameter under the braid (cm)

C = Number of carriers

d = Braid strand diameter (cm)

P = Picks per cm (PPCM)

N = Number of ends per carrier

[1] For a more detailed explanation of braid coverage calculations, please refer to *ANSI/SCTE 51 – Method for Determining Drop Cable Braid Coverage*.

This phenomenon is not entirely new to the CATV industry. The IEC standards organization has proposed a document (IEC 62153-4-1) that discusses this issue, but does not go into great detail in terms of supporting test data or possible failure modes of this design flaw. This paper will discuss various braid constructions and demonstrate how those designs influence the overall shielding effectiveness of Drop cable products. The intent of this paper is to inform professionals throughout the CATV industry of the over-braid phenomena and hopefully prompt further research in this area.

2. Measurement Methodologies

There are various shielding effectiveness measurement methods used to characterize the shielding performance of Drop cables. Three of the more common methods used for Drop cables include the Triax Chamber (ANSI/SCTE 78), GTEM Cell (48-3), and CoMeT Tube (IEC 62153-4-4). The measurement procedure selected for performance characterization of Drop cables documented in this paper is the CoMeT (Coupling Measuring Tube) because it is becoming increasingly popular in the CATV industry. There are several reasons why the CoMeT is increasing in popularity. Those reasons include greater precision in measurements, the fact that it can be used by both connector and cable manufacturers, and the complete measurement system can be purchased "off the shelf". Figure 2 below shows the CoMeT measurement system.

Figure 2 – CoMeT Measurement System

The CoMeT measurement system consists of several components as shown in Figure 3. The theory behind the operation of the CoMeT is relatively simple to one with a technical background in the relevant area. An RF generator (typically a Network Analyzer) transmits an array of RF signals over a pre-defined frequency range. The frequency range selected for this experiment was 30-MHz to 1000-MHz. These signals travel through the cable under test and are terminated with an impedance matching resistor (75-ohms for the CATV industry). The opposite end of the resistor is connected to the outside of the outer conductor. The outer conductor of the cable under test becomes the center conductor of the CoMeT "Tube".

Since the outer conductor of the cable under test becomes the center conductor of the tube, any electromagnetic energy coupled to the outside surface of cable under test will be measured by the network analyzer in reference to the signal injected into the cable under test. Equation (4) demonstrates how the shielding effectiveness is calculated.

$$SE(dB) = 20 * \log(\frac{V_r}{V_c}) \qquad (4)$$

Where:

SE = Shielding Effectiveness in decibels

V_c = Coupled Voltage (leakage)

V_r = Reference Voltage (injected)

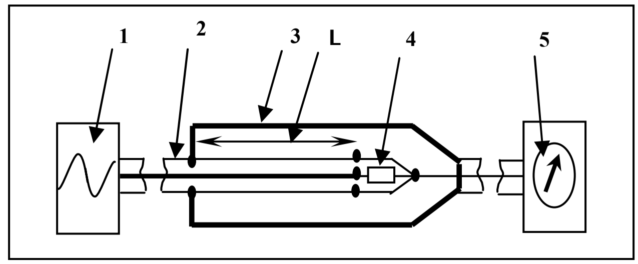

Figure 3 – CoMeT Measurement System

Where:

1. Output of the network analyzer
2. Cable Under Test (CUT)
3. Measuring Tube
4. Matching resistor
5. Receiving port of the network analyzer

L. Measured Length

3. Braid Design

3.1 Contributing Factors

Modeling the shielding effectiveness of Drop cables is not an exact science. There are many factors that contribute to the characteristic shielding performance of any coaxial cable that utilizes a tape and braid design. Some of those factors include, but are not limited to the following:

- Percent braid coverage
- Braid angle
- Number of braid wire ends (strands)
- Shielding tape design
- Number of picks per cm
- Strand diameter
- Braid tension
- Jacket compression
- Measurement methodology

For this experiment, the focus was concentrated on the percentage of braid coverage, braid angle, number of ends, and number of picks per centimeter. The operators, braiding machines, and jacketing lines were kept consistent throughout the experiment. The same dielectric component and jacket material were used in each design in an effort to reduce part-to-part variability. Table 1 shows the listing of designs fabricated for this experiment.

Table 1 - Listing of Braid Designs

	Design of Experiment			
	% Braid	Angle (^{o})	# Ends	PPCM
Design #1	66	22.0	4.00	2.48
Design #2	69	21.9	4.25	2.48
Design #3	79	27.2	5.00	3.15
Design #4	90	15.5	7.00	1.65
Design #5	95	23.6	7.25	2.68
Design #6	96	13.3	8.00	1.38

While formulating the braid designs listed in Table 1, many considerations factored into the final decision on which designs would be manufactured and analyzed. Some of those considerations include braid machine gear ratios, available tooling, and speed issues. It was decided that the 6-designs listed in Table 1 would be sufficient to prove that the over-braid phenomena is real, and that they would provide sufficient variation of the selected parameters for analysis.

3.2 Braid Classification

In regards to the braid design, there are three classifications. The first is the under-braid design, where not enough braid is present to fully optimize the shielding effectiveness of the cable. The second scenario is the optimized braid design, where the best shielding performance is achieved. The last classification is the over-braid phenomena, where too much braid is present and this braid design actually degrades the shielding performance.

The experiment outlined in this paper only breaks the designs into two categories, primarily because the optimum design is not clear at this point. Therefore, the first three braid designs in Table 1 are classified as "low braid", while the last three braid designs are classified as "high braid". The low braid designs are those that have braid coverages less than 80% of the surface area of the cable. The high braid designs are listed as those with 90% or greater braid coverage of the surface area.

The analyses of the results will start with these two classifications in mind, then will proceed further in order to hypothesize the impact of a number of design variables.

3.3 Shielding Measurements & Results

3.3.1 Measurements. The 6-braid designs were fabricated and measured using the CoMeT measurement system as described in section 2[2]. Ten samples were tested for each design. The average was derived to produce a single measurement trace. It has been demonstrated in past analyses, that this method of averaging significantly reduces test variation associated with measurement errors.

[2] For a more detailed explanation of the measurement procedure, please refer to IEC 62153-4-4.

3.3.2 Results. The results are located in Figures 4 & 5.

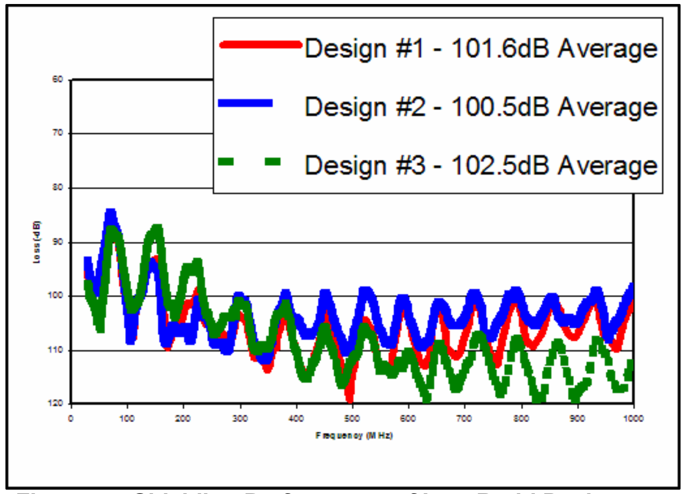

Figure 4 – Shielding Performance of Low Braid Designs

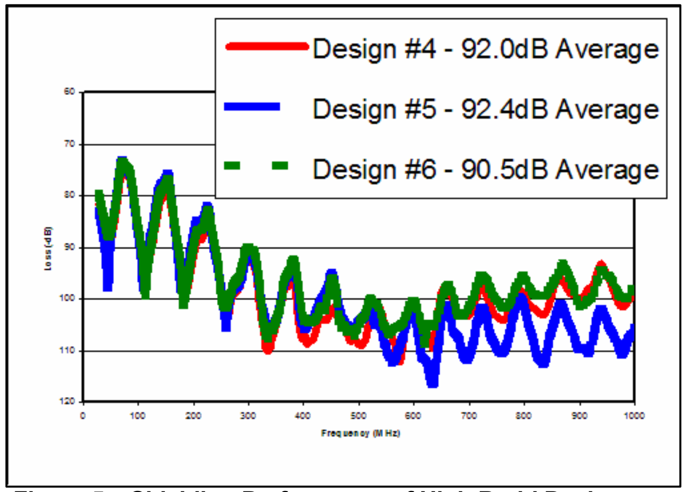

Figure 5 – Shielding Performance of High Braid Designs

Intuitive review of the results in Figures 4 & 5 show that there is a difference between the low braid and high braid designs, with negligible difference between designs within the same category. In order to demonstrate this point, the results were analyzed using statistical tools in the next section.

3.4 Hypothesis Testing

Hypothesis testing was performed on the results stated in the previous section. The statistical tool used for this analysis was the 2-sample t-test. Several tests were run pairing up every combination of braid designs. At a 95% confidence interval, the results from these t-tests indicated that the null hypothesis (the mean of both populations were equal) could not be rejected between each category of braid designs. In other words, designs 1 thru 3 and designs 4 thru 6 were similar enough in terms of their means that they could not be rejected as being equal to each other. On the other hand, when the results from designs in the low braid and high braid classifications were compared utilizing the 2-sample t-test, the P-values were less than 0.05 indicating that the null hypothesis must be rejected. In other words, the alternate hypothesis must be accepted in that these designs means were significantly different. An illustration of the results is located in Figure 6 where the best performing high braid design was compared to the worst performing low braid design. The p-value is equal to 0.000, which means that these two sample populations are different.

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Two-sample T for Design2 vs Design5

N    Mean  StDev  SE Mean
Design2  10  100.48   1.98     0.63
Design5  10   92.36   2.03     0.64

Difference = mu (Design2) - mu (Design5)
Estimate for difference:  8.120
95% CI for difference:  (6.229, 10.011)
T-Test of difference = 0 (vs not =): T-Value = 9.06  P-Value = 0.000
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Figure 6 – Hypothesis Testing Between Design Categories

3.5 Design Factor Analysis

It was hypothesized prior to this experiment that the braid angle, number of picks per centimeter, and matched number of ends on the carriers would provide some insight into the variables of significance in characterizing the over-braid phenomena, as well as how to optimize the shielding performance of the cable based solely on the braid design. In order to examine the results further, it was decided to separate the results of the low braid designs and high braid designs

Table 2 shows the three low braid designs in descending order of shielding performance. It has already been proven statistically that there in not enough of a difference between the means of these 3-designs to determine which factors dominated the shielding performance of the cables. The same can be said for the high braid designs listed in Table 3, also in descending order of shielding performance. Any comparison between designs within the same category shows no more than 2-dB difference in the means, which is insignificant in terms of shielding effectiveness.

Therefore, it was decided to compare the results between Tables 2 & 3. It has already been demonstrated in section 3.4 that the low braid designs have outperformed the high braid (over-braid) designs. Based on these results, the only definitive characteristics between the designs are the number of ends and overall braid coverage. All three low braid designs use a lower number of ends and have lower overall optical braid coverage than the high braid designs.

Table 2 – Analysis of Low Braid Designs

	Design of Experiment				
	SE (dB)	PPCM	# Ends	Angle	%
Design #3	102.5	3.15	5.00	27.2	78.7
Design #1	101.6	2.48	4.00	22.0	65.6
Design #2	100.5	2.48	4.25	21.9	68.9

Table 3 – Analysis of High Braid Designs

	Design of Experiment				
	SE (dB)	PPCM	# Ends	Angle	%
Design #5	92.4	2.68	7.25	23.6	94.7
Design #4	92.0	1.65	7.00	15.5	90.2
Design #6	90.5	1.38	8.00	13.3	95.6

The only other item of interest is the visual inspection of the 6-designs. It appears that the braid on the low braid designs is tighter and more uniform than those of the high braid designs. This visual evidence may be nothing more than a benefit of the lower number of ends and higher braid angles, but the authors thought that it was at least worth noting.

4. Conclusions

The information provided in this paper proves that the over-braid phenomenon exists. Why it was never discussed within the industry until recently is uncertain. Possibly the advancement in measurement technology has made identifying this anomaly possible. Regardless the method of discovery, the paradigm over the years was that the greater the optical braid coverage over the surface of a Drop cable, the greater the shielding performance.

With the advancement in technology that allows the broadband industry to implement additional applications and data through existing CATV networks, shielding performance is critical for successful deployment.

The benefit of this project is to provide sound research data to CATV industry professionals. The results of continued experimentation are improved manufacturing efficiency, reduced scrap-associated costs, reduced inventory, reduced non-value added costs, and overall improved product performance for the customer regarding the shielding effectiveness of the cable.

Further research in this area is needed to fully characterize the shielding effectiveness of the braid design. This phenomenon appears to be more prevalent in smaller diameter cables and should be considered in future evaluations; especially since new industry trends are migrating towards smaller diameter products.

5. Acknowledgments

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6. References

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[3] IEC 62153-4-4, "Metallic communication cable test methods – Part 4-4: Electro Magnetic Compatibility (EMC) – Shielded screening attenuation, test method for measuring of the screening attenuation up to and above 3 GHz," (2006).

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