Noise Considerations in Coaxial Cable Systems

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ABSTRACT

Coaxial cables will be used to transport analog and digital signals to and from the home. The full spectrum of the coaxial system, from 5 MHz to 1 GHz will be utilized for the delivery of video, voice and data. The natural shielding characteristics of coaxial cable will play a primary role in helping to maintain signal integrity and ensure error free transmission. This paper addresses the shielding performance of coaxial cable and its related components. This is accomplished through a discussion of leakage mechanisms and laboratory shielding tests.

INTRODUCTION

Signal distortion due to noise ingress in a coaxial cable system has generated considerable concern and discussion. In the past, shielding was primarily an egress (signal leakage) issue. This was driven by Part 76 of the Federal Communications Commissions (FCC) Rules and Regulations. Radiated emissions are required to be measured and must meet the following limits as shown in Table 1.

Freq., MHz	Signal Strength Limit, µV/m	Distance, ft.
f ≤ 54	15	100
54 < f ≤ 216	20	10
216 < f	15	100

TABLE 1. - FCC Limits

In most cases, if the conditions were satisfied, then the shielding integrity was sufficient enough to alleviate any noise ingress issues. The appropriate question becomes, whether or not meeting the FCC leakage requirements also satisfies the needs of a digitally based two-way interactive communications systems. To try and answer this question, we need to discuss what the communications system will look like.

It appears that the network will end up being a fiber-star coax-bus extending from a fiber ring or virtual ring architecture. The coax plant will then consist of coax feeders and distribution cable extending from a node to the tap at the curb with amplifiers in-between. From the tap, drop cable, connectors and splitters will be used to connect the customer to the coax-bus. It is obvious that the coaxial cable and its related components will be in contact with numerous noise sources. Sources of noise could be anything from indoor microwave ovens, computers and appliances to outdoor ignition switches, power devices and terrestrial broadcast antennas. The coaxial cable system, therefore, has the unfortunate potential of behaving as a distributed antenna, picking up unwanted signals from the home and throughout the neighborhood.

It then becomes obvious that an understanding of cable shielding would be beneficial, when designing these networks, so as to help ensure acceptable performance. The shielding performance of an outer conductor, whether it is for a cable, connector, tap or splitter - is a function of material, design/construction, installation technique and field conditions as well as frequency of operation.

The three mechanisms which can contribute to the overall shielding performance are absorption (diffusion), aperture leakage (coupling) and wave reflection (mismatch). Each of these mechanisms are a function of frequency and are described in greater detail in the next section.

It appears that the frequency allocations will be re-formatted, in order to meet the network needs. Table 2 gives a representation of what a typical frequency allocation might look like.

Freq., MHz	Direction	Format
5-40	Upstream	Digital
54-550	Downstream	Analog
550-750	Downstream	Digital
750-1000	Two-Way	Digital

TABLE 2. - Typical Frequency Allocation

The other obvious consideration is the carrier-to-noise requirements needed for each particular service. Digital telecommunications systems operate better than 1 x 10^{-10} Bit Error Rate (BER), where 1 x 10^{-3} BER is rendered unusable.[1] For the upstream communications, a carrier-to-noise ratio of 15.8 dB for QPSK and 23.3 dB for 16 Quadrature Amplitude Modulation (QAM) is required. For downstream QAM modulation, a carrier-to-noise ratio of 25 dB is required for 64 QAM and 16 dB for 16 QAM.[2]

SHIELDING MECHANISMS

The metallic outer conductor of a coaxial device creates a natural isolation between the internal communication signal and the external environment. The internal electrical and magnetic fields are contained within the first few thousands of an inch. The fields and corresponding currents are attenuated by the factor $e^{-\alpha z}$. The skin depth is defined as the distance the energy must travel in order for its amplitude to decay exponentially, e^{-1}, or 37 percent of its initial value.[3] (See Figure 1) For aluminum, one skin depth is 0.001 inches at 10 MHz and 0.0001 inches at 1 GHz. The skin depth can then be used to calculate the absorption loss through a conductive shield (Fig. 1 and 2).[3] This equates to about 9 dB of shielding for one skin depth, therefore, a 0.010 inch shield would have approximately 90 dB of shielding at 10 MHz.

The shield absorption term does not account for any signal leakage that occurs through holes or apertures in the outer conductor. Aperture leakage is usually the dominant factor in cable shielding and is a complicated phenomenon. Figure 3a illustrates the effect that aperture orientation has on shielding effectiveness. Current flow in a coaxial shield is intended to be longitudinal along the length of the outer conductor. An opening in the shield causes a disruption in the flow of electrons as they have to travel around it. It is this disruption of current flow that causes signal leakage or coupling through the outer conductor. Figure 3b illustrates the approximated relationship among width of opening, frequency of operation and shielding effectiveness. The equation illustrates that the shielding effectiveness is inversely related to the signal frequency and circumferential slot width. For example, a 0.010 in. slot placed in the outer conductor of a trunk cable will have a shielding effectiveness of 94 dB at 10 MHz and will degrade to 54 dB at 1 GHz.

Reflective losses will also occur at the outer conductor interface. This is typically a noise ingress issue. The electromagnetic wave propagation of the signal inside a coaxial device is along the length of the cable. Since the angle of incidence of the wave propagation to the outer conductor is zero degrees, there is essentially no reflective component. This is not the case for external fields which can ingress into the coax. External fields can impinge on the outer conductor at an unlimited number of angles. Reflections occur as the incident wave which is traveling through a high impedance medium (free space Z_{free} = 377 Ohms) meets a low impedance medium ($Z_{aluminum} = 4.67 \times 10^{-7} \times f^{1/2}$). This generates a reflected signal who's energy is proportional to the ratio of free space impedance to the shield impedance. This is shown in the equation below and a plot can be found in Figure 2

$$\text{S.E. Reflection} = 20 \cdot \log \frac{377}{4 \cdot (4.67 \cdot 10^{-7} \cdot f^{1/2})} \text{ dB}$$

S.E. MEASUREMENT TECHNIQUE

Due to the complexity of the leakage component found within the coaxial cable network, computation is not possible, therefore, shielding effectiveness must be determined by measurement.

The most obvious way to do this and the method which most closely simulates actual performance of the leakage component is to measure the ingress energy within the component resulting from a known external electromagnetic field, or conversely to measure the egress (energy emitted) resulting from a known energy level within the component under test. The systems engineer would then be able to use this information to determine shielding effectiveness specifications for the individual components as well as predict the shielding effectiveness of the entire system with high reliability.

Traditionally, within the CATV industry, the parameter used to measure the penetration of electromagnetic energy through a cable's shield is the transfer impedance (Zt) and is measured using the triaxial chamber test setup. The transfer impedance has been used to give a comparison between cable shields and is quite useful for this purpose. However, its ability to determine the cable's shielding effectiveness (i.e., radiated field strengths) is questionable. Other limitations of the triaxial chamber setup include only being able to measure cables and not connectors, splitters and other components. The industry needs:

- An industry test standard where acceptance standards can be applied globally, measured uniformly and compared directly.
- Meaningful measurements that correlate to Open Area Test Site (OATS) measurements.
- Capabilities which include repeatability and accuracy. Ability to measure shielding effectiveness of cables, connectors, taps and other components (not limited by geometry).

GTEM Cell

A new test cell which offers the above mentioned industry needs where either emissions or immunity testing can be performed is the Gigahertz Transverse Electromagnetic Cell, the GTEM cell and is illustrated in Figure 4. The GTEM represents a significant advancement in state-of-the-art EMC testing. As part of a measurement system, it allows more types of testing to be done in less time while improving accuracy and repeatability of results.

The GTEM cell is an offshoot of the TEM cell, as developed at the National Institute of Science and Technology (NIST). It is a section of 50 ohm transmission line with a unique geometry. At the input a normal 50 ohm coaxial transmission line is transformed into a rectangular cross section. The cell is flared along the longitudinal axis to increase the cross sectional dimensions of the transmission line. The septum, or center conductor, is transformed from a round cross section to a flat wide conductor, located well above the center of the cell. This maintains the 50 ohm characteristic impedance, while increasing the volume of the cell under the septum, allowing a larger test volume. The GTEM can perform measurements from DC to 1 GHz and above and emissions testing has been found to correlate with open area test site measurements. Connectors and other components can also be tested for emissions or immunity, allowing their shielding performance to be measured.

The GTEM has been used to measure the shielding effectiveness of various leakage components and the data is presented in this paper. Refer to Figure 4 for the GTEM Test Setup. The shielding effectiveness parameter is defined as the level difference, in dB, between the signal level inside the Device Under Test (DUT) to the signal level immediately outside the DUT, measured with a 0 dB gain 1/2 wave dipole tuned antenna.

S.E. OF COAXIAL CABLE COMPONENTS

This section details the results of the S.E. measurements for the various coaxial cable components. Measurements were performed using the GTEM cell, as described in the previous section (Refer to Figure 4 for measurement setup). Table 3 gives a summary of the components and their related plots.

S.E. Plots

Description of Component	Figure No.
Longitudinal Slot	5
Circumferential Slot	6
Expansion Loop Failure	7
Connectors (T&D)	8
Splitters (Drop Cable)	9
Taps (4-port)	10
Connectors (Drop Cable)	11
Drop Cable (Unflexed)	12
Drop Cable (Flexed)	13

TABLE 3. - S.E. Plots

Slots

It can be seen from the S.E. plots in Figures 5 and 6, that the circumferential slot has much greater RF leakage than the longitudinal slot. This is because a slot placed circumferentially, normal to the direction of current flow, abrupts a greater portion of the current densities, thus causing greater leakage.

Figure 7 shows the S.E. of an expansion loop failure for a solid outer conductor cable design, i.e, T&D coaxial cable. Failure at the expansion loop is a result of work hardening of the coaxial cable's outer conductor, due to the continuous flexing that takes place. Failure occurs in the center of the expansion loop, where a circumferential break in the outer conductor occurs. Because the expansion loop failure represents a circumferetial slot, the circumferential slot and expansion loop S.E. plots are very similar (Figures 6 and 7, respectively).

Connectors (T&D)

The majority of signal leakage sources within a coaxial cable system are caused by the connector/cable termination. Leakage is typically due to the loosening of the connector/cable outer fitting, effectively leaving a gap in the outer conductor of the coaxial cable. It is through this circumferential slot that electromagnetic energy reaches the exterior region.

From looking at Figure 8, it can be seen that T&D connectors, when installed properly, have very good S.E. performance, approximately 125 dB average and 115 dB minimum shielding effectiveness. However, with the slightest loosening of the connector, the S.E. is seen to decrease considerable, from 115 dB to 53 dB minimum S.E.

Taps

Figure 10 shows the S.E. of a 14 dB, four port tap, with and without its ports terminated. The tap is seen to have acceptable S.E. performance, as long as its unused ports are terminated properly. The unused ports, when left unterminated, are seen to decrease the average S.E. from 135 dB to 110 dB.

Splitters

Various constructions of drop cable splitters can be found within the industry which have different levels of S.E. performance. Figure 9, for example, shows the S.E. performance of a splitter having a soldered back vs a splitter having a glued back. The two splitter designs are seen to have very different S.E. performance, 106 dB vs 43 dB respectively.

Connectors (Drop Cable)

Figure 11 shows the S.E. measurements for various types of drop cable connectors. There was found to be little difference among the crimp, compression and push-on connectors.

Drop Cable (Unflexed and Flexed)

Figure 12 shows a S.E. comparison among standard, tri and quad-shield constructions as well as non-bonded standard shield. Results were as expected, showing that cables with more shielding have greater S.E. performance.

Flexure is used to simulate aging which includes cyclic stress from temperature changes, wind and ice loading. Flexure has greatest effect on the tape and does not significantly degrade the braid's performance.[3]

Figure 13 demonstrates the S.E. of the drop cable constructions after flexure, all samples being equally conditioned.

Conclusion

From looking at the S.E. performance of the various coaxial cable components, it becomes evident that the systems engineer should specify the S.E. requirements of the individual components which are to be used within the coaxial cable system. This will then help to ensure that the system, after being built, will have adequate S.E. performance, initially and also after being aged, in order to reduce maintenance.

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ACKNOWLEDGMENTS

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Shielding Effectiveness Through Absorption Loss (Skin Effect)

Shielding Effectiveness:

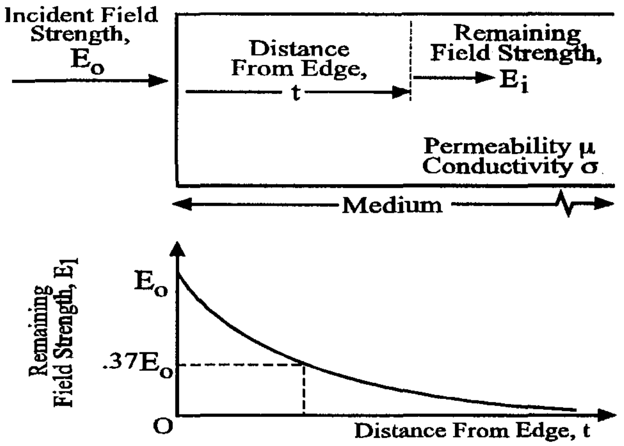
$$\text{S.E.} = 20 \log\left(\frac{E_o}{E_i}\right) = 20 \log\left(\frac{H_o}{H_i}\right) \text{ dB}$$

Electric and Magnetic Field Diffusion:

$$E_i = E_o\, e^{-t/\delta} \qquad H_i = H_o\, e^{-t/\delta}$$

Skin Depth:

$$\delta = \frac{2.6}{\sqrt{f\, \mu_r \sigma_r}} \text{ in.}$$



Absorption Loss:

$$A = 3.34\ t \sqrt{f\, \mu_r \sigma_r} \text{ dB}$$

Where:

- E_o, E_i is the outside and inside electric field wave intensity
- H_o, H_i is the respective magnetic fields
- t is the distance within the shield
- μ_r is the relative permeability (aluminum $\mu_r = 1$)
- σ_r is the relative conductivity (aluminum $\sigma_r = 0.61$)

Figure 1

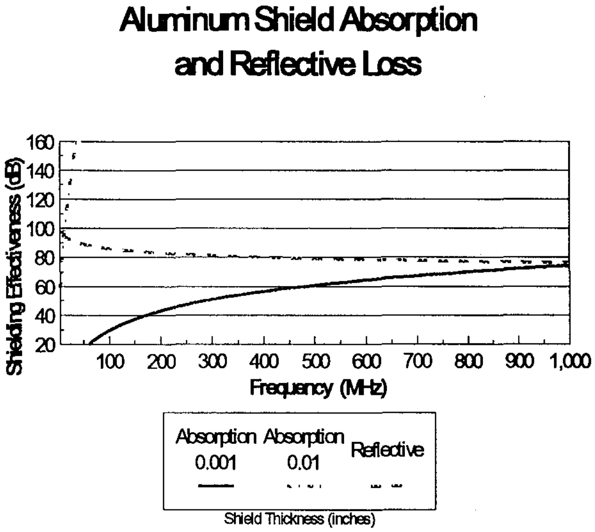
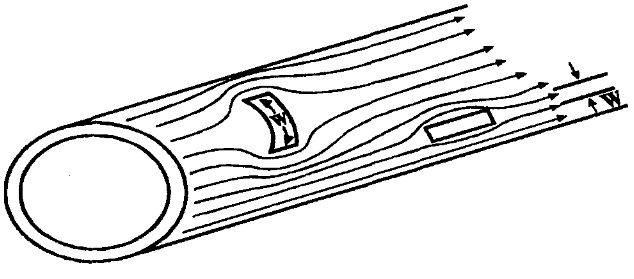


Figure 2

Shielding Effectiveness As A Function of Aperture Leakage



$$\text{S.E.} = 20 \log\left(\frac{\lambda}{2W}\right) \text{ dB}$$

$$= 20 \log\left(\frac{5{,}906\ V_f}{fW}\right) \text{ dB}$$

Where:

- V_f is the velocity factor (0.88 for foam T&D)
- f is the frequency in MHz
- W is the slot width in inches

Figure 3a

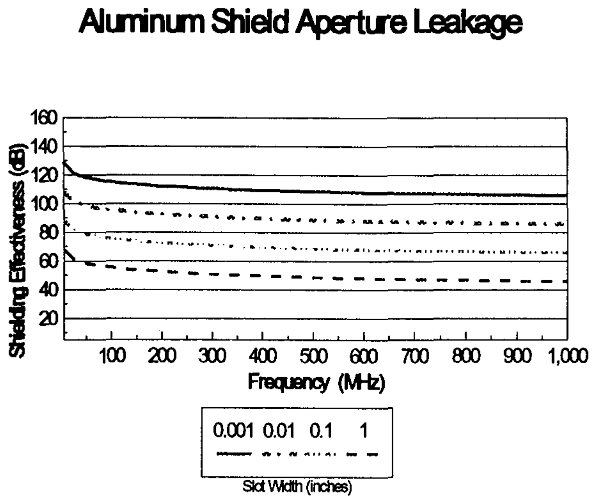


Figure 3b

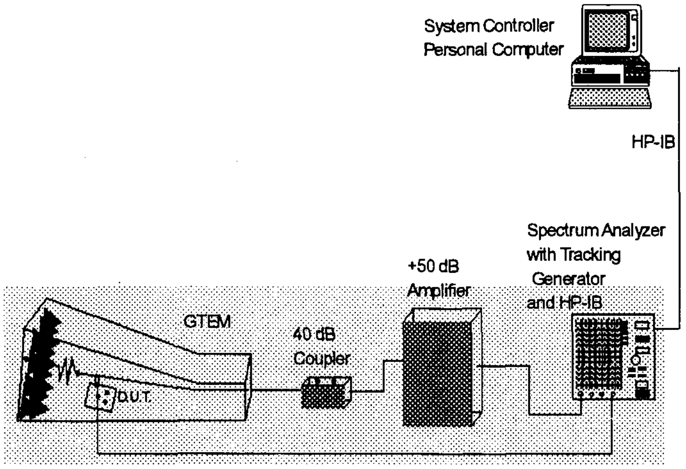


Figure 4

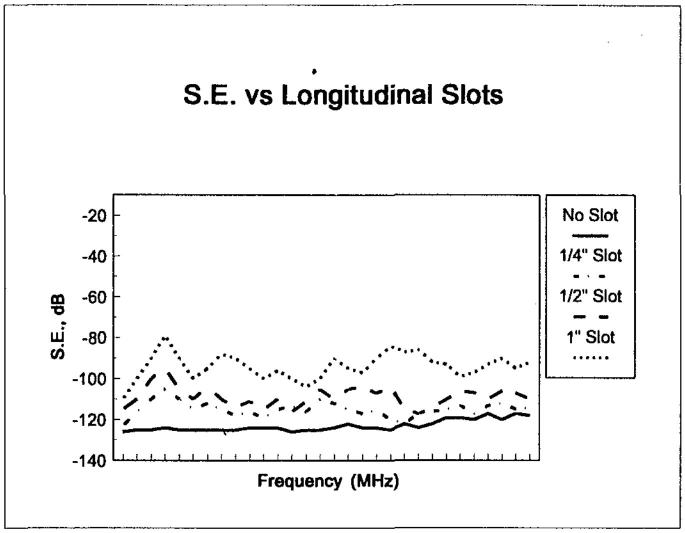


Figure 5a

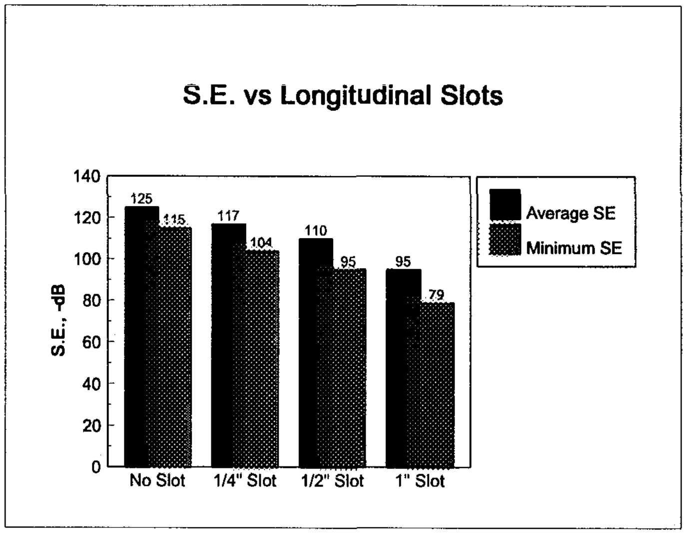


Figure 5b

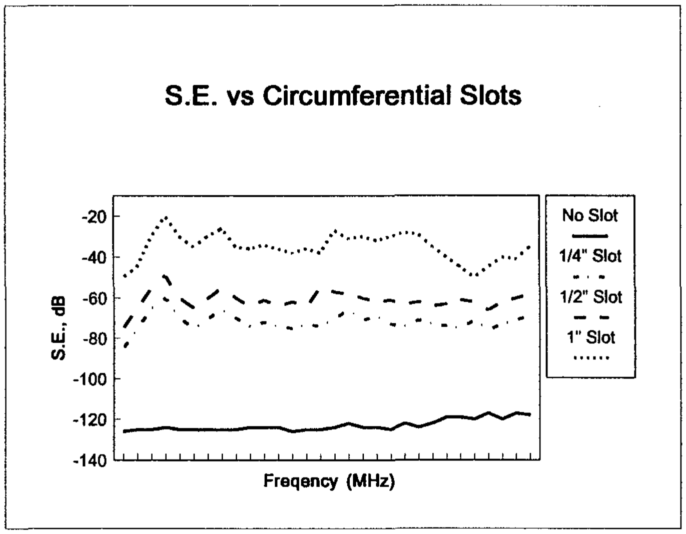


Figure 6a

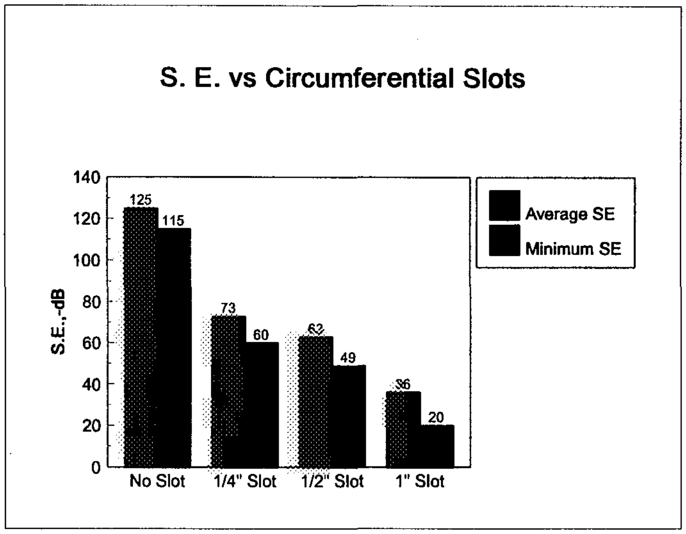


Figure 6b

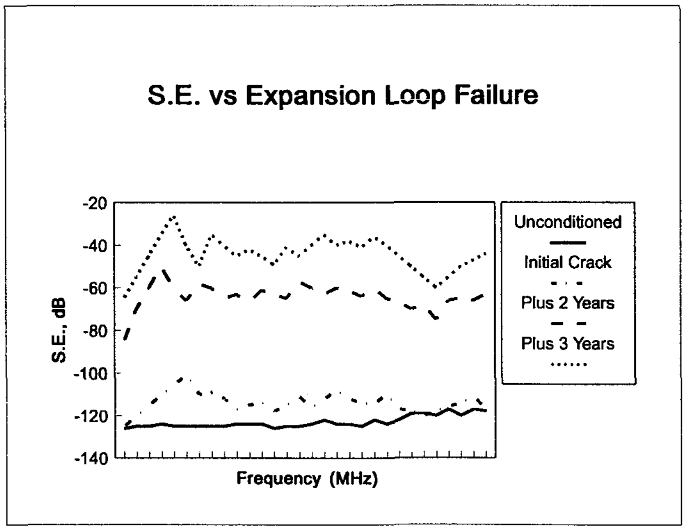


Figure 7a

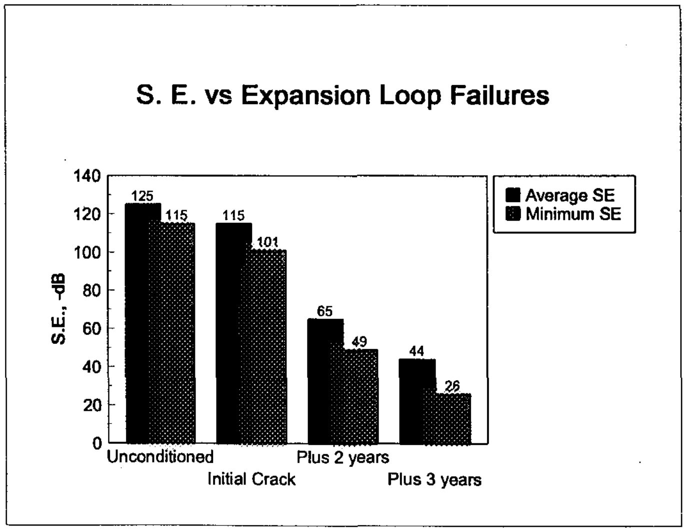


Figure 7b

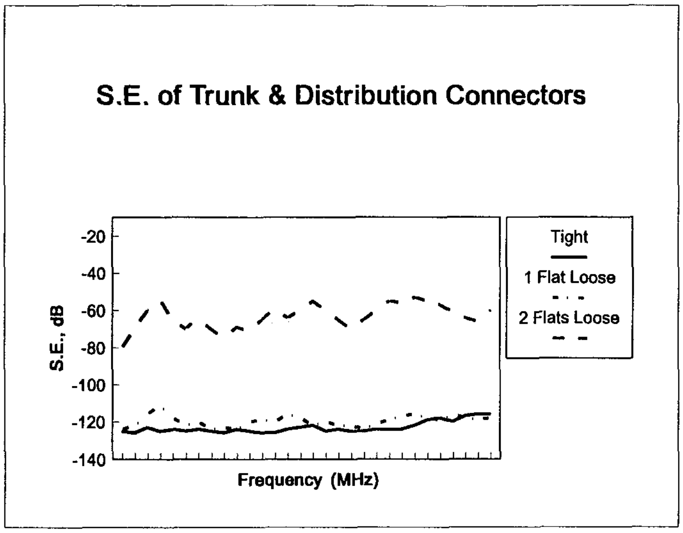


Figure 8a

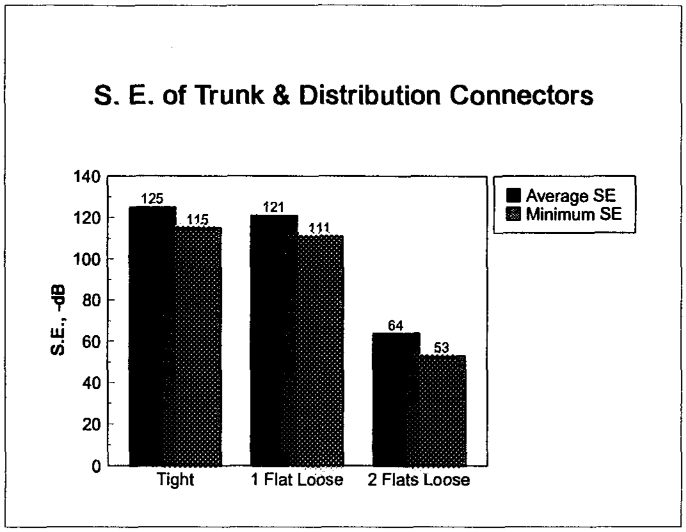


Figure 8b

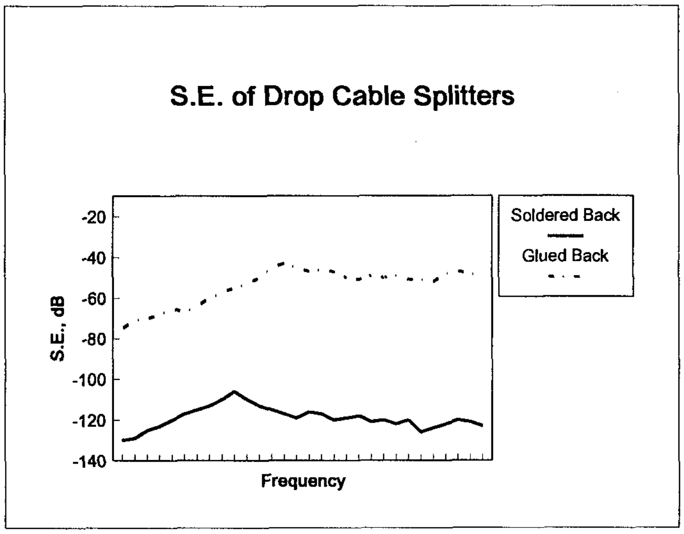
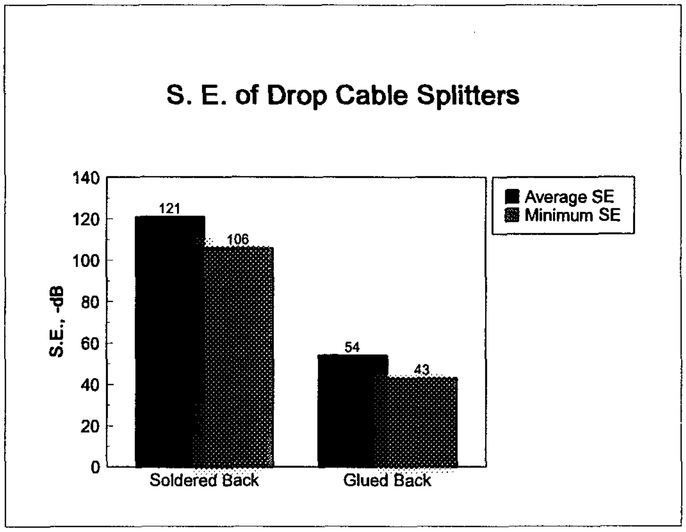


Figure 9a



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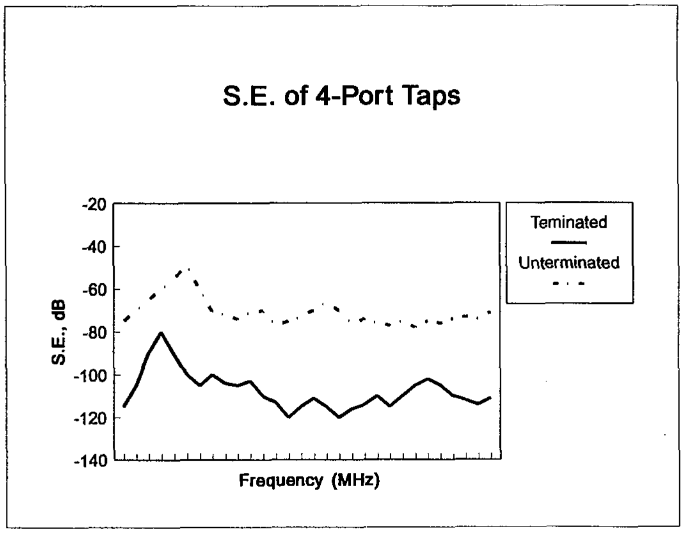
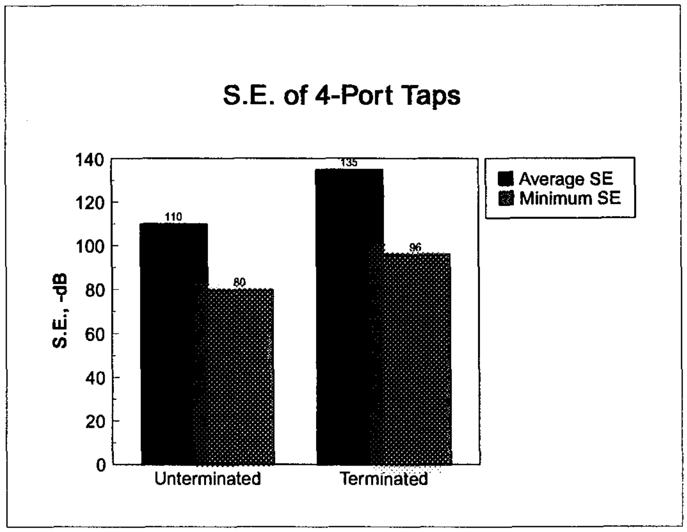


Figure 10a



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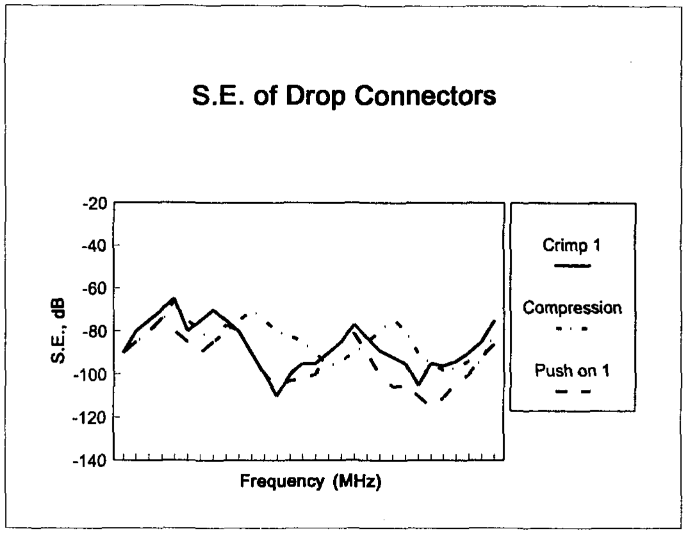
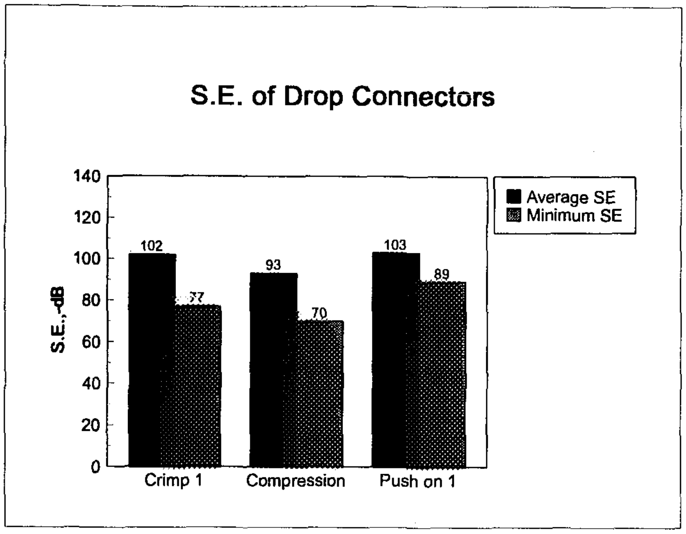


Figure 11a



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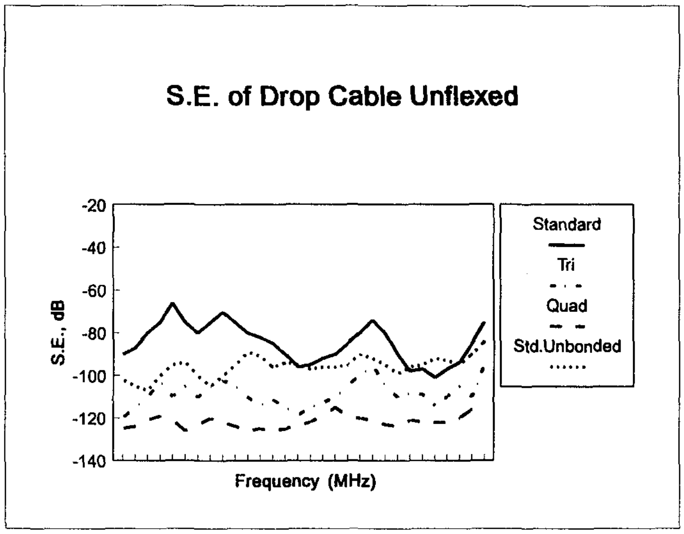

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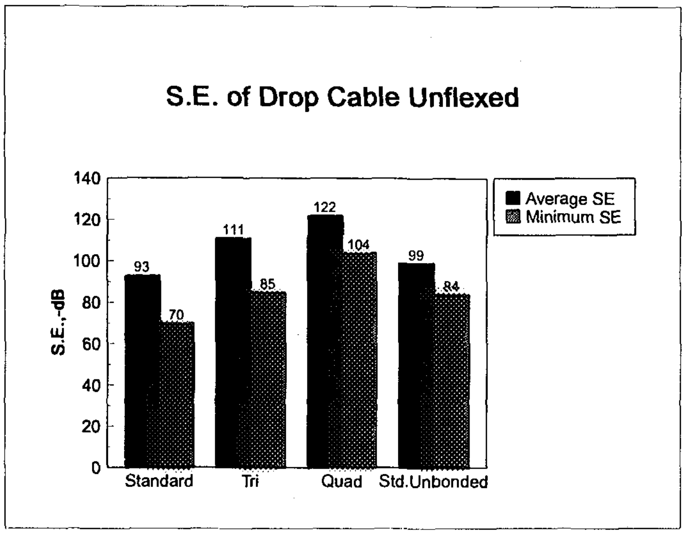

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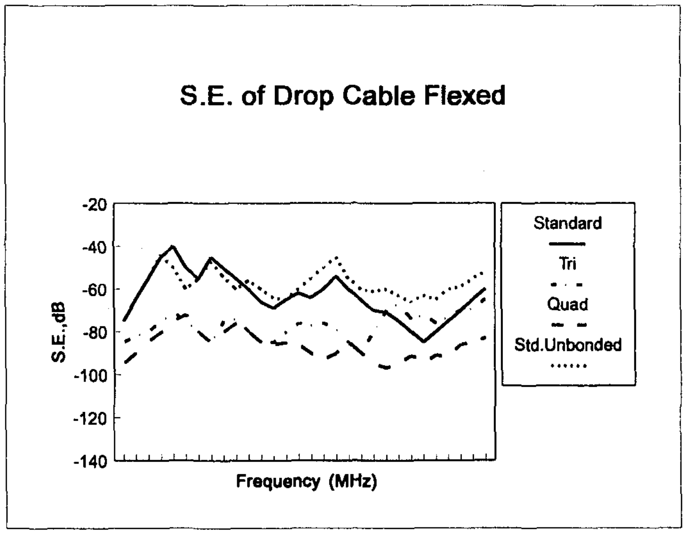

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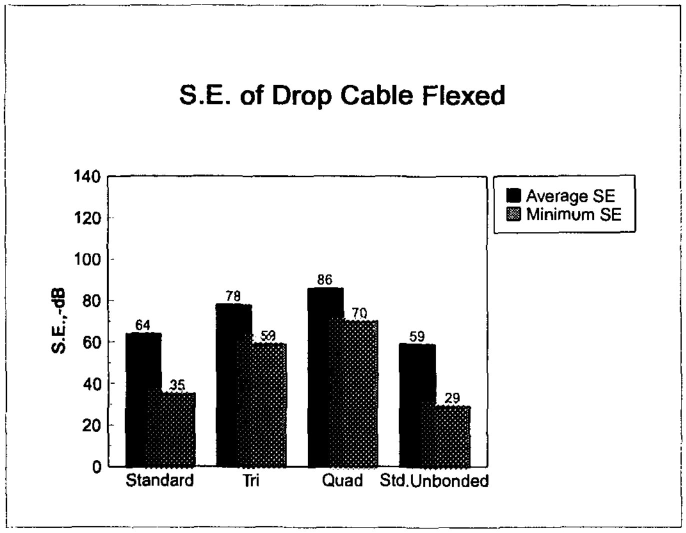

Figure 13b