Automotive Cable Shielding Effectiveness and Radiated Emissions

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Abstract

High-frequency operation in modern vehicles can produce electromagnetic interference (EMI), and wiring harnesses can act as both sources and recipients of unwanted coupling. Corrosion, ageing and deterioration may change cable performance after manufacture. This study examines automotive cable shielding through three-dimensional modelling in Ansoft HFSS and measurements of antilock braking system (ABS) and airbag cables at different deterioration levels. The simulation represents a conductor near a printed circuit board, while measurements use a semi-anechoic chamber and a network analyser. The results describe frequency-dependent coupling and differences among cable samples. The study also discusses the relationship between these observations and the emission limits illustrated from CISPR 25.

Keywords: *Ansoft HFSS, Automotive, Electromagnetic field, Shielding Effectiveness.*

Introduction

Advances in electronics have increased the importance of controlling interference between devices. Electromagnetic interference is an unwanted disturbance that affects electrical or electronic performance. It can arise when signals from surrounding devices, or from another part of the same system, couple into the intended signal path and cause undesirable outputs or malfunction.

Electromagnetic compatibility (EMC) is the ability of equipment to operate satisfactorily in its intended electromagnetic environment without introducing unacceptable disturbances. Both emissions and immunity matter. Radio-frequency applications span approximately 3 kHz to 300 GHz and include navigation, broadcasting, mobile communications, GPS, Wi-Fi and satellite links. Interference control is relevant across these applications.

Increasing component density, operating speed and integration makes EMC design more demanding.

Common control techniques include shielding, grounding, short routing and twisted pairs. Grounding and bonding provide suitable paths and connections for unwanted currents, while shielding limits electromagnetic coupling. Single-point, multipoint and hybrid grounding arrangements serve different design needs. A shield acts as a barrier between a source and a receiver; its effectiveness depends on the material, geometry, frequency and treatment of discontinuities.

Vehicle wiring harnesses can receive interference and radiate unwanted energy, potentially affecting electronic and safety systems. Shielding helps limit this coupling, but ageing, corrosion and deterioration can change its performance. This paper reviews shielding principles and enclosure effects, describes an automotive cable simulation, and presents measurements of ABS and airbag cables.

Literature Review

EMC testing considers whether equipment limits its emissions and withstands disturbances from its environment. Designers can reduce noise at its source through component selection and circuit design, or limit propagation through filtering and shielding. A suitably designed enclosure can reduce electromagnetic leakage and external coupling.

Circuit-level controls may need to be supplemented by shielding enclosures. An enclosure can limit both outgoing and incoming electromagnetic energy when its materials, connections and openings are appropriately designed. Figure 1 illustrates the role of a shield [1].

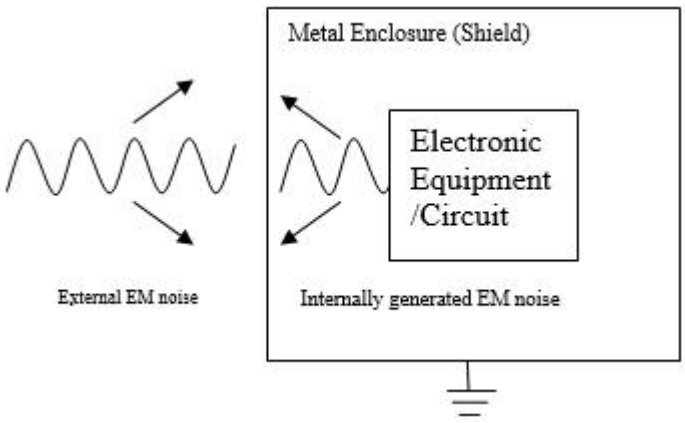


Figure 1: Role of Shield

A shield separates two regions and controls electromagnetic propagation between them. Shielding effectiveness compares an unshielded response with a shielded response under a defined

measurement arrangement [2]. Holes, seams, slots and cable penetrations can reduce performance if they are not properly treated [3]. Practical equipment needs access, ventilation and interconnections, making the design of these openings an important part of enclosure shielding.

Electromagnetic shielding reduces transmission through a material or structure. Apertures, cables and wires can provide leakage paths when shielding is incomplete. The literature cited here reports differences between magnetic-field and electric-field leakage through apertures [3].

The number and size of apertures, enclosure geometry and material properties all influence shielding effectiveness. These features require careful assessment. A transmission-line method has been used to calculate the shielding of metallic enclosures with apertures and to examine the improvement obtained with a two-layer enclosure [4].

Electric vehicles contain extensive electrical and electronic systems. Finite-element tools have been used to study magnetic fields and exposure [5]. One cited estimate assigns cables, batteries and electronics approximately one quarter of the weight of a fully automated electric vehicle [6]. Long cable runs can support high-frequency emissions and coupling into low-voltage systems [7]. Energy storage and magnetic sensors are further topics in the electromagnetic assessment of electric and hybrid vehicles [8].

A coaxial transmission-line investigation examined the EMI shielding of stainless-fibre composites for automotive applications. The cited study reports improved shielding over a frequency range extending to 1.5 GHz compared with polypropylene composites, indicating potential applications in automotive and electronic components [9].

Interconnects between subsystems can also contribute to radiation. Connections that provide continuity at DC or low frequencies may behave differently at high frequencies. Changes in material or physical dimensions can introduce impedance mismatches and reflections. Previous work has examined low-frequency interference from vehicle cables [10], emissions and shielding design for high-voltage harnesses [11], vehicle-level numerical analysis [12], and electromagnetic topology models that represent a vehicle as interconnected subsystems [13].

A wiring harness bundles conductors carrying signals and electrical power. Its total conductor length can extend over several kilometres. Vibration, temperature, corrosion and ageing can cause deterioration. Earlier cable studies have considered EMC and crosstalk between bundles [14]. Another comparison reports better performance for shielded twisted-pair automotive Ethernet cables below 3 GHz and for shielded parallel-pair cables above 3 GHz [15].

Network, audio and safety-system cables can act as unintended antennas. A design may meet its

initial emission requirements yet change during service as vibration, corrosion and ageing affect contacts and connections. These changes can influence shielding performance.

Corrosion changes metallic materials and their electrical properties; its rate depends on the materials and environment. Connector performance matters in automatic steering, braking and other vehicle control systems [16]. A cited harness investigation reports connector resistance reaching three times its initial value [17]. Maintaining conductivity and appropriate low-impedance connections therefore matters for shielding. Dissimilar metals can promote galvanic or other electrochemical reactions, and changes in cable impedance can affect emissions [18]. Multiconductor transmission-line modelling has also been used to analyse induced currents, with reported agreement between analytical calculations and HFSS simulations [19]. Cable position and termination impedance are additional influences on radiated emissions [20].

A circuit model for a lossy shielded cable used the method of characteristics to represent incident-wave effects. The cable was divided into uniform sections, and its current and voltage distributions were compared with other modelling techniques [21].

An earlier technical note by Bhuvaneswari, Manivannan and Salil examined the prediction of automotive cable shielding effectiveness [23]. The present account also describes ABS and airbag cable measurements.

Methodology

HFSS Simulation

High-frequency operation in hybrid and electric vehicles can couple disturbances into nearby devices. ABS and airbag systems are relevant examples because of their safety functions. Deteriorated cables can also become sources of interference, motivating the simulation and measurement work described below.

Figure 2 shows an HFSS model of a single-core conductor near a single-trace printed circuit board (PCB). The conductor is treated as the radiation source and the PCB as the receiving structure. Two receiver ports are located at opposite ends of the PCB, and a transmitter port is located at the conductor. The three ports are defined as follows.

- Port 1 – Receiver 1 at one end of PCB

- Port 2 – Receiver 2 at other end of PCB
- Port 3 – Transmitter at the conductor side

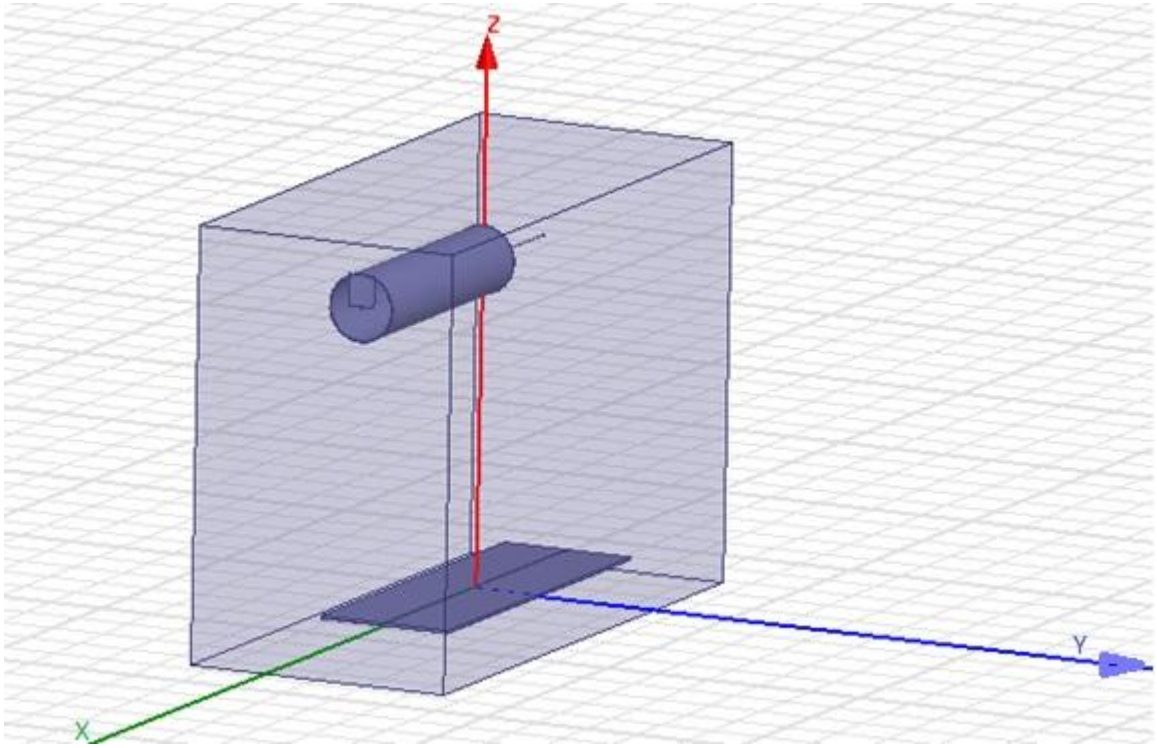


Figure 2: HFSS MODEL

S-parameters describe the port responses of the model. Equation (1) reproduces the source S-parameter matrix at 1 GHz. These port-coupling quantities should be distinguished from calibrated radiated field-strength measurements.

$$S_{1,2,3} = \begin{bmatrix} -6.87 & -6 & -49.7 \\ -6 & -6.73 & -55.5 \\ -49.7 & -55.5 & -16.8 \end{bmatrix} \quad (1)$$

The reported coupling between ports 1 and 2 differs from the coupling between either PCB receiver and the conductor at port 3. The responses also vary with frequency, particularly above 3 GHz.

Experimental Measurements

The measurements examine ABS and airbag cable samples with different ageing and deterioration levels. The equipment under test (EUT) is operated in a condition intended to produce maximum emissions. It is connected between a network analyser and a 50-ohm load, with the antenna positioned 1 m from the EUT, as illustrated in Figure 3.

The measurements were carried out at an Electromagnetics Research Laboratory engaged in antenna, communication, electronic packaging, EMI and EMC testing activities.

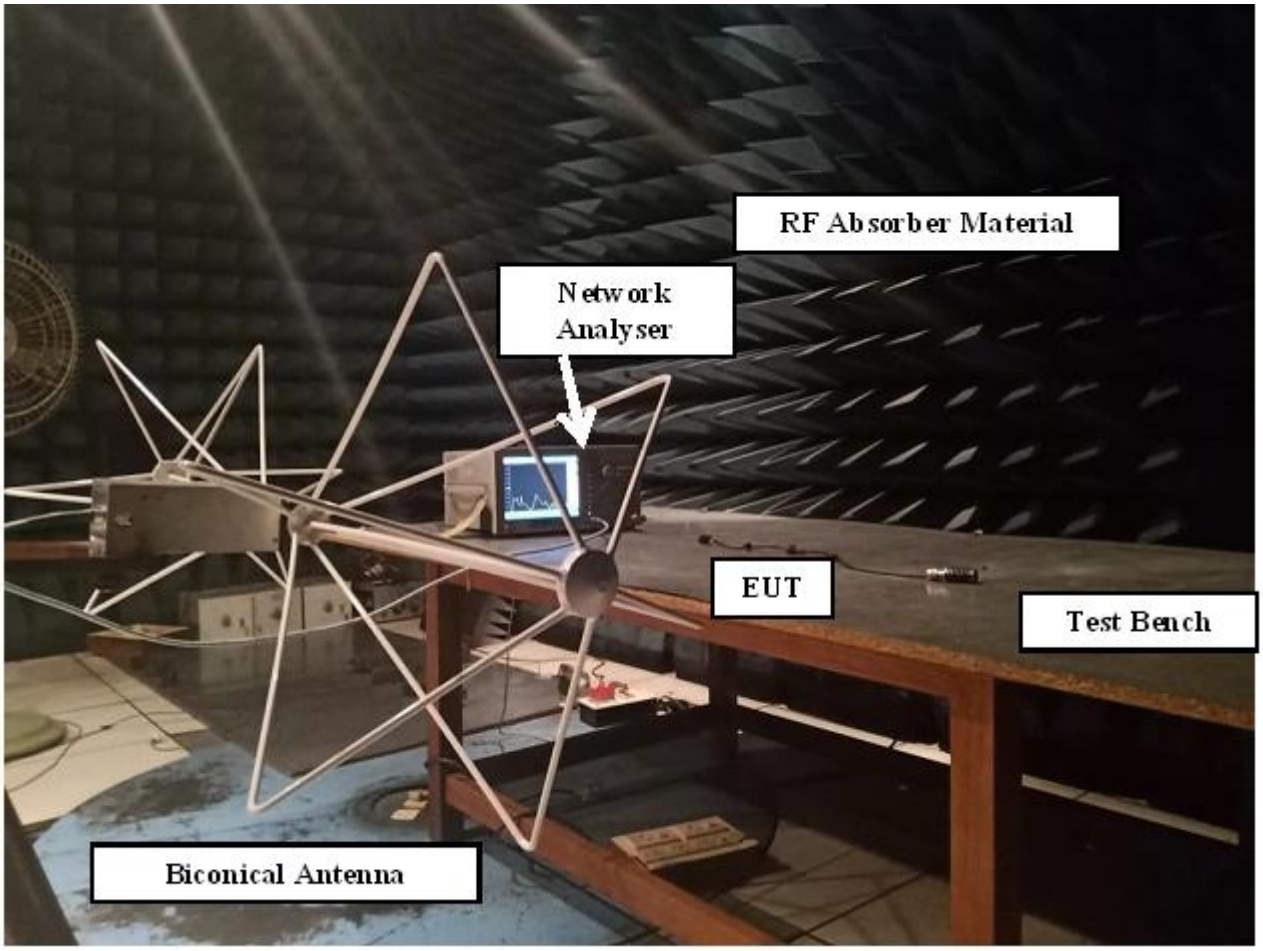


Figure 3: Radiated Emission Measurement

Results and Discussion

Figures 4–6 reproduce the simulated responses for the three port pairs. The source attributes the

differences between the conductor-to-PCB responses and the PCB receiver-to-receiver response to termination impedance and coupling conditions. Although the original plot labels use shielding effectiveness, the plotted S-parameters describe port responses.

The responses show substantial variation above 3 GHz. In the port 2–3 response, port 3 represents the transmitter and port 2 the receiver. A comparison of these dB values alone does not establish compliance with radiated-emission field-strength limits.

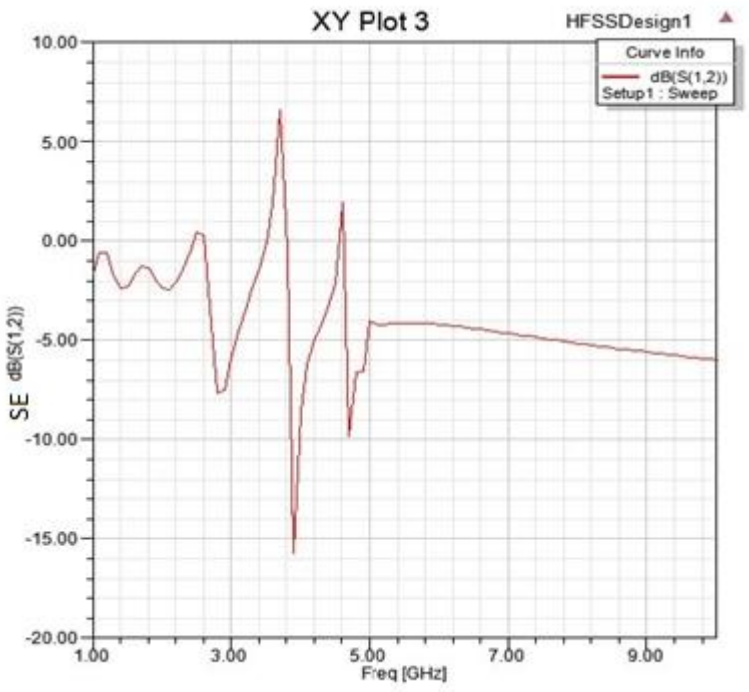


Figure 4: Shielding Effectiveness between ports 1, 2

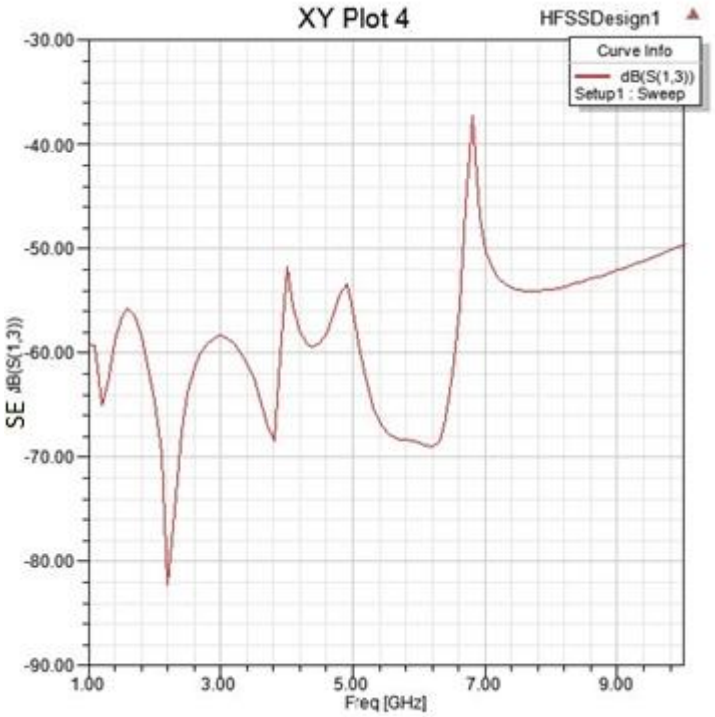


Figure 5: Shielding Effectiveness between ports 1, 3

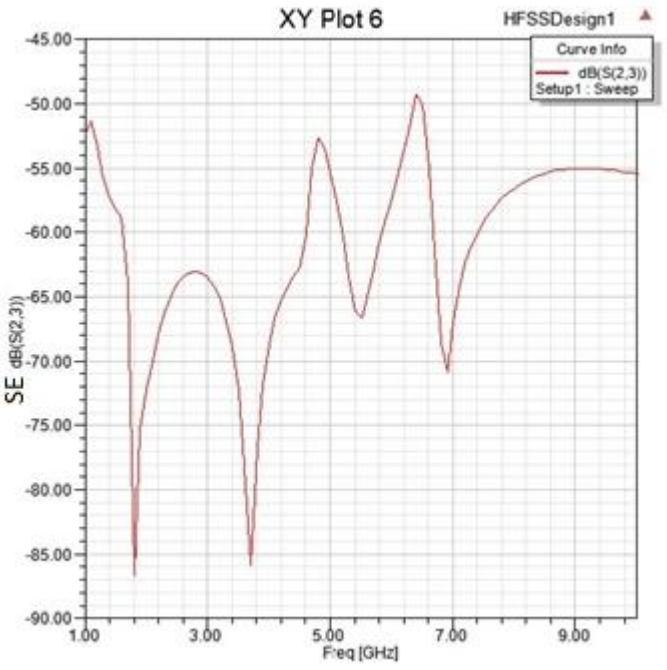


Figure 6: Shielding Effectiveness between ports 2, 3

The experimental measurements cover ABS and airbag cables. A −30 dB reference value was set on

the network analyser. Figure 10 reproduces the source illustration of CISPR 25 radiated-emission limits [22]. Its field-strength units differ from the dB labels on the cable plots, so a compliance assessment would also require the applicable calibration, detector, bandwidth, test class and measurement configuration.

ABS Cable Measurements

Figures 7–9 show the ABS cable measurements over 30–300 MHz, 300 MHz–1 GHz and 700 MHz–6 GHz, respectively.

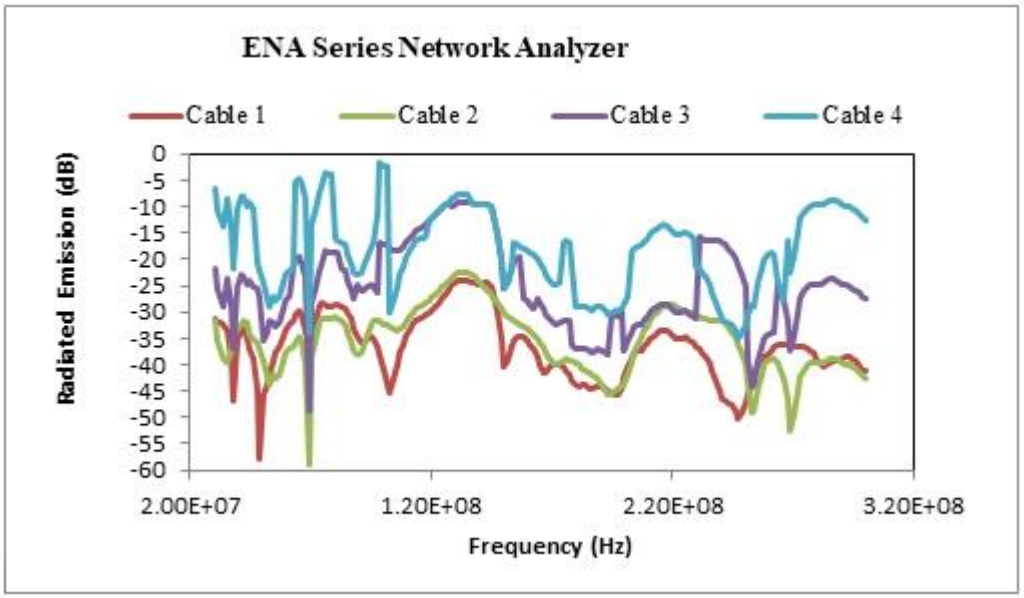


Figure 7: Radiated Emission of ABS cable in 30 MHz – 300 MHz range

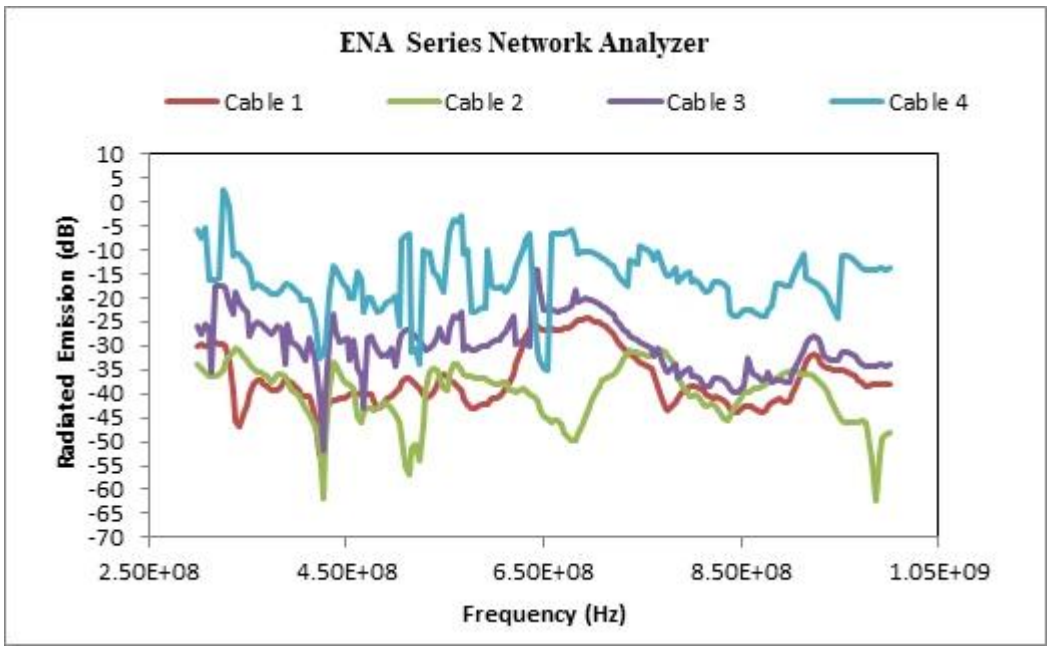


Figure 8: Radiated Emission of ABS cable in 300 MHz – 1 GHz range

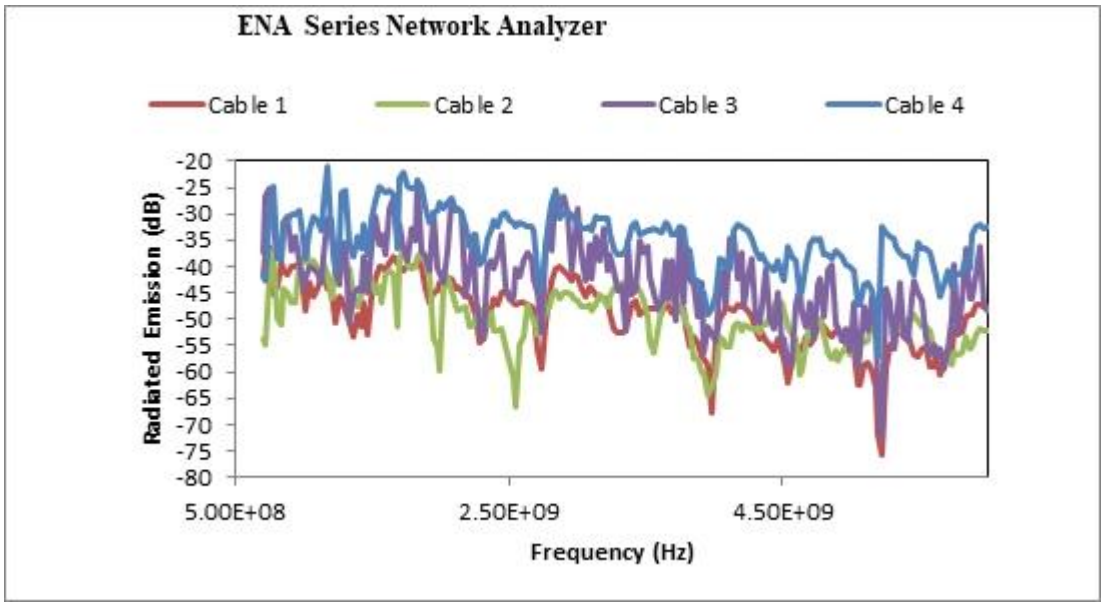


Figure 9: Radiated Emission of ABS cable in 700 MHz – 6 GHz range

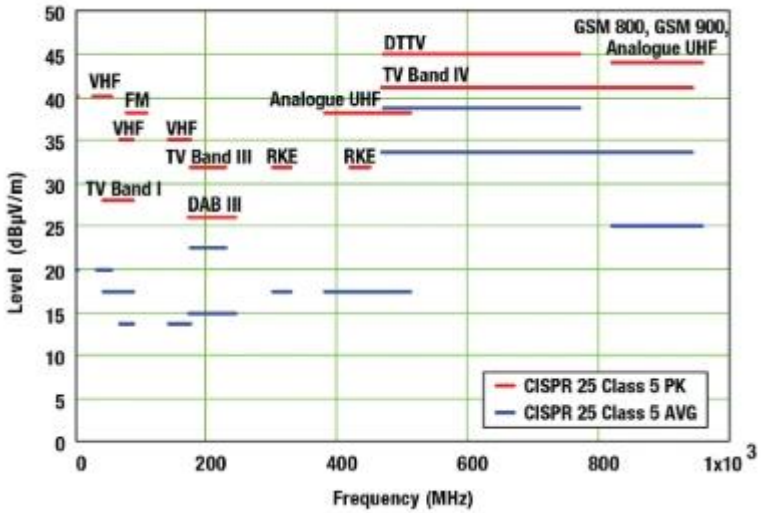


Figure 10: CISPR 25 Radiated Emission limits[22]

The ABS measurements show differences among samples and frequency ranges. Table 1 retains the reported percentage comparisons of cables 2, 3 and 4 with cable 1; these values are relative sample comparisons rather than percentages above a standard limit. Figure 11 reproduces the source comparison plot. The plot and table do not agree in every magnitude, so they should not be treated as independent confirmation of a single numerical result.

Table 1: Comparison of ABS cable measurement

Frequency Range	Increase in Radiated Emission (%) of cable 2 w.r.t to cable 1	Increase in Radiated Emission (%) of cable 3 w.r.t to cable 1	Increase in Radiated Emission (%) of cable 4 w.r.t to cable 1
30 MHz – 300 MHz	3%	32%	52%
300 MHz – 1 GHz	-11%	19%	57%
700 MHz – 6 GHz	-1%	14%	29%

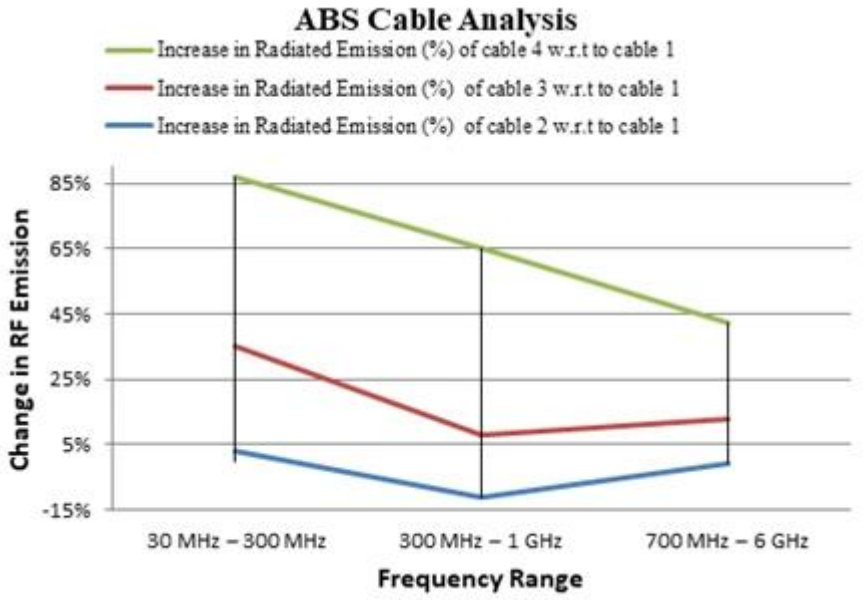


Figure 11: ABS cable comparison

Airbag Cable Measurements

Figures 12–14 show the airbag cable measurements over 30–300 MHz, 300 MHz–1 GHz and 700 MHz–6 GHz, respectively.

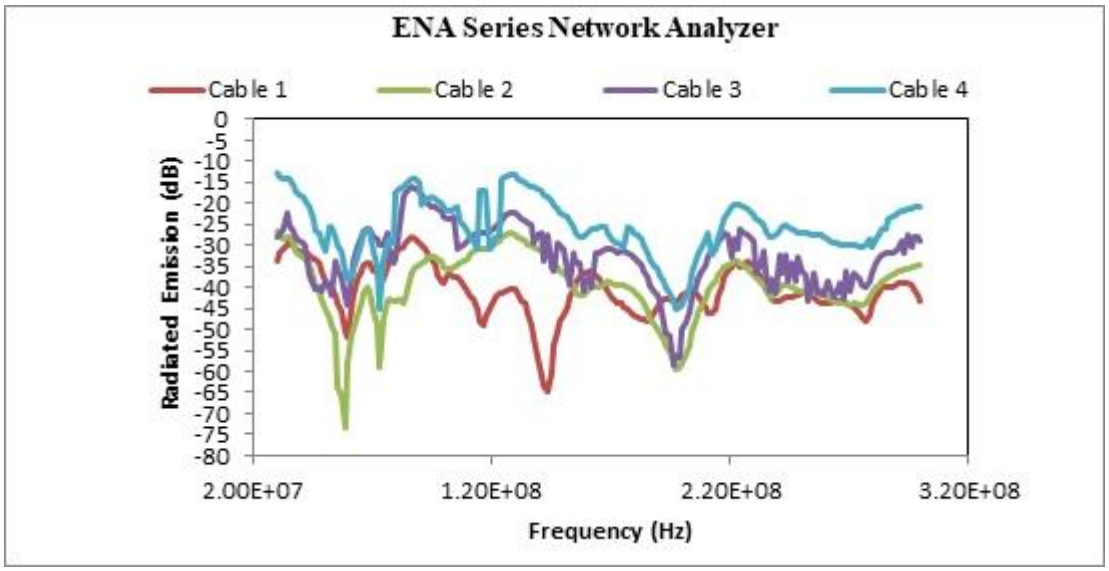


Figure 12: Radiated Emission of Airbag cable in 30 MHz – 300 MHz range

The airbag measurements also differ among samples. Table 2 compares each sample with cable 1,

and Figure 15 reproduces the corresponding source plot. The percentages are reported sample comparisons. They should not be read as a calibrated determination of how far a sample exceeds CISPR 25 limits.

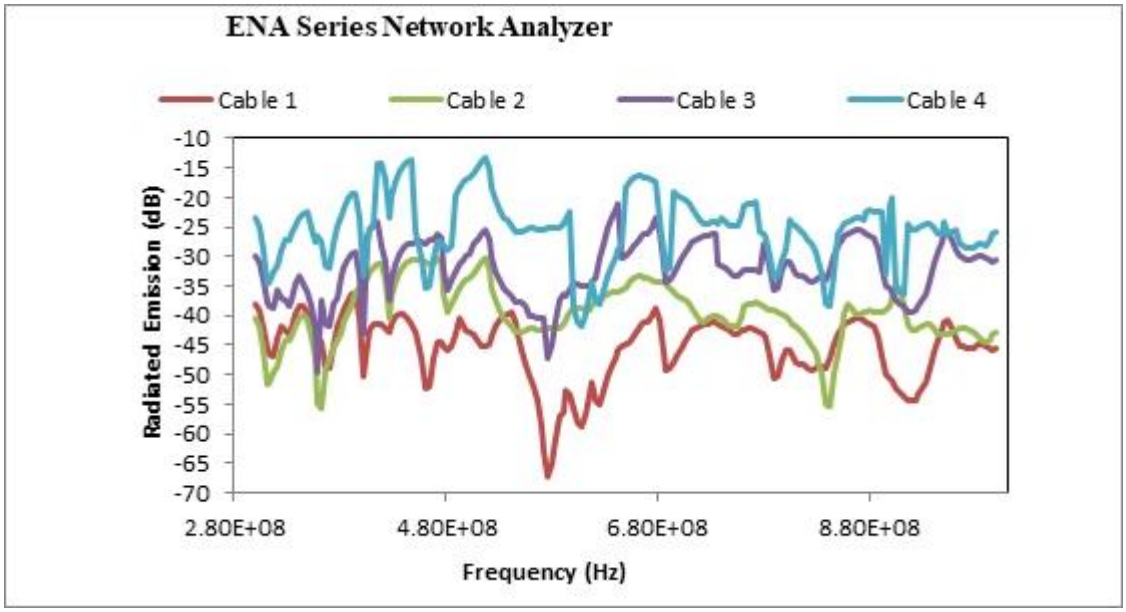


Figure 13: Radiated Emission of Airbag cable in 300 MHz – 1 GHz range

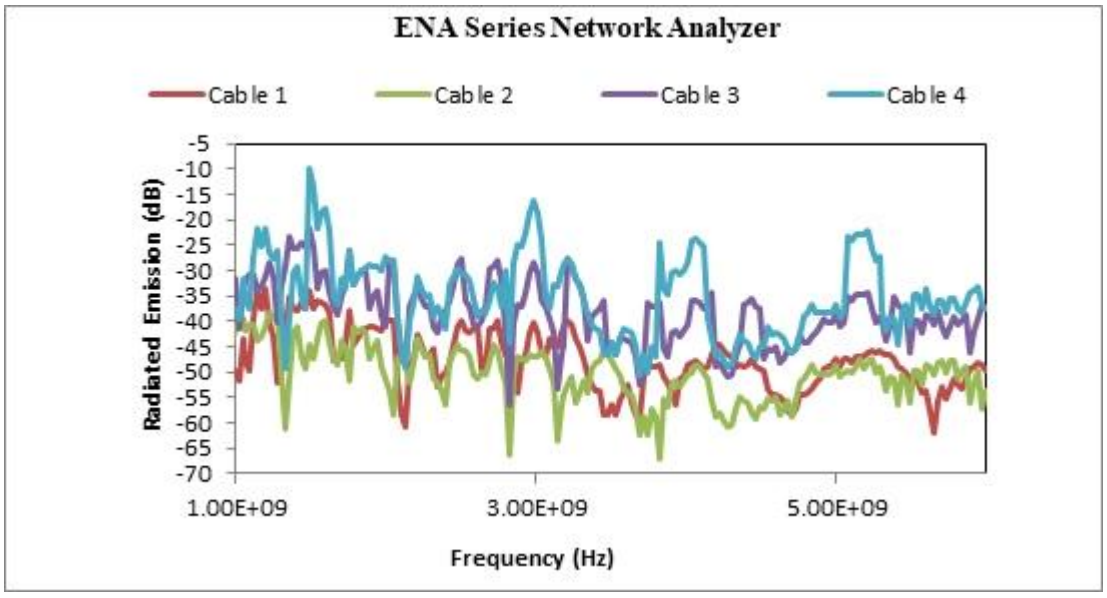


Figure 14: Radiated Emission of Airbag cable in 700 MHz – 6 GHz range

Table 2: Comparison of Airbag cable measurement

Frequency Range	Increase in Radiated Emission (%) of cable 2 w.r.t to cable 1	Increase in Radiated Emission (%) of cable 3 w.r.t to cable 1	Increase in Radiated Emission (%) of cable 4 w.r.t to cable 1
30 MHz – 300 MHz	1%	19%	37%
300 MHz – 1 GHz	12%	29%	46%
700 MHz – 6 GHz	-7%	20%	27%

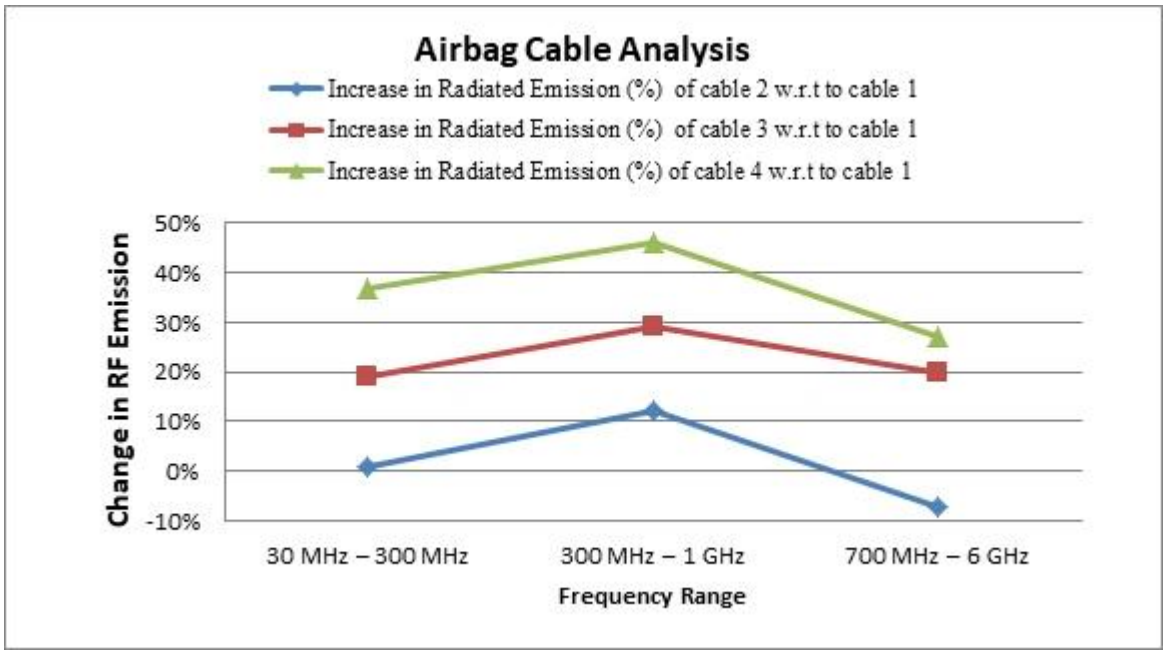


Figure 15: Airbag cable comparison

Conclusion

The simulation and measurements illustrate the frequency-dependent electromagnetic behaviour of automotive cables and the importance of maintaining shield and connector integrity. The experiments cover the stated frequency ranges up to 6 GHz and compare ABS and airbag cable samples at different deterioration levels. The results support further investigation of ageing and termination effects, while the inconsistent ABS comparison magnitudes and the distinction between network-analyser responses and field-strength limits constrain quantitative interpretation. Reliable vehicle EMC assessment requires appropriate shielding design, maintained connections and a documented compliance measurement procedure.

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