EMI Shielding of RG-58

Problem Statement

The topic of the application note is EMI shielding, a scenario where 1) microstrip line, or 2) coaxial cable is placed in the field of the radiating antennas such as rectangular waveguide horn. In both cases the horn is aligned with y-axis (i.e., the main beam is directed along y-axis) and the transmission lines, which are terminated with 50 Ohms loads at both ends, are placed at 1 m from the horn aperture, in parallel with z-axis and symmetrically with respect to xOy-plane. The radiating antenna is 15 dB standard gain horn antenna operating at 10 GHz. The microstrip line 20 cm long is made at duroid substrate (relative dielectric constant is $\varepsilon_r = 3.38$, $\tan\delta = 0.0022$), and substrate thickness is h = 0.508 mm), whose total width is also 20 cm. The coaxial cable of total length 2 m is of type RG58: radius of inner conductor is 0.45 mm, inner radius of outer conductor is 0.975 mm, and relative dielectric constant of filler is $\varepsilon_r = 2$ and $\tan\delta = 0.0007$.

There has been a strong interest on the effects of the shielding effectiveness in coaxial cables, almost always focused to RG-58. By short search on the internet, various datasheets for the requested cable appear, part of them showing that the inner conductor is protected by braided wires, or even with additional 16 μm aluminum foil.

Figure 1. RG-58 Coaxial cable

Thus, from EMI point of view, there are 3 mechanisms for field penetration into the cable. Basic mechanism occurs in the case when cable ends are physically opened and the currents induced along outer surface of outer conductor closes through loads and inner conductor. In the case when ends are shielded, the penetration occurs in two ways, through aluminum foil and through the holes and gaps between braided wires.

In the next section we shall present basic mechanism that occurs in the case of both cables and compare the results, while other mechanisms that occur in cases of fully shielded coaxial cables will be elaborated in later sections.

Shielding Effectiveness of Microstip Line and Coaxial Cable (Basic Mechanism)

In order to reduce the number of unknowns and speed up the simulation scenarios, both lines are modeled using two symmetry planes (Fig. 2). The ends of microstrip lines are terminated by 50 Ohms loads, which are connected between the beginning of the line (indicated as port in Fig. 3) and the ground.

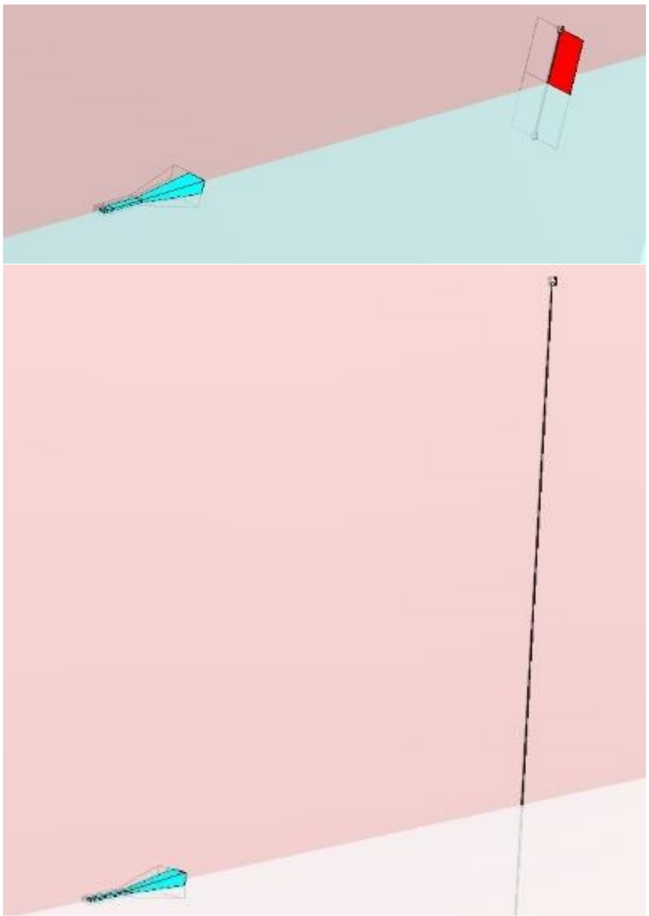

Figure 2. Simulation scenario for microstrip line (upper) and coaxial cable (lower)

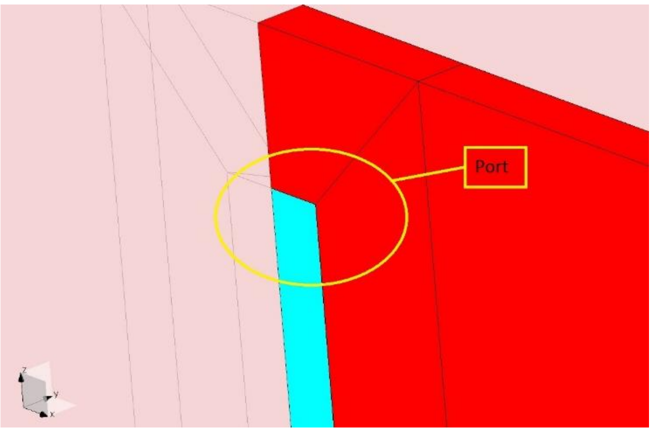

Figure 3. Open end of microstrip line is terminated by 50 Ohms load.

Ends of inner and outer coaxial line conductors are connected by wires supporting 50 Ohms loads, away from the antenna and forward to it, as shown by green in Figure 4. In particular, the horn antenna is almost perfectly matched at 10 GHz and excitation is set so that power of 50 W is radiated and requested power dissipated at load is directly calculated.

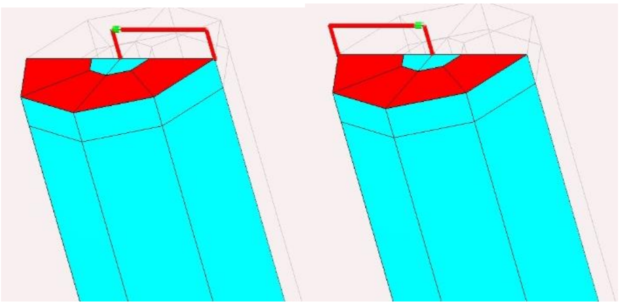

Figure 4. Open end of coax connected by wires supporting 50 Ohms load (shown by green point), in two ways, away from the antenna (upper) and toward the antenna (lower).

Results for power delivered to each of loads (on both sides of lines) are given in Table 1. It is seen that in the case of coaxial cable, the delivered power depends on the physical way of performing the termination. Similar behavior can be supposed for the microstrip line.

Table 1. Power received at the 50 Ohms termination (basic mechanism)

Scenario description	Power [µW]
Microstrip line	4.038
Coax: terminated away from the antenna	0.194
Coax: terminated toward the antenna	3.982

Shielding Effectiveness of Coaxial Cable (Penetration through Aluminum Foil)

Outer conductor of RG58 cable is made of braided wires and in some cases supported by aluminum foil. It is shown that the aluminum foil has much higher shielding effectiveness than braided wires. Hence, in this section we researched only the influence of the foil.

Figure 5 shows half of the coaxial cable (symmetry applied), where the inner conductor is modeled as PEC (perfect electric conductor) shown in cyan, while the outer conductor is modeled as a separate dielectric domain, shown in orange, with relative dielectric constant $\varepsilon_r = 1$ and conductivity of aluminum $\sigma = 37$ MS/m.

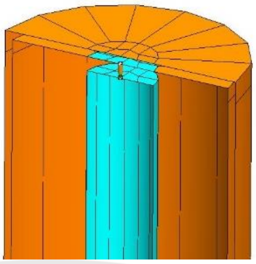

Figure 5. Outer coax conductor is modeled as dielectric material of $\varepsilon_r = 1$ and $\sigma = 37$MS/m

Owing to the improvements of the WIPL-D Method-of-Moments engine introduced in last couple of years, the simulation suite now allows to run precise calculations where the field inside is suppressed over 200 dB compared to the outside field.

Supposing that outer shield of the cable contains aluminum foil of 16 µm thickness the power delivered to each of the loads becomes extremely small, as can be seen from Table 2.

Table 2. Power received at the 50 Ohms termination (penetration through 16 µm thick foil)

Scenario description	Power [µW]
Coax fully shielded with aluminum foil	$0.235\ 10^{-12}$

Shielding Effectiveness of Coaxial Cable (Penetration through braided wires)

In the case when aluminum foil is omitted, the attenuation of field inside the cable is due to braided wires. In most precise modelling of such outer conductor surface of each wire is separately modeled. However, such model would require too much resource for electrically longer cables.

We believe that accuracy of modelling is practically not affected, if each group of wires, which is braided with other group of wires, is represented as a strip conductor, and stop conductors are then braided. In a model we made the braided strip conductors are physically spaced, e.g. at distance of 0.1 mm and 0.01 mm = 10 µm, as shown in Figure 6.

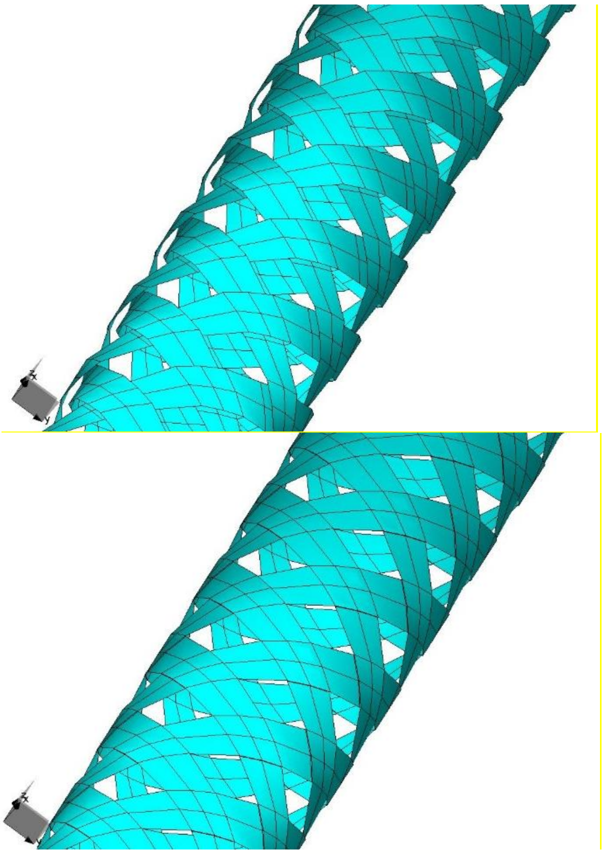

Figure 6. Outer coax conductor is modeled by braiding strips, as space distance of 0.1 (upper) and 0.01 mm (lower)

We have performed a study to show that at spacing smaller than 3 µm the penetration is practically the same as in the case of zero spacing (see Figure 7). The figure shows near field of coaxial cable when the width of the braids is constant, but the spacing is decreased to 0.2 µm. The results remain stable despite the small distance between mesh elements.

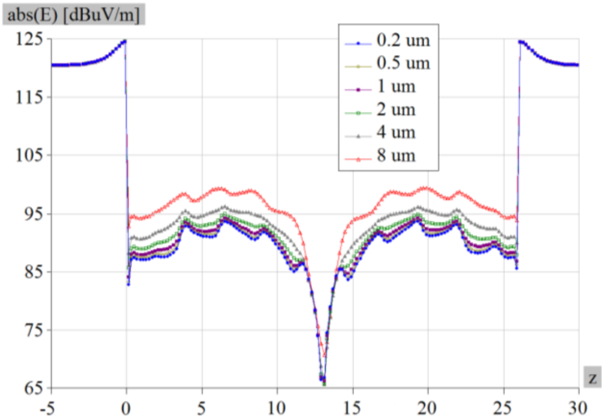

Figure 7. The near field inside coaxial cable for the model with braided strips, gap between strips down to 0.2 µm

Since in the physical model the wires are in physical contact it can be concluded that model with zero spacing is appropriate. In this case field penetrate into the cable through the holes between braided group of strips; based on this we made few models of outer conductor, as shown in Figure 8.

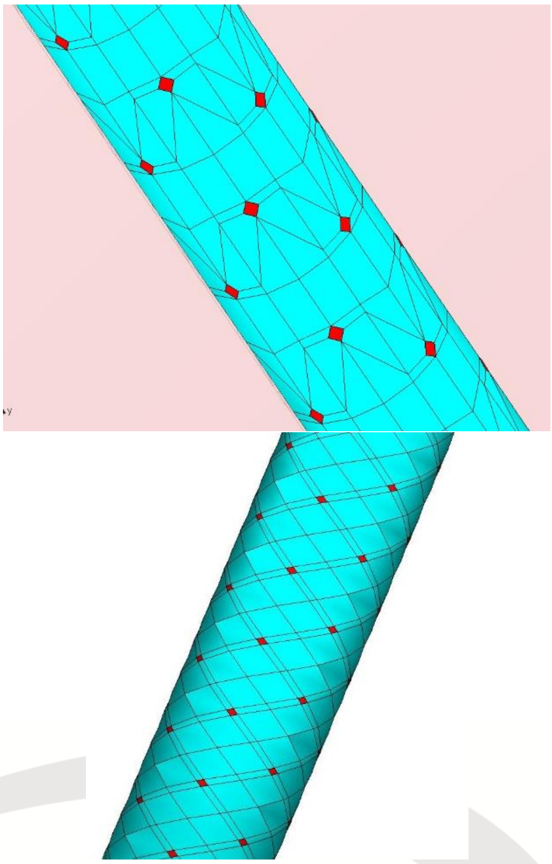

Figure 8. Braiding strips are placed at zero spacing, while red rhombs show the holes to dielectric filler

Adjusting density and size of the holes in some expected range the field inside the cable can be reduced 60 dB to 90 dB with respect to field outside the cable. The penetration in this case is much larger than in the case of aluminum foil. However, even in the case of reduction of inner field for 60 dBs with the respect to outer field the power delivered to each of loads is relatively small, as can be seen in Table 3.

Table 3. Power received at the 50 Ohms termination (penetration through braded wires - field inside the cable is attenuated ~60 dB with respect to outside field)

Scenario description	Power [µW]
Coax shielded with braided wires	61.61 10^{-6}

Shielding Effectiveness of Coaxial Cable (Penetration through braided wires equivalent model)

In order to develop two equivalent models, one with braided wires and the other with partially transparent outer shield via finite sigma, we have performed a series of simulation for the different field suppression levels.

For the sake of simulation, the model is illuminated by plane wave (scattering mode). The wall thickness is chosen as 0.1 mm. Since WIPL-D team does not know the actual suppression level needed, we have chosen the attenuation as 60 dB, 70 dB, 80 dB or 90 dB. This seems practical from the engineering point of view. Since the outside field is more or less constant away from the metal surface at 135 dBuV/m level, we have adjusted the Sigma inside the metal to acquire desired attenuations. The field inside is shown in Figure 9 (1 mm away of the coax center, right in the middle of the dielectric coax fill).

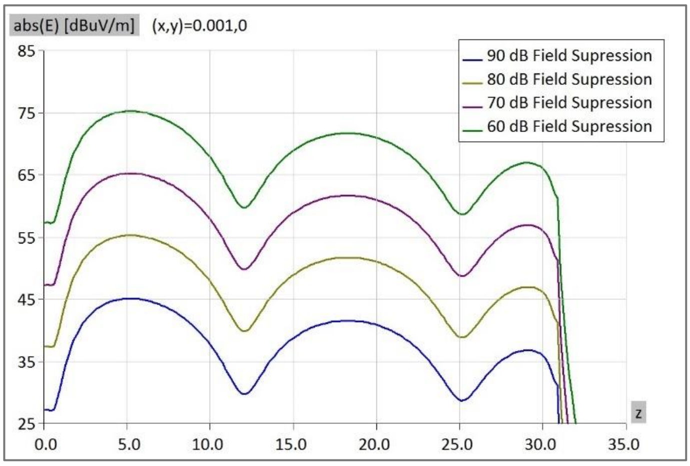

Figure 97. Field inside the coaxial cable

The advantages of using such a model are extremely low simulation time and complexity of the model. The simulation lasts a few seconds and yields extremely accurate results. For the demonstration purposes, we simulated 30 mm of cable length, which corresponds to 1 lambda at 10 GHz.

The simple logic determines the penetration of field, the size of holes. We adjusted the width of helix strip (which controls the size of the holes) until we reached 60 dB, 70 dB, 80 dB and 90 dB field suppression. Then we compared the field inside the waveguide for the model with imperfect shield and the model with field penetrating via the small Sigma.

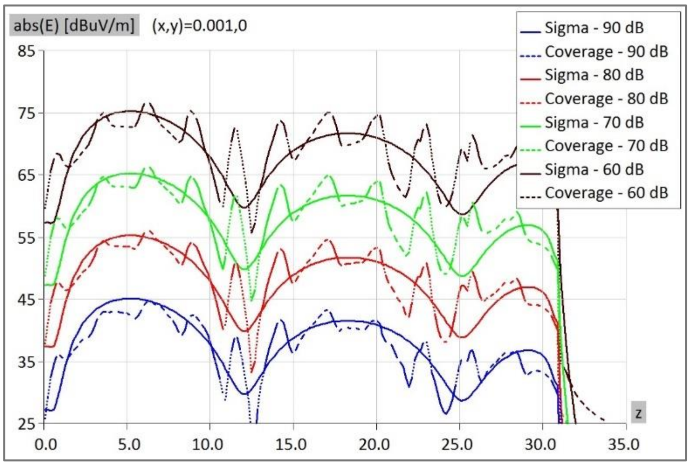

Figure 10. Field inside coaxial cable suppressed by two different mechanisms

Although the two mechanisms work in a completely different way, we see the same field behavior (dependent on the cable length. The levels can be adjusted via Sigma. The field obtained via shielding imperfection show numerous minimums and maximums. They correspond to the positions of the openings on the shield coverage.

In order to verify that such models can be equivalent, we have placed 50 Ohm termination at the coax end in both cases, and calculated current levels.

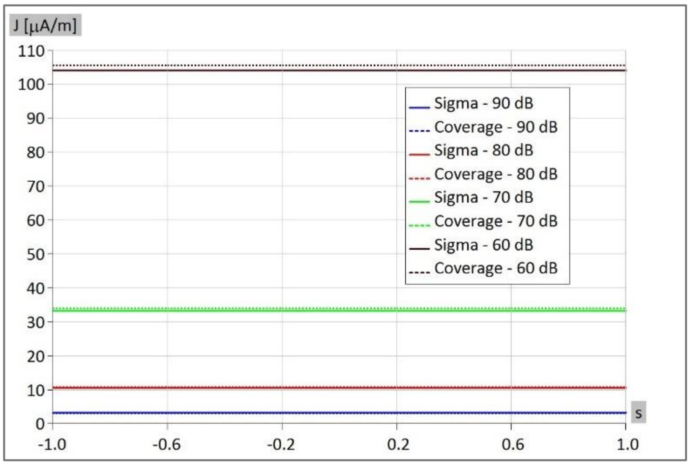

Figure 11. Current at the 50 Ohms termination

Again, the levels agree. The advantage of using the model with equivalent Sigma is that it is order of magnitude faster, it can be simulated at very long cable lengths and is very simple to build and use.

Conclusion

What we have demonstrated in the document is that WIPL-D can be efficiently used for simulating EMI propagation of field inside the cables and lines. We have demonstrated an advanced model of coax cable with imperfection braid shield, which can be easily replaced with a very simple equivalent model. After such a transformation, run times are measured in seconds and even the most complicated simulations are analyzed easily

We have used such an equivalent model to run a demanding scenario with the total of 2 m coax length. We have demonstrated that with even the smallest suppression of field, the field inside is two orders of magnitude smaller than the field when we leave a coax end open. Next, we show that the field induced in microstrip line is additional order of magnitude larger.

Simulation times and required number of unknowns is given in Table 2. All simulations were carried out on a Server with 2 processors each with 10 cores. In the case of regular PC with single quad processor all times should be multiplied by ~5.

Table 4. Simulation requirements for the 3 scenarios

Scenario	Number of unknowns	Simulation time [sec]
Microstrip line	7,230	29
Coaxial line with unshielded ends	6,925	93
Coaxial line with aluminum foil	11,877	78
Coaxial line with braided strips	35,080*	252

*Matrix inversion time is improved is by using single inexpensive GPU card.