Modeling shielded cables in Xyce based on transmission-line theory

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***Abstract*—Electromagnetic shields are usually employed to protect cables and other devices; however, these are generally not perfect, and may permit external magnetic and electric fields to penetrate into the interior regions of the cable, inducing unwanted current and voltages. The aim of this paper is to verify a circuit model tool with our previously proposed analytical model [1] for evaluating currents and voltages induced in the inner conductor of braided-shield cables. This circuit model will enable coupling between electromagnetic and circuit simulations.**

I. Introduction

Shielding a device from coupling of an external electromagnetic environment can be challenging. The shielding performance is often indicated by a quantity called shielding effectiveness (SE), which quantifies the reduction of the electromagnetic field at a given point in space caused by placing a shield between the source and that point [2]–[5]. In [1], we have reported a transmission-line formulation of multiple-shield cables for determining the SE of cables in the presence of arbitrary terminations. The voltages and currents associated with a shielded cable are illustrated in Fig. 1.

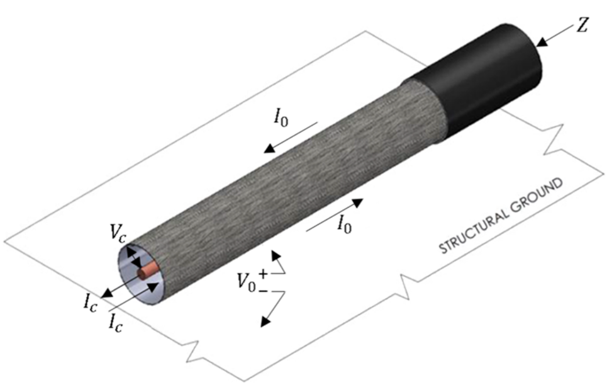

Fig. 1. An illustration of the geometry of a shielded cable, with associated voltages and currents.

Here we use the analytical model in [1] to develop a circuit model tool for evaluating currents and voltages induced in the inner conductor of braided-shield cables for a combined electromagnetic-circuit capability (note the concept is general, and the circuit model can be simulated by any SPICE-like simulators; we use the Sandia circuit simulator Xyce for this work [6]). Preliminary modeling utilizes braided shield parameters based on Kley's model [7], while future investigations will employ shield parameters that depend on the actual cable geometry through the first principles multipole model [8]–[10].

II. Shielded cable geometry

Following the transmission line model, the approximate per-unit-length transmission line circuits for a single-shield cable are shown in Fig. 2.

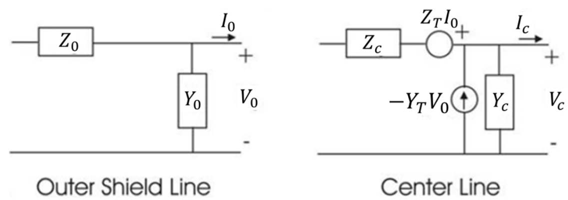

Fig. 2. The transmission line model is shown for (left) the outer shield line, and (right) the center conductor line.

In the lossless case, the circuit implementation of the outer shield is defined by a series of L-C tanks, as shown by the top circuit in Fig. 3, each containing an inductor of inductance $L_0\Delta z$, and a capacitor of capacitance $C_0\Delta z$, where Δz is the length of the unit cell. L_0 and C_0 are per-unit-length properties of the shield to chassis. The external electromagnetic wave impinging on the cable is modeled by a voltage source V_g, and the circuit is matched to $Z_L = \sqrt{L_0/C_0}$ on either end, but more complex loads can be considered.

The shield properties (related to the braid weave characteristics and material) are accounted for in the per-unit-length transfer impedance Z_T and transfer admittance Y_T in Fig. 2, which capture the magnetic and electric field coupling mechanisms from the exterior of the cable to the inner conductor. There are also the per-unit-length (series) self-impedance Z_c and (shunt) self-admittance Y_c in Fig. 2, which are formed by the inner conductor and the shield. In the circuit model, this is implemented as the bottom circuit in Fig. 3. Here, the problem is driven by current and voltage sources induced from the outer shield through the transfer parameters. In other words, coupling between the outer braid and inner conductor is ensured by using output from the first circuit as an input used to define a component of the inner circuit. For instance, the voltage across the capacitor of the first unit cell of the outer braid, V_1, is used to define a current source in the first unit cell of the inner conductor ($-Y_T \Delta z V_1$). The inner conductor is assumed to be connected to resistive loads of 0.5 Ohms, but more complex loads can be considered. In this case, we are assuming a lossless configuration, although resistive components can be added to account for losses in both circuits.

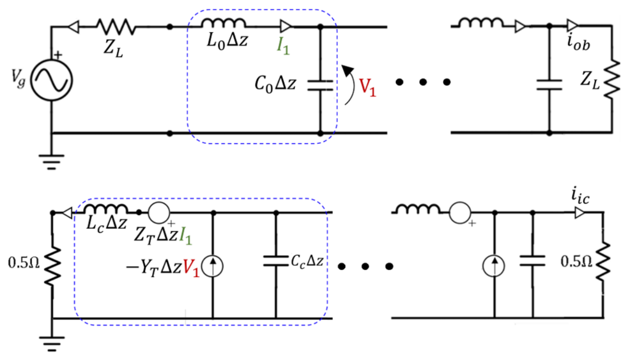

Fig. 3. Circuit models for the (top) outer braid and (bottom) inner conductor transmission lines in the lossless case. The unit cell is indicated by a dotted blue line.

We now consider a 22-inch-long, lossless commercial single shield REMEE cable for our test case, which has an optical coverage of 59% [1]. The monochromatic time harmonic dependence exp($j\omega t$) is implicitly assumed here. Following Kley's model [7], the outer braid exhibits $L_0 = 206.06$ nH/m and $C_0 = 53.99$ pF/m.

The transfer parameters for the REMEE cable are $Z_T = j\omega L_T$ and $Y_T = j\omega C_T$, where $L_T = 5614.63$ pH/m, and $C_T = 565.43$ fF/m. The impedance and admittance for the inner conductor are given by $Z_c = j\omega L_c$ and $Y_c = j\omega C_c$, respectively, where $L_c = 259.85$ nH/m, and $C_c = 98.48$ pF/m.

We use the AC analysis available in Xyce to solve the circuit in the frequency domain. We computed voltages and currents across the loads of both the outer braid and inner conductor. Using these quantities, we can compute the SE using $SE = 20 \cdot log_{10}(i_{ic}/i_{ob})$, where for the purposes of this paper i_{ic} and i_{ob} represent the currents across the right loads in the inner conductor and outer braid, respectively.

III. Results

Since the accuracy of the numerical solution is dependent on the number of cells in the circuit defining the cable in Fig. 3, a convergence study of the SE was performed for an increasing number of cells in Xyce. In Fig. 4, we report both the results from Xyce for increasing number of cells and the result from a previously developed transmission line model [1]. We observe that the analytical solution verifies the Xyce model when greater than 50 cells (with less than $\sim$3% error) are used in the simulation, as better illustrated by the inset of Fig. 4. The error decreases for an increasing number of cells. The shielding effectiveness exhibits a resonating behavior near 177 MHz (due to the finite length of the cable), with peak value of about -3.18 dB shielding.

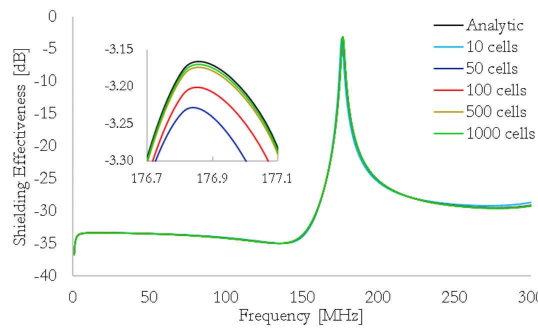

Fig. 4. SE (from Xyce) is plotted versus frequency for an increasing number of unit cells at the right termination. The analytic solution is plotted in black for comparison.

IV. Conclusion

In this paper we have developed a circuit implementation of braided shield cables to evaluate currents and voltages induced to the inner conductor by an external electromagnetic radiation. Results from Xyce agree well with our analytic solution. While we have analyzed only the lossless case in this paper for brevity, resistive elements can be added to take into account the dissipative nature of metals. We believe this circuit model represents a step toward multi-physics electromagnetic and circuital simulations [11].

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