Transfer Funtions for Fast Electromagnetic and Circuit Modeling

Bassel Alesh

Advisers:
Professor Jose Schutt-Aine
Professor Andreas Cangellaris

December 11, 2017

Introduction

The Issue at Hand

As the electronics industry continues to grow at a rapid pace, the need for: **faster** and yet **more accurate** computer-aided simulation tools is at an all time high. Engineers need to perform accurate simulations in an expedient enough fashion to guide design decisions during the design stage of an electrical component or a system.

Different tools such as Ansys HFSS, CST Microwave Studio, AWR Microwave Office, and more now have integrated **electromagnetic solvers** to accommodate this demand, but there is room for improvement.

Introduction

What This Thesis Proposes

This thesis presents a set of such models used as part of a modeling and simulation framework for electromagnetic interference aware electronic system integration.

By leveraging basic electromagnetic principles and boundary conditions, transfer functions were created to model:

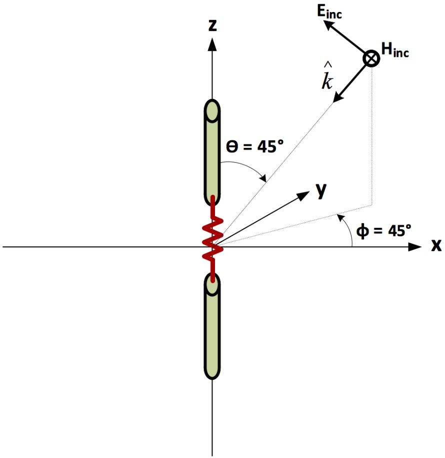
- Antennas
- Transmission Lines
- Shielded Cables

in a way that allowed them to be integrated as building blocks of a larger system.

Antennas

Short Dipole Example from [2]

The amplitude of the electric field is 120π Volts per meter. The wave is propagating in free space with a frequency of $300\sqrt{2}$ MHz. The antenna has a characteristic impedance of 50 Ω with a 50 Ω load attached to it.



The results obtained from the Python script are then:

```
power received = 5.625 Watts
power delivered = 5.625 Watts (due to the matched load)
voltage at the load = 23.717 Volts
```

Transmission Lines

Two Wire Transmission Lines: Introduction

The transmission line configuration that will be examined is that the two-wire transmission line. **When an incident field is present, distributed per-unit-length voltage and current sources will be induced on the line.** Here, $\alpha = \phi = 0^\circ$ (vertical polarization) and $\psi = 60^\circ$.The loads are given as $Z_1 = Z_2 = \frac{Z_c}{2}$.

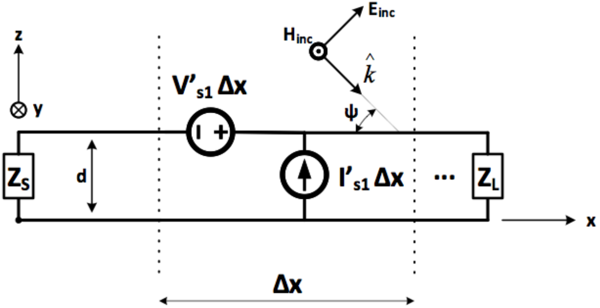


Figure 1: Distributed sources along the transmission line

Transmission Lines

Two Wire Transmission Lines: Induced Source Derivations

The text [4] defines **source vectors** that characterize the distributed sources induced along the line.

$$\begin{bmatrix} S_1 \\ S_2 \end{bmatrix} = \begin{bmatrix} \frac{1}{2}\int_0^L e^{\gamma x_s}[V'_{S1}(x_s) + Z_c I'_{S1}(x_s)]dx_s \\ -\frac{1}{2}\int_0^L e^{\gamma(L-x_s)}[V'_{S1}(x_s) - Z_c I'_{S1}(x_s)]dx_s \end{bmatrix} \tag{1}$$

These source vectors can be used to compute the voltages and currents at the ends of the line using the simple matrix below, with ρ corresponding to the reflection coefficient at each side of the line.

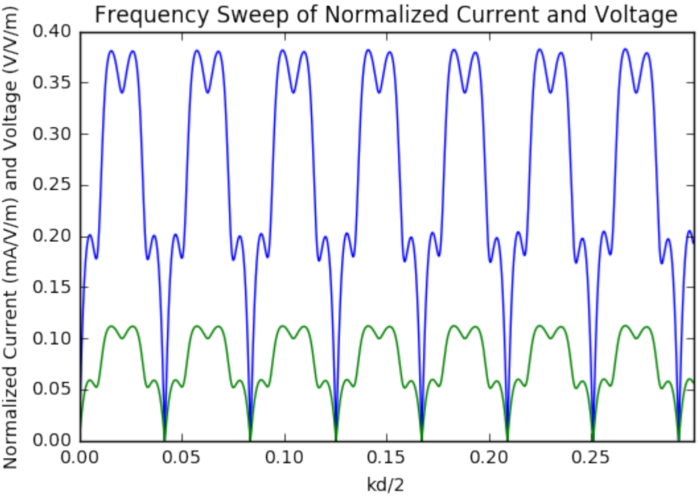
$$\begin{bmatrix} I(0) \\ I(L) \end{bmatrix} = \frac{1}{Z_c}\begin{bmatrix} 1-\rho_1 & 0 \\ 0 & 1-\rho_2 \end{bmatrix} \begin{bmatrix} -\rho_1 & e^{\gamma L} \\ e^{\gamma L} & -\rho_2 \end{bmatrix}^{-1} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} V(0) \\ V(L) \end{bmatrix} = \begin{bmatrix} 1+\rho_1 & 0 \\ 0 & 1+\rho_2 \end{bmatrix} \begin{bmatrix} -\rho_1 & e^{\gamma L} \\ e^{\gamma L} & -\rho_2 \end{bmatrix}^{-1} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} \tag{3}$$

Transmission Lines

Two Wire Transmission Lines: Results

In this example, the normalized current at the load (I = L) of a line is plotted against $\frac{kd}{2}$.



Transmission Lines

Two Wire Transmission Lines: Example

The full program can be run through the command line when given the proper input parameters:

1. Wire radius
2. Line separation
3. Line length
4. Sheet resistance
5. Voltage at the beginning of the line
6. Load impedance at the beginning of the line
7. Load impedance at the end of the line
8. ψ
9. ϕ
10. α
11. Specified frequency of the incident wave
12. Field magnitude

Resulting Output:

```
Voltage Due to Coupling:
0.0401604605305
Load Voltage:
(12.4047489677+0j)
```

Transmission Lines

Single Wire Transmission Line

For a single wire transmission line over a ground plane, the source vectors have double the magnitude:

$$\begin{bmatrix} S_1 \\ S_2 \end{bmatrix} = \begin{bmatrix} \int_0^L e^{\gamma x_s}[V'_{S1}(x_s) + Z_c I'_{S1}(x_s)]dx_s \\ -\int_0^L e^{\gamma(L-x_s)}[V'_{S1}(x_s) - Z_c I'_{S1}(x_s)]dx_s \end{bmatrix} \tag{4}$$

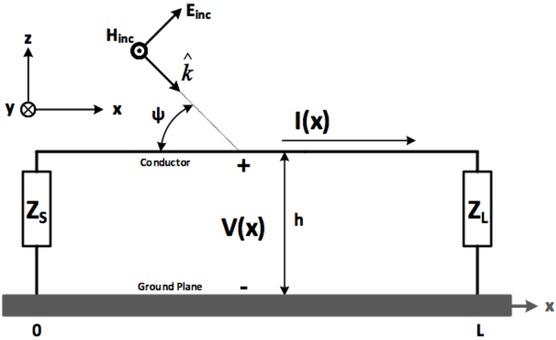
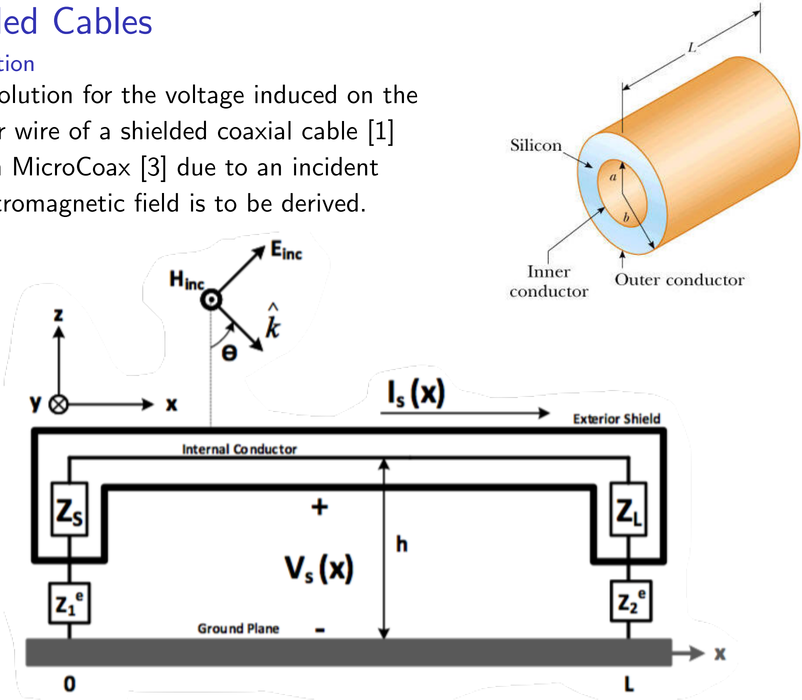


Figure 3: Single Line over Perfectly Conducting Ground Plane

Shielded Cables

Introduction

A solution for the voltage induced on the inner wire of a shielded coaxial cable [1] from MicroCoax [3] due to an incident electromagnetic field is to be derived.



Shielded Cables

Derivations

Under the presence of an incident electromagnetic wave, the shielded cable forms distributed voltages and currents along both the outer shield and the inner cable.

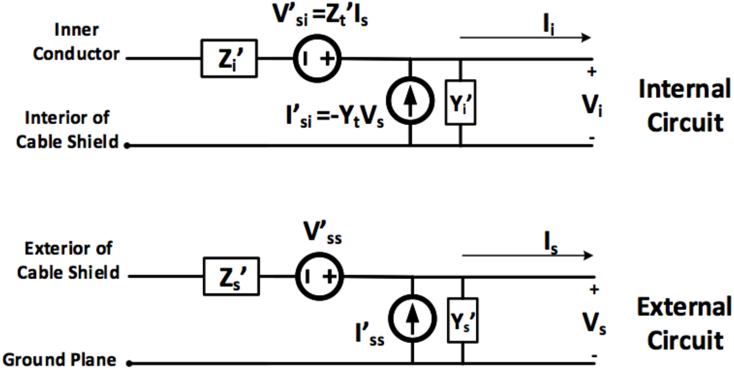


Figure 4: Outer (bottom) and inner (top) conductor circuit diagrams

Shielded Cables

Example: Exterior Shield Results

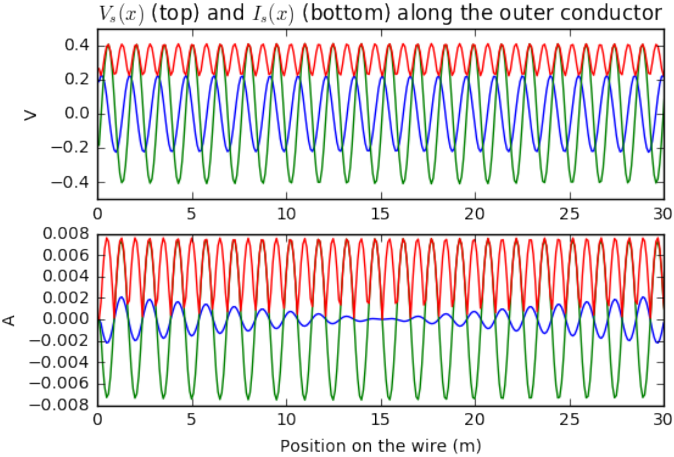


Figure 5: Real (blue), imaginary (green), and magnitude (red) plots of $V_s(x)$ (top) and $I_s(x)$ (bottom) along the outer conductor

Shielded Cables

Example: Inner Cable Results

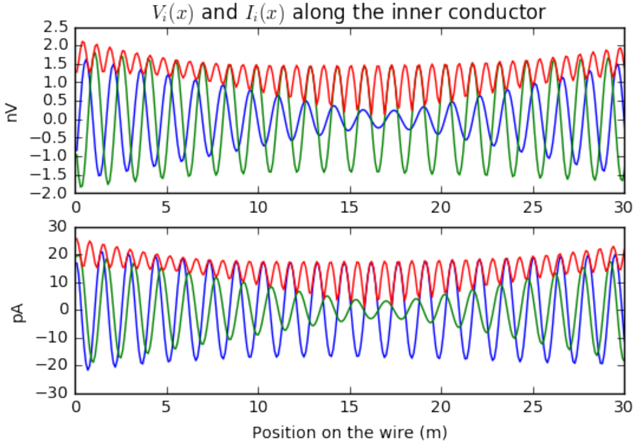


Figure 6: Real (blue), imaginary (green), and magnitude (red) plots of $V_i(x)$ (top) and $I_i(x)$ (bottom) along the inner conductor

Framework and Workflow

The Bigger Picture

The transfer functions discussed in this thesis were written up in Python. Each one was built to take in the necessary input variables, and print out the desired output variables. By taking this black box approach, different blocks can be cascaded together to simulate a larger system.

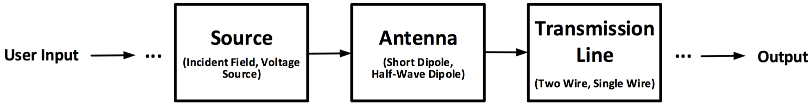


Figure 7: Example of the Simulation Workflow

Conclusion and Final Remarks

- Electromagnetic simulations are very important as they assess and test not only the functionality of an electronic device, but also ensure that no interference would cause any harm to its circuitry.
- By stepping through the solutions in Python, quick simulations can be performed on an electronic component of interest without the need for computer-aided tests and analyses.
- The work presented could be expanded into a library of different circuit components that could be cascaded together to mimic the behavior of a real-world system.

References

Clark Christensen.
Coaxial Cable Figure. Physics, BYU.
https://www.physics.byu.edu/faculty/christensen/Physics%20220/FTI/27%20Current%20and%20Resistance/27.8%20Radial%20resistance%20of%20a%20coaxial%20cable%20(sample%20problem).htm.

Erhan Kudeki.
ECE 350 Lecture Notes, August 2016.

Micro-Coax.
Standard Copper 50-Ohm Semi-Rigid Cable.
Rev. D.

F. M. Tesche, M. V. Ianoz, and T. Karlsson.
EMC analysis methods and computational models.
John Wiley and Sons, 1997.