ECE 1259: Electromagnetics - Team 8

Design Project Prototype

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I Documentation

Description

The function `coax.m` will accept some user-defined parameters of a coaxial cable and calculate the:

- Characteristic impedance of the line (Z_0, in Ω)
- Reflection coefficient of the line (Ξ)
- Voltage standing wave ratio of the line (VSWR)
- Input impedance looking into the line with a connected load (Z_{in}, in Ω)
- Cutoff frequency of the line (f_{cutoff}, in Hz)
- Line's breakdown voltage (V_{br}, in V)
- Attenuation constant of the line (α, in Np)
- Phase constant of the line (β, in $\frac{rad}{m}$)
- Distributed parameters (R', L', C', G')

The function accepts input arguments sequentially via the command line and displays the calculated output values in the terminal.

Method

From the input parameters, we derive the parameter values:

$$R' = \frac{1}{2\pi}(\frac{1}{a} + \frac{1}{b})\sqrt{\frac{\pi f \mu_d}{\sigma_c}}$$

$$L' = \frac{\mu_r}{2\pi} ln(\frac{b}{a})$$

$$C' = \frac{2\pi\epsilon_r}{ln(\frac{b}{a}})$$

$$G' = \frac{2\pi\sigma_d}{ln(\frac{b}{a})}$$

$$\gamma = \sqrt{(R' + j\omega L')(G' + j\omega C')} = \alpha + j\beta$$

$$Z_0 = \frac{R' + j\omega L'}{\gamma}$$

$$\Xi = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$$VSWR = \frac{1 + |\Xi_L|}{1 - \Xi_L}$$

$$Z_{in} = Z_0 \cdot \frac{Z_L + Z_0 tanh(\gamma l)}{Z_0 + Z_L tanh(\gamma l)}$$

$$f_{cutoff} = \frac{11.8}{\sqrt{\epsilon_r} \cdot \pi \cdot (\frac{b+a}{2})}$$

$$V_{br} = E_{br} \cdot (b - a)$$

Input Arguments

The user has an option to select from a list of commonly used dielectric materials and commonly used conductor materials with hard-coded physical parameters. Below is a table of the materials that can be selected into the program:

Table 1: Material List

Material List	
Conductor Materials	Dielectric Materials
aluminum	air
carbon	alumina
copper	glass
gold	ice
graphite	polyethylene
iron (99.8%)	polystyrene
iron (99.96%)	barium titanate
lead	quartz
nichrome	silicon
nickel	soil
silver	teflon
solder	water
stainless steel	seawater
tin	mica
tungsten	

If the user wants to use an unlisted material, they may enter the custom physical parameters below:

`er` - Electric permittivity (ϵ_r) of the dielectric.
`sig_C` - Conductance (σ_c, in $\frac{S}{m}$) of the conductor.
`sig_D` - Conductance (σ_d, in $\frac{S}{m}$) of the dielectric.
`mu_R` - Relative permeability (μ_r) of the conductor.
`Ebr` - Electric Field Breakdown (E_{br}, in $\frac{V}{m}$)

Regardless of whether the user selects a value from the table of pre-selected materials or custom physical parameters are entered, the user is be prompted to enter in the below values via the command line:

`innerRadius` - Radius (in meters) of the cable's inner conductor.
`outerRadius` - Radius (in meters) of the cable's outer conductor.
`ZL` - Impedance of the load (Z_L, in Ω) of the load to be connected to the coaxial cable.
`len` - Length (in meters) of the coaxial cable.
`freq` - Frequency (in Hz) of the signals to be sent through the coaxial cable

Examples

Exmaple 1

For a power transmission line, let us suppose that the user wishes to design a coaxial cable with the below-stated values:

Table 2: Example 1

Example 1	
Input	Value
Conductor Material	Aluminum
σ_c	$38E^6$
μ_r	1.00002
Dielectric Material	Polyethylene
ϵ_r	2.26
E_{br}	$47E^6 V/M$
σ_d	$1E^{-16}$
Inner Radius	.001 m
Outer Radius	.005 m
Z_L	1000 Ω
Length of Wire	1000 m
Frequency (Hz)	60 Hz

The user will enter in the presupposed values sequentially with the MATLAB command prompts, as shown:

```
Conductor Material: aluminum
Dielectric Material: polyethylene
Radius (in meters) of the cable's inner conductor: 0.001
Radius (in meters) of the cable's outer conductor: 0.005
Impedance of the load (Z_{L}, in Omega) of the load
to be connected to the coaxial cable: 1000
Length (in meters) of the coaxial cable: 1000
Frequency (in Hz): 60
```

The function will then output the below tabulated values:

Table 3: Example 1

Example 1	
Output	Value
R' (Ω)	$4.768E^{-4}\Omega$
L' (Henrys)	$3.219E^{-7}H$
C' (Farads)	$7.808E^{-16}F$
G' (Siemens)	$3.904E^{-16}S$
γ $(\alpha + j\beta)$	$(2.336 + j3.005)E^{-6}$
α (Np)	$2.336E^{-6}Np$
β $(\frac{rad}{m})$	$3.005E^{-6}\ \frac{rad}{m}$
Z_0 (Ω)	102.07Ω
Z_{in} (Ω)	999.6Ω
Ξ	.8054
$VSWR$	9.859
f_c (Hz)	$832.8Hz$
V_{br} (Volts)	$188000V$

The output format will look as such:

```
R is 4.768364e-04 Ohms
L is 3.218940e-07 Henrys
C is 7.808315e-11 Farads
G is 3.903963e-16 Siemens

Gamma is 2.335777e-06 + j3.004668e-06
Alpha is 2.335777e-06
Beta is 3.004668e-06

Zo is 1.020723e+02 Ohms
Zin is 9.996141e+02 Ohms
Reflection Coefficient is 8.054037e-01
VSWR is 9.859305e+00

Cutoff frequency is 8.328306e+02 Hz
Vbr is 188000 Volts
```

Limitations

A major limitation of our code is that the database of materials is rather small, and the user must either select from these values or know the physical parameters of an unlisted material.

Additionally, our code is only useful when materials, radii, length, and signal frequency of the coaxial cable are known. For example, if the R', L', G', and C' parameters are known, the code is unable to accept those values without manipulation of the script.

Since most of our issues stem from user intuition, we will be implementing a GUI with drop down menus that list the available materials and allow the user to conveniently modulate parameters.

Testing Results

After the Matlab code prototype was completed, the code underwent testing using pre-existing examples to verify that our code gave correct values. First, in order to test the functionality of distributed parameter calculation, example 6.1 from the EMAG solutions was used. A table of inputs and outputs can be seen below along with the Matlab command window for those corresponding values.

Example 1 (6.1 EMAG Solution)			
Variables	Input Values	Expected Values	Final Code Values
a	0.47mm	-	-
b	1.435mm	-	-
f	8.00E+08	-	-
dielectric	polyethylene	-	-
conductor	copper	-	-
G'	-	0	0
C'	-	0.000000000113	0.0000000001125886
L'	-	0.000000223	0.0000002232375
R'	-	3.32	3.317235

```
Conductor Material:
copper
Dielectric Material:
polyethylene
Radius (in meters) of the cable's inner conductor:
0.47e-3
Radius (in meters) of the cable's outer conductor:
1.435e-3
Real impedance of the load (Z_{L}, in Omega) of the load to be connected to the coaxial cable:
100
Imaginary impedance of the load (Z_{L}, in Omega) of the load to be connected to the coaxial cable:
50
Length (in meters) of the coaxial cable:
1
Frequency (in Hz).
8e8

R is 3.317220e+00 Ohms
L is 2.232355e-07 Henrys
C is 1.125886e-10 Farads
G is 5.629149e-16 Siemens

Gamma is 3.724855e-02 + j2.519992e+01
Alpha is 3.724855e-02
Beta is 2.519992e+01

Zo is 4.452817e+01 + j(-6.581806e-02) Ohms
Zin is 1.069756e+02 + j(-6.581806e-02) Ohms
Reflection Coefficient is 4.498042e-01
VSWR is 2.911426e+00

Cutoff frequency is 2.623088e+03 Hz
Vbr is 4.535500e+04 Volts
```

[htp]

Our code did not have the capability to directly test values such as the characteristic impedance, gamma, etc. That being said, the code was altered simply for the sake of testing whether or not some of the remaining variables. For example, the functionality of gamma and the characteristic impedance calculations was tested by reverse engineering EMAG solution 6.5 and altering the code to accept user R, L, G, and C values. Using this altered code, the RLGC values were input and the correct gamma and characteristic impedance were observed as seen in the Matlab command window below.

Example (6.5 EMAG Solution)			
Variables	Input Values	Expected Values	Final Code Values
R'	2.37	-	-
L'	1.39E-07	-	-
G'	7.63E-06	-	-
C'	4.00E-10	-	-
Gamma	-	0.0638+j4.68	0.06363+j4.6855
Zo	-	18.6 - j0.253	18.64307- j0.2526242

```
Conductor Material:
copper
Dielectric Material:
polyethylene
Radius (in meters) of the cable's inner conductor:
.43e-3
Radius (in meters) of the cable's outer conductor:
1.47e-3
Real impedance of the load (Z_{L}, in Omega) of the load to be connected to the coaxial cable:
1
Imaginary impedance of the load (Z_{L}, in Omega) of the load to be connected to the coaxial cable:
1
Length (in meters) of the coaxial cable:
1
Frequency (in Hz).
1e8
is RLCG know? Y/N
y
Put in R:
2.37
Put in L:
139e-9
Put in C:
400e-12
Put in G:
7.63e-6

R is 2.370000e+00 Ohms
L is 1.390000e-07 Henrys
C is 4.000000e-10 Farads
G is 7.630000e-06 Siemens

Gamma is 6.363362e-02 + j4.685513e+00
Alpha is 6.363362e-02
Beta is 4.685513e+00

Zo is 1.864307e+01 + j(-2.526242e-01) Ohms
Zin is 1.518559e+02 + j(-2.526242e-01) Ohms
Reflection Coefficient is -8.944618e-01
VSWR is 1.895864e+01

Cutoff frequency is 2.629991e+03 Hz
Vbr is 4.888000e+04 Volts
```

Again using this altered code, the functionality of both the input impedance and the reflection coefficient was tested by replicating EMAG solution 6.15. The expected values and collected values can be seen below.

Example (6.15 EMAG Solution)			
Variables	Input Values	Expected Values	Final Code Values
R'	2.37	-	-
L'	1.39E-07	-	-
G'	7.63E-06	-	-
C'	4.00E-10	-	-
RL	2.50E+01	-	-
XL	1.26E+00	-	-
F	200MHz	-	-
Reflection Coeff	-	0.119 angle 168	.1190245 ang 168.0617
Input Impedance	-	34.82 angle -12.4	34.82830 ang -12.37727

```
Conductor Material:
copper
Dielectric Material:
polyethylene
Radius (in meters) of the cable's inner conductor:
1
Radius (in meters) of the cable's outer conductor:
2
Real impedance of the load (Z_{L}, in Omega) of the load to be connected to the coaxial cable:
25
Imaginary impedance of the load (Z_{L}, in Omega) of the load to be connected to the coaxial cable:
1.25663706144
Length (in meters) of the coaxial cable:
1
Frequency (in Hz).
2e8
is RLCG know? Y/N
y
Put in R:
.1
Put in L:
1e-6
Put in C:
1e-9
Put in G:
10e-6

R is 1.000000e-01 Ohms
L is 1.000000e-06 Henrys
C is 1.000000e-09 Farads
G is 1.000000e-05 Siemens

Gamma is 1.739253e-03 + j3.973835e+01
Alpha is 1.739253e-03
Beta is 3.973835e+01

Zo is 3.162278e+01 + j(-1.132407e-03) Ohms
Zin is 3.482830e+01 with angle -1.237727e+01 Ohms
Reflection Coefficient is 1.190245e-01 with angle 1.680617e+02
VSWR is 1.270211e+00

Cutoff frequency is 1.665661e+00 Hz
Vbr is 47000000 Volts
```

II Next Steps

Our final design tool will include a MATLAB-based GUI in which the user can enter input values, and on which output values are displayed. The GUI will include a dropdown menu in which the user will be able to select common conductor and dielectric materials, which will abstract away the physical parameters of each material.

Therefore, we will implement a complete .csv file full of common conductors and dielectrics, along with their physical properties.

The GUI will also display sliders for variables like the radii of the inner/outer conductors, load impedance, and cable length. Furthermore, the GUI will show a Bode plot of the cable and perhaps an image to visualize the cable cross-section.

We will modify our Z_L field to accept a complex-valued load impedance input, as well as change the units to use the `num2eng` library for easier readability.

Finally, we'll update and finalize detailed syntax/example documentation through the use of a diverse set of test cases. If we have time, we'd like to do some user testing to develop the UI into something user-centric.

III Teamwork

Team Process

As a team, we decided to divide the work into several sections including code design, code testing, user interface design, and scribe/analysis. After completion of the project, all parts would come together to create a cohesive tool. The members and their respective roles are detailed below:

- Mark Hofmeister: User-interface design
- Braden Kullback: Code design
- Dylan Murphy: Code verification
- Owen Knight: Scribe/analysis

It was understood that code design would most likely require more than just one person to complete as it was the bulk of the prototype, so we came up with a game plan in order to deal with this. Firstly, we brainstormed as a group as to what we wanted to implement in the project, so that task was not solely on the shoulders of the designer. Secondly, we decided that once the code designer believed a fully functioning prototype was complete, they would send it off to the code tester, where small bugs would be fixed. Next, the code designer would confer with the team one last time in-person to have all team members give input on the code or code functions. Lastly, the code would be sent off for testing and any last bugs would be ironed out.

In the end, we carried the plan out in its entirety to a great deal of success. Following the steps we were able to achieve a working prototype before the deadline in a timely manner, with no need for cramming.

Looking Forward

While the final product is not complete yet, we have learned a great deal about teamwork and management of team projects. As a result of constructing the prototype, we were able to glimpse the importance of getting peer evaluation of work. Throughout the project, the code has transformed greatly as a result of having members review the code and add parts that may not have been considered previously.

Also, we were able to see first hand the importance of deadlines and keeping up with individual work. If even one team member would have submitted something late, it could have possibly forced another member to halt their work until the previous team member finished their part.