Design and Build of a Dipole Antenna for EMC Testing

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Abstract

This paper discusses a practical approach to the design and build of a sleeve dipole antenna used for ElectroMagnetic Compatibility (EMC) testing. The antenna was designed and constructed by a student while employed at an EMC consulting firm as part of Grand Valley State University's Engineering Cooperative Education Program. The physical antenna must meet the design specifications related to its input impedance and operating frequency. The design process begins with a theoretical model leading to the rough design dimensions of the antenna. The next step in the design process is the creation of a complex 3D simulation model that closely represents the analytical model of the antenna. The simulation model is modified using a full wave 3D solver with an optimizer. The optimizer tunes the antenna element lengths to match the desired input impedance as closely as possible over the desired operating frequency range. The optimization results are implemented in a physical antenna which is subsequently subjected to impedance measurements using a Vector Network Analyzer (VNA) in an EMC laboratory. Laboratory measurements reveal the fact that despite following a detailed analytical design process and using advanced simulation software, the actual physical antenna still must be tuned to satisfy the performance specifications. The tuning is performed by altering the antennas element lengths until the desired input impedance is achieved over the desired operating frequency range.

Section 1 Half-Wave Dipole Antenna

Half-wave dipole consists of a thin wire fed or excited at the midpoint by a voltage source. The total length of a dipole equals half-wave length. Each leg of a dipole has a length equal to the quarter of a wavelength, as shown in Fig. 1(a). Often the voltage source is connected to the antenna via transmission line, as shown in Fig. 1 (b).

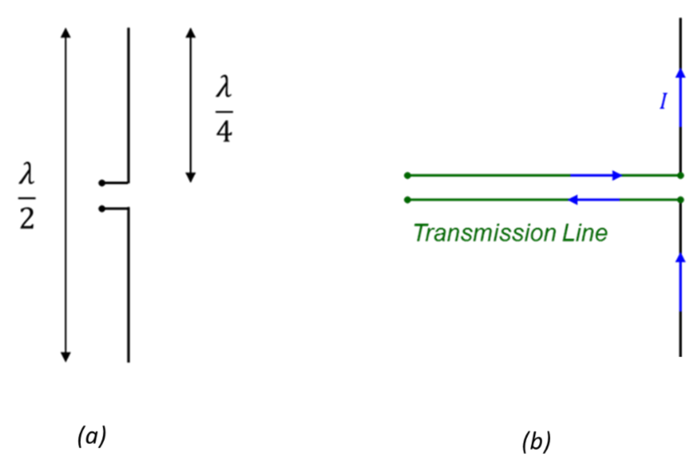

Figure 1: a) Half-wave dipole antenna b) antenna connected to a transmission line

The far-fields of the half-wave dipole can be obtained by dividing the dipole antenna into infinitesimal dipoles of length *dz* as shown in Fig. 2.

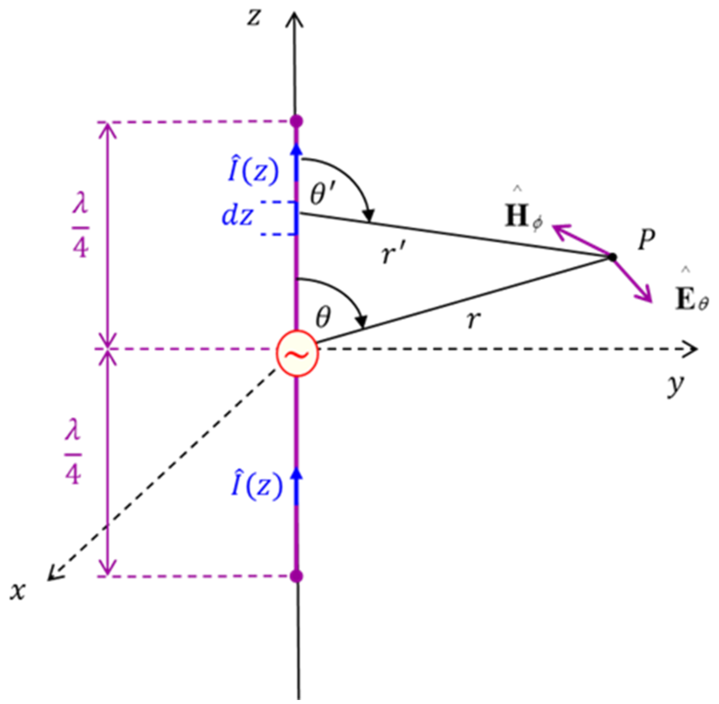

Figure 2: Half-wave dipole subdivision into infinitesimal dipoles

Treating each infinitesimal dipole as a Hertzian dipole the electric and magnetic fields are obtained as [1]:

$$\hat{E}_\theta = j\frac{\eta_0 \hat{I}_0 e^{-j\beta_0 r}}{2\pi r} F(\theta) \tag{1a}$$

$$\hat{H}_\phi = j\frac{\hat{I}_0 e^{-j\beta_0 r}}{2\pi r} F(\theta) \tag{1b}$$

where (θ) , is the so-called *space factor* given by

$$F(\theta) = \frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta} \tag{2}$$

The impedance of the half-wave dipole is

$$Z_L = 73 + j42.5\ [\Omega] \tag{3}$$

To maximize the power delivered to the dipole antenna its length is usually shortened to make the impedance purely real. This length adjustment is usually performed through simulations and laboratory measurements (instead of the analytical calculations). This is main topic addressed in our paper. We discuss these adjustments using a special kind of a dipole antenna – the sleeve dipole. Sleeve dipoles, described in the next section, have increased bandwidth and their impedance variations are less sensitive to length, as compared to the half-wave dipoles.

Section 2 Full Wave 3D Simulation of the Sleeve Dipole

Section 2.1 Simulation of a Sleeve Dipole with 1/4 λ Elements

A 3D model of a sleeve dipole was drawn in CST Microwave Studio. Electrical material properties were assigned. Images of the antenna used in simulations are shown in Figs. 3 and 4.

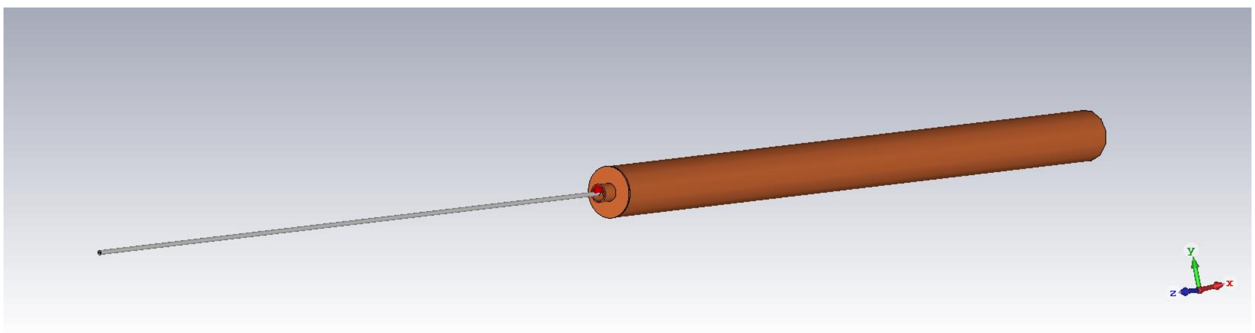

Figure 3: Sleeve Dipole Elements without Enclosure Shown

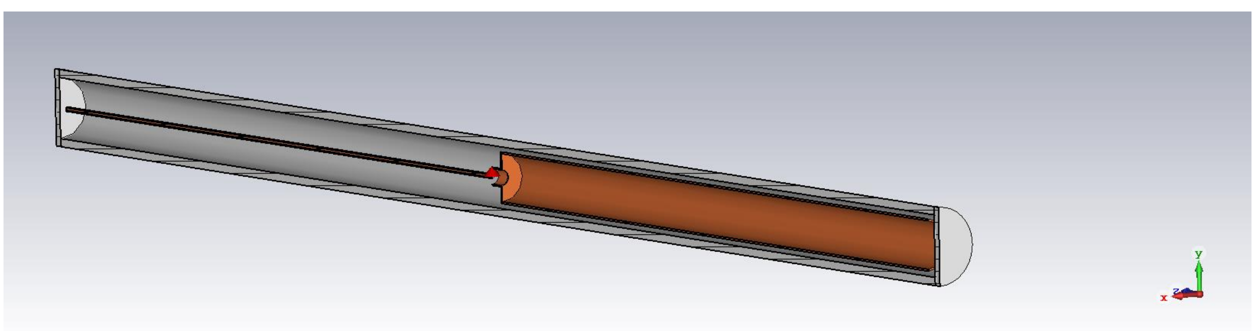

Figure 4: Cutaway of Antenna 3D with PVC Enclosure

Before the simulation process could be started the length of the antenna elements had to be determined. The desired operating frequency of the antenna was 220-225 MHz. the frequency $f_0 = 225.5\ MHz$ and the signal propagation velocity, c, equal to the speed of light, this length was determined as

$$l = \frac{\lambda}{4} \approx \frac{c}{4 f_0} = \frac{3\times10^8}{4\times222.5\times10^6} = 337\ mm \tag{4}$$

The simulation was performed from DC to 300 MHz. Both elements of the antenna were set to the same length. The resulting reflection coefficient magnitude (s_{11} parameter magnitude) is shown in Figs. 5 and 6. Figure 5 reveals that the antenna resonates at 199 MHz which is not within the antenna's desired operating frequency of 220 MHz to 225 MHz.

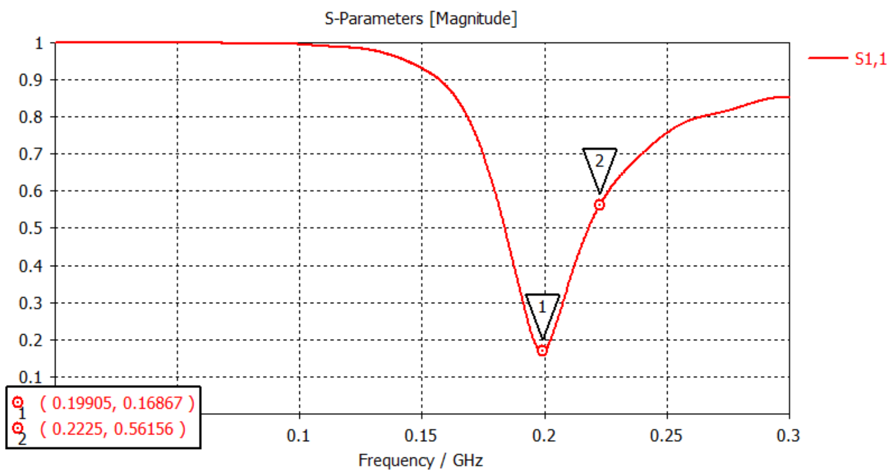

Figure 5: S_{11} Linear Magnitude of S_{11} Parameter – 1/4 Wavelength Elements

Figure 6 confirms this result by showing that impedance is real at 200.8 MHz, and equal to 71.5 Ω.

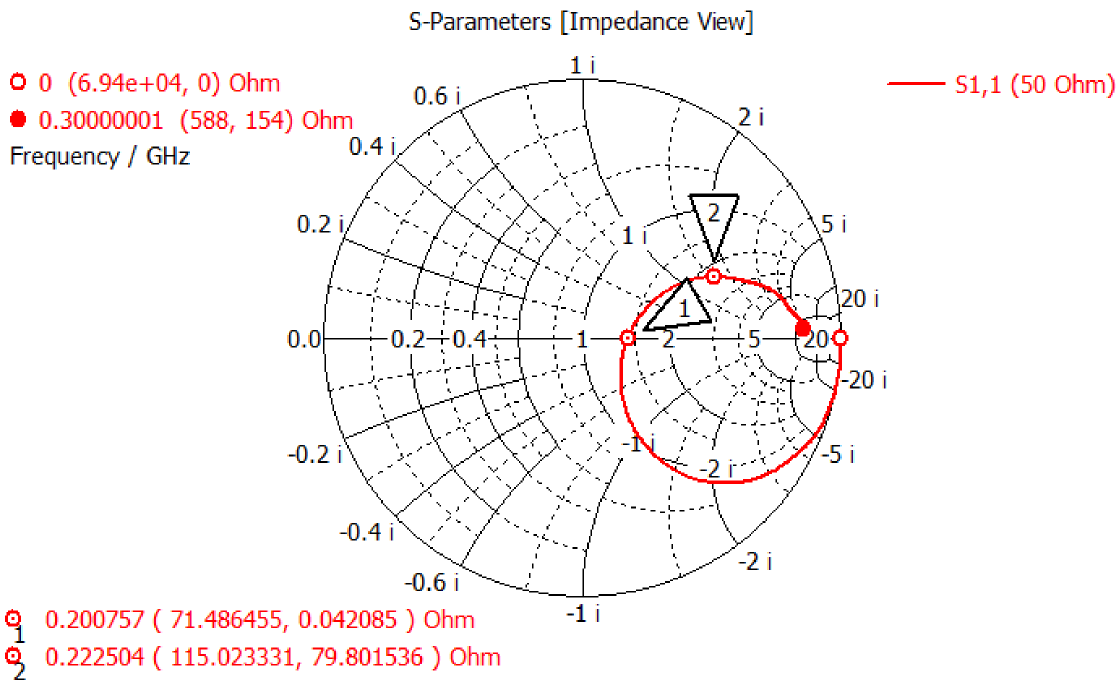

Figure 6: Smith Chart of S_{11} Parameter – 1/4 Wavelength Elements

The electric field of the simulated antenna was inspected to determine if it was operating as a ½ wavelength dipole with ¼ wavelength elements. Figure 8 and Figure 9 show the electric fields at 222.5 MHz on a plane as magnitudes and vectors respectively. Figure 8 shows the field when the sinusoidal excitation is at maximum voltage and Figure 9 when it is at zero voltage. It was determined that both elements were electrically longer than ¼ wavelength. On Figure 9, minimum and maximum potential was expected at the ends of the elements. A minimum in potential was expected near the center which was not the case.

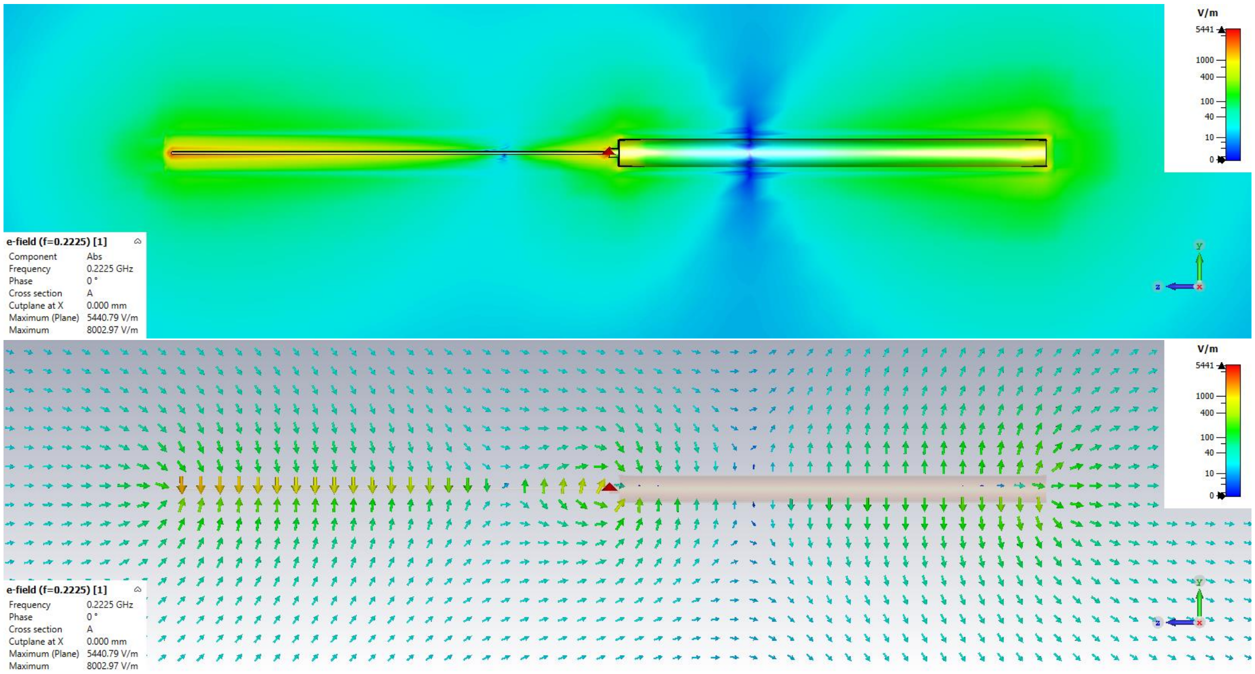

Figure 8: Electric Field with 222.5 MHz Cosine Excitation at θ = 0° Phase, $V_1 = V_{max}$

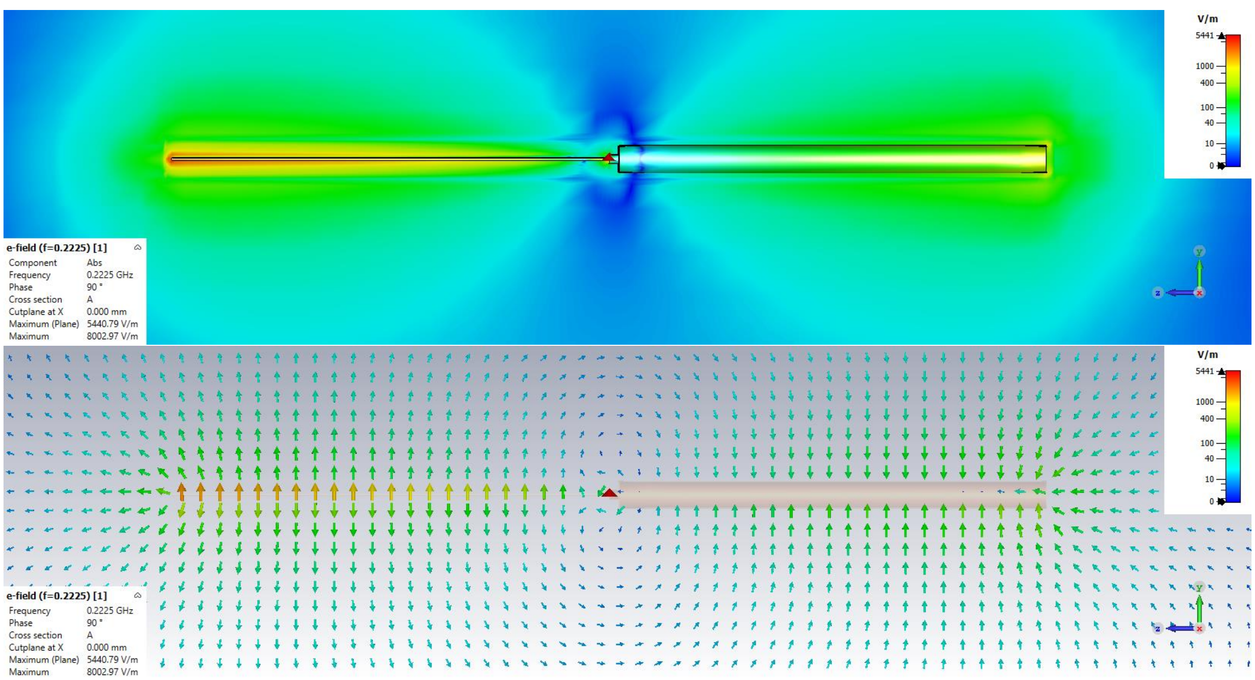

Figure 9. Electric Field with 222.5 MHz Cosine Excitation at θ = 90° Phase, $V_1 = 0$

Section 2.2 Optimization of the Dipole Element Lengths

In order to determine the optimal antenna length the simulators optimizer was run with a goal of minimum S_{11} magnitude in the frequency range 202 – 225 MHz. The antenna element lengths were set as free parameters, not necessarily equal, in the range of 150 mm to 340 mm.

The optimizer found the optimum element lengths to be 218 mm for the tube element and 330 mm for the wire element. A plot of the magnitude of the antennas s_{11} is shown in Figure 9. This plot reveals the minimum magnitude at 223.5 MHz, which is in the desired range.

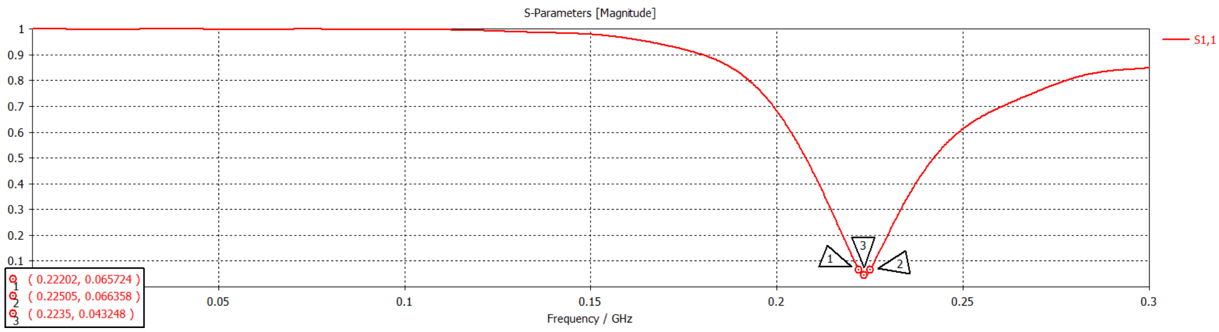

Figure 10: Linear Magnitude of S_{11} Parameter – Optimized Element Lengths

The impedance is real valued at 223.5 MHz as shown by the Smith chart in Figure 11. It was also observed that this simulation with asymmetrical elements has a wider bandwidth than the simulation with symmetrical elements.

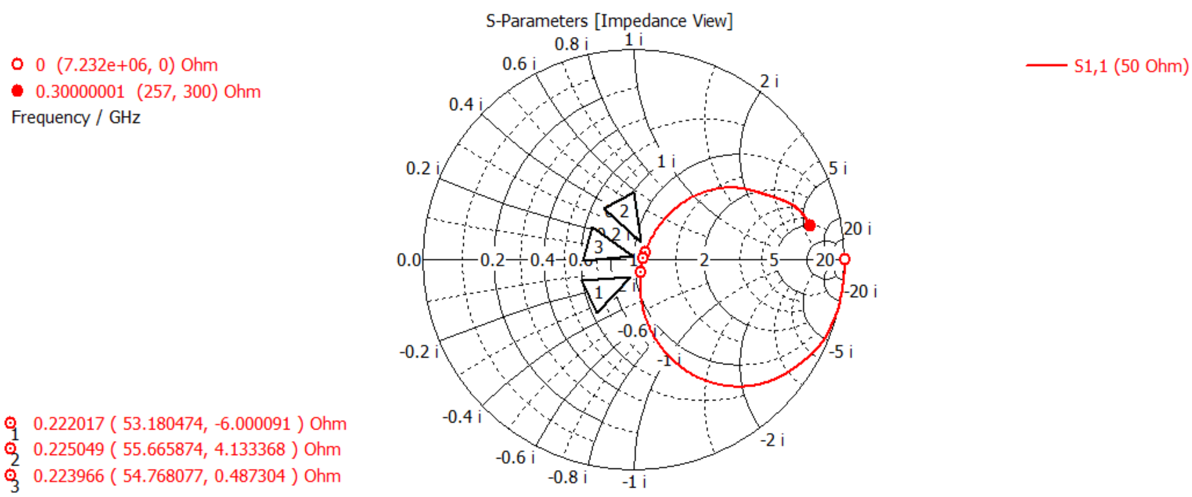

Figure 11. Smith Chart of S_{11} Parameter – 1/4 Wavelength Elements

The simulated electric fields at 222.5 MHz were again inspected to ensure that the antenna was operating as a ½ wavelength dipole. The electric fields shown in Figure 12 and 13 match closely with what would be expected. Figure 13 shows the expected minimum and maximum field magnitudes at the ends of the elements and a minimum in the center. Figure 13 shows that the phase center of the antenna is located on the wire element a significant distance from the feedpoint.

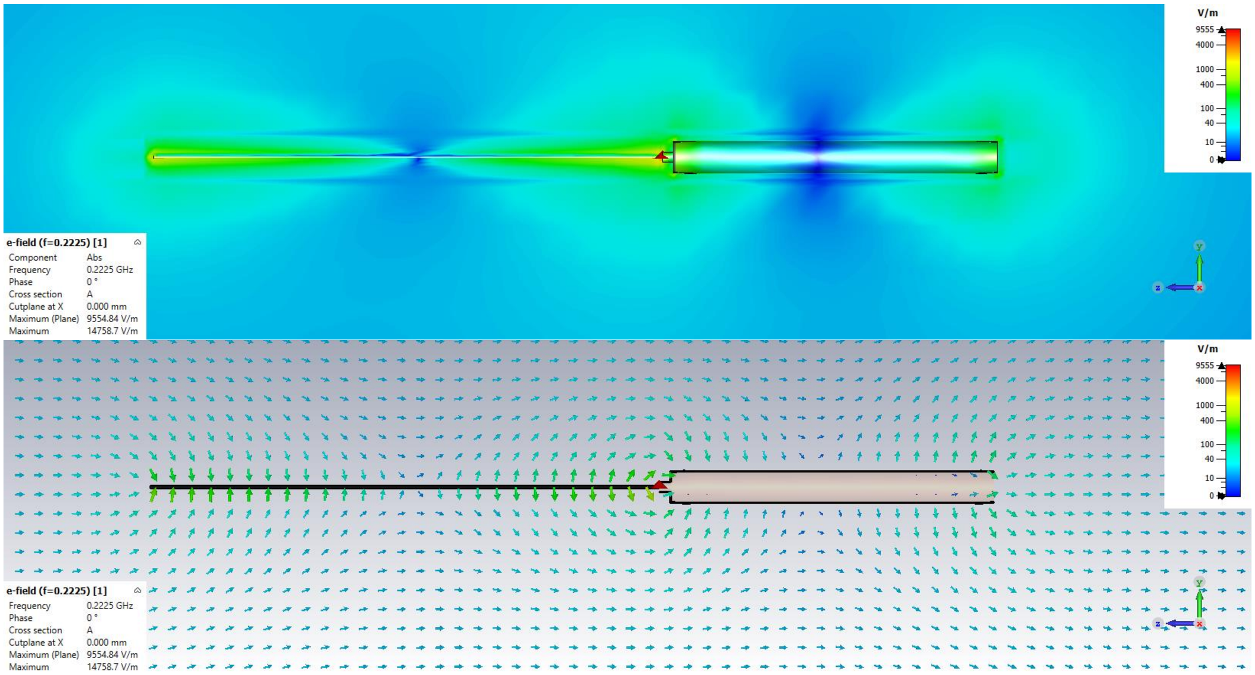

Figure 12: Electric Field with 222.5 MHz Cosine Excitation at θ = 0° Phase, $V_1 = V_{max}$

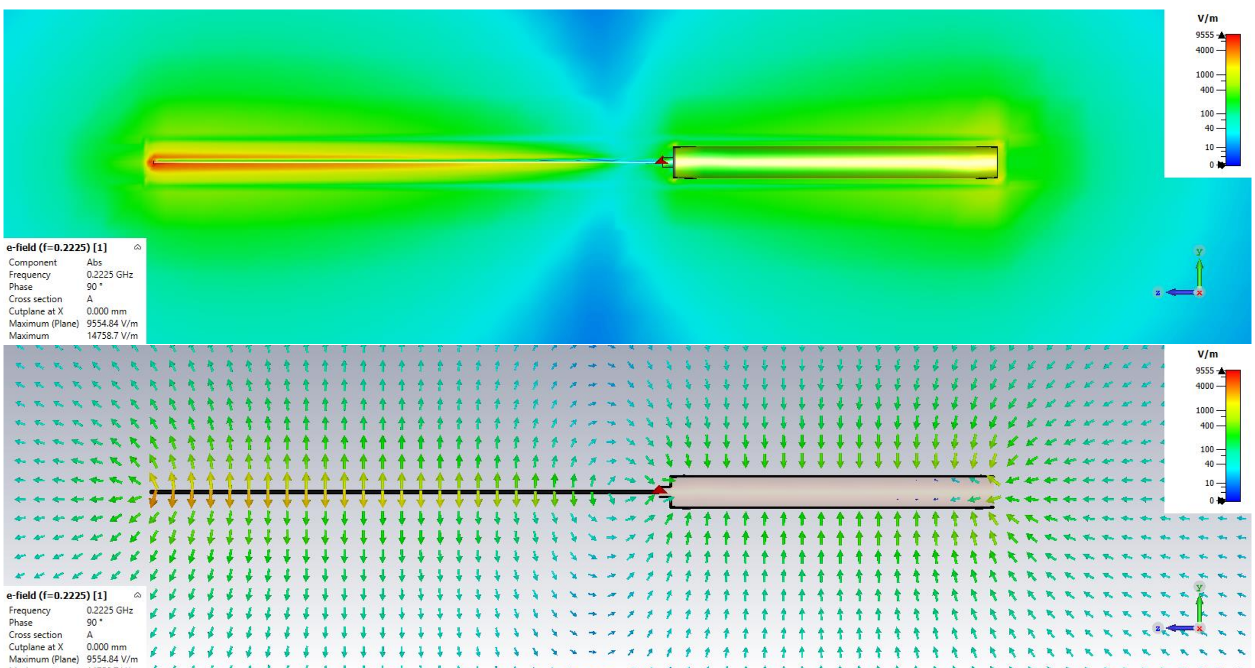

Figure 13: Electric Field with 222.5 MHz Cosine Excitation at θ = 90° Phase, $V_1 = V_{max}$

Section 3 Construction and Tuning of a Sleeve Dipole

The simulation results were used to create a physical antenna shown in Figs. 14 and 15. The antenna was constructed using a piece of copper pipe, copper end cap, a BNC female to solder-cup bulkhead and a length of 18 AWG solid core wire with PVC insulation. The enclosure was made from PVC pipe and end caps. The feedline is a 50 Ω coaxial cable with 50 Ω BNC male connectors. The antenna was constructed using the element lengths found by the optimizer. The wire element was 330 mm and the copper tubing element was 218 mm.

Figure 14. Sleeve Dipole Removed from Enclosure

Figure 15. Sleeve Dipole inside Enclosure

To limit the common mode current on the antenna feedline, three ferrite chokes were placed on the antennas feedline as shown in Figure 11.

The sleeve dipoles reflection coefficient (S_{11} parameter magnitude) was measured using a vector network analyzer in the setup shown in Figure 14.

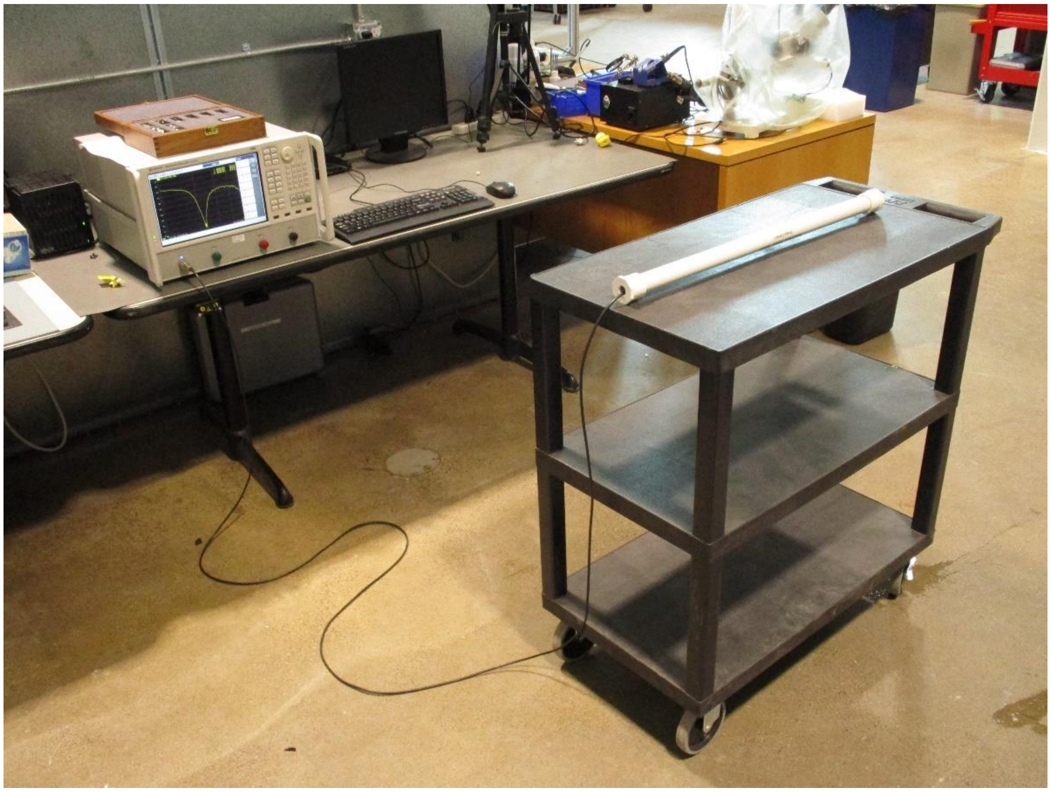

Figure 14. VNA Antenna Measurement Setup

The minimum was found to be at 210.6 MHz (instead of the target 222.5 MHz), as revealed by the plot in Fig. 16

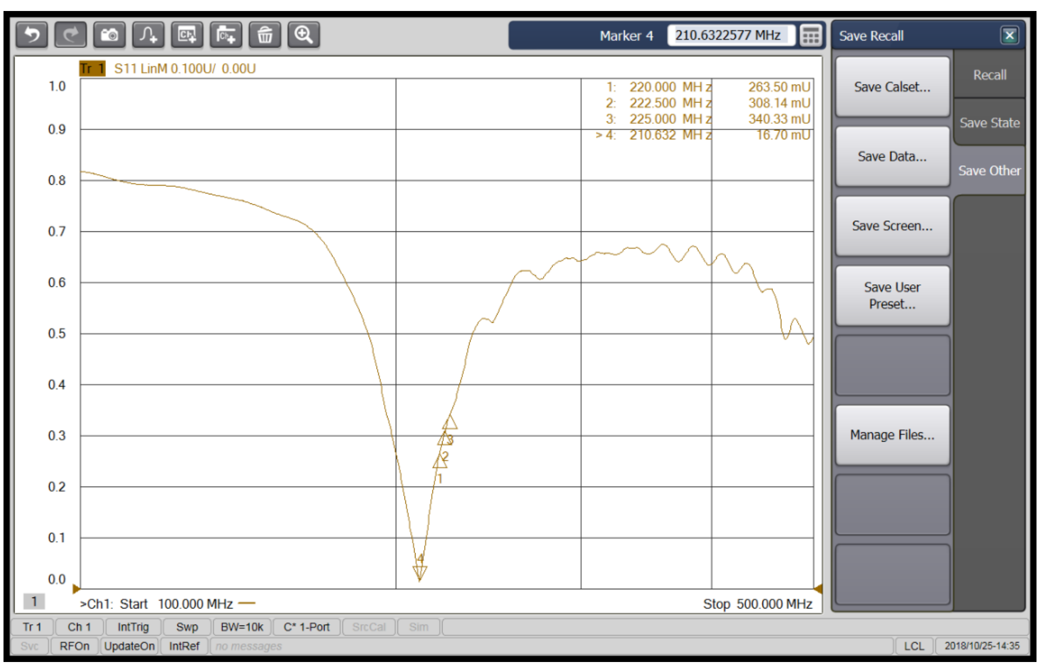

Figure 16: S_{11} Magnitude of un-tuned Antenna

To determine the target length of the antenna elements the relationship in Eq. (5) was used:

$$\frac{f_{measured}}{f_{target}} = \frac{l_{target}}{l_{measured}} \tag{5}$$

The target lengths were determined as

$$l_{target} = l_{measured}\frac{f_{measured}}{f_{target}} = 218\ mm\frac{210.6x10^6}{222.5x10^6} = 206\ mm \tag{6}$$

$$l_{target} = l_{measured}\frac{f_{measured}}{f_{target}} = 330\ mm\frac{210.6x10^6}{222.5x10^6} = 312\ mm \tag{7}$$

Lengths of wire and copper tubing were cut from the antenna to achieve the target length. The antennas S_{11} parameter magnitude was measured again with the VNA, as shown in Fig. 15, and it was found to have an acceptable S_{11} parameter magnitude in the operating range of 220 MHz to 225 MHz.

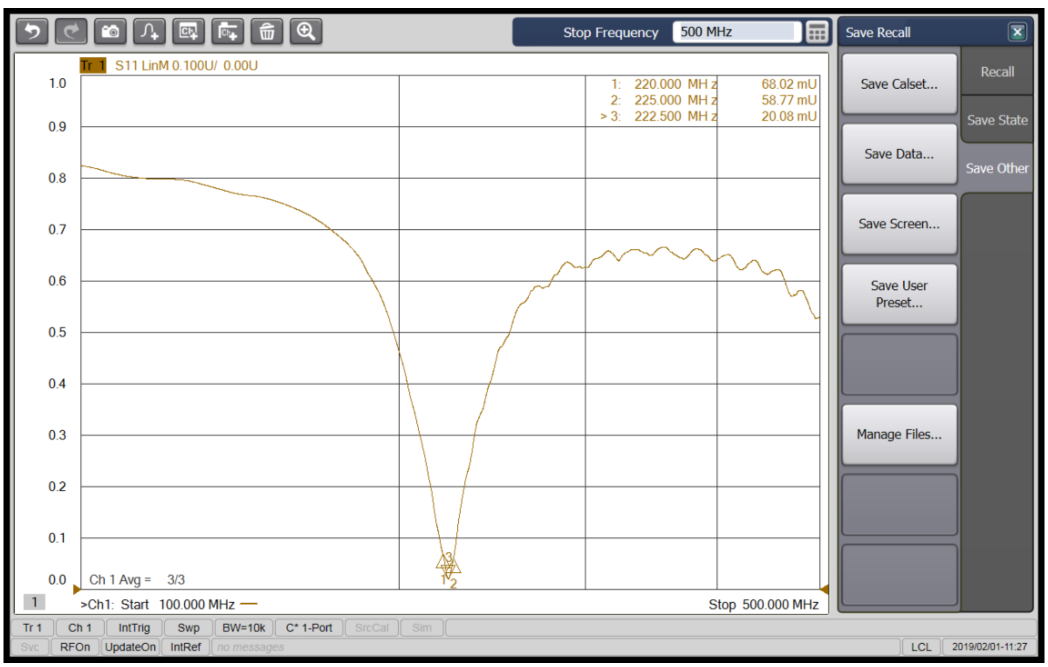

Figure 17. S_{11} Parameter Magnitude of Tuned Antenna

Section 5 Summary and Conclusions

A theoretical model of a dipole antenna were used to create a 3D model of a dipole antenna that would be too complex to analyze analytically. Simulations were used to optimize and verify that the antenna design would function correctly when constructed. The results were used to construct an actual antenna. The actual antenna was tuned and verified to be working properly with a VNA. This shows that the process of utilizing a theoretical antenna model can be a process that requires several intermediary steps before the antenna can be physically realized.

References

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