Tyler McKean

Nov 1st, 2020

ENGIN 435 – Antenna Design

Project 2: How It Works

The second project of the semester involved designing and modeling the different parameters that factor into how smallish antennas function optimally. When selecting an operating frequency for the antenna, perhaps the most important parameter that contributes to the design process is the wavelength. Designing the antenna structure such that it accommodates for a certain ratio of the wavelength will allow the antenna to radiate efficiently, otherwise there may be a mismatch on the structure where the antenna can not operate at full capacity for the selected operating frequency. The project asked us to model four different smallish antenna structures: dipole, monopole, loop antenna, and normal mode helix. In order to model and simulate how these antennas radiate, I used an electromagnetic simulation software environment called FEKO, where I could change structural parameters and then export the results in MATLAB, where I plotted my results for easy comparison. Since we are using the student edition of FEKO, our simulation capabilities were quite limited. So, for most of this project, we were asked to simulate these smallish antennas around an operating frequency of 300MHz and investigate how several parameters like the physical current distribution on the antenna, both the real and imaginary impedances varying across frequency, and the radiation patterns all change when the physical model is scaled in size. Not all antennas behaved the same to this scaling process, so I will elaborate how each of these antenna structures reacted to this process and provide graphs and animations to further the examination in better detail.

The most popular and widely used antenna out of the set is the Dipole. The dipole consists of two conducting elements, such as a simple piece of wire, of which the current flows in the same direction at each node at the ends of the wire, which allows it to radiate. For this project we were asked to model an electric dipole made from a PEC material and vary the dipole's length from 0.1 meters to 0.7 meters at a resonant frequency of 300MHz. We were asked to either make an animation or provide a 2D graph of the current distribution vs length, of which I chose the latter for this antenna but made animations for the others. The graph for current vs length can be seen in Figure 1 below.

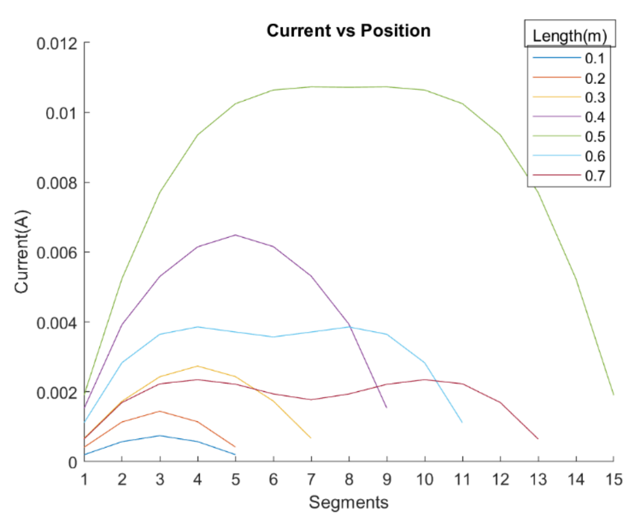
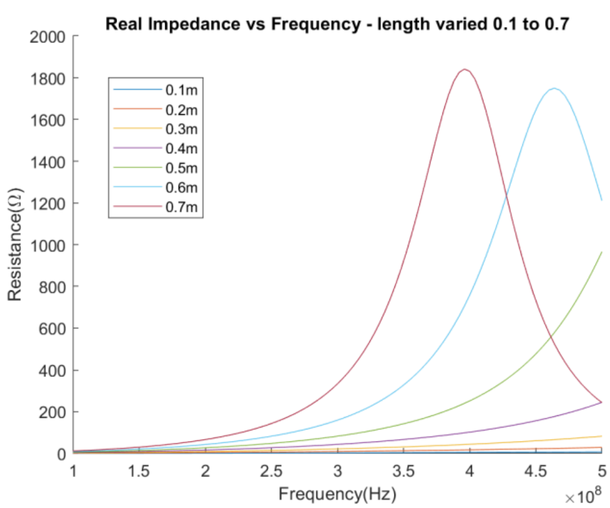
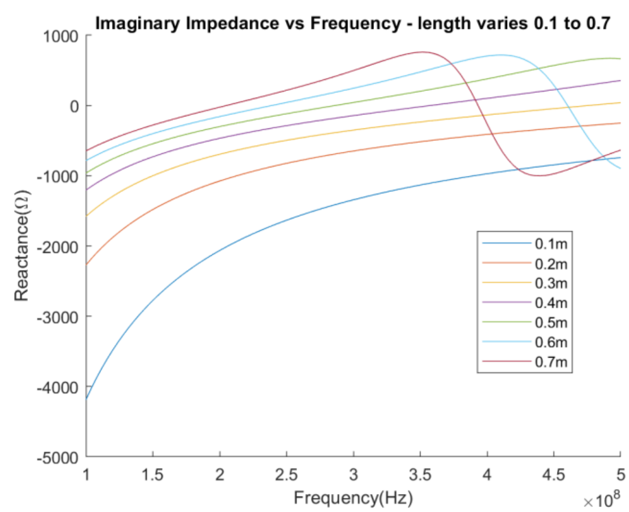


Figure 1 - Current distribution on a dipole @ 300MHz as the length is varied from 0.1m to 0.7m

When stimulating the varying lengths of the dipole in FEKO, the EM software broke up the model into segments ranging from 5 segments for length equal to 0.1m and 15 segments at length equal to 0.7m. It is important to note that the feed point for antenna was placed exactly in the center of the resonant structures for each simulation. The operating frequency of the dipole is at 300MHz which means that the corresponding wavelength would be the speed of light divided by 300MHz equaling to lambda being 1 meter. So, the dipole length simulations run from about one tenth of a wavelength to about seven tenths of a wavelength. When the length was equal to 0.5m, the dipole was then modelled as a half wavelength dipole and had a maximum current value of about 11mA based on Figure 1. This is because each conductive element on either side of the feed point was oriented as a quarter wavelength and the currents on each side are perfectly in phase and experienced constructive interference. So, the currents are oscillating up and down in unison, which allows the structure to radiate at its maximum. For lengths above and below 0.5m, the dipole has similar characteristics to transmission line theory; if the dipole's length was exactly the same as the wavelength, 1m, a current minima would occur at the feed point at the center of the structure and look like an open circuit, thus no power could be delivered and the structure would not radiate. From Figure 1, the lengths 0.6m and 0.7m are approaching a dip at the center of the current distribution, which would occur if I ran the simulation up to length equaling 1m. A half wavelength antenna orientation is then seen as a short circuit, in comparison, because the antenna can drive its maximum current with the least amount of input impedance.





Figures 2a & 2b – Real and Imaginary Impedances of Dipole @ 100MHz to 500MHz with lengths vaired from 0.1m to 0.7m

The plots for the real and imaginary impedances of the dipole can be seen in Figures 2a & 2b above and display these transmission line theory characteristics. In the real impedance plots, the impedances resemble shapes close to a Gaussian pulse as the exponentially grow from and decay back down to zero. For lengths 0.6m and 0.7m, the impedance shapes are approaching the resonant frequency from the right and if the simulation was to taken at length equals to 1m, the Gaussian-like shape would be centered at 300MHz. This is the open circuit phenomenon I mentioned before, where the current minima would occur at the feed point and the input impedance would like it's infinite, which is conveyed by the peak values in the resistance. When the dipole is at a half wavelength the real impedance looks to be somewhere around 70 ohms, which is around the typical input resistance for a half wavelength dipole. The imaginary impedance shown in Figure 2b is about 43 ohms for when length equals 0.5m, which is around the typical value of j42.5 for a half wavelength dip ole. At lengths less than 0.5m, the imaginary impedance is purely capacitive, which is represented by the negative values at the start of the frequency sweep. The antenna is said to have zero reactance at lengths just slightly less than 0.5λ, so around 0.48λ the antenna would be at resonance.

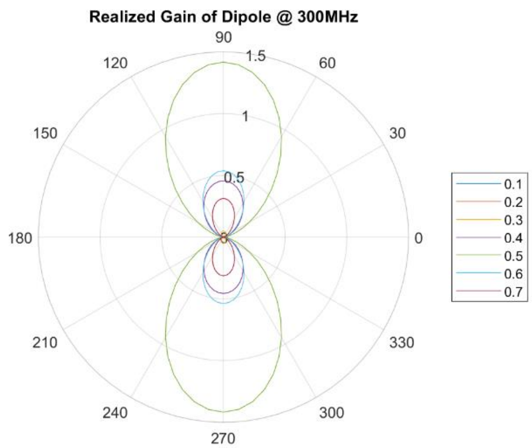


Figure 3 - Vertical Cuts of Dipole's Realized Gain @ 300MHz as the length is varied from 0.1m to 0.7m.

The dipole's realized gain for each of the length variations can be seen in Figure 3 above. The Realized Gain is similar to the regular Gain, which is the efficiency multiplied by the directivity, but Realized Gain has an additional factor called the matching efficiency that is multiplied by the Gain. This gives us a more realized perspective of the Gain because the simulation software will account for a near perfect efficiency that is multiplied by the Directivity, so the matching efficiency will account for the mismatch of the wavelength to the physical lengths of the antenna. This is why the value of 0.5m has the highest value in the polar plot, because the antenna is modelled as a half wavelength dipole and has the highest matching efficiency compared to lengths above and below 0.5m.

The second antenna structure we were asked to model and simulate was a Monopole, which is very similar to a dipole. The monopole is a single conductive element, such a rod or wire, but is perpendicularly mounted to a conductive ground plane. The feed point is attached to the lower end of the monopole close to the ground plane. This antenna will only radiate about half the power of the dipole since the structure is half that of a dipole and can only radiate above the ground plane. A phenomenon called Image Theory impacts this antenna structure, which states that at the boundary of the ground plane, the fields should be zero and no radiation can occur below it. If the ground plane could go off towards infinity this monopole would have a similar radiation pattern to a dipole, because the upper radiation of the monopole would be reflected from the ground plane and form the lower half of a dipole's radiation. In Figure 4 below, an animation of the current distribution on the monopole and ground plane is shown. This animation shows the ground plane being varied from 0.1m by 0.1m to 2m by 2m, and at every step as the length is increased the ground plane has a surface current value of 0 A/m. The monopole itself seems to have a current max when the ground plane is 0.5m by 0.5m which would orient the wire and ground plane at a perfect quarter wavelength for the operating frequency of 300MHz. Once this dimension is passed the currents on both the monopole and ground plane continue to reduce in values, which indicate that the structure is approaching an open circuit with a very high impedance. Since the monopole will only radiate half the power of the dipole it also has half the value in impedance of the dipole too. When the monopole is modelled at a quarter wavelength the expected value for the impedance is about 36.5 + j21.25Ω.

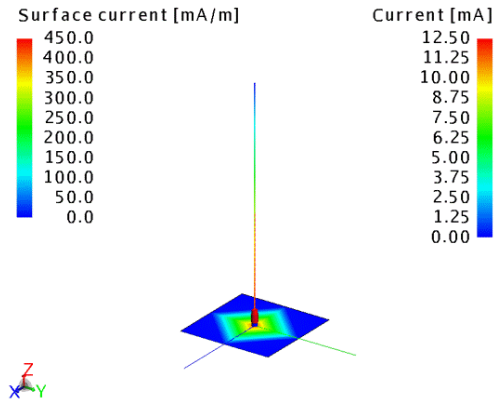
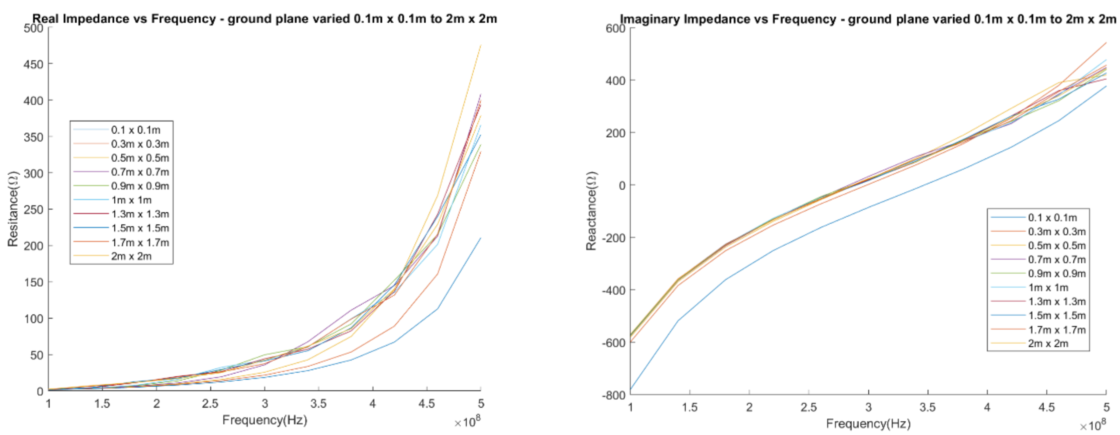


Figure 4 - Current Distribution animation of Monopole @ 300 MHz as ground plane is varied from 0.1m x 0.1m to 2m x 2m



Figures 5a & 5b - Real and Imaginary Impedances of Monopole from 100MHz to 500MHz as ground plane is varied from 0.1m x 0.1m to 2m x 2m

Looking at Figures 5a & 5b, the values around 300MHz appear to be close to 40Ω for the real impedance and around j20Ω for the reactance in the imaginary impedance plot. I found that the ground plane variations did not vary the impedances as both the real and imaginary values are all closely traced to each other, except at the starting value of 0.1m by 0.1m.

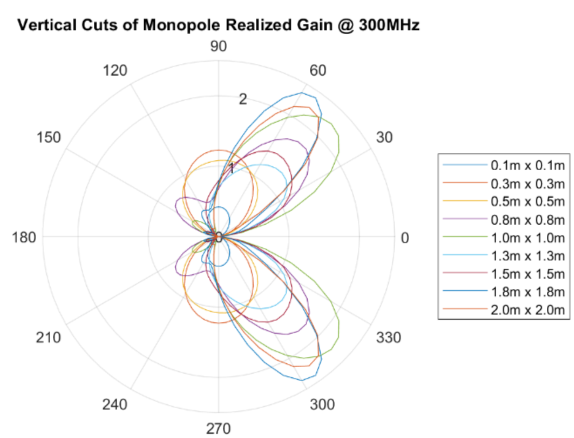


Figure 6 - Vertical Cuts of Monopole's Realized Gain @ 300MHz as ground plane is varied from 0.1m x 0.1m to 2m x 2m

The biggest observation I noticed when varying the ground plane was the radiation pattern shifted from a horizontal orientation and tilted towards a vertical orientation as the ground plane increased in area. The pattern changes can be seen in Figure 6 above, which shows a polar plot of the realized gain as the ground plane is increased from 0.1m by 0.1m to 2m by 2m. The pattern is shown to have a figure eight shape at the lower values and gradually takes on a butterfly-like shape for latter set of ground plane values. Comparing the realized gain plots of the monopole to the dipole, the monopole max gain values are in fact double the max values of the dipole. The directivity of the monopole is doubled because the beam solid angle above the ground plane is one half that of a similar dipole, which leads to a doubling in the directivity.

The next antenna structure I modeled in FEKO was a loop antenna with parasitic loading. This structure had a piece of conductive wire wrapped around a rectangular piece of metal inside the loop with a varying gap between the wire and metal. The feed point for the antenna was placed in the center of the bottom wire, while keeping the circumference of the wire constant. Shrinking that metal rectangle inside the loop, I varied the gap between the wire and metal from 5mm to 2.5cm. A varied-gap current distribution animation can be seen below in Figure 7.

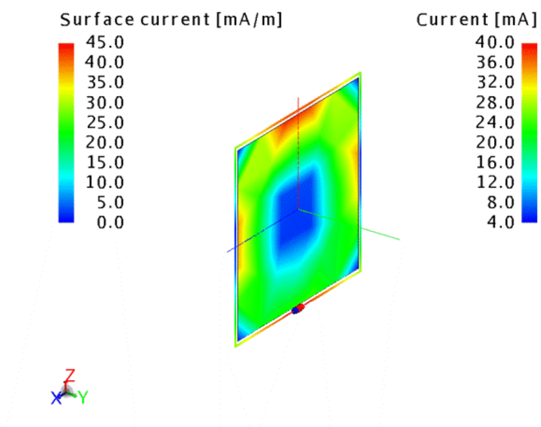


Figure 7 - Current Distribution animation of Loop antenna @ 300MHz with the gap varied from 5mm to 2.5cm

Observing the animation, I noticed the currents only decreased on both the wire and metal rectangle as the gap between the two increased.

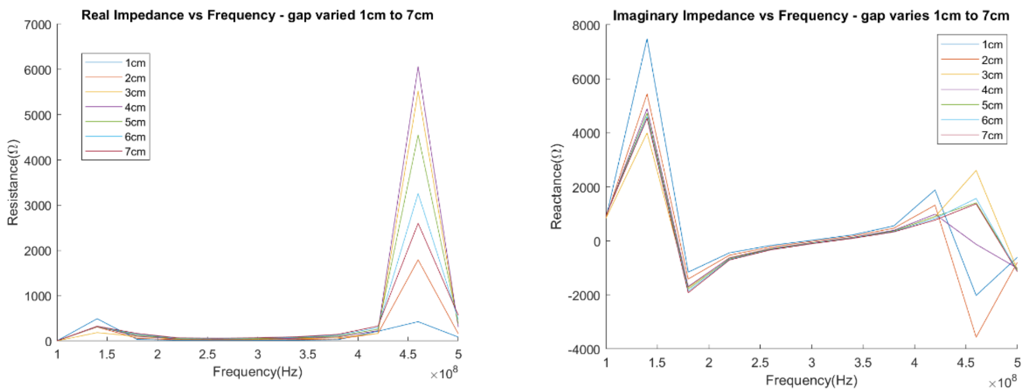


Figure 8a & 8b - Real and Imaginary Impedance of Loop Antenna @ 300 MHz as gap is varied from 1cm to 7cm

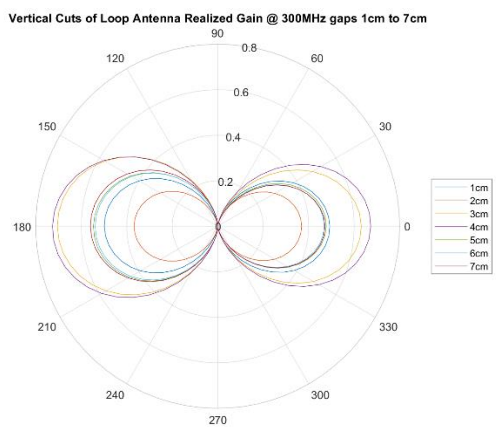


Figure 9 - Vertical Cuts of Loop Antenna's Realized Gain @ 300MHz as gap is varied from 1cm to 7cm

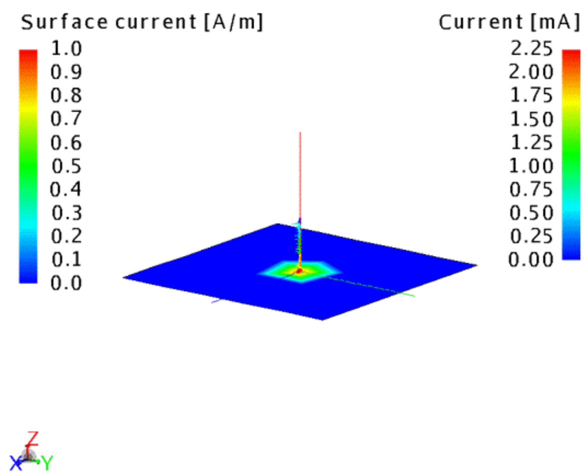


Figure 10 - Current Distribution for Helix Antenna @ 300MHz with spacing between turns varied 5cm-20cm

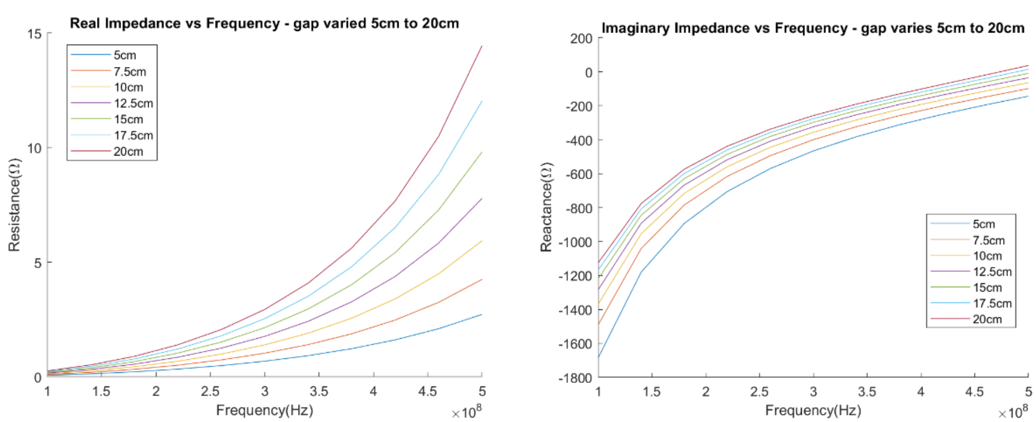


Figure 11a & 11b - Real and Imaginary Impedance of Helix Antenna @ 300MHz with gap varied 5cm to 20cm

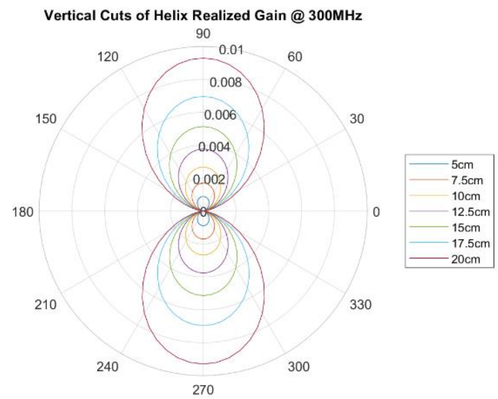


Figure 12 - Vertical Cuts of Helix Antenna's Realized Gain @ 300MHz with gap varied 5cm to 20cm