Learning how to use Ansoft & CST

A Major Qualifying Project Report
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by

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Abstract:

I searched information for each type of antennas and the methods behind HFSS and CST is for getting some basic ideas of this project. I used these softwares to build up the structures for each type of antennas, and use these softwares to run simulations for each type of antennas for experiences. The experiences learned from using these computer programs for simulations will help me to become a better engineer in the future.
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**Introduction:**

HFSS from Ansoft and CST microwave studio are very popular computer softwares that are used for antenna models design. Before building antennas, people can use these softwares to help them for finding the results they want. There are lots of different types of antennas in the world. And, there are different theories behind these antennas and different methods behind these two computer softwares. In this project, we will use HFSS or CST to build structures and simulate for different type of antennas, which are mushroom cell antenna, patch antenna, dielectric antenna, and spiral antenna.
Background:

Before doing analysis, we need to understand some basic ideas of antennas. What Maxwell's equations and the wave equation, dipole, bandwidth, polarization, size vs. wavelength, the finite element method, and the finite-difference time-domain method are.

Maxwell's equations and the wave equation

Maxwell's equation was published by Jam Clerk Maxwell in 1873. Maxwell's equations describe the electric and magnetic phenomena at the macroscopic level. The general forms of time varying Maxwell equations are:

1.) \[ \nabla \times \overrightarrow{E} = -\frac{\partial \overrightarrow{B}}{\partial t} - \overrightarrow{M} \]
2.) \[ \nabla \times \overrightarrow{H} = -\frac{\partial \overrightarrow{D}}{\partial t} + \overrightarrow{J} \]
3.) \[ \nabla \cdot \overrightarrow{D} = \rho \]
4.) \[ \nabla \cdot \overrightarrow{B} = 0 \]

The quantities of these equations are defined as:

\( \overrightarrow{B} \) is the magnetic flux density. (Wb/m\(^2\))
\( \overrightarrow{D} \) is the electric flux density. (Coul/m\(^2\))
\( \overrightarrow{E} \) is the electric field intensity. (V/m)
\( \overrightarrow{H} \) is the magnetic field intensity. (A/m)
\( \overrightarrow{J} \) is the electric current density. (A/m\(^2\))
\( \overrightarrow{M} \) is the magnetic current density. (V/m\(^2\))
\( \rho \) is the electric charge density. (Coul/m\(^3\))
In free-space, the relations between the electric and magnetic field intensities and flux densities are:

5.) \( \vec{B} = \mu_0 \vec{H} \)
6.) \( \vec{D} = \varepsilon_0 \vec{E} \)

\( \mu_0 = 4\pi \times 10^{-7} \) Henry/m is the permeability of free space, and \( \varepsilon_0 = 8.854 \times 10^{-12} \) farad/m is the permittivity of free space. Equation 1.) to 4.) are linear but not independent of each other. Maxwell’s equations in phasor form are:

7.) \( \nabla \times \vec{E} = -j\omega \vec{B} - \vec{M} \)
8.) \( \nabla \times \vec{H} = j\omega \vec{D} + \vec{J} \)
9.) \( \nabla \cdot \vec{D} = \rho \)
10.) \( \nabla \cdot \vec{B} = 0 \)

Figure 1. Examples with arbitrary volume, surface, and line currents for electric and magnetic currents
In a source free, isotropic, linear, and homogeneous region, Maxwell's equations in phasor form are:

11.) \[ \nabla \times \vec{E} = -j\omega \mu \vec{H} \]
12.) \[ \nabla \times \vec{H} = j\omega \epsilon \vec{E} \]

These two equations can be solved to the following equation:

13.) \[ \nabla \times \nabla \times \vec{E} = -j\omega \mu \nabla \times \vec{H} = \omega^2 \mu \epsilon \vec{E} \]

Then it can be simplified to:

14.) \[ \nabla^2 \vec{E} + \omega^2 \mu \epsilon \vec{E} = 0 \]
15.) \[ \nabla^2 \vec{H} + \omega^2 \mu \epsilon \vec{H} = 0 \]

where constant \( k = \omega \sqrt{\mu \epsilon} \) (l/m), which is called the wavenumber, or propagation constant of the medium [1].

**Dipole**

The line of force created between the arms of a small center-fed dipole. In the first quarter of the time period, the charge has reached its maximum value, and the lines have traveled outwardly a radial distance \( \lambda/4 \). In the next quarter of time period, the lines have traveled another \( \lambda/4 \), which is total of \( \lambda/2 \) from the initial point, and the charge density has begun to diminish. Which means the lines of force have been created by opposite charges and traveled a distance \( \lambda/4 \) during the second quarter of the first half period [8].
**Bandwidth**

The bandwidth of an antenna can be defined as the frequency range that antenna performs with respect to some characteristic and conforms to a specified standard. The bandwidth can be considered as the range of frequencies, which are on either side of the center frequency. Input impedance, pattern, gain, polarization, etc. are defined as the characteristics. The characteristics of an antenna are not vary in the same manner or affected by the frequency, so there is no unique characterization of the bandwidth. For different cases, the specifications are set to meet the particular application's needs. The distinction is the variation between pattern and input impedance. And the pattern bandwidth and impedance bandwidth are use to emphasize this distinction. The bandwidth is usually formulated in terms of beamwidth, side lobe level, and pattern characteristics [8].

**Polarization**

The polarization of an antenna is defined as the polarization of the wave that antenna transmitted. Different parts of the pattern may have different polarizations because the polarization of the radiated energy varies with the direction from the center of the antenna [8].

**Size vs. Wavelength**

There is a relationship between the wavelength of an antenna and the size of an antenna. The wavelength $\lambda$ is defined as the distance between two successive maxima, minima, or any reference points at a fixed instant of time.

$$16.) \quad \lambda = \frac{2\pi}{\beta}$$

The phase velocity, $v_p$, is defined as:
17.) \[ \nu_p = \frac{\omega}{\beta} = \lambda f \]

The phase constant will be different with three types of medium, which are lossless, general lossy, and good conductor.

In lossless medium,

18.) \[ \beta = \omega \sqrt{\mu \varepsilon} \]

In general lossy,

19.) \[ \beta = \text{Im}(\gamma) \]

In good conductor,

20.) \[ \beta = \text{Im}(\gamma) = \sqrt{\omega \mu \sigma} / 2 \]

As the length of the antenna increase, the beam becomes narrower. The 3-dB beamwidth of each:

21.) \( l << \lambda \) \hspace{1cm} 3-dB beamwidth = 90°
22.) \( l = \lambda / 4 \) \hspace{1cm} 3-dB beamwidth = 87°
23.) \( l = \lambda / 2 \) \hspace{1cm} 3-dB beamwidth = 78°
24.) \( l = 3\lambda / 4 \) \hspace{1cm} 3-dB beamwidth = 64°
25.) \( l = \lambda \) \hspace{1cm} 3-dB beamwidth = 47.8°

In each pattern, the maxima and minima repeat every integral number of half wavelength. The space between a null and a maximum in each of the wave patterns is \( \lambda / 4 \) [8].
Ground plane

It is not able to build an infinite size of a ground plane on an antenna, but a very large structure can be approximated close. The radiation characteristics of antenna, which are current distribution, pattern, impedance, etc., can be modified considerably by the edge effects. There are two methods, which are Moment Method (MM) and Geometrical Theory of Diffraction (GTD), can be used for the edge effects. The moment method is the solution that is described in the form of an integral. It can be use to handle any shape. It requires using a digital computer for numerical computations. It is also referred to a low frequency asymptotic. When the size of the radiating object is larger than wavelength, high frequency asymptotic techniques can be use for analysis. This is also considering as Geometrical Theory of Diffraction (GTD), which was developed by Keller. The advantages of GTD are, 1.) It is simple to use, 2.) It can be used to solve complicate problems that do not have exact solutions, 3.) It provides physical insight into the radiation and scattering mechanisms from the various parts of the structure, 4.) It yields accurate results which compare extremely well with experiments and other methods, 5.) It can be combined with other techniques such as the Moment Method [8].
The Finite Element Method (FEM)

The finite element method, FEM, is a tool for solving differential equations. Those differential equations are in electromagnetics, solid, and structural mechanics, fluid dynamics, acoustics, and thermal conduction. FEM is a favorite method that is using in many branches of engineering because of it has ability to deal with complex geometries. This is done by using unstructured grids, which refers to as meshes. The unstructured meshes allow for higher resolution locally in order to resolve good structures of the geometry and fast variations. The FEM is better suited for problems with oblique and curved boundaries and fine structures that many need higher resolution locally. The FEM has another good ability, which is the method gives a well-defined representation of the searched function everywhere in the solution domain. This makes it to be able to apply many mathematical tools. The explicit formula for updating the fields in time-domain simulations cannot be derived in the general case is the disadvantage of the FEM. A linear system equations need to be solved in order to update the fields. The FEM requires more computer resources, which are CPU time and memory [7].

The general recipe of the FEM is solving a differential equation. The equation is \( L[f] = s \). \( L \) is an operator. \( s \) is the source. And \( f \) is the unknown function, which is computed in the region \( \Omega \). 1.) Subdivide the solution domain \( \Omega \) into cells or elements. 2.) Approximate the solution by an expansion in a finite number of basic functions. 3.) Make the residual, \( r = L[f] - s \), as small as possible. 4.) Test or weighting functions, \( w_i \), for weighting the residual \( r \). 5.) Set the weighted residuals to zero and solve for the unknown \( f_i \) [7].
High frequency structural simulator (HFSS) is designed by Ansoft Corporation. HFSS is using FEM modeling for analyzing. The figures showed below are for giving an idea about how to start HFSS program and how it looks like.

Figure 2. Short cut of HFSS 10

![HFSS 10 Short cut](image)

After the HFSS is opened, we can start to build up the structure by using the tools that it provides. Then, we can use HFSS to simulate the structure that we have built. As figure 3 showed, the structure that is built into HFSS needs to be built in 3-D space.

Figure 3. HFSS window

![HFSS window](image)
The Finite-Difference Time-Domain Method (FDTD)

The finite-difference time-domain method, FDTD, is one of the popular computational methods for microwave problems. The FDTD is simple to program, more efficient, easier for dealing with different problems. Dealing with boundaries that are not aligned with the Cartesian grid is its major weakness. The FDTD uses explicit time-stepping, which makes it more efficient than time-domain FEM. The FDTD does not need matrix to be stored, which reduces the memory's usage, and it can solve problems with a large number of unknowns. A time-step limit in three dimensions of the FDTD is \( \Delta t < \frac{h}{c} \sqrt{3} \) (\( \Delta t \) is the time-step, \( h \) is the cell size, and \( c \) is the speed of light, which is around \( 3 \times 10^8 \) m/s.). The FDTD cannot be used in eddy current problems because of its short limit of the time-step. The FDTD is used in the propagation of electromagnetic waves problems and the geometries problems where characteristic lengths are comparable to a wavelength. To perform an FDTD simulation and then Fourier transform selected signals in time is a powerful way for finding resonant frequencies of a microwave cavity. The major advantage of time-domain methods of the FDTD is that a single FDTD run can produce frequency-domain result at any desire number of frequencies, and while the simulation proceeds, the time signals from an FDTD simulation can be Fourier transformed. The FDTD is now the basic tool in CEM, and research articles [7].

For the 1D wave equation, the FDTD divides the z-axis into intervals of length \( \Delta z \) and the time-axis into intervals of length \( \Delta t \). The important parameter is \( R = c \Delta t / \Delta z \), which is the number of the grid cells the exact solution propagates in one time-step. For \( R = 1 \), \( \Delta t = \Delta z / c \). This choice of \( \Delta t \) is called the magic time step. The errors of the spatial and temporal difference are mostly canceled. The signals propagate exactly one cell per time step for either direction. For \( R < 1 \), \( \Delta t < \Delta z / c \). When is the \( R \) smaller, the numerical dispersion is stronger. For \( R > 1 \), \( \Delta t > \Delta z / c \). This algorithm is unstable. When \( c \Delta t > \Delta z \), the signal of the true solution propagates more than one cell per time step, and that is not possible [7].
CST microwave studio is using FDTD modeling for analyzing. The figures showed below are for giving an idea about how to start CST microwave studio program and how it looks like.

![Figure 4. Short cut of CST microwave studio](image)

![Figure 5. CST microwave studio window](image)

After the CST microwave studio is opened, we can start to build up the structure by using the tools that it provides as like using HFSS. Then, we can use CST to simulate the structure that we have built as well. As figure 5 showed, the structure that is built into CST is created in 3-D space.
Analysis:

Mushroom cell antenna

In many antennas, a ground plane or reflector is used by a flat metal. When the antenna is too close to the conductive surface, the image current will cancel the currents in antenna. This will made antenna to have a poor radiation efficiency. This problem is often solved by heaving a quarter-wavelength space between the radiating element and the ground plane. When there are multiple antennas sharing the same ground plane, the surface current can made unwanted mutual coupling. A smooth conducting sheet has low surface impedance, but an array of mushroom on a flat metal sheet can cause the high impedance surface. The surface impedance of a single mushroom cell is defined as:

26.) \[ Z_s = \frac{j\omega L}{1-\omega^2 LC} \]

where

27.) \[ L = \mu_0 h \]

28.) \[ C = \frac{D\varepsilon_0 (\varepsilon_r + 1)}{\pi} \ln \left( \frac{2D}{\pi w} \right) \]

\( h \) is the height between the mushroom cap and the ground plane. \( D \) is the grid period. \( w \) is the distance between the mushrooms. \( \varepsilon_r \) is the relative permittivity of the PCB.

The reflection coefficient from the surface is defined as:

29.) \[ R = \frac{Z_s - \eta}{Z_s + \eta} \]

\( \eta \) is the impedance of the free space. The reflection coefficient is used for finding the reflected
field. When the height from the surface is zero, the reflection coefficient can be defined as:

30.) \[ E_\pm = R \cdot E_\pm \]

\( E_\pm \) is the incident field.

When the height from the surface is one, the reflection coefficient is defined as:

31.) \[ E_\pm = R \cdot E_\pm e^{j2k\ell} \]

For a perfect conductor it becomes:

32.) \[ E_\pm = -E_\pm e^{j2k\ell} = E_\pm e^{j(\pi + 2k\ell)} \]

Comparing 35.) and 36.) will get a ratio, \( \text{Re}^j\pi \). Which can calculated the impedance of a surface and the magnitude and phase of the reflection coefficient [2][3][4][5].

Figure 6. A single mushroom cell antenna
We are going to use HFSS for simulating mushroom cell antenna. Sievenpiper's example will be included in the examples. We will change few parameters for more simulations and see how the result changes by changing via size, mushroom height, relative gap width, and relative dielectric constant.
Patch antenna

The patch antennas and the microstrip antennas have a close relation, which microstrip antennas are referred to as patch antenna. The patch antenna's radiating elements and the feed lines are constructed on the dielectric substrate. There are lots of shapes of the radiating patch, which are square, rectangular, thin strip (dipole), circular, elliptical, triangular, and other configuration. The patch antenna has a metal patch placed above a ground plane [8].

![Figure 7. Example of a patch antenna with a body model and without](image)

There are four popular configurations that are used to feed microstrip antennas are the microstrip line, coaxial probe, aperture coupling, and proximity coupling. The microstrip line feed is easy to build, and simple to match by controlling the inset position and simple to model. When the substrate thickness increases, the surface wave and spurious feed radiation increase, which can be designed for limiting the bandwidth. The coaxial line feed uses the inner conductor of the coax to attach to the radiation patch when the outer conductor is connected to the ground plane. The coaxial probe feed is also easy to build and match, and has low spurious radiation. It also has narrow bandwidth, but it is difficult to model. The aperture coupling is the most difficult to build of those four. It has narrow bandwidth, is easier to model, and has moderate spurious [8].
For this patch antenna, we are going to use Ansoft to do some simulations on the shoulder patch antenna. We will use the HFSS to run the simulations by changing the position of the feed on the patch antenna or the size of the patch. For the position simulations, the position of the feed will be changing from 0% to 100% of patch width and from 0% to 100% of the patch length. For the size simulations, the position of the feed will stay at the same percentage of the patch width and the patch length, but the size of the patch will be changing.
Bow-tie antenna

Bow-tie antenna has two triangular metal plates that are symmetrical to each other. It can also be simulated to a wire along the periphery of its surface which reduces the weight and the wind resistance of the structure. The input impedances and radiation patterns of wire bow-tie antennas have been computed by using the Moment Method when mounted above the ground plane. The bow-tie antenna does not present as broadband characteristics as corresponding solid biconical antenna. The bow-tie antenna is more narrowband than the biconical surface of revolution or triangular sheet antenna [8].
Dielectric patch antenna

Dielectric patch antenna made by replacing a metal patch by a dielectric brick on a patch antenna. The relative dielectric constant of the dielectric brick needs to be very high. There is a thick dielectric disk antenna above a ground plane, and they are separated by a narrow gap with a lower value of the dielectric constant. When the height of the dielectric-patch increases, the resonant frequency of the dielectric-patch antenna changes. When the distilled water is used for a dielectric material, the resonant frequency can be tuned at least 40-50% by increasing the height of the distilled water. When the metal patch is replaced by a low-loss dielectric brick the conduction currents no longer exist. When the dielectric is very thick and the relative dielectric constant is high, both polarization currents and the resulting bound surface charge density will be large [6].

\[ \bar{J}_D = j\omega (\varepsilon_{D-1}) \varepsilon_D \bar{E} \]

\( \varepsilon_D \) is the relative dielectric constant of the dielectric brick. \( \bar{J}_D \) is the polarization current [6].

Figure 9. Example of a dielectric patch antenna
In this antenna, we going to have a $60\, mm \times 60\, mm$ ground plane, antenna height is $5\, mm$, the dielectric patch is $45\, mm \times 45\, mm \times 15\, mm$. And will change the positions of the feed in the patch area, $45\, mm \times 45\, mm$. For the simulation, we will break the area of a $45\, mm \times 45\, mm$ into four pieces, which are A, B, C, and D parts. The position of feed will be changing from 0% to 100 % of half patch width and from 0% to 100% of half patch length for part A, from -100% to 0 % of half patch width and from 0% to 100% of half patch length for part B, from -100% to 0 % of half patch width and from -100% to 0% of half patch length for part C, and from 0% to 100 % of half patch width and from -100% to 0% of half patch length for part D.

![Figure 10. The area A, B, C, and D of the patch area of $45\, mm \times 45\, mm$](image-url)
The equiangular spiral is a geometric configuration. Its surface can be described by angles. It is used for designing frequency independent antennas. Designating the length of the arm is for specifying a finite size antenna. When the total arm length is comparable to the wavelength, the lowest frequency of operation occurs. The shape of an equiangular plane spiral curve can be derived as:

\[ \frac{\partial f}{\partial \theta} = f'(\theta) = A \delta \left( \frac{\pi}{2} - \theta \right) \]

where \( A \) is a constant and \( \delta \) is the Dirac delta function.

In wavelength, 21.) can be written as:

\[ r_{\theta=\pi/2} = \rho = \begin{cases} A e^{a\phi} = \rho_0 e^{a(\phi-\phi_0)}, & \theta = \pi/2 \\ 0, & \text{elsewhere} \end{cases} \]

where \( A = \rho_0 e^{-a\phi_0} \).

Another form of 21.):

\[ \rho_\lambda = \frac{\rho}{\lambda} = A e^{a\phi} = \lambda e^{a(\phi-\phi_0)} \]

where \( \phi_L = \frac{1}{a} \ln(\lambda) \).

1/a is the rate of expansion of the spiral and \( \psi \) is the angle between the radial distance \( \rho \) and the tangent to the spiral. From equation 22.), changing the wavelength will vary the variable \( \phi_L \).

The total length \( L \) of the spiral can be defined as:

\[ L = \int_0^{2\pi} r d\theta = \int_0^{2\pi} A e^{a\phi} d\theta = A \int_0^{2\pi} e^{a(\phi-\phi_0)} d\theta = A \int_0^{2\pi} e^{a\phi} d\theta \]

\[ = A \left[ \frac{1}{a} \ln(\rho) \right]_0^{2\pi} = A \left[ \tan \psi \ln \left( \frac{\rho}{A} \right) \right]_0^{2\pi} = A \left( \tan \psi (\ln \rho - \ln A) \right) \]
38.) \[ L = \int_{\alpha_1}^{\alpha_2} \left[ \rho^2 \left( \frac{\partial \phi}{\partial \rho} \right)^2 + 1 \right]^{1/2} \rho \, d\rho \]

Reduce the function by using 21.):

39.) \[ L = (\rho_1 - \rho_0) \sqrt{1 + \frac{1}{a^2}} \]

\( \rho_0 \) and \( \rho_1 \) are represent the inner and outer radii of the spiral [8].
CST & MATLAB

For spiral antenna, we need to use MATLAB codes and CST microwave studio. An Archimedean spiral can be described in polar form \((r, \theta)\):

\[
r = a + b\theta^{1/x}
\]

\(a\) and \(b\) are real numbers. When \(x = 1\), it is a normal Archimedean spiral. \(a\) is the number of turns of the spiral, and \(b\) is the distance between successive turns of the spiral. First, using MATLAB codes to create a spiral, which is showed below:

![Figure 11. The code output from MATLAB codes](image)

\[
\text{Figure 11. The code output from MATLAB codes}
\]
Then, open CST microwave studio to create a new project. Loading the MATLAB code into CST file by creating curve points, which is showed below:

![Figure 12. The spiral shows in CST by loading MATLAB code file](image)

After that, start to run the simulations or add some materials that you want for the simulations. The following example is showed blow has water material, Teflon, spiral, and PCB board:

Figure 13. Left side of this figure shows the whole materials, and the right side of this figure shows the zoom-in of the PCB board area from the left figure.

As the figure above, the blue square, which is water, has the size of $300mm \times 300mm \times 150mm$, Teflon has the size of $75mm \times 75mm \times 1mm$ and $\varepsilon_r = 2.2$, PCB is $75mm \times 75mm \times 1.6mm$ and $\varepsilon_r = 4.4$, and the parameterize trace's width is $0.3mm$ and thickness is. The simulations will be running at $0.55, 0.6, 0.625, 0.7$ GHz.
MATLAB Codes:

```matlab
clear all
N = 10; % number of full turns;
step = pi/12; % discretization step (orig pi/6)
b = 0.3; % separation between turns in mm
a = b*step^4/(1-cos(step^4)); % offset from center in mm
n = 1; % power
theta = [0:step:2*pi*N];
r = a + b*theta.^(1/n);
x = r.*cos(theta);
y = r.*sin(theta);

theta = theta + pi;
r1 = a + b*theta.^(1/n);
x1 = r.*cos(theta);
y1 = r.*sin(theta);

plot(x, y, 'b', 'LineWidth', 2); grid on; hold on;
plot(x1, y1, 'r', 'LineWidth', 2); grid on; hold on;
axis('equal'); title('Units - meters')

z = [x' y'];
save('spiral1_new.txt','z','-ASCII');
z = [x1' y1'];
save('spiral2_new.txt','z','-ASCII');
```
Results:

Mushroom cell antenna

After running the simulation of the mushroom cell antenna by Ansoft program, results are showed on following. Sievenpiper's example is with $D = 2.44\,\text{mm}$, $w = 0.15\,\text{mm}$, $h = 1.57\,\text{mm}$, $\text{via} = 0.15\,\text{mm}$, and $\varepsilon_r = 2.51$:

![Graph showing normalized frequency and phase](image)

Figure 14. The result from Sievenpiper's example
From figure 15 and 16, you can see the results change by increasing via size from 0.3mm to 0.6mm of Sievenpiper's example.

Figure 15. The result from Sievenpiper's example, but via is twice larger, 0.3mm

Figure 16. The result from Sievenpiper's example, but via is four times larger, 0.6mm
From figure 17 to figure 23, the results are showed by changing relative mushroom height, relative gap width, and relative dielectric constant. Those examples are with $D = 3.5\text{mm}$, $w = 0.5\text{mm}$, $h = 1\text{mm}$, and $\varepsilon_r = 2.2$:

Figure 17. The result of the FFS from Ref. for a low-profile dipole antenna

Figure 18. The result of a high-epsilon mushroom FSS
Figure 19. The result of a narrow-gap mushroom FSS

Figure 20. The result of a wide-gap mushroom FSS
Figure 21. The result of a narrow-gap air-filled mushroom FSS

Figure 22. The result of a wide-gap air-filled mushroom FSS
Figure 23. The result of a high-epsilon mushroom FSS with a relatively large height

D=2.44mm, w=0.15mm, h=1.57mm, \( \varepsilon_r = 10 \)

Normalized frequency \([D/\lambda_g]\)

Phase [degrees]

Frequency [GHz]

Tretyakov
Seivenpiper
HFSS
Patch antenna

After running lots of simulations of changing patch sizes and feed positions, we found out that the most of good results, which have lower value than -2dB, have feed outside the patch. We came out with a result on following figure, which is when feed is at the position of 15% of the patch's width and 60% of the patch's length (When the patch's width is 43.3 mm and the patch's length is 55 mm).

Figure 24. The best result for shoulder patch antenna
The following figures, which are figure 25 to 47, are the results that have feed outside the patch. From figure 25 to 47, the result, which has the value lower than -2dB, has the feed on the edge of the patch. Which means the feed is outside of the patch area. Figure 25 and 26 are the result from the feed that is at 20% of patch width and 20% of patch length with changing patch sizes. Figure 25 has the patch width changes from 5mm to 25mm, and the patch length changes from 30mm to 60mm. Figure 26 has the patch width changes from 5mm to 25mm, and the patch length changes from 60mm to 90mm.

![Graph showing results for feed outside the patch](image)

**Figure 25.** The result for the feed that is at 20% of patch width and 20% of patch length with the patch length changing from 30mm to 60mm.
Figure 26. The result for the feed that is at 20% of patch width and 20% of patch length with the patch length changing from 60mm to 90mm.

Figure 27 and 28 are the results from the feed that is at 60% of patch width and 15% of patch length with changing patch sizes. Figure 27 has the patch width changes from 10mm to 30mm, and the patch length changes from 40mm to 80mm. Figure 28 has the patch width changes from 30mm to 50mm, and the patch length changes from 40mm to 80mm.
Figure 27. The result for the feed that is at 60% of patch width and 15% of patch length with the patch width changing from 10mm to 30mm

Figure 28. The result for the feed that is at 60% of patch width and 15% of patch length with the patch width changing from 30mm to 50mm
Figure 29 and 30 are the results from the feed that is at 20% of patch width and 100% of patch length with changing patch sizes. Figure 29 has the patch width changes from 10mm to 30mm, and the patch length changes from 40mm to 80mm. Figure 30 has the patch width changes from 30mm to 50mm, and the patch length changes from 40mm to 80mm.

Figure 29. The result for the feed that is at 20% of patch width and 100% of patch length with the patch width changing from 10mm to 30mm
Figure 30. The result for the feed that is at 20% of patch width and 100% of patch length with the patch width changing from 30mm to 50mm

Figure 31 and 32 are the results from the feed that is at 40% of patch width and 100% of patch length with changing patch sizes. Figure 31 has the patch width changes from 10mm to 30mm, and the patch length changes from 40mm to 80mm. Figure 32 has the patch width changes from 30mm to 50mm, and the patch length changes from 40mm to 80mm.
Figure 31. The result for the feed that is at 40% of patch width and 100% of patch length with the patch width changing from 10mm to 30mm.

Figure 32. The result for the feed that is at 40% of patch width and 100% of patch length with the patch width changing from 30mm to 50mm.
Figure 33, 34, and 35 are the results from the feed that is at 50% of patch width and 100% of patch length with changing patch sizes. Figure 33 has the patch width changes from 5mm to 25mm, and the patch length changes from 50mm to 80mm. Figure 34 has the patch width changes from 25mm to 45mm, and the patch length changes from 50mm to 80mm. Figure 35 has the patch width changes from 45mm to 65mm, and the patch length changes from 50mm to 80mm.

Figure 33. The result for the feed that is at 50% of patch width and 100% of patch length with the patch width changing from 5mm to 25mm.
Figure 34. The result for the feed that is at 50% of patch width and 100% of patch length with the patch width changing from 25mm to 45mm.

Figure 35. The result for the feed that is at 50% of patch width and 100% of patch length with the patch width changing from 45mm to 65mm.
Figure 36 and 37 are the results from the feed that is at 0% of patch width and 100% of patch length with changing patch sizes. Figure 36 has the patch width changes from 10mm to 30mm, and the patch length changes from 40mm to 80mm. Figure 37 has the patch width changes from 30mm to 50mm, and the patch length changes from 40mm to 80mm.

Figure 36. The result for the feed that is at 0% of patch width and 100% of patch length with the patch width changing from 10mm to 30mm.
Figure 37. The result for the feed that is at 0% of patch width and 100% of patch length with the patch width changing from 30mm to 50mm

Figure 38 and 39 are the results of the patch width is 10mm and the patch length is 70mm. Figure 38 has the feed positions changing from 0% to 100% with patch width, and from 0% to 50% with the patch length. Figure 39 has the feed position changing from 0% to 100% with patch width, and from 50% to 100% with the patch length.
Figure 38. The result for the patch width is 10mm and the patch length is 70mm with feed position changing from 0% to 50% with the patch length.

Figure 39. The result for the patch width is 10mm and the patch length is 70mm with feed position changing from 50% to 100% with the patch length.
Figure 40 and 41 are the results of the patch width is 10mm and the patch length is 72mm. Figure 40 has the feed positions changing from 0% to 100% with patch width, and from 0% to 50% with the patch length. Figure 41 has the feed position changing from 0% to 100% with patch width, and from 50% to 100% with the patch length.

Figure 40. The result for the patch width is 10mm and the patch length is 72mm with feed position changing from 0% to 50% with the patch length
Figure 41. The result for the patch width is 10mm and the patch length is 72mm with feed position changing from 50% to 100% with the patch length.

Figure 42 and 43 are the results of the patch width is 15mm and the patch length is 66mm. Figure 42 has the feed positions changing from 0% to 100% with patch width, and from 0% to 50% with the patch length. Figure 43 has the feed position changing from 0% to 100% with patch width, and from 50% to 100% with the patch length.
Figure 42. The result for the patch width is 15 mm and the patch length is 66 mm with feed position changing from 0% to 50% with the patch length.

Figure 43. The result for the patch width is 15 mm and the patch length is 66 mm with feed position changing from 50% to 100% with the patch length.
Figure 44 and 45 are the results of the patch width is 15mm and the patch length is 68mm. Figure 44 has the feed positions changing from 0% to 100% with patch width, and from 0% to 50% with the patch length. Figure 45 has the feed position changing from 0% to 100% with patch width, and from 50% to 100% with the patch length.

Figure 44. The result for the patch width is 15mm and the patch length is 68mm with feed position changing from 0% to 50% with the patch length
Figure 45. The result for the patch width is 15mm and the patch length is 68mm with feed position changing from 50% to 100% with the patch length.

Figure 46 and 47 are the results of the patch width is 43.3mm and the patch length is 55mm. Figure 46 has the feed positions changing from 0% to 100% with patch width, and from 0% to 50% with the patch length. Figure 47 has the feed position changing from 0% to 100% with patch width, and from 50% to 100% with the patch length.
Figure 46. The result for the patch width is 43.3mm and the patch length is 55mm with feed position changing from 0% to 50% with the patch length.

Figure 47. The result for the patch width is 43.3mm and the patch length is 55mm with feed position changing from 50% to 100% with the patch length.
Dielectric patch antenna

From the figure 26 to 29, we can see that the return loss only reach around -0.1 at 800MHz. As the results showed, we might need to run the simulation farther to 1GHz+ to have better return loss.

Figure 48. Dielectric results for area A

Figure 49. Dielectric results for area B
Figure 50. Dielectric results for area C

Figure 51. Dielectric results for area D
Spiral antenna

The results of the spiral antenna from the CST are showed on the following figures.

Figure 52. S-parameter from CST microwave studio
Figure 53. Spiral antenna directivity at 0.55 GHz

Figure 54. Spiral antenna directivity at 0.6 GHz

Figure 55. Spiral antenna directivity at 0.625 GHz
Figure 56. Spiral antenna directivity at 0.7 GHz
Conclusions:

After this project, I have learned a lot of things. I have learned how to use HFSS program and CST microwave studio to build the structures and use them to run the simulations for each type of antennas. I also learned five different types of antennas, which are mushroom cell antenna, patch antenna, bow-tie antenna, dielectric antenna, and spiral antenna. By different applications, sometimes using HFSS is better and sometime use CST microwave studio is better. HFSS is better for problems with oblique and curved boundaries and fine structures that need higher resolution locally. CST is better for producing frequency-domain results at any desire number of frequencies. HFSS and CST are very useful tools for analysis antenna problems.
Bibliography: