Fields, Waves and Antennas Lab-02 report

Designing antennas using CST studio learning edition

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INTRODUCTION

Finite integration techniques

Finite integration technique (FIT) are mathematical methods used to solve Maxwell's equations in computational electromagnetics. FIT discretizes the integral form of Maxwell's equations, making it possible to compute electromagnetic fields in complex structures and materials. FIT techniques are used extensively in the design and analysis of electromagnetic devices and systems, including antennas, microwave circuits, and photonic devices.

FIT transforms the continuous spatial domain into a discrete one by dividing the computational domain into small grid cells (usually rectangular or hexahedral). Further this computational domain is divided into a mesh or grid. Each cell in the grid is a small volume where the electromagnetic field values are calculated. The discretized equations are solved using numerical methods to obtain the field distributions.

Finite integration technique is applied in CST studio software, which helps engineers and researchers to simulate and perfect electromagnetic devices accurately and efficiently. Some common electromagnetic applications are antenna design, microwave components, and for studying Electromagnetic compatibility (EMC)

CST studio Suite 2023

CST Studio Suite is an extensive software solution designed to simulate electromagnetic fields across a wide range of frequency bands. It integrates multiple simulation tools into a single interface, enabling precise analysis and optimization of electromagnetic devices such as antennas, microwave components, and electromechanical systems. The suite's powerful solvers can manage high-frequency, low-frequency, and static electromagnetic problems, making it essential for designing efficient and compliant devices. Its applications span across industries, including telecommunications, automotive, aerospace, and biomedical engineering, providing engineers with the tools needed to ensure best performance and compliance with standards.

CST software uses various numerical methods, such as the Finite Integration Technique (FIT) and Finite Element Method (FEM), to solve Maxwell's equations and simulate electromagnetic phenomena accurately. Time domain solvers for transient analysis and frequency domain solvers for Harmonic excitation analysis.

Dipole Antenna at different frequencies

Dipole means “two poles.”

A dipole antenna is the simplest type of radio antenna, consisting of a conductive wire rod that is half the length of the largest wavelength the antenna is to generate. This wire rod is split in the middle, and the two sections are separated by an insulator. Each rod is connected to a coaxial cable at the end closest to the middle of the antenna. Voltage is applied between the conductors acts as source from centre.

The length of dipole antenna is Half of its wavelength and gap for feed element is quarter of wavelength and Radius of antenna should be (1/100) th or (1/200) th of wavelength. Characteristic impedance typically around 73 ohms, although this can vary slightly depending on the design and environment. It is commonly matched to a transmission line or feed system with a characteristic impedance of 50 ohms. Half wave dipole functions between range from 3KHz to 300GHz. They are commonly used in Radio receivers.

Design considerations for 1GHz dipole antenna

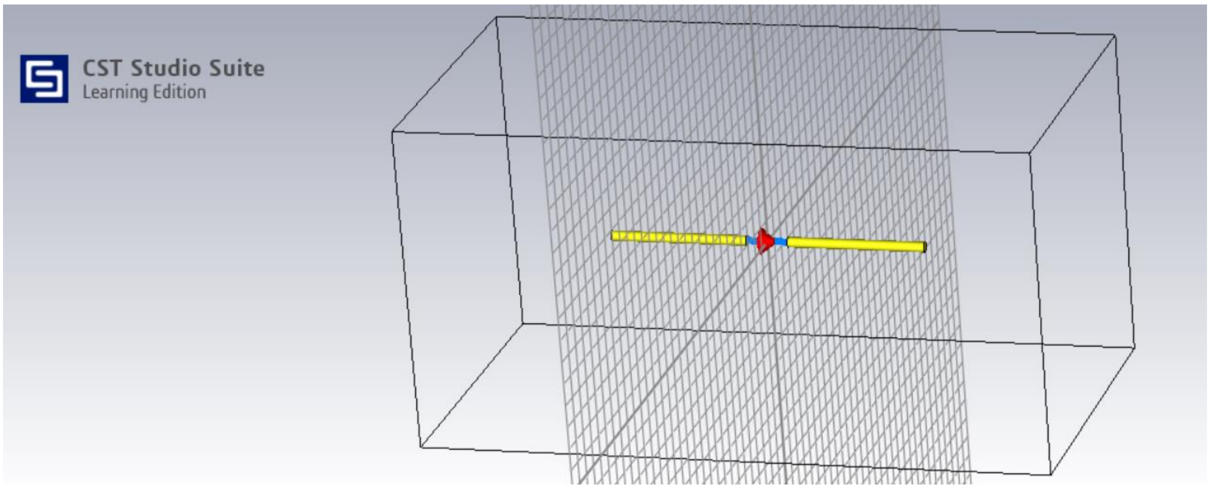


Fig – (1.1) 1GHz Dipole Antenna in CST studio

Length: 150mm,
Frequency = 1GHz,
Wavelength = 300 mm,
Radius = R = 2.5 mm,
Feed element(gap) = 20 mm,
Z0=73 ohms might vary depending on design,
Material of the dipoles and type= copper (annealed) lossy.

S Parameter

S-parameters, or Scattering parameters, are key parameters used in RF (Radio Frequency) and microwave engineering to characterize the behaviour of linear electrical networks, such as amplifiers, filters, antennas, and transmission lines. They provide a quantitative description of how signals behave when they pass through or are reflected by these networks.

S11: Reflection coefficient at Port 1 (incident wave reflection coefficient)

S12: Transmission coefficient from Port 2 to Port 1 (forward transmission)

S21: Transmission coefficient from Port 1 to Port 2 (reverse transmission or isolation)

S22: Reflection coefficient at Port 2 (incident wave reflection coefficient)

In other words, S11 and S22 represent how much of the signal sent into Port 1 or Port 2 is reflected (reflection coefficient). S21 and S12 indicate how much of the signal sent into Port 1 appears at Port 2 and vice versa (transmission coefficient).

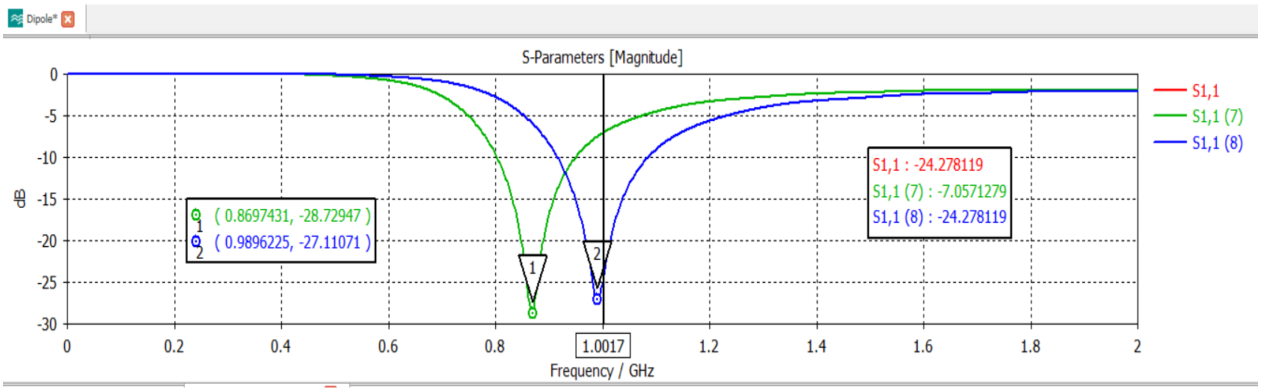


Fig (1.2) S- parameter of 1GHz Dipole antenna

For this 1 GHz dipole antenna, I have change Length of dipole multiple times to reach resonance frequency. At the nearest point I multiplied length with ratio of observed frequency and antenna operating frequency which is 0.8697/1GHz = CTE, to reach exact resonance frequency.

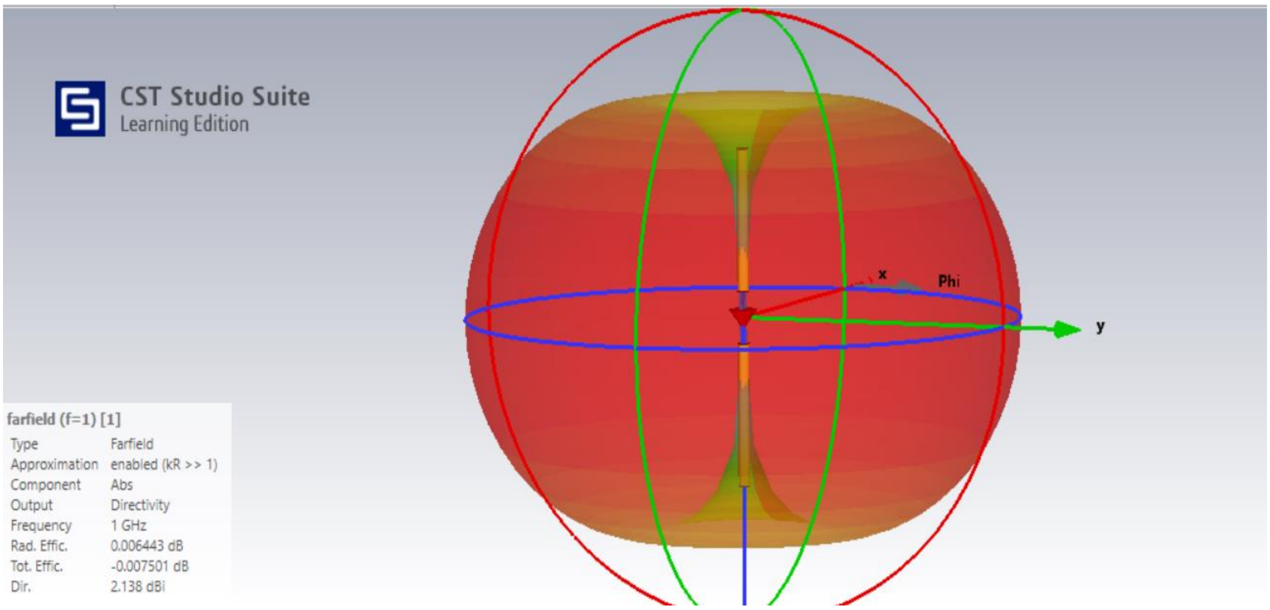


Fig (1.3) 3D Far Field plot of 1GHz Dipole antenna

Far Field 3D and 1D plots

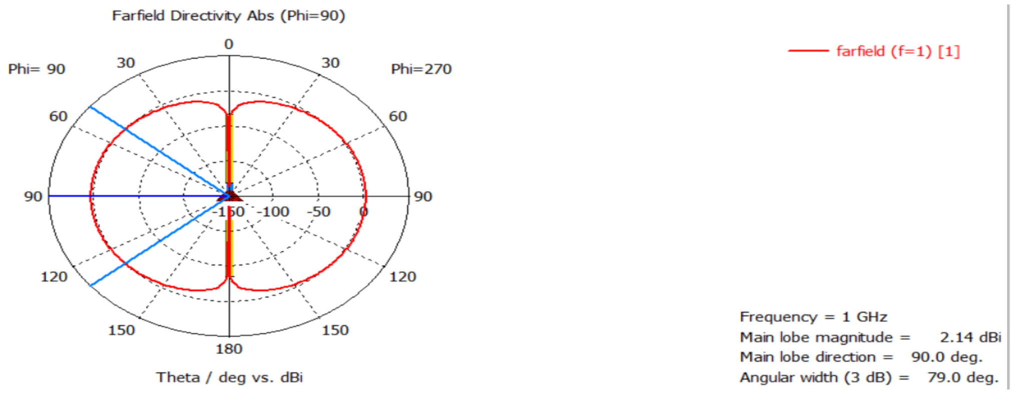


Fig (1.4) 1D Far field plot of 1GHz Dipole antenna

From far-field plots, Directivity is 2.13dBi and gain is 2.14dBi, efficiently radiates power with minimal losses, focusing energy slightly compared to an isotropic radiator

Dipole antenna design at 2.4GHz

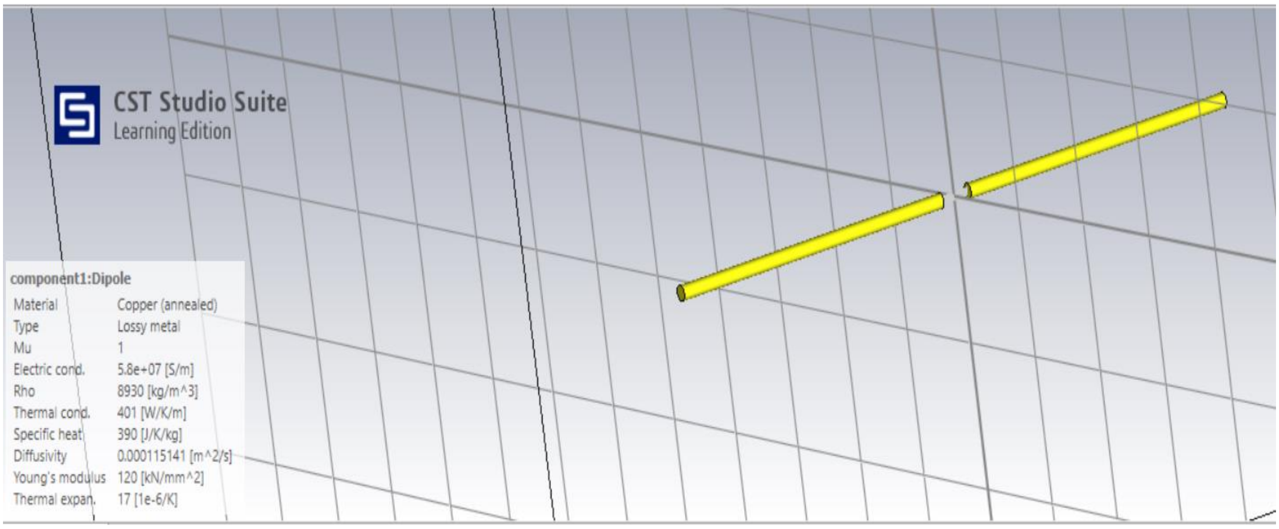


Fig (1.5) - Dipole antenna for 2.4GHz

Design parameters

Wavelength=lambda=115

Length=0.5* wavelength

Gap (feed element) = 0.25* wavelength

Radius= (1/200) *wavelength

Below plot shows S parameter at different frequencies; to bring it towards resonance frequency, I have changed the value of lambda multiple times to achieve desired results.

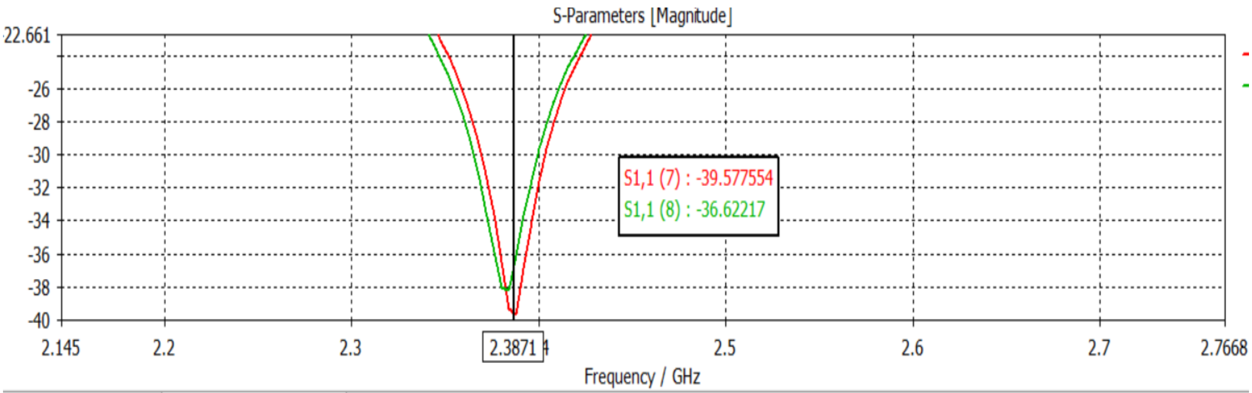
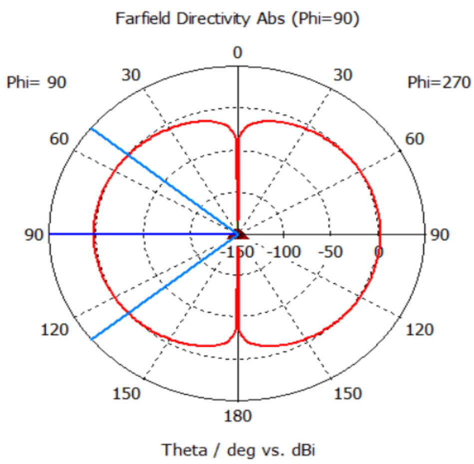
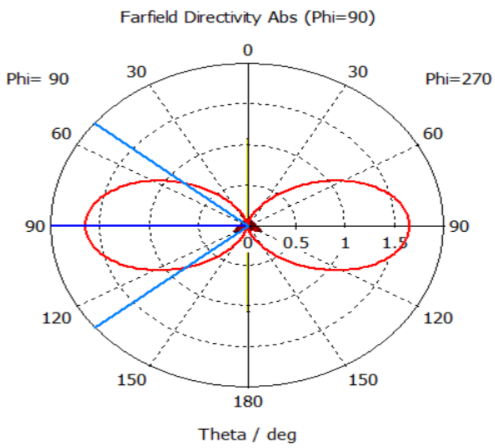


Fig (1.6) S- parameter for 2.4GHz Dipole Antenna

Far-field plot in 1D and 3D





observed gain is 2.16dB

Fig (1.7) 1D plot for 2.4GHz Dipole antenna

Fig(1.8) 3D plot for 2.4GHz of Dipole Ant

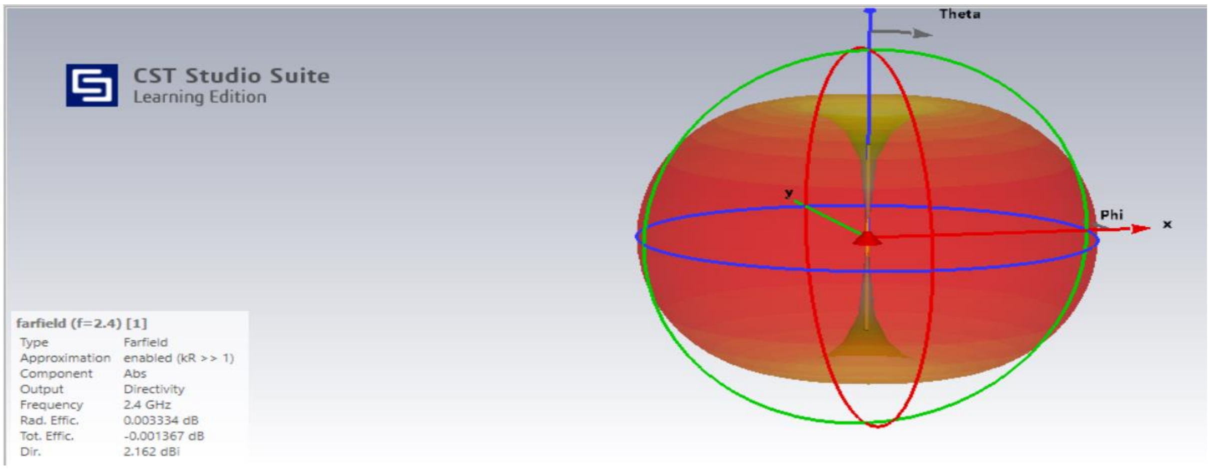
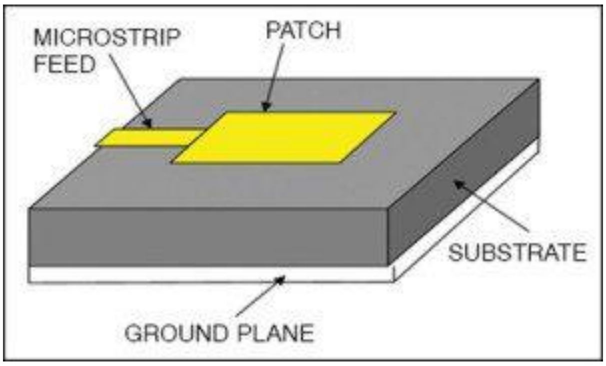


Fig (1.9) Far field plot of 2.4GHz Dipole antenna

<u>Design and Simulation of Microstrip patch antenna at 5.8GHz</u>

Microstrip Patch Antenna:

Microstrip antenna is widely used for wireless communication systems. The microstrip patch antenna includes a radiating patch placed on one side of a dielectric substrate (FR4), with a copper ground plane on the opposite side, as illustrated in Figure (2.1).



Fig(2.1): Microstrip patch antenna

The patch of microstrip antenna is made up of conducting material such as copper or gold and we also considered in our design rectangular share for designing patch and filled with copper. Due to fringing fields between patch edge and ground plane, radiation occurs in microstrip patch antenna. In total three types of radiation patterns we can see from antenna, first part is radiated into space which is useful radiation. The second component involves diffracted waves that reflect between the patch and the ground plane, enhancing the overall power transmission efficiency. Third part of wave which remained trapped in the dielectric substrate due to total reflection at the air-dielectric separation surface. These trapped waves are undesirable.

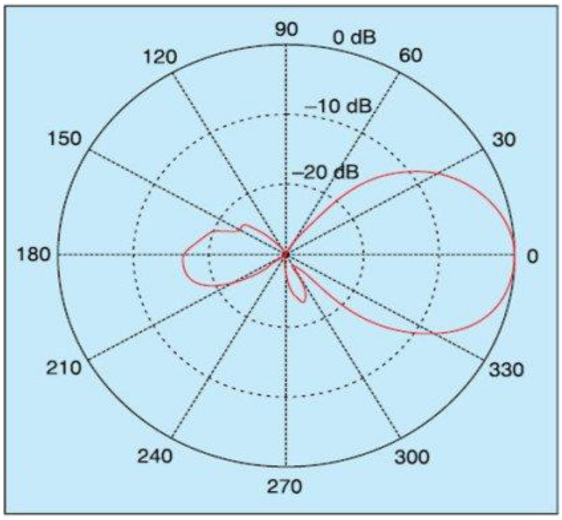


Fig (2.2): Radiation pattern of Microstrip patch antenna

Microstrip patch antenna used several applications such as mobile or satellite communications, GPS systems, Radio frequency identification and so on...

Simulation of Microstrip patch antenna in CST studio at 5.8GHz

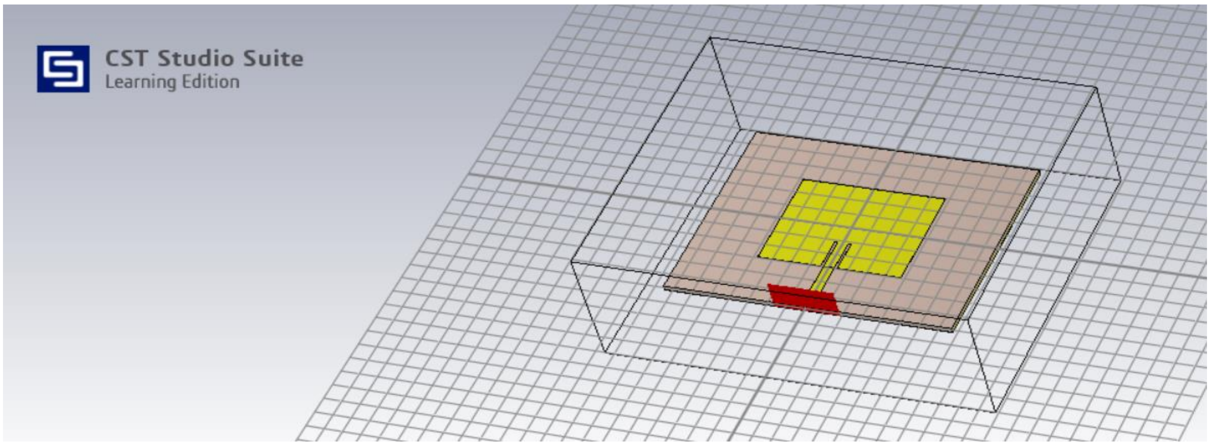
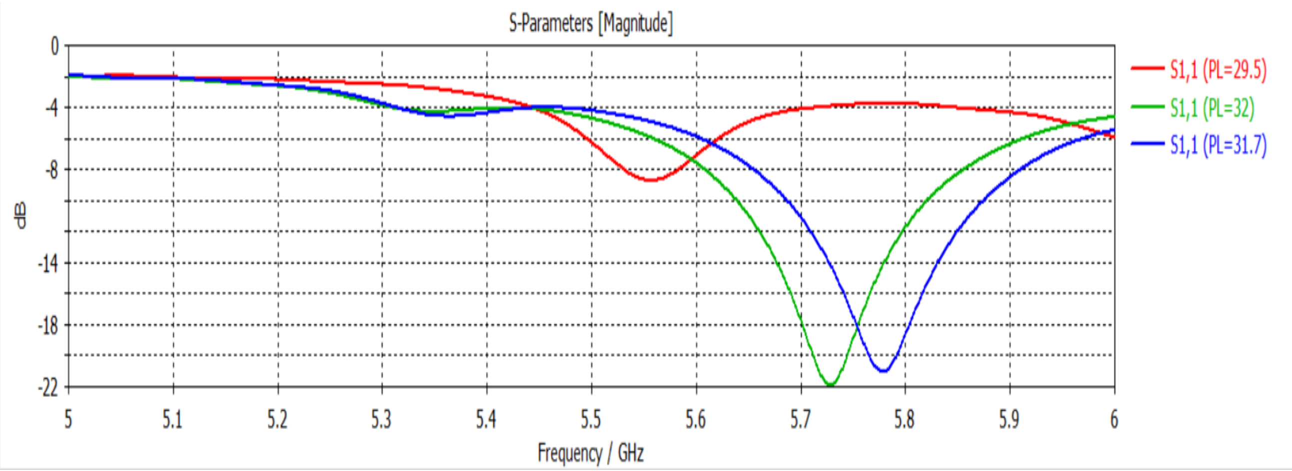


Fig (2.3) Microstrip patch antenna in CST studio

Design parameters

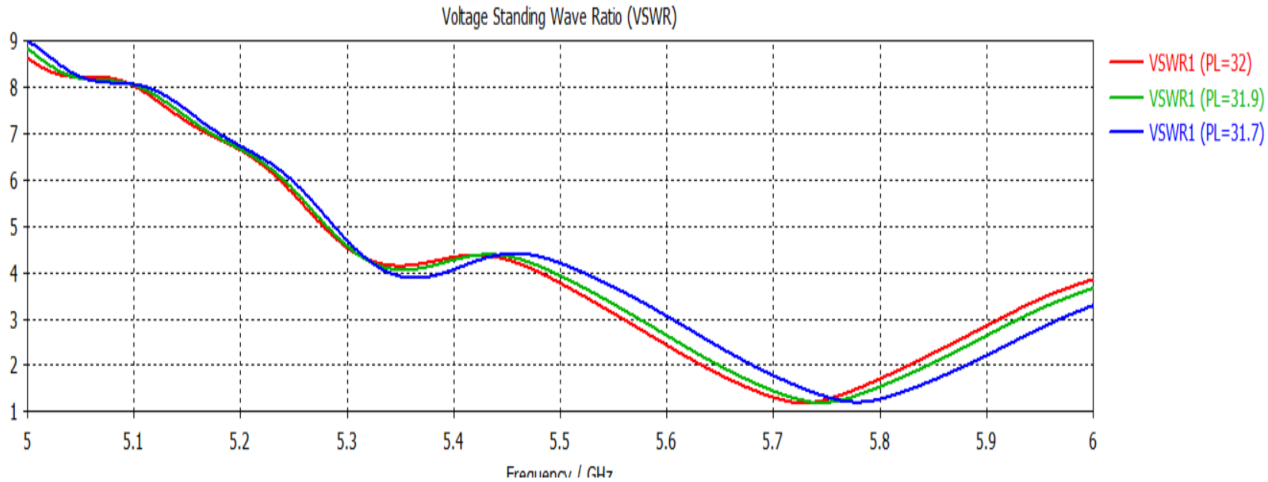
Substrate Length = 59
Substrate width = 76
Substrate height = 1.5
Patch Length = 31.7
Patch width =38
Microstrip length = (Substrate Length/2) -(Patch Length/2) =13.65
Microstrip width = 2.86
Inset length =9
Inset width = 0.74
Metal thickness= 0.035



Fig(2.4) S- Parameter for Microstrip patch antenna at 5.8GHz

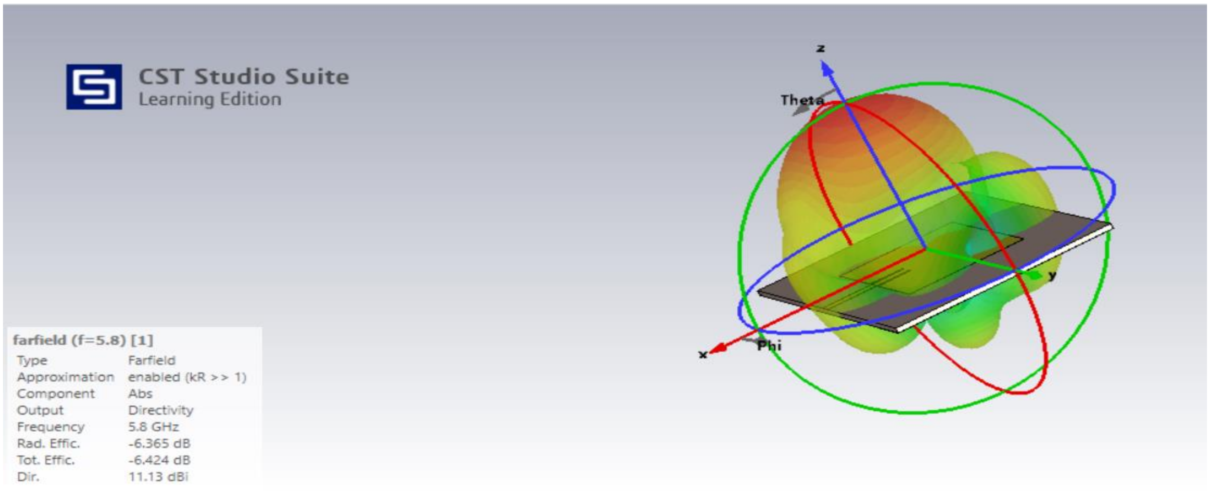
Fig(2.4) shows how s11 parameter varying with frequencies and in dB scale, to reach resonant frequency at 5.8GHz, I tried to change Length of patch and Microstrip length multiple times to reach 5.8GHz of frequency. Finally, I have obtained -18dB at 5.8GHz when PL=31.7.

Plot of Voltage standing wave ratio

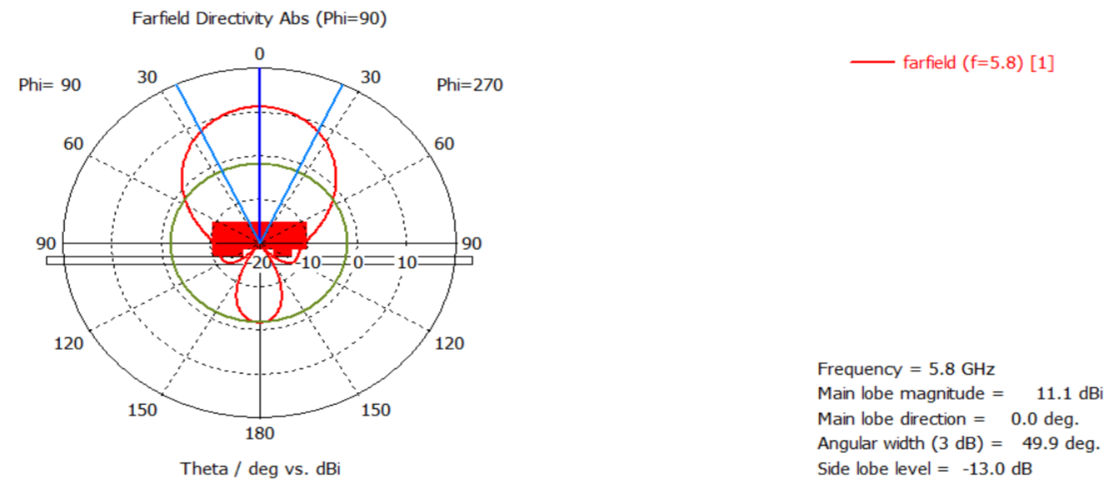


Fig(2.5) VSWR plot for Microstrip patch antenna at 5.8GHz

Far-field Plot of microstrip patch antenna in 3D & 1D



Fig(2.6) 3D radiation pattern for Microstrip antenna in CST



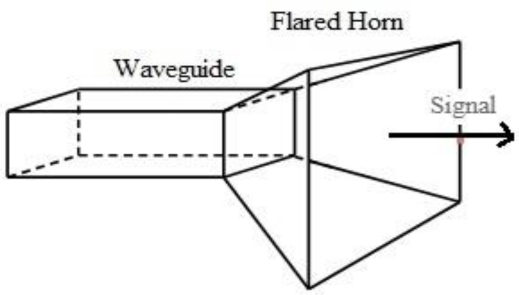
Fig(2.7) 1D radiation pattern for Microstrip antenna in CST

From the above far field radiation patterns, we can see a gain of 11.1dBi and directivity of 11.1dBi which is helpful in radiating mainly to one direction and results in efficient performance of antenna.

Design and Simulation of Horn Antenna

Horn Antenna:

A horn antenna is an aperture type of antenna specifically designed for microwave frequencies. Due to its flared end or horn-shaped structure, the antenna achieves greater directivity, enabling efficient transmission of signals over long distances. Horn antennas operate within the microwave frequency range, typically spanning from 300 MHz to 30 GHz, making them suitable for super high and ultra-high frequency applications.

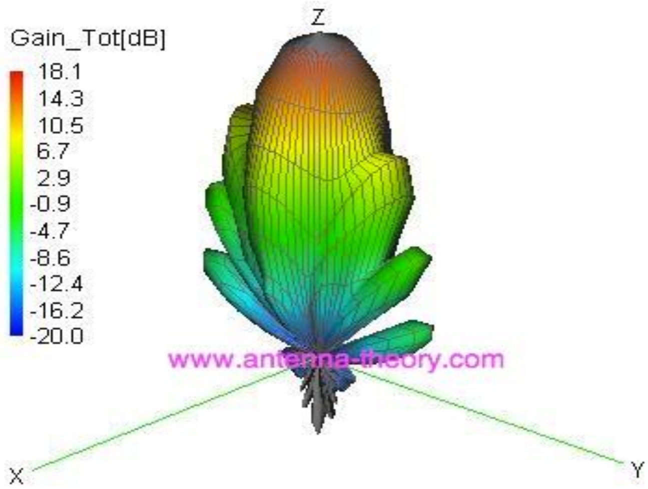


Fig(3.1) Horn Antenna Source: elprocus.com

The horn shape helps to gradually transition the electromagnetic waves from the waveguide into free space, reducing reflection and impedance mismatch. Horn antennas are commonly used in radar systems, satellite communications, and as feed antennas for large parabolic dishes due to their simplicity, efficiency, and directional capabilities.

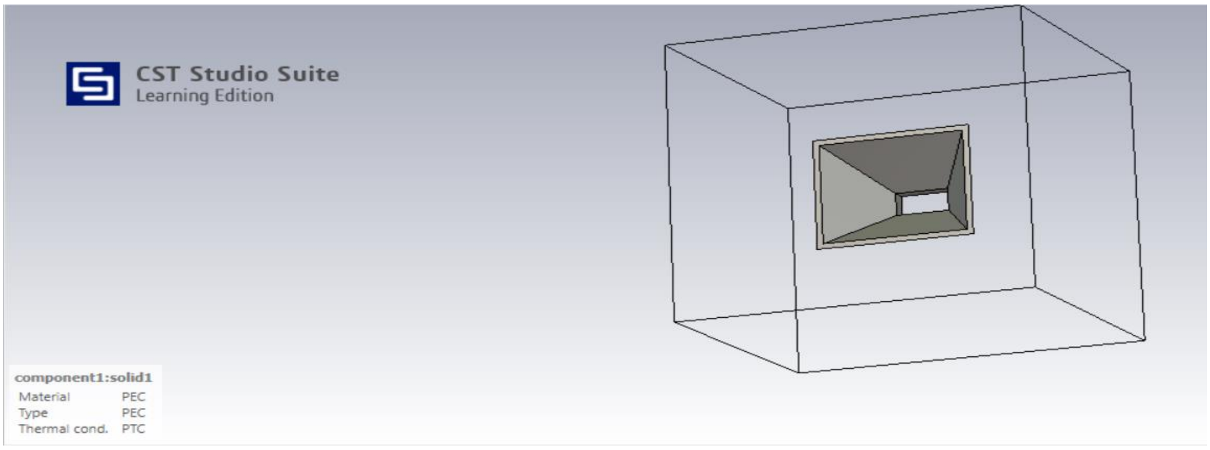
Radiation Pattern

Radiation pattern of a horn antenna is typically characterized by a main lobe that is highly directional, it focuses energy on a specific direction. This main lobe is usually accompanied by smaller side lobes and a back lobe, which are much weaker. The beamwidth of the main lobe depends on the horn's dimensions and shape, with larger horns generally providing narrower and more focused beams. The horn antenna's radiation pattern ensures efficient energy transmission and the reception, making it ideal for applications requiring precise targeting and minimal interference.



Fig(3.2): Horn Radiation

Simulation of Horn antenna with f=9GHz in CST studio



Fig(3.3) Horn antenna design in CST studio

Design parameters

Horn length = 30mm

Frequency =9GHz

wavelength=33.3mm

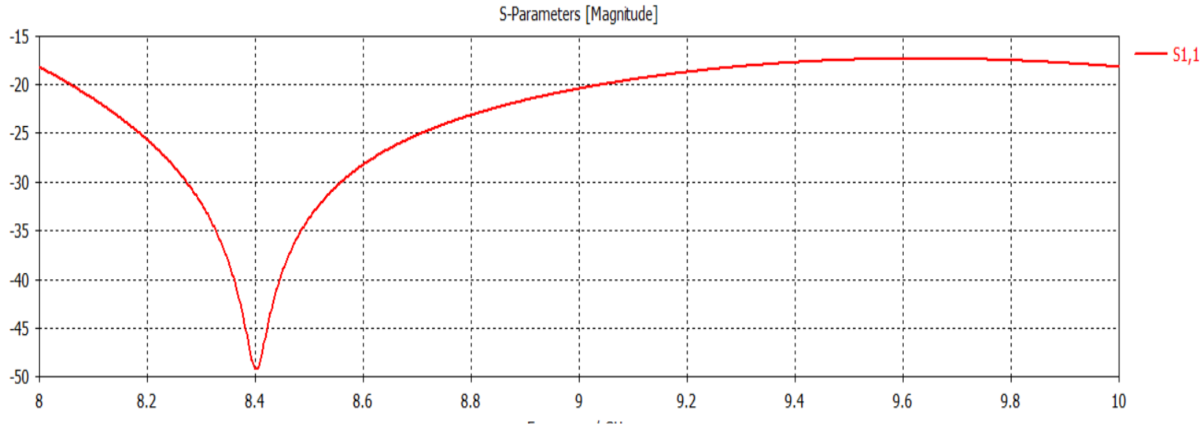
Wall thickness = 2mm

Taper angle =30

Name	Expression	Value	Description
taper_angle	= 30	30	
horn_length	= 30	30	
waveguide_width	= 20	20	
waveguide_height	= 10	10	
fmax	= 200/waveguide_width	10	
f5	= fmax	10	
f4	= 0.5*(fctr+fmax)	9.5	
fctr	= 180/waveguide_width	9	
f2	= 0.5*(fctr+fmin)	8.5	
fmin	= 160/waveguide_width	8	
f1	= fmin	8	
wall_thickness	= 2	2	
<new parameter>			

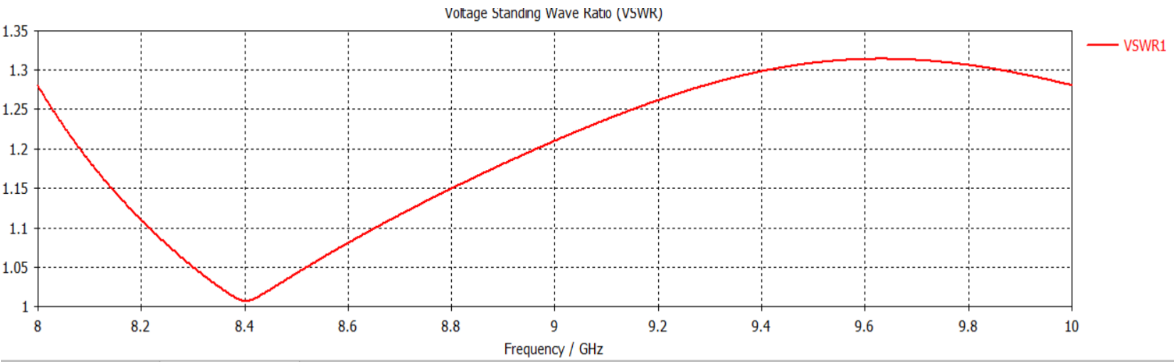
Fig(3.4) Horn antenna design parameters

S- parameter plot



Fig(3.5) S parameter plot for Horn antenna

VSWR plot



Fig(3.6) VSWR plot for Horn Antenna

Far-field plot in 3D for 8GHz

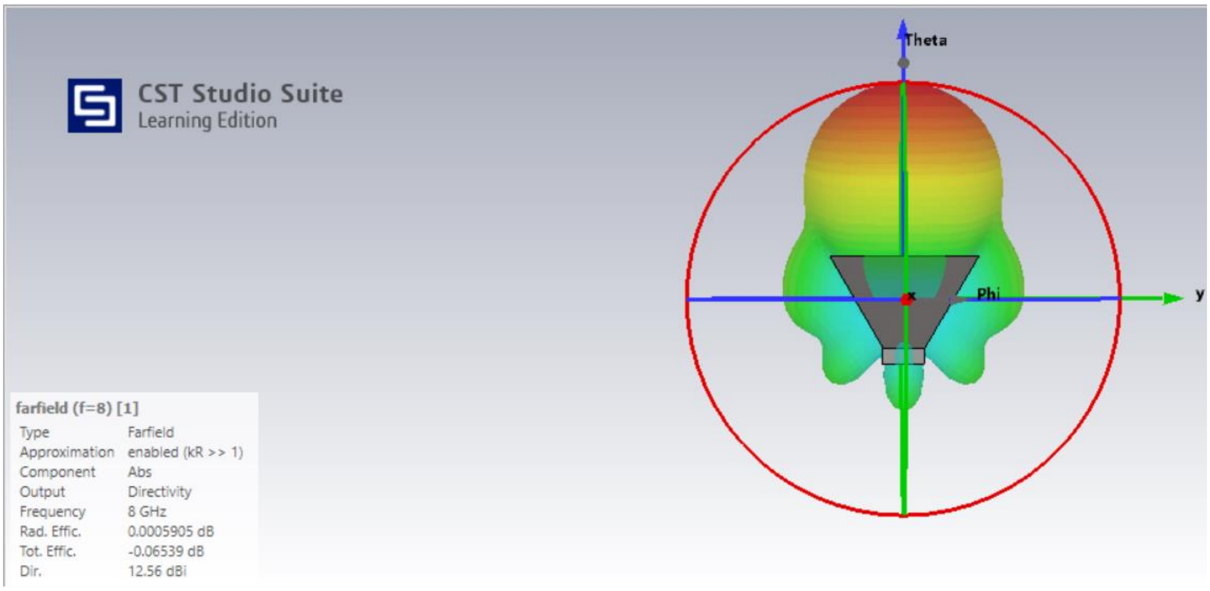
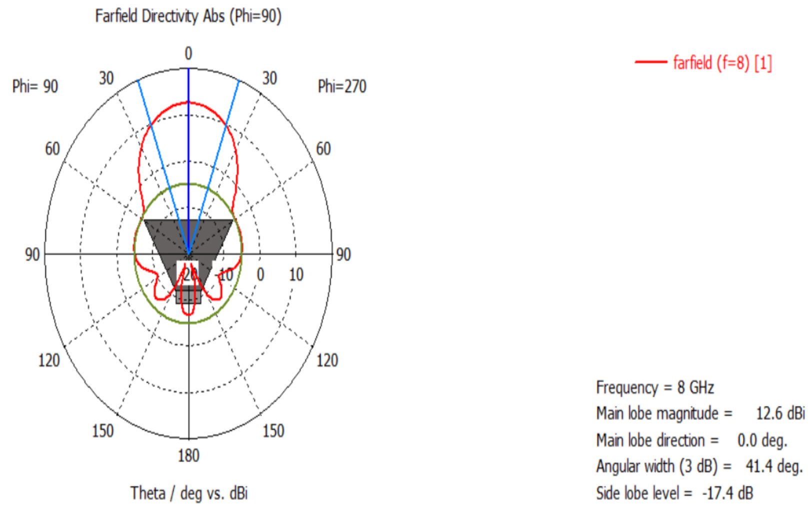


Fig (3.7): Far field 3D radiation pattern of Horn antenna

Far-field plot in 1D for 8GHz



Fig(3.8)) Far field 1D radiation pattern of Horn antenna

A gain and directivity of12.5 and 12.6 dBs means the antenna effectively concentrates energy into a specific direction, enhancing signal strength and reducing interference from otherdirections.

In Conclusion, got familiarized with CST studio suite by designing antennas at different frequencies for a Dipole, 5.8GHz Microstrip patch antenna and Horn antenna. From obtained results studied how radiation pattern for these antennas forming and how to design and changing values to reach desired outcome.

References:

1. https://www.electronicsforu.com/technology-trends/microstrip-antenna-applications
2. The Horn Antenna - Radiation Pattern (antenna-theory.com)
3. Horn Antenna : Working, Types, Radiation Pattern & Its Applications (elprocus.com)