WR 19 WAVEGUIDE FOR MILLIMETER WAVE

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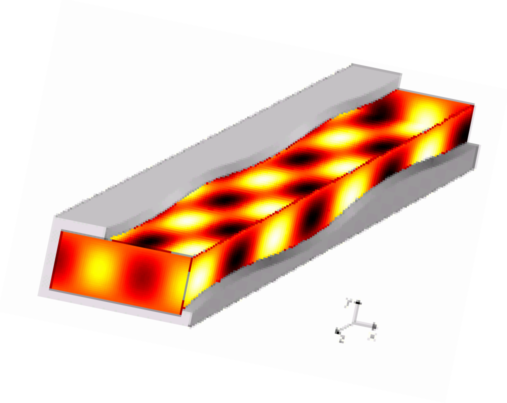
Background

- We tend to think about electromagnetic technology as a new or modern development. The fact is that more than 100 years ago the early pioneers in electromagnetism were experimenting with horn antennas. Sir Oliver Lodge (1851- 1940) demonstrated microwave waveguide transmission lines in 1894. From there we just need to go one step further to get a horn antenna. The man that took the step three years later in 1897 was Sir Jagadish Chandra Bose (1858-1937). Bose’s horn operated in the millimetre wave range and was able to ring bells and ignite powder at a distance during his experiments in Calcutta. His horn and waveguide were circular. These experiments and use of horn antennas makes Bose the father of this type of antenna and of millimetre wave technology. Incidentally, Bose performed some of his experiments in the 60 GHz range which is becoming popular nowadays with the advent of Wireless HD technologies.

Waveguide

Waveguides are a special category of transmission line that are used to guide the EM waves (specifically high freq. waves) along the length of the tube. We can think it as a hollow metallic tube of uniform cross section whose shape and dimension depend upon characteristics of wave (Lower cut-off frequency, wavelength range etc.). The Total Internal Reflection (successive reflections from the inner walls of the tube) phenomena is used in the transmission of wave that's why waves are transmitted through the waveguide with minimal loss of energy.



Why we are focusing on a specific range of frequency i.e., 40-60 GHz?

All the electronic devices that we used and which uses EM waves for functioning e.g., Mobiles, Television, radios etc. works in very specific range of frequency under radio wave frequency spectrum typically under 6 GHz but due to increase in no. of appliances this frequency range is getting crowded so we need to move to a frequency range which is not much crowded that's why we are focusing on freq. range 40-60 GHz.

But there is a problem in transmission of these high frequency radio waves let us understand it.

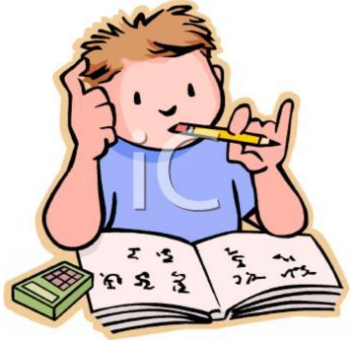
Wavelength of EM wave = (c / Frequency of EM wave) c = Speed of light;

As we increase the range of frequency of the EM wave the wave length gets decreased which result into decrement in the transmission range other than this free space loss are also very high in millimeter waves.

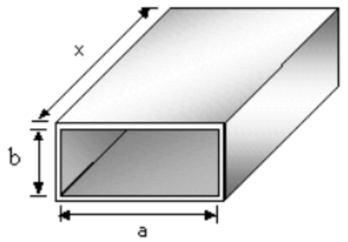
To counter this we need a medium through which our millimeter wave can transmit without any major losses and we call this medium as Waveguide.

Waveguides have various types classified on the basis of their shapes e.g., Rectangular, circular, elliptical etc. but we are focusing only on Rectangular waveguide (more specifically on Rectangular waveguide that transmit waves of frequency range 40-60 GHz)

Cut off Frequency



The lower cutoff frequency (or wavelength) for a particular mode in rectangular waveguide is determined by the following equations (note that the length, x, has no bearing on the cutoff frequency):



$$(f_c)_{mn} = \frac{1}{2\cdot\pi\cdot\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m\cdot\pi}{a}\right)^2+\left(\frac{n\cdot\pi}{b}\right)^2} \quad [Hz]$$

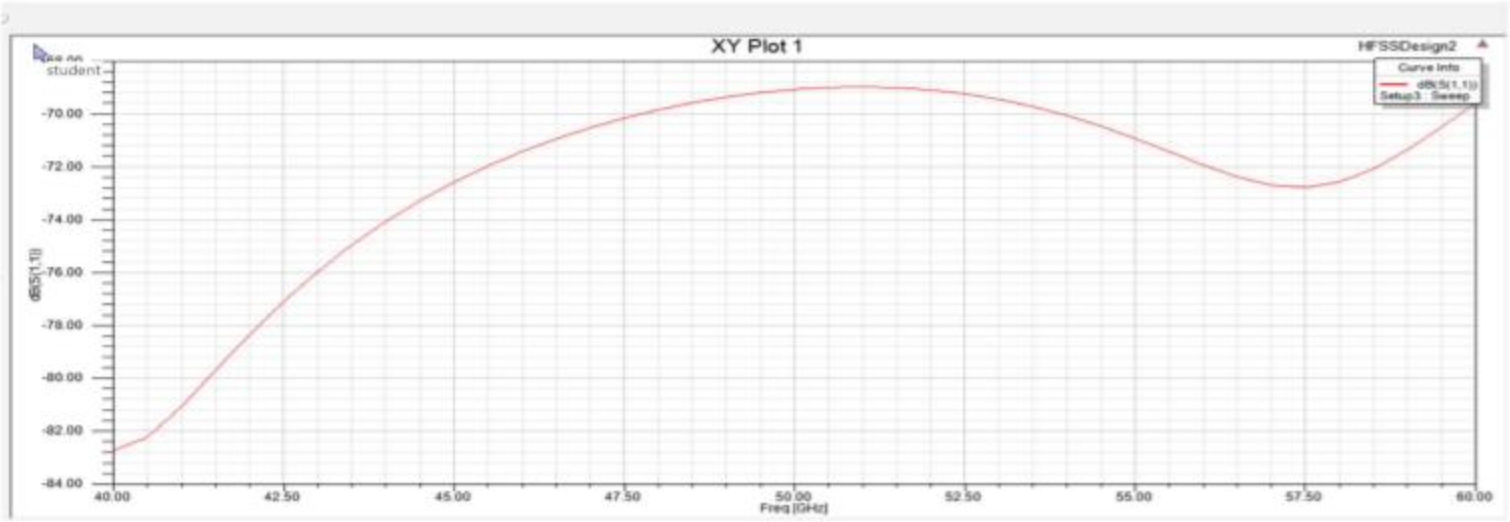
$$(\lambda_c)_{mn} = \frac{2}{\sqrt{\left(\frac{m}{a}\right)^2+\left(\frac{n}{b}\right)^2}} \quad [m]$$

a = Inside width(mm), longest dimension
b = Inside height(mm), shortest dimension
m = Number of ½ wavelength field variation in "a" direction
n = Number of ½ wavelength field variation in "b" direction

For our waveguide i.e. WR - 19 recommended frequency 40-60 GHz a = 4.775mm, b = 2.387mm, and if we use fundamental TE_{10} mode the lower cut off frequency comes out to be 31.391 GHz.

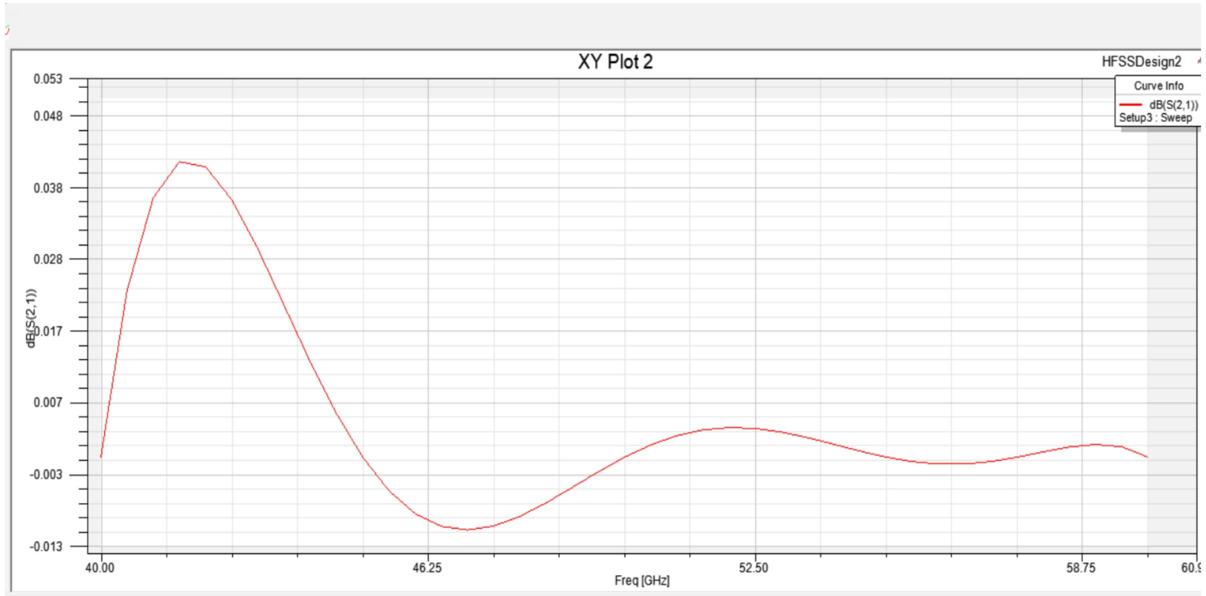
Plot of S_{11} vs Frequency

S_{11} is the input port voltage reflection coefficient. It is equal to the ratio of a reflected wave and an incident wave. This is the origin of the rule of the thumb, that the maximum acceptable value of S_{11} for an interconnect structure is about -13dB. In short, it should be very less. In our waveguide it is in between -83dB to -71dB which means we won't see impact of these reflections on transmitted signal in our frequency between 40GHz to 60 GHz



Plot of S_{21} vs Frequency

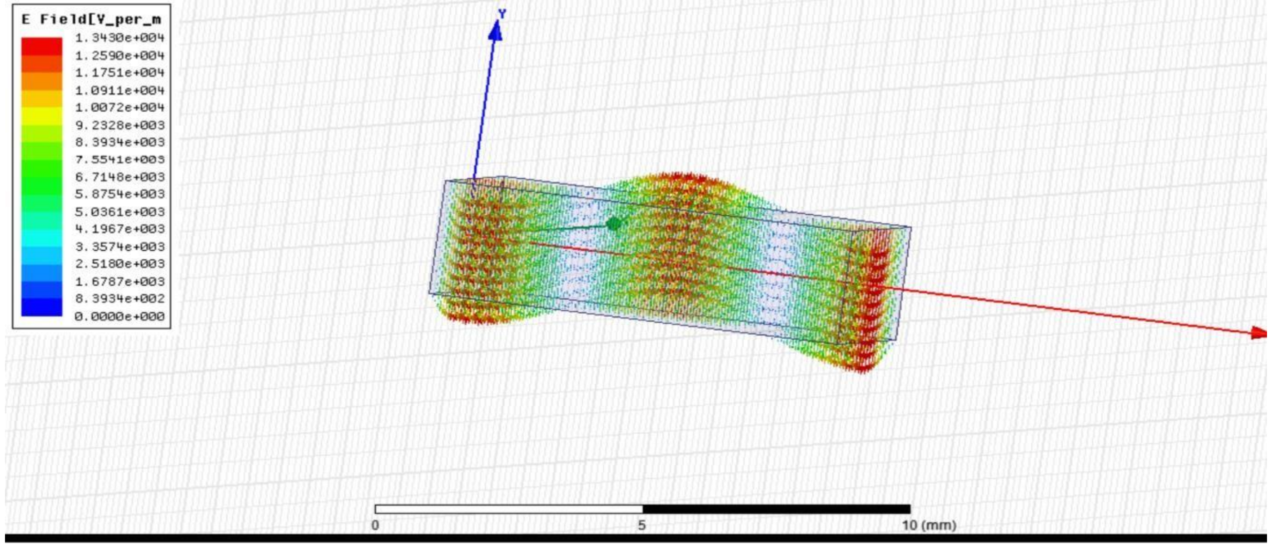
S_{21} is a measure if the signal coming out port-2 relative to the RF stimulus entering port-1. It represents the power transferred from port-1 to port-2. Ideally, it should be zero. For our waveguide, we see its maxima is 0.042 which is still close to 0 as we are operating at a very high frequency of 40 GHz-60 GHz.



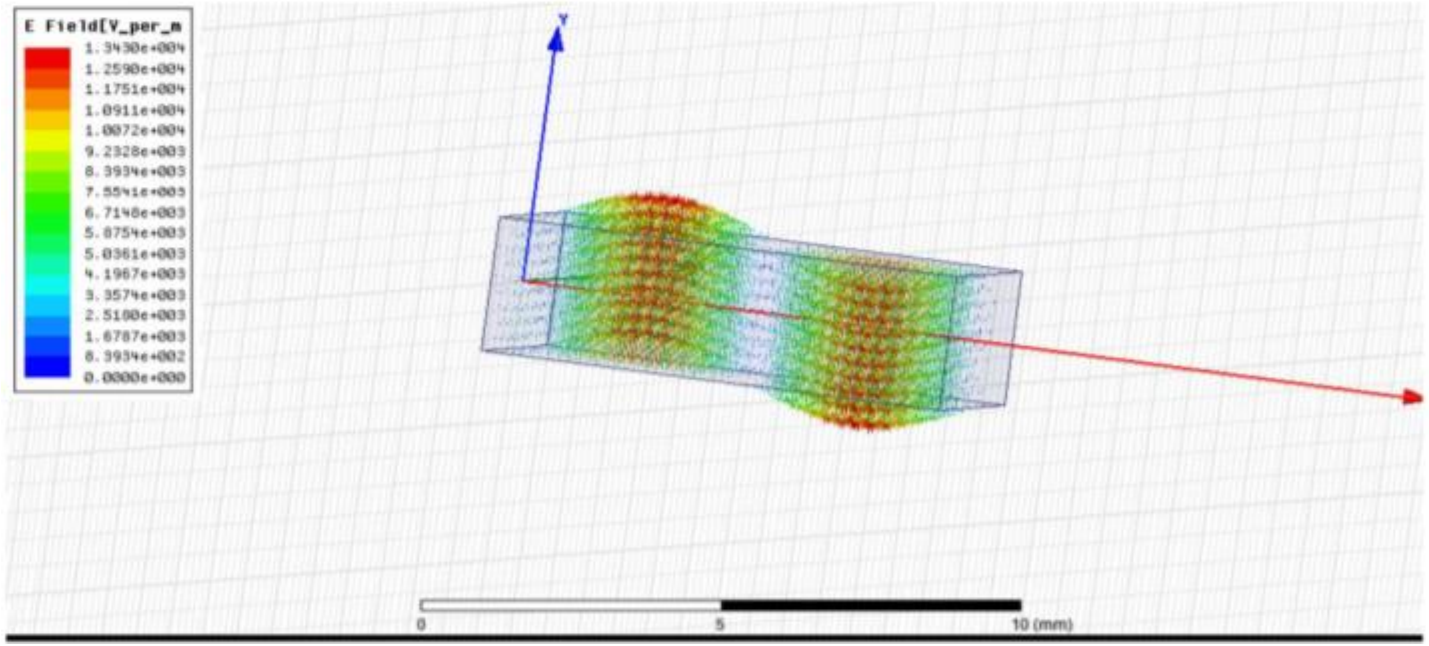
Simulation snapshots

Below are the simulation snapshots of the waveguide at the different points of time showing its propagation

At t = 0 s

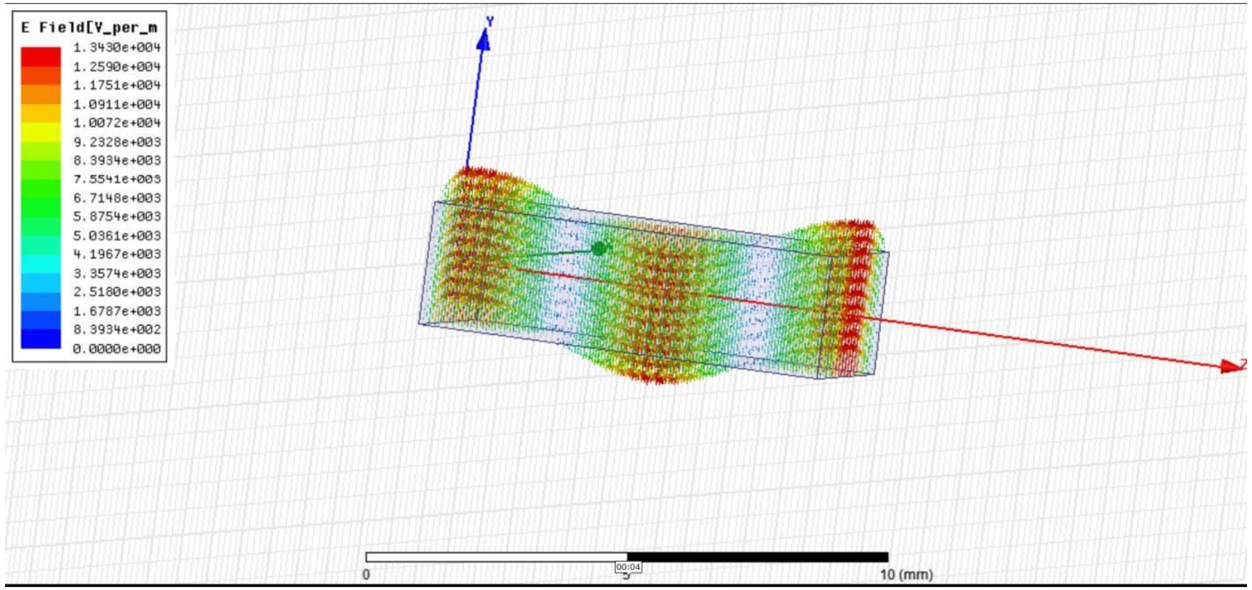


At t = 2s



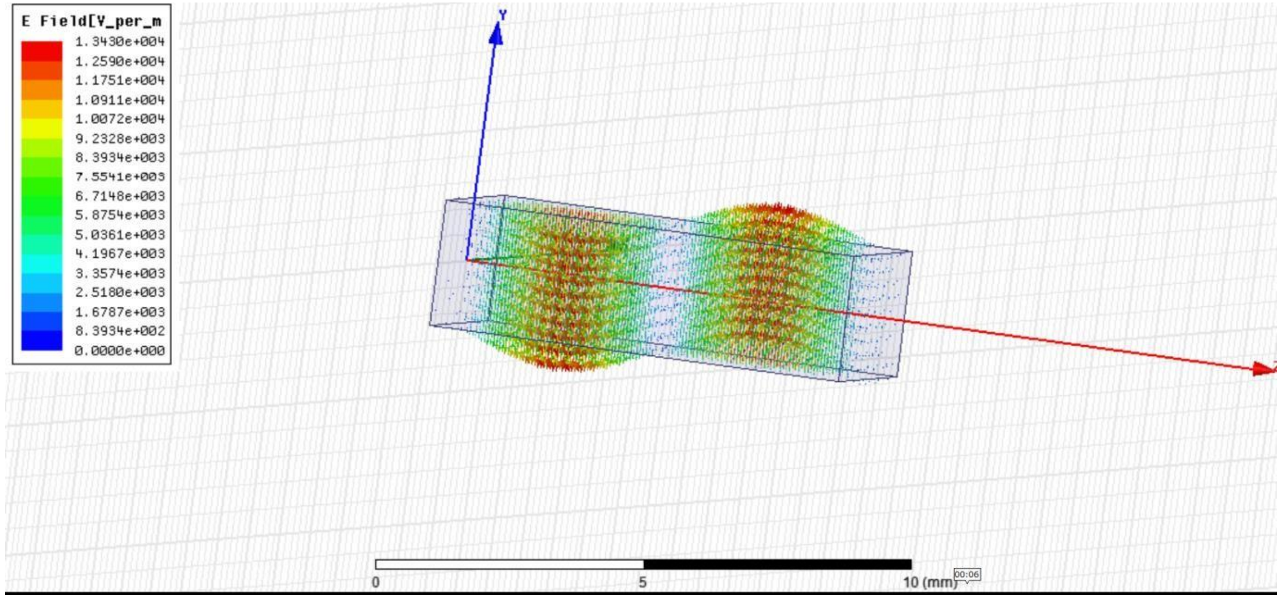
E Field[V_per_m
1.3430e+004
1.2590e+004
1.1751e+004
1.0911e+004
1.0072e+004
9.2328e+003
8.3934e+003
7.5541e+003
6.7148e+003
5.8754e+003
5.0361e+003
4.1967e+003
3.3574e+003
2.5180e+003
1.6787e+003
8.3934e+002
0.0000e+000
Y
0
5
10 (mm)

At t = 4s



E Field[V_per_m
1.3430e+004
1.2590e+004
1.1751e+004
1.0911e+004
1.0072e+004
9.2328e+003
8.3934e+003
7.5541e+003
6.7148e+003
5.8754e+003
5.0361e+003
4.1967e+003
3.3574e+003
2.5180e+003
1.6787e+003
8.3934e+002
0.0000e+000
Y
Z
0
5
10 (mm)
00:04

At t = 6s


E Field[V_per_m
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1.0072e+004
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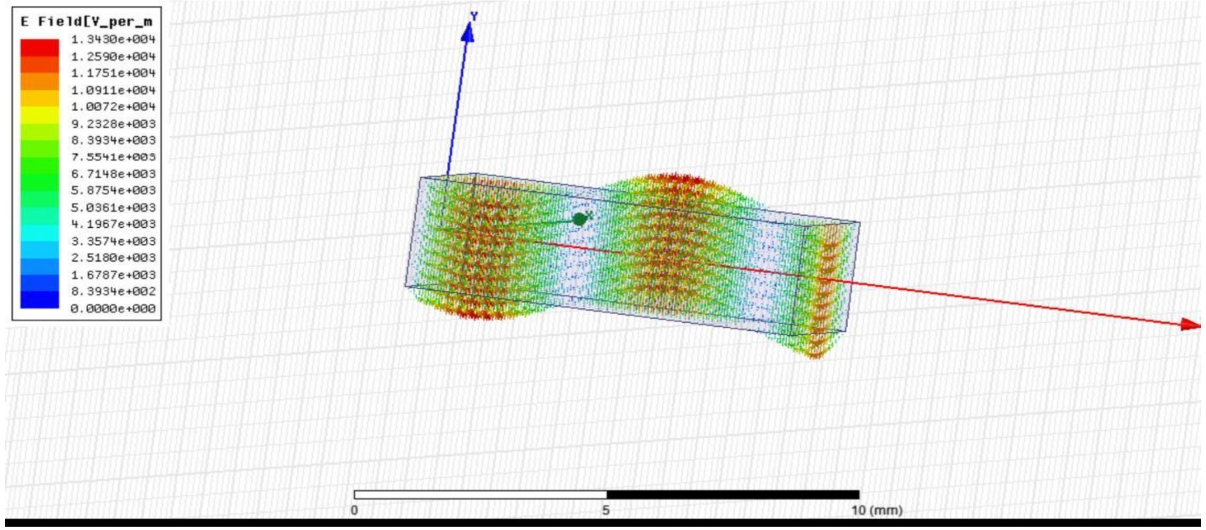
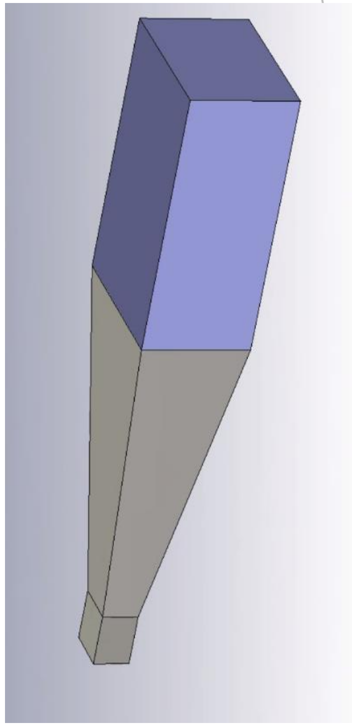
8.3934e+003
7.5541e+003
6.7148e+003
5.8754e+003
5.0361e+003
4.1967e+003
3.3574e+003
2.5180e+003
1.6787e+003
8.3934e+002
0.0000e+000
Y
0
5
10 (mm)

At t= 8s


E Field[V_per_m
1.3430e+004
1.2590e+004
1.1751e+004
1.0911e+004
1.0072e+004
9.2328e+003
8.3934e+003
7.5541e+003
6.7148e+003
5.8754e+003
5.0361e+003
4.1967e+003
3.3574e+003
2.5180e+003
1.6787e+003
8.3934e+002
0.0000e+000
Y
0
5
10 (mm)

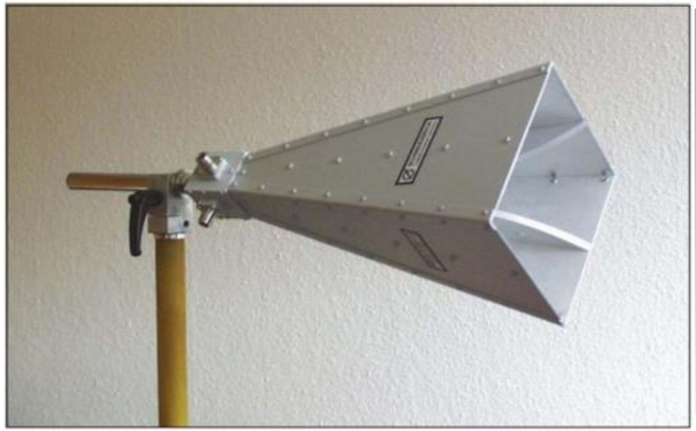
STANDARD GAIN HORN ANNTENA

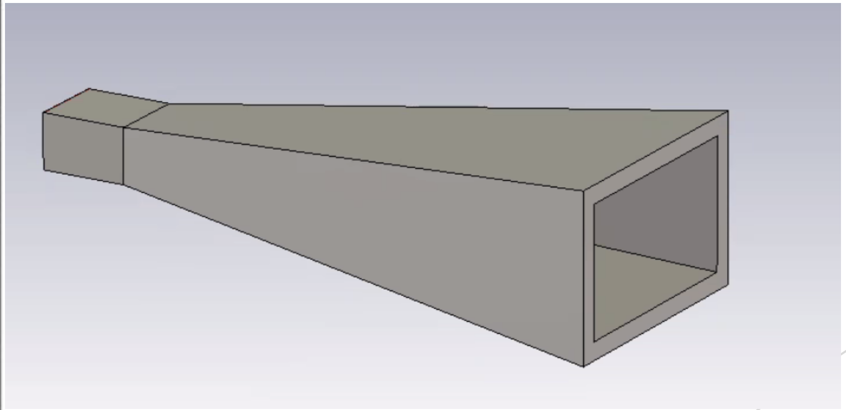
The horn antenna is essentially a section of waveguide where the open end is flared to provide a transition to the areas of free space. The horn antenna is a simple development of the waveguide transmission line. Using some simple theory, it is quite possible to see how the horn antenna works.

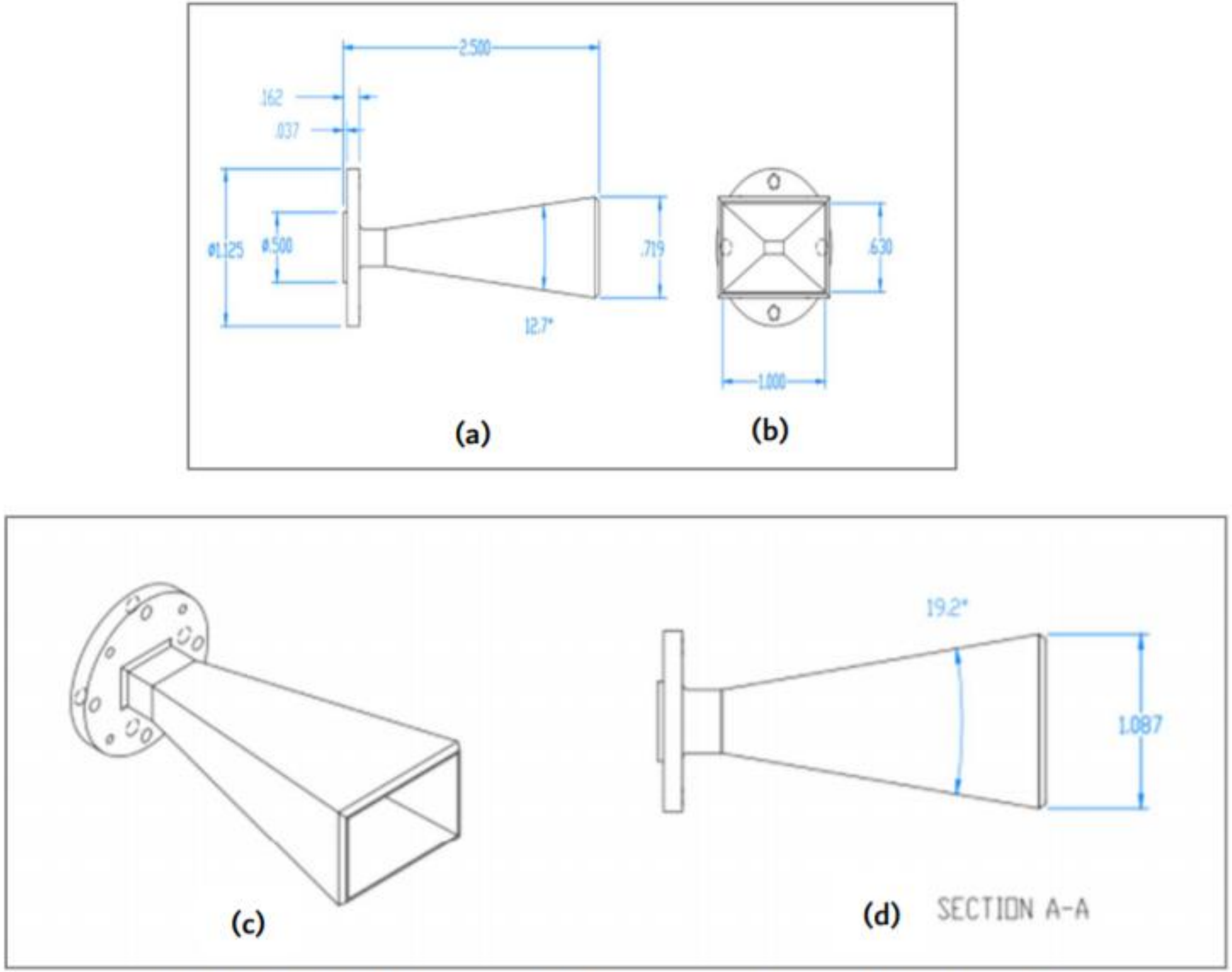


CONSTRUCTION & WORKING OF HORN ANTENNA

The energy of the beam when slowly transform into radiation, the losses are reduced and the focusing of the beam improves. A Horn antenna may be considered as a flared-out wave guide, by which the directivity is improved and the diffraction is reduced.







(a) side view1, (b) Front view, (c) perspective view and (d) side view2

Horn antenna theory for radiation

In order to understand how a horn antenna radiates, some simple explanations and theory can be used. The waves of the signal will propagate down the horn antenna towards the aperture. As they travel along the flared opening, the waves travel as spherical wave fronts, having their apex at the apex of the horn - a point referred to as the phase centre of the horn antenna. As the phase front progressing along the horn antenna are spherical, the phase increases smoothly from the edges of the aperture plane to the center. The difference in phase between the centre point and the edges is called the phase error. This increases with the flare angle reducing the gain, but increasing the beam width. As a result, horn antennas have wider beam widths when compared to similar-sized plane-wave antennas like parabolic reflectors. The theory also shows that as the size of a horn antenna increases in terms of its electrical size, i.e., the number of wavelengths for the various dimensions, so the phase error increases. This has the effect of giving the horn antenna a wider beam width. In order to provide a narrow beam width a longer horn is required, i.e., having a smaller angle of flare. This enables the phase angle to be kept more constant. However, the phase error issues mean that horn sizes are practically limited to around 15 wavelengths otherwise larger sizes would require a much longer antenna.

Formulas for horn antenna apertures

$$Aperture_E = \sqrt{2\,\lambda\,L_E}$$

$$Aperture_H = \sqrt{3\,\lambda\,L_H}$$

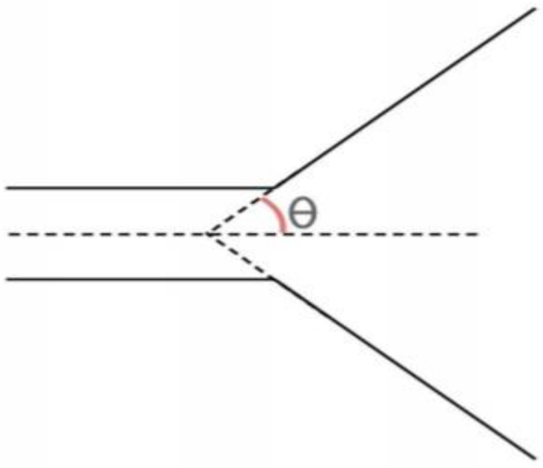
ApertureE is the width of the aperture in the E-field direction.
ApertureH is the width of the aperture in the H-field direction.
LE is the slant length of the side in the E-field direction.
LH is the slant length of the side in the H-field direction.

Mechanical Specifications:

Size	Value(inches/mm)
Width	1.00/25.4
Height	0.63/16
Length	2.50/63.5

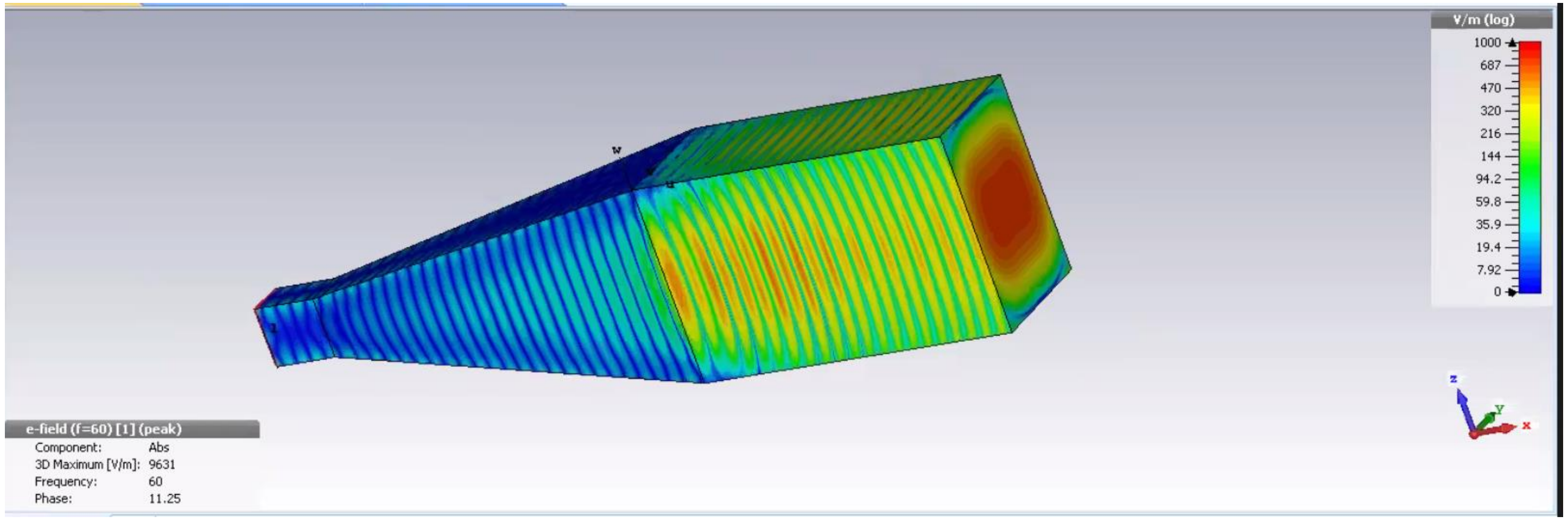
Horn antenna angle of flare

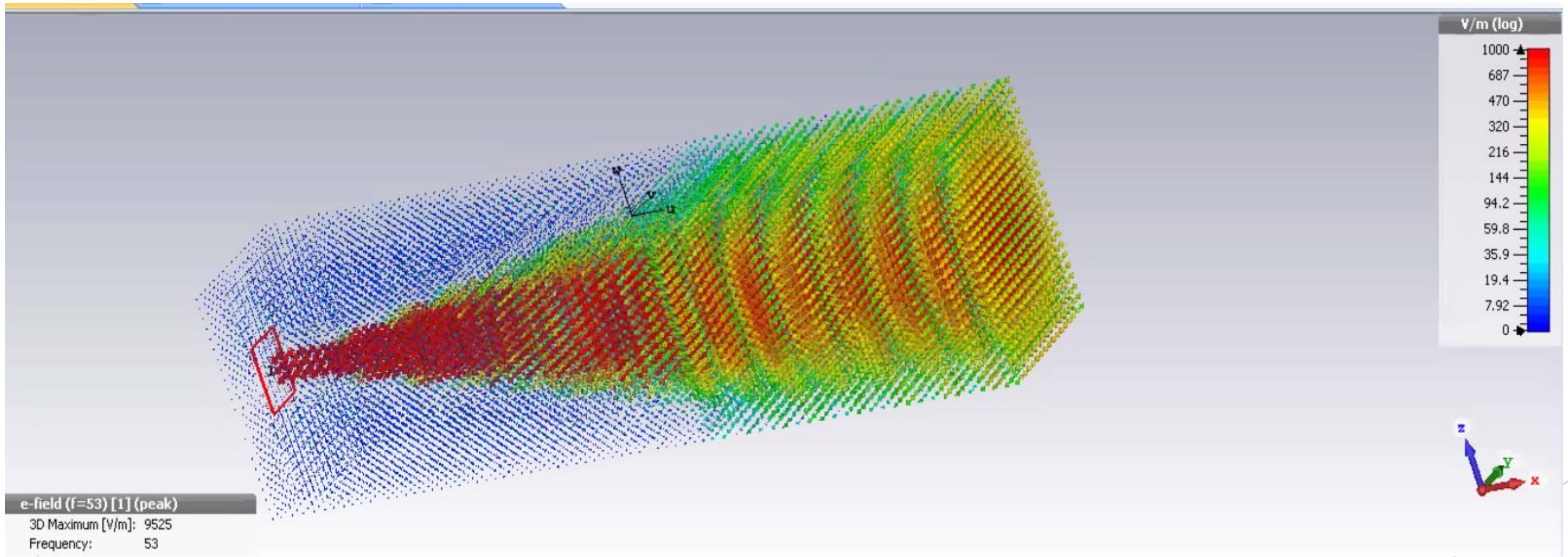
One of the key properties of the horn antenna is the angle at which the horn flares out. This affects many areas of the performance including the gain and directivity as described below. The angle of flare is defined in the diagram below and there can be a different angle for both the E-plane (E field) and the H-plane (H field). These are referred to as θE and θH.



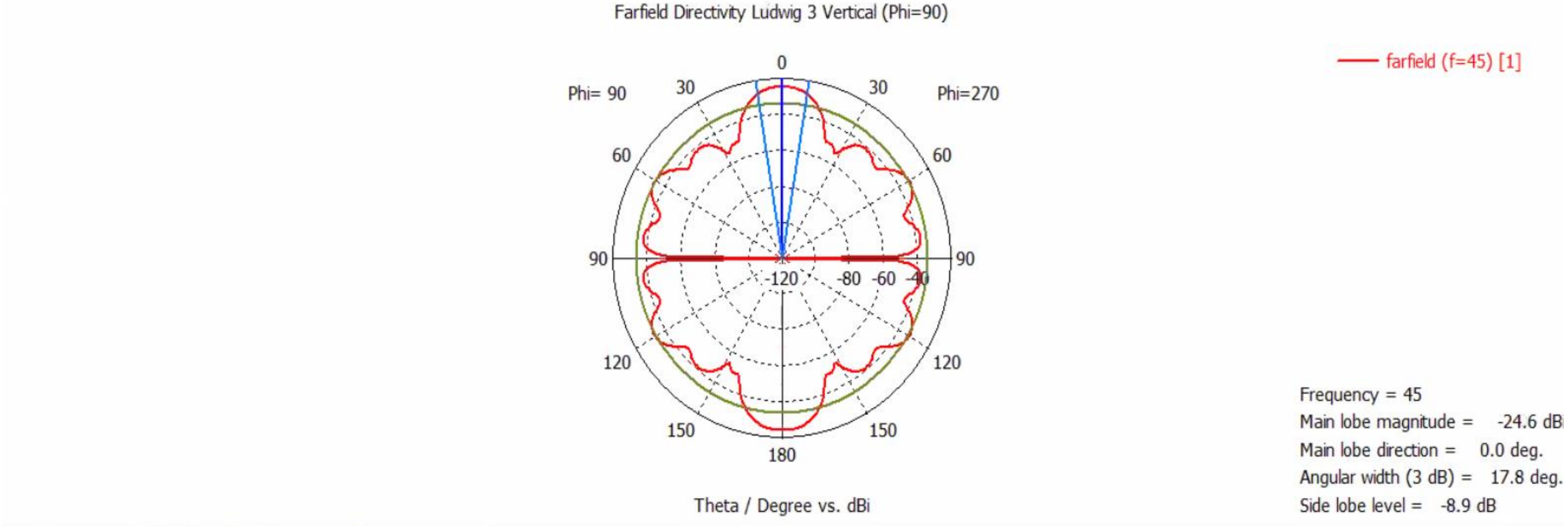
Flare angle of a horn antenna

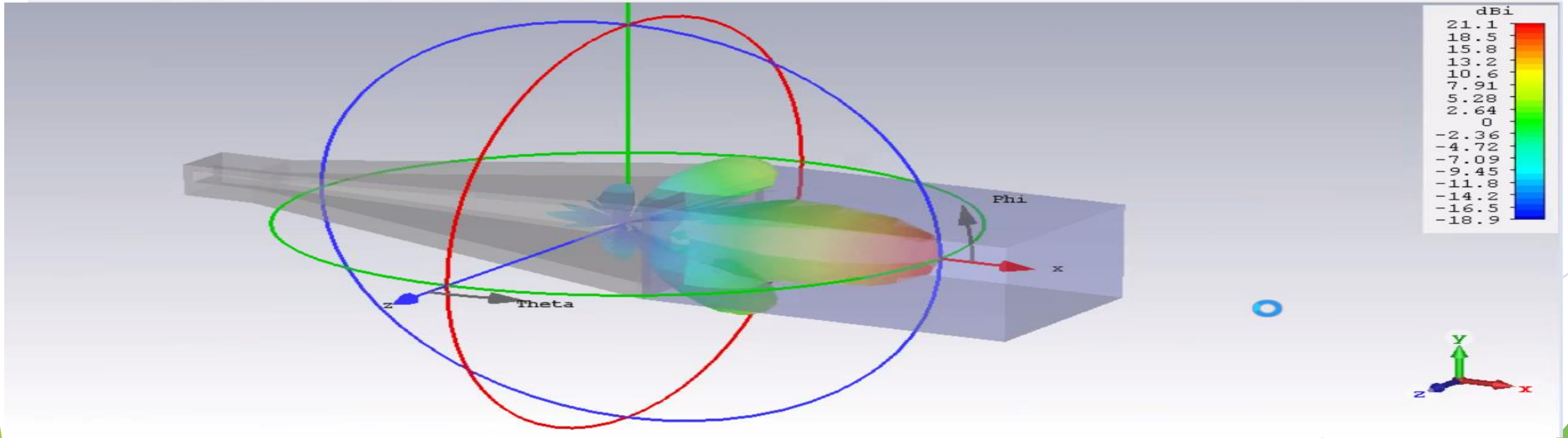
E-Field pattern in WR-19 Horn Antenna



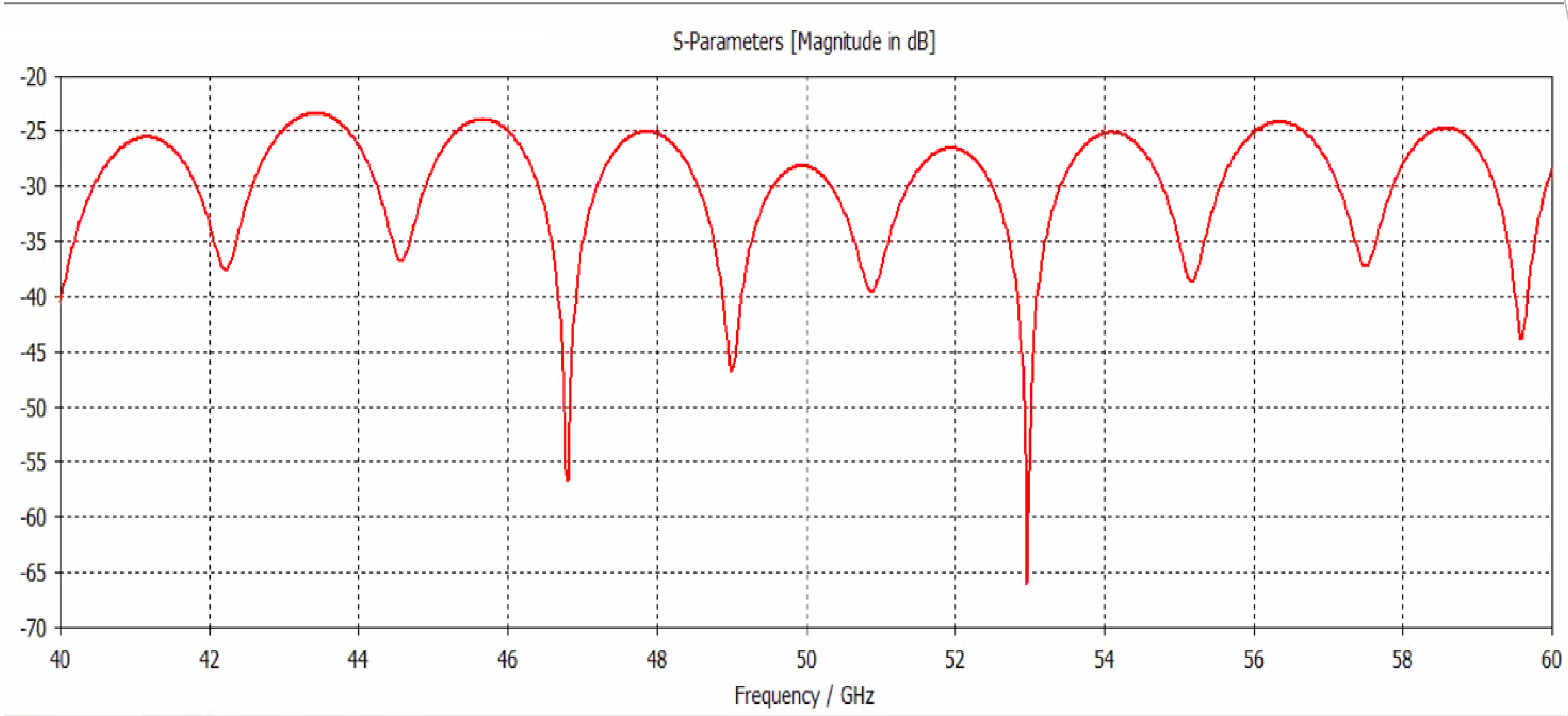


Far field and Radiation pattern in WR-19 Horn Antenna

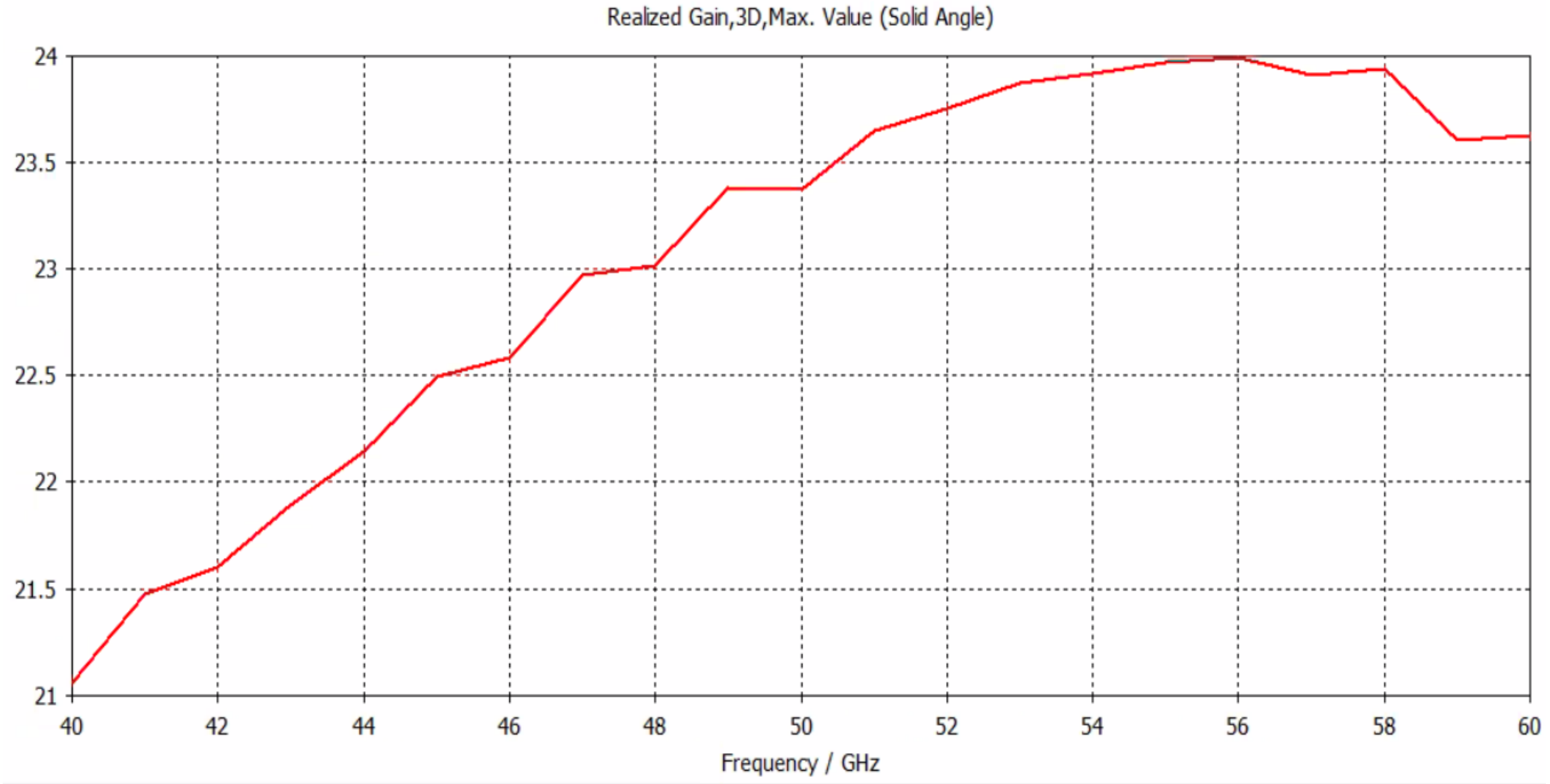




S-parameter (S11) graph [Power(dB) vs frequency graph]



Gain Graph for WR-19 horn antenna



What we learned from the project

- Firstly we learned what is waveguide and its application in real world. Then we figure out about WR-19, studied it theoretically first and then about its application.
- After learning about WR-19 we moved on to the simulating part on the software HFSS Ansys and learned how to do simulating on it.
- On HFSS we used the recommended frequency and inner dimensions used for WR-19 for simulating the waveguide.
- After simulating it successfully we got the different points of time showing the propagation of the wave. And we also plot the S_{11} and S_{21} vs the Frequency plots.
- We understood the reason of using high frequency range as it is getting crowded due to various frequencies.
- We got to know why we use waveguide instead of optical fibre as to minimize loss.
- We also made horn antenna for this frequency range ,simulated it in CST Microwave Studio and plotted various graphs
- On completing the above mentioned steps, we successfully learned what a waveguide is, what is WR-19 and how to simulate it on HFSS and CST.

Points to Ponder

- While working on this mini project , we got insights on the contribution of our eminent scientist Dr. J.C. Bose in the field of 5G Technology .His efforts must be truly appreciated and it's a proud moment for us. Our national hero must not be forgotten.
- Reference Links:
- https://economictimes.indiatimes.com/people/indias-jagadishchandra-bose-is-the-reason-why-the-world-will-enjoy-super-fast-5ginternet/the-indian-behind-5g-internet/slideshow/57736482.cms
- https://theprint.in/features/j-c-bose-father-of-radio-science-who-wasforgotten-by-west-due-to-his-aversion-to-patents/552556/