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Project Title:

8-Element MIMO Dual-band Antenna System for 5G applications in Mobile Devices.

ABSTRACT:
The 8 Dual-band MIMO(Multiple Input- Multiple Output) systems can cover in the ranges from (3Ghz to 5.0Ghz) due to this transmission of N77, N78 and N79 5G high transmission can be possible. In this Antenna, there are two resonant modes such as TM01 and TM10 which have values of 0.75λ and 1.0λ. We have figured out that the resonant frequencies between 0.5 λ and 1.0 λ can be excited and result in another new resonant frequency which is 0.75 λ which accelerates the 5G dual-band transmission in mobile phones. We can achieve a dual-band antenna using the coupling techniques for loop antennas with these modes. The dual-band MIMO system can achieve impeccable results in mobile phones which has led to the genesis of certain 5G transmission. The characteristics we calculated are antenna isolation, envelope correlation coefficient (ECC) and Chanel Capacity (CC). We have designed a MIMO model on Ansys HFSS Software with 8 antennas on two clearance areas of the substrate, which has 50-ohm microstrip lines as the feed which is parallel to the plane and the SMA Coaxial Cable Connector is perpendicular to the ground of the antenna connecting to the feed line and to the ground, due to this we can observe maximum radiation transmission in two resonance modes such as 0.75λ and 1λ which gives us a dual-band transmission for mobile phones and no Efficiency Degradation when the system is held by hand.

Keywords: Resonant Frequencies- 0.75λ and 1.0λ, Coupled loop antenna, Coaxial SMA, Dual Band transmission.

1. INTRODUCTION:

The Fifth Generation (5G) transmission has many perks compared to its older generations; it provides a peak speed of 20GHps which is immensely fast when compared to 4G transmission which has 1GHps. Because 5G has more capacity, it can connect more devices, enhancing the quality of Internet service in congested locations. Because of the increased bandwidth and low latency, the networks are expected to be increasingly used as general internet service providers (ISPs) for laptops and desktop computers, competing with existing ISPs like cable internet, and enabling new applications, in the internet-of-things (IoT) and machine-to-machine areas.

For mobile devices, the ideal antenna for dual-band transmission is an 8 MIMO(multiple-input and multiple-output) system which initially as proposed only work for single band and dual-band operations but due to the birth of the 5G New Radio, there are three bands for wideband applications which are N77(3.3-4.2GHz), N78(3.3-3.8 GHz)and N79(4.4-5.0GHz). But designing the dual-band MIMO system is a crucial task as you may encounter issues like the 1) deployment of a large number of multi-antennas within a small footprint area in a mobile handset, 2) ensuring minimal electromagnetic interference (mutual coupling) between the antenna elements in such a compact design. But these can be rectified with trial and error methods while designing the antenna.

In this antenna, we are using 8 coupled loop antennas which are of 2 types: top coupled and two-side coupled antennas. Mobile phone networks work using signals on specific frequency bands and a phone must support those bands in order to work with the network. Dual-band refers to the phone's ability to work with two different bands. It is important to specify which bands exactly the Networks in different geographical locations work on different bands - GSM networks in the Americas use the 850 MHz and 1900 MHz bands while networks in Europe, Brazil, Asia and Africa use the 900/1800 MHz bands.

Generally, in loop antennas, the resonant modes used are 0.5, 1.0 and 1.5 in which dual-band cannot be normally obtained as these resonant frequencies are far away from each other. Therefore the resonant frequency 1.5 is shifted to the 1.0 resonant frequency to adopt dual-band transmission. The 2.0 mode of the folded loop antenna, with a resonance frequency near to that of the 1.5 modes, can be attained by adding one tuning section at the core and two additional tuning sections at the feeder branch. As a result, a broader bandwidth covering the high band (1710-2170MHz) is possible to achieve. Therefore, the loop antenna supports three resonance modes: 1.0, 1.5, and 2.0, while a matching network was used to cover the low band.

These two modes of the proposed coupled-loop antenna are 3.50GHz and 4.50GHz. One can know that the first resonance (3.50GHz) mode of the coupled-loop antenna works as its 0.75λ mode. One can conclude that the proposed coupled-loop antenna can support its 0.75λ and 1.0λ modes, whereas the other loop antennas support its 0.5λ, 1.0λ and 1.5λ modes.
Most importantly, the two resonance modes, i.e., the 0.75λ and 1.0λ modes, can widen the bandwidth of the coupled-loop antenna. This wider bandwidth works very well in the frequency range of 3.3-5.0GHz, which can cover all the 5G N77, N78 and N79 bands.

For these two resonant modes of 8 wideband MIMO system, we have implemented a coaxial cable which is comprised of a coaxial Outer shell and an Inner coaxial cable (perfect electric conductor material). A basic coaxial cable consists of a wire centre conductor and a braided or solid metallic "shield" aluminum or, usually copper or aluminum surrounding it. A coaxial cable has been a great tool to deliver high-frequency signals for distances without much loss. It also has the enclosing shield conductor which isolates the cable from external electromagnetic fields, so it is very immune to interference.

Therefore For maximum 5G transmission and no efficiency degradation, we have introduced this coaxial cable and have seen great results which will be discussed and deduced further in this paper.

2. COUPLED LOOP ANTENNAS:

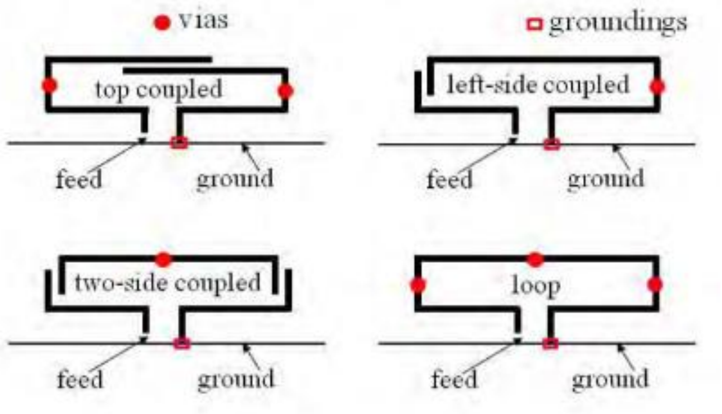


Figure 2.0) Different coupled loop antennas

In this MIMO system, we are using loop antennas where the loop antenna is made of single or multiple turns with circular or rectangular shapes.

Benefits of Coupled Loop antennas:

- It is light in weight.
- It is simple and compact in structure.
- It is economical.
- It is suitable for portable applications such as direction finding etc.
- It is available in large varieties viz. Adcock antenna, Alford loop, cloverleaf antenna, Bellini-Tosi antenna etc.

There are 4 different coupled loop antennas: top coupled, left-side coupled, two-side coupled, and loop coupled antennas, which can be implemented and introduced in antennas for optimum transmission. In general, a coupled loop antenna had two inner and two outer branches which are connected and overlap each other at certain lengths.

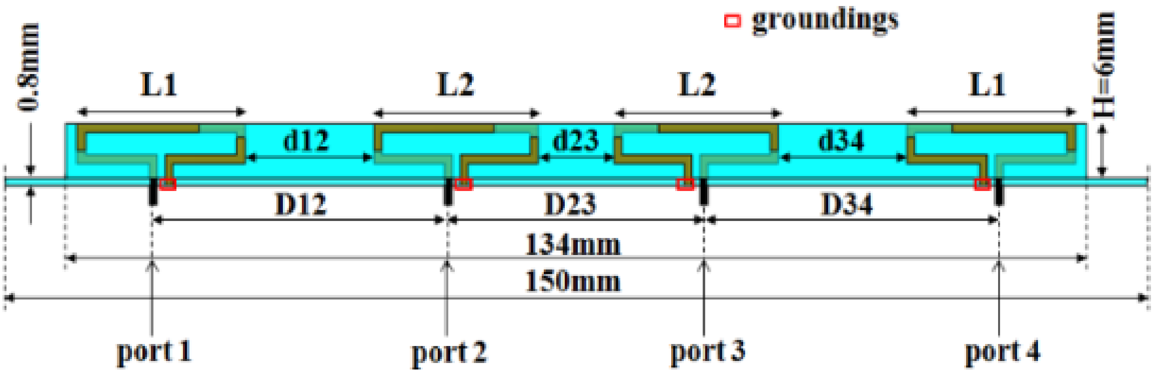
In our model, we will be using four top looped antennas and four side coupled loop antennas on each clearance area of the substrate wherein we will implement 2 of each on each side.

2.1. PROPOSED 8 ANTENNA DUAL-BAND MIMO SYSTEM DIMENSIONS:

2.1.1 DIMENSIONS OF THE PROPOSED DUAL-BAND MIMO SYSTEM:

The dual-band 8 MIMO system can cover (3.3GHz to 5.0GHz) and has 8 antennas which are arranged along the edges of the mobile terminal. The dimension of the entire system substrate is 150mm×75mm× 0.8mm. The two clearance areas are (75mm×8mm). There are two small substrates which are on each side of the main substrate, these two small substrate’s dimensions are 134mm×6mm×0.8mm and have 4 antennas connected on each side. The 4 antennas are of two different coupled loop antennas which help for wideband transmission. The antenna strip height and width are 6mm and 1mm. The placement of the four antennas are is quite intricate where each antenna length is either 22mm or 21.5mm, the distance between the antennas Ant1 to Ant2, Ant2 to Ant3 and Ant 3 to Ant 4 are d12, d23 and d34. The Distance between the feed lines of each antenna is D12, D23 and D34.

As seen at the outcome of the MIMO system, it has been proposed that if the length of the first antenna is kept at 22mm we have seen a massive increase in the antenna’s total efficiency as the frequency 3.3GHz increases from 36% to 65% when L varies from 21mm to 22mm.



(b)

An antenna prototype of the proposed wideband 8-antenna MIMO system with L1 = 22mm, L2 = 21.5mm, and d23= 10mm was fabricated and measured. These values led to the ideal transmission (3.3 to 5.0 GHz). From these values we have calculated:

Dimensions of the antennas:
D12 = 42.5mm = D34
d12 = 18.5mm = d34 (since d12=d34)
d23= 10mm
D23 = 32.5mm
L1 = 22mm
L1 = 22mm
h = 1.5mm
D (overlap length) = 10mm
Width of the antenna = 1mm
Coaxial probe:
Outer coaxial probe = 0.5mm (radius)
Inner coaxial probe = 0.25mm (radius)
Length = 5mm
Feed:
Feedline width = 1mm
Feedline length = 10.2mm

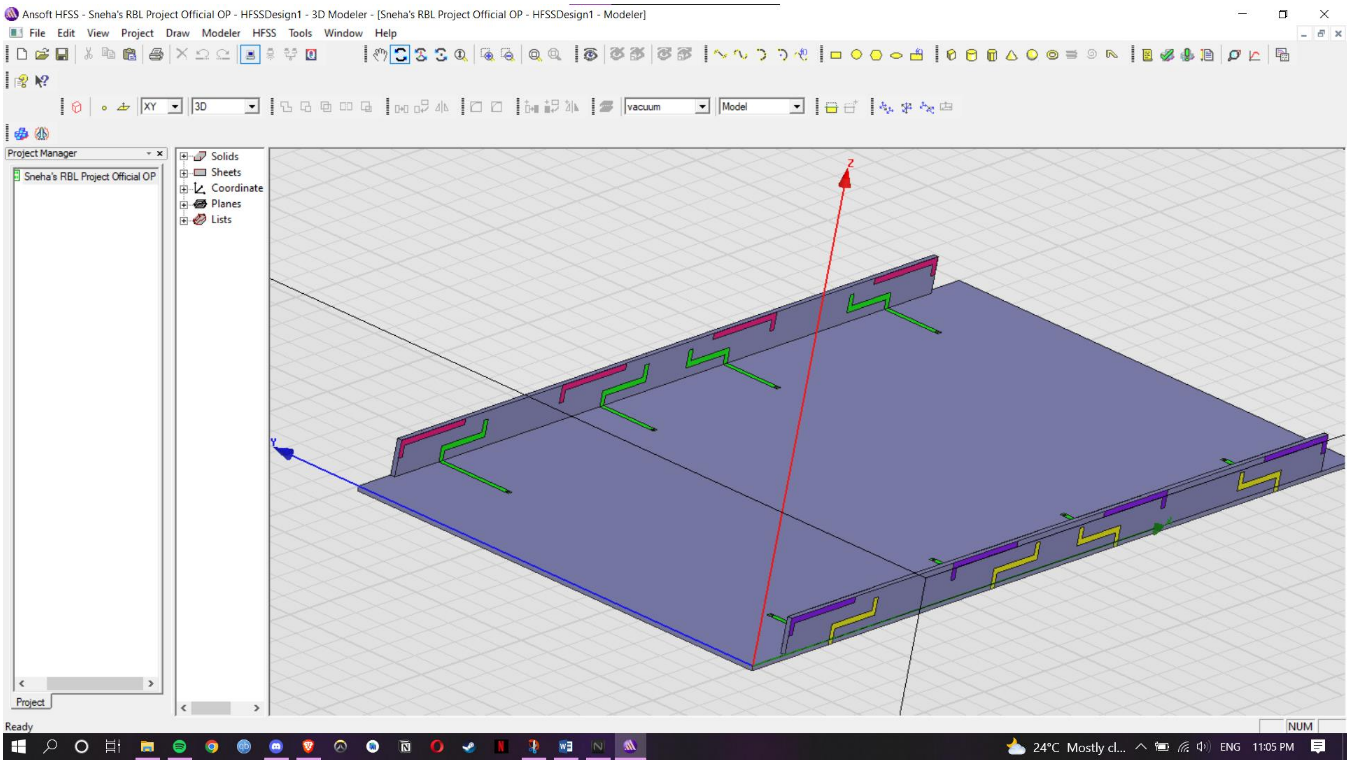


Figure 2) MIMO Model

3. FEEDING TECHNIQUE:

In our antenna, we have used a feed line of width 1mm and a length of 10.2mm which can give us accurate results and more impedance near 50ohms. This impedance at 50ohms can lead to efficient radiation and can be optimal for usage in mobile phones for accurate connections.

The feed line is made of perfect electric conductor material and is linked with the coaxial cable, the dimensions of the feedline were calculated in order to achieve this 50 ohms impedance

This feed line was placed on the upper surface of the substrate and further connected to the inner antenna branch for all the antennas. These branches are then united in order to become a single whole sheet for wideband transmission.

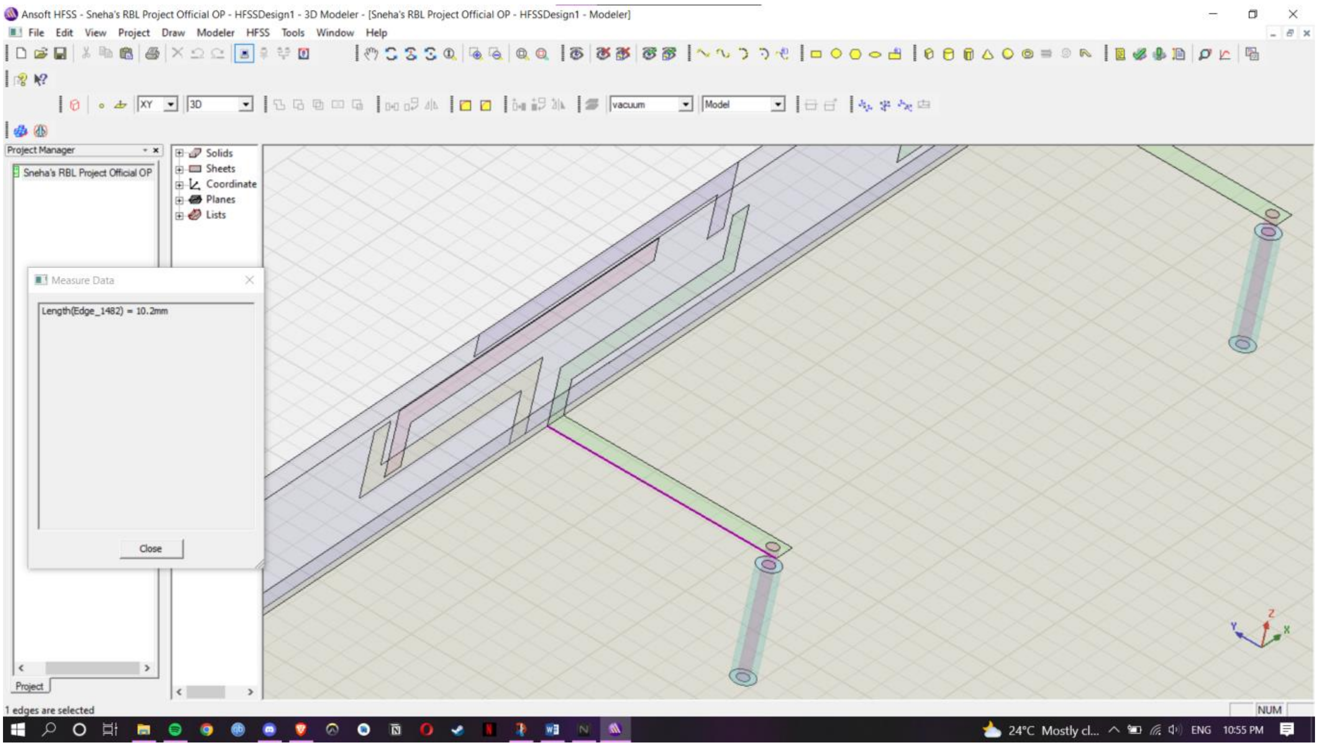


Figure 3.0) Feedline connected with inner antenna branch with 10.2mm length and 1mm width

4. PROBLEM DEFINED:

In particular, the proposed wideband 8-antenna MIMO system shows quite high isolation, low envelope correlation coefficient, and good channel capacity, which are all good enough for practical 5G MIMO antenna application in mobile terminals.

4.1.COAXIAL PROBE FEEDING:

The Coaxial feed or probe feed is a very common technique used for feeding Microstrip patch antennas. The inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane. The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the feedline in order to match with its input impedance.

However, its major drawback is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates. Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems.

It is seen in our model that our substrate is of 0.8mm thickness, so it is easier to drill a hole for the coaxial cable from the substrate, once this is done an outer shell is created for the coaxial cable of a radius of 0.5mm and from the substrate bottom to a certain length (5mm). Further, the inner coax is given a radius of 0.25mm and from the bottom of the substrate to 5mm. and another inner coax is given a radius of 0.25 from the substrate to the feedline.

This gives us a coaxial cable for the feedline which is assigned a Lumped port at the bottom of the coaxial cable, this lumped port enables us to give an input impedance of 50ohms. Each and every antenna’s feed is assigned a coaxial port which leads to efficiency and dual-band transmission and optimum 50ohms impedance.

There are different types of feeding techniques such as:

1. Proximity Coupled Feed:
2. Aperture Coupled Feed
3. **Coaxial Probe Feed**
4. Aperture Coupled Feed

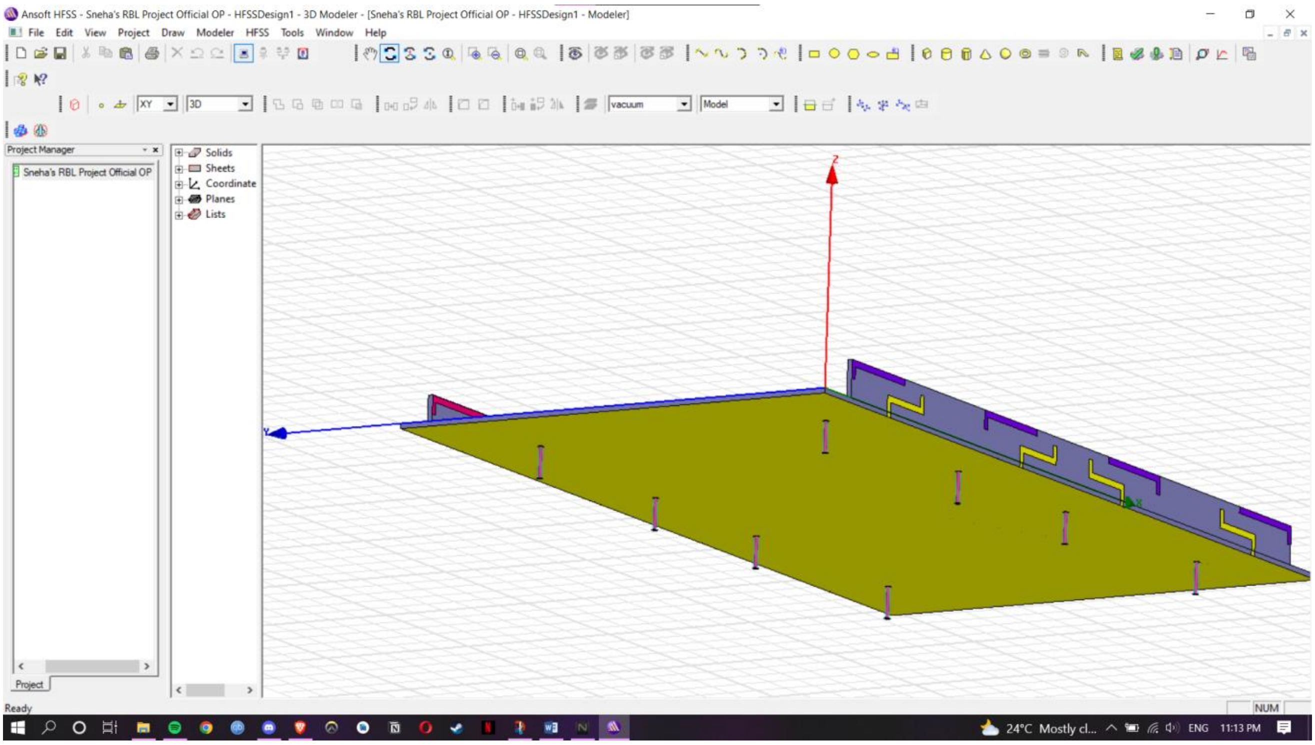


Figure 5.1) Coaxial Cables underneath the substrate.

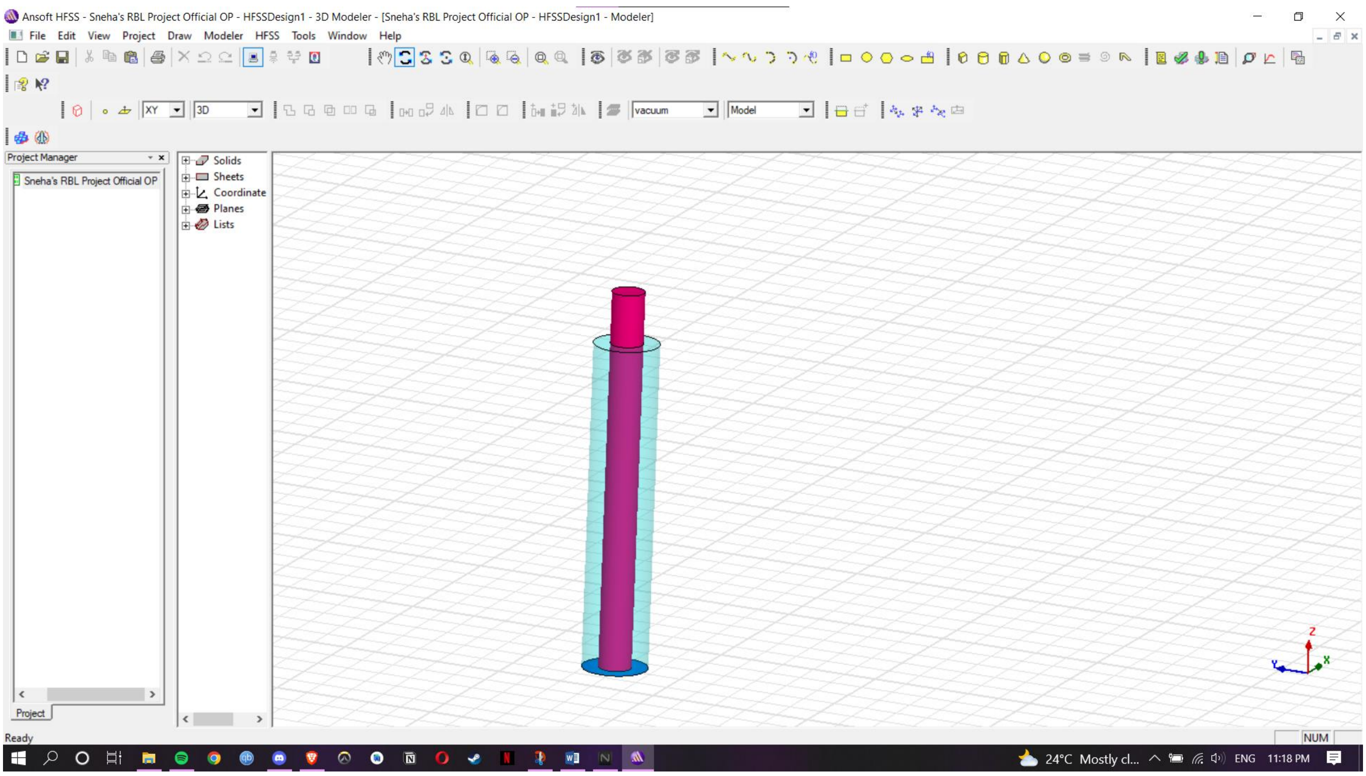


Figure 5.2) Coaxial Cable with outer and inner coax

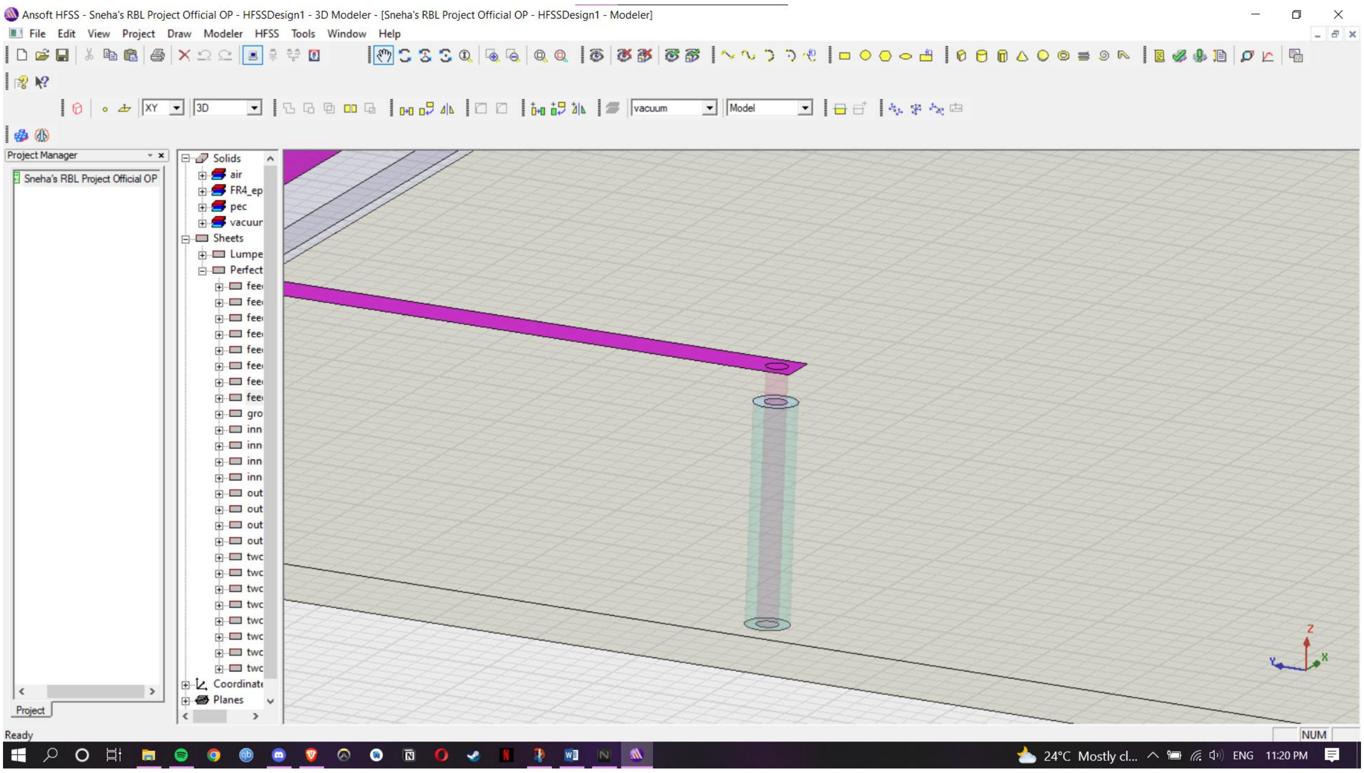


Figure 5.3) Coaxial Cables with feedline

5.2.1 8 ANTENNA DUAL-BAND MIMO SYSTEM USING COAXIAL FEEDS AND DIFFERENT RESONANT FREQUENCIES:

Multiple-Input Multiple-Output (MIMO) is a wireless technology that uses multiple transmitters and receivers to transfer more data at the same time.
MIMO technology uses a natural radio-wave phenomenon called multipath. With multipath, transmitted information bounces off walls, ceilings, and other objects, reaching the receiving antenna multiple times at different angles and slightly different times. In the past, multipath caused interference and slowed down wireless signals. With multipath, MIMO technology uses multiple, smart transmitters and receivers with an added spatial dimension, increasing performance and range.
In the proposed coupled-loop MIMO antenna system, the system consisting of only one single antenna element will be considered first. The detailed dimension and configuration of the single antenna unit or element (Ant1). This antenna unit contains four radiating branches: two inner branches and two outer branches. The inner and outer branches are located on the inner and outer surfaces of the small PCB, respectively.

The antenna is fed at one end of the left inner branch and grounded at one end of the right outer branch. The four branches are symmetrically located (except they are located at the two different surfaces of the small PCB) along the central line of the antenna element. There are three overlapped sections between the four branches: one of them is located at the top centre of the antenna and two of them are located at the left and right sides of the antenna;
These two modes of the proposed coupled-loop antenna are 3.50GHz and 4.50GHz. One can know that the first resonance (3.50GHz) mode of the coupled-loop antenna works as its 0.75λ mode. One can conclude that the proposed coupled-loop antenna can support its 0.75λ and 1.0λ modes, whereas the other loop antennas support its 0.5λ, 1.0λ and 1.5λ modes.
Most importantly, the two resonance modes, i.e., the 0.75λ and 1.0λ modes, can widen the bandwidth of the coupled-loop antenna. This wider bandwidth works very well in the frequency range of 3.3-5.0GHz, which can cover all the 5G N77, N78 and N79 bands.

The antenna comprises of 8 antennas which are placed in the inner and outer regions of the small side substrate. These antennas are to be of accurate dimensions and lengths in order to obtain the dual-band. All the lower inner antenna branches are connected to the feed line which is of the same material and are united, further the lower outer branch is grounded to the ground which is placed below the substrate. This gives us the two resonant modes TM01 and TM10 which is of resonant modes 0.75λ and 1λ. There is a overlap of 1.5mm in the lower and upper antenna overlap and there is a 10mm overlap in the two upper antennas. On one small side there are two top coupled antennas and two two-side antennas. The parameters bring out an efficient transmission of the antennas and gives us a dual-band, which is very useful in mobile devices.

The coaxial cables are added to every coupled loop antenna perpendicularly to the surface, where the feed line is 50 ohms and an excitation which is a wave port is supplied to the coaxial cable bottom edge. The coaxial cables enhance the transmission. First we must drill a hole for the coaxial cable from the substrate, once this is done an outer shell is created for the coaxial cable of a radius of 0.5mm and from the substrate bottom to a certain length (5mm). Further, the inner coax is given a radius of 0.25mm and from the bottom of the substrate to 5mm. and another inner coax is given a radius of 0.25 from the substrate to the feedline. This gives us a coaxial cable for the feedline which is assigned a Lumped port at the bottom of the coaxial cable, this lumped port enables us to give an input impedance of 50ohms. Each and every antenna's feed is assigned a coaxial port which leads to efficiency and dual-band transmission and optimum 50ohms impedance.

After designing the model of our 8 dual-band MIMO system, we have assigned the boundaries and excitations of our model in order to make our model work like a real antenna within the software, where we can observe the outputs.

The materials that have been assigned are :

1. The substrate is given a material of the name FR4_epoxy where this material is The proposed antenna has been designed using Flame Retardant 4(FR4) substrate of dielectric constant Ɛr= 4.4 and is placed in between the copper patch and ground plane.
2. The small side substrates, antennas, feedlines, wave-ports, inner coax and ground are made of perfect Electric conductor.
3. The Radiation box is given the dimensions of 360mm x 280mm x 80mm, whose faces are assigned radiation material and the bottom part of the radiation box is not assigned.

2. We must check whether our designs boundaries, model and excitations have any errors or not, hence we must validate our model and further analyze all the conditions. Then our model will get simulated.

3. Once the simulation is done, we must create a new analysis for our results, adding the appropriate parameters, we can plot a rectangular plot or far-field plot for our model. Identify the resonant frequencies for the wave-ports of each feedline antenna and we can see that we have obtained a dual-band at the output.

After looking at the outputs we can observe the dual-band for all the antennas which have wave-ports, this indicates that our dual-band 8-antenna MIMO system has not only good isolation but also good antenna total efficiency which is excellent for mobile device transmission.

6 SOFTWARE/HARDWARE USED:

6.1) 2012 Ansys (Hfss)

6.2) Personal Computer

7 EXPERIMENTAL SETUP:

7.1 Firstly open Ansys electronic desktop. Click on the new HFSS model and proceed to design the 8 antennae dual-band model with the appropriate dimensions and materials assigned.
7.2 After designing, Assign appropriate boundary conditions and excitations.
7.3 Validate to check if there are any errors in our design
7.4 Analyze all and simulate.
7.5 Plot rectangular plot and far-field plot for the antenna design and observe the outputs.

8 CALCULATIONS: ECC AND CC OF THE MIMO SYSTEM:

To demonstrate the performance of the proposed dual-band 8-antenna MIMO system, the 2D and 3D antenna radiation patterns, the envelope correlation coefficient (ECC) and the channel capacity (CC) of the MIMO system.

8.1 Envelope Correlation Coefficient (ECC):

To quantitatively evaluate the performance of the proposed wideband MIMO antenna system, the envelope correlation coefficient was also analyzed. For simplification, it is assumed that the multipath environment is isotropic in the sense of both power density and polarizations [33]. Therefore, the envelope correlation between antenna I and antenna j can be calculated by the complex radiation far field as follows:

$$ECC(i,j) = \frac{\left| \oiint A_{ij}(\theta,\varphi)\sin\theta d\theta d\varphi \right|^2}{\oiint A_{ii}(\theta,\varphi)\sin\theta d\theta d\varphi \cdot \oiint A_{jj}(\theta,\varphi)\sin\theta d\theta d\varphi} \quad (1)$$

8.2 Channel Capacity (CC):

The channel capacity (CC) that is used to evaluate the performance of MIMO systems can be defined as follows:

$$CC = E\left\{log_2\left[det\left(I + \frac{SNR}{n_T}\right)H_{scale}H_{scale}T\right]\right\}$$

and the channel matrix H scale can be calculated as follow:

$$H_{scale} = \sqrt{\rho_{scale,R\,X}}H_{i.i.d}\sqrt{\rho_{scale,TX}}$$

the antenna total efficiency needs to be taken into account when the channel capacity of the MIMO antenna system is calculated:

$$\rho_{scale,RX} = \sqrt{\eta_{total}}\rho_{RX}\sqrt{\eta_{total}}$$

9 RESULTS AND DISCUSSIONS:

9.1 ALL ANTENNA TRANSMISSION GRAPHICAL REPRESENTATION

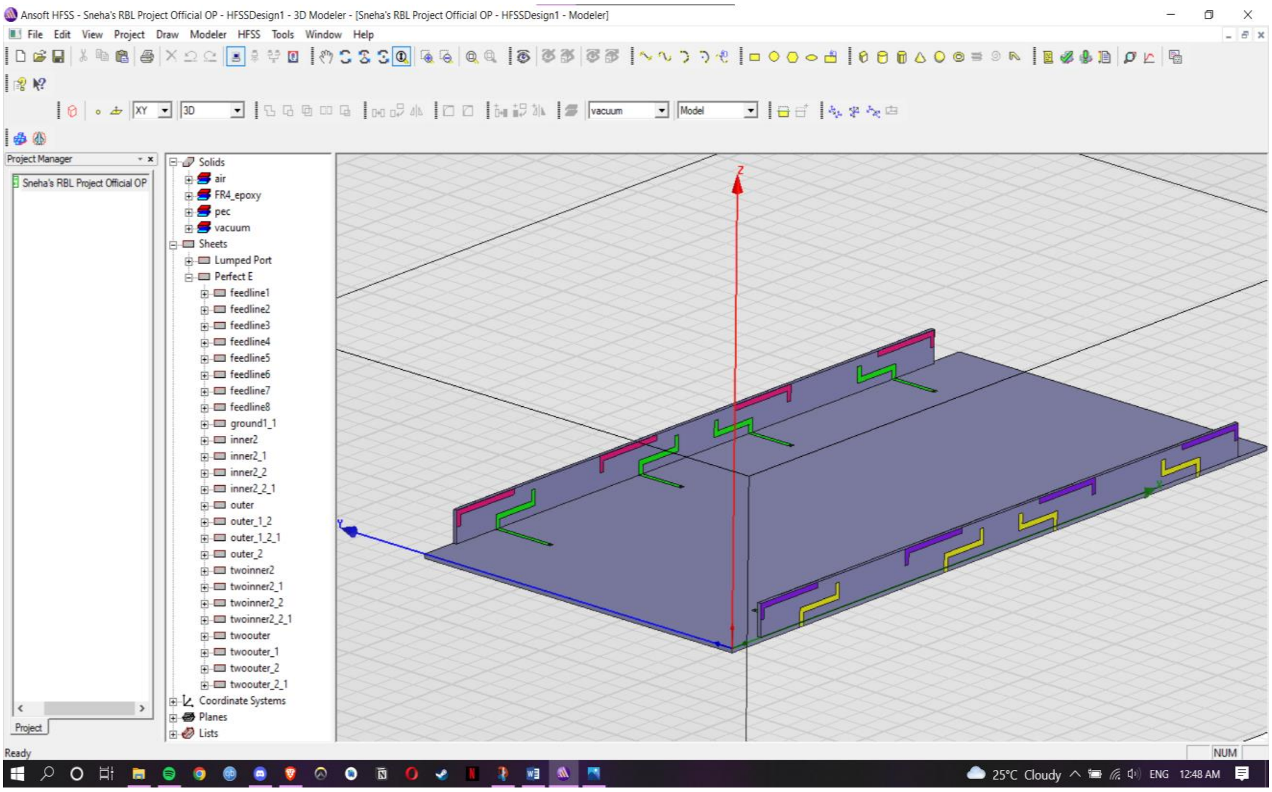


Figure 9.1.1) Antenna Design in HFSS

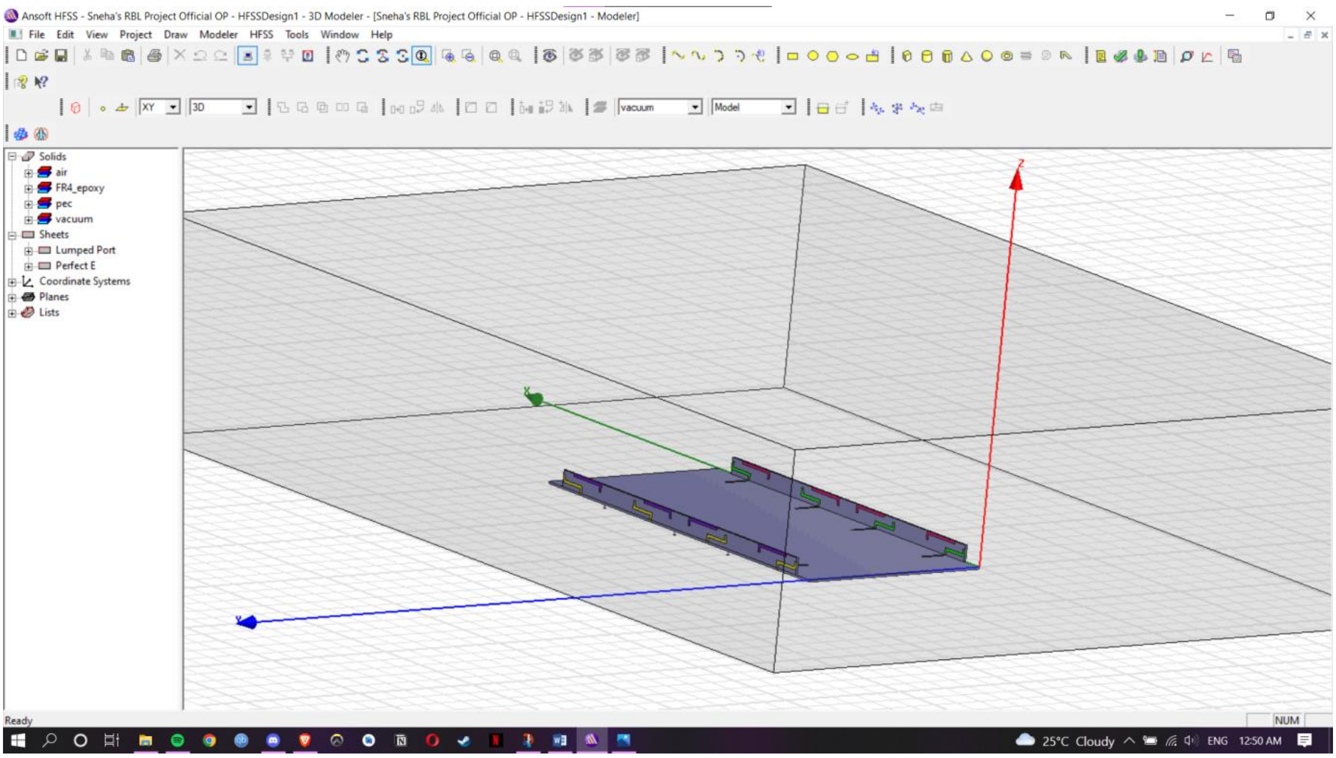


Figure 9.1.2) Antenna model with radiation box

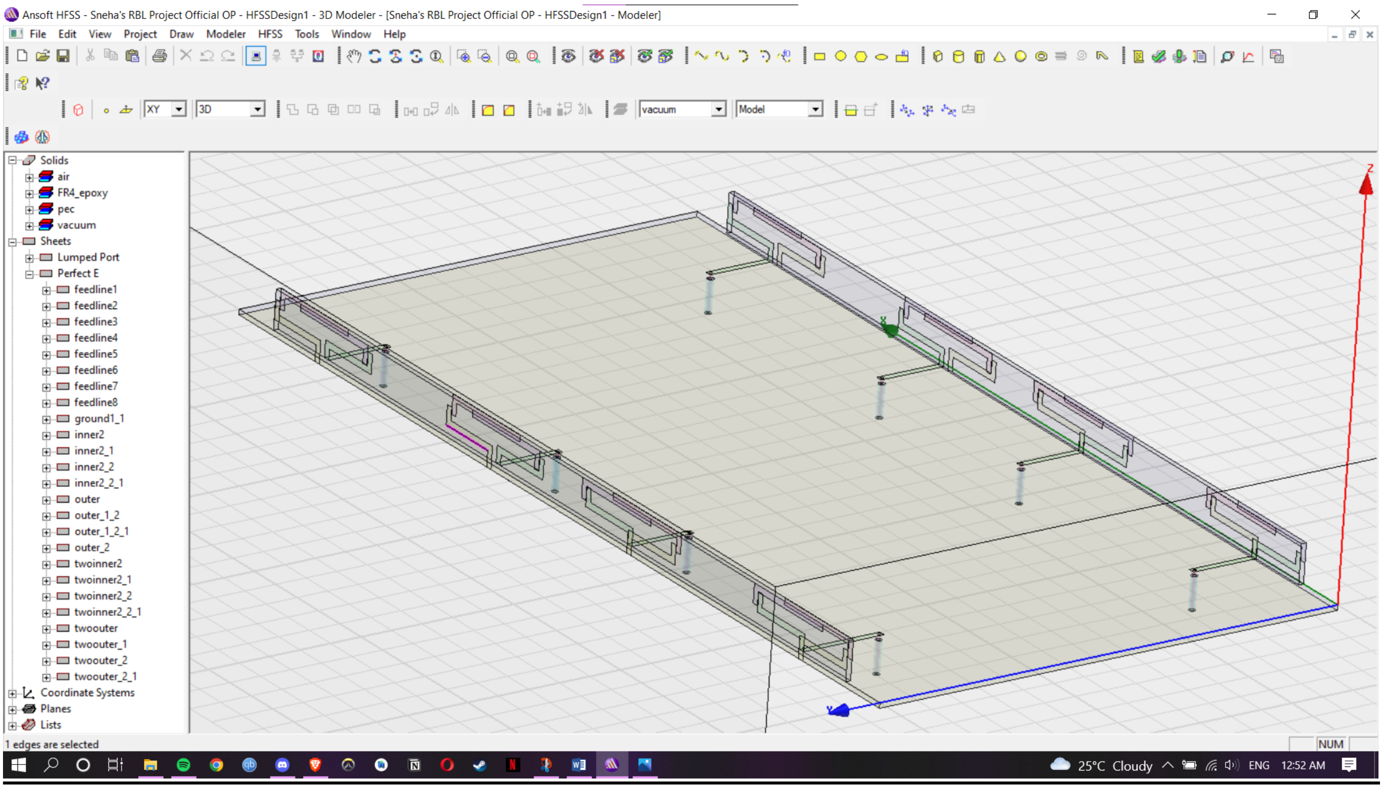


Figure 9.1.3) Antenna system, feedlines and coax cables

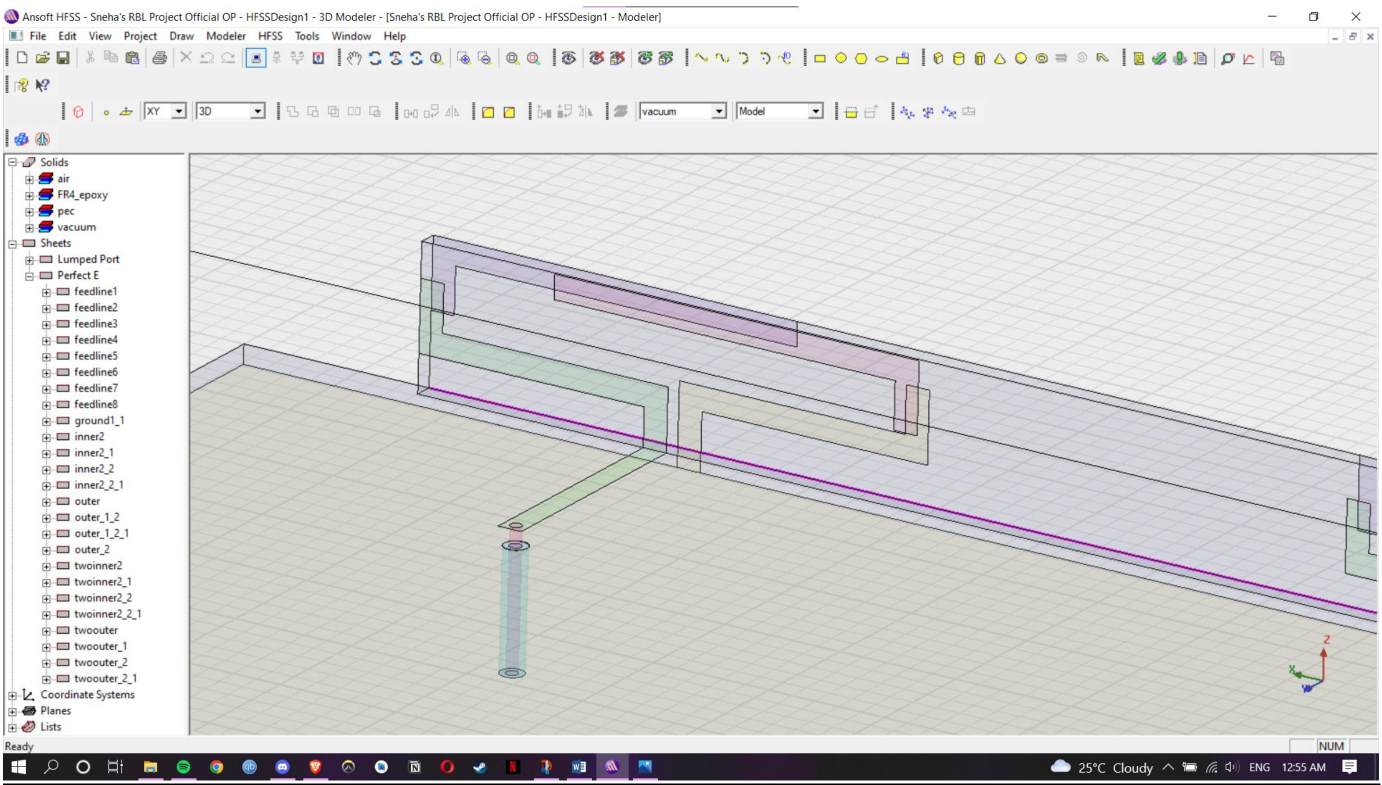


Figure 9.1.4) Inner view of antenna 1

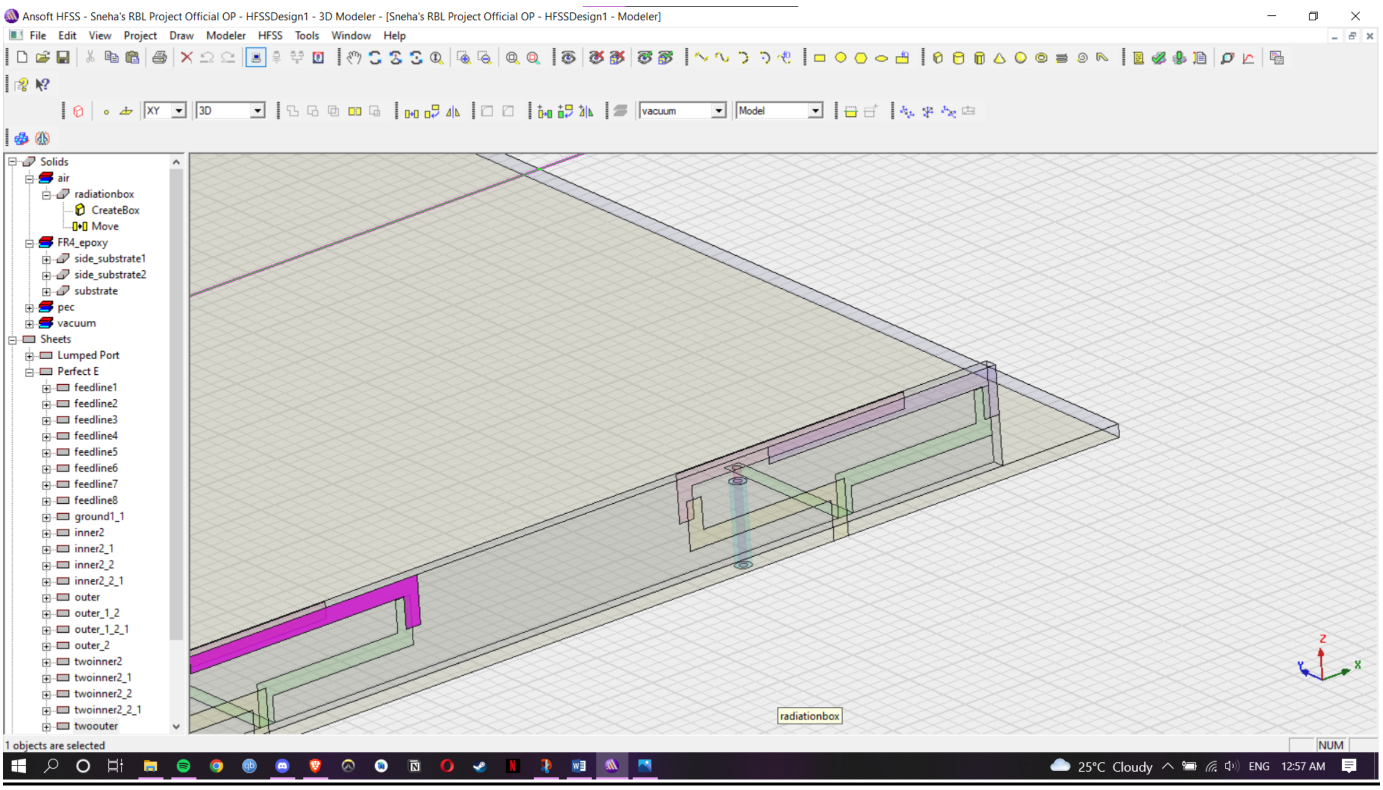


Figure 9.1.5) Outer view of antenna 1

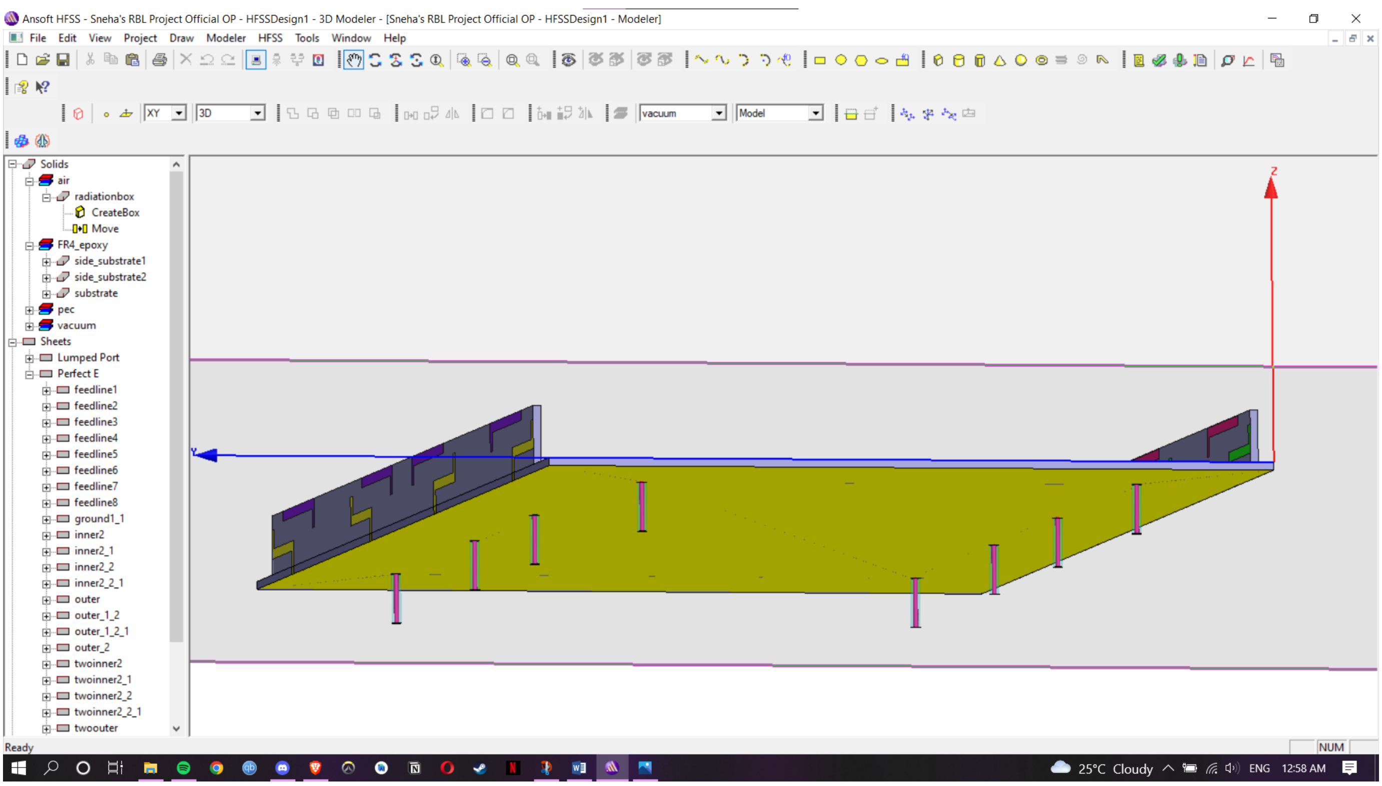


Figure 9.1.6) Coax Cables of the antenna

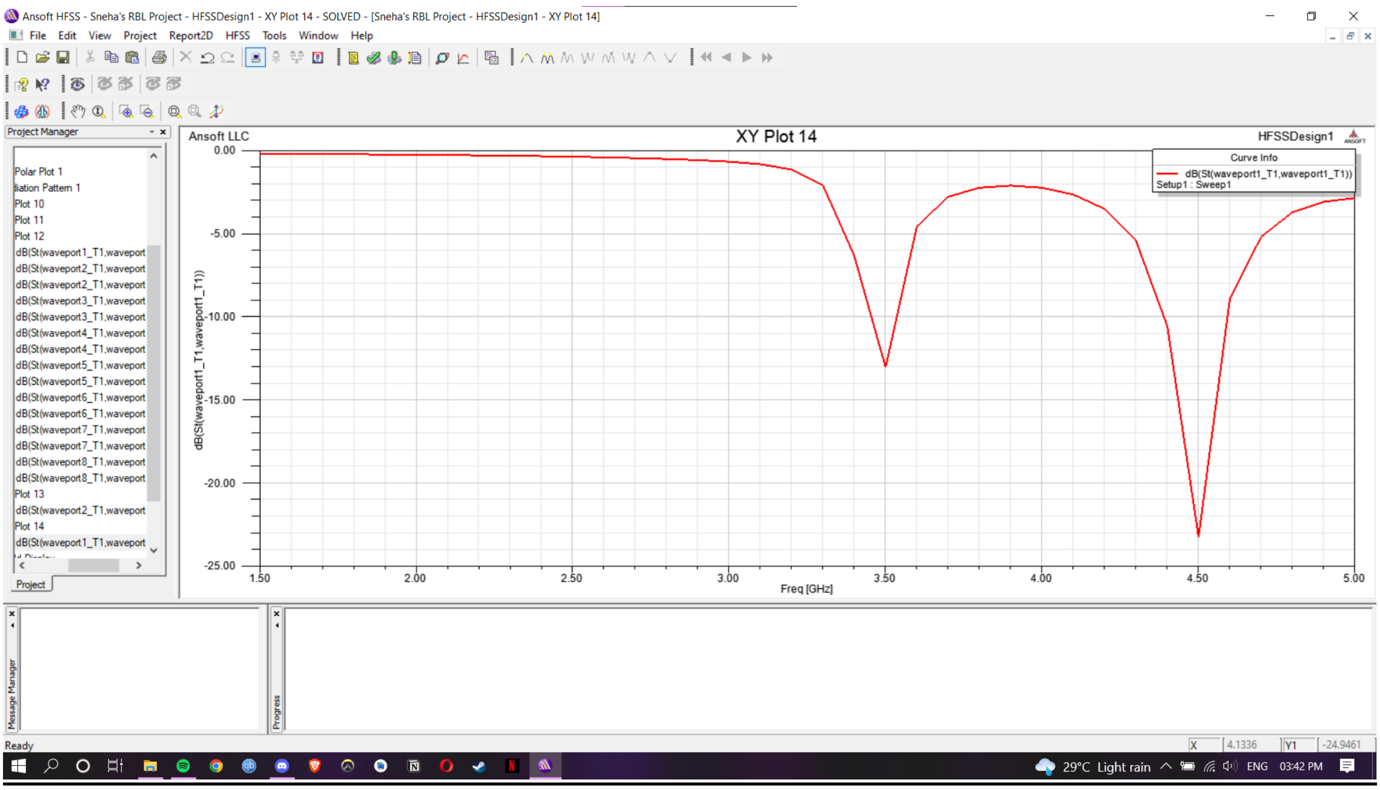


Figure 9.1.7) Antenna Wave-port 1 output wave, we get a dual-band

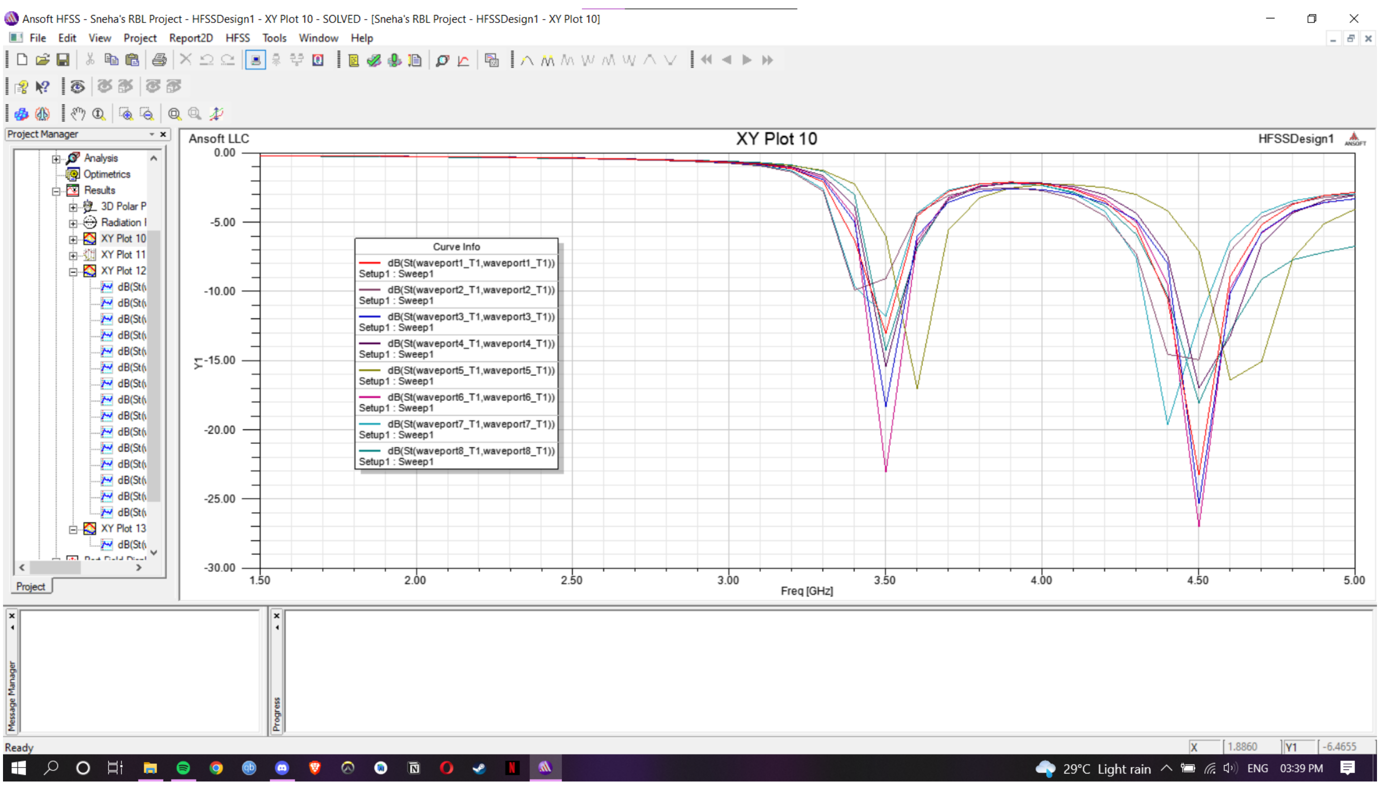


Figure 9.1.8) Outputs of Antennas 1 to 8; where all are dual-bands

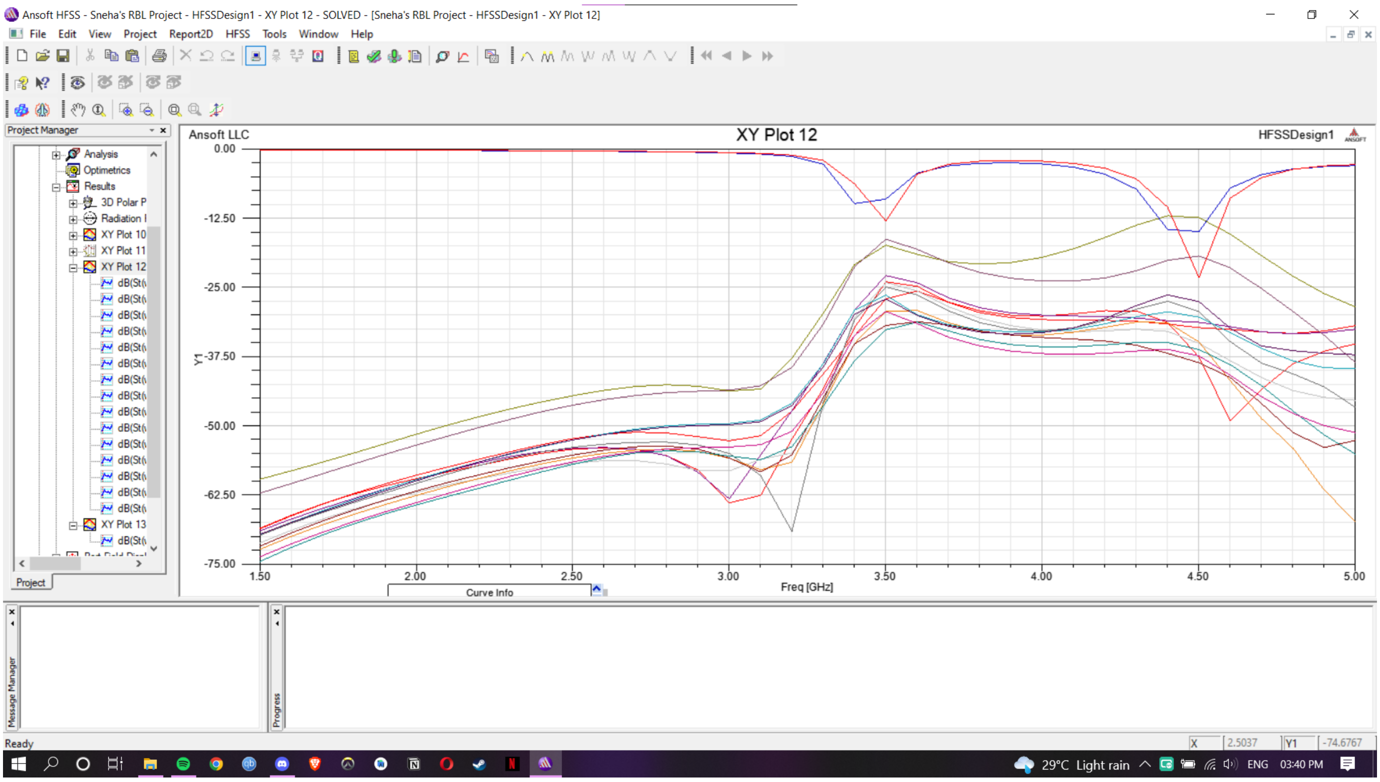


Figure 9.1.9) SWR of antennas and antenna waveport outputs combined

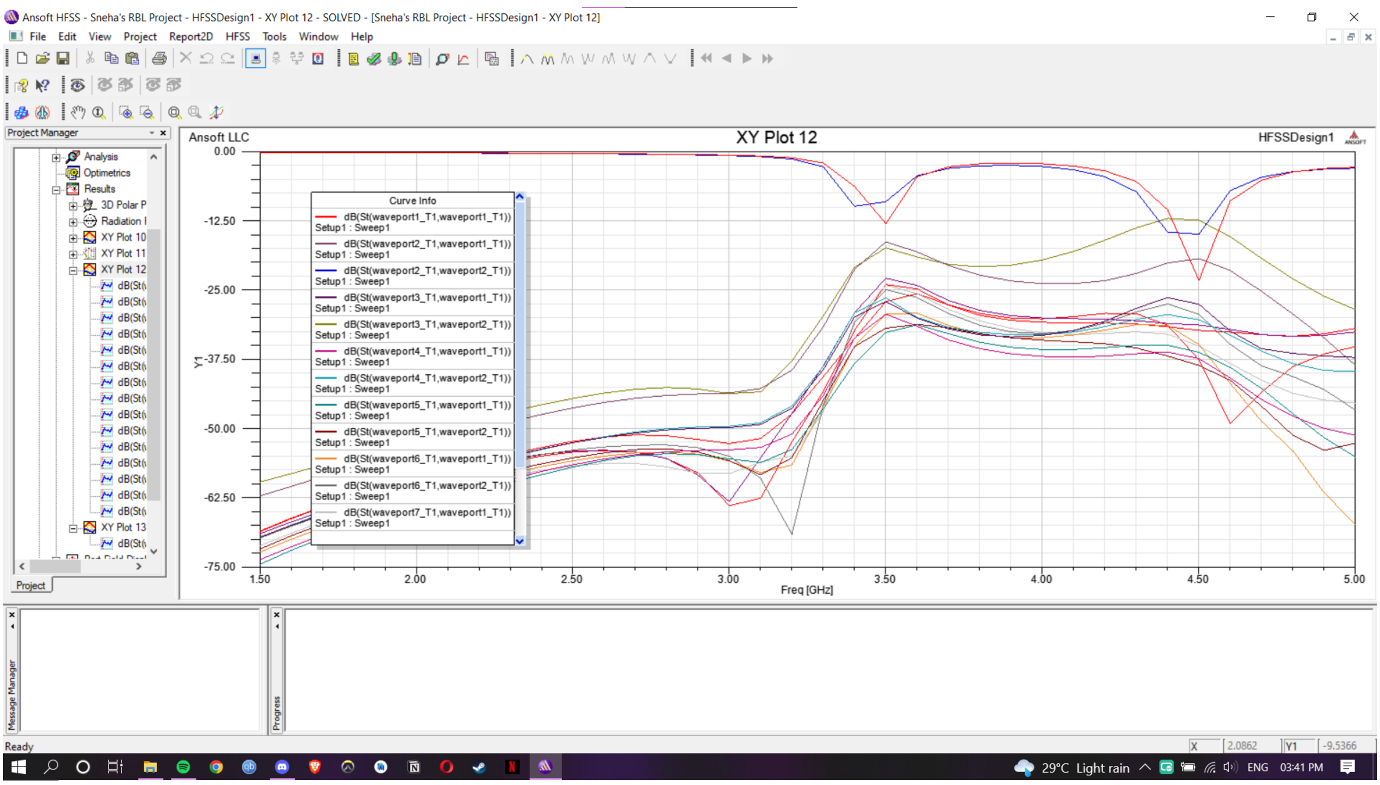


Figure 9.1.10) SWR of antennas and antenna waveport outputs combined with curve info

10 CONCLUSION:

A dual-band 8-antenna MIMO system that can cover the 3.3-5.0GHz band is proposed for the 5G application in mobile terminals. Particularly, the MIMO antenna system is based on a coupled-loop antenna element with three coupling sections in its radiating branches: one on the top centre and two on the left and right sides. The frequencies obtained are 3.50Hz and 4.50Hz, most importantly, due to the above special arrangement, a new resonance mode the first resonance (0.75λ) mode of the loop antenna is generated for the first time. As a consequence, the combination of this new mode of the loop antenna makes the bandwidth of the proposed coupled-loop antenna a dual-band, which can cover all the 5G N77, N78 and N79 bands.

The performance of the 8-antenna MIMO system is confirmed by both simulation and measurement, and good MIMO antenna performance is obtained. In particular, the proposed dual-band 8-antenna MIMO system shows good isolation due to the feeding mechanism used and, the envelope correlation coefficient is quite accurate with its counter antennas, and good channel capacity, which is all good enough for practical 5G MIMO antenna application in mobile terminals.