SİVAS UNIVERSITY OF SCIENCE AND TECHNOLOGY
FACULTY OF ENGINERING AND NATURAL SCIENCES

ANTENNA DESIGN LABORATORY

Experiments Manual Report

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1-DIPOLE ANTENNA DESIGN EXPERIMENT

OBJECTIVES

- Designing a dipole antenna using Anten'it antenna design kit.
- To investigate return loss and antenna length-frequency relation.
- Understand the differences of balanced and unbalanced antennas.
- Plot the radiation pattern of a dipole antenna.

BRIEF INFORMATION ABOUT THE DIPOLE ANTENNA:

Dipole Antenna:

The dipole and monopole are the essential wire antennas. The complex antennas are generally a combination of essential antennas. In order to understand the complex antennas, we need to learn the essential antennas very well. This experiment aims to understand the characteristics of a dipole antenna.

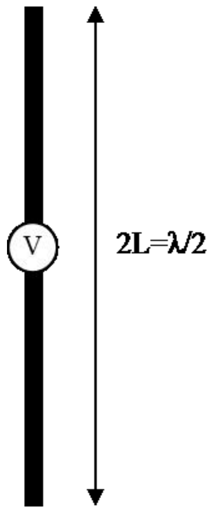
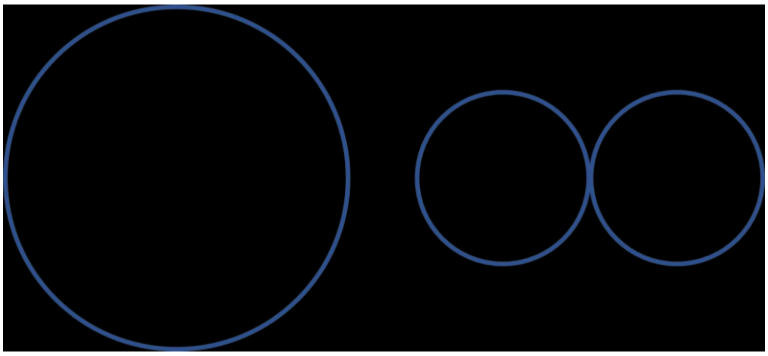


Figure 1 Dipole antenna

One of the well-known antennas is the half-wavelength dipole ($2L= \lambda/2$ in Figure 1). Dipole antenna includes two metal rods. Different from the Hertzian dipole, the real dipole antenna has a finite length as in Figure 1.

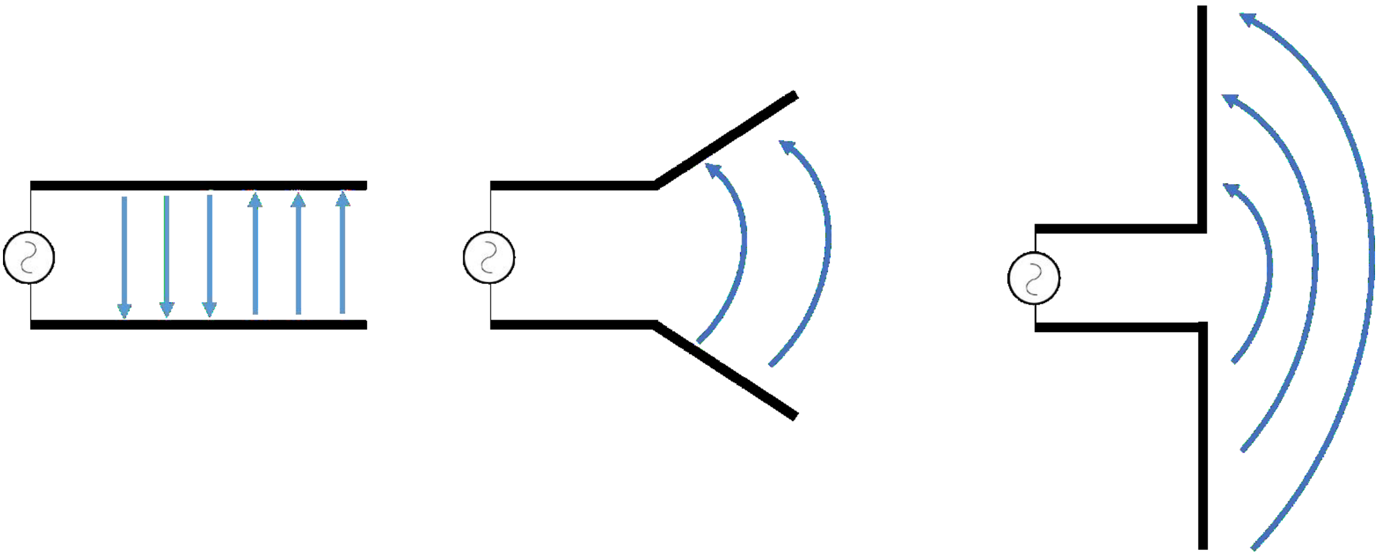
Remember the half wavelength dipole antenna radiation pattern; it has omnidirectional characteristics as in Figure 2. Omnidirectional pattern radiates equal power level in the perpendicular directions to the antenna which is called azimuth axis. The power changes in the elevation axis; at the top of the antenna the radiation drops to zero where in the perpendicular axis, it has the maximum radiation.



a) Azimuth axis b) Elevation Axis

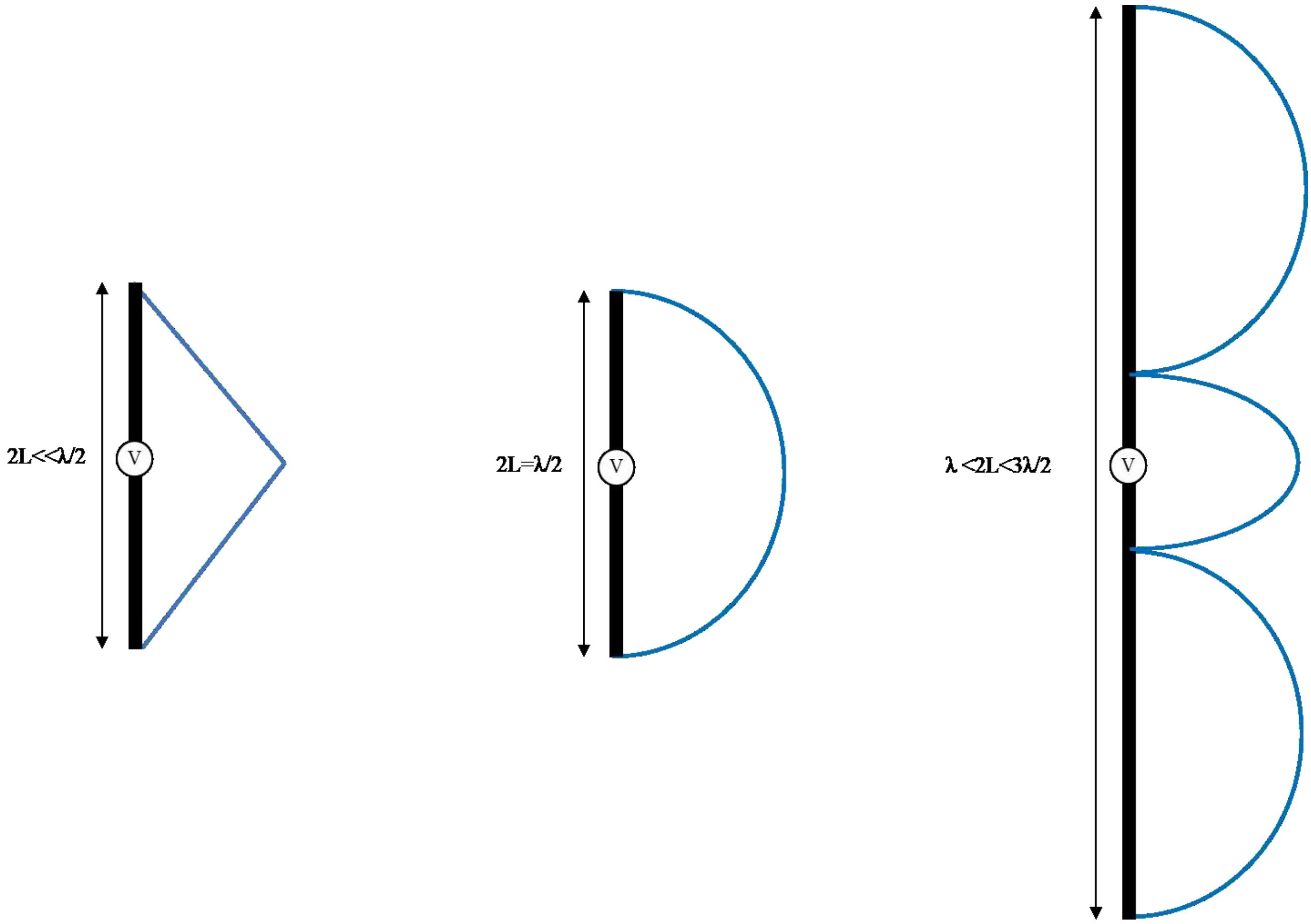
Figure 2 Radiation pattern of a half-wavelength dipole antenna.

Let's think about a transmission line as in Figure 3a. The electrical field is between two wires and it is not radiating. When we bend each wire as in Figure 3b, electrical field starts radiating. Figure 3c is a dipole antenna with 90° flare angle.



a) Transmission Line b) Flared Transmission Line c) Dipole

Figure 3 Transformation from transmission line to dipole



a) Short Dipole b) Half Wavelength Dipole c) Long Dipole

Figure 4 Current (Amplitude) distribution on a dipole for different dipole lengths

The radiation pattern diagrams in Figure 2 belong to half-wavelength dipole antenna which has a current distribution as in Figure 4b. The current distribution on the antenna brings out the radiation pattern of the antenna. The current distribution of a linear wire dipole antenna is shown in Figure 4. The current distribution on a dipole is directly related to length of the antenna. The unit of length is wavelength. A short dipole means that the length is very shorter than half-wavelength and a long dipole means that the length is longer than half-wavelength. As the length changes, the current distribution on the antenna changes.

Balun:

There are balanced and unbalanced type of antennas. Unbalanced antennas have a ground plane which is ideally an infinite ground plane but practically a local ground plane. Figure 5 shows the infinite ground plane referring earth ground. It is a real ground where the voltage difference is zero. There is a voltage difference between the local ground plane and earth ground. This difference is related to the dimensions of the local ground plane. If the ground plane dimensions are small enough, there will be more than one interaction; first one is between the rod antenna and the local ground plane, second one is between the rod and the earth ground plane and the third one is between the local ground plane and the earth ground. Each of these will create an electrical field. This makes the antenna radiation very complicated and hard to understand.

In unbalanced antennas, the outer conductor of the cable is connected to the local ground plane where the inner conductor is connected to the antenna rod as in Figure 5. This creates electrical field between the ground plane and the rod. The balanced antennas are independent from the ground plane. The electrical field is between two rods. In order to create this independency, we need to use a balun. Balun is a transformer which changes the unbalanced line into a balanced line (**Bal**anced to **un**balanced). We use balun transformer in dipole antennas.

Let's assume that we don't use a balun. Then, one rod would be connected to inner conductor of the cable where the other rod would be connected to the outer conductor. The outer conductor is connected to the ground of the device (Network analyzer, spektrum analyzer, signal generator etc.). But the ground plane would be very small because only the rod would be the ground plane. Then the electrical field would be very complicated as described in the previous paragraphs. This lets the radiation pattern to be very far from the ideal radiation pattern as in Figure 2.

Figure 6 shows a coaxial cable, a balun and a dipole antenna. Coaxial cables have unbalanced structure. The outer conductor of the coaxial cable is ground, and the electrical field is between the inner and the outer conductors. One side of the balun is connected to this unbalanced cable and the other side is connected to the balanced antenna. By this way, the dipole is fed balanced.

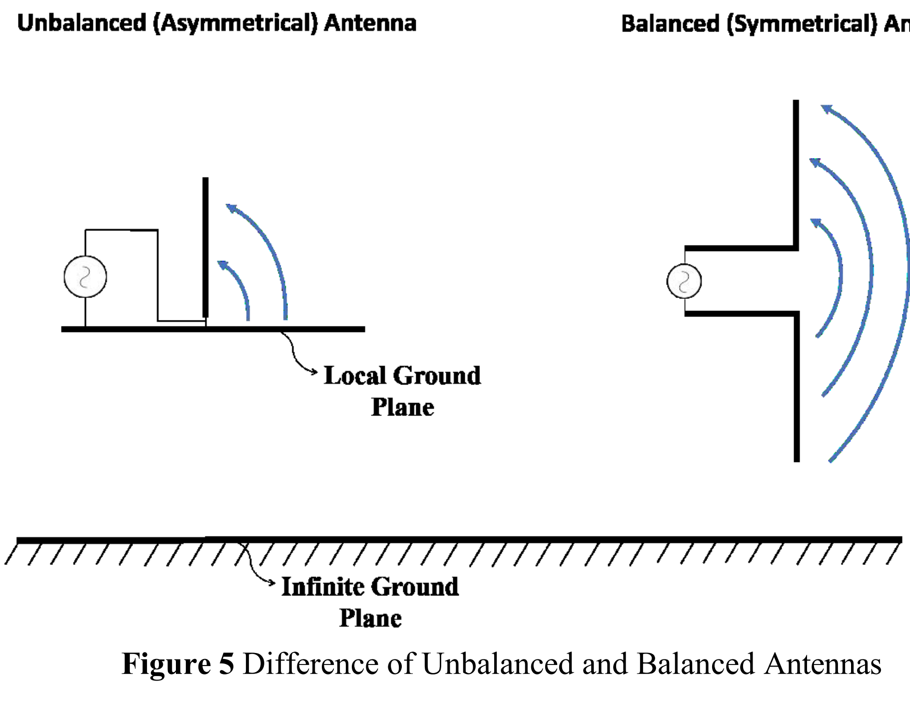


Figure 5 Difference of Unbalanced and Balanced Antennas

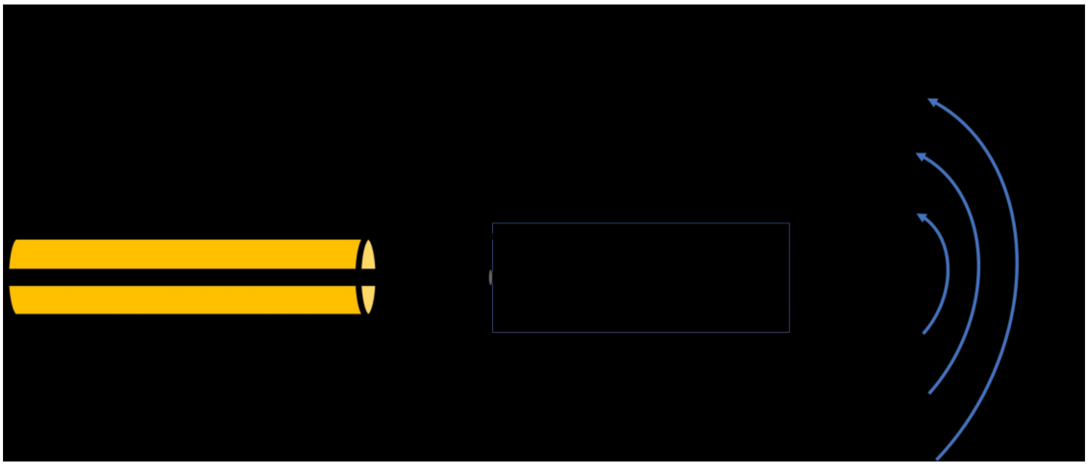


Figure 6 Balun

Bandwidth:

The impedance bandwidth of the antenna is a frequency range between the highest and lowest frequency where return loss is below a certain value. For most of the applications, 10 dB return loss is a rule of thumb. Elementary antennas have typical bandwidth characteristics, but the frequency bandwidth changes with the center frequency. Therefore, the percentage bandwidth is used as an antenna parameter. The percentage bandwidth is a ratio of the frequency range divided by the center frequency as in Equation 1.

$$B = \frac{f_h - f_l}{f_c} \quad (1)$$

f_h: The highest frequency intersecting -10 dB S_{11}[dB]
f_l: The lowest frequency intersecting -10 dB S_{11}[dB]
f_c: Center frequency

EXPLANATION ABOUT DESIGNING DIPOLE ANTENNA WITH ANTEN'IT:

The box in Figure 7 is the dipole antenna kit. There is a balun and metal cells in the box. We will use them for the design of an antenna. The balun has SMA-female connector.

Figure 7 Dipole Antenna Kit

You need to locate the metal cells over the balun in this experiment. The operating frequency of the antenna is a parameter of the dipole dimensions.

The calculation of height:

The cubic part of Anten'it metal cells is 3 mm, and the top (thin) cylinder is 2 mm height. Although the total height is 5 mm, 2 mm is interlaced to another cell, and the height resolution is 3 mm. Figure 8 shows the dimensions of a 1X1 metal cell. The dimensions of other cells are multiples of 1X1 dimensions.

For example, if you interlace 3 bricks into each other, the total height will be 3 X 3 mm + 2 mm which corresponds to 11 mm or if you interlace 5 bricks into each other, the total height will be 5 X 3 mm + 2 mm which corresponds to 17 mm.

The balun has nearly 1 mm height. When we locate 10 bricks at both sides of the balun, the total size will be 20 X 3 mm + 2 X 2 mm + 1.5 mm (balun height) = 65.5 mm.

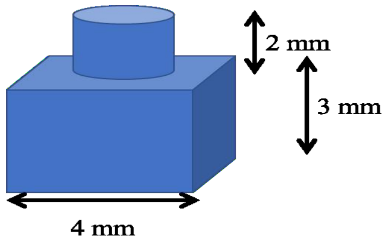


Figure 8 Anten'it cell dimensions

Removing the cells:

Removing the cells is one of the most important parts to learn. The misusage can damage the kits. There are some removing tools in the kit and the tool must be selected depending on the cell type. Each cell in the kit needs to be used gently.

In this experiment, use your hands to remove the cells. If you try to remove the cells with your hands but you can't remove them after some trial, then use the special removing plier for removing the cells. Figure 9 shows the removing plier and its special head.

In case, you must use the removing plier, you need to use it 90 degree to the top cylinder of the cells. For 1X3 and larger cells, use the cylinder at the center. If you can't remove the cell easily, change to another cylinder. Figure 10 shows an example usage of the removing plier.

a)

b)

Figure 9 Removing Plier

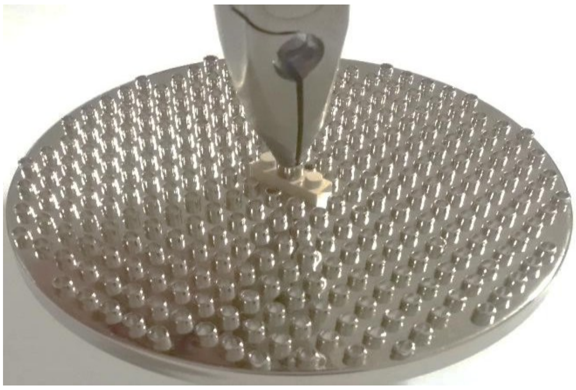


Figure 10 The usage of removing plier

PRELIMINARY WORK:

1. How does the dipole antenna work?
2. What is the relation between wavelength and antenna size?
3. What are the differences between unbalanced and balanced antennas?
4. Explain the meaning of isotropic, omnidirectional and directional antenna.
5. Why do we use decibel format? Explain what dBi is and why we use it.
6. Where is the E-plane and H-plane of the dipole antenna?
7. What percentage of the input power is reflected when S_{11} is -10 dB?

EXPERIMENTAL PROCEDURE:

1. Connect the cable to the Network Analyser and connect the SSMA-Female to SMA-Male adapter to the SSMA-male side of the cable as shown in Figure 11. Calibrate the Network Analyzer for 1 port measurement between 500 MHz and 2.000 MHz.

Figure 11 Cable to SSMA-SMA Adaptor Connection

2. The balun is shown in Figure 12. Locate the "metal cells" over the balun.

Figure 12 Balun

3. Calculate the dipole antenna size for 860 MHz. Find out the nearest Anten'it size with the dimensions in Section 3 (Calculation of height) of this document. Write the calculated sizes below:

Calculated dipole size:	
The nearest Anten'it size:	

4. Build the antenna.
5. Connect the cable to the balun.
6. Display S_{11} dB scale on the network analyzer screen.
7. Measure S11 in dB scale. Write down the center frequency and % bandwidth of the dipole antenna.

Dipole Antenna Center frequency:	
Dipole Antenna Bandwidth (%):	

8. Add or remove metal cells to see the frequency change.
9. Build the antenna as in step 7 again.
10. Display S_{11} in Smith Chart on the network analyzer screen. Write down the resonance impedance (The resonance impedance is the impedance with no imaginary part.).

Resonance Impedance [ohm]:	

11. Measure the E-plane (Elevation) of the dipole antenna at the center frequency of the antenna with a turn table. If the turn table is manual, write down the power levels for each E-plane angle. Normalize the power levels to the peak level.

E-plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		
330		

Gain [dBi]:	

12. Sketch the normalized power levels in E-plane axis on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

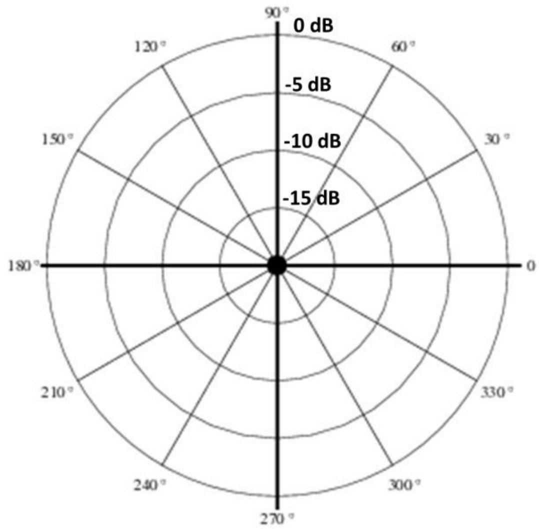


Figure 13 E-Plane Pattern of the Dipole Antenna in Polar Coordinates

13. Measure the H-Plane (Azimuth) pattern of the antenna with a turn table. If the turn table is manual, write down the power levels for each H-plane angle. Normalize the power levels to the peak level.

H-Plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		
330		

14. Sketch the normalized power levels in H-plane on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

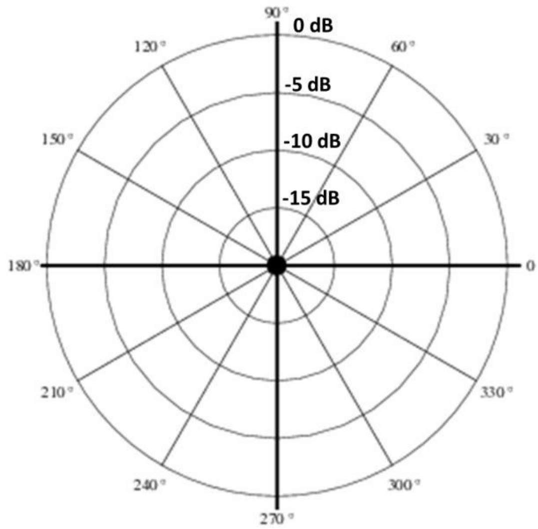


Figure 14 H-Plane Pattern of the Dipole Antenna in Polar Coordinates

RESULTS:

- State the objective of the experiment and give a short summary of the procedure.
- What are the differences of the measured and theoretical radiation patterns of dipole antenna ?
- Compare the theory and experimental results.
- Discuss the results of your experiment.

2-MONOPOLE ANTENNA DESIGN EXPERIMENT

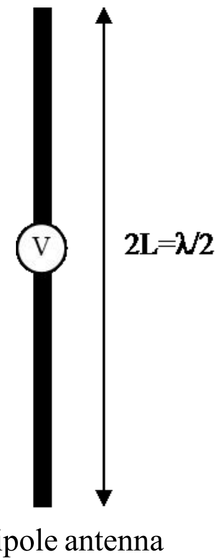
OBJECTIVES

- Designing a monopole antenna using Anten'it antenna design kit.
- To investigate return loss and antenna length-frequency relation.
- Understand the differences of the thin, thick and capacitive loaded monopole antennas.
- Plot the radiation pattern of a monopole antenna.

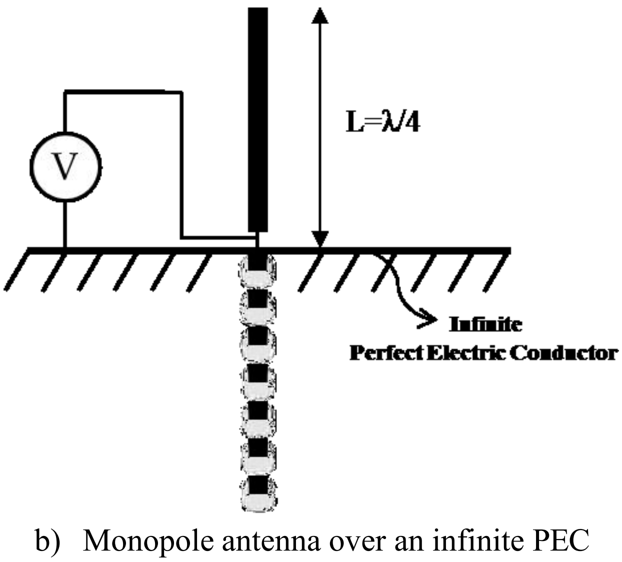
BRIEF INFORMATION ABOUT THE MONOPOLE ANTENNA:

Monopole Antenna:

The dipole and monopole are the essential wire antennas. The complex antennas are generally a combination of essential antennas. In order to understand the complex antennas, we need to learn the essential antennas very well. This experiment aims to understand the characteristics monopole antenna. We will design and discuss three different configurations of monopole antennas; thin monopole, thick monopole and capacitive loaded monopole.



a) Dipole antenna which is the equivalent of monopole

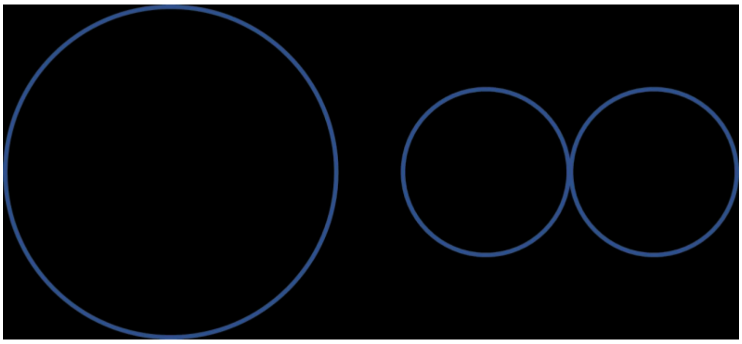


b) Monopole antenna over an infinite PEC

Figure 1 The explanation of conversion from a dipole to a monopole with the mirroring principle

One of the well-known antenna is the half-wavelength dipole (2L= λ/2 in Figure 1a). Dipole antenna includes two metal rods. Different from the Hertzian dipole, the real dipole antenna has a finite length as in Figure 1a. It has an omnidirectional radiation pattern as shown in Figure 2a. A monopole consists one rod of the dipole and a ground plane. As in the image theory, the ground plane acts like an electric boundary that mirrors the remaining rod of the dipole. Thus, the behaviour of the monopole is electrically the same as the entire dipole. By this way, the monopole generates the same radiation characteristics in the upper hemisphere. The image theory also provides the monopole to have half input impedance of the dipole; 36 ohm. 36 ohm is a close impedance value to the 50 ohm which is appropriate for matching to 50 ohm systems. The physical dimension of the monopole is L= $\lambda/4$. Since the infinite ground plane is a theoretical assumption, the finite size of the real ground plane has additional effects such as radiating a part of the electromagnetic energy to the lower hemisphere or the difference from the theoretical impedance characteristics.

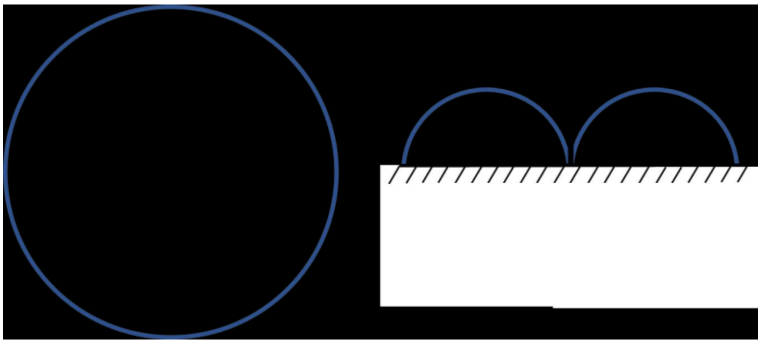
Remember the half wavelength dipole antenna radiation pattern; it has omnidirectional characteristics as in Figure 2. Omnidirectional pattern radiates equal power level in the perpendicular directions to the antenna which is called azimuth axis. The power changes in the elevation axis; at the top of the antenna the radiation drops to zero where in the perpendicular axis, it has the maximum radiation.



a) Azimuth axis b) Elevation Axis

Figure 2 Radiation pattern of a half-wavelength dipole antenna.

The monopole antenna theoretically has similar radiation characteristics with the dipole in the upper hemisphere as shown in Figure 3.



a) Azimuth axis b) Elevation Axis

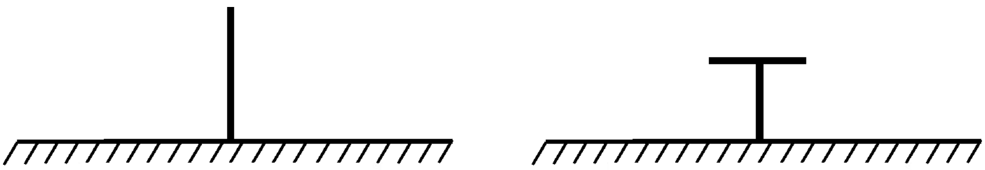
Figure 3 Radiation pattern of a quarter-wavelength monopole antenna.

Thick Monopole:

36 ohm radiation resistance of the thin monopole antenna decreases with the increase in the thickness of the monopole rod. The decrease of the impedance at the resonance frequency can be observed in the smith chart. The length to thickness ratio is a parameter of the bandwidth where it may also have negative effects such as increasing the capacitive energy between the monopole and the ground plane.

Capacitive Loaded Monopole:

There are some different methods to decrease the size of the physical length of the monopole. Inductive and capacitive loading are two common methods to reduce the size of the antenna. Remember that, the capacitor consists of two parallel plates. When we add a parallel plate to the top of the rod, we can assume that there is a capacitor between the top of the monopole and the ground plane. This technic is useful to decrease the monopole length where it also has negative effects to the antenna gain and the bandwidth. Therefore, it is a design challenge for an antenna engineer to compromise between the size, efficiency and bandwidth depending on the requirements of the application.



a) λ/4 Monopole   b) Capacitive Loaded Monopole

Figure 4 Reducing the size of the quarter-wavelength monopole with capacitive loading

Bandwidth:

The impedance bandwidth of the antenna is a frequency range between the highest and lowest frequency where return loss is below a certain value. For most of the applications, 10 dB return loss is a rule of thumb. Elementary antennas have typical bandwidth characteristics, but the frequency bandwidth changes with the center frequency. Therefore, the percentage bandwidth is used as an antenna parameter. The percentage bandwidth is a ratio of the frequency range divided by the center frequency as in Equation 1.

$$B = \frac{f_h - f_l}{f_c} \tag{7}$$

f_h: The highest frequency intersecting -10 dB S_{11}[dB]
f_l: The lowest frequency intersecting -10 dB S_{11}[dB]
f_c: Center frequency

EXPLANATION ABOUT DESIGNING A MONOPOLE ANTENNA WITH ANTEN'IT:

The box in Figure 5 is the monopole antenna kit. There are metal cells for thin monopole, thick monopole and capacitive loaded monopole. We will use each of these sections for the design of an antenna. For instance, we will use the cell in thin monopole section for thin monopole design. Feed dielectric cells have holes and feed metal cells have special insert. SSMA to SMA adaptor is for one port calibration of the network analyser.

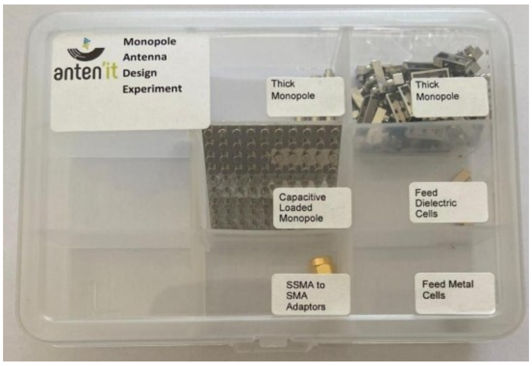


Figure 5 Monopole Antenna Kit

Figure 6 shows the feed cells of this experiment. The beige colour represents the dielectric cells with 2.6 dielectric constant. There are 3 feed dielectric cells. One of them has a cylinder with a hole. The inner conductor of the connector will go through this hole and touch the feed insert of the feed metal cell. There are two feed metal cells in this experiment. 1X1 circular one is for thin monopole where 1X3 feed metal cell is for thick monopole and capacitive loaded monopole design experiments.

The dielectric cells are used as a spacer for this experiment.

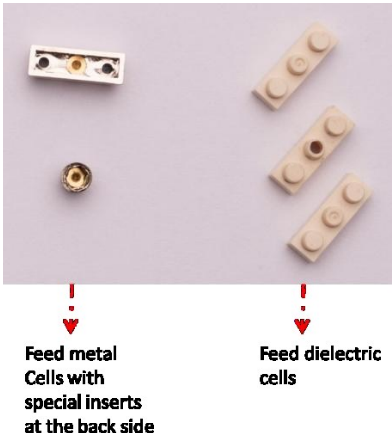


Figure 6 Feed Cell

For thin monopole experiment, there are long cells with 9 mm and standard cells with 3 mm height. Use long cells at the bottom and standard pieces at the top in order to have a rigid antenna. Large and small cells are shown in Figure 7.

Figure 7 Standard (Left) and long (Right) metal cells

See an example monopole antenna built with Anten'it in Figure 8.

Figure 8 An example monopole antenna

<u>The calculation of height:</u>

The cubic part of Anten'it metal cells has 3 mm and the top (thin) cylinder has 2 mm height. Although the total height is 5 mm, 2 mm interlace to another cell and the height resolution is 3 mm. Figure 9 shows the dimensions of a 1X1 metal cell. The dimensions of other cells are multiples of 1X1 dimensions.

For example, if you interlace 3 bricks into each other, the total height will be 3 X 3 mm + 2 mm which corresponds to 11 mm or if you interlace 5 bricks into each other, the total height will be 5 X 3 mm + 2 mm which corresponds to 17 mm.

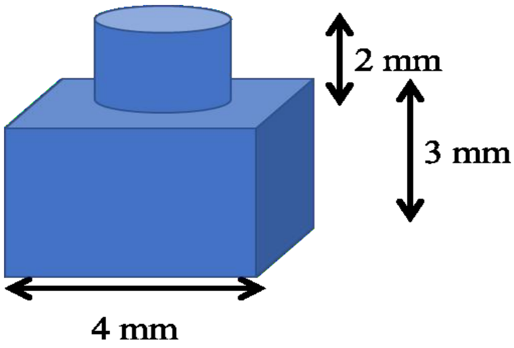


Figure 9 Anten'it cell dimensions

Removing the cells:

Removing the cells is one of the most important parts to learn. The misusage can damage the kits. There are some removing tools in the kit and the tool must be selected depending on the cell type. Each cell in the kit needs to be used gently.

In this experiment, use your hands to remove the cells. If you try to remove the cells with your hands but you can't remove them after some trial, then use the special removing plier for removing the cells. Figure 10 shows the removing plier and its special head.

In case, you must use the removing plier, you need to use it 90 degree to the top cylinder of the cells. For 1X3 and larger cells, use the cylinder at the center. If you can't remove the cell easily, change to another cylinder. Figure 11 shows an example usage of the removing plier.

a)

b)

Figure 10 Removing Plier

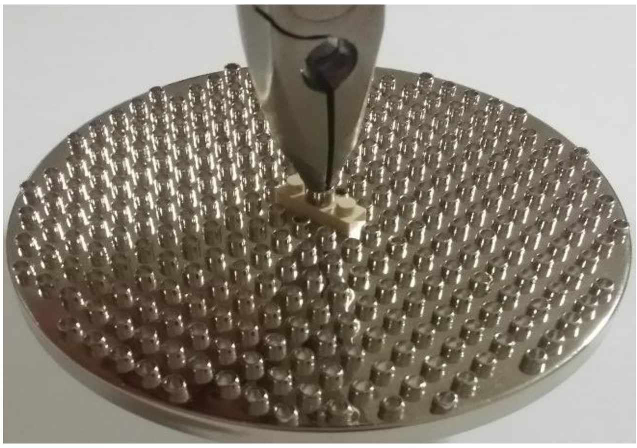


Figure 11 The usage of removing plier

PRELIMINARY WORK:

1. How does the dipole antenna work?
2. What is the relation between wavelength and antenna size?
3. What is image theory? Explain it briefly and show electric and magnetic field directions for all configurations (vertical and horizontal antenna above PEC or PMC).
4. What are the differences between dipole and monopole antenna?
5. Explain the meaning of isotropic, omnidirectional and directional antenna.
6. Why do we use decibel format? Explain what dBi is and why we use it.
7. Where is the E-plane and H-plane of the monopole antenna?
8. What percentage of the input power is reflected when S_{11} is -10 dB?

EXPERIMENTAL PROCEDURE:

1. Connect the cable to the Network Analyser and connect the SSMA-Female to SMA-Male adapter to the SSMA-male side of the cable as shown in Figure 12.

Figure 12 Cable to SSMA-SMA Adaptor Connection

2. Calibrate the Network Analyser for 1 port measurement between 800 MHz and 6 GHz.
3. Disconnect the SSMA to SMA adaptor after the calibration as shown in Figure 13.

Figure 13 Disconnect the cable from SSMA-SMA Adaptor

4. The ground plane is shown is Figure 14. Locate the “dielectric feed cell with a hole” over the inner conductor pin of the connector. Locate the “1X1 circular metal feed cell” over the hole.

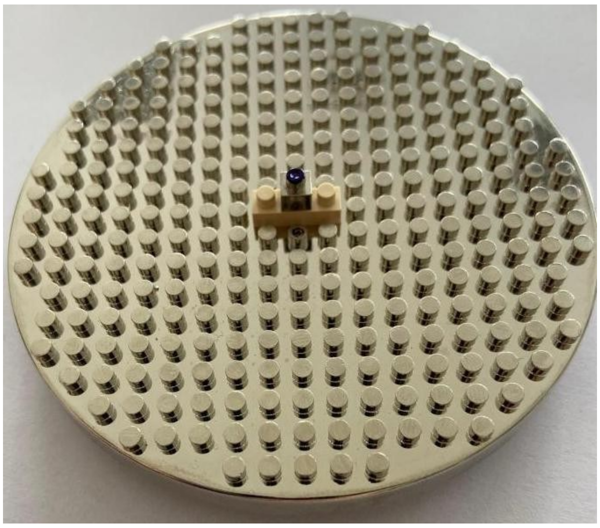


Figure 14 Ground plane with a dielectric feed cell and a metal feed cell

5. Use a multi-meter or voltmeter in order to check if the inner conductor of the connector is connected to the feed cell. Turn the multi-meter to “short” buzzer option. With one probe

touch to the inner conductor of the SSMA connector from the bottom of the ground plane and with the other probe touch to the feed cell. If the buzzer is ringing, they are connected to each other, and we can start the experiment.

Figure 15 Buzzer

6. Calculate the monopole antenna size for 1630 MHz. Find out the nearest Anten'it size with the dimensions in Section 3 (Calculation of height) of this document. Write the calculated sizes below:

Calculated monopole size:	
The nearest Anten'it size:	

7. Build the antenna. Be careful that the calculated monopole size is the total size including the dielectric and metal cells.
8. Connect the cable to the connector at the ground plane of the monopole antenna as shown in Figure 16.

Figure 16 Connection to the connector at the ground plane of the monopole

9. Display S_{11} dB scale on the network analyser screen.
10. Measure S11 in dB scale. Write down the center frequency and % bandwidth of the thin monopole antenna.

Thin Monopole center frequency:	
Thin Monopole bandwidth (%):	
Thin Monopole center frequency at the second resonance:	
The ratio of the second resonance and first resonance center frequencies:	

11. Add or remove metal cells to see the frequency change.
12. Remove all metal and dielectric pieces from the ground plane.
13. Connect the dielectric cells for a thick monopole as shown in Figure 17.

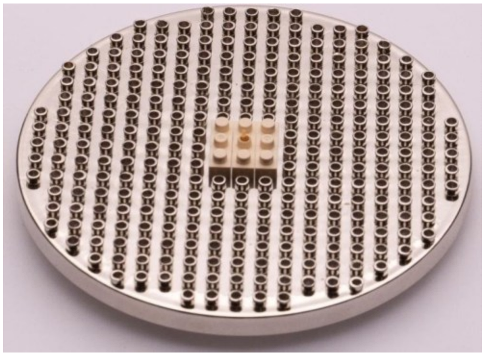


Figure 17 Dielectric Cell Configuration for Thick Monopole Antenna

14. Connect the 1X3 feed metal cell to the top of the dielectric cell as shown in Figure 18.

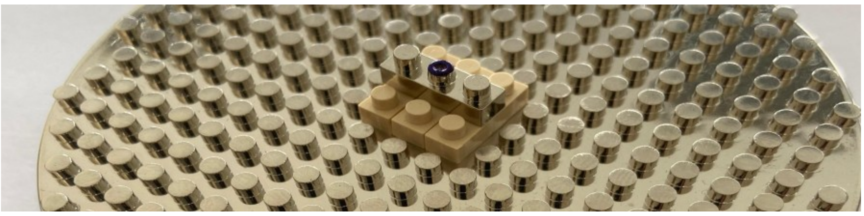


Figure 18 Connection of the Feed Cell for Thick Monopole Antenna

15. Disconnect the cable from the antenna. Use a multi-meter or voltmeter in order to check if the inner conductor of the connector is connected to the feed cell. Turn the multi-meter to “short” buzzer option. With one probe touch the inner conductor of the SSMA connector from the bottom of the plate and with the other probe touch to the feed cell. If the buzzer is ringing, they are connected to each other, and we can start the experiment.

16. Connect the 1X3 cells at each side of the feed cell. Connect other 1X3 metal cells to build the antenna as shown in Figure 19.

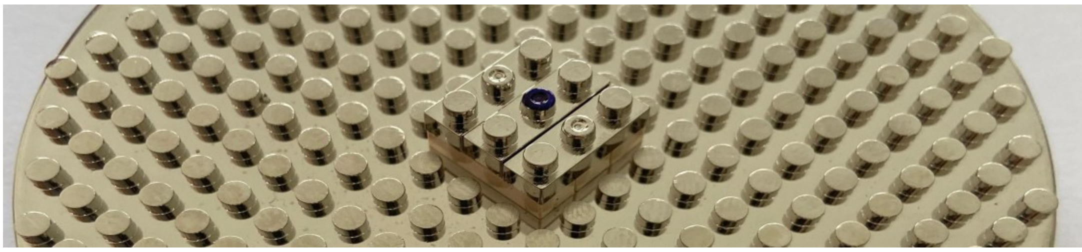


Figure 19 Connection of the two metal cells in both sides of the feed metal cell

17. Build the thick monopole in the same height as the thin monopole antenna. Measure the return loss in dB scale. Write down the center frequency and calculate the bandwidth.

Thick Monopole Center frequency:	
Thick Monopole Bandwidth (%):	

18. Remove the top 1 row (3 mm) of metal cells from the thick monopole antenna. Locate the circular 2X2 cell at the top of the thick monopole. Locate the 10X10 metal cell over the circular 2X2 cell. This new antenna is called capacitive loaded monopole antenna. Measure the return loss and calculate the bandwidth.

Capacitive Loaded Monopole Center frequency:	
Capacitive Loaded Monopole Bandwidth (%):	
The percentage of shortening: (Comparing the thick monopole and capacitive loaded monopole lengths)	

19. Dismount the 2X2 circular and 10X10 metal cells and add one row again in order to get the same antenna as in step 17.

20. Measure the E-plane (Elevation) of the thick monopole antenna at the center frequency of the antenna with a turn table. If the turn table is manual, write down the power levels for each E-plane angle. Normalize the power levels to the peak level.

E-plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		
330		

Gain [dBi]:	

21. Sketch the normalized power levels in E-plane axis on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

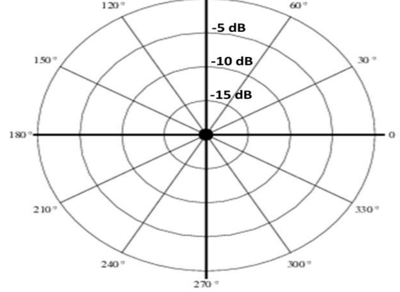


Figure 20 E-Plane Pattern of the Monopole Antenna in Polar Coordinates

22. Measure the H-Plane (Azimuth) pattern of the antenna with a turn table. If the turn table is manual, write down the power levels for each H-plane angle. Normalize the power levels to the peak level.

H-Plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		
330		

23. Sketch the normalized power levels in H-plane on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

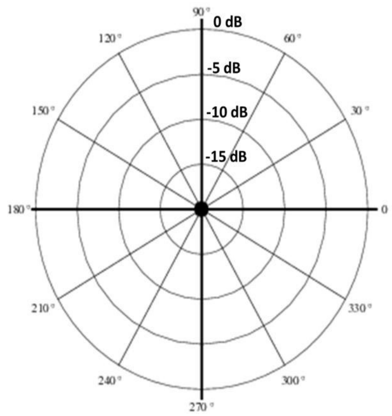


Figure 21 H-Plane Pattern of the Monopole Antenna in Polar Coordinates

RESULTS:

- State the objective of the experiment and give a short summary of the procedure.
- What are the measured differences between the thin and thick monopole antennas?
- What are the measured differences between the thick and capacitive loaded antennas?
- Compare the theory and experimental results.
- Discuss the results of your experiment.

3-NORMAL MODE HELIX ANTENNA DESIGN EXPERIMENT

OBJECTIVES

- Designing normal mode helix antenna using Anten'it antenna design kit.
- To investigate return loss and antenna length-frequency relation.
- Understand the difference in antenna parameters by the change of helix diameter
- Plot the radiation pattern of a normal mode helix antenna.

BRIEF INFORMATION ABOUT THE NORMAL MODE HELIX ANTENNA:

Helix or helical antennas include a metal wire wound into a helical shape over a ground plane as shown in Figure 1. A helix radiates in different modes depending on its shape and frequency. There are three well-known modes; normal mode, axial mode and conical mode. Each mode has different characteristics. Figure 1 shows that the normal mode has omnidirectional, axial mode has directional and conical mode has multi-lobe radiation characteristics.

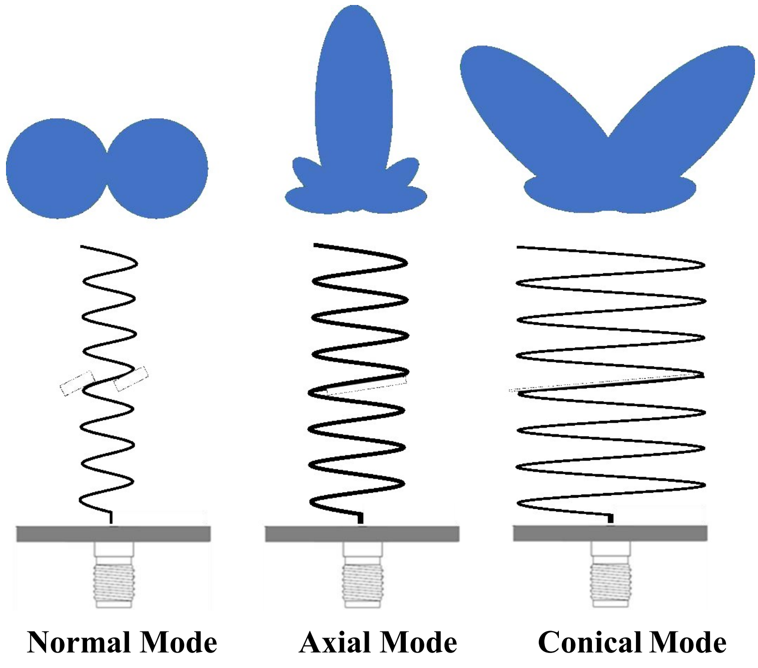


Figure 1 Modes of helix antennas

If the diameter of the helix is small enough compared to the wavelength, its maximum radiation is in the same direction with the normal of the helix axis. This type of antenna is called normal mode helix antenna (NMHA). NMHA is often used as a short version of a monopole antenna. The total wire length of the wire used in helix is theoretically 0.25 λ. The electrical total wire length of the helix antenna is expected to be longer than 0.25 λ because of the low efficiency characteristics of the antenna.

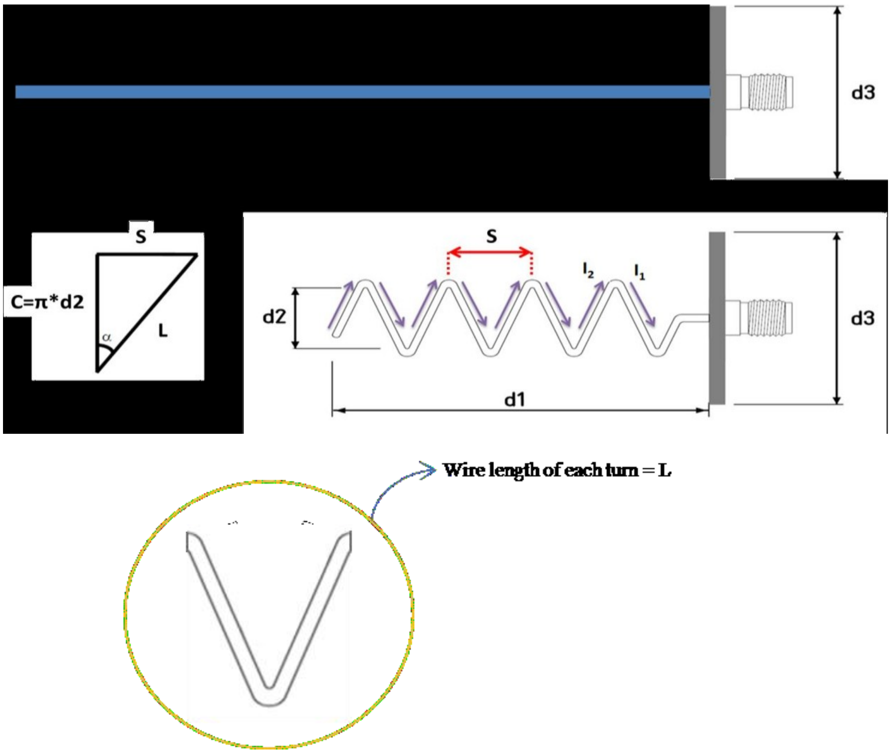


Figure 2 Monopole Antenna and Normal Mode Helix Antenna

Figure 2 shows monopole and normal mode helix antennas. The total wire length is equal to monopole height, where the helix height (d1) is shorter than the monopole. Due to the winding of the wire, the current distribution on the helix has a horizontal component besides the vertical component. I_1 and I_2 are currents on the helix; the horizontal components of the helix cancel each other in the far-field when the loop is small. As a result, the radiation pattern of the helix antenna only has vertical components. That is why its radiation pattern is similar to the monopole antenna.

d1: Helix height
d2: Helix diameter
d3: Ground plane diameter
S: Space between turns

C: Circumference of loop
L: Wire Length of each turn
n: Number of turns
T: Total wire length
α: pitch angle

The wire length at each turn can be calculated with (1)

$$L = \sqrt{S^2 + C^2} \tag{1}$$

And the total wire length is

$$T = n.L \tag{2}$$

The helix height is

$$d1 = n.S \tag{3}$$

$$\alpha = \arctan S/C \tag{4}$$

The design process starts with the total length T = 0.25 λ and the unknowns in equations (1), (2), (3) and (4) are calculated with the known parameters. For example, if there is a height, diameter and pitch angle limit of the antenna, then the number of turns will be calculated with the formulas and that will be the initial point. Normal mode helix antenna calculation is not practically useful, but it is generally used to find the initial dimensions.

If α= 90°, the helix becomes a monopole and if α= 0°, it becomes an n-turn loop antenna. Therefore, the helix must have a pitch angle between 0° and 90°. The helix antenna has an equivalent model of consisting of a wire (dipole antenna) and an n-turn loop as shown in Figure 3. If the total wire length stays the same and pitch angle increases, the loop becomes smaller and the length of the helix becomes longer. Thus, the radiation characteristics get closer to the radiation characteristics of a monopole. If the total wire length stays the same and pitch angle decreases, the loop becomes larger and the length of the helix becomes shorter. Thus, the radiation characteristics get closer to the radiation characteristics of a loop. The equivalent models of the antennas help us to understand the working principle of the antenna easier.

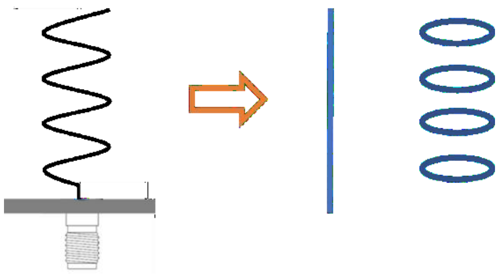


Figure 3 Normal Mode Helix Antenna Equivalent Model

In general, the impedance of the helix antenna is not appropriate to match 50 ohms. S_{11} may be far away from -10 dB but it is possible to see the center frequency even if the antenna is not matched. Matching circuits are used in order to match the NMHA to 50 ohms. In this experiment, there is no matching circuit. The change in the center frequency will be observed. We will be interested in the first resonance, and the first resonance may be between -3 dB to -6 dB S_{11} level.

EXPLANATION ABOUT DESIGNING NORMAL MODE HELIX ANTENNA WITH ANTEN'IT:

The box in Figure 4 is the normal mode helix antenna (NMHA) kit. We will build two normal mode helix antennas with different pitch angles in this experiment. The first helix antenna is called NMHA-1 where the second one is NMHA-2. Each experiment has its own dielectric and metal feed cells. The dielectric feed cells and feed metal cells of NMHA-1 are in the same division of the box (NMHA-1 Feed Cells). Similar to that, the dielectric feed cells and feed metal cells of NMHA-2 is in the same division of the box (NMHA-2 Feed Cells). The dielectric cells in this experiment are used as spacers.

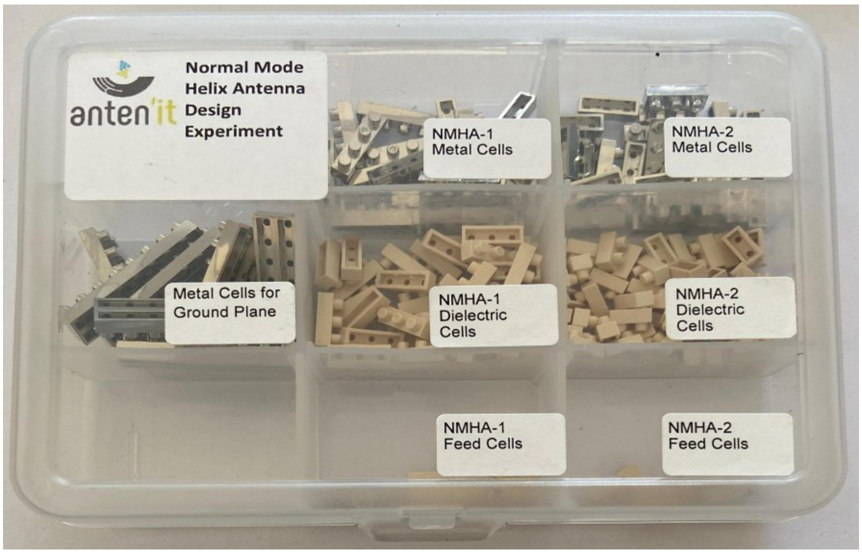
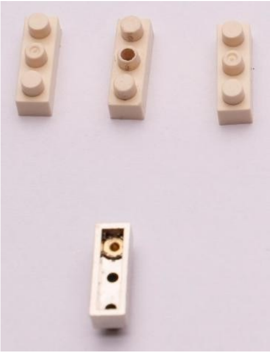
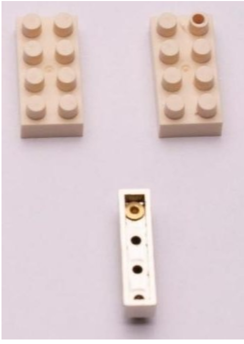


Figure 4 NMHA Experiment box

Figure 5a shows the dielectric and metal feed cells of NMHA-2. One of the dielectrics has a hole. This hole must be located over the inner conductor pin of the connector. The inner conductor goes through this dielectric cell and touches the insert in the metal feed cell. The insert of the metal feed cell can be seen in Figure 5a. Similar to that, Figure 5b shows the dielectric and metal cells of NMHA-1. The inner conductor of the connector needs to go through the hole in the dielectric feed cell and touch the insert of the metal feed cell.



a) Dielectric and metal feed cells of NMHA-2



b) Dielectric and metal feed cells of NMHA-1

Figure 5 Dielectric and metal feed cells of NMHA kit

<u>Normal Mode Helix Antenna Design with Anten'it AntennTraining Kit</u>

The smallest Anten'it cell has 5 mm (height) X 4 mm (length) X 4 mm (width) dimensions as in Figure 6. The cubic part of Anten'it metal cells is 3 mm, and the top cylinders have 2 mm height. Although the total height is 5 mm, 2 mm interlaces to another cell, and the height resolution is 3 mm. Figure 6 shows the dimensions of a 1X1 metal cell. The dimensions of other cells are multiples of 1X1 dimensions. Therefore, the dimensions of the helix antenna must be in 4 mm steps in length and width and 3 mm steps in height. Dielectric cells with 2.6 dielectric constant are used as spacers in order to have a mechanically durable structure.

The physical dimension calculations for Anten'it helix have a different method compared to the conventional helix antenna.

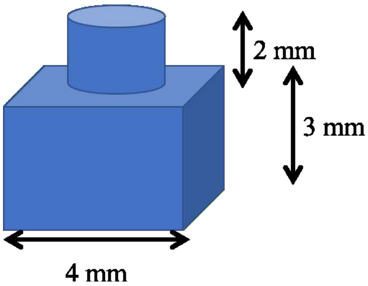


Figure 6 Anten'it cell dimensions

Calculation for NMHA-1 with 16 mm side length

The outer diameter (it is not the diameter, but the side length of the square) of helix is 16 mm (<< λ) which is appropriate for this kit. There is no real diameter in the antenna built with Anten'it, because the smallest cell is in square form. The inner circumference of the square is 4 times 8 mm which is equal to 32 mm.

C = 32 mm

It is also possible to calculate the wire length of each 1X4 metal cell just by adding 8 mm (length) to 3 mm (height) which is 11 mm. Therefore, each 1X4 metal cell creates a wire length of 11 mm to the helix antenna.

L= 11 mm

The dielectric feed cell height is 3 mm. Thus, the total wire length calculation must be

T = 3 mm + (number of 1X4 cells) X 11 mm (5)

Calculation for NMHA-2 with 9 mm side length

The outer diameter (it is not the diameter, but the side length of the square) of helix is selected as 9 mm (<< λ) which is appropriate for this kit. There is no real diameter in the antenna built with Anten'it, because the smallest cell is in square form. The inner circumference of the square is 4 times 4 mm which is equal to 16 mm. (If you wish to simulate a helix and compare the results, the comparison should be with a diameter of C/π.)

C = 16 mm

It is also possible to calculate the total wire effect of each 1X3 metal cell just by adding 4 mm (length) to 3 mm (height) which is 7 mm. Therefore, each 1X3 metal cell creates a wire length of 7 mm to the antenna.

L= 7 mm

The feed cell (dielectric cell between ground plane and the first 1X3 metal cell) height is 3 mm. Thus, the total wire length calculation must be

T = 3 mm + (number of 1X3 cells) X 7 mm (6)

Removing the cells:

Removing the cells is one of the most important parts to learn. The misusage can damage the kits. There are some removing tools in the kit and the tool must be selected depending on the cell type. Each cell needs to be used gently.

In this experiment, use your hands to remove the cells. If you try to remove the cells with your hands for some trial but you can't remove, then use the special removing plier for the cells. Figure 7 shows the removing plier and its special head.

In case, you must use the removing plier, you need to use it 90 degrees to the top cylinder of the cells. If the cell has a larger dimension, then use the cylinder at the center. If you can’t remove the cell easily, change to another top cylinder. Figure 8 shows an example usage of the removing plier.

a) b)

Figure 7 Removing Plier

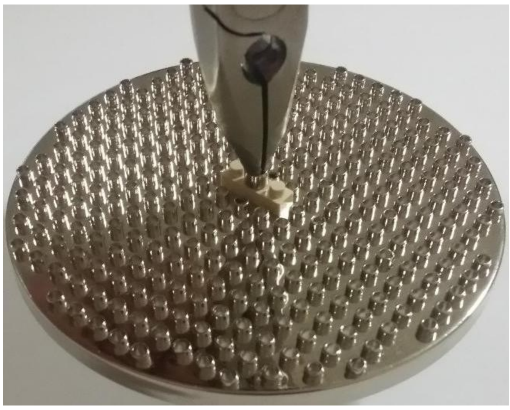


Figure 8 The usage of removing plier

<u>Construction of the ground plane for this experiment</u> (The same ground plane will be used for axial mode helical antenna)

There are 3 pieces of 20X20 ground planes without holes and 1 piece of 20X20 with holes with a connector mounted for this experiment. Please build the ground plane starting from connecting the 20X20 ground plane with holes and a 20X20 ground plane without holes. Then connect both 4 plates into each other as shown in Figure 9. The connection pieces in the photo are 2X8 metal cells (See in Figure 4 “Metal Cells for Ground Plane”). But other dimensions such as 2X4 or 2X2 can also be used for the connection. These pieces are for electrical and mechanical connection. It is important to build this structure before starting the experiment because you need a mechanically rigid structure during the experiment.

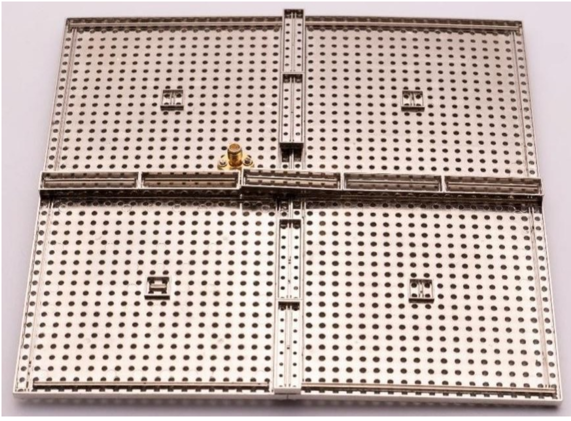


Figure 9 Ground Plane Connection

Hint 1: Start locating the metal cells from the edges by aligning the edges first.

Hint 2: If you can't have a rigid ground plane structure, you can also use metal or dielectric connection cells on the top side of the ground plane as shown in Figure 10.

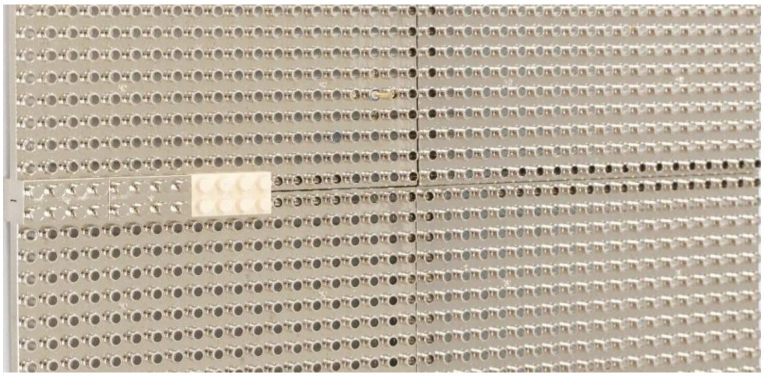


Figure 10 Ground Plane Connection Hint

PRELIMINARY WORK:

1. What are the techniques to shorten a monopole antenna?
2. Explain how normal mode helix antenna works
3. Show E-plane and H-plane of NMHA?
4. What are the advantages and disadvantages of NMHA compared to monopole antenna?

5. Which parameters affect the center frequency of NMHA?

EXPERIMENTAL PROCEDURE:

6. Connect the cable to the Network Analyser and connect the SSMA-Female to SMA-Male adapter to the SSMA-male side of the cable as shown in Figure 11.

Figure 11 Cable to SSMA-SMA Adaptor Connection

7. Calibrate the Network Analyser for 1 port measurement between 400 MHz to 1500 MHz.
8. Disconnect the SSMA to SMA adaptor after the calibration as shown in Figure 12.

Figure 12 Disconnect the cable from SSMA-SMA Adaptor

9. Locate the beige dielectric cells (2.6 dielectric constant) above the ground plane. Locate the metal cells above the dielectric cells. The hole must be above the pin of the connector. Locate 1X3 dielectric cells above the 2X4 cells as shown in Figure 13.

Figure 13 Dielectric cells above the ground plane

10. The feed cell has a special connection insert (as explained in section 3). This connection insert needs to be located above the pin. The mounted feed cell is shown in Figure 14.

Figure 14 Feed cell location over the dielectric cells

11. Use a multi-meter or voltmeter in order to check if the inner conductor of the connector is connected to the feed cell. Turn the multi-meter to "short" buzzer (Figure 15) option. With one probe touch the inner conductor of the SSMA connector from the bottom of the plate and with the other probe touch to the feed cell. If the buzzer is ringing, they are connected to each other, and we are ready for the experiment.

Figure 15 Buzzer

12. Use 1X4 metal cells for building the antenna.

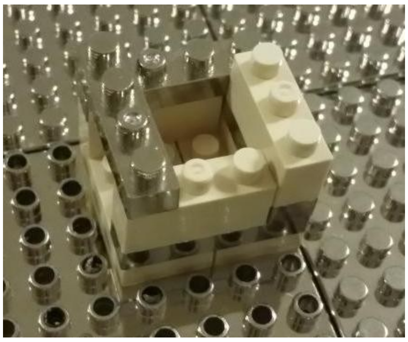


Figure 16 First turn of the helix

13. Connect the cable to the connector at the ground plane of the NMHA as shown in Figure 17.

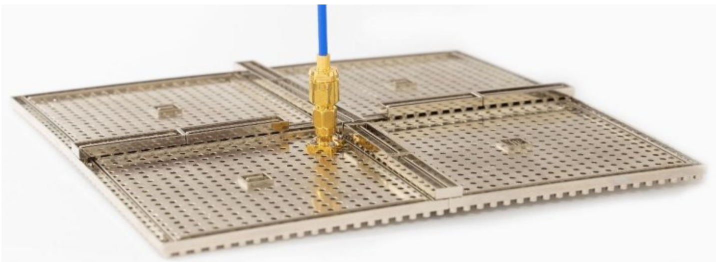


Figure 17 Connection to the connector at the ground plane of the NMHA

14. Calculate the NMHA-1 total wire length and number of cells via T= 0.25 λ and Equation 5 for 692 MHz. Write the calculated values below:

Calculated Total wire length for NMHA-1:	
Nearest length which is possible with Anten'it:	
Number of cells (1X4) Required:	

15. Locate the 1X4 metal cells and 1X3 dielectric cells in order to build the NHMA-1 with the calculated values.
16. Display S_{11} dB scale on the network analyser screen. Measure S_{11} in dB scale. Write down the center frequency of the initial design

Initial NMHA-1 Center frequency:	
NMHA-1 Return Loss:	

17. Add or remove metal cells to reach the target frequency (S parameters won't be below -10 dB but you can catch the resonance.). When you reach the target frequency, write down the total wire length of your design using equation 5. Write down the center frequency. Calculate the pitch angle using equation 5. Use the circumference of the square at the inner part of the helix for the pitch angle calculation.

NHMA-1 total wire length:	
NHMA-1 center frequency:	
NHMA-1 pitch Angle:	

18. Remove all metal and dielectric pieces from the ground plane.

19. Locate the 1X3 feed dielectric cell with a hole above the inner conductor of the connector. Locate 2 more 1X3 feed dielectric cells near that cell. Locate the 1X3 feed metal cell above the inner conductor pin. Be careful to locate the insert of the feed cell above the pin. The NHMA-2 experiment needs to start as in Figure 18.

Figure 18 NMHA-2 above the ground plane.

20. Use a multi-meter or voltmeter in order to check if the inner conductor of the connector is connected to the feed cell. Turn the multi-meter to "short" buzzer option. With one probe touch the inner conductor of the SSMA connector from the bottom of the plate and with the other probe touch to the feed cell. If the buzzer is ringing, they are connected to each other, and we can start the experiment.

21. Calculate the NMHA-2 total wire length via T= 0.25 λ and number of cells via Equation 6 for 692 MHz. Write the calculated values below:

Calculated Total wire length for NMHA-2:	
Nearest length which is possible with Anten'it:	
Number of cells (1X3) Required:	

22. Locate the 1X3 metal cells and 1X2 dielectric cells in order to build the NHMA-2 with the calculated values.
23. Display S_{11} dB scale on the network analyser screen. Measure S_{11} in dB scale. Write down the center frequency of the initial design

Initial NMHA-2 center frequency:	
NHMA-2 return Loss:	

24. Add or remove metal cells to reach the target frequency. Calculate the total wire length of your design using equation 6. Write down the center frequency. Calculate the pitch angle using equation 5. Use the circumference of the square at the inner part of the helix for the calculation.

NHMA-2 total wire length:	
NHMA-2 center frequency:	
NHMA-2 pitch Angle:	

25. Measure the E-plane (Elevation) of the NMHA-2 at the center frequency of the antenna with a turn table. If the turn table is manual, write down the power levels for each E-plane angle. Normalize the power levels to the peak level.

E-plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		

150		
180		
210		
240		
270		
300		
330		

26. Sketch the normalized power levels in E-plane axis on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

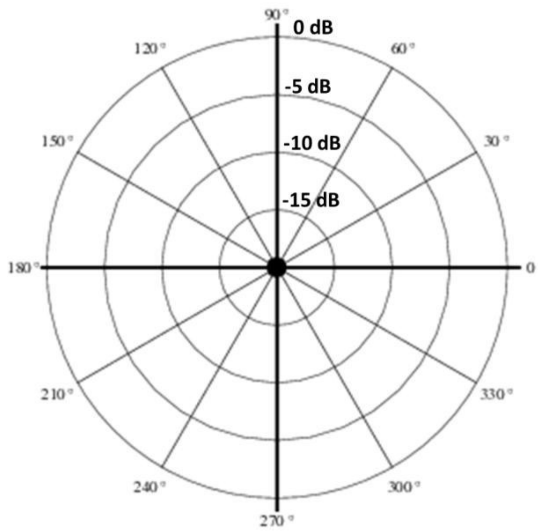


Figure 19 E-Plane Pattern of the NMHA-2 in Polar Coordinates

27. Measure the H-Plane (Azimuth) pattern of the NMHA-2 with a turn table. If the turn table is manual, write down the power levels for each H-plane angle. Normalize the power levels to the peak level.

H-Plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		
150		

180		
210		
240		
270		
300		
330		

28. Sketch the normalized power levels in H-plane on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

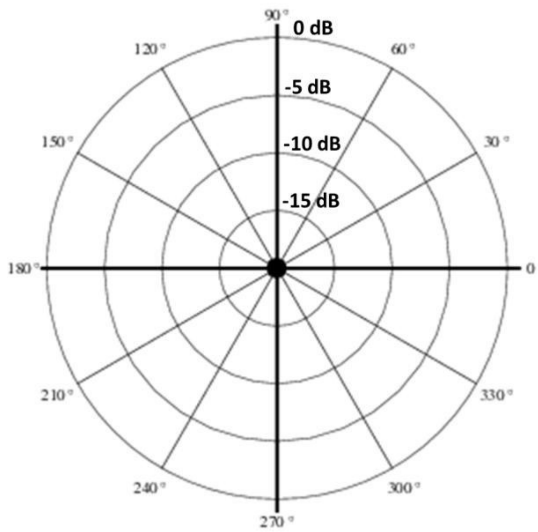


Figure 20 H-Plane Pattern of the NMHA-2 Antenna in Polar Coordinates

RESULTS:

- State the objective of the experiment and give a short summary of the procedure.
- Compare the S_{11} values of NMHA-1 and NMHA-2. How can you explain the difference?
- Why is there a difference between NMHA-1 and NMHA-2?
- Compare the theory and experimental results.
- Discuss the results of your experiment.

4-AXIAL MODE HELICAL ANTENNA DESIGN EXPERIMENT

OBJECTIVES

- To become familiar with the helical antenna.
- Design an axial mode helical antenna for a specific frequency.
- To investigate the characteristics of axial mode helical antenna.
- To learn the parameters of a directive antenna
- To learn polarization types.

BRIEF INFORMATION ABOUT THE AXIAL MODE HELIX ANTENNA:

Helix or helical antennas include a metal wire wound into a helical shape over a ground plane as shown in Figure 1. A helix radiates in different modes depending on its shape and frequency. There are three well-known modes; normal mode, axial mode and conical mode. Each mode has different characteristics. Figure 1 shows that the normal mode has omnidirectional, axial mode has directional and conical mode has multi-lobe radiation characteristics.

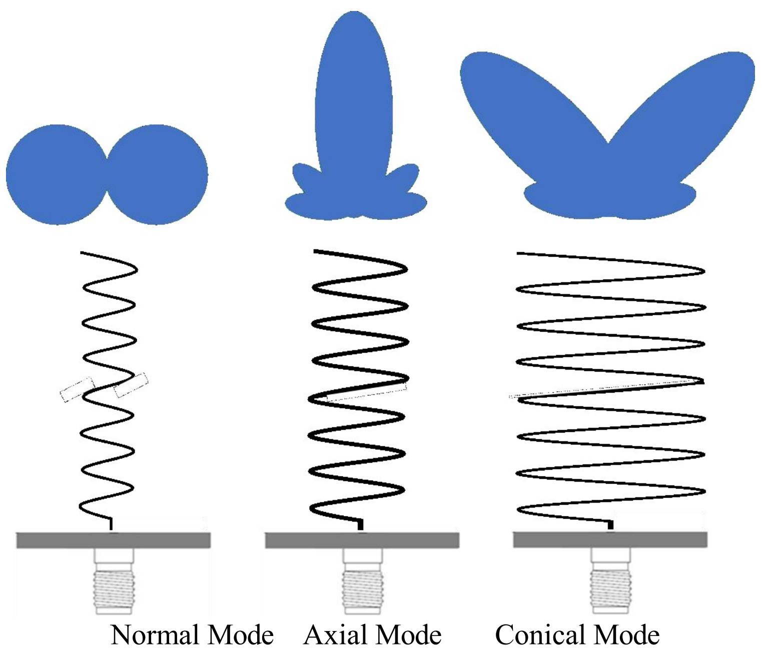


Figure 1 Modes of helix antennas

Axial mode helical antenna has some interesting specifications such as wide impedance bandwidth, directive radiation pattern and circular polarization. The circular polarization can be left hand or right hand. Depending on the polarization type, the antenna can be constructed such a left-hand screw wound or right-hand screw wound. When the diameter of the helix is not electrically small, the horizontal components of the current do not cancel each other in the far field. The current on the helix creates a circular polarization if the circumference (C) is in the order of one wavelength. This type of operation is different from normal mode helix antenna which acts like a small monopole. The circular polarized radiation pattern also becomes directive. The directivity changes depending on the number of turns (n) and spacing (S). The directive pattern of the axial mode produces maximum radiation along the helix axis. Figure 2 shows the parameters of a typical helix.

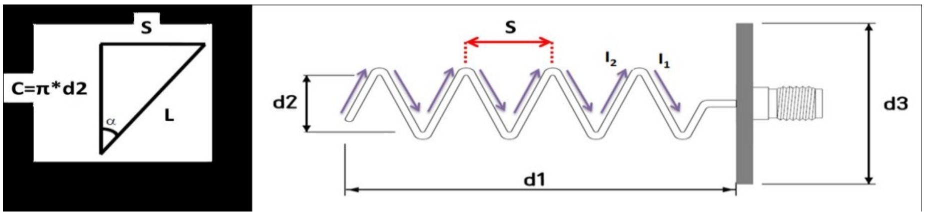
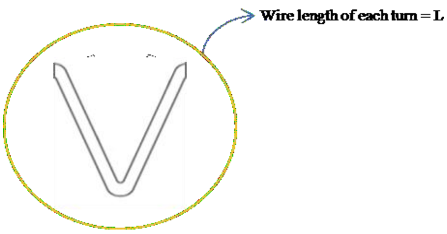


Figure 2 Axial Mode Helix Antenna



d1: Helix height
d2: Helix diameter
d3: Ground plane diameter
S: Height between turns
C: Circumference of loop
L: Wire Length of each turn
N: Number of turns
T: Total wire length
α: pitch angle

The wire length at each turn can be calculated with (1)

$$L = \sqrt{S^2 + C^2} \quad (1)$$

And the total wire length is

$$T = N.L \quad (2)$$

The helix height is

$$d1 = N.S \quad (3)$$

$$\alpha = \arctan S/C \quad (4)$$

There are also some empirical formulas related to the axial mode helical antenna. D is the directivity of the antenna.

$$D = 15N\frac{C^2 S}{{\lambda_0}^2} \quad (5)$$

Equation 5 shows us the circumference; spacing and number of turns are the important parameters to determine the directivity of the axial mode helical antenna.

AR represents the axial ratio. It is directly related to the number of turns. As the number of turns increase, the axial ratio will be close to 1 which means that the polarization is perfectly circular.

$$AR = \frac{2N+1}{2N} \quad (6)$$

The axial ratio in circular polarization is a ratio between the amplitude of two orthogonal components of E-field. The larger component is divided by the smaller in order to get the axial ratio. A perfect axial ratio means E-field components are equal and the axial ratio is 1 which corresponds to 0 dB in dB scale. 3 dB axial ratio is a commonly used parameter for most of the circular polarized antennas. Depending on the application, the need for the axial ratio may change. The bandwidth of the axial ratio is another parameter of the axial mode helical antenna. It refers to the frequency range where the axial ratio is below 3 dB.

Bandwidth for Wideband Antennas:

We used percentage bandwidth in the previous experiments. This parameter is used well for resonance antennas. But it is not appropriate to explain the bandwidth of wideband antennas. Therefore, another ratio called bandwidth ratio (Equation 7) is used for wideband antennas. f_H shows the highest and f_L shows the lowest frequency of the bandwidth. For example, if an antenna works between 0.8-2.4 GHz, then the bandwidth ratio is 3:1.

$$\text{Bandwidth Ratio} = f_H : f_L \quad (7)$$

EXPLANATION ABOUT DESIGNING AXIAL MODE HELIX ANTENNA WITH ANTEN'IT:

The box in Figure 3 is the axial mode helix antenna (AMHA) kit. We will build two axial mode helix antennas with different number of turns in this experiment. The effect of the number of turns over the gain and axial ratio of the antenna will be experimented. There are dielectric and metal cells with different dimensions. The feed cells include only one feed metal cell and one dielectric cell which are shown in Figure 10.

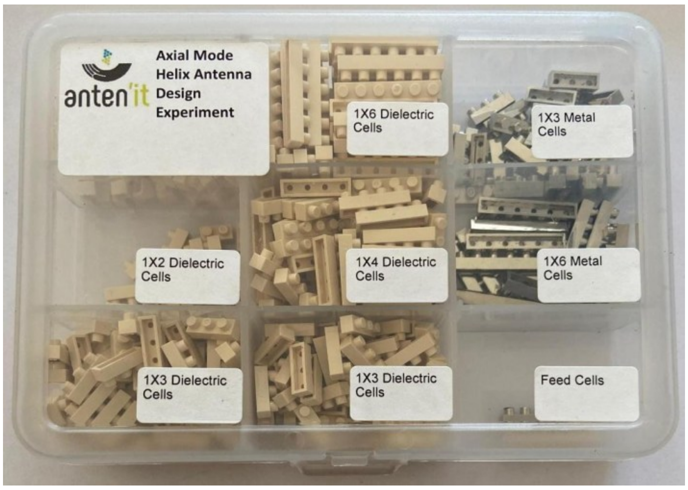


Figure 3 Axial Mode Helix Antenna Experiment Box

Removing the cells:

Removing the cells is one of the most important parts to learn. The misuse can damage the kits. There are some removing tools in the kit and the tool must be selected depending on the cell type. Each cell needs to be used gently.

In this experiment, use your hands to remove the cells. If you try to remove the cells with your hands for some trial but you can't remove, then use the special removing plier for the cells. Figure 4 shows the removing plier and its special head.

In case you must use the removing plier, you need to use it 90 degrees to the top cylinder of the cells. If the cell has a larger dimension, then use the cylinder at the center. If you can't remove the cell easily, change to another top cylinder. Figure 5 shows an example usage of the removing plier.

a) b)

Figure 4 Removing Plier

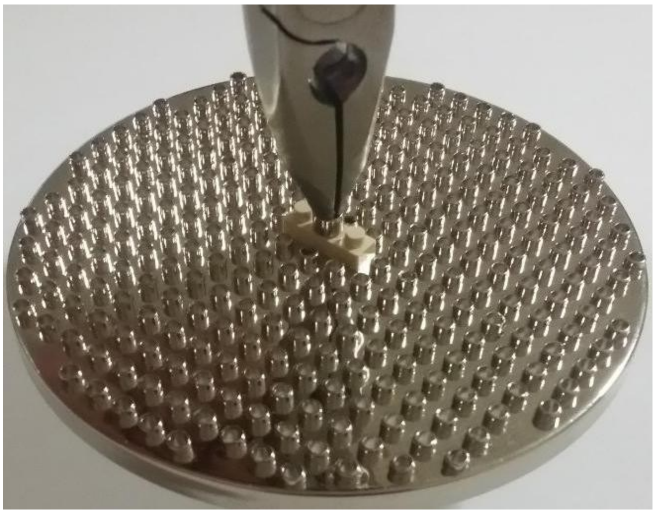


Figure 5 The usage of removing plier

<u>Constructions of the ground plane for this experiment</u> (If you already have the ground plane for normal mode helix antenna, use the same configuration and skip this part.)

- You need to use the "metal cells for ground plane" in <u>NMHA Kit</u> for this construction.

There are 3 pieces of 20X20 ground planes without holes and 1 piece of 20X20 with holes with a connector mounted for this experiment. Please build the ground plane starting from connecting the 20X20 ground plane with holes and a 20X20 ground plane without holes. Then connect both 4 plates into each other as shown in Figure 6. The connection pieces in the photo are 2X8 metal cells. But other dimensions such as 2X4 or 2X2 can also be used for the connection. These pieces are for electrical and mechanical connection. It is important to build this structure before starting the experiment because you need a mechanically rigid structure during the experiment.

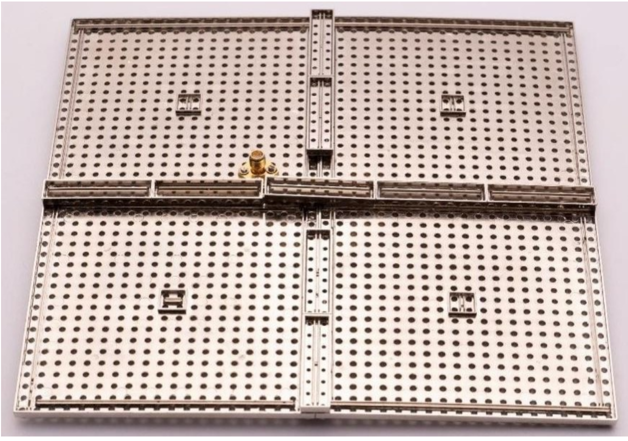


Figure 6 Ground Plane Connection

<u>Hint:</u> If you can't have a rigid ground plane structure, you can also use metal or dielectric connection cells on the top side of the ground plane as shown in Figure 7.

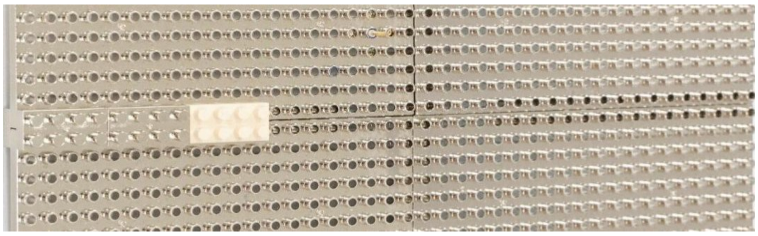


Figure 7 Ground Plane Connection Hint

PRELIMINARY WORK:

1. State the differences between axial mode and normal mode helical antennas.
2. What is the relation between the circumference of the antenna and radiation type (omnidirectional, directional)?
3. What is co-polarization and cross-polarization? Explain them.
4. What is circular polarization? What are the differences between linear and circular polarization?
5. How do we decide the polarization type? What are the applications of circular polarization?
6. Is there an axial ratio parameter in a linear polarized antenna?
7. How can we measure the axial ratio?
8. What is half power beamwidth (HPBW) of an antenna?

EXPERIMENTAL PROCEDURE:

9. Connect the cable to the Network Analyser and connect the SSMA-Female to SMA-Male adapter to the SSMA-male side of the cable as shown in Figure 8.

Figure 8 Cable to SSMA-SMA Adaptor Connection

10. Calibrate the Network Analyser for 1 port measurement between 1000 MHz to 6000 MHz.
11. Disconnect the SSMA to SMA adaptor after the calibration as shown in Figure 9.

Figure 9 Disconnect the cable from SSMA-SMA Adaptor

12. Locate the 1X6 feed dielectric cell above the ground plane. The hole must be above the pin of the connector. See the feed metal cell in Figure 10. The feed metal cell has a connection insert in it. This connection insert needs to be located above the pin.

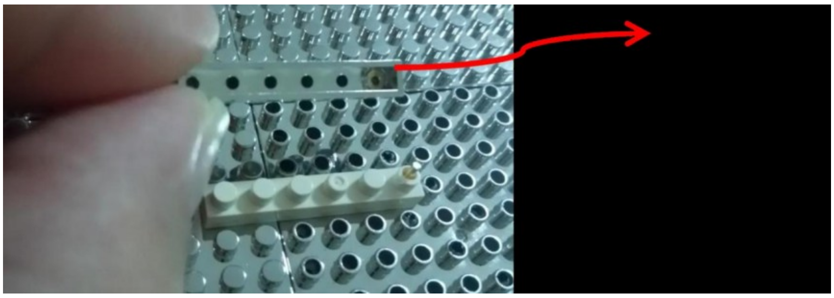


Figure 10 Feed metal cell special insert and feed dielectric cell

13. Locate the dielectric cells as in Figure 11. Use 1X1, 1X2, 1X3, 1X4 and 1X6 dielectric cells. Use the 1X2, 1X4, 1X3 and 1X6 cell dimensions for spacers. Locate the feed metal cell above the feed dielectric cell.

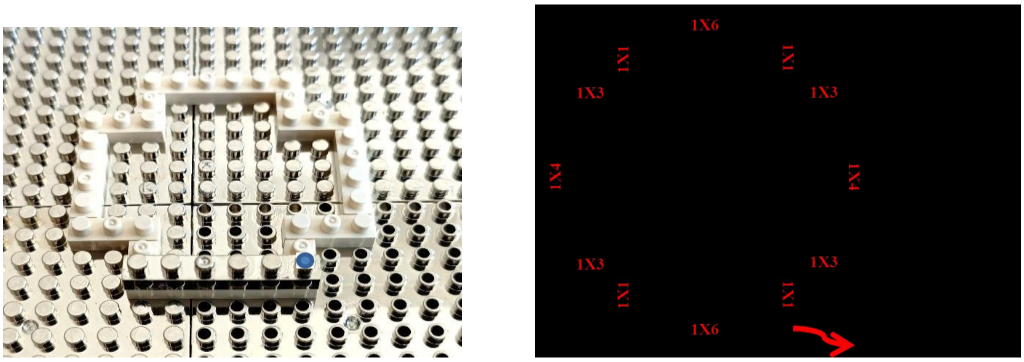


Figure 11 Dielectric cells connected above the ground

14. Use a multi-meter or voltmeter in order to check if the inner conductor of the connector is connected to the feed cell. Turn the multi-meter to "short" buzzer option. With one probe touch to the inner conductor of the SSMA connector from the bottom of the plate and with the other probe touch to the feed cell. If the buzzer is ringing, they are connected to each other and the connection is ready for the experiment.

Figure 12 Buzzer

15. Locate the dielectric and metal cells in order to build the first turn for left hand circular polarization (LHCP). The dielectric cells are used as spacers for this experiment.

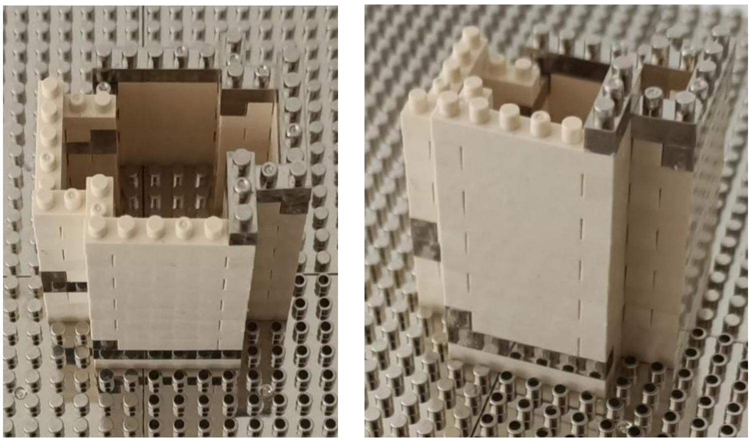


Figure 13 First turn of the AMHA-1

16. Calculate the following values:

Inner Circumference for AMHA-1:	
Calculate the corresponding frequency of the inner circumference:	
Measure the spacing (S):	
Calculate the number of turns (N) for 8.5 dBi directivity:	
Calculate the axial ratio [dB] for the number of turn:	

17. Build the antenna with the calculated number of turns.
18. Connect the cable to the connector at the ground plane of the AMHA as shown in Figure 14.

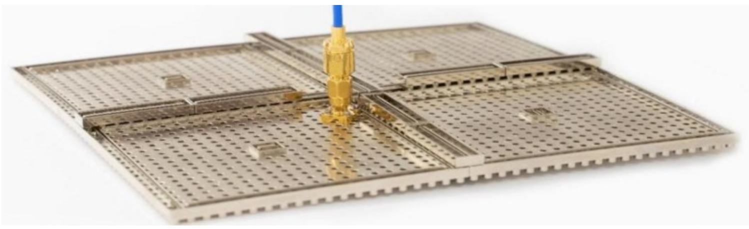


Figure 14 Connection to the connector at the ground plane of the AMHA

19. Display S_{11} dB scale on the network analyser screen. Measure S_{11} in dB scale. Write down the frequency range of the design.

AMHA frequency range:	

AMHA bandwidth ratio:	

20. Measure the E-plane (The direction of E-field is circular for this antenna, so there is no real E-plane. But we need to select one of the orthogonal planes as E-plane and the other one as H-plane for the measurement) of the AMHA at the center frequency of the antenna with a turn table. If the turn table is manual, write down the power levels for each E-plane angle. Normalize the power levels to the peak level. Use the frequency calculated in step 8.

E-plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		
330		

21. Sketch the normalized power levels in E-plane axis on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

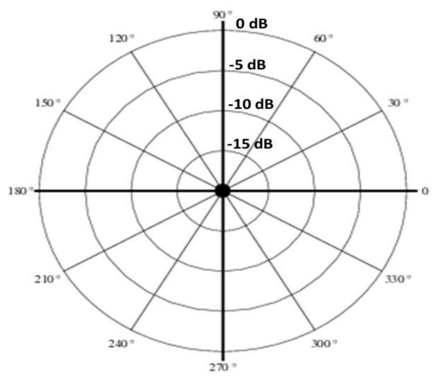


Figure 15 E-Plane Pattern of the AMHA in Polar Coordinates

22. Measure the H-Plane pattern of the AMHA with a turn table. If the turn table is manual, write down the power levels for each H-plane angle. Normalize the power levels to the peak level. Use the frequency calculated in step 8.

H-Plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		
330		

23. Sketch the normalized power levels in H-plane on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

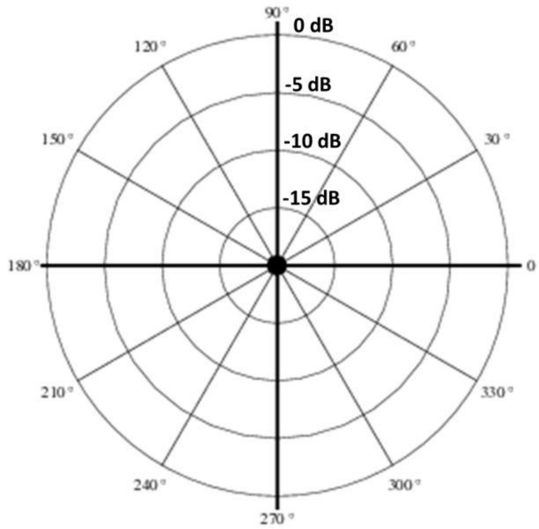


Figure 16 H-Plane Pattern of the Monopole Antenna in Polar Coordinates

24. Write down the measured gain and HPBW in both planes.

AMHA gain:	
AMHA E-Plane HPBW:	
AMHA H-Plane HPBW:	

25. Measure the axial ratio of the antenna at the frequency calculated in step 8, at the lowest frequency and the highest frequency.

Axial Ratio at the lowest frequency:	
Axial Ratio at the design frequency (Step 8):	
Axial Ratio at the highest frequency:	

26. Add one more turn to the AMHA-1 and calculate the following values for the new AMHA-2.

AMHA-2 directivity:	
Calculate the axial ratio [dB] for AMHA-2:	

27. Measure the gain and axial ratio of AMHA-2.

AMHA-2 gain:	
AMHA-2 Axial Ratio:	

28. Connect the AMHA-2 and measure S_{11} of the new configuration.

AMHA-1 frequency range:	

RESULTS:

- State the objective of the experiment and give a short summary of the procedure.
- Is there a difference of the calculated and measured axial ratio values? Explain why.
- Have you ever heard about Axial Ratio Bandwidth? Explain the different axial ratios at different frequencies (Step 17).

- Is there any difference between the measured frequency range values of AMHA-1 and AMHA-2 ? Explain why.
- Is there any difference between the gain values of AMHA-1 and AMHA-2? Explain why.
- Is there any difference between axial ratio values of AMHA-1 and AMHA-2? Explain why.
- Compare the theory and experimental results
- Discuss the results of your experiment

5-PATCH ANTENNA DESIGN EXPERIMENT

OBJECTIVES

- To become familiar with the patch antenna.
- To investigate the characteristics of microstrip patch antenna.
- Designing a patch antenna using Anten'it antenna design kit.

BRIEF INFORMATION ABOUT THE PATCH ANTENNA:

Patch antenna is a directive and narrow band antenna. There are three layers in a patch antenna. They are ground planes, dielectric and patch layers. Patch is a metal plate which radiates. The dielectric layer can either be air or a dielectric substrate due to the mechanical or electrical requirements. The feed is positioned between the ground plane and the patch. The inner conductor of the connector contacts the patch where the outer conductor of the connector contacts the ground plane.

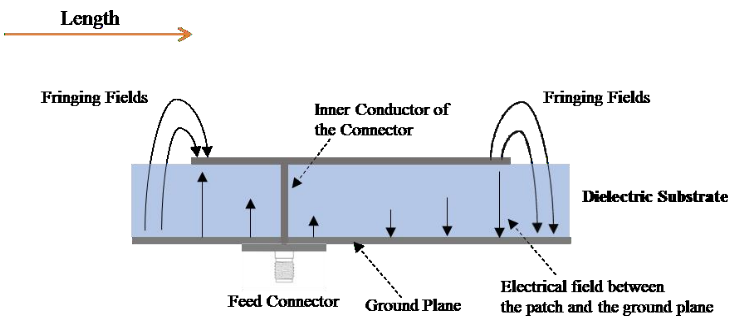


Figure 1 Patch antenna explanation

Figure 1 shows a patch antenna with a dielectric substrate. The electrical field is between the patch and the ground plane. These electrical fields store energy in between the patch and the ground. We also see electrical fields which are not between two parallel plates. They are called fringing fields. Fringing fields are electrical fields which are at the edges of the patch. They are the only fields which contribute to the radiation in the far field.

The feed on the patch excites the patch and creates the current distribution on the patch surface. Figure 2 shows that the current magnitude is maximum in the middle of the patch along the "length axis". This current distribution occurs at the resonance frequency, and the resonance frequency depends on the physical dimension of the resonant length. The resonant length must be approximately half-wavelength. The width of the antenna can be shorter, longer or at the same dimensions with the length. The width has a less effect at the resonance frequency of the patch antenna. It changes the impedance of the antenna.

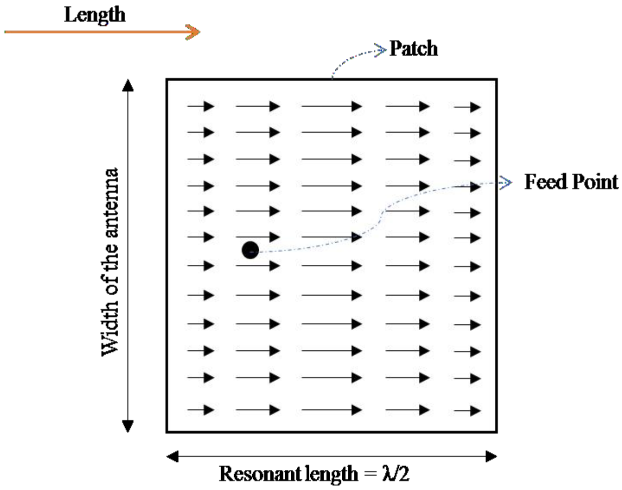


Figure 2 Current distribution on the patch surface

The current distribution on the patch surface can also be shown as in Figure 3. The voltage drops to zero in the middle of the length axis. These two parameters generate the impedance distribution along the length axis. The impedance is high at the edges while it is zero in the middle of the length axis. The high impedance is like an open circuit, and the zero impedance is a short circuit. There is a point which needs to be 50 ohms (Note that the magnitude of the complex impedance is 50 ohms. It is not a pure real 50 ohm.) between the middle and the edge of the patch. Therefore, the movement of the connector must result in difference in antenna impedance.

The feed point is at the center of the width axis for the linear polarized patch antenna. When it is not mounted to the center, it creates different modes on the patch.

The effective dielectric constant and the height of the substrate are two main parameters changing the bandwidth of the patch antenna. We need to select the dielectric material depending on our requirements. The dielectric material has a dielectric constant represented as ε_r. Figure 1 shows that the electrical field between the patch and the ground plane pass through the dielectric material. The resonance frequency of the patch is directly related to the dielectric constant of the substrate as in Equation 1. Patch antenna length is formulized as below:

$$\frac{c/2}{2f_0\sqrt{\varepsilon_{eff}}} \quad (1)$$

If the dielectric constant of the substrate is high, this results in a smaller patch dimension and a narrower bandwidth. There are also more detailed formulas in the literature. Either they or equation (1) can be used to have an initial design (In case other formulas will be used, the height of the substrate is 3 mm.).

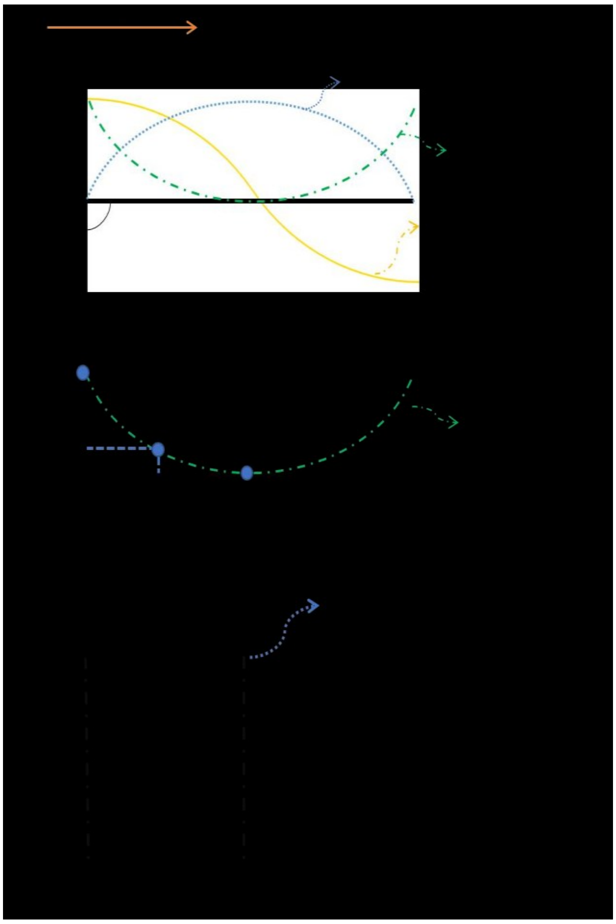


Figure 3 Impedance of the patch antenna

Effective Permittivity:

The electrical field between the patch and the ground is partly in the dielectric substrate and a part of it is into the air. Therefore, the effective permittivity must be smaller than the permittivity of the substrate.

EXPLANATION ABOUT DESIGNING A PATCH ANTENNA WITH ANTEN'IT:

The box in Figure 4 is the patch antenna kit. The "PCB type metal cells" in this kit is totally different from metal cells in other Anten'it kits. The sides of the metal cells are grey in colour. The beige dielectrics have 2.6 dielectric constant (relative permittivity) and blue dielectrics have 4.4 dielectric constant. There are two ground planes with holes in this kit as in Figure 5. The beige dielectric cells are mounted over one of the ground planes, and the blue dielectric cells are mounted to the other ground plane.

Figure 4 Patch Antenna Kit

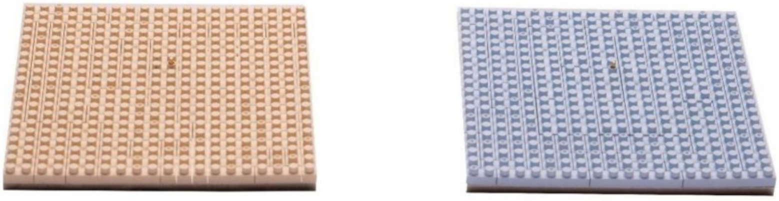


Figure 5 Ground planes with 2.6 and 4.4 dielectric constants

Removing the cells:

Removing the cells is one of the most important parts to learn. The misusage can damage the kits. Do not touch the sides of the PCB type metal cells with another tool except the "Brick Remover" in this kit. Each cell needs to be used gently. Brick remover holds two of the cylinders in the same time. You just need to push to the high end of the remover as in Figure 6.

In this experiment, it is ***forbidden to use the removing plier or any other tool unless it is advised by Anten'it***.

The removing tool for this experiment is a plastic remover. In order to get the best efficiency, we need to start dismounting the cells from outside. First, remove the smallest PCB type metal cells which are outside. Second, remove the cells which are outside but larger. Third, remove the cells except the feeding cell. Finally, remove the feed cell. Always use the cylinders in the middle to use the remover as in Figure 6.

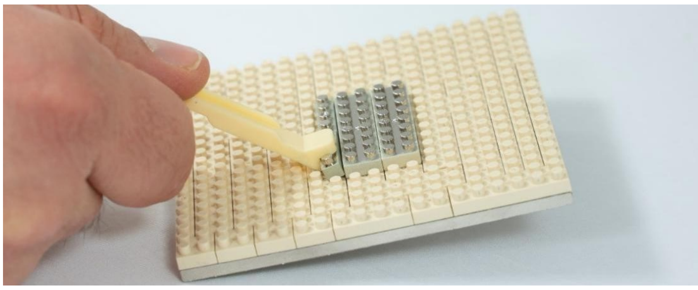


Figure 6 Plastic Remover for Patch Antenna Design Experiment

Patch Antenna Design with Anten'it Antenna Training Kit:

A patch can easily be built with Anten'it kits. We need to know that resolution of the smallest (1X1) piece is 3 mm in height and 4 mm in width and length. Therefore, the results of the calculations must be transformed to the multiples of these values in order to build the antenna. Antenna design is an iterative process; you can iterate by adding or removing new cells to the antenna.

The calculation of height:

The cubic parts of Anten'it metal cells are 3 mm, and the top cylinders are 2 mm height. Although the total height is 5 mm, 2 mm interlaces to another cell, and the height resolution is 3 mm. Figure 7 shows the dimensions of a 1X1 metal cell. The dimensions of other cells are multiples of 1X1 dimensions.

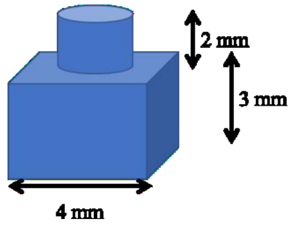


Figure 7 Anten'it cell dimensions

The bandwidth and gain characteristics of two patch antennas will be observed in this experiment. The feed position and impedance relation will also be tested. There are two inserts at the backside of the feed cell in Figure 8 which will help us to see the impedance change during the experiment.

Figure 8 Anten'it PCB type feed metal cell inserts

PRELIMINARY WORK:

1. Explain the probe-fed rectangular patch antenna and its parameters.
2. Explain the effects of the length and width of the patch and the dielectric constant and height of the substrate on the operating frequency of the antenna.
3. Explain the feeding methods of the patch antenna.
4. Explain the effect of the location of the connector.
5. What is the effect of antenna aperture over the directivity of an antenna? Be careful that the aperture – directivity relation is in terms of wavelength.
6. Remember that two parallel plates form a capacitor. Patch antenna has two parallel plates too. Explain the difference.

EXPERIMENTAL PROCEDURE:

7. Connect the cable to the Network Analyser and connect the SSMA-Female to SMA-Male adapter to the SSMA-male side of the cable as shown in Figure 9.

Figure 9 Cable to SSMA-SMA Adaptor Connection

8. Calibrate the Network Analyser for 1 port measurement between 1500 MHz to 3500 MHz.
9. Disconnect the SSMA to SMA adaptor after the calibration as shown in Figure 10.

Figure 10 Disconnect the cable from SSMA-SMA Adaptor

10. Locate the feed metal cell. The red point shows the feed point for this experiment. Locate the third cylinder of the feed metal cell over the inner conductor of the connector as in Figure 11. Locate 1X4 and 1X1 metal cells as in the figure. Do not dismount them during the antenna design.

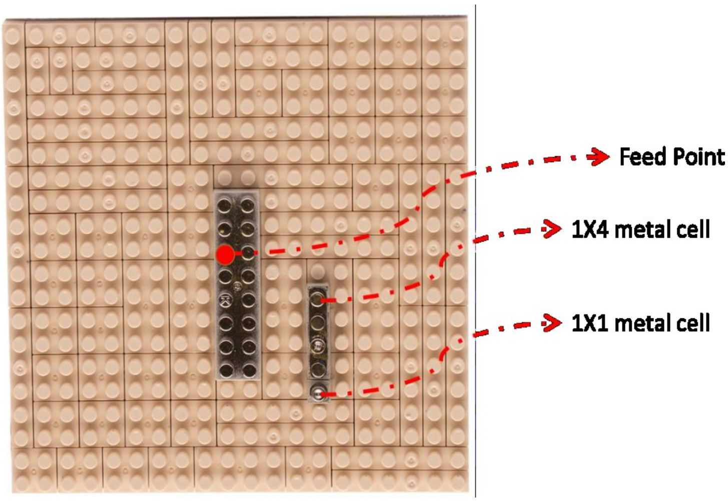


Figure 11 Feed metal cell, 1X4 and 1X1 cell locations for this experiment

11. Use a multi-meter or voltmeter in order to check if the inner conductor of the connector is connected to the feed cell. Turn the multi-meter to “short” buzzer (Figure 12) option. With one probe touch the inner conductor of the SSMA connector from the bottom of the plate and with the other probe touch to the feed cell. If the buzzer is ringing, they are connected to each other, and the connection is ready for the experiment.

Figure 12 Buzzer

12. Calculate the patch antenna dimensions via equation (1) for 2460 MHz (Assume that $=$ $_{ff}$)

Calculated Patch-1 Antenna Length	
Patch-1 Antenna Length with Anten’it	

13. Locate the PCB type metal length in step 4 and connect the antenna to network analyser. Make sure that the feed point is in the center of the “width” dimension of the patch.

14. Measure the S_{11} parameters. Check if the S_{11} of target frequency is below -10 dB. If not, add or remove cells to reach it. Write the center frequency and calculate percentage bandwidth and $_{ff}$ using Eq. (1). Display Smith Chart screen in the network analyser and push the button memory. Keep the data in memory (We will use the data in memory in the next steps).

Patch-1 Measured Center Frequency	
Patch-1 Bandwidth (%)	
$_{ff}$	

15. Turn to logarithmic S_{11} scale again. Add one more row to the end (the farthest side from the feed point) of the patch. Write the center frequency again. Check if the new center frequency fits to the equation (1).

Patch-2 Measured Center Frequency	
Patch-2 Bandwidth (%)	

16. Turn back to Patch-1 antenna configuration in step 8 and change the feed position to the second cylinder of the PCB type feed metal cell (move all PCB type cells in order to feed from the second cylinder of the PCB type metal feed cell).

17. Measure new S_{11} parameters and display Smith Chart screen in the network analyser. See the memory in step 8 and the data. Compare the real impedances on the smith chart. Find the resonance impedance (pure real impedance) for both graphs on the smith chart.

Patch-1 Feed Position-3 Resonance Impedance [ohms]	
Patch-1 Feed Position-2 Resonance Impedance [ohms]	

18. Turn back to Patch-1 antenna configuration by changing the feed position to the third cylinder of the metal cell again.

19. Measure the Patch-1 gain at the center frequency.

Patch-1 Gain [dBi]	

20. Measure the E-plane radiation pattern of the Patch-1 at the center frequency via a turn table. If the turn table is manual, write down the power levels for each E-plane angle. Normalize the power levels to the peak level.

E-plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		
330		

21. Sketch the normalized power levels in E-plane axis on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

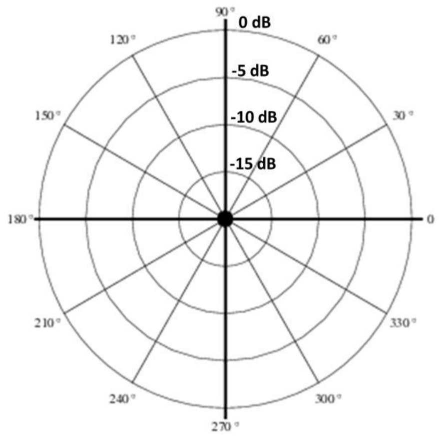


Figure 13 E-Plane Pattern of the Patch-1 in Polar Coordinates

22. Measure the H-Plane pattern of the Patch-1 with a turn table. If the turn table is manual, write down the power levels for each H-plane angle. Normalize the power levels to the peak level.

H-Plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		
330		

23. Sketch the normalized power levels in H-plane on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

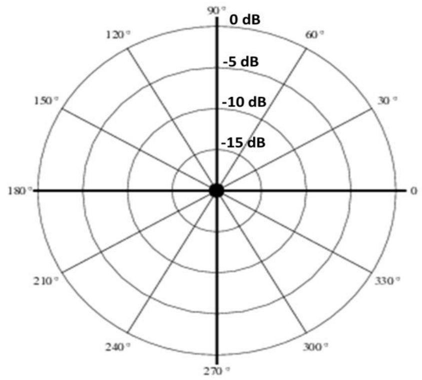


Figure 14 H-Plane Pattern of the Patch-1 Antenna in Polar Coordinates

24. Write down the half power beamwidth (HPBW) both for E and H planes. Calculate the aperture dimensions (Only PCB type metal cell dimensions) in terms of wavelength.

Patch-1 E-Plane HPBW [degrees]	
Patch-1 H-Plane HPBW [degrees]	
Patch-1 Aperture (Length X Width) in terms wavelengths at the center frequency	

25. Make a cross-polarization measurement and observe the change in the power level.

Cross-polarization level :	

26. Remove the PCB type metals. Locate the PCB type metal cells and the feed over the other ground plane with blue dielectrics (4.4 dielectric constant). Build the same configuration as in Patch-1 antenna. New antenna is called Patch-3. Calculate the new center frequency via equation (1).

Calculated Patch-3 frequency	

27. Measure S_{11} parameters for Patch-3 antenna. Write down the center frequency, calculate bandwidth (%) and $_{ff}$.

Measured Patch-3 frequency	

Patch-3 Bandwidth (%)	
ff	

28. Measure the gain of Patch-3 at the measured center frequency.

Patch-3 Gain [dBi]	

29. Measure the E-plane of the Patch-3 at the measured center frequency via a turn table. If the turn table is manual, write down the power levels for each E-plane angle. Normalize the power levels to the peak level.

E-plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		
330		

30. Sketch the normalized power levels in E-plane axis on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

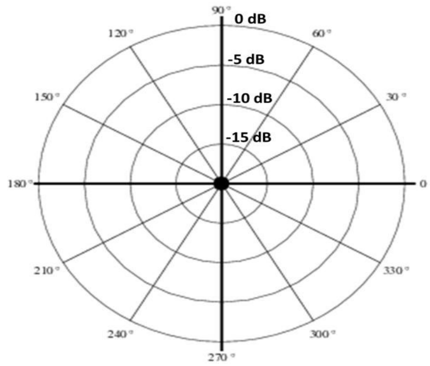


Figure 15 E-Plane Pattern of the Patch-1 in Polar Coordinates

31. Measure the H-Plane pattern of the Patch-3 at the measured center frequency via a turn table. If the turn table is manual, write down the power levels for each H-plane angle. Normalize the power levels to the peak level.

H-Plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		
330		

32. Sketch the normalized power levels in H-plane on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

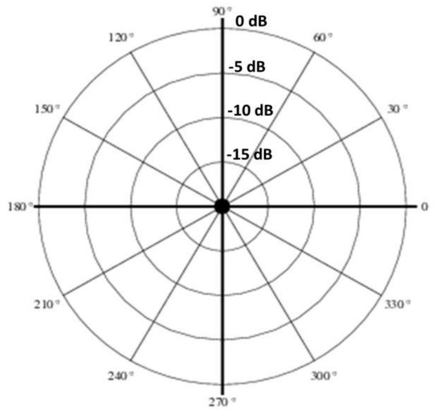


Figure 16 H-Plane Pattern of the Patch-1 Antenna in Polar Coordinates

33. Write down the half power beamwidth both for E and H planes. Calculate the aperture dimensions (Only PCB type metal cell dimensions) in terms of wavelength.

Patch-3 E-Plane HPBW [degrees]	
Patch-3 H-Plane HPBW [degrees]	
Patch-3 Aperture (Length X Width) in terms wavelengths at the measured center frequency	

RESULTS:

- State the objective of the experiment and give a short summary of the procedure.
- Why did you observe a change at the center frequency of Patch-1 antenna when you add or remove new metal cells?
- What is the relation between the aperture size of the antenna in terms of wavelength and antenna gain?
- What is the relation between antenna gain and HPBW?
- How did the impedance change with the change of the feed position? Explain if the results match the theory.
- How did the center frequency, bandwidth (%), HPBW in E and H planes, antenna gain change with the change of the dielectric constant? Explain why. Compare the theory and experimental results.
- Discuss the results of your experiment.

6-PATCH ANTENNA ARRAY DESIGN EXPERIMENT

OBJECTIVES

- To investigate how antenna arrays work
- To investigate the effect of array factor to an array radiation pattern
- To investigate the characteristics of microstrip patch antenna array

BRIEF INFORMATION ABOUT THE THEORY:

Antenna arrays are composed of single antenna elements interacting each other in order to generate a specific function. It provides to synthesize the radiation characteristics of the array pattern with the antenna element radiation parameters and the arrangement configuration of the array.

Antenna elements can be arranged either one or two dimensional. With the arrangement, the overall radiation pattern of the array changes. Independent from the single antenna (antenna element) characteristics, the configuration of the array which means the location of each element changes the radiation characteristics of the array. We call this term "array factor". The overall antenna array radiation is a multiplication of the antenna element radiation pattern and the array factor.

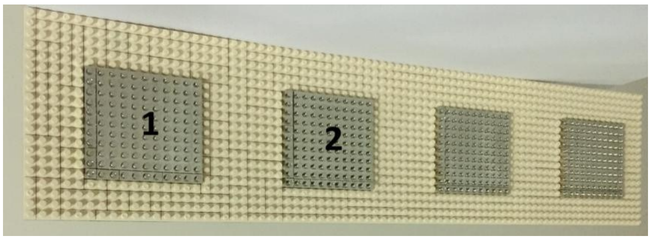


Figure 1 Example of a 1-D array (1X4 linear array antenna)

An array with identical radiation patterns and progressive phase is called uniform array. Figure 2 shows linear antenna array configuration. These antennas are isotropic. We use isotropic antennas for the calculation of antenna factor and multiply it with the antenna element radiation pattern for simpler calculations. The interelement spacing is d. Let's assume that a wave comes from a far distance with the angle θ from the Z-axis. Therefore, the wave will be a planar wave (nearly). When the signal is received by antenna 4, it is not received by antenna 3. Because, the wave must travel "d cosθ" more to reach antenna 3. It must travel "2d cosθ" to reach antenna 2 and "3d cosθ" to reach antenna 1. If we assume that the array is uniform, the array factor is given in equation (1). "N" is the number of antennas, "k" is the wave number, "θ" is the angle between the wave and the "z" axis and "β" is the phase between the elements.

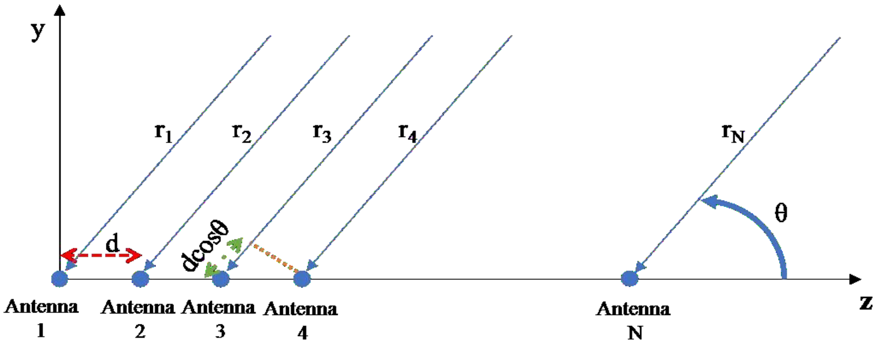


Figure 2 N Element Linear Array

$$F = 1 + {}^{(doc+\ )} + {}^{2(doc+\ )} + {}^{3(doc+\ )} + \dots + {}^{(-1)(doc+\ )}$$

$$F = \sum_{=1} \left({}^{(-1)(doc+\ )} \right) \tag{1}$$

Array antennas can be designed to radiate in broadside or endfire. Broad size radiation means the antenna array radiates perpendicular to the array where endfire means that the array radiates in the same direction with the array elements. Figure 3 shows the broadside and endfire directions.

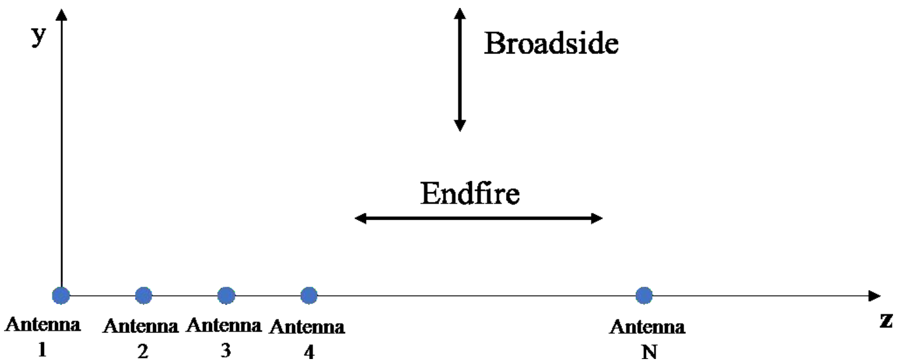


Figure 3 Broadside and Endfire Arrays

Similar to linear array, planar arrays have the same logic for the calculation of the array factor. Figure 4 shows a planar array with N elements in y-axis and M elements in x-axis. The interelement spacing is d_x for the x axis, and d_y for the y axis. If we assume that the array is uniform in both axes, the array factor is given in equation (2). “N” is the number of antennas in y-axis, “M” is the number of antennas in x-axis, “k” is the wave number, “θ” is the angle between the wave and the “z” axis, “Ø” is the angle between the wave and the “x” axis, and “β_x” is the phase between the elements in x- axis and “β_y” is the phase between the elements in y-axis.

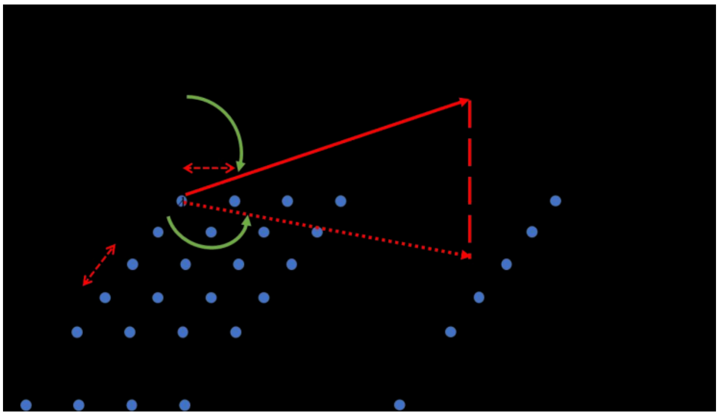


Figure 4 N X M Element Planar Array

$$F = \sum_{=1} \left\{ \sum_{=1} \left(^{(-1)(d \sin \ o\emptyset +)} \right) \right\} \left(^{(-1)(d \sin \ \sin \emptyset +)} \right) \quad (2)$$

EXPLANATION ABOUT DESIGNING A PATCH ANTENNA ARRAY WITH ANTEN’IT:

The box in Figure 5 is the patch antenna array kit. In the same manner with the patch antenna kit, the metal cells of this kit are also “PCB type metal cells”. There will be 4 patch antennas in the arrays. The box divisions with the name of “Patch-1/2/3/4 PCB type metal cells” are seperated to build each antenna element of the array. You need to use all bricks in the “patch-1 PCB type metal cells” division to build the antenna that you designed in the patch antenna experiment. You don’t need to design the patch antenna element again in this experiment. You need to focus on the array design. PCB type feed cells division includes the PCB type metal cells for each antenna. Metal cells for ground plane are to connect the ground planes of the antennas to each other as in Figure 10.

There are 4 ground planes with holes for this experiment. Beige dielectric cells are already mounted on the ground planes. The beige dielectrics have 2.6 dielectric constant. There are 4 feed cells and 2 pieces of 50 ohm terminations in the box. Use 50 ohm terminations for unused ports when you measure S-parameters.

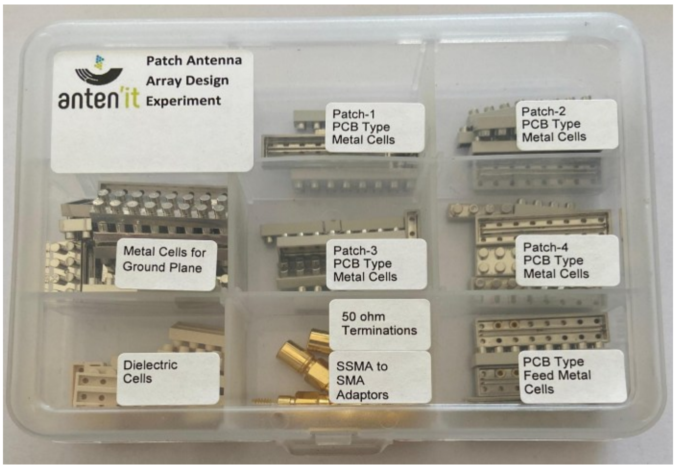


Figure 5 Patch Antenna Array Design Experiment Box

In order to connect the patch antenna array to the power divider, 4 pieces of equal length (1 meter) cables are included in the kit. Be careful that these cables are not phase stable cables. The results may change with the movement of the cable.

Removing the cells:

Removing the cells is one of the most important part to learn. The misusage can damage the kits. Do not touch the sides of the PCB type metal cells with another tool except the "Brick Remover" in this kit. Each cell needs to be used gently. Brick remover holds two of the cylinder in the same time. You just need to push to the high end of the remover as in Figure 6.

In this experiment, it is ***forbidden to use the removing plier or any other tool unless it is advised by Anten'it.***

The removing tool for this experiment is a plastic remover. In order to get the best efficiency, we need to start dismounting the cells from outside. First, remove smallest PCB type metal cells which are at the outside. Second, remove the cells which are at the outside but larger. Third, remove the cells except the feed cell. At last, remove the feed cell. Always use the cylinders in the middle to use the remover as in Figure 6.

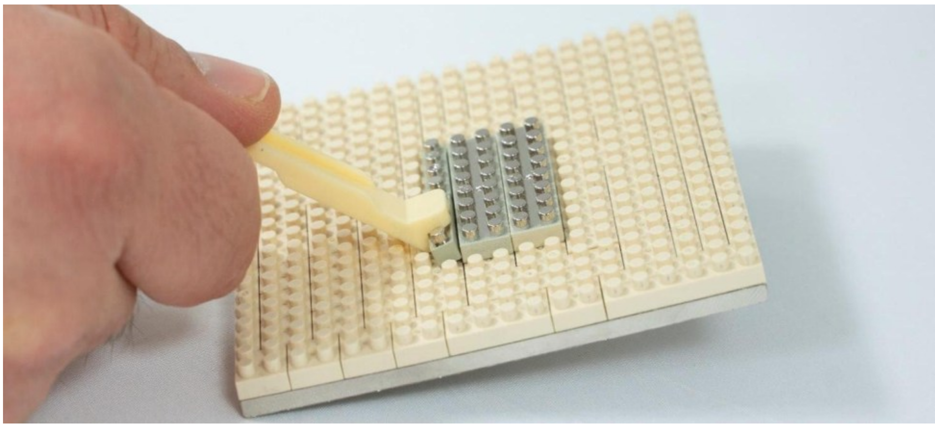


Figure 6 Plastic Remover for Patch Antenna Design Experiment

PRELIMINARY WORK:

1. Explain the radiation pattern types (Endfire-Broadside) of array antennas.
2. How do directivity and radiation pattern change as number of antennas increase in an array?
3. Explain the uniform array, Taylor distribution, Chebyshev distribution.
4. Calculate the array factor for the 1X4 uniform linear array with interelement spacing d= 0.66λ.
5. Calculate the array factor for the 2X2 uniform planar array with interelement spacing d= 0.66λ.
6. Multiply the linear (1X4) array factor of d=0.66λ with the patch-1 antenna radiation pattern in the patch antenna experiment by using Octave, Matlab or another tool.
7. Explain mutual coupling. Does the calculation in step 6 include mutual coupling?

EXPERIMENTAL PROCEDURE:

8. Connect the cables to the Network Analyzer and connect the SSMA-Female to SMA-Male adapter to the SSMA-male side of the cable as shown in Figure 7.

Figure 7 Cable to SSMA-SMA Adaptor Connection

9. Calibrate the Network Analyser for 2 port measurement between 1500 MHz to 3500 MHz.
10. Disconnect the SSMA to SMA adaptors after the calibration as shown in Figure 8.

Figure 8 Disconnect the cable from SSMA-SMA Adaptor

11. Locate beige dielectric cells with 2.6 dielectric constant over the PCB type ground planes.
12. Connect the ground planes with the dielectrics as in Figure 9.
13. Mount the 2X8 and 2X4 metal cells (Metal cells in the ground plane division of the experiment box) in order to connect the ground planes as in Figure 10.

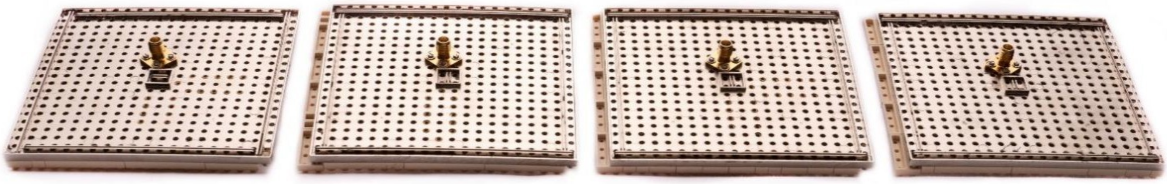


Figure 9 The backview of the ground planes

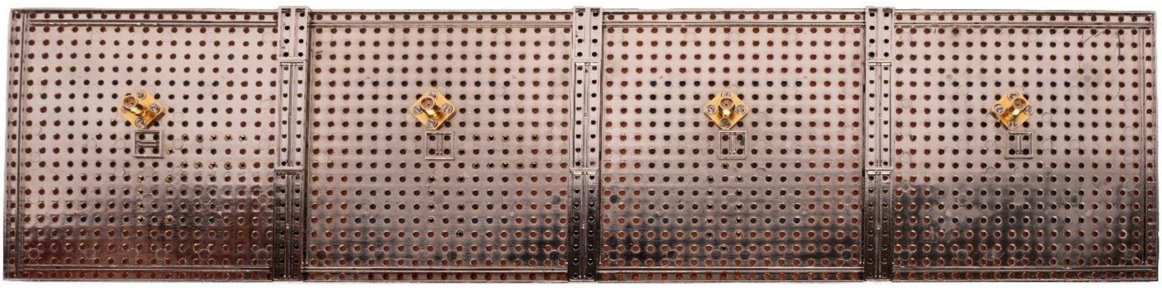


Figure 10 Connection of the ground planes with the 2X8 and 2X4 metal cells

14. Locate the PCB type feed metal cells and PCB type metal cells over the beige dielectric cells in order to build 1X4 patch array. The patch antenna is this experiment has the same dimensions with the patch antenna experiment. Check if the interelement spacing is approximately 0.66λ (at 2460 MHz) as in Figure 11.

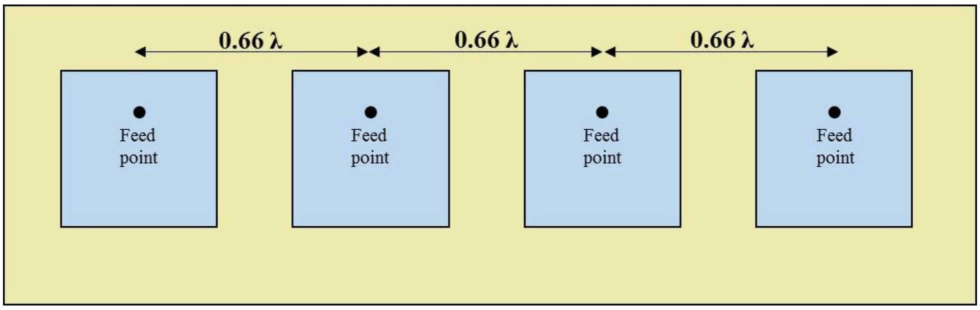


Figure 11 The distance between antenna elements

15. Use a multi-meter or voltmeter in order to check if the inner conductors of the 4 connectors are connected to the feed cell for each antenna. Turn the multi-meter to “short” buzzer option. With one probe touch to the inner conductor of the SSMA connector from the bottom of the plate and with the other probe touch to the feed cell. If the buzzer is ringing, they are connected to each other and the connection is ready for the experiment.

Figure 12 Buzzer

16. Connect the antenna 1 to port 1 of the Network Analyser and antenna 2 to port 2 of the Network Analyser (Antenna 1 and 2 are shown in Figure 1).

17. Terminate the unused antenna ports with 50 ohm terminations.

18. Measure S_{11}, S_{22}, S_{12}, S_{21} and write down the values for 2460 MHz to the table below.

S_{11}[dB]	
S_{22}[dB]	
S_{12}[dB]	
S_{21}[dB]	

19. Check the S parameters of the other two antennas if they work properly.

20. Check the insertion loss and return loss specifications of the 1X4 equal split power divider.

21. Connect the array elements to 1X4 equal split power divider. And measure the reflection coefficient at the output of the power divider.

Reflection coefficient of the 1X4 antenna array connected to a 1X4 equal split power divider [dB]	

22. Measure the E-plane of the 1X4 Patch antenna array with the power divider at 2460 MHz via a turn table. If the turn table is manual, write down the power levels for each E-plane angle. Normalize the power levels to the peak level.

E-plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
5		
10		
15		
20		
25		
30		
35		
40		
45		
50		
60		
70		
80		
90		
270		
280		
290		
300		
310		
315		

320		
325		
330		
335		
340		
345		
350		
355		

23. Sketch the normalized power levels in E-plane axis on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

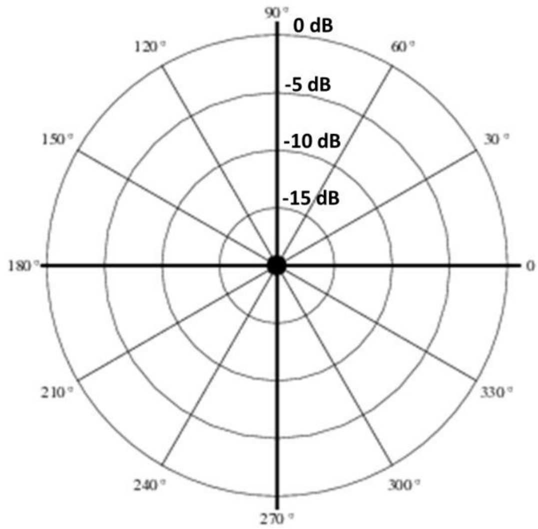


Figure 13 E-Plane Pattern of the 1X4 patch array in Polar Coordinates

24. Write down the measured results.

Gain [dBi]	
E-Plane HPBW [degrees]	
Side lobe level in E-Plane [dB]	

25. Measure the H-plane of the 1X4 Patch antenna array with the power divider at 2460 MHz via a turn table. If the turn table is manual, write down the power levels for each H-plane angle. Normalize the power levels to the peak level.

E-plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:

0		
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		
330		

26. Sketch the normalized power levels in H-plane axis on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

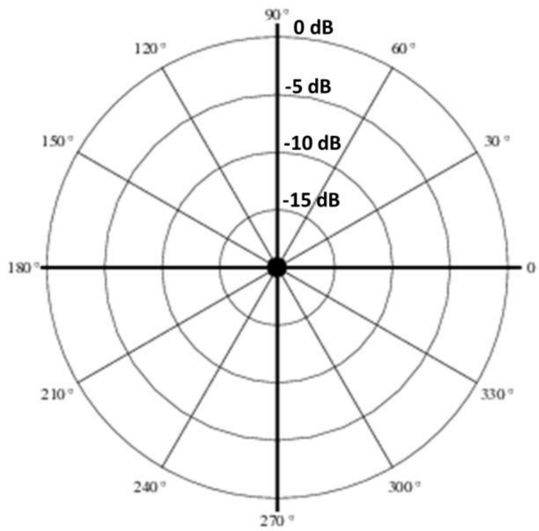


Figure 14 E-Plane Pattern of the 1X4 patch array in Polar Coordinates

27. Write down the measured results.

Gain [dBi]	
H-Plane HPBW [degrees]	
Side lobe level in H-Plane [dB]	

28. Disconnect the power divider and cables.

29. Disconnect each 20X20 ground plane from the 1X4 linear array.

30. Build the array as 2X2 planar array.

31. Connect the array elements to 1X4 equal split power divider.

32. Measure the E-plane of the 2X2 Patch antenna array with the power divider at 2460 MHz via a turn table. If the turn table is manual, write down the power levels for each E-plane angle. Normalize the power levels to the peak level.

E-plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
5		
10		
15		
20		
25		
30		
35		
40		
45		
50		
60		
70		
80		
90		
270		
280		
290		
300		
310		
315		
320		
325		
330		

335		
340		
345		
350		
355		

33. Sketch the normalized power levels in E-plane axis on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

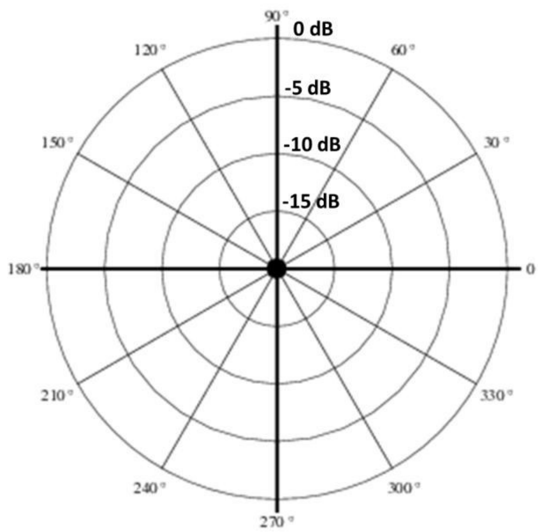


Figure 15 E-Plane Pattern of the 2X2 patch array in Polar Coordinates

34. Measure the H-plane of the 2X2 Patch antenna array with the power divider at 2460 MHz via a turn table. If the turn table is manual, write down the power levels for each H-plane angle. Normalize the power levels to the peak level.

H-plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
5		
10		
15		
20		
25		
30		
35		

40		
45		
50		
60		
70		
80		
90		
270		
280		
290		
300		
310		
315		
320		
325		
330		
335		
340		
345		
350		
355		

35. Sketch the normalized power levels in H-plane axis on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

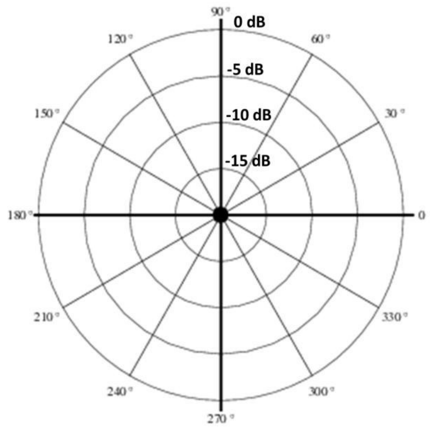


Figure 16 H-Plane Pattern of the Patch-1 in Polar Coordinates

36. Write down the measured results.

2X2 Patch Array Gain [dBi]	
E-Plane HPBW [degrees]	
H-Plane HPBW [degrees]	
E-Plane Side lobe level [dB]	
H-Plane Side love level [dB]	

37. Please dismount the “PCB type metal cells”, “PCB type feed metal cells” and “metal cells for ground planes” and locate them into the box.

RESULTS:

- State the objective of the experiment and give a short summary of the procedure.
- Which parameters change the radiation pattern of antenna array?
- Is there any difference between measured S_{11} and S_{22} in step 13? Explain why?
- What is the meaning of S_{21} in step 13?
- Do the measured array pattern results similar to the calculated results? What are the differences? Which effects may cause the differences?
- Why is the HPBW of the array narrower than the single patch-1 element in patch antenna experiment?
- Why did we have different HPBW in E-plane measurements of 1X4 and 2X2 arrays?
- Compare the theory and experimental results.
- Discuss the results of your experiment.

7-DISCONE ANTENNA DESIGN EXPERIMENT

OBJECTIVES

- Designing a discone antenna using Anten'it antenna training kit.
- To investigate return loss and antenna dimensions & frequency relation.
- Plot the radiation pattern of a discone antenna.

BRIEF INFORMATION ABOUT THE DISCONE ANTENNA:

Biconical Antenna

A biconical antenna is a thicker version of a dipole antenna with two cones instead of two rods. Remember that, thicker dipole rods create a wider impedance bandwidth. The cones of a biconical antenna create a broader impedance bandwidth which makes it a broadband antenna. Figure 1 shows a conventional biconical antenna. This is a balanced (symmetrical) antenna which needs a balun.

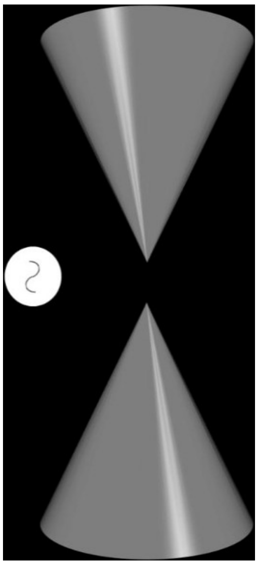


Figure 1 Conventional Biconical Antenna

Discone Antenna:

The discone is a monopole type of antenna with very wideband characteristics. Biconical and discone antennas have the same relationship as dipole and monopole have. Discone is the monopole version of a biconical antenna. We have experimented that the monopole antenna thickness increases the bandwidth in the previous experiment. By tapering the diameter of the monopole rod, a very wideband matching can be achieved. The conventional discone shown in Figure 2 has its outer conductor connected to the cone and its inner conductor connected to the disc. The electrical field between the cone and the disc creates the radiation.

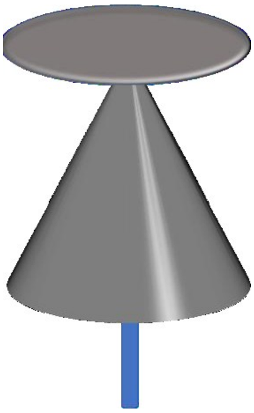
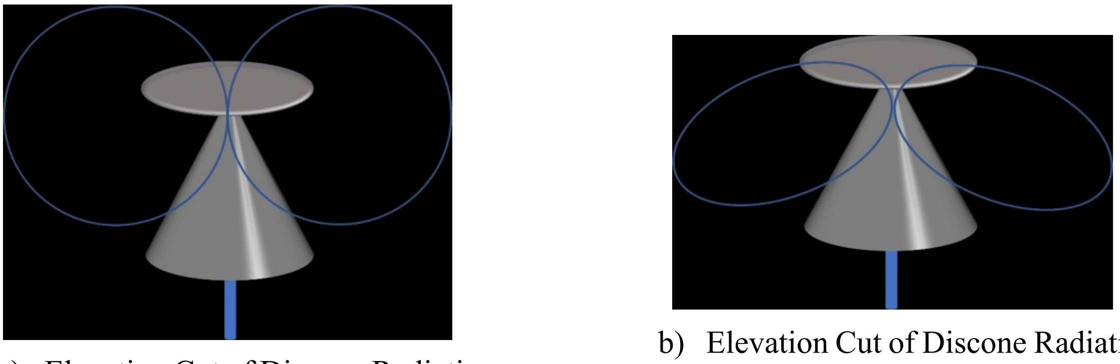


Figure 2 Conventional Discone Antenna

The radiation pattern of the discone is very similar to the radiation pattern of a monopole antenna. It is omnidirectional in H-plane. The polarization of the discone is linear.

Because of the wideband characteristics of a discone antenna, the elevation cut of the radiation pattern changes with the frequency. At lower frequencies, the elevation pattern is similar to a monopole antenna as shown in Figure 3a. At higher frequencies, the azimuth pattern is still omnidirectional but the elevation pattern steers to the opposite direction of the disc as shown in Figure 3b.



a) Elevation Cut of Discone Radiation Pattern at Low Frequencies

b) Elevation Cut of Discone Radiation Pattern at High Frequencies

Figure 3 Radiation patterns of a discone antenna

There are many formulas for designing a discone antenna in the literature. You can also find different formulas with different design parameters. These formulas are the initial points to design this kind of antenna. Antenna designers generally need to iterate the design to reach the target frequency.

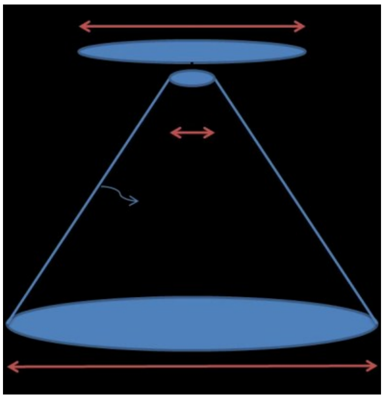


Figure 4 Discone antenna dimensions

d: disc diameter

D_{min}: top diameter of the cone

D_{max}: bottom diameter of the cone

L: length of the cone

λ_{min} : wavelength at the lowest target frequency

λ_{max} : wavelength at the highest target frequency

$$d = 0.40\ \lambda_{max} \qquad (1)$$

$$D_{max} = 0.3\ \lambda_{min} \qquad (2)$$

$$L = 0.35\ \lambda_{min} \qquad (3)$$

Bandwidth for Wideband Antennas:

We used percentage bandwidth in the previous experiments. This parameter is used well for resonance antennas. But it is not appropriate to explain the bandwidth of wideband antennas. Therefore, another ratio called bandwidth ratio (Equation 4) is used for wideband antennas. f_H shows the highest and f_L shows the lowest frequency of the bandwidth. For example, if an antenna works between 0.8-2.4 GHz, then the bandwidth ratio is 3:1.

$$\text{Bandwidth Ratio} = f_H : f_L \qquad (4)$$

EXPLANATION ABOUT DESIGNING A DISCONE ANTENNA WITH ANTEN'IT:

The box in Figure 5 is the discone antenna kit. There are metal cells, feed dielectric cells and feed metal cells in the kit. One of the feed dielectric cells has a hole and feed metal cell has special inserts. There are many metal cells to give a freedom of design for this experiment.

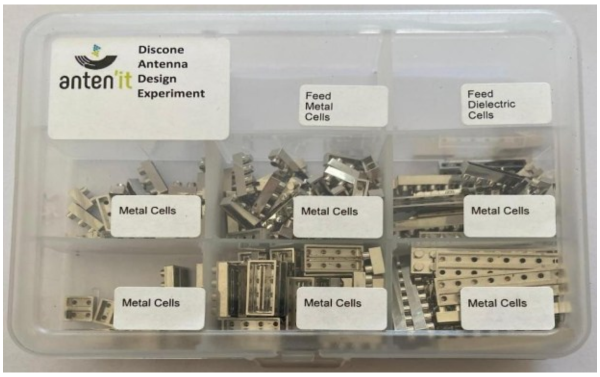


Figure 5 Discone Antenna Experiment Box

Figure 6 shows the feed dielectric cells of this experiment. The beige colour represents the dielectric cells with 2.6 dielectric constant. They are used both as insulators to prevent the disc to contact with the cone and as spacers to provide a mechanically stable structure.

Figure 7 shows the metal feed cells with an insert at the bottom side. This insert is to contact with the inner conductor.

Apart from the conventional discone antenna, Anten'it discone antenna connector is mounted on the disc. The outer conductor of the connector is connected to the disc where the inner conductor of the connector is connected the cone. This doesn't change the characteristics of the antenna.

Figure 6 Feed Dielectric Cells

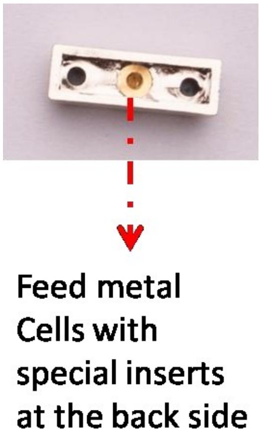


Figure 7 Feed Metal Cells

<u>The calculation of dimensions with Anten'it kit:</u>

The cubic part of Anten'it metal cells has 3 mm and the top (thin) cylinder has 2 mm height. Although the total height is 5 mm, 2 mm interlace to another cell and the height resolution is 3 mm. Figure 9 shows the dimensions of a 1X1 metal cell. The dimensions of other cells are multiples of 1X1 dimensions.

For example, if you interlace 3 bricks into each other, the total height will be 3 X 3 mm + 2 mm which corresponds to 11 mm or if you interlace 5 bricks into each other, the total height will be 5 X 3 mm + 2 mm which corresponds to 17 mm.

The length and width of a cell is 4 mm or a multiple of 4 mm. Figure 9 shows a 1X1 cell. 1X1 represents that the cell has 1 cylinder in length and 1 cylinder in width. For example, 2X2 cell means a cell with 2 cylinders in width and 2 cylinders in length which corresponds to 4 cylinders in total.

There is only one disc with 80 mm diameter in this experiment. After you calculate antenna dimensions, you need to turn them into Anten'it resolution. Then, you can start iterating and reach the target design frequency. You can either use the formulas or start directly with a flare angle and iterate. We recommend to take the flare angle at least 22,5° ($\theta/2$ in Figure 8) and iterate your design via a network analyzer. You can try different antenna lengths and flare angles.

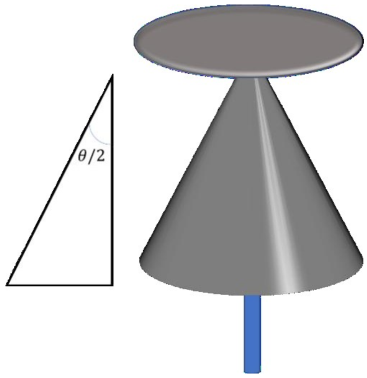


Figure 8 Discone antenna flare angle

D_{min} in Figure 4 is effective at higher frequencies. The D_{min} will be 9 mm X 9 mm square in this experiment. This is because a thinner dimension can not build a mechanically stable antenna.

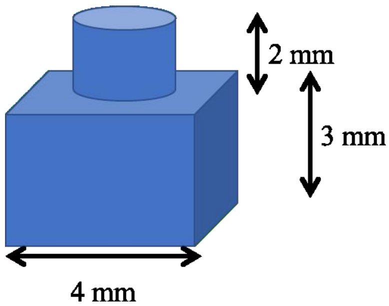


Figure 9 Anten'it cell dimensions

Figure 10 shows an example point to start the design of the antenna.

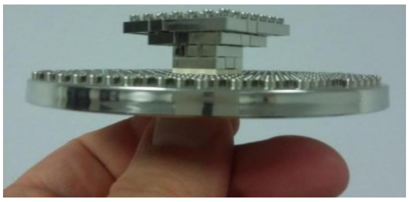


Figure 10 A clue about the antenna shape

Removing the cells:

Removing the cells is one of the most important parts to learn. The misusage can damage the kits. There are some removing tools in the kit and the tool must be selected depending on the cell type. Each cell in the kit needs to be used gently.

In this experiment, use your hands to remove the cells. If you try to remove the cells with your hands but you can't remove them after some trial, then use the special removing plier for removing the cells. Figure 11 shows the removing plier and its special head.

In case, you must use the removing plier, you need to use it 90 degree to the top cylinder of the cells. For 1X3 and larger cells, use the cylinder at the center. If you can't remove the cell easily, change to another cylinder. Figure 12 shows an example usage of the removing plier.

a)

b)

Figure 11 Removing Plier

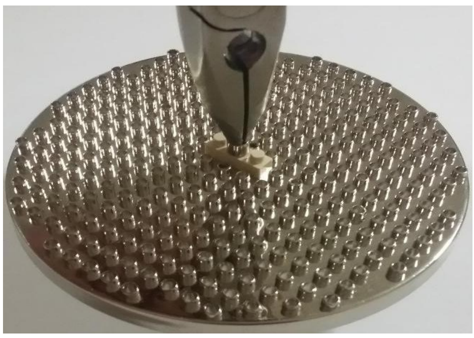


Figure 12 The usage of removing plier

PRELIMINARY WORK:

1. How does the discone antenna work?
2. What are the differences between biconical and discone antenna?
3. Where is the E-plane and H-plane of the discone antenna?
4. What is a typical bandwidth ratio for a discone antenna?

EXPERIMENTAL PROCEDURE:

1. Connect the cable to the Network Analyser and connect the SSMA-Female to SMA-Male adapter to the SSMA-male side of the cable as shown in Figure 13.

Figure 13 Cable to SSMA-SMA Adaptor Connection

2. Calibrate the Network Analyser for 1-port measurement between 800 MHz and 6 GHz.
3. Disconnect the SSMA to SMA adaptor after the calibration as shown in Figure 14.

Figure 14 Disconnect the cable from SSMA-SMA Adaptor

4. The circular ground plane with 80 mm diameter is shown in Figure 15. Locate the "dielectric feed cell with a hole" over the inner conductor pin of the connector. Locate the other dielectric cells at the sides of it.

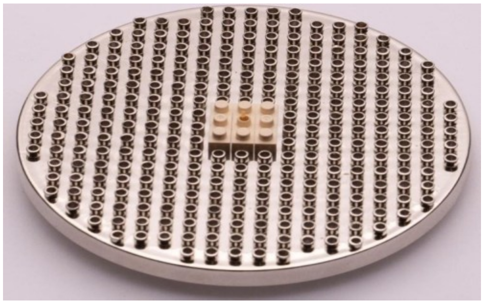


Figure 15 Ground plane Dielectric Cell Configuration for Discone Antenna

5. Connect the 1X3 feed metal cell to at the top of the dielectric cell as shown in Figure 16.

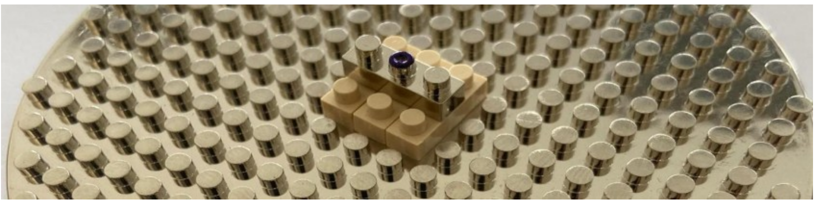


Figure 16 Connection of the Feed Cell of the Discone Antenna

6. Use a multi-meter or voltmeter in order to check if the inner conductor of the connector is connected to the feed cell. Turn the multi-meter to "short" buzzer option. With one probe touch to the inner conductor of the SSMA connector from the bottom of the ground plane and with the other probe touch to the feed cell. If the buzzer is ringing, they are connected to each other and we can start the experiment.

Figure 17 Buzzer

7. Connect the 1X3 cells at each side of the feed cell. Connect other 1X3 metal cells to build the antenna as shown in Figure 18.

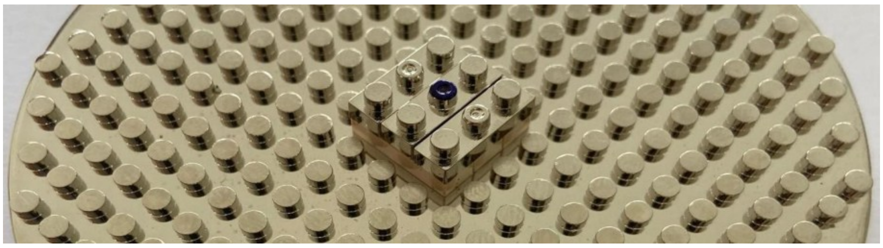


Figure 18 Connection of the two metal cells in both sides of the feed metal cell

8. Calculate the discone antenna size the lowest frequency of 1400 MHz. We recommend you to have the flare angle as at least 22,5° ($\theta/2$ in Figure 8). Make your design with a starting point. You can either use the formulas or select a flare angle and iterate your design.

Wavelength at the lowest target frequency (λmin):
Anten'it disc diameter: 80 mm
Flare Angle:

9. Build the antenna.

10. Connect the cable to the connector at the ground plane of the discone antenna as shown in Figure 19.

Figure 19 Connection to the connector at the ground plane of the discone

11. Display S_{11} dB scale on the network analyser screen.

12. Measure S11 in dB scale. Write down the lowest frequency, highest frequency and bandwidth ratio of the discone antenna.

Discone Antenna Lowest frequency:	
Discone Antenna Highest frequency	
Discone Antenna Bandwidth ratio:	
Antenit buttom diameter of cone	
Anten'it length of the cone:	
Flare angle:	

13. Measure the E-plane (Elevation) of the thick discone antenna at the center frequency of the antenna with a turn table. If the turn table is manual, write down the power levels for each E-plane angle. Normalize the power levels to the peak level.

E-plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		
330		

Gain [dBi]:	

14. Sketch the normalized power levels in E-plane axis on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

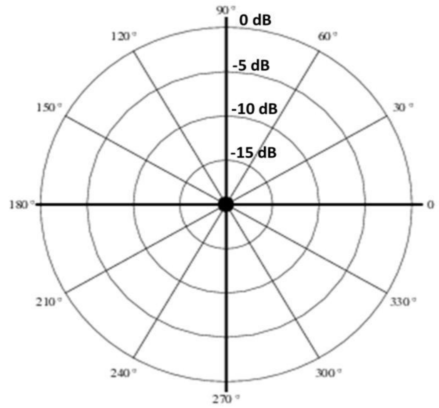


Figure 20 E-Plane Pattern of the Discone Antenna in Polar Coordinates

15. Measure the H-Plane (Azimuth) pattern of the antenna with a turn table. If the turn table is manual, write down the power levels for each H-plane angle. Normalize the power levels to the peak level.

H-Plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		
330		

16. Sketch the normalized power levels in H-plane on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

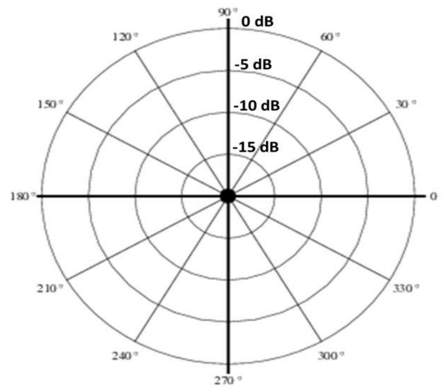


Figure 21 H-Plane Pattern of the Discone Antenna in Polar Coordinates

17. Connect the antenna to the network analyzer again.

18. Try to build a higher bandwidth ratio (HBR Discone) discone antenna by changing the antenna dimensions. (You can read the related parts in the text books of Balanis or Stutzman)

HBR Discone Antenna Lowest frequency:	
HBR Discone Antenna Highest frequency:	
HBR Discone Antenna Bandwidth ratio:	
HBR Discone bottom diameter of the cone:	
HBR Discone length of the cone:	
HBR Discone flare angle:	

- What are the measured differences between the monopole and discone antennas?
- Did you find a way to increase the bandwidth ratio of the discone antenna? How did you explore it? Which method did you use?
- Compare the theory and experimental results.
- Discuss the results of your experiment.

8-HORN ANTENNA DESIGN EXPERIMENT

OBJECTIVES

- Designing a horn antenna using Anten'it antenna training kit.
- To design a waveguide
- To understand antenna dimensions & half power beam width (HPBW) & gain relation.
- Plot the radiation pattern of a horn antenna.

BRIEF INFORMATION ABOUT THE HORN ANTENNA:

Waveguides

Waveguides are low-loss transmission lines with high-power handling capability. Transmission lines can be characterized by characteristic impedance, attenuation and propagation constant parameters. Transmission line with two or more conductors may support TEM (transverse electromagnetic) waves. Waveguides with single conductor support TE (transverse electric) or/and TM (transverse magnetic) waves. There are some types of waveguides such as parallel plate waveguides, rectangular waveguides and circular waveguides.

Rectangular waveguides can propagate TM and TE modes but not the TEM waves. TM and TE modes have cut-off frequencies. Cut-off frequency is the frequency below which the propagation is not possible. In another words, the cut-off frequency is the lowest frequency for which a mode propagates in the waveguide. Any frequency lower than the cut-off frequency attenuates instead of propagating.

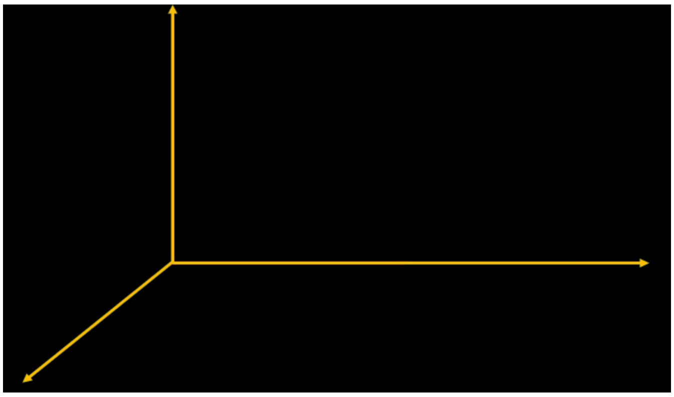


Figure 1 Waveguide

The wave in the waveguide propagates in "z" direction. "a" represents the width in "x" direction and "b" represents the height in "y" direction. We assume that "a" is always larger than "b". The cut-off frequency is dependent on the shape and dimensions of the waveguide. Each mode has a cut-off frequency.
The rectangular waveguide cut-off frequency is formulized below:

$$f_c = \frac{1}{2\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2} \quad (1)$$

f_c is the cut-off frequency, μ is the magnetic permeability, ε is the dielectric permittivity, m and n are the mode numbers, a and b are the waveguide dimensions. TE_{mn} are the TE modes and TM_{mn} are the TM modes. TE modes start with TE_{10} and TM modes start with TM_{11}.

The mode with the lowest cut-off frequency is called the dominant mode. Since TE modes start with TE_{10}, the lowest and dominant cut-off frequency occurs for the TE_{10} mode.

TE_{10} mode cut-off frequency formula is given below:

$$f_c = \frac{1}{2a\sqrt{\mu\varepsilon}} \quad (2)$$

If the waveguide is air filled, then the formula becomes:

$$f_c = \frac{c}{2a} \quad (3)$$

At a given frequency, the modes over the cut-off frequency propagate and the modes below the cut-off frequency don't propagate. If there is more than one mode propagating at a frequency, the waveguide is called overmoded at that frequency.

Let's give an example to understand the modes clearly. Consider an air-filled waveguide with dimensions a=20 mm and b=15 mm and write the cut-off frequencies for the first few modes.

The formula for an air-filled waveguide can be simplified as below:

$$f_c = \frac{1}{2\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m}{0.02}\right)^2 + \left(\frac{n}{0.015}\right)^2} \quad (4)$$

Mode	m	n	[GHz]
TE	1	0	7,5
TE	0	1	10
TE, TM	1	1	12,5
TE	2	0	15
TE, TM	2	1	18,02

For example, if we want to propagate at 6 GHz with this waveguide, it doesn't work at that frequency. If we work at 9 GHz, there is only one mode TE_{10} in the waveguide. If we go higher than 10 GHz, there will be more than one mode in the waveguide.

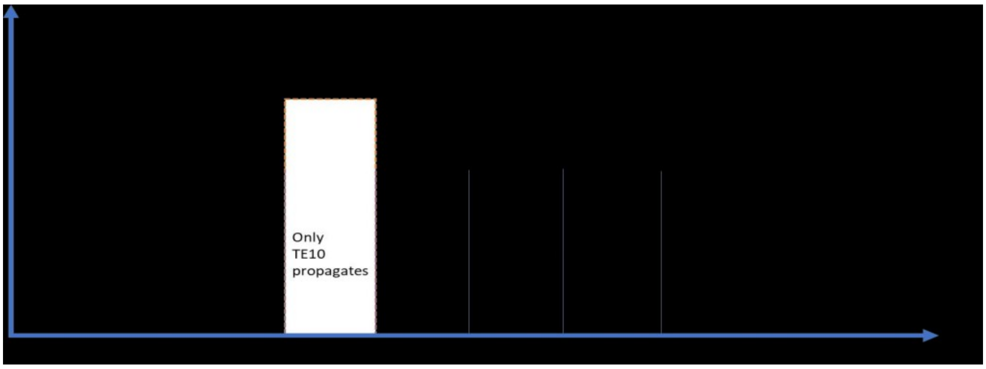


Figure 2 Modes versus frequency

The electric field lines are TE_{10} mode is shown in the figure below. The electric field distribution changes at each mode. TE_{10} is the most common mode used in horn antennas.

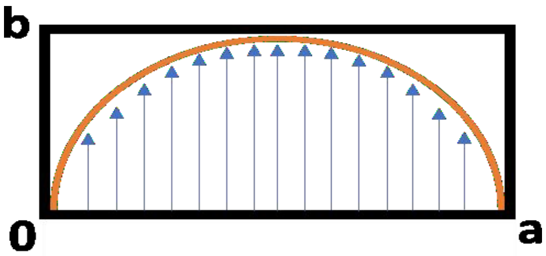


Figure 3 TE_{10} Electric Field Lines

Horn Antennas

A horn antenna is basically an opened-out waveguide. The horn makes a transition from the waveguide to the air or to another medium. If we open one part of the waveguide, this is called open-ended waveguide. Open-ended waveguide radiates but in order to make a better transition to the impedance of the free-space (377 Ω), a horn-flare is used. The flare of the horn also increases the directivity of the antenna. There are different horn antenna types and we will design a pyramidal horn antenna in this experiment.

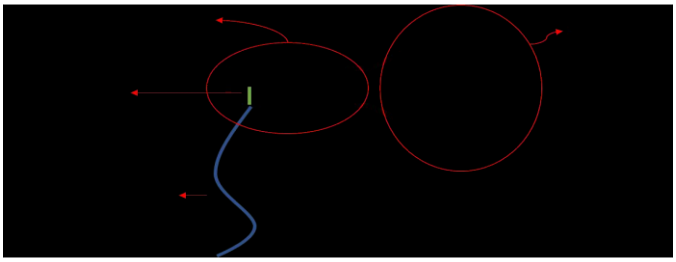


Figure 4 Horn Antenna

The flare angle in the figure is a design parameter of horn antenna.

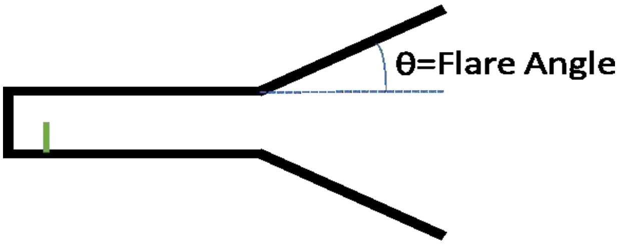
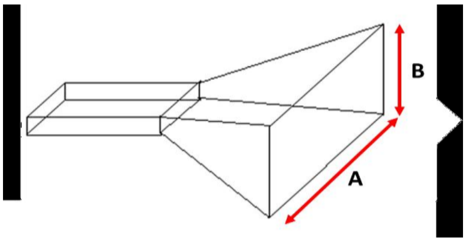


Figure 5 Horn Antenna Flare angle and aperture dimensions



A and B are aperture dimensions of the horn antenna. The aperture of the horn antenna is directly related to the directivity of the horn antenna. In order to design a horn antenna, we need to have target frequency range, gain and half-power beamwidth (HPBW). The equation below gives the directivity of a horn antenna with the aperture dimensions.

$$= {}^{4} \frac{B}{2} \qquad (5)$$

e_A is the aperture efficiency. The physical area of the aperture is AB but electrically the aperture may be less than the physical dimension. Aperture efficiency is a percentage of the electrical aperture and physical aperture. This parameter must be between 0 and 1.

H-plane HPBW is mainly related to A and E-plane HPBW is mainly related to B dimensions. The exact dimensions for target HPBW must be found via iterations. There are some empirical formulas in Antenna Engineering Handbook (4.th edition) of John L. Volakis (section 14.4) and we will use these formulas for our design in this experiment.

HPBW in H-Plane [degrees] = $3B_{-l}$= (40λ/A)+15° (6)

HPBW in E-Plane [degrees] = $3B_{-l}$= 44λ/B (7)

Designing a Horn Antenna

In order to start the design of a horn antenna, first the waveguide must be designed for the target frequency range. The “a” and “b” must be calculated for the lowest and highest operating frequencies. We want the waveguide to work at TE_{10} mode only. Therefore, the waveguide frequency range must be between the cut-off frequencies of two modes. The lowest mode is always the TE_{10} mode. The highest frequency of the antenna is the cut-off frequency of the second lowest mode for pyramidal horn antenna. The second lowest mode may change depending on the waveguide dimensions. (1), (2) and (3) are the equations to design the waveguide for the lowest and highest frequencies.

The second step is to build the waveguide and locate the RF connector. The RF connector must be mounted on the “a” side of the waveguide and it must be in the middle of “a”.

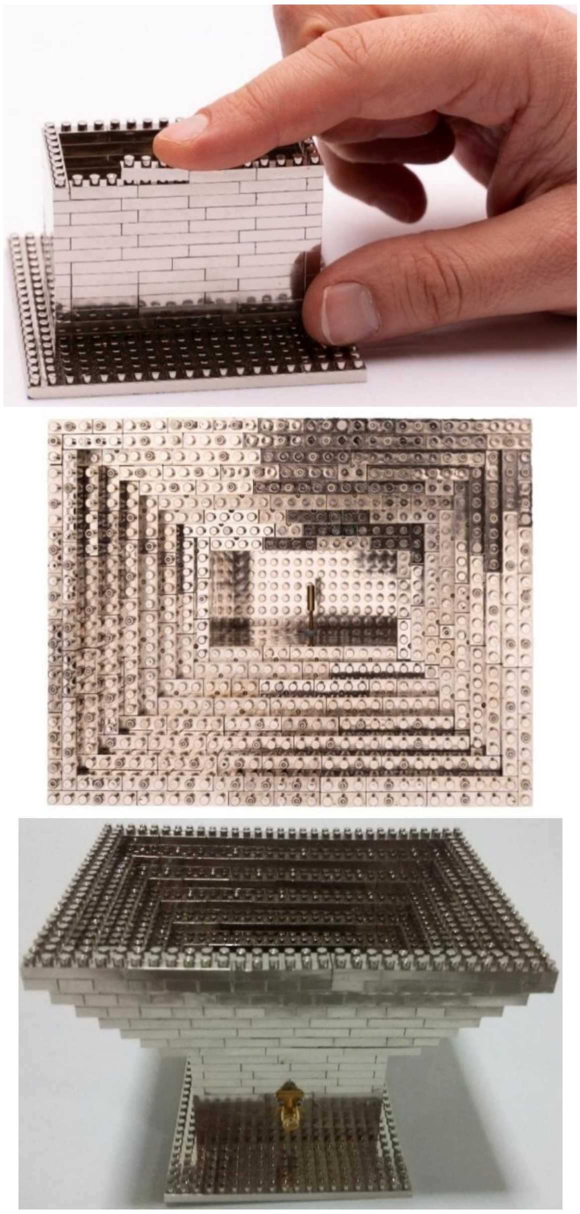


Figure 6 Example waveguide and horn antenna built with Anten'it

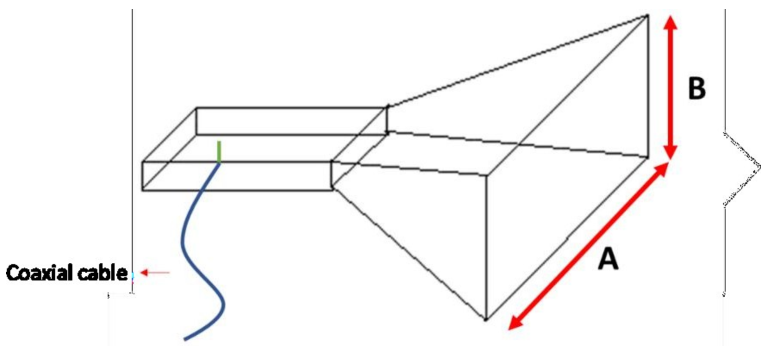


Figure 7 Location of feed in the middle of "a" dimension

The distance of feed point from the back plane of the waveguide is a design parameter. This distance changes the reflection coefficient. The designer needs to find the right position to get the lowest reflection coefficient. Another design parameter to get the best reflection coefficient is the feed length. The figure below shows the feed block for the horn antenna experiment. There is threat over the inner conductor of the connector and there is a ring over the inner conductor of the feed. The designer needs to find the best position of the ring in order to get the lowest reflection coefficient. You can change the position of the ring with your hands.

Figure 8 Horn Feed Block

After building the waveguide, the horn needs to be built. The horn aperture is directly related to the directivity and HPBW both in H-plane and E-plane as in the equations (5), (6) and (7). Another design parameter is the flare angle. The flare angle changes the reflection coefficient of the horn antenna. The designer needs to calculate the horn aperture dimensions for the given HPBW and directivity. You can take the aperture efficiency as 1 in this experiment. In the real antenna, this parameter is expected to be close to between 0.5 to 1.

For example, if we would like to have a 45º HPBW in H-plane and 30º HPBW in E-plane at 10 GHz, then “A” needs to be 40 mm and “B” needs to be 44 mm. The antenna directivity with e_a= 1 is then approximately 24,5 which corresponds to 13,9 dBi as in equation (8).

D [dBi] = 10 log (D [linear]) (8)

Bandwidth for Wideband Antennas:

We used percentage bandwidth in the previous experiments. This parameter is used well for resonance antennas. But it is not appropriate to explain the bandwidth of wideband antennas. Therefore, another ratio called bandwidth ratio (Equation 9) is used for wideband antennas. f_H shows the highest and f_L shows the lowest frequency of the bandwidth. For example, if an antenna works between 0.8-2.4 GHz, then the bandwidth ratio is 3:1.

Bandwidth Ratio = $f_H : f_L$ (9)

EXPLANATION ABOUT DESIGNING A HORN ANTENNA WITH ANTEN'IT:

The box in Figure 9 is the horn antenna kit. There are metal cells and a feed block in the kit. There are many metal cells to give a freedom of design for this experiment. The metal cells for the waveguide and horn are in different partitions. The metal cells for the waveguide needs to be "1Xn" metal cells such as 1X1, 1X2, 1X3, 1X4 and 1X6. The metal cells for the horn needs to be "2Xn" metal cells such as 1X2, 2X2, 2X4 and 2X8.

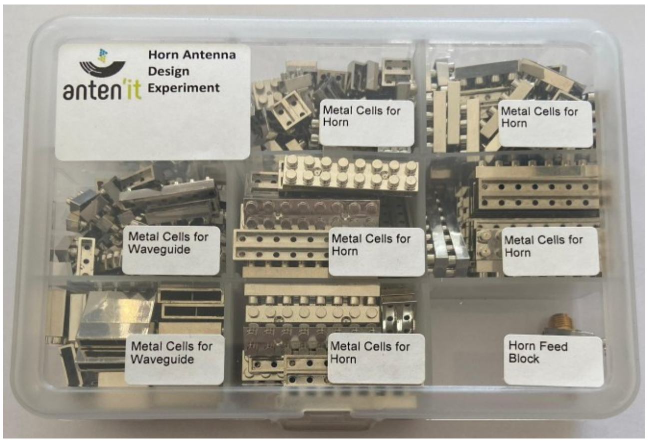


Figure 9 Horn Antenna Design Experiment Box

The calculations must be applied to the inner dimensions of the waveguide and horn. Because we deal with the inner dimensions for this antenna. Therefore, the calculation of the horn aperture gives us the inner dimensions of the horn and the calculation of the waveguide gives us the inner dimensions of the waveguide.

The design parameters of the horn antenna in this experiment can be listed as below:

A: Aperture width

B: Aperture height

a: Waveguide width

b: Waveguide height

Wg_length: Waveguide length

Flare Angle: Horn Flare Angle

L_feed: Feed length

D_feed: Distance of feed from the back plane (closed) of the waveguide

Horn antenna is designed by iterating these parameters. Since, there are many parameters, we recommend building the waveguide 0.72λ of the target frequency (6 GHz) and take the flare angle as 33.7º (inner dimensions). This will decrease the number of design parameters for a laboratory experiment.

The calculation of dimensions with the Anten'it kit:

The cubic part of Anten'it metal cells has 3 mm and the top (thin) cylinder has 2 mm height. Although the total height is 5 mm, 2 mm interlace to another cell and the height resolution is 3 mm. Figure 10 shows the dimensions of a 1X1 metal cell. The dimensions of other cells are multiples of 1X1 dimensions.

For example, if you interlace 3 bricks into each other, the total height will be 3 X 3 mm + 2 mm which corresponds to 11 mm or if you interlace 5 bricks into each other, the total height will be 5 X 3 mm + 2 mm which corresponds to 17 mm.

The length and width of a cell is 4 mm or a multiple of 4 mm. Figure 10 shows a 1X1 cell. 1X1 represents that the cell has 1 cylinder in length and 1 cylinder in width. For example, 2X2 cell means a cell with 2 cylinders in width and 2 cylinders in length which corresponds to 4 cylinders in total.

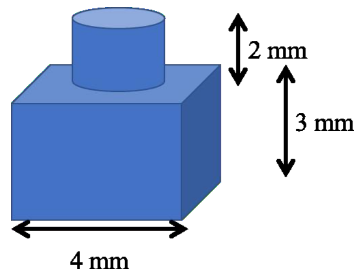


Figure 10 Anten'it cell dimensions

Removing the cells:

Removing the cells is one of the most important parts to learn. The misusage can damage the kits. There are some removing tools in the kit and the tool must be selected depending on the cell type. Each cell in the kit needs to be used gently.

In this experiment, use your hands to remove the cells. If you try to remove the cells with your hands but you can’t remove them after some trial, then use the special removing plier for removing the them. Figure 11 shows the removing plier and its special head.

In case, you must use the removing plier, you need to use it 90 degree to the top cylinder of the cells. For 1X3 and larger cells, hold the cylinder at the center. If you can’t remove the cell easily, change to another cylinder. Figure 12 shows an example usage of the removing plier.

a)

b)

Figure 11 Removing Plier

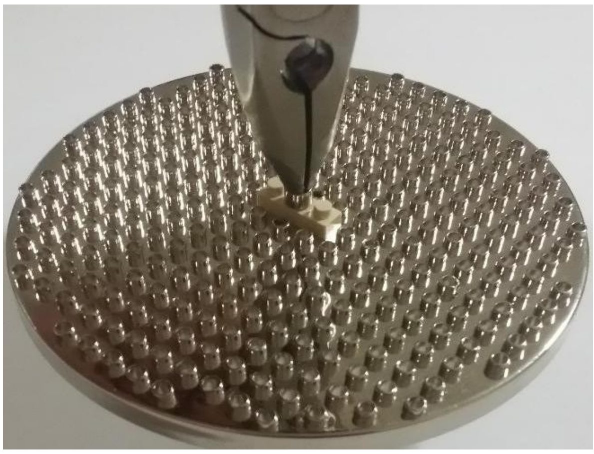


Figure 12 The usage of removing plier

PRELIMINARY WORK:

1. What are TE, TM and TEM modes? How does electric field lines change with different TE and TM modes? What is the direction of propagation, E-field and H-field for TE and TM modes?
2. What is the difference of coaxial cable and waveguide in terms of modes?
3. How does the horn antenna work? Where is the E-plane and H-plane of the horn antenna?
4. What are the analytical calculations to find the waveguide dimensions and horn dimensions?
5. How is it possible to increase the directivity of a horn antenna?
6. What does the relation of antenna gain and directivity?
7. Is it possible to measure the directivity of an antenna?
8. What is aperture efficiency?
9. Is the horn antenna an omnidirectional antenna or a directive antenna?

EXPERIMENTAL PROCEDURE:

10. Connect the cable to the Network Analyser and connect the SSMA-Female to SMA-Male adapter to the SSMA-male side of the cable as shown in Figure 13.

Figure 13 Cable to SSMA-SMA Adaptor Connection

11. Calibrate the Network Analyser for 1-port measurement between 2 GHz and 6 GHz.

12. We will design a 4.3-6 GHz horn antenna in this experiment. Follow the steps below.

13. Calculate the waveguide dimensions for waveguide operating between 3.75 and 7.5 GHz. These are the cut-off frequencies of the lowest mode and the second lowest mode. Second lowest mode for this experiment is TE01. Use equations (2), (3) and (4). Write down the waveguide dimensions and fill the mode table for these dimensions and check if “a” and “b” are the correct dimensions.

a	b

Mode	**m**	**n**	**[GHz]**
TE	1	0	
TE	0	1	
TE, TM	1	1	
TE	2	0	
TE, TM	2	1	

14. The back plane is the 20X20 ground plane with 80 mm X 80 mm dimensions as shown in Figure 14. The horn feed block is shown in Figure 15.

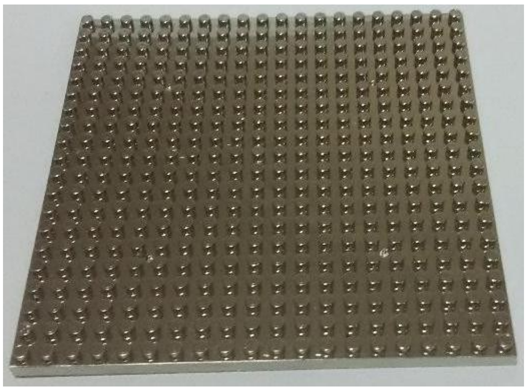


Figure 14 Back plane for Horn Antenna

Figure 15 Horn Feed Block

15. Locate the feed block one row over the back plane as shown in Figure 16 (There will be one brick between the backplane and horn feed block). Be careful to locate the feed block in the middle of “a”. The waveguide height will be 0.72λ at 6 GHz. Use 1X1, 1X2, 1X3, 1X4 and 1X6 cells to build the waveguide.

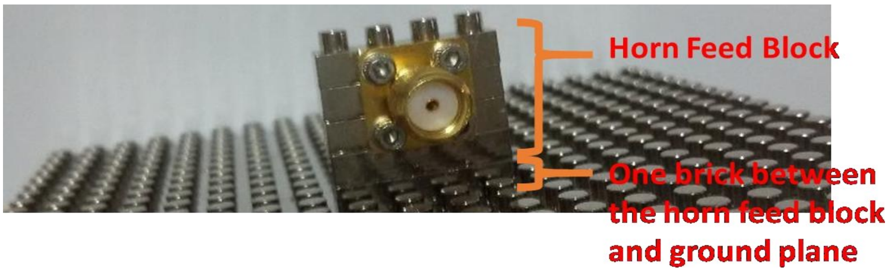


Figure 16 Locate the Horn Feed Block

16. Connect the open-ended waveguide to the network analyzer. Change the position of the ring over the inner conductor of the feed block to have the best reflection coefficient for 4.3 - 6 GHz frequency range.

17. Calculate the A and B dimensions for 50.7º HPBW in H-plane and 61º HPBW in E-plane. Use equations (6) and (7).

A	B

18. Calculate the Directivity using Equation (5). Assume that aperture efficiency e_A is 1.

Calculated Directivity:	

19. The flare angle for this experiment is 33,7º. The flare angle is for the inner dimensions of the horn. Calculate the height of the flare.

Calculated Flare Height:	

20. Build the horn with 2X1, 2X2, 2X4 and 2X8 metal cells.

21. Measure the reflection coefficient of the horn antenna. Change the position of the ring to get the best reflection coefficient between 4.3 and 6 GHz. Calculate the bandwidth ratio of the antenna.

Lowest Frequency:	
Highest Frequency:	
Bandwidth Ratio:	

22. Let's define this antenna as a Horn-1 antenna. Measure the E-plane (Elevation) of the horn-1 antenna at 6 GHz with a turn table. If the turn table is manual, write down the power levels for each E-plane angle. Normalize the power levels to the peak level.

E-plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
5		
10		
15		
20		
25		
30		
35		
40		
60		
90		
120		
150		
180		
210		
240		
270		
300		
320		
325		
330		
335		
340		
345		
350		
355		

Gain [dBi]:	
E-Plane HPBW [degrees]:	

23. Sketch the normalized power levels in E-plane axis on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

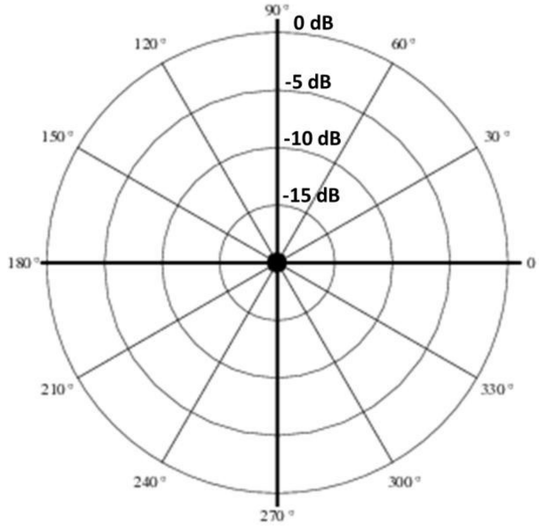


Figure 17 E-Plane Pattern of the Horn Antenna in Polar Coordinates

24. Measure the H-Plane (Azimuth) pattern of the horn-1 antenna with a turn table. If the turn table is manual, write down the power levels for each H-plane angle. Normalize the power levels to the peak level.

H-plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
5		
10		
15		
20		
25		
30		
35		
40		
60		
90		

120		
150		
180		
210		
240		
270		
300		
320		
325		
330		
335		
340		
345		
350		
355		

H-Plane HPBW:	

25. Sketch the normalized power levels in H-plane on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

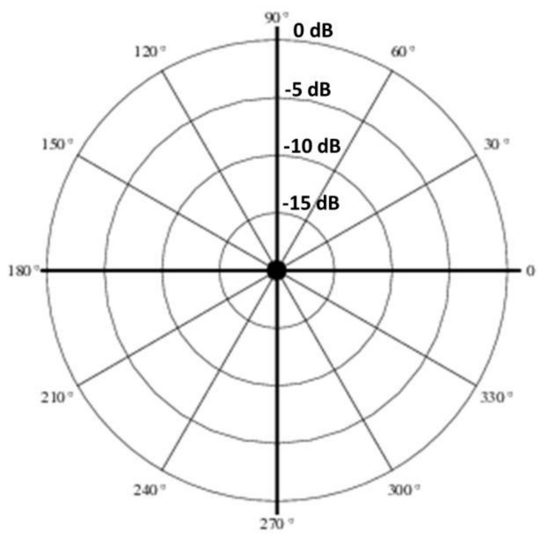


Figure 18 H-Plane Pattern of the Horn-1 Antenna in Polar Coordinates

26. Calculate the A and B dimensions for 40º HPBW in H-plane and 36,7º HPBW in E-plane. Use equations (6) and (7).

A	B

27. Calculate the Directivity again using Equation (5). Assume that aperture efficiency e_A is 1.

Calculated Directivity:	

28. Connect the antenna to the network analyzer again. Check the reflection coefficient. If it doesn't match to 4.3-6 GHz frequency range, change the position of the ring over the inner conductor of the connector.

29. Measure the E-plane (Elevation) of the horn-2 antenna at 6 GHz with a turn table. If the turn table is manual, write down the power levels for each E-plane angle. Normalize the power levels to the peak level.

E-plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
5		
10		
15		
20		
25		
30		
35		
40		
60		
90		
120		
150		
180		
210		

240		
270		
300		
320		
325		
330		
335		
340		
345		
350		
355		

Gain [dBi]:	
E-Plane HPBW:	

30. Sketch the normalized power levels in E-plane axis on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

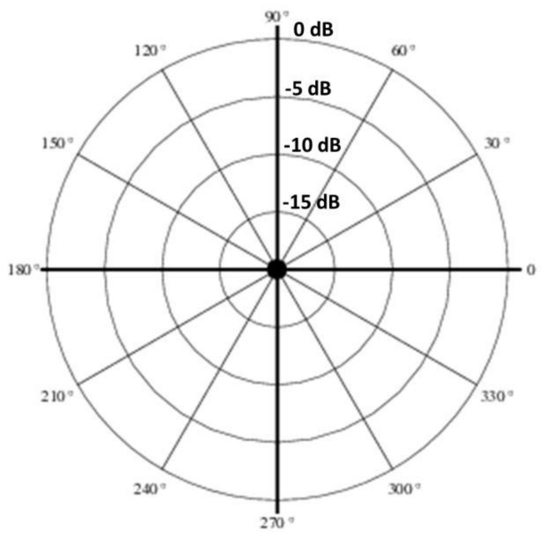


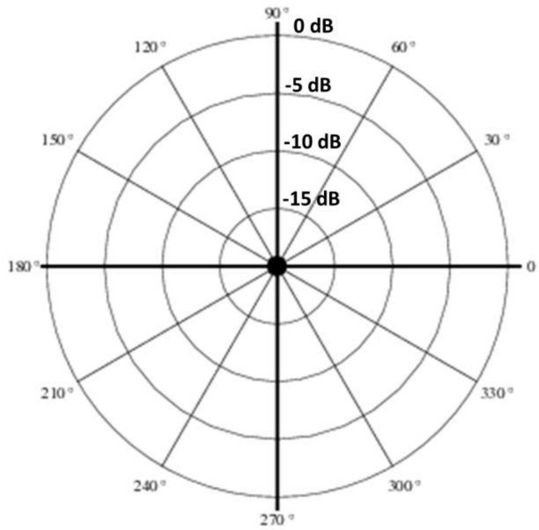
Figure 19 E-Plane Pattern of the Horn-2 Antenna in Polar Coordinates

31. Measure the H-Plane (Azimuth) pattern of the horn-2 antenna with a turn table. If the turn table is manual, write down the power levels for each azimuth angle. Normalize the power levels to the peak level.

H-plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
5		
10		
15		
20		
25		
30		
35		
40		
60		
90		
120		
150		
180		
210		
240		
270		
300		
320		
325		
330		
335		
340		
345		
350		
355		

H-Plane HPBW:	

32. Sketch the normalized power levels in H-plane on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.



33. Write down the HPBW both for E and H-planes again for horn-2 antenna.

	HPBW in E-Plane	HPBW in H-Plane
Measured		

RESULTS:

- State the objective of the experiment and give a short summary of the procedure.
- What parameters effect the reflection coefficient of horn antenna?
- Which parameters are effective on the HPBW of the horn antenna?
- What is the aperture and gain relationship for an aperture antenna?
- What are the reflection coefficient and radiation pattern differences between horn-1 and horn-2 antennas? How did the radiation pattern change by changing the aperture of the horn antenna?
- Compare the theory and experimental results.
- Discuss the results of your experiment.

10-PLANAR INVERTED-F ANTENNA (PIFA) DESIGN EXPERIMENT

OBJECTIVES

- To become familiar with the planar inverted-F antenna (PIFA).
- To investigate the characteristics of PIFA.
- Designing a PIFA using Anten'it antenna training kit.

BRIEF INFORMATION ABOUT THE PLANAR INVERTED-F ANTENNA:

Patch and patch antenna are two different terms throughout the text.

Definitions:

Patch antenna: Patch antenna is a type of antenna which includes at least one patch layer, dielectric layer and ground plane layer.
Patch: Patch is the top layer of the patch antenna. PIFA and some other types of antennas have patch layers too.

The analogy between the dipole and monopole antennas can be applied to patch and planar inverted-F antennas (PIFAs). The image theory is implemented to the patch antenna by decreasing the length of the patch to its half-size and short-circuiting it to the ground plane.

Remember from the patch antenna experiment that the center of the patch antenna has zero impedance which is the same as short circuit. When we short the patch in the half dimension of the length-axis and cut away one half, the patch antenna size is reduced into half. The resonance frequency stays nearly the same, but the physical dimensions become smaller. This is an advantage over the classical patch antenna. The disadvantage is that the aperture becomes smaller, which is the effective parameter on the gain and directivity of the antenna.

As in the patch antenna, PIFA has three layers. They are ground plane, dielectric and patch layers. Patch is a metal plate which radiates. The dielectric layer can either be air or a dielectric substrate due to the mechanical or electrical requirements. The inner conductor of the connector (feed) contacts to the patch where the outer conductor of the connector contacts with the ground plane.

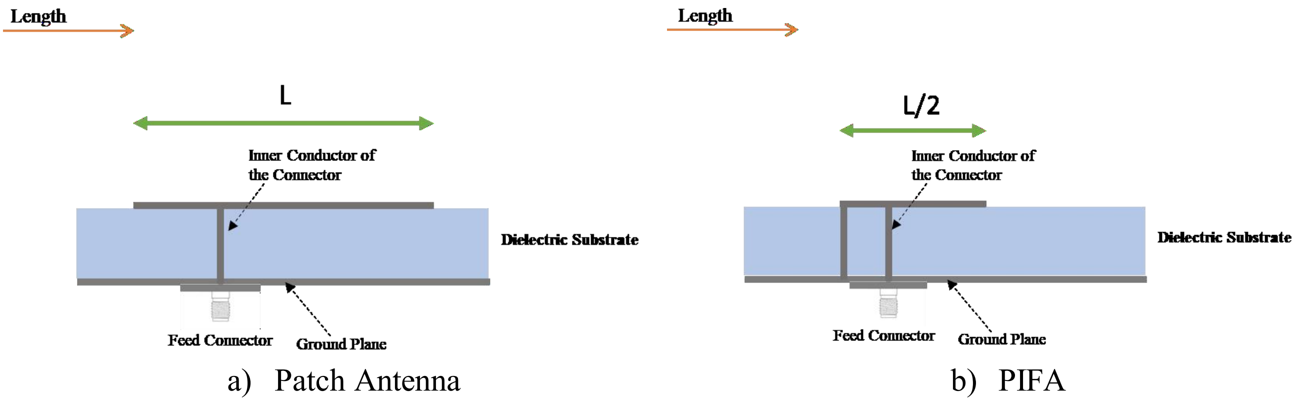


Figure 1 Patch antenna and PIFA explanation

Figure 1 shows a patch antenna and PIFA. The patch part of PIFA has L/2 dimensions which corresponds to λ/4. There is a method to decrease the patch dimensions of the PIFA. This method uses the principle of lengthening the current path over the patch. RF current mainly flows near the patch edges. As in Figure 2, the short circuit connection size can be shortened to increase the current path. This may cause to have the current both in length and width dimensions which results in inducing different polarizations.

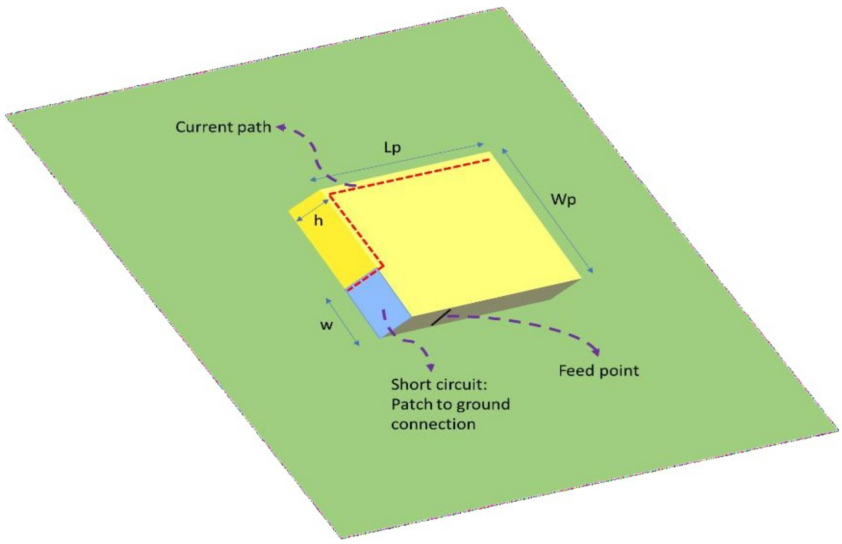


Figure 2 Current path on the patch of the PIFA

$$_{IA} = p + p - \; + h \qquad (1)$$

L_{PIFA}: the length of the RF current path
L_p: the length of the patch
W_p: the width of the patch
w: the width of the short circuit pin
h: the height of the dielectric substrate

The first resonance of the PIFA must be approximately;

$$_{e1} = \frac{0}{4(_{IA})\ _{e}\ \sqrt{\ }} \qquad (2)$$

The feed position may need to be relocated in order to have the lowest reflection coefficient.

EXPLANATION ABOUT DESIGNING A PLANAR INVERTED-F ANTENNA WITH ANTEN'IT:

The box in Figure 3 is the PIFA kit. The "PCB type metal cells" in this kit is totally different from "metal cells" in other Anten'it kits. The sides of the metal cells have grey colour. The beige dielectrics have 2.6 dielectric constant (relative permittivity). You need to use the same ground plane with beige dielectric cells as in the patch antenna experiment. The beige dielectric cells are already mounted over the ground plane.

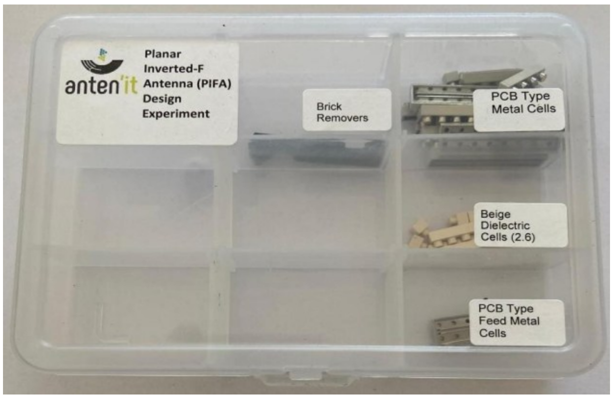


Figure 3 PIFA Design Experiment Box

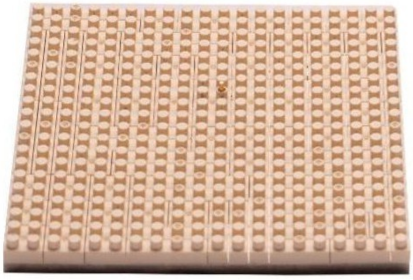


Figure 4 Ground plane with 2.6 dielectric constants

Removing the cells:

Removing the cells is one of the most important part to learn. The misusage can damage the kits. Do not touch the sides of the PCB type metal cells with another tool except the "Brick Remover" in this kit. Each cell needs to be used gently. Brick remover holds two of the cylinders in the same time. You just need to push to the high end of the remover as in Figure 5.

In this experiment, it is ***forbidden to use the removing plier or any other tool unless it is advised by Anten'it.***

The removing tool for this experiment is a plastic remover. In order to get the best efficiency, we need to start dismounting the cells from outside. First, remove the smallest PCB type metal cells which are at the outside. Second, remove the cells which are at the outside but larger. Third, remove the cells except the feed cell. At last, remove the feed cell. Always use the cylinders in the middle to use the remover as in Figure 5.

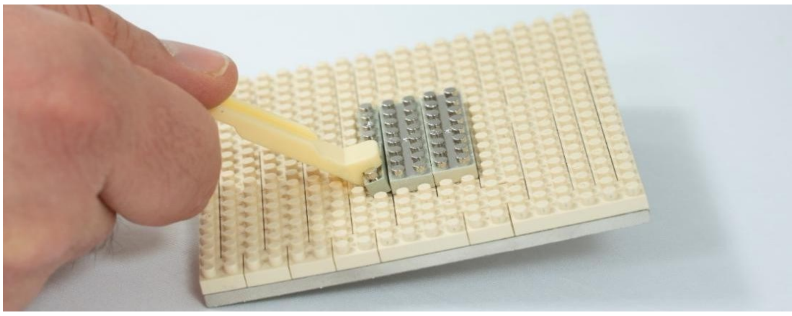


Figure 5 Plastic Remover for Patch Antenna Design Experiment

Patch Antenna Design with Anten'it Antenna Training Kit:

A patch antenna can easily be built with Anten'it kits. We need to know that resolution of the smallest (1X1) piece is 3 mm in height and 4 mm in width and length. Therefore, the results of the calculations must be transformed to the multiples of these values in order to build the antenna. Antenna design is an iterative process, you can iterate by adding or removing new cells to the antenna.

<u>The calculation of height:</u>

The cubic parts of Anten'it metal cells have 3 mm and the top cylinders have 2 mm height. Although the total height is 5 mm, 2 mm interlace to another cell and the height resolution is 3 mm. Figure 6 shows the dimensions of a 1X1 metal cell. The dimensions of other cells are multiples of 1X1 dimensions.

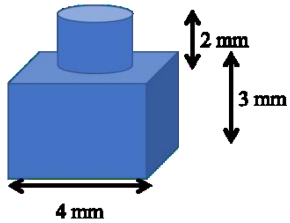


Figure 6 Anten'it cell dimensions

Figure 7 Anten'it PCB type feed metal cell inserts

PRELIMINARY WORK:

1. Explain the differences of patch and planar inverted-f antennas.
2. How do you expect the directivity and gain of the PIFA comparing to the patch antenna?
3. Explain how PIFA works.
4. What is co-polarization and cross-polarization? Do we desire to have low or high cross-polarization levels?

EXPERIMENTAL PROCEDURE:

5. Connect the cable to the Network Analyser and connect the SSMA-Female to SMA-Male adapter to the SSMA-male side of the cable as shown in Figure 8.

Figure 8 Cable to SSMA-SMA Adaptor Connection

6. Calibrate the Network Analyser for 1 port measurement between 1500 MHz to 3500 MHz.
7. Disconnect the SSMA to SMA adaptor after the calibration as shown in Figure 9.

Figure 9 Disconnect the cable from SSMA-SMA Adaptor

8. The first part of the experiment will be building the same patch as in the patch antenna design experiment. If you merge these two experiments, you can jump directly into step 10.

9. Locate the feed metal cell. The red point shows the feed point for this experiment. Locate the third cylinder of the feed metal cell over the inner conductor of the connector as in Figure 10. Locate 1X4 and 1X1 metal cells as in the figure. Do not dismount them during the antenna design.

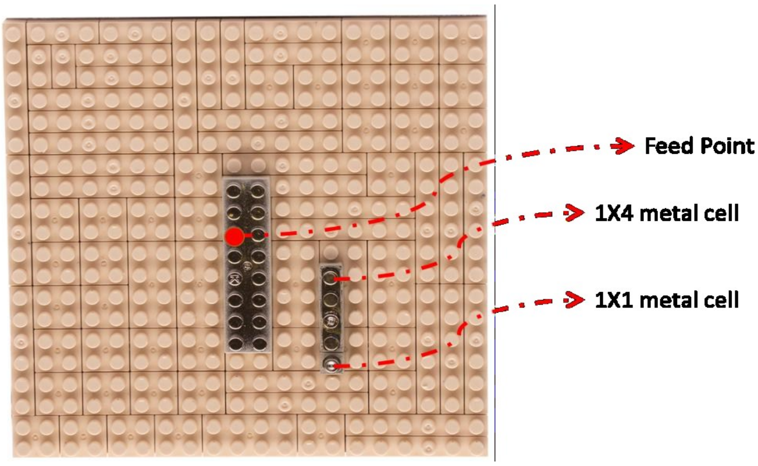


Figure 10 Feed metal cell and 1X4 and 1X1 cell location for this experiment

10. Use a multi-meter or voltmeter in order to check if the inner conductor of the connector is connected to the feed cell. Turn the multi-meter to "short" buzzer (Figure 11) option. With one probe touch to the inner conductor of the SSMA connector from the bottom of the plate and with the other probe touch to the feed cell. If the buzzer is ringing, they are connected to each other and the connection is ready for the experiment.

Figure 11 Buzzer

11. Calculate the patch antenna dimensions via equation (3) for 2460 MHz (Assume that= $_e$)

$$= \frac{/2}{\sqrt{_e}} \tag{3}$$

Calculated Patch-1 Antenna Length	
Patch-1 Antenna Length with Anten'it	

12. Locate the PCB type metal cells with the length in step 4 and connect the antenna to network analyser. Make sure that the feed point is in the center of the "width" dimension of the patch.

13. Measure the S_{11} parameters. Check if the S_{11} of target frequency is below -10 dB. If not, add or remove cells to reach it. Write the center frequency.

Patch-1 Measured Center Frequency	

14. Turn the patch antenna into planar inverted-F antenna. Dismount the dielectric cells at the edge of the patch and locate the metal cells to make a short along the side of the patch. The short pins are shown in Figure 12. The "PCB type feed metal cell" over the short pins is shown in Figure 13. Build the same structure as patch antenna.

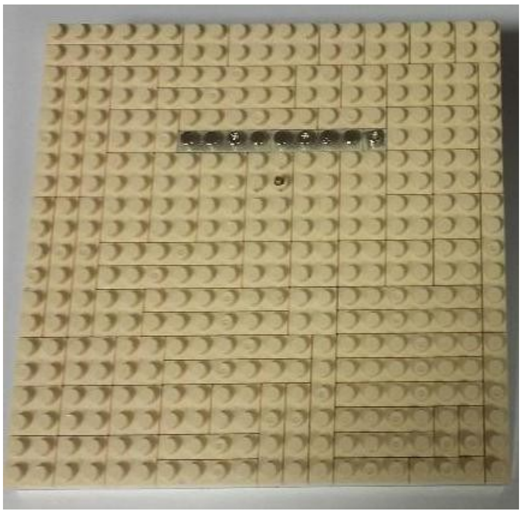


Figure 12 PIFA short pins

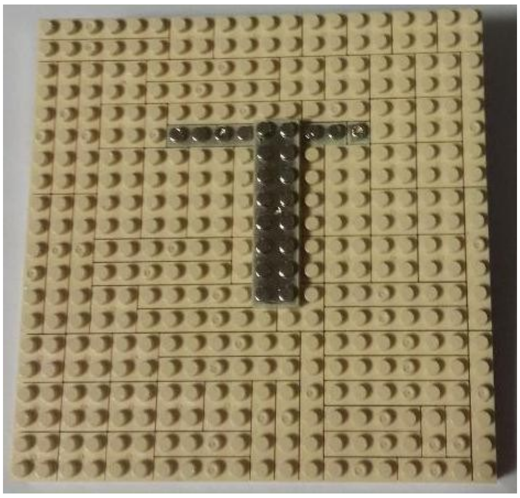


Figure 13 PCB Type Feed Metal Cells over the short pins

PIFA center frequency	
The ratio of the PIFA center frequency/Patch center frequency:	

15. Take out some of the short pins to see the principle in equations (1-2) and Figure 2. Try to go to the lowest center frequency by changing different short pin configurations. Write down the lowest PIFA frequency. This design will be called as "Lowest-1 PIFA" in the text.

Lowest-1 PIFA Center Frequency	
The ratio of the Lowest-1 PIFA center frequency/Patch center frequency:	

16. Measure the Lowest-1 PIFA gain at the center frequency.

Lowest-1 PIFA Gain [dBi]:	

17. Measure the E-plane radiation pattern of the Lowest-1 PIFA at the center frequency via a turn table. If the turn table is manual, write down the power levels for each E-plane angle. Normalize the power levels to the peak level.

E-plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		

120		
150		
180		
210		
240		
270		
300		
330		

18. Sketch the normalized power levels in E-plane axis on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

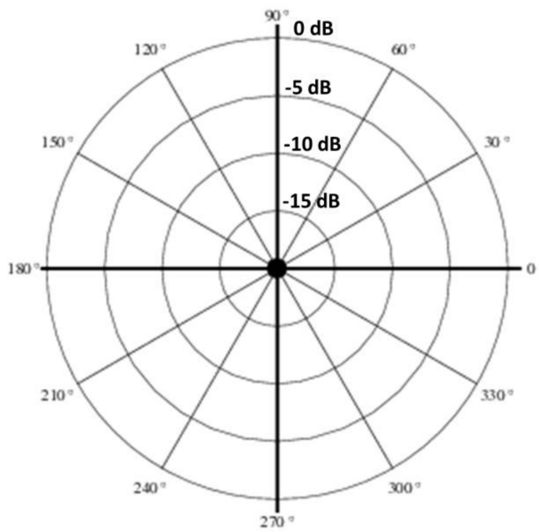


Figure 14 E-Plane Pattern of the Lowest-1 PIFA in Polar Coordinates

19. Measure the H-Plane pattern of the Lowest-1 PIFA with a turn table. If the turn table is manual, write down the power levels for each H-plane angle. Normalize the power levels to the peak level.

H-Plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		

150		
180		
210		
240		
270		
300		
330		

20. Sketch the normalized power levels in H-plane on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

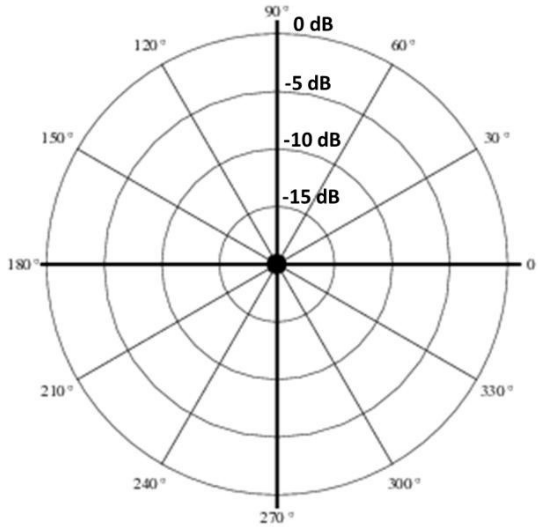


Figure 15 H-Plane Pattern of the Lowest-1 PIFA Antenna in Polar Coordinates

21. Make a cross-polarization measurement and observe the change in the power level.

22. Compare the results with the cross-polarization level in the patch antenna design experiment.

Cross-polarization level in patch antenna (From patch antenna experiment):	
Cross-polarization level in Lowest-1 PIFA:	

RESULTS:

- State the objective of the experiment and give a short summary of the procedure.
- How did the gain change between patch and PIFA antennas?
- What is the trade-off between using a patch antenna and PIFA? When you use PIFA, which advantages and which disadvantages do you get over patch antenna?
- Did you see a direct effect of the principle in equation (1-2) and Figure 2?
- What is the difference in the cross-polarization levels of the Lowest-1 PIFA and patch antennas? Why did you get these results?
- Discuss the results of your experiment.

10-SLEEVE MONOPOLE ANTENNA DESIGN EXPERIMENT

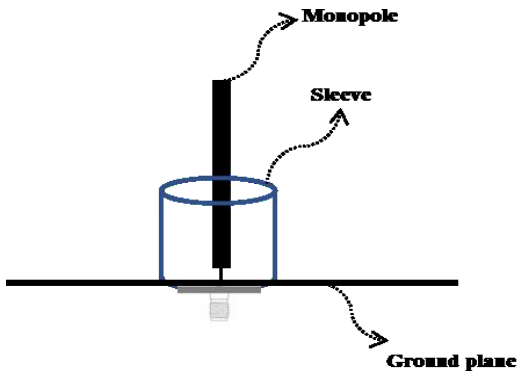
OBJECTIVES

- Designing a sleeve monopole antenna using Anten'it antenna training kit.
- To investigate return loss and antenna length-frequency relation.
- Understand the differences of the monopole and sleeve monopole antennas.
- Plot the radiation pattern of a sleeve monopole antenna.

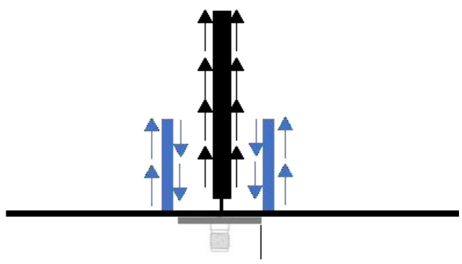
BRIEF INFORMATION ABOUT THE SLEEVE MONOPOLE ANTENNA:

Sleeve Monopole Antenna:

We have designed some different forms of monopole antennas including thin, thick and capacitive loaded monopoles in the monopole antenna design experiment. The bandwidth of the antenna was changing with the wire thickness and the center frequency was shifted to a lower frequency in the monopole antenna design experiment. Apart from those antennas, sleeve monopole antenna has two resonant elements; one of them is the monopole and the other one is the outer part of the sleeve. Therefore, antenna engineers can shift the resonance frequencies of both elements and design the antenna for their requirements.



a) Sleeve Monopole Antenna Explanation



b) Current Flow over the Sleeve and the Monopole

Figure 1 The explanation of Current Flow over the Sleeve Monopole Antenna

Figure 1a shows the sleeve monopole structure. There is a cylindrical metal tube around the monopole. This metal cylinder is called sleeve. It is physically and electrically connected to the ground plane. Therefore, the inner part of the sleeve acts such as the outer conductor of a coaxial cable.

The monopole creates the first resonance with its Lm height. Lm is approximately $\lambda_1/4$. The sleeve creates the second resonance with its Ls height. Ls is approximately $\lambda_2/4$. Therefore, there are two frequencies a sleeve monopole antenna operates. If these two frequencies are very close to each other, you can see them as one resonance. When they become apart from each other, it is easier to see each resonance corresponding to monopole and sleeve.

Antenna engineers need to calculate the corresponding heights ($\lambda_1/4$ and $\lambda_2/4$) for f_1 the f_2 frequencies, build the antenna and iterate the design in order to meet the target frequency range.

There are many techniques to create a broadband monopole antenna. Sleeve monopole is one of them. The advantage of sleeve monopole is its stable pattern specifications over the wide frequency range. The pattern characteristics of the sleeve monopole antennas are nearly the same as the monopole antennas.

Bandwidth:

The impedance bandwidth of the antenna is a frequency range between the highest and lowest frequency where return loss is below a certain value. For most of the applications, 10 dB return loss is a rule of thumb. Elementary antennas have typical bandwidth characteristics, but the frequency bandwidth changes with the center frequency. Therefore, the percentage bandwidth is used as an antenna parameter. The percentage bandwidth is a ratio of the frequency range divided by the center frequency as in Equation 1.

$B = = 100$ (1)

f_H: The highest frequency intersecting -10 dB S_{11}[dB]
f_L: The lowest frequency intersecting -10 dB S_{11}[dB]
f_C: Center frequency

EXPLANATION ABOUT DESIGNING A SLEEVE MONOPOLE ANTENNA WITH ANTEN'IT:

The box in Figure 2 is the sleeve monopole antenna kit. There are metal cells for monopole and sleeve. Feed dielectric cells have holes and feed metal cells have special inserts. We will use each of these sections in the experiment. SSMA to SMA adaptor (You can have it in monopole antenna experiment kit) is for one port calibration of the network analyser.

Figure 2 Sleeve Monopole Antenna Experiment Box

Figure 3 shows the feed cells of this experiment. The beige colour represents the dielectric cells with 2.6 dielectric constant. Feed dielectric cell has a cylinder with a hole. The inner conductor of the connector will go through this hole and touch the feed insert of the feed metal cell. There is only one feed metal cell in this experiment. The feed dielectric cell is used as a spacer for this experiment.

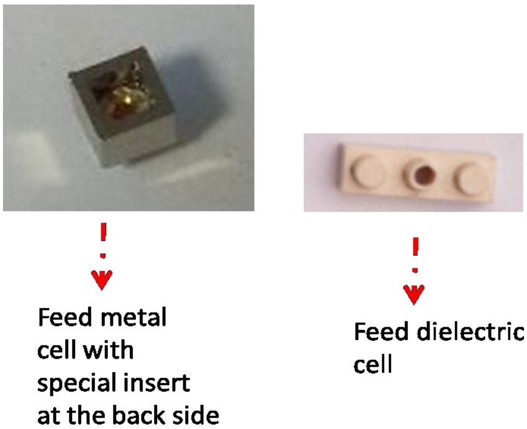


Figure 3 Feed Cells

The metal cells for sleeve needs to be directly located over the ground plane.

<u>The calculation of height:</u>

The cubic part of Anten'it metal cells has 3 mm and the top (thin) cylinder has 2 mm height. Although the total height is 5 mm, 2 mm interlace to another cell and the height resolution is 3 mm. Figure 4 shows the dimensions of a 1X1 metal cell. The dimensions of other cells are multiples of 1X1 dimensions.

For example, if you interlace 3 bricks into each other, the total height will be 3 X 3 mm + 2 mm which corresponds to 11 mm or if you interlace 5 bricks into each other, the total height will be 5 X 3 mm + 2 mm which corresponds to 17 mm.

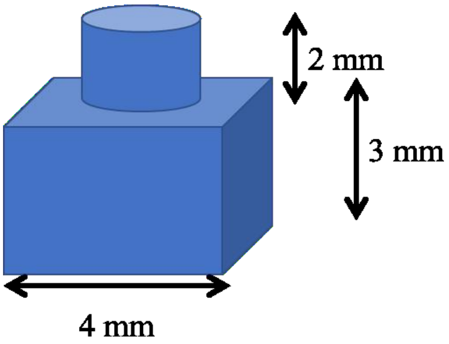


Figure 4 Anten'it cell dimensions

Removing the cells:

Removing the cells is one of the most important parts to learn. The misusage can damage the kits. There are some removing tools in the kit and the tool must be selected depending on the cell type. Each cell in the kit needs to be used gently.

In this experiment, use your hands to remove the cells. If you try to remove the cells with your hands but you can't remove them after some trial, then use the special removing plier for removing the cells. Figure 5 shows the removing plier and its special head.

In case, you must use the removing plier, you need to use it 90 degree to the top cylinder of the cells. For 1X3 and larger cells, use the cylinder at the center. If you can't remove the cell easily, change to another cylinder. Figure 6 shows an example usage of the removing plier.

a) b)

Figure 5 Removing Plier

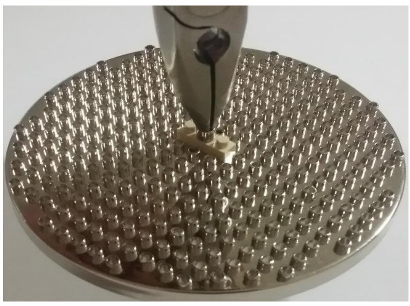


Figure 6 The usage of removing plier

PRELIMINARY WORK:

1. How does the sleeve monopole antenna work?
2. Why do we use sleeve monopole antennas? What are the advantages over monopole antennas?
3. What are the other alternative wideband monopole antenna types?
4. Where is the E-plane and H-plane of the sleeve monopole antenna?

EXPERIMENTAL PROCEDURE:

5. Connect the cable to the Network Analyser and connect the SSMA-Female to SMA-Male adapter to the SSMA-male side of the cable as shown in Figure 7.

Figure 7 Cable to SSMA-SMA Adaptor Connection

6. Calibrate the Network Analyser for 1 port measurement between 800 MHz and 6 GHz.
7. Disconnect the SSMA to SMA adaptor after the calibration as shown in Figure 8.

Figure 8 Disconnect the cable from SSMA-SMA Adaptor

8. Mount the dielectric feed cell and metal feed cell over the inner conductor of the connector as in Figure 6.

9. Use a multi-meter or voltmeter in order to check if the inner conductor of the connector is connected to the feed cell. Turn the multi-meter to "short" buzzer option. With one probe touch to the inner conductor of the SSMA connector from the bottom of the ground plane and with the other probe touch to the feed cell. If the buzzer is ringing, they are connected to each other and we can start the experiment.

Figure 9 Buzzer

10. Calculate the monopole antenna size for 1630 MHz. Find out the nearest Anten'it size with the dimensions in Section 3 (Calculation of height) of this document. Write the calculated sizes below:

Calculated monopole height:	
The nearest Anten'it monopole height:	

11. Build the antenna. Be careful that the calculated monopole size is the total size including the dielectric and metal cells.

12. Connect the cable to the connector at the ground plane of the monopole antenna as shown in Figure 10.

Figure 10 Connection to the connector at the ground plane of the monopole

13. Display S_{11} dB scale on the network analyser screen.

14. Measure S11 in dB scale. Write down the center frequency and % bandwidth of the thin monopole antenna.

Monopole center frequency:	
Monopole bandwidth between -6 dB S_{11} points (%):	

15. The smallest sleeve diameter (inner) with Anten'it is 12 mm. Use 12 mm sleeve diameter and add calculate the sleeve height for 3260 MHz (2 X 1630 MHz). See multiple resonances.

Calculated sleeve height:	
The nearest Anten'it sleeve height:	

16. Find the optimum dimensions to get the maximum bandwidth (You can change the dimensions of monopole and sleeve). The lowest frequency intersecting the -6 dB S_{11} needs to be 1640 MHz.

Optimum monopole dimensions:	
Optimum sleeve monopole dimensions:	
Sleeve Monopole center frequency:	
Sleeve monopole bandwidth between -6 dB S_{11} points (%):	

17. Measure the E-plane (Elevation) of the sleeve monopole antenna at the center frequency of the antenna with a turn table. If the turn table is manual, write down the power levels for each E-plane angle. Normalize the power levels to the peak level.

E-plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		
330		

Gain [dBi]:	

18. Sketch the normalized power levels in E-plane axis on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

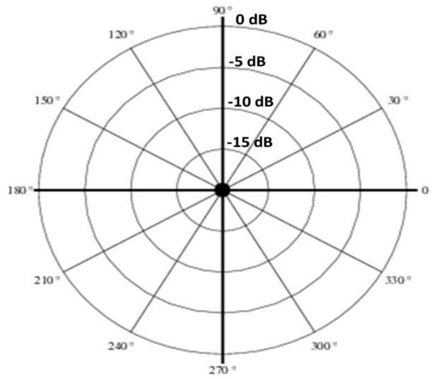


Figure 11 E-Plane Pattern of the Sleeve Monopole Antenna in Polar Coordinates

19. Measure the H-Plane (Azimuth) pattern of the antenna with a turn table. If the turn table is manual, write down the power levels for each H-plane angle. Normalize the power levels to the peak level.

H-Plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		
330		

20. Sketch the normalized power levels in H-plane on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

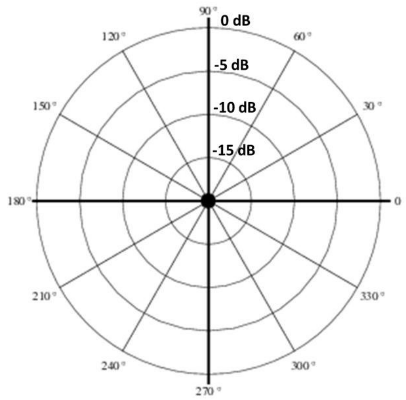


Figure 12 H-Plane Pattern of the Sleeve Monopole Antenna in Polar Coordinates

RESULTS:

- State the objective of the experiment and give a short summary of the procedure.
- How does the resonances change with the height of the monopole and sleeve?
- How did you get the optimum bandwidth? Which procedure did you follow?
- Compare the theory and experimental results.
- Discuss the results of your experiment.

11-DIELECTRIC RESONATOR ANTENNA DESIGN EXPERIMENT

OBJECTIVES

- Designing a dielectric resonator antenna (DRA) using Anten'it antenna design kit.
- Understand the effect of dielectric permittivity in dielectric resonator antennas.
- Plot the radiation pattern of a DRA.

BRIEF INFORMATION ABOUT THE DIELECTRIC RESONATOR ANTENNA:

Dielectric Resonator Antennas are resonators that radiate energy when excited appropriately. There are many different techniques to excite the dielectric resonator. The dimensions of the DRA are proportional to $\lambda_0/\sqrt{\ }$, where is the dielectric constant of the dielectric resonator and λ_0 is the wavelength in free space. As the dielectric constant increase, the size of the DRA decreases. This results in an increase in Q-factor.

Q-factor:

The Q-factor (quality factor) of an antenna is a basic way to quantify the bandwidth of an antenna. The Q-factor is defined as the ratio between the power stored and the radiated power. Therefore, Q-factor of an antenna is a measure of the radiation efficiency of the antenna. The Q-factor is inversely proportional to the bandwidth.

DRA:

For a specific frequency, the size of the DRA is inversely proportional to the dielectric constant of the resonator. The dielectric constant and the shape of the antenna effect the bandwidth of the antenna. There are many different feeding techniques and resonator shapes in the literature.

A resonator has an infinite number of resonant modes and each of them corresponds to a resonance frequency.

In coaxial probe feed excitation, the inner conductor of the feed is extended as a probe which induces the dielectric resonator. The current flows vertical to the DRA height. The strength of coupling depends on the length and location of the probe. Various modes can also be excited based on the probe location and the order of coupling is related to the probe height.

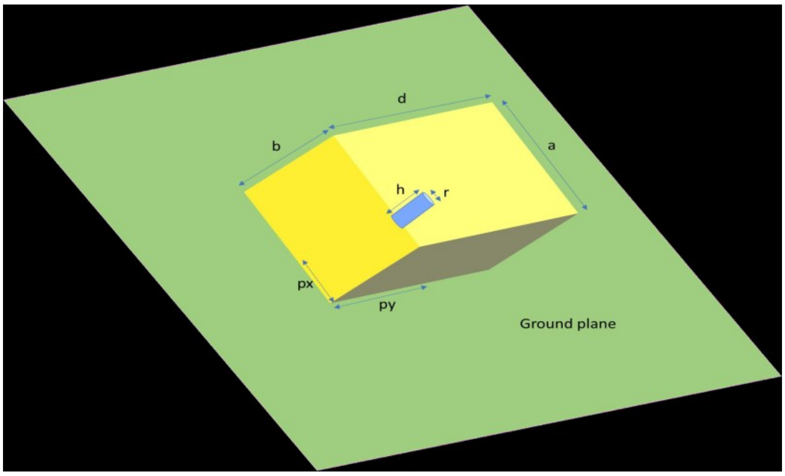


Figure 1 The figure of DRA

Figure 1 shows the DRA. Yellow part is the dielectric resonator where the blue cylinder is the feed (feed is the extension of the inner conductor of the coaxial connector). a, b and d represent the dimensions of the dielectric resonator, h represents the height of the probe and r represents the radius of the probe. px and py show the position of the probe by reference to the edge of the resonator. The equations below are to calculate the dimensions of the DRA (a, b and d).

$$ {}_0 = \frac{}{2\sqrt{-}} \sqrt{{}^2 + {}^2 + {}^2} \qquad (1) $$

$$ = - \qquad (2) $$

$$ = \frac{}{2} \qquad (3) $$

$$ = {}^2 \, - \tanh\left(\frac{{}^0}{}\right) - \qquad (4) $$

$$_0 = \sqrt{^2 + ^2} \qquad (5)$$

The probe is in the center of “a” dimension. The probe is between the center and side of d dimension. The probe height must be shorter than the height of the DRA (b).

Bandwidth:

The impedance bandwidth of the antenna is a frequency range between the highest and lowest frequency where return loss is below a certain value. For most of the applications, 10 dB return loss is a rule of thumb. Elementary antennas have typical bandwidth characteristics, but the frequency bandwidth changes with the center frequency. Therefore, the percentage bandwidth is used as an antenna parameter. The percentage bandwidth is a ratio of the frequency range divided by the center frequency as in Equation 6.

$$B = \frac{}{} 100 \qquad (6)$$

f_H: The highest frequency intersecting -10 dB S_{11}[dB]
f_L: The lowest frequency intersecting -10 dB S_{11}[dB]
f_C: Center frequency

EXPLANATION ABOUT DESIGNING A DRA WITH ANTEN’IT:

The box in Figure 2 is the DRA kit. There is one 1x1 feed metal cell and two 1x1 metal cells for probe. There is one feed dielectric cell with a hole. The feed dielectric cell, feed metal cell and 1X1 metal cells are to build the probe.

We will use the ground plane with holes (PCB type ground plane) in this experiment.

There are many white dielectric cells with 8 dielectric constant. These cells will be used to build the DRA.

SSMA to SMA adaptor is for one port calibration of the network analyser. This adaptor is in monopole antenna design experiment box.

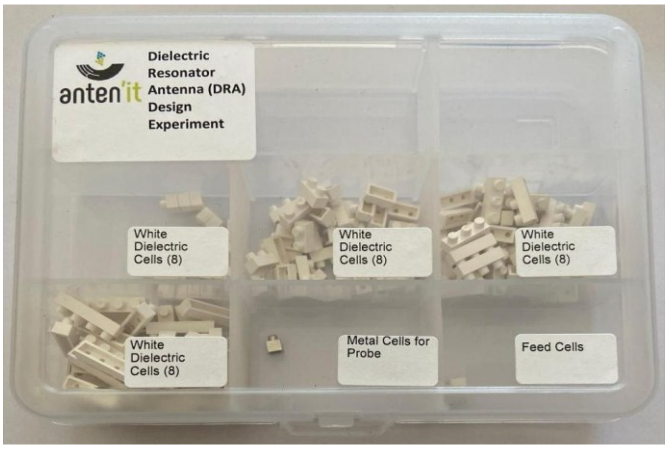


Figure 2 DRA Experiment Box

Figure 3 shows the feed cells of this experiment. The dielectric feed cell has a cylinder with a hole. The inner conductor of the connector will go through this hole and touch the feed insert of the feed metal cell. The other dielectric cells will surround the probe and build a DRA.

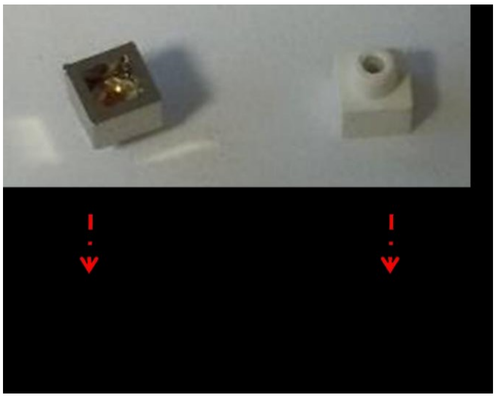


Figure 3 Feed Cells

We will learn an iteration process in this experiment. ε_r is the dielectric constant of the white dielectric cells. Due to the air gaps within the bricks and some parts of the electric field vector is out of the dielectric part of the DRA, the effective dielectric constant ε_{r_eff} is smaller than ε_r. This is very similar to the effective dielectric constant in patch antenna.

The outer dimensions of the DRA (a,b and d) must be calculated before the experiment (in excel). The input parameters are frequency and ε_{r_eff} and the output parameters are a, b and d. We will start the design process by using ε_r of the material instead of the real ε_{r_eff}. Because we don't know the real ε_{r_eff}. ε_{r_eff} may change depending on the shape and dimensions of the antenna. Then we will build the antenna, measure the reflection coefficient (the lower frequency @ -6 dB S_{11}) and change the frequency value in excel. Then, we will iterate and find the corresponding ε_{r_eff} in excel for approximately the same a,b and d values. This is the real ε_{r_eff} for this antenna.

We will use ε_{r_eff} and target frequency of the experiment in excel and recalculate a,b and d.

There are some points to be careful about:

- “a” is longer than “d” (In Figure 1, “a” seems smaller than “d”. It is only to show the dimensions. “a” is larger than “d” in our antenna.).

- Anten’it cells has 4 mm resolution in length and width axes, and 3 mm resolution in height axis.

- The probe must be in the middle of “d” dimension. Therefore, the number of cells in this dimension must be an odd number. Even if the calculations give you an even number, use the closest odd number.

- Take $k_x = k_y = k_z$ in the calculations.

- The feed point must be between the middle of “a” and the side of the DRA as in Figure 4. Please make sure that the feed point is not in the center of “a” dimension during the experiment.

- We will start with the probe height of 14 mm (Including the dielectric feed cell height). It consists one dielectric feed cell, one feed metal cell and two metal cells. If you can’t reach the target frequency parameters, you can change the height of the probe.

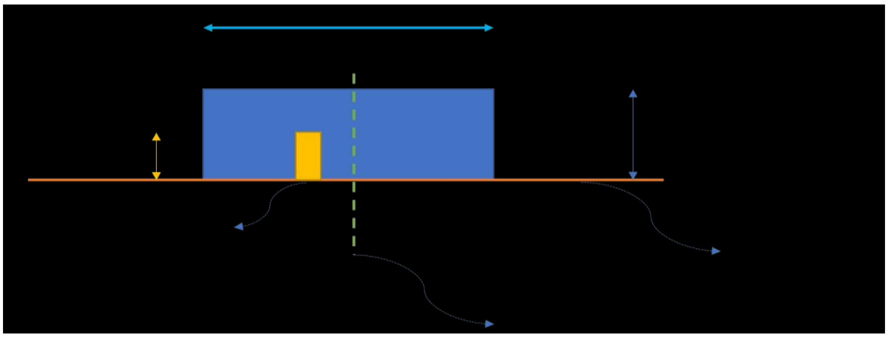


Figure 4 DRA Antenna “a” axis and probe position

__**The calculation of height:**__

The cubic part of Anten’it metal cells has 3 mm and the top (thin) cylinder has 2 mm height. Although the total height is 5 mm, 2 mm interlace to another cell and the height resolution is 3 mm. Figure 5 shows the dimensions of a 1X1 metal cell. The dimensions of other cells are multiples of 1X1 dimensions.

For example, if you interlace 3 bricks into each other, the total height will be 3 X 3 mm + 2 mm which corresponds to 11 mm or if you interlace 5 bricks into each other, the total height will be 5 X 3 mm + 2 mm which corresponds to 17 mm.

In DRA experiment, the 2 mm cylinder height is not effective as a resonator. Therefore, you need to calculate 3 bricks as 3 X 3 = 9 mm. This calculation is only valid for the DRA height calculation.

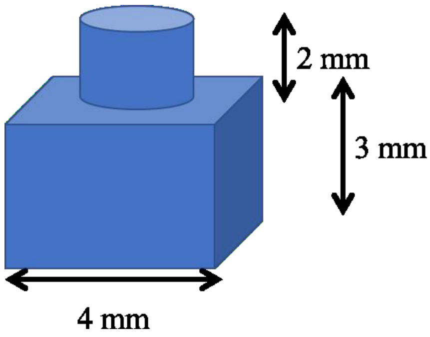


Figure 5 Anten'it cell dimensions

Removing the cells:

Removing the cells is one of the most important parts to learn. The misusage can damage the kits. There are some removing tools in the kit and the tool must be selected depending on the cell type. Each cell in the kit needs to be used gently. White dielectric cells are very fragile.

The removing tool for this experiment is a plastic remover. In order to get the best efficiency, we need to start dismounting the cells from outside. First, remove smallest PCB type metal cells which are at the outside. Second, remove the cells which are at the outside but larger. Third, remove the cells except the feed cell. At last, remove the feed cell. Always use the cylinders in the middle to use the remover as in Figure 6.

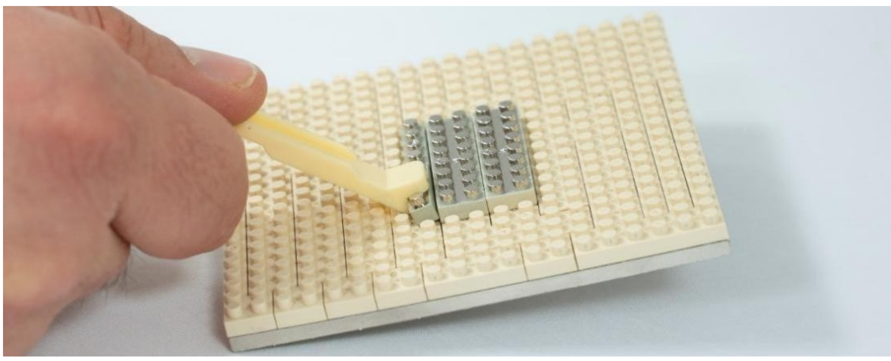


Figure 6 Plastic Remover

PRELIMINARY WORK:

1. Build an excel chart with the design equations in section 2 of this document before the experiment. The output parameters are the a, b and d dimensions. a, b and d must be variable for different dielectric constant and frequency values. You need to change dielectric constant and frequency (input parameters) and calculate new a,b and d dimensions during the experiment. Take $k_x = k_y = k_z$ in the calculation.
2. How does the dielectric resonator antenna (DRA) work?
3. What is the difference of dielectric constant and effective dielectric constant?
4. Where is the E-plane and H-plane of the DRA?
5. What percentage of the input power is reflected when S_{11} is -6 dB?

EXPERIMENTAL PROCEDURE:

6. Connect the cable to the Network Analyser and connect the SSMA-Female to SMA-Male adapter to the SSMA-male side of the cable as shown in Figure 7.

Figure 7 Cable to SSMA-SMA Adaptor Connection

7. Calibrate the Network Analyser for 1 port measurement between 1500 MHz and 6 GHz.
8. Disconnect the SSMA to SMA adaptor after the calibration as shown in Figure 8.

Figure 8 Disconnect the cable from SSMA-SMA Adaptor

9. The ground plane is shown is Figure 9. Locate the "dielectric feed cell with a hole" over the inner conductor pin of the connector. Locate the "1X1 metal feed cell" over the hole.

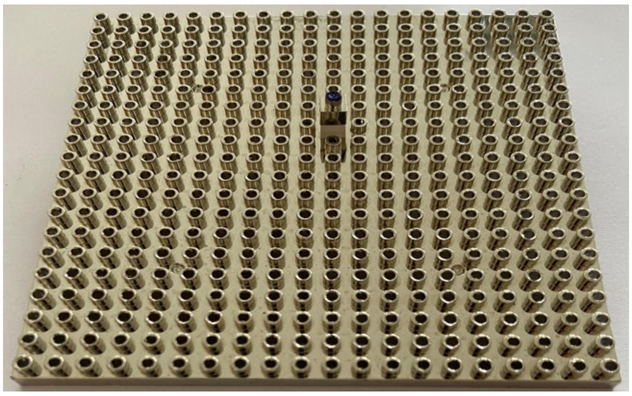


Figure 9 Ground plane with a dielectric feed cell and a metal feed cell

10. Use a multi-meter or voltmeter in order to check if the inner conductor of the connector is connected to the feed cell. Turn the multi-meter to "short" buzzer option. With one probe touch to the inner conductor of the SSMA connector from the bottom of the ground plane and with the other probe touch to the feed cell. If the buzzer is ringing, they are connected to each other and we can start the experiment.

Figure 10 Buzzer

11. Locate two 1X1 metal cells over the feed metal cell.

12. Use the excel document that you prepare before the experiment. Input parameters are the frequency and dielectric constant. The dielectric constant is 8. The design frequency for this experiment is 2.8 GHz. Calculate a, b and d dimensions by using the formulas (1-5). Use the nearest Anten'it sizes with the calculations in Section 3 of this document. Write down the calculated sizes below:

Frequency:	
Dielectric constant:	
Calculated "a":	
"a" to be used in the experiment:	
Calculated "b":	
"b" to be used in the experiment:	

Calculated “d”:	
“d” to be used in the experiment:	

13. Locate the white dielectric cells for the calculated sizes. The probe must be positioned as explained in section 3.
14. Connect the cable to the connector at the ground plane and measure the reflection coefficient.
15. Display S_{11} dB scale on the network analyser screen.
16. Measure S11 in dB scale. Write down the lowest frequency intersecting -6 dB S_{11}.

DRA-1 lowest frequency:	

17. We assume that the effective dielectric constant is equal to the dielectric constant of the material (8). This is a good initial point, but it is not correct. Use your excel sheet and change the frequency to DRA-1 lowest frequency. Find out the <u>effective dielectric constant</u> for the measured DRA-1 lowest frequency. Be careful that a, b and d must be close to the previous dimensions.

18. Use the excel sheet to calculate the new a, b and d dimensions with the effective dielectric constant and 2.8 GHz design frequency. The new antenna is called DRA-2.

Frequency:	
Effective Dielectric constant:	
Calculated “a”:	
“a” to be used in the experiment:	
Calculated “b”:	
“b” to be used in the experiment:	
Calculated “d”:	
“d” to be used in the experiment:	

19. Locate the white dielectric cells in order to build the DRA-2. If the antenna doesn’t work at 2.8 GHz, iterate your design by adding or removing cells. Be careful that the feed point still ensures the important points in section 3.

DRA-2 lowest frequency:	

20. Measure the E-plane of the DRA at the center frequency with a turn table. If the turn table is manual, write down the power levels for each E-plane angle. Normalize the power levels to the peak level.

E-plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		
330		

Gain [dBi]:	

21. Sketch the normalized power levels in E-plane axis on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

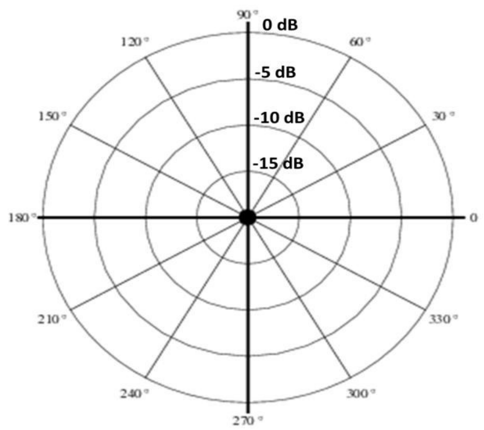


Figure 11 E-Plane Pattern of the DRA in Polar Coordinates

22. Measure the H-Plane pattern of the DRA with a turn table. If the turn table is manual, write down the power levels for each H-plane angle. Normalize the power levels to the peak level.

H-Plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		
330		

23. Sketch the normalized power levels in H-plane on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

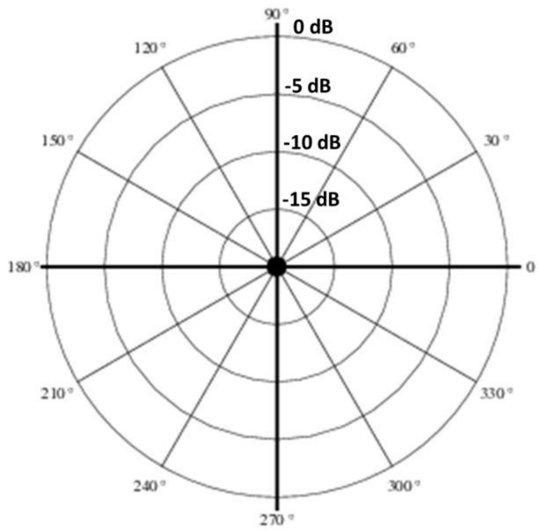


Figure 12 H-Plane Pattern of DRA in Polar Coordinates

RESULTS:

- State the objective of the experiment and give a short summary of the procedure.
- What are the measured differences between the calculated and measured dimensions?
- What is the effective dielectric permittivity?
- Compare the theory and experimental results.
- Discuss the results of your experiment.

12-DIELECTRIC RESONATOR MONOPOLE ANTENNA DESIGN EXPERIMENT

OBJECTIVES

- Designing a dielectric resonator monopole antenna (DRMA) using Anten'it antenna design kit.
- To investigate bandwidth of a DRMA.
- Plot the radiation pattern of a DRMA.

BRIEF INFORMATION ABOUT THE DIELECTRIC RESONATOR MONOPOLE ANTENNA:

Dielectric Resonator Monopole Antennas (DRMA) are referred to by different names in the literature. Monopole-dielectric resonator antenna, monopole using dielectric resonator antenna loading, monopole antenna loaded by a dielectric ring are some expressions that you can find in the literature.

There are many different techniques to increase the bandwidth of a monopole antenna. DRMA includes a monopole antenna and a dielectric ring (dielectric resonator antenna) around it. There is an air gap between the dielectric ring and the monopole. This is a method to induce the dielectric resonator antenna. The dielectric resonator ring is designed to radiate in a circularly symmetrical pattern which corresponds to an omnidirectional pattern. The omnidirectional pattern of the monopole and the dielectric resonator ring creates a wideband omnidirectional antenna.

The monopole needs to be in the middle of the dielectric resonator ring in order to excite it. Hence, the monopole has two functions in this antenna. One of them is to work as a conventional monopole and the other one is to excite the dielectric resonator ring. Each of them creates a resonance at different frequencies. Thus, the bandwidth of the dielectric resonator monopole antenna becomes the summed bandwidth of these two resonances.

Each antenna can be modelled as a resonance circuit as a composition of R, L and C components. For example, monopole and dipole antennas can be modelled as series resonance circuits in their first resonances and patch antennas can be modelled as a parallel resonance circuit in its first resonance. The wideband DRMA can be considered as two cascaded resonance circuits working at different frequencies. These two frequencies need to be close to each other in order to generate a wide bandwidth antenna.

The monopole will be radiating at the lower frequency and the dielectric resonator antenna (DRA) ring will be radiating at the higher frequency. Therefore, the design procedure includes the design of the monopole antenna at the lower band and the design of the DRA at a higher band. Thus, there are many design parameters for this antenna.

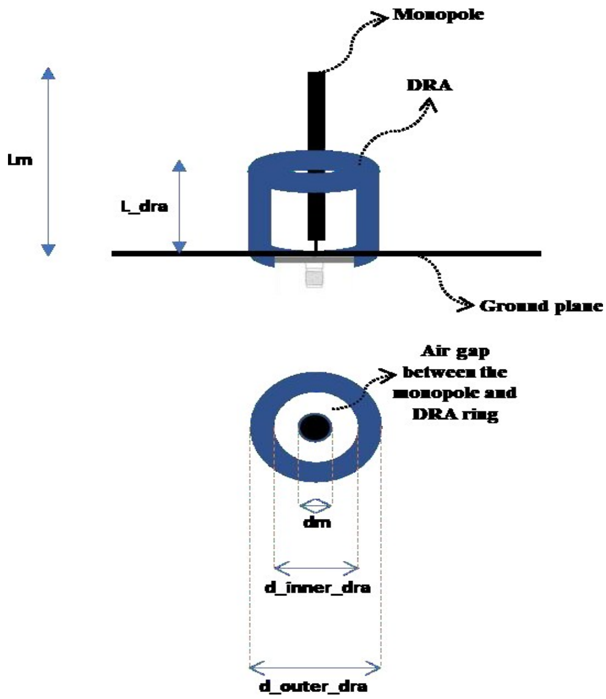


Figure 1 The figure of DRMA

Figure 1 shows the dielectric resonator monopole antenna. Each dimension change the specifications of the antenna. The design needs to be iterated to reach the target requirements.

Lm: height of the monopole
dm: diameter of the monopole (inner diameter of the air gap)
d_inner_dra: inner diameter of the dielectric ring (outer diameter of the air gap)
d_outer_dra: outer diameter of the dielectric ring
L_dra: height of the DRA ring
ε_r: dielectric constant of the DRA

The interaction of the DRA and monopole is not clearly formulized yet. The complex operational principle of this antenna necessitates us to know both monopole and DRA. Then, we need to find initial dimensions to start our design and iterate to reach the target parameters. This antenna is used for its wideband characteristics, so it is important to see its wideband characteristics in this experiment.

The first resonance of the monopole and the resonance of DRA may possibly combine with the third resonance of the monopole. Therefore, we may see three resonances together.

The initial design formulas for DRMA is below:

f_m: Lower end of the first resonance of the monopole
L_m: /4
dm: 4 mm
d_inner_dra: 12 mm (The smallest dimension for the inner dimensions of the DRA ring with Anten'it)
d_outer_dra = d_inner_dra/0.33
L_dra = 0.4 $L_m \leq$ L_dra $\leq$ 0.5 L_m
ε_r: 8

Dielectric permittivity is not an input parameter in these formulas. But it is actually a very important parameter for this kind of antenna. That is why, we will use these formulas to calculate the initial design parameters and iterate to get the best solution in this experiment.

Bandwidth for Wideband Antennas:

We used percentage bandwidth in the previous experiments. This parameter is used well for resonance antennas. But it is not appropriate to explain the bandwidth of wideband antennas. Therefore, another ratio called bandwidth ratio is used for wideband antennas. f_H shows the highest and f_L shows the lowest frequency of the bandwidth. For example, if an antenna works between 0.8-2.4 GHz, then the bandwidth ratio is 3:1.

Bandwidth Ratio = $f_H : f_L$

f_H: The highest frequency intersecting -10 dB S_{11}[dB]
f_L: The lowest frequency intersecting -10 dB S_{11}[dB]
f_C: Center frequency

EXPLANATION ABOUT DESIGNING A DIELECTRIC RESONATOR MONOPOLE ANTENNA WITH ANTEN'IT:

The box in Figure 2 is the DRMA kit. There are 1x1 metal cells for monopole, white dielectric cells with 8 dielectric constant, feed dielectrics and feed metal cells (In feed cells partition of the box). Feed dielectric cell has a hole and feed metal cells has a special insert. SSMA to SMA adaptor is for one port calibration of the network analyzer (Use the adaptor in the monopole antenna experiment box).

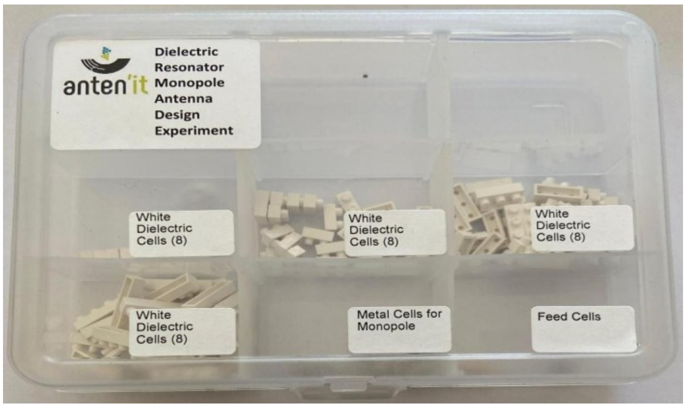


Figure 2 Dielectric Resonator Monopole Antenna Design Experiment Box

Figure 3 shows the feed cells of this experiment. The beige (2.6 dielectric constant) colour represents the dielectric cells with holes. There is only one beige dielectric cell and it has a cylinder with a hole. The inner conductor of the connector will go through this hole and touch the feed insert of the feed metal cell. This cell is used as a spacer in this experiment. For building the monopole antenna in this experiment, you need to use 1x1 metal cells.

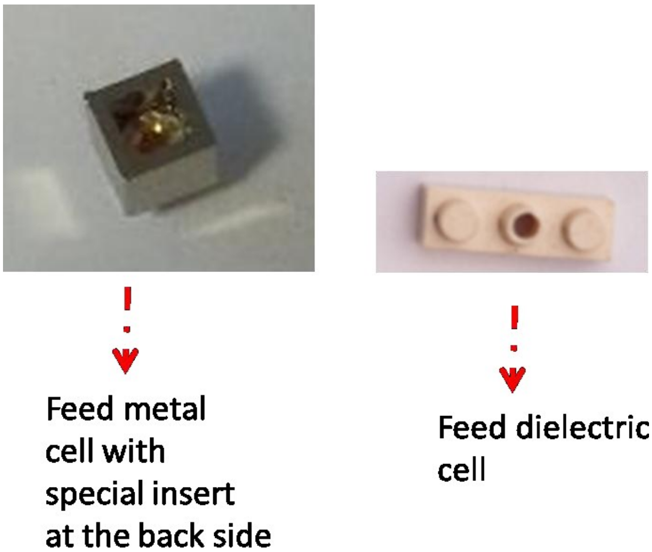


Figure 3 Feed Cells

The calculation of height:

The cubic part of Anten'it metal cells has 3 mm and the top (thin) cylinder has 2 mm height. Although the total height is 5 mm, 2 mm interlace to another cell and the height resolution is 3 mm. Figure 4 shows the dimensions of a 1X1 metal cell. The dimensions of other cells are multiples of 1X1 dimensions.

For example, if you interlace 3 bricks into each other, the total height will be 3 X 3 mm + 2 mm which corresponds to 11 mm or if you interlace 5 bricks into each other, the total height will be 5 X 3 mm + 2 mm which corresponds to 17 mm.

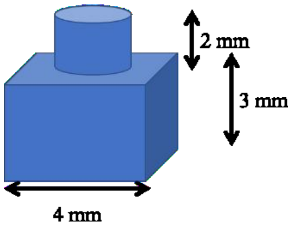


Figure 4 Anten'it cell dimensions

Removing the cells:

Removing the cells is one of the most important parts to learn. The misusage can damage the kits. There are some removing tools in the kit and the tool must be selected depending on the cell type. Each cell in the kit needs to be used gently.

In this experiment, use your hands to remove the cells. If you try to remove the cells with your hands but you can't remove them after some trial, then use the special removing plier for removing the cells. Figure 5 shows the removing plier and its special head.

In case, you must use the removing plier, you need to use it 90 degree to the top cylinder of the cells. For 1X3 and larger cells, use the cylinder at the center. If you can't remove the cell easily, change to another cylinder. Figure 6 shows an example usage of the removing plier.

a) b)

Figure 5 Removing Plier

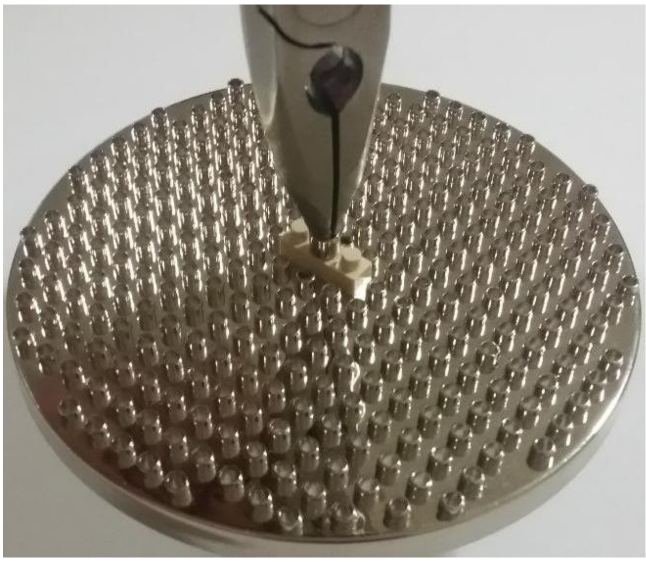


Figure 6 The usage of removing plier

PRELIMINARY WORK:

1. How does the monopole antenna work?
2. How does the DRA work?
3. What other techniques do you know for increasing the bandwidth of the monopole antenna?
4. Where is the E-plane and H-plane of this antenna?
5. Prepare an excel document before the experiment. Frequency is the input. Monopole and DRA dimensions are the outputs. Use the design formulas in section 2.

EXPERIMENTAL PROCEDURE:

6. Connect the cable to the Network Analyser and connect the SSMA-Female to SMA-Male adapter to the SSMA-male side of the cable as shown in Figure 7.

Figure 7 Cable to SSMA-SMA Adaptor Connection

7. Calibrate the Network Analyser for 1 port measurement between 1500 MHz and 6 GHz.
8. Disconnect the SSMA to SMA adaptor after the calibration as shown in Figure 8.

Figure 8 Disconnect the cable from SSMA-SMA Adaptor

9. The ground plane is shown is Figure 9. Locate the "dielectric feed cell with a hole" over the inner conductor pin of the connector. Locate the "1X1 metal feed cell" over the hole.

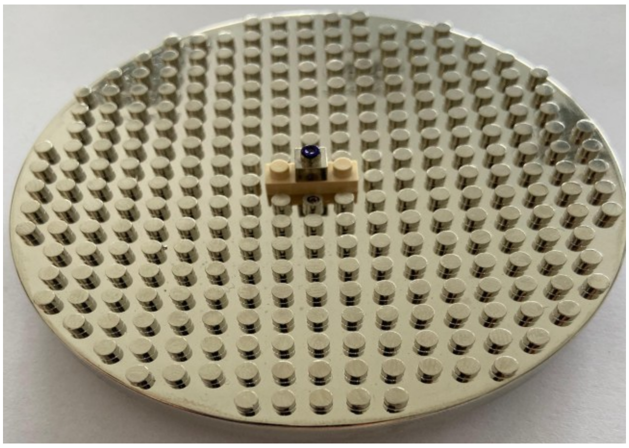


Figure 9 Ground plane with a dielectric feed cell and a metal feed cell

10. Use a multi-meter or voltmeter in order to check if the inner conductor of the connector is connected to the feed cell. Turn the multi-meter to "short" buzzer option. With one probe touch to the inner conductor of the SSMA connector from the bottom of the ground plane and with the other probe touch to the feed cell. If the buzzer is ringing, they are connected to each other and we can start the experiment.

Figure 10 Buzzer

11. Calculate the monopole antenna size for 2800 MHz. Find out the nearest Anten'it size with the dimensions in Section 3 (Calculation of height) of this document. Use the excel document and write down the outputs below:

Calculated monopole height:	
Anten'it monopole height:	
dm:	4 mm
d_inner_dra:	12 mm
d_outer_dra:	
L_dra:	
ε_r :	8

12. Build the antenna. Be careful that the calculated monopole size is the total size including the dielectric and metal cells.

13. Connect the cable to the connector at the ground plane of the monopole antenna as shown in Figure 11.

Figure 11 Connection to the connector at the ground plane of the monopole

14. Display S_{11} dB scale on the network analyzer screen.

15. Measure S11 in dB scale. Write down the lowest frequency intersecting S11 = -10 dB and bandwidth ratio of the monopole antenna.

Monopole-Lowest frequency intersecting -10 dB:	
Bandwidth ratio:	

16. Change the monopole size and see the change of the resonance frequency of the monopole.

17. Build the dielectric resonator ring with white dielectric cells. The ring will be in stepped circular form as in the example in Figure 12.

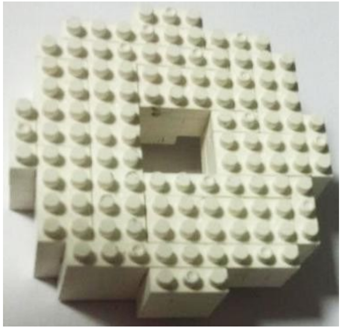


Figure 12 Stepped circular geometry of the dielectric ring

18. Measure S11 in dB scale. Write down the lowest frequency intersecting S11 = -10 dB and bandwidth ratio of the DRMA.

DRMA lowest frequency intersecting S11 = -10 dB:	
Bandwidth ratio:	

19. Add or remove white dielectric cells and see the change of the resonance frequency of the DRA.

20. Add or remove metal cells and white dielectric cells to generate the maximum bandwidth.

Maximum bandwidth ratio:	

21. Measure the E-plane (Elevation) of the DRMA at the second resonance (the resonance of the dielectric ring) of the antenna with a turn table. If the turn table is manual, write down the power levels for each E-plane angle. Normalize the power levels to the peak level.

E-plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		
150		
180		
210		

240		
270		
300		
330		

Gain [dBi]:	

22. Sketch the normalized power levels in E-plane axis on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

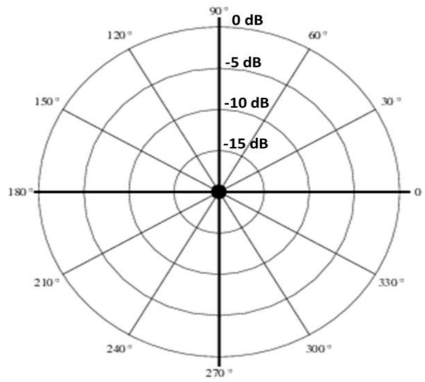


Figure 13 E-Plane Pattern of the DRMA in Polar Coordinates

23. Measure the H-Plane (Azimuth) pattern of the antenna with a turn table. If the turn table is manual, write down the power levels for each H-plane angle. Normalize the power levels to the peak level.

H-Plane Angle [degree]:	Power Level [dBm]:	Normalized Power Levels:
0		
30		
60		
90		
120		
150		

180		
210		
240		
270		
300		
330		

24. Sketch the normalized power levels in H-plane on the polar coordinates. Link the values between measurement points and see the radiation pattern graph.

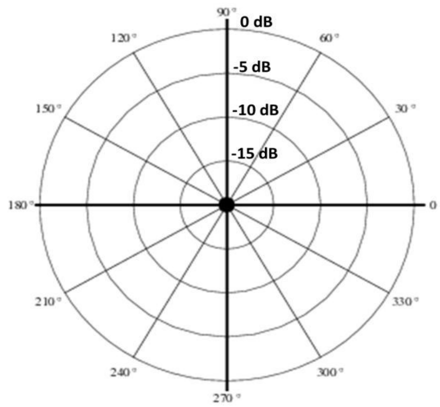


Figure 14 H-Plane Pattern of the DRMA in Polar Coordinates

RESULTS:

- State the objective of the experiment and give a short summary of the procedure.
- How does the resonance of the DRA change? What parameters change the resonance frequency?
- How did you get the maximum frequency bandwidth?
- Compare the theory and experimental results.
- Discuss the results of your experiment.