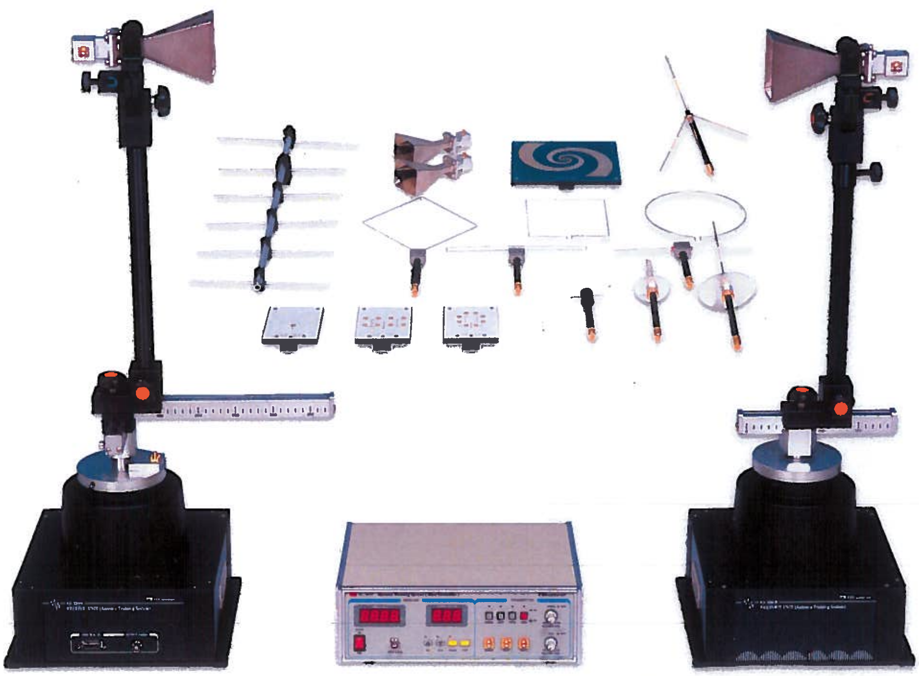
ED Corporation

ANTENNA TRAINER

User's Manual

ED–3200



ED Co., Ltd.

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

1. GENERAL INFORMATION

ED-3200 Antenna Trainer consists of Propagation Pattern and Gain of Antenna, and there are each different Antenna of 10types according to the driving style.
In this, RF Source Unit supplying RF current of 500MHz, 2GHz, 10GHz and Controller which can control the direction of antenna, in addition the software which can do a simulation of antenna copying pattern and characteristics by PC(IBM PC 486 or Pentium) interface is offered.
Since this Antenna Trainer makes the using frequency to be high, it is possible to experiment on characteristic of antenna propagation in narrow space(some 100㎡), also moving and custody of System are easy.
Especially, since consists of transmitting & receiving antenna of telecommunicational repeater and the antenna used for receiving of artificial satellite mainly, the more practical training is possible.
In particular, for Dipole or Yagi Antenna, the number and spacing of Element is controlled, you can design yourself for directional characteristic and gain.

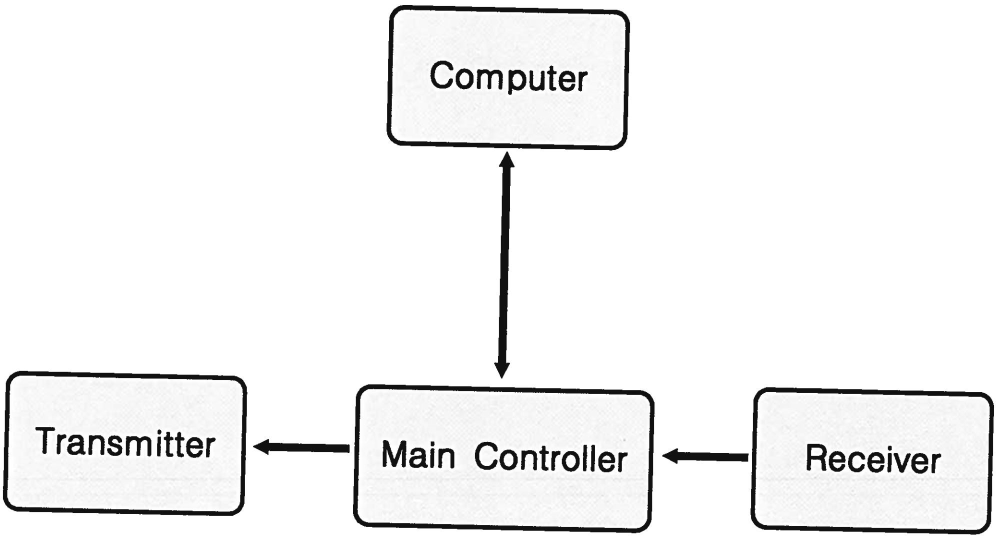


Figure 1-1 Flow Chart for Experimental Device on Antenna

2. NOTES

1. Please check the driving procedure and the input power used for this instrument after read this book before use it.
2. Please check if connect ED-3200A(Main Controller) to Motor Control Cable of ED-3200C(Receiver) before turn on.
3. Avoid operation or storage of the instrument within 3m existed the reflector from the antenna of transmitter and receiver.
4. Make the antenna to run using the main controller or PC surely.
5. Don't make to stop by physical power when the antenna of receiver runs.
6. The input voltage of AC is 220V exclusive use.
7. Avoid storage of the instrument in humid area.

3. ATTACHMENTS

Please check if there are below attachments when open this pack after purchase the instrument.

① ED-3200A (Main Controller)

- Main Controller - 1 EA
- PC Connecting Cable(2m) - 1 EA
- Motor Control Cable(1m) - 1 EA
- User's Manual - 1 EA

② ED-3200B (Transmit Unit)

- Body - 1 EA

③ ED-3200C (Receive Unit)

- Body - 1 EA

④ ED-3200D (Antennas)

- See Table 1-1

4. NAME OF EACH PARTS

1) MAIN CONTROLLER

Below figure is a Main Controller. This is divided into a receiver and transmitter. At first, the left receiver consists of Signal Level, Window displaying the revolving angle, Power Switch, BNC Type jack, Switch controlling the revolving direction (CW, CCW) and Step Controlling Switch.

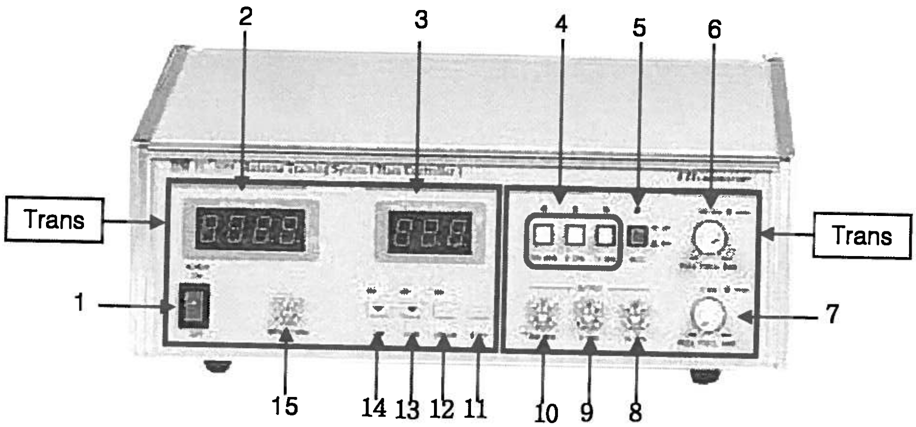


Figure 1–2 Main Controller

1. POWER SWITCH (Main Power On/Off SWITCH)
2. SIGNAL INTENSITY DISPLAYER (–50dB ~ –10dB)
3. REVOLVING ANGLE DISPLAYER (0° ~ 360°)
4. 500MHz, 2GHz, 10GHz OSCILLATION ON/OFF SWITCH & LED
5. MODULATION SWITCH (MODULATION On/Off SWITCH)
6. 500MHz FINE ADJUSTMENT SWITCH (480MHz ~ 650MHz)
7. 2GHz FINE ADJUSTMENT SWITCH (1.85GHz ~ 2.15GHz)
8. 10GHz OSCILLATION OUTPUT TERMINAL
9. 2GHz OSCILLATION OUTPUT TERMINAL
10. 500MHz OSCILLATION OUTPUT TERMINAL

11. STEP SWITCH (1°/ 5°/10°)

12. ORIGIN SWITCH

13. ANTIDIRECTION ROTATING SWITCH

14. NORMAL DIRECTION ROTATING SWITCH

15. 1kHz SIGNAL INPUT TERMINAL

2) TRANSMITTER

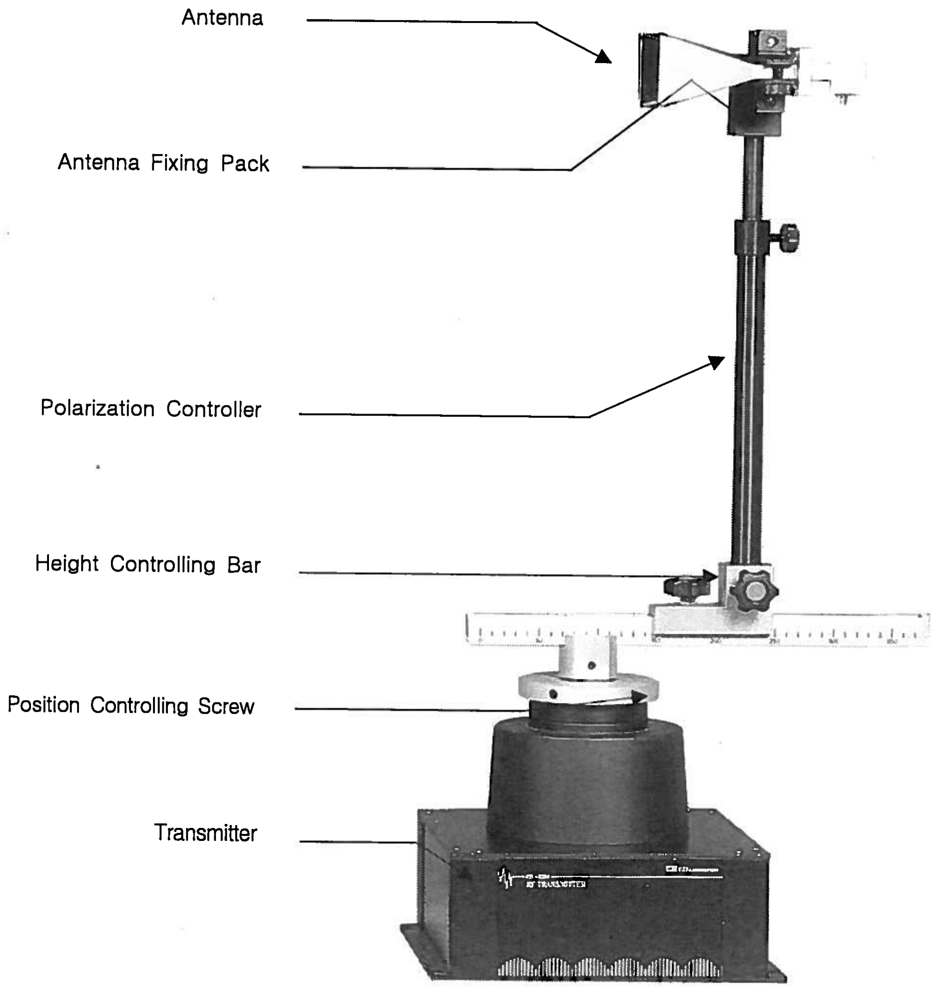


Figure 1-3 Transmitter

3) RECEIVER

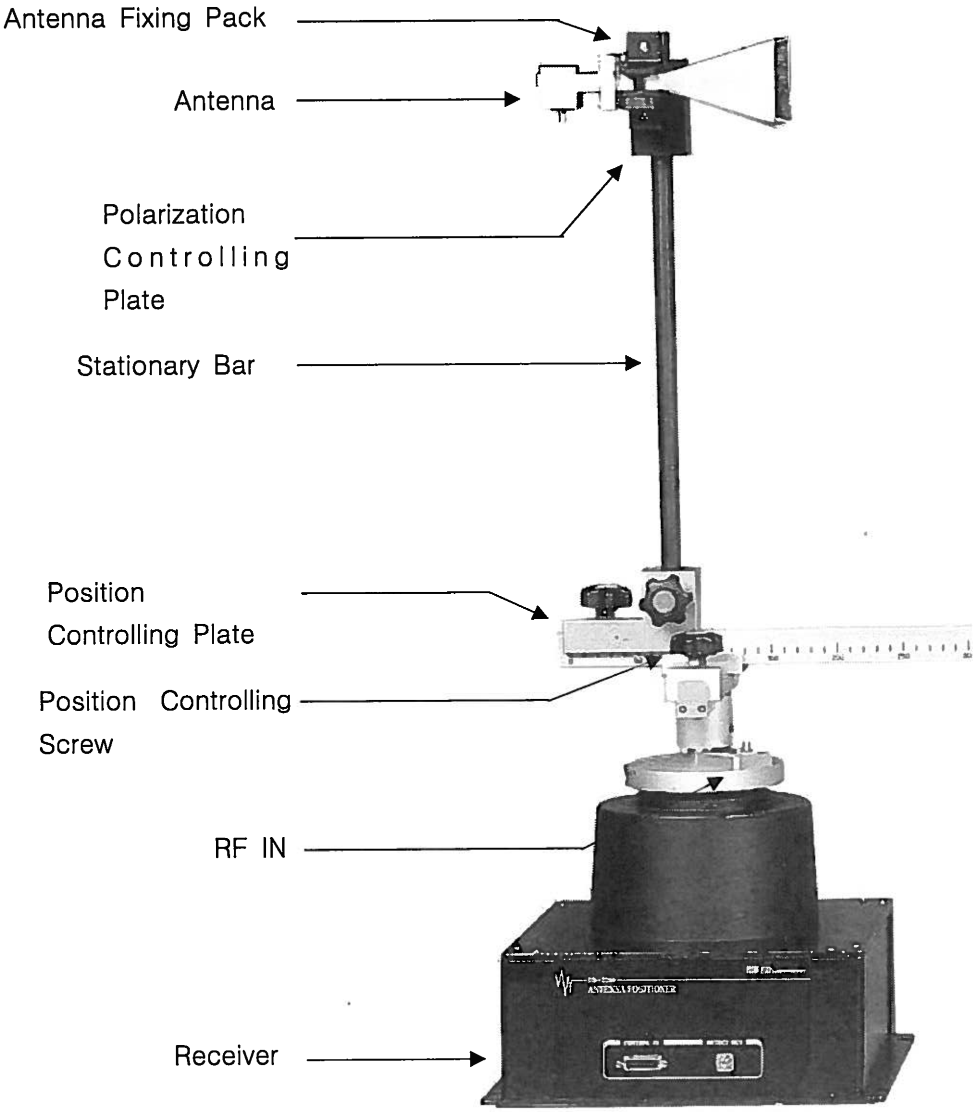


Figure 1-4 Receiver

4) ANTENNA FOR TYPE

The antenna can be divided into 500MHz, 2GHz and 10GHz usages generally.

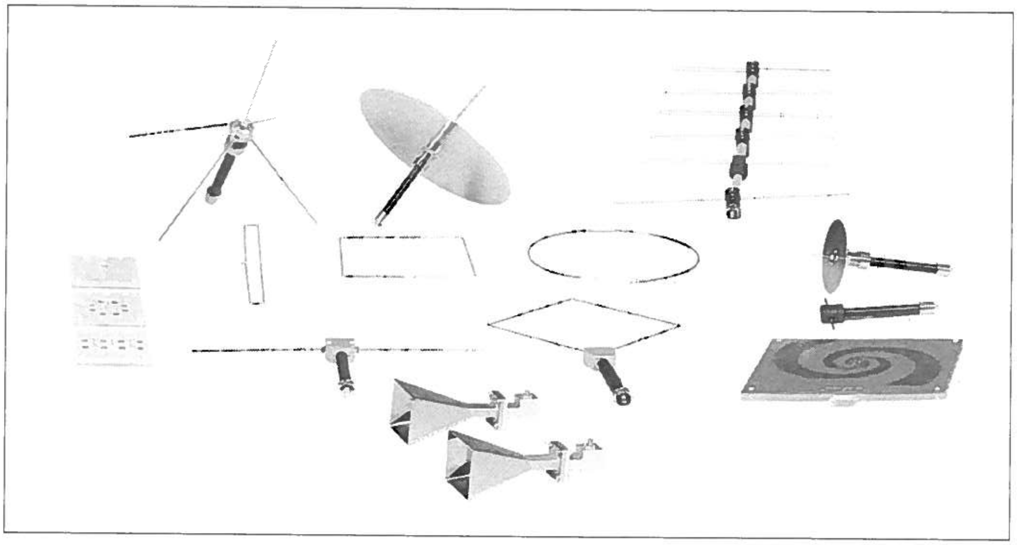


Figure 1-5 Antenna for Each Kind

Using Frequency	Antenna Type	Quantity
500MHz	Dipole Ant.	1ea
	Folded Dipole Ant.	1ea
	Yagi Ant.	2ea
	Monopole Ant	1ea
	Drooping Ant.	1ea
	Circular Loop	1ea
	Square Loop	1ea
	Diamond Loop	1ea
2GHz	Dipole Ant.	2ea
	Spiral Ant.	1ea
	Monopole Ant.	1ea
10GHz	Helical Ant.	1ea
	Horn Ant.	2ea
	Rectangular Patch Ant.	1ea
	MicroStrip Planar Array Ant. (Rectangular)	1ea
	MicroStrip Planar Array Ant. (Circular)	1ea

Table 1-1

CHAPTER 2
INSTALLATION & EXECUTION OF PROGRAM

1. INSTALLATION OF PROGRAM

Operate 「Execution」 of Start Menu in Windows or execute the program Setup.exe in 1/2 of Setup Program diskette using 「Searcher」. Only, have to terminate the other executing program before execute the installation program.
In directory setting screen as below, select the install object folder users want in setting screen or click the Finish button.

Figure 1-1

After some time, below screen of file copying procedure is output. If click Cancel in this time, all install works are canceled.

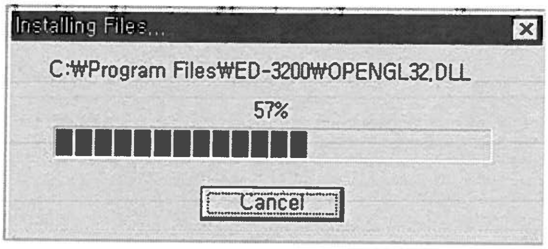


Figure 1-2

If the message "Please insert disk number2" is displayed on route install, insert disk2/2 and click the OK button.

Figure 1-3

If the install is completed, the below screen is displayed. Select OK here, all install work is completed.

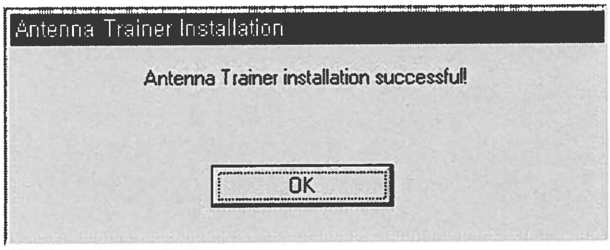


Figure 1-4

After some time below folder is generated automatically. If click the icon ED-3200 Antenna Trainer, program is executed. Click the icon ED-3200 Antenna Trainer to delete the program.

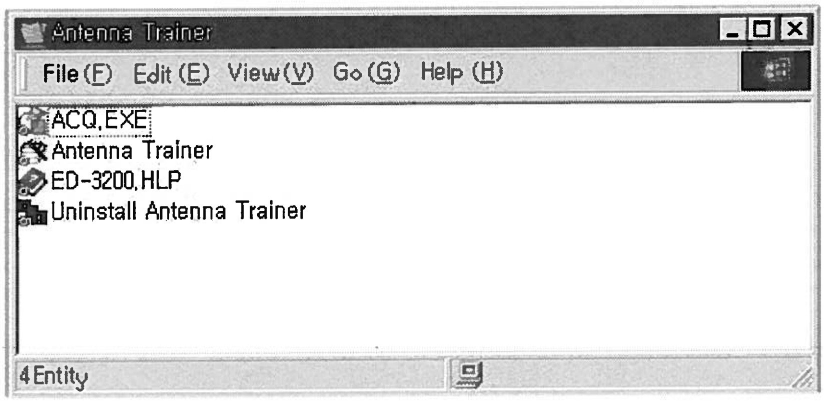


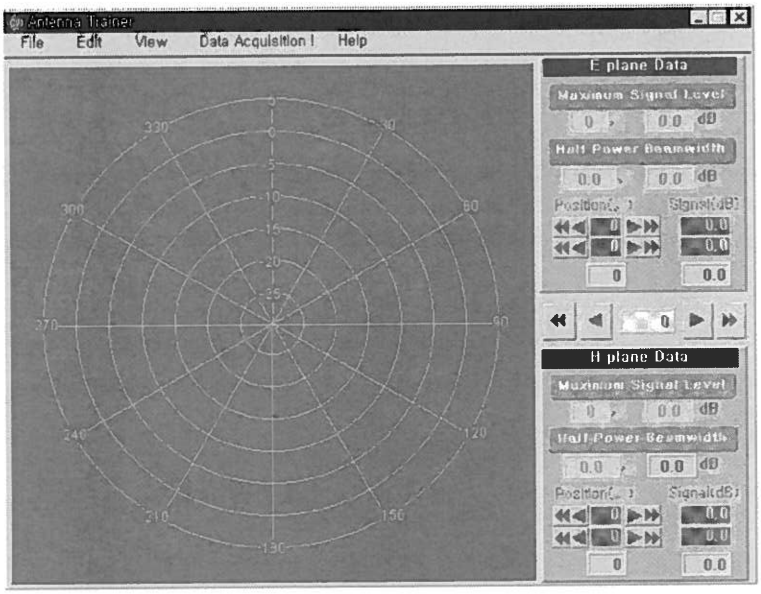
Figure 1-5

If the install is completed the files related to execution and below the low folder
of 2type are generated in the folder appointed by user(Default is Antenna) and its details is as below.

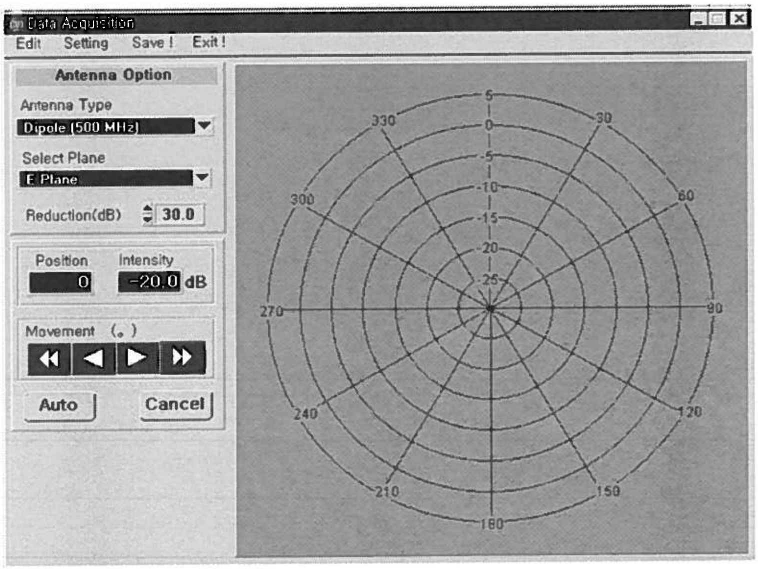
- Sample : Sample Pattern
- Images : Antenna Picture for each type
- ED-3200 : Folder which data to be saved when experiment.

2. EXECUTION

1). PROGRAM USED FOR ANALYSIS



2). PROGRAM USED FOR DATA ACQUISITION



※ For the fine information, see Experiment in Chapter 3

CHAPTER 3
BASIC STUDY & EXPERIMENT

EXPERIMENT 3-1.
HALF-WAVE(λ/2) DIPOLE ANTENNA

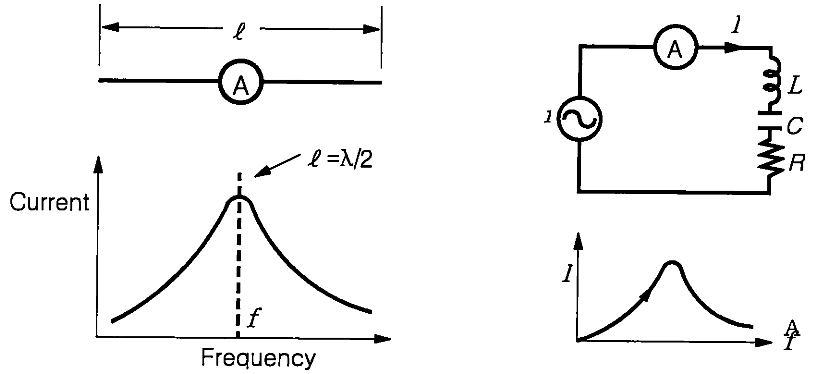
Let's measure the radial pattern about E-Plane and H-Plane for λ/2dipole antenna used for 500MHz in this experiment. We will study a polarization characteristic of dipole antenna. Let's calculate the antipower beam width of λ/2 dipole antenna.

BASIC STUDY

1. RESONANCE OF LEAD

Though very short lead, if the high frequency current flow, it makes a difference radial efficiency but the electromagnetic wave in proportion to the current strength. The question is how make to flow the optimum current to a lead.

The current flow into a lead of high frequency open both end, In the frequency f_0, occurred a resonance phenomenon alike LCR direct current of (B).



(A) (B) *L-C-R* Direct Resonance Circuit

Figure 1-1 Antenna and Resonance Circuit

As Figure 1-1(A), connect the high frequency galvanometer in the center of direct lead of suitable length *l*.
Set the frequency in low and make to high it slowly, the current begins to flow into an antenna. As make the frequency to be increased continuously, the current of antenna increase gradually so like Figure it to be maximum at some

frequency f_0, and make it more higher and the current is to be decreased oppositely.
It can know that the relation between frequency and antenna current alike LCR direct resonance characteristic in Figure(B). Accordingly it can be shown that both end is opened and the lead to be center power feed resonant at frequency f_0. In this time the length of lead is about 1/2 of f_0 wave.
Why does the lead of length l resonant with a high frequency has double wave length. It can be thought as below.

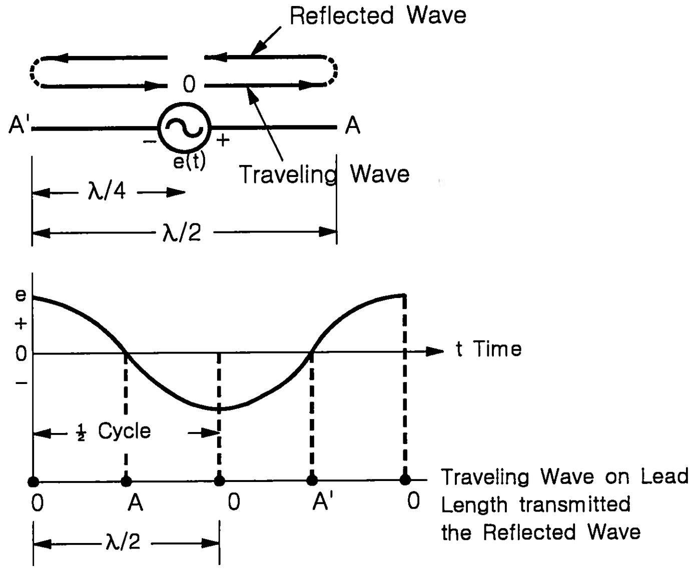


Figure 1-2 The reason that the electric wave of wave λ resonate to lead λ/2

As Figure 1-2, the high frequency current travel along lead to vertical direction A by the high frequency e(t) to be power feed at lead O point. This is called a traveling wave, the traveling speed is same as electric wave spread through space. The current arriving a lead terminal point A is reflected by ∞impendence completely and return to power along lead. This is a reflected wave.
Therefore the traveling wave and reflected wave transmitted from power continuously are existed on the lead. Now set a frequency of power in a resonance frequency, the traveling wave and reflected wave are to reciprocated on a one lead like O⇌A(or O⇌A') as below. If the polarity of power is inversed fitted when the reflected wave return to power the traveling power and reflected wave on lead become more strong.
The relation between a length of lead l and resonance frequency f_0 in this time become

$$l \fallingdotseq \frac{150}{f_0(MHz)}[m] \qquad (1-1)$$

2. The Excitation of Antenna

If the lead is to resonated, the traveling wave and reflected wave of same size is occurred on the lead, and the voltage and current on lead become as Figure 1 -3 with occurring a interference each other by these.
Figure shows the size of each voltage and current, and the voltage becomes maximum in the center and minimum in both end. Also voltage is opposite to current, maximum in both end and minimum in the center.

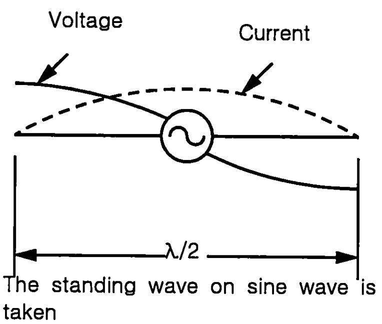


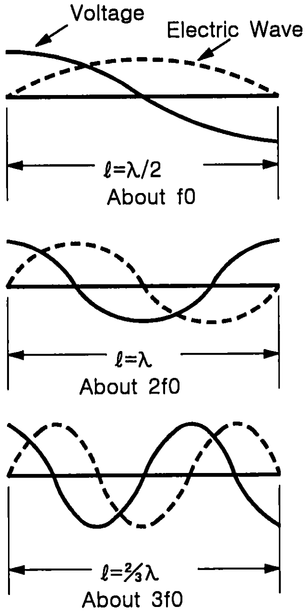
Figure 1-3 Voltage Current Distribution on both end open λ/2 lead

Since the standing wave was occurred a standing wave on lead the size of voltage and current is to set according to position. As a on-board antenna is a means to flow high frequency current into a lead makes this standing wave to be occurred on lead. Figure 1-3 shows that one standing wave is occurred in the lead of $\lambda/2$ length.

In Figure 1-1 if the frequency of power make to be 2times, 3times... of resonance frequency f_0, how it will become.
As for f_0, the $\lambda/2$ lead is to be λ for $2f_0$, and to be $3\lambda/2$ for $3f_0$, anything become integral multi $\lambda/2$. Figure 1-4 shows voltage and current distribution on lead.

The resonance frequency of LCR direct current but (On experiment, it isn't one. In the specific multi-frequency the resonance can be occurred.) In the case of lead, in some integral multi frequency the resonance is occurred for the lowest resonance frequency f_0. Here f_0 is named a basic frequency of lead or inherent frequency, and $2f_0$, $3f_0$, ... is named harmonics resonance frequency.
The case of using the lead of antenna by resonating with high frequency is

named high frequency excitation.



f0 : Inherent Frequency

The lead of constant length resonate with integral multi high frequency of inherent frequency f0.

Figure 1-4 High Frequency Excitation of Harmonics

For the voltage and current distribution on lead, current is minimum and voltage is maximum at both end, and current is maximum and voltage is minimum at point of distance$\lambda/4$, and it is inversed by periods of $\lambda/4$. The maximum point of voltage(or current) is named the anti-node, minimum point named the node. In case of exciting the antenna lead with a standing wave, Figure 1-5 shows the method to connect to the current anti-node and voltage anti-node, and that is named the current power feed and this is named the voltage power feed.

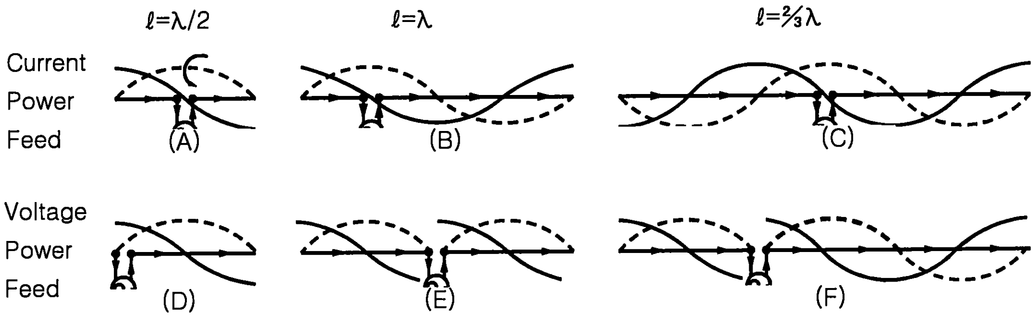
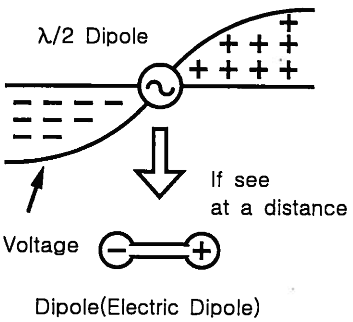


Figure 1-5 Current & Voltage Power Feed of Antenna on Both End Open of Length λ/2, λ, 3λ/2 and the Voltage & Current Distribution



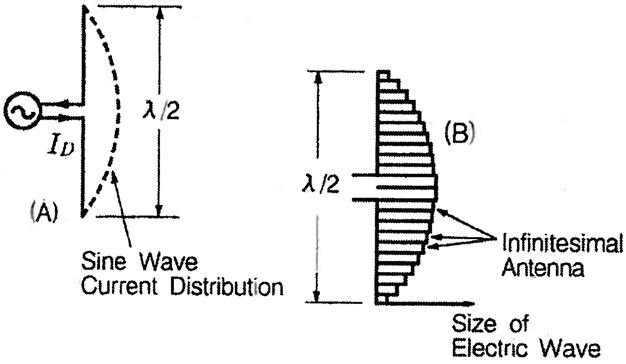


Figure 1-6 Dipole Antenna

Figure 1-7
(A) Center Feed Half Wave Doublet
(B) Half Wave Doublet is a Assembling of Major Infinitesimal Antenna of Different Size.

In Figure 1-5 indicating the current direction in some time it have to be considered that the current direction of standing wave adjoining each other becomes inverse(180anti-phase) and that the voltage and current distribution become different according to a point of power feed.
As an example, Figure (B) and Figure (E) is all high frequency antenna of lengthλ but the current direction and voltage polarity on lead is to differ, and the radiation characteristic, especially the directivity is to differ entirely because of the position of power feed point is different.

3. HALF-WAVE DIPOLE

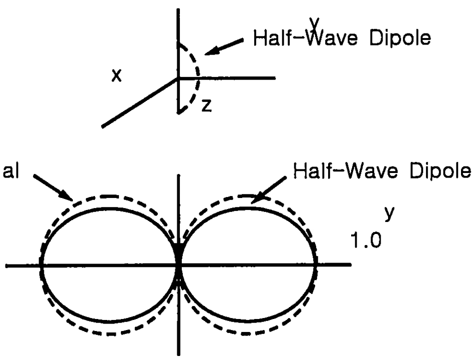
As this antenna is a useful one of the simplest structure, it is called a half-wave doublet or dipole simply. The doublet(or dipole) means a electric dipole, and in case of a voltage distribution in Figure 1-6, means what the left and right of lead become a constant and nonoscillatory charge according to the polarity of power.
The standard of half-wave dipole is what does center feed in Figure 1-7(A). This is called a center fed dipole.
In the case of the thickness of lead is very slim in comparison with wave, the current distribution becomes sine wave as the dotted line in Figure 1-7(A), It can see an assembling of a infinitesimal antenna. Therefore the radial field strength of half-wave dipole can be calculated with an assembling of

infinitesimal antenna, and for the maximum strength of right angle direction with lead, when the current of power feed point is I(A), it becomes

$$E = \frac{60I}{R}[mV/m] \qquad (1-2)$$

R is isolated distance[km] from antenna.

The directional characteristic of half-wave dipole is almost similar to the infinitesimal antenna, it becomes a shape 8 and shape of cubic donuts.



For the comparison, indicate the directivity of infinitesimal antenna with dotted line. Some is 1 at maximum direction but as a matter of fact, in case of half-wave dipole, it is large as 1.045times. The cubic directivity becomes more flatter than infinitesimal antenna rotating around the axisZ.

Figure 1-8 Field Directivity of Half-Wave Dipole(side y·z)

The radial resistance of this half-wave dipole antenna is calculated like a case of infinitesimal dipole as below and

$$Radial\ Resistance = \frac{Full\ Radial\ Power\ of\ Antenna}{[\,Current\ Effective\ Value\ of\ Current\ Maximum\ Point\ on\ Wire]^2}$$

the value is 73.13Ω.

In case of center feed, as the feed point is a maximum current point, the radial resistance 73.13Ω is a simulated load resistance consuming the power as same as radial power in point of power, and if ignore the high frequency resistance on lead, it becomes same as the resistance of input impedance. When the length of lead is just 1/2 of wave in free space the radial power in above formula(numerator) divided into a effective power and uneffective power, and uneffective power is to display a reactance for power as a condenser or coil, and the value is 42.55Ω in inductive. Accordingly the radial impedance of half-wave dipole becomes

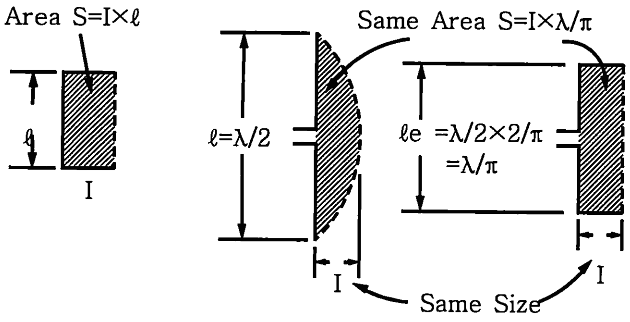
Resistance Element	73.13Ω
Reactance Element	42.55Ω (Inductive)

Like following formula 1-3, show the field strength of maximum radial direction to the required formula in the radial power Pr.

$$P_r = P^2 \times 73.13[W] \qquad \therefore I = \sqrt{\frac{P_r}{73.13}}[A] \tag{1-3}$$

Therefore, substitute the value of current for the formula 1-2 and becomes

$$E \fallingdotseq \frac{7\sqrt{P_r}}{R[km]}[mV/m] \tag{1-4}$$



(A) Infinitesimal Antenna (C) λ/2 Dipole (C) λ/2 Dipole Effective Wave

Figure 1-9 The field strength at right angle direction with lead is proportioned to the area of oblique side.

It was explained already that the field strength(maximum radial direction) of infinitesimal is proportioned to the volume of current and length flowing into lead (See Formula 1-2). The volume *Il* of current I[A] and length *l*[m] is a size corresponding to the area S of oblique part as indicated in Figure 1-9(A). Only the unit isn't [m^2] but [m·A]. If use this S the field strength of infinitesimal antenna becomes from the formula 1-4.

$$E = \frac{60\pi}{\lambda R} S \tag{1-5}$$

As the half-wave dipole is the assembling of infinitesimal antenna, rightly it will proportioned to the area S of oblique part in the same Figure(B). But the size of flowing current isn't definite, and the size of current is changed with sine wave in this case therefore it is difficult to indicate with the area S but if indicate the result, becomes

$$S = Il\frac{2}{\pi} = I\frac{\lambda}{2}\frac{2}{\pi} = I\frac{\lambda}{\pi}[mA] \tag{1-6}$$

and you can see that this area S becomes same size as a globular part in Figure(C). The length of lead direction of this globularity *le* is

$$le = l\frac{2}{\pi} = \frac{\lambda}{2}0.638 = \frac{\lambda}{3.14} \tag{1-7}$$

and this *le* is named the effective wave of half-wave dipole.

The field strength at right angle direction with the lead of half-wave dipole is same as a current of anti-node and becomes same as the antenna flowing definitely through the length λ/3.14 in Figure 1-9(C). The antenna like this is to keep away from the condition of infinitesimal antenna l<λ but substitute S got in the effective wave of half-wave dipole in Formula 1-5 and becomes

$$E = \frac{60\pi}{\lambda R}I\frac{\lambda}{\pi} = \frac{60I}{R} \tag{1-8}$$

and accord with Formula 1-2.

As above the field strength at right angle with lead is settled by current according to the lead and volume S of length.

As Figure 1-5, the antenna excited by harmonics which the length of lead is to multi-integer of λ/2 is named Harmonics Antenna. As an example when use the half-wave dipole in 2GHz used for 500MHz, it becomes harmonics antenna of 4times.

Figure 1-10 shows a directivity in free space of harmonics antenna of 2-4times.
To illustrate the directivity of harmonics antenna in free space, use generally this method as follows. Make the current of current anti-node to same size for each antenna, and draw by making the maximum radial direction of half-wave dipole to 1 for the easy to compare with half-wave dipole. Figure shows only the right directivity of lead, surely left is same shape and the actual cubic directivity becomes a complex cubic forming when rotate in axis of lead.

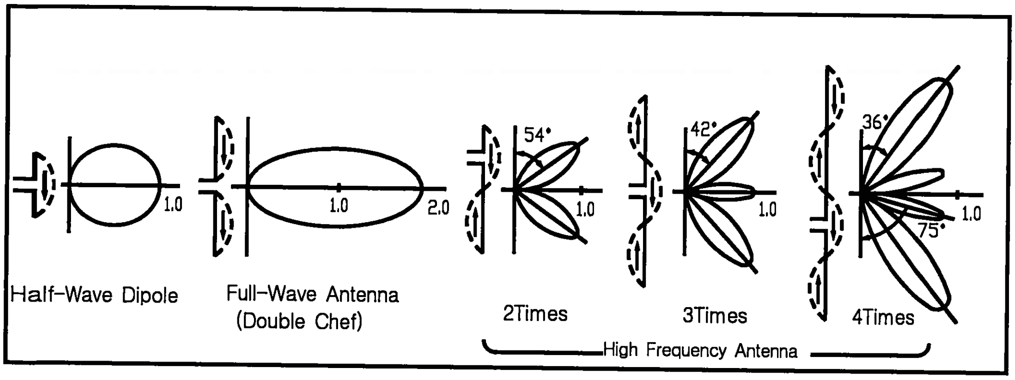


Figure 1-10 Directivity of Half-Wave, Full-Wave and Harmonics

As the multiple of harmonics is increased in Figure, the direction growing the maximum radiation get near to the direction of lead, and indicate the relation between the spacing angle and length in Figure 1-11. Also Figure 1-10 shows the directivity of center power feed antenna of 1wave, by the way this antenna becomes same shape as right and left sine wave current. Therefore it isn't named harmonics antenna but full-wavelength (1wavelength) since the maximum radiation is occurred to right angle direction with lead.

Redial Resistance of Harmonics Antenna(Current Anti-Node) becomes

2Times - 90Ω, 3Times - 100Ω, 4Times - 114Ω,
5Times - 121Ω, 6Times - 126Ω, 7Times - 131Ω

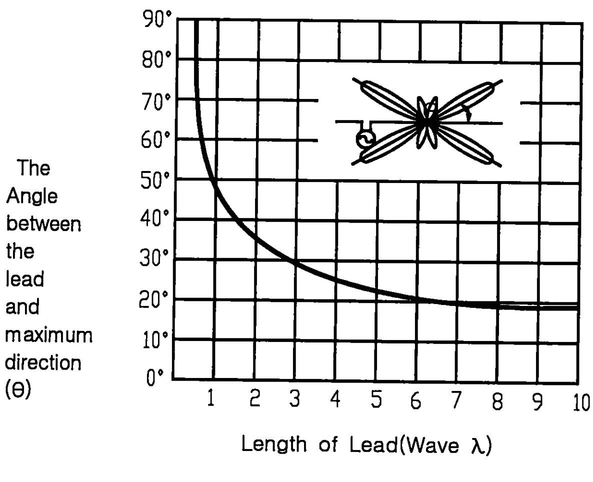


Figure 1-11 Relation between Length of Harmonics Antenna and Maximum Radial Direction

EXPERIMENT PROCEDURE

SETTING OF EXPERIMENT APPLIANCE

1. Set the main controller, transmitting & receiving antenna positioner and computer which are main appliance of antenna experiment set.

2. Set the height controlling bar of a transmitter and fix the 500MHz Yagi antenna fixed on antenna fixing pack to the polarization control plate attached a controlling bar. And set the antenna at a level with ground to get a even polarized characteristic. The transmitting antenna set as Figure 1-12 has even polarized characteristic.

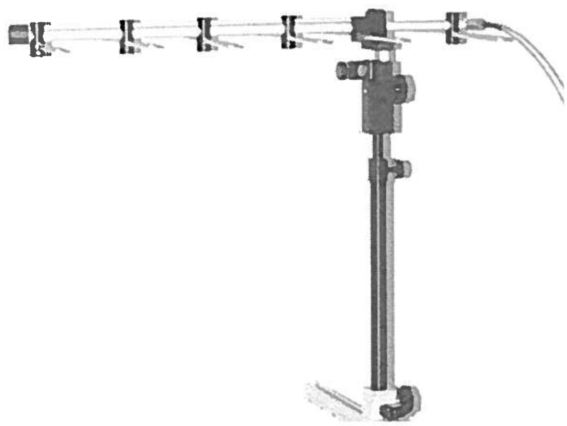


Figure 1-12 Setting of Even Polarized Transmitting Antenna

   Set OFF the oscillation switch for frequency in a transmitter of a main controller, and connect the 500MHz oscillation output terminal and a Yagi antenna with a SMA Cable used for 2m.

3. After set an antenna stationary bar to a transmitter, fix a dipole antenna to a polarization control plate attached on a stationary bar. And set an antenna at right angle with ground to get a even polarization characteristic, and control the antenna to take place in center of a rotating axis of receiver using two control pin. See Figure 1-12 to set.

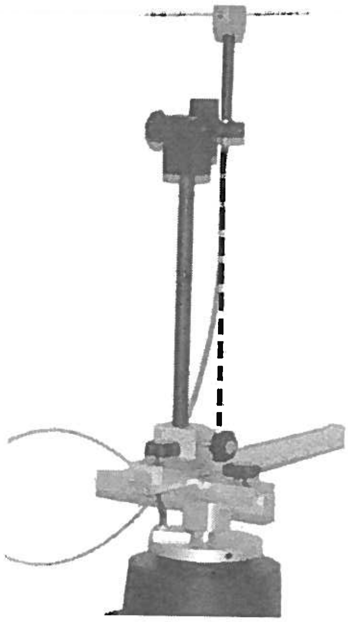


Figure 1-13 Setting of a Even Polarization Receiving Antenna

Connect a dipole antenna and RF IN terminal of receiver with a SMA cable used for 1m, and connect a OUT PUT(1kHz) terminal of receiver and a Input(1kHz) in receiver of main controller with a BNC Cable.

4. Calculate the length of λ/2dipole in 500MHz and measure a length of actual antenna by using below formula, and record in Table 1-1.

The exact oscillation frequency of RF signal generator is 500MHz.

$$\lambda = \frac{c}{f} \quad , \quad L = \frac{\lambda}{2}$$

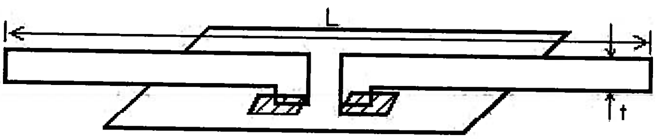


Table 1-1 The Length of $\lambda/2$ Antenna [cm]

	Length of Antenna Theoretically	Length of Actual Antenna
λ		
$\lambda/2$		
L		
t		

Note : The antenna length has to be decided by considering the ratio between a length of conductor and diameter, end effect(load effect in the end of lead) and impedance discontinuity. In this case, the length of antenna has to be shorter than $\lambda/2$.

5. As Figure 1-14, the distance between antennas is isolated as r=1.5m. Control the transmitting·receiving antenna to opposite each other.

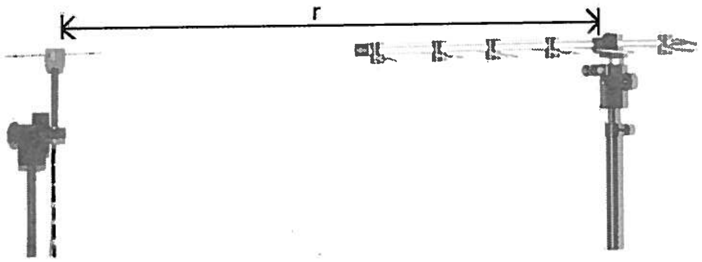


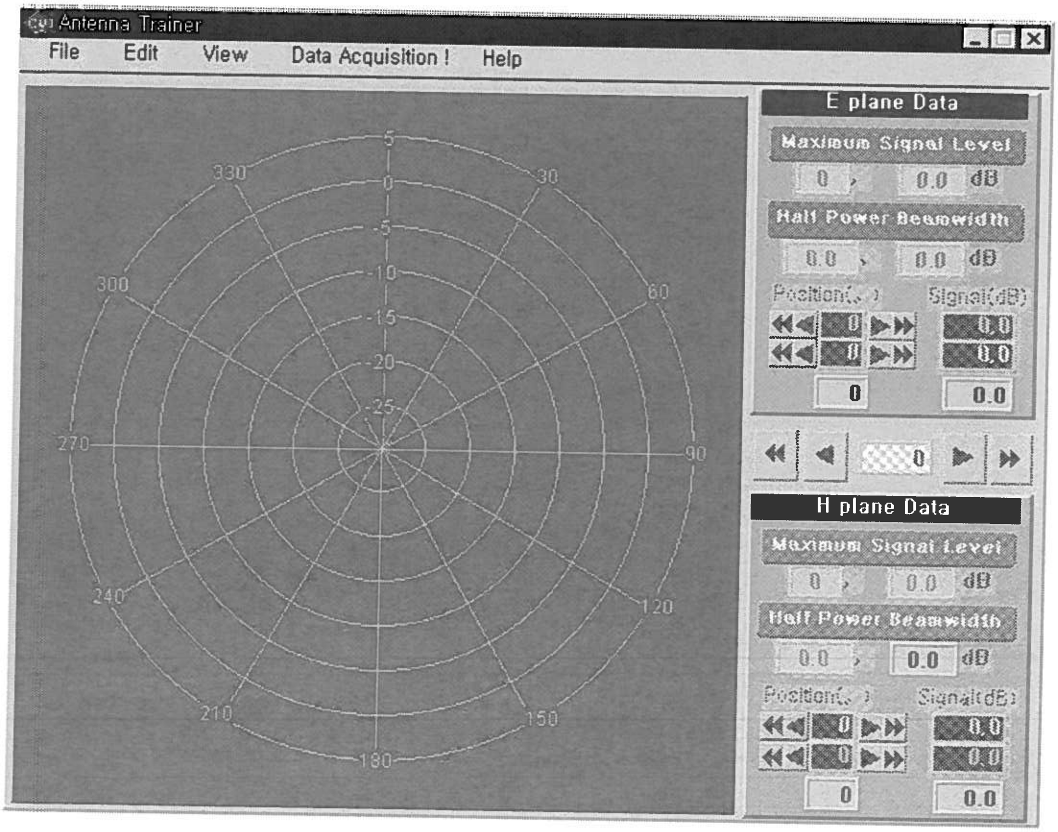
Figure 1-14 Distance between Antennas r

6. Set the oscillation switch and modulation switch for frequency in state of the power is turned off as below.
   - Power OFF
   - 500MHz Oscillation Switch off
   - 2 GHz Oscillation Switch off
   - 10 GHz Oscillation Switch off
   - Modulation Switch (Mod) off

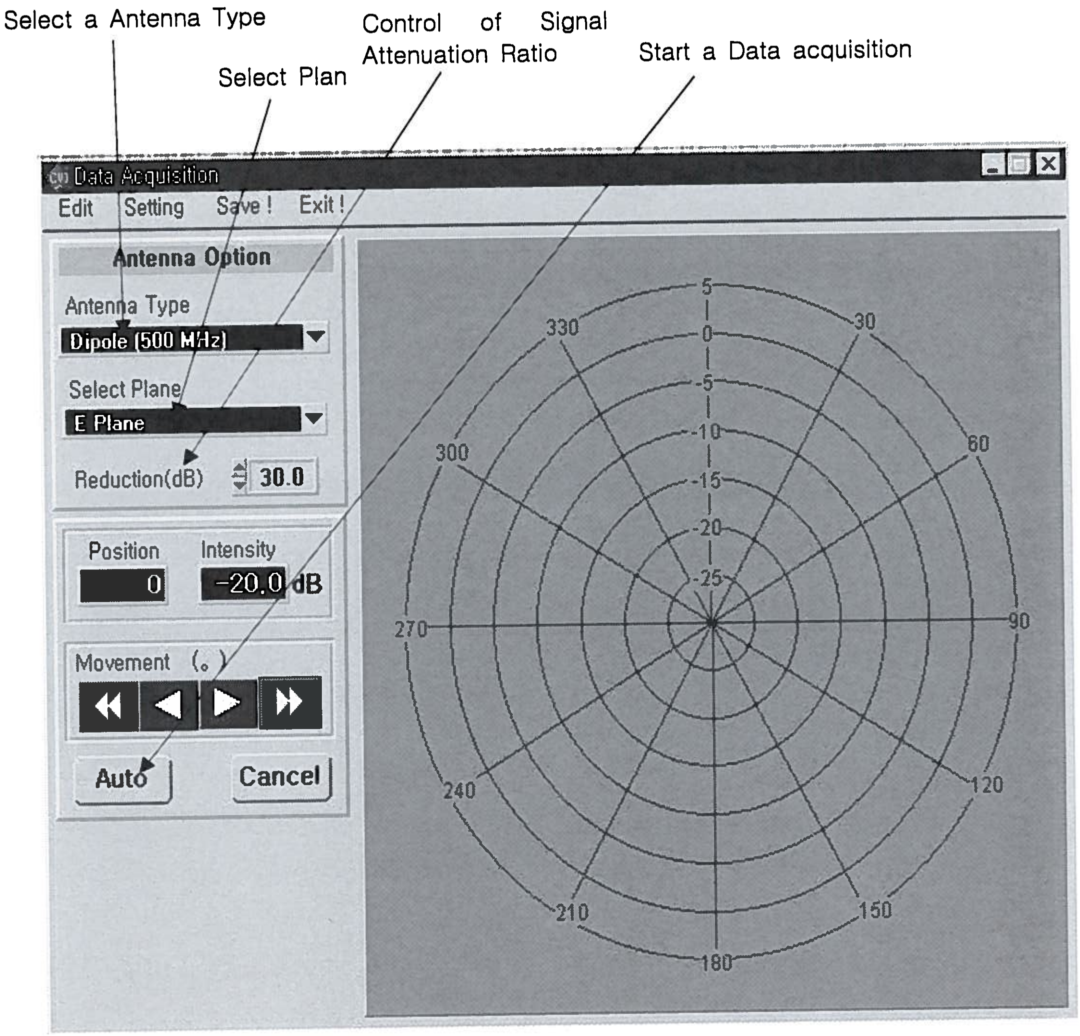
7. Turn the power of main controller on and set a oscillation switch and modulation switch for frequency as below.

- Power ON
- 500MHz Oscillation Switch on
- 2 GHz Oscillation Switch off
- 10 GHz Oscillation Switch off
- Modulation Switch (Mod) on

8. After set as above, execute a experiment appliance program for antenna. Execute the exe. file named Windows ED-3200 antenna Trainer. Then below window is generated. Here click the data acquisition in pop up menu and set the data acquisition window.



If below window is set, select a antenna type. And do initial state after execute a delete screen in edit menu. Then select E-Plane as Plane, and control to be displayed 0 on antenna gain displayer by controlling a signal attenuation. If the control is completed, click the AUTO button to start a data acquisition.



9. Finish a data acquisition, save a got radial pattern to file. Use a data box to confirm the radial pattern. Set MSP(Maximum Signal Position) to 0°, can see a radial pattern of antenna exactly.

10. Set an 500MHz Yagi antenna used for receiving at right angle with ground by rotating 90° the polarization control plate with spinning a fixing bolt attached to polarization control plate to get a even polarization characteristic.

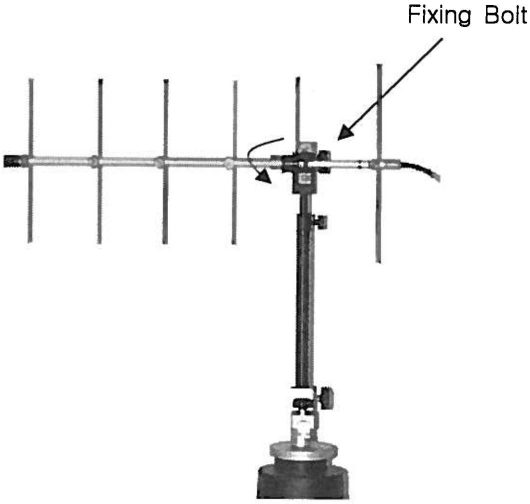


Figure 1-15 Setting of a Even Polarization Transmitting Antenna

11. Set as Figure 1-16 for the λ/2 dipole antenna used for receiving get a even polarization characteristic. Here set the antenna at right angle with a rotating axis by loosing the control screw and moving the position control plate.

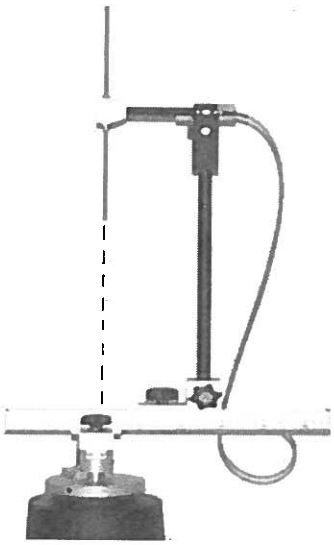


Figure 1-16 Setting of an even polarization receiving antenna

[Reference] According to the position of a receiving cable, it can be the case that the partial of transmitting signal is received through a cable. During experiment the radial pattern, have to control the position of connected cable to a receiving antenna to prevent the error by this effect. Have to make an effort to maintain a short length of cable connecting the receiving antenna and main control period. Have to set to be placed near a mast cable with maintaining a symmetry.

12. Keep the drawing pattern of E-Plan, after click again the antenna initial state in the edit menu of the software, select H-Plane as Plane, and click the Auto button for a data acquisition. Completed the data acquisition, save two pattern to file.

13. Keep the 500MHz Yagi antenna used for transmitting to get a vertical polarization characteristic, and set λ/2 dipole antenna used for receiving to get a even polarization characteristic as Figure 1-17.

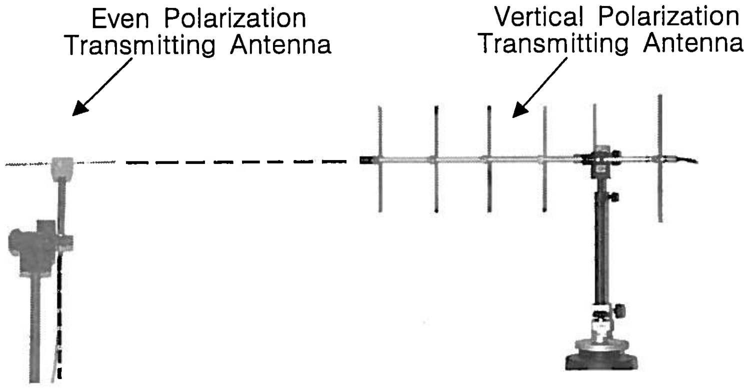


Figure 1-17 Setting of Transmitting and Receiving Antenna

14. Click the delete screen in a edit menu of program and after click the antenna initial state, click the Auto button for a data acquisition.

15. Observe three radial pattern. Are you expect the third experiment result ? Explain.

16. Set again each transmitting·receiving antenna to get a vertical polarization characteristic. The distance between antennas is r=1.5m. Keep the surroundings of antenna with the first experiment. Get E-Plane radial pattern of λ/2 dipole antenna and save in the Dummy-Plane.
Theoretically this radial pattern must same as the first pattern if except the effect by electric damage. If the pattern is different very much, have to do properly by finding the point which can be generated a reflection. After do properly, experiment continuously and save a new pattern in E-plane.

17. Click the data indicate line in the view menu at a upper menu of a data analysis program. Two cursor used for E-Plane(Blue, White) and two cursor used for H-Plane(Yellow, Green) are appeared. Click the arrow at side of presentation window for each color, the same color cursor is moved and the value of a presentation window will be changed. These indicate the position angle of cursor and the receiving power in that time as dB, and the difference the angle between cursors with power display on below two presentation window. Record in Table 1-2 the got value in this time.

Table 1-2 Power for Angle

Angle	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Receiving Power of E-Plane for Angle												
Receiving Power of H-Plane for Angle												

18. Get the angle received the maximum power in E-Plane pattern and the receiving power in that time. Click the Maximum Single Level button on E-Plane data window and confirm if it is corresponded the measured value and the got maximum value by moving the cursor. And record on below Table 1-3.

Table 1-3 Comparing E-Plane and Theoretic Value

The Value using a cursor	Receiving Power	
	Angle	
The Value by Maximum Single Level Icon	Receiving Power	
	Angle	

19. Get the half angle of main beam power size in the E-Plane pattern. Click the Half Power Beamwidth button on the E-Plane window to confirm if it is corresponded the measuring value and got value using a cursor.

【참고】 Keep in mind what the power is decreased is same as 3dB attenuation. (10log0.5=-3dB)

Calculate the anti-power beam width in E-Plane of a λ/2 dipole antenna using below formula.

$$HPBW_E = | \Theta_{HPBWleft} - \Theta_{HPBWright} |$$

$HPBW_E$=________

【참고】 If the right and left of HPBW have a angle of 0°, must add 360°to $\Theta_{HPBWleft}$ in the formula.

20. Repeat 18times the experiment procedure in the H-Plane radial pattern.

$HPBW_E$=________

21. Click the data indicating line in a view menu to delete all the cursors. Compare the experiment values with the given value in the antenna software. If the calculated result isn't corresponded to this values, experiment and calculate again. (When there are difference more 7°)

22. Save the data of E-Plane and H-Plane and output the results.

23. After pull a cell of dipole antenna of some 5㎜, experiment again from No. 1 through No. 22 based on above experiment procedure. Since the object of this experiment is the frequency change in accordance with the change of antenna length, the receiving power for a 500MHz frequency will be some changed.
So record about the difference by comparing with former results after experiment former in order once again.

▣ EXCERCISE ▣

1. What's role of an antenna in telecommunication?

2. What's the isotropic source. Also what's this usage?

3. What's the radial pattern? Explain the difference between the transmitting and receiving pattern of an antenna.

4. Explain about a dipole antenna.

5. How to divide the radial characteristic of an antenna? What's the radial pattern of a dipole antenna?

EXPERIMENT 3-2. FOLDED DIPOLE ANTENNA

Let's measure the radial pattern about E-Plane and H-Plane for a folded dipole antenna in this experiment. We will study the radial characteristic of a folded dipole antenna. Let's calculate the anti-power beam width of a folded dipole antenna using an antenna software.

BASIC STUDY

1. Folded Dipole

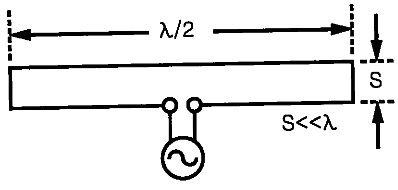


Figure 2-1 λ/2 Folded Dipole

As Figure 2-1, The Folded Dipole antenna can be made by connecting two parallel dipole antenna with a fine lead. Also the antenna folding a conductor as the length is $\lambda/2$, and of fine and long shape is named a $\lambda/2$ folded dipole(or half-wave folded antenna).

For a $\lambda/2$ folded dipole antenna, when make a conductor spacing S to be narrow in proportion to a wave and a thickness of a conductor is same, both conductor size is same and flow a current of same phase as Figure 2-2(A).

Since the sum of current flowing into two conductor is same as a current of a $\lambda/2$ dipole fed by an same input power as Figure 2-2(C), the field strength and directivity characteristic of a $\lambda/2$ folded dipole is same as a $\lambda/2$ dipole. But an impedance is different with $\lambda/2$ dipole. That's why the impedance is inverse proportioned to 2multiplication of power feed point current in case of an antenna of same input power in $P = R * I^2$, $R = P/I^2$.

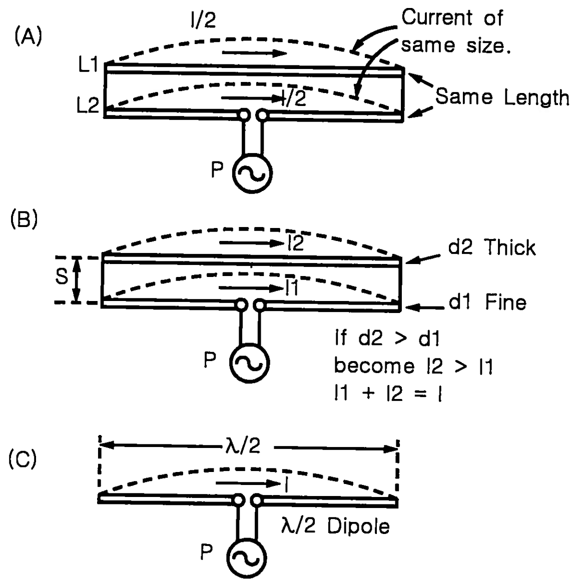


Figure 2-2 Current Distribution of a λ/2 folded dipole and dipole

For the half-wave dipole in Figure 2-2(C), the current is 0 at both end of dipole, and it is a sine wave to be maximum value I_D at center. Accordingly the current distribution of dipole can be indicated as below.

$$I(z) = I_D \sin\left[\frac{2\pi}{\lambda}\left(\frac{L}{2} - |z|\right)\right] \qquad (2\text{-}1)$$

Here Z is a coordinates axis for the direction of antenna length, and L is a length of antenna.

In Figure 2-2(A), the half-wave folded dipole has a current distribution of sine wave at dipole lead 1. Only, The maximum value on center isn't I_D but $I_D/2$. This sine wave current become go down 0 at both end of lead1, and become maximum in center of a dipole lead2 by increasing again at a dipole lead2.

Add the distribution of two current flowing into the lead 1 and lead 2 of a folded dipole, it is same as a current distribution of a dipole antenna. Accordingly the radial current is also same. Also the input impedance of a folded dipole can be taken with below formula.

$$P_D = \frac{1}{2} Z_D I_D^2 = P_F = \frac{1}{2} Z_F I_F^2 = \frac{1}{2} Z_F \left(\frac{I_D}{2}\right)^2 \qquad (2\text{-}2)$$

where, P_D, Z_D, I_D is a power impedance of dipole and current and

P_F, Z_F, I_F is a impedance of a folded dipole and current respectively.

Consequently, you can see that the input impedance of a fold dipole become larger than a dipole input impedance of 73Ω.

$$Z_F = (4)Z_D = (4)(73) = 292\Omega \qquad (2\text{-}3)$$

When it is same the input power as a thickness of a conductor in Figure 2-2(A),(C), as the current of $\lambda/2$folded dipole is half of a $\lambda/2$dipole, the input impedance become $73\,\Omega \times 2^2 = 73\times4 \fallingdotseq 300\,\Omega$.
When the thickness is different in Figure 2-2(B), it is characterized that many current flow into a lead of thick side. In this time, I_2/I_1, the ratio divided before and after is changed variously according to the thickness and spacing S of a conductor.
When the conductor in side of non power feed is thick, become an impedance over 4 times as large as a $\lambda/2$dipole. It characterize like this that the radial characteristic of a $\lambda/2$ folded dipole is same as a $\lambda/2$ dipole but the impedance value become difference.
Figure 2-3 shows the impedance change for a $\lambda/2$ dipole according to change the diameter d_2, d_1 and spacing S of a parallel conductor. As the ratio of d_2/d_1, and as spacing S is small, the ratio of impedance change become large. When you want to make this change ration to be large, the 3lines folded dipole consisting of 3conductors is used as Figure 2-4.
Also in this case, the impedance change ratio is changed by the thickness and spacing of each lead complexly, but Figure shows the simple case, and when three all are same diameter, the change ratio become $3^2=9$. Also can increase the number of a parallel conductor. If all conductor is same thick, the change ratio can be calculated in N^2(Number of Conductor).
The folded dipole has a impedance change property in compared with $\lambda/2$ dipole. except this it has the merit as below

i) Driving Frequency Range is taken widely.

ii) Though the non-balanced class power feed lead as a coaxial cable directly, the matching become easy. etc.

Therefore it used for the radiator elements of Yagi antenna.
Since the radial resistance of radiator become lower value than 20Ω in Yagi antenna, if use the folded dipole which the impedance change ratio is 4 for a radiator, the input impedance can be 70-80Ω. So it become matching to the 300Ω power feed if the impedance change ratio is 30(three line type) with the coaxial cable of characteristic impedance 75Ω.

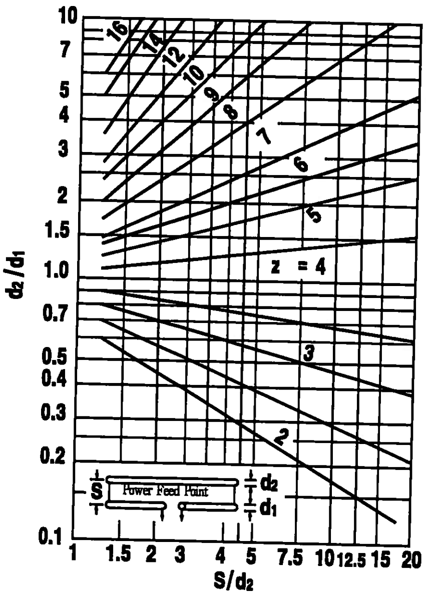


Figure 2-3 Impedance Change of 2Line Type Folded Dipole

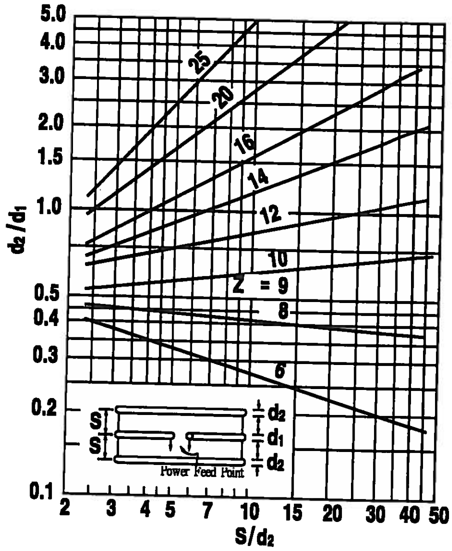


Figure 2-4 Impedance Change of 3Line Type Folded Dipole

2. Impedance Matching

For the most suitable power transmitting, it must same the power impedance as load impedance. Figure 2-5 indicates the simple circuit of power voltage V_s, internal resistance R_s and load resistance R_L. The maximum power transmitting is generated when $R_s = R_L$.

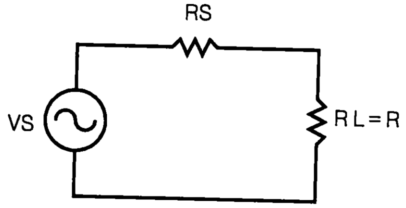


Figure 2-5 Impedance Matching between a power and load for the maximum power transmitting

The same rule is applied for the antenna system. For the maximum power transmitting, the antenna input impedance Z_{ant} must same as a transmitting lead or waveguide impedance Z_L as Figure 2-6.

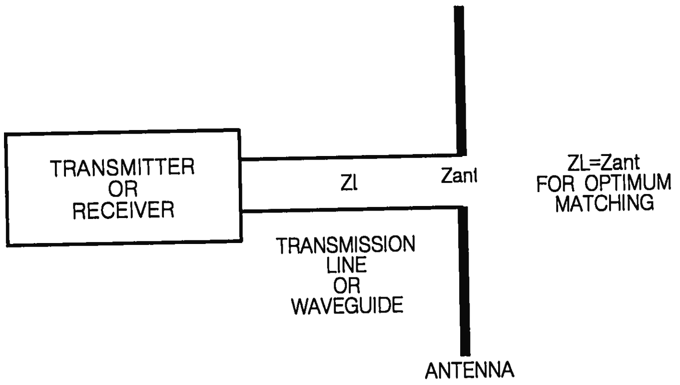


Figure 2-6 Impedance at a transmitting lead and antenna connecting point

When the transmitting lead and antenna don't match completely, instead of the partial transmitting power is radiated through an antenna, it is returned by reflecting.
In case of the receiving antenna, the partial power received by antenna isn't transmitted to receiver, and re-radiation will be occurred through a receiving antenna.
When impedance non-matching, Figure 2-4 shows the relational formula between power transmitted through impedance nonuniform point and the reflected power.

$$P_T = 1 - P_{Rfl} = 1 - \left| \frac{SWR-1}{SWR+1} \right|^2 = 1 - \left| \frac{Z_{ant} - Z_L}{Z_{ant} + Z_L} \right|^2 \qquad (2\text{-}4)$$

where, P_T is the power transmitted through a impedance nonuniform point
P_{rfl} is the power reflected at a impedance nonuniform point
SWR is a sine wave ration(SWR= Z_{ant}/Z_L).

If complete matching, since Z_{ant} = Z_L, $SWR = \frac{Z_{ant}}{Z_L} = 1$, the sine wave isn't occurred.
In this case, the reflected power isn't.

$$P_{Rfl} = \left| \frac{SWR-1}{SWR+1} \right|^2 = \left| \frac{0}{1} \right|^2 = 0 \qquad (2\text{-}5)$$

Accordingly, all the power is transmitted.
When power feed into transmitting lead in 4times half-wave folded dipole 73Ω of a lead impedance(4×73=292Ω), the sine wave generated. The sine wave

ratio in this time become

$$SWR = \frac{Z_{ant}}{Z_L} = \frac{4}{1} = 4 \qquad (2\text{-}6)$$

$$P_T = 1 - P_{Rfl} = 1 - \left| \frac{SWR-1}{SWR+1} \right|^2 = 1 - \left| \frac{3}{5} \right|^2 = 0.64 \qquad (2\text{-}7)$$

In this time 64% of power is transmitted, 36% is reflected. This result isn't the worst state. But it isn't advisable also. Accordingly it is desirable that do an impedance matching between the transmitting lead and antenna as Figure 2-7.

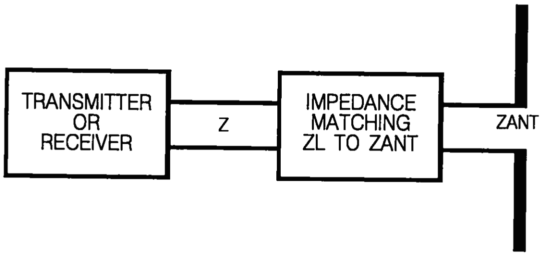


Figure 2-7 Impedance Matching between the Transmitting lead and Antenna

3. Half-Wave Folded Dipole

The antenna experiment set contains a 0.5 ㎓ half-wave folded dipole antenna. As former case, The dipole of this type has a 292Ω input impedance.

The transmitting lead given to connect to 0.5 ㎓ antenna is a 50Ω coaxial cable. It is presented 2ways to connect a 50Ω coaxial cable and a 292Ω folded dipole antenna. One is without Balun, and another is with a balun used for 4:1 impedance change.

3.1 Connecting without a Balun

Figure 2-8 shows the configuration connecting a 50Ω coaxial cable, a 300Ω parallel round lead and some 300Ω half-wave folded antenna without a Balun. The relation between the transmitted power P_T and the reflected power P_{Rfl} is

$$P_T = 1 - P_{Rfl} = 1 - \left| \frac{SWR-1}{SWR+1} \right|^2 = 1 - 0.51 = 0.49 \qquad (2\text{-}8)$$

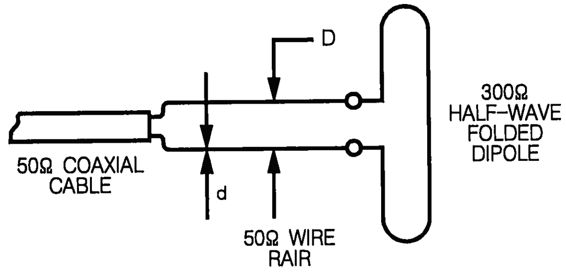


Figure 2-8 Folded Dipole Without Balun

If the impedance is matched completely, the power of 100% is transmitted. But some 50% is transmitted in this time, the remained half will be reflected. The lost 3dB is what has a damage of −3dB in compared with a complete impedance.

3.2 Connection using a Balun of 4:1 impedance change

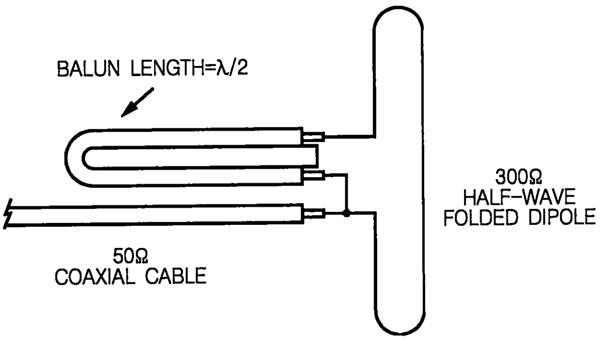


Figure 2-9 Folded Dipole with Balun

Figure 2-9 shows the connection of a 50Ω coaxial cable and a 300Ω half-wave folded dipole with a Balun of 4:1 impedance change. It's better that connect the 72Ω coaxial cable as RG-59U to a parts assembled the folded dipole and balun. But in this case connect with 50 Ω coaxial cable, the 4:1 change isn't desirable change. When match 50Ω and 300Ω, needed 6:1 impedance change desirably. But despite of the incomplete matching, it is sufficient to an improving effect with only 4:1 impedance change.

Since the 4:1 impedance converter let the 300Ω impedance change to 75Ω impedance, the impedance change with a 50Ω coaxial cable make a sine wave of 75/50=1.5 to be occurred. In this case, The relation between a transmitting power and a reflected power is as below.

$$P_T = 1 - P_{Rfl} = 1 - \left| \frac{SWR-1}{SWR+1} \right|^2 = 1 - 0.04 = 0.96 \qquad (2-9)$$

Accordingly, all the power of 100% isn't transmitted, and it is transmitted only 96% and reflected only 4%.

The power transmitting effect of half-wave folded dipole with balun become better as good as 2times than a folded dipole without it. This lead a result of difference as almost 3dB when measure.

EXPERIMENT PROCEDURE

SETTING OF EXPERIMENT APPLIANCE

1. Set the transmitting·receiving antenna positioner which is a main appliance of a experiment set and computer.

2. Set the height control bar on a transmitter and fix a 500MHz Yagi antenna on a antenna fixing pack, and then set an antenna on a polarization control plate. In this time, set an antenna to get an even polarization characteristic evenly with ground. The receiving antenna setting as Figure 2-10 has an even polarization characteristic.

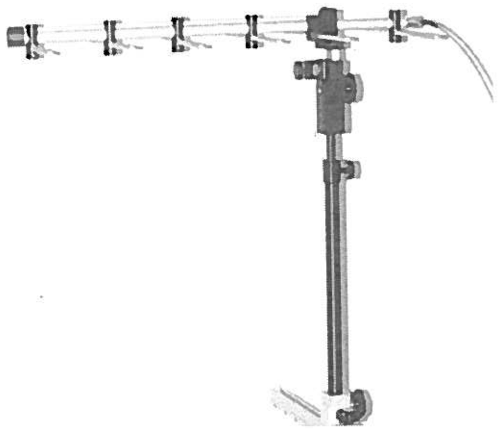


Figure 2-10 Setting of Even Polarization Transmitting Antenna

On condition that a power OFF of main controller, set the frequency select switch in transmitter in OFF, and connect a 500MHz oscillation output terminal and a Yagi antenna with SMA Cable.

3. Connect the stationary bar to a receiver and fix the folded dipole antenna used the 4:1 impedance conversion balun to get an even polarization characteristic at a polarization control plate. Place an antenna on rotation center of a receiver using the position control plate. See Figure 2-11 to set.

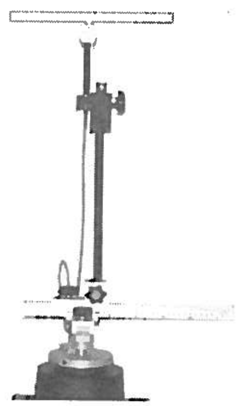


Figure 2-11 Setting of Even Polarization Receiving Antenna

Connect the folded dipole antenna used for receiving and the RF IN terminal in receiver with a SMA Cable used for 1m, and connect the OUT PUT(1kHz) terminal in receiver and the INPUT(1kHz) terminal in a main controller with a BNC Cable.

4. Calculate a folded dipole in 500MHz using below formula, and measure an actual length of antenna. Then record in Table 2-1.

The exact oscillation frequency of a RF signal generator is 500MHz.

$$\lambda = \frac{c}{f} \quad , \quad d = 4t \quad , \quad L = \frac{\lambda}{2}$$

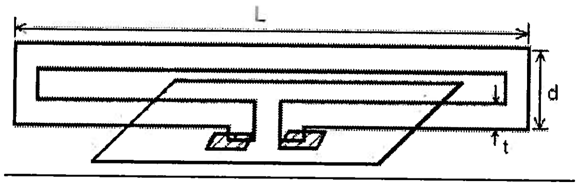


Table 2-1 The Length of Folded Dipole Antenna[cm]

	Theoretical Length of Antenna	Actual Length of Antenna
λ		
λ/2		
L		
d		
t		

5. Make the spacing between antennas to be isolated as r=1.5m as Figure 2-12, and set to be parallel the center part of Yagi antenna and folded dipole antenna.

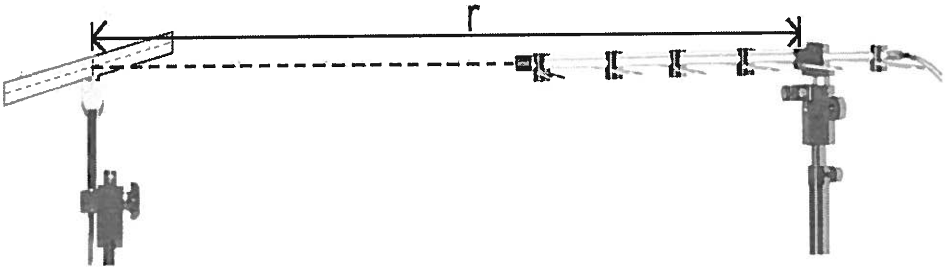


Figure 2-12 Distance between Antennas r

6. On condition that the power OFF of main controller, execute an antenna software after setting as below.
   - Power OFF
   - 500MHz Oscillation Switch off
   - 2 GHz Oscillation Switch off
   - 10 GHz Oscillation Switch off
   - Modulation Switch (Mod) off

7. Turn on the main controller power and set the oscillation switch and modulation switch as below.
   - Power ON
   - 500MHz Oscillation Switch on
   - 2 GHz Oscillation Switch off
   - 10 GHz Oscillation Switch off
   - Modulation Switch (Mod) on

8. Execute a ED-3200 Antenna Trainer program and select the antenna type, then select E-Plane as Plane, and control to be displayed 0 on the antenna gain displayer by controlling the signal attenuation. If the control is completed, start a data acquisition.

9. The data acquisition is completed, save got radial pattern into file. Use a data box to see a radial pattern exactly. Set MSP(Maximum Signal Position) on 0°, can see a radial pattern of this antenna.

10. For the 500MHz Yagi antenna used for receiving get an even polarization characteristic, set the polarization control plate to the right angle position with ground by rotating 90° as Figure 2-13.

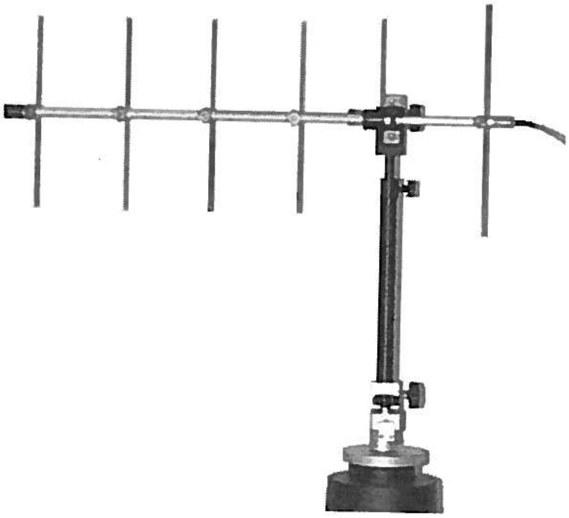


Figure 2-13 Setting of Even Polarization Transmitting Antenna

11. For the folded dipole antenna used for receiving, set by losing the position control screw and making a polarization control plate to rotate 90°and then setting it fitting the center of antenna in center of a rotational axis of receiver. And make the center of Yagi antenna used for transmitting and center of folded dipole antenna used for receiving to parallel each other.

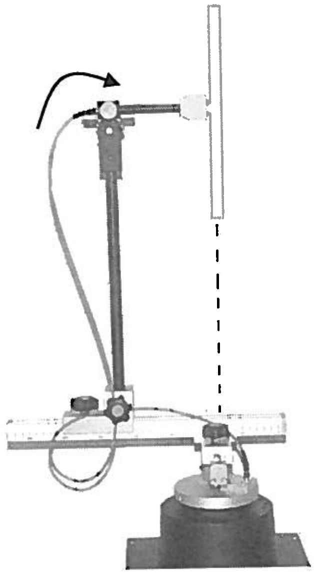


Figure 2-14 Setting of Vertical Polarization Receiving Antenna

12. Keep the drawn pattern in state of E-Plan, and after click Initialize in edit menu of software, select H-Plane as Plane and then click a Auto button for a data acquisition. The data acquisition is completed, save two drawn pattern in file.

13. Keep the 500MHz Yagi antenna used for transmitting to get a vertical polarization characteristic, and make the folded dipole antenna used for receiving to get an even polarization characteristic. In this time, set the Yagi antenna taken a vertical polarization characteristic and the folded dipole antenna taken an even polarization characteristic in parallel fitting its center by referring Figure 2-15.

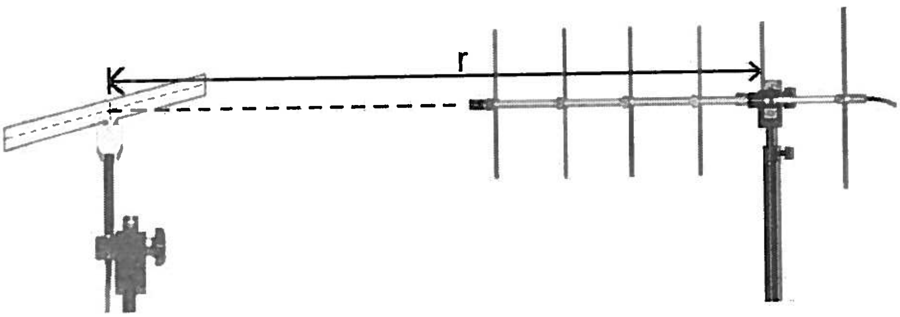


Figure 2-15 Even and Vertical Antenna

14. After click Antenna Initialize in Edit Menu of a software, click Screen Delete in Edit Menu of a software then click the Auto button for a data acquisition.

15. Observe three radial pattern. Especially take note of the third experimental result.

16. Set again for each receiving·transmitting antennas get an even polarization characteristic. The distance between antennas is r=1.5m. Set the environmental condition to same as the first experiment. Take E-Plane radial pattern of a folded dipole antenna and save in Dummy-Plane.
Theoretically this radial pattern must same as the first pattern except an effect caused by a power damage. If the pattern differ so much, must do properly by finding the position where a reflection can be occurred. After do suitably, experiment continuously and save a new pattern in E-plane.

Click Data Indication Line in upper Edit Menu of a data analysis program. On the screen, 2 cursors used for E-Plane(Blue, White) and 2 cursors used for H-Plane (Yellow, Green) is appeared. Click the cursor by both side of color displayer, the values on a displayer will be changed with the cursor of same color moving. These indicate a position angle of cursor and a receiving power in that time by dB, and the angle between cursors and difference of power is displayed on 2 displayer.
Record the taken values in Table 2-2.

Table 2-2 Receiving Power for Angle

Angle	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Receiving Power of E-Plane by Angle												
Receiving Power of H-Plane by Angle												

17. Take an angle which the maximum power is received in E-Plane pattern and a receiving power in that time using the a cursor. Click the Maximum Single Level button on a E-Plane data window and confirm if the measured value is

same as a taken value by using the cursor, then record in below Table 2-3.

Table 2-3 Comparison of E-Plane and Theoretic Value

Taken Value with Cursor	Receiving Power	
	Angle	
Value by Maximum Single Level Icon	Receiving Power	
	Angle	

18. Take a half angle of a main beam size in the E-Plane pattern by using two cursors. Click the Half Power Beam Width button on the E-Plane data window and confirm if a measured value and the taken value by using a cursor is accord.

Calculate a half power beam width of a folded dipole antenna in E-Plane by using below formula.

$$HPBW_E = | \theta_{HPBWleft} - \theta_{HPBWright} |$$

$HPBW_E$=________

19. Repeat the 18th experiment procedure in a radial pattern of H-Plane.

$HPBW_E$=________

20. Delete all cursors by clicking a data indication line in Edit Menu. Compare the experimental value with the values taken from antenna software. If the calculated result differ from these values, repeat an experiment and calculation. (when difference over 7°).

21. Save the data of E-Plane and H-Plane, and output this result.

22. Until now experimented with a folded dipole antenna using the impedance conversion balun of 4:1. To find a difference of an antenna with 4:1 impedance conversion balun and without it, experiment based on the experiment procedure from No. 1 through No. 21. And compare the data in this time(without 4:1 impedance conversion balun) with the data with it and record.

▣ EXCERCISE ▣

1. Explain why there is a difference between the impedance of a folded dipole and a $\lambda/2$ dipole.

2. Explain some difference between when to be impedance matching and when to be impedance matching.

3. Explain how change of a gain, directivity and antenna efficient etc when feed directly to a folded dipole with 75Ω coaxial cable and when feed with 4:1 balun.

4. Explain the impedance change caused by the distance d of a folded dipole antenna.

5. What's the polarization characteristic of a folded dipole antenna.

EXPERIMENT 3-3. λ/4 GROUND ANTENNA

Let's experiment a radial pattern of E-Plane and H-Plane for the λ/4 folded antenna used for 500MHz in this experiment. Let's see a polarization characteristic of a λ/4 folded antenna. Calculate a half power beam width of a λ /4 folded antenna.

BASIC STUDY

After an existence of a electric wave is proved by Herz in 1888, in 1901 Marconi succeeded the crossing telecommunication of Atlantic by finding the antenna, so the electric wave was to be used in telecommunication. It is a ground antenna that used in that time so it is used to call Marconi Antenna. The ground antenna is a representative initial antenna, and it is used majority for a long wave and medium wave antenna.

1. Ground

The ground antenna is an antenna contacted a output terminal in transmitter or one axis of power feed lead to the earth. The power feed for this antenna is fed between earth and antenna conductor as Figure 3-1.

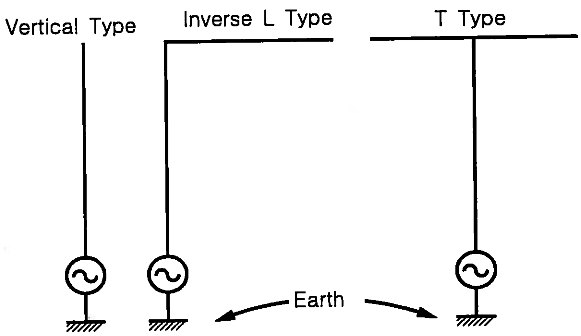


Figure 3-1 Representative Ground Antenna

In case of a λ/2 dipole antenna in different from a ground antenna, connect the both end of a high frequency source.
Generally in case of a folded antenna, the length of a conductor may shorter as 1/2 than non ground antenna, it has a merit that it is easy to match if a power feed point is low. But since a returning road of antenna current pass earth, it has demerits that the antenna efficient go down as a damage is large caused by ground resistance if a ground is insufficient.

2. VERTICAL GROUND ANTENNA

Let's think the case of the conductor length is λ/4(four-first frequency). Suppose that the earth is complete conductor flat, it is equivalent to λ/2 dipole in free space because can consider a image antenna of length λ/4 as Figure 3-2.

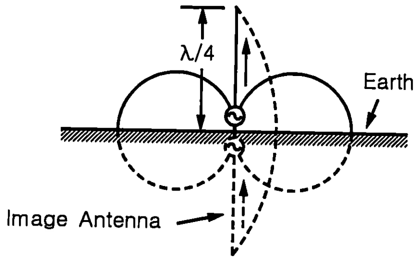


Figure 3-2 Power Distribution and Directivity of λ/4 Vertical Ground Antenna

Accordingly the field strength of earth is half of λ/2 dipole radial field strength flowing the same size current into center(current anti-node) of lead. Also power feed point impedance becomes half of a center feedλ/2 dipole, and the resistance becomes about 36Ω.
Since the cubic directivity take on earth only, in the λ/4 vertical antenna, it becomes shape like what cut a doughnuts circularly to half and lay face down the section as Figure 3-2.
Figure 3-3 indicates a directivity of vertical side and a field strength on earth when change length of a conductor. The strength of field in Figure is a value within a radial power of 1km and distance of 1mile(about 1.6km). When the length of conductor is 5λ/8= 0.625λ, the field strength on earth becomes maximum, and indicate about 1.4times of the distance is 0.25λ.

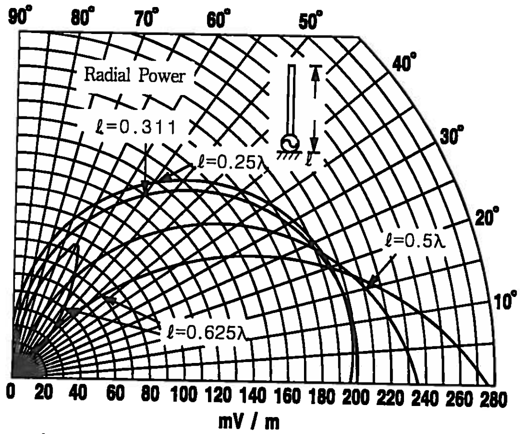


Figure 3-3 Length(Height) of Vertical Antenna and Vertical Side Pattern

Since a gain of a folded antenna standardize a verticalλ/4 antenna, it becomes

about 2times(3dB) of a 5λ/8 vertical antenna. If longer than 5λ/8, the sub lobe of an obtuse angle becomes large and the field strength go down.
The power feed impedance of a vertical ground antenna becomes half of a dipole antenna, it becomes different for the thickness of conductor as well as non ground antenna.
Figure 3-4 indicates the impedance change for a length and thickness of conductor.

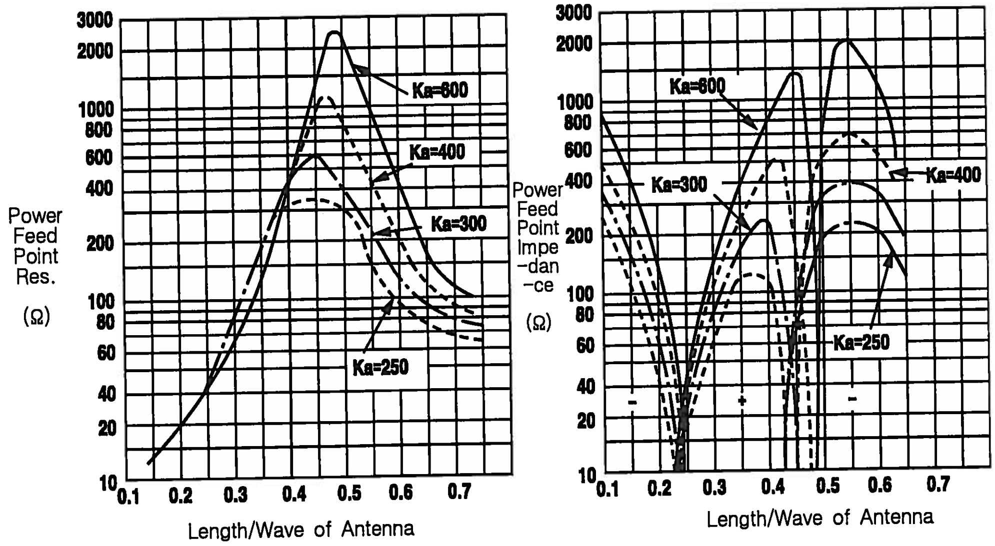


Figure 3-4 Power Feed Point Impedance of Vertical Ground Antenna

3. λ/4 Ground Antenna

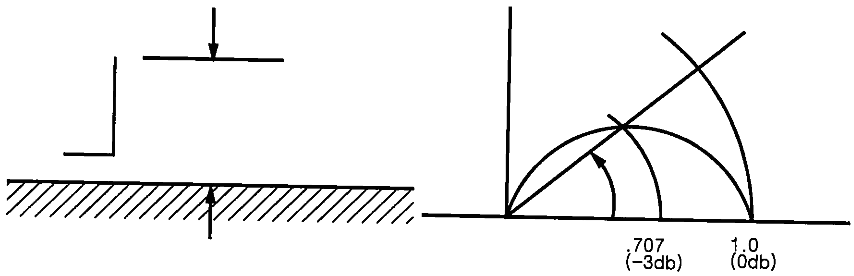
Theλ/4 ground antenna is equivalent to a λ/2 vertical dipole antenna by earth, complete conductor.
Figure 3-5 shows ideal pattern of an even and a vertical directivity of this antenna. The vertical directivity is about below 45°, very low. Also even directivity is non directivity, as if radiate the electric wave equivalently to all directions.
Since the power feed point impedance of this antenna is 36Ω, can use a coaxial cable of 50Ω as a power feed lead, but put a gamma, match or element one more in parallel to use for good matching.
Take the element length of antenna from below formula.

$$l = \frac{75}{f(MHz)}(m)$$

But this is theoretical, in actual antenna, by considering an uniaxial ratio, take with below.

$$l = \frac{71.3}{f(MHz)}(m)$$

Figure 3-5 shows the case that a$\lambda/4$ ground antenna is on the face of a complete conductor. This is a half length of a $\lambda/2$ or half wave dipole.



(A) Physical Expression (B) Radial Pattern

Figure 3-5 $\lambda/4$ Ground Antenna on Complete Ground Antenna

In monopole antenna($\lambda/4$ ground antenna), it is like that the current flow into a pole of one side. Also the input voltage is half of a dipole. Accordingly the input impedance of a monopole becomes half of the input impedance of a dipole.

$$Z_{in(\lambda/4monopole)} = 36\Omega \qquad (3\text{-}1)$$

Since the current is same as $\lambda/2$dipole, the radial power may be same. But the beam width becomes half of dipole because there are the ground face. Accordingly the directivity and gain become 2times of a dipole.

$$G_{\lambda/4monopole} = 2\times1.64 = 3.2 \text{ or } 5dB \qquad (3\text{-}2)$$

The radial pattern of a$\lambda/4$ monopole on the ground face is same type as the radial pattern of a$\lambda/2$ dipole over (zero) angle.
The theoretical radial pattern is given in Formula 3-3, and it is same shape as a half wave dipole.

$$F(\Theta)_{\lambda/4monopole} = \frac{1}{2}\frac{\cos\left(\frac{\pi}{2}\cos\Theta\right)}{\sin\Theta}, \quad \Theta > 0 \qquad (3\text{-}3)$$

If the monopole put on the ground face as the height d/2 as Figure 3-6, the monopole antenna drive as if two antenna is arranged. The electric waves radiated from upper part and lower part antennas becomes different with each height on the ground face.

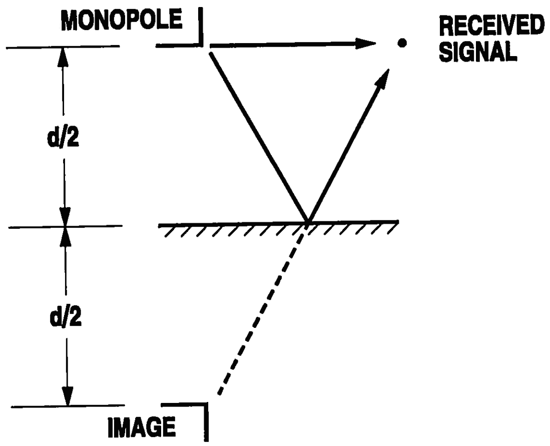


Figure 3-6 Radial Coupling by Monopole and Image Monopole

This is to generate an Array factor.
Figure 3-6 shows the coupling shape of the electron wave radiated from a monopole and image monopole, this is similar what couple the radial electric wave by a dipole on a complete conductor.

λ/4 Ground Antenna

Figure 3-7 shows the λ/4 ground antenna. This antenna is fed power through hall of a large ground from 50Ωcoaxial cable.
The size of ground face is important for the design of ground antenna. The ideal ground face is unlimited size. Actually the ground face of radius 5λ is almost ideal ground, it must have a minimum radius 0.5λ. The ground antenna designed in the set for antenna experiment has a ground face of size 0.5λ. Also the coaxial cable feeding to antenna has 50Ω impedance. Accordingly take a coupling by making the impedance of λ/4 ground antenna to change to 36Ω.
The characteristic impedance of a coaxial cable is a function between a 'a', radius of central conductor and 'b', distance till central conductor and ground

conductor. The relation is given as Formula 3-4.

$$Z_0 = 60 \log\left(\frac{b}{a}\right) \tag{3-4}$$

When a = 0.1595 cm, b = 0.317 cm, the characteristic impedance becomes 41.5Ω, this is a geometric average value of 50Ω, characteristic impedance of coaxial cable and 36Ω, input impedance of λ/4 ground antenna.

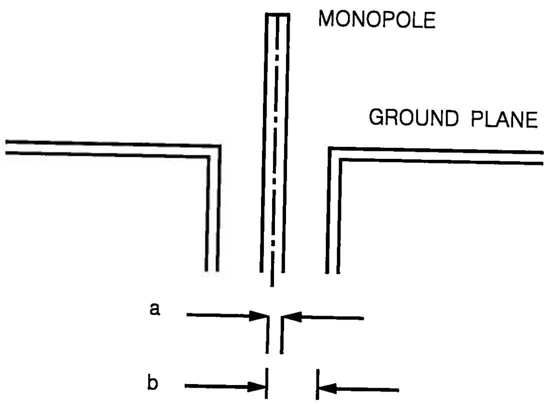


Figure 3-7 Coaxial Power Feed λ/4 Ground Antenna and Ground Face

EXPERIMENT PROCEDURE

1. Set a main controller, transmitting and receiving antenna positioner and computer which are main instrument of an experiment set for antenna.

2. Set the height controller on a transmitter and fix an 500MHz Yagi antenna on fixing pack of an antenna, then fix an antenna on follow control plate. In this time set an antenna in parallel with earth to get an even polarization characteristic. The transmitting antenna set as Figure 3-8 has an even polarization characteristic.

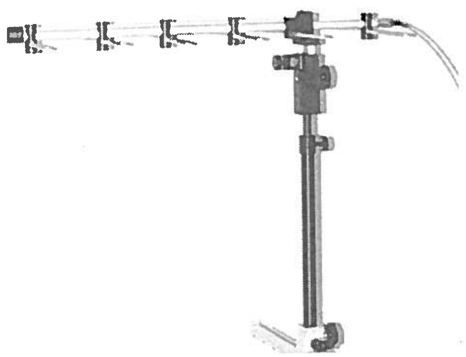


Figure 3-8 Setting of Even Polarization Antenna

Set the frequency selecting switch to OFF, and connect the 500MHz oscillation output terminal and Yagi antenna with a SMA cable.

3. Fix the $\lambda/4$ ground antenna to get an even polarization characteristic on the polarization control plate of receiver. Set an antenna in center of rotating axis of receiver by using the moving control plate of receiver. Set by referring Figure 3-9.

Connect the $\lambda/4$ ground antenna and the RF IN terminal of receiver with a SMA Cable used for 1m, and also connect the OUT PUT(1kHz) of receiver and the input(1kHz) terminal of main receiver with a BNC Cable used for 1m.

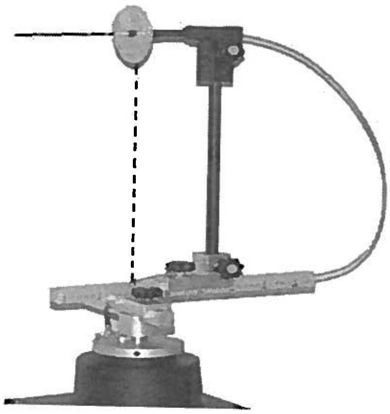


Figure 3-9 Setting of Even Polarization Receiving Antenna

4. Calculate the length of λ/4 ground by using below formula, and measure the length of an actual antenna, then record in Table 3-1.

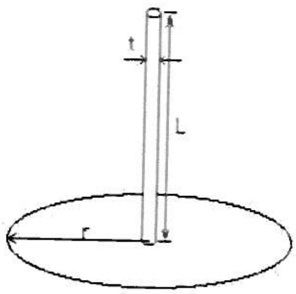


Table 3-1 Length of λ/4 Ground Antenna [cm]

	Theoretical Antenna Length	Actual Antenna Length
λ		
λ/2		
L		
r		
t		

5. Make the distance between antenna as r=1.5m to isolated, adjust the center of a transmitting antenna and receiving antenna in parallel. See Figure 3-10 to set.

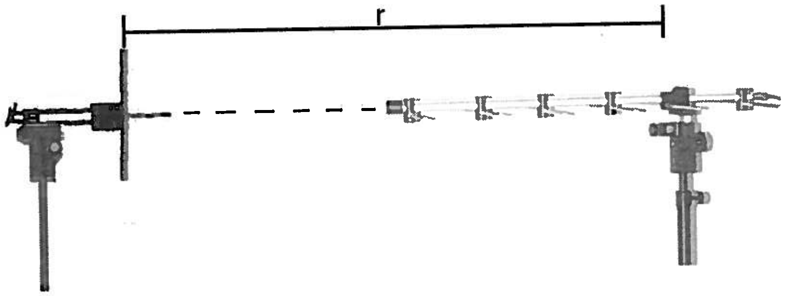


Figure 3-10 Distance between Antennas

6. Set in condition of the power of main controller as below.
   - Power OFF
   - 500MHz oscillation switch off
   - 2 GHz oscillation switch off
   - 10 GHz oscillation switch off
   - Modulation switch (Mod) off

7. Turn on the power of main controller, and set the oscillation switch and modulation switch as below, then execute the Antenna Trainer program.
   - Power ON
   - 500MHz oscillation switch on
   - 2 GHz oscillation switch off
   - 10 GHz oscillation switch off
   - Modulation switch (Mod) on

8. Open the window of data acquisition in Antenna Trainer program and select an antenna. And select E-Plane as Plane and adjust to be displayed 0 on gain displayer by adjusting the quantity of signal attenuation. This adjust is completed, start the data acquisition.

9. The data acquisition is completed, save get radial pattern in file. To confirm the radial pattern exactly, use the data box. Set the MSP(Max. Signal Position) to 0°, can see exact radial pattern.

10. Set the 500MHz Yagi antenna used for receiving to get an vertical polarization characteristic in parallel with earth by rotating the polarization control plate as 90°as 3-11.

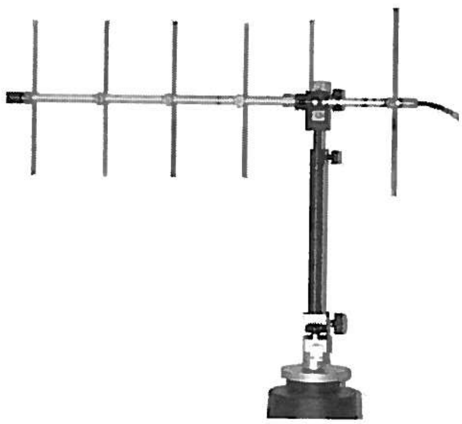


Figure 3-11 Setting of Vertical Polarization Transmitting Antenna

11. Set the $\lambda/4$ ground antenna used for receiving in vertical with earth to get a vertical polarization characteristic as Figure 3-12, and set in center of rotating axis by moving the position control plate.
    And in this time set the center of receiving antenna and the ground plate of a monopole antenna in a straight line.

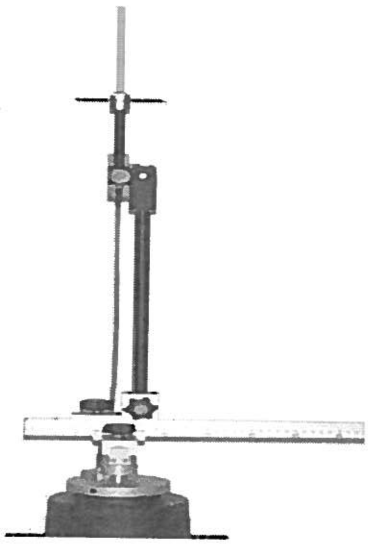


Figure 3-12 Setting of Vertical Polarization Receiving Antenna

12. Keep the pattern drawn in E-Plan and click the Antenna Initialize in Edit Menu of a software, and click the auto button to data acquisition. Data acquisition is completed save two drawn pattern in file.

13. Keep the 500MHz Yagi antenna used for transmitting to get a vertical polarization characteristic and set the $\lambda/4$ ground antenna used for receiving to get an even polarization characteristic.

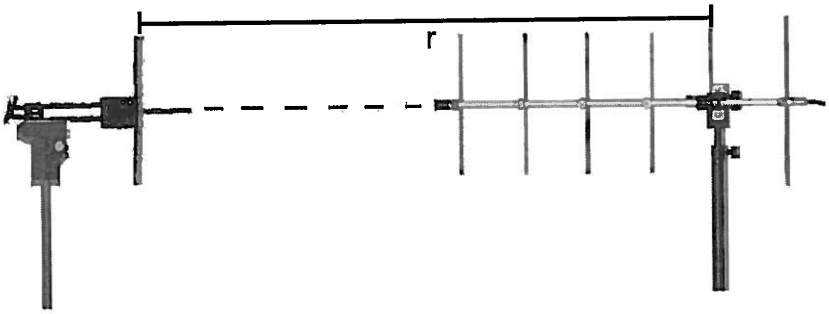


Figure 3-13 Even and Vertical Antenna

14. After click Antenna Initialize in Edit Menu of a software, click Screen Delete and click the auto button for a data acquisition.

15. Observe three radial pattern.

16. Set again each transmitting·receiving antennas to get an even polarization characteristic. The distance between antennas is r=1.5m. Make the surrounding condition to same as the first experiment. Take a E-Plane radial pattern of a $\lambda/4$ ground antenna and save in Dummy-Plane.
Theoretically, except an effect by power damage, this radial pattern must same as the first radial pattern. If the pattern is different so much, have to do properly by finding the point where a reflection can be occurred. After do properly, continue the experiment and save the new pattern in E-Plane.

Click the data indicating line on upper View Menu of a data analysis program. Two cursor (Blue, White) used for E-Plane, and two cursor (Yellow, Green) used for H-Plane are appeared on the screen. Click the arrow mark on both side of color displayer, the value in displayer will be changed by moving the cursor of same color. This shows the position angle of cursor and the receiving power in this time by dB, and shows the angle between cursors and the difference of power in below displayer. Record the taken value in below 3-2.

Table 3-2 **Receiving Power for Angle**

Angle	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Receiving Power of E-Plane for Angle												
Receiving Power of H-Plane for Angle												

17. Take the angle received a maximum power in E-Plane pattern and receiving power in that time by using a cursor. Confirm if the measured value by pressing the Maximum Single Level button on E-Plane data window and the value taken by using cursor are accorded, and record in below table 3-3.

Table 3-3 Comparison of E-Plane and Theoretic Value

Taken Value by using a cursor	Receiving Power	
	Angle	
Value by Maximum Single Level Icom	Receiving Power	
	Angle	

18. Take a half angle of a power size of main beam in E-Plane pattern by using two cursors. Confirm if the measured value by pressing the Half Power Beam width button on E-Plane data window and the value taken by using cursor are accorded.

Calculate the half power beam width in E-Plane of λ/4 ground antenna by using below formula.

$$HPBW_E = \mid \theta_{HPBWleft} - \theta_{HPBWright} \mid$$

$HPBW_E$=__________

19. Repeat No. 18 in this experiment procedure with the radial pattern of H-Plane.

$$HPBW_E = \_\_\_\_\_\_\_\_$$

20. Delete all the cursors by clicking the data indicating line on View Menu. Compare the experimental values with the given value in antenna software. If a calculated result is not accorded with this values, experiment and calculate again.

21. Save the data of E-Plane and H-Plane, and output the result.

▣ EXCERCISE ▣

1. Why does the length of ground antenna becomes half of a dipole?

2. How over large size is the ground face of a ground antenna?

3. What/s the input impedance of a $\lambda/4$ ground antenna?

4. Describe the radial pattern of a $\lambda/4$ ground antenna.

5. What's the polarization characteristic of a $\lambda/4$ ground antenna?

EXPERIMENT 3-4. DROOPING ANTENNA

In this experiment, let's the radial pattern of E-Plane and H-Plane for a drooping antenna used for 500MHz. We will study the polarization characteristic of a drooping antenna. Let's calculate the half-power beam width of a drooping antenna by using an antenna software.

BASIC STUDY

1. Drooping Antenna

There is an element of λ/4 length vertically from a central lead of a coaxial cable as Figure 4-1. Also, as this is the antenna attached a ground lead of λ /4 length radially in sheath conductor, the lead has an optional angle with earth, this is the antenna attached the counter poise ground lead of a kind instead of a ground of λ/4 ground antenna.

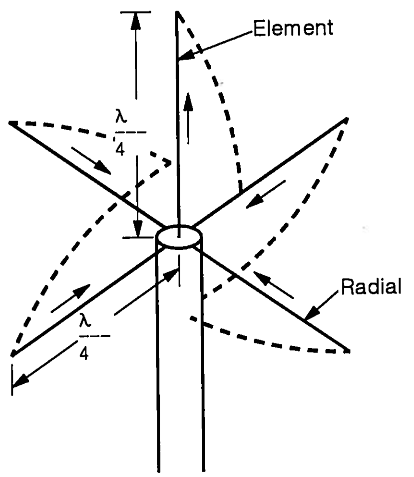


Figure 4-1 Ground·Plane

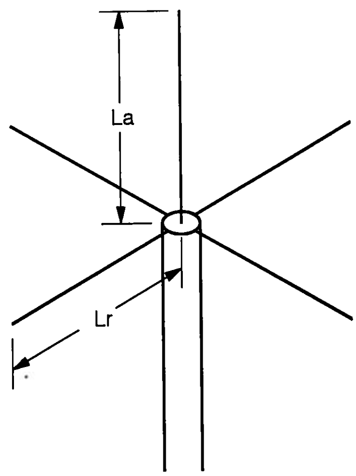


Figure 4-2 Vertical Element La

For there is this counter poise ground lead, this is prevented a current from leaking from a sheath conductor of a coaxial cable to external, and there is no unnecessary radiation of an electric wave in cable. Assemble vectorially the radial current placed in optional angle for earth, since the radial length is λ/4, a radial field is decided by the current flowing into vertical element and the sum of a vector of a radial current.

This antenna has a similar characteristic to λ/2 dipole antenna, but the radiation of an electric wave can't be occurred almost to the direction of earth, and the radiation is occurred in the area bounded by the central lead and ground lead. Accordingly this is used mainly in a simultaneous call with the airplane taken off and landed in the control tower of airport. The length of a central element is taken by follow formula.(Figure 4-2)

$$La = \frac{71.3}{f(MHz)}\,(m)$$

Also the length of radial is taken by follow formula since make the length of radial to be longer as 2 ~ 3% than a vertical element for the radial of an electric wave becomes maximum in vertical direction.

$$L_r = \frac{73}{f(MHz)}\,(m)$$

Since the impedance at the power feed point of this drooping antenna is very low as 21 ~ 24Ω, if feed directly with 50 ~ 75Ω of a coaxial cable, SWR is to be worse. So to go up the impedance at the power feed point of this antenna, following method has been used.

Figure 4-3 shows the folding shape of a vertical element. Since the impedance at the power feed point becomes 4times of it before fold, can go up to 84 ~ 96Ω.

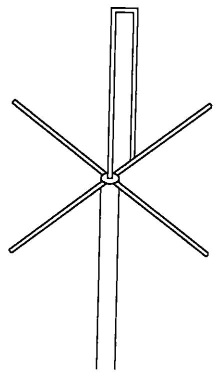


Figure 4-3 Fold the Vertical Element

In figure 4-4, as incline the counter poise ground element to below, the impedance at a power feed point becomes higher.

Figure 4-5 indicates the angle of a ground element and the value of an impedance. this becomes about 21Ω when becomes 90。 and 50Ω in about 3

0 ~ 38。, and becomes 70Ω when go down just below 0。.
Figure 4-6 shows the setting of gamma ·matching system in a power feed part, Make the impedance at a power feed point to match to the characteristic impedance of a coaxial cable by controlling the length of a gamma·load place parallel with a vertical element, and the variable condenser between the load and the central conductors of a coaxial cable.
Figure 4-7 shows the antenna taken a matching by placing a vertical radial in a coaxial antenna. As connect a parallel radial, d, a distance between a central lead of a coaxial cable and a vertical element, is taken by below formula.

$$d(m) = \frac{\lambda}{2\pi} \cos^{-1}\sqrt{\frac{Z_A}{Z_O}}$$

Z_A : Impedance at a power feed point of drooping antenna

Z_O : Characteristic Impedance of Coaxial Cable

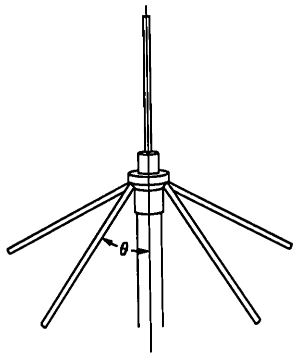


Figure 4-4 Vertical and Impedance

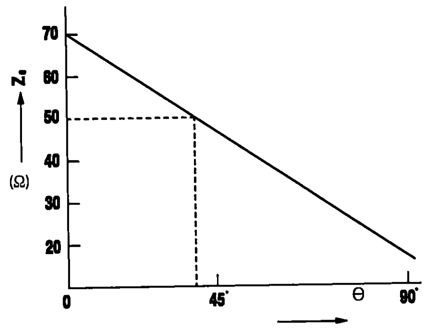


Figure 4-5 Angleθ and Impedance of Vertical Element

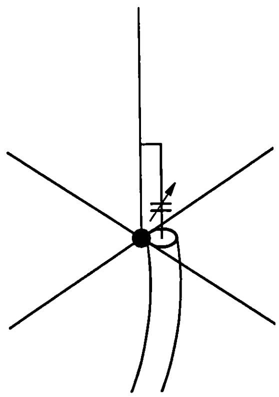


Figure 4-6 Gamma·Match

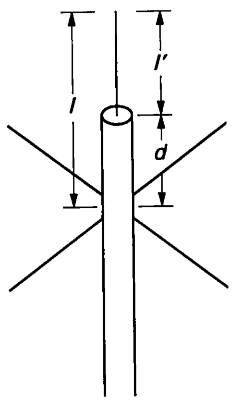


Figure 4-7 Place the Vertical Radial in a Coax

The experiment set of an antenna contain a drooping monopole antenna in addition to a standard monopole. The drooping monopole is very easy design method of monopole. Figure 4-8 shows a drooping monopole exemplarily.

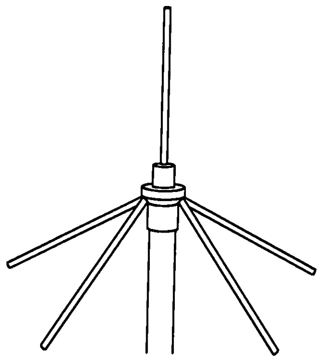


Figure 4-8 Drooping Monopole

To explain the characteristic of a drooping antenna, consider a half-wave dipole having impedance of 73Ω as Figure 4-9. If each leads consisting the half of below part is divided to 180°as Figure 4-9(c), it becomes aλ/4 ground antenna taking the characteristic impedance of 37.5Ω. But as Figure 4-9(b), if consist of each leads stretching for 90° (45° from a right angle), it becomes a drooping antenna getting a characteristic impedance of almost 50Ω. This is matched exactly up to the characteristic impedance of a coaxial cable.

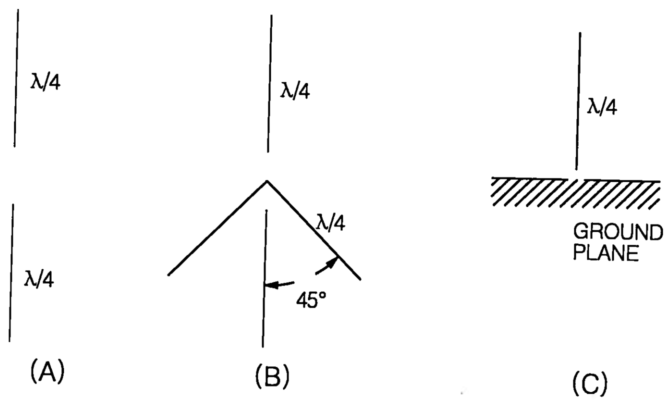


Figure 4-9 (A) Half-Wave Dipole (B) Drooping Antenna (C) λ/4 Ground Antenna

EXPERIMENT PROCEDURE

SETTING OF EXPERIMENTAL INSTRUMENT

1. Set a transmitting·receiving antenna positioner and a computer which are main instrument of an antenna experimental set.

2. Set a height controller on a transmitter and fix the 500MHz Yagi antenna on a fixing pack of an antenna, then set on the polarization control plate. Set this at a parallel position with earth for the antenna get a parallel polarization characteristic. The transmitting antenna set as Figure 4-10 has a parallel polarization characteristic.

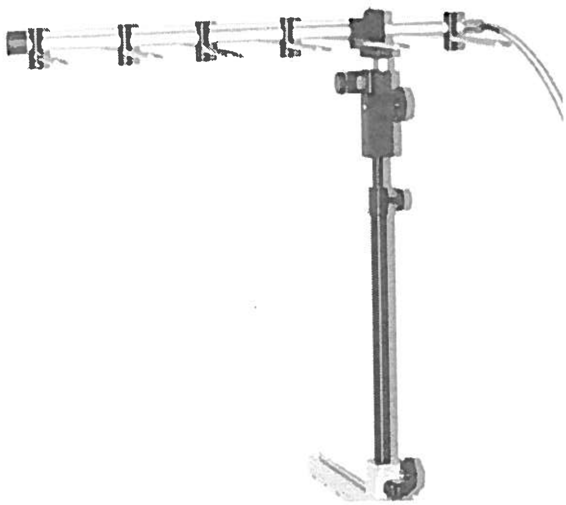


Figure 4-10 Setting of a Parallel Polarization Transmitting Antenna

Set OFF the selection switch and modulation switch in a transmitting of main controller, connect a 500MHz oscillation output terminal and Yagi antenna with SMA used for 2m.

3. Attach the stationary bar on a receiver. And fix the drooping antenna on a polarization control plate of upper stationary bar to be got a parallel polarization characteristic. Set it in center of a rotational axis of a receiver by loosing the position control screw of a receiver and moving the control plate. See Figure 4-11 to set.

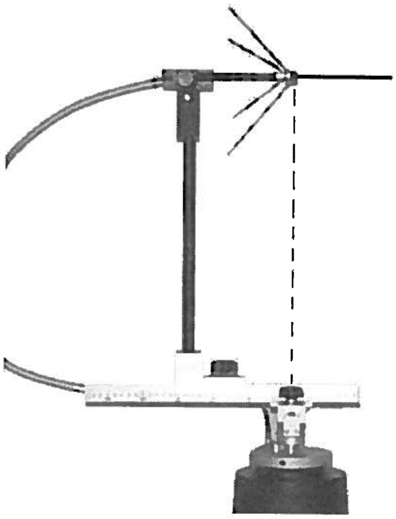


Figure 4-11 Setting of Parallel Polarization Receiving Antenna

Connect a coupling terminal of a drooping antenna and a RF IN terminal of a receiver with a SMA cable used for 1m, and connect a OUT PUT(1kHz) terminal of a receiver and a Input(1kHz) terminal of a main controller with a BNC cable used for 1m.

4. Calculate the length of a drooping antenna and measure the actual length of an antenna in 500MHz by using below formula, and record in Table 4-1.

$$\lambda = \frac{c}{f} \quad , \quad d = 4t \quad , \quad L = \frac{\lambda}{2}$$

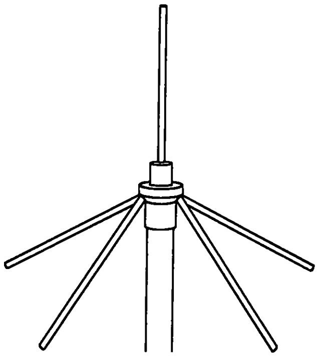


Figure 4-12 Drooping Antenna

Table 4-1 Length of Drooping Antenna [cm]

	Theoretical Antenna Length	Actual Antenna Length
λ		
L		
d		
t		

5. As Figure 4-13, the distance between antennas is isolated as r=1.5m. Make the center of each transmitting·receiving antenna to be in a straight line at a same height.

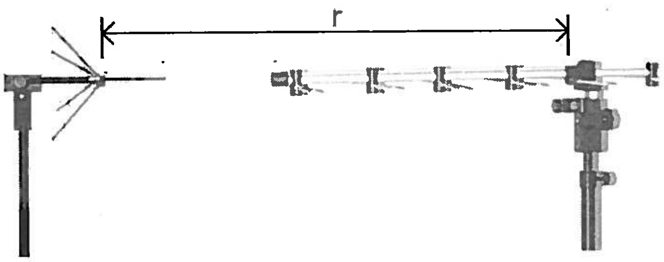


Figure 4-13 Distance between Antennas r

6. Set in condition of the power of a main controller as below.
   - Power OFF
   - 500MHz Oscillation Switch off
   - 2 GHz Oscillation Switch off
   - 10 GHz Oscillation Switch off
   - Modulation Switch (Mod) off

7. After set a switch in main controller as below, execute the Antenna Trainer Program.
   - Power ON
   - 500MHz Oscillation Switch on
   - 2 GHz Oscillation Switch off
   - 10 GHz Oscillation Switch off
   - Modulation Switch (Mod) on

8. The program window is executed, make the data acquisition in Pop Up Menu to be executed. Here after select Antenna, select E-Plane as Plane, and control the signal attenuation to be displayed 0 in a displayer for an antenna gain. The control is completed, start the data acquisition.

9. Data acquisition is finished, save the taken radial pattern in file. To confirm the radial pattern exactly, use a data box. Set MAP(Max. Signal Position) to 0°, can see a radial pattern of this antenna exactly.

10. For the 500MHz Yagi antenna used for transmitting get a vertical polarization characteristic, loose a fixing screw on a polarization control plate and make the control plate to rotate as 90°.

Figure 4-14 Setting of a Vertical Polarization Transmitting Antenna

11. For the drooping antenna used for receiving get a vertical polarization characteristic, set as Figure 4-15.

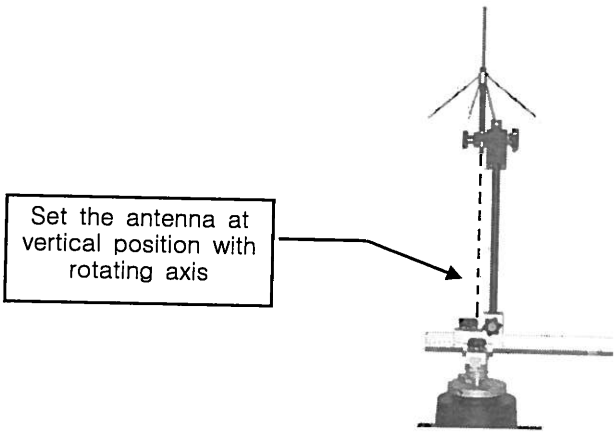


Figure 4-15 Setting of a Vertical Polarization Receiving Antenna

12. After click Antenna Initialize of Edit Menu of a software, acquire a data by clicking the Auto button. The data acquisition is completed, save the pattern in file after select H-Plane as Plane.

13. Keep a 500MHz Yagi antenna used for transmitting to get a vertical polarization characteristic, and set a drooping antenna to get an even polarization characteristic. In this time, for the center of a transmitting antenna taken a vertical polarization characteristic and a receiving antenna get an even polarization characteristic is to be in strait line, see Figure 4-16 to set.

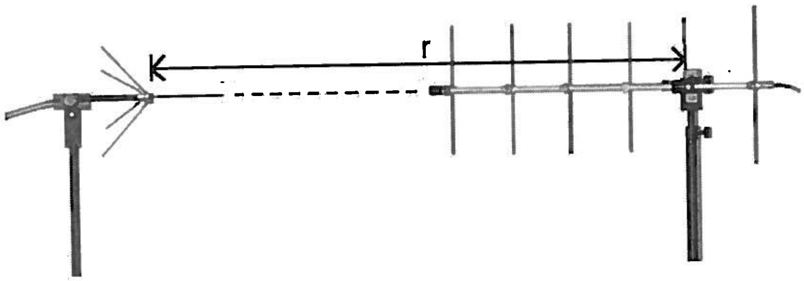


Figure 4-16 Vertical and Even Antenna

14. Click Antenna Initialize in Edit Menu of a software, and click Delete Screen in Edit Menu again, then acquire a data by clicking the Auto button.

15. Observe three radial pattern.

16. Set again each transmitting·receiving antenna to get a vertical polarization characteristic. The distance between antennas is r=1.5m. Make a surrounding condition to same as the first experiment. Take a E-Plane radial pattern of a drooping antenna and save in Dummy-Plane.

    Theoretically except an effect caused by a power damage, this radial pattern must same as the first pattern. If the pattern is differ very much, have to do suitably by finding a point where a reflection can be occurred. After do suitably, continue the experiment and save a new pattern in E-plane.

    Click the data indicating line in the Edit Menu of upper menu of a data analysis program. Two cursors(Blue, White) used for E-Plane and two cursors(Yellow, Green) used for H-Plane are appeared. Click the arrow mark at both side of a color displayer, the value in a displayer by moving the cursor of same color. These display the position angle of cursor and the receiving power as dB, The difference of an angle between cursors from a power on below two displayer. Record the values in below Table 4-2.

Table 4-2 Receiving Power for Angle

Angle	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Receiving Power of E-Plane for Angle												
Receiving Power of H-Plane for Angle												

17. Take a receiving angle of max. power in E-Plane pattern and the receiving power in that time by using a cursor. Confirm if the measured value and the theoretic value are accorded by clicking the Maximum Single Level of E-Plane data window. Confirm if the taken value by using a cursor and record in below Table 4-3.

Table 4-3 Comparison of E-Plane with Theoretic Value

Taken Value by Using a Cursor	Receiving Power	
	Angle	
Value by Maximum Signal Level Icon	Receiving Power	
	Angle	

18. Take half angel of a main beam power in E-Plane pattern by using two cursors. Click the Half Power Beamwidth button.

Calculate a half power beam width of a drooping antenna in E-Plane by using below formula.

$$HPBW_E = | \theta_{HPBWleft} - \theta_{HPBWright} | = \_\_\_\_\_\_\_\_$$

19. Repeat the experiment of no. 18 in radial pattern of H-Plane.

$$HPBW_h = \_\_\_\_\_\_\_\_$$

20. Delete all cursors by clicking a data indicating line in Edit Menu. Compare the experimental values with a given values in an antenna software. If the calculated result isn't accord with these values, experiment and calculate again.

21. Save the data of E-Plane and H-Plane, and output the result.

22. Experiment from above no. 3 to no. 21 with taking the place of a ground plate(Large, Small) based on the experiment procedure. And compare this experimental result with above result, record.

▣ EXCERCISE ▣

1. Where is the using place mainly for a drooping antenna, Why so?

2. What is the role of four lead placed in each corner of a drooping antenna?

3. What's the shape of a radial pattern for a drooping antenna?

4. The impedance and radial pattern according to a gradient angle of four lead placed on each corner of a drooping antenna. Take an impedance and radial pattern in case of the gradient angle of four lead is 30°, 45°, 60°, 90°.

5. What is the radial characteristic with a drooping antenna?

EXPERIMENT 3-5. FULL-WAVE LOOP ANTENNA

In this experiment, let's measure a radial pattern for a E-Plane and H-Plane of a full-wave loop antenna. We will study a polarization characteristic of a full-wave loop antenna. Let's calculate a half-power beam width of a full-wave loop antenna by using an antenna software.

BASIC STUDY

1. Infinitesimal Loop Antenna

The infinitesimal loop antenna which is smaller size than $8/\lambda$ or $8/\lambda$ has dual relation to a infinitesimal dipole antenna, it is used for a special application such as direction searching.
Here the duality theory is a theory settling the substitutional relation formed between a radial by power resources(infinitesimal dipole) and a radial by magnetic current resources(infinitesimal loop).

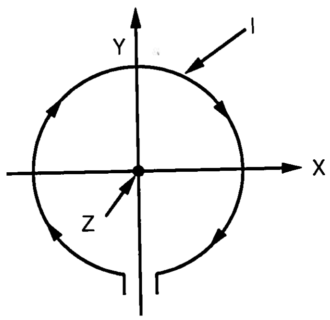


Figure 5-1 Current in Infinitesimal Loop Antenna

Since a loop length of an infinitesimal loop antenna is very shorter than wave, in all part, can regard the current as an amplitude and phase, etc as Figure 5-1. Accordingly the field to direction of Z axis becomes "0"(zero).
For all direction except Z axis, the radial pattern not to be "0" alike an infinitesimal antenna. This infinitesimal loop antenna can be substituted for an infinitesimal antenna placed in zero point along z axis without change of a radial pattern. But the input resistance of an infinitesimal loop antenna is very little value as below 1Ω. Accordingly use it as a receiving antenna but it is difficulty to use for a transmitting antenna because of the radial resistance is too little.

2. Full-Wave Loop Antenna

1. The loop antenna(full-wave loop antenna) of wave(λ) is used efficiently for has a proper gain, and input impedance is a value treating easy(about 100Ω). There are various type of a loop antenna. That is a round shape, square, rectangle and diamond. These all have a similar radial pattern and gain.
For the radial pattern of a full-wave loop antenna, it is important to suppose the current ranging along the loop line, and to understand how get the electromagnetic field generated along it is added and offset.

2.1 Current Distribution of Full-Wave Loop Antenna

Let's think the circle loop antenna of 1λ of length on X-Y plane. The power feed point can be placed anywhere. But the direction of power feed has an important effect on a radial pattern.

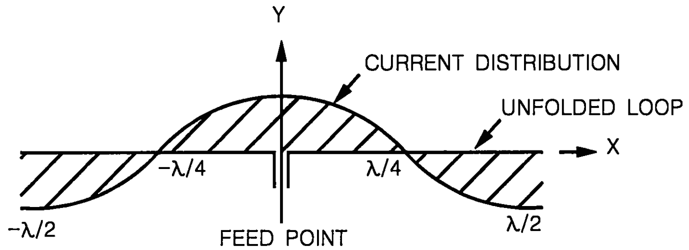


Figure 5-2 Current Distribution of Loop Antenna of Length 1λ

Let us suppose that the power feed point is on the bottom of Y axis, and the loop spread along X axis without fold by being divided as same length as Figure 5-2. In this figure, it can be seen to have a current distribution like a cosine wave has a max. value at power feed.
Figure 5-3 shows the distribution of a circle loop antenna and how get the electromagnetic field generated along this is added and offset. The electromagnetic field radiated in this case get add in direction of +Y, -Y and +Z, -Z, but get offset in direction of +X, -X.

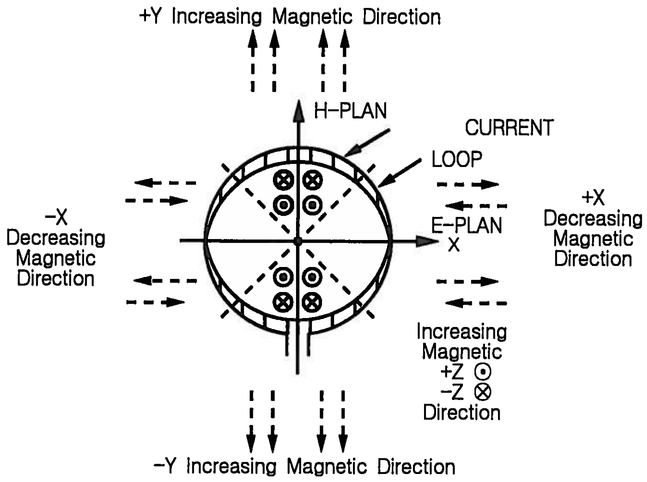


Figure 5-3 Current Distribution of Circle Loop Antenna

2.2 Radial Pattern of Full-Wave Loop Antenna

There are 3 important plane in a loop antenna. That is E-Plane, H-Plane and Loop Plane contained in antenna. To explain this plane, let us consider a square loop antenna.

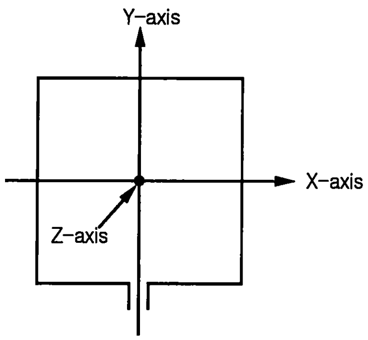
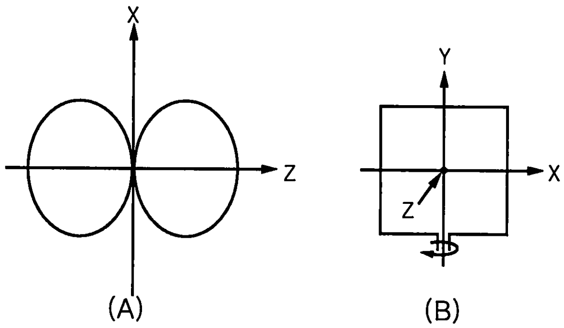


Figure 5-4 Square Loop Antenna

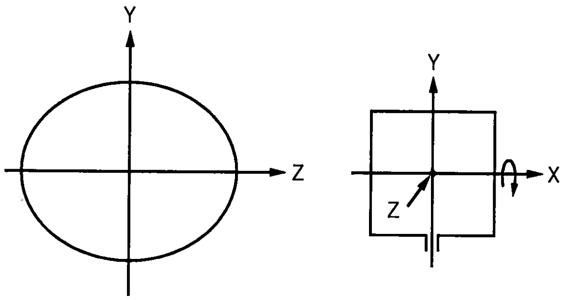
The loop antenna is placed to be parallel in front of you on X-Y Plane, and Z axis is placed toward you as Figure 5-4. Compare a loop with a central feed dipole, X-Z plane is E-plane, Y-Z plane is H-plane and Loop plane is X-Y plane.



(A) (B)

Figure 5-5 (A) E-Plane Radial Pattern (B) To Measure a E-Plane of Full-Wave Loop Antenna Radial Pattern, must Rotate

The theoretical radial pattern in E-Plane(X-Z Plane) is as Figure 5-5(A). To measure this radial pattern, the loop must be rotated toward Y axis as Figure 5-5(B).



(A) (B)

Figure 5-6 (A) H-Plane Radial Pattern (B) Rotation to measure of Full-Wave Loop Antenna H-Plane Radial Pattern

To measure a radial pattern of H-Plane(x – y plane) indicated in Figure 5-6(A), a loop must be revolved on x axis as Figure 5-6(B).

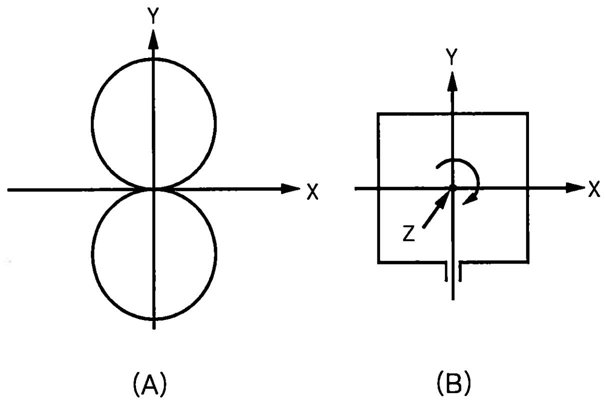


Figure 5-7 (A) Loop Plane Radial Pattern of Full-Wave Radial Pattern (B) Rotation to Measure a Loop Plane Radial Pattern

Finally, to measure a radial pattern of loop plane(x – y plane) indicated in Figure 5-7(A), the loop must rotated on z axis as Figure 5-7(B). Let us consider more exactly the theoretical radial pattern of E-Plane, H-Plane and Loop Plane expressed in each Figure 5-5(A), 5-6(A) and 5-7(A).

The radial pattern is similar the E-Plane and Loop Plane, but the amplitude of a radial.

As Figure 5-6, the electromagnetic field in center of loop is appeared very strongly as to be a composition of electromagnetic occurred by phase current. But on Y axis outside of a loop, the electromagnetic field becomes more stronger but there is a little phase difference. The electromagnetic field of a loop plane becomes smaller than E-plane electromagnetic field.

2.3 Polarization

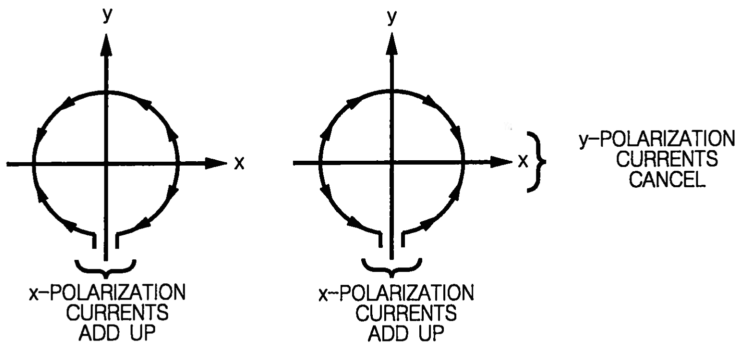
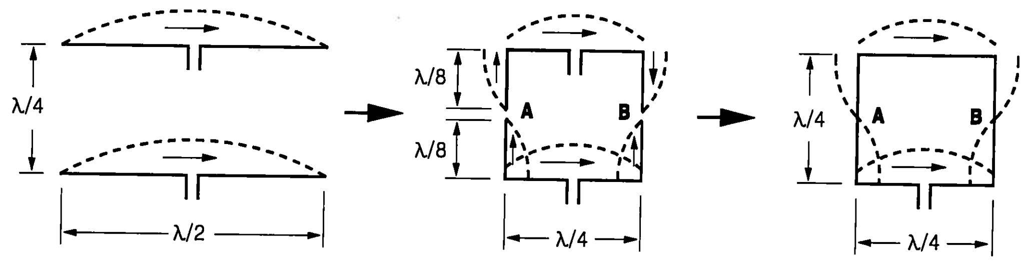


Figure 5-8 Polarization of E-Plane in x Direction

Figure 5-8(A), (B) shows the current flowing into a loop antenna in different moment each other. In figure, to the direction of x axis, to be added the current flowing into loop of both half. On the other hand, to Y axis, to be offset a current. Accordingly E wave becomes polarized toward X axis. With same principle, in case of a vertical feed which a loop has a feed point in the upper side or lower, E wave becomes polarized in parallel. In case of a even feed which a loop has feed point in left or right, E wave becomes polarized in even.

2.4 Impedance, Gain, Beam width

When a size of loop is 1λ, the input resistance of loop antenna becomes a value about 100Ω. In this input resistance, the input reactance goes down to very small value. Under this condition, the loop antenna is used very efficiently, to be get a proper beam width. In this time this loop antenna has a gain about 3.09dB. This is less than 3.82dB, gain of a full-wave dipole but larger than 2.15dB, gain of a half-wave dipole.
Resultingly, theoretically the beam width of this loop antenna is between 47°of a full-wave loop antenna and 78°of a half-wave dipole.
It can't say that the circle loop is a cube, but almost same as square. If feed the antenna at one position, since the sine wave is generated to be a current anti-node at opposite point to feed point, and to be a node at a central points, becomes max. radiation toward front and rear, vertical with earth.



(A) λ/4Spacing Step Dipole (B) λ/8 Fold and Bend of Both Side (C) 1Wave Loop

Figure 5-9 Method Thinking the 1wave Loop Antenna

Accordingly it can seems that the square loop antenna in (A) is what isolate both side of the two folded and bended λ/2 doublet as each λ/8 to get by spacing λ/4. The same, it can seems that the loop of diamond shape in (B) is what isolate the antenna of inverted V shape.

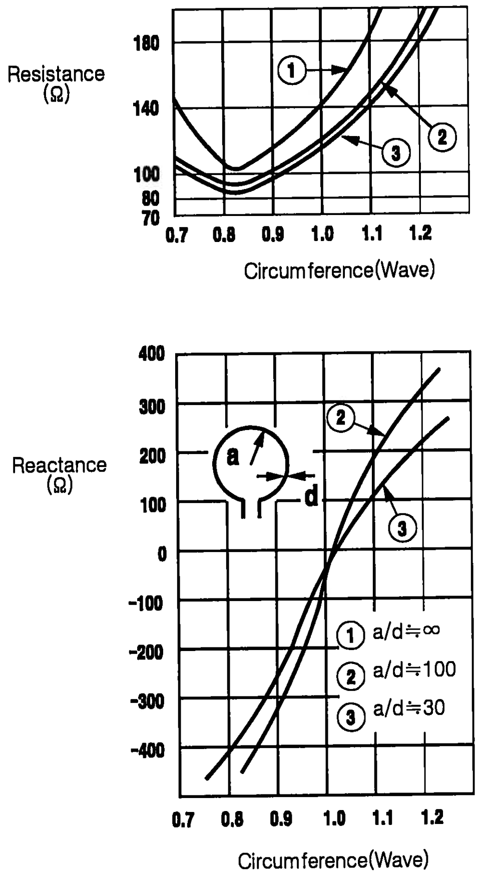


Figure 5-10 Input Impedance of 1Wave Circle Loop

The gain of a full wave loop antenna is different according to thickness of element, but a square loop is about 1dB, and a circle loop is some 1.2~2dB.

Figure 5-10 shows the change of input impedance around resonance frequency of a circle loop. When an antenna is tuned, the input impedance of a loop using a thin lead is about 140Ω. Also the tuning frequency is related to the thickness of an element like $\lambda/2$ dipole, but becomes frequency that the entire length becomes a little longer than 1wave. Also since this loop antenna has a larger range of using frequency than $\lambda/2$dipole, when use with a copper wire of some 2m as 1 element loop, the length of an element, l is $l=\lambda\times(1.02\sim1.03)$.

EXPERIMENT PROCEDURE

1. Set a main controller, transmitting·receiving antenna positioner and computer which are main instruments of antenna experiment set.

2. Set a height controller on a transmitter and fix 500MHz Yagi antenna on an antenna fixing pack, then set these on a polarization control plate. Set an antenna at vertical position for earth to get an even polarization characteristic. The transmitting antenna set as Figure 5-11 get an even polarization characteristic.
   Connect 500MHz oscillation output terminal of main controller and the cable connecting terminal of Yagi antenna with SMA cable used for 2m.

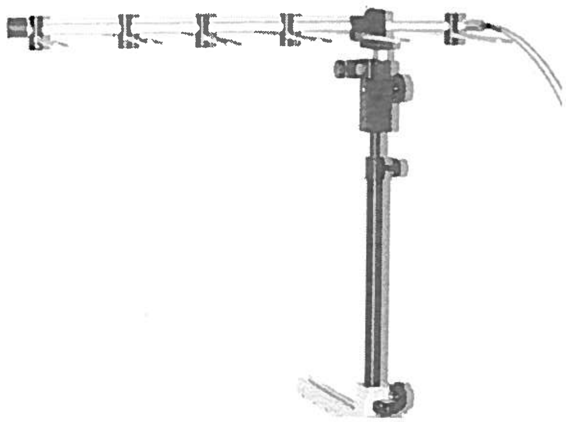


Figure 5-11 Even Polarization Transmitting Antenna

Full-Wave Circle Loop Antenna

3. Fix the full wave circle loop antenna on the polarization control plate of receiver to get an even polarization characteristic. Place an antenna to rotating center of receiver by using a position control plate of receiver. See Figure 5-12 to set.

Figure 5-12 Setting of Even Polarization Receiving Antenna

Connect a cable connecting terminal of a full wave circle loop antenna and a RF IN terminal of receiver with SMA cable used for 1m, and the OUTPUT(1kHz) terminal of receiver and a Input(1kHz) terminal of receiver in main controller with BNC cable used for 1m.

4. Calculate the length of a full wave circle loop in 500MHz with below formula, and measure an actual length of antenna and record in Table 5-1.

$$\lambda = \frac{c}{f} \quad , \quad L = 2\pi r$$

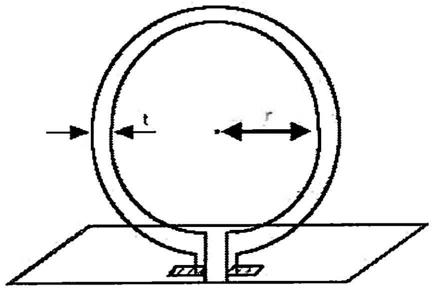


Figure 5-13 Full-Wave Circle Loop Antenna

Table 5-1 Length of Full-Wave Circle [cm]

	Theoretical Antenna Length	Actual Antenna Length
λ		
r		
t		

5. The length between antennas is isolated as r=1.5m as Figure 5-14. Make a center of each transmitting · receiving antennas to place in a straight line of same height.

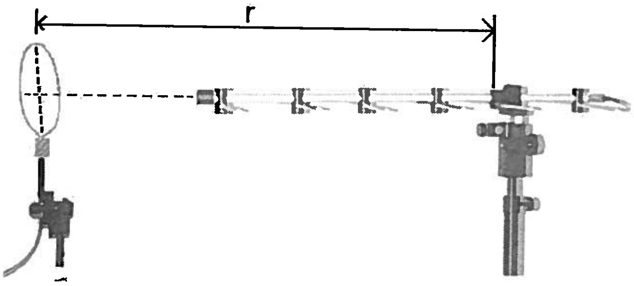


Figure 5-14 Distance between Antenna

6. Set as below in condition of power off.
   - Power OFF
   - 500MHz Oscillation Switch off
   - 2 GHz Oscillation Switch off
   - 10 GHz Oscillation Switch off
   - Modulation Switch (Mod) off

7. After set a switch in main controller as below, execute the Antenna Trainer program.
   - Power ON
   - 500MHz Oscillation Switch on
   - 2 GHz Oscillation Switch off
   - 10 GHz Oscillation Switch off
   - Modulation Switch (Mod) on

8. If the program window is executed, execute a data acquisition in Pop Up Menu. Select Antenna here and select E-Plane as Plane, then adjust to be displayed 0 in the gain displayer by adjusting a signal attenuation. If the adjustment is completed, start a data acquisition.

9. After first experiment, save the taken radial pattern by making be this to antenna 1, in data box as E-Plane. To confirm the radial pattern exactly, use a data box.
Adjust MSP(Max. Signal Position) to 0°, can see exactly the radial pattern of this antenna.

10. Make a polarization control plate to rotate 90°to get a vertical polarization characteristic. Don't change the polarizing direction of a circle loop antenna used for receiving. Experiment again and make be Antenna 2 and save this radial pattern in a data box as E-Plane.

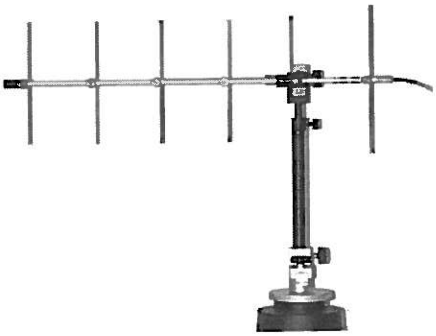


Figure 5-15 Vertical Polarization Transmitting Antenna

11. Set the full-wave circle loop antenna used for receiving to get a vertical polarization characteristic as Figure 5-16.

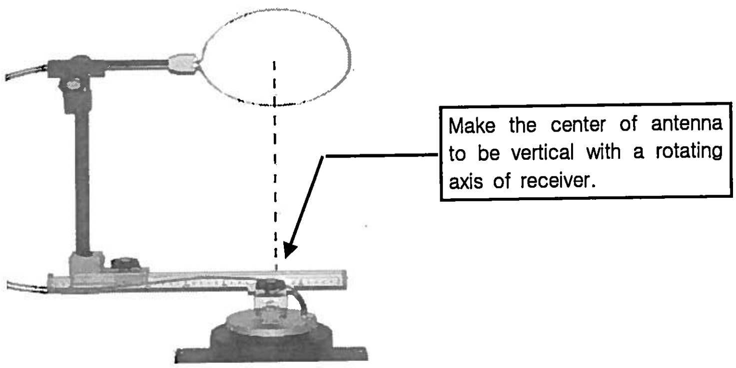


Figure 5-16 Vertical Polarization Receiving Antenna

12. After click Antenna Initialize in Edit Menu of a software, select H-Plane as Plane and click the Auto button for a data acquisition. If the data acquisition is finished, save in a data box of antenna 1.

13. Observe three radial pattern.

14. Set a transmitting·receiving antennas again to get an even polarization characteristic respectively. The distance between antennas is r=1.5m. Make the surrounding condition to same as the first environment. Take the E-Plane radial pattern of a full wave circle loop antenna and named Antenna 3 then save in a data box.

Theoretically, except an effect caused by power damage, this radial pattern must same as the first pattern. If the pattern is differ very much, have to do suitably by finding a position where the reflection can be occurred. After do suitably, continue the experiment and save new pattern in Antenna 3 data box.

Click the cursor button on Tool window of computer. Two cursors forming the angle of 0°respectively are appeared. The values arranged on right of screen will be changed. These indicate a max. value of main beam and a power size(dB) at cursor's position, and an angle and cursor's position is displayed at right bottom of window.

Select a green cursor by dragging. Whenever move this cursor around window, the value of cursor 2 is changed. This is an amplitude difference(dB) between max. value and cursor's position.

15. Use two cursors to take a half angle of a main beam power in E-Plane pattern of Antenna 1 data box.

Use below formula to calculate a half-wave beam width in E-Plane of a full-wave circle loop antenna.

$$HPBW_E = | \theta_{HPBWleft} - \theta_{HPBWright} | = \_\_\_\_\_\_\_\_$$

16. Repeat 14th experiment procedure in a radial pattern of the third data box.

$$HPBW_E = \_\_\_\_\_\_\_\_$$

17. Close an option of cursor. (The window return to the initial screen.) Compare the experimental values with a given values by antenna software. If a calculated values is not accorded to this values, experiment and calculate again.

【Ref.】 The position of a hal wave beam width take with antenna software though it stray from right -3dB point. To observe the cursor's position selected by software, open the cursor option then select a pattern you want. Select the Options, Set Cursors at -3dB item. The cursor will be placed automatically. Use this item to take fast the approximate value of a half power beam width in the next experiment. If you necessary, can adjust the to be high accuracy.

18. Save the data of antenna 1, 3 and output the result. Must shows a radial pattern of two data box.

Full-Wave Square Loop Antenna

19. Fix a full-wave square loop antenna on a polarization control plate of receiver to be got an even polarization characteristic. Use a position control plate of receiver to place the antenna in rotating center of receiver. See Figure 5-17 to set.

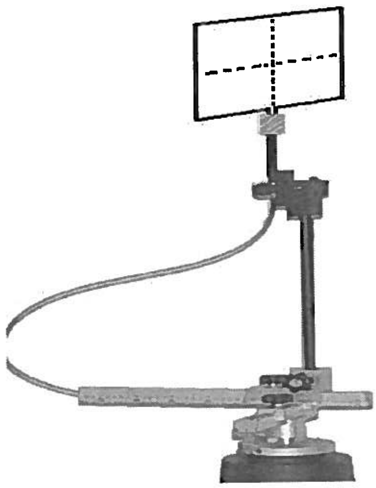


Figure 5-17 Even Polarization Transmitting Antenna

Connect the cable connecting terminal of a full-wave square loop antenna to a RF IN terminal of receiver with SMA cable used for 1m, and connect a OUT PUT(1kHz) terminal of receiver to Input(1kHz) terminal of a main controller with BNC cable used for 1m.

20. Use below formula to calculate the length of a full-wave square loop and to measure the length of an actual antenna in 500MHz, then record in Table 5-2.

$$\lambda = \frac{c}{f} \quad , \quad L = 2\pi r$$

Table 5-2 Length of Full-Wave Square Loop Antenna [cm]

	Theoretical Antenna Length	Actual Antenna Length
λ		
r		
t		

21. The distance between antennas is isolated as r=1.5m as Figure 5-18. Set center of each transmitting·receiving antenna in a straight line of same height.

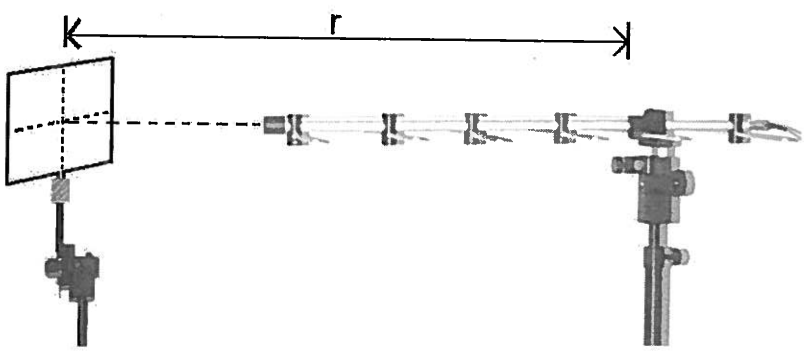


Figure 5-18 Distance between Antenna

22. Set as below in condition of main controller power off.

- Power OFF
- 500MHz Oscillation Switch off
- 2 GHz Oscillation Switch off
- 10 GHz Oscillation Switch off
- Modulation Switch (Mod) off

23. After set a switch in main controller as below, execute the Antenna Trainer program.
  - Power ON
  - 500MHz Oscillation Switch on
  - 2 GHz Oscillation Switch off
  - 10 GHz Oscillation Switch off
  - Modulation Switch (Mod) on

24. If the program window is executed, execute a data acquisition in Pop Up menu. Select Antenna here and select E-Plane as Plane, then control to be displayed 0 in an antenna gain displayer by adjusting a signal attenuation. If the adjustment is completed, start the data acquisition.

25. After the first experiment, named the taken radial pattern to Antenna 1, and save in data box as E-Plane. To confirm a radial pattern exactly, use a data box.
If adjust MSP(Max. Signal Position) to 0°, can see the radial pattern of this antenna.

26. Make a Yagi antenna used for receiving to rotate 90°the polarization control plate to be got a vertical polarization characteristic. Don't change the polarizing direction of a square loop antenna used for receiving. Experiment again, and named Antenna 2 then save this radial pattern as E-Plane.

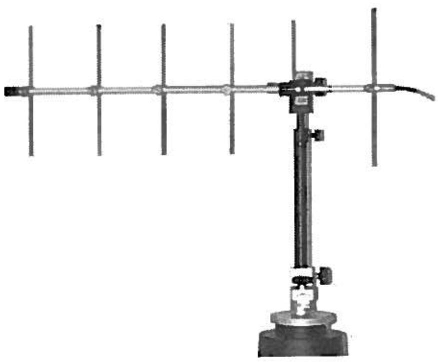


Figure 5-19 Vertical Polarization Transmitting Antenna

27. Set a full-wave square loop antenna used for receiving to be got a vertical polarization characteristic as Figure 5-20.

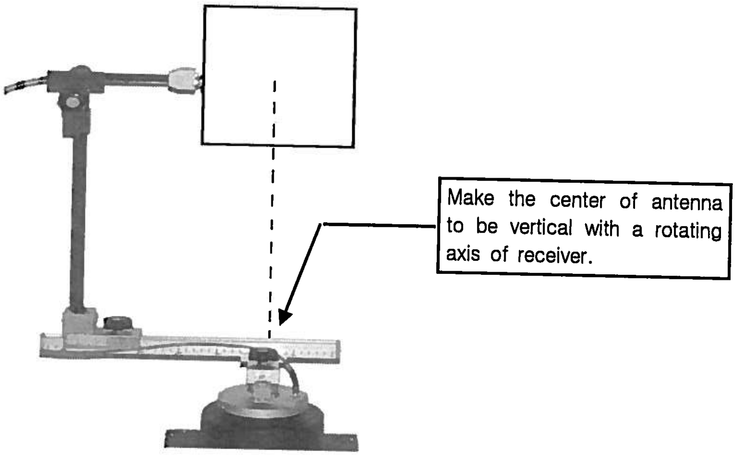


Figure 5-20 Vertical Polarization Receiving Antenna

28. After click Antenna Initialize in Edit Menu of a software, select H-Plane as Plane, then click the Auto button for a data acquisition. The data acquisition is finished, save the pattern in Antenna 1 as file.

27. Observe three radial pattern.

29. Set again the transmitting·receiving antennas to be got an even polarization characteristic. The distance between antennas is r=1.5m. Make the surrounding condition of antenna to same as the first experiment. Take the E-Plane radial pattern of a full-wave circle loop antenna, save in the data box.

    Theoretically, if except an effect caused by power damage, this radial pattern must same as the first pattern. If the pattern is difference very much, have to do suitably by finding a position where the reflection can be occurred. After do suitably, continue an experiment and save new pattern in Antenna 3 data box.

    Click the cursor button on tool window of a computer. Two cursors making angle of 0°each other are appeared. The values arranged at right side of screen will be changed. These indicate the max. value of a main beam and the power size of cursor position(dB), and the angle and cursor position is displayed in the right bottom of the window.

    Select a green cursor by dragging. Whenever move this cursor around window, the value of cursor 2 is changed. This is a difference of amplitude(dB) between max. value of a pattern and a cursor position.

30. Use two cursors to take a half angle of main beam power size in E-Plane of a data box.

Calculate a half-power beam width in E-Plane of a full-wave square loop antenna with below formula.

$$HPBW_E = | \theta_{HPBWleft} - \theta_{HPBWright} | = \_\_\_\_\_\_\_\_$$

31. Repeat 29th experiment procedure in a radial pattern of the third data box.

$$HPBW_E = \_\_\_\_\_\_\_\_$$

31. Close an option of cursor.(Window return to the initial screen.) Compare the experimental values with give values of an antenna software. If the calculated result is not accorded to these values, experiment and calculate again.

【Ref.】 The position of a hal wave beam width take with antenna software though it stray from right –3dB point. To observe the cursor's position selected by software, open the cursor option then select a pattern you want. Select the Options, Set Cursors at –3dB item. The cursor will be placed automatically. Use this item to take fast the approximate value of a half power beam width in the next experiment. If you necessary, can adjust the to be high accuracy.

32. Save the data and output the result. In output, have to present the radial pattern of two data box.

Full–Wave Diamond Loop Antenna

33. Fix a full–wave diamond loop antenna to be got an even polarization characteristic on a polarization control plate of receiver. Use the position control plate of receiver to place an antenna in rotating center of receiver. See Figure 5–21 to set.

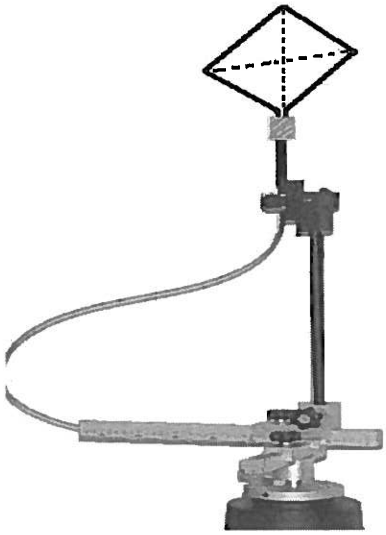


Figure 5-21 Even Polarization Receiving Antenna

Connect the cable connecting terminal of a full-wave diamond loop antenna and RF IN terminal of receiver with SMA cable used for 1m, and the OUT PUT(1kHz) terminal of receiver and the Input(1kHz) terminal in receiver of a main controller with BNC cable used for 1m.

34. Use below formula to calculate a length of a full-wave diamond loop and measure actual length of an antenna in 500MHz, then record in Table 5-3.

$$\lambda = \frac{c}{f} \quad , \quad L = 2\pi r$$

Table 5-3 Length of Full-Wave Diamond Loop Antenna [cm]

	Theoretical Antenna Length	Actual Antenna Length
λ		
r		
t		

35. The distance between antennas is isolated as r=1.5m as Figure 5-22. Make the center of a transmitting · receiving antennas to be in straight line of same

height each other.

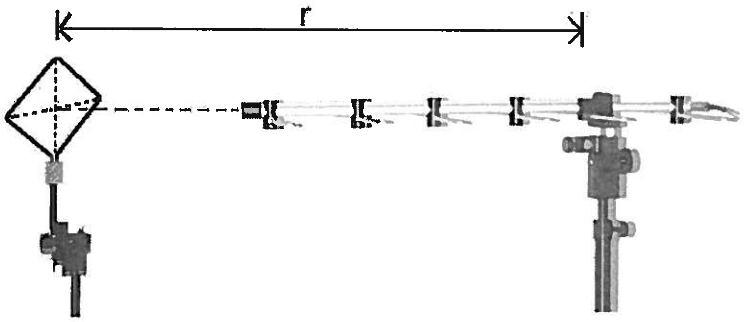


Figure 5-22 Distance between Antenna

36. Set as below in condition of main controller power off.
    - Power OFF
    - 500MHz Oscillation Switch off
    - 2 GHz Oscillation Switch off
    - 10 GHz Oscillation Switch off
    - Modulation Switch (Mod) off

37. After set the switch in main controller as below, execute the Antenna Trainer program.
    - Power ON
    - 500MHz Oscillation Switch on
    - 2 GHz Oscillation Switch off
    - 10 GHz Oscillation Switch off
    - Modulation Switch (Mod) on

38. If a program window is executed, execute the data acquisition in Pop Up Menu. After select Antenna here, select E-Plane as Plane, then control to be displayed 0 in antenna gain displayer by adjusting a signal attenuation. The adjustment is completed, start a data acquisition.

39. After the first experiment, named the taken radial pattern to Antenna 1, and save it in a data box as E-Plane. To confirm a radial pattern exactly, use a

data box. Set MSP(Max. Signal Position) to 0°, can see a radial pattern of this antenna exactly.

40. Make a polarization control plate to rotate 90°for the Yagi antenna used for transmitting get a vertical polarization characteristic. Don't change a polarization direction of a full-wave diamond loop antenna used for receiving. Experiment again, named to Antenna 2 and save this radial pattern in E-Plane.

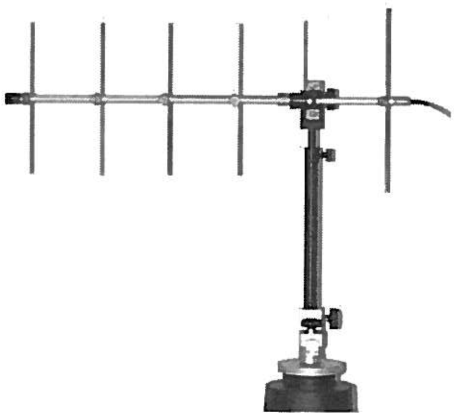


Figure 5-23 Vertical Polarization Transmitting Antenna

41. Set a full-wave diamond loop antenna used for receiving to be got a vertical polarization characteristic as Figure 5-24.

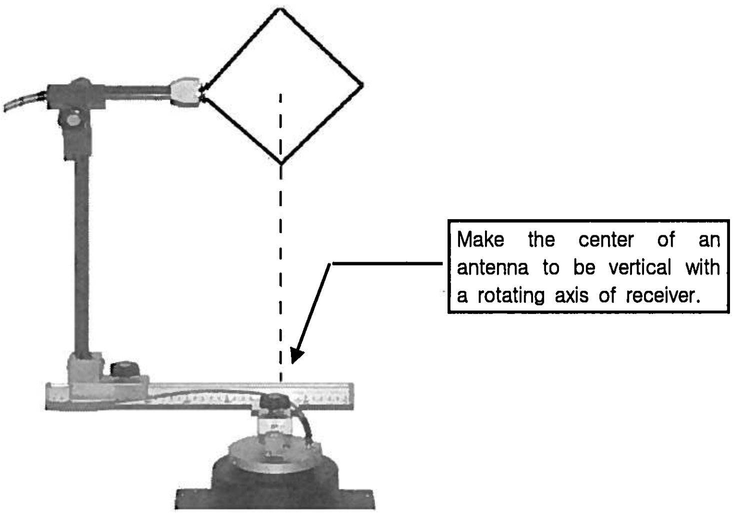


Figure 5-24 Vertical Polarization Receiving Antenna

42. After click Antenna Initialize in Edit Menu of a software, select H-Plane as Plane then click the Auto button for data acquisition. If a data acquisition is finished, save the pattern in Antenna 1 as file.

43. Observe three radial pattern.

44. Set again the transmitting·receiving antenna to be got an even polarization characteristic. The distance between antennas is r=1.5m. Make a surrounding condition of antenna to same as the first experiment. Take the E-Plane radial pattern of a full-wave diamond loop antenna, and save in data box.
Theoretically, except an effect caused by power damage, this radial pattern must same as the first pattern. If the pattern differ very much, have to do suitably by finding a position where the reflection can be occurred. After do suitably, continue the experiment and named the new pattern to Antenna 3 then save in data box.

Click the cursor button on tool window on computer. Tow cursors making the angle of 0°are appeared. The values arranged on right side of a screen will be changed. These indicate the max. value of a main beam and a power size(dB) at cursor position, and the angle and cursor position is displayed in the bottom of window.

Select the green cursor by dragging. Whenever move this cursor, the value of cursor 2 is changed. This is a difference of amplitude between max. value of the pattern and cursor position.

45. Use tow cursors to take an half angle of main beam power size in E-Plane pattern of a data box.

Calculate a half-wave beam width in E-Plane of a full-wave diamond loop antenna with below formula.

$$HPBW_E = | \theta_{HPBWleft} - \theta_{HPBWright} | = \_\_\_\_\_\_\_\_$$

46. Repeat No. 44 of experiment procedure in radial pattern of the third data box.

$$HPBW_E = \_\_\_\_\_\_\_\_$$

47. Close an option of cursor. (Window return to the initial screen.) Compare the experimental values with the given values. If the calculated result is not accorded to these values, experiment and calculate again.

【참고】 The position of a hal wave beam width take with antenna software though it stray from right −3dB point. To observe the cursor's position selected by software, open the cursor option then select a pattern you want. Select the Options, Set Cursors at −3dB item. The cursor will be placed automatically. Use this item to take fast the approximate value of a half power beam width in the next experiment. If you necessary, can adjust the to be high accuracy.

48. Save the data and output the result. In output, must shows the radial pattern of two data box.

▣ EXERCISE ▣

1. Express the current distribution raging along lead of a full-wave loop antenna by drawing.

____

____

2. Make clear that the infinitesimal loop antenna and the infinitesimal loop antenna is duality.

____

____

3. Try to draw the radial pattern the circle, square and diamond full-wave loop antenna respectively and explain the difference.

____

____

4. Explain what is the polarization characteristic with a circle, square and diamond full-wave loop antenna respectively.

____

____

EXPERIMENT 3-6. YAGI ANTENNA

Let's measure a radial pattern in E-Plane and H-Plane for Yagi antenna. We will study the polarization characteristic of Yagi antenna. Let's calculate a half-power beam width of Yagi antenna.

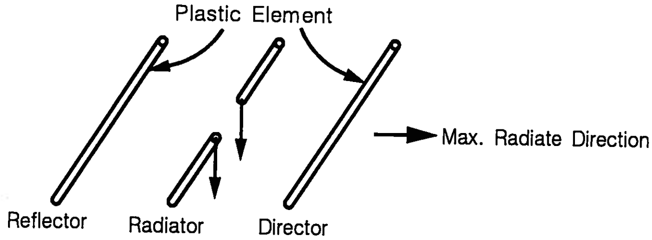
BASIC STUDY

1. YAGI ANTENNA

As the Yagi antenna is an antenna invented by Dr. Yagi and Uda, it is most representative antenna for endfire array.
It is in 1930 that this Yagi antenna is used for a wireless telephone of VHF mark. Since generally the Yagi antenna has a simple structure and high quality function as a beam antenna, it is used in place of VHF, UHF mainly.

1.1 Operation of Parasitic Element

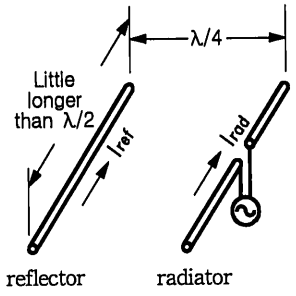
Figure 6-1 shows a 3 element Yagi antenna to be got a good characteristic and having a simple structure. There are a central element connected with a transmitter(or receiver) by feeder, that is radiator, and a reflecter and director leaving a space of $\lambda/4$ at the front and rear, and these are the parasitic element which is not connected with transmitter.



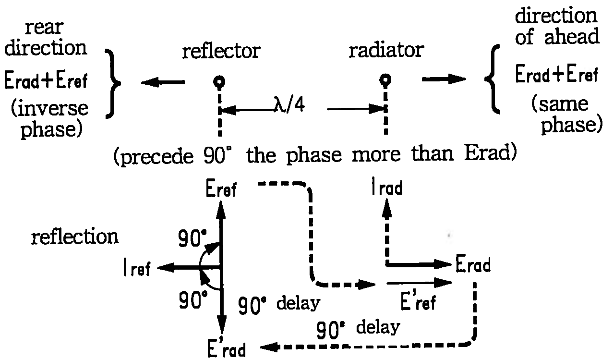
(Reflector and Director are a Parasitic Elements)

Figure 6-1 3 Element Yagi Antenna

Let's know why does these parasitic element is operated as a reflector or director. Let's give an example with operation of a reflector.
It is suppose that place little longer reflector than λ/2 space out λ/4 at left side of a radiator as Figure 6-2(A).



(A) 2 Element Yagi Antenna attached Reflector



(B) Flow Chart about Operation of a Parasitic Reflector(See main text)

Figure 6-2 Operation of Parasitic Element(In case of Reflector)

In this case, what the phase is delayed 90°till an electron wave radiated from radiator reach to the reflector and the phase of current(Iref) flowing into reflector(To be inductive reactance because of a length is little longer than λ/2) is to be more delayed 90° than the radial field in a radiator. And the electron wave reradiated from reflector is to be delayed again 90°phase since the current flowing through a reflector delay 90°. Though this is a very particular, but to be as Figure(B) by indicating in vectorial. That is, the phase of an electron wave radiated from reflector(Field Eref)(Status not radiated from reflector yet) becomes finally more delayed 270°than the electron wave(Field Erad) radiated from radiator, this means that Eref precede 90°the phase more than Erad.
During Eref process to ahead that is, toward a radiator and reach the point of radiator, also a phase is delayed 90°. Therefore E'ref is added by becoming a same phase with Erad so can see that the electron wave in direction of ahead becomes strong.
Oppositely for the rear direction, since E'rad reached from a radiator becomes more delayed 90°than Eref as the first explanation, it becomes inverse phase with Eref and is attenuated. So when the size of E'rad and Eref is same, the radiation at rear direction becomes 0.
Think like this, in the case of a little shorter director than λ/2, the operation is explained in the same way if consider that the phase of Idir is more precede 90° than E'rad. Actually the spacing between the radiator and the parasitic element is not always limited as λ/4. Because of the mutual impedance

between elements and they give an effect each other, it is not simple as above explanation.
According to the length, thickness and spacing between elements, the characteristic of an actual antenna is changed complexively.

1.2 Multi-Element Yagi Antenna

As the original Yagi antenna is an replaced antenna of VHF, UHF, it is useful to arrange many parasitic elements in the directivity and gain of an Yagi antenna since the physical size is not large so much.
Only, as above explanation, if arrange over 4 element, the characteristic of an antenna becomes complex as impossible as the exact indication with computer. Therefore show the design of the multi-element Yagi antenna taken experimentally here.
Also it is the shape of an antenna which place one reflector at rear of a radiator and place the entire element at front of a radiator as a director.

(1) Relation between Element Number and Gain

Figure 6-3 shows the relation between the element number and gain, and according to the gain wanted, the element number is decided. Figure 6-4 shows the relation between the length at axis direction of element arrangement(Whole Length of Array) and gain. If becomes over 6 element, the increasing of gain is decided by length at axis direction of array than element number. To increase the gain to 2times(Increase 3dB), can not help increasing about 2times the length at axis direction of array.

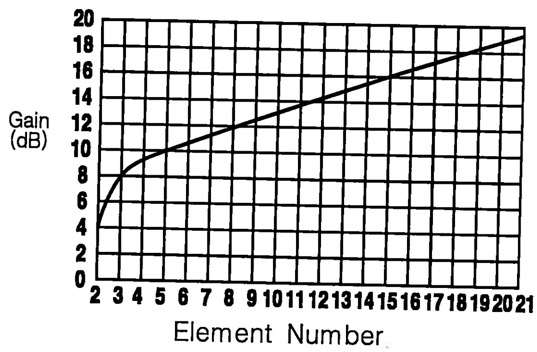


Figure 6-3 Relation between Element Number and Gain.

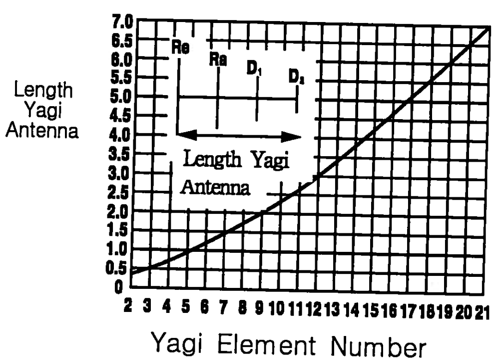


Figure 6-4 Relation between Length of Antenna and Element Number

(2) Element Spacing

Figure 6-1 shows each element spacing in the case of 2~8 element and over 9 element. When make each element to the most proper length, the change of gain is within 1dB.

Element Number	R_e–R_a	R_a–D_1	D_1–D_2	D_2–D_3	D_3–D_4	D_4–D_5	D_5–D_6
2	0.15λ–0.2λ						
2		0.071–0.11λ					
3	0.16 – 0.23	0.16–0.19					
4	0.18 – 0.22	0.13–0.17	0.14λ–0.18λ				
5	0.18 – 0.22	0.14–0.17		0.17λ–0.32λ			
6	0.16 – 0.20	0.14–0.17	0.16–0.25	0.22–0.30	0.25λ–0.32λ		
8	0.16 – 0.20	0.14–0.16	0.18–0.25	0.25–0.35	0.27–0.32	0.27λ–0.32λ	0.30λ–0.40λ
over 9	0.16 – 0.20	0.14–0.16	0.18–0.25	0.25–0.35	0.27–0.32	0.27–0.38	0.35–0.42

(3) Length of Director

When make No.1, NO.2,....... in order from the most near element from a radiator, if the diameter of element in Figure 6-5, can take the most suitable length of each director.

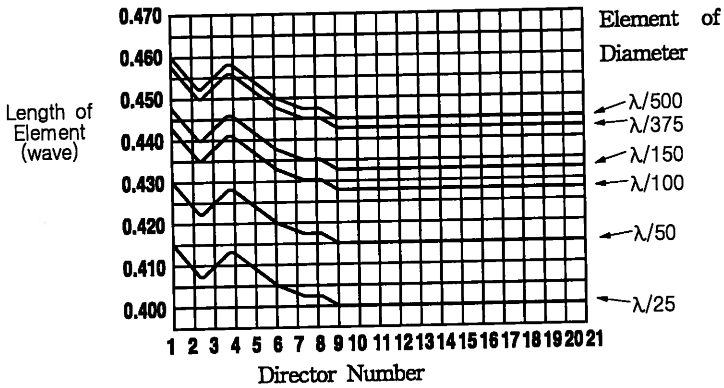


Figure 6-5 Method taking each Director

The length of a radiator has not relation almost to the characteristic of an antenna, and the length of reflector is not important so much in over 4 element. Therefore set to the said length in 3 element then have only to adjust later on.

Yagi antenna or Yagi-Uda antenna is named for Prof. H.Yagi and Lab. S.Uda experimenting the parasitic array in Japan, 1920.
This antenna is designed by the idea that since each antenna has own current distribution, if superpose each antenna, the multi antenna can be constructed. The radial pattern of this multi antenna is a result from the addition and difference of an electron wave radiated from currents distributed to each antenna.
In a folded dipole antenna, the radial pattern for the special direction is increased by being added each other the current distribution of 2 lead near by each other. Also between the current distribution of a loop antenna, that is between the currents distributed at each point of a loop antenna at a distance of same distance, making the proper radial pattern by being added and subtracted each other. The pencil beam-radiation pattern is generated in Helical antenna by an effect that the wave progressing form one loop of open wire to another loop is added each other.
These are the examples for the driving antenna array effect, that is the effect arraying the numerous antenna elements connected with feed circuit by any type. Like this, it is called the antenna constructed with various antenna element to the antenna array.
This array effect can be got by using the parasitic antenna element. This parasitic antenna element is a conductor or lead which are not connected with feed circuit. In this case, the array effect caused by the current induced to the parasitic antenna element by an electron wave. This parasitic antenna elements becomes excited by Near-field coupling radiated from a driving antenna element(Launcher).

2. Basic Principle of Yagi Antenna

Figure 6-6 shows the Yagi antenna having a 6 antenna element.

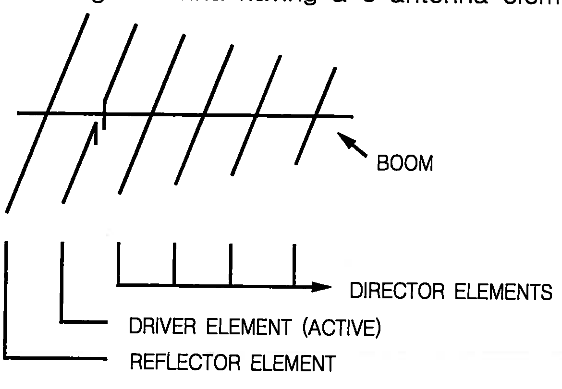


Figure 6-6 6 Antenna Element Yagi Antenna

The Yagi antenna consists of a constituent as follows.

- Driving Antenna or Radiator connected with a feed circuit.
  As this is an antenna element fed directly from a transmitter, can use an antenna element of different type such as a half-wave dipole or folded dipole antenna.

- Reflector placed on one side of a driving antenna element.
  Make a radial power to reflect again toward a driving antenna. Theoretically can place several reflector with same spacing and length. But actually one reflector is accepted generally because of the merits of the reflector over one is not much.

- Director placed on one different side of a driving antenna element.
  It is means that the parasitic antenna elements over one operating connection of a radial power. Actually the several directors are used for the Yagi antenna, and it is shorter as distance from a radiator, make it to isolate with little shorter spacing.

The reflector is longer as 5% than a driving antenna element, and the first inductor is shorter as 5%. The optimum spacing for the Yagi antenna get a max. directivity is when the driving antenna element, reflector and the first inductor is within $0.15\lambda \sim 0.25\lambda$ respectively. When use several inductors, the remained inductors is little short, and it is isolated with little distance spacing. The spacing of a driving antenna element, reflector and the first inductors have an effect on an impedance matching. But the spacing between antenna elements has not an effect so much on the change. The effect of a driving antenna element for a parasitic antenna element nearby is what can induce the current that the phase becomes inverse with the size of an incident wave being same almost for the parasitic antenna elements.
It has a merits that the antenna gain is increased if have the inductor over one. But as increase the number of a inductor, the merits is disappeared little by little. Because of the parasitic inductor far away from the driving antenna element and the induced current organized to a parasitic inductor becomes decreased. So the degree contributing to the antenna gain is to be weak little by little.
This relation is given in Figure 6-7 and Table 6-1.

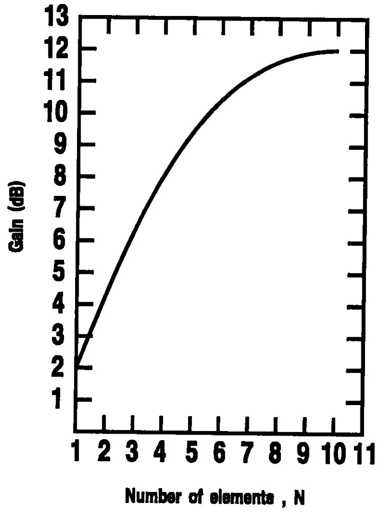


Figure 6-7 Relation between
the Number of all element of Yagi Antenna and Gain

Elements	Gain
3	8.7
4	9.9
5	10.5
6	11.1

Table 6-1 Gain of Yagi Antenna according to
the Number of Array Element (Spacing=1.5λ)

The input impedance of Yagi antenna is a function of input impedance of a radiator but it is affected very much from a parasitic elements. It is easy to take that the theoretical input impedance for a 3 element dipole array is about 25Ω. The change of a input impedance according to the antenna structure is large comparatively, and the values from 20Ω to 100Ω are often used.
Like know as above discuss, Yagi antenna is one type on antenna structure not special antenna model. Actually there are various transformation of Yagi antenna.
Since the easy method to analysis the Yagi antenna, the analysis and optimize for this antenna do always with computer calculation and simulation. Fortunately many experimental and numerical studies have been doing, the results are recorded in the thesis, text book and technical book etc.

EXPERIMENT PROCEDURE

Setting of Experiment Instrument

1. Set the main controller, transmitting·receiving antenna positioner and computer which are main instruments of the antenna experiment set.

2. Set a height control bar on a transmitter and fix 500MHz Yagi antenna on the antenna fixing pack then set this on the polarization control plate. In this time, set this to be even with earth for an antenna get an even polarization characteristic. The transmitting antenna set as Figure 6-3 get an even polarization characteristic.
Connect the 500MHz oscillation output terminal of main controller and the cable connecting terminal of Yagi antenna with SMA cable used for 2m.

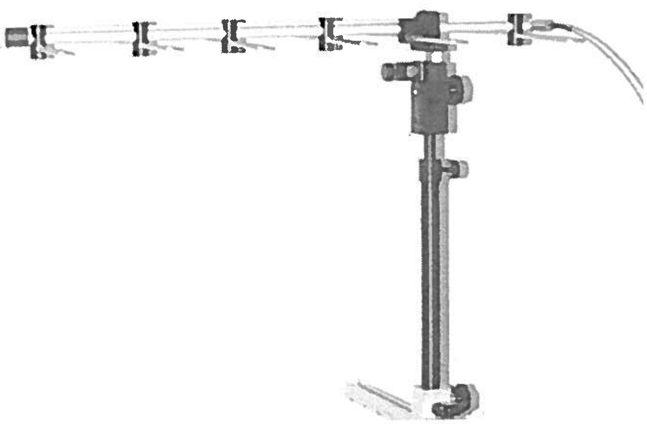


Figure 6-8 Even Polarization Transmitting Antenna

3. Fix the 500MHz Yagi antenna to get an even polarization characteristic on the polarization control plate of a receiver. Use the position control plate of a receiver to place an antenna in rotating center of a receiver. See Figure 6-4 to set.

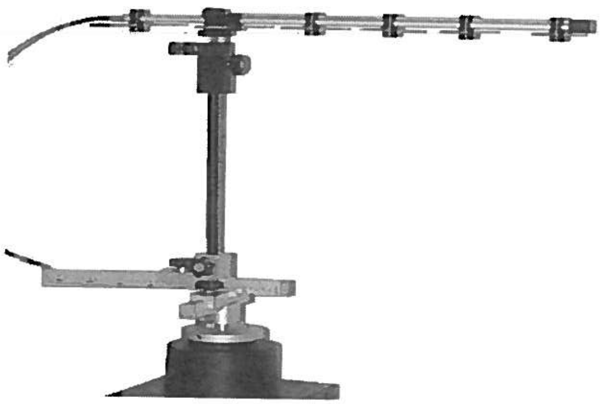


Figure 6-9 Setting of Even Polarization Receiving Antenna

Connect the Yagi antenna and RF In terminal of a receiver with SMA cable used for 1m, and connect OUT PUT(1kHz) terminal of a receiver and Input(1kHz) in receiver of main controller with BNC Cable used for 1m.

4. Use below formula, calculate the length of Yagi antenna and measure the actual length of antenna in 500MHz then record in Table 6-2.
The exact oscillation frequency of RF signal generator is 500MHz.

$$\lambda = \frac{c}{f}$$

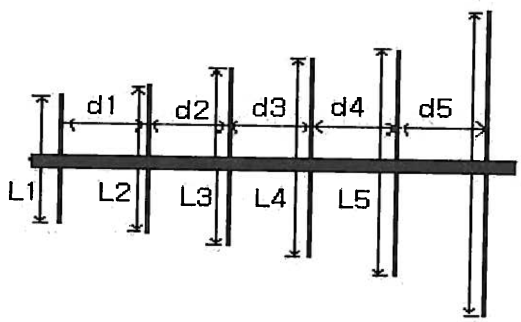


Figure 6-10 Yagi Antenna

Table 6-2 Length of Yagi Antenna [cm]

	λ	λ/2	L1	L2	L3	L4	L5	L6	d1	d2	d3	d4	d5	d6
Theoretical Antenna Length														
Actual Antenna Length														

5. As Figure 6-11, the distance between antennas is isolated as r=1.5m. Make a center of each transmitting·receiving antennas to place in a straight line each other.

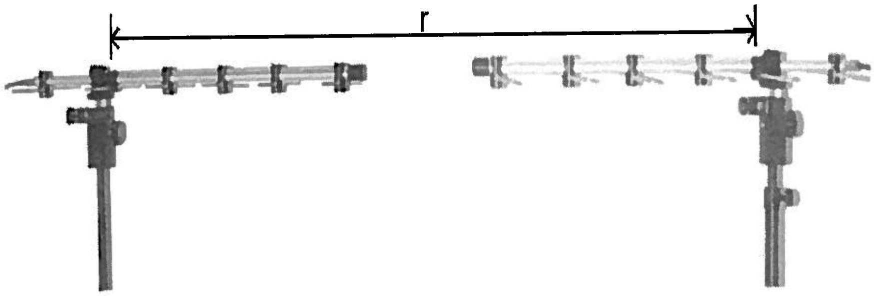


Figure 6-11 Distance between Antennas r

6. Set as below in condition of turning off the power of main controller.
   - Power OFF
   - 500MHz Oscillation Switch off
   - 2 GHz Oscillation Switch off
   - 10 GHz Oscillation Switch off
   - Modulation Switch (Mod) off

7. After set a switch in main controller as below, execute the Antenna Trainer program.
   - Power ON
   - 500MHz Oscillation Switch on
   - 2 GHz Oscillation Switch off
   - 10 GHz Oscillation Switch off
   - Modulation Switch (Mod) on

8. The program window is executed, execute Data Acquisition in Pop Up menu. Here after select Antenna, select E-Plane as Plane and control to be displayed 0 in gain displayer by adjusting the signal attenuation. The adjustment is completed, start Acquisition.

9. If the data acquisition is completed, save the taken radial pattern in file. Use the data box to confirm a radial pattern exactly. If set MSP(Max. Signal Position) to 0°, can see the radial pattern of this antenna.

10. Make the control plate to rotate 90°for the 500MHz Yagi antenna used for transmitting get a vertical polarization characteristic by loosing the screw on the polarization control plate.

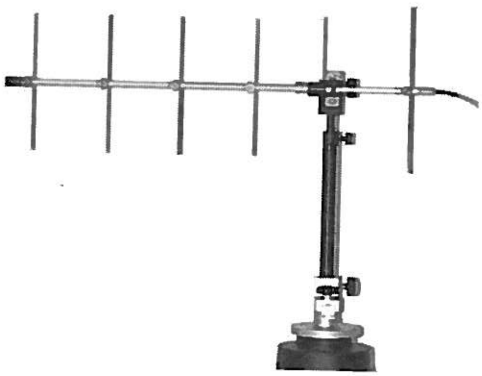


Figure 6-12 Setting of Vertical Polarization Transmitting Antenna

11. Set as Figure 6-13 for Yagi antenna used for receiving get a vertical polarization characteristic.

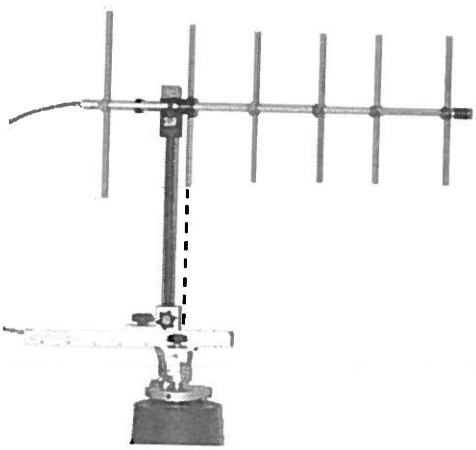


Figure 6-13 Setting of Vertical Polarization Receiving Antenna

12. Click Antenna Initialize in Edit Menu of a software, click the Auto button to data acquisition. If the data acquisition is finished, after select H-Plane as Plane, save the pattern in file.

13. Keep the 500MHz Yagi antenna used for transmitting to get a vertical polarization characteristic and set as Figure 6-9 for the Yagi antenna used for receiving get a vertical polarization characteristic.

14. Click Antenna Initialize in Edit Menu of a software, and click again Delete Screen then click the Auto button to data acquisition.

15. Observe three radial pattern.

16. Set a transmitting·receiving antennas get a vertical polarization characteristic respectively. The distance between antennas is r=1.5m. Make a surrounding condition of antenna to be same as the first experiment. Take the E-Plane radial pattern of an Yagi antenna and save in Dummy-Plane.

    Theoretically if except an effect caused by a power damage, this radial pattern has to be same as the first pattern. If the pattern is different very much, have to do suitably by finding the position where a reflection can be occurred. After do suitably, continue an experiment and save new pattern in E-Plane.

    Click Data Indicating Line in View Menu of upper menu of a data analysis program. Two cursors(Blue, White) used for E-Plane and tow cursors(Yellow, Green) used for H-Plane are appeared on the screen. If click an arrow on both side of a displayer of each color, the values in the displayer will be changed by moving the cursor of same color. These indicate the angle of cursor position and the receiving power in that time as dB, show the difference of angle between cursors and power in below 2 displayer.
    Record the values in below Table 6-3.

Table 6-3 Receiving Power for Angle

Angle	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Receiving Power of E-Plane for Angle												
Receiving Power of H-Plane for Angle												

17. Use the cursor to take the receiving angle of max. power in E-Plane pattern and the receiving power in that time. Click the Maximum Single Level button on the E-Plane data window to confirm if a measured value is accorded to a taken value with cursor. Record this in Table 6-3.

Table 6-4 Comparison of E-Plane with Theoretic Value

Taken Value with Cursor	Receiving Power	
	Angle	
Value by Maximum Single Level Icon	Receiving Power	
	Angle	

18. Take a half angle of main beam power in E-Plane pattern by using a cursor. Click the Half Power Beamwidth button on data window to confirm if same the measured value with button as taken value with cursor.

Calculate a half-power beam width of Yagi antenna in E-Plane with below formula.

$$HPBW_E = | \ \theta_{HPBWleft} - \theta_{HPBWright} \ | = \_\_\_\_\_\_\_\_$$

19. Repeat No. 18 of the experiment procedure in H-Plane radial pattern.

$$HPBW_h = \_\_\_\_\_\_\_\_$$

20. Delete all cursors by clicking the data indicating line in view menu. Compare

the experimental values with given value in the antenna software. If the calculated result is not accorded to this values, experiment and calculate again.

21. Save the E-Plane and H-Plane data and output the result.

22. After remove L1, L2, L3 in Figure 6-10 and make 3 element antenna, complete below table by repeating item 1 ~ 21.

Table 6-5 Characteristic of 3 Element Yagi Antenna

Maximum Single Level	Receiving Power	
	Angle	
Half-Power Beam Width		

23. After couple L3 in Figure 6-10 and make 4 element Yagi antenna, complete below table by repeating item 1 ~ 21.

Table 6-6 Characteristic of 4 Element Yagi Antenna

Maximum Single Level	Receiving Power	
	Angle	
Half-Power Beam Width		

24. After couple L2 in Figure 6-10 and make 5 element Yagi antenna, complete below table by repeating item 1 ~ 21.

Table 6-7 Characteristic of 5 Element Yagi Antenna

Maximum Single Level	Receiving Power	
	Angle	
Half-Power Beam Width		

25. Complete below table by synthesizing the experiment up to now.

Table 6-8 Characteristic of Yagi Antenna according to the number of Element

Number of Element	3	4	5	6
Maximum Single Level				
Half-Power Beam Width				

▣ EXERCISE ▣

1. Figure the driving principle of Yagi antenna by electron field.

2. Make clear the manufacturing way and electric characteristic of a radiators, reflectors and inductors.

3. Explain the relation between the number of element and gain of Yagi antenna.

4. Explain about the radial pattern of Yagi antenna.

5. What's the polarization characteristic of Yagi antenna.

EXPERIMENT 3-7. SPIRAL ANTENNA

Let's measure a radial pattern for E-Plane and H-Plane of a spiral antenna in this experiment. We will study about a polarization characteristic of a spiral antenna. Let's calculate a half-power beam width of a spiral antenna by using antenna software.

BASIC STUDY

1. Spiral Antenna

The spiral antenna having wide band is introduced by V.H Rumsey in 1957, later J.D Dyson gives proof experimentally that the plane equiangular spiral and conical spiral antenna etc. have an independent characteristic of frequency in 1959.

Generally if the frequency of antenna is changed, the physical size of antenna is changed. Accordingly if the physical size of antenna is decided, the ranged of using frequency can not help limiting. But as a spiral antenna is what make an antenna arm to rotate exponential functionally, it can be used in wide band because can replace the change of physical size to the change of rotating angle. And the characteristic impedance and radial pattern has a frequency independence not changed in wide frequency band, and it has the characteristic of small size, lightweight and non-directivity. So it is used widely for the air communications, radar system and receiving antenna of civilian satellite etc.

1.1 Geometrical Structure of Spiral Antenna

As the spiral antenna of all frequency independent antenna, there are Conical Spiral, Log Periodic Antenna and Equiangular Spiral Antenna etc.

The equiangular spiral antenna has a characteristic that the distance from a starting point to optional point is increased exponential functionally for spin angle, and also has a structure that the arm rotate as 180°and expand. For this antenna, the radiation is occurred strongly if the traveling wave in arm becomes same phase in lead element nearby, and the radiation is not occurred by attenuating if becomes an inverse phase.

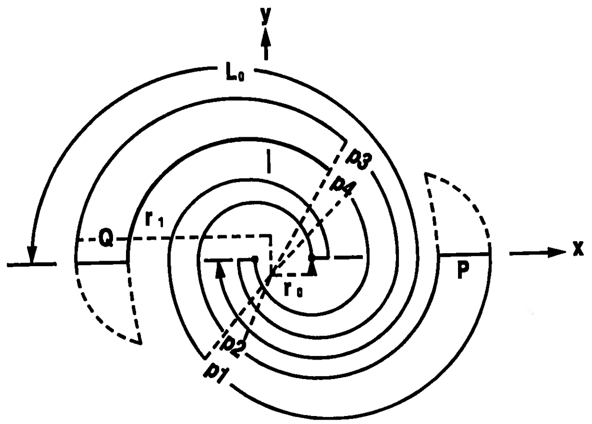


Figure 7-1 2Arm Equiangluar Spiral Antenna

The geometrical structure of a spiral antenna is taken by below formula.

$$\rho_1 = r_0 \exp^{a(\phi)} \qquad (7\text{-}1)$$

$$\rho_2 = r_0 \exp^{a(\phi - \delta)} \qquad (7\text{-}2)$$

$$\rho_3 = r_0 \exp^{a(\phi - \pi)} \qquad (7\text{-}3)$$

$$\rho_4 = r_0 \exp^{a(\phi - \pi - \delta)} \qquad (7\text{-}4)$$

where,

a : Spiral Constant

r_0 : Radius in Antenna Feed

ρ1 : Distance from starting point of P arm to outside wire.

ρ2 : Distance from starting point of P arm to inside wire.

ρ3 : Distance from starting point of Q arm to outside wire.

ρ4 : Distance from starting point of Q arm to inside wire.

ϕ : Spin Angle from starting point.

δ : Rotary Angle

a is Spiral Constant deciding the expansion of antenna. If the value a is little, the expanding speed becomes lower, and if the value a is large, the expanding speed becomes faster. Accordingly if the value a is to be large, the arm becomes little relatively and the value a is little, the length of arm becomes longer. r_0 decide max. frequency, and the r_1 decide lower frequency.

The relation of a driving frequency and radius is as below.

$$r_0 = \lambda_h / 4 \tag{7-5}$$

$$r_1 = \lambda_L / 4 \tag{7-6}$$

Accordingly the frequency band of antenna is as below.

$$\frac{c}{4\,r_1} \leq f \leq \frac{c}{4\,r_0}\ . \tag{7-7}$$

c : Spread Speed of Electron Wave in Free Space

The spin distance of a spiral antenna from starting point to optional point on antenna is as below.

$$L = \int_{r_0}^{r_1} \left[r^2 \left(\frac{d\Phi}{dr}\right)^2 + 1 \right]^{1/2} dr \tag{7-8}$$

1.2 Radial Pattern

The spiral antenna has a circle polarity and bilateral beam pattern, and the type of this radial pattern is not changed almost according to the frequency change. If the field polarity of radiational pattern, can regards it as a threshold deciding the band width offset, and the band width, ratio of upper frequency and lower frequency, becomes over 20 : 1.

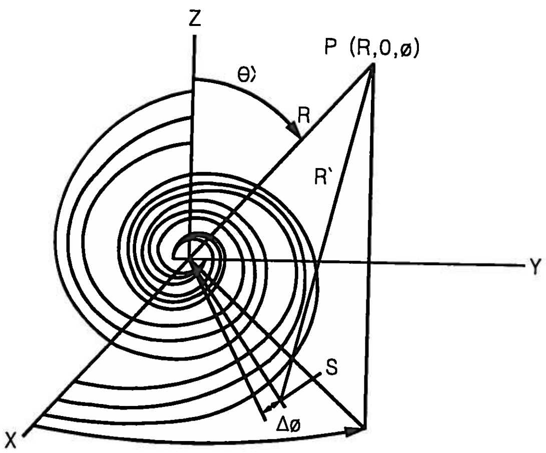


Figure 7–2 Coordinates System of Antenna and Radial Electron Field

EXPERIMENT PROCEDURE

1. Set the main controller, transmitting·receiving antenna positioner and computer which are main instruments of the antenna experiment set.

2. Set a height control bar on a transmitter and fix 500MHz Yagi antenna on the antenna fixing pack then set this on the polarization control plate. In this time, set this to be even with earth for an antenna get an even polarization characteristic. The transmitting antenna set as Figure 6-3 get an even polarization characteristic.
   Connect the 500MHz oscillation output terminal of main controller and the cable connecting terminal of Yagi antenna with SMA cable used for 2m.

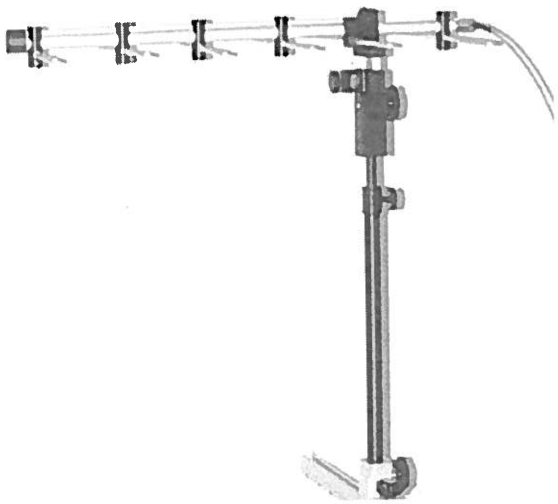


Figure 7-3 Even Polarization Transmitting Antenna

3. Fix the 500MHz Yagi antenna to get an even polarization characteristic on the polarization control plate of a receiver. Use the position control plate of a receiver to place an antenna in rotating center of a receiver. See Figure 7-4 to set.

Figure 7-4 Setting of Even Polarization Receiving Antenna

Connect the Yagi antenna and RF In terminal of a receiver with SMA cable used for 1m, and connect OUT PUT(1kHz) terminal of a receiver and Input(1kHz) in receiver of main controller with BNC Cable used for 1m.

4. As Figure 6-11, the distance between antennas is isolated as r=1.5m. Set the transmitting · receiving antennas at opposite position of same height.

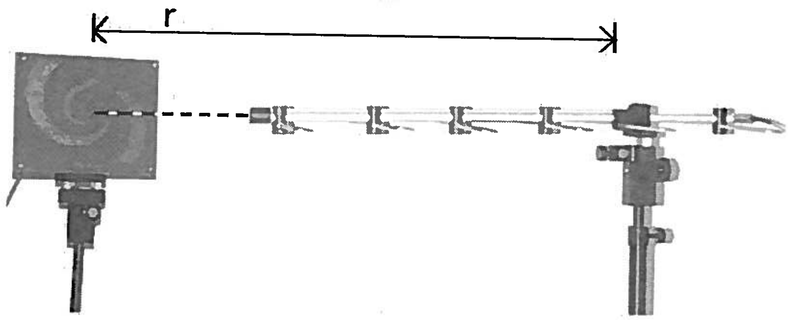


Figure 7-5 Distance of Antennas r

5. Set as below in condition of turning off the power of main controller.
   - Power OFF
   - 500MHz Oscillation Switch off
   - 2 GHz Oscillation Switch off
   - 10 GHz Oscillation Switch off
   - Modulation Switch (Mod) off

6. After set a switch in main controller as below, execute the Antenna Trainer program.
   - Power ON
   - 500MHz Oscillation Switch on
   - 2 GHz Oscillation Switch off
   - 10 GHz Oscillation Switch off
   - Modulation Switch (Mod) on

7. The program window is executed, execute Data Acquisition in Pop Up menu. Here after select Antenna, select E-Plane as Plane and control to be displayed 0 in gain displayer by adjusting the signal attenuation. The adjustment is completed, start Acquisition.

8. If the data acquisition is completed, save the taken radial pattern in file. Use the data box to confirm a radial pattern exactly. If set MSP(Max. Signal Position) to 0°, can see the radial pattern of this antenna.

9. Make the control plate to rotate 90°for the 500MHz Yagi antenna used for transmitting get a vertical polarization characteristic by loosing the screw on the polarization control plate.

Figure 7-6 Setting of Vertical Polarization Transmitting Antenna

10. Make a center of a spiral antenna used for receiving to be vertical with a rotary axis, and set as Figure 7-7 to get a vertical polarization characteristic.

11 . Click Antenna Initialize in Edit Menu of a software, click the Auto button to data acquisition. If the data acquisition is finished, after select H-Plane as Plane, save the pattern in file.

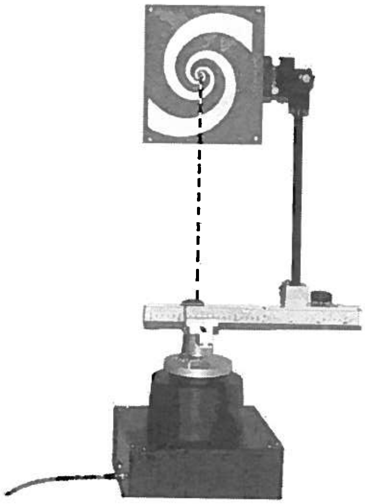


Figure 7-7 Vertical Polarization Receiving Antenna

12. Keep the 500MHz Yagi antenna used for transmitting to get a vertical polarization characteristic and set the spiral antenna used for receiving to get a vertical polarization characteristic.

13. Click Antenna Initialize in Edit Menu of a software, and click again Delete Screen then click the Auto button to data acquisition.

14. Observe three radial pattern.

15. Set a transmitting·receiving antennas get a vertical polarization characteristic respectively. The distance between antennas is r=1.5m. Make a surrounding condition of antenna to be same as the first experiment. Take the E-Plane radial pattern of a spiral antenna and save in Dummy-Plane.

    Theoretically if except an effect caused by a power damage, this radial pattern has to be same as the first pattern. If the pattern is different very much, have to do suitably by finding the position where a reflection can be occurred. After do suitably, continue an experiment and save new pattern in E-Plane.

Click Data Indicating Line in View Menu of upper menu of a data analysis program. Two cursors(Blue, White) used for E-Plane and tow cursors(Yellow, Green) used for H-Plane are appeared on the screen. If click an arrow on both side of a displayer of each color, the values in the displayer will be changed by moving the cursor of same color. These indicate the angle of cursor position and the receiving power in that time as dB, show the difference of angle between cursors and power in below 2 displayer. Record the values in below Table 7-1.

Table 7-1 Receiving Power for Angle

Angle	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Receiving Power of E-Plane for Angle												
Receiving Power of H-Plane for Angle												

16. Use the cursor to take the receiving angle of max. power in E-Plane pattern and the receiving power in that time. Click the Maximum Single Level button on the E-Plane data window to confirm if a measured value is accorded to a taken value with cursor. Record this in Table 7-2.

Table 7-2 Comparison of E-Plane and Theoretic Value

Taken Value with Cursor	Receiving Power	
	Angle	
Value by Maximum Single Level Icon	Receiving Power	
	Angle	

17. Take a half angle of main beam power in E-Plane pattern by using a cursor. Click the Half Power Beamwidth button on data window to confirm if same the measured value with button as taken value with cursor.

Calculate a half-power beam width of spiral antenna in E-Plane with below formula.

$$HPBW_E = \mid \theta_{HPBWleft} - \theta_{HPBWright} \mid = \underline{\qquad\qquad}$$

18. Repeat No. 17 of the experiment procedure in H-Plane radial pattern.

$HPBW_h$=________

19. Delete all cursors by clicking the data indicating line in view menu. Compare the experimental values with given value in the antenna software. If the calculated result is not accorded to this values, experiment and calculate again.

20. Save the E-Plane and H-Plane data and output the result.

21. Set the switch in main controller as below.
    - 500MHz Oscillation Switch off
    - 2 GHz Oscillation Switch on
    - 10 GHz Oscillation Switch off
    - Modulation Switch (Mod) on

22. Repeat the experiment procedure 8 ~ 20 on same spiral antenna fed 2GHz.

23. Compare the radial pattern fed each 500MHz and 2GHz to same spiral antenna.

▣ EXCERCISE ▣

1. What's the wide band antenna?

2. Explain the basic concept for use the spiral antenna as the wide band antenna.

3. Are there the difference between a radial pattern of a spiral antenna and of a dipole antenna? Explain the difference and the reason occurred it.

4. Explain the usage of a spiral antenna.

5. What's the polarization characteristic of a spiral antenna?

EXPERIMENT 3-8. HELICAL ANTENNA

Let's measure the radial pattern for E-Plane and H-Plane of a Helical antenna used for 10GHz in this experiment. We will study the polarization characteristic of a Helical antenna. Let's calculate a half-power beam width of a Helical antenna by using an antenna software.

BASIC STUDY

1. Circularly Polarized Wave

The preceding experimented antennas is what have a linear polarization characteristic. In the case of the straight wire antenna such as a dipole, folded dipole and monopole, the radiated field becomes same as a direction of physical wire. For example, in the case of a transmitting plane dipole, the field is on plane and the magnetic field is on vertical plane. This antenna is able to receive most largely the wave which the field is on plane.

Also the loop antenna has a linear polarization characteristic. For example, the vertical full-wave loop antenna fed from floor does function like an even dipole, radiates the wave type of even polarization. Perhaps, if feed not from floor but from right or left side, the radial wave type is to be vertical polarization.

The square waveguide transmit a linear polarized wave type. In prior experiment of measurement for E-Plane and H-Plane, you can confirm that must use all the same polarization. If two transmitting·receiving antenna is arranged rightly and control the steering direction to get same polarization characteristic, becomes accept well the signal. But if one antenna of two rotate 90°, becomes receive a weak signal for the cross-polarization isolation. Theoretically since the cross-polarization isolation is large unlimitedly, any signal must not be received. But actual cross-polarization isolation is not to be unlimited.

There are an elliptically polarized wave and circular polarization in kind of a polarization of an antenna. The elliptically polarized wave is generated by the collate of two field vector(regards two vectors as different tow linear polarization each other). Two vectors are placed vertically each other, have same frequency and travel toward same direction. But their amplitude and phase have a different value respectively. If the amplitude of two vectors is same respectively and have a phase difference of 90°exactly, becomes a circular polarization. If the amplitude of one vector or other vector is 0, becomes a linear polarization. It can regards that the linear polarization and circular polarization is the special

case of an elliptically polarized wave.
To be a circular polarization, must make the field to rotate rapidly according to travel the wave. There can be many ways to generate the circular polarization. One thing is what radiate together an even polarization wave having the phase difference of 90°with a vertical polarization wave. This is similar to draw Lissajous pattern of perfect circle as input a sine wave having a phase difference of 90°for X, Y axis input by Oscilloscope.

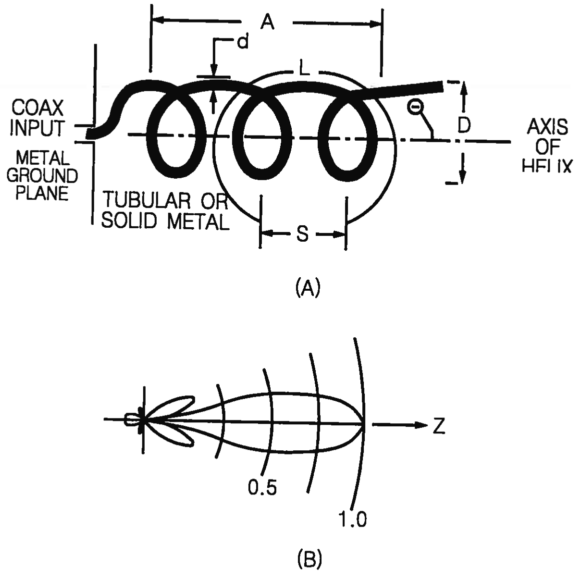
Another way is what send the electron wave along the helix lead of proper size. Since the wave move along helix, make the field rotating rapidly. This principle is applied to the helix antenna. The rotation of field is one of clockwise and counterclockwise. If the field rotate to right finger when the thumb indicate toward traveling direction by grasping right hand, this polarization is called right circular polarization.

If opposite direction, it is called left circular polarization. The cross-polarization isolation in circular polarization weigh heavily. The right circular polarization antenna can not receive the signal to be left circular polarized. The inverse also is effected. But each antenna get offset a little the signal to be linear polarized toward optional direction and can receive.

Although the linear polarization is used in major case, the circular polarization would be used very usefully according to the communication system. For one example, it is difficult to maintain a direction of antenna regularly in the satellite communication system. Accordingly the linear polarization in this case becomes receive a fading. If use a circular polarization, the strength of receiving signal becomes regular almost regardless a direction of satellite antenna.

2. Helical Antenna

Figure 8-1 shows a typical axial-mode of a helical antenna. That is the helical antenna is designed to radiate the electron wave from grounding plane toward helix axis, and to have a radial pattern of pencil-beam type rotating toward coiled direction of a helix. The helical antenna of this type has a merits which easy to match as the wide band and input impedance is about 120Ω-140Ω as well as has a very efficient radial pattern.



(A) Plane(Geometry) (B) Radial Model of Pencil-beam

Figure 8-1 Axial-mode Helical Antenna

The initial letter used to draw helix.

N = Number of Rotation(Over 3times)

S = Space of Rotation = C $\tan\alpha$

pitch, distance between the centers of a helix that is, rising height when 1 rotate($\frac{1}{10} \sim \frac{1}{2}\lambda$)

A = Axial Length = NS

D = Diameter of Helix

d = Diameter of Conductor(Lead)

L = Length of Rotation

(About $= \pi D,\ \frac{3}{4} \sim \frac{4}{3}\lambda$)

α = pitch angle = $\tan^{-1}(S/C)$

pitch angle of helix α

The helical antenna becomes radiate an electron wave in axial mode when the circumference is given about length of one wave. The using frequency range of a helical antenna is given as formula(8-1).

$$3/4\lambda < C < 4/3\lambda \quad (8\text{-}1)$$

The sine wave travel from grounding plane toward opposite end point along helix. Therefore the helical antenna is called a traveling wave antenna.
To understand the operating principle of a helical antenna, consider one helix loop of λcircumference as Figure 8-2. As the circumference of helix in optional moment t_1 isλ, the current is a positive value(+) in one plane of loop, and negative value(-) in opposite value. As show in figure, can connect I^+ point and I^- point with arrow mark in same geometric direction, and this makes to act alike dipole of one kind.
In t_2, after short time, the current moves as short distance along helix. Now the dipole becomes a shape rotated a little. That is, this imaginary dipole becomes rotate identically with each frequency(ω) of a transmitted wave type. In Figure 8-2, the radial pattern toward both sides will be 0. The radiation of electron wave will be only toward axial direction of a helix.

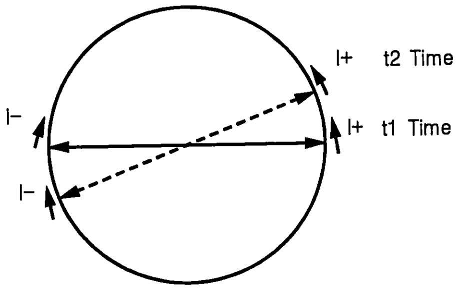


Figure 8-2 One Loop of Helical Antenna

If each loop forming helix is all folded and is same phase, it is going to get a strong radial pattern along both axis of helix as Figure 8-3. But Figure 8-3 isn't a radial pattern of helical antenna in axial mode. Since the phase difference is generated by occurring a propagation delay along helix, for the radial pattern, two lobes are not generated but one lobe toward axis.
The helical antenna has similar radial pattern to the end-fire antenna taking unique lobe toward endfire because the position of antenna array elements and the phase of feed current.
The coiled direction of helix decide a direction of circular polarization. When see helix in side of grounding plane, the coiling toward clockwise makes right circular polarization to generate and toward counterclock wise makes left circular polarization to generate.

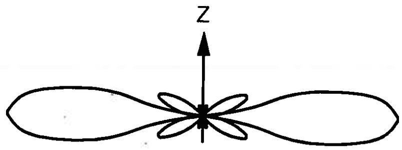


Figure 8-3 Radial Pattern of Pencil Beam

3. Axial Ratio and Gain

When receive the signal to be circular polarization, the response of helical antenna has to maintain as identical size ideally though the field of receiving signal is rotated. To explain this, consider the case using the antenna to be circular polarization like dipole as a transmitting antenna, and using the helical antenna as receiving antenna. The polarization of transmitting signal will be changed by rotating dipole. The ideal helical antenna must get same receiving level for all direction of a dipole that is for all polarization. But the radial characteristic of a helical antenna can be asymmetry a little because a helix has a limited size. Accordingly the receiving characteristic for the polarization of special direction can be appeared somewhat better than for other direction.
Here the response index of a polarization toward special direction for a polarization toward other direction is called the axial ratio of a helical antenna or the circularity. This gives a definition with a ratio between amplitudes indicating max. response and an amplitude of polarization indicating min. response. It can be said that the antenna responding same for all polarization has axial ratio of 1.0(or 0dB).
The axial ratio is given as below.

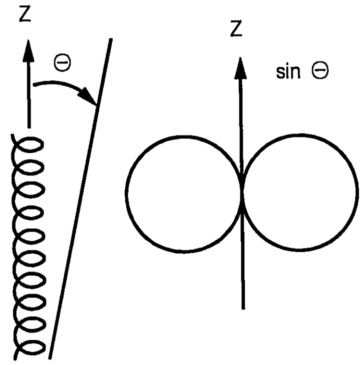
$$AR=\frac{2N+1}{2N} \tag{8-2}$$

where AR is an axial ratio
N is a number of helix.
The axial ratio can be measured through a receiving and transmitting between antennas to be direct polarization with a helical antenna. If measure max. and min. amplitude by rotating one antenna, the axial ratio can be calculated with two amplitude ratio directly. Ideally, the helical antenna take a value between axial ratio 1 and 1.1(0 and 0.83dB). To take these result, must make the open end of helix to grow less little by little. It is not easy to get an axial ratio of some 1.12(1dB) for the helix of an actual regular diameter. If indicate the gain of a helical antenna based on experiment, as below.

$$G=8.3\left(\frac{\pi D}{\lambda}\right)^{[(N+2)/2-1]}\cdot\left(\frac{NS}{\lambda}\right)^{0.8}\cdot\left[\frac{\tan(12.5^\circ)}{\tan(a)}\right]^{(N/2)/2} \tag{8-3}$$

4. Normal Mode

The helical antenna taking the different radial pattern entirely can be made as Figure 8-4. This helical antenna is driven with normal mode, the max. radial direct is vertical with an axis of antenna.
In normal mode driving, the circumference of helix must less in proportion to the wave. Because make the current to distribute into the phase and amplitude almost identically along helix. The helix of this type has a low electric length and low efficiency.



(A) Geometric Structure (B) Radial Pattern

Figure 8-4 Normal Mode Helical Antenna

EXPERIMENT PROCEDURE

1. Set a transmitting·receiving antenna positioner and a computer which are main instrument of an antenna experimental set.

2. Fix 10GHz Horn antenna on the polarization control plate in transmitter. Set it to be even with earth to get an even polarization characteristic. The transmitting Horn antenna as Figure 8-5 gets an even polarization characteristic.
   Connect 10GHz oscillation output terminal in main controller and Cable connecting terminal of Horn antenna with SMA cable used for 2m.

Figure 8-5 Setting of Even Polarization Horn Antenna

3. Fix the Helical antenna on the polarization control plate in receiver to measure an axial mode radial characteristic. Use the position control screw in receiver, place the ground plane to be vertical with a rotary axis in receiver. See Figure 8-6 to set.

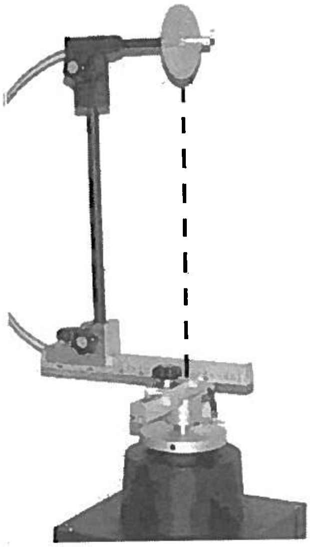


Figure 8-6 Setting of Axial Mode Helical Antenna

Connect the Helical antenna and RF In terminal of a receiver with SMA cable used for 1m, and connect OUT PUT(1kHz) terminal of a receiver and Input(1kHz) in receiver of main controller with BNC Cable used for 1m.

4. Use below formula, calculate the length of Helical and measure the actual length of Helical then record in Table 8-1.

The exact oscillation frequency of RF signal generator is 10GHz.

$$\lambda = \frac{c}{f}$$

Table 8-1 Length of Antenna [cm]

	Theoretic Length of Antenna	Actual Length of Antenna
λ		
A	* To be Decided by Number of Antenna*	
L		
D		
S		

5. As Figure 8-7, the distance between antennas is isolated as r=1m. Set the transmitting · receiving antennas at opposite position of same height. Make the center of a helix conductor of helical antenna and the center of square horn part of a horn antenna to place in straight line.

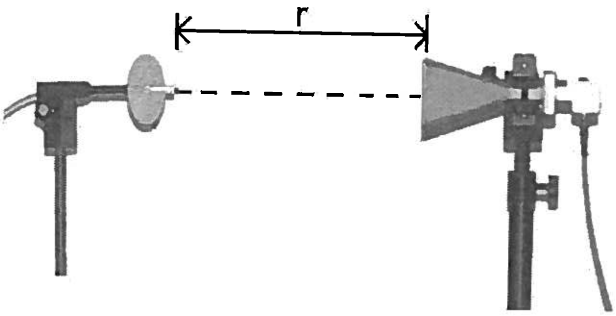


Figure 8-7 Distance between Antenna r

6. Set as below in condition of turning off the power of main controller.
   - Power OFF
   - 500MHz Oscillation Switch off
   - 2 GHz Oscillation Switch off
   - 10 GHz Oscillation Switch off
   - Modulation Switch (Mod) off

7. After set a switch in main controller as below, execute the Antenna Trainer program.
   - Power ON
   - 500MHz Oscillation Switch off
   - 2 GHz Oscillation Switch off
   - 10 GHz Oscillation Switch on
   - Modulation Switch (Mod) on

8. The program window is executed, execute Data Acquisition in Pop Up menu. Here after select Antenna, select E-Plane as Plane and control to be displayed 0 in gain displayer by adjusting the signal attenuation. The adjustment is completed, start Acquisition.

9. If the data acquisition is completed, save the taken radial pattern in file. Use the data box to confirm a radial pattern exactly. If set MSP(Max. Signal Position) to 0°, can see the radial pattern of this antenna.

10. Make the polarization control plate to rotate 90° for the 10GHz Horn antenna used for transmitting get a vertical polarization characteristic.

Figure 8-8 Rotation of Vertical Polarization Transmitting Antenna

11. Fix to measure the axial mode radial characteristic of a Helical antenna.

12. Click Antenna Initialize in Edit Menu of a software, click the Auto button to data acquisition.

13. Set again for the transmitting antenna get an even polarization characteristic and for receiving antennas get an axial mode radial characteristic. The distance between antennas is r=1.0m. Make a surrounding condition of antenna to be same as the first experiment. Take the axial mode radial pattern of a helical antenna and save in Dummy-Plane.

    Theoretically if except an effect caused by a power damage, this radial pattern has to be same as the first pattern. If the pattern is different very much, have to do suitably by finding the position where a reflection can be occurred. After do suitably, continue an experiment and save new pattern in E-Plane.
    Click Data Indicating Line in View Menu of upper menu of a data analysis program. Two cursors(Blue, White) used for Axial Mode(E-Plane) and tow cursors(Yellow, Green) used for Normal Mode(H-Plane) are appeared on the screen. If click an arrow on both side of a displayer of each color, the values

in the displayer will be changed by moving the cursor of same color. These indicate the angle of cursor position and the receiving power in that time as dB, show the difference of angle between cursors and power in below 2 displayer. Record the values in below Table 8-2.

Table 8-2 Receiving Power for Angle

Angle	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Receiving Power of E-Plane for Angle												
Receiving Power of H-Plane for Angle												

14. Use the cursor to take the receiving angle of max. power in Axial Mode and the receiving power in that time. Click the Maximum Single Level button on the axial mode(E-Plane) window to confirm if a measured value is accorded to a taken value with cursor. Record this in Table 8-3.

15. Take a half angle of main beam power in axial mode pattern by using two cursors. Click the Half Power Beamwidth button on axial mode(E-Plane) data window to confirm if same the measured value with button as taken value with cursors.

Table 8-3 Comparison of E-Plane with Theoretic Value

Taken Value with Cursor	Receiving Power	
	Angel	
Value by Maximum Single Level Icon	Receiving Power	
	Angle	

Calculate a half-power beam width of a helical antenna in axial mode(E-Plane) with below formula.

$$HPBW_E = \mid \theta_{HPBWleft} - \theta_{HPBWright} \mid = \_\_\_\_\_\_\_\_$$

16. Repeat No. 15 of the experiment procedure in H-Plane radial pattern.

$HPBW_h$=__________

17. Delete all cursors by clicking the data indicating line in view menu. Compare the experimental values with given value in the antenna software. If the calculated result is not accorded to this values, experiment and calculate again.

18. Save the E-Plane and H-Plane data and output the result.

■ EXCERCISE ■

1. Take the Axial ratio by substituting A, D, S, N in Table 8-1 to Formula 8-2.

2. Take a gain by substituting A, D, S, N in Table 8-1 to Formula 8-3.

3. What's the circular polarization? Arrange the type of polarization and explain the difference between each polarization.

4. Explain the normal mode and axial mode of a helical antenna.

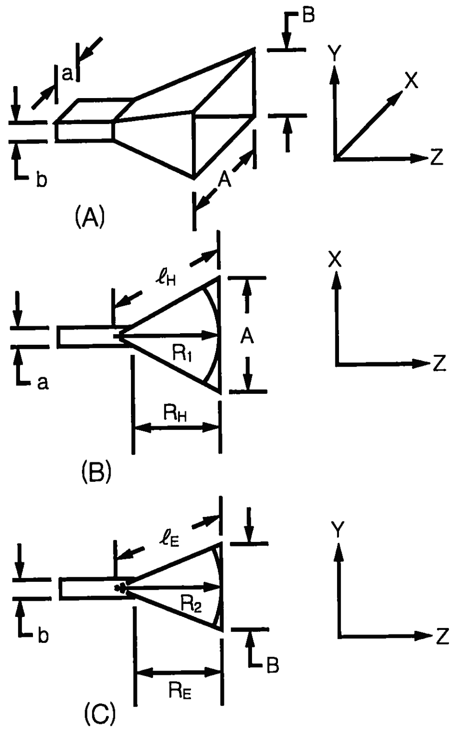
EXPERIMENT 3-9. HORN ANTENNA EXPERIMENT

Let's measure the radial pattern for E-Plane and H-Plane of Horn antenna used for 10GHz in this experiment. We will study a radial pattern of a Horn antenna. Let's calculate a half-power beam width of a horn antenna.

BASIC STUDY

1. Pyramidal Horn Antenna

The pyramidal horn antenna is one type of antenna used very much. Figure 9-1 shows the geometry model.



(A) Geometry Structure (B) Section of H-Plane (C) Section of E-Plane

Figure 9-1 Pyramidal Horn Antenna

The waveguide can spread a shape of numerous modes of electron wave that is 3 dimension passing into waveguide. Each mode consists of unique own electron field. If the opening angle of a pyramidal antenna is small sufficiently, only the dominant mode of waveguide has a mean. Other modes can be spreaded by being evanescent mode.

The flux line of main mode is expanded into the cylindrical type with a sector horn antenna, and into global type with a pyramidal horn antenna. Figure 9-2 shows the shape.

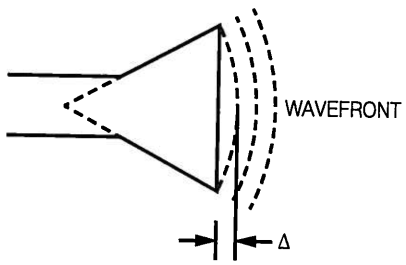


Figure 9-2 Phase Error by Wave Front of Horn Antenna (△)

As above figure, the wave front is not plane but curved surface. This is the cause inducing the phase error, can be considered in analysis of antenna characteristic. The phase error is indicated by generalized route error that is s and t.

$$s=\frac{\triangle_E}{\lambda}=\frac{B^2}{8\lambda\, l_E} \tag{9-1}$$

$$t=\frac{\triangle_H}{\lambda}=\frac{A^2}{8\lambda\, l_H} \tag{9-2}$$

where s and t are generalized route error.

λ is wave

A, B, L_E and L_H are values given in Figure 9-1.

The approximate gain of a pyramidal horn antenna can be calculated by Formula 9-3.

$$G=\frac{32}{\pi}\left(\frac{A}{\lambda}\right)\left(\frac{B}{\lambda}\right)L_E\,L_H \tag{9-3}$$

where L_E and L_H are a damage value by phase error caused by becoming open little by little.
The formula indicated by dB is as below.

$$G_{(dB)} = 10.08 + 10 \log_{10}\left[\left(\frac{A}{\lambda}\right)\left(\frac{B}{\lambda}\right)\right] - L_{E(dB)} - L_{H(dB)} \qquad (9\text{-}4)$$

The values of $L_{E(dB)}$ and $L_{H(dB)}$ can be taken if calculate s and t at first with formula 9-1 and 9-2.

2. Electric Wave Damage in Free Space

The power received by antenna decrease according to far away from transmitting antenna. In free space, the receiving signal power is in inverse proportion to the square of distance between a transmitting antenna and receiving antenna. The power damage caused by an isolated distance between antennas is called the electric wave damage L_F. If show the electric wave damage on the free space by mathematic formula, becomes

$$L_{F(dB)} = 10\log\left(\frac{4\pi r}{\lambda}\right)^2 = 20\log\frac{4\pi r}{\lambda} \qquad (9\text{-}5)$$

where r is a distance between antennas
λ is an electric wave period in a free space (same unit as r).

For given wave, formula 9-5 shows that L_F is changed by only distance between antennas. This relational expression can be taken experimentally as measure the receiving power from antennas placed in other distance with transmitted signal from some antenna.
However must maintain the direction between two antennas during experiment since the antennas have a directivity generally. If can know the isolated distance between antennas, can calculate the power attenuation between receiving power in optional distance and in other distance. The numerical formula indicating this is

$$A_{dB} = 20\log\frac{r_2}{r_1} \qquad (9\text{-}6)$$

where A is a damage indicated by dB
r_1 and r_2 are distance between the first antenna and second antenna.

To decide a direction characteristic of an antenna numerically, the concept of directivity or direction gain is used generally. The directivity is max. radial intensity toward given direction for the average radial intensity. The isotropic antenna radiating an identical power toward all direction, that is in ideal antenna, the antenna gain(direction gain) equal to directivity.

3. Measuring Gain of Antenna

Of various method to measure a gain of antenna, as the most thing is a method of reference antenna(compare method or substitute method), this is method comparing the receiving power of a reference antenna P_{Ref} and of a test antenna P_{Test} mutually. The gain of a test antenna can be indicated by Formula 9-7.

$$G_{Test} = \frac{P_{Test}}{P_{Ref}} G_{Ref} \qquad (9\text{-}7)$$

Indicate by dB, becomes as below.

$$G_{Test(dB)} = P_{Test(dB)} - P_{Ref(dB)} + G_{Ref(dB)} \qquad (9\text{-}8)$$

Before use a substitution method, must do calibration the reference antenna. One thing of the method is what use two same antenna. If the transmitting·receiving power, the gain can be calculated with Formula 9-9.

$$G = \frac{4\pi r}{\lambda}\sqrt{\frac{P_{Rec}}{P_o}} \qquad (9\text{-}9)$$

Where,

G is gain

r is distance between antennas

P_o and P_{Rec} are transmitting·receiving power respectively

λ is wave in free space(same unit as r).

EXPERIMENT PROCEDURE

1. Set a transmitting·receiving antenna positioner and a computer which are main instrument of an antenna experimental set.

2. Fix 10GHz Horn antenna on the polarization control plate in transmitter. Set it to be even with earth to get an even polarization characteristic. The transmitting Horn antenna set as Figure 9-3 gets an even polarization characteristic.
   Connect 10GHz oscillation output terminal in main controller and Cable connecting terminal of Horn antenna with SMA cable used for 2m.

Figure 9-3 Setting of Even Polarization Horn Antenna

3. Fix the Horn antenna on the polarization control plate in receiver to get an even polarization characteristic at vertical position with earth. Place the antenna in rotary center of receiver by using the position control plate. See Figure 9-4 to set.

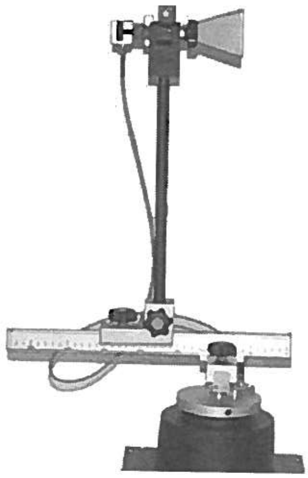


Figure 9-4 Even Polarization Receiving Antenna

Connect the Horn antenna and RF In terminal of a receiver with SMA cable used for 1m, and connect OUT PUT(1kHz) terminal of a receiver and Input(1kHz) in receiver of main controller with BNC Cable used for 1m.

4. Measure the length of a 10GHz Horn antenna in Figure 9-1 and record in Table 9-1.

Table 9-1 Length of Antenna [cm]

	Actual Antenna Length
a	
b	
A	
B	
L_E	
R_E	
L_H	
R_H	

5. As Figure 9-5, the distance between antennas is isolated as r=1m. Place the

transmitting·receiving antenna on opposite position of same height.

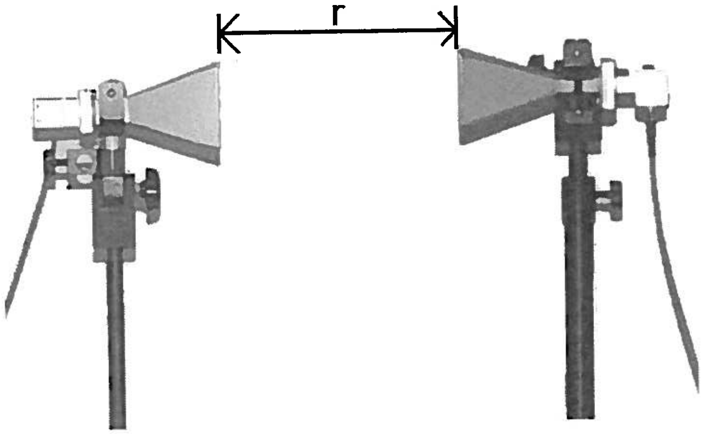


Figure 9-5 Distance between Antenna r

6. Set as below in condition of turning off the power of main controller.
   - Power OFF
   - 500MHz Oscillation Switch off
   - 2 GHz Oscillation Switch off
   - 10 GHz Oscillation Switch off
   - Modulation Switch (Mod) off

7. After set a switch in main controller as below, execute the Antenna Trainer program.
   - Power ON
   - 500MHz Oscillation Switch on
   - 2 GHz Oscillation Switch off
   - 10 GHz Oscillation Switch off
   - Modulation Switch (Mod) on

8. The program window is executed, execute Data Acquisition in Pop Up menu. Here after select Antenna, select E-Plane as Plane and control to be displayed 0 in gain displayer by adjusting the signal attenuation. The adjustment is

completed, start Acquisition.

9. If the data acquisition is completed, save the taken radial pattern in file. Use the data box to confirm a radial pattern exactly. If set MSP(Max. Signal Position) to 0°, can see the radial pattern of this antenna.

10. Make the control plate to rotate 90°for the 10GHz Horn antenna used for transmitting get a vertical polarization characteristic.

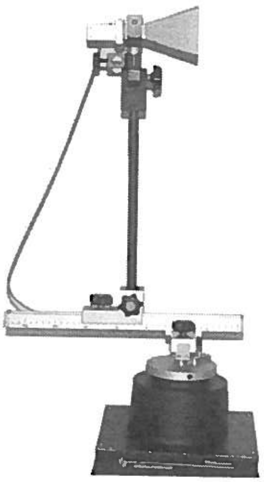


Figure 9-6 Setting of Horn Antenna

11. Set the Horn antenna used for receiving as Figure 9-6 to get a vertical polarization characteristic.

12. Click Antenna Initialize in Edit Menu of a software, click the Auto button to data acquisition. If the data acquisition is finished, after select H-Plane as Plane, save the pattern in file.

13. Keep the 10GHz Horn antenna used for transmitting to get a vertical polarization characteristic and set the horn antenna used for receiving to get a vertical polarization characteristic.

14. Click Antenna Initialize in Edit Menu of a software, and click again Delete Screen then click the Auto button to data acquisition.

15. Observe three radial pattern.

16. Set a transmitting·receiving antennas get a vertical polarization characteristic respectively. The distance between antennas is r=1.0m. Make a surrounding condition of antenna to be same as the first experiment. Take the E-Plane radial pattern of a horn antenna and save in Dummy-Plane.

    Theoretically if except an effect caused by a power damage, this radial pattern has to be same as the first pattern. If the pattern is different very much, have to do suitably by finding the position where a reflection can be occurred. After do suitably, continue an experiment and save new pattern in E-Plane.

    Click Data Indicating Line in View Menu of upper menu of a data analysis program. Two cursors(Blue, White) used for E-Plane and tow cursors(Yellow, Green) used for H-Plane are appeared on the screen. If click an arrow on both side of a displayer of each color, the values in the displayer will be changed by moving the cursor of same color. These indicate the angle of cursor position and the receiving power in that time as dB, show the difference of angle between cursors and power in below 2 displayer. Record the values in below Table 9-2.

Table 9-2 Receiving Power for Angle

Angle	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Receiving Power of E-Plane for Angle												
Receiving Power of H-Plane for Angle												

17. Use the cursor to take the receiving angle of max. power in E-Plane pattern and the receiving power in that time. Click the Maximum Single Level button on the E-Plane data window to confirm if a measured value is accorded to a taken value with cursor. Record this in Table 9-3.

Table 9-3 Comparison of E-Plane with Theoretic Value

Taken Value with Cursor	Receiving Power	
	Angle	
Value by Maximum Single Level Icon	Receiving Power	
	Angle	

18. Take a half angle of main beam power in E-Plane pattern by using two cursors. Click the Half Power Beamwidth button on data window to confirm if accord the measured value with button as taken value with cursor.

Calculate a half-power beam width of horn antenna in E-Plane with below formula.

$$HPBW_E = | \theta_{HPBWleft} - \theta_{HPBWright} | = \_\_\_\_\_\_\_\_$$

19. Repeat No. 18 of the experiment procedure in H-Plane radial pattern.

$$HPBW_H = \_\_\_\_\_\_\_\_$$

20. Delete all cursors by clicking the data indicating line in view menu. Compare the experimental values with given value in the antenna software. If the calculated result is not accorded to this values, experiment and calculate again.

21. Save the E-Plane and H-Plane data and output the result.

▣ EXCERCISE ▣

1. When make the isolated distance of antenna to be 2times in Figure 9-4, how dB is

   decreased ?

2. Explain the effect caused by the opening angle of a pyramidal horn antenna.

3. Explain what 's the shape similar to the radial pattern of a pyramidal horn antenna.

4. Take the gain of antenna with numerical formula and experiment, and explain the difference.

5. What's the radial pattern of a Horn antenna?

EXPERIMENT 3-10. SINGLE PATCH ANTENNA

Let's measure a radial pattern for E-Plane of a single patch antenna in this experiment. We will study the radial characteristic of a single patch antenna. Let's calculate a half-wave beam width of a single patch antenna by using the antenna software.

BASIC STUDY

1. Characteristic of Square Patch Antenna

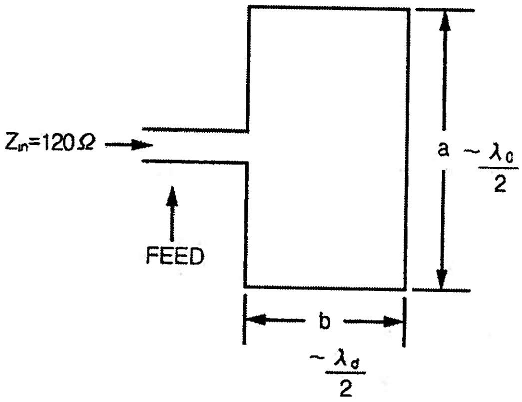


Figure 10-1 Basic Square MicroStrip Antenna

Figure 10-1 shows the size of a basic square MicroStrip patch antenna. The conductance of antenna is a function of width a, and the resonance frequency is a function of length b. The length b is given as below.

$$b \approx 0.49\lambda_d = 0.49\frac{\lambda_0}{\sqrt{\epsilon_r}} \qquad (10\text{-}1)$$

Where λ_d is a wave in a dielectric substance

λ_0 is a wave in a free space

ϵ_r is a relative dielectric constant of a base material

Because the change of dielectric constant and feed inductance, it is necessary to identify the exact length of patch when measure.

Figure 10-2 show the current flowing into patch and the field around it. The field is on the edge of patch connected with feeder mainly and is on opposite edge. This field caused by a radial characteristic of antenna.

The wave radiated from antenna get an even polarization characteristic as Figure 10-2. That is the even direction is E-Plane(x-y plane), and the vertical direction is H-Plane(y-z plane).

The b, spacing between two edge of a patch antenna is about length($0.49\lambda_d$) of half-wave in the dielectric substance. This is a reason that the opposite slot becomes an antenna exciting to the inverse phase. But the field radiating to two parallel slot becomes add to same phase in direction of broadside(that is direction of y) of antenna.

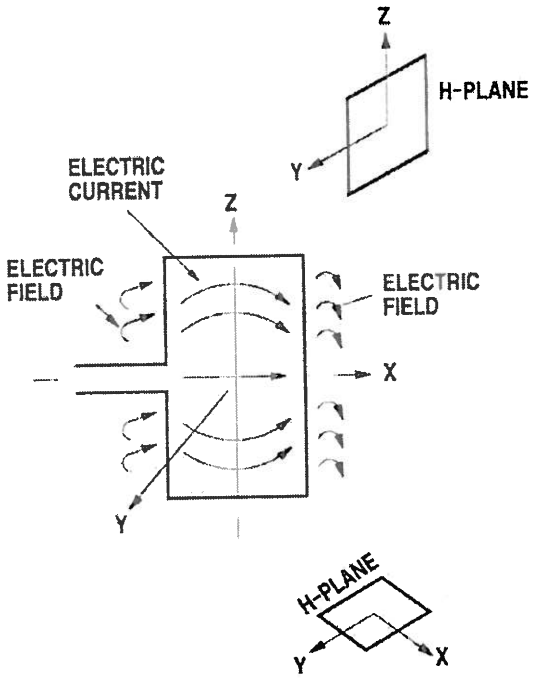


Figure 10-2 Current Distribution and Main Type of Field

2. Radial Pattern in case of two slots is distributed

One analogy to calculate the characteristic of square patch antenna simply and clearly is what compare the patch antenna in Figure 10-1 with the waveguide slot antenna taking 2-slot in Figure 10-3.

Since the 2-slot waveguide slot antenna in Figure 10-3 is equal to the patch antenna in Figure 10-3, two radial pattern is appeared identically.

To understand the radial pattern of 2-slot waveguide antenna, pay attention to what select distance b for the field radiated from both slot becomes same phase as Figure 10-4. The distance between each slot becomes same at any point on y axis.

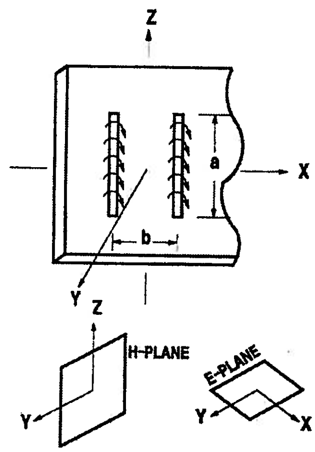


Figure 10-3 Two Parallel Slot in Waveguide

Therefore the field caused by two slot becomes radiate maximally since to be added by becoming same phase. In other direction, it is not added completely as same phase for the distance between two slots is different. Accordingly the radial pattern will be get a main lobe, maximum size at direction of y axis.

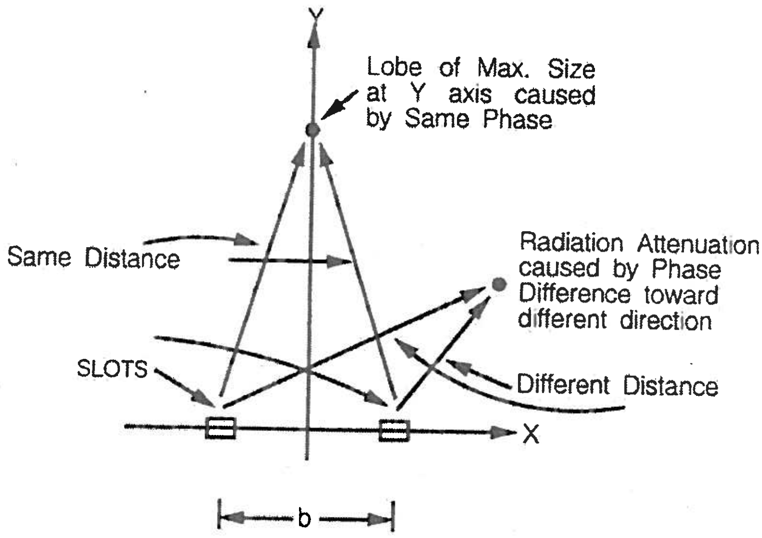


Figure 10-4 Analysis of E-Plane Far-Field in Square Patch

Figure 10-4 show the picture drawing one slot by 3 dimension. In this figure, axis and each Ø, Θ are used as a variable number of basic formula. a and b in Formula 10-2 and 10-3 is a related value to the width a and length b of patch in Figure 10-4.

The height H in Figure 10-4 is a value related to the thickness of base material of dielectric substance in Figure 10-1 and 10-2.

The radial pattern of E-Plane for two slots excited by same amplitude and phase is given as below formula

$$F_{patch}(\emptyset) = \frac{\sin(\frac{\beta h}{2}\cos\emptyset)}{\frac{\beta h}{2}\cos\emptyset}\cos(\frac{\beta h}{2}\cos\emptyset) \qquad (10\text{-}2)$$

Where h is a height of slot(same as the thickness of antenna base material)

b is a distance between two slots(same as the length of patch antenna)

$\beta = \frac{2\pi}{\lambda}.0$

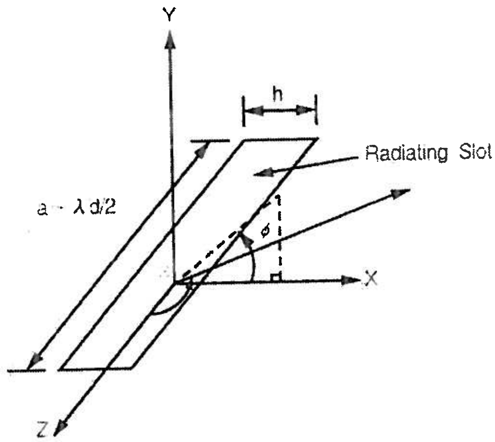


Figure 10-5 Type for Calculation of E-, H-Plane Radial Pattern

The H-Plane pattern is given as below.

$$F_{patch}(\theta) = \frac{\sin(\frac{\beta a}{2}\cos\emptyset)}{\frac{\beta a}{2}\cos\emptyset}\sin\theta \qquad (10\text{-}3)$$

where, a is a length of slot.

Theoretically, E-Plane pattern and H-Plane pattern have to be appeared as Figure 10-5.

3. Input Impedance of Microstrip Antenna

As the input impedance of 2-slot array antenna and $\lambda/2$ square patch antenna is a resistant element(Reactance element 0), have a good radial characteristic. The approximate value of an input resistance is as below.

$$R_{in} \approx \frac{60/\lambda_0}{a} = \frac{60/\lambda_0}{\lambda_0/2} = 120\Omega \tag{10-4}$$

where, a is a length of slot

λ_0 is a wave in free space

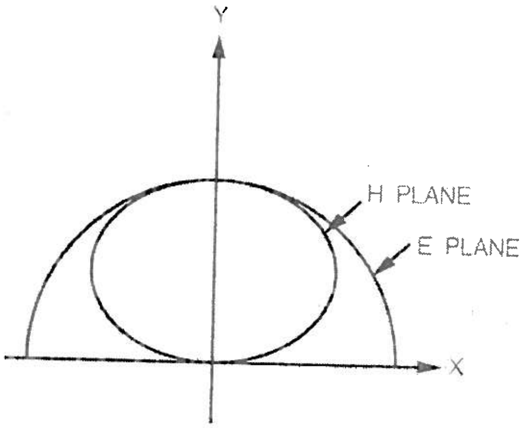


Figure 10-6 Theoretic E-, H-Plane Radial Pattern for two slots excited to Same Phase with Same Size(b=$\lambda_d/2$, where $\lambda_d < \lambda$).

Theoretically as the input impedance of patch is about 120Ω, the impedance of a Microstrip line and input unit of coaxial cable must be 120Ω. But to connect with the 50Ω coaxial cable using in experiment set for antenna, the 50Ω Microstrip line is used.

To match the impedance between 50Ω Microstrip line and 120Ω patch, use the $\lambda/4$ impedance inverter as Figure 10-7. The $\lambda/4$ impedance inverter is a useful technique for the impedance matching in narrow band. The characteristic impedance Z_L of $\lambda/4$ impedance inverter to much Z_1 and Z_2 is as below.

$$Z_L = \sqrt{Z_1 Z_2} \tag{10-5}$$

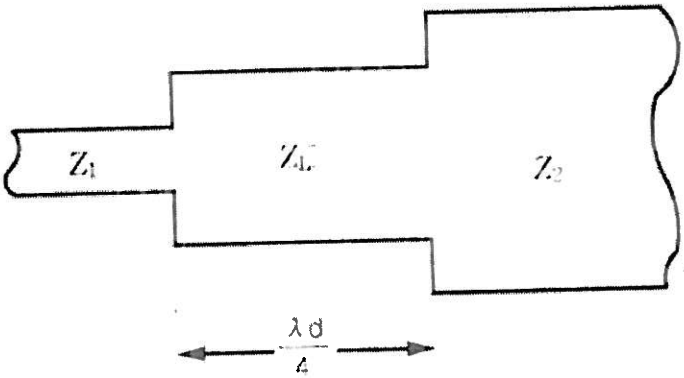


Figure 10-7 $\lambda/4$ **of Impedance** Z_L **for matching impedance** Z_1**,** Z_2**.**

Z_1 is an impedance of a coaxial cable or Microstrip line taking 50Ω, if Z_2 is an impedance of a patch antenna, the characteristic impedance of $\lambda/4$ impedance inverter connected to patch and micro is as below.

$$Z_L = \sqrt{Z_1 Z_2} = \sqrt{(50)(120)} = 78\Omega \tag{10-6}$$

Figure 10-8 shows the single patch antenna in antenna set and $\lambda/4$ impedance inverter of 78Ω.

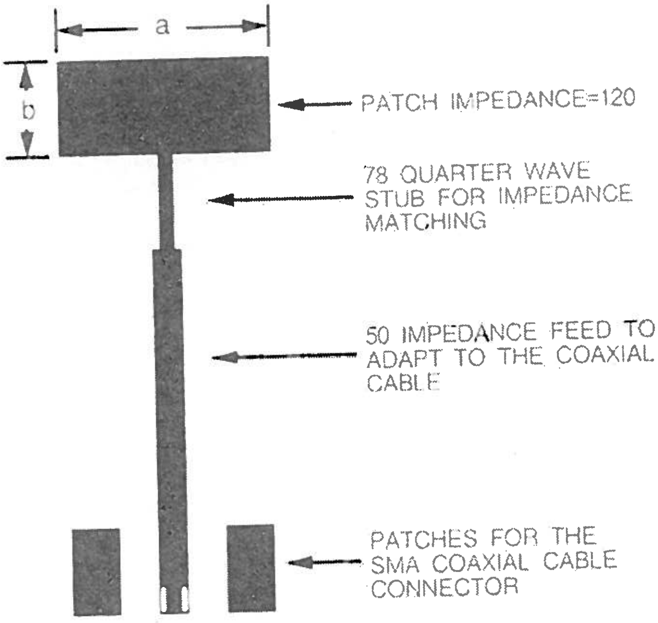


Figure 10-8 Single Patch Antenna(Unit : mm)

EXPERIMENT PROCEDURE

1. Set a transmitting·receiving antenna positioner and a computer which are main instrument of an antenna experimental set.

2. Fix 10GHz Horn antenna on the polarization control plate in transmitter. Set it to be even with earth to get an even polarization characteristic. The transmitting Horn antenna as Figure 10-9 gets an even polarization characteristic.
   Connect 10GHz oscillation output terminal in main controller and cable connecting terminal of Horn antenna with SMA cable used for 2m.

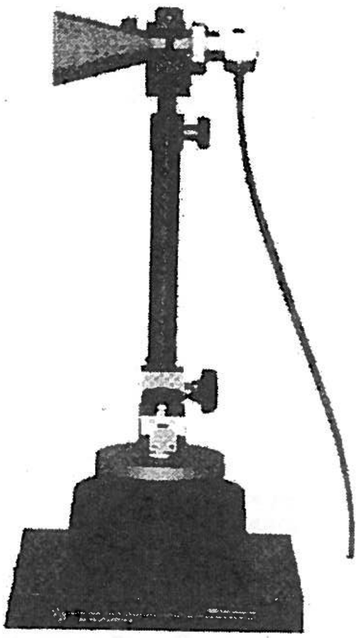


Figure 10-9 Setting of Even Polarization Transmitting Antenna

3. Fix the Horn antenna on the polarization control plate in receiver to measure an axial mode radial characteristic. Use the position control screw in receiver, place the ground plane to be vertical with a rotary axis in receiver. See Figure 10-10 to Set.

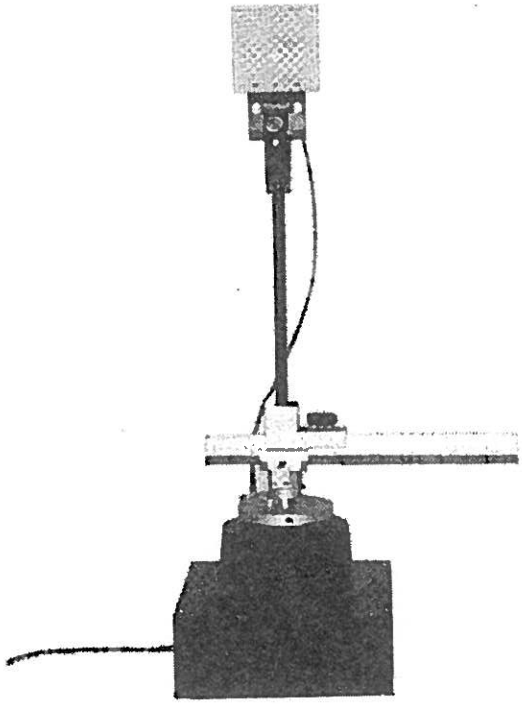


Figure 10-10 Setting of Even Polarization Receiving Antenna

Connect the single patch antenna and RF In terminal of a receiver with SMA cable used for 1m, and connect OUT PUT(1kHz) terminal of a receiver and Input(1kHz) in receiver of main controller with BNC Cable used for 1m.

4. Measure the length of a single patch antenna and record in Table 10-1.

Table 10-1 Length of Antenna [mm]

	Actual Length of Antenna
$\lambda/2$	
a	
b	
t	

5. As Figure 10-11, the distance between antennas is isolated as r=1m. Set the horn antenna used for transmitting and the single patch antenna used for receiving at even position with earth. Make the center of a front part(Horn Part)

of horn antenna and the center of a single patch antenna to place in straight line.

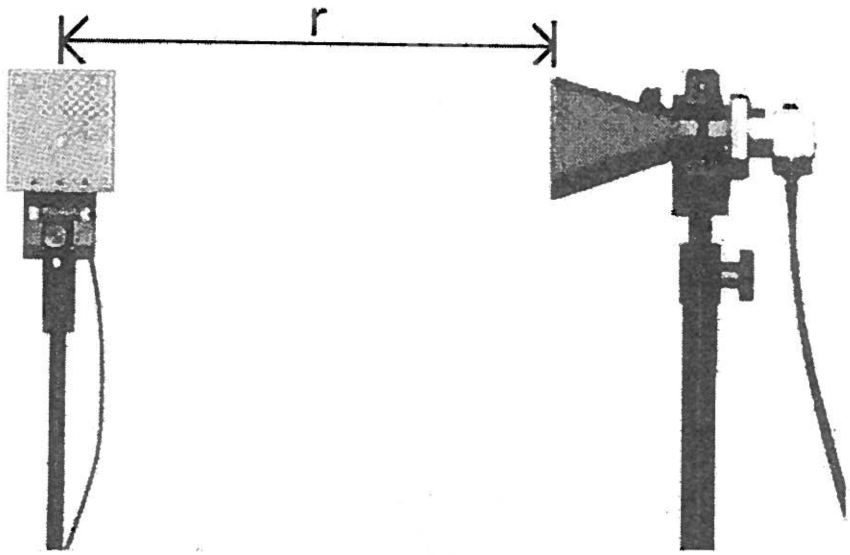


Figure 10-11 Distance between Antennas r

6. Set as below in condition of turning off the power of main controller.
   - Power OFF
   - 500MHz Oscillation Switch off
   - 2 GHz Oscillation Switch off
   - 10 GHz Oscillation Switch off
   - Modulation Switch (Mod) off

7. After set a switch in main controller as below, execute the Antenna Trainer program.
   - Power ON
   - 500MHz Oscillation Switch off
   - 2 GHz Oscillation Switch off
   - 10 GHz Oscillation Switch on
   - Modulation Switch (Mod) on

8. The program window is executed, execute Data Acquisition in Pop Up menu. Here after select Antenna, select E-Plane as Plane and control to be displayed 0 in gain displayer by adjusting the signal attenuation. The adjustment is completed, start Acquisition.

9. If the data acquisition id completed, save the taken radial pattern in file. Use the data box to confirm a radial pattern exactly. If set MSP(Max. Signal Position) to 0°, can see the radial pattern of this antenna.

10. Make the control plate to rotate 90° for the horn antenna is to be vertical with earth.

11. Make the single patch antenna used for receiving to be vertical with a rotary axis and set as Figure 10-12 to get a vertical polarization characteristic. In this time make the center point of front and the center of antenna used for receiving to be in straight line.

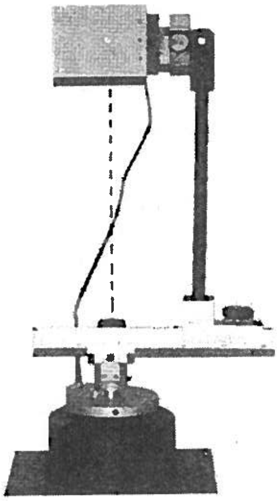


Figure 10-12 Setting of Single Patch Antenna

12. Click Antenna Initialize in Edit Menu of a software, click the Auto button to data acquisition is acquisition if finished, after select H-Plane as Plane, save the pattern in file.

13. Keep the Horn antenna used for transmitting to get a vertical polarization characteristic and set the horn antenna used for receiving to get a vertical polarization characteristic as Figure 10-10.

14. Click Antenna Initialize in Edit Menu of a software, and click again Delete

Screen then click the Auto button to data acquisition.

15. Observe three radial pattern.

16. Set a transmitting ·receiving antennas get a vertical polarization characteristic respectively. The distance between antenna id r=1.0m. Make a surrounding condition of antenna to be same as the first experiment. Take the E-Plane radial pattern of a single patch antenna and save in Dummy-Plane.

Theoretically if except an effect caused by a power damage, this radial pattern has to be same as the first pattern. If the pattern is different very much, have to do suitably by finding the pattern. where a reflection can be occurred. After do suitably, continue an experiment and save new pattern in E-Plane.

Click Data Indicating Line in View Menu of upper menu of a data analysis program. Two cursors(Blue, White) used for E-Plane and two cursors(Yellow, Green) used for H-Plane are appeared on the screen. If click an arrow on both side of a displayer of each color, the values in the displayer will be changed by moving the cursor of same color. These indicate the angle of cursor position and the receiving power in that time as dB, show the difference of angle between cursors and power in below 2 displayer. Record the value in below Table 10-2.

Table 10-2 Receiving Power for Angle

Angle	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Receiving Power of E-Plane for Angle												
Receiving Power of H-Plane for Angle												

17. Use the cursor to take the receiving angle of max. power in E-Plane pattern and the receiving power in that time. Click the Maximum Single Level button on

the E-Plane data window to confirm if a measured valued accorded to a taken value with cursor. Record this in Table 10-3.

Table 10-3 Comparison of E-Plane with Theoric Value

Taken Value with Cursor	Receiving Power	
	Angle	
Value by Maximum Single Level Icon	Receiving Power	
	Angle	

18. Take a half angle of main beam power in E-Plane pattern by using two cursors. Click the Half Power Beamwidth button on data window to confirm if accord the measured value with button as taken value with cursor.

Calculate a half-power beam width of single patch antenna in E-Plane.

$$HPBW_E = \mid \theta_{HPBWleft} - \theta_{HPBWright} \mid = \underline{\hspace{4cm}}$$

19. Repeat No.18 of the experiment procedure in H-Plane radial pattern.

$$HPBW_H = \underline{\hspace{4cm}}$$

20. Delete all cursors by clicking the data indicating line in view menu. Compare the experimental values with given value in the antenna software. If the calculated result is not accorded to this value, experiment and calculate again.

21. Save the E-Plane and H-Plane data and Out the result.

▣ EXCERCISE ▣

1. Mean to feed to the Microstrip patch antenna of 120Ω input impedance with a coaxial cable of 50Ω characteristic impedance. In this case, design $\lambda/4$ impedance inverter by 2 position.

2. In Figure 10-1, decide a and b of a square Microstrip patch antenna used for 2.4 GHz

3. Compare and explain the radial pattern of a Microstrip patch antenna and a horn antenna.

4. Take a gain of a single patch antenna.

5. What's the polarization characteristic of a single patch antenna?

EXPERIMENT 3-11.
2 DIMENSION ARRAY ANTENNA

Let's measure the radial pattern for E-Plane and H-Plane of 2 dimension array antenna. We will study the polarization characteristic of a 2dimension array antenna. Let's calculate a half-power beam width of a 2 dimension array antenna.

BASIC STUDY

1. Microstrip Plane Array Antenna

As the array element is a parameter giving an effect on radial pattern of an antenna of special array structure, the entire radial pattern of given array antenna can be forecasted by the principle of pattern multiplication. Where the pattern multiplication is means what multiply the radial pattern of individual antenna element by the array element.
As the square Microstrip antenna and the 2-slot waveguide antenna is equivalent each other, the radial pattern is same.
The E-Plane radial pattern for a 2-slot antenna excited to same phase and equal amplitude made of multiplying the E-Plane radial pattern of a 1-slot antenna by the array element for two elements. Accordingly this formula is as below.

$$E_{patch}(\Phi) = \frac{\sin\left(\frac{\beta h}{2}\cos\Phi\right)}{\frac{\beta h}{2}\cos\Phi}\cos\left(\frac{\beta h}{2}\cos\Phi\right) \qquad (11\text{-}1)$$

where
h is a width of slot(same as a base material thickness of a patch antenna)
b is a distance between two slots(same as length of a patch antenna)

$$\beta = \frac{2\pi}{\lambda}$$

1.1 Serial Array and Parallel Array

The square patch antenna is used as basic element of a Microstrip array antenna. In this time, we will treat two type of array(Plane array antenna of type of parallel feed and serial feed)

The Microstrip array antenna consists of some Microstrip antenna elements and Microstrip feed circuit. The feed circuit consists of the manual elements such as power distributor and transmitting line as well as the active elements such as phase shifter, amplifier, launcher and frequency mixer etc. The feed line is connected to the radial element directly and give not an effect on the radial pattern directly.

The best merits of a Microstrip antenna is what can etch the arrayed antenna on one base material as well as feed line. That is, can contain various elements to antenna with low price. The array antenna is very thin and can contain numerous elements so it can achieve to high effect.

The other merits of array antenna is a reliability. As it is manufactured by etching the copper panel, becomes the least of all the problem on manufacturing such as open or short-circuit. But the array antenna using a patch antenna has very narrow band of using frequency so it can be used only in band given exactly.

The Microstrip array antenna of parallel feed type is what feed with parallel to give suitable phase to each element. But to make main beam at vertical position with plane of arrayed antenna, generally feeding with same phase.

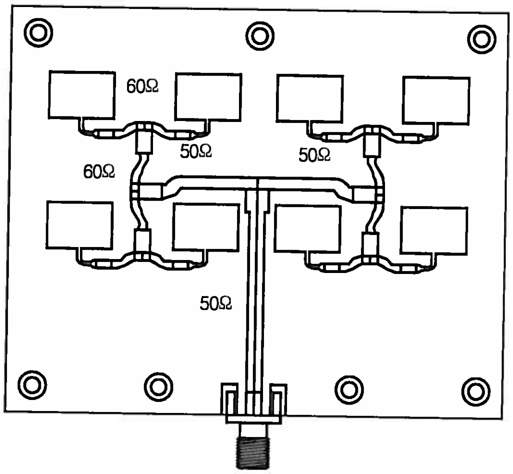


Figure 11-1 Microstrip Patch Array

To make the phase of current feeding to each element, must array the transmitting line and antenna elements to be symmetry. The structure like tree called cooperate feed is used generally to transmit the power with same phase. But it can be occurred the problem on designed space when there are many elements. If use numerous matching element called $\lambda/4$ inverter, can match exactly all radial elements to 50Ω feeding to antenna as Figure 11-1.

It is possible to connect the array element with serial. It may be efficient well but the serial feed type is complex to design in compared with parallel feed type caused by the dependent relation between each element. The element of each patch antenna is had to be seen equivalent value to 2-slot antenna, and had to be considered the mutual coupling effect between patches for calculation.

In the case of parallel feed array antenna, if increase the number of element to 2 times, the increasing of gain can be forecasted becomes restricted by feed damage. This damage is occurred by coupling of inductance and capacity between numerous feed line. In case of serial feed antenna, the connection between patches is linear accordingly the problem becomes few relatively.

This two type can be coupled by serial·parallel array taken merit of two feed type. As the numerous small serial arrays connect with parallel, it is possible to make the feed circuit to be simple and to design large sized array antenna decreasing power damage.

EXPERIMENT PROCEDURE

1. Set a transmitting·receiving antenna positioner and a computer which are main instrument of an antenna experimental set.

2. Fix 10GHz Horn antenna on the polarization control plate in transmitter. Set it to be even with earth to get an even polarization characteristic. The transmitting Horn antenna as Figure 11-2 gets an even polarization characteristic.
   Connect 10GHz oscillation output terminal in main controller and Cable connecting terminal9 of Horn antenna with SMA cable used for 2m.

Figure 11-2 Setting of Even Polarization Transmitting Antenna

3. Fix the 2 dimension array antenna on the polarization control plate in receiver to measure an axial mode radial characteristic. Use the position control screw in receiver, place the ground plane to be vertical with a rotary axis in receiver. See Figure 11-3 to set.

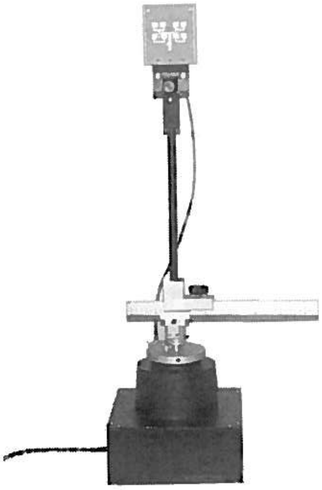


Figure 11-3 Setting of Even Polarization Receiving Antenna

Connect the 2 dimension array antenna and RF In terminal of a receiver with SMA cable used for 1m, and connect OUT PUT(1kHz) terminal of a receiver and Input(1kHz) in receiver of main controller with BNC Cable used for 1m.

4. Measure the length of a 2 dimension array antenna and record in Table 11-1.

Table 11-1 Length of Antenna and Feeder[mm]

	Length of Antenna
$\lambda/2$	
a	
b	

5. As Figure 11-3, the distance between antennas is isolated as r=1m. Set the horn antenna used for transmitting and the single patch antenna used for receiving at to be even and opposite each other. Make the center of a front part(Horn Part) of horn antenna and the center of a single patch antenna to place in straight line.

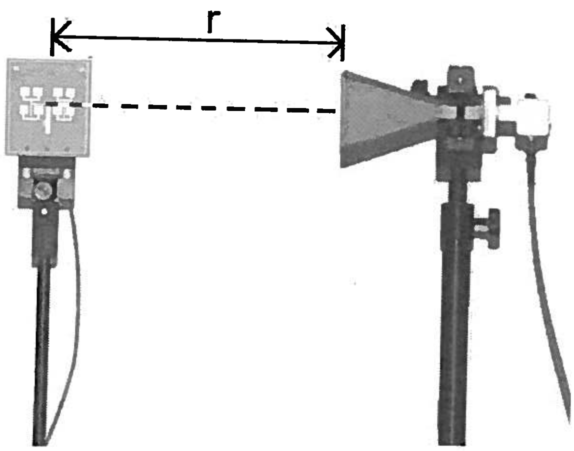


Figure 11-4 Distance between Antennas r

6. Set as below in condition of turning off the power of main controller.
   - Power OFF
   - 500MHz Oscillation Switch off
   - 2 GHz Oscillation Switch off
   - 10 GHz Oscillation Switch off
   - Modulation Switch (Mod) off

7. After set a switch in main controller as below, execute the Antenna Trainer program.
   - Power ON
   - 500MHz Oscillation Switch off
   - 2 GHz Oscillation Switch off
   - 10 GHz Oscillation Switch on
   - Modulation Switch (Mod) on

8. The program window is executed, execute Data Acquisition in Pop Up menu. Here after select Antenna, select E-Plane as Plane and control to be displayed 0 in gain displayer by adjusting the signal attenuation. The adjustment is completed, start Acquisition.

9. If the data acquisition is completed, save the taken radial pattern in file. Use the data box to confirm a radial pattern exactly. If set MSP(Max. Signal Position) to 0°, can see the radial pattern of this antenna.

10. Make the control plate to rotate 90°for the Horn antenna is to be vertical with earth.

11. Make the 2 dimension array antenna used for receiving to be vertical with a rotary axis and set as Figure 11-5 to get a vertical polarization characteristic. In this time make the center point of front horn and the center of antenna used for receiving to be in straight line.

12. Click Antenna Initialize in Edit Menu of a software, click the Auto button to data acquisition. If the data acquisition is finished, after select H-Plane as Plane, save the pattern in file.

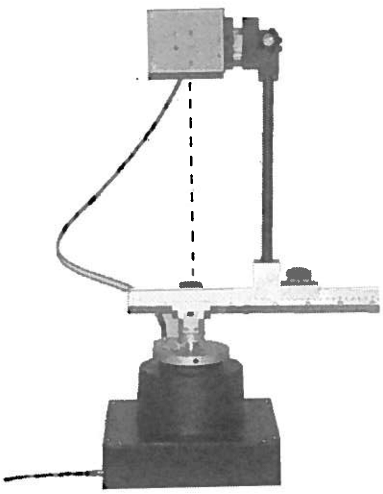


Figure 11-5 Setting of 2 dimension array antenna

13. Keep the Horn antenna used for transmitting to get a vertical polarization characteristic and set the 2 dimension array antenna used for receiving to get a vertical polarization characteristic. In this time, make transmitting and receiving antenna to be opposite position and Make the center of a front horn part of transmitting antenna and the center of receiving antenna to place in straight line.

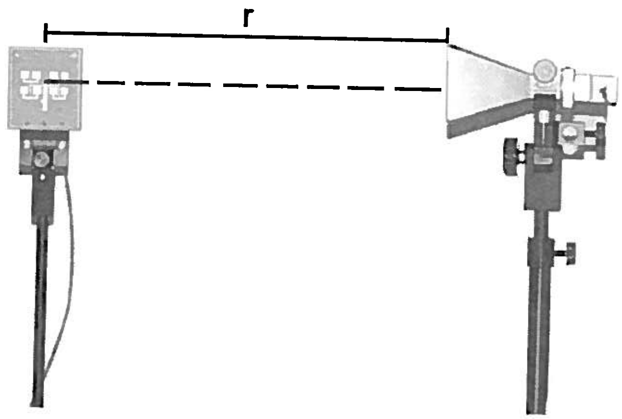


Figure 11-6 Vertical and Ever Antenna

14. Click Antenna Initialize in Edit Menu of a software, and click again Delete Screen then click the Auto button to data acquisition.

15. Observe three radial pattern.

16. Set a transmitting·receiving antennas get a vertical polarization characteristic respectively. The distance between antennas is r=1.0m. Make a surrounding condition of antenna to be same as the first experiment. Take the E-Plane radial pattern of 2 dimension array antenna and save in Dummy-Plane.

    Theoretically if except an effect caused by a power damage, this radial pattern has to be same as the first pattern. If the pattern is different very much, have to do suitably by finding the position where a reflection can be occurred. After do suitably, continue an experiment and save new pattern in E-Plane.

    Click Data Indicating Line in View Menu of upper menu of a data analysis program. Two cursors(Blue, White) used for E-Plane and tow cursors(Yellow, Green) used for H-Plane are appeared on the screen. If click an arrow on both side of a displayer of each color, the values in the displayer will be changed by moving the cursor of same color. These indicate the angle of cursor position and the receiving power in that time as dB, show the difference of angle between cursors and power in below 2 displayer. Record the values in below Table 11-2.

Table 11-2 Receiving Power for Angle

Angle	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Receiving Power of E-Plane for Angle												
Receiving Power of H-Plane for Angle												

17. Use the cursor to take the receiving angle of max. power in E-Plane pattern and the receiving power in that time. Click the Maximum Single Level button on the E-Plane data window to confirm if a measured value is accorded to a taken value with cursor. Record this in Table 11-3.

Table 11-3 Comparison of E-Plane with Theoretic Value

Taken Value with Cursor	Receiving Power	
	Angle	
Value by Maximum Single Level Icon	Receiving Power	
	Angle	

18. Take a half angle of main beam power in E-Plane pattern by using two cursors. Click the Half Power Beamwidth button on data window to confirm if accord the measured value with button as taken value with cursor.

Calculate a half-power beam width of 2 dimension array antenna in E-Plane.

$$HPBW_E = | \theta_{HPBWleft} - \theta_{HPBWright} | = \underline{\qquad\qquad}$$

19. Repeat No. 18 of the experiment procedure in H-Plane radial pattern.

$$HPBW_h = \underline{\qquad\qquad}$$

20. Delete all cursors by clicking the data indicating line in view menu. Compare the experimental values with given value in the antenna software. If the calculated result is not accorded to this values, experiment and calculate again.

21. Save the E-Plane and H-Plane data and output the result.

▣ EXCERCISE ▣

1. Means to array four Microstrip patch antenna of 120Ω input impedance, and to feed with a coaxial cable of 50Ω characteristic impedance. In this case, design $\lambda/4$ impedance inverter by 3 position.

2. Draw 2 dimension lay out in case of arraying 16 Microstrip patch antenna used for 10 GHz.

3. Compare and explain the radial pattern of single Microstrip antenna and 2 dimension array antenna.

4. Take a gain of a Microstrip antenna arraying by 2 dimension the 8 Microstrip patch antenna used for 10 GHz.

5. What's the polarization characteristic of a 2 dimension array antenna?

EXPERIMENT 3-12. CIRCLE ARRANGING ANTENNA

Let's measure radiation pattern about E-Plane and H-Plane of circle arranging antenna this experiment. We'll study polarization characteristic of circle arranging antenna. Using software, let's calculate half-power beam width of circle arranging antenna.

BASIC STUDY

1. Array Factor

Let's consider the case that each element is arranged linearly like d equally as seen figure 12-1, for examine calculating method of arranging factor of antenna.

In case of receiving far electron magnetic field on the transversal plane, $\Theta = 0$, distance between signaler and each element is essentially identified. Thus current supplied to elements is added exactly the same phase.

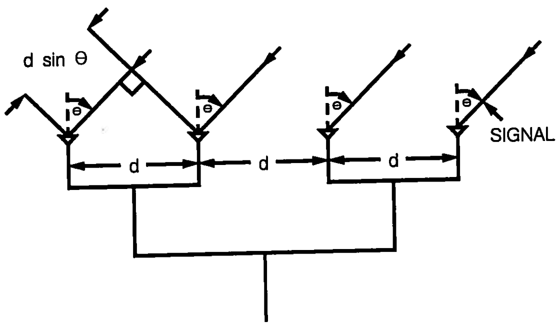


Figure 12-1 4-Element Linear Array

Figure 12-1, when Θ> 0, according to moving right element into left element, each element is far from signaler as *d* sinΘ than fore element. This reason makes phase of current supplied to each element different. Phase difference Ψ is given by :

$$\Psi = \beta d \sin \Theta \qquad (12\text{-}1)$$

Array factor(AF) for linear arranging made up of *N* piece element is written :

$$AF = e^{j(N-1)\Psi/2} \frac{\sin(N\Psi/2)}{\sin(\Psi/2)} \qquad (12-2)$$

In above formula, phase factor $e^{j(N-1)\Psi/2}$ indicates phase difference between the phase center and the starting point. Omitting this phase factor, it is given by :

$$AF = A_0 \frac{\sin(N\Psi/2)}{\sin(\Psi/2)} \qquad (12-3)$$

When $\Psi = 0$, $A_0 N$ is the maximum value. [It is easily got that unfold denominator, numerator by power series and take limit to Ψ]. Dividing formula 12-3 by maximum value, you can get the normalized array factor $f(\Psi)$ of N element

arranging antenna which is considered fixed space and identical value and phase center is located in the starting point.

$$f(\Psi) = \frac{\sin(N\Psi/2)}{N\sin(\Psi/2)} \qquad (12-4)$$

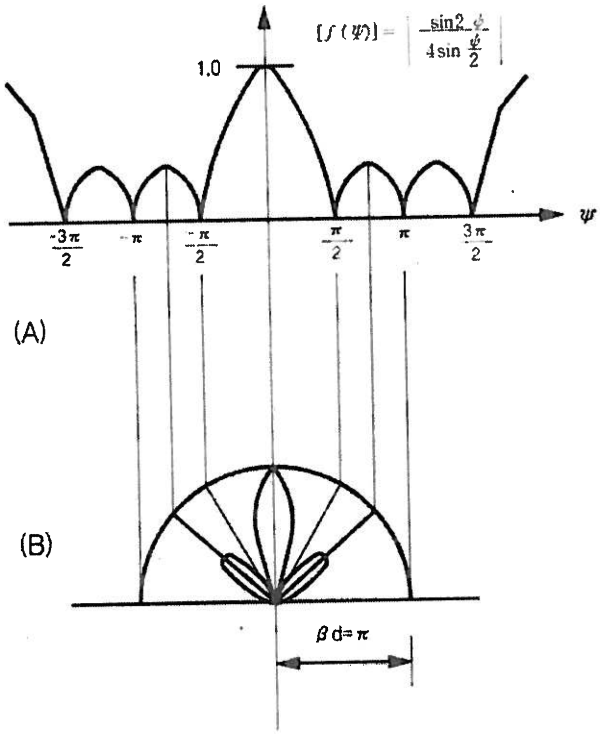


FIGURE 12-2 (A) 4-Array Factor for Element Arranging
(B) Radiation Pattern for $d = \lambda/2$

Figure 12-2(A) gives normalized array factor. This figure represents answer of arranging antenna as function of phase difference Ψ between elements near arranging antenna. When the phase difference is 0, i. e. when signalling power is located on the broadside, answer is the maximum.

Figure 12-2(B) used diagrammatic method which indicates radiation pattern of antenna by polar coordinate. Figure is described half-circle which radius is βd. For example, when the interval of element is $\lambda/2$, the radius becomes

$\beta d = (2\pi/\lambda)(\lambda/2) = \pi$.

After drawing half-circle, from each points in the figure which indicate array factor by figure to the half-circle draw a vertical line down. From the crossings between each vertical line and half-circle to the starting point of the circle draw another lines down. Then, along this segments of the lines, you make a point selecting points part from the starting points as same length as width of the array factor.

For example, when $\Psi = \pi/2$, array factor is 0, so in the polar coordinate, point corresponding to it is the starting point. Array factor between $\Psi = \pi/2$ and $\Psi = \pi$ is the maximum. This is identical with maximum value in the polar coordinate.

2. SINGLE CIRCLE ARRANGING

Generally, linear arranging antenna is easy array of element and making of feeder. But in the H-Plane and E-Plane, in order to design identically type of beam, the number of element always must be multiplied double for one line, because of this, it has a fault that area required becomes greater.
Circle arranging antenna which antenna structure is symmetrical on the angle can realize high benefit antenna as arranging many antenna on the small area.
Moreover circle arranging antenna by non-linear arranging has a merit which can get a radiation pattern of Taylor water supply type.

Like figure 12-3, field of circle arranging antenna which isotropic element with *N* quantity on the x-y plane as the same space is located along the circle with radius a is given :

$$E_n(r, \theta, \phi) = \sum_{n=1}^{N} a_n \frac{e^{jkR_n}}{R_n} \tag{12-5}$$

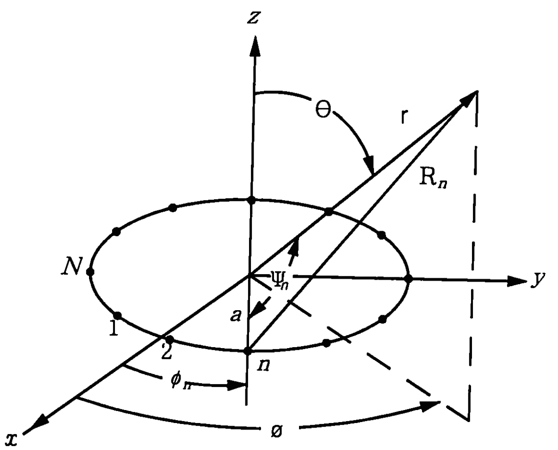


Figure 12-3 N-Circle Arranging Structure

R_n is the distance from the n-th element to the observing point. At the observing point, field is given as the following formula :

$$E_n(r, \theta, \phi) = \frac{e^{-jkr}}{r} \sum_{n=1}^{N} I_n e^{j[ka \sin\theta \cos(\phi - \phi_n) + \alpha_n]} \tag{12-6}$$

I_n amplitude of current excited to the n-th element

ϕ_n angle of n-th element on the x-y plane

α_n phase of current excited to the n-th element

As $\frac{e^{-jkr}}{r}$ indicates isotropic element, if it is assumed that dimension and phase of current power feeding to each element of the single-circle arranging antenna with N quantity is equal, array factor can be written as follows :

$$AF(\theta, \phi) = I \sum_{n=1}^{N} e^{j[ka \sin\theta \cos(\phi - \phi_n)]} \tag{12-7}$$

To make power feed by micro strip line the same phase, micro strip arranging antenna element must be an even number. Because feeder structure can be symmetrical. In case of single circle arranging, radiation pattern is widely affected by the element number of antenna and distance to the center point.

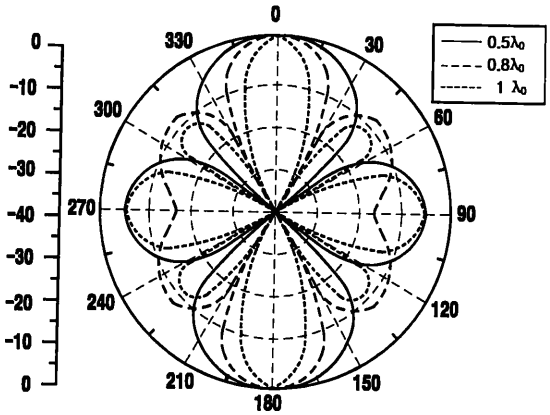


FIGURE 12-4 Radiation Pattern Change of Circle Arranging Antenna According to the Isolated Distance Change (y-z plane)

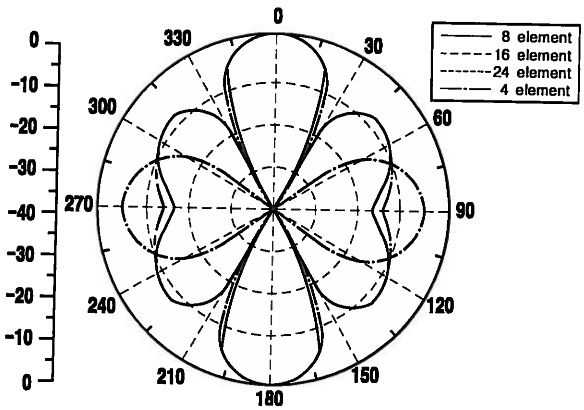


FIGURE 12-5 Radiation Pattern Change According to the Circle Arranging Element Number Change (y-z plane)

3. MEASUREMENT

Measurement equipment and system used in order to measure characteristics of the circle arranging antenna is like figure 12-1 and 12-6.

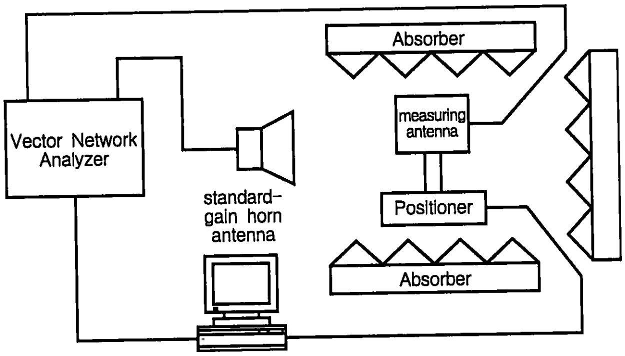


Figure 12-6 Antenna Measuring System

Table 12-1 Measuring Equipment

Equipment	Model	Use
network analyzer	HP-8510	s-parameter measure
spectrum analyzer	HP-8592B	frequency sphere power analyzing
sweep oscillator	HP-8350	by frequency power supply
standard gain horn	DGB-520	standard gain providing

To measure radiation pattern and gain of circle arranging antenna, the standard horn antenna having 8.4~12.6[GHz] frequency band and the Anechoic chamber etc. is used. And using network analyzer, measure the resonance frequency and the reflected loss. Measure received signal circling 360°antenna which will be measured at the 1[m] distance from standard horn antenna. Figure 12-7 shows the gain according to the frequency of standard-gain horn antenna(DGB-520).

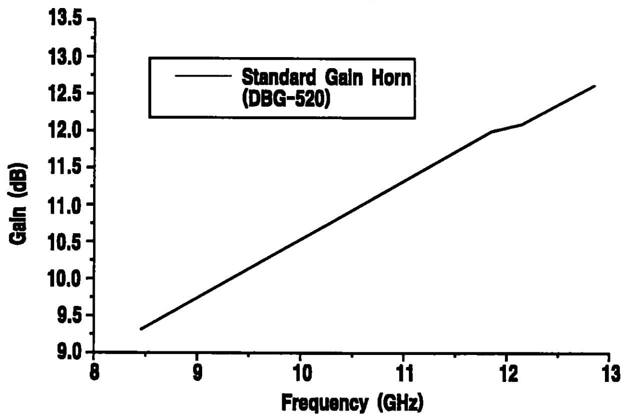
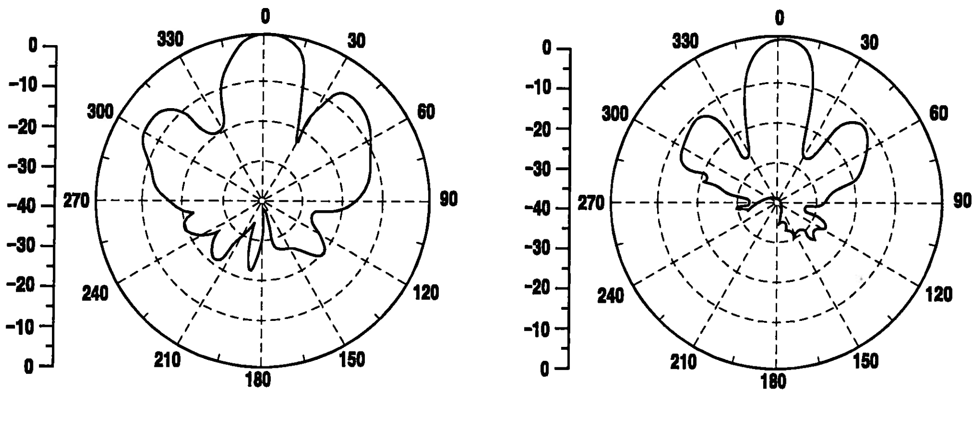


Figure 12-7 Standard Gain Horn Antenna (DGB-520).

Figure 12-8 is the result that measure radiation pattern of single circle arranging antenna made of 8-elements.

Operating frequency of antenna is 10[GHz], gain is 13.1[dBi], -3[dB] beam width is about ±12°on the H-plane and about -14.5° ~ +12°on the E-plane.

Also, maximum size of sub lobe represents -11.4[dB] on the H-plane and -7.5[dB] on the E-plane.



(a) E-plane (b) H-plane

Figure 12-8 Radiation Pattern of Circle Arranging Antenna(8-element).

EXPERIMENT PROCEDURE

1. Set main controller which is main equipment of antenna experiment set, receiving
-transmitting antenna positioner and computer.

2. Fix the 10GHz Horn antenna on the polarization controlling plate of transmitter. Set horizontally to the ground in order to have horizontal polarization characteristics. Like figure 12-9, installed transmitting horn antenna bear the character of horizontal polarization. Connect 500MHz launching output terminal of main controller and cable connecting terminal of horn antenna by SMA cable for 2m.

Figure 12-9 Horizontal Polarization Transmitting Antenna

3. Fix the two-dimensional arranging antenna on polarization controlling plate of receiver horizontally to the ground in order to bear the character of horizontal polarization. Place antenna on the circling center of antenna receiver using position controlling plate. Install referring figure 12-10.

Figure 12-10 Installation of Horizontal Polarization Receiving Antenna

Connect the cable connecting terminal of circle arranging antenna and RF IN terminal of receiver by SMA cable for 1m. And connect output(1kHz) terminal of receiver and receiving section input(1kHz) terminal of main controller by BNC cable for 1m.

4. Measure length of the circle arranging antenna and record on the table 12-1.

Table 12-1 Length of antenna and feeder [mm]

	Length of antenna
$\lambda/2$	
a	
b	

5. Like figure 12-11, distance between antennas is isolated by r=1m. Install the horn antenna for transmitting and the single patch antenna for receiving horizontally and to face each other. At this time, put the front section(horn section) square center of horn antenna and the center of single patch antenna in a straight line.

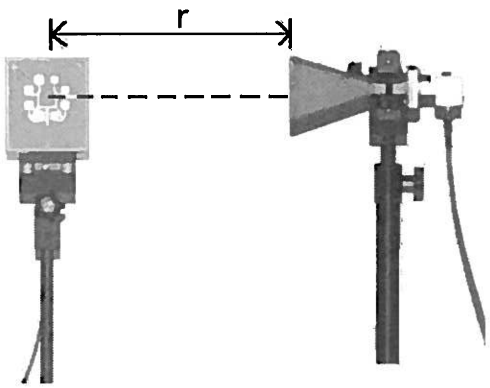


Figure 12-11 Distance r between antennas

6. Set like below, in the condition of power is off.
   - Power off
   - 500MHz launching switch off
   - 2 GHz launching switch off
   - 10 GHz launching switch off
   - Modulating switch (Mod) off

7. Execute the antenna trainer program, after setting switch in the main controller like below.
   - Power source on
   - 500MHz launching switch off
   - 2 GHz launching switch off
   - 10 GHz launching switch on
   - Modulating switch (Mod) on

8. After executing program window, execute data-gain in the pop up menu. After selecting antenna, select E-Plane and control in order to be indicated 0 on the antenna gain display window controlling signal attenuation. After control is finished, start data-gain.

9. After data-gain is over, store obtained radiation pattern by file. Use data box in order to ensure correctly radiation pattern. Set MSP(maximum signal place) on 0°, and you can find out radiation pattern of this antenna.

10. Let the polarization controlling plate circle 90°, for horn antenna have vertical polarization character.

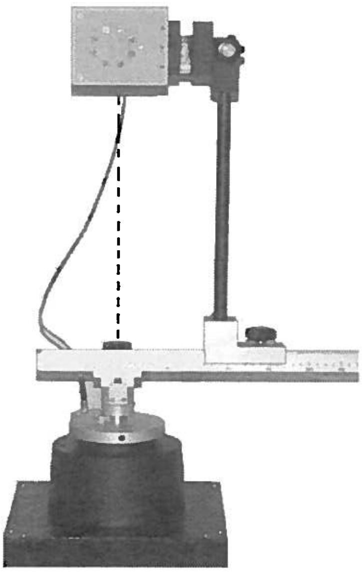


Figure 12–12 Installation of circle arranging antenna

11. Install like figure 12–12, for circle arranging antenna for receiving have vertical polarization character.

12. Click antenna initialization on the editing menu of software and gain the data putting Auto button. After finishing data–gain, select H–Plane and save the pattern in a file.

13. Keep the horn antenna for transmitting in order to bear the character of vertical polarization and install the circle arranging antenna for receiving in order to bear the character of horizontal polarization to face each other.

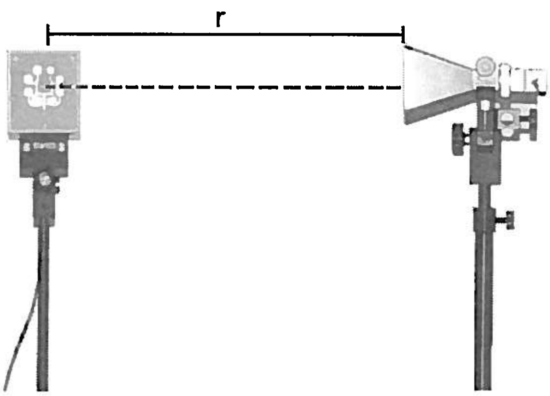


Figure 12-13 Vertical Horizontal Antenna

14. Click antenna initialization on the editing menu of software, click screen deletion on the editing menu again and gain the data putting Auto button.

15. Observe three radiation patterns.

16. Install again each receiving & transmitting antenna in order to bear the character of horizontal polarization. Distance between antennas is r=1.0m. Identify the environment surrounding antenna with first experiment. Get the E-Plane radiation pattern of circle arranging antenna and save in the Dummy-Plane.

Theoretically, this radiation pattern must be equal with first pattern except effect by electric power loss. If the pattern is quite different, you must take proper measure finding place where radiation can occur. After taking proper measure, keep going experiment and save the new pattern in the E-plane.

Click data indicating line on the view menu in the upper menu of data analysis program. Two cursors for E-plane(sky blue, white) and two cursors for H-plane(yellow, green) represent on the screen. Click arrow being both sides to the displayer of each color, and values of displayer will be changed moving same color cursor. These indicate angle which cursor is located on and receiving electric power at that time in dB. Also, they indicate angle between cursors and difference of electric power in two displayers below. Record values obtained at this time on the table 12-2 below.

Table 12-2 Receiving electric power by angle

angle	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Receiving electric power of E-Plane by angle												
Receiving electric power of E-Plane by angle												

17. Using cursor, get the angle and receiving electric power at that time being received maximum electric power on the E-Plane pattern. Record on the table 12-3 that being identified value being measured putting Maximum Single Level button of E-Plane data window and value being obtained using cursor.

Table 12-3 Receiving electric power, Comparison of angle

Value obtained by cursor	Receiving electric power	
	Angle	
Value by Maximum Single Level icon	Receiving electric power	
	Angle	

18. Using two cursors, get the angle being half of electric power magnitude of main beam. Confirm that it is identical which value being measured putting Half Power Beam width button of E-Plane data window and value being obtained using cursor.

Figure the half-electric power beam width on the E-Plane of circle arranging antenna.

$$HPBW_E = | \theta_{HPBWleft} - \theta_{HPBWright} | = \underline{\qquad\qquad}$$

19. Repeat experiment order No. 18 by the radiation pattern of H-Plane.

$$HPBW_h = \underline{\qquad\qquad}$$

20. Eliminate all cursor clicking data indicating line of view menu. Compare experiment values with values being given in the antenna software. If the results of calculation isn't identical with this values, experiment and figure again.

21. Save data of E-Plane and H-Plane and output result.

▣ EXERCISES ▣

1. Mean to power feed micro strip patch antenna 8 having input impedance 120 Ω by coaxial cable having characteristic impedance 50Ω on the circle arranging antenna. At this case, design λ/4 impedance converter for 4 position.

2. Draw layout in case of circle arranging the micro strip patch antenna 16 for 10 GHz.

3. Compare and explain that radiation patterns of the single micro strip patch antenna with the circle arranging antenna.

4. Get the gain of micro strip antenna which the micro strip patch antenna 16 for 10 GHz is circle arranged.

5. What is the polarization character of circle arranging micro strip antenna?