LABORATORY MANUAL

COURSE NAME:- ANTENNA LAB

COURSE CODE :- 6EC4-22

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

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Director
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ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

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EXPERIMENT LIST

PART-I (Antenna)

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2. Measurement of Radiation Pattern, Gain, HPBW of a folded dipole antenna.
3. Measurement of Radiation Pattern, Gain, HPBW of a loop antenna
4. Measurement of Radiation Pattern, Gain, VSWR, input impedance and reflection coefficient for given Monopole antenna
5. Measurement of Radiation Pattern, Gain, VSWR, input impedance and reflection coefficient for given Yagi antennas
6. Study of the Radiation Pattern, Gain, HPBW of a horn antenna
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8. Study the radiation pattern, gain, VSWR, and input impedance of a rectangular microstrip patch antenna
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10. Study the effect of ground plane on the radiation pattern of an antenna
11. Study antenna designing in CST Microwave Studio
12. Design a rectangular microstrip patch antenna using CST MWS

PART-II (Optical Fiber)

To perform following experiments based on Fiber Optic Trainer.

13. To set up Fiber Optic Analog link and Digital link.
14. Measurement of Propagation loss and numerical aperture.

Beyond Syllabus

15. Designing of Patch Antenna operating for UWB band frequency range for mobile communication (Simulation Based).
16. Designing of Antenna for 5 G frequency range (Simulation Based).

VISION, MISSION OF DEPARTMENT

VISION

"To establish an acknowledged Department of academics in the field of Electronics and Communication Engineering."

MISSION

- To equip the students with strong foundations to enable them for continuing education in the field of Electronics and Communication Engineering.
- To provide quality education & to make the students entrepreneur and employable.
- To undertake research and development in the field of Electronics and Communication Engineering.

Programme Educational Objectives

PEO1: The graduates will be competent enough to apply current knowledge and skill to solve problems of the society.
PEO2: The graduates will be capable of identifying, formulating, analyzing and creating engineering solutions using modern tools to develop novel products solutions.
PEO3: The graduates will be professional, lifelong learning skills, ethics, research skills and leadership for independent or team working within a group.

Programme Outcomes

PO 1: Engineering Knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
PO 2: Problem Analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
PO 3: Design/Development of Solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
PO 4: Conduct Investigations of Complex Problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
PO 5: Modern Tool Usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools prediction and modeling to complex engineering activities with an understanding of the limitations.
PO 6: The Engineer and Society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO 7: Environment and Sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and the need for sustainable development.
PO 8: Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
PO 9: Individual and Team Work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
PO 10: Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and receive clear instructions.
PO 11: Project Management and Finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in team, to manage projects and in multidisciplinary environments.
PO 12: Life-Long Learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

Programme Specific Outcomes

PSO1: Graduates possesses the ability to understand and apply basic knowledge of core Electronics & Communication Engineering for the benefit of society.
PSO2: Graduates will be proficient to apply electronic modern IT tools for the design and analysis of complex electronic systems in furtherance to research activities.
PSO3: The ability to be adaptable to the multidisciplinary nature at workplace, develop excellent Interpersonal Skills & Leadership qualities that benefits the individual &organization.

Course Outcomes

After completion of this course, students will be able to –

LO-1 Describe the basic concept of antenna radiation mechanism used in wireless communication.
LO-2 Explain the different mode of communication used in different application as mobile, satellite.
LO-3 Analyze the behavior of different type of antenna based on its fundamental parameters.
LO-4 Evaluate the factors that affect the power received by the receiving antenna.
LO-5 Design real time application based antenna for used in communication operating band.

PCE/ECE/VI SEM/ 6EC4-22

CO-PO Mapping Matrix of Course

	PO-1 (Engineering Knowledge)	PO-2 (Problem Analysis)	PO-3 (Design/Development of Solutions)	PO-4 (Conduct Investigations of Complex Problems)	PO-5 (Modern Tool)	PO-6 (Engineer and Society)	PO-7 (Environment and Sustainability)	PO-8 (Ethics)	PO-9 (Individual and Team Work)	PO-10 (Communication)	PO-11 (Project Management and Finance)	PO-12 (Life-Long Learning)
CO-1	3	-	-	-	-	-	-	-	-	-	-	-
CO-2	3	-	-	-	-	-	-	-	-	-	-	-
CO-3	-	3	-	2	-	-	-	-	-	-	-	-
CO-4	-	-	3	3	3	-	-	-	-	-	3	-
CO-5	-	-	3	-	-	-	-	-	-	-	-	-

CO-PSO Mapping Matrix of course

COs and LOs	PSO-1 (Apply Basic Knowledge)	PSO-2 (Modern IT Tools)	PSO-3 (Skills & Leadership)
CO-1	3	2	-
CO-2	3	2	-
CO-3	3	2	-
CO-4	3	2	-
CO-5	3	2	-

PREREQUISITES LAB

Sr.No.	Name of Lab/Subject	Code
1	Electron Magnetic Field Theory	5EC4-07
2	Analog & Digital Communication	4EC4-07

MARKING SCHEME

RTU MARKS SCHEME

Maximum Marks Allocation		
Internal Exam	External Exam	Total
30	20	50

RAJASTHAN TECHNICAL UNIVERSITY, KOTA

SYLLABUS

III Year - VI Semester: B.Tech. (Electronics & Communication Engineering)

6EC4-22: Antenna and Wave Propagation Lab

Credit: 1 | **Max. Marks: 50(IA:30, ETE:20)**

0L+0T+2P | **End Term Exam: 2 Hours**

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Office of Dean Academic Affairs
Rajasthan Technical University, Kota

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ROTOR PLAN

Rotor 1		Rotor 2	
1	Study the gain pattern, HPBW, FNBW and Directivity of a dipole antenna.	**8**	Study of the Radiation Pattern, Gain, HPBW of a horn antenna
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LAB PLAN

Total Number of Experiment 14

Total Number of Turns Required 12

Number of Turns Required For

Experiment Number	Turns	Scheduled Lab
Experiment 1	1	
Experiment 2	1	
Experiment 3	1	
Experiment. 4& 5	1	
Experiment. 6 & 7	1	
Internal Evaluation	1	
Experiment 8	1	
Experiment 9	1	
Experiment. 10	1	
Experiment 11 & 12	1	
Experiment 13 & 14	1	
Internal Evaluation	1	

LAB EVALUATION SHEET

POORNIMA COLLEGE OF ENGINEERING, JAIPUR
DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINNERING
EVALUTION SHEET (To Be Pasted on board)

Session: Lab Code: 6EC4-22
Year/Semester: **Lab Name: AWP Lab**
Rotor:- I **Name of the Faculty:-**

ROTOR: - I **Name of the Faculty:-**

S. No.	Reg. No.	Name of Student	Exp 1		Exp 2		Exp 3		Exp 4		Exp 5	
			Marks	Date	Marks	Date	Marks	Date	Marks	Date	Marks	Date
1												
2												
3												
4												
5												
6												

ROTOR:- II **Name of the Faculty:-**

S. No.	Reg. No.	Name of Student	Exp 6		Exp 7		Exp 8		Exp 9		Exp 10	
			Marks	Date	Marks	Date	Marks	Date	Marks	Date	Marks	Date
7												
8												
9												
10												
11												
12												

LAB RULES (DO'S & DON'T)

RESPONSIBILITIES OF USERS

Users are expected to follow some fairly obvious rules of conduct:

ALWAYS

- Enter the lab on time and leave at the proper time.
- Wait for the previous class to leave before the next class enters.
- Keep the bag in the respective racks.
- Utilize lab hours in the corresponding.
- Turn off the instrumentation before leaving the lab unless a member of lab staff has specifically told you not to do so.
- Leave the labs at least as nice as you found them.
- If you notice a problem with a piece of equipment (e.g. a CRO doesn't respond) please report it to lab staff immediately. Do not attempt to fix the problem yourself.

NEVER

- Don't damage the equipment.
- Don't bring any external material in the lab, except your lab record, copy and books.
- Don't bring the mobile phones in the lab. If necessary, then keep them in silence mode.

Please be considerate of those around you, especially in terms of noise level. While labs are a natural place for conversations of all types.

INSTRUCTIONS (SAFETY PRECAUTIONS)

BEFORE ENTERING IN THE LAB

- All the students are supposed to prepare the theory regarding the next experiment.
- Students are supposed to bring the lab copy.
- Previous programs should be written in the lab copy.
- All the students must follow the instructions, failing which he/she may not be allowed in the lab.

WHILE WORKING IN THE LAB

- Adhere to experimental schedule as instructed by the lab in-charge.
- Get the previous experiment result signed by the instructor.
- Get the output of the current experiment checked by the instructor in the lab copy.
- Each student should work on his/her assigned experiment kit at each turn of the lab.
- Take responsibility of valuable accessories.
- Concentrate on the assigned practical

ZERO LAB
INTRODUCTION TO THE SUBJECT

Basics of Antenna

Definition: Antennas are a fundamental component of modern communication system. By definition, an antenna acts as a transducer between a guided wave in a transmission line and electromagnetic wave in free space. Antennas demonstrate a property known as reciprocity, which is an antenna will maintain the same characteristics regardless if it is transmitting or receiving. When a signal is fed into antenna, the antenna will emit radiation distributed in space a certain way. A graphical representation of the relative distribution of the radiated power in space is called a radiation pattern. The gain of antenna in any direction is power density radiated in direction divided by power density this would have been radiated by a lossless (perfect) isotropic radiator having the same total accepted input power.

Wavelength

We often refer to antenna size relative to wavelength. For example: a half-wave dipole, which is approximately a half-wavelength long. Wavelength is the distance a radio wave will travel during one cycle. The formula for wavelength is below:

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

Where:

λ is the wavelength, and is expressed in units of length, typically meters, feet, or inches.

c is the speed of light, 29,979,307,700 centimeters/second, or 11,802,877,050 inches/second.

f is the frequency

For example: the wavelength in air at 825 MHz is: $\frac{11.803 \times 10^{[illegible]}}{825 \times 10^{6}} = 14.307$ in/cycle

Note: The length of a half-wave dipole is slightly less than a half-wavelength due to end effect. The speed of propagation in coaxial cable is slower than in air, so the wavelength in the cable is shorter. The velocity of propagation of electromagnetic waves in coax is usually given as a percentage of free space velocity, and is different for different types of coax.

Impedance Matching

For efficient transfer of energy, the impedance of the radio, the antenna, and the transmission line connecting the radio to the antenna must be the same. Radios typically are designed for 50 ohms impedance and the coaxial cables (transmission lines) used with them also have a 50 ohm impedance. Efficient antenna configurations often have impedance other than 50 ohms; some sort of impedance matching circuit is then required to transform the antenna impedance to 50 ohms.

VSWR and Reflected Power

The Voltage Standing Wave Ratio **(VSWR)** is an indication of how good the Impedance match is. VSWR is often abbreviated as SWR. A high VSWR is an indication that the signal is reflected prior to being radiated by the antenna. VSWR and reflected power are different ways of measuring and expressing the same thing. A VSWR of 2.0:1 or less is considered good. Most commercial antennas, however, are specified to be 1.5:1 or less over some bandwidth. Based on a 100 watt radio, a 1.5:1 VSWR equates to a forward power of 96 watts and a reflected power of 4 watts, or the reflected power is 4.2% of the forward power.

Bandwidth

Bandwidth can be defined in terms of radiation patterns or VSWR/reflected power. The definition used in this book is based on VSWR. Bandwidth is often expressed in terms of percent bandwidth, because the percent bandwidth is constant relative to frequency. If bandwidth is expressed in absolute units of frequency, for example MHz, the bandwidth is then different depending upon whether the frequencies in question are near 150, 450, or 825 MHz. A mathematical analysis of bandwidth is provided on the next page.

Percent bandwidth is defined as:

$$BW = 100\,\frac{F_H - F_L}{F_C} \quad \text{where:}$$

F_H is the highest frequency in the band
F_L is the lowest frequency in the band

F_C is center frequency of the band $\qquad F_C = \frac{F_H + F_L}{2}$

Example: If you need an antenna that operates in the 150 - 156 MHz band, you need an antenna that covers at least a $\frac{156-150}{153}100 = 3.9\%$ bandwidth.

The problem might need to be worked a different way, if the antenna is tuned to 460 MHz and provides a 1.5:1 VSWR bandwidth of 5%, what are FL and FH. The equations above can be solved for FH and FL:

$$F_H = F_C\left(1 + \frac{BW}{200}\right) \text{ and } F_L = F_C\left(1 - \frac{BW}{200}\right)$$

Plugging the numbers into the equations: and the answers are

$$F_H = 460\left(1 + \frac{5}{200}\right) = 471.5\text{MHz}$$

$$F_L = 460\left(1 - \frac{5}{200}\right) = 448.5\text{MHz}$$

Directivity and Gain

Directivity is the ability of an antenna to focus energy in a particular direction when transmitting or to receive energy better from a particular direction when receiving.
The relationship between gain and directivity: *Gain = efficiency/Directivity*.
Gain is given in reference to a standard antenna. The two most common reference Antennas are the isotropic antenna and the resonant half-wave dipole antenna. The isotropic antenna radiates equally well in "all" directions. Real isotropic antennas do not exist, but they provide useful and simple theoretical antenna patterns with which to compare real antennas. An antenna gain of 2 (3 dB) compared to an isotropic antenna would be written as 3 dBi. The resonant half-wave dipole can be a useful standard for comparing to other antennas at one frequency or over a very narrow band of frequencies. To compare the dipole to an antenna over a range of frequencies requires an adjustable dipole or a number of dipoles of different lengths.

Gain Measurement

One method of measuring gain is by comparing the antenna under test against a known standard antenna. This is technically known as a gain transfer technique. At lower frequencies, it is convenient to use a 1/2-wave dipole as the standard. At higher frequencies, it is common to use a calibrated gain horn as a gain standard, with gain typically expressed in dBi. Another method for measuring gain is the 3 antenna method. Transmitted and received power at the antenna terminals is measured between three arbitrary antennas at a known fixed distance. The Friis transmission formula is used to develop three equations and three unknowns. The equations are solved to find the gain expressed in dBi of all three antennas.

Antenna Placement

Correct antenna placement is critical to the performance of an antenna. An antenna mounted on the roof will function better than the same antenna installed on the hood or trunk of a car. Knowledge of the vehicle may also be an important factor in determining what type of antenna to use. You do not want to install a glass mount antenna on the rear window of a vehicle in which metal has been used to tint the glass. The metal tinting will work as a shield and not allow signals to pass through the glass. When installing antennas at a base station, a stainless steel mast should be used to properly pass stray RF current away from the antenna and provide proper support.

Radiation Patterns

The radiation or antenna pattern describes the relative strength of the radiated field in various directions from the antenna, at a fixed or constant distance. The radiation pattern is a "reception pattern" as well, since it also describes the receiving properties of the antenna. The radiation pattern is three-dimensional, but it is difficult to display the three dimensional radiation patterns in a meaningful manner, it is also time consuming to measure a three-dimensional radiation pattern. Often radiation patterns are measured that are a slice of the three-dimensional pattern, which is of course a two-dimensional radiation pattern which can be displayed easily on a screen or piece of paper. These pattern measurements are presented in either a rectangular or a polar format.

Near-Field and Far-Field Patterns

The radiation pattern in the region close to the antenna is not exactly the same asthe pattern at large distances. The term near- field refers to the field pattern that exists close to the antenna; the term far-field refers to the field pattern at large distances. The far-field is also called the radiation field, and is what is most commonly of interest. The near-field is called the induction field although it also has a radiation component).Ordinarily, it is the radiated power that is of interest, and so antenna patterns are usually measured in the far-field region. For pattern measurement it is important to choose a distance sufficiently large to be in the far-field, well out of the near-field. The minimum permissible distance depends on the dimensions of the antenna in relation to the wavelength. The accepted formula for this distance is:

$$r_{min} = \frac{2D^2}{\lambda}$$

Where:

r_{min} is the minimum distance from the antenna

D is the largest dimension of the antenna

λ is the wavelength

When extremely high power is being radiated (as from some modern radar antennas), the near-field pattern is needed to determine what regions near the antenna, if any, are hazardous to human beings.

Beamwidth

Depending on the radio system in which an antenna is being employed there can be many definitions of beamwidth. A common definition is the half power beamwidth. The peak radiation intensity is found and then the points on either side of the peak represent half the power of the peak intensity are located. The angular distance between the half power points traveling through the peak is the beamwidth. Half the power is — 3dB, so the half power beamwidth is sometimes referred to as the 3dB beamwidth.

Antenna Polarization

Polarization is defined as the orientation of the electric field of an electromagnetic wave. Polarization is in general described by an ellipse. Two often used special cases of elliptical polarization are linear polarization and circular polarization. The initial polarization of a radio wave is determined by the antenna that launches the waves into space. The environment through which the radio wave passes on its way from the transmit antenna to the receive antenna may cause a change in polarization.

With linear polarization the electric field vector stays in the same plane. In circular polarization the electric field vector appears to be rotating with circular motion about the direction of propagation, making one full turn for each RF cycle. The rotation may be righthand or left-hand.

Choice of polarization is one of the design choices available to the RF system designer. For example, low frequency (< 1 MHz) vertically polarized radio waves propagate much more successfully near the earth than horizontally polarized radio waves, because horizontally polarized waves will be canceled out by reflections from the earth. Mobile radio systems waves generally are vertically polarized. TV broadcasting has adopted horizontal polarization as a standard. This choice was made to maximize signal-to-noise ratios. At frequencies above 1 GHz, there is little basis for a choice of horizontal or vertical polarization, although in specific applications, there may be some possible advantage in one or the other. Circular polarization has also been found to be ofadvantage in some microwave radar applications to minimize the "clutter" echoes received from raindrops, in relation to the echoes from larger targets such as aircraft. Circular polarization can also be used to reduce multipath. The majority of the antennas utilized in this experiment are vertically polarized because of their predominance in antenna applications.

Pre Lab Questions:

1. Define Antenna
2. Give antenna parameters
3. Define Impedance Matching.
4. Define VSWR.
5. Relationship between Directivity & Gain
6. What is need for radiation pattern?
7. What is the difference between radiation intensity and gain?
8. What is the formula for directivity and Gain?

EXPERIMENT NO. 1

Aim: Study the gain pattern, HPBW, FNBW and Directivity of a dipole antenna.

Apparatus: Amitech Antenna Transmitter and Receiver Kit, Antenna Stepper Motor Controller, Dipole Antenna, Antenna tripod and stepper pod with connecting cables, RF Generator, PC on which antenna software was installed,dipole

Theory:

The most commonly quoted parameter in regards to antennas is S11. S11 represents how much power is reflected from the antenna, and hence is known as the **reflection coefficient** (sometimes written as gamma: Γ or **return loss**. If S11=0 dB, then all the power is reflected from the antenna and nothing is radiated. If S11=-10 dB, this implies that if 3 dB of power is delivered to the antenna, -7 dB is the reflected power. The remainder of the power was "accepted by" or deliverd to the antenna. This accepted power is either radiated or absorbed as losses within the antenna. Since antennas are typically designed to be low loss, ideally the majority of the power delivered to the antenna is radiated.

The basic setup is shown in figure:

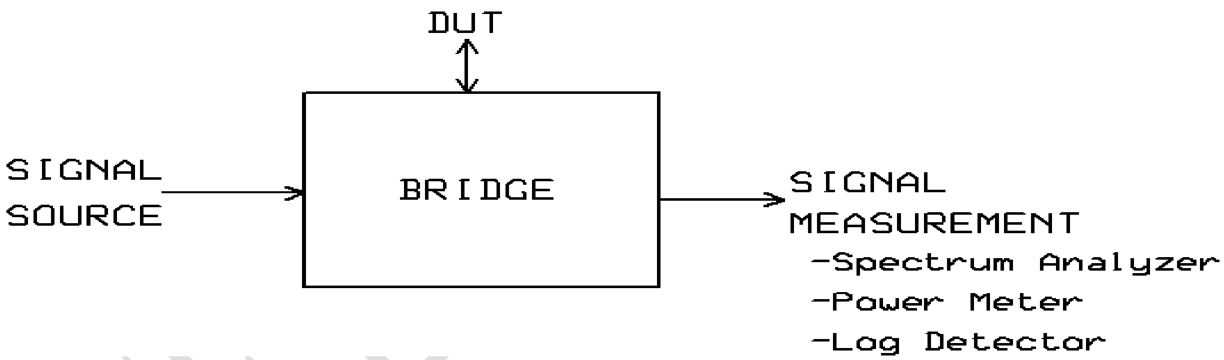
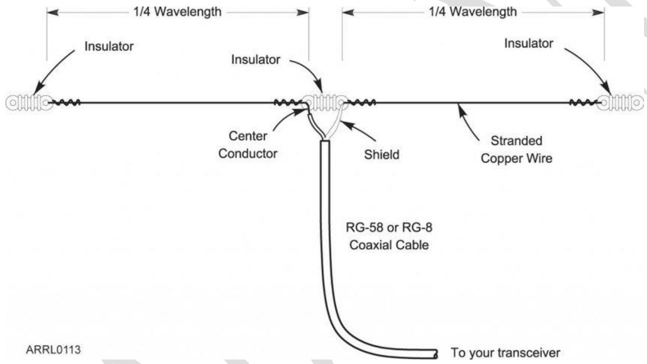


Figure1.1: Basic Setup"DUT" is the device under test; it receives a signal and returns a reflection.

We need a signal source, whose frequency we must set manually, and we need a way to measure the output level in dbm, which we will have to record manually. It is possible to get some automation by using a sweep generator; more on this later. The bridge routes the input signal to the DUT and outputs a signal proportional to the reflection received from the DUT. The bridge itself can take various forms. One such bridge is decribed later. For the moment, suffice it to say that it is not difficult to build a reflection bridge which can isolate the reflection well enough to measure return losses in the range 0-30 db with as much accuracy as we generally need. We use a type of calibration called "reference calibration", whereby we establish a referenceoutput level representing zero return loss, attach the DUT, and compare the DUT reflection level to the reference level. For example, if the reference level is -2 dbm, and the output with the DUT attached is -23 dbm, the return loss is 21 dbm. The reference is established by using two measurement standards: an open and a short. The open is a coax connector whose backside has nothing attached. The short is a connector whose backside is directly shorted by a metal strip or disc connecting the center pin to the body of the connector. Of course, we can get an open circuit by not attaching anything to the output connector, but at higher frequencies the shorttransmission line represented by the open connector has some effect, and we want the distance to the actual point of the open circuit to be about the same as the distance to the actual short. Below a couple hundred MHz, we probably don't actually need to attach an open connector. To get a reference level representing zero return loss, we can just measure the output with the open standard attached. An open circuit has a return loss of zero. A short circuit also has a return loss of zero (meaning 100% reflection), but the phase of the reflection is 180 degrees different between an open and a short. Because we are not measuring phase (return loss is a scalar quantity), the output with the open and short attached should look identical, in theory. In practice, there will generally be some difference between the open and short reflection outputs, though it is often less than 0.5 db.



Return loss is derived from the voltage of the signal reflected by a device under test (DUT). Ifwe know the voltage of the signal sent to the DUT and the voltage of the reflection, the reflection coefficient is the ratio of the reflected signal to the incident signal:

Reflection Coefficient = Γ= Reflected Voltage/Incident Voltage

That ratio is what we will use to measure the reflection coefficient. Another formula, useful when you know the impedance of the DUT, is as follows:

Reflection Coefficient =

$$\text{Reflection Coefficient} = \Gamma = \frac{Z - Z_0}{Z + Z_0}$$

Z=DUT impedance;

Z0=Reference Impedance (here, 50 ohms)

We will always use a reference impedance of 50 ohms here.

Return loss is the magnitude of that reflection coefficient expressed in decibels as a non-negative number:

Return Loss= –20*Log(|Γ|)

(Since |Γ|<=1, return loss will be non-negative)
In our case, the conversion into decibels is done automatically by the instrument measuring the bridge output, as that instrument will measure in db. Return loss can be translated into SWR, or into the percent of power reflected by the DUT, or, roughly, into impedance. Table shows those values for various levels of return loss.

Return Loss	Reflect Coef. Mag.	SWR	% Power Reflected	R>50 ohms	R<50 ohms
0	1.000	INF	100.00	INF	0.0
1	0.891	17.4	79.43	869.5	2.9
2	0.794	8.72	63.10	436.2	5.7
3	0.708	5.85	50.12	292.4	8.5
4	0.631	4.42	39.81	221.0	11.3
5	0.562	3.57	31.62	178.5	14.0
6	0.501	3.01	25.12	150.5	16.6
7	0.447	2.61	19.95	130.7	19.1
8	0.398	2.32	15.85	116.1	21.5
9	0.355	2.10	12.59	105.0	23.8
10	0.316	1.92	10.00	96.2	26.0
15	0.178	1.43	3.16	71.6	34.9
20	0.100	1.22	1.00	61.1	40.9
25	0.056	1.12	0.32	56.0	44.7
30	0.032	1.07	0.10	53.3	46.9
35	0.018	1.04	0.03	51.8	48.3
40	0.010	1.02	0.01	51.0	49.0
50	0.003	1.01	0.00	50.3	49.7
60	0.001	1.00	0.00	50.1	49.9

Table1.1: Translating return loss to reflection coefficient, SWR, percentage of power reflected, and equivalent resistance, one greater than and one less than 50 ohms.

The correspondence of return loss and impedance deserves a little more attention. Any given return loss can be generated by a variety of impedances; each such impedance generates the same magnitude of reflection coefficient, but different phases. Since return loss is a scalar quantity, it does not include the phase, so all those impedances generate the same return loss.
Figure shows the impedances that generate a reflection coefficient whose magnitude (denotedby rho]) is 0.33, corresponding to a return loss of 9.6 db.

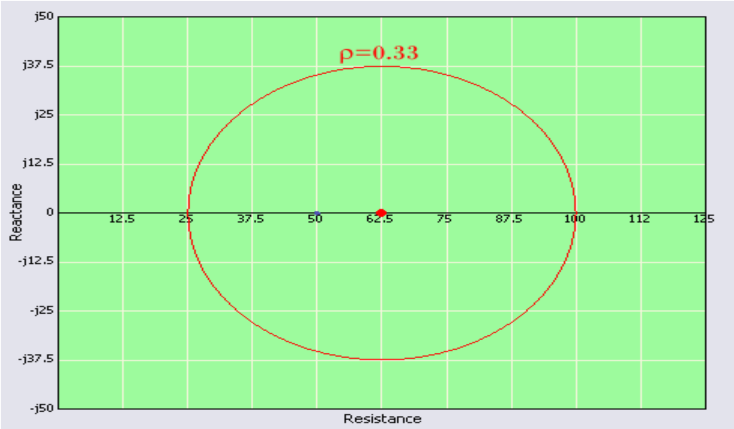


Figure 1.2: Impedances which generate a reflection coefficient with magnitude of 0.33 (return loss of 9.6 db).

There are two pure resistance values which create any finite return loss. As shown in above Figure, if the lower one is 50/N (N=2 in this case), then the higher one is 50*N. As the reflectioncoefficient decreases (return loss increases), the circle gets smaller and smaller and its center moves closer and closer to 50 ohms. Therefore, return loss can be thought of as a measure of how close the impedance is to 50 ohms.

Experimental set up:

Procedure:

1. Place the main unit on the table and connect power cord.
2. Adjust Level Potentiometer of RF generator to middle position. Select switch to ‘INT’ position and adjust Level.
3. Select the switch to ‘FWD’ position and adjust FS, ADJ Potentiometer to middle position.
4. Install Transmitting mast, place it beside the main unit and connect it to the .main unit’s ‘RF OUT’ using a BNC to BNC cable of 25” long.
5. Install Receiving mast and keep it at some distance from the Transmitter mast.
6. Place RF detector Unit beside the Receiving mast and connect it to the Receiving mast using a BNC to BNC cable of 25” long
7. Keep the base of Transmitting mast such that the ‘0’degree position of Goniometry should be directed towards the RF Detector and also align the marker of the mast with ‘0’ degree position.
8. Install Detector Antenna on the Receiving mast. Keep its direction towards the

Transmitting mast by rotating it in counter clockwise direction.

Calculation:

S.No	Angle in Degrees	Detector (reading(mA))	Gain in dB

Result: Successfully measured the input return loss versus frequency forhalf wave dipoleantenna.

///General principles:

Plotting a polar diagram involves measuring and recording received signal strength at known intervals of angular positions.

To do this you require a constant level RF signal source (from either transmitter or signal generator or a noise generator) and receiver. The RS 232 output of the receiver is connected to the com port in a computer.

To measure the transmitting station's polar diagram the receiving station's antenna remains stationary and the transmitting station's antenna rotates. To measure the receiving station's polar diagram the transmitting station's antenna remains stationary and the receiving station's antenna rotates.

Uploading:

The stepper motor controller provides a 10 ms pulse on reaching a particular position which is available at pulse out of SCU (stepper Controller unit).This pulse out is then connected to Trigger Stepper BNC of Rx. The Rx(receiver) stores the dBuV reading when an externally provided trigger pulse is received. Hence when the stepper controller is operated in auto mode with step size of 1 degree and start position of 0 degrees it will give 359 pulses to the Rx for taking 359 readings before coming to a halt. For each pulse received from SCU , the Rx stores the instantaneous dBuV reading of Rx which then can be uploaded to PC from Rx menu – Uploading. The receiver can accept trigger pulses from transmitter also and advance the frequency in selected step sizes. The receiver will store the instantaneous dBuV reading on receiving the trigger pulse. This mode will help plot return loss, antenna bandwidth plots etc.

Real time Plot:

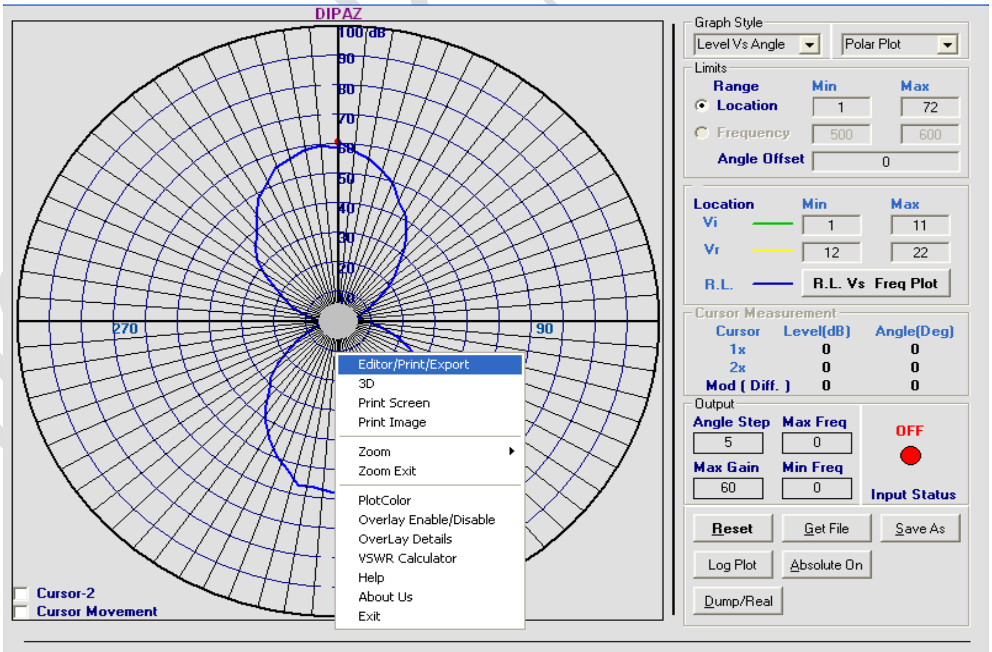
For real time plot simply connect the receiver to the comport of the PC. Open the software user interface and press the realtime button. Now the antenna will be plotted while it is being rotated.

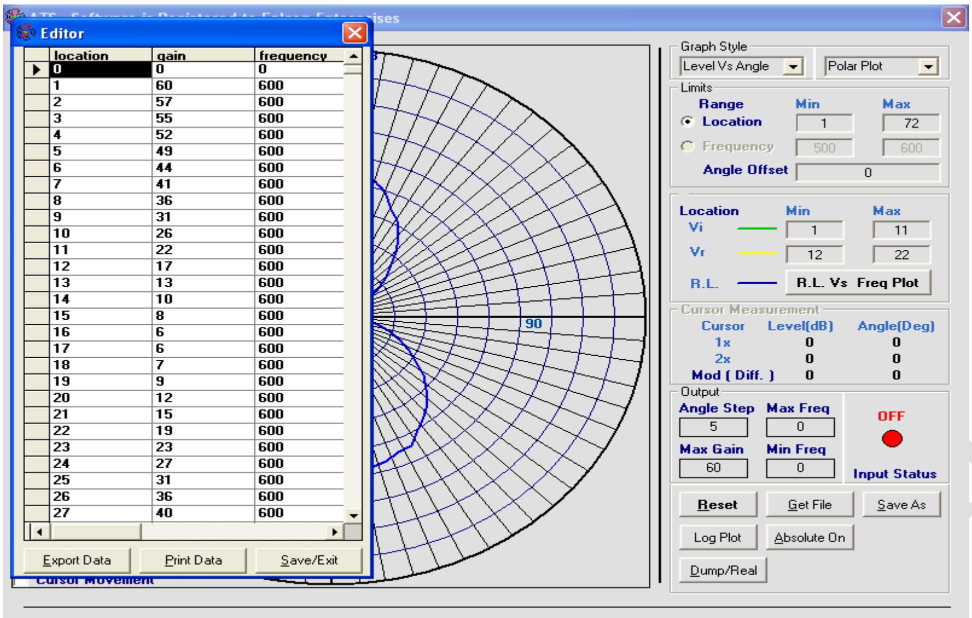
Software Operation Steps:

Starting from Top under Heading **Graph Style** Select either 1. **Level Vs. Angle** or 2. **Level Vs. Freq.** Select **Level Vs. Angle** option for plotting antenna gain readings with respect to angle. As antenna is rotated with the help of stepper motor controller, antenna gain readings are stored at particular rotated angles in receiver. This data containing frequency, RF level(gain) and location is dumped into PC.

In the below table location specifies the angle for eg., 1st location means 5 degree in case 5 degree step size is selected from stepper motor controller unit whereas 72nd location means 360 degree rotated angular position. Similarly 2nd location means 2 degree in case 1 degree step is chosen and 20 degree in case 10 degree step size is selected.

Now, select **Locations Min 1** and **Max 72** under **Limit Range** menu in case 5 degree step size is chosen for motor rotation. The **Frequency Min** and **Max** option below **Location** is disabled and shall be enabled only when **Level Vs. Freq** option is selected from **Graph Style** menu. **Angle Offset** option under **Limits** menu is used to rotate the antenna plot under polar plot graph by angles ranging from 1 to 360 degrees or more. Below **Limit** menu is **Location Min** and **MaxVi, Vr** and **R.L.** option which is used for plotting Incident voltage Vs. frequency, Reflected Voltage Vs. frequency and finally Return Loss Vs. Frequency plot using directional coupler or return loss Bridge. This option is used while plotting **Level Vs. Freq**.





Quiz:

1. Define folded dipole.
2. Draw the radiation pattern of folded dipole antenna.
3. Give the application of folded dipole antenna.
4. Write the frequency range of RF signal.
5. Explain the properties of Dipole, Folded Dipole and Log Periodic Antenna.
6. Define log periodic antenna.

EXPERIMENT NO. 2

Aim: Measurement of Radiation Pattern, Gain, HPBW of a folded dipole antenna.

Apparatus: Transmission trainer kit, receiver meter, half wave and quarter wave dipole antenna, dipole antenna, probes, tri-pod stand.

Theory:

The half wave dipole is perhaps the simplest and most fundamental antenna design possible. Hertz used a dipole antenna during his initial radio experimentation. This is why a dipole is often referred to as the "hertz dipole" antenna. The dipole is so practical that it is utilized (in some form) in at least half of all antenna systems used today.

Fig2.1: Detector

Here are some key principles of the dipole antenna:

1. A dipole antenna is a wire or conducting element

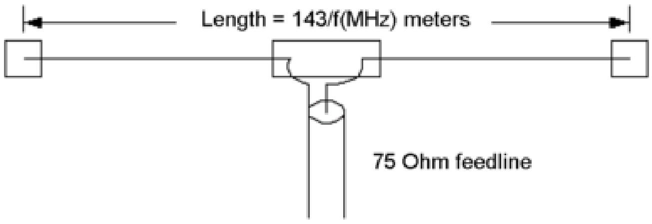
whose length is half the transmitting wavelength. To calculate the length of a half wave dipole in free space, one may use the following equation:

Length (ft) = 492 / frequency (MHz)

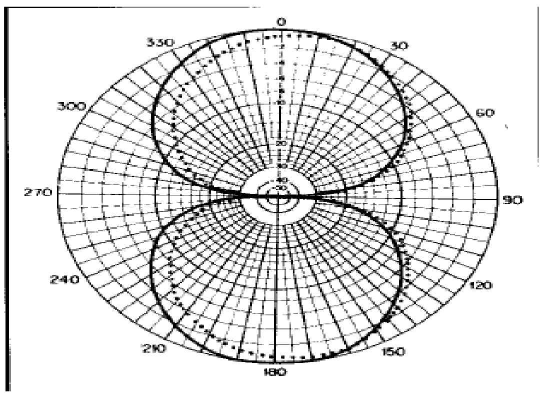
2. A dipole antenna is fed in the center. By using a piece of coaxial cable transmission line, one may feed the center conductor of a transmission line to a ¼ wavelength piece of wire. The outer shield or ground of the cable may be connected to the remaining ¼ wavelength piece of wire.

Thus, you have a dipole antenna, fed in the center, with an overall length of ½ wavelength. The total ½ wavelength of wire is to be stretched out evenly, being perpendicular to the transmission line. How exactly does the signal come out of the cable and emanate from the wires into space? The ¼ wavelength wire which is fed by the center conductor of the transmission line is known as the hot portion. One quarter othe wave leaks from the attached wire, and the remaining quarter of the wave “hops” over to the grounded second ¼ wavelength wire. Since these two pieces of ¼.

Wavelength wire work together to emit the wave, we often refer to a dipole as a perfect resonant antenna. Why is this important? If an antenna is resonant, it will be matched to the transmission line and/or transmitter and the bulk of the signal will actually be transmitted, not reflected back and wasted as heat (i.e. Standing Wave Ratio SWR). It should be noted that a dipole has an impedance of 75 ohms, not 50 ohms. Ordinarily a mismatch could cause a problem, but the mismatch of 50 ohm cable feeding a 75 ohm antenna is minimal with a resultant SWR of 1.5:1. This corresponds to roughly a 5% waste of power.



Radiation Pattern:



Calculation:

S.No	**Angle in Degrees**	**Detector (reading(mA))**	**Gain in dB**

1. 3-dB Beamwidth = Difference in angle between points on polar plot drawn at 3 dB less to the max gain given by that particular antenna.
2. Antenna Efficiency = It is the ratio of the radiated power to the input power of the antenna:

$$\varepsilon_R = \frac{P_{radiated}}{P_{input}}$$

where ε_T is the antenna's total efficiency, M_L is the antenna's loss due to impedance mismatch, and ε_R is the antenna's radiation efficiency.

Since M_L is always a number between 0 and 1, the total antenna efficiency is always less than the antenna's radiation efficiency. Said another way, the radiation efficiency is the same as the total antenna efficiency if there was no loss due to impedance mismatch.

3. Directivity: It is the ratio of maximum radiation intensity (power per unit surface) radiated by the antenna in the maximum direction divided by the intensity radiated by isotropic antenna radiating the same total power as that antenna.

Result :

Radiation pattern of antenna is plotted and Beamwidth of antenna is_____, Directivity of antenna_____,Antenna efficiency of antenna____

EXPERIMENT NO. 3

Aim: Measurement of Radiation Pattern, Gain, HPBW of a loop antenna

Theory:

Loop antennas feature simplicity, low cost and versatility. They may havevarious shapes: circular, triangular, square, elliptical, etc. They are widely usedin communication links up to the microwave bands (up to 3 GHz). They arealso used as electromagnetic (EM) field probes in the microwave bands.Electrically small loops are widely used as compact transmitting and receivingantennas in the low MHz range (3 MHz to 30 MHz, or wavelengths of about 10m to 100 m).Loop antennas are usually classified as electrically small (/3 C ~ lemda) andelectrically large (C ~ lemda). Here, C denotes the loop's circumference.The small loops of a single turn have small radiation resistance (< 1 Ω) usuallycomparable to their loss resistance. Their radiation resistance, however, can beimproved by adding more turns. Also, the small loops are narrowband. Typicalbandwidths are less than 1%. However, clever impedance matching can providelow-reflection transition from a coaxial cable to a loop antenna with a tuningfrequency range as high as 1:10.1 Moreover, in the HF and VHF bands where theloop diameters are on the order of a half a meter to several meters, the loop canbe made of large-diameter tubing or coaxial cable, or wide copper tape, whichcan drastically reduce the loss.

The small loops, regardless of their shape, have a far-field pattern very similarto that of a small electric dipole perpendicular to the plane of the loop. This isexpected because the small loops are effectively magnetic dipoles. Note,however, that the field polarization is orthogonal to that of the electric dipole (E lemda instead of Eλ).As the circumference of the loop increases beyond /3 λ , the patternmaximum shifts towards the loop's axis and when C ~λ , the maximum of thepattern is along the loop's axis.

The small loop antennas have the following features:

1) high radiation resistance provided multi-turn ferrite-core constructionsare used;

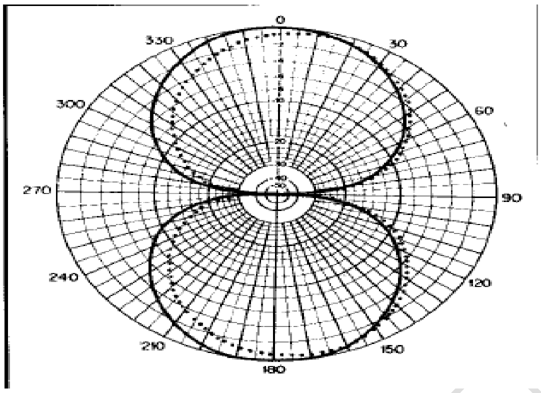
2) high losses, therefore, low radiation efficiency;

3) simple construction, small size and weight.

Small loops are usually not used as transmitting antennas due to their lowefficiency. However, they are much preferred as receiving antennas in AM radioreceivers because of their high signal-to-noise ratio (they can be easily tuned toform a very high-Q resonant circuit), their small size and low cost.Loops are constructed as magnetic field probes to measure magnetic fluxdensities. At higher frequencies (UHF and microwave), loops are used tomeasure the EM field intensity. In this case, ferrite rods are not used.

Since the loop is a typical linearly polarized antenna, it has to be orientedproperly to optimize reception. The optimal case is a linearly polarized wave withthe H-field aligned with the loop's axis.

Radiation Pattern:



Calculation:

S.No	Angle in Degrees	Detector (reading(mA))	Gain in dB

Result:

Radiation pattern of loop antenna is plotted and Beamwidth of antenna is_____, Directivity of antenna_____,Antenna efficiency of antenna____.

Quiz:

1. Define loop Antenna.
2. Draw the radiation pattern of loop antenna.
3. Give the application of loop antenna.
4. Write the frequency range of loop Antenna.
5. What are the different properties of loop Antenna

EXPERIMENT NO. 5

Aim: Measurement of Radiation Pattern, Gain, VSWR, input impedance and reflection coefficient for given Yagi antennas.

Apparatus: Transmission trainer kit, Receiver meter, probes, 3, 4 or 5element YagiUda antenna (folded dipole), probes etc.

Theory:

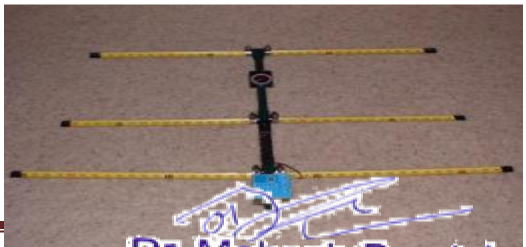
A **Yagi-Uda Antenna**, commonly known simply as a **Yagi antenna** or **Yagi**, is a directional antennasystemconsisting of an array of a dipoleand additional closely coupled parasitic elements (usually a reflector and one or more directors). The dipole in the array is driven, and another element, 5% longer, operates as a reflector. Other shorter parasitic elements are typically added in front of the dipole as directors. This arrangement gives the antenna directionality that a single dipole lacks. Yagi are directional along the axis perpendicular to the dipole in the plane of the elements, from the reflector through the driven element and out via the director(s). If one holds out one's arms to form a dipole and has the reflector behind oneself, one would receive signals with maximum gain from in front of oneself.

Yagi-Uda antennas which include one or more director elements, which, by virtue of their being arranged at approximately a quarter-wavelength mutual spacing and being progressively slightly shorter than a half wavelength, direct signals of increasingly higher frequencies onto the active dipole. (See also log-periodic antenna.) Thus, the complete antenna achieves a distinct response bandwidth determined by the length, diameter, and spacing of all the individual elements; but its overall gain is proportional to its length, rather than simply the number of elements.

Yagi-Uda antenna signal-gathering action compared to other end-fire, backfire and traveling-wave types.All the elements usually lie in the same plane, typically supported on a single boom or crossbar. The parasitic elements do not need to be coplanar, but can be distributed on both sides of the plane of symmetry. Many Yagi-Uda antennas (including the one pictured) are designed to operate on multiple bands; the resulting design is made more complicated by the presence of a resonant parallel coil and capacitor combination (called a "trap") in the elements. Traps are used in pairs on a multiband antenna. The trap serves to isolate the outer portion of theelement from the inner portion for the trap design frequency. In practice, the higher frequency traps are located closest to the boom of the antenna.

Elements of Yagi Uda:

The Yagi antenna is used frequently because it offers gain an directivity. The Yagi antenna was developed by a Japanese engineer Yagi-Uda. Its design is based exclusively on dipoles. A quick glance at a standard TV antenna will show a series of dipoles in parallel to each other with fixed spacing between the



elements. The number of elements used will depend on the gain desired and the limits of the supporting structure. A three element Yagi consists of a director, a driven element, and a reflector. Below is a picture of how these elements are configured:

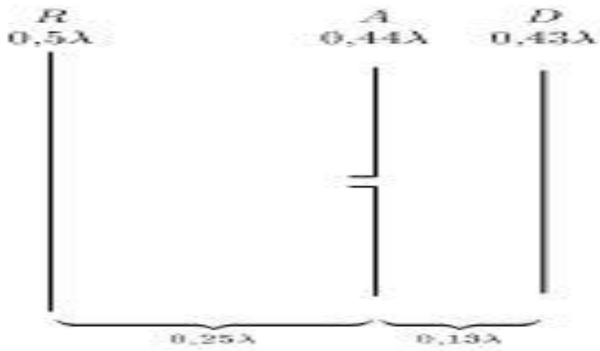


Figure 2.2:Director, a driven element, and a reflector.

Notice that the driven element is in the center and is nothing more than a center fed dipole. To the right of the driven element is the reflector. The reflector is slightly longer than the driven element to allow for proper tuning. The reflector is simply a passive piece of metal slightly longer than ½ wavelengths.

A Yagi antenna often has an impedance of 200 ohms and needs to be matched down to standard 50 ohm cable. A method used to correct this mismatch is to insert a gamma match between the feedline and the antenna.

The antenna gain is a function of the number of dipole elements and can be approximated (for the main lobe) as

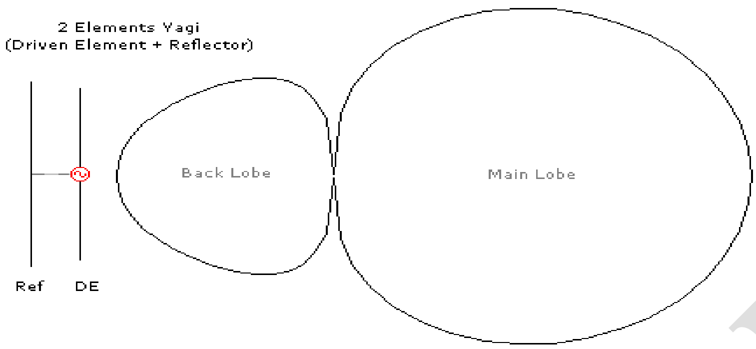
$$\mathbf{G_T = 1.66 * N}$$

Where N is the number of elements (dipoles) in the Yagi-Uda antenna.

Developed Yagi-Uda antennas (including the one pictured) are designed to operate on multiple bands; the resulting design is made more complicated by the presence of a resonant parallel coil and capacitor combination (called a "trap" or LC) in the elements.

Traps are used in pairs on a multiband antenna. The trap serves to isolate the outer portion of the element from the inner portion for the trap design frequency.

Radiation Pattern:



Calculation:

S.No	Angle in Degrees	Detector (reading(mA))	Gain in dB

1. 3-dB Beamwidth: Difference in angle between points on polar plot drawn at 3 dB less to the max gain given by that particular antenna.
2. Antenna Efficiency: It is the ratio of the radiated power to the input power of the antenna.

$$\varepsilon_R = \frac{P_{radiated}}{P_{input}}$$

$$\varepsilon_T = M_L \cdot \varepsilon_R$$

Where ε_T is the antenna's total efficiency, M_L is the antenna's loss due to impedance mismatch, and ε_R is the antenna's radiation efficiency.Since M_L is always a number between 0 and 1, the total antenna efficiency is always less than the antenna's radiation efficiency. Said another way, the radiation efficiency is the same as the total antenna efficiency if there was no loss due to impedance mismatch.

1. Directivity = It is the ratio of maximum radiation intensity (power per unit surface) radiated by the antenna in the maximum direction divided by the intensity radiated by isotropic antenna radiating the same total power as that antenna.

Result:

Radiation pattern of Yagi Uda antenna is plotted and Beamwidth of antenna is_____, Directivity of antenna_____,Antenna efficiency of antenna____.

Quiz:

1. Define Yagi Uda Antenna.
2. Draw the radiation pattern of Yagi Uda antenna.
3. Give the application of Yagi Uda antenna.
4. Write the frequency range of Yagi uda Antenna.
5. What are the different properties of Yagi Uda Antenna

EXPERIMENT NO. 5

Aim: Study the effect of inset feed on the input impedance of a rectangular patch antenna.

Apparatus: Amitech Antenna Transmitter & Receiver Kit and software, 2x1 EM coupled and 2x2 EM coupled rectangular patch antennas.

Theory:

An **antenna array** (often called a '**phased array**') is a set of 2 or more antennas. The signals from the antennas are combined or processed in order to achieve improved performance over that of a single antenna. The antenna array can be used to:

Increase the overall gain, provide diversity reception, cancel out interference from a particular set of directions, "steer" the array so that it is most sensitive in a particular direction, determine the direction of arrival of the incoming signals, to maximize the Signal to Interference Plus Noise Ratio (SINR).

An antenna array is a set of *N* spatially separated antennas. The number of antennas in an array can be as small as 2, or as large as several thousand. In general, the performance of an antenna array (for whatever application it is being used) increases with the number of antennas (elements) in the array; the drawback of course is the increased cost, size, and complexity. The following figures show some examples of antenna arrays.

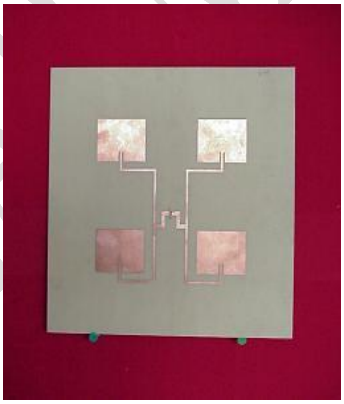


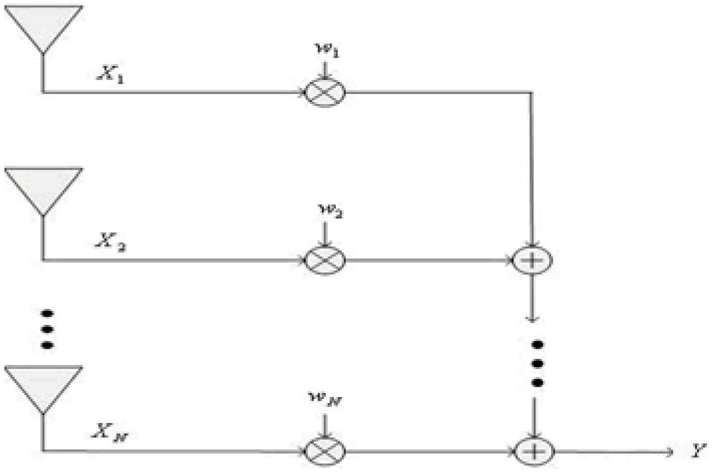
Figure 5.1: **Four-element micro strip antenna array**

An origin and coordinate system are selected, and then the *N* elements are positioned, each at location given by:

$$\mathbf{d}_n = [x_n \;\; y_n \;\; z_n]$$

The positions of the elements in the phased array are illustrated in the following

Let X_1, X_2…….X_n represent the output from antennas 1 thru *N*, respectively. The output from these antennas are most often multiplied by a set of *N* weights - $w_1, w_2, \ldots, w_N$ - and added together as shown in Figure:



The output of an antenna array can be written succinctly as:

$$Y = \sum_{n=1}^{N} w_n X_n$$

We'll now derive the most important function in array theory - the Array Factor. Consider a set of *N* identical antennas oriented in the same direction, each with radiation pattern given by:

$$R(\theta, \phi)$$

Assume that element *i* is located at position given by:

$$\mathbf{r}_i = (x_i, y_i, z_i)$$

Suppose that the signals from the elements in the antenna array are each multiplied by a complex weight (w_i) and then summed together to form the phased array output, *Y*.

The output of the antenna array will vary based on the angle of arrival of an incident plane wave (as described here). In this manner, the array itself is a spatial filter - it filters incoming signals based on their angle of arrival. The output *Y* is a function of (θ, ϕ), the arrival angle of a wave relative to the array. In addition, if the array is transmitting, the radiation pattern will be identical in shape to the receive pattern, due to reciprocity.

Y can be written as:

$$Y = R(\theta,\phi) w_1 e^{-j\mathbf{k}\cdot\mathbf{r}_1} + R(\theta,\phi) w_2 e^{-j\mathbf{k}\cdot\mathbf{r}_2} + \cdots + R(\theta,\phi) w_N e^{-j\mathbf{k}\cdot\mathbf{r}_N}$$

where k is the wavevector of the incident wave. The above equation can be factor simply as:

$$Y = R(\theta,\phi)\sum_{i=1}^{N} w_i e^{-j\mathbf{k}\cdot\mathbf{r}_i}$$

$$= R(\theta,\phi)AF$$

$$\boxed{AF = \sum_{i=1}^{N} w_i e^{-j\mathbf{k}\cdot\mathbf{r}_i}}$$

The quantity *AF* is the Array Factor. The Array Factor is a function of the positions of the antennas in the array and the weights used. By tayloring these parameters the antenna array's performance may be optimized to achieve desirable properties. For instance, the antenna array can be steered (change the direction of maximum radiation or reception) by changing the weights.

Using the steering vector, the Array Factor can be written compactly as:

$$AF = \mathbf{w}^T \mathbf{v}(\mathbf{k})$$

In the above Array Factor equation, *T* is the transpose operator. We'll now move on to weighting methods (selection of the weights) used in antenna arrays, where some of the versatility and power of antenna arrays will be shown.

Side Note: If the elements are identical (antenna array made up of all the same type of antennas), and have the same physical orientation (all point or face the same direction), then the radiation (or reception) pattern for an antenna array is simply the Array Factor multiplied by the radiation pattern $R(\theta,\phi)$. This concept is known as *pattern* multiplication.

The Array Antennas:

This set of routines can be used to plot patterns for linear, rectangular planar, and circular planar arrays, to compute the input impedance of an infinite array of printed dipoles, and to plot a grating lobe diagram for planar arrays. Arrays of subarrays or elements with arbitrary patterns, and planar arrays with elements having arbitrary positions, can also be treated, and patternsynthesis can be performed for linear arrays using the Woodward-Lawson method. The array pattern routines are very flexible, allowing you to specify amplitude and phase variations, amplitude and phase errors, and the type of radiating element.

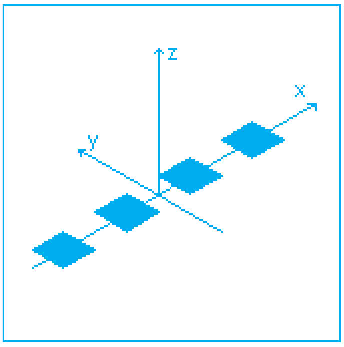
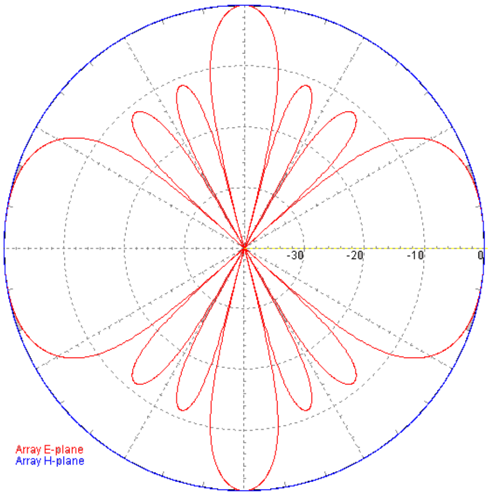


Figure 5.2: Uniform Linear Array Design and Analysis

This routine is used to plot patterns and compute directivity of a linear array antenna. You can specify array size, amplitude taper, phase distribution, and element type. Co-pol and cross-pol patterns can be calculated in an arbitrary elevation plane, and can be plotted either separately or together on a polar or rectangular pattern plot, or saved to data files. The routine can also be used to compute the directivity of the array. As indicated in the picture at the top left of the form, the array is assumed to lie along the *x*-axis; if a ground plane is present (depending on the element type), it is positioned below the array parallel to the *x*-*y* plane. The patterns computed using the array factor of the array multiplied by the element factor. Mutual coupling effects are not included in this routine. Directivity is computed by numerical integration of the pattern, which can be time consuming for large arrays.



The given Patch antenna is linearly polarized along the direction of the feed. The theorized gain of given PatchX1 is 7dbi. Practical test shall give 2 db over reference dipole. Front to back ratio is 10 db.Maximum gain in the direction perpendicular to its plane and a distinct nulls in direction of board. The patch is a directional antenna with higher gain as compared to a dipole antenna. The more the number of patch arrays, the higher is the gain.

Plotting a polar diagram involves measuring and recording received signal strength at known intervals of angular positions.To do this you require a constant level RF signal source (from either transmitter or signal generator or a noise generator) and receiver. The

RS 232 output of the receiver is connected to the com port in a computer. To measure the transmitting station's polar diagram the receiving station's antenna remains stationary and the transmitting station's antenna rotates. To measure the receiving station's polar diagram the transmitting station's antenna remains stationary and the receiving station's antenna rotates.

Uploading:

The stepper motor controller provides a 10 ms pulse on reaching a particular position which is available at pulse out of SCU (stepper Controller unit).This pulse out is then connected to Trigger Stepper BNC of Rx. The Rx(receiver) stores the dBuV reading when an externally provided trigger pulse is received. Hence when the stepper controller is operated in auto mode with step size of 1 degree and start position of 0 degrees it will give 359 pulses to the Rx for taking 359 readings before coming to a halt. For each pulse received from SCU , the Rx stores the instantaneous dBuV reading of Rx which then can be uploaded to PC from Rx menu – Uploading. The receiver can accept trigger pulses from transmitter also and advance the frequency in selected step sizes. The receiver will store the instantaneous dBuV reading on receiving the trigger pulse. This mode will help plot return loss, antenna bandwidth plots etc.

Real time Plot:

For real time plot simply connect the receiver to the comport of the PC. Open the software user interface and press the realtime button. Now the antenna will be plotted while it is being rotated.

Software Operation Steps*:*

Starting from Top under Heading **Graph Style** Select either 1. **Level Vs. Angle** or 2. **Level Vs. Freq.** Select **Level Vs. Angle** option for plotting antenna gain readings with respect to angle. As antenna is rotated with the help of stepper motor controller, antenna gain readings are stored at particular rotated angles in receiver. This data containing frequency, RF level(gain) and location is dumped into PC.

Result:

Study of Antenna array theory is successfully done and demonstration using single EM coupled rectangular patch, 2x1 EM coupled and 2x2 EM coupled rectangular patch antennas is done with the help of software operation on Amitech Antenna Transmitter and Receiver Kit.

EXPERIMENT NO. 6

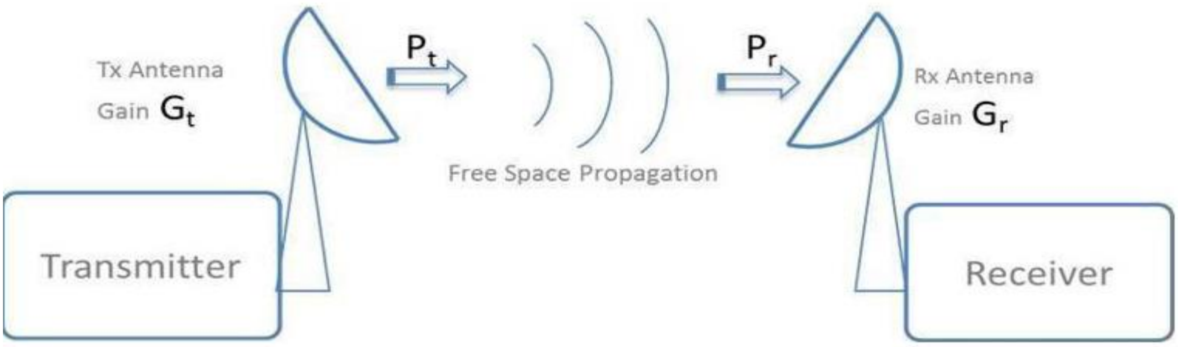
Aim: Communication link budget calculations- Friis formula and demonstration with transmit and receive antenna setup.

Apparatus: Transmitting antenna, Receiving antenna, transmit and receive antenna setup.

Theory: Communication link budget calculations- Friis formula:

FRIIS Transmission Equation

Consider the simplified wireless communication system shown in the Figure. transmitter with an output power Pt is fed into a transmitting antenna with a gain Gt . The signal is picked up by a receiving antenna with a gain Gr. The received power is Pr and the distance is R. The received power can be calculated in the following if we assume that there is no atmospheric loss, polarization mismatch, impedance mismatch at the antenna feeds, misalignment, and obstructions. The antennas are operating in the far-field regions. The power density at the receiving antenna for an isotropic transmitting antenna is given as:



Simplified wireless communication system.

$$S_I = \frac{P_t}{4\pi R^2} \quad (\mathrm{W/m^2})$$

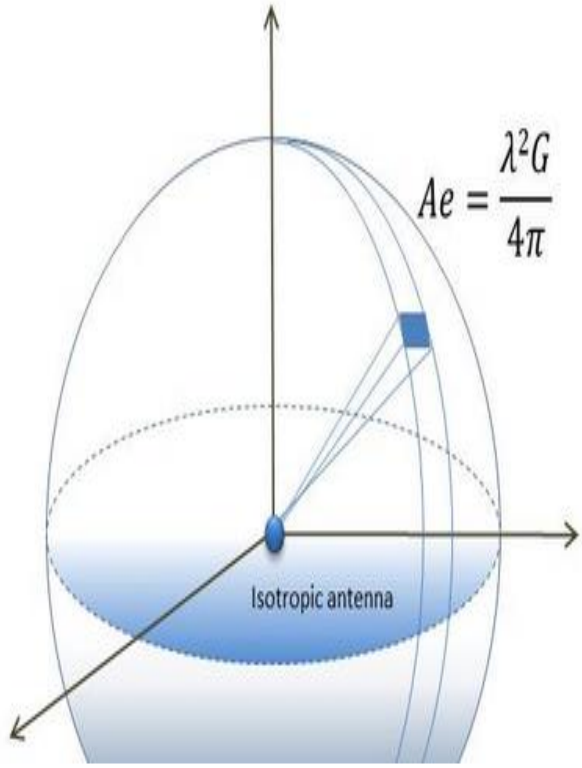
Since a directive antenna is used, the power density is modified and given by

$$S_D = \frac{P_t}{4\pi R^2} G_t \quad (\mathrm{W/m^2})$$

The received power is equal to the power density multiplied by the effective area of the receiving antenna

$$P_r = \frac{P_t G_t}{4\pi R^2} A_{\mathrm{er}} \quad (\mathrm{W})$$

The effective area is related to the antenna gain by the following expression:



$$G_r = \frac{4\pi}{\lambda_0^2} A_{er} \quad \text{or} \quad A_{er} = \frac{G_r \lambda_0^2}{4\pi}$$

Substituting gives

$$P_r = P_t \frac{G_t G_r \lambda_0^2}{(4\pi R)^2}$$

This equation is known as the Friis power transmission equation.

The received power is proportional to the gain of either antenna and inversely proportional to R^2.

If Pr=Si,min, the minimum signal required for the system, we have the maximum range given by

$$R_{max} = \left[\frac{P_t G_t G_r \lambda_0^2}{(4\pi)^2 S_{i,min}} \right]^{1/2}$$

To include the effects of various losses due to misalignment, polarization mismatch, impedance mismatch, and atmospheric loss, one can add a factor Lsys that combines all losses, the Equation becomes

$$R_{\max} = \left[\frac{P_t G_t G_r \lambda_0^2}{(4\pi)^2 S_{i,\min} L_{\text{sys}}} \right]^{1/2}$$

Where Si,min can be related to the receiver parameters.

$$F = \frac{S_i/N_i}{S_o/N_o}$$

$$S_i = S_{i,\min} = N_i F \left(\frac{S_o}{N_o}\right)_{\min}$$
$$= kTBF \left(\frac{S_o}{N_o}\right)_{\min}$$

Where k is the Boltzmann constant, T is the absolute temperature, and B is the receiver bandwidth. Substituting gives

$$R_{\max} = \left[\frac{P_t G_t G_r \lambda_0^2}{(4\pi)^2 kTBF (S_o/N_o)_{\min} L_{\text{sys}}}\right]^{1/2}$$

where P_t = transmitting power (W)

G_t = transmitting antenna gain in ratio (unitless)

G_r = receiving antenna gain in ratio (unitless)

λ_0 = free-space wavelength (m)

$k = 1.38 \times 10^{-23}$ J/K (Boltzmann constant)

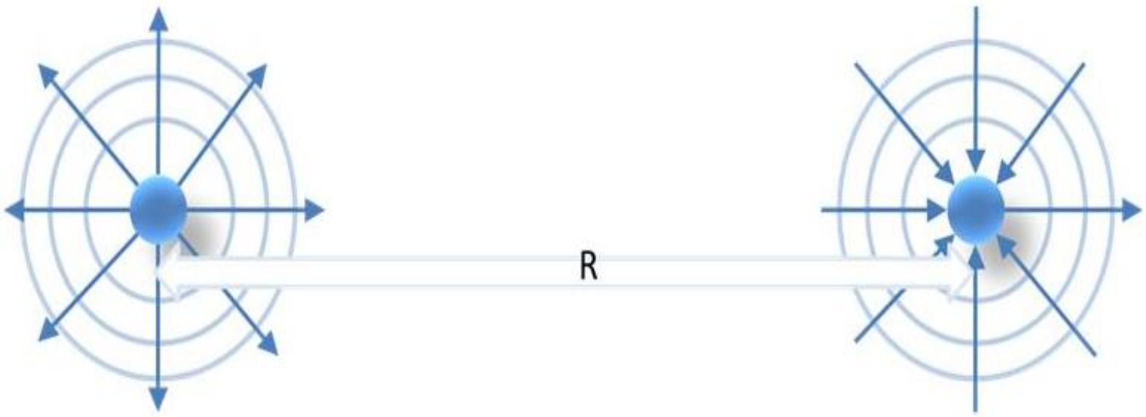
T = temperature (K)
B = bandwidth (Hz)
F = noise factor (unitless)
$(S_o/N_o)_{min}$ = minimum receiver output SNR (unitless)
L_{sys} = system loss in ratio (unitless)
R_{max} = maximum range (m)

The output SNR for a distance of R is given as

$$\frac{S_o}{N_o} = \frac{P_t G_t G_r}{kTBFL_{sys}} \left(\frac{\lambda_0}{4\pi R}\right)^2$$

Space Loss

Space loss accounts for the loss due to the spreading of RF energy as it propagates through free space. As can be seen, the power density (Pt/4πR2) from an isotropic antenna is reduced by 1/R2 as the distance is increased. Consider an isotropic transmitting antenna and an isotropic receiving antenna, as shown in the figure.



The Equation becomes

$$P_r = P_t\left(\frac{\lambda_0}{4\pi R}\right)^2$$

since Gr ¼ Gt ¼ 1 for an isotropic antenna. The term space loss (SL) is defined by

$$\text{SL in ratio} = \frac{P_t}{P_r} = \left(\frac{4\pi R}{\lambda_0}\right)^2$$

$$\text{SL in dB} = 10 \log \frac{P_t}{P_r} = 20 \log \left(\frac{4\pi R}{\lambda_0} \right)$$

Link Equation and Link Budget

For a communication link, the Friis power transmission equation can be used to calculate the received power. The Equation is rewritten here as

$$P_r = P_t G_t G_r \left(\frac{\lambda_0}{4\pi R} \right)^2 \frac{1}{L_{sys}}$$

This is also called the link equation. System loss Lsys includes various losses due to, for example, antenna feed mismatch, pointing error, atmospheric loss, and polarization loss.
Converting the Equation in decibels, we have

$$10 \log P_r = 10 \log P_t + 10 \log G_t + 10 \log G_r - 20 \log \left(\frac{4\pi R}{\lambda_0} \right) - 10 \log L_{sys}$$

$$P_r = P_t + G_t + G_r - SL - L_{sys} \quad \text{(in dB)}$$

Result:
Studied the Communication link budget calculations- Friis formula and demonstrate it with transmit and receive antenna setup.