Antenna Training Systems/ XPO-ANT

Student's Workbook

And

Instructor's Guide

0644-100301

Warranty

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Company warrants that this product will be free from defects in materials & workmanship for a period of one (1) year from the date of shipment. If any such product proves defective during this warranty period, company at its option, either will repair the defective product without charge for parts & labor, or will provide a replacement in exchange for the defective product.

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After your product is older than warranty period or warranty has been voided in any manner, you may return the product to us for repair. Please make sure to ship prepaid; properly pack the product in original carton then dispatch.

Important

Following precautions must maintain while taking readings;

1) Carefully connect the antenna and mast assembly to its mounting holder box and tighten M8 screw with the brass wing nuts. Check the mounted antenna whether it is properly tighten or not, if not again check the assembly before doing any experiment. Do not forget to insert washer between the mast pipe & holder box vertical wall to prevent it from getting crushed as you tighten wing nut.

2) Connect the BNC-to-BNC coaxial cables to both transmitting & receiving antennas to RF generator & power meter respectively and check loose connections, if there.

3) Do not disturb or even touch the elements of antennas mounted on the base-plate. And also do not touch the screws & wires that connect the elements from one-another, otherwise distortion may occur due to loose connections.

4) The location of antenna is very important for getting good performance results. Hence objects such as metal columns, walls, other conducting materials/elements etc will not surround the antenna area otherwise the efficiency of that antenna may get reduced. (For ideal 8 shape polar graph, antenna Expt .should be performed 30 * 30 feet lab on center table. So that nearest reflecting surface should be 15 feet away in all direction.)

5) Both antennas must face each-other; there is no any obstruction part in between them. Means keep both antennas in a direct line of sight with no obstructions. If this is not possible and reception is poor, you should try different location to optimize reception.

6) While taking readings for antenna performance measurements, avoid walking of people from antenna surroundings.

7) Due to presence of large metallic bodies/conducting bodies, which absorb/reflect Electromagnetic radiations, by which you may get distortion in polar plot, i.e. away from figure of circle (omni-directional), Figure of 8 (Bi-directional), lopsided 8 (Uni-directional). So, ignore those distortions & check whether overall above broad classification is borne out by the plot for particular antenna.

8) Zero on the polar s/w & mast physical zero may not always match, unless you do it yourself.

9) Keep connecting BNC-to-BNC cable as straight as possible else attenuation will result.

Warning

1) Supply voltage should be in the range 220/240VAC switch settable @ 50Hz (60Hz optional).

2) Don't short the Output of RF generator & RF power Meter to ground directly though it is deserved to drive into 50-ohm impedance.

3) Antenna expt. should be performed 30x30 lab on center table, so that nearest reflecting surfaces like glass window panes, partition, aluminum pads, cement wall etc. should be at least 15 feet away in all directions, else typical 8 shape polar graph is difficult to be obtained. It will tend to be critical.

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1. Introduction

☞ Unit Objective

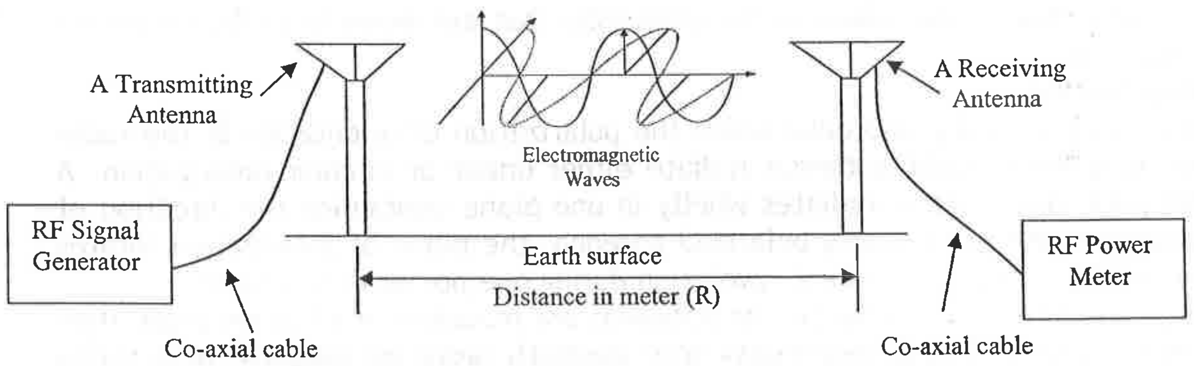
On the completion of this unit, you will be able to understand basic principles related to Antenna. And also understand the provided Antenna Trainer set & its general arrangement for different experiments. And also understand different antenna measurement techniques such as how to measure & plot antenna radiation pattern using Excel graph plotting technique or by using PC based graph utility software, measurement of Beamwidth, Antenna gain measurement using absolute gain measurement technique or measurement using a reference antenna, how to interface panel for auto plotting of antenna radiation pattern etc.

☞ Discussion on Fundamentals

1) What is an Antenna, its working principle & parameters related to antenna:

An antenna is an electrical device which converts electric currents into Electromagnetic wave and vice versa. An Antenna at transmitting side required a radio transmitter (RF generator) to feed oscillating radio frequency (RF) electric current to the antenna's terminals, and the antenna radiates the energy from the current as electromagnetic waves. In receiver side, an antenna collects some of the power of transmitted electromagnetic wave in order to produce a small voltage at its terminals, which is applied to a receiver (RF power meter) to be measured & displayed. Hence, an antenna can be used for both transmitting and receiving purpose as shown below;

Fig 1.1 Basic Antenna Transmitting & Receiving diagram



Any Antenna consists of an arrangement of metallic conductors or conducting elements, electrically connected to the receiver or transmitter. An oscillating electric current forced through the antenna by a transmitter will create an oscillating magnetic field around the antenna elements, while the charge of the electrons also creates an oscillating electric field along the elements. These time-varying fields radiate away from the antenna into space as a moving electromagnetic field wave. Conversely, during reception, the oscillating electric and magnetic fields of an incoming radio wave exert force on the electrons in the antenna elements, causing them to move, creating oscillating currents in the antenna.

Antennas may also contain reflective or directive elements which provide to direct the radio waves into a particular beam or a desired radiation pattern. Antennas can be designed to transmit or receive radio waves in all directions equally called Omni-directional antennas and to transmit waves in a beam in a particular direction, and receive from that one direction only, called directional or high gain antennas.

a) 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 given as;

$$\lambda = c/f$$

where,

λ = wavelength in cm.
c = Speed of light in cm/sec.
f = Frequency in Hz.

b) Efficiency:

It is the ratio of power actually radiated by an antenna to the electrical power it receives from a transmitter.
Efficiency is defined as the ratio of power radiated by test to-the total power input to the antenna, total power (Pt) = POWER RADIATED + POWER LOSS.

c) 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.

d) Beamwidth:

The 3-dB beamwidth or half-power beamwidth of an antenna is typically defined for each of the principal planes. The 3-dB beamwidth in each plane is defined as the angle between the points in the main lobe that are down from the maximum gain by 3 dB.

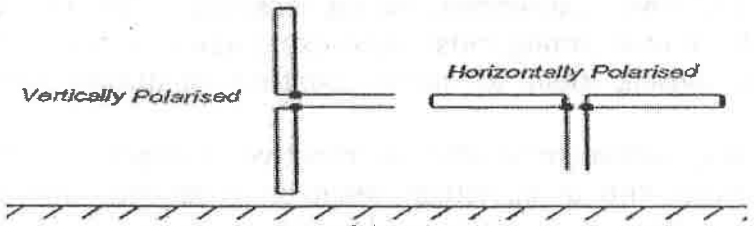
e) Polarization:

The electric field plane determines the polarization or orientation of the radio wave. In general, most antennas radiate either linear or circular polarization. A linear polarized antenna radiates wholly in one plane containing the direction of propagation. But in circularly polarized antenna, the plane of polarization rotates in a circle making one complete revolution during one period of the wave.

Typically in our experiments, the antennas are mounted in XY-plane while they are rotate around Z-axis, this results into **"Azimuth radiation pattern"** of antenna under test due to horizontal polarization.

An antenna is said to be vertically polarized (linear) when its electric field is perpendicular to the Earth's surface. An example of a vertical antenna is a broadcast tower for AM radio or the "whip" antenna on an automobile. Horizontally polarized (linear) antennas have their electric field parallel to the Earth's surface. Television transmissions use horizontal polarization.

Fig 1.2 Antenna horizontal & vertical polarization placements



f) Impedance matching & VSWR:

Input impedance is defined as the impedance presented by the antenna at its terminals or the ratio of the voltage to current at its terminals. If the antenna is not matched to the interconnecting transmission line, a standing wave is induced along the transmission line. The ratio of the maximum voltage to the minimum voltage along the line is called the Voltage Standing Wave Ratio (VSWR). The VSWR is a measure of how much power is delivered to a device as opposed to the amount of power that is reflected from the device. If the source and load impedance are the same, the VSWR is 1:1; there is no reflected power. So the VSWR is also a measure of how closely the source and load impedance are matched.

Here in this trainer system, the RF generator & power meter is of 50 ohm, but the impedance of antennas are different as per their design like 300 ohm, 100 ohm etc. Hence for matching of impedance a Balun is used in holder box for conversion of antenna impedance to 50 ohm only for getting maximum efficiency.

g) Front-to-back ratio:

The front-to-back ratio (F/B) is used as a figure of merit that attempts to describe the level of radiation from the back of a directional antenna. Basically, the front-to-back ratio is the ratio of the peak gain in the forward direction to the gain 180-degrees behind the peak. Of course on a dB scale, the front-to-back ratio is just the difference between the peak gain in the forward direction and the gain 180-degrees behind the peak.

h) Friis transmission equation for antenna gain measurement:

The Friis transmission equation gives the power received by one antenna under idealized conditions given another antenna some distance away transmitting a known amount of power.

Basic form of equation;

The Friis transmission equation is given as follows of two antennas, the ratio of power available at the output of the receiving antenna (P_r) to power input to the transmitting antenna (P_t) is given by

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

Where,

G_t and G_r = are the antenna gains (with respect to an isotropic radiator) of the transmitting and receiving antennas respectively,

λ = is the wavelength,

and R = is the distance between the two antennas.

The inverse of the factor in parentheses is called free-space path loss. To use the equation as written, the antenna gain may not be in units of decibels, and the wavelength and distance units must be the same. The Friis equation in case of gain has units of dB is given as;

$$P_r = P_t + G_t + G_r + 20\log_{10}\left(\frac{\lambda}{4\pi R}\right)$$

Here, Antenna gain is expressed in units of dB and power has units of dBm.

2) Understanding Antenna Trainer set @ 500 MHz:

The antenna training set (XPO-ANT) provided with the following numbers of Antennas with their separate Red base-plate & holder-box from bottom;

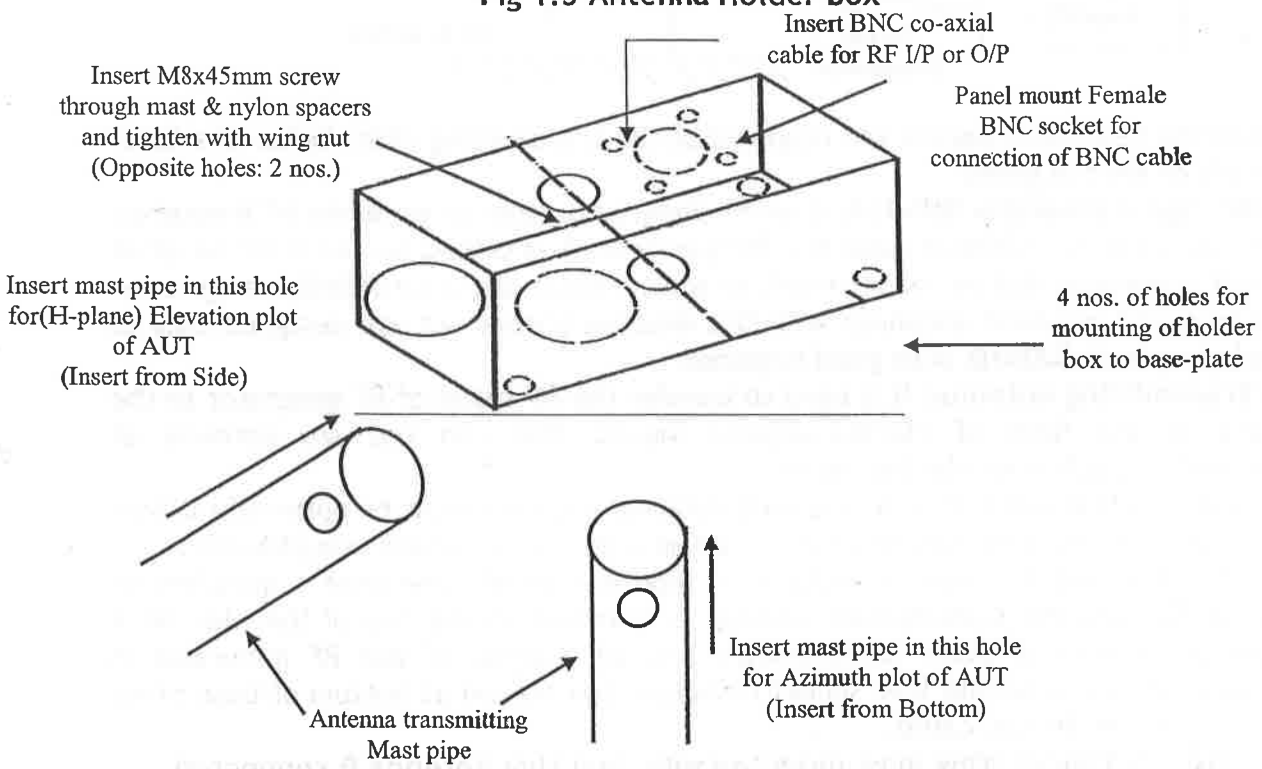
Table 1.1 List of Antennas & their mounting setups

Sr. No.	Antenna name	No. of element(s) required	No. of Base-plate required	Base-plate tags for antenna elements mounting
1.	Half-wave folded dipole.	One	Small: 1 Big: 0	FDP
2.	Half-wave simple dipole.	One	Small: 1 Big: 0	FDP
3.	Quarter-wave simple dipole.	One	Small: 1 Big: 0	FDP
4.	3λ/2 simple dipole.	One	Small: 1 Big: 0	FDP
5.	Half-wave Folded-dipole with Reflector.	Two	Small: 0 Big: 1	YU4, YU6
6.	Yagi-Uda 3 elements.	Three	Small: 0 Big: 1	YU1, YU2 & YU3
7.	Yagi-Uda 5 elements.	Five	Small: 1 Big: 1	YU1, YU2, YU3, YU4 & YU5
8.	Yagi-Uda 7 elements.	Seven	Small: 1 Big: 1	YU1, YU2, YU3, YU4, YU5, YU6 & YU7
9.	Circular Loop.	One turn	Small: 1 Big: 0	LOOP
10.	Log-periodic.	Seven	Small: 0 Big: 3	LP1, LP2, LP3, LP4, LP5, LP6 & LP7
11.	Helical.	Three turns	Small: 0 Big: 1	HEL
12.	Half-wave End-Fire.	Two	Small: 1 Big: 1	YU1, Last FDP/LOOP pads
13.	Quarter-wave End-Fire.	Two	Small: 0 Big: 1	LP4, LP3
14.	Broad-side array.	Six	Small: 0 Big: 2	YU1, YU2, LP3,LP4, LP2,YU7
15.	Co-linear array.	Two	Small: 1 Big: 1	YU1, Last FDP/LOOP pads
16.	Slot Antenna.	One	Specially Designed PCB	At IN & GND pads on PCB.
17.	Discone Antenna.	GI. Cone & Disc	Small: 0 Big: 1	Disc: At LP2 & LP4. Cone: At Grounding pads.
18.	Parabolic Reflector.	Dipole: 2, GI reflector	Small: 0 Big: 1	Dipole: YU1 & connected to reflector using L-angle.
19.	Microstrip Patch.	One	Specially Designed PCB	At IN & GND pads on PCB.
20.	Variable Length Antenna. (400mm to 1200mm)	Two (variable length)	Small: 1 Big: 0	SPR (middle pads)

Each antenna is fixed on top of FR4, 2.4mm wide base plate (Red masked) attached to a moulded holder box located on its bottom. The moulded holder box may be mounted on top of tall mast of either transmitter or receiver using M8 bolt & wing nut for easy fixing & removal. Two spacers of delrin nylon material are provided between walls of holder box & inserted pipe for tight fit.

The Antenna holder box has one panel mount BNC female connector to connect the antenna assembly to either RF generator or RF power meter with the provided BNC-to-BNC co-axial cable. The complete drilling detail of antenna holder box is shown below;

Fig 1.3 Antenna Holder box



NOTE:

a) For finding of Azimuth radiation pattern of Antenna Under Test (AUT), insert the mast pipe from bottom side to holder box & rotate mast from 0 to 360^0.

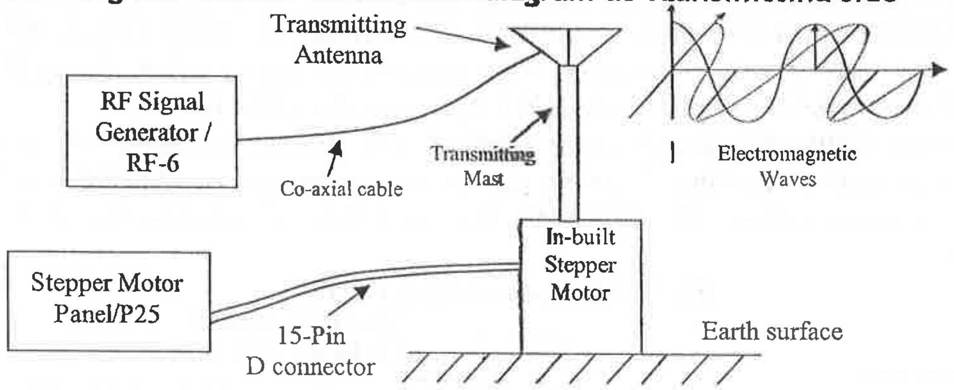
b) For finding of Elevation radiation pattern of Antenna Under Test (AUT), insert the mast pipe from left side to holder box & rotate mast from 0 to 360^0.

The BNC at holder box internally connected with a Balun (Balance to unbalance transformer), this transformer is useful for matching the impedance of different antennas with the 50 ohm driving generator or receiver (if at receiving side) for getting maximum efficiency at the time of power transfer.

Actually Baluns are used to attach a symmetrical (balanced) circuit to a asymmetrical (unbalanced) circuit & to have a precise 180-degree phase shift, with minimum loss and equal balanced impedances. For design of a balun, we used a ferrite wire-wound transformer, which covers frequencies ranging from few kHz to beyond 2GHz and different design for different antenna assembly to match perfectly with the 50 ohm system, so as to produce maximum RF power transfer.

3) **Trainer transmitting side arrangement:**

Fig 1.4 Trainer connection diagram at Transmitting side



Following resources/panels are required at the transmitting side, below the brief details of each is given;

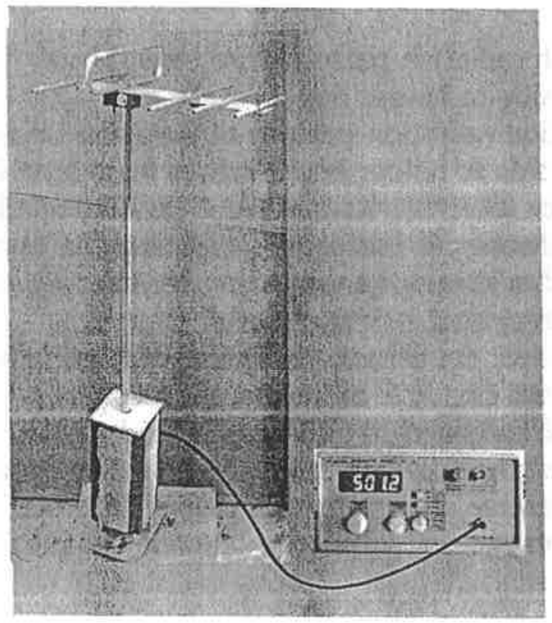
a) RF signal generator/RF-6: It is an RF signal generator to generate RF frequency ranging from 10 - 600MHz using the frequency knob provided on the front bezel of signal generator. But for experimenting any antenna, set it to 500MHz range only, because the provided antennas with the Antenna trainer set are designed only to work proper at 500MHz with good response.

b) Transmitting Antenna: It is used to transfer the RF signal of RF generator to the space in the form of electromagnetic waves. You can use any antenna at transmitting side from the list above.

c) Transmitting mast: It is a manually rotating antenna mast or optionally driven by stepper motor with flexibility to mount all provided antennas using M8 screw.

The transmitting mast consists of SS pipe and stand. The pipe is attached to the stand, and the transmitting antenna is mounted on the top of the pipe on a base plate held in place using holder box. RF output of the RF generator is connected to the female BNC socket on holder box placed at bottom of base-plate by using a BNC to BNC cable.

Fig 1.5 Transmitting mast mounted with Yagi-Uda Antenna & connected to RF signal generator using BNC-to-BNC cable



Physical specifications of transmitting mast;

Dimension of transmitting mast:

Height = 850 mm.

Weight = 3.5 kg.

Setup procedure for transmitting mast:

i) Complete transmitting mast is provided with the trainer set with a 2 kg-cm stepper motor (optional) internally installed with 15-pin D connector cable (female) kept covered by an acrylic box. You only need to place this mast at proper surface/place having enough empty spaces around it to prevent ghost interference or absorption of RF energy from target objects for transmitting purpose, while doing experiments.

ii) For mounting of different antennas on the mast, two nos of parallel holes are provided at top end of the mast. Use an M8 x 45mm screw to mount antenna through the holes of holder box attached at bottom of antenna base-plate as per your experiment. And tighten it properly by using the wing-type brass nut & check it is paralleled with ground, so as not to mismatch the line-of-sight arrangement at the time of experiment.

iii) Connect the output of RF signal generator to the BNC provided at holder box using a BNC-to-BNC co-axial cable and set the frequency of RF generator at 500MHz only for any experiments.

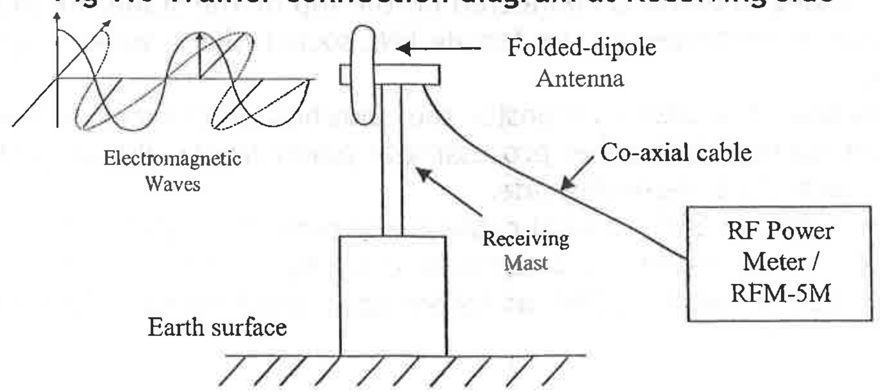
iv) Connect the Panel-P25 to the 15-pin D connector provided at the transmitting mast, which is collected from the wires of stepper motor to rotate the mast while doing experiment of radiation pattern or you can rotate the mast by your hand also.

d) Stepper motor driver panel/P25: A panel P25 is optionally provided with trainer set. This panel contains stepper motor driving circuitry to drive the in-built stepper motor on the transmitting mast, used only for Radiation pattern measurement of an antenna under test. When stepper driver facility is not provided then user may rotate transmitting mast by hand also by 10^0 increase using scale pointer.

e) Co-axial cable: A BNC to BNC co-axial cable is also provided with the trainer set to connect the RF generator to antenna directly by connecting one side to output of generator & other to BNC at holder box, which contains internally a Balun.

4) Trainer receiving side arrangement:

Fig 1.6 Trainer connection diagram at Receiving side

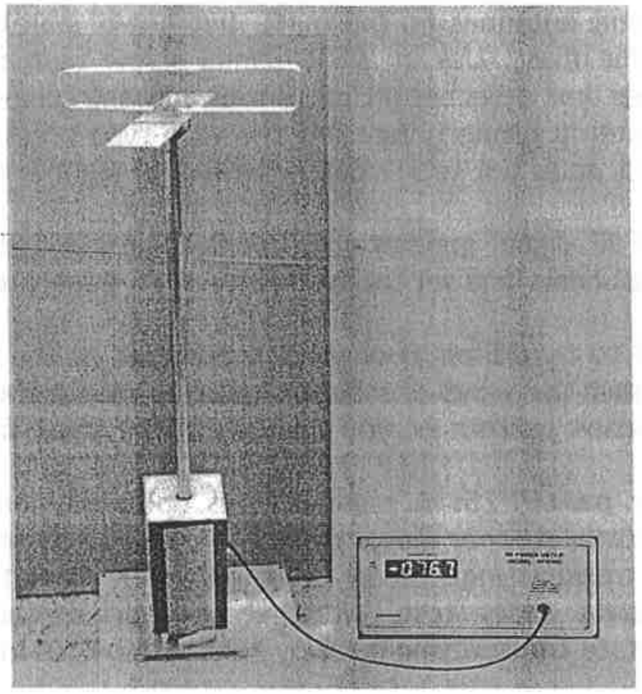


Following resources are required at the receiving side, below the brief details of each is given;

a) RF power meter/RF-5M: Whatever the power absorbed by the receiving antenna will be displayed on it in the unit of dBm. The power measurement readings are ranging from -60 to +3 dBm.

b) Receiving mast: It is like a transmitting mast used as stand for receiving antenna, normally at receiving side a folded-dipole antenna is used & fixed it as only for receiving purpose mount it using M8 screw. It does not contain any stepper motor part inside it and is prevented from rotation.

Fig 1.7 Receiving mast mounted with Folded-dipole Antenna & connected to RF power meter using BNC-to-BNC cable



Physical specifications of receiving mast;

Dimension of receiving mast:

Height = 850 mm.

Weight = 3.0 kg.

The Receiving mast consists of SS pipe and stand. The stand is attached to the SS pipe, and the Receiving antenna is connected on the top of the stand. RF Input of the RF Power meter is connected to the female BNC socket of the stand by using a BNC to BNC cable.

c) Receiving Antenna: It is used to transfer the absorbed electromagnetic waves of space to electric current for further processing at power meter. Please prefer to use folded-dipole antenna at receiving side.

d) Co-axial cable: A BNC to BNC co-axial cable is also provided with the trainer set to connect the RF power meter to antenna directly by connecting one side to output of power meter & other to BNC at holder box, which contains internally a Balun.

Setup procedure for receiving mast:

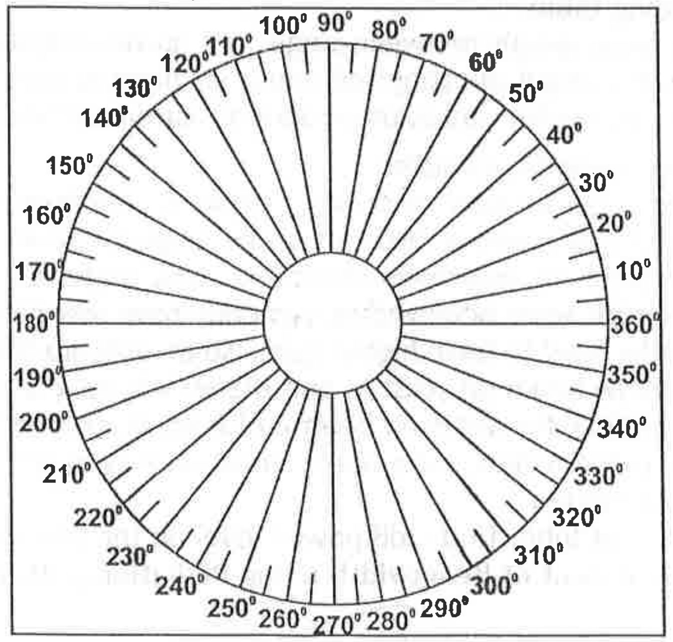
i) Procedure is same as transmitting mast, only at receiving mast there is no any stepper motor inside it. Mount folded-dipole antenna at receiving mast only use an M8 x 45mm screw to mount antenna using the holes of holder box attached at bottom of antenna base-plate as per your experiment. And tight it properly by using the wing-type brass nut and check it is parallel to ground, so not to mismatch the line-of-sight arrangement at the time of experiment.

ii) Connect the RF input BNC of RF power meter to the BNC provided at holder box using a BNC-to-BNC co-axial cable and note down the power readings by observing on the display.

5) Printed 360^0 angle scale:

On the top surface of acrylic box at transmitting mast a 360^0 paper angle scale is stuck with an angle pointer internally connected the pipe. This angle scale provides a full 360^0 rotation measurement with 10^0 small divisions as shown below; For antenna radiation pattern measurement use the above printed scale with pointer. Rotate the antenna by your hand (for manual operation) with 10^0 division increment and note down readings on power meter in each case (this will be studied in next unit).

Fig 1.8 Printed 360^0 angle scale uses for antenna radiation pattern measurement



6) Antenna Measurement techniques:

a) Measurement & plotting of Antenna Radiation Pattern:

The radiation pattern or simply antenna pattern is the graphical representation of the radiation properties of the antenna as a function of space. That is, the antenna's pattern describes how the antenna radiates energy out into space (or how it receives energy). It is important to state that an antenna radiates energy in all directions, at least to some extent, so the antenna pattern is actually three-dimensional.

Follow the given procedure for radiation pattern measurement of an antenna;

i) The antenna under test (AUT) must be mounted at transmitting side and one another antenna is required for receiving of energy whatever radiating from transmitting antenna at a proper line-of-sight of arrangement.

ii) Now rotating the AUT in some degree of increment either clockwise or counter clockwise (preferably clockwise) upto complete 360^0 rotation using by your hand precisely or optionally by stepper motor arrangement & observing the power in power meter (display is in dBm) at receiving side for each degree of increment of transmitting antenna, indicate the antenna response in each direction.

iii) Now note down the reading for this angle rotation (say for 10^0 rotation) & fill the observation table.

iv) Repeat the same procedure for complete 360^0 rotation of transmitting antenna and fill the corresponding table.

v) Now finally plot a polar-graph between angle and power output (measured in power meter) using excel graph plotting technique or directly plot the pattern by graph utility software, shows the radiation pattern of Antenna Under Test.

b) Measurement of Antenna Beamwidth:

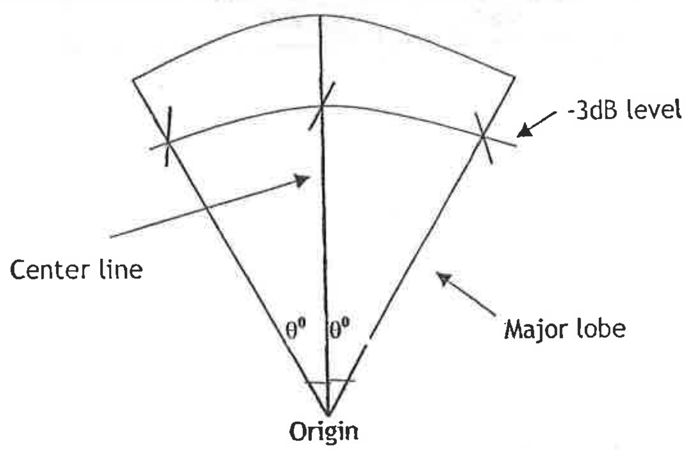
A directional antenna can be said to direct a beam of radiation in one or more directions, the width of this beam is defined as the angle between its half-power points or -3 dB points at its maximum direction, this angle is called antenna beamwidth. Antennas with wide beamwidths typically have low gain and antennas with narrow beamwidths tend to have higher gain. So an antenna that directs most of its energy into a narrow beam (at least in one plane) will have a higher gain.

Follow the given procedure for antenna beamwidth measurement;

i) From the radiation pattern plot, take major lobe, means in which position the antenna radiation is maximum.

ii) Now by considering that lobe, find -3dB power level on the center line of plot.

Fig 1.9 Measurement of Beamwidth using Radiation pattern plot



iii) Draw an arc at either side of the plot using a compass or by your hand accurately from the origin of plot as shown above.

iv) Now from the either cut positions, draw straight lines to origin. These lines show some angle difference from the center line as shown above i.e. two θs in degree;

Hence, Beamwidth = $+2\theta^0$

c) Measurement of Antenna Gain:

<u>Important Note</u>: To be consistent in comparing different antennas, it is necessary to have a standard environment surrounding the antenna. Ideally, measurements should me made with the measured antenna so far removed from any objects causing environmental effects that it can be considered in open space. This is an impractical situation. Professional laboratories use **electromagnetic anechoic chambers** (also called echo-free chambers) that simulate almost perfectly the open space situation. These are very expensive and for our purposes can be substituted by a roof, a terrace or an open field. The place should be as far as possible (at least 50 metre) from power lines, aerials and microwave radio transmitters and without any metallic structure or conductive surface, concrete walls, other building, trees etc. This is often difficult to achieve, but the environment should be controlled so that successful and accurate measurements can be made in a reasonable wide area.

The gain of an antenna in any given direction is defined as the ratio of the power gain in a given direction to the power gain of a reference antenna in the same direction. Here the reference antenna to use as an isotropic radiator, which is lossless and radiates its energy equally in all directions (Omni-directional), hence the gain of an isotropic radiator is G = 1dB. But one thing is to be noted here that an isotropic radiator can never be built, it is only assumed and hence it is hypothetical in consideration.

The unit of gain of an antenna is expressed in dBi, means decibels relative to an isotropic radiator for gain with respect to an isotropic radiator (whose gain is 1dB). Gain expressed in dBi is computed using the following formula;

$$\text{Gain (dBi)} = 10 * \text{Log}\left[\frac{\text{Gain (Measured)}}{\text{Gain (Isotropic)}}\right]$$

Where,

Log = Logarithm by base 10.

Gain (Isotropic) = 1 dB.

Gain (Measured) = Measured gain of Antenna under test.

There are two methods to measure gain of an antenna under test (AUT), one is absolute gain measurement method & other is gain measurement using a reference antenna.

i) Absolute Gain measurement method: In this method, a FRIIS transmission equation is used as given below;

$$\frac{P_R}{P_T} = G_T * G_R * \left[\frac{\lambda}{4\Pi R}\right]^2$$

Where,
P_R = Received power at receiver antenna side (in Watts),
P_T = Transmitted power from transmitter antenna side (in Watts),
G_R = Receiver antenna gain (unit less),
G_T = Transmitter antenna gain i.e. AUT (unit less),
λ = Wavelength of transmitted signal = 0.6m (for 500MHz),
R = Distance between two antennas (in meter).
Then,

$$G_T * G_R = \frac{P_R}{P_T}\left[\frac{4\Pi R}{\lambda}\right]^2$$

ii) Gain measurement using a reference antenna: In this method, a reference antenna of known gain is used as a reference for gain measurement of Antenna under test (AUT) by using the following equation;

$$G_{AUT} \text{ (in dBi)} = G_{Ref} \text{ (in dBi)} + [P_{Meas} \text{ (in dBm)} - P_{Ref} \text{ (in dBm)}]$$

Where,
G_{AUT} = Measured Gain of Antenna Under Test (in dBi).
G_{Ref} = Gain of reference antenna.
P_{Meas} = Power meter reading when Antenna under test is connected at transmitting side (in dBm).
P_{Ref} = Power meter reading when reference antenna is connected at transmitting side (in dBm).

NOTE: An absolute gain measurement method is used for gain measurement of folded dipole antenna to make this antenna as reference (we will study this method in next chapter) and for all other provided antennas, the gain is measured using folded dipole as reference antenna.

7) Precautions at the time of experiment:

While doing experiments related to antenna measurements, you must take the following precautions as illustrated below and if any of the points not suppressed/covered, then results will not repeatable.

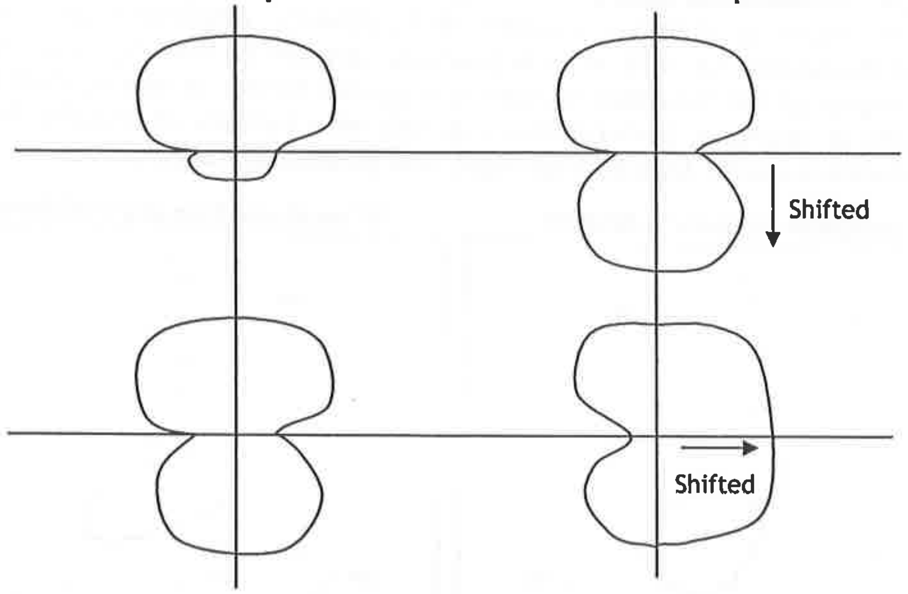
a) Carefully connect the antenna and mast assembly to its mounting holder box and tighten M8 screw with the brass wing nuts. Check the mounted antenna whether it is properly tighten or not, if not again check the assembly before doing any experiment. Do not forget to insert washer between the mast pipe & holder box vertical wall to prevent it from getting crushed as you tighten wing nut.

b) Connect the BNC-to-BNC coaxial cables to both transmitting & receiving antennas to RF generator & power meter respectively and check their loose connections, if there.

c) Do not disturb or even touch the elements of antennas mounted on the base-plate. And also do not touch the screws & wires that connect the elements from one-another, otherwise distortion may occur due to loose connections.

d) The placement location of antenna is very important for getting good performance results. Hence objects such as metal columns, walls, other conducting materials/elements etc will not surround the antenna area otherwise polar plots will get distorted/lopsided giving incorrect picture as illustrated below;

Fig. 1.10 Samples of incorrect plots



e) Keep both the transmitting & receiving antennas at the same height that is why both masts are designed physically of same height. Hence for best performance to achieve while transmitting and/or receiving, keep both antennas at same height.

f) Both antennas must face each-other; there is no any obstruction part in between them. Means keep both antennas in a direct line of sight with no obstructions. If this is not possible and reception is poor, you should try different mounting positions to optimize reception.

g) While taking readings for antenna performance measurements, avoid walking of people from antenna surroundings.

NOTES:

a) If any of the above precautions are not followed then results may get disturbed and may be different from observations provided in the IG section of this manual.

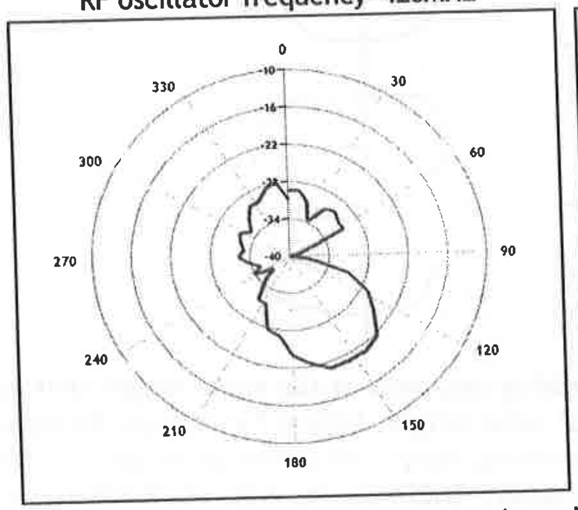
b) While taking readings, if somewhere power meter reading changes or flickers in some values & not showing stable or constant values then check loose connection of BNC-to-BNC cable and please tight it properly to observe accurate readings.

c) If you are rotating AUT using stepper, after completion of 360^0 of rotation, the BNC-to-BNC cable connected to the AUT will get twist with the mast, so after taking readings again rotate the AUT in opposite direction using BS5-11 (stepper direction control socket) to come to the previous cable connection or disconnect BNC cable & again connect with proper manner and then go for next experiments. Do this for completion of each expt.

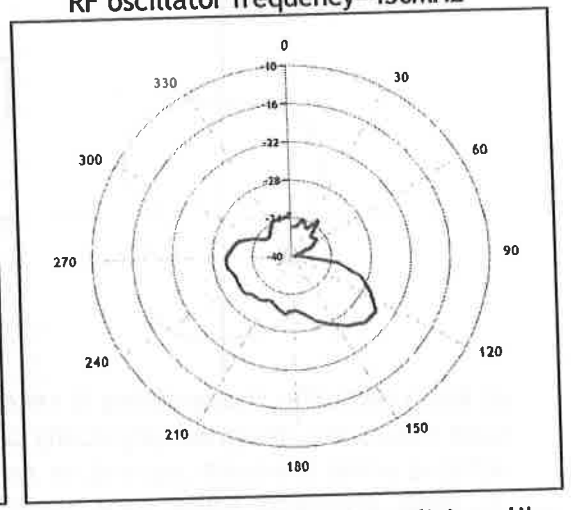
d) The observations illustrated in the IG section of this trainer set must not necessarily match to your observations for the same antenna using same setup whatever procedure given in every unit, because of the above illustrated points. So no need of worry about matching of readings, only match the characteristics or patterns, these must be same to match the observations.

e) To obtain more accurate/ correct patterns of antenna response you may have to adjust the frequency through trial and error on RF generator/ oscillator between 350 MHz to 500 MHz, at certain frequency you will be able to obtain close to standard pattern (80% atleast). Amplitude keep it max without distortion, i.e. 90% of knob position. Observe by making small changes in RF frequency the resultant pattern changes for better or worse, thus locate the point of optimum performance e.g. left side pattern at 420MHz for yagi uda antenna is better formed than right side pattern at 430MHz.

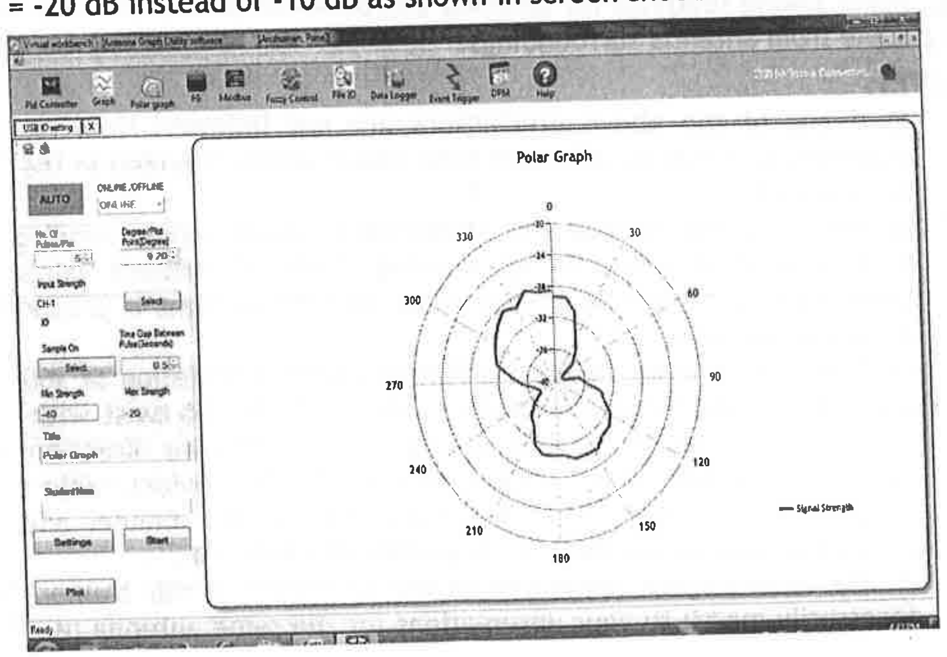
RF oscillator frequency=420MHz



RF oscillator frequency=430MHz



f) In case the output of power meter is on lower side due to various conditions like distance between antenna, very crammed room reflecting RF energy etc. then on left side panel on the screen you have option set. Set min strength = -40 & max strength = -20 dB instead of -10 dB as shown in screen shot below.



8) Reciprocity in Antenna Measurements

1. The basic procedure is to place a transmitting or receiving source antenna at different location with respect to the Antenna Under Test (AUT) and thus get a number of samples of the pattern. The different locations are normally achieved by rotating the AUT. To ensure the "sharpness" of the pattern sample only one direct signal path should exist between the AUT and the source antenna. This can be achieved in a reflectionless environment like in an anechoic chamber or in free space.
2. The AUT can act as either a receiving antenna or a transmitting antenna .This is of course due to the Reciprocity principle.
3. Two important consequences of the principle from the antenna measurement point of view were given:
   ☞The transmitting and receiving patterns are the same.
   ☞ Power flow is the same either way.
   Thus it is clear that all radiation parameters of the AUT can be measured in either transmission or reception mode.
4. However, in practical antenna measurements one has to be careful in applying the reciprocity principle. The important conditions for the validity of the principle were given:
   ☞ The emfs in the terminals of the interchanged antennas are of the same frequency.
   ☞ The media are linear, passive and isotropic
   ☞ The power flow is equal for matched impendances only.
5. The third condition is perhaps the most difficult and may lead into measurement result,which seem to violate the reciprocity principle.

☞ First time installation procedure

Follow the given procedure for first time installation of complete XPO-ANT trainer set for both transmitting & receiving side arrangement;

a) The overall height of Antenna stand (both transmitting & receiving masts) is of 85cm. However for ease in packaging, the mast is made of two sections; one is stainless-steel hollow pipe of 58cm at upper side of mast with two cross holes at lower end & one M8 hole at top end to mount antenna holder box and other is bottom stand of 27cm overall height with a central shaft (not hollow pipe) which is held between two bearings.

Now you have to connect upper hollow pipe to bottom stand with the provided cross holes on hollow pipe using M5 screw nuts inserted transverse to couple the upper hollow pipe to bottom stand.

b) Separate antenna is provided with separate antenna base plate (red masked PCB) with antenna holder box. The holder box contains a Balun, which is connected between input BNC socket and antenna apparatus. Two nos. of white nylon washers are mounted to cushion centrally mast pipe with M8 hole for avoiding compression of holder box when tightening with M8 wing nut.

Now take a complete assembled antenna as per your experiment list with holder box. Place this antenna on top of mast and tighten with the provided M8 metal screw with wing-nut & nylon washers from inside.

c) One folded-dipole antenna is provided to be used only at receiving side. Permanently mount this folded-dipole antenna at receiving antenna mast by using M8 screw. And at transmitting antenna mast mount removable antenna with which you are going to perform experiment using M8 screw & wing nut.

d) **Reassembly of Antennas:** Unpack the antennas from bubble-sheet firmly. The long-element antenna pipes (such as Log-periodic: 4 pipes of LP6 & LP7 and $3\lambda/2$ simple dipole: 2 pipes), whose one of two fixing screws are removed at the time of dispatch. So, that pipes can be mounted again at the time of unpacking for expt. using provided M3 screws. Hence mount those pipes using screws & nuts.

e) **For radiation pattern measurement:** Actually the radiation pattern of an antenna under test is a three-dimensional pattern in nature, but we can not plot this pattern practically. For this separate two-dimensional patterns need to measure of the same antenna. Hence for plotting these two-dimensional patterns, an arrangement is provided with the holder box (connected at bottom of antenna base-plate) with two nos. of holes, one is at Bottom & other at Side. Mount antenna using bottom hole of holder box on the transmitting mast for measurement of antenna "Azimuth pattern" and mount using side hole for antenna "Elevation pattern", for this refer holder box diagram shown in previous page.

☞ Keywords / New-words

a) Balun: Balun stands for Balance to unbalance transformer, this transformer is useful for matching the impedance of different antennas with the 50 ohm driving generator or receiver.

b) Omnidirectional antenna: An omnidirectional antenna is an antenna that has a non-directional pattern i.e. circular pattern in a given plane with a directional pattern in any orthogonal plane.

c) Directional antenna: A directional antenna is one that radiates its energy more effectively in one (or some) direction than others. Typically, these antennas have one main lobe and several minor lobes.

d) Isotropic radiator: is a theoretical point source of electromagnetic or sound waves which radiates the same intensity of radiation in all directions. It has no preferred direction of radiation. It radiates uniformly in all directions over a sphere centered on the source. Isotropic radiators are used as reference radiators with which other sources are compared.

e) The unit dBm: It is sometimes referred as dBmW is an abbreviation for the power ratio in decibels (dB) of the measured power referenced to one milliwatt.

☞ Equipments Required

The following equipments are required for doing any experiment provided in this XPO-ANT trainer as listed below;

a) Transmitting antenna mast - 1 no.
b) Receiving antenna mast - 1 no.
c) RF signal generator/RF6 - 1 no.
d) RF power meter/RF5M - 1 no.
e) Co-axial cable - 2 nos.
f) Stepper motor driver panel/P25 - 1 no.
g) Folded dipole antenna at receiving side - 1 no.
h) Respective transmitting antenna as per experiment - 1 no. in each case.
i) Directional Coupler - 1 no.
j) 1metre, 4mm Black & Red patch cords - 1 no (each).

2. Understanding Resource Panels

☞ Unit Objective

On the completion of this unit, you will be able to understand different resource panels or accessories provided with XPO-ANT trainer such as RF signal generator, RF power meter & Stepper motor driver panel P25. How to use polar graph software using stepper driver panel for plotting Antenna radiation pattern is also provided in this unit.

The following resource panels are provided with the XPO-ANT trainer set as given in below table.

However what is supplied depends on what you have ordered.

Table 2.1 Various resource panels

Sr. No.	Panel name or function	Panel code	Qty.
1.	RF signal generator	RF-6	01
2.	RF Power meter	RFM-5M	01
3.	Stepper motor driver panel	P25	01
4.	Directional Coupler	MS1	01
5.	To plot Antenna radiation pattern using VWB software	----	----

☞ Discussion on Fundamentals

Following resource panels are provided with the XPO-ANT trainer set as detailed below with their specifications & operating procedure;

1) RF Signal generator/RF-6: It is an RF signal generator to generate RF frequency ranging from 10 - 600MHz using the frequency knob provided on the front bezel of signal generator.

a) Salient Features:

i) Wide frequency range from 10MHz to 600MHz.
ii) Internal/external modulation (AM/FM).
iii) 1KHz/100KHz (with separate BNC) for Internal modulation /External Use.
iv) Digital display for frequency readout.
v) 50Ω output with BNC connector.

b) Technical specifications:

Table 2.2 Technical specifications of RF generator

Sr. No.	Items	Specifications
1.	Frequency Range	10MHz to 600MHz.
2.	Output	BNC, driving into 50 Ohm impedance.
3.	Resolution	100KHz
4.	Output Level (in dBm)	Low:-3dBm to -27dBm dynamic range over 10-600MHz. High:+9dBm to -27dBm dynamic range over 10-250MHz.
5.	Frequency & Amplitude controls	10 turn POT for each
6.	Display	4.$^{1/2}$ dig 7-seg Red LED
7.	Operating Temp	0 to 50°C (Accuracy specified at 25°C).
8.	Power	220V/240V switch settable@ 50Hz.
9.	Dimension / Weight	295 (W) X 220 (D) X 98 (H) / Approx.1.9 Kg

c) Front bezel description:

Fig 2.1 Front bezel of RF generator

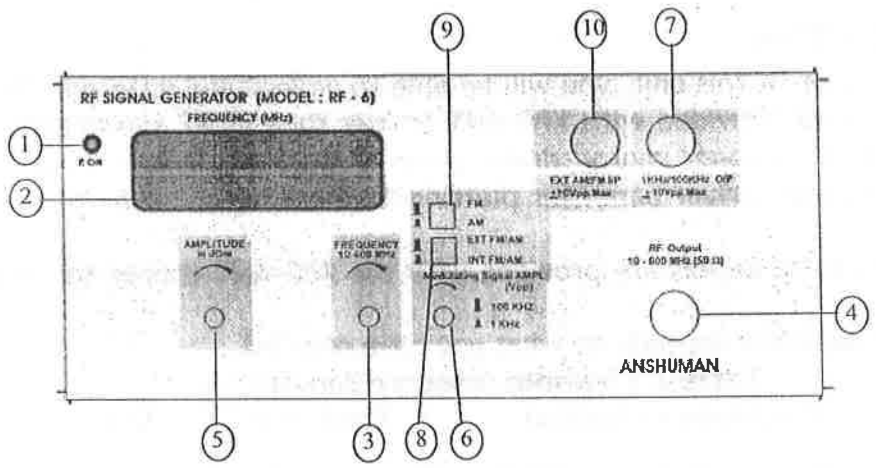


Table 2.3 RF generator front view description

Points	Nomenclature	Function
1.	Power-ON LED	Indicates instrument is in Power ON mode.
2.	Seven segment display	Display Frequency in MHz
3.	Frequency adjust knob	Varies frequency from 10 MHz to 600MHz.
4.	Output BNC Connector	RF Output with 50Ω impedance (10-600MHz)
5.	Amplitude adjust knob	Varies amplitude from +9dBm to -27dBm.
6.	a. Amplitude knob normal position	Varies amplitude from 0-10Vpp @ Freq. 1KHz for Internal Modulation / Ext use.
	b. Amplitude knob Pulled out position	Varies amplitude from 0-2.5Vpp @ Freq. 100KHz for Internal Modulation / Ext use.
7.	BNC Connector	Frequency output 1KHz (When amplitude POT at normal position). Frequency output 100KHz (When amplitude POT at pulled out position).
8.	EXT FM/AM or INT FM/AM (Push button switch)	External frequency modulation/Amplitude modulation is enabled, when unpressed. Internal frequency modulation/Amplitude modulation is enabled, when pressed.
9.	FM/AM (Push button switch)	Frequency modulation is enabled, when unpressed. Amplitude modulation is enabled, when pressed.
10.	FM/ AM (BNC connector)	Input for external amplitude/frequency modulation (If EXT. FM/AM is unpressed & FM/AM push button pressed for FM or FM/AM push button unpressed for AM).

d) Operating procedure:

First switch-ON the RF generator by using ON/OFF switch provided on the hind side of panel & check the power-ON LED on front side.
For varying amplitude: Use Amplitude knob, located at left side on front bezel.
For varying frequency: Use frequency knob, located at right of amplitude knob on front bezel.

Use the 7-segment display for observing frequency generated by RF generator & use RF output BNC for taking RF signal output from this panel.

2) RF power meter/RFM-5M: The power meter indicates power readings, whatever the power absorbed by the receiving antenna in the unit of dBm. The power measurement reading are ranging from 0 - 75 dBm.

a) Features:

i) Wide frequency range from 10MHz to 500MHz (Standard model) /300MHz to 7GHz (Advanced / Optional model with two separate BNCs one BNC per range).

ii) Bright $4^{1/2}$ Digital display for frequency readout.

iii) Max Power input +20dBm/+12dBm.

iv) 50Ω input with BNC connector.

b) Technical specifications:

Table 2.4 RF power meter technical specifications

Sr. No.	Items	Specifications
1.	Frequency Range	10MHz to 500MHz.
2.	Input Power Range	+15dBm to -60dBm.
3.	Power Accuracy	+/- 2.5dB of full scale.
4.	Display	$4.^{1/2}$ digit 7 segment Red LED. (LCD16X2 optional).
5.	Power	220V/240V switch settable@ 50Hz/(60Hz optional) +/-10%,15VA.
6.	Dimension & Weight	295 (W) X 220 (D) X 98 (H) & Approx 1.9 Kg.

c) Front bezel description:

Fig 2.2 Front bezel of RF power meter

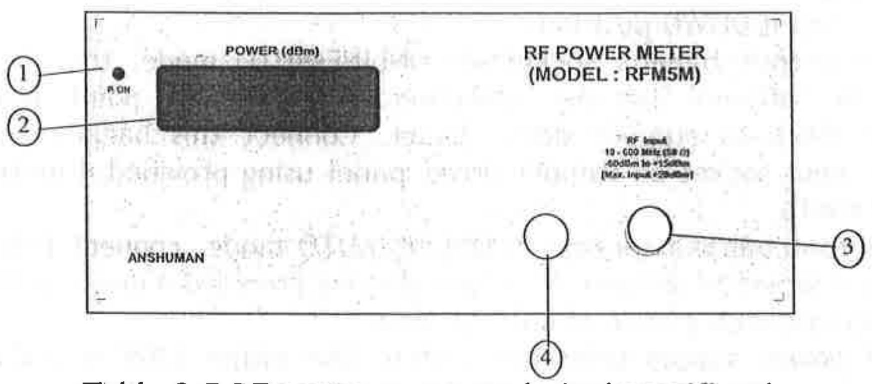


Table 2.5 RF power meter technical specifications

Points	Nomenclature	Function
1.	Power-ON LED.	Indicates Instrument is in Power ON mode.
2.	Display 7-segment	Display Power in dBm.
3.	Output BNC Connector	RF Input with 50Ω impedance (10-500MHz).
4.	Output BNC Connector (optional)	RF Input with 50Ω impedance (300MHz - 7GHz).

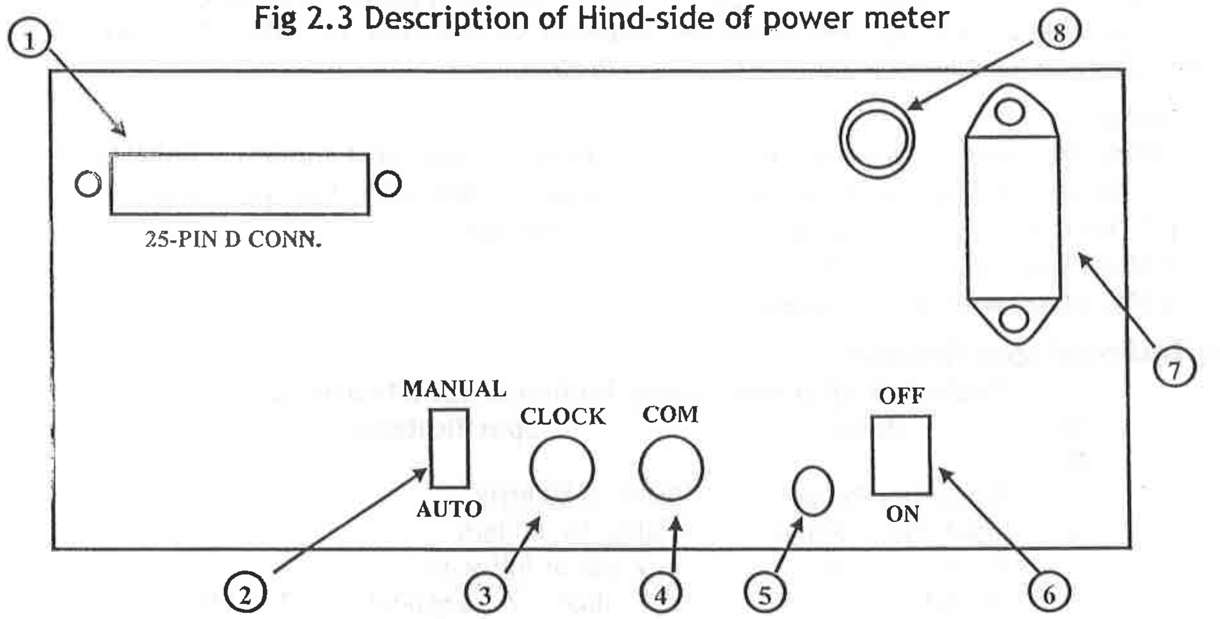
d) Operating procedure:

First switch-ON the RF power meter by using ON/OFF switch provided on the hind side of panel & check the power-ON LED on front side.

Use the 7-segment display for observing power of input RF signal (whatever) & use RF input BNC to input RF signal for observing its power level.

e) Power meter Hind-side description:

Fig 2.3 Description of Hind-side of power meter



Description of different switches/sockets provided on hind-side of meter:

1) 25-Pin D Male connector: This 25-pin D connector is provided for connection of USB I/O module to make communication between PC & hardware using USB cable provided.

2) AUTO/MANUAL selection switch: This toggle switch is used for selection of AUTO or MANUAL modes of operation while software in ONLINE mode. Keep this switch in UP-position for ONLINE-MANUAL (this is the default position) & for ONLINE-AUTO, keep it DOWN-position.

3) Clock-pulse output banana socket: In ONLINE-AUTO mode, the clock-pulse generated from software (as per selection of pulse/plot point button) is transferred as clock to stepper driver panel. Connect this banana socket to external-clock input socket on stepper driver panel using provided 4 metre patch cords (use red cord).

4) Common output banana socket: In ONLINE-AUTO mode, connect this banana socket to ground socket of stepper driver panel using provided 4 metre patch cords (use black cord) to match ground of both systems.

5) 220V/240V power supply selection switch: Use either 220V or 240V power supply input as per your current mains supply using this toggle switch.

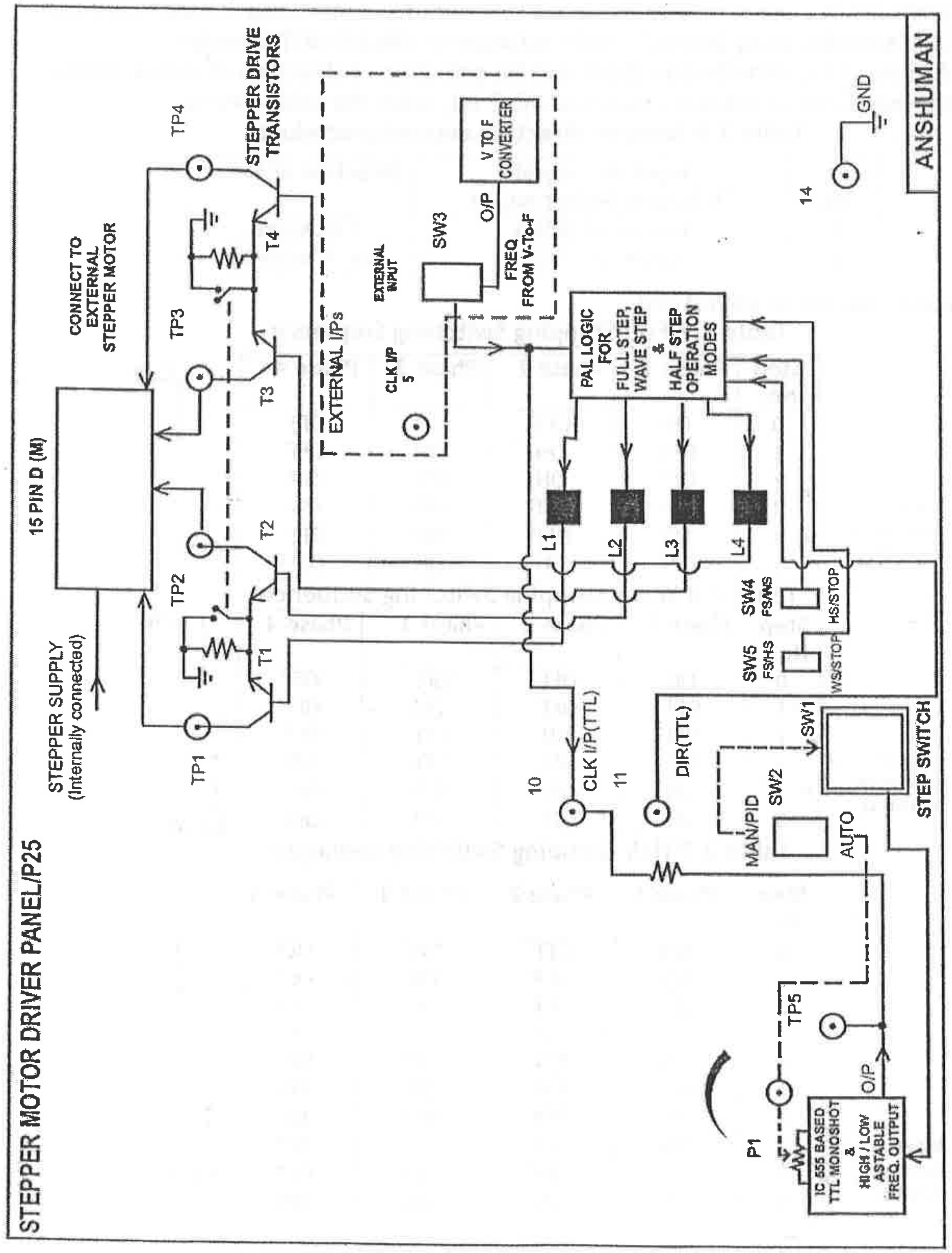
6) Power supply ON/OFF switch: This switch is used to power ON or OFF selection of power meter.

7) Mains power supply connector: By using this connector, connect mains directly to this connector using provided power cord.

8) Fuse: This fuse is useful for switch-OFF the complete system, in case of short-circuits or current crosses the rated range.

3) **Stepper Motor driver panel/P25:** A panel P25 is optionally provided with trainer for auto positioning of transmitting antenna mast. This panel contains stepper motor driving circuitry to drive the in-built stepper motor on the transmitting mast, used only for Radiation pattern measurement of an antenna under test (AUT). When stepper driver facility is not provided then user may rotate transmitting mast by hand also by 10^0 increase using printed scale & pointer.

Fig 2.4 Stepper motor driver Panel P25 (Overlay view)



a) The Panel P25 consists of following functional blocks;

i) Four numbers winding current switches (Transistor-TIP122) with heavy duty Heat-sinks on underside of Panel. Four test points **TP1 to** TP4 are connected at Collector of each transistor.

ii) IC555 timer circuit is provided on the panel itself works either in Monoshot mode (TTL clock pulse input) using provided step push **button** (SW1), **when SW2 is in UP position** or you can also apply continuous step **pulses** using POT 'P1', when **SW2 is in DOWN position** (Do not use SW2 in DOWN position, for AUTO clocking of programmable IC, use the software & set the clock for continuous stepper rotation using "Pulses/plot point button", while software in ONLINE-AUTO mode).

iii) A BS5-No. 11 is provided on the Panel for selection of direction of motor either in clockwise (C.W) or counter clock wise (C.C.W), refer the table below;

Table 2.6 Stepper direction control procedure

Sr. No.	Input Dir. signal To Banana Socket no. 11	Direction of Motor
1.	Low Level (GND)	Clockwise.
2.	Open (or, TTL)	Anti-Clockwise.

b) Stepper modes of operation:

Table 2.7 Full Stepping Switching Sequence

Step No.	Phase 1	Phase 2	Phase 3	Phase 4
0	ON	OFF	ON	OFF
1	OFF	ON	ON	OFF
2	OFF	ON	OFF	ON
3	ON	OFF	OFF	ON
4	ON	OFF	ON	OFF
5	OFF	ON	ON	OFF

Above sequences repeating

C.W

C.C.W

Table 2.8 Wave Stepping Switching Sequence

Step No.	Phase 1	Phase 2	Phase 3	Phase 4
0	ON	OFF	OFF	OFF
1	OFF	OFF	ON	OFF
2	OFF	ON	OFF	OFF
3	OFF	OFF	OFF	ON
4	ON	OFF	OFF	OFF
5	OFF	OFF	ON	OFF

Above sequences repeating

C.W

C.C.W

Table 2.9 Half Stepping Switching Sequence

Step No.	Phase 1	Phase 2	Phase 3	Phase 4
0	ON	OFF	OFF	OFF
1	ON	OFF	ON	OFF
2	OFF	OFF	ON	OFF
3	OFF	ON	ON	OFF
4	OFF	ON	OFF	OFF
5	OFF	ON	OFF	ON
6	OFF	OFF	OFF	ON
7	ON	OFF	OFF	ON
8	ON	OFF	OFF	OFF
9	ON	OFF	ON	OFF

Above sequences repeating

C.W

C.C.W

For selection of different stepping modes of stepper motor, two nos. of switches are provided on the Panel (SW4 & SW5), refer below table for these configurations;

Table 2.10 Switches setting for stepper operation modes selection

Sr. No.	Switches settings		Stepper modes of operation
	SW5	SW4	
1.	UP	UP	Full Stepping
2.	DOWN	UP	Wave Stepping
3.	UP	DOWN	Half Stepping
4.	DOWN	DOWN	Stop (Motor will not Rotate).

Note: At Power ON condition, keep both switches in down position (stop mode).

c) Wiring schedule for stepper operation:

i) Full Stepping operation: (Default)

> **Wiring Sequence:** SW5 - UP, SW4 - UP, SW2 - UP (Manual), SW3 - UP.
> Apply external clock to BS5-5 & BS5-14, in case of ONLINE-AUTO mode.
> And use SW1 for step input, in case of ONLINE-MANUAL mode.

ii) Wave Stepping operation:

> **Wiring Sequence:** SW5 - DOWN, SW4 - UP, SW2 - UP (Manual), SW3 - UP.
> Apply external clock to BS5-5 & BS5-14, in case of ONLINE-AUTO mode.
> And use SW1 for step input, in case of ONLINE-MANUAL mode.

iii) Half Stepping operation:

> **Wiring Sequence:** SW5 - UP, SW4 - DOWN, SW2 - UP (Manual), SW3 - UP.
> Apply external clock to BS5-5 & BS5-14, in case of ONLINE-AUTO mode.
> And use SW1 for step input, in case of ONLINE-MANUAL mode.

NOTE:

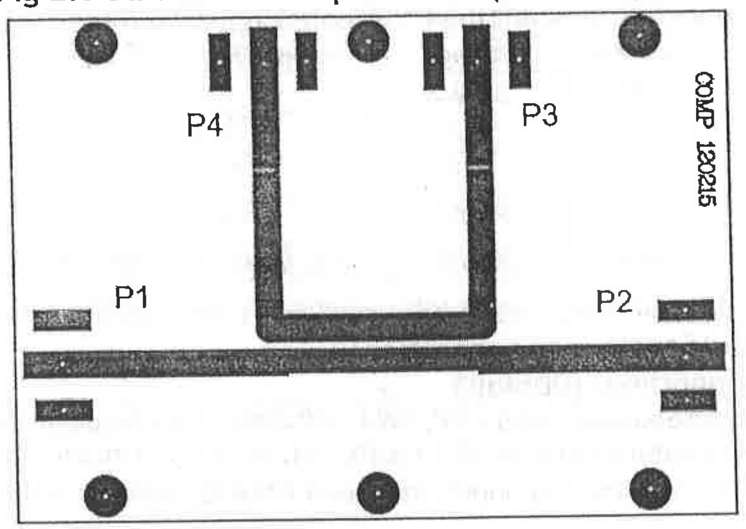
1) In each case, put switch 'SW2' & 'SW3' in UP position, so as to accept external clock input from RF power meter.
2) Apply GND signal to BS5 no. 11 for Clockwise direction of motor, if required, but by default the motor rotation is in Anti-clockwise direction.
3) Use BS5-5 (for external clock-pulse input) & BS5-14 (for Ground input) for RF power meter connections to accept external clock & COM from power meter.
4) Use push button 'SW1' to apply single clock to stepper in case of ONLINE-MANUAL mode.
5) Power supply to panel is internally connected from underside of PCB & for stepper; it is connected through 15-pin D connector.

Table 2.11 List of Panel sockets & miscellaneous functions

Sr. No.	socket or switch or pot	Function
I) Sockets:		
3.	BS5-10	For observation of TTL clock input of programmable IC.
4.	BS5-11	Stepper direction control socket.
5.	BS5-5	External TTL clock input socket from RF power meter.
6.	BS5-14	GND socket to connect to COM of RF-PM for clock pulse i/p.
II) Switches & Pot:		
1.	SW1	Step input clock switch in case of manual mode operation.
2.	SW2	Manual and auto selection clock for programmable IC.
3.	SW4 & SW5	For selection of stepper modes of operation (See above table).
5.	P1	Pot for stepper speed control in case of auto mode operation.

4) Directional Coupler:

Fig 2.5 Directional Coupler / MS1 (PCB view)



Directional coupler is a passive reciprocal network having four-ports, all four ports are ideally matched and the circuit is ideally lossless. Directional couplers can be realized in microstrip, stripline, coax and waveguide. The provided Directional coupler is a microstrip one.

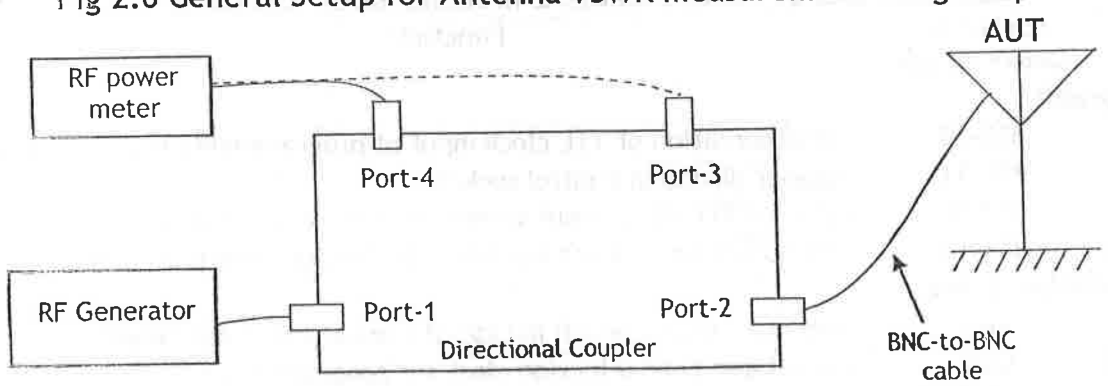
A directional coupler has four ports, where port-1 is regarded as the **"Input port"**, port-2 is regarded as the **"Through port"** (where most of the incident signal exits), port-4 is regarded as the **"Coupled port"** (where a fixed fraction of the input signal appears, usually expressed in dB), and port-3 is regarded as the **"Isolated port"**, which is usually terminated.

The PCB view of directional coupler is shown, in which, if port-1 is the input port, port-2 is the through port (because it is connected with a straight line). Port-4 is the coupled port, and port-3 is the isolated port. For a signal, incident on port-2, port-1 is the through port, port-3 is the coupled port and port-4 is the isolated port. Hence a Directional coupler is a passive reciprocal network.

Application of Directional coupler for VSWR measurement:

The directional coupler is used for measurement of antenna VSWR by the following setup as shown below;

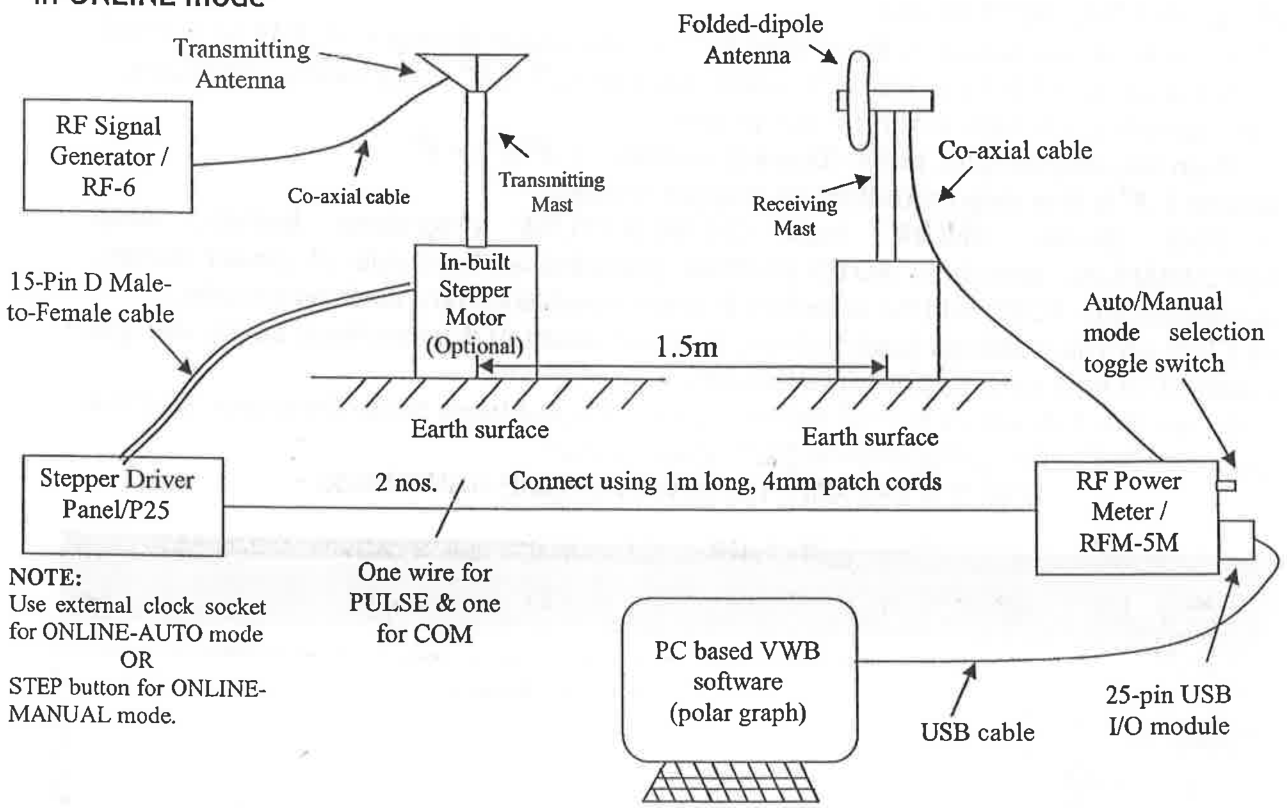
Fig 2.6 General Setup for Antenna VSWR measurement using Coupler



5) To plot Antenna radiation pattern using VWB software

Note:- Refer appendix to know more about VWB software package. We need only "polar graph" facility supported by VWB software. It contains many other function blocks but you may ignore them and use only "polar graph".

Fig. 2.7 Hardware set-up block diagram for plotting Antenna Radiation pattern in ONLINE mode



A) HARDWARE SETUP :

i) Mount firmly AUT (in this case, Folded-dipole antenna) at top of transmitting mast & other folded-dipole antenna at receiving mast using M8x45 screw & wing nut, maintain there distance of 1.5 metre approx.

ii) Connect **CLOCK & COM output sockets** of RF power meter (provided at hind-side of meter) to stepper driver panel as per below wiring sequence using patch-cords. And make some more settings on P25 as given in below wiring sequence.

Wiring Sequence: CLOCK (From power meter) - 5 (on P25), COM (From power meter) - 14 (on P25),
FOR ONLINE-AUTO MODE (Set on P25): SW2 - **UP**, SW3 - UP, SW4 - UP, SW5 - UP (Full Step).
FOR ONLINE-MANUAL MODE (Set on P25): SW2 - UP, SW3 - DOWN, SW4 - UP, SW5 - UP.

<u>NOTE:</u> 1000nF disc capacitor may be soldered internally at BS5-5 on P25 to limit spurious clocking.

iii) Connect **USB I/O module to 25-pin male connector** provided at hind-side of power meter. From here, connect USB cable to PC.

iv) Keep the **AUTO/MANUAL switch** at hind-side on RF power meter at Auto position (i.e. Down position), this is the default position of this switch.

v) Connect RF signal generator (keep it in OFF mode) to AUT & RF power meter (keep it in OFF mode) to receiving antenna using BNC-to-BNC cable.

B) SOFTWARE SETUP :

Double click to open VWB software. Click on "Polar graph" facility.

There are two modes of operation in "polar graph" software i.e. ONLINE (AUTO/MANUAL) & OFFLINE modes.

a) For ONLINE-AUTO mode:

This mode of operation is illustrated to capture signal strength of AUT at 5 clock pulses & delay of 0.1 second with angle steps of AUT is 9^0 as per below equations;

For capturing strength after 5 clock pulses,

Then set degree/plot point (Degree) button = $1.8^0 \times 5 = 9^0$.

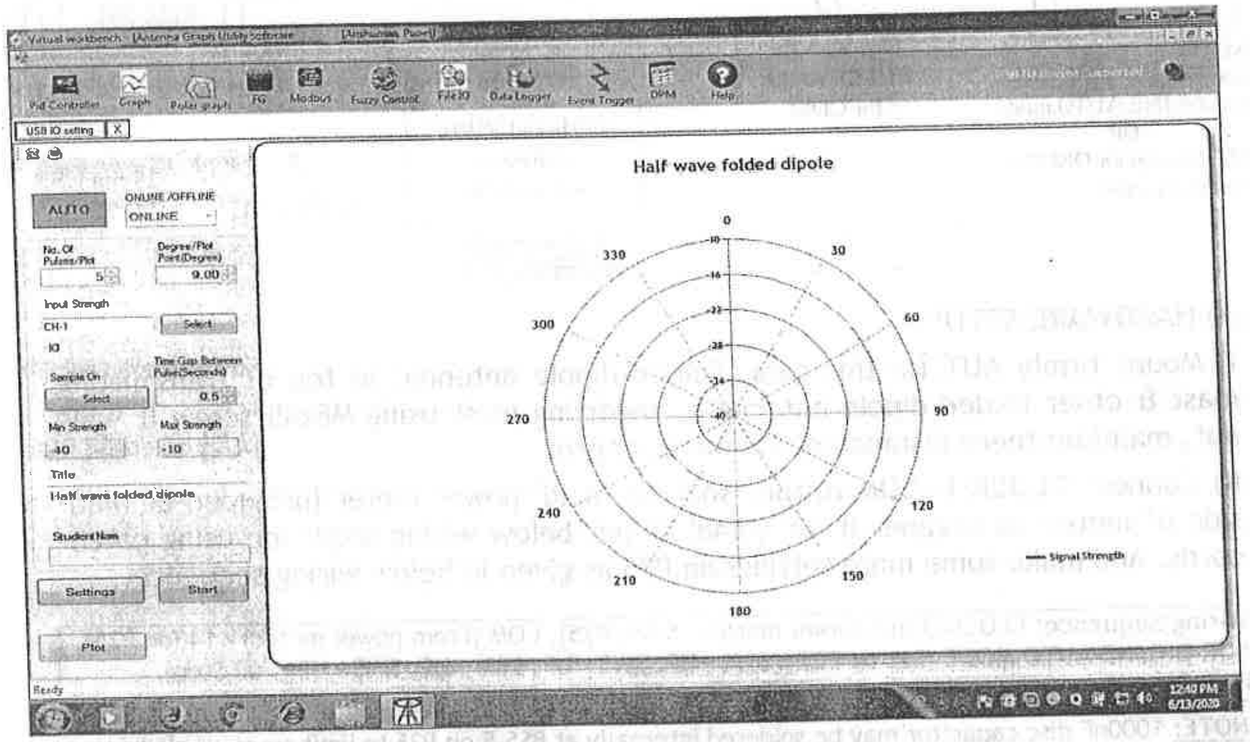
Where 1.8^0 is the step resolution of stepper motor.

i) First choose **ONLINE** from ONLINE/OFFLINE drop-down button. Keep AUTO/MANUAL switch in **AUTO** position provided at hind-side of power meter. Automatically **AUTO** will be selected in polar graph software as shown below.

ii) Click on the **Settings** push button, then all disabled buttons/text boxes will get enabled to edit data as per requirements.

Now set the followings No. of pulses/plot=5, Degree/plot point (Degree)= 9, Time gap between pulse (Seconds)= ~~0.1~~ 0.5 as shown below;

Fig. 2.8 Software window in ONLINE-AUTO mode



iii) Set **Input strength** as **CH-1**, because it is internally set by hardware.

iv) Set **mini strength** (-40) & **max strength** (-10) as per your observations for AUT.

v) Write **Title** of pattern as half wave Folded-dipole antenna pattern on the title text box.

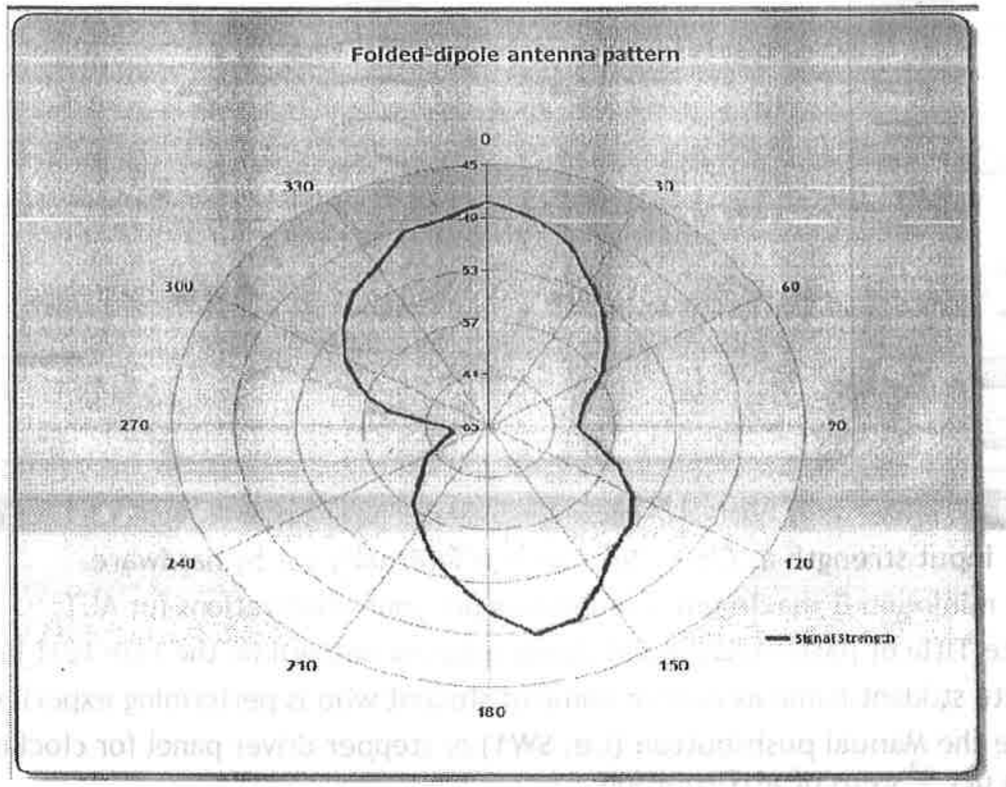
vi) Write **student name** as user or name of student who is performing experiment.

vii) Now click on the **Save-settings button** to save the above settings. By doing this, all setting buttons/boxes will get disabled. And the heading at polar chart area will get convert into the title name (i.e. Folded-dipole antenna pattern) as you have written in the Title text box as shown below.

viii) Now click on **START button** to capture signal strength from AUT and follow the precaution points given in introduction chapter **(i.e. unit-1/point-H)**. Use **STOP button** to stop the AUT movements at any instance.

ix) After completion of all 360^0 rotation of AUT, the AUT rotation will get stopped automatically & you can observe final polar graph on the PC, which is the Radiation pattern of Folded-dipole antenna as shown below;

Fig. 2.9 Observed Radiation pattern of Folded-dipole antenna



x) Now after completion of total observations, you can take print-out or can save the observed graph using the **Print & Save icons**.

xi) The signal strengths observed at every angle steps (i.e. the steps setting by user) are also saved automatically in the setup folder of this software as **tempdata.ans** (i.e. where the setup file is stored in your PC), generally this will saved in the following path;

C:\Program Files\STS\SetupPolar\Polar graph\ tempData.ans

Use "Notepad" to read this file by using open-with icon & select Notepad.

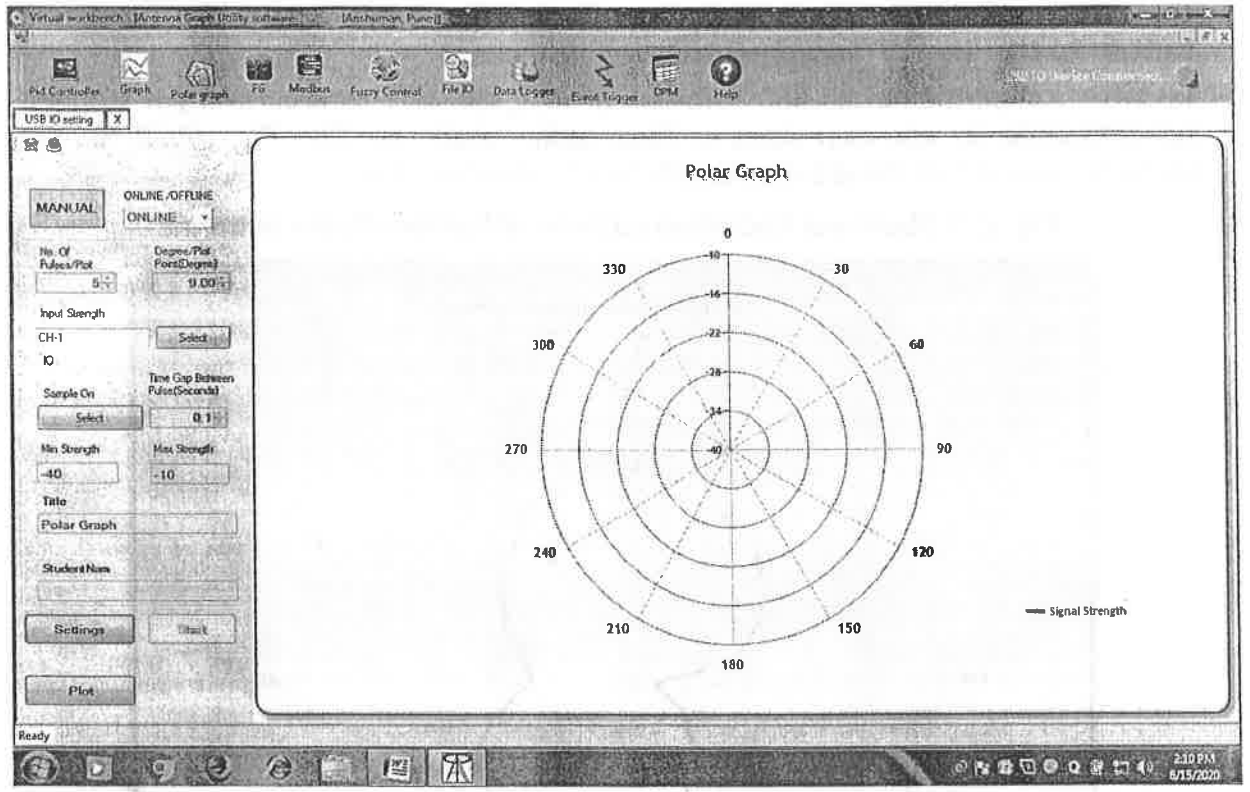
b) For ONLINE-MANUAL mode:

<u>NOTE:</u> Make all hardware settings/configurations given above.

i) First choose **ONLINE** from ONLINE/OFFLINE drop-down button. Keep AUTO/MANUAL switch in **MANUAL** position provided at hind-side of RF power meter. Automatically **MANUAL** will be selected in polar graph software as shown below.

ii) There is no need of settings for No. of pulses/plot and Time gap between pulse buttons. Set only Degree/plot point button as per your observation i.e. 9^0.

Fig. 2.10 Software window in ONLINE-MANUAL mode



iii) Set **input strength** as CH-1, because it is internally set by hardware.

iv) Set **minimum & maximum strengths** as per your observations for AUT.

v) Write **Title** of pattern as Folded-dipole antenna pattern on the title text box.

vi) Write student name as user or name of student who is performing experiment.

vii) Use the **Manual push-button (i.e. SW1)** of stepper driver panel for clocking the AUT as per 9^0 steps of AUT rotation.

viii) Now use the **PLOT button** to capture signal strength. Click only after 9^0 of AUT rotation as per No. of pulses/plot button settings used for ONLINE-AUTO mode. Means clock the AUT using **SW1 switch** of stepper driver panel after 5 clock input to AUT for 9^0 step rotation using this button & then click on the POLT button.

ix) The signal strengths observed at every angle steps (i.e. the steps setting by user) are also saved automatically in the setup folder of this software as **tempdata.ans** (i.e. where the setup file is stored in your PC).

x) Now after completion of total observations, you can take print-out or can save the observed graph using the **Print & Save icons**.

c) For OFFLINE mode:

<u>NOTE:</u> There is no need of hardware settings/configuration, whatever given above.

i) First choose **OFFLINE** from ONLINE/OFFLINE drop-down button in software.

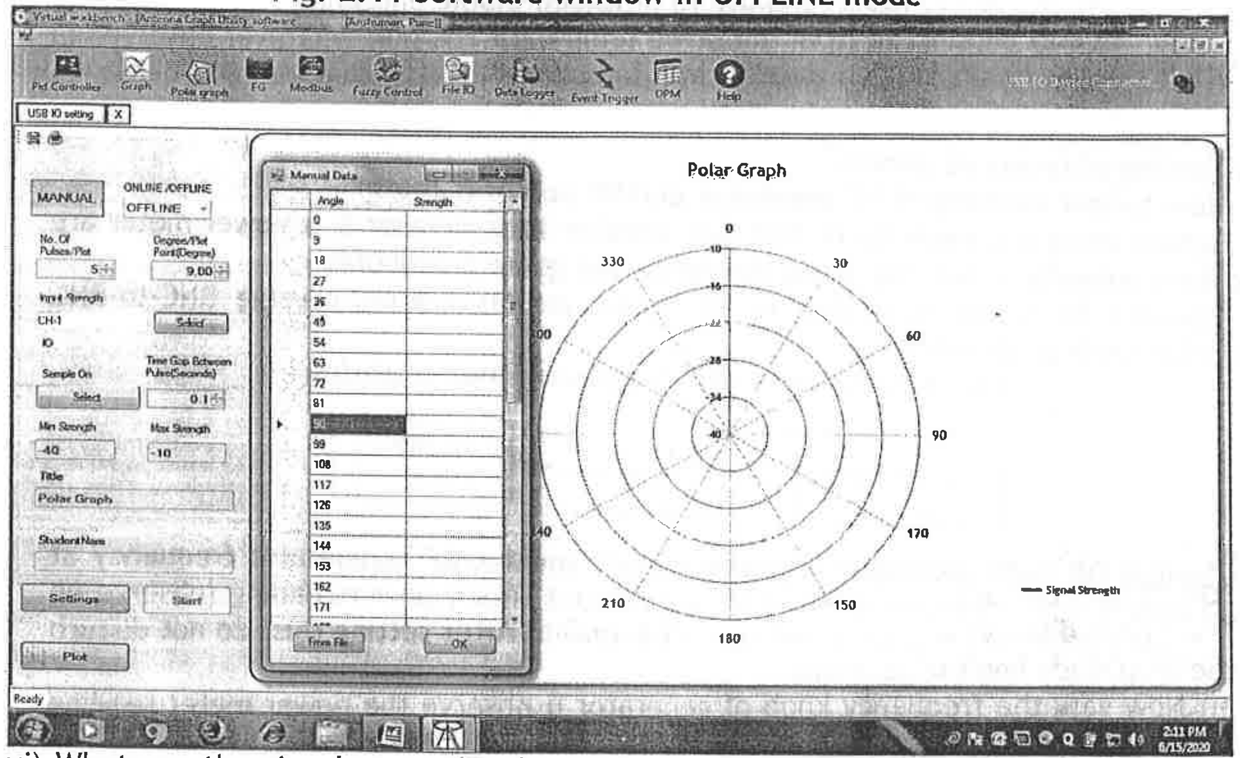
ii) There is no need of settings for No. of pulses/plot and Time gap between pulse buttons. Set only Degree/plot point button as per your observed readings i.e. at 9^0

steps (considered as normal observation steps) of AUT rotation.

iii) Set **minimum & maximum strengths** as per your observed readings.

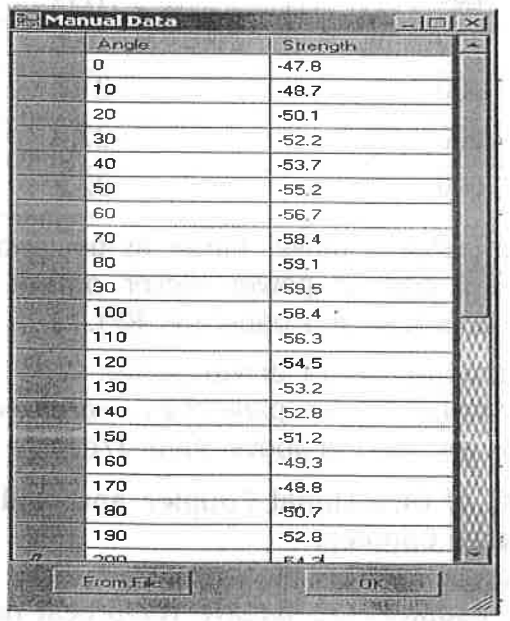
iv) Write Title of pattern as "Folded-dipole antenna pattern" on the title text box and Write student name as user or name of student who is performing experiment, then the setting window will appear a shown;

Fig. 2.11 Software window in OFFLINE mode



vi) Whatever the signal strengths observed manually as per experiments provided in the separate chapters, directly fill in the table of Angle versus strength in OFFLINE mode manual data entry table as shown (click on the **PLOT button** to pop-up the table) as shown below;

Fig. 2.12 Filled manual data entry table in OFFLINE mode



Angle	Strength
0	-47.8
10	-48.7
20	-50.1
30	-52.2
40	-53.7
50	-55.2
60	-56.7
70	-58.4
80	-59.1
90	-59.5
100	-58.4
110	-56.3
120	-54.5
130	-53.2
140	-52.8
150	-51.2
160	-49.3
170	-48.8
180	-50.7
190	-52.8
200	[illegible]

NOTE: Please fill the complete rows of signal strengths for each angle, if any one left to fill, then polar graph will not show. So, while filling table fills each row corresponding to different angles.

vii) Now after filling the complete table, click on the **OK button** on the same manual data table window, then finally a polar graph will appear on the polar chart area. This is the radiation pattern of folded-dipole antenna.

You can also import file from the saved temp-data.ans file, whatever observed in ONLINE-mode by clicking on the **"From-File button"** of Manual data entry table.

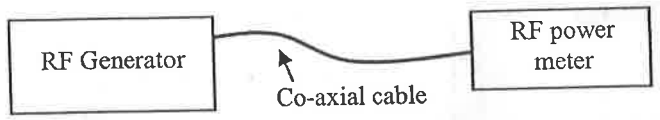
6) Testing of resource panels:

a) How to test working of RF generator and RF power meter:

Before doing any experiment first test whether RF generator & power meter are working properly or not, for doing this follow the given procedure;

i) Connect RF signal generator to RF power meter directly using BNC-to-BNC co-axial cable as shown below,

Fig. 2.13 RF generator & power meter testing



ii) Switch ON both generator & power meter, and set RF generator frequency at **300 MHz** & use amplitude knob of RF generator to set power reading (observe on 7-segment display) of power meter to **-20.0 dBm**. After setting this, do not disturb the amplitude knob of generator.

iii) Now vary the frequency knob of generator & observe the power meter reading (in dBm) as per the below table;

Table 2.12 Testing procedure of RF generator & power meter

Sr. No.	RF generator output (in MHz)	RF power meter readings (in dBm)
1.	100	-15.7
2.	200	-17.9
3.	300	-20.0
4.	400	-21.8
5.	500	-27.3
6.	600	-32.2

NOTE: While testing RF generator & power meter as per above readings, assume some tolerances of upto 2-3 dBm in power meter output (this is because of frequency at which you are operating this panel i.e. RF).

b) How to test working of stepper motor driver panel:

For testing of stepper motor driver panel/P25, refer wiring sequences for stepper modes of operations provided in above point-3/c.

c) How to test parameters of Directional Coupler and finding Antenna Return Loss & VSWR using Directional Coupler:

A) Directional Coupler & its parameters measurement:

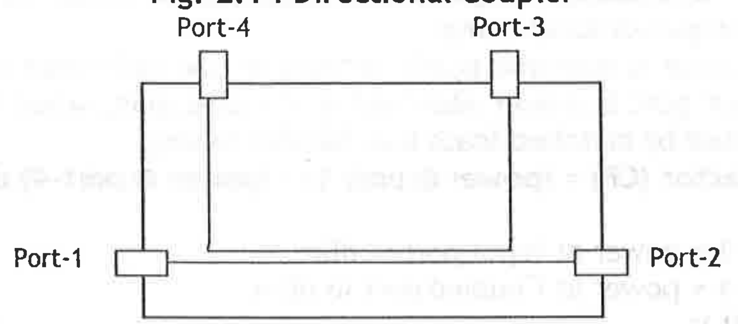
i) Definition: Directional couplers are passive reciprocal networks having four-ports, all four ports are ideally matched and the circuit is ideally lossless.

Directional couplers can be realized in microstrip, stripline, coax and waveguide. They are used for sampling a signal, sometimes both the incident and reflected waves (this application is called a reflectometer, which is an important part of a network analyzer). Directional couplers generally use distributed properties of microwave circuits, the coupling feature is generally a quarter (or multiple) quarter-wavelengths. Lumped element couplers can be constructed as well.

A directional coupler has four ports, where port-1 is regarded as the **"Input port"**, port-2 is regarded as the **"Through port"** (where most of the incident signal exits), port-4 is regarded as the **"Coupled port"** (where a fixed fraction of the input signal appears, usually expressed in dB), and port-3 is regarded as the **"Isolated port"**, which is usually terminated.

If the signal enters from "though" port, most of it exits from the "input" port, but the coupled port is now the port that was previously regarded as the "isolated port". The coupled port is a function of which port is the incident port.

Fig. 2.14 Directional Coupler



The PCB view of directional coupler is shown, in which, if port-1 is the input port, port-2 is the through port (because it is connected with a straight line). Port-4 is the coupled port, and port-3 is the isolated port. For a signal incident on port-2, port-1 is the through port, port-3 is the coupled port and port-4 is the isolated port. Hence a Directional coupler is a passive reciprocal network.

ii) Forward versus backward wave couplers:

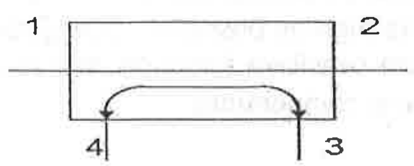
Waveguide couplers are **"Forward wave couplers"**, that means for a signal incident on port-1, port-3 is the coupled port (port-4 is isolated) and Microstrip or stripline couplers are **"Backward wave couplers"**, that means for a signal incident on port-1, port-4 is the coupled port (port-3 is isolated).

The coupled port on a microstrip or stripline directional coupler is closest to the input port because it is a backward wave coupler, what we supply is a microstrip-line directional coupler. On a waveguide broadwall directional coupler, the coupled port is closest to the output port because it is a forward wave coupler.

Bi-directional coupler:

A directional coupler, of which isolated port is not internally terminated, called Bi-directional coupler. You can use such a coupler to form a reflectometer.

Fig. 2.10 Schematic of Bi-directional Coupler



Reflectometer:

This is the component that allows you to measure S-parameter magnitudes using a network analyzer. A directional coupler only does what it is supposed to if it sees matched impedance at all four ports.

Errors due to finite directivity; Directivity can cause errors if load is not matched. 40dB directivity will have a very small error, 20 dB may be unacceptable accuracy.

B) Performance Parameters of Directional Coupler:

Coupling factor (CF):

The coupling factor represents the primary property of a directional coupler. Coupling factor is a negative quantity; it cannot exceed 0 dB and in practice does not exceed −3 dB. Coupling factor is not constant, but varies with frequency. While different designs may reduce the variance, a perfectly flat coupler theoretically cannot be built. Directional couplers are specified in terms of the coupling accuracy at the frequency band center.

The coupling-factor is mathematically defined as the difference of power input to coupler at input port & power observed at Coupled port, when the two other ports are terminated by matched loads (i.e. 50 ohm loads),

Coupling factor (CF) = (power @ port-1) - (power @ port-4) dBm

Where,

Power @ port-1 = power at input port in dBm.

Power @ port-4 = power at Coupled port in dBm.

Main-line Loss (ML):

Main-line loss of a directional coupler can be defined as the difference in signal levels in dBm between the input port and the output port, when the two other ports are terminated by matched loads (i.e. 50 ohm loads) to know how much the losses in coupler main-line,

Main-line loss (ML) = (power @ port-1) - (power @ port-2) dBm

Where,

Power @ port-1 = power at input port in dBm.

Power @ port-2 = power at output port in dBm.

Directivity (D):

It is defined as the power level difference between Coupled port & Isolated port, when the two other ports are terminated by matched loads (i.e. 50 ohm loads). This is a measure of how independent the coupled and isolated ports are. Because it is impossible to build a perfect coupler, there will always be some amount of unintended coupling between all the signal paths.

Directivity (D) = (power @ port-4) - (power @ port-3) dBm

Where,

Power @ port-4 = power at Coupled port in dBm.

Power @ port-4 = power at Isolated port in dBm.

The directivity should be as high as possible. The directivity is very high at the design frequency and is a more sensitive function of frequency because it depends on the cancellation of two wave components

Isolation (I):

Isolation of a directional coupler can be defined as the difference in signal levels in dBm between the input port and the Isolated port, when the two other ports are terminated by matched loads (i.e. 50 ohm loads),

Isolation (I) = (power @ port-1) - (power @ port-3) dBm

Where,
Power @ port-1 = power at input port in dBm.
Power @ port-3 = power at Isolated port in dBm.

C) Scattering Parameters of a Directional Coupler:

S-parameters refer to the scattering matrix ('S' in S-parameter refers to **Scattering**). The scattering matrix is a mathematical construct that quantifies how RF energy propagates through a multi-port network. For an RF signal incident on one port, some fraction of the signal bounces back out of that port, some of it scatters and exits other ports, and some of it disappears as heat or even electromagnetic radiation. The S-matrix for an N-port contains a N^2 coefficients (S-parameters), each one representing a possible input-output path.

S-parameters refer to "RF signal out versus in" in the most basic sense. S-parameters come in a matrix, with the number of rows and columns equal to the number of ports.

Parameters along the diagonal of the S-matrix are referred to as **"Reflection coefficients"** because they only refer to what happens at a single port, while off-diagonal S-parameters are referred to as **"Transmission coefficients"**, because they refer to what happens from one port to another. Here are the S-matrices for two and three-port networks are given;

For 2-port network

$$S = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix}$$

For 3-port network

$$S = \begin{pmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{pmatrix}$$

And so on..

For the Directional coupler provided with the Trainer set having four-ports as described above, hence for this coupler the S-parameter matrix is defined as;

$$S = \begin{pmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{pmatrix}$$

Ideal considerations:

i) Incident at any port, ideally will not reflect signal from that port itself,

Hence, $S_{11} = S_{22} = S_{33} = S_{44} = 0$.

ii) As we know a Directional coupler is a passive reciprocal network, then we can write, Sij = Sji. Hence, $S_{12} = S_{21}$, $S_{13} = S_{31}$ etc.

iii) Isolated port ideally can be assumed to have zero output with respect to incident port. When incident signal at port-1; port-3 will be the isolated port & when incident at port-2; port-4 will be the isolated port,

Then, $S_{13} = S_{31} = 0$.

And, $S_{24} = S_{42} = 0$.

Then above Four-port S-parameter matrix will reduces to;

$$S = \begin{pmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{21} & 0 & S_{23} & 0 \\ 0 & S_{32} & 0 & S_{34} \\ S_{41} & 0 & S_{43} & 0 \end{pmatrix}$$

Thus only four coefficients viz. S_{12} (= S_{21}), S_{41} (= S_{14}), S_{23} (= S_{32}) and S_{43} (= S_{34}) need to be measured experimentally.

For the S-parameter subscripts "ij", j is the port that is excited (the input port) by using RF signal generator, and "i" is the output port (observe by using RF power meter) and all other ports are terminated by matched load (generally by 50Ω termination). Thus S_{11} refers to the ratio of signal that reflects from port-1 for a signal incident on port-1 itself, in case of linear scale measurements. But, in case of measurements in dBm, calculate difference of both powers to get the S-parameter,

Hence, Sij = (Power level @ port-j) - (Power level @ port-i) dBm.

—————(1)

Where,

Port-i = The port at which RF signal in applied by RF signal generator.

Port-j = The port from which output RF power level measured by power meter.

D) Return Loss (R_L) & Voltage Standing Wave Ratio (VSWR):

Definition: The voltage standing wave ratio may be illustrated by considering the voltage at various points along a cable driving a poorly matched antenna. A mismatched antenna reflects some of the incident power back towards the transmitter and since this reflected wave is traveling in the opposite direction as the incident wave, there will be some points along the cable where the two waves are in phase and other points where the waves are out of phase (assuming a sufficiently long cable). If one could attach an RF power at these two points, the two voltages could be measured and their ratio would be the SWR.

The VSWR is a measure of how much power is delivered to a device as opposed to the amount of power that is reflected from the device. If the source and load impedance are same, the VSWR is 1:1; i.e. there is no reflected power. So the VSWR is also a measure of how closely the source and load impedance are matched.

Here in this trainer system, the RF generator & power meter is of 50 ohm, but the impedance of antennas are different as per their design like 300 ohm, 100 ohm etc. Hence for matching of impedance a Balun is used inside the antenna holder box for conversion of antenna impedance to 50 ohm only for getting maximum efficiency.

But due to some design methods or accessories used (i.e. element, internal Balun etc), antenna impedance may get changed from the specific 50 ohm design. For this, a VSWR measurement is illustrated for all antennas provided with the trainer set using the Directional coupler.

Mathematical equations: For measurement of antenna Return Loss & VSWR, use the Directional coupler & calculate by following mathematical equations;

$$\text{Return Loss } (R_L) = -(P_F - P_R) \text{ dBm} \qquad \text{———} \quad (2)$$

Where,

P_F = Power observed at port-4; when RF input at port-1, AUT at port-2 & terminate port-3 by 50Ω i.e. Forward power (in dBm).

P_R = Power observed at port-3; when RF input at port-1, AUT at port-2 & terminate port-4 by 50Ω i.e. Reflected power (in dBm).

And negative sign indicates; the loss and loss is always in negative.

$$\text{Reflection co-efficient } (\Gamma) = \text{Antilog } (R_L / 20) \qquad \text{———} \quad (3)$$

Where,

Antilog = Indicates Anti-logarithm of logarithmic base-10.

And, VSWR can be calculated from the following equation;

$$\text{VSWR} = (1 + \Gamma) / (1 - \Gamma) \qquad \text{———} \quad (4)$$

☞ Procedure

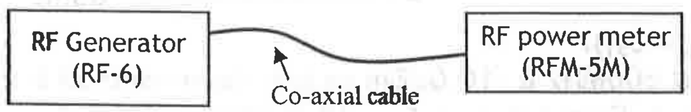
A) Measurement of Performance & Scattering parameters of Directional Coupler:

a) Coupling factor (CF):

With respect to port-1 (or, $S_{14} = S_{41}$):

1) Set RF signal generator at 500MHz & -10.0 dBm, by directly connecting RF generator to RF power meter using BNC-to-BNC cable as shown below. Vary amplitude knob of generator & observe power meter reading to set it at -10.0dBm.

Fig. 2.15 Setting of RF signal generator



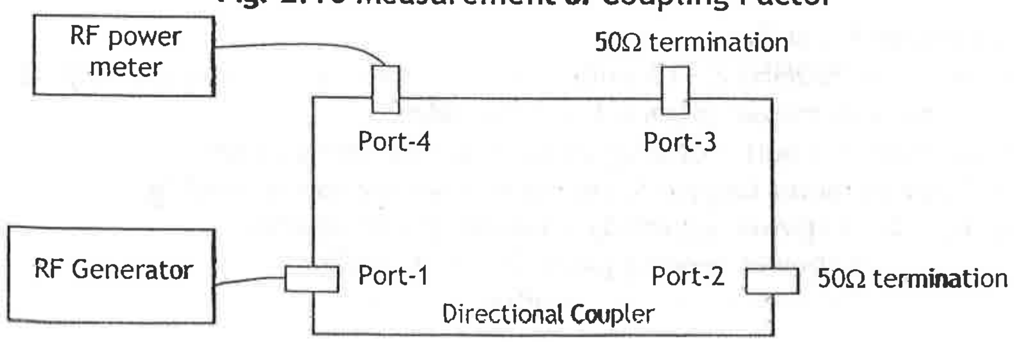
2) Switch OFF both the RF signal generator & RF power meter. Disconnect RF generator from power meter and connect to the port-1 of Directional coupler.

Hence, Power @ port-1 = -10.0 dBm.

3) Terminate port-2 & port-3 of coupler by 50Ω BNC termination as shown below;

4) Now connect RF power meter to port-4 of coupler by using BNC-to-BNC cable & note down the power meter reading.

Fig. 2.16 Measurement of Coupling Factor



Hence, Coupling factor (or, $S_{14} = S_{41}$) = (power @ port-4) - (power @ port-1) dBm
= ------------------------ dBm.

With respect to port-2 (or, $S_{23} = S_{32}$):

1) Set generator at **500MHz & -10.0dBm** as per above method & apply to port-2.
Hence, Power @ port-2 = -10.0 dBm.
2) Terminate port-1 & port-4 of coupler by 50Ω BNC terminations.
3) Connect power meter to port-3 and note down the meter reading;
Hence, Coupling factor (or, $S_{23} = S_{32}$) = (power @ port-3) - (power @ port-2) dBm
= (power level @ port-3) - (-10.0) dBm.
= ------------------------ dBm.

b) Main-line Loss (or, $S_{12} = S_{21}$):

i) Set generator at **500MHz & -10.0dBm** as per above method & apply to port-1.
Hence, Power @ port-1 = -10.0 dBm.
ii) Terminate port-3 & port-4 of coupler by 50Ω BNC terminations.
iii) Connect power meter to port-2 and note down the meter reading;
Hence, Main-line loss (or, $S_{12} = S_{21}$) = (power @ port-2) - (power @ port-1) dBm
= (power level @ port-2) - (-10.0) dBm.
= ------------------------ dBm.

c) Directivity (or, $S_{13} - S_{41}$ or ideally -CF) :

i) Set generator at **500MHz & -10.0dBm** as per above method & apply to port-1.
Hence, Power @ port-1 = -10.0 dBm.
NOTE: The S_{13} parameter is ideally considered as zero, then S_{13} = 0 dBm.
ii) Now terminate port-2 & port-3 of coupler by 50Ω BNC terminations.
iii) Connect power meter to port-4 and note down the meter reading;
Hence, Directivity (or, $S_{13} - S_{41}$) = 0 - (S_{41}) dBm = - (S_{41}) dBm
= - [(power level @ port-4) - (-10.0)] dBm.
= ------------------------ dBm.

d) Isolation (or, $S_{13} = S_{31}$):

i) Set generator at **500MHz & -10.0dBm** as per above method & apply to port-1.
Hence, Power @ port-1 = -10.0 dBm.
ii) Terminate port-2 & port-4 of coupler by 50Ω BNC terminations.
iii) Connect power meter to port-3 and note down the meter reading;
Hence, Main-line loss (or, $S_{13} = S_{31}$) = (power @ port-3) - (power @ port-1) dBm
= (power level @ port-3) - (-10.0) dBm.
= ------------------------ dBm.

NOTE: Ideally considering isolated port output as zero (i.e. $S_{13} = S_{31} = 0$). Thus you normally observe minimum power output as compare to other measurements, so consider this minimum reading as 0 dBm, something like a tare on weighing scale.

e) Measurement of S_{43} or S_{34}:

i) Set generator at **500MHz & -10.0dBm** as per above method & apply to port-4.
Hence, Power @ port-4 = -10.0 dBm.
ii) Terminate port-1 & port-2 of coupler by 50Ω BNC terminations.
iii) Connect power meter to port-3 and note down the meter reading;
Hence, $S_{43} = S_{34}$ = (power @ port-3) - (power @ port-4) dBm
= (power level @ port-3) - (-10.0) dBm.
= ------------------------ dBm.

NOTE: Remove the negative sign from the final result of each S-parameter and only consider the magnitudes, because of reciprocity of Directional coupler.

f) Relationship of S-parameters with parameters of Directional coupler :

i) Coupling Factor (CF) = (S_{41}).

ii) Main-line Loss (ML) = (S_{21}).

iii) Directivity (D) = (S_{31}) - (S_{41}).

iv) Isolation (I) = (S_{31}).

B) Measurement of Antenna Return-Loss & VSWR:

For measurement of Antenna VSWR, follow the given step-by-step procedure;

a) Mount Antenna Under Test (AUT) at top of mast using M8x45 screw & wing nut. There is no need of transmitting & receiving of signal for this measurement.

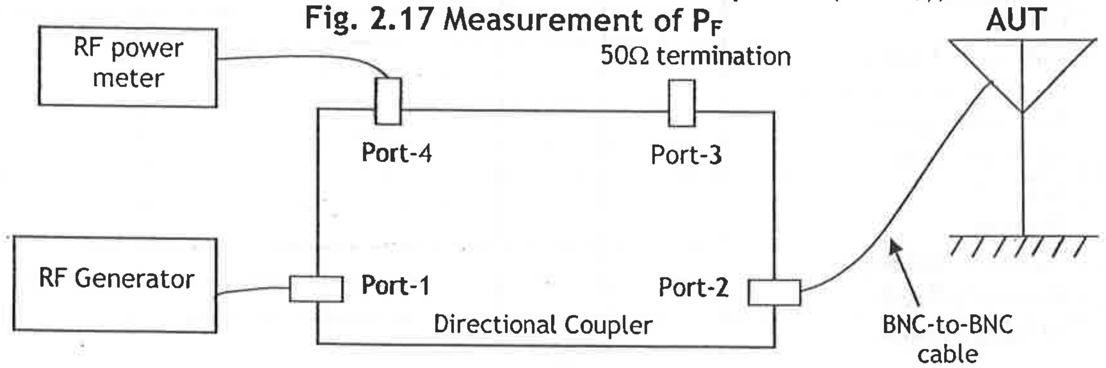
b) Set RF signal generator at **500MHz & -10.0dBm,** by directly connecting RF generator to RF power meter using BNC-to-BNC cable and vary amplitude knob of RF generator & observe power meter reading to set it at -10.0dBm.

c) After RF generator setting, disconnect it from power meter & connect to port-1 of Directional coupler (keep both at OFF mode).

d) Connect AUT at port-2 of Directional coupler using BNC-to-BNC cable as shown.

e) Now, terminate port-3 by 50Ω BNC termination & connect RF power meter to port-4 & note down the meter reading, which is Forward power (i.e. P_F);

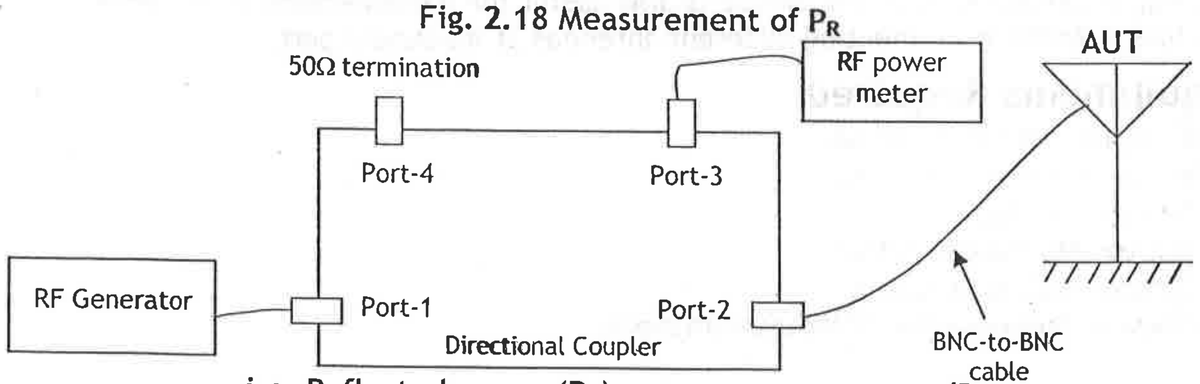
Fig. 2.17 Measurement of P_F



i.e. Forward power (P_F) = ------------------------ dBm.

f) At the same above setup, disconnect power meter from port-4 & terminate this port by 50Ω BNC termination and connect meter to port-3 & note down the meter reading, which is Reflected power (i.e. P_R);

Fig. 2.18 Measurement of P_R



i.e. Reflected power (P_R) = ------------------------ dBm.

g) Calculate Return Loss, Reflection co-efficient & VSWR from the following equations & fill the below observation table.

Return Loss (R_L) = - (P_F - P_R) dBm

Reflection co-efficient (Γ) = Antilog (R_L / 20)

And, VSWR = $(1 + \Gamma) / (1 - \Gamma)$

NOTE: Follow the same above procedures for each Antenna and calculate each parameter from the above equations. Only replace AUT one-by-one & take complete readings for each AUT and fill the respective rows of the below observation table;

Table 2.13 Observation Table of Antenna Return-Loss & VSWR

Sr. No.	Name of Antennas	Measured Parameters				
		P_F (dBm)	P_R (dBm)	Return Loss (dBm)	Reflection Co-efficient	VSWR (No unit)
1.	Half-wave folded dipole.					
2.	Half-wave simple dipole.					
3.	Quarter-wave simple dipole.					
4.	$3\lambda/2$ simple dipole.					
5.	Half-wave Folded-dipole with Reflector.					
6.	Yagi-Uda 3 elements.					
7.	Yagi-Uda 5 elements.					
8.	Yagi-Uda 7 elements.					
9.	Circular Loop.					
10.	Log-periodic.					
11.	Helical.					
12.	Half-wave End-Fire.					
13.	Quarter-wave End-Fire.					
14.	Broad-side array.					
15.	Co-linear array.					
16.	Slot.					
17.	Discone.					
18.	Parabolic Reflector.					
19.	Microstrip Patch.					
20.	Variable Length.					

☞ Conclusion

Hence, from the above observed readings, you can conclude that a Directional coupler is a passive reciprocal network / device, which is observed from the scattering parameters. And this device is also useful for measurement of Antenna return loss & VSWR by connecting different antennas at its output port.

☞ Equipments Required

a) RF Signal generator (RF-6).
b) RF power meter (RFM-5M).
c) Directional Coupler.
d) BNC-to-BNC coaxial cables.
e) 50 ohm BNC termination.
f) Different Antennas for VSWR measurement.

3. Study of Half-wave Folded Dipole Antenna

☞ Unit Objective

On the completion of this unit you will be understand the basic principles related to folded dipole antenna and practically measure the following characteristics of folded dipole antenna;

i) The Radiation pattern (Azimuth XY-plane plot).
ii) Antenna Beamwidth.
iii) Antenna Front-to-Back ratio.
iv) The absolute Gain using FRIIS transmission equation.

NOTE: For gain measurement of other antennas provided in this trainer set, a reference gain measurement method is used (you will study this method in next unit) & for this a folded dipole antenna is used as reference. Here in this unit, the gain of folded dipole antenna is measured using absolute gain measurement method to make this antenna as reference for gain measurement of other antenna.

☞ Discussion on Fundamentals

A folded dipole antenna is a half-wavelength ($\lambda/2$) dipole. Means the physical antenna is constructed of conductive elements whose combined length is about half of a wavelength at its intended frequency of operation. This is a simple antenna that radiates its energy out toward the horizon (perpendicular to the antenna).

For gain measurement of folded-dipole, we used the absolute gain measurement method. For this, a FRIIS transmission equation is used as given below;

$$\frac{P_R}{P_T} = G_T * G_R * \left[\frac{\lambda}{4\Pi R}\right]^2 \quad \text{———} \quad (2)$$

Where,
P_R = Received power at receiver antenna side (in Watts),
P_T = Transmitted power from transmitter antenna side (in Watts),
G_R = Receiver antenna gain (unit less),
G_T = Transmitter antenna gain i.e. AUT (unit less),
λ = Wavelength of transmitted signal = 60 cm (for 500MHz),
R = Distance between both antennas (in meter).
Then,

$$G_T * G_R = \frac{P_R}{P_T}\left[\frac{4\Pi R}{\lambda}\right]^2 \quad \text{————} \quad (3)$$

☞ Procedure

A) Measurement of Radiation pattern:

i) Mount a folded dipole ($\lambda/2$) Antenna (used as AUT) on top of the transmitting mast by using holder box connected below the base-plate of antenna and tight with M8x45mm screw & wing nut.

ii) Connect output of RF generator to folded dipole using BNC-to-BNC cable at BNC input of bottom holder box, which contains balun internally connected between antenna & input BNC socket.

iii) Mount another folded dipole Antenna (used as receiving antenna) on top of the receiving mast by using holder box connected below the base-plate of antenna and tight with M8x45mm screw & wing nut.

iv) Connect input of RF power meter to receiving antenna using BNC-to-BNC cable.
v) Keep distance of 1.5m (approx. 5 feet) between transmitting & receiving antennas. And keep both antennas at line-of-sight & facing each-other by considering there sight as 0^0 position.
vi) Switch ON both the RF power meter & the RF signal generator.
vii) Adjust frequency on RF generator between 350 to 500 MHz to obtain close to standard pattern (80% atleast) and set amplitude knob at maximum clock-wise position.
viii) Adjust transmitting antenna pointer to 0^0 and take reading on RF power meter (near receiving antenna). Now rotate transmitting antenna in clockwise or anti-clockwise **(use BS5-11 on stepper driver panel for stepper direction control)** with 10^0 angle increment & take corresponding reading on power meter.

Now take another reading with angle step of 10^0 up to 360^0 of complete rotation & note-down the corresponding readings.
ix) After taking all readings, fill the below table.

Table 3.1 Radiation pattern observation table of Folded dipole antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	
2.	10	
3.	20	
4.	30	
5.	40	
6.	50	
7.	60	
8.	70	
9.	80	
10.	90	
11.	100	
12.	110	
13.	120	
14.	130	
15.	140	
16.	150	
17.	160	
18.	170	
19.	180	
20.	190	
21.	200	
22.	210	
23.	220	
24.	230	
25.	240	
26.	250	
27.	260	
28.	270	
29.	280	
30.	290	
31.	300	
32.	310	
33.	320	
34.	330	
35.	340	
36.	350	

x) Now, plot the polar graph between angle (in degree) versus observed power meter readings (in dBm) on your paper by drawing a polar circle of different radius from minimum to maximum (draw min. & max. radii as per your observations on graph). Means in your all 360^0 observations, you got -56.0dBm as minimum power output & -30.0 dBm as maximum power output, then on polar circle, take first radius as -56.0 (which in minimum) & last will be -30.0 and take radius step as suitable.

NOTE: You can also use "VWB" software to plot antenna radiation pattern either in ONLINE mode or OFFLINE mode as given below; **Please** refer Chapter 2 for complete hardware wiring & procedure for **"To plot Antenna radiation pattern using VWB software"** in detail.

i) In ONLINE mode: There are two sections in ONLINE mode, one is ONLINE-AUTO & other is ONLINE-MANUAL. In this ONLINE mode, you can directly interface hardware to antenna PC based software and acquire signal strength at different angular position of transmitting antenna by providing **CLOCK** signal from software to stepper driver panel to rotate transmitting antenna as per selection of buttons provided on the software.

ii) In OFFLINE mode: Whatever the data observed as per above procedure for antenna radiation pattern measurement directly fill in the table of antenna software & click the "PLOT button" on software to plot the antenna radiation pattern.

B) Measurement of Beamwidth:

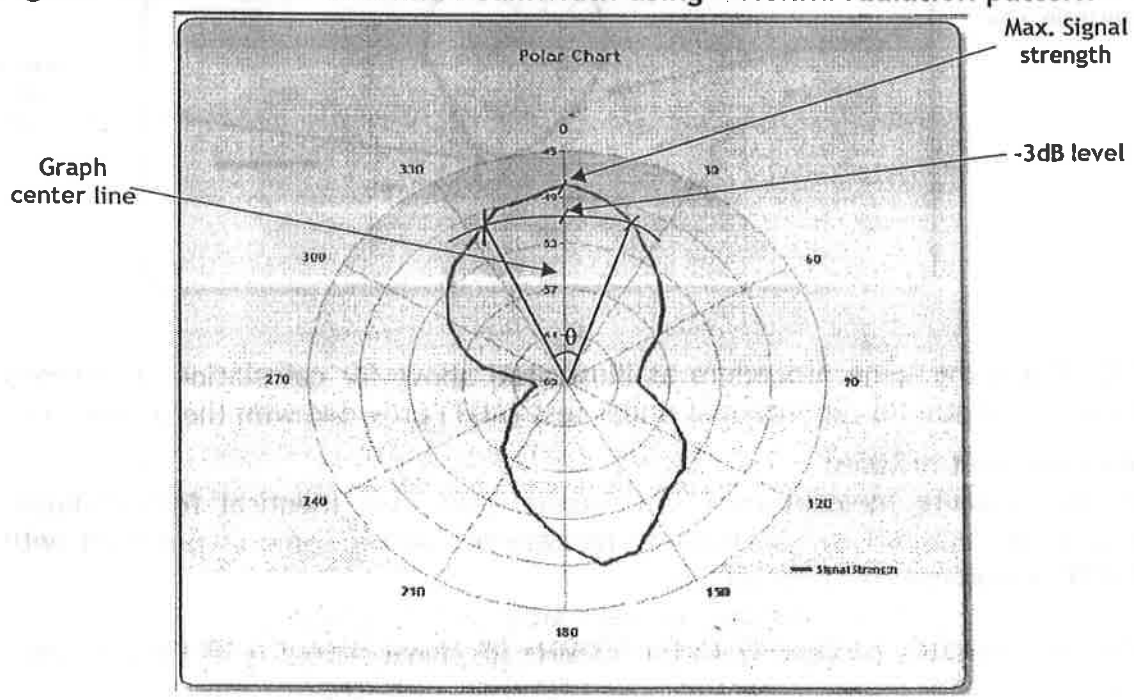
Follow the given procedure to calculate beamwidth from radiation pattern;

i) From the observed radiation pattern of folded dipole antenna, find the angle at which the signal strength of observed RF signal is maximum.

ii) Then from that level, mark -3dB level (towards the center of graph) on center line and draw an arc from center of polar graph to -3dB level.

iii) The arc will cut the graph at either side. Then from here, draw straight lines from the arc cut-out on graph to center of graph as shown below.

Fig 3.1 Calculation of Antenna Beamwidth using Antenna radiation pattern



iv) Now measure the either side angles from center line of graph. Note down that angles & add them, this will be the Beamwidth of antenna under test;

Hence, Beamwidth = θ = --------------------- Degree.

NOTE: Follow the same procedure as illustrated above for calculation of Antenna Beamwidth for all antennas under test (AUT) provided with the trainer set.

C) Measurement of Front-to-Back Ratio:

The front-to-back ratio is the ratio of the peak gain in the forward direction to the gain 180-degrees behind the peak, while considering the linear scale. But in a dB scale, the front-to-back ratio is just the difference between the peak gain in the forward direction (i.e. maximum gain of main lobe) and the gain 180-degrees behind the peak. **It can be calculated from the observed "Radiation pattern of the antenna under test".**

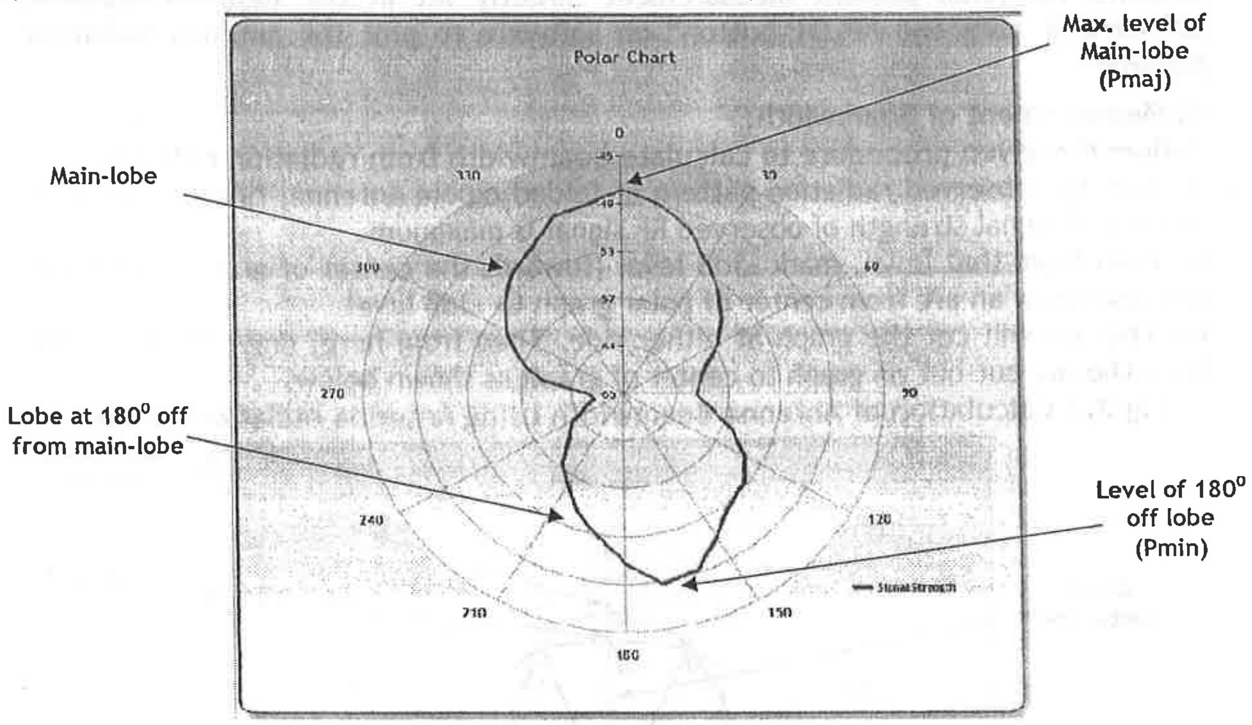
Hence, Front-to-back ratio = (Pmaj - Pmin) dBm.

Where,

Pmaj = Maximum power level of main-lobe in dBm.

Pmin = Power of minor-lobe or power level at 180^0 behind the main-lobe in dBm.

Fig 3.2 Calculation of Antenna Front-to-back ratio by Antenna radiation pattern



NOTE: Follow the same procedure as illustrated above for calculation of Antenna Front-to-Back ratio for all antennas under test (AUT) provided with the trainer set.

D) Measurement of Gain:

i) In this absolute measurement of antenna gain, two identical folded dipole antennas are required by considering the gain of each is same as provided with XPO-ANT complete experimental set.

Hence, $G_T = G_R = G$.

ii) Use RF Generator (Model: RF-6) for 500MHz RF signal output & RF Power meter (Model: RFM5M) for measurement of power level in each step.

iii) Connect dipoles on the provided masts, one as transmitting antenna (Antenna Under Test) & other as receiving or measuring antenna. And keep both antennas at a distance of 5 feet (or 1.5m).

Hence, $R = 1.5m$.

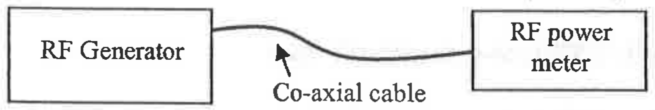
iv) The value of λ can be calculated for f = 500MHz RF signal as;

Hence, $\lambda = c / f = (3*10^8) / (5*10^8) = 0.6m$.

Follow the given steps to measure the absolute gain of Folded-dipole antenna using FRIIS equation;

i) Connect the RF power meter directly to the RF generator as shown below & do not ON the RF generator, measure the power meter reading, this is the reference power reading of RF generator without RF input,

Fig. 3.3 Setup for Measurement of P_T



i.e. $P_{Ref(RF0)}$ = ---------------------- dBm.

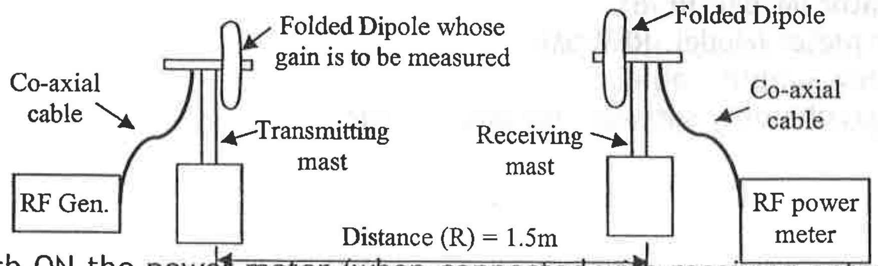
Without disturbing the above setup, switch ON the RF generator and set it to 500MHz & set the power meter reading to +2 dBm using amplitude knob of signal generator (means set it to maximum position).

Then the transmitted power can be calculated as,

i.e. $P_T = [+2] - [P_{Ref(RF0)}]$ dBm.

ii) Now switch OFF the RF power meter & generator. And connect RF generator to transmitting antenna **(keep it at OFF mode)** & connect power meter to receiving antenna. And keep both antennas in line-of-sight & facing each-other at a distance of 1.5m (approx. 5 feet) as shown below & do not disturb the setup until the completion of experiment.

Fig. 3.4 Setup for Measurement of P_R



Now switch ON the power meter (when connected with receiving antenna, as in the above setup) & keep RF generator in OFF mode, note down the power meter reading, this is the reference power reading when connected to receiving antenna without RF input,

i.e. P_{Ref} = ------------------------ dBm.

At the same setup switch ON the RF generator without disturbing the frequency & amplitude knobs, calculate the measured power (P_{Meas}),

i.e. P_{Meas} = ----------------------- dBm.

Then the received power can be calculated as,

i.e. $P_R = [P_{Meas}] - [P_{Ref}]$ dBm.

iii) Substitute the above measured values in above equation-3 ;

$$G_T * G_R = \frac{P_R}{P_T}\left[\frac{4\Pi R}{\lambda}\right]^2$$

As, $G_T = G_R = G$, R = 1.5m and λ = 0.6m

Then,

$$G * G = G^2 = \frac{P_R}{P_T}\left[\frac{(4)*(3.14)*(1.5)}{(0.6)}\right]^2$$

$$\Rightarrow G^2 = \frac{P_R}{P_T}\ (986.0)$$

$$\Rightarrow G = \text{--------------------}\ \text{(Unit-less)} = \text{Gain (Measured)}$$

iv) For calculation of Gain in dBi, use equation-1 as,

$$\text{Gain (dBi)} = 10 * \text{Log}\left[\frac{\text{Gain (Measured)}}{\text{Gain (Isotropic)}}\right]$$

$$= 10 * \text{Log}\ (G / 1) = 10 * \text{Log}\ (G) = \text{------------------}\ \text{dBi.}$$

☞ Conclusion

Hence, from the above observed readings, you can conclude that folded-dipole antenna is a bi-directional antenna and its gain is measured by absolute Gain measurement method is approximately as 24 dBi.

☞ Equipments Required

a) Two nos. of folded dipole antennas of same physical shape & mounting setup.
b) Transmitting Mast with in-built stepper.
c) Receiving mast.
d) RF generator (Model: RF-6).
e) RF power meter (Model: RFM-5M).
f) 2 nos. of BNC-to-BNC cable.
g) Antenna graph utility software hardware setup.

4. Study of Half-wave Simple Dipole Antenna

☞ Unit Objective

On the completion of this unit you will be understand the basic principles related to Half-wave simple dipole antenna and practically measure the following characteristics of this antenna;

i) The Radiation pattern (Azimuth XY-plane plot).
ii) Antenna Beamwidth.
iii) Antenna Front-to-Back ratio.
iv) The Gain using standard reference antenna.

NOTE: For gain measurement of this antenna, use folded dipole antenna as reference antenna, the gain of which already measured at previous unit using absolute gain measurement method.

☞ Discussion on Fundamentals

This antenna contains one half-wave element, means the length of antenna element is one-half of wavelength & hence the name half-wave dipole. Mount this antenna as per your experiments using provided M8x45mm screw & wing nut.

On red-masked base-plate, the element is placed or mounted on its proper location (drills). Rotate this mounted antenna using transmitting mast assembly from 0^0 to 360^0 to get its Radiation pattern.

Gain measurement:

For gain measurement of this antenna, we used reference gain measurement method. In which three antennas are required; one is a reference antenna of known gain (i.e. folded dipole in our case), second is any type of antenna connected at receiving side, whose gain not necessarily to be known (i.e. another folded dipole, but at receiving side) and third is an antenna whose gain is to be measured (i.e. Antenna Under Test, AUT).

Use following equation for measurement of gain using reference antenna method;

$$G_{HWSD}(dBi) = G_{Ref(folded)}(dBi) + [P_{Meas(HWSD)}(dBm) - P_{Ref(folded)}(dBm)] \quad \_\_\_\text{(1)}$$

Where,

G_{HWSD} = Measured Gain of AUT antenna (in dBi).

$G_{Ref(folded)}$ = Gain of reference Folded dipole antenna
= **24 dBi** (this is measured in previous unit).

$P_{Meas(HWSD)}$ = Power meter reading when AUT is connected at transmitting side (in dBm).

$P_{Ref(folded)}$ = Power meter reading when reference folded dipole antenna is connected at transmitting side (in dBm).

☞ Procedure

A) Measurement of Radiation pattern:

i) Mount this antenna (used as AUT) on top of the transmitting mast by using holder box connected below the base-plate of antenna and tight with M8x45mm screw & wing nut.

ii) Connect output of RF generator to this AUT using BNC-to-BNC cable at BNC input of bottom holder box, which contains balun internally connected between antenna & input BNC socket.

iii) Mount a folded dipole Antenna (used as receiving antenna) on top of the receiving mast by using holder box connected below the base-plate of antenna and tight with M8x45mm screw & wing nut.
iv) Connect input of RF power meter to receiving antenna using BNC-to-BNC cable.
v) Keep distance of 1.5m (approx. 5 feet) between transmitting & receiving antennas. And keep both antennas at line-of-sight & facing each-other by considering there sight as 0^0 position.
vi) Switch ON both the RF power meter & the RF signal generator.
vii) Adjust frequency on RF generator between 350 to 500 MHz to obtain close to standard pattern (80% atleast) and set amplitude knob at maximum clock-wise position.
viii) Adjust transmitting antenna pointer to 0^0 and take reading on RF power meter (near receiving antenna). Now rotate transmitting antenna in clockwise or anti-clockwise (use BS5-11 on stepper driver panel for stepper direction control) with 10^0 angle increment & take corresponding reading on power meter.
Now take another reading with angle steps of 10^0, up to 360^0 of complete rotation & note-down the corresponding readings.
ix) After taking all readings, fill the below table.

Table 4.1 Rad. pattern observation table of Half-wave simple dipole antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	
2.	10	
3.	20	
4.	30	
5.	40	
6.	50	
7.	60	
8.	70	
9.	80	
10.	90	
11.	100	
12.	110	
13.	120	
14.	130	
15.	140	
16.	150	
17.	160	
18.	170	
19.	180	
20.	190	
21.	200	
22.	210	
23.	220	
24.	230	
25.	240	
26.	250	
27.	260	
28.	270	
29.	280	
30.	290	
31.	300	
32.	310	
33.	320	
34.	330	
35.	340	
36.	350	

x) Now, plot the polar graph between angle (in degree) versus observed power meter readings (in dBm) on your paper by drawing a polar circle of different radius from minimum to maximum (draw min. & max. radii as per your observations on graph). Means in your all 360^0 observations, you got -56.0dBm as minimum power output & -30.0 dBm as maximum power output, then on polar circle, take first radius as -56.0 (which in minimum) & last will be -30.0 and take radius step as suitable.

NOTE: You can also use "VWB" software to plot antenna radiation pattern either in ONLINE mode or OFFLINE mode as given below; Please refer Chapter 2 for complete hardware wiring & procedure for **"To plot Antenna radiation pattern using VWB software"** in detail.

i) **In ONLINE mode:** There are two sections in ONLINE mode, one is ONLINE-AUTO & other is ONLINE-MANUAL. In this ONLINE mode, you can directly interface hardware to antenna PC based software and acquire signal strength at different angular position of transmitting antenna by providing CLOCK signal from software to stepper driver panel to rotate transmitting antenna as per selection of buttons provided on the software.

ii) **In OFFLINE mode:** Whatever the data observed as per above procedure for antenna radiation pattern measurement directly fill in the table of antenna software & click the "OK button" on software to plot the antenna radiation pattern.

B) Measurement of Beamwidth:

From the observed radiation pattern of this AUT antenna, find the -3dB power level on center line and draw an arc from center of pattern to -3dB level and then measure the either side angles. Note down that angle as beamwidth of antenna;

Beamwidth = ---------------------- Degree.

C) Measurement of Front-to-Back Ratio:

From the observed radiation pattern of this AUT antenna, find the power level of main-lobe (i.e. lobe having more strength) & write it as "Pmaj" and then find power level lobe, which is 180^0 off from main lobe, write it as "Pmin", then calculate Front-to-Back Ratio using the below equation;

Front-to-Back Ratio = Pmaj - Pmin (in dBm) ------------------ dBm.

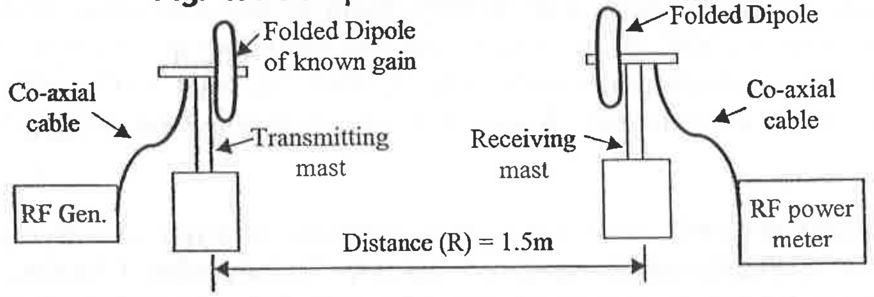
D) Measurement of Gain:

Use RF Generator (Model: RF-6) for 500MHz RF signal output & RF Power meter (Model: RFM-5M) for measurement of power level in each step.

Follow the given steps to measure the gain of this antenna using folded-dipole antenna as reference;

i) Connect folded dipole antenna on receiving side using on provided receiving mast and connect other folded dipole antenna of known gain (use the same antenna whose gain calculated in previous unit, as reference antenna) on transmitting mast. Keep both antennas in line-of-sight & facing each-other at a distance of 1.5m as shown;

Fig. 4.1 Setup for Measurement of P_{Ref}



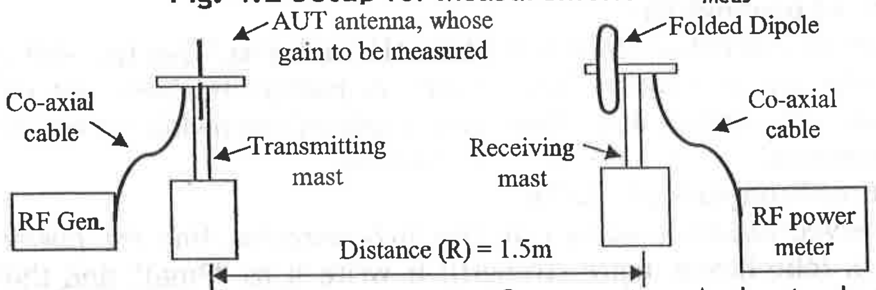
ii) Set RF generator at 500MHz RF output & connect to transmitting antenna and connect RF power meter to receiving antenna. Do not disturb the setup & location of devices/panels until the completion of experiment. Keep the amplitude knob of signal generator at maximum position, so as to transfer maximum strength of RF signal through transmitting antenna.

iii) Now switch ON both RF power meter & RF generator and measure the power meter reading, this is the power reading of reference folded dipole antenna,

i.e. $P_{Ref(folded)}$ = --------------------- dBm.

iv) Without disturbing the above setup, switch OFF both the RF power meter & generator. Now replace the reference folded dipole antenna of transmitting side with AUT antenna facing to folded dipole antenna of receiving side as shown;

Fig. 4.2 Setup for Measurement of P_{Meas}



v) Now switch ON both the RF power meter & generator. And note down the power meter reading, this is the measured power level of AUT antenna,

i.e. $P_{Meas(HWSD)}$ = --------------------- dBm.

vi) Substitute the measured values in above equation-1;

= G_{HWSD} (in dBi) = 24 (in dBi) + [$P_{Meas(HWSD)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= --------------------- dBi.

☞ Conclusion

Hence, from the above observed readings, you can conclude that Half-wave simple dipole antenna is a Bi-directional antenna and its gain is measured by reference Gain measurement method is approximately as 40.8 dBi.

☞ Equipments Required

a) Two nos. of folded dipole antennas of same physical shape & mounting setup.
b) Half-wave simple dipole antenna.
c) Transmitting Mast with in-built stepper.
d) Receiving mast.
e) RF generator (Model: RF-6).
f) RF power meter (Model: RFM-5M).
g) 2 nos. of BNC-to-BNC cable.
h) VWB software hardware setup.

5. Study of Quarter-wave Simple Dipole Antenna

☞ Unit Objective

On the completion of this unit you will be understand the basic principles related to Quarter-wave simple dipole antenna and practically measure the following characteristics of this antenna;

i) The Radiation pattern (Azimuth XY-plane plot).
ii) Antenna Beamwidth.
iii) Antenna Front-to-Back ratio.
iv) The Gain using standard reference antenna.

☞ Discussion on Fundamentals

This antenna contains one Quarter-wave element, means the length of antenna element is one-fourth of wavelength & hence the name Quarter-wave dipole. Mount this antenna as per your experiments using provided M8x45mm screw & wing nut.

On red-masked base-plate, the element is placed or mounted on its proper location (drills). Rotate this mounted antenna using transmitting mast assembly from 0^0 to 360^0 to get its Radiation pattern.

Gain measurement:

For gain measurement of this antenna, we used reference gain measurement method (as in case of Half-wave simple dipole antenna) and calculated the Gain using the following equation;

Use following equation for measurement of gain using reference antenna method;

$G_{QWSD}(dBi) = G_{Ref(folded)}(dBi) + [P_{Meas(QWSD)}(dBm) - P_{Ref(folded)}(dBm)]$ ____(1)

Where,

G_{QWSD} = Measured Gain of AUT antenna (in **dBi**).
$G_{Ref(folded)}$ = Gain of reference Folded dipole antenna
= **24 dBi** (this is measured in previous unit).
$P_{Meas(QWSD)}$ = Power meter reading when AUT is connected at transmitting side.
$P_{Ref(folded)}$ = Meter reading when reference antenna at transmitting side (in dBm).

☞ Procedure

A) Measurement of Radiation pattern:

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Mount this antenna on top of the transmitting mast by using M8x45mm screw.
ii) Connect output of RF generator to this AUT using BNC-to-BNC cable.
iii) Mount a receiving folded dipole Antenna on top of the receiving mast.
iv) Connect input of RF power meter to receiving antenna using BNC-to-BNC cable.
v) Keep distance of 1.5m (approx. 5 feet) between them and keep both antennas at line-of-sight & facing each-other by considering there sight as 0^0 position.
vi) Switch ON both the RF power meter & the RF signal generator.
vii) Adjust frequency on RF generator to 350 to 500 MHz and set amplitude knob at maximum clock-wise position.

Note:- To obtain more accurate/ correct patterns of antenna response you may have to adjust the frequency through trial and error on RF generator/ oscillator between 350 MHz to 500 MHz, at certain frequency you will be able to obtain close to standard pattern (80% atleast).

viii) Adjust transmitting antenna pointer to 0^0 and take reading on RF power meter (near receiving antenna). Now rotate transmitting antenna & take corresponding reading on power meter. Now take another reading with angle steps of 10^0, up to 360^0 of complete rotation & note-down the corresponding readings.

ix) After taking all readings, fill the below table.

Table 5.1 Rad. pattern observation table of Quarter-wave simple dipole

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	
2.	10	
3.	20	
4.	30	
5.	40	
6.	50	
7.	60	
8.	70	
9.	80	
10.	90	
11.	100	
12.	110	
13.	120	
14.	130	
15.	140	
16.	150	
17.	160	
18.	170	
19.	180	
20.	190	
21.	200	
22.	210	
23.	220	
24.	230	
25.	240	
26.	250	
27.	260	
28.	270	
29.	280	
30.	290	
31.	300	
32.	310	
33.	320	
34.	330	
35.	340	
36.	350	

x) Now, plot the polar graph between angle (in degree) versus observed power meter readings (in dBm) on your paper or use VWB software (in OFFLINE-mode).

NOTE: You can also use "VWB" software to plot antenna radiation pattern either in ONLINE mode or OFFLINE mode as given below; Please refer Chapter 2 for complete hardware wiring & procedure for **"To plot Antenna radiation pattern using VWB software"** in detail.

B) Measurement of Beamwidth:

From the observed radiation pattern of this AUT antenna, find the -3dB power level on center line and draw an arc from center of pattern to -3dB level and then measure the either side angles. Note down that angle as beamwidth of antenna;

Beamwidth = ---------------------- Degree.

C) Measurement of Front-to-Back Ratio:

From the observed radiation pattern of this AUT antenna, find the power level of main-lobe (i.e. lobe having more strength) & write it as "Pmaj" and then find power level lobe, which is 180^0 off from main lobe, write it as "Pmin", then calculate Front-to-Back Ratio using the below equation;

Front-to-Back Ratio = Pmaj - Pmin (in dBm) ------------------ dBm.

D) Measurement of Gain:

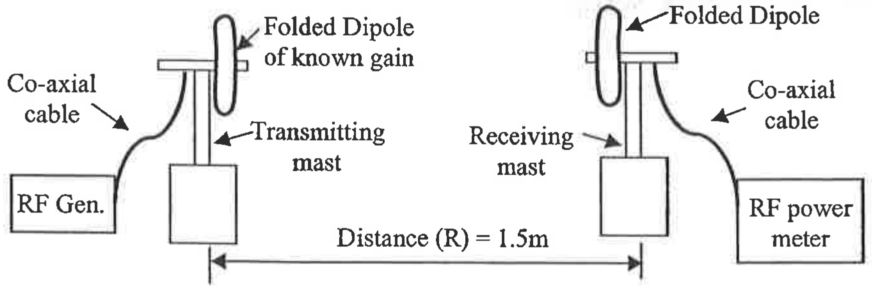
Use RF Generator (Model: RF-6) for 500MHz RF signal output & RF Power meter (Model: RFM-5M) for measurement of power level in each step.

Follow the given steps to measure the gain of this antenna using folded-dipole antenna as reference;

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Connect folded dipole antenna on receiving side and connect other folded dipole antenna of known gain on transmitting mast.

Fig. 5.1 Setup for Measurement of P_{Ref}



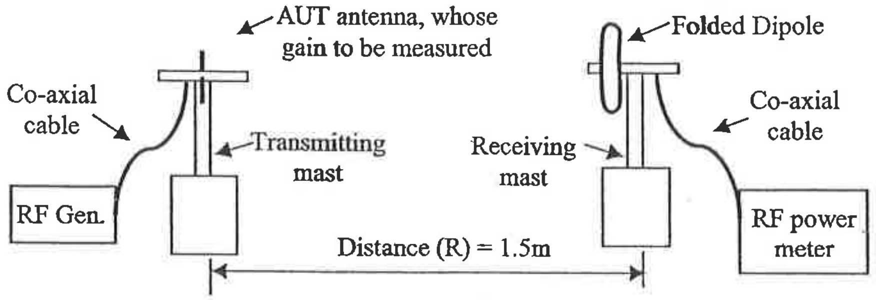
ii) Set RF generator at 500MHz RF output & keep the amplitude knob of signal generator at maximum position and connect to transmitting antenna and connect RF power meter to receiving antenna.

iii) Now switch ON both RF power meter & RF generator and measure the power meter reading, this is the power reading of reference folded dipole antenna,

i.e. $P_{Ref(folded)}$ = --------------------- dBm.

iv) Now replace the reference folded dipole antenna of transmitting side with AUT antenna facing to folded dipole antenna of receiving side as shown;

Fig. 5.2 Setup for Measurement of P_{Meas}



v) Now switch ON both the RF power meter & generator. And note down the power meter reading, this is the measured power level of AUT antenna,

i.e. $P_{Meas(QWSD)}$ = ---------------------- dBm.

vi) Substitute the measured values in above equation-1;

= G_{QWSD} (in dBi) = 24 (in dBi) + [$P_{Meas(QWSD)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= ---------------------- dBi.

☞ Conclusion

Hence, from the above observed readings, you can conclude that Quarter-wave simple dipole antenna is a directional antenna and its gain is measured by reference Gain measurement method is approximately as 36.9 dBi.

☞ Equipments Required

a) Two nos. of folded dipole antennas of same physical shape & mounting setup.
b) Quarter wave simple dipole antenna.
c) Transmitting Mast with in-built stepper.
d) Receiving mast.
e) RF generator (Model: RF-6).
f) RF power meter (Model: RFM-5M).
g) 2 nos. of BNC-to-BNC cable.
h) VWB software hardware setup.

6. Study of 3λ/2 Simple Dipole Antenna

☞ Unit Objective

On the completion of this unit you will be understand the basic principles related to 3λ/2 simple dipole antenna and practically measure the following characteristics of this antenna;

i) The Radiation pattern (Azimuth XY-plane plot).
ii) Antenna Beamwidth.
iii) Antenna Front-to-Back ratio.
iv) The Gain using standard reference antenna.

☞ Discussion on Fundamentals

This antenna contains one 3λ/2 element, means the length of antenna element is three times the half wavelength & hence the name 3λ/2 dipole. Mount this antenna as per your experiments using provided M8x45mm screw & wing nut.

On red-masked base-plate, the element is placed or mounted on its proper location (drills). Rotate this mounted antenna using transmitting mast assembly from 0^0 to 360^0 to get its Radiation pattern.

Gain measurement:

For gain measurement of this antenna, we used reference gain measurement method (as in case of Half-wave simple dipole antenna) and calculated the Gain using the following equation;

Use following equation for measurement of gain using reference antenna method;

$G_{3HWSD}(dBi) = G_{Ref(folded)}(dBi) + [P_{Meas(3HWSD)}(dBm) - P_{Ref(folded)}(dBm)]$ ____ (1)

Where,

G_{3HWSD} = Measured Gain of AUT antenna (in dBi).
$G_{Ref(folded)}$ = Gain of reference Folded dipole antenna
= **24 dBi** (this is measured in previous unit).
$P_{Meas(3HWSD)}$ = Power meter reading when AUT is connected at transmitting side.
$P_{Ref(folded)}$ = Meter reading when reference antenna at transmitting side (in dBm).

☞ Procedure

A) Measurement of Radiation pattern:

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Mount this antenna on top of the transmitting mast by using M8x45mm screw.
ii) Connect output of RF generator to this AUT using BNC-to-BNC cable.
iii) Mount a receiving folded dipole Antenna on top of the receiving mast.
iv) Connect input of RF power meter to receiving antenna using BNC-to-BNC cable.
v) Keep distance of 1.5m (approx. 5 feet) between them and keep both antennas at line-of-sight & facing each-other by considering there sight as 0^0 position.
vi) Switch ON both the RF power meter & the RF signal generator.
vii) Adjust frequency on RF generator between 350 to 500 MHz to obtain close to standard pattern (80% atleast) and set amplitude knob at maximum clock-wise position.

viii) Adjust transmitting antenna pointer to 0^0 and take reading on RF power meter (near receiving antenna). Now rotate transmitting antenna & take corresponding reading on power meter. Now take another reading with angle steps of 10^0, up to 360^0 of complete rotation & note-down the corresponding readings.

ix) After taking all readings, fill the below table.

Table 6.1 Rad. pattern observation table of 3λ/2 simple dipole antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	
2.	10	
3.	20	
4.	30	
5.	40	
6.	50	
7.	60	
8.	70	
9.	80	
10.	90	
11.	100	
12.	110	
13.	120	
14.	130	
15.	140	
16.	150	
17.	160	
18.	170	
19.	180	
20.	190	
21.	200	
22.	210	
23.	220	
24.	230	
25.	240	
26.	250	
27.	260	
28.	270	
29.	280	
30.	290	
31.	300	
32.	310	
33.	320	
34.	330	
35.	340	
36.	350	

x) Now, plot the polar graph between angles (in degree) versus observed power meter readings (in dBm) on your paper or use polar graph software (in OFFLINE-mode).

NOTE: You can also use "VWB" software to plot antenna radiation pattern either in ONLINE mode or OFFLINE mode as given below; Please refer Chapter 2 for complete hardware wiring & procedure for **"To plot Antenna radiation pattern using VWB software"** in detail.

B) Measurement of Beamwidth:

From the observed radiation pattern of this AUT antenna, find the -3dB power level on center line and draw an arc from center of pattern to -3dB level and then measure the either side angles. Note down that angle as beamwidth of antenna;

Beamwidth = ---------------------- Degree.

C) Measurement of Front-to-Back Ratio:

From the observed radiation pattern of this AUT antenna, find the power level of main-lobe (i.e. lobe having more strength) & write it as "Pmaj" and then find power level lobe, which is 180^0 off from main lobe, write it as "Pmin", then calculate Front-to-Back Ratio using the below equation;

Front-to-Back Ratio = Pmaj - Pmin (in dBm) ------------------ dBm.

D) Measurement of Gain:

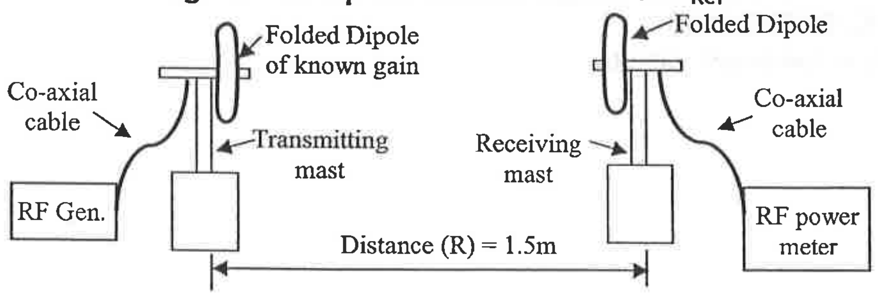
Use RF Generator (Model: RF-6) for 500MHz RF signal output & RF Power meter (Model: RFM-5M) for measurement of power level in each step.

Follow the given steps to measure the gain of this antenna using folded-dipole antenna as reference;

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Connect folded dipole antenna on receiving side and connect other folded dipole antenna of known gain on transmitting mast.

Fig. 6.1 Setup for Measurement of P_{Ref}



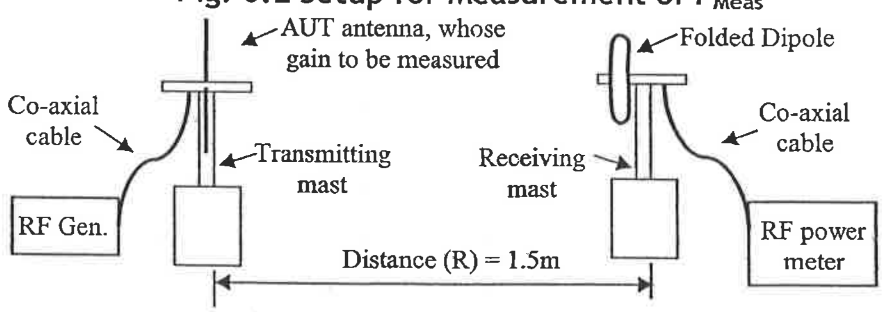
ii) Set RF generator at 500MHz RF output & keep the amplitude knob of signal generator at maximum position and connect to transmitting antenna and connect RF power meter to receiving antenna.

iii) Now switch ON both RF power meter & RF generator and measure the power meter reading, this is the power reading of reference folded dipole antenna,

i.e. $P_{Ref(folded)}$ = --------------------- dBm.

iv) Now replace the reference folded dipole antenna of transmitting side with AUT antenna facing to folded dipole antenna of receiving side as shown;

Fig. 6.2 Setup for Measurement of P_{Meas}



v) Now switch ON both the RF power meter & generator. And note down the power meter reading, this is the measured power level of AUT antenna,

i.e. $P_{Meas(3HWSD)}$ = ---------------------- dBm.

vi) Substitute the measured values in above equation-1;

= G_{3HWSD} (in dBi) = 24 (in dBi) + [$P_{Meas(3HWSD)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= ---------------------- dBi.

☞ Conclusion

Hence, from the above observed readings, you can conclude that 3λ/2 simple dipole antenna is a directional antenna and its gain is measured by reference Gain measurement method is approximately as 32.1 dBi.

☞ Equipments Required

a) Transmitting Mast with in-built stepper.
b) 3λ/2 simple dipole antenna.
c) Receiving mast.
d) RF generator (Model: RF-6).
e) RF power meter (Model: RFM-5M).
f) 2 nos. of BNC-to-BNC cable.
g) VWB software hardware setup.

7. Study of Half-wave Folded-dipole with Reflector Antenna

☞ Unit Objective

On the completion of this unit you will be understand the basic principles related to Half-wave folded dipole with reflector antenna and practically measure the following characteristics of this antenna;

i) The Radiation pattern (Azimuth XY-plane plot).
ii) Antenna Beamwidth.
iii) Antenna Front-to-Back ratio.
iv) The Gain using standard reference antenna.

☞ Discussion on Fundamentals

This antenna contains one Half-wave folded-dipole element as driven element & one is reflector element. Mount this antenna as per your experiments using provided M8x45mm screw & wing nut.

On red-masked base-plate, the element is placed or mounted on its proper location (drills). Rotate this mounted antenna using transmitting mast assembly from 0^0 to 360^0 to get its Radiation pattern.

Gain measurement:

For gain measurement of this antenna, we used reference gain measurement method (as in case of Half-wave simple dipole antenna) and calculated the Gain using the following equation;

Use following equation for measurement of gain using reference antenna method;

$G_{HWFR}(dBi) = G_{Ref(folded)}(dBi) + [P_{Meas(HWFR)}(dBm) - P_{Ref(folded)}(dBm)]$ ___(1)

Where,

G_{HWFR} = Measured Gain of AUT antenna (in dBi).
$G_{Ref(folded)}$ = Gain of reference Folded dipole antenna
= **24 dBi** (this is measured in previous unit).
$P_{Meas(HWFR)}$ = Power meter reading when AUT is connected at transmitting side.
$P_{Ref(folded)}$ = Meter reading when reference antenna at transmitting side (in dBm).

☞ Procedure

A) Measurement of Radiation pattern:

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Mount this antenna on top of the transmitting mast by using M8x45mm screw.
ii) Connect output of RF generator to this AUT using BNC-to-BNC cable.
iii) Mount a receiving folded dipole Antenna on top of the receiving mast.
iv) Connect input of RF power meter to receiving antenna using BNC-to-BNC cable.
v) Keep distance of 1.5m (approx. 5 feet) between them and keep both antennas at line-of-sight & facing each-other by considering there sight as 0^0 position.
vi) Switch ON both the RF power meter & the RF signal generator.
vii) Adjust frequency on RF generator between 350 to 500 MHz to obtain close to standard pattern (80% atleast) and set amplitude knob at maximum clock-wise position.

viii) Adjust transmitting antenna pointer to 0^0 and take reading on RF power meter (near receiving antenna). Now rotate transmitting antenna & take corresponding reading on power meter. Now take another reading with angle steps of 10^0, up to 360^0 of complete rotation & note-down the corresponding readings.

ix) After taking all readings, fill the below table.

Table 7.1 Rad. pattern observation table of Half-wave dipole with reflector

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	
2.	10	
3.	20	
4.	30	
5.	40	
6.	50	
7.	60	
8.	70	
9.	80	
10.	90	
11.	100	
12.	110	
13.	120	
14.	130	
15.	140	
16.	150	
17.	160	
18.	170	
19.	180	
20.	190	
21.	200	
22.	210	
23.	220	
24.	230	
25.	240	
26.	250	
27.	260	
28.	270	
29.	280	
30.	290	
31.	300	
32.	310	
33.	320	
34.	330	
35.	340	
36.	350	

x) Now, plot the polar graph between angles (in degree) versus observed power meter readings (in dBm) on your paper or use VWB software (in OFFLINE-mode).

NOTE: Please refer Chapter 2 for complete hardware wiring & procedure for **"To plot Antenna radiation pattern using VWB software"** in detail.

B) Measurement of Beamwidth:

From the observed radiation pattern of this AUT antenna, find the -3dB power level on center line and draw an arc from center of pattern to -3dB level and then measure the either side angles. Note down that angle as beamwidth of antenna;

Beamwidth = ----------------------- Degree.

C) Measurement of Front-to-Back Ratio:

From the observed radiation pattern of this AUT antenna, find the power level of main-lobe (i.e. lobe having more strength) & write it as "Pmaj" and then find power level lobe, which is 180^0 off from main lobe, write it as "Pmin", then calculate Front-to-Back Ratio using the below equation;

Front-to-Back Ratio = Pmaj - Pmin (in dBm) ------------------ dBm.

D) Measurement of Gain:

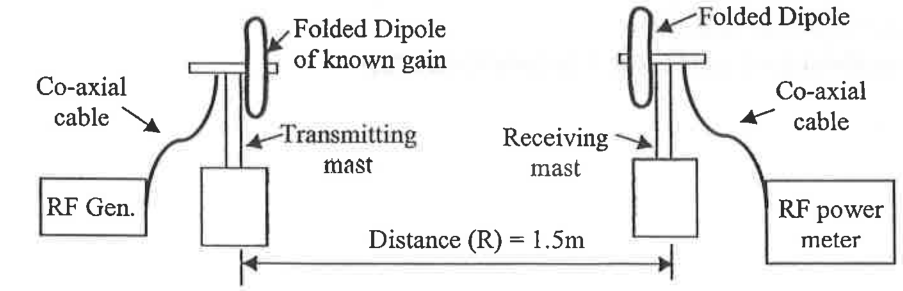
Use RF Generator (Model: RF-6) for 500MHz RF signal output & RF Power meter (Model: RFM-5M) for measurement of power level in each step.

Follow the given steps to measure the gain of this antenna using folded-dipole antenna as reference;

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Connect folded dipole antenna on receiving side and connect other folded dipole antenna of known gain on transmitting mast.

Fig. 7.1 Setup for Measurement of P_{Ref}



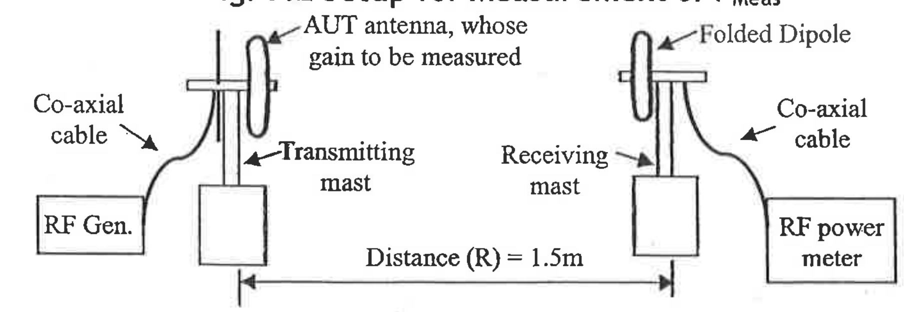
ii) Set RF generator at 500MHz RF output & keep the amplitude knob of signal generator at maximum position and connect to transmitting antenna and connect RF power meter to receiving antenna.

iii) Now switch ON both RF power meter & RF generator and measure the power meter reading, this is the power reading of reference folded dipole antenna,

i.e. $P_{Ref(folded)}$ = --------------------- dBm.

iv) Now replace the reference folded dipole antenna of transmitting side with AUT antenna facing to folded dipole antenna of receiving side as shown;

Fig. 7.2 Setup for Measurement of P_{Meas}



v) Now switch ON both the RF power meter & generator. And note down the power meter reading, this is the measured power level of AUT antenna,

i.e. $P_{Meas(HWFR)}$ = ---------------------- dBm.

vi) Substitute the measured values in above equation-1;

= G_{HWFR} (in dBi) = 24 (in dBi) + [$P_{Meas(HWFR)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= ---------------------- dBi.

☞ Conclusion

Hence, from the above observed readings, you can conclude that Half-wave folded dipole with reflector antenna is a directional antenna and its gain is measured by reference Gain measurement method is approximately as 38.1 dBi.

☞ Equipments Required

a) Two nos. of folded dipole antennas of same physical shape & mounting setup.
b) Half-wave folded-dipole with reflector antenna.
c) Transmitting Mast with in-built stepper.
d) Receiving mast.
e) RF generator (Model: RF-6).
f) RF power meter (Model: RFM-5M).
g) 2 nos. of BNC-to-BNC cable.
h) Antenna graph utility software hardware setup.

8. Study of Yagi Uda Antennas

☞ Unit Objective

On the completion of this unit you will be understand the basic principles related to Yagi Uda antenna and practically measure the following characteristics of Yagi-Uda antenna (for 3-elements, 5-elements and 7-elements);

i) The Radiation pattern (Azimuth XY-plane plot).
ii) Antenna Beamwidth.
iii) Antenna Front-to-Back ratio.
iv) The Gain using standard reference antenna.

☞ Discussion on Fundamentals

Yagi-Uda antennas contain one folded-dipole antenna, one reflector and no. of directors as per selection either 3-element or 5-element or 7-element. Mount antennas as per your experiments using provided M8x45mm screw & wing nut.

On red-masked base-plate, the elements of Yagi-Uda antenna will be placed or mounted on their proper location (drills) as per below mentioned nomenclatures;

Reflector - YU1, Folded dipole - YU2, Director1 - YU3, Director2 - YU4, Director3 - YU5, Director4 - YU6 and Director5 - YU7.

Gain measurement:

For gain measurement of this antenna, we used reference gain measurement method (as in case of Half-wave simple dipole antenna) and calculated the Gain using the following equation;

Use following equation for measurement of gain using reference antenna method;

$G_{Yagi}(dBi) = G_{Ref(folded)}(dBi) + [P_{Meas(Yagi)}(dBm) - P_{Ref(folded)}(dBm)]$ ____(1)

Where,

G_{Yagi} = Measured Gain of AUT antenna (in dBi).
$G_{Ref(folded)}$ = Gain of reference Folded dipole antenna
= **24 dBi** (this is measured in previous unit).
$P_{Meas(Yagi)}$ = Power meter reading when AUT is connected at transmitting side.
$P_{Ref(folded)}$ = Meter reading when reference antenna at transmitting side (in dBm).

☞ Procedure

A) Measurement of Radiation pattern:

i) Mount Yagi-Uda Antennas one-by-one from 3E to 7E (used as AUT) on top of the transmitting mast by using holder box connected below the base-plate antennas and tight with M8x45mm screw & wing nut each time.
ii) Connect output of RF generator to this AUT using BNC-to-BNC cable.
iii) Mount a receiving folded dipole Antenna on top of the receiving mast.
iv) Connect input of RF power meter to receiving antenna using BNC-to-BNC cable.
v) Keep distance of 1.5m (approx. 5 feet) between them and keep both antennas at line-of-sight & facing each-other by considering there sight as 0^0 position.
vi) Switch ON both the RF power meter & the RF signal generator.
vii) Adjust frequency on RF generator between 350 to 500 MHz to obtain close to standard pattern (80% atleast) and set amplitude knob at maximum clock-wise position.

viii) Adjust transmitting antenna pointer to 0^0 and take reading on RF power meter (near receiving antenna). Now rotate transmitting antenna & take corresponding reading on power meter. Now take another reading with angle steps of 10^0, up to 360^0 of complete rotation & note-down the corresponding readings.

ix) After taking all readings, fill the below table.

Table 8.1 Radiation pattern observation table of Yagi-Uda antennas

Sr. No.	Angle (in degree)	Observed power (in dBm)		
		3E	5E	7E
1.	0			
2.	10			
3.	20			
4.	30			
5.	40			
6.	50			
7.	60			
8.	70			
9.	80			
10.	90			
11.	100			
12.	110			
13.	120			
14.	130			
15.	140			
16.	150			
17.	160			
18.	170			
19.	180			
20.	190			
21.	200			
22.	210			
23.	220			
24.	230			
25.	240			
26.	250			
27.	260			
28.	270			
29.	280			
30.	290			
31.	300			
32.	310			
33.	320			
34.	330			
35.	340			
36.	350			

x) Now, plot the polar graph between angles (in degree) versus observed power meter readings (in dBm) on your paper or use VWB software (in OFFLINE-mode).

NOTE: Please refer Chapter 2 for complete hardware wiring & procedure for **"To plot Antenna radiation pattern using VWB software"** in detail.

B) Measurement of Beamwidth:

From the observed radiation pattern of this AUT antenna, find the -3dB power level on center line and draw an arc from center of pattern to -3dB level and then measure the either side angles. Note down that angle as beamwidth of antenna;

Beamwidth = ---------------------- Degree.

C) Measurement of Front-to-Back Ratio:

From the observed radiation pattern of this AUT antenna, find the power level of main-lobe (i.e. lobe having more strength) & write it as "Pmaj" and then find power level lobe, which is 180^0 off from main lobe, write it as "Pmin", then calculate Front-to-Back Ratio using the below equation;

Front-to-Back Ratio = Pmaj - Pmin (in dBm) ------------------ dBm.

D) Measurement of Gain:

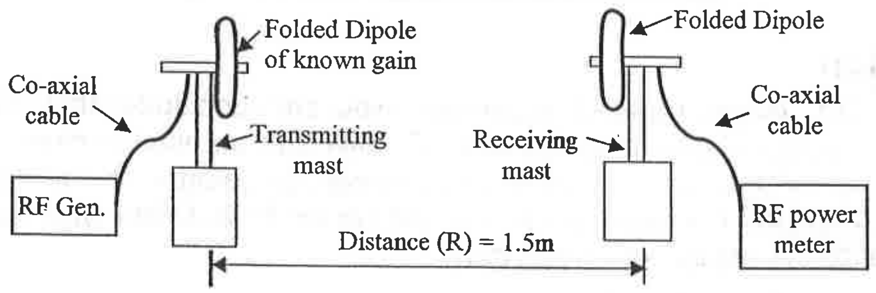
Use RF Generator (Model: RF-6) for 500MHz RF signal output & RF Power meter (Model: RFM-5M) for measurement of power level in each step.

Follow the given steps to measure the gain of this antenna using folded-dipole antenna as reference;

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Connect folded dipole antenna on receiving side and connect other folded dipole antenna of known gain on transmitting mast.

Fig. 8.1 Setup for Measurement of P_{Ref}



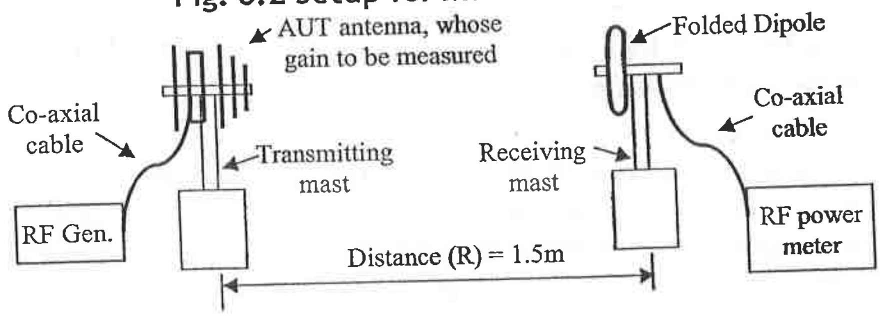
ii) Set RF generator at 500MHz RF output & keep the amplitude knob of signal generator at maximum position and connect to transmitting antenna and connect RF power meter to receiving antenna.

iii) Now switch ON both RF power meter & RF generator and measure the power meter reading, this is the power reading of reference folded dipole antenna,

i.e. $P_{Ref(folded)}$ = --------------------- dBm.

iv) Without disturbing the above setup, switch OFF both the RF power meter & generator. Now replace the reference folded dipole antenna of transmitting side with Yagi Uda antenna (3E to 7E one-by-one) facing to folded dipole antenna of receiving side as shown;

Fig. 8.2 Setup for Measurement of P_{Meas}



v) Now switch ON both the RF power meter & generator. And note down the power meter reading(s), this is the measured power level of Yagi Uda antenna,

i.e. $P_{Meas(Yagi-3E)}$ = --------------------- dBm.

i.e. $P_{Meas(Yagi-5E)}$ = --------------------- dBm.

i.e. $P_{Meas(Yagi-7E)}$ = --------------------- dBm.

vi) Substitute the measured values in above equation-1 for different elements Yagi-Uda antenna;

i.e. G_{Yagi} (in dBi) = $G_{Ref(folded)}$ (in dBi) + [$P_{Meas(Yagi)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= G_{Yagi} (in dBi) = 24 (in dBi) + [$P_{Meas(Yagi)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

For Yagi-Uda antennas of different elements, the Gain will be;

$G_{Yagi(3E)}$ (in dBi) = 24 (in dBi) + [$P_{Meas(Yagi-3E)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= --------------------- dBi.

$G_{Yagi(5E)}$ (in dBi) = 24 (in dBi) + [$P_{Meas(Yagi-5E)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= --------------------- dBi.

$G_{Yagi(7E)}$ (in dBi) = 24 (in dBi) + [$P_{Meas(Yagi-7E)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= --------------------- dBi.

☞ Conclusion

Hence, from the above observed readings, you can conclude that Yagi-Uda antenna is a directional antenna and gain of 7E Yagi-Uda antenna is more than 3E Yagi-Uda, because of more nos. of antenna elements as compare to 3E Yagi-Uda. And gain of 3E Yagi-Uda is 29 dBi, for 5E is 30 dBi & for 7E is 32 dBi with reference folded dipole antenna (whose gain is 24 dBi).

☞ Equipments Required

a) Two nos. of folded dipole antennas of same physical shape & mounting setup.
b) Yagi Uda antenna (3-elements, 5-elements & 7-elemenst).
c) Transmitting Mast with in-built stepper.
d) Receiving mast.
e) 2 nos. of BNC-to-BNC cable.
f) RF generator (Model: RF-6).
g) RF power meter (Model: RFM-5M).
h) VWB software hardware setup.

9. Study of Circular Loop Antenna

☞ Unit Objective

On the completion of this unit you will be understand the basic principles related to Circular Loop antenna and practically measure the following characteristics of this antenna;

i) The Radiation pattern (Azimuth XY-plane plot).
ii) Antenna Beamwidth.
iii) Antenna Front-to-Back ratio.
iv) The Gain using standard reference antenna.

☞ Discussion on Fundamentals

The single-turn loop antenna is a metallic conductor bent into the shape of a closed curve, such as a circle or a square (here in this trainer set circular antenna is provided) with a gap in the conductor to form the terminals. Actually, a loop antenna is a radio antenna consisting of a loop of wire, tubing, or other electrical conductor with its ends connected to a balanced transmission line (i.e. Balun, internally connected under the holder box).

As per the physical description there are two distinct antenna designs of this loop antenna; one is small loop with a size much smaller than a wavelength (>>λ), and the resonant or large loop antennas with a circumference approximately equal to or greater than the wavelength (=<λ).

NOTE: Use the same procedure for measurement of antenna radiation pattern & gain of this antenna, whatever used for half-wave simple dipole antenna.

☞ Procedure

A) Measurement of Radiation pattern:

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Mount this antenna on top of the transmitting mast by using M8x45mm screw.
ii) Connect output of RF generator to this AUT using BNC-to-BNC cable.
iii) Mount a receiving folded dipole Antenna on top of the receiving mast.
iv) Connect input of RF power meter to receiving antenna using BNC-to-BNC cable.
v) Keep distance of 1.5m (approx. 5 feet) between them and keep both antennas at line-of-sight & facing each-other by considering there sight as 0^0 position.
vi) Switch ON both the RF power meter & the RF signal generator.
vii) Adjust frequency on RF generator between 350 to 500 MHz to obtain close to standard pattern (80% atleast) and set amplitude knob at maximum clock-wise position.
viii) Adjust transmitting antenna pointer to 0^0 and take reading on RF power meter (near receiving antenna). Now rotate transmitting antenna & take corresponding reading on power meter. Now take another reading with angle steps of 10^0, up to 360^0 of complete rotation & note-down the corresponding readings.
ix) After taking all readings, fill the below table.

Table 9.1 Radiation pattern observation table of Circular-Loop antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	
2.	10	
3.	20	
4.	30	
5.	40	
6.	50	
7.	60	
8.	70	
9.	80	
10.	90	
11.	100	
12.	110	
13.	120	
14.	130	
15.	140	
16.	150	
17.	160	
18.	170	
19.	180	
20.	190	
21.	200	
22.	210	
23.	220	
24.	230	
25.	240	
26.	250	
27.	260	
28.	270	
29.	280	
30.	290	
31.	300	
32.	310	
33.	320	
34.	330	
35.	340	
36.	350	

x) Now, plot the polar graph between angles (in degree) versus observed power meter readings (in dBm) on your paper or use "VWB" software (in OFFLINE-mode).
NOTE: Please refer Chapter 2 for complete hardware wiring & procedure for **"To plot Antenna radiation pattern using VWB software"** in detail.

B) Measurement of Beamwidth:

From the observed radiation pattern of this AUT antenna, find the -3dB power level on center line and draw an arc from center of pattern to -3dB level and then measure the either side angles. Note down that angle as beamwidth of antenna;

Beamwidth = ---------------------- Degree.

C) Measurement of Front-to-Back Ratio:

From the observed radiation pattern of this AUT antenna, find the power level of main-lobe (i.e. lobe having more strength) & write it as "Pmaj" and then find power level lobe, which is 180^0 off from main lobe, write it as "Pmin", then calculate Front-to-Back Ratio using the below equation;

Front-to-Back Ratio = Pmaj - Pmin (in dBm) ------------------ dBm.

D) Measurement of Gain:

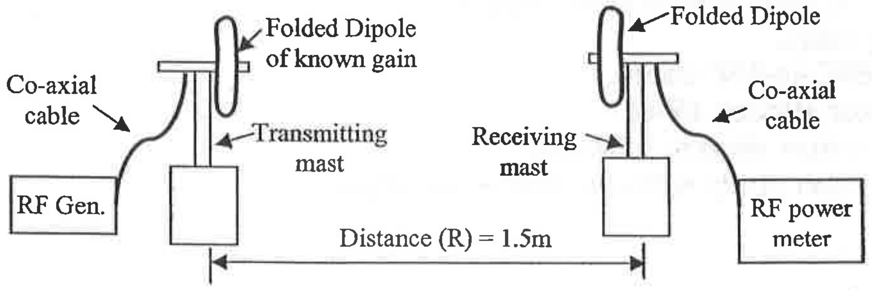
Use RF Generator (Model: RF-6) for 500MHz RF signal output & RF Power meter (Model: RFM-5M) for measurement of power level in each step.

Follow the given steps to measure the gain of this antenna using folded-dipole antenna as reference;

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Connect folded dipole antenna on receiving side and connect other folded dipole antenna of known gain on transmitting mast.

Fig. 9.1 Setup for Measurement of P_{Ref}



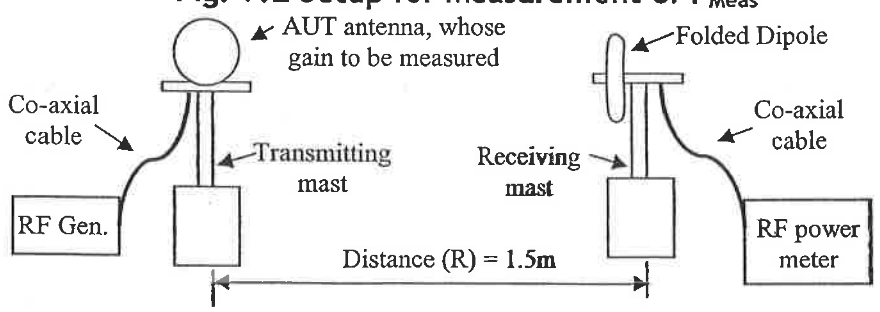
ii) Set RF generator at 500MHz RF output & keep the amplitude knob of signal generator at maximum position and connect to transmitting antenna and connect RF power meter to receiving antenna.

iii) Now switch ON both RF power meter & RF generator and measure the power meter reading, this is the power reading of reference folded dipole antenna,

i.e. $P_{Ref(folded)}$ = --------------------- dBm.

iv) Without disturbing the above setup, switch OFF both the RF power meter & generator. Now replace the reference folded dipole antenna of transmitting side with this AUT antenna facing to folded dipole antenna of receiving side as shown;

Fig. 9.2 Setup for Measurement of P_{Meas}



v) Now switch ON both the RF power meter & generator. And note down the power meter reading, this is the measured power level of loop antenna,

i.e. $P_{Meas(CLoop)}$ = ---------------------- dBm.

vi) Use the same equation, whatever used for Circular-loop as given below;

i.e. G_{CLoop} (in dBi) = $G_{Ref(folded)}$ (in dBi) + [$P_{Meas(CLoop)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= 24 (in dBi) + [$P_{Meas(CLoop)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= --------------------- dBi.

☞ Conclusion

Hence, from the above observed readings, you can conclude that circular-loop antenna is a directional antenna and its gain is approximately as 31 dBi.

☞ Equipments Required

a) Two nos. of folded dipole antennas of same physical shape & mounting setup.
b) Circular Loop antenna.
c) Transmitting Mast with in-built stepper.
d) Receiving mast.
e) 2 nos. of BNC-to-BNC cable.
f) RF generator (Model: RF-6).
g) RF power meter (Model: RFM-5M).
h) Antenna graph utility software hardware setup.

10. Study of Log Periodic Antenna

☞ Unit Objective

On the completion of this unit you will be understand the basic principles related to Log-periodic antenna and practically measure the following characteristics of this antenna;

i) The Radiation pattern (Azimuth XY-plane plot).
ii) Antenna Beamwidth.
iii) Antenna Front-to-Back ratio.
iv) The Gain using standard reference antenna.

☞ Discussion on Fundamentals

Log-periodic antennas are broadband antenna; the provided log-periodic antenna is designed for the broadband range of 200MHz to 700MHz. For this frequency range, seven nos. of elements having different lengths are required, the lengths of these distinct elements are calculated by using the standard equations as given in Appendix-A.

NOTE: Use the same procedure for measurement of antenna radiation pattern & gain of this antenna, whatever used for half-wave simple dipole antenna.

☞ Procedure

A) Measurement of Radiation pattern:

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Mount this antenna on top of the transmitting mast by using M8x45mm screw.
ii) Connect output of RF generator to this AUT using BNC-to-BNC cable.
iii) Mount a receiving folded dipole Antenna on top of the receiving mast.
iv) Connect input of RF power meter to receiving antenna using BNC-to-BNC cable.
v) Keep distance of 1.5m (approx. 5 feet) between them and keep both antennas at line-of-sight & facing each-other by considering there sight as 0^0 position.
vi) Switch ON both the RF power meter & the RF signal generator.
vii) Adjust frequency on RF generator between 350 to 500 MHz to obtain close to standard pattern (80% atleast) and set amplitude knob at maximum clock-wise position.
viii) Adjust transmitting antenna pointer to 0^0 and take reading on RF power meter (near receiving antenna). Now rotate transmitting antenna & take corresponding reading on power meter. Now take another reading with angle steps of 10^0, up to 360^0 of complete rotation & note-down the corresponding readings.
ix) After taking all readings, fill the below table.

Table 10.1 Radiation pattern observation table of Log-periodic antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)		
		@ 250MHz	@ 500MHz	@ 650MHz
1.	0			
2.	10			
3.	20			
4.	30			
5.	40			
6.	50			
7.	60			
8.	70			
9.	80			
10.	90			
11.	100			
12.	110			
13.	120			
14.	130			
15.	140			
16.	150			
17.	160			
18.	170			
19.	180			
20.	190			
21.	200			
22.	210			
23.	220			
24.	230			
25.	240			
26.	250			
27.	260			
28.	270			
29.	280			
30.	290			
31.	300			
32.	310			
33.	320			
34.	330			
35.	340			
36.	350			

x) Now, plot the polar graph between angles (in degree) versus observed power meter readings (in dBm) on your paper or use VWB software (in OFFLINE-mode).

NOTE: Please refer Chapter 2 for complete hardware wiring & procedure for **"To plot Antenna radiation pattern using VWB software"** in detail.

B) Measurement of Beamwidth:

From the observed radiation pattern of this AUT antenna, find the -3dB power level on center line and draw an arc from center of pattern to -3dB level and then measure the either side angles. Note down that angle as beamwidth of antenna;

Beamwidth = ---------------------- Degree.

C) Measurement of Front-to-Back Ratio:

From the observed radiation pattern of this AUT antenna, find the power level of main-lobe (i.e. lobe having more strength) & write it as "Pmaj" and then find power level lobe, which is 180^0 off from main lobe, write it as "Pmin", then calculate Front-to-Back Ratio using the below equation;

Front-to-Back Ratio = Pmaj - Pmin (in dBm) ------------------ dBm.

D) Measurement of Gain:

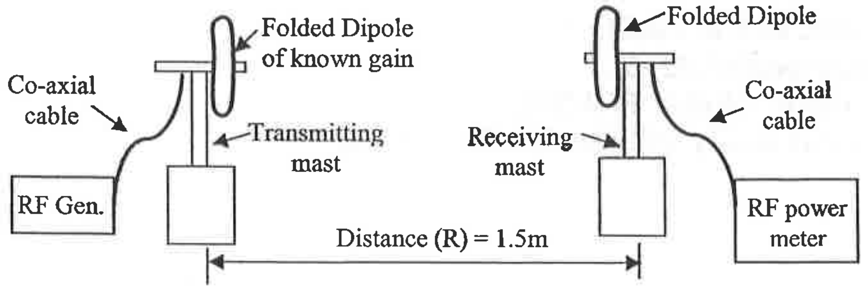
Use RF Generator (Model: RF-6) for 500MHz RF signal output & RF Power meter (Model: RFM-5M) for measurement of power level in each step.

Follow the given steps to measure the gain of this antenna using folded-dipole antenna as reference;

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Connect folded dipole antenna on receiving side and connect other folded dipole antenna of known gain on transmitting mast.

Fig. 10.1 Setup for Measurement of P_{Ref}



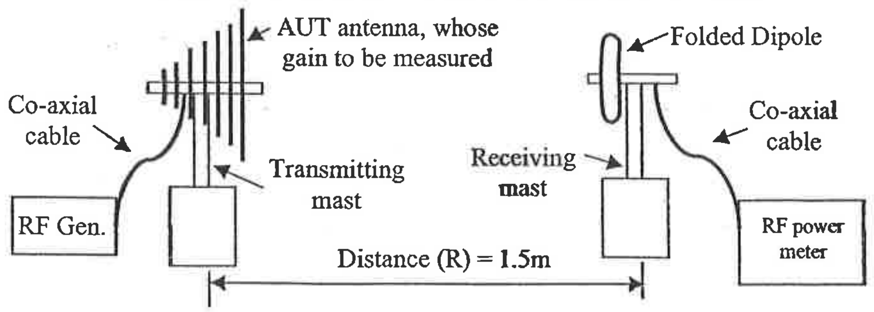
ii) Set RF generator at 500MHz RF output & keep the amplitude knob of signal generator at maximum position and connect to transmitting antenna and connect RF power meter to receiving antenna.

iii) Now switch ON both RF power meter & RF generator and measure the power meter reading, this is the power reading of reference folded dipole antenna,

i.e. $P_{Ref(folded)}$ = --------------------- dBm.

iv) Without disturbing the above setup, switch OFF both the RF power meter & generator. Now replace the reference folded dipole of transmitting side with this AUT antenna facing to folded dipole antenna of receiving side as shown;

Fig. 10.2 Setup for Measurement of P_{Meas}



v) Now switch ON both the RF power meter & generator. And note down the power meter reading, this is the measured power level of log-periodic antenna,

i.e. $P_{Meas(Log)}$ = --------------------- dBm.

vi) Use the same equation, whatever used for Log-periodic as given below;

i.e. G_{Log} (in dBi) = $G_{Ref(folded)}$ (in dBi) + [$P_{Meas(Log)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= 24 (in dBi) + [$P_{Meas(Log)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= --------------------- dBi.

☞ Conclusion

Hence, from the above observed readings, you can conclude that Log-periodic antenna is a directional antenna and its gain is approximately as 32.8 dBi.

☞ Equipments Required

a) Two nos. of folded dipole antennas of same physical shape & mounting setup.
b) Log periodic antenna.
c) Transmitting Mast with in-built stepper.
d) Receiving mast.
e) 2 nos. of BNC-to-BNC cable.
f) RF generator (Model: RF-6).
g) RF power meter (Model: RFM-5M).
h) Antenna graph utility software hardware setup.

11. Study of Helical Antenna

☞ Unit Objective

On the completion of this unit you will be understand the basic principles related to Helical antenna and practically measure the following characteristics of this antenna;

i) The Radiation pattern (Elevation plane plot).
ii) Antenna Beamwidth.
iii) Antenna Front-to-Back ratio.
iv) The Gain using standard reference antenna.

☞ Discussion on Fundamentals

This antenna is designed as the shape of Helix, wound with fixed dimensions in three nos. of same diameter turns. The spacing between each turns is maintained by providing a white delrin rod of specified height as per usable RF frequency range (i.e. 500 MHz); different equations are given below for Helical antenna design;

One Helix circumference = λ = 60 cm = 2*(pie)*R.
Then, R = 9.5 cm and Diameter = 19 cm.
Where, Circumference = 2*(pie)*R.
R = Radius of one helical turn (in cm).
This complete design equations are given Appendix-A.

NOTE: Use the same procedure for measurement of antenna radiation pattern & gain of this antenna, whatever used for half-wave simple dipole antenna.

☞ Procedure

A) Measurement of Radiation pattern:

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Mount this antenna on top of the transmitting mast by using M8x45mm screw.
ii) Connect output of RF generator to this AUT using BNC-to-BNC cable.
iii) Mount a receiving folded dipole Antenna on top of the receiving mast.
iv) Connect input of RF power meter to receiving antenna using BNC-to-BNC cable.
v) Keep distance of 1.5m (approx. 5 feet) between them and keep both antennas at line-of-sight & facing each-other by considering there sight as 0^0 position.
vi) Switch ON both the RF power meter & the RF signal generator.
vii) Adjust frequency on RF generator between 350 to 500 MHz to obtain close to standard pattern (80% atleast) and set amplitude knob at maximum clock-wise position.
viii) Adjust transmitting antenna pointer to 0^0 and take reading on RF power meter (near receiving antenna). Now rotate transmitting antenna & take corresponding reading on power meter. Now take another reading with angle steps of 10^0, up to 360^0 of complete rotation & note-down the corresponding readings.
ix) After taking all readings, fill the below table.

Table 11.1 Radiation pattern observation table of Helical antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	
2.	10	
3.	20	
4.	30	
5.	40	
6.	50	
7.	60	
8.	70	
9.	80	
10.	90	
11.	100	
12.	110	
13.	120	
14.	130	
15.	140	
16.	150	
17.	160	
18.	170	
19.	180	
20.	190	
21.	200	
22.	210	
23.	220	
24.	230	
25.	240	
26.	250	
27.	260	
28.	270	
29.	280	
30.	290	
31.	300	
32.	310	
33.	320	
34.	330	
35.	340	
36.	350	

x) Now, plot the polar graph between angles (in degree) versus observed power meter readings (in dBm) on your paper or use VWB software (in OFFLINE-mode).

NOTE: Please refer Chapter 2 for complete hardware wiring & procedure for **"To plot Antenna radiation pattern using VWB software"** in detail.

B) Measurement of Beamwidth:

From the observed radiation pattern of this AUT antenna, find the -3dB power level on center line and draw an arc from center of pattern to -3dB level and then measure the either side angles. Note down that angle as beamwidth of antenna;

Beamwidth = ---------------------- Degree.

C) Measurement of Front-to-Back Ratio:

From the observed radiation pattern of this AUT antenna, find the power level of main-lobe (i.e. lobe having more strength) & write it as "Pmaj" and then find power level lobe, which is 180^0 off from main lobe, write it as "Pmin", then calculate Front-to-Back Ratio using the below equation;

Front-to-Back Ratio = Pmaj - Pmin (in dBm) ------------------ dBm.

D) Measurement of Gain:

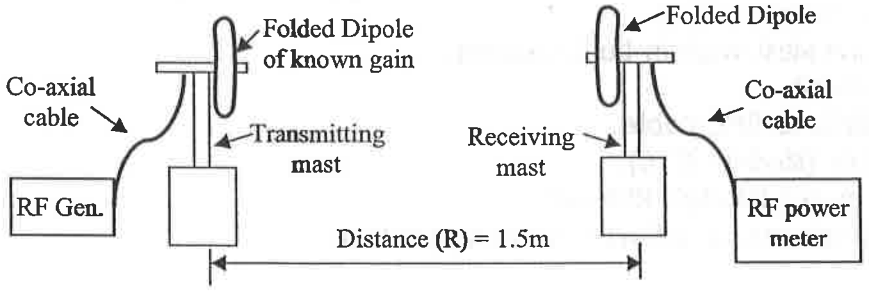
Use RF Generator (Model: RF-6) for 500MHz RF signal output & RF Power meter (Model: RFM-5M) for measurement of power level in each step.

Follow the given steps to measure the gain of this antenna using folded-dipole antenna as reference;

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Connect folded dipole antenna on receiving side and connect other folded dipole antenna of known gain on transmitting mast.

Fig. 11.1 Setup for Measurement of P_{Ref}



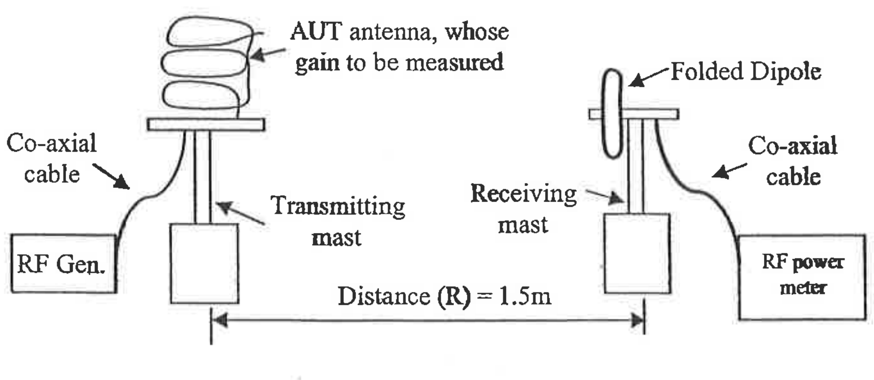
ii) Set RF generator at 500MHz RF output & keep the amplitude knob of signal generator at maximum position and connect to transmitting antenna and connect RF power meter to receiving antenna.

iii) Now switch ON both RF power meter & RF generator and measure the power meter reading, this is the power reading of reference folded dipole antenna,

i.e. $P_{Ref(folded)}$ = --------------------- dBm.

iv) Without disturbing the above setup, switch OFF both the RF power meter & generator. Now replace the reference folded dipole of transmitting side with this AUT antenna facing to folded dipole antenna of receiving side as shown;

Fig. 11.2 Setup for Measurement of P_{Meas}



v) Now switch ON both the RF power meter & generator. And note down the power meter reading, this is the measured power level of log-periodic antenna,

i.e. $P_{Meas(Helical)}$ = --------------------- dBm.

vi) Use the same equation, whatever used for Log-periodic as given below;

i.e. $G_{Helical}$ (in dBi) = $G_{Ref(folded)}$ (in dBi) + [$P_{Meas(Helical)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= 24 (in dBi) + [$P_{Meas(Helical)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= --------------------- dBi.

☞ Conclusion

Hence, from the above observed readings, you can conclude that Helical antenna is a directional antenna and its gain is approximately as 23.7 dBi.

☞ Equipments Required

a) Two nos. of folded dipole antennas of same physical shape & mounting setup.
b) Helical antenna.
c) Transmitting Mast with in-built stepper.
d) Receiving mast.
e) 2 nos. of BNC-to-BNC cable.
f) RF generator (Model: RF-6).
g) RF power meter (Model: RFM-5M).
h) Antenna graph utility software hardware setup.

12. Study of Half-wave End-Fire Antenna

☞ Unit Objective

On the completion of this unit you will be understand the basic principles related to Half-wave end-fire antenna and practically measure the following characteristics of this antenna;

i) The Radiation pattern (Azimuth XY-plane plot).
ii) Antenna Beamwidth.
iii) Antenna Front-to-Back ratio.
iv) The Gain using standard reference antenna.

☞ Discussion on Fundamentals

This antenna is designed by placing two half-wave simple elements at a distance of half-wavelength and feeding the RF signal at one end of each element with 180^0 out-of-phase from one-another, because of this distance separation and feeding at one-end, this antenna is named as Half-wave end-fire antenna.

NOTE: Use the same procedure for measurement of antenna radiation pattern & gain of this antenna, whatever used for half-wave simple dipole antenna.

☞ Procedure

A) Measurement of Radiation pattern:

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Mount this antenna on top of the transmitting mast by using M8x45mm screw.
ii) Connect output of RF generator to this AUT using BNC-to-BNC cable.
iii) Mount a receiving folded dipole Antenna on top of the receiving mast.
iv) Connect input of RF power meter to receiving antenna using BNC-to-BNC cable.
v) Keep distance of 1.5m (approx. 5 feet) between them and keep both antennas at line-of-sight & facing each-other by considering there sight as 0^0 position.
vi) Switch ON both the RF power meter & the RF signal generator.
vii) Adjust frequency on RF generator between 350 to 500 MHz to obtain close to standard pattern (80% atleast) and set amplitude knob at maximum clock-wise position.
viii) Adjust transmitting antenna pointer to 0^0 and take reading on RF power meter (near receiving antenna). Now rotate transmitting antenna & take corresponding reading on power meter. Now take another reading with angle steps of 10^0, up to 360^0 of complete rotation & note-down the corresponding readings.
ix) After taking all readings, fill the below table.

Table 12.1 Radiation pattern observation table of Half-wave End-fire antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	
2.	10	
3.	20	
4.	30	
5.	40	
6.	50	
7.	60	
8.	70	
9.	80	
10.	90	
11.	100	
12.	110	
13.	120	
14.	130	
15.	140	
16.	150	
17.	160	
18.	170	
19.	180	
20.	190	
21.	200	
22.	210	
23.	220	
24.	230	
25.	240	
26.	250	
27.	260	
28.	270	
29.	280	
30.	290	
31.	300	
32.	310	
33.	320	
34.	330	
35.	340	
36.	350	

x) Now, plot the polar graph between angles (in degree) versus observed power meter readings (in dBm) on your paper or use VWB software (in OFFLINE-mode).

NOTE: Please refer Chapter 2 for complete hardware wiring & procedure for **"To plot Antenna radiation pattern using VWB software" in detail.**

B) Measurement of Beamwidth:

From the observed radiation pattern of this AUT antenna, find the -3dB power level on center line and draw an arc from center of pattern to -3dB level and then measure the either side angles. Note down that angle as beamwidth of antenna;

Beamwidth = ---------------------- Degree.

C) Measurement of Front-to-Back Ratio:

From the observed radiation pattern of this AUT antenna, find the power level of main-lobe (i.e. lobe having more strength) & write it as "Pmaj" and then find power level lobe, which is 180^0 off from main lobe, write it as "Pmin", then calculate Front-to-Back Ratio using the below equation;

Front-to-Back Ratio = Pmaj - Pmin (in dBm) ------------------ dBm.

D) Measurement of Gain:

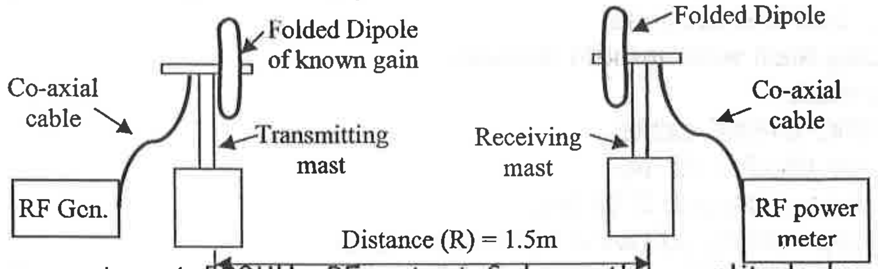
Use RF Generator (Model: RF-6) for 500MHz RF signal output & RF Power meter (Model: RFM-5M) for measurement of power level in each step.

Follow the given steps to measure the gain of this antenna using folded-dipole antenna as reference;

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Connect folded dipole antenna on receiving side and connect other folded dipole antenna of known gain on transmitting mast.

Fig. 12.1 Setup for Measurement of P_{Ref}



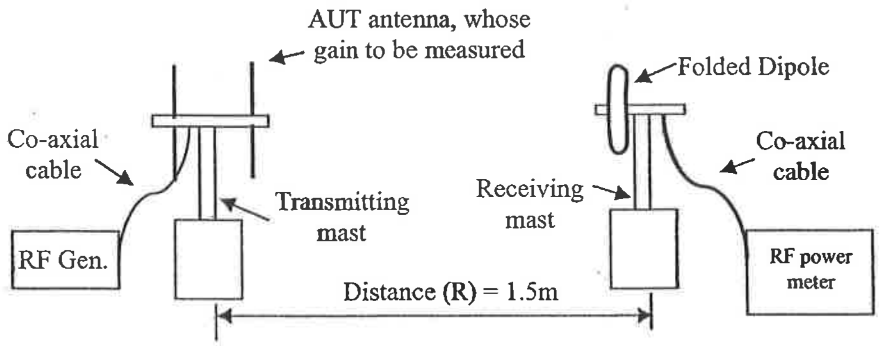
ii) Set RF generator at 500MHz RF output & keep the amplitude knob of signal generator at maximum position and connect to transmitting antenna and connect RF power meter to receiving antenna.

iii) Now switch ON both RF power meter & RF generator and measure the power meter reading, this is the power reading of reference folded dipole antenna,

i.e. $P_{Ref(folded)}$ = --------------------- dBm.

iv) Without disturbing the above setup, switch OFF both the RF power meter & generator. Now replace the reference folded dipole of transmitting side with this AUT antenna facing to folded dipole antenna of receiving side as shown;

Fig. 12.2 Setup for Measurement of P_{Meas}



v) Now switch ON both the RF power meter & generator. And note down the power meter reading, this is the measured power level of log-periodic antenna,

i.e. $P_{Meas(HWEF)}$ = --------------------- dBm.

vi) Use the same equation, whatever used for Log-periodic as given below;

i.e. G_{HWEF} (in dBi) = $G_{Ref(folded)}$ (in dBi) + [$P_{Meas(HWEF)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= 24 (in dBi) + [$P_{Meas(HWEF)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= --------------------- dBi.

☞ Conclusion

Hence, from the above observed readings, you can conclude that Half-wave End-fire antenna is a directional antenna and its gain is approximately as 39.5 dBi.

☞ Equipments Required

a) Two nos. of folded dipole antennas of same physical shape & mounting setup.
b) Half-wave End-fire antenna.
c) Transmitting Mast with in-built stepper.
d) Receiving mast.
e) 2 nos. of BNC-to-BNC cable.
f) RF generator (Model: RF-6).
g) RF power meter (Model: RFM-5M).
h) Antenna graph utility software hardware setup.

13. Study of Quarter-wave End-Fire Antenna

☞ Unit Objective

On the completion of this unit you will be understand the basic principles related to Quarter-wave end-fire antenna and practically measure the following characteristics of this antenna;

i) The Radiation pattern (Azimuth XY-plane plot).
ii) Antenna Beamwidth.
iii) Antenna Front-to-Back ratio.
iv) The Gain using standard reference antenna.

☞ Discussion on Fundamentals

This antenna is designed by placing two half-wave simple elements at a distance of Quarter-wavelength and feeding the RF signal at one end of each element with 180^0 out-of-phase from one-another, because of this distance separation and feeding at one-end, this antenna is named as Quarter-wave end-fire antenna.

NOTE: Use the same procedure for measurement of antenna radiation pattern & gain of this antenna, whatever used for half-wave simple dipole antenna.

☞ Procedure

A) Measurement of Radiation pattern:

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Mount this antenna on top of the transmitting mast by using M8x45mm screw.
ii) Connect output of RF generator to this AUT using BNC-to-BNC cable.
iii) Mount a receiving folded dipole Antenna on top of the receiving mast.
iv) Connect input of RF power meter to receiving antenna using BNC-to-BNC cable.
v) Keep distance of 1.5m (approx. 5 feet) between them and keep both antennas at line-of-sight & facing each-other by considering there sight as 0^0 position.
vi) Switch ON both the RF power meter & the RF signal generator.
vii) Adjust frequency on RF generator between 350 to 500 MHz to obtain close to standard pattern (80% atleast) and set amplitude knob at maximum clock-wise position.
viii) Adjust transmitting antenna pointer to 0^0 and take reading on RF power meter (near receiving antenna). Now rotate transmitting antenna & take corresponding reading on power meter. Now take another reading with angle steps of 10^0, up to 360^0 of complete rotation & note-down the corresponding readings.
ix) After taking all readings, fill the below table.

Table 13.1 Radiation pattern observation table of Quarter-wave End-fire

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	
2.	10	
3.	20	
4.	30	
5.	40	
6.	50	
7.	60	
8.	70	
9.	80	
10.	90	
11.	100	
12.	110	
13.	120	
14.	130	
15.	140	
16.	150	
17.	160	
18.	170	
19.	180	
20.	190	
21.	200	
22.	210	
23.	220	
24.	230	
25.	240	
26.	250	
27.	260	
28.	270	
29.	280	
30.	290	
31.	300	
32.	310	
33.	320	
34.	330	
35.	340	
36.	350	

x) Now, plot the polar graph between angles (in degree) versus observed power meter readings (in dBm) on your paper or use VWB software (in OFFLINE-mode).

NOTE: Please refer Chapter 2 for complete hardware wiring & procedure for **"To plot Antenna radiation pattern using VWB software"** in detail.

B) Measurement of Beamwidth:

From the observed radiation pattern of this AUT antenna, find the -3dB power level on center line and draw an arc from center of pattern to **-3dB** level and then measure the either side angles. Note down that angle as beamwidth of antenna;

Beamwidth = ---------------------- Degree.

C) Measurement of Front-to-Back Ratio:

From the observed radiation pattern of this AUT antenna, find the power level of main-lobe (i.e. lobe having more strength) & write it as "Pmaj" and then find power level lobe, which is 180^0 off from main lobe, write it as "Pmin", then calculate Front-to-Back Ratio using the below equation;

Front-to-Back Ratio = Pmaj - Pmin (in dBm) ------------------ dBm.

D) Measurement of Gain:

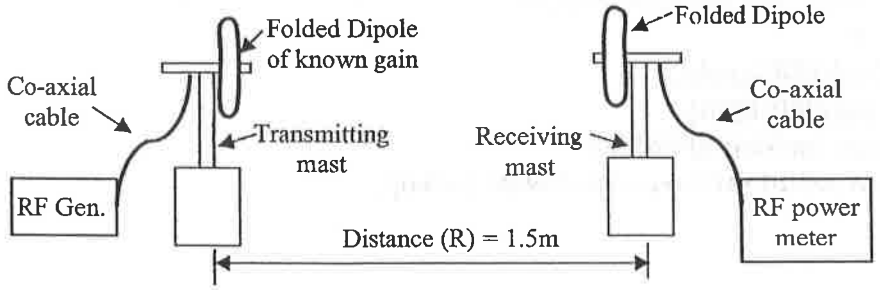
Use RF Generator (Model: RF-6) for 500MHz RF signal output & RF Power meter (Model: RFM-5M) for measurement of power level in each step.

Follow the given steps to measure the gain of this antenna using folded-dipole antenna as reference;

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Connect folded dipole antenna on receiving side and connect other folded dipole antenna of known gain on transmitting mast.

Fig. 13.1 Setup for Measurement of P_{Ref}



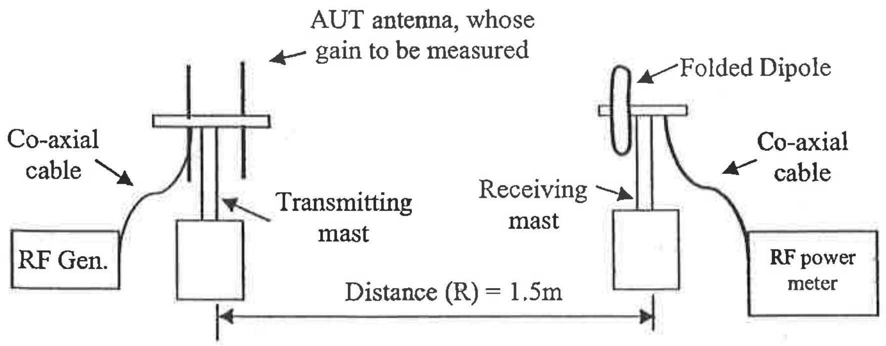
ii) Set RF generator at 500MHz RF output & keep the amplitude knob of signal generator at maximum position and connect to transmitting antenna and connect RF power meter to receiving antenna.

iii) Now switch ON both RF power meter & RF generator and measure the power meter reading, this is the power reading of reference folded dipole antenna,

i.e. $P_{Ref(folded)}$ = --------------------- dBm.

iv) Without disturbing the above setup, switch OFF both the RF power meter & generator. Now replace the reference folded dipole of transmitting side with this AUT antenna facing to folded dipole antenna of receiving side as shown;

Fig. 13.2 Setup for Measurement of P_{Meas}



v) Now switch ON both the RF power meter & generator. And note down the power meter reading, this is the measured power level of log-periodic antenna,

i.e. $P_{Meas(QWEF)}$ = --------------------- dBm.

vi) Use the same equation, whatever used for Log-periodic as given below;

i.e. G_{QWEF} (in dBi) = $G_{Ref(folded)}$ (in dBi) + [$P_{Meas(QWEF)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= 24 (in dBi) + [$P_{Meas(QWEF)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= --------------------- dBi.

☞ Conclusion

Hence, from the above observed readings, you can conclude that Quarter wave End-fire antenna is a directional antenna and its gain is approximately as 37.7 dBi.

☞ Equipments Required

a) Two nos. of folded dipole antennas of same physical shape & mounting setup.
b) Quarter-wave End-fire antenna.
c) Transmitting Mast with in-built stepper.
d) Receiving mast.
e) 2 nos. of BNC-to-BNC cable.
f) RF generator (Model: RF-6).
g) RF power meter (Model: RFM-5M).
h) Antenna graph utility software hardware setup.

14. Study of Broad-side array Antenna

☞ Unit Objective

On the completion of this unit you will be understand the basic principles related to Broad-side antenna and practically measure the following characteristics of this antenna;

i) The Radiation pattern (Azimuth XY-plane plot).
ii) Antenna Beamwidth.
iii) Antenna Front-to-Back ratio.
iv) The Gain using standard reference antenna.

☞ Discussion on Fundamentals

This antenna is designed by placing six nos. of half-wave simple elements at fixed distances and feeding the RF signal at one end of each element with in-phase to each & form an array of same elements, because of this assembly, this antenna got the name Broad-side array antenna.

NOTE: Use the same procedure for measurement of antenna radiation pattern & gain of this antenna, whatever used for half-wave simple dipole antenna.

☞ Procedure

A) Measurement of Radiation pattern:

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Mount this antenna on top of the transmitting mast by using M8x45mm screw.
ii) Connect output of RF generator to this AUT using BNC-to-BNC cable.
iii) Mount a receiving folded dipole Antenna on top of the receiving mast.
iv) Connect input of RF power meter to receiving antenna using BNC-to-BNC cable.
v) Keep distance of 1.5m (approx. 5 feet) between them and keep both antennas at line-of-sight & facing each-other by considering there sight as 0^0 position.
vi) Switch ON both the RF power meter & the RF signal generator.
vii) Adjust frequency on RF generator between 350 to 500 MHz to obtain close to standard pattern (80% atleast) and set amplitude knob at maximum clock-wise position.
viii) Adjust transmitting antenna pointer to 0^0 and take reading on RF power meter (near receiving antenna). Now rotate transmitting antenna & take corresponding reading on power meter. Now take another reading with angle steps of 10^0, up to 360^0 of complete rotation & note-down the corresponding readings.
ix) After taking all readings, fill the below table.

Table 14.1 Radiation pattern observation table of Broad-side array antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	
2.	10	
3.	20	
4.	30	
5.	40	
6.	50	
7.	60	
8.	70	
9.	80	
10.	90	
11.	100	
12.	110	
13.	120	
14.	130	
15.	140	
16.	150	
17.	160	
18.	170	
19.	180	
20.	190	
21.	200	
22.	210	
23.	220	
24.	230	
25.	240	
26.	250	
27.	260	
28.	270	
29.	280	
30.	290	
31.	300	
32.	310	
33.	320	
34.	330	
35.	340	
36.	350	

x) Now, plot the polar graph between angles (in degree) versus observed power meter readings (in dBm) on your paper or use VWB software (in OFFLINE-mode).

NOTE: Please refer Chapter 2 for complete hardware wiring & procedure for "To plot Antenna radiation pattern using VWB software" in detail.

B) Measurement of Beamwidth:

From the observed radiation pattern of this AUT antenna, find the -3dB power level on center line and draw an arc from center of pattern to -3dB level and then measure the either side angles. Note down that angle as beamwidth of antenna;

Beamwidth = ---------------------- Degree.

C) Measurement of Front-to-Back Ratio:

From the observed radiation pattern of this AUT antenna, find the power level of main-lobe (i.e. lobe having more strength) & write it as "Pmaj" and then find power level lobe, which is 180^0 off from main lobe, write it as "Pmin", then calculate Front-to-Back Ratio using the below equation;

Front-to-Back Ratio = Pmaj - Pmin (in dBm) ------------------ dBm.

D) Measurement of Gain:

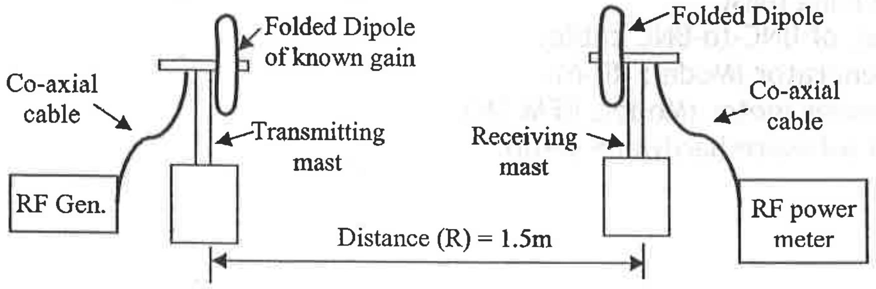
Use RF Generator (Model: RF-6) for 500MHz RF signal output & RF Power meter (Model: RFM-5M) for measurement of power level in each step.

Follow the given steps to measure the gain of this antenna using folded-dipole antenna as reference;

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Connect folded dipole antenna on receiving side and connect other folded dipole antenna of known gain on transmitting mast.

Fig. 14.1 Setup for Measurement of P_{Ref}



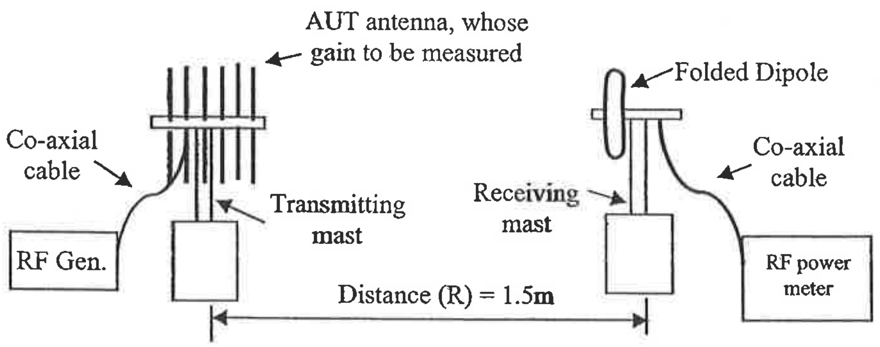
ii) Set RF generator at 500MHz RF output & keep the amplitude knob of signal generator at maximum position and connect to transmitting antenna and connect RF power meter to receiving antenna.

iii) Now switch ON both RF power meter & RF generator and measure the power meter reading, this is the power reading of reference folded dipole antenna,

i.e. $P_{Ref(folded)}$ = --------------------- dBm.

iv) Without disturbing the above setup, switch OFF both the RF power meter & generator. Now replace the reference folded dipole of transmitting side with this AUT antenna facing to folded dipole antenna of receiving side as shown;

Fig. 14.2 Setup for Measurement of P_{Meas}



v) Now switch ON both the RF power meter & generator. And note down the power meter reading, this is the measured power level of log-periodic antenna,

i.e. $P_{Meas(BSA)}$ = ---------------------- dBm.

vi) Use the same equation, whatever used for Log-periodic as given below;

i.e. G_{BSA} (in dBi) = $G_{Ref(folded)}$ (in dBi) + [$P_{Meas(BSA)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= 24 (in dBi) + [$P_{Meas(BSA)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= ---------------------- dBi.

☞ Conclusion

Hence, from the above observed readings, you can conclude that Broad-side antenna is a directional antenna and its gain is approximately as 33.1 dBi.

☞ Equipments Required

a) Two nos. of folded dipole antennas of same physical shape & mounting setup.
b) Broad-side array antenna.
c) Transmitting Mast with in-built stepper.
d) Receiving mast.
e) 2 nos. of BNC-to-BNC cable.
f) RF generator (Model: RF-6).
g) RF power meter (Model: RFM-5M).
h) VWB software hardware setup.

15. Study of Co-linear Antenna

☞ Unit Objective

On the completion of this unit you will be understand the basic principles related to Co-linear antenna and practically measure the following characteristics of this antenna;

i) The Radiation pattern (Azimuth XY-plane plot).
ii) Antenna Beamwidth.
iii) Antenna Front-to-Back ratio.
iv) The Gain using standard reference antenna.

☞ Discussion on Fundamentals

This antenna is designed by placing two of half-wave simple elements in co-linear positions at a distance of half-wavelength and feeding the RF signal at one end of each element with in-phase to each, because of this assembly, this antenna got the name Co-linear antenna.

NOTE: Use the same procedure for measurement of antenna radiation pattern & gain of this antenna, whatever used for half-wave simple dipole antenna.

☞ Procedure

A) Measurement of Radiation pattern:

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Mount this antenna on top of the transmitting mast by using M8x45mm screw.
ii) Connect output of RF generator to this AUT using BNC-to-BNC cable.
iii) Mount a receiving folded dipole Antenna on top of the receiving mast.
iv) Connect input of RF power meter to receiving antenna using BNC-to-BNC cable.
v) Keep distance of 1.5m (approx. 5 feet) between them and keep both antennas at line-of-sight & facing each-other by considering there sight as 0^0 position.
vi) Switch ON both the RF power meter & the RF signal generator.
vii) Adjust frequency on RF generator between 350 to 500 MHz to obtain close to standard pattern (80% atleast) and set amplitude knob at maximum clock-wise position.
viii) Adjust transmitting antenna pointer to 0^0 and take reading on RF power meter (near receiving antenna). Now rotate transmitting antenna & take corresponding reading on power meter. Now take another reading with angle steps of 10^0, up to 360^0 of complete rotation & note-down the corresponding readings.
ix) After taking all readings, fill the below table.

Table 15.1 Radiation pattern observation table of Co-linear array antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	
2.	10	
3.	20	
4.	30	
5.	40	
6.	50	
7.	60	
8.	70	
9.	80	
10.	90	
11.	100	
12.	110	
13.	120	
14.	130	
15.	140	
16.	150	
17.	160	
18.	170	
19.	180	
20.	190	
21.	200	
22.	210	
23.	220	
24.	230	
25.	240	
26.	250	
27.	260	
28.	270	
29.	280	
30.	290	
31.	300	
32.	310	
33.	320	
34.	330	
35.	340	
36.	350	

x) Now, plot the polar graph between angles (in degree) versus observed power meter readings (in dBm) on your paper or use VWB software (in OFFLINE-mode).

NOTE: Please refer Chapter 2 for complete hardware wiring & procedure for **"To plot Antenna radiation pattern using VWB software" in detail.**

B) Measurement of Beamwidth:

From the observed radiation pattern of this AUT antenna, find the -3dB power level on center line and draw an arc from center of pattern to -3dB level and then measure the either side angles. Note down that angle as beamwidth of antenna;

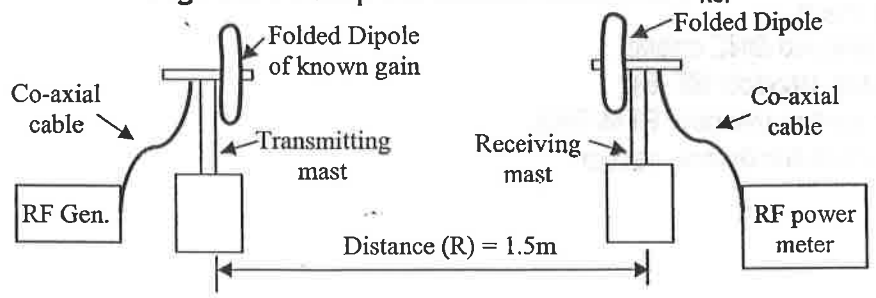
Beamwidth = ---------------------- Degree.

C) Measurement of Front-to-Back Ratio:
From the observed radiation pattern of this AUT antenna, find the power level of main-lobe (i.e. lobe having more strength) & write it as "Pmaj" and then find power level lobe, which is 180^0 off from main lobe, write it as "Pmin", then calculate Front-to-Back Ratio using the below equation;

Front-to-Back Ratio = Pmaj - Pmin (in dBm) ------------------ dBm.

D) Measurement of Gain:
Use RF Generator (Model: RF-6) for 500MHz RF signal output & RF Power meter (Model: RFM-5M) for measurement of power level in each step.
Follow the given steps to measure the gain of this antenna using folded-dipole antenna as reference;
NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;
i) Connect folded dipole antenna on receiving side and connect other folded dipole antenna of known gain on transmitting mast.

Fig. 15.1 Setup for Measurement of P_{Ref}

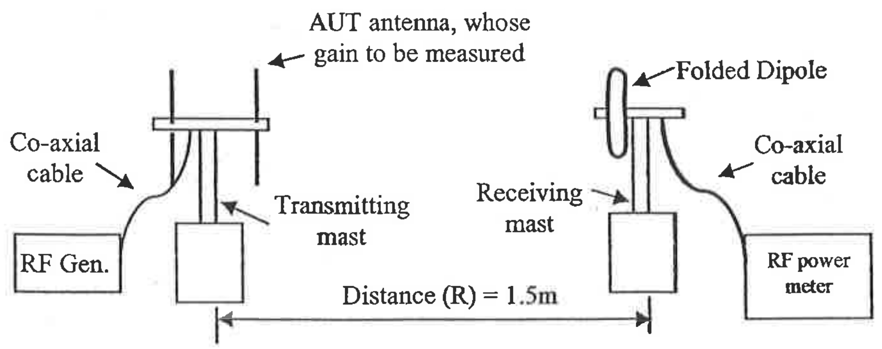


ii) Set RF generator at 500MHz RF output & keep the amplitude knob of signal generator at maximum position and connect to transmitting antenna and connect RF power meter to receiving antenna.
iii) Now switch ON both RF power meter & RF generator and measure the power meter reading, this is the power reading of reference folded dipole antenna,

i.e. $P_{Ref(folded)}$ = --------------------- dBm.

iv) Without disturbing the above setup, switch OFF both the RF power meter & generator. Now replace the reference folded dipole of transmitting side with this AUT antenna facing to folded dipole antenna of receiving side as shown;

Fig. 15.2 Setup for Measurement of P_{Meas}



v) Now switch ON both the RF power meter & generator. And note down the power meter reading, this is the measured power level of log-periodic antenna,

i.e. $P_{Meas(COL)}$ = --------------------- dBm.

vi) Use the same equation, whatever used for Log-periodic as given below;

i.e. G_{COL} (in dBi) = $G_{Ref(folded)}$ (in dBi) + [$P_{Meas(COL)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= 24 (in dBi) + [$P_{Meas(COL)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= --------------------- dBi.

☞ Conclusion

Hence, from the above observed readings, you can conclude that Co-linear antenna is a directional antenna and its gain is approximately as 36.7 dBi.

☞ Equipments Required

a) Two nos. of folded dipole antennas of same physical shape & mounting setup.
b) Co-linear antenna.
c) Transmitting Mast with in-built stepper.
d) Receiving mast.
e) 2 nos. of BNC-to-BNC cable.
f) RF generator (Model: RF-6).
g) RF power meter (Model: RFM-5M).
h) VWB software hardware setup.

16. Study of Slot Antenna

☞ Unit Objective

On the completion of this unit you will be understand the basic principles related to Slot antenna and practically measure the following characteristics of this antenna;

i) The Radiation pattern (Vertical polarization plane plot).
ii) Antenna Beamwidth.
iii) Antenna Front-to-Back ratio.
iv) The Gain using standard reference antenna.

☞ Discussion on Fundamentals

This antenna is designed by providing a slot of half-wavelength in a conducting copper surface (i.e. antenna red-masked copper PCB). This slot or cut-out has RF signal feed from Balun, the slot acts as half-wave dipole antenna, because of the half-wave slot, this antenna got the name Slot antenna. The pattern of folded-dipole antenna at horizontal polarization & pattern of slot antenna at vertical polarization are same.

NOTE: Use the same procedure for measurement of antenna radiation pattern & gain of this antenna, whatever used for half-wave simple dipole antenna.

☞ Procedure

A) Measurement of Radiation pattern:

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Mount this antenna on top of the transmitting mast by using M8x45mm screw.
ii) Connect output of RF generator to this AUT using BNC-to-BNC cable.
iii) Mount a receiving folded dipole Antenna on top of the receiving mast.
iv) Connect input of RF power meter to receiving antenna using BNC-to-BNC cable.
v) Keep distance of 1.5m (approx. 5 feet) between them and keep both antennas at line-of-sight & facing each-other by considering there sight as 0^0 position.
vi) Switch ON both the RF power meter & the RF signal generator.
vii) Adjust frequency on RF generator between 350 to 500 MHz to obtain close to standard pattern (80% atleast) and set amplitude knob at maximum clock-wise position.
viii) Adjust transmitting antenna pointer to 0^0 and take reading on **RF** power meter (near receiving antenna). Now rotate transmitting antenna & take corresponding reading on power meter. Now take another reading with angle steps of 10^0, up to 360^0 of complete rotation & note-down the corresponding readings.
ix) After taking all readings, fill the below table.

Table 16.1 Radiation pattern observation table of Slot antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	
2.	10	
3.	20	
4.	30	
5.	40	
6.	50	
7.	60	
8.	70	
9.	80	
10.	90	
11.	100	
12.	110	
13.	120	
14.	130	
15.	140	
16.	150	
17.	160	
18.	170	
19.	180	
20.	190	
21.	200	
22.	210	
23.	220	
24.	230	
25.	240	
26.	250	
27.	260	
28.	270	
29.	280	
30.	290	
31.	300	
32.	310	
33.	320	
34.	330	
35.	340	
36.	350	

x) Now, plot the polar graph between angles (in degree) versus observed power meter readings (in dBm) on your paper or use VWB software (in OFFLINE-mode).

<u>NOTE:</u> Please refer Chapter 2 for complete hardware wiring & procedure for "To plot Antenna radiation pattern using VWB software" in detail.

B) Measurement of Beamwidth:

From the observed radiation pattern of this AUT antenna, find the -3dB power level on center line and draw an arc from center of pattern to -3dB level and then measure the either side angles. Note down that angle as beamwidth of antenna;

Beamwidth = ---------------------- Degree.

C) Measurement of Front-to-Back Ratio:

From the observed radiation pattern of this AUT antenna, find the power level of main-lobe (i.e. lobe having more strength) & write it as "Pmaj" and then find power level lobe, which is 180^0 off from main lobe, write it as "Pmin", then calculate Front-to-Back Ratio using the below equation;

Front-to-Back Ratio = Pmaj - Pmin (in dBm) ------------------ dBm.

D) Measurement of Gain:

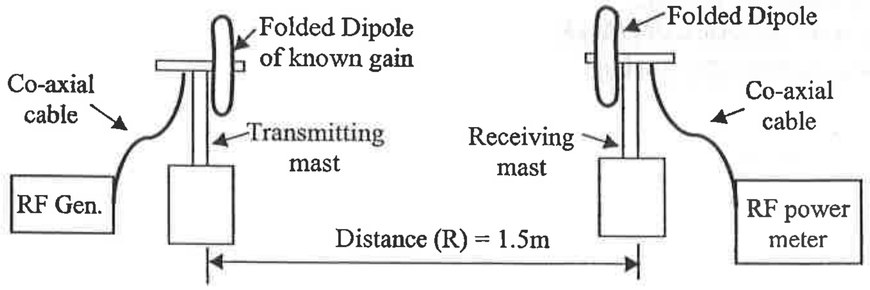
Use RF Generator (Model: RF-6) for 500MHz RF signal output & RF Power meter (Model: RFM-5M) for measurement of power level in each step.

Follow the given steps to measure the gain of this antenna using folded-dipole antenna as reference;

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Connect folded dipole antenna on receiving side and connect other folded dipole antenna of known gain on transmitting mast.

Fig. 16.1 Setup for Measurement of P_{Ref}



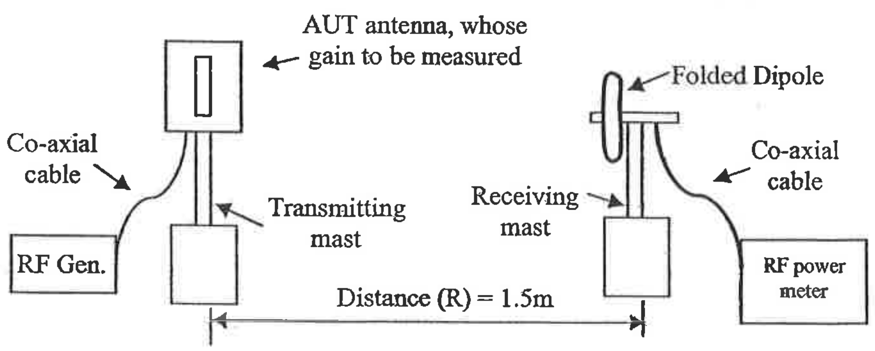
ii) Set RF generator at 500MHz RF output & keep the amplitude knob of signal generator at maximum position and connect to transmitting antenna and connect RF power meter to receiving antenna.

iii) Now switch ON both RF power meter & RF generator and measure the power meter reading, this is the power reading of reference folded dipole antenna,

i.e. $P_{Ref(folded)}$ = --------------------- dBm.

iv) Without disturbing the above setup, switch OFF both the RF power meter & generator. Now replace the reference folded dipole of transmitting side with this AUT antenna facing to folded dipole antenna of receiving side as shown;

Fig. 16.2 Setup for Measurement of P_{Meas}



v) Now switch ON both the RF power meter & generator. And note down the power meter reading, this is the measured power level of log-periodic antenna,

i.e. $P_{Meas(SLOT)}$ = ---------------------- dBm.

vi) Use the same equation, whatever used for Log-periodic as given below;

i.e. G_{SLOT} (in dBi) = $G_{Ref(folded)}$ (in dBi) + [$P_{Meas(SLOT)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= 24 (in dBi) + [$P_{Meas(SLOT)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= ---------------------- dBi.

☞ Conclusion

Hence, from the above observed readings, you can conclude that Slot antenna is a Bi-directional antenna and its gain is approximately as 28.0 dBi.

☞ Equipments Required

a) Two nos. of folded dipole antennas of same physical shape & mounting setup.
b) Slot antenna.
c) Transmitting Mast with in-built stepper.
d) Receiving mast.
e) 2 nos. of BNC-to-BNC cable.
f) RF generator (Model: RF-6).
g) RF power meter (Model: RFM-5M).
h) VWB software hardware setup.

17. Study of Discone Antenna

☞ Unit Objective

On the completion of this unit you will be understand the basic principles related to Discone antenna and practically measure the following characteristics of this antenna;

i) The Radiation pattern (Azimuth XY-plane plot).
ii) Antenna Beamwidth.
iii) Antenna Front-to-Back ratio.
iv) The Gain using standard reference antenna.

☞ Discussion on Fundamentals

This antenna is designed by mounting two separate conducting surfaces by an insulator, these two conducting surfaces are Disc & other is Cone. The disc is acts as Radiator & feeding RF signal from the Balun output and Cone is acts as Grounding surface & feeding grounding of RF signal. In our design, we use two galvanized iron sheet for disc & cone and these are separated by Fiber spacers from four sides & mounted on antenna red-mask base plate. Because of this two Disc & Cone assembly, this antenna got the name Discone antenna.

NOTE: Use the same procedure for measurement of antenna radiation pattern & gain of this antenna, whatever used for half-wave simple dipole antenna.

☞ Procedure

A) Measurement of Radiation pattern:

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Mount this antenna on top of the transmitting mast by using M8x45mm screw.
ii) Connect output of RF generator to this AUT using BNC-to-BNC cable.
iii) Mount a receiving folded dipole Antenna on top of the receiving mast.
iv) Connect input of RF power meter to receiving antenna using BNC-to-BNC cable.
v) Keep distance of 1.5m (approx. 5 feet) between them and keep both antennas at line-of-sight & facing each-other by considering there sight as 0^0 position.
vi) Switch ON both the RF power meter & the RF signal generator.
vii) Adjust frequency on RF generator between 350 to 500 MHz to obtain close to standard pattern (80% atleast) and set amplitude knob at maximum clock-wise position.
viii) Adjust transmitting antenna pointer to 0^0 and take reading on RF power meter (near receiving antenna). Now rotate transmitting antenna & take corresponding reading on power meter. Now take another reading with angle steps of 10^0, up to 360^0 of complete rotation & note-down the corresponding readings.
ix) After taking all readings, fill the below table.

Table 17.1 Radiation pattern observation table of Discone antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	
2.	10	
3.	20	
4.	30	
5.	40	
6.	50	
7.	60	
8.	70	
9.	80	
10.	90	
11.	100	
12.	110	
13.	120	
14.	130	
15.	140	
16.	150	
17.	160	
18.	170	
19.	180	
20.	190	
21.	200	
22.	210	
23.	220	
24.	230	
25.	240	
26.	250	
27.	260	
28.	270	
29.	280	
30.	290	
31.	300	
32.	310	
33.	320	
34.	330	
35.	340	
36.	350	

x) Now, plot the polar graph between angles (in degree) versus observed power meter readings (in dBm) on your paper or use VWB software (in OFFLINE-mode).

NOTE: Please refer Chapter 2 for complete hardware wiring & procedure for "To plot Antenna radiation pattern using VWB software" in detail.

B) Measurement of Beamwidth:

From the observed radiation pattern of this AUT antenna, find the -3dB power level on center line and draw an arc from center of pattern to -3dB level and then measure the either side angles. Note down that angle as beamwidth of antenna;

Beamwidth = ---------------------- Degree.

C) Measurement of Front-to-Back Ratio:

From the observed radiation pattern of this AUT antenna, find the power level of main-lobe (i.e. lobe having more strength) & write it as "Pmaj" and then find power level lobe, which is 180^0 off from main lobe, write it as "Pmin", then calculate Front-to-Back Ratio using the below equation;

Front-to-Back Ratio = Pmaj - Pmin (in dBm) ------------------ dBm.

D) Measurement of Gain:

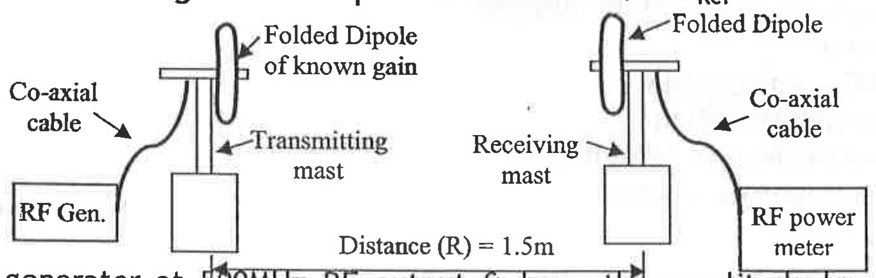
Use RF Generator (Model: RF-6) for 500MHz RF signal output & RF Power meter (Model: RFM-5M) for measurement of power level in each step.

Follow the given steps to measure the gain of this antenna using folded-dipole antenna as reference;

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Connect folded dipole antenna on receiving side and connect other folded dipole antenna of known gain on transmitting mast.

Fig. 17.1 Setup for Measurement of P_{Ref}



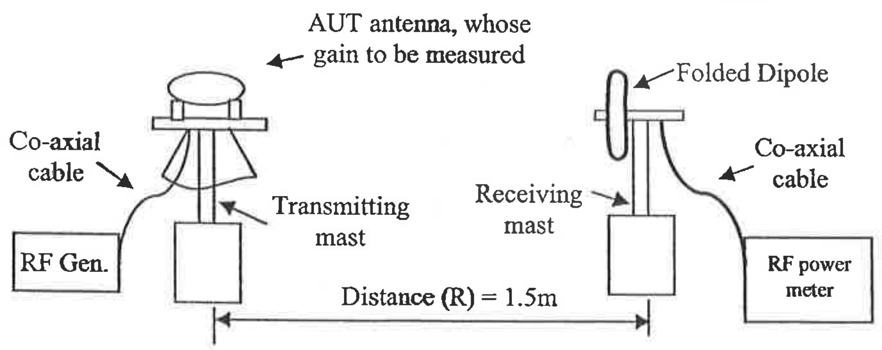
ii) Set RF generator at 500MHz RF output & keep the amplitude knob of signal generator at maximum position and connect to transmitting antenna and connect RF power meter to receiving antenna.

iii) Now switch ON both RF power meter & RF generator and measure the power meter reading, this is the power reading of reference folded dipole antenna,

i.e. $P_{Ref(folded)}$ = --------------------- dBm.

iv) Without disturbing the above setup, switch OFF both the RF power meter & generator. Now replace the reference folded dipole of transmitting side with this AUT antenna facing to folded dipole antenna of receiving side as shown;

Fig. 17.2 Setup for Measurement of P_{Meas}



v) Now switch **ON** both the RF power meter & generator. And note down the power meter reading, this is the measured power level of log-periodic antenna,

i.e. $P_{Meas(DISC)}$ = ---------------------- dBm.

vi) Use the same equation, whatever used for Log-periodic as given below;

i.e. G_{DISC} (in dBi) = $G_{Ref(folded)}$ (in dBi) + [$P_{Meas(DISC)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= 24 (in dBi) + [$P_{Meas(DISC)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= ---------------------- dBi.

☞ Conclusion

Hence, from the above observed readings, you can conclude that Discone antenna is a Omni-directional antenna and its gain is approximately as 32.8 dBi.

☞ Equipments Required

a) Two nos. of folded dipole antennas of same physical shape & mounting setup.
b) Co-linear antenna.
c) Transmitting Mast with in-built stepper.
d) Receiving mast.
e) 2 nos. of BNC-to-BNC cable.
f) RF generator (Model: RF-6).
g) RF power meter (Model: RFM-5M).
h) VWB software hardware setup.

18. Study of Parabolic Reflector Dish Antenna

☞ Unit Objective

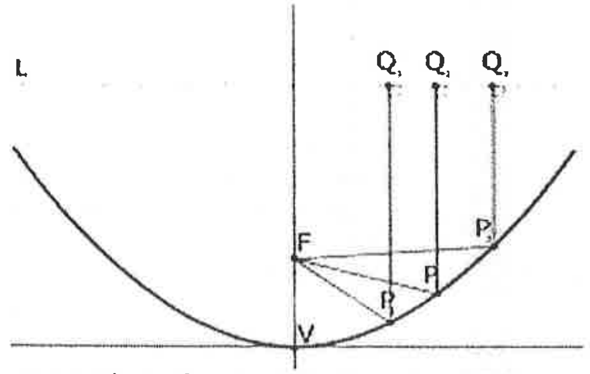
On the completion of this unit you will be understand the basic principles related to Parabolic Reflector antenna and practically measure the following characteristics of this antenna;

i) The Radiation pattern (Azimuth XY-plane plot).
ii) Antenna Beamwidth.
iii) Antenna Front-to-Back ratio.
iv) The Gain using standard reference antenna.

☞ Discussion on Fundamentals

A parabolic antenna is an antenna that uses a parabolic reflector, a curved surface with the cross-sectional shape of a parabola, to direct the radio waves. The most common form is shaped like a dish and is popularly called a dish antenna or parabolic dish. The main advantage of a parabolic antenna is that it is highly directive; it functions similarly to a searchlight or flashlight reflector to direct the radio waves in a narrow beam, or receive radio waves from one particular direction only. Parabolic antennas are used as high-gain antennas for point-to-point communication. In a parabolic antenna, incoming parallel radio waves (Q_1 - Q_3) are reflected to a point at the dish's focus (F), where they are received by a small feed antenna (here Simple half-wave dipole) as shown;

Fig 18.1 Basic construction of Parabolic Reflector Antenna



NOTE: Use the same procedure for measurement of antenna radiation pattern & gain of this antenna, whatever used for half-wave simple dipole antenna.

☞ Procedure

A) Measurement of Radiation pattern:

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Mount this antenna on top of the transmitting mast by using M8x45mm screw.
ii) Connect output of RF generator to this AUT using BNC-to-BNC cable.
iii) Mount a receiving folded dipole Antenna on top of the receiving mast.
iv) Connect input of RF power meter to receiving antenna using BNC-to-BNC cable.
v) Keep distance of 1.5m (approx. 5 feet) between them and keep both antennas at line-of-sight & facing each-other by considering there sight as 0^0 position.
vi) Switch ON both the RF power meter & the RF signal generator.

vii) Adjust frequency on RF generator between 350 to 500 MHz to obtain close to standard pattern (80% atleast) and set amplitude knob at maximum clock-wise position.

viii) Adjust transmitting antenna pointer to 0^0 and take reading on RF power meter (near receiving antenna). Now rotate transmitting antenna & take corresponding reading on power meter. Now take another reading with angle steps of 10^0, up to 360^0 of complete rotation & note-down the corresponding readings.

ix) After taking all readings, fill the below table.

Table 18.1 Radiation pattern observation table of Parabolic Reflector antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	
2.	10	
3.	20	
4.	30	
5.	40	
6.	50	
7.	60	
8.	70	
9.	80	
10.	90	
11.	100	
12.	110	
13.	120	
14.	130	
15.	140	
16.	150	
17.	160	
18.	170	
19.	180	
20.	190	
21.	200	
22.	210	
23.	220	
24.	230	
25.	240	
26.	250	
27.	260	
28.	270	
29.	280	
30.	290	
31.	300	
32.	310	
33.	320	
34.	330	
35.	340	
36.	350	

x) Now, plot the polar graph between angles (in degree) versus observed power meter readings (in dBm) on your paper or use VWB software (in OFFLINE-mode).

<u>NOTE:</u> Please refer Chapter 2 for complete hardware wiring & procedure for **"To plot Antenna radiation pattern using VWB software"** in detail.

B) Measurement of Beamwidth:

From the observed radiation pattern of this AUT antenna, find the -3dB power level on center line and draw an arc from center of pattern to -3dB level and then measure the either side angles. Note down that angle as beamwidth of antenna;

Beamwidth = ---------------------- Degree.

C) Measurement of Front-to-Back Ratio:

From the observed radiation pattern of this AUT antenna, find the power level of main-lobe (i.e. lobe having more strength) & write it as "Pmaj" and then find power level lobe, which is 180^0 off from main lobe, write it as "Pmin", then calculate Front-to-Back Ratio using the below equation;

Front-to-Back Ratio = Pmaj - Pmin (in dBm) ------------------ dBm.

D) Measurement of Gain:

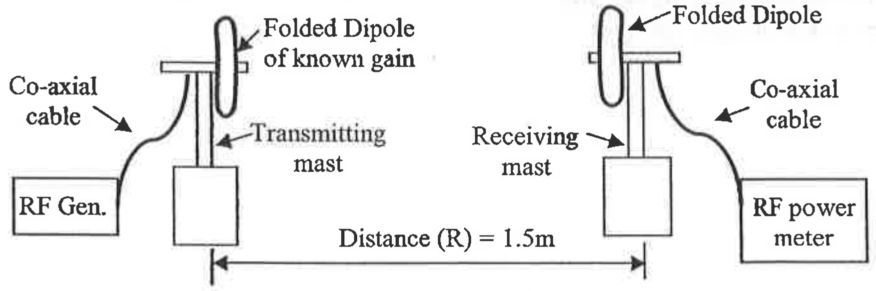
Use RF Generator (Model: RF-6) for 500MHz RF signal output & RF Power meter (Model: RFM-5M) for measurement of power level in each step.

Follow the given steps to measure the gain of this antenna using folded-dipole antenna as reference;

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Connect folded dipole antenna on receiving side and connect other folded dipole antenna of known gain on transmitting mast.

Fig. 18.2 Setup for Measurement of P_{Ref}



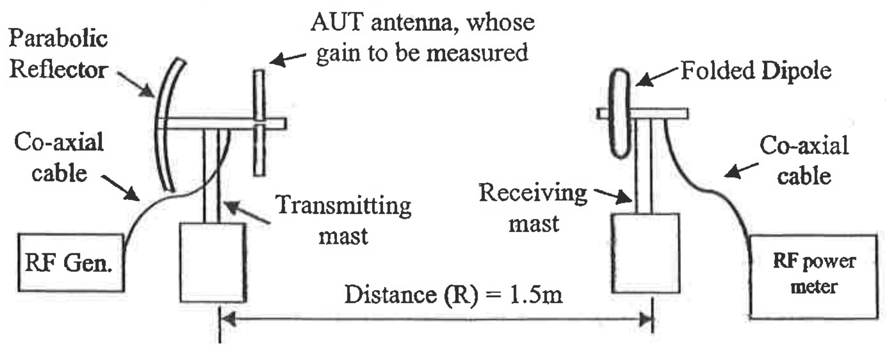
ii) Set RF generator at 500MHz RF output & keep the amplitude knob of signal generator at maximum position and connect to transmitting antenna and connect RF power meter to receiving antenna.

iii) Now switch ON both RF power meter & RF generator and measure the power meter reading, this is the power reading of reference folded dipole antenna,

i.e. $P_{Ref(folded)}$ = --------------------- dBm.

iv) Without disturbing the above setup, switch OFF both the RF power meter & generator. Now replace the reference folded dipole of transmitting side with this AUT antenna facing to folded dipole antenna of receiving side as shown;

Fig. 18.3 Setup for Measurement of P_{Meas}



v) Now switch ON both the RF power meter & generator. And note down the power meter reading, this is the measured power level of AUT;

i.e. $P_{Meas(PARA)}$ = --------------------- dBm.

vi) Use the same equation, whatever used for Folded-dipole as given below;

i.e. G_{PARA} (in dBi) = $G_{Ref(folded)}$ (in dBi) + [$P_{Meas(PARA)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= 24 (in dBi) + [$P_{Meas(PARA)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= --------------------- dBi.

☞ Conclusion

Hence, from the above observed readings, you can conclude that Parabolic Antenna is a directional antenna and its gain is approximately as 42.2 dBi.

☞ Equipments Required

a) Two nos. of folded dipole antennas of same physical shape & mounting setup.
b) Parabolic Reflector antenna made of GI sheet.
c) Transmitting Mast with in-built stepper.
d) Receiving mast.
e) 2 nos. of BNC-to-BNC cable.
f) RF generator (Model: RF-6).
g) RF power meter (Model: RFM-5M).
h) VWB software hardware setup.

19. Study of Microstrip Patch Antenna

☞ Unit Objective

On the completion of this unit you will be understand the basic principles related to Patch antenna and practically measure the following characteristics of this antenna;

i) The Radiation pattern (Elevation-plane plot).
ii) Antenna Beamwidth.
iii) Antenna Front-to-Back ratio.
iv) The Gain using standard reference antenna.

☞ Discussion on Fundamentals

A patch antenna is a narrowband, wide-beam antenna fabricated by etching the antenna element pattern in metal trace bonded to an insulating dielectric substrate, such as a printed circuit board, with a continuous metal layer bonded to the opposite side of the substrate which forms a ground plane. Common microstrip antenna shapes are square, rectangular, circular and elliptical (here in this set it is of Square), but any continuous shape is possible. They are often mounted on the exterior of aircraft and spacecraft, or are incorporated into mobile radio communications devices.

NOTE: Use the same procedure for measurement of antenna radiation pattern & gain of this antenna, whatever used for half-wave simple dipole antenna.

☞ Procedure

A) Measurement of Radiation pattern:

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Mount this antenna on top of the transmitting mast by using M8x45mm screw.
ii) Connect output of RF generator to this AUT using BNC-to-BNC cable.
iii) Mount a receiving folded dipole Antenna on top of the receiving mast.
iv) Connect input of RF power meter to receiving antenna using BNC-to-BNC cable.
v) Keep distance of 1.5m (approx. 5 feet) between them and keep both antennas at line-of-sight & facing each-other by considering there sight as 0^0 position.
vi) Switch ON both the RF power meter & the RF signal generator.
vii) Adjust frequency on RF generator between 350 to 500 MHz to obtain close to standard pattern (80% atleast) and set amplitude knob at maximum clock-wise position.
viii) Adjust transmitting antenna pointer to 0^0 and take reading on RF power meter (near receiving antenna). Now rotate transmitting antenna & take corresponding reading on power meter. Now take another reading with angle steps of 10^0, up to 360^0 of complete rotation & note-down the corresponding readings.
ix) After taking all readings, fill the below table.

Table 19.1 Radiation pattern observation table of Patch antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	
2.	10	
3.	20	
4.	30	
5.	40	
6.	50	
7.	60	
8.	70	
9.	80	
10.	90	
11.	100	
12.	110	
13.	120	
14.	130	
15.	140	
16.	150	
17.	160	
18.	170	
19.	180	
20.	190	
21.	200	
22.	210	
23.	220	
24.	230	
25.	240	
26.	250	
27.	260	
28.	270	
29.	280	
30.	290	
31.	300	
32.	310	
33.	320	
34.	330	
35.	340	
36.	350	

x) Now, plot the polar graph between angles (in degree) versus observed power meter readings (in dBm) on your paper or use VWB software (in OFFLINE-mode).

NOTE: Please refer Chapter 2 for complete hardware wiring & procedure for **"To plot Antenna radiation pattern using VWB software"** in detail.

B) Measurement of Beamwidth:

From the observed radiation pattern of this **AUT** antenna, find the -3dB power level on center line and draw an arc from center of pattern to -3dB level and then measure the either side angles. Note down that angle as beamwidth of antenna;

Beamwidth = ---------------------- Degree.

C) Measurement of Front-to-Back Ratio:

From the observed radiation pattern of this AUT antenna, find the power level of main-lobe (i.e. lobe having more strength) & write it as "Pmaj" and then find power level lobe, which is 180^0 off from main lobe, write it as "Pmin", then calculate Front-to-Back Ratio using the below equation;

Front-to-Back Ratio = Pmaj - Pmin (in dBm) ------------------ dBm.

D) Measurement of Gain:

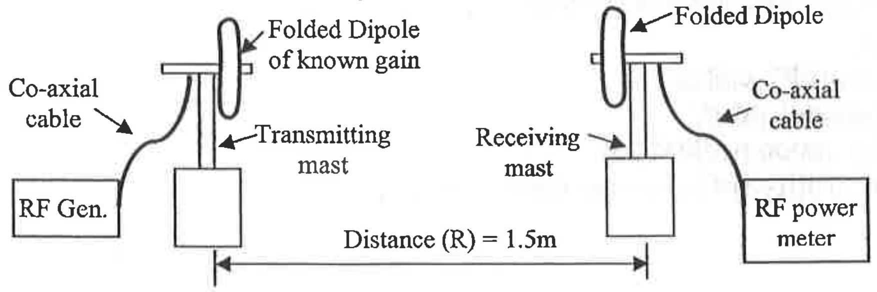
Use RF Generator (Model: RF-6) for 500MHz RF signal output & RF Power meter (Model: RFM-5M) for measurement of power level in each step.

Follow the given steps to measure the gain of this antenna using folded-dipole antenna as reference;

NOTE: Follow same procedure as in case of Half-wave simple-dipole antenna done in previous unit, only some brief procedures are given below;

i) Connect folded dipole antenna on receiving side and connect other folded dipole antenna of known gain on transmitting mast.

Fig. 19.1 Setup for Measurement of P_{Ref}



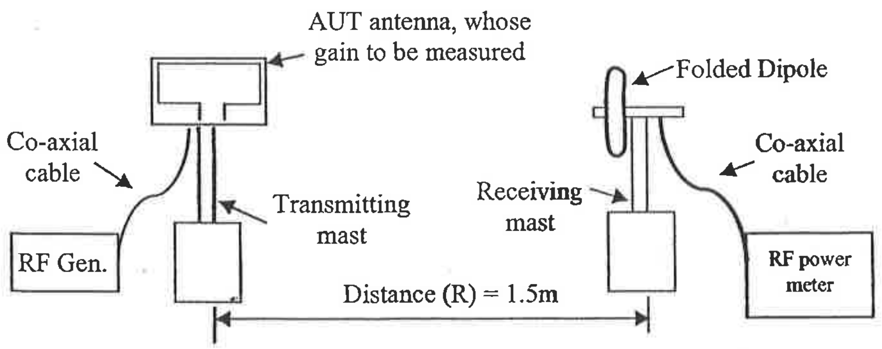
ii) Set RF generator at 500MHz RF output & keep the amplitude knob of signal generator at maximum position and connect to transmitting antenna and connect RF power meter to receiving antenna.

iii) Now switch ON both RF power meter & RF generator and measure the power meter reading, this is the power reading of reference folded dipole antenna,

i.e. $P_{Ref(folded)}$ = --------------------- dBm.

iv) Without disturbing the above setup, switch OFF both the RF power meter & generator. Now replace the reference folded dipole of transmitting side with this AUT antenna facing to folded dipole antenna of receiving side as shown;

Fig. 19.2 Setup for Measurement of P_{Meas}



v) Now switch ON both the RF power meter & generator. And note down the power meter reading, this is the measured power level of AUT;

i.e. $P_{Meas(PATCH)}$ = ---------------------- dBm.

vi) Use the same equation, whatever used for half-wave Folded-dipole as given;

i.e. G_{PATCH} (in dBi) = $G_{Ref(folded)}$ (in dBi) + [$P_{Meas(PATCH)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= 24 (in dBi) + [$P_{Meas(PATCH)}$ (in dBm) - $P_{Ref(folded)}$ (in dBm)]

= ---------------------- dBi.

☞ Conclusion

Hence, from the above observed readings, you can conclude that Microstrip patch antenna is a directional antenna and its gain is approximately as 40.7 dBi.

☞ Equipments Required

a) Two nos. of folded dipole antennas of same physical shape & mounting setup.
b) Microstrip Patch antenna.
c) Transmitting Mast with in-built stepper.
d) Receiving mast.
e) 2 nos. of BNC-to-BNC cable.
f) RF generator (Model: RF-6).
g) RF power meter (Model: RFM-5M).
h) Antenna graph utility software hardware setup.

20. Antenna Resonance experiment using Variable Length $\lambda/2$ simple Dipole Antenna

☞ Unit Objective

On the completion of this unit you will be able to understand the basic principles of Variable Length antenna and Antenna resonance study by using this variable length antenna to adjust the antenna length for a fixed frequency & signal strength to get maximum reception at the receiving side (using RF power meter).

☞ Discussion on Fundamentals

This variable length antenna contains a simple dipole type antenna element (2 nos at either side, made-up of steel rod). As the name mentioned variable length, means the length of this antenna is variable (either expanded or compressed as per experiment).

There are two different methods, we are illustrating for study of Antenna Resonance experiment as given below;

A) **Signal transmission method:** In this case, mount the variable length antenna (AUT) to the transmitting mast & RF signal is fed to that AUT and at a distance of say, approx. 10 feet, there is a receiving antenna (which is folded dipole) which received the signal (whatever transmitted by the AUT) & finally measurement is done using the connected RF power meter to the receiving antenna.

<u>NOTE:</u> While doing this experiment by varying length of antenna for fixed transmission frequency, check the maxima of observed power. Means from the number of observations (for different lengths of antenna), find the maximum observed power from that observations; which indicates maximum reception when antenna length matched with the transmitted frequency.

B) **Directional Coupler method:** In this case, mount the AUT to the mast & connect to Through port (port-2) of Directional Coupler (DC) and apply RF signal to the Input port (port-1). Terminate Forward Port (port-4) by 50 Ohm BNC termination & connect the power meter to Reflected port (port-3) & finally measurement is done using the connected RF power meter to the Reflected port.

<u>NOTE:</u> While doing this experiment by varying length of antenna for fixed transmission frequency, check the minima of observed power. Means from the number of observations (for different lengths of antenna), find the minimum observed power from that observations; which indicates minimum reflections when antenna length matched with the transmitted frequency.

When maxima observed (in case of Signal transmission method) & minima observed (in case of Directional Coupler method); you can verify the antenna length as per the fed frequency, both will relate with the following equation;

$$f = c / \lambda$$

where,

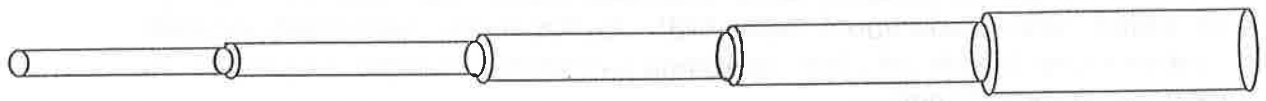
λ = wavelength (in mm).

c = Speed of light (in mm/sec).

f = Frequency (in MHz).

NOTE: The length of Antenna will be the half-wavelength (i.e. $\lambda/2$), now when you observe maxima or minima for an antenna length at same RF frequency; calculate λ and then find Half-wavelength, both will relate as per above equation.

Fig. 20.1 Structure of Variable Length Antenna



The variable length antennas are so provided that they are expandable in the parts of 100mm per slots as shown, each antenna has 4 nos of expandable slots & maximum length of each slot is 100mm. The minimum length of variable length antenna is 200mm (when all slots are compressed) & after stretching all slots, the length of antenna expanded upto 600mm.

For each side of base-plate;

Length of each slot (4 nos) = 100mm.

Antenna minimum length = 200mm.

Total length of each antenna = (100 x 4) + 200 = 600 mm.

Hence, complete variable length antenna ($\lambda/2$ length) = 600 + 600 = **1200mm.**

Two identical variable length antennas at both side of base plate are provided with the length ranging from 200mm to 600mm each as mentioned above, means total length of antenna (i.e. $\lambda/2$ length) **varies from 400mm to 1200mm**, so operating RF frequency for that Antenna length is **ranging from 125 MHz to 375 MHz**; in which 400mm antenna length corresponds to 375MHz & 1200mm corresponds to 125MHz.

NOTE:

1) In performing Antenna Resonance experiment using variable length simple dipole antenna, you have to vary length of antenna equally (from both side) with the help of a Measuring Scale each time for the fixed transmission frequency.

2) Set the RF signal frequencies as per table given below with constant RF signal strength of **0dBm** for different variable length antenna size, means you have to set 0dBm each time for different RF frequency (as per method given below).

☞ Procedure

A) Antenna Resonance study using Signal Transmission Method:

i) Mount this AUT on top of the transmitting mast by using M8x45mm screw.

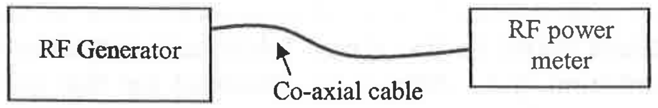
ii) Connect output of RF generator to this AUT using BNC-to-BNC cable.

iii) Mount a receiving folded dipole Antenna on top of the receiving mast.

iv) Connect input of RF power meter to receiving antenna using BNC-to-BNC cable.

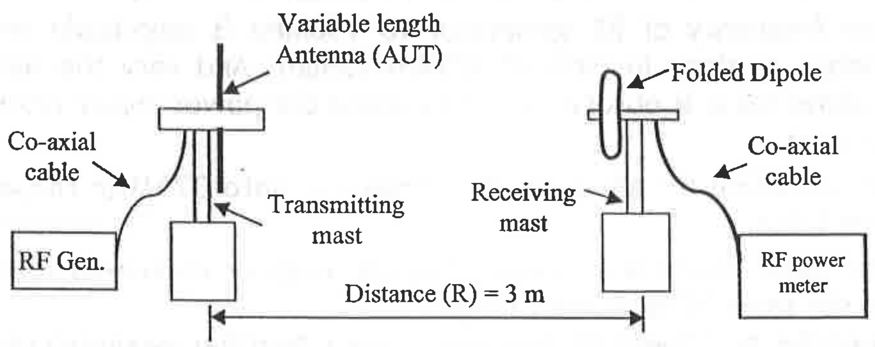
v) First set **RF generator to 125MHz** & connect to the power meter and set the power meter display to 0dBm by varying the amplitude knob of generator as shown (this is the procedure to set RF signal strength to 0dBm for each frequency range);

Fig. 20.2 Signal generator strength setting to 0dBm using Power meter



vi) Now connect RF generator to AUT & keep distance of 3m (approx. 10 feet) between both antennas at line-of-sight arrangement as shown below;

Fig. 20.3 Setup for signal transmission method



vii) Adjust the length of variable length antenna to 200mm at each side (this is the minimum length of the AUT), means total of 400mm by the help of measuring scale accurately. Now, switch ON both the RF power meter & signal generator and note down the power meter. Now vary the total length of antenna from 400mm to 500mm (250mm at both side accurately) & note down the power meter reading.

Now follow the same procedure for different length of antenna (i.e. 600mm, 700mm, 800mm, 900mm, 1000mm, 1100mm & 1200mm) at the same transmitted frequency of 125MHz & 0dBm and fill the column of 125MHz range.

Table 20.1 Antenna resonance observations using signal transmission method

Sr. No.	Antenna Length (λ/2) (in mm)	Observed power at the frequency (f) (in dBm)							
		At f=125MHz	At f=150MHz	At f=168MHz	At f=188MHz	At f=215MHz	At f=250MHz	At f=300MHz	At f=375MHz
1.	400								
2.	500								
3.	600								
4.	700								
5.	800								
6.	900								
7.	1000								
8.	1100								
9.	1200								

NOTE: The frequency values listed in the above table correspond to the length of simple dipole variable antenna (i.e. 400mm to 1200mm) by the above equation. For example at 400mm antenna length:

Antenna Length = $\lambda/2$ = 400mm,

Then, λ = 800mm,

$\therefore$ f = c / λ = (3 x 10^11) / (800) = **375MHz**, and so on.

viii) Now set the frequency of **RF generator to 150MHz** & amplitude to 0dBm (using power meter, as done in case of 125MHz range). And vary the length of antenna as per above table & observe and note down the power meter readings in 150MHz range column.

ix) Do the same procedure for all frequency range i.e. **upto 375MHz range** & fill the corresponding table.

x) Now from the above observation table, find the peak or maximum reading of power meter for the same RF frequency range.

Means for example, at 125MHz RF frequency range, find the maximum observed reading, corresponding to which antenna length (say 1200mm). Then calculate the wavelength & then half-wavelength (equals to Antenna length) for the same frequency using the above equation.

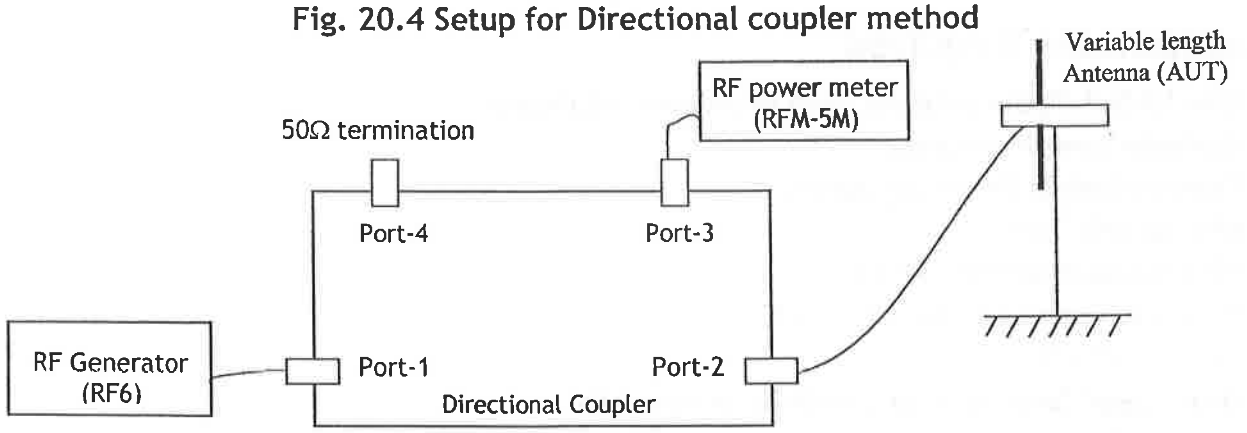
And finally, the length of antenna is matched for that transmitted frequency of 125MHz, as you got maximum reception at this antenna length. And hence, you observed the Antenna resonance behavior for this length, which corresponds to the transmitted RF signal from the AUT.

NOTE: While observing readings, somewhere you will get the approximate result of calculated half-wavelength (length of Antenna) for the corresponding transmitted RF frequency; consider that wavelength as correspond to the transmitted frequency, because the reasons as illustrated in Precaution points.

B) Antenna Resonance study using Directional Coupler method:

i) First set the RF frequency to 125MHz & signal strength to 0dBm using power meter as per procedure illustrated in above method.
ii) Connect Variable length antenna (AUT) to the **Through port** (Port-P2) of Directional coupler (DC) & RF signal generator to the **Input port** (Port-P1).
iii) Terminate **Coupled port** (Port-P4) of DC by 50 Ohm BNC termination.
iv) Connect RF power meter **to Isolated port** (Port-P3) of DC as shown below;

Fig. 20.4 Setup for Directional coupler method



v) Refer points-vii to x of the above method (Antenna resonance study using signal transmission method), for procedure to observe readings by adjusting the length of variable length antenna from 400mm to 1200mm for the same RF frequency & signal strength. And fill the below table of observed readings versus RF frequency.

Now vary the input RF frequency to 150MHz & follow the same procedure as illustrated above. Fill the corresponding columns for upto 375MHz frequency range.

Table 20.2 Antenna resonance observations using Directional Coupler method

Sr. No.	Antenna Length (λ/2) (in mm)	Observed power at the frequency (f) (in dBm)							
		At f=125MHz	At f=150MHz	At f=168MHz	At f=188MHz	At f=215MHz	At f=250MHz	At f=300MHz	At f=375MHz
1.	400								
2.	500								
3.	600								
4.	700								
5.	800								
6.	900								
7.	1000								
8.	1100								
9.	1200								

vi) Now from the above observation table, find the least or minimum reading of power meter for the same RF frequency range.

As per above method, find λ / 2 length using the above equation for the frequency in which you got the minimum reflections from the antenna.

And finally, the length of antenna is matched for that transmitted frequency in which you got minimum reflection at the isolated port of Directional coupler. And hence, you observed the Antenna resonance behavior for this length, which corresponds to the transmitted RF signal from the AUT.

☞ Conclusion

Hence, from the above observed readings, you can conclude that, the length of an RF Antenna is designed for a specific RF frequency. If any case, the length of Antenna changed (from the designed operating frequency value) or even the operating frequency get changed (for the corresponding designed antenna length); you will observe loss of received power while signal transmission.

☞ Equipments Required

a) One folded dipole antenna used as receiving antenna.
b) Variable Length antenna.
c) Transmitting & Receiving masts.
d) BNC-to-BNC cable.
e) RF generator (Model: RF-6).
f) RF power meter (Model: RFM-5M).
g) Measuring Scale.
h) Directional Coupler & 50 ohm BNC termination.

Instructor's Guide for
ANTENNA TRAINING SYSTEMS / XPO-ANT

Following are typical set of observations taken by our R & D Engineer exactly following same procedure which is stated in SW. Please allow variations up to 20% due to huge metallic objects which reflect or absorb RF energy, thereby contracting or expanding the lobes in polar plot.

<u>NOTE:</u> 1) Due to presence of large metallic bodies/conducting bodies, which absorb/reflect Electromagnetic radiations, by which you may get distortion in polar plot, i.e. away from figure of circle (omni-directional), Figure of 8 (Bi-directional), lopsided 8 (Uni-directional). So, ignore those distortions & check whether overall above broad classification is borne out by the plot for particular antenna.

2) Zero on the polar s/w & mast physical zero may not always match, unless you do it yourself.

3) Keep connecting BNC-to-BNC cable as straight as possible else attenuation will result.

4) Read carefully the warning instructions in the introduction unit of this trainer set and follow the procedure given in different units & try to maintain the warning points so as to match your observations as per results illustrated in this IG section.

CH-2: Understanding Resource Panels:

Coupling factor (or, $S_{14} = S_{41}$) = (-32.5) - (-10.0) dBm
= -22.5 dBm.

Coupling factor (or, $S_{23} = S_{32}$) = (-30.5) - (-10.0) dBm.
= -20.5 dBm.

Main-line loss (or, $S_{12} = S_{21}$) = (-11.4) - (-10.0) dBm.
= -1.4 dBm.

Directivity (or, $S_{13} - S_{41}$) = - (S_{41}) dBm = - (-32.5) - (-10.0) = **22.5 dBm**

Main-line loss (or, $S_{13} = S_{31}$) = (-42.3) - (-10.0) dBm
= -32.3 dBm.

$S_{43} = S_{34}$ = (-12.5) - (-10.0) dBm = **-2.5 dBm.**

Table 2.13 Observation Table of Antenna Return-Loss & VSWR

Sr. No.	Name of Antennas	Measured Parameters				
		P_F (dBm)	P_R (dBm)	Return Loss (dBm)	Reflection Co-efficient	VSWR (No unit)
1.	Half-wave folded dipole.	-19.4	-24.1	-4.7	0.58	3.78
2.	Half-wave simple dipole.	-20.7	-25.8	-5.2	0.55	3.44
3.	Quarter-wave simple dipole.	-20.7	-24.5	-3.8	0.64	4.62
4.	3λ/2 simple dipole.	-21.6	-28.9	-7.3	0.43	2.51
5.	Half-wave Folded-dipole with Reflector.	-19.9	-24.4	-4.5	0.59	3.93
6.	Yagi-Uda 3 elements.	-22.5	-29.2	-6.7	0.46	2.71
7.	Yagi-Uda 5 elements.	-20.9	-31.3	-10.4	0.30	1.86
8.	Yagi-Uda 7 elements.	-19.3	-26.4	-7.1	0.44	2.57
9.	Circular Loop.	-20.7	-28.2	-7.5	0.42	2.45
10.	Log-periodic.	-21.3	-29.1	-7.9	0.40	2.34
11.	Helical.	-18.9	-23.3	-4.4	0.60	4.02
12.	Half-wave End-Fire.	-21.3	-29.1	-7.8	0.40	2.34
13.	Quarter-wave End-Fire.	-22.2	-31.3	-9.1	0.35	2.08
14.	Broad-side array.	-20.5	-27.7	-7.2	0.43	2.53
15.	Co-linear array.	-20.8	-25.2	-4.4	0.60	4.02
16.	Slot.	-28.0	-31.8	-3.8	0.64	4.55
17.	Discone.	-27.7	-31.7	-4.0	0.63	4.40
18.	Parabolic Reflector.	-21.7	-27.2	-5.5	0.53	3.26
19.	Microstrip Patch.	-27.0	-32.8	-5.8	0.51	3.10
20.	Variable Length.	-20.7	-25.8	-5.2	0.55	3.44

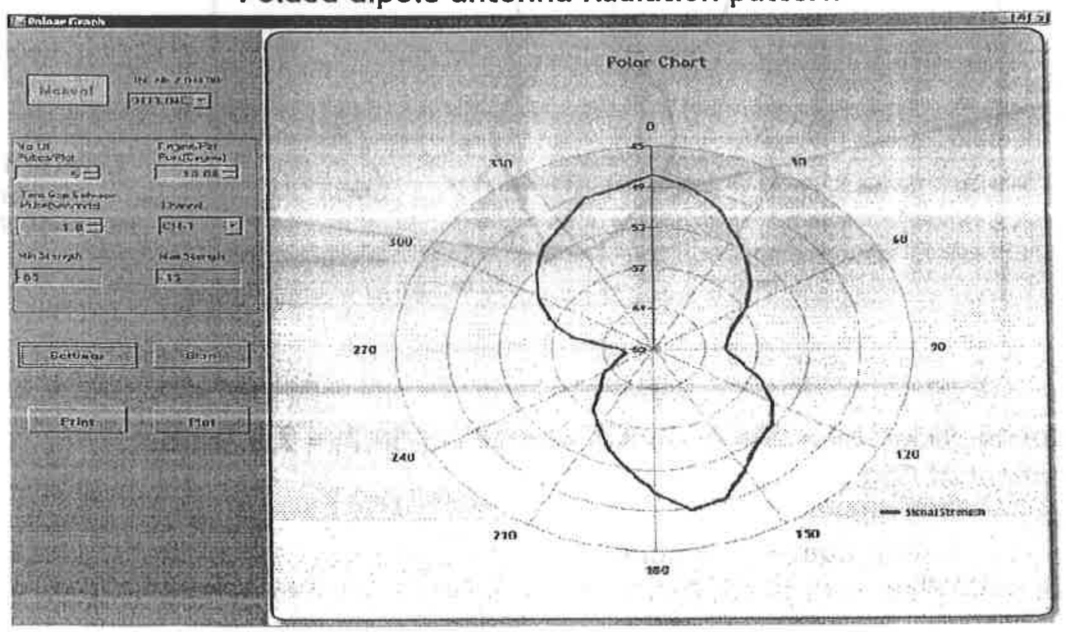
CH-3: Study of Half-wave Folded Dipole Antenna

A) Measurement of Radiation pattern:

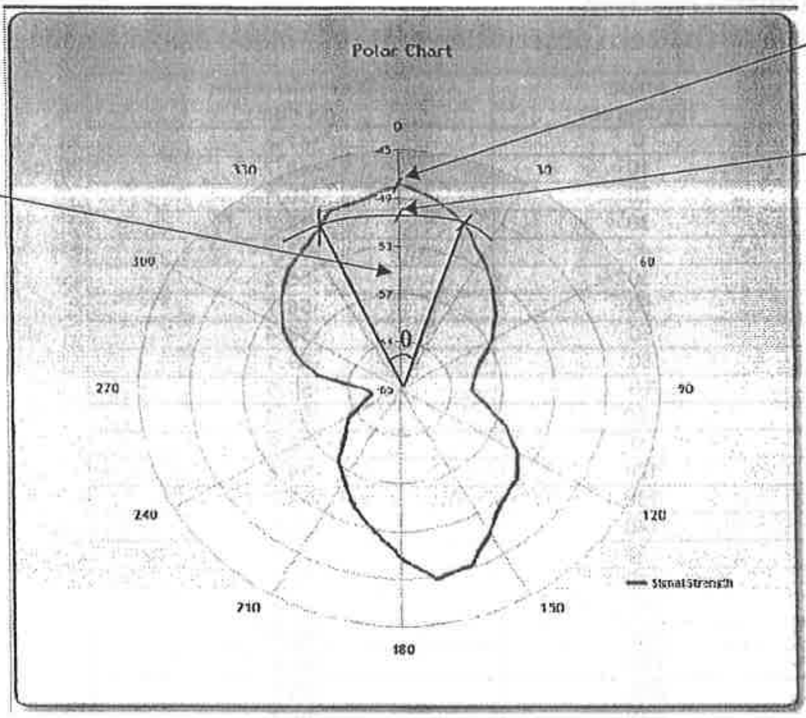
Table 3.1 Radiation pattern observation table of Folded dipole antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	-47.8
2.	10	-48.7
3.	20	-50.1
4.	30	-52.2
5.	40	-53.7
6.	50	-55.2
7.	60	-56.7
8.	70	-58.4
9.	80	-59.1
10.	90	-59.5
11.	100	-58.4
12.	110	-56.3
13.	120	-54.5
14.	130	-53.2
15.	140	-52.8
16.	150	-51.2
17.	160	-49.3
18.	170	-48.8
19.	180	-50.7
20.	190	-52.8
21.	200	-54.3
22.	210	-56.1
23.	220	-57.3
24.	230	-59.4
25.	240	-60.3
26.	250	-61.9
27.	260	-62.7
28.	270	-62.3
29.	280	-58.4
30.	290	-56.3
31.	300	-54.5
32.	310	-53.1
33.	320	-51.7
34.	330	-50.8
35.	340	-49.1
36.	350	-48.8

Folded dipole antenna Radiation pattern

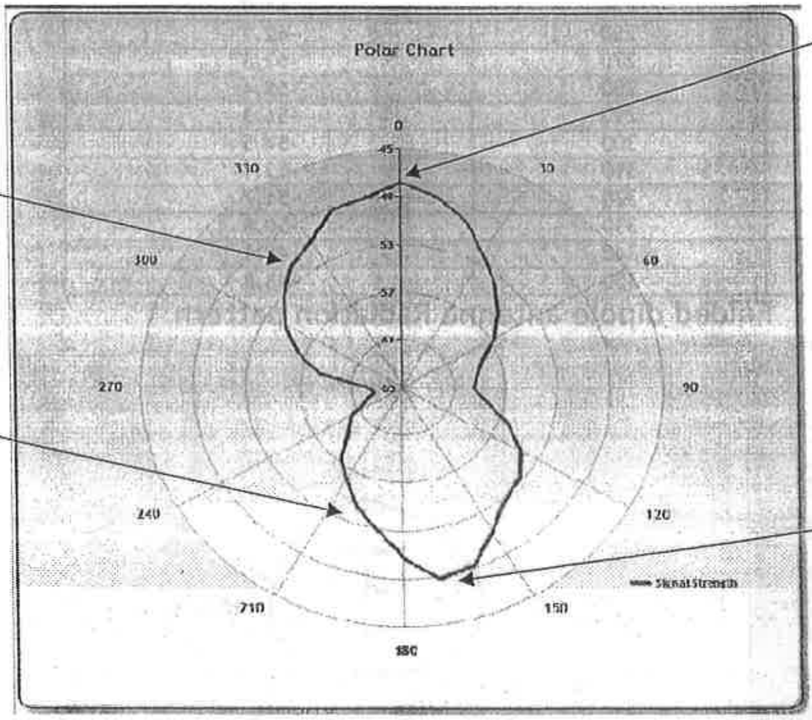


B) Measurement of Beamwidth:



Hence, Beamwidth = $\theta = 20^0$ (at right side) + 25^0 (at left side) = $\mathbf{45^0}$.

C) Measurement of Front-to-Back Ratio:



Hence, Front-to-back ratio = (Pmaj - Pmin) = (-47.8) - (-50.7) = **2.9 dBm.**

D) Measurement of Gain:

$P_{Ref(RF0)}$ = -70.5 dBm.

P_T = [+2] - [-70.5] dBm = 72.5 dBm.

P_{Ref} = -60.7 dBm.

P_{Meas} = -42.2 dBm.

P_R = [P_{Meas}] - [P_{Ref}] = [-42.2] - [-60.7] = 18.5 dBm.

And G = 248 (unit-less).

= 10 * Log (248 / 1) = **24 dBi.**

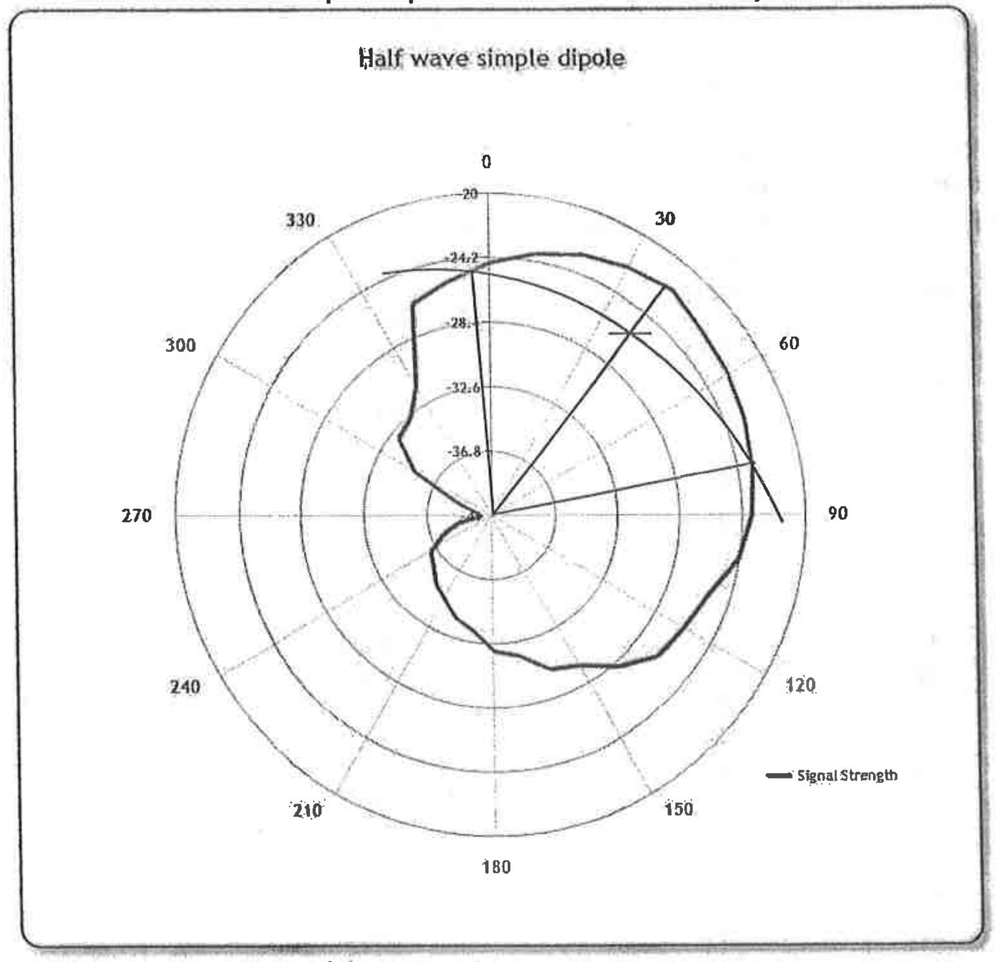
CH-4: Study of Half-wave Simple Dipole Antenna

A) Measurement of Radiation pattern:

Table 4.1 Rad. pattern observation table of Half-wave simple dipole antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	-24.5
2.	10	-23.7
3.	20	-22.9
4.	30	-22.3
5.	40	-21.9
6.	50	-22.4
7.	60	-22.6
8.	70	-22.9
9.	80	-23.2
10.	90	-23.6
11.	100	-24.3
12.	110	-25.7
13.	120	-26.3
14.	130	-26.7
15.	140	-28.1
16.	150	-29.7
17.	160	-30.3
18.	170	-31.7
19.	180	-32.1
20.	190	-33.3
21.	200	-33.9
22.	210	-34.7
23.	220	-35.2
24.	230	-35.9
25.	240	-36.3
26.	250	-37.7
27.	260	-38.8
28.	270	-40.3
29.	280	-40.0
30.	290	-38.7
31.	300	-35.2
32.	310	-33.1
33.	320	-32.8
34.	330	-31.2
35.	340	-26.3
36.	350	-25.5

Half-wave simple dipole antenna Radiation pattern



B) Measurement of Beamwidth:

Beamwidth = $\theta = 40^0$ (at right side) + 42^0 (at left side) = **82^0.**

C) Measurement of Front-to-Back Ratio:

Front-to-back ratio = **(-21.9)** - **(-35.2)** = **13.3 dBm.**

Where, -21.9 dBm is the maximum power level of main-lobe.
and, -35.2 dBm is the power level at 180^0 off from -21.9 level i.e. level @ 220^0.

D) Measurement of Gain:

$P_{Ref(folded)}$ = -41.3 dBm.
$P_{Meas(HWSD)}$ = -24.5 dBm.

Hence, G_{HWSD} = 24 + [(-24.5) - (-41.3)] = **40.8 dBi.**

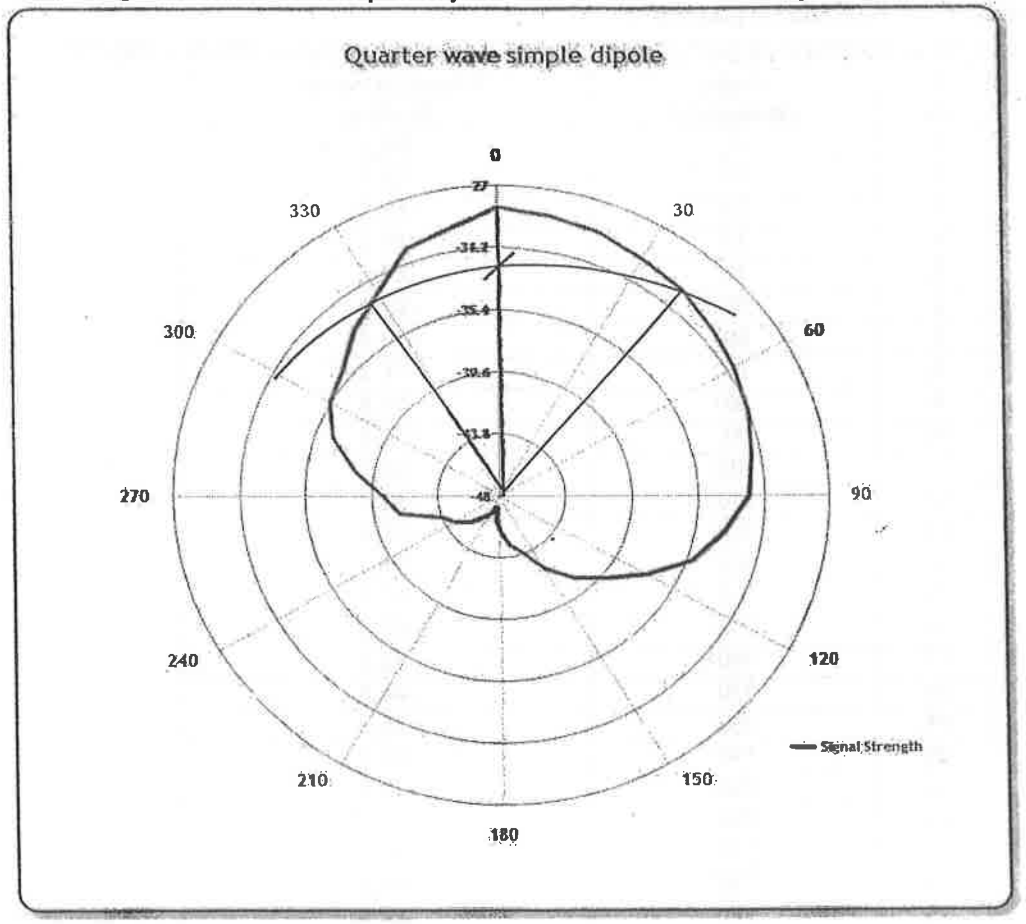
CH-5: Study of Quarter-wave Simple Dipole Antenna

A) Measurement of Radiation pattern:

Table 5.1 Rad. pattern observation table of Quarter-wave simple dipole

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	-28.4
2.	10	-28.7
3.	20	-29.0
4.	30	-29.5
5.	40	-29.8
6.	50	-30.3
7.	60	-30.7
8.	70	-31.2
9.	80	-31.8
10.	90	-32.2
11.	100	-33.7
12.	110	-35.1
13.	120	-37.3
14.	130	-39.4
15.	140	-40.7
16.	150	-42.3
17.	160	-43.9
18.	170	-44.6
19.	180	-45.5
20.	190	-46.2
21.	200	-47.3
22.	210	-46.7
23.	220	-46.1
24.	230	-45.3
25.	240	-44.5
26.	250	-43.8
27.	260	-41.2
28.	270	-40.3
29.	280	-38.4
30.	290	-36.5
31.	300	-35.3
32.	310	-34.7
33.	320	-33.3
34.	330	-32.1
35.	340	-30.2
36.	350	-29.6

Quarter-wave simple dipole antenna Radiation pattern



B) Measurement of Beamwidth:

Beamwidth = θ = 45^0 (at right side) + 36^0 (at left side) = **81^0.**

C) Measurement of Front-to-Back Ratio:

Front-to-back ratio = **(-28.4)** - **(-45.5)** = **17.1 dBm.**

D) Measurement of Gain:

$P_{Ref(folded)}$ = -41.3 dBm.

$P_{Meas(QWSD)}$ = -28.4 dBm.

Hence, G_{QWSD} = 24 + [(-28.4) - (-41.3)] = **36.9 dBi.**

CH-6: Study of $3\lambda/2$ Simple Dipole Antenna

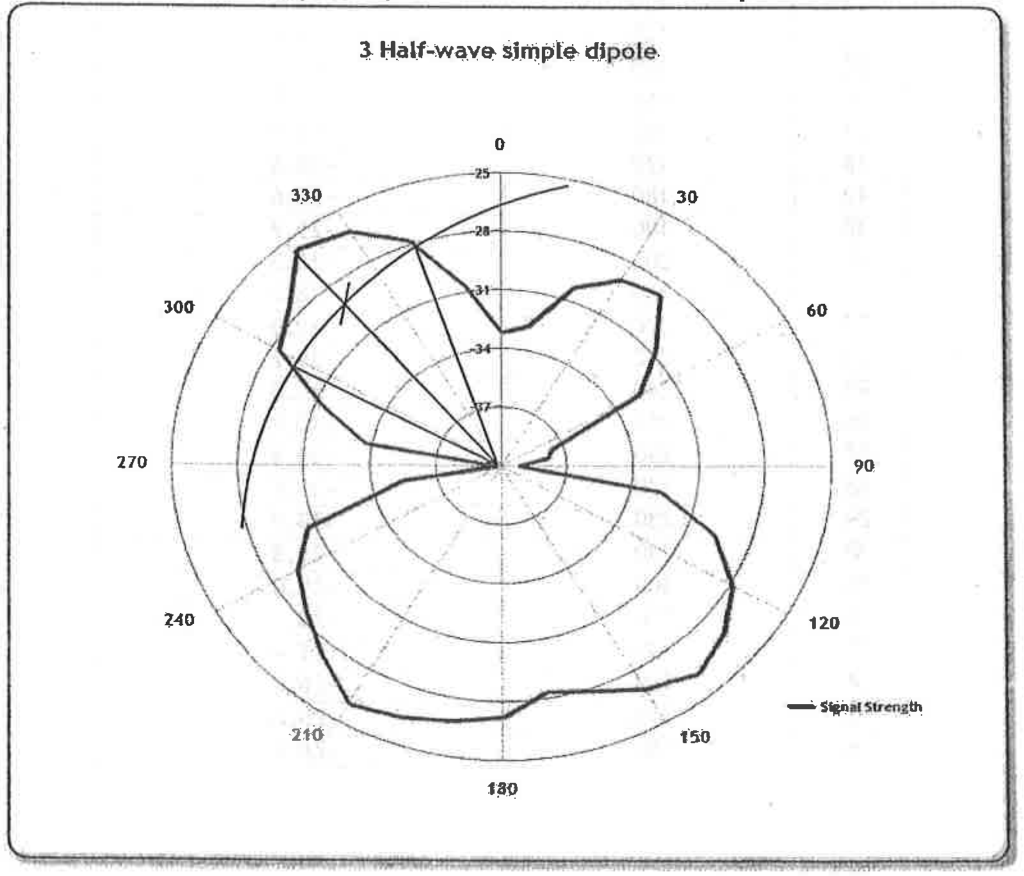
A) Measurement of Radiation pattern:

Table **6.1** Rad. pattern observation table of $3\lambda/2$ simple dipole antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	-33.2
2.	10	-32.7
3.	20	-30.3
4.	30	-29.0
5.	40	-28.6
6.	50	-30.8
7.	60	-32.7
8.	70	-37.6
9.	80	-37.8

10.	90	-39.2
11.	100	-32.6
12.	110	-29.7
13.	120	-27.9
14.	130	-26.8
15.	140	-26.2
16.	150	-26.9
17.	160	-27.8
18.	170	-28.3
19.	180	-27.2
20.	190	-26.8
21.	200	-26.4
22.	210	-26.0
23.	220	-27.3
24.	230	-28.4
25.	240	-29.3
26.	250	-30.6
27.	260	-35.4
28.	270	-39.8
29.	280	-33.7
30.	290	-31.4
31.	300	-28.3
32.	310	-27.4
33.	320	-25.6
34.	330	-26.2
35.	340	-27.8
36.	350	-30.7

3λ/2 Simple Dipole Antenna Radiation pattern



B) Measurement of Beamwidth:

Beamwidth = $\theta = 25^0$ (at right side) + 22^0 (at left side) = 47^0.

C) Measurement of Front-to-Back Ratio:

Front-to-back ratio = **(-25.6)** - (-26.2) = **0.6 dBm.**

D) Measurement of Gain:

$P_{Ref(folded)}$ = -41.3 dBm.

$P_{Meas(3HWSD)}$ = -33.2 dBm.

Hence, G_{3HWSD} = 24 + [(-33.2) - (-41.3)] = **32.1 dBi.**

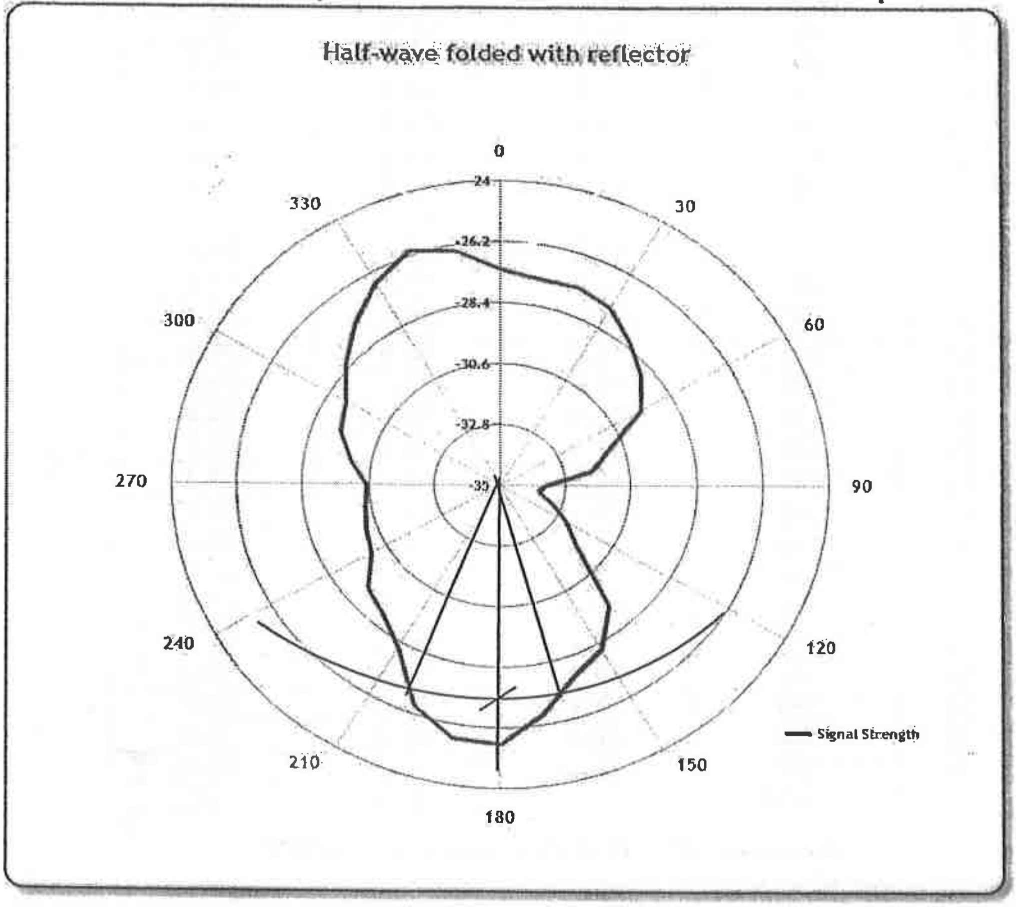
CH-7: Study of Half-wave folded-dipole with reflector Antenna

A) Measurement of Radiation pattern:

Table 7.1 Rad. pattern observation table of Half-wave dipole with reflector

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	-27.2
2.	10	-27.4
3.	20	-27.4
4.	30	-27.6
5.	40	-28.2
6.	50	-28.8
7.	60	-29.5
8.	70	-31.1
9.	80	-31.9
10.	90	-33.5
11.	100	-33.7
12.	110	-33.2
13.	120	-32.5
14.	130	-31.7
15.	140	-29.3
16.	150	-28.2
17.	160	-27.7
18.	170	-26.6
19.	180	-25.6
20.	190	-25.7
21.	200	-26.5
22.	210	-28.2
23.	220	-28.9
24.	230	-29.2
25.	240	-30.0
26.	250	-30.2
27.	260	-30.4
28.	270	-30.5
29.	280	-29.9
30.	290	-29.3
31.	300	-29.0
32.	310	-28.2
33.	320	-27.4
34.	330	-26.6
35.	340	-26.0
36.	350	-26.4

Half-wave folded Dipole with reflector Antenna Radiation pattern



B) Measurement of Beamwidth:

Beamwidth = $\theta = 25^0$ (at right side) + 15^0 (at left side) = $\mathbf{40^0}$.

C) Measurement of Front-to-Back Ratio:

Front-to-back ratio = **(-25.6) - (-27.2)** = **1.6 dBm.**

D) Measurement of Gain:

$P_{Ref(folded)}$ = -41.3 dBm.

$P_{Meas(HWFR)}$ = -27.2 dBm.

Hence, G_{HWFR} = 24 + [(-27.2) - (-41.3)] = **38.1 dBi.**

CH-8: Study of Yagi-Uda Antenna

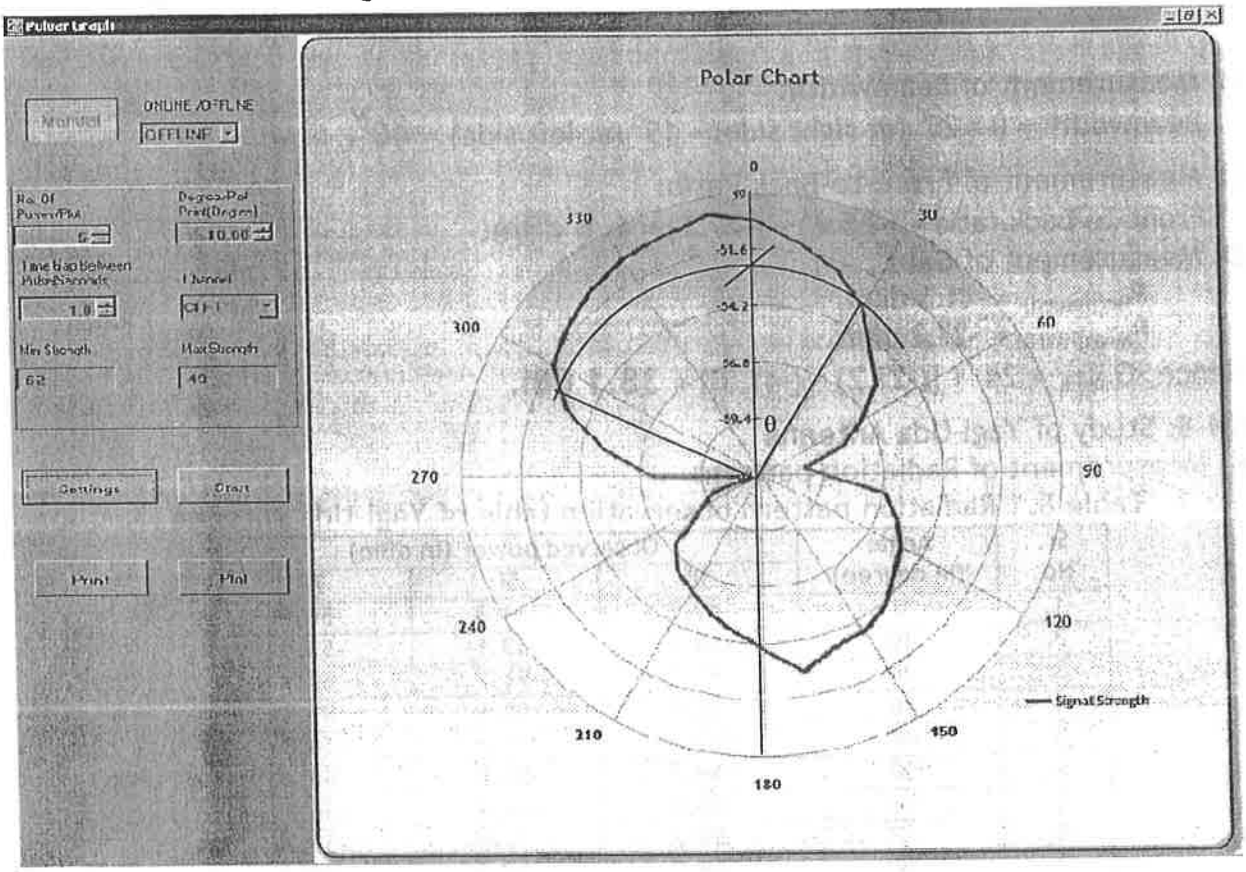
A) Measurement of Radiation pattern:

Table 8.1 Radiation pattern observation table of Yagi-Uda antenna

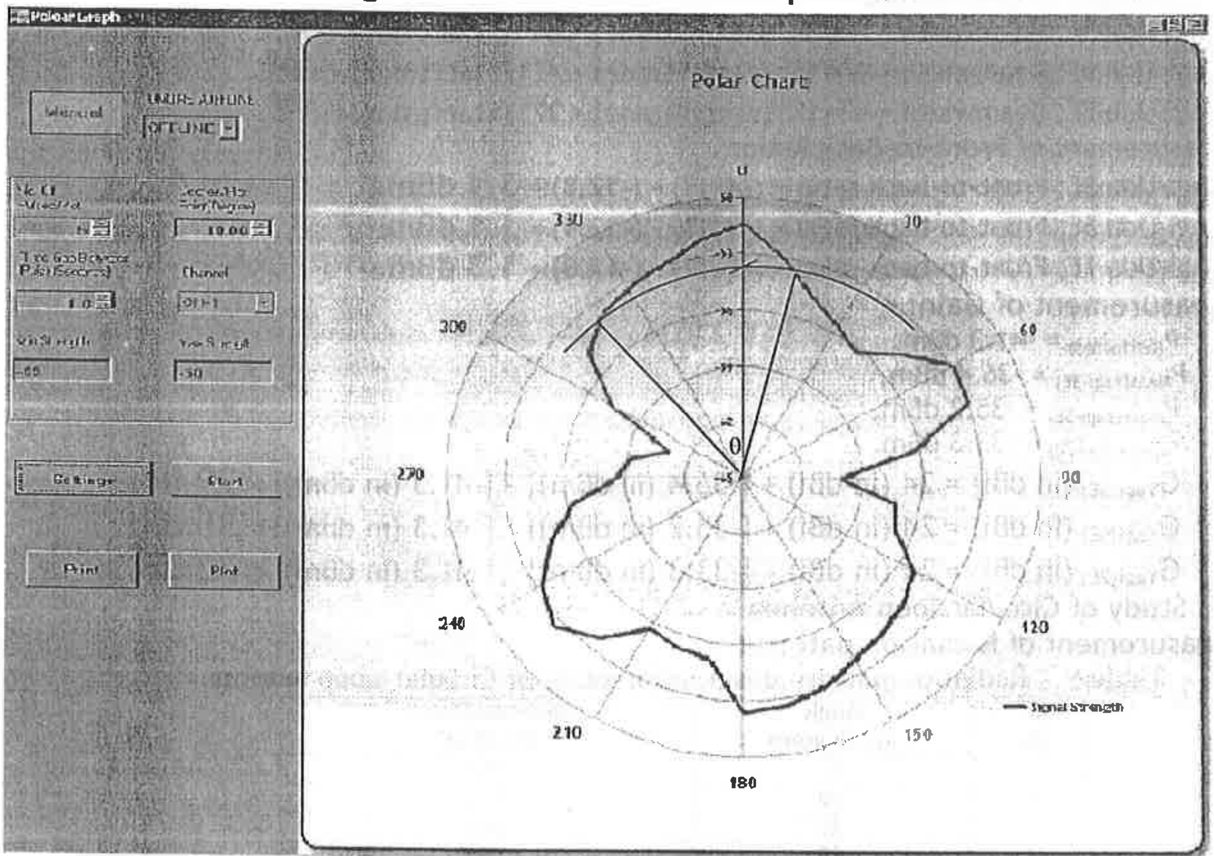
Sr. No.	Angle (in degree)	Observed power (in dBm)		
		3E	5E	7E
1.	0	-49.7	-51.3	-50.7
2.	10	-50.2	-53.1	-53.4
3.	20	-51.2	-54.7	-54.7
4.	30	-52.0	-55.6	-55.8
5.	40	-53.2	-56.2	-54.3
6.	50	-54.7	-54.7	-55.4
7.	60	-55.6	-52.8	-56.8
8.	70	-57.2	-53.0	-57.2
9.	80	-58.3	-56.3	-58.1
10.	90	-60.2	-60.1	-59.2

11.	100	-59.3	-57.3	-56.3
12.	110	-56.7	-56.9	-55.7
13.	120	-55.9	-55.1	-55.3
14.	130	-55.2	-54.6	-54.7
15.	140	-54.8	-54.2	-53.8
16.	150	-54.1	-53.8	-53.4
17.	160	-53.7	-53.1	-52.9
18.	170	-53.5	-52.6	-52.3
19.	180	-52.8	-52.4	-52.0
20.	190	-53.9	-55.1	-53.0
21.	200	-54.7	-55.2	-55.3
22.	210	-55.2	-55.6	-56.6
23.	220	-55.8	-53.7	-56.0
24.	230	-56.3	-52.6	-55.6
25.	240	-57.1	-53.3	-56.7
26.	250	-58.8	-54.7	-57.3
27.	260	-59.7	-56.2	-59.7
28.	270	-61.6	-58.6	-60.3
29.	280	-57.3	-59.1	-62.8
30.	290	-55.2	-60.9	-62.3
31.	300	-53.1	-57.3	-59.7
32.	310	-51.7	-54.8	-56.3
33.	320	-51.2	-53.7	-54.7
34.	330	-50.8	-53.3	-53.9
35.	340	-50.4	-52.9	-52.3
36.	350	-50.2	-52.1	-51.5

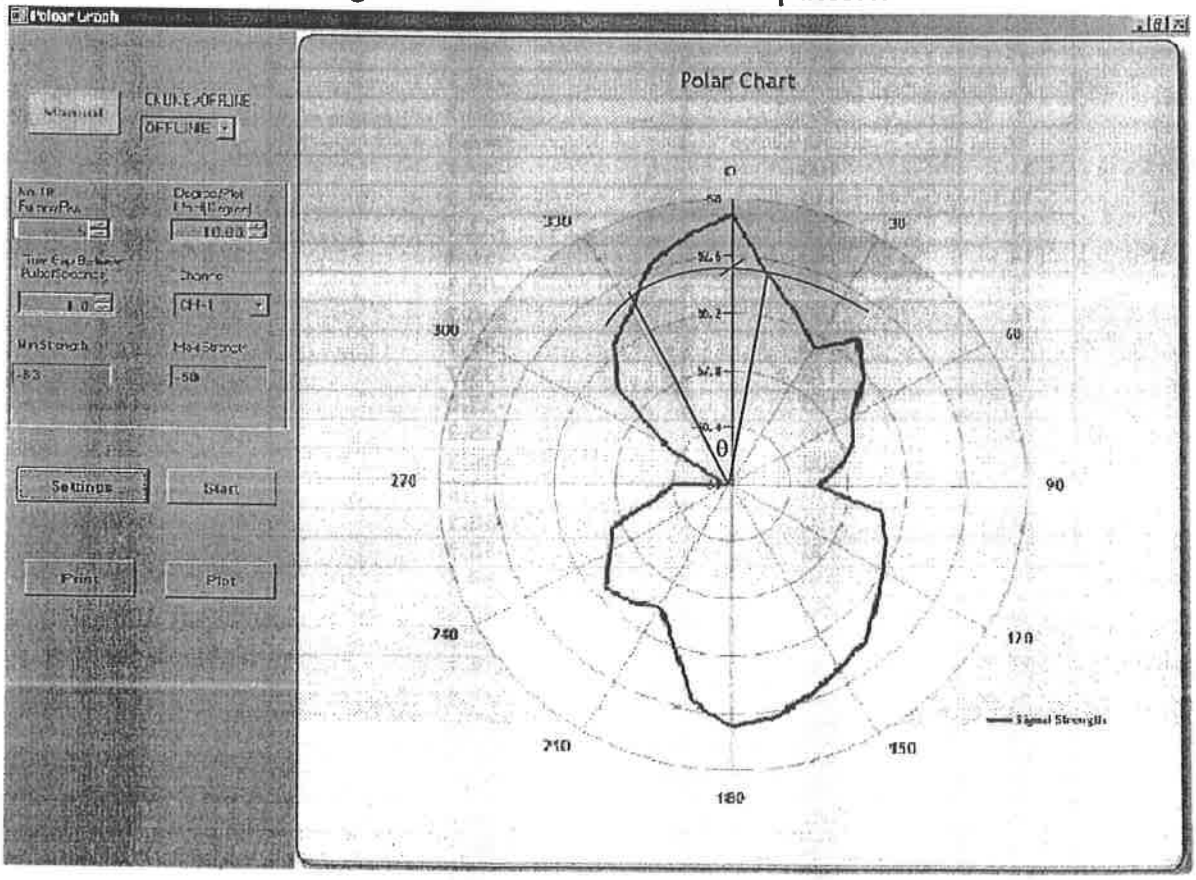
Yagi-Uda 3E antenna Radiation pattern



Yagi-Uda 5E antenna Radiation pattern



Yagi-Uda 7E antenna Radiation pattern



B) Measurement of Beamwidth:

For Yagi-Uda 3E; Beamwidth = θ = 30^0 (at right side) + 64^0 (at left side) = **94^0.**

For Yagi-Uda 5E; Beamwidth = θ = 18^0 (at right side) + 42^0 (at left side) = **60^0.**

For Yagi-Uda 7E; Beamwidth = θ = 12^0 (at right side) + 27^0 (at left side) = **39^0.**

C) Measurement of Front-to-Back Ratio:

For Yagi-Uda 3E; Front-to-back ratio = (-49.7) - (-52.8) = **3.1 dBm.**

For Yagi-Uda 5E; Front-to-back ratio = (-51.3) - (-52.4) = **1.1 dBm.**

For Yagi-Uda 7E; Front-to-back ratio = (-50.7) - (-52.0) = **1.3 dBm.**

D) Measurement of Gain:

$P_{Ref(folded)}$ = -41.3 dBm.

$P_{Meas(Yagi\text{-}3E)}$ = -36.4 dBm,

$P_{Meas(Yagi\text{-}5E)}$ = -35.2 dBm,

$P_{Meas(Yagi\text{-}7E)}$ = -33.3 dBm.

$G_{Yagi(3E)}$ (in dBi) = 24 (in dBi) + [-36.4 (in dBm)] - [-41.3 (in dBm)] = **29 dBi.**

$G_{Yagi(5E)}$ (in dBi) = 24 (in dBi) + [-35.2 (in dBm)] - [-41.3 (in dBm)] = **30 dBi.**

$G_{Yagi(7E)}$ (in dBi) = 24 (in dBi) + [-33.3 (in dBm)] - [-41.3 (in dBm)] = **32 dBi.**

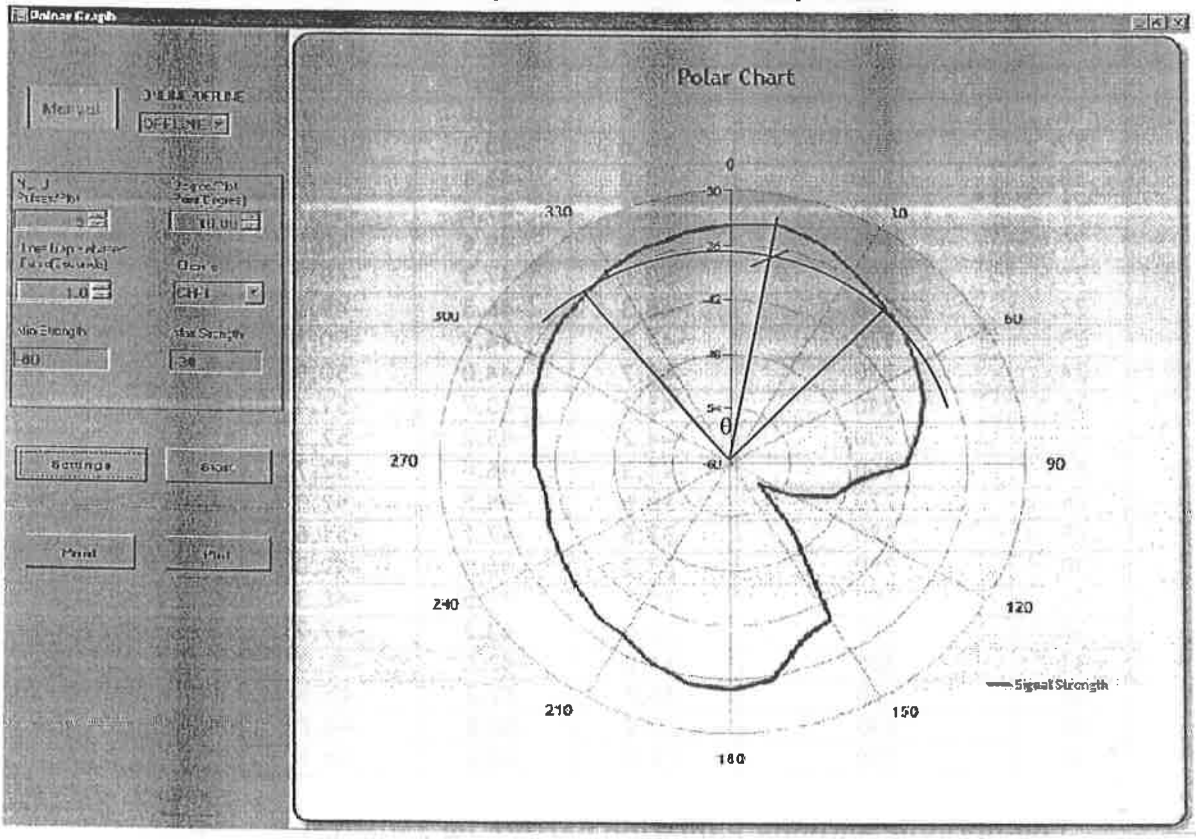
CH-9: Study of Circular-loop Antenna

A) Measurement of Radiation pattern:

Table 9.1 Radiation pattern observation table of Circular-Loop antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	-33.7
2.	10	-33.3
3.	20	-34.1
4.	30	-35.5
5.	40	-36.7
6.	50	-37.3
7.	60	-38.4
8.	70	-39.3
9.	80	-40.9
10.	90	-42.3
11.	100	-47.7
12.	110	-49.3
13.	120	-52.9
14.	130	-56.4
15.	140	-50.3
16.	150	-40.2
17.	160	-39.2
18.	170	-35.7
19.	180	-35.0
20.	190	-35.2
21.	200	-36.3
22.	210	-37.8
23.	220	-38.1
24.	230	-38.9
25.	240	-39.6
26.	250	-40.0
27.	260	-40.5
28.	270	-39.7
29.	280	-39.4
30.	290	-38.3
31.	300	-37.5
32.	310	-36.7
33.	320	-36.1
34.	330	-35.3
35.	340	-34.5
36.	350	-34.1

Circular loop antenna Radiation pattern



B) Measurement of Beamwidth:

Beamwidth = $\theta = 45^0$ (at right side) + 40^0 (at left side) = **85^0**.

C) Measurement of Front-to-Back Ratio:

Front-to-back ratio = (-33.3) - (-35.2) = **1.9 dBm.**

D) Measurement of Gain:

$P_{Ref(folded)}$ = -41.3 dBm.

$P_{Meas(Loop)}$ = -34.2 dBm.

G_{Loop} (in dBi) = 24 (in dBi) + [-34.2 (in dBm)] - [-41.3 (in dBm)]

= **31.1 dBi.**

CH-10: Study of Log-periodic Antenna

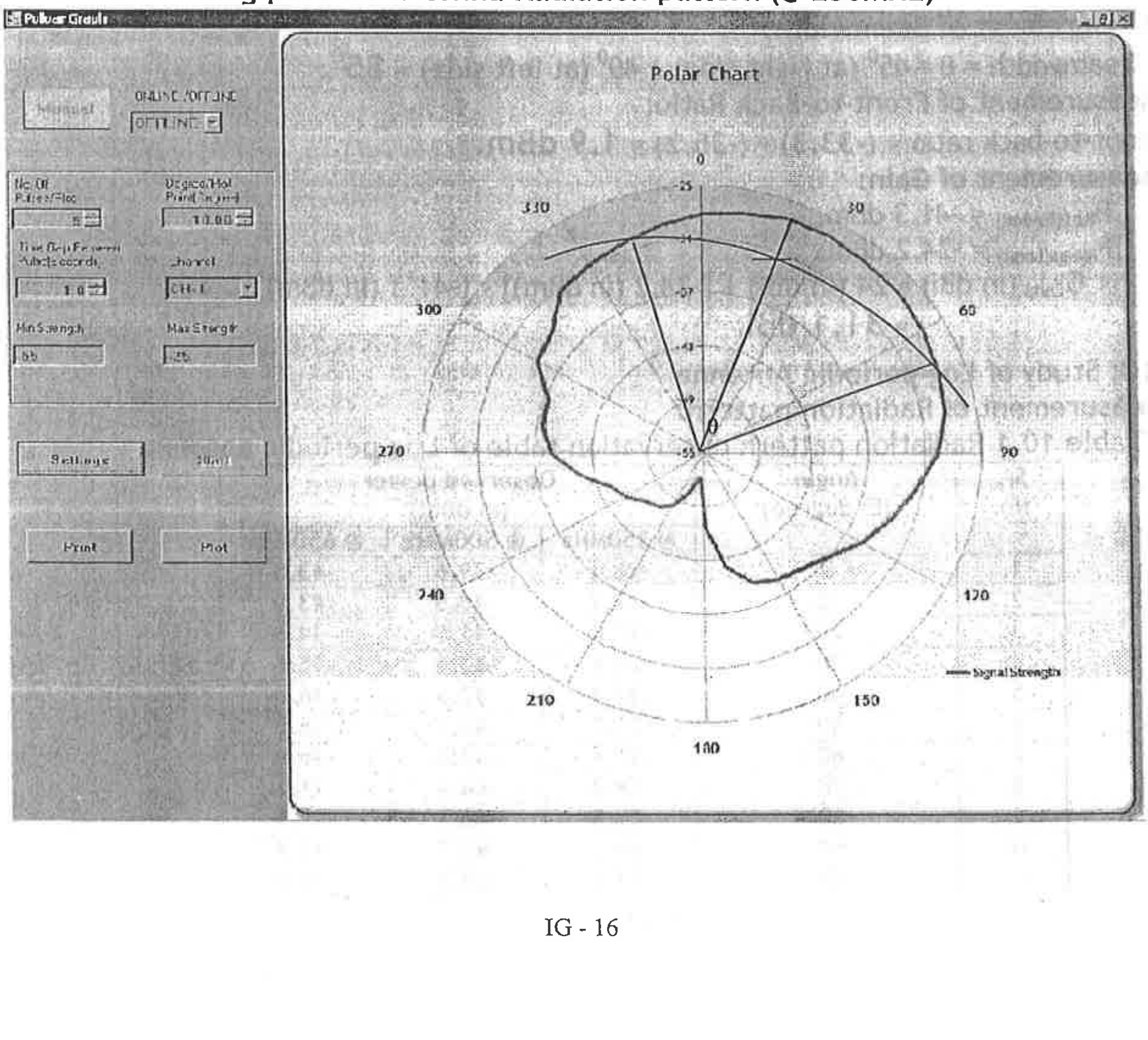
A) Measurement of Radiation pattern:

Table 10.1 Radiation pattern observation table of Log-periodic antenna

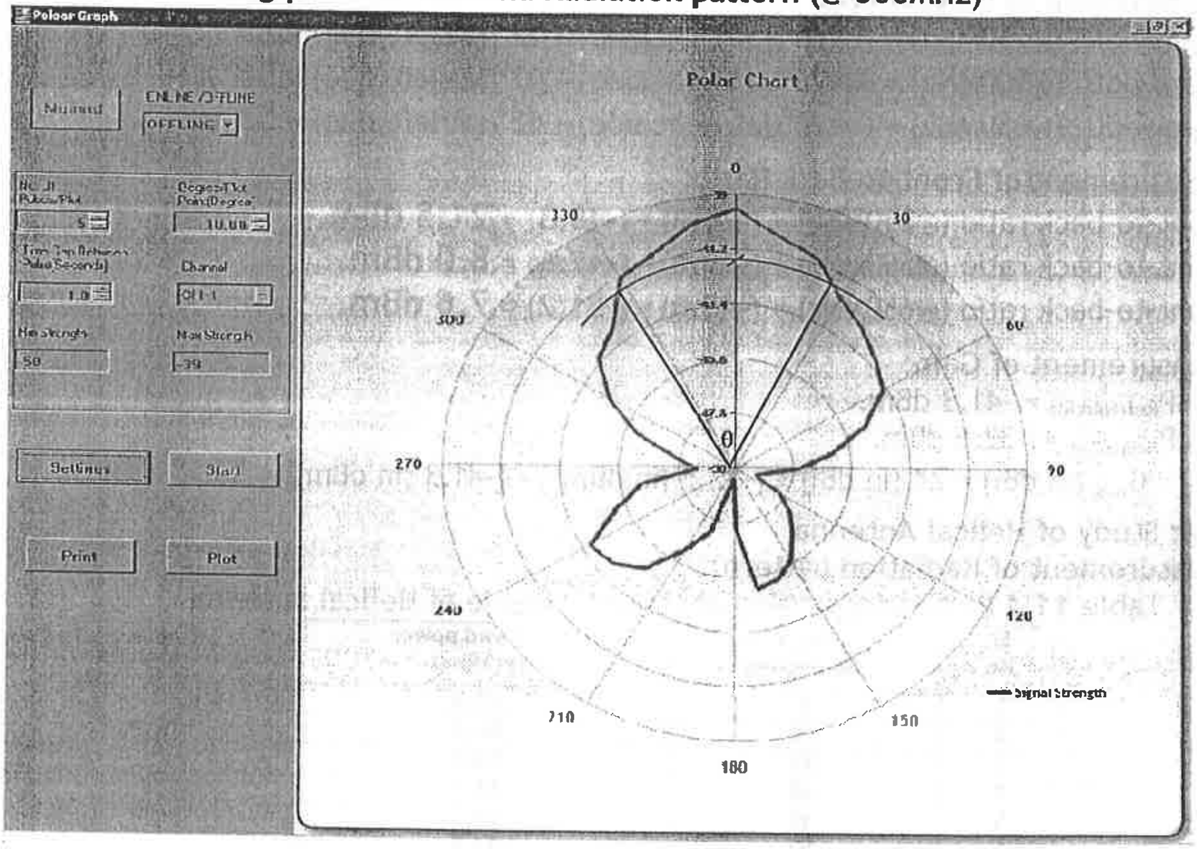
Sr. No.	Angle (in degree)	Observed power (in dBm)		
		@ 250MHz	@ 500MHz	@ 650MHz
1.	0	**-28.1**	**-39.6**	**-43.6**
2.	10	**-27.7**	**-40.5**	**-43.9**
3.	20	**-27.0**	**-41.0**	**-44.5**
4.	30	**-26.8**	**-42.1**	**-45.6**
5.	40	**-27.1**	**-42.6**	**-46.0**
6.	50	**-27.2**	**-43.1**	**-46.5**
7.	60	**-27.5**	**-43.6**	**-46.9**
8.	70	**-28.0**	**-44.8**	**-47.0**
9.	80	**-28.5**	**-46.3**	**-47.5**
10.	90	**-29.7**	**-47.7**	**-47.7**
11.	100	-31.8	-48.9	-48.0

12.	110	-33.5	-49.2	-48.5
13.	120	-35.1	-48.1	-49.0
14.	130	-37.1	-47.3	-49.6
15.	140	-38.3	-46.7	-50.2
16.	150	-38.9	-45.8	-50.4
17.	160	-39.6	-45.3	-51.0
18.	170	-42.1	-45.1	-51.5
19.	180	-46.8	-47.6	-51.2
20.	190	-52.3	-49.6	-50.5
21.	200	-50.6	-47.3	-49.7
22.	210	-48.3	-46.3	-49.3
23.	220	-47.2	-44.7	-50.3
24.	230	-46.7	-44.0	-50.9
25.	240	-45.2	-43.7	-51.4
26.	250	-44.2	-45.2	-52.3
27.	260	-41.3	-46.4	-52.7
28.	270	-38.6	-48.5	-52.0
29.	280	-37.5	-47.7	-51.6
30.	290	-37.2	-46.0	-49.0
31.	300	-34.5	-44.5	-48.3
32.	310	-33.8	-43.2	-47.7
33.	320	-31.2	-42.7	-46.3
34.	330	-30.7	-41.2	-45.9
35.	340	-29.9	-40.8	-44.7
36.	350	-29.0	-40.0	-44.1

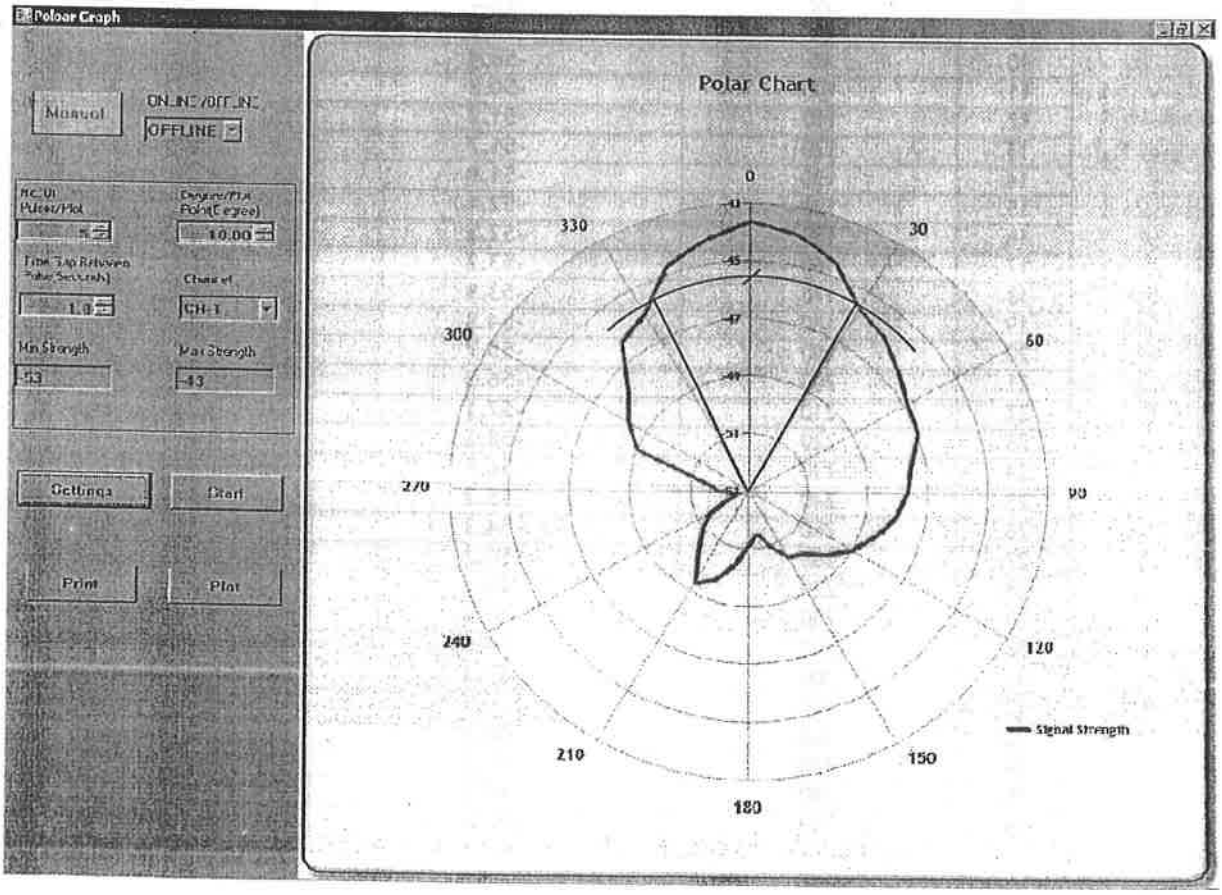
Log-periodic antenna Radiation pattern (@ 250MHz)



Log-periodic antenna Radiation pattern (@ 500MHz)



Log-periodic antenna Radiation pattern (@ 650MHz)



B) Measurement of Beamwidth:

Beamwidth (@250MHz) = $\theta = 65^0$ (at right side) + 18^0 (at left side) = **83^0.**

Beamwidth (@500MHz) = $\theta = 26^0$ (at right side) + 32^0 (at left side) = **58^0.**

Beamwidth (@650MHz) = $\theta = 28^0$ (at right side) + 25^0 (at left side) = **53^0.**

C) Measurement of Front-to-Back Ratio:

Front-to-back ratio (@250MHz) = (-26.8) - (-48.3) = **21.5 dBm.**

Front-to-back ratio (@500MHz) = (-39.6) - (-47.6) = **8.0 dBm.**

Front-to-back ratio (@650MHz) = (-43.6) - (-51.2) = **7.6 dBm.**

D) Measurement of Gain:

$P_{Ref(folded)}$ = -41.3 dBm.

$P_{Meas(Log)}$ = -32.5 dBm.

G_{Log} (in dBi) = 24 (in dBi) + [-32.5 (in dBm)] - [-41.3 (in dBm)] = **32.8 dBi.**

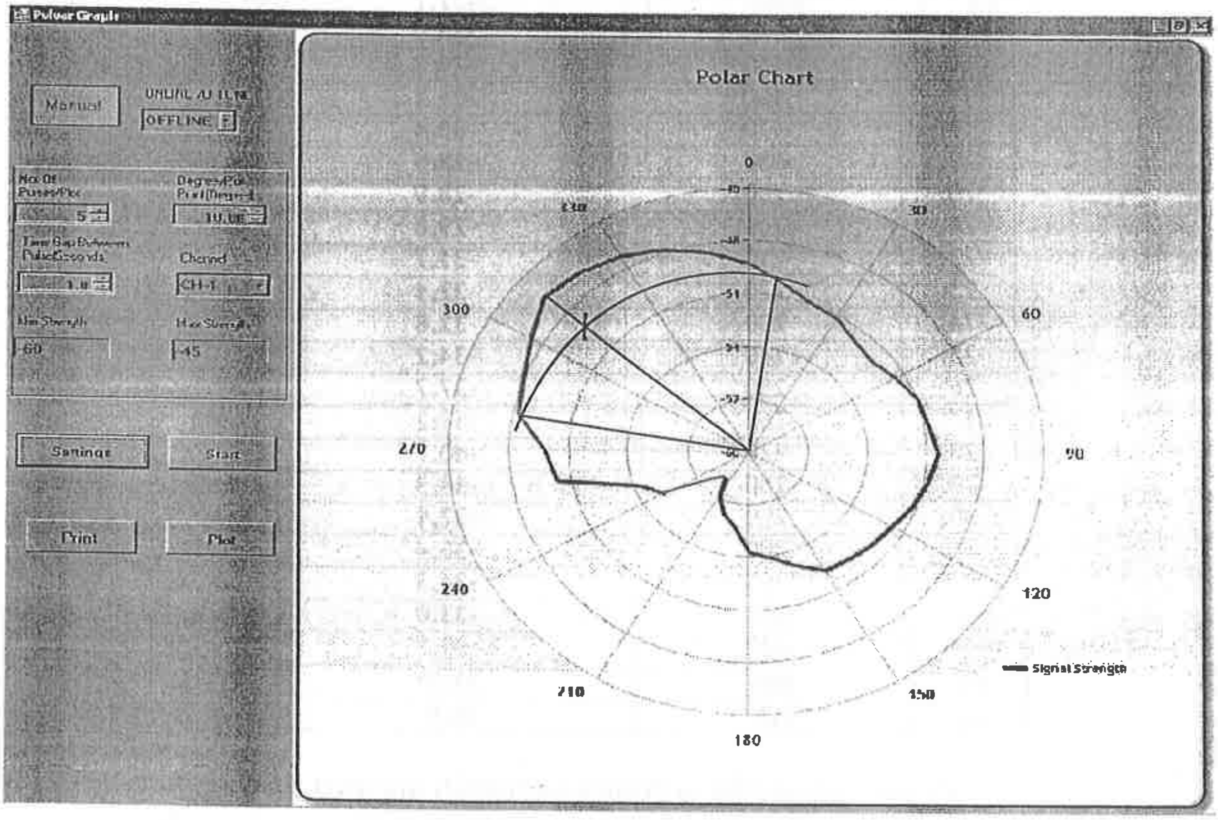
CH-11: Study of Helical Antenna

A) Measurement of Radiation pattern:

Table 11.1 Radiation pattern observation table of Helical antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	-49.3
2.	10	-50.2
3.	20	-50.9
4.	30	-51.2
5.	40	-51.7
6.	50	-51.9
7.	60	-51.5
8.	70	-51.0
9.	80	-50.8
10.	90	-50.4
11.	100	-50.8
12.	110	-51.2
13.	120	-51.7
14.	130	-51.9
15.	140	-52.1
16.	150	-52.3
17.	160	-53.2
18.	170	-53.9
19.	180	-54.3
20.	190	-55.7
21.	200	-56.3
22.	210	-57.1
23.	220	-58.2
24.	230	-56.7
25.	240	-55.2
26.	250	-54.3
27.	260	-50.2
28.	270	-49.7
29.	280	-48.2
30.	290	-47.9
31.	300	-47.3
32.	310	-46.5
33.	320	-46.8
34.	330	-47.2
35.	340	-47.8
36.	350	-48.5

Helical antenna Radiation pattern



B) Measurement of Beamwidth:

Beamwidth = θ = 10^0 (at right side) + 80^0 (at left side) = **90^0.**

C) Measurement of Front-to-Back Ratio:

Front-to-back ratio = **(-26.8)** - **(-48.3)** = **21.5 dBm.**

D) Measurement of Gain:

$P_{Ref(folded)}$ = -41.3 dBm.

$P_{Meas(Helical)}$ = -41.6 dBm.

$G_{Helical}$ (in dBi) = 24 (in dBi) + [-41.6 (in dBm)] - [-41.3 (in dBm)] = **23.7 dBi.**

CH-12: Study of Half-wave End-fire Antenna

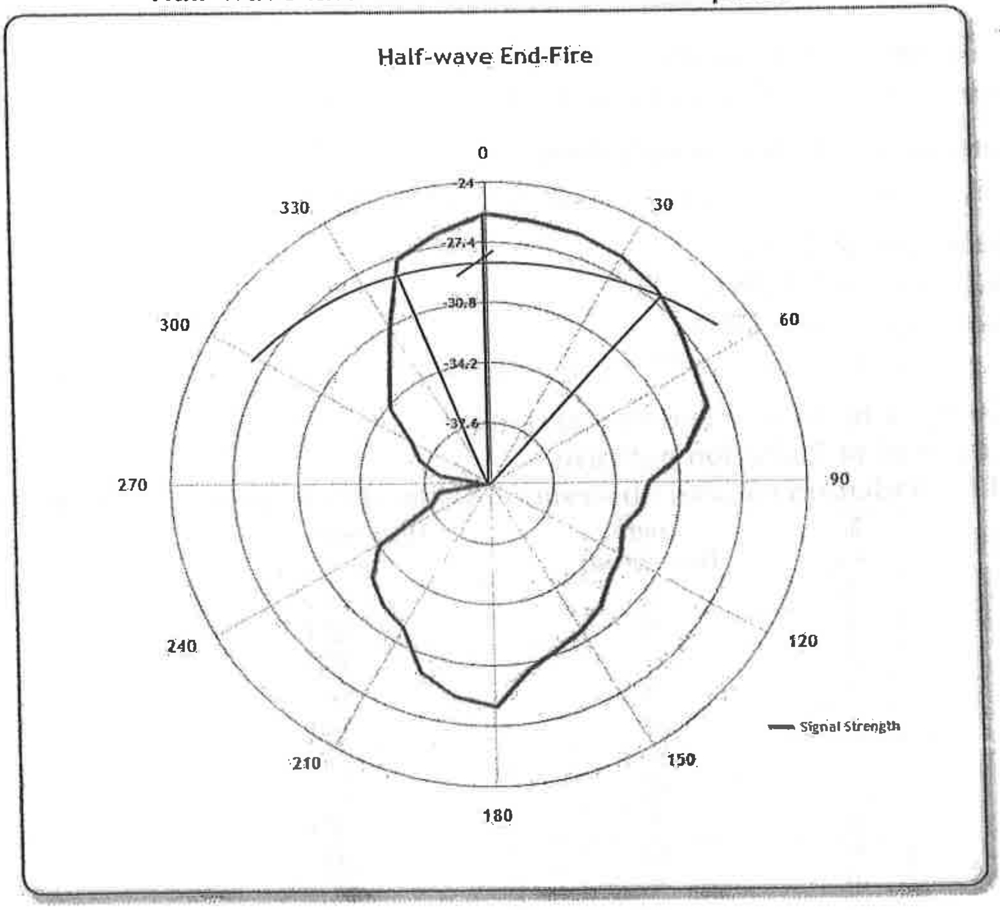
A) Measurement of Radiation pattern:

Table 12.1 Radiation pattern observation table of Half-wave End-fire antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	**-25.8**
2.	10	**-26.0**
3.	20	**-26.1**
4.	30	**-26.3**
5.	40	**-26.8**
6.	50	**-27.5**
7.	60	**-28.1**
8.	70	**-28.4**
9.	80	**-30.2**
10.	90	**-32.5**
11.	100	**-32.8**
12.	110	**-33.5**

13.	120	**-33.0**
14.	130	**-32.7**
15.	140	**-32.0**
16.	150	**-31.5**
17.	160	**-31.1**
18.	170	**-30.4**
19.	180	**-28.5**
20.	190	**-28.9**
21.	200	**-29.8**
22.	210	**-31.7**
23.	220	**-32.1**
24.	230	**-32.8**
25.	240	**-34.2**
26.	250	**-37.7**
27.	260	**-38.2**
28.	270	**-40.7**
29.	280	**-38.3**
30.	290	**-37.1**
31.	300	**-36.4**
32.	310	**-34.3**
33.	320	**-33.0**
34.	330	**-30.8**
35.	340	**-27.5**
36.	350	**-26.6**

Half-wave End-fire antenna Radiation pattern



B) Measurement of Beamwidth:

Beamwidth = $\theta = 43^0$ (at right side) + 20^0 (at left side) = **63^0.**

C) Measurement of Front-to-Back Ratio:

Front-to-back ratio = **(-25.8) - (-28.5)** = **2.7 dBm.**

D) Measurement of Gain:

$P_{Ref(folded)}$ = -41.3 dBm.

$P_{Meas(HWEF)}$ = -25.8 dBm.

Hence, G_{HWEF} = 24 + [(-25.8) - (-41.3)] = **39.5 dBi.**

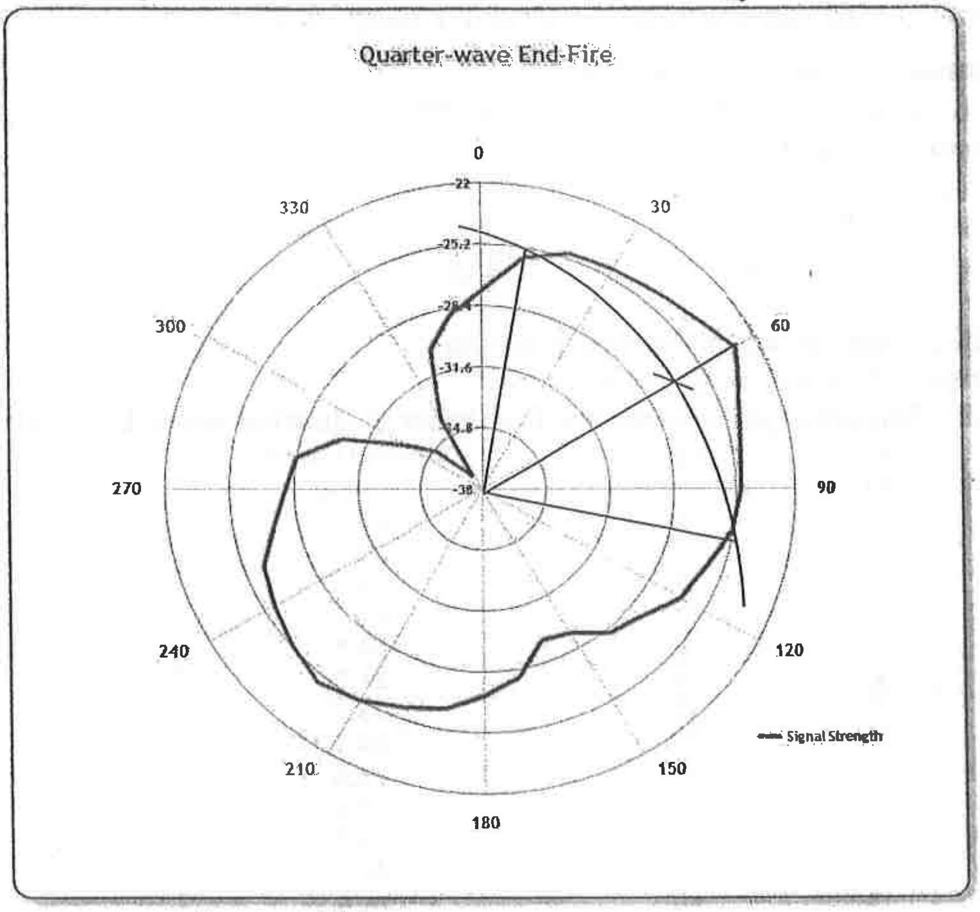
CH-13: Study of Quarter-wave End-fire Antenna

A) Measurement of Radiation pattern:

Table 13.1 Radiation pattern observation table of Quarter-wave End-fire

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	-27.6
2.	10	-25.7
3.	20	-24.9
4.	30	-24.7
5.	40	-24.5
6.	50	-24.0
7.	60	-23.2
8.	70	-24.2
9.	80	-24.8
10.	90	-25.0
11.	100	-25.3
12.	110	-26.1
13.	120	26.6
14.	130	-27.7
15.	140	-28.2
16.	150	-29.3
17.	160	-29.6
18.	170	-28.0
19.	180	-27.2
20.	190	-26.3
21.	200	-25.8
22.	210	-25.2
23.	220	-24.8
24.	230	-25.2
25.	240	-25.7
26.	250	-26.1
27.	260	-27.2
28.	270	-27.9
29.	280	-28.3
30.	290	-30.3
31.	300	-33.3
32.	310	-34.9
33.	320	-37.1
34.	330	-33.8
35.	340	-30.2
36.	350	-28.7

Quarter-wave End-fire antenna Radiation pattern



B) Measurement of Beamwidth:

Beamwidth = $\theta = 45^0$ (at right side) + 50^0 (at left side) = **95^0**.

C) Measurement of Front-to-Back Ratio:

Front-to-back ratio = **(-23.2) - (-25.7)** = **2.5 dBm.**

D) Measurement of Gain:

$P_{Ref(folded)}$ = -41.3 dBm.

$P_{Meas(QWEF)}$ = -27.6 dBm.

Hence, G_{QWEF} = 24 + [(-27.6) - (-41.3)] = **37.7 dBi.**

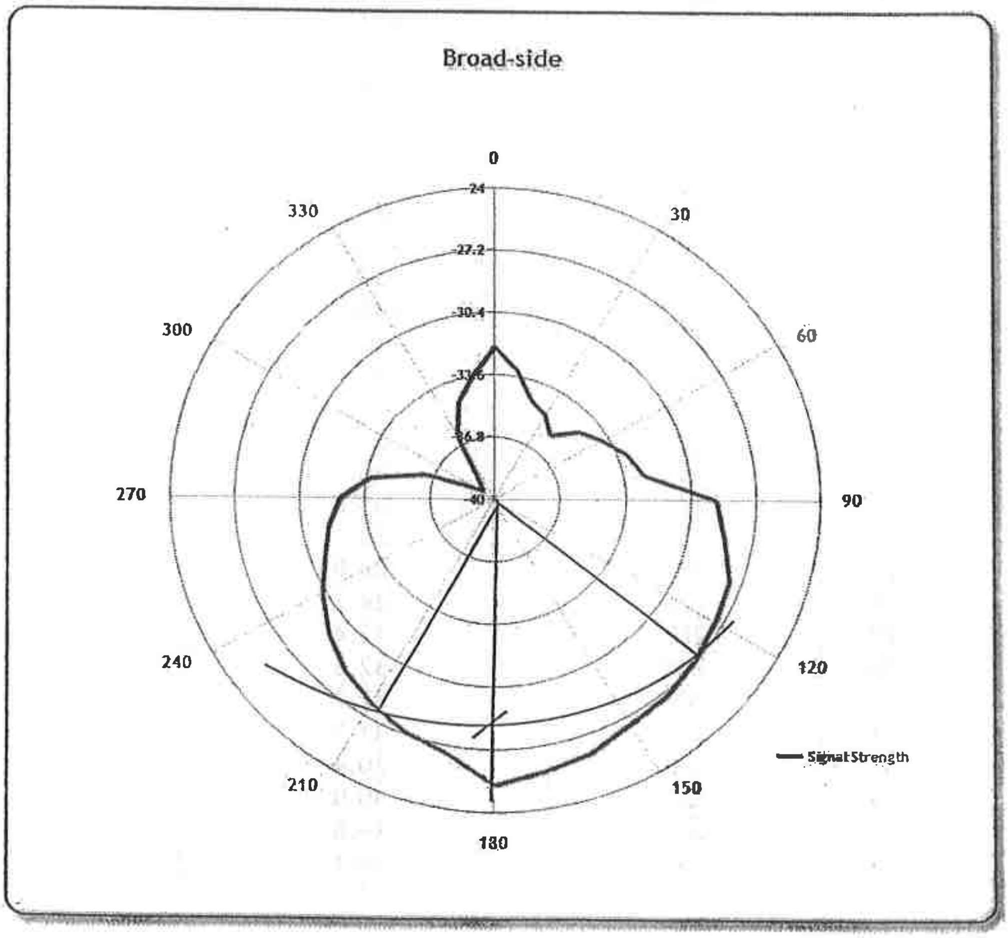
CH-14: Study of Broad-side array Antenna

A) Measurement of Radiation pattern:

Table 14.1 Radiation pattern observation table of Broad-side array antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	**-32.2**
2.	10	**-33.3**
3.	20	**-34.6**
4.	30	**-35.0**
5.	40	**-35.7**
6.	50	**-34.6**
7.	60	**-33.9**
8.	70	**-33.2**
9.	80	**-32.7**
10.	90	**-29.2**
11.	100	**-28.6**

12.	110	-27.8
13.	120	-37.6
14.	130	-37.3
15.	140	-27.0
16.	150	-26.8
17.	160	-26.2
18.	170	-25.9
19.	180	-25.4
20.	190	-26.8
21.	200	-27.3
22.	210	-27.9
23.	220	-28.5
24.	230	-29.3
25.	240	-30.2
26.	250	-31.1
27.	260	-31.7
28.	270	-32.4
29.	280	-33.7
30.	290	-36.3
31.	300	-38.7
32.	310	-39.3
33.	320	-38.7
34.	330	-36.3
35.	340	-34.7
36.	350	-33.6



B) **Measurement of Beamwidth:**

Beamwidth = $\theta = 28^0$ (at right side) + 50^0 (at left side) = **78^0.**

C) **Measurement of Front-to-Back Ratio:**

Front-to-back ratio = **(-25.4) - (-33.6)** = **8.2 dBm.**

D) **Measurement of Gain:**

$P_{Ref(folded)}$ = -41.3 dBm.

$P_{Meas(BSA)}$ = -32.2 dBm.

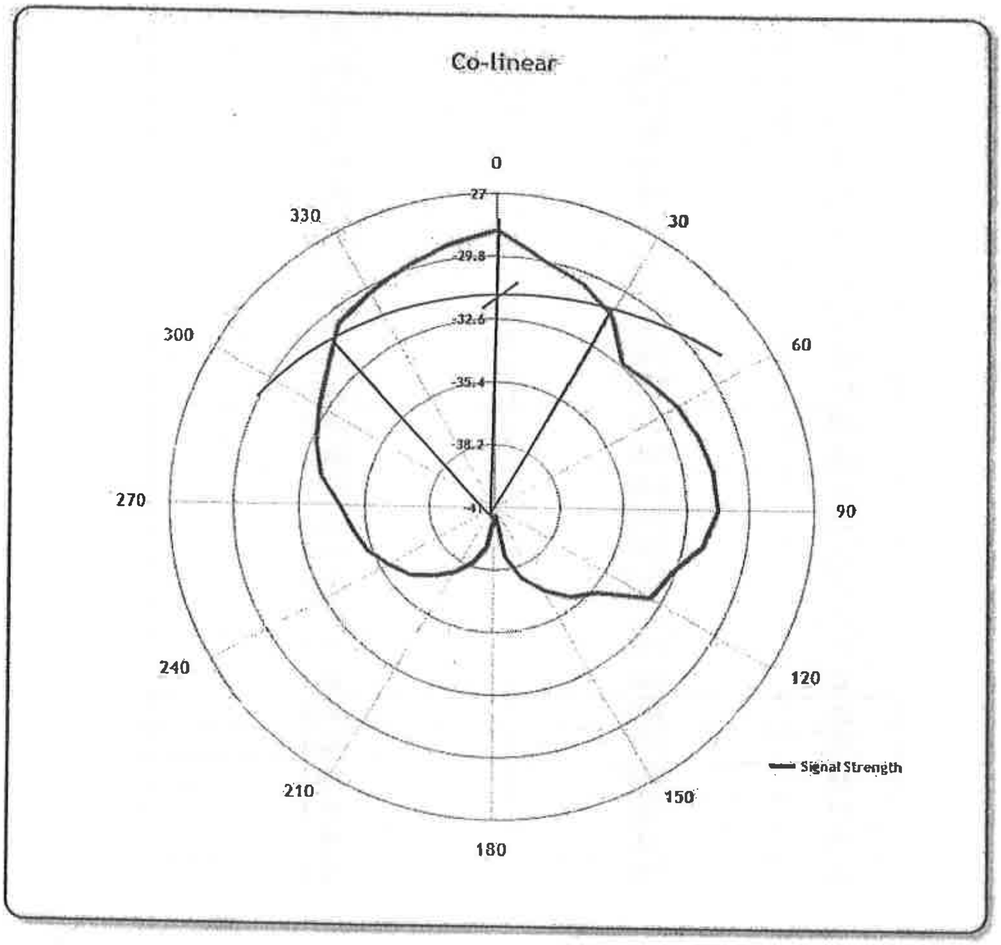
Hence, G_{BSA} = 24 + [(-32.2) - (-41.3)] = **33.1 dBi.**

CH-15: Study of Co-linear Antenna

A) Measurement of Radiation pattern:

Table 15.1 Radiation pattern observation table of Co-linear array antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	-28.6
2.	10	-29.7
3.	20	-30.3
4.	30	-31.0
5.	40	-32.5
6.	50	-32.2
7.	60	-31.8
8.	70	-31.5
9.	80	-31.3
10.	90	-31.2
11.	100	-31.7
12.	110	-32.8
13.	120	-33.1
14.	130	-35.2
15.	140	-35.9
16.	150	-36.8
17.	160	-37.7
18.	170	-38.8
19.	180	-40.7
20.	190	-39.2
21.	200	-38.4
22.	210	-37.7
23.	220	-37.0
24.	230	-36.3
25.	240	-35.8
26.	250	-35.2
27.	260	-34.8
28.	270	-34.3
29.	280	-33.4
30.	290	-32.8
31.	300	-32.2
32.	310	-31.5
33.	320	-30.4
34.	330	-30.0
35.	340	-29.6
36.	350	-29.1



B) Measurement of Beamwidth:

Beamwidth = $\theta = 30^0$ (at right side) + 45^0 (at left side) = **85^0**.

C) Measurement of Front-to-Back Ratio:

Front-to-back ratio = **(-28.6) - (-40.7)** = **12.1 dBm.**

D) Measurement of Gain:

$P_{Ref(folded)}$ = -41.3 dBm.

$P_{Meas(COL)}$ = -28.6 dBm.

Hence, G_{COL} = 24 + [(-28.6) - (-41.3)] = **36.7 dBi.**

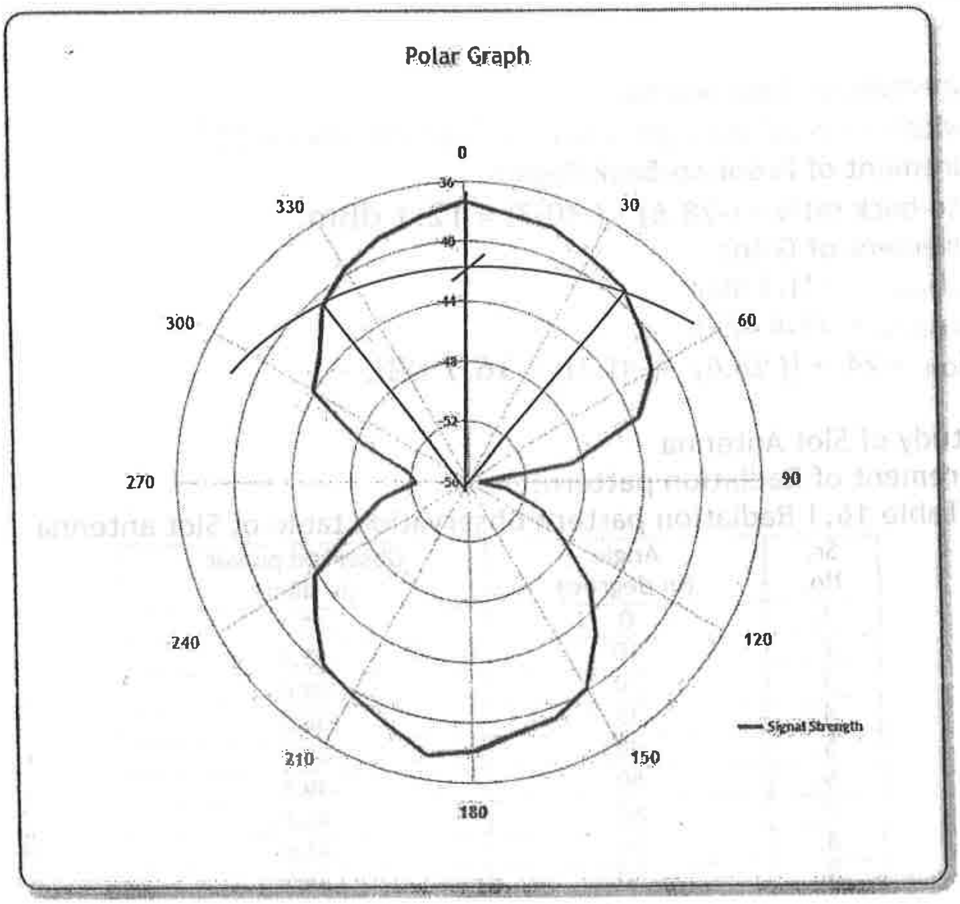
CH-16: Study of Slot Antenna

A) Measurement of Radiation pattern:

Table 16.1 Radiation pattern observation table of Slot antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	-37.3
2.	10	-37.9
3.	20	-38.0
4.	30	-38.8
5.	40	-39.2
6.	50	-40.3
7.	60	-41.4
8.	70	-43.5
9.	80	-48.7

10.	90	-55.2
11.	100	-53.4
12.	110	-50.7
13.	120	-48.6
14.	130	-45.3
15.	140	-42.7
16.	150	-40.2
17.	160	-39.3
18.	170	-39.0
19.	180	-38.2
20.	190	-37.6
21.	200	-38.9
22.	210	-39.7
23.	220	-40.3
24.	230	-42.1
25.	240	-43.7
26.	250	-47.8
27.	260	-49.9
28.	270	-52.3
29.	280	-51.7
30.	290	-48.2
31.	300	-43.8
32.	310	-42.9
33.	320	-40.7
34.	330	-39.6
35.	340	-38.7
36.	350	-38.1



B) Measurement of Beamwidth:

Beamwidth = $\theta = 42^0$ (at right side) + 40^0 (at left side) = **82^0.**

C) Measurement of Front-to-Back Ratio:

Front-to-back ratio = (-37.3) - (-38.2) = **0.9 dBm.**

D) Measurement of Gain:

$P_{Ref(folded)}$ = -41.3 dBm.

$P_{Meas(SLOT)}$ = -37.3 dBm.

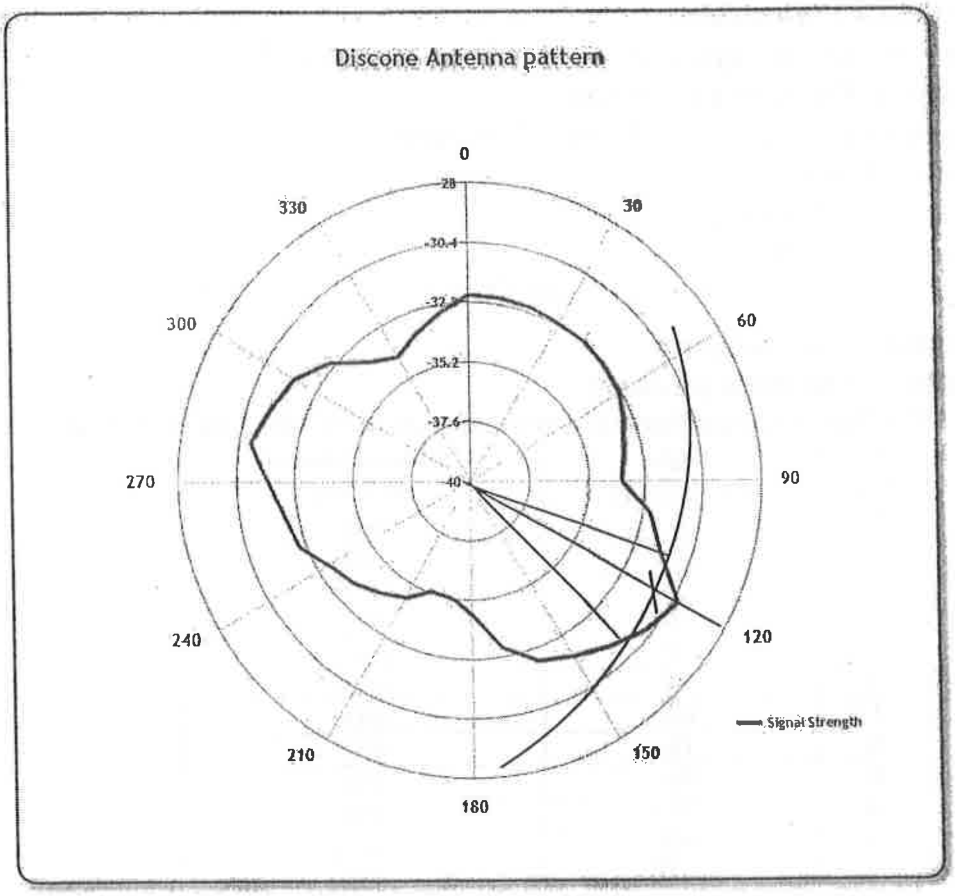
Hence, G_{SLOT} = 24 + [(-37.3) - (-41.3)] = **28.0 dBi.**

CH-17: Study of Discone Antenna

A) Measurement of Radiation pattern:

Table 17.1 Radiation pattern observation table of Discone antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	-32.5
2.	10	-32.5
3.	20	-32.6
4.	30	-32.7
5.	40	-32.7
6.	50	-32.8
7.	60	-32.9
8.	70	-33.3
9.	80	-33.6
10.	90	-33.8
11.	100	-32.5
12.	110	-31.7
13.	120	-30.2
14.	130	-30.7
15.	140	-31.3
16.	150	-31.9
17.	160	-32.3
18.	170	-33.2
19.	180	-34.6
20.	190	-35.2
21.	200	-35.3
22.	210	-34.6
23.	220	-34.2
24.	230	-33.7
25.	240	-33.3
26.	250	-32.5
27.	260	-32.2
28.	270	-31.7
29.	280	-30.8
30.	290	-31.3
31.	300	-31.7
32.	310	-32.5
33.	320	-33.7
34.	330	-34.2
35.	340	-33.7
36.	350	-33.1



B) **Measurement of Beamwidth:**

Beamwidth = $\theta = 20^0$ (at right side) + 18^0 (at left side) = **38^0.**

C) **Measurement of Front-to-Back Ratio:**

Front-to-back ratio = **(-30.2) - (-31.7)** = **1.5 dBm.**

D) **Measurement of Gain:**

$P_{Ref(folded)}$ = -41.3 dBm.

$P_{Meas(DISC)}$ = -32.5 dBm.

Hence, G_{DISC} = 24 + [(-32.5) - (-41.3)] = **32.8 dBi.**

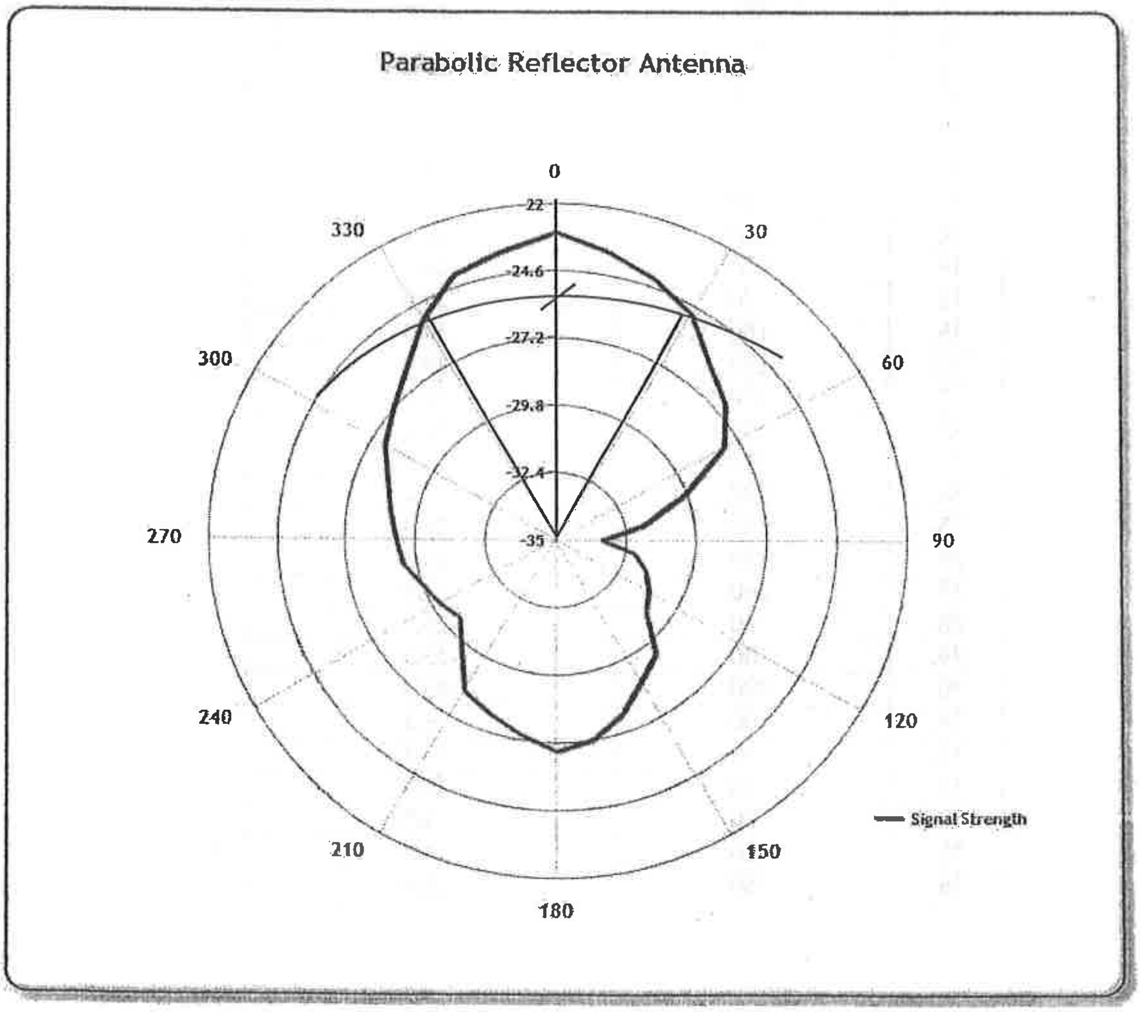
CH-18: Study of Parabolic Reflector Dish Antenna

A) Measurement of Radiation pattern:

Table 18.1 Radiation pattern observation table of Parabolic Reflector antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	-23.1
2.	10	-23.7
3.	20	-24.3
4.	30	-24.9
5.	40	-26.1
6.	50	-26.8
7.	60	-27.8
8.	70	-29.9
9.	80	-31.7
10.	90	-33.3
11.	100	-32.1
12.	110	-31.5

13.	120	-31.1
14.	130	-30.7
15.	140	-29.3
16.	150	-28.8
17.	160	-27.9
18.	170	-27.2
19.	180	-26.9
20.	190	-27.4
21.	200	-27.9
22.	210	-28.3
23.	220	-29.6
24.	230	-30.4
25.	240	-30.1
26.	250	-29.8
27.	260	-29.3
28.	270	-29.1
29.	280	-28.8
30.	290	-28.4
31.	300	-27.7
32.	310	-27.2
33.	320	-26.4
34.	330	-25.2
35.	340	-24.1
36.	350	-23.7



B) **Measurement of Beamwidth:**

Beamwidth = $\theta = 30^0$ (at right side) + 30^0 (at left side) = **60^0.**

C) **Measurement of Front-to-Back Ratio:**

Front-to-back ratio = (-23.1) - (-26.9) = **3.8 dBm.**

D) **Measurement of Gain:**

$P_{Ref(folded)}$ = -41.3 dBm.

$P_{Meas(PARA)}$ = -23.1 dBm.

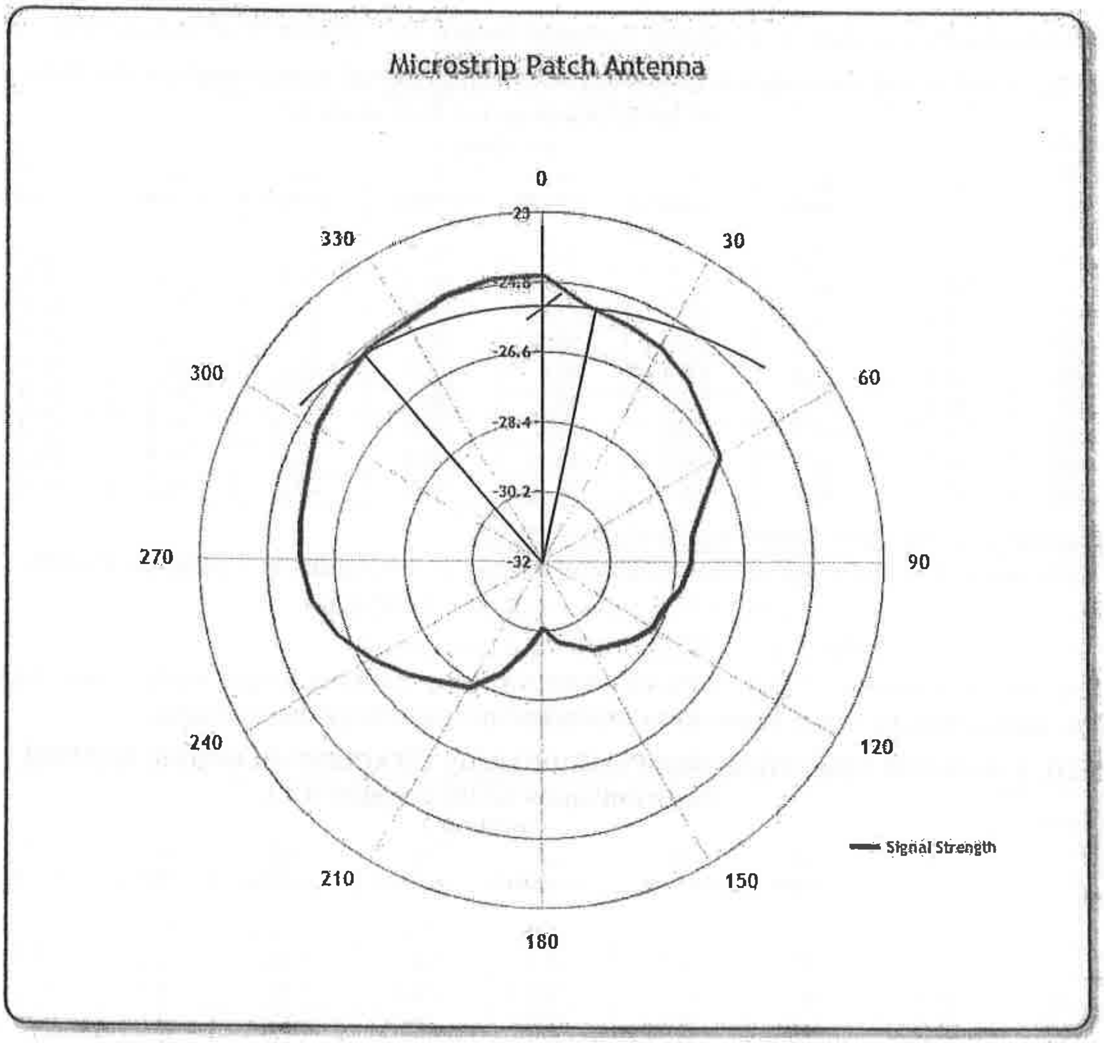
Hence, G_{PARA} = 24 + [(-23.1) - (-41.3)] = **42.2 dBi.**

CH-19: Study of Microstrip Patch Antenna

A) Measurement of Radiation pattern:

Table 19.1 Radiation pattern observation table of Microstrip Patch antenna

Sr. No.	Angle (in degree)	Observed power (in dBm)
1.	0	-24.6
2.	10	-25.3
3.	20	-25.5
4.	30	-25.6
5.	40	-25.9
6.	50	-26.3
7.	60	-26.5
8.	70	-27.4
9.	80	-27.9
10.	90	-28.0
11.	100	-28.2
12.	110	-28.5
13.	120	-28.6
14.	130	-28.9
15.	140	-29.2
16.	150	-29.4
17.	160	-29.7
18.	170	-29.9
19.	180	-30.3
20.	190	-29.7
21.	200	-28.9
22.	210	-28.2
23.	220	-27.9
24.	230	-27.4
25.	240	-26.9
26.	250	-26.3
27.	260	-25.9
28.	270	-25.7
29.	280	-25.6
30.	290	-25.5
31.	300	-25.2
32.	310	-25.1
33.	320	-24.9
34.	330	-24.9
35.	340	-24.7
36.	350	-24.6



B) Measurement of Beamwidth:

Beamwidth = θ = 13^0 (at right side) + 42^0 (at left side) = **55^0.**

C) Measurement of Front-to-Back Ratio:

Front-to-back ratio = (-24.6) - (-30.3) = **5.7 dBm.**

D) Measurement of Gain:

$P_{Ref(folded)}$ = -41.3 dBm.

$P_{Meas(PATCH)}$ = -24.6 dBm.

Hence, G_{PATCH} = 24 + [(-24.6) - (-41.3)] = **40.7 dBi.**

CH-20: Antenna Resonance expt using variable length λ/2 simple dipole Antenna

Table 20.1 Antenna resonance observations using signal transmission method

Sr. No.	Antenna Length (λ/2) (in mm)	Observed power at the frequency (f) (in dBm)							
		At f=125MHz	At f=150MHz	At f=168MHz	At f=188MHz	At f=215MHz	At f=250MHz	At f=300MHz	At f=375MHz
1.	400	-28.3	-28.8	-36.2	-35.3	-30.1	-35.3	-38.3	-25.4
2.	500	-28.5	-30.6	-32.0	-36.4	-28.4	-36.5	-38.0	-26.0
3.	600	-29.6	-34.8	-27.6	-31.6	-27.6	-32.2	-35.1	-26.9
4.	700	-28.5	-36.9	-23.3	-30.2	-28.0	-27.8	-31.2	-28.4
5.	800	-25.6	-30.8	-23.2	-30.6	-28.7	-25.1	-30.2	-29.4
6.	900	-20.7	-28.3	-23.3	-31.5	-30.7	-23.3	-29.4	-31.8
7.	1000	-19.5	-27.2	-23.6	-32.5	-34.0	-23.2	-29.3	-32.3
8.	1100	-19.3	-26.6	-24.2	-34.3	-38.8	-23.3	-29.4	-28.2
9.	1200	-19.1	-26.7	-24.0	-35.0	-34.5	-23.7	-30.1	-27.9

Verifications: (From the above observation table)

For Frequency 125MHz: Maximum observed power = **-19.1dBm @ 1200mm length.**

Calculations; λ = c / f = (3 x 10^11) / (125 x 10^6) = 2400mm.

Then, λ / 2 = 2400 / 2 = 1200mm (Hence matched).

And check for all frequency range; all will match with the antenna length within limitation of length measurement which is prone to Human errors as being done manually.

Table 20.2 Antenna resonance observations using Directional Coupler method

Sr. No.	Antenna Length (λ/2) (in mm)	Observed power at the frequency (f) (in dBm)							
		At f=125MHz	At f=150MHz	At f=168MHz	At f=188MHz	At f=215MHz	At f=250MHz	At f=300MHz	At f=375MHz
1.	400	-29.5	-26.7	-31.1	-28.0	-25.0	-24.0	-22.4	-22.4
2.	500	-29.5	-27.3	-32.0	-29.6	-24.2	-23.7	-22.3	-22.9
3.	600	-29.4	-28.4	-29.9	-30.4	-23.8	-24.1	-23.4	-23.1
4.	700	-29.3	-33.2	-25.4	-29.9	-24.2	-25.3	-25.5	-23.0
5.	800	-29.6	-37.8	-24.1	-29.2	-24.6	-26.1	-26.3	-23.1
6.	900	-32.1	-28.3	-23.9	-28.6	-26.2	-27.8	-25.8	-23.1
7.	1000	-36.8	-27.7	-23.7	-27.7	-27.6	-28.4	-25.2	-22.9
8.	1100	-38.2	-27.0	-24.0	-27.1	-30.1	-29.0	-24.0	-23.0
9.	1200	-34.5	-26.8	-24.5	-26.5	-32.9	-28.4	-23.4	-23.6

Verifications: (From the above observation table)

For Frequency 125MHz: Minimum observed power = **-38.2dBm @ 1100mm length.**

Calculations; λ = c / f = (3 x 10^11) / (125 x 10^6) = 2400mm.

Then, λ / 2 = 2400 / 2 = 1200mm, which is approximate & hence matched.

And check for all frequency range; all will match with the antenna length within limitation of length measurement which is prone to Human errors as being done manually.

Measurement of Gain at 375MHz range:

$P_{Ref(folded)}$ = -41.3 dBm.

$P_{Meas(VARIABLE)}$ = -25.4 dBm.

Hence, $G_{VARIABLE}$ = 24 + [(-25.4) - (-41.3)] = **39.9 dBi.**

APPENDIX - A
Antenna Electrical Specifications & Design Considerations

The Antenna Training system / XPO-ANT trainer set is provided with different types of antennas, all antennas are designed by our R & D team by following the universal standard techniques & measurement methods. Here Antenna Electrical specifications table is provided with the measured parameters, whatever observed or measured in our R & D lab. So, follow the one-short table of Antennas specification to compare with your experimental results / observations.

<u>NOTE:</u> Consider some differences in your observed readings from below specifications, because of setup, expt. location, and environmental conditions etc (As per precaution points given in **unit-1/point-7**).

Table A.1 Electrical specifications of Antennas

Sr. No.	Name of Antenna	Measured Parameters				
		Gain (dBi)	Front-to-Back Ratio (dBm)	Beam-width (Degree)	Return Loss (dBm)	VSWR (No unit)
1.	Half-wave folded dipole (Used as Reference antenna).	24.0 *	2.9	45^0	-4.7	3.78
2.	Half-wave simple dipole.	40.8	13.3	82^0	-5.2	3.44
3.	Quarter-wave simple dipole.	36.9	17.1	81^0	-3.8	4.62
4.	$3\lambda/2$ simple dipole.	32.1	0.6	47^0	-7.3	2.51
5.	Half-wave Folded-dipole with Reflector.	38.1	1.6	40^0	-4.5	3.93
6.	Yagi-Uda 3 elements.	29.0	3.1	94^0	-6.7	2.71
7.	Yagi-Uda 5 elements.	30.0	1.1	60^0	-10.4	1.86
8.	Yagi-Uda 7 elements.	32.0	1.3	39^0	-7.1	2.57
9.	Circular Loop.	31.1	1.9	85^0	-7.5	2.45
10.	Log-periodic.	32.8	8.0	58^0	-7.9	2.34
11.	Helical.	23.7	21.5	90^0	-4.4	4.02
12.	Half-wave End-Fire.	39.5	2.7	63^0	-7.8	2.34
13.	Quarter-wave End-Fire.	37.7	2.5	95^0	-9.1	2.08
14.	Broad-side array.	33.1	8.2	78^0	-7.2	2.53
15.	Co-linear array.	36.7	12.1	85^0	-4.4	4.02
16.	Slot.	28.0	0.9	82^0	-3.8	4.55
17.	Discone.	32.8	1.5	38^0	-4.0	4.40
18.	Parabolic Reflector.	42.2	3.8	60^0	-5.5	3.26
19.	Microstrip Patch.	40.7	5.7	55^0	-5.8	3.10
20.	Variable Length (@ 375MHz range)	39.9	13.3	82^0	-5.2	3.44

* Indicates, the Gain of Folded-dipole antenna, which is used as reference antenna for all other antennas under test.

The provided antennas are designed for the RF frequency of 500MHz range only, by considering this frequency range the lengths of element or diameter of wire of each antenna is different, which is decided by wavelength (λ). For this the following equation is referred;

$$\therefore \lambda = c/f$$

Where, λ = Wavelength of RF frequency (in cm),
c = Velocity of light = 3 x 10^10 cm/sec,
and f = RF frequency to be used = 500MHz.

Then wavelength for this RF frequency range will be,

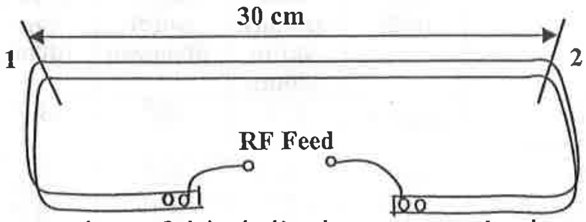
$$\lambda = 60\text{cm}.$$

Now as per the above calculated wavelength for 500MHz RF signal, different antennas are designed as illustrated below;

1) Design of Half-wave Folded-dipole Antenna:

i) Length calculation: As the name Half-wave, this antenna is designed by considering its element length as half of signal wavelength at 500MHz RF signal.
Hence, length of folded-dipole element = λ / 2 = 60 / 2 = 30 cm as shown below;

Fig. A.1 Half-wave folded dipole antenna



On red-masked base-plate, folded-dipole antenna is placed at FDP drill.

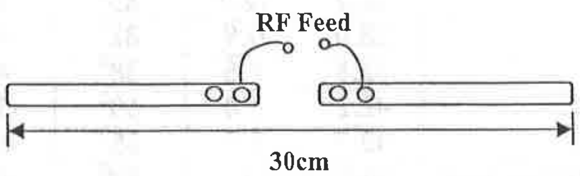
ii) Antenna element specifications:

Material - Aluminium pipe.
Thickness - 0.8 mm.
ID/OD - 7.4mmϕ/9mmϕ.

2) Design of Half-wave simple-dipole Antenna:

i) Length calculation: Design method is same as Half-wave folded-dipole, but it kept straight, not fold.
Hence, length of simple dipole element = λ / 2 = 60 / 2 = 30 cm as shown below;

Fig. A.2 Half-wave simple dipole antenna



On red-masked base-plate, Half-wave simple-dipole antenna is placed at FDP drill.

ii) Antenna element specifications:

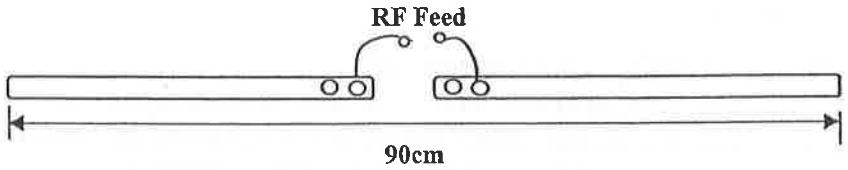
Material - Aluminium pipe.
Thickness - 0.8 mm.
ID/OD - 7.4mmϕ/9mmϕ.

3) Design of 3λ/2 simple-dipole Antenna:

i) Length calculation: The design of this antenna is done by considering its name as given;

Length of dipole element = 3 λ / 2 = 180 / 2 = 90 cm as shown below;

Fig. A.3 (3λ/2) simple dipole antenna



On red-masked base-plate, Half-wave simple-dipole antenna is placed at FDP drill.

ii) Antenna element specifications:

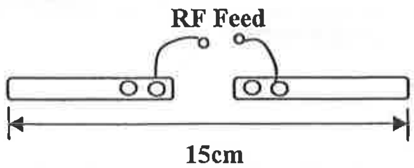
Material - Aluminium pipe.
Thickness - 0.8 mm.
ID/OD - 7.4mmϕ/9mmϕ.

4) Design of Quarter wave simple-dipole Antenna:

i) Length calculation: The design of this antenna is done by considering its name as given;

Length of dipole element = λ / 4 = 60 / 4 = 15 cm as shown below;

Fig. A.4 Quarter-wave simple dipole antenna



On red-masked base-plate, Half-wave simple-dipole antenna is placed at FDP drill.

ii) Antenna element specifications:

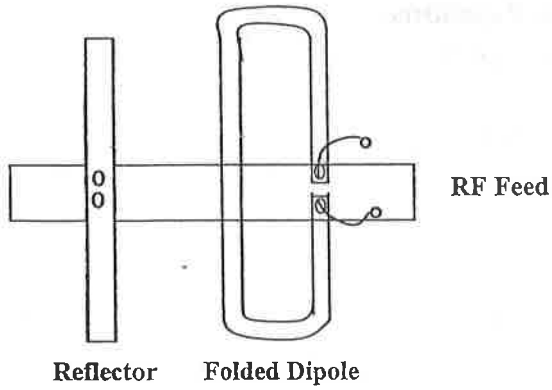
Material - Aluminium pipe.
Thickness - 0.8 mm.
ID/OD - 7.4mmϕ/9mmϕ.

5) Design of Half-wave folded-dipole with reflector Antenna:

i) Length calculation: It consists of one folded-dipole antenna with a reflector at back of this folded element. The folded element is the feed whereas the reflector acts as reflector for the unwanted waves from the back of antenna. The design of this antenna is as given below;

Length of reflector = 30 cm & length of folded-element = 30 cm.

Fig. A.5 Half-wave folded-dipole with reflector antenna



On red-masked base-plate, this antenna is placed as;
Reflector - YU4 & Folded-dipole - YU6.

ii) Antenna element specifications:

Material - Aluminium pipe.
Thickness - 0.8 mm.
ID/OD - 7.4mmϕ/9mmϕ.

6,7,8) Design of Yagi-Uda Antennas (three antennas):

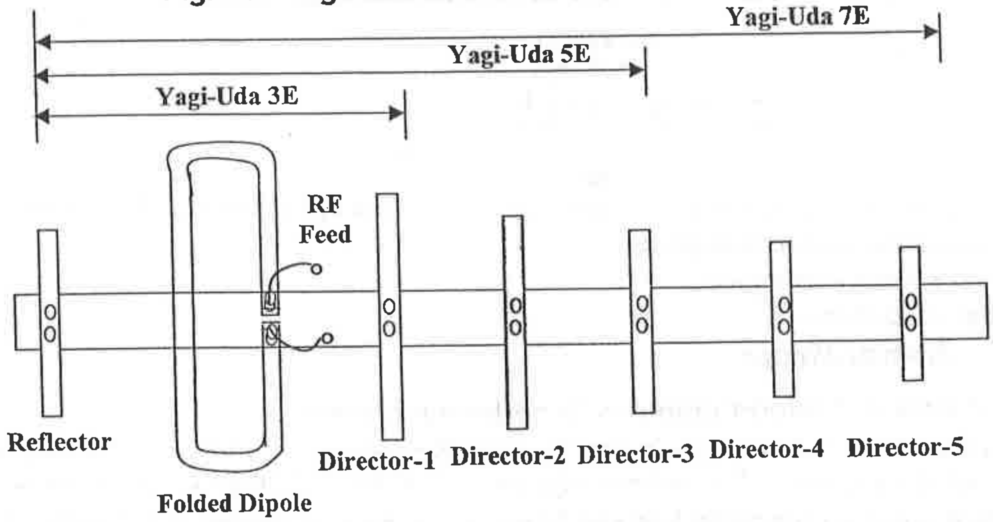
i) Length calculation: Yagi-Uda antenna contains one folded-dipole antenna, one reflector and no. of directors as per selection either 3-element or 5-element or 7-element. This antenna is designed by using the following equations;

Length of Dipole = ((5905) * (2.54)) / (RF_{freq})   (in cm).
= (14998) / (500) = 30 cm.

Length of Reflector = 30 cm.
Length of Director-1 = 27.5 cm, Length of Director-2 = 26 cm,
Length of Director-3 = 24.5 cm, Length of Director-4 = 23 cm
and Length of Director-5 = 21.5 cm.

For more than 3-element Yagi-Uda antenna, you can mount elements as subsequent directors from director-1, as director-2 & 3 for 5-element antenna and director-4 & 5 for 7-element antenna as shown;

Fig. A.6 Yagi-Uda antennas with folded-dipole



On red-masked base-plate, the elements of Yagi-Uda antenna will be placed or mounted on their proper location (drills) as per below mentioned nomenclatures;
Reflector - YU1, Folded dipole - YU2, Director1 - YU3, Director2 - YU4, Director3 - YU5, Director4 - YU6 and Director5 - YU7.

ii) Antenna element specifications:

Material - Aluminium pipe.
Thickness - 0.8 mm.
ID/OD - 7.4mmϕ/9mmϕ.

9) Design of Circular Loop Antenna:

i) Length calculation: This antenna is designed as large circular loop by considering its circumference as approximately equal to λ,

Hence, Loop circumference = λ = 60 cm.

$\Rightarrow$ 2*(pie)*R* N_L = 60 cm.

$\Rightarrow$ 2*(pie)*R* (1) = 60 cm. (if N_L = 1)

$\Rightarrow$ R = (60) / (2*pie) cm.

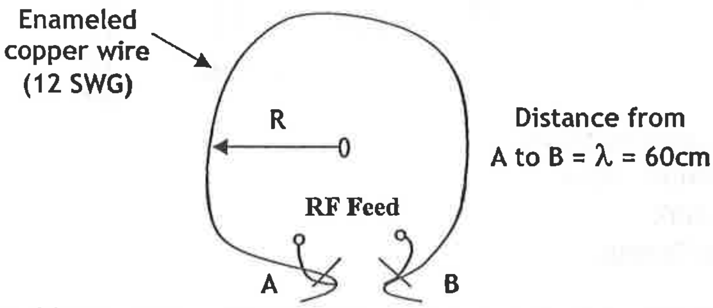
$\Rightarrow$ R = 9.5 cm.

Where, Circumference = 2*(pie)*R* N_L.

N_L = Turns of antenna loop.

R = Radius of loop (in cm).

Fig. A.7 Circular Loop antenna



On red-masked base-plate, Circular-loop antenna is placed at LOOP drill.

ii) Antenna element specifications:

Material - Enameled copper wire.

Gauge - 12 SWG.

10) Design of Log-periodic Antenna:

i) Length calculation: Actually Log-periodic antennas are broadband antenna and the provided antenna with trainer set is designed for the broadband range of 200MHz to 700MHz. For this frequency range, seven nos. of distinct length elements are required, the lengths of these distinct elements are calculated by using the following equations with reference to large element, this large element is active at minimum designed frequency (i.e. 200MHz) and the successive elements are reduced by 80% from its previous one as given below;

Length of large element (LP7) = (2*c) / (4*F_{min}) = (2*3*10^10) / (4*200*10^6) = 75cm.

Second element (LP6) = (LP7) * (0.8) = (75.0) * (0.8) = 60.0 cm.

Third element (LP5) = (LP6) * (0.8) = (60.0) * (0.8) = 48.0 cm.

Fourth element (LP4) = (LP5) * (0.8) = (48.0) * (0.8) = 38.4 cm.

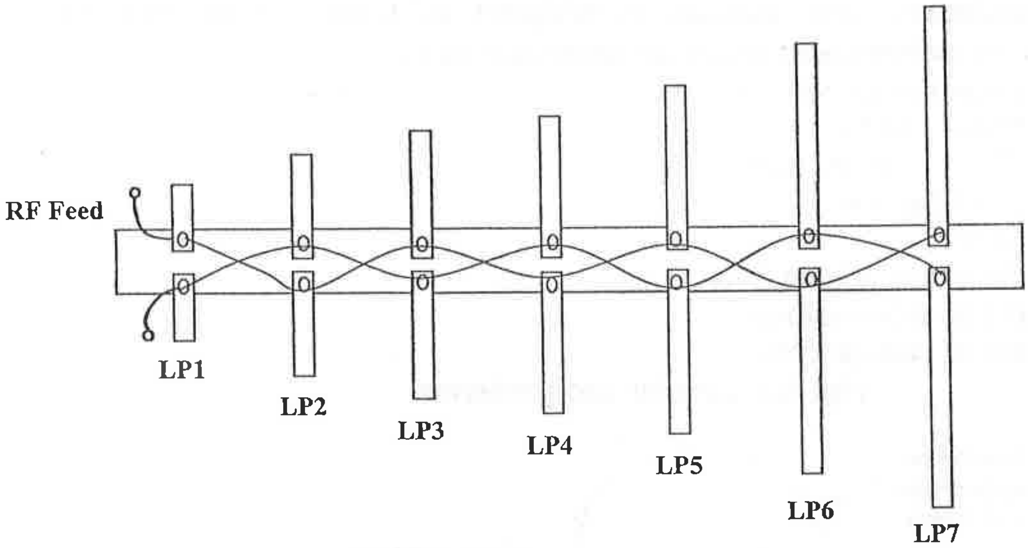
Fifth element (LP3) = (LP4) * (0.8) = (38.4) * (0.8) = 30.7 cm.

Sixth element (LP2) = (LP3) * (0.8) = (30.7) * (0.8) = 24.5 cm.

Seventh element (LP1) = (LP2) * (0.8) = (24.5) * (0.8) = 19.6 cm.

The last element will active in maximum usable frequency i.e. at 700 MHz.

Fig. A.8 Log-periodic Antenna



ii) Antenna element specifications:

Material - Aluminium pipe.
Thickness - 0.8 mm.
ID/OD - 7.4mmϕ/9mmϕ.

11) Design of Helical Antenna:

i) Length calculation: As the name Helical, this antenna is designed as the shape of Helix, wound with fixed dimensions in three nos. of same diameter turns. The spacing between each turns is maintained by providing a white delrin rod of specified height as per usable RF frequency range (i.e. 500 MHz), different equations are given below for Helical antenna design;

One Helix circumference = λ = 60 cm.

$\Longrightarrow$ 2*(pie)*R = 60 cm.

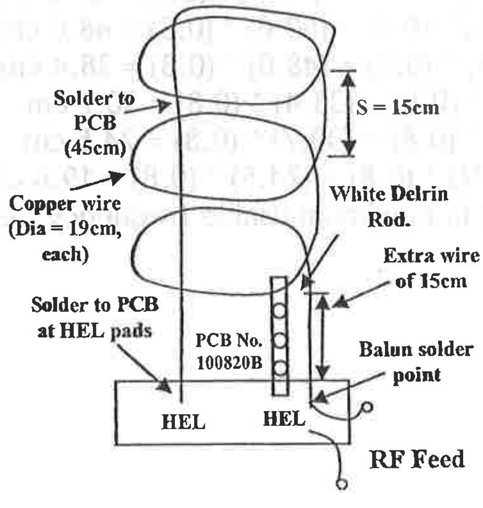
$\Longrightarrow$ 2*R = D = (60) / (λ) cm.

$\Longrightarrow$ D = 19 cm.

Spacing between two turns (s) = (λ) / (4) = (60 cm) / 4 = 15 cm.

Diameter of Ground plane (DG) = (3*λ) / (4) = (180 cm) / (4) = 45 cm.

Fig. A.9 Helical Antenna



ii) **Antenna element specifications:**

Material - Enameled copper wire.

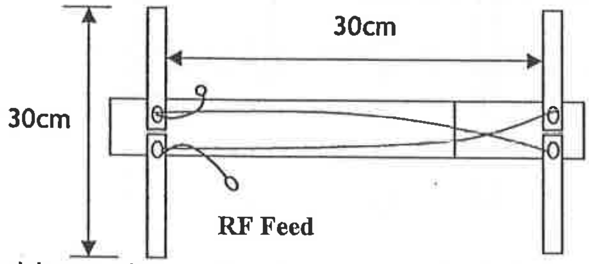
Gauge - 12 SWG.

12) Design of Half-wave End-fire Antenna:

i) **Length calculation:** This antenna is designed by placing two half-wave simple elements at a distance of half-wavelength and feeding the RF signal at one end of each element with 180^0 out-of-phase from one-another, because of this distance separation and feeding at one-end, this antenna got the name Half-wave end-fire antenna.

The elements of this antenna are placed by combining two PCBs, one big & one small PCB to maintain the distance of elements as 30cm & length of each element is also 30cm.

Fig. A.10 Half-wave End-Fire Antenna



On red-masked base-plate, the first element of this antenna is placed at YU1 on first big PCB & second element at last pads of small PCB as shown above.

ii) **Antenna element specifications:**

Material - Aluminium pipe.

Thickness - 0.8 mm.

ID/OD - 7.4mmϕ/9mmϕ.

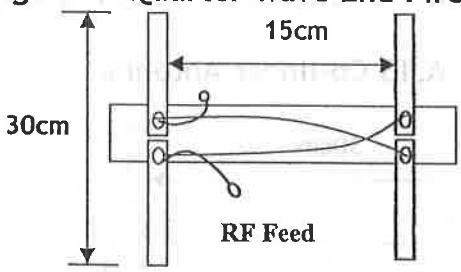
13) Design of Quarter-wave End-fire Antenna:

i) **Length calculation:**

This antenna is designed by placing two half-wave simple elements at a distance of Quarter-wavelength and feeding the RF signal at one end of each element with 180^0 out-of-phase from one-another, because of this distance separation and feeding at one-end, this antenna got the name Quarter-wave end-fire antenna.

The elements of this antenna are placed at the distance of 15cm on big PCB.

Fig. A.11 Quarter-wave End-Fire Antenna



On red-masked base-plate, the first element of this antenna is placed at LP4 on & second element at LP3 as shown above.

ii) **Antenna element specifications:**

Material - Aluminium pipe.

Thickness - 0.8 mm.

ID/OD - 7.4mmϕ/9mmϕ.

14) **Design of Broad side array Antenna:**

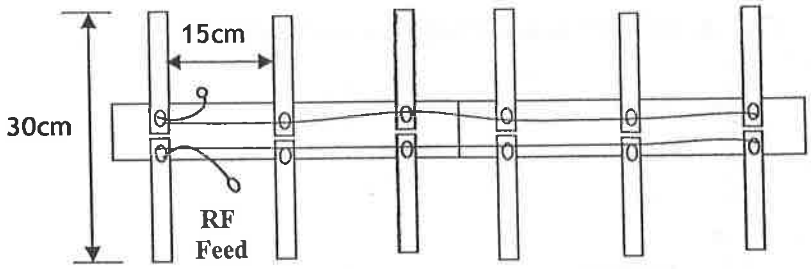
i) **Length calculation:**

This antenna is designed by placing six nos. of half-wave simple elements at fixed distances and feeding the RF signal at one end of each element with in-phase to each & form an array of same elements, because of this assembly, this antenna got the name Broad-side array antenna. The elements can be placed at same distances from one-another ranging from $\lambda/8$ to $\lambda/4$ and length of each element is $\lambda/2$.

Length of each element = $\lambda/2$ = 30 cm (6 nos.).

Distance between elements = $\lambda/7$ = 8.5 cm.

Fig. A.12 Broad-side array Antenna



On red-masked base-plate, two big PCBs are connected, on first PCB, the elements are placed at YU1, YU2 & LP3 and on second PCB, and elements are placed at LP4, LP2 & YU7 as shown above.

ii) **Antenna element specifications:**

Material - Aluminium pipe.

Thickness - 0.8 mm.

ID/OD - 7.4mmϕ/9mmϕ.

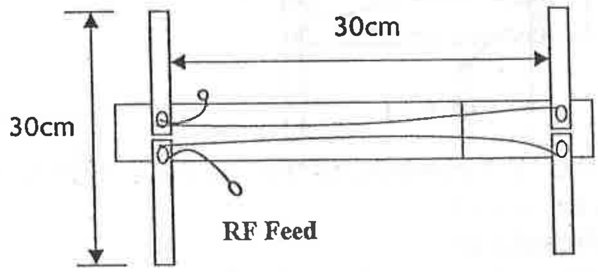
15) **Design of Co-linear Antenna:**

i) **Length calculation:**

This antenna is designed by placing two of half-wave simple elements in co-linear positions at a distance of half-wavelength and feeding the RF signal at one end of each element with in-phase to each, because of this assembly, this antenna got the name Co-linear antenna.

The elements of this antenna are placed by combining two PCBs, one big & one small PCB to maintain the distance of elements as 30cm & length of each element is also 30cm.

Fig. A.13 Co-linear Antenna



On red-masked base-plate, the first element of this antenna is placed at **YU1** on first big PCB & second element at **last** pads of small PCB as shown above.

ii) Antenna element specifications:

Material - Aluminium pipe.
Thickness - 0.8 mm.
ID/OD - 7.4mmϕ/9mmϕ.

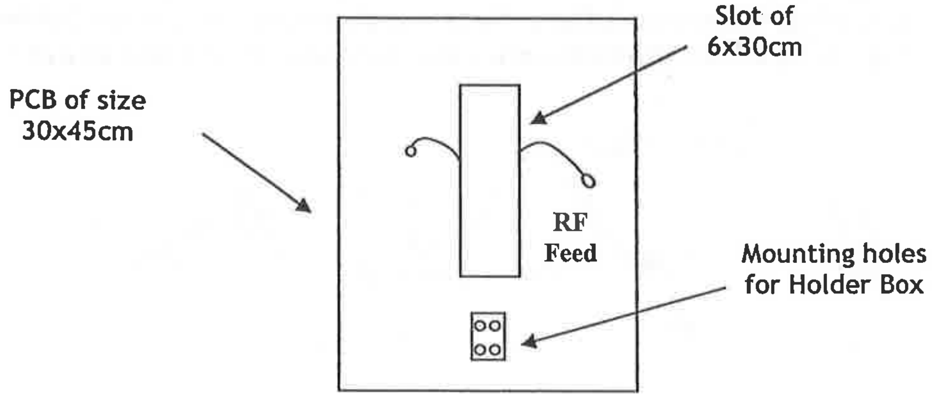
16) Design of Slot Antenna:

i) Length calculation:

This antenna is designed by providing a slot of half-wavelength in a conducting copper surface (i.e. antenna red-masked copper PCB). This slot or cut-out has RF signal feed from Balun, the slot acts as half-wave dipole antenna, because of the half-wave slot, this antenna got the name Slot antenna.

For designing of slot antenna, a special antenna PCB is made with the size of 30x45cm & a slot of $\lambda/2$ = 30 cm having thickness of (0.1) λ = 6 cm as shown;

Fig. A.14 Slot Antenna



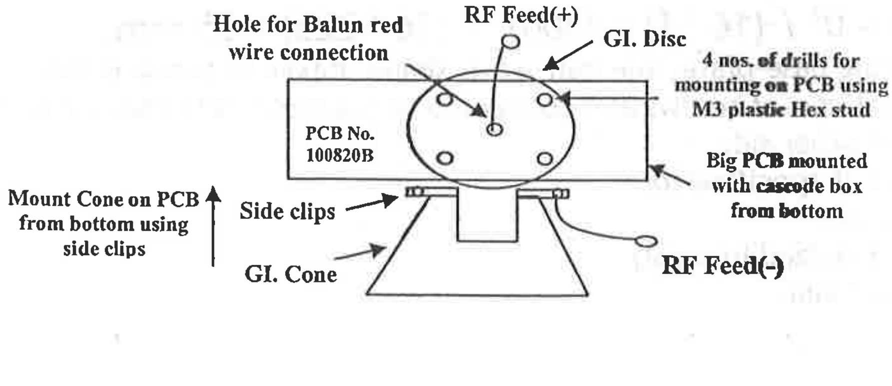
ii) Antenna element specifications: No external material used.

17) Design of Discone Antenna:

i) Length calculation:

This antenna is designed by mounting two separate conducting surfaces by an insulator, these two conducting surfaces are Disc & other is Cone. The disc is acts as Radiator & feeding RF signal from the Balun output and Cone is acts as Grounding surface & feeding grounding of RF signal. In our design, we use two galvanized iron sheet for disc & cone and these are separated by Fiber spacers from four sides & mounted on antenna red-mask base plate. Because of this two Disc & Cone assembly, this antenna got the name Discone antenna.

Fig. A.15 Discone Antenna



This Discone antenna is designed by using two separate elements, one is Disc acts as Radiator & other is Cone acts as ground, but are separated by insulating material i.e. plastic studs (4 nos.) as shown above.

On red-masked big base-plate, the cone is mounted with 2 nos. of screws and Disc is also mounted on PCB from top.

ii) Antenna element specifications:

Material - Galvanized Iron (GI).

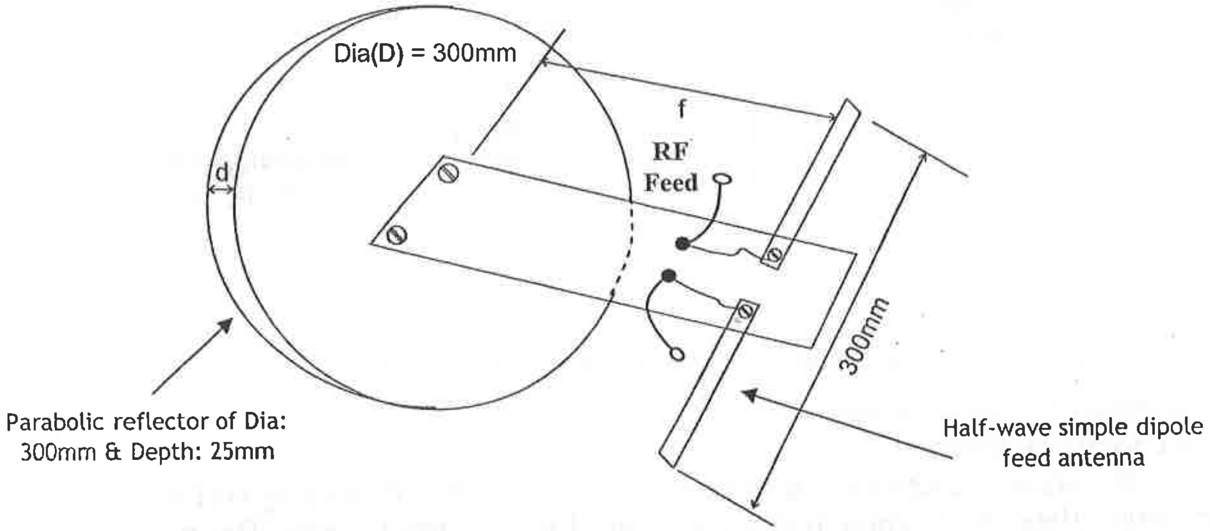
Thickness - 0.7 mm.

13) Design of Parabolic Reflector Dish Antenna:

i) Length calculation:

This antenna is designed by mounting a feed antenna (half-wave simple dipole antenna, in this set) acts as receiver/transmitter to a parabolic shaped round reflector (made up of GI sheet, thickness: 0.7mm) using L-angles at the center of reflector, hence the name Parabolic reflector dish antenna as shown below;

Fig. A.16 Parabolic Reflector Dish Antenna (Isometric view)



The distance of simple dipole feed antenna from the reflector is mathematically arranged by using the following equation as given;

$$f = D^2 / (16 * d)$$

Where, f = Focal length, i.e. the distance from reflector to Feed antenna (in mm).

D = Diameter of parabolic reflector (in mm).

and d = Depth of parabolic reflector (in mm).

As the focal length (f) = 225 mm & Diameter (D) = 300 mm.

$$\text{Then, } d = D^2 / (16 * f) = (300)^2 / (16 * 225) = 25 \text{ mm.}$$

On red-masked big base-plate, the half-wave simple dipole antenna is mounted at YU1 pads with 2x2 nos. of screws and connected to parabolic reflector using two nos of L-angles from other side.

ii) Antenna element specifications:

For Parabolic reflector:

Material - Galvanized Iron (GI).

Thickness - 0.7 mm.

For Feed antenna:

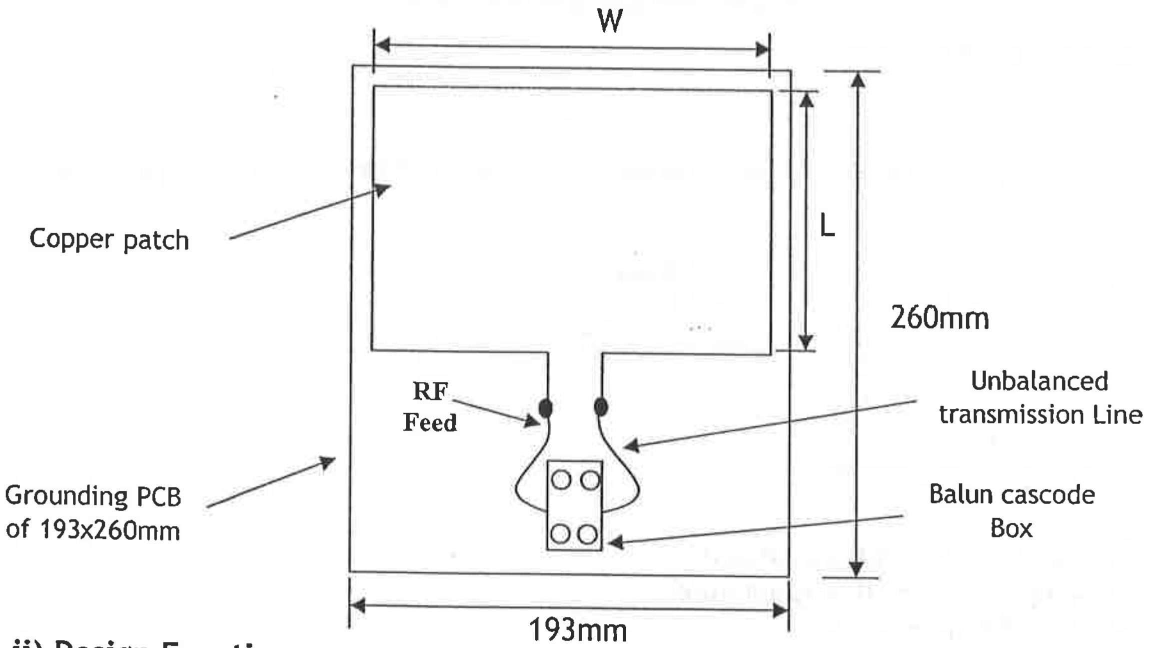
Material - Aluminium pipe.
Thickness - 0.8 mm.
ID/OD - 7.4mmϕ/9mmϕ.

19) Design of Microstrip Patch Antenna:

i) Length calculation:

This antenna is designed by providing a copper patch (or, space) on a specially designed PCB (size: 193x260 mm) having complete ground surface from back acts as reflector surface & at top of PCB, one square patch is provided having area 176 x 137 mm. This patch is connected to the internal Balun with the provided unbalanced transmission line feed pads as shown;

Fig. A.17 Microstrip Patch Antenna



ii) Design Equations:

$$L = c / [2 * f * \sqrt{(\varepsilon r)}]$$

Where, L = Length of copper patch (in mm).

c = Velocity of light = 3 x 10^11 mm/sec.

ε = Permittivity of patch PCB material i.e. 4.8 (For FR4 PCB).

Then, $L = (3 * 10^{11}) / [2 * (500 * 10^6) * \sqrt{(4.8)}] = 137$ mm.

And,

$$W = c / [2 * f * \sqrt{((\varepsilon r+1)/2)}]$$

Then, $W = (3 * 10^{11}) / [2 * (500 * 10^6) * \sqrt{((4.8+1)/2)}] = 176$ mm.

iii) Antenna element specifications: No external material used.

20) Design of Variable Length Antenna:

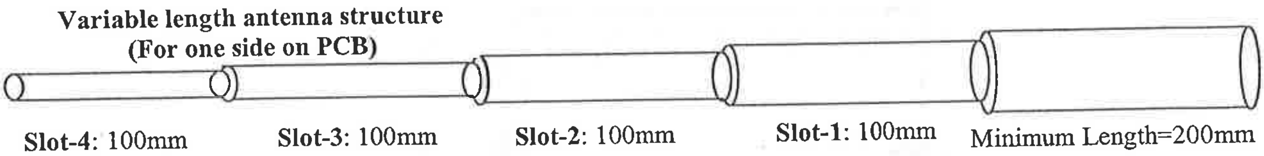
i) Length calculation:

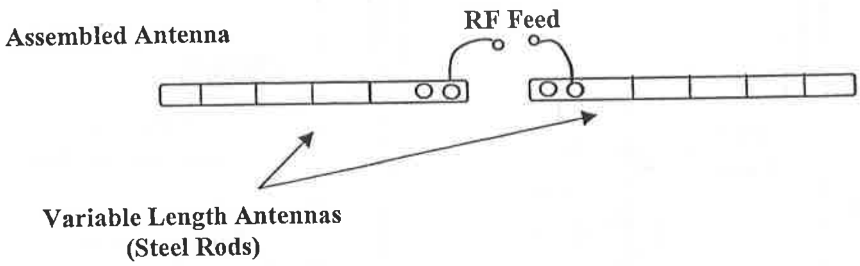
This antenna is designed in such a way that, you can perform Antenna Resonance experiment by varying length or adjusting length of Antenna by your hand precisely to get better response while transmission .

This assembled antenna is provided with two nos. of slotted (adjustable) variable length steel rod at two sides on Red-masked base-plate by feeding RF signal through internal Balun arrangement.

The measurement using this antenna is by considering antenna as half-wave simple dipole for the matched RF input frequency. Means while performing experiment, when you vary the length of antenna, you will get maximum reception from a no. of observations of different antenna length for the fixed RF frequency, and this will be the half-wave observation of the input frequency.

Fig. A.18 Variable Length Antenna





ii) Antenna element specifications:

Material - Steel Rod (expandable).
Slots - 100mm (4 nos).
Variable length: 400mm to 1200mm.
Operating frequency: 125MHz to 375MHz.

Appendix B
Virtual Workbench Software

☞ Unit objective

On completion of this unit, you will able to understand working of VWB 11.x software for polar graph. What has been supplied to you depends on what you have ordered and not what is described in this manual.

☞ Discussion on Fundamentals

A) Revision history

Table B.1: Revision history

B) System Revision Requirement

S N	Name of software	Version number/ Date	Function block														
			I/F	Analog I+O	PID	Graph	Graph facility	RS485 MODBUS	Fuzzy control	F G	Polar graph	Event trigger	Data logger	DPM	MPPT	Animation	Future
1	PID	10.3	√	4+1	√	√	XT	-	-	√	Separate antenna software is made	Is part of antenna software	-	-	-	-	
2	PID	10.4	√	4+1	√	√	XT	-	-	√			-	-	-	-	
3	PID	10.5	√	4+1	√	√	XT	-	-	√			-	-	-	-	
4	PID	10.6	√	4+1	√	√	XT	-	-	√			-	-	-	-	
5	PID	10.7	√	4+1	√	√	XT	-		√			-	-	-	-	
6	PID	10.8	√	4+1	√	√	XT	-	-	√			-	-	-	-	
7	PID	10.9	√	4+1	√	√	XT	-	-	√			-	-	-	-	
8	VWB	11.0	√	8+2	√	√	XT&XY	√	√	√	√	√	√	-	-	-	
9	VWB	11.1	√	8+2	√	√	XT&XY	√	√	√	√	√	√	-	-	-	
10	VWB	11.2	√	8+2	√	√	XT&XY	√	√	√	√	√	√	√	-	-	
11	VWB	11.3 13/11/19	√	8+2	√	√	XT&XY	√	√	√	√	√	√	√	√	-	

The CIP/CIP-II with VWB 11.x works on Windows XP/Win7/Win8/Win10. A higher speed machine will work better. A lower speed machine will sometimes create wrong communication with CIP/CIP-II through parallel /USB port due to jamming/overload due to window overheads. However you need at least Pentium P4 in GHz for WIN 7/8/10/XP. The CIP/CIP-II with VWB 11.x is best viewed in 1024X768 pixel area, in case not, you are required to adjust the screen height and width. The VWB software has many facilities hence the name! e.g. MIMO PID controller, graph plotting (XY/ XT), Polar graph, Fuzzy controller, DPM screen, Data logging with built in calculator, Modbus interface, MPPT, event trigger / scheduler to implement repetitive activity like automatic graph plotting etc.

Fig. B.1: PC interface all options

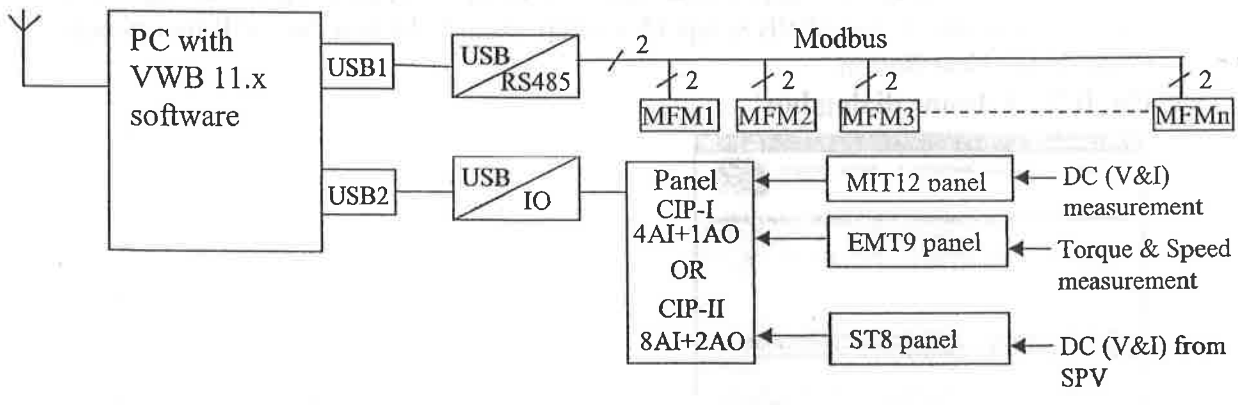


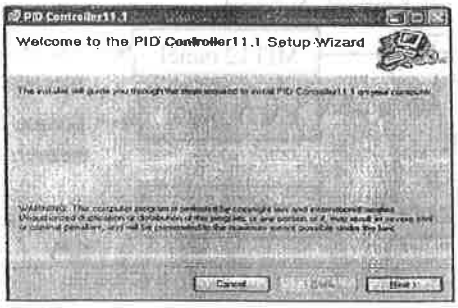
Table B.2: Table of resources/ facilities
C: Control, M: Measure, S: Settings

SN	Name of resources/ facility	C/ M/ S	Sub parts	EMT	PCT (FL, PTF, 3T, 4T, ChemPCT)	Antenna	PID	Fuzzy	STT (MPPT)
1	USB IO setting	S	For DC sensor o/p (0-2.5Vdc) measurement Select to one of 4+1 / 8+2 AIO & DIO channels (optional)	√	√	√	√	√	√
2	PID controller	C	Control settings buttons, Cascade control, MIMO controller		√		√		
3	Graph plotting	M	XT mode, XY mode,	√	√				√
4	Polar graph	M	Online/offline mode, auto/manual, degree/plot point, number of pulses/plots, Input strength, time gap, start/stop, plot, print, save, close/minimize/maximize icon			√			
5	Function generator	C	Parameter setting buttons:- FG type (Wave selection), offset, frequency, amplitude, duty cycle, DAC, Start/stop		√		√	√	
6	Modbus	M	For AC power measurement:- Meter/port selection, Connect/disconnect, close, instantaneous values, total harmonic distortion, configuration	√ For AC					
7	Fuzzy control	C	Numeric value display, Bar graph display, Control settings					√	
8	File IO	M	Brows, Preview, Sample on, Sample time,				√		
9	Data logger	M	Data profile, parameter name, multifactor, acquisition type, device, Auto increment, Formulae Acquisition at sample time & calculate Max 32 variables	√ For observation table filling. DC torque/ speed sensor measurement					√
10	Event trigger	C	O/P step change, time gap between the pulse, ramp, triangle, monoshot, DAC, automode, manual mode	√ For automatic graph plotting		√ Built in or separate			
11	DPM	M	Setting buttons, DPM profile, start button, read data, stop button	√			√		
12	MPPT	C	3 control strategies Inc Cond, P & O, 75% Voc						√

C) Installation Procedure from CD

1) Insert the VWB setup 11.x CD in your computer. Without CD ROM you will not be able to install 200MB software. Select folder for VWB 11.x Win XP Setup or VWB 11.x for Win 7,8 or 10 Setup depending on our system configuration.
2) Click on VWB Setup 11.3 application file. The installation procedure will start now and the "welcome to the VWB setup 11.x setup wizard" Dialog Box will be opened. Click on the Next Button.

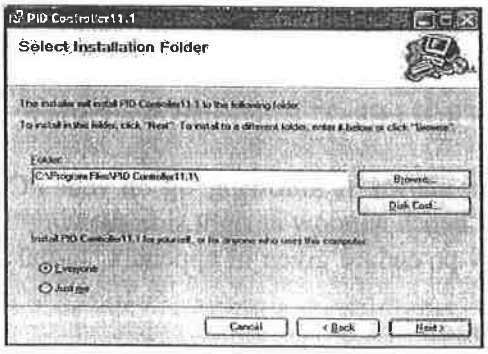
Fig. B.2: Welcome dialog box



3) After clicking the Next Button, "Select installation folder" Dialog Box will be opened. By default it will take C:\Program Files\Default Company Name\ PID controller 11.x Setup or VWB 11.x\ or you can select the location of your choice with the help of

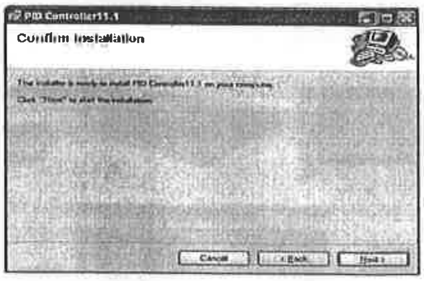
Browse Button. Preferably install on D or E drive. Select Everyone & Click on the Next Button.

Fig. B.3: Select installation dialog box



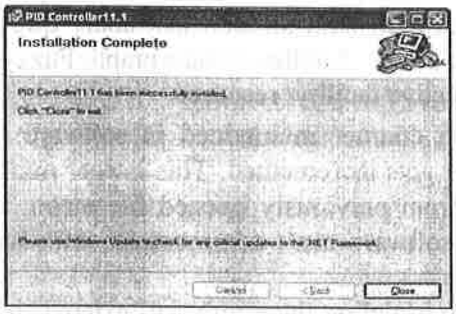
4) After clicking the Next Button," Confirm installation" Dialog Box will be opened. Click on Next button.

Fig. B.4: Confirm installation dialog box



5) After clicking the Next Button," Installing VWB setup 11.x" Dialog Box will be opened & it will start copying files, after copying the files " Installation Complete" Dialog Box will be opened. Click on the close to complete the Set Up.

Fig. B.5: Installation complete dialog box



6) This will complete the installation of Computer Software Trainer on your PC.
7) After installing the software create the Shortcut for PID CONTROLLER 11.x .EXE send it to Desktop.
8) After installation check for the following files in your destination folder (e.g. C:\Program Files\ PID Controller11\ & you may find following folders
   a) AE (folder) b) Kry Card (folder) c) Logger (Folder) d) rishabhDeltaEnergy (folder) e) PID ControllerAPP.exe etc.
9) If all the above files are present in your folder, s/w is said to be properly installed. However if you are using some other modbus device not covered then, you need to configure its address to read data from it.

D) Connecting the Computer Interface Panel (CIA/CIP) to PC

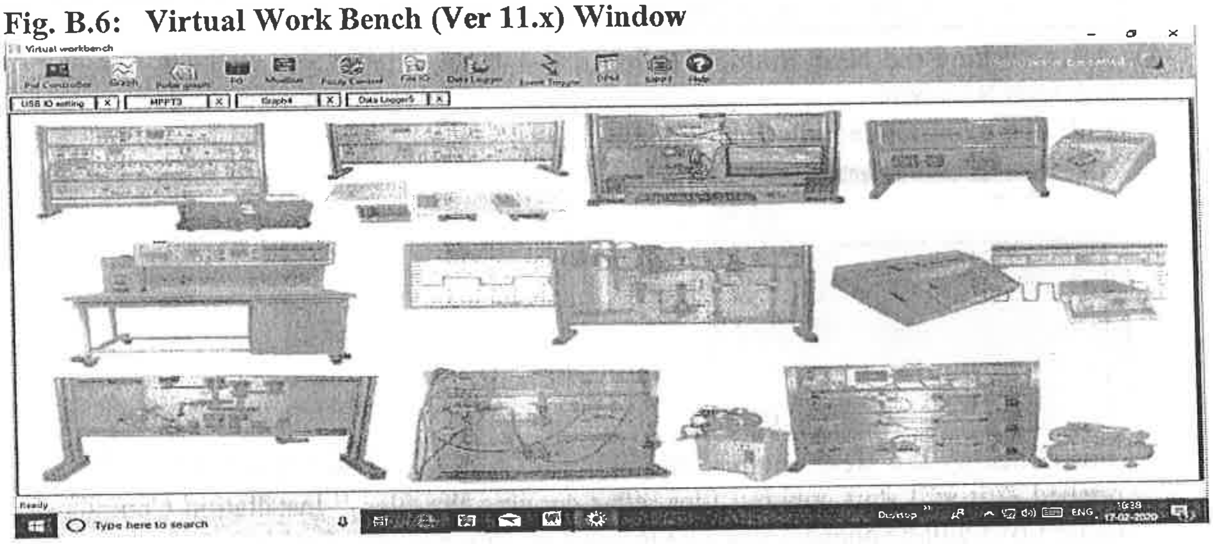
1) Make the connection of Computer Interface panel to the PC with the help USB IO module & USB cable.
2) Make the Power supply of Trainer ON.
3) At PC follow below steps to start communication.

E) Procedure for Operation

On the screen bring the Cursor to PID CONTROLLER 11.x (Virtual Workbench) Icon & Double Click.

After double clicking you will see the window shown in following fig on your PC screen. Check the green light will glow in main virtual bench window at right side showing 'USB IO device connected' if not connected then follow procedure given in appendix 'Initial Starting Procedure of XPO-PID'.

Fig. B.6: Virtual Work Bench (Ver 11.x) Window



This is the generalized window of the virtual work bench used for different applications. This window consists of different file menus each with its icon just under title bar like USB IO setting, File IO, PID controller, FG, Graph, Modbus, Polar graph, Fuzzy control etc. By clicking on icons, you will open respective facility/ resource.

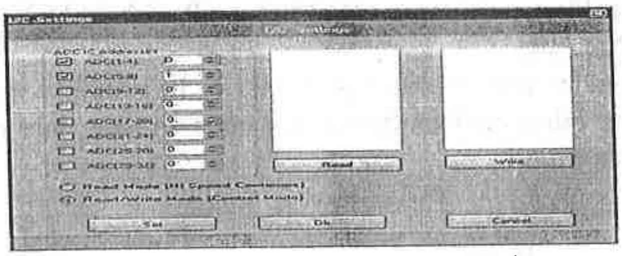
☞ **Note:-** There exists a integer running counter maintained in software. As you double click on any icon of resource, counter gets incremented. This integer number gets attached to the file menu to distinguish it from previously opened file menu. USB IO always given integer1 since without which software can't communicate with hardware, followed by PID controller 2, 3,…etc.

USB IO setting is a radio button just under it to define the number of external interfaces like AIO etc.

1) **USB IO Setting:**

Now for ADC setting click on 'USB IO Setting' button just below the file IO menu button, you will get USB IO setting window as shown below

Fig. B.7: USB IO setting Window

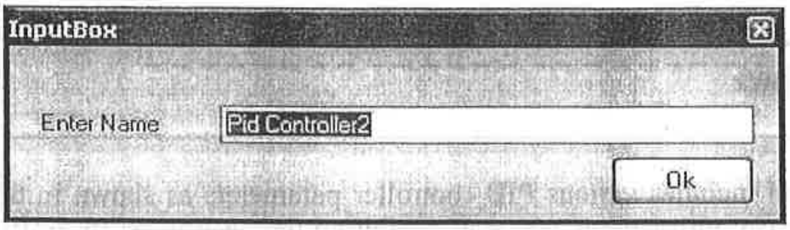


In this ADC setting window there are numbers of ADC selection depending on applications. For MIMO system using CIP-II panel as we need 2 DACs click on ADC (1-4) & ADC (5-8) and give address 0 & 1 respectively. Select 'Read write mode', then press set & then press OK.

2) **PID Controller:**

For PID control experiment click on 'PID controller', menu you will get input box as shown below.

Fig. B.8: Input Box Window



In this box you can give name your PID controller then press OK following PID controller window will open.

Note: All such active & passive components of this virtual bench can be given user defined names. The software anyway provides default names with auto naming extension e.g. PID2 or fileIO3 or Datalogger4 etc.

A) **Single PID controller operation:**

This is the main window of PID controller as shown below. This is your main control panel of the controller.

Fig. B.9: Main PID controller window

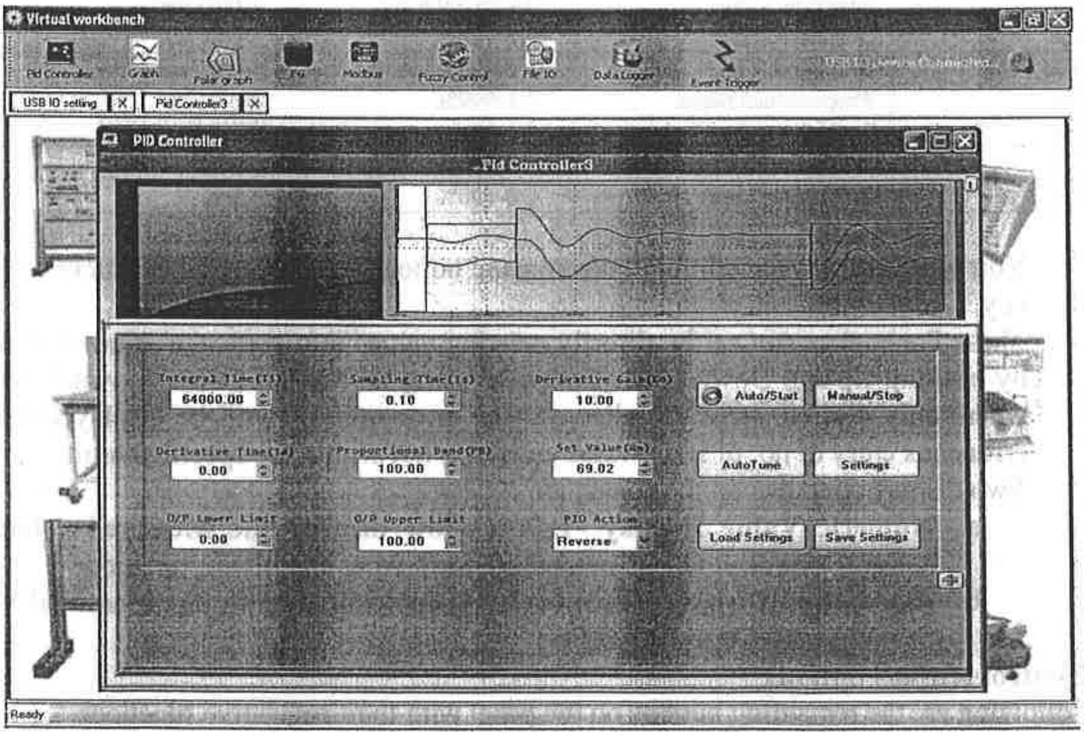
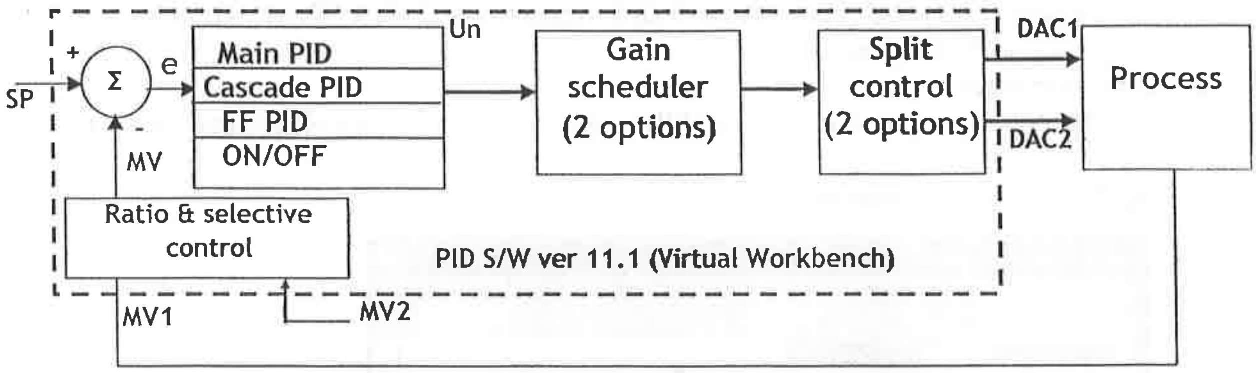


Fig. B.10: Control system block diagram



This control panel includes various PID controller parameters as shown in the table given below that you will have to set. ADC sampling time can be set from 0.1sec to 99.9sec. However even if you set 0.1sec, windows OS due to its overheads may not actually allow you that conversion rate but slow down the sampling time by margin of around 20%. This % will decrease as you set higher & higher Ts time. This is the interval at which ADC is triggered for conversion. It will always convert data from any 2 out of 4 channels at every Ts rate, as set by the channel select button under settings.

Table B.3: Parameters & their ranges

Symbol	Parameter	Range	Resolution
Ti	Integral Time	0.01-64000 sec	0.01 sec
Ts	Sampling Time	0.01-99.9 sec	0.01 sec
Kd	Derivative Gain	0-1000	0.01 sec
Td	Derivative Time	0-999.9 sec	0.01 sec
Pb	Proportional Band	1-999%	0.01 %
Rn	Set Value	0-99.9	0.1 %
Ul	O/P Lower Limit	0-100%	1 %
Un	O/P Upper Limit	0-100%	1 %

You can shift between edit button/command button either using mouse clicks or TAB key.

These Parameters can set by directly entering values into particular window or while by clicking Up and Down arrow button, or using the Up and Down key on keyboard where only discrete steps are allowed. The error message will be displayed for any erroneous entry of no. or if the value entered is not within the specified limit.

Two display windows on the screen are

a. **Numeric Value Display** -This window displays the Measured value, Set Value, Controller O/P in percentage form when the PID in run mode.
b. **Bar Graph Display** - This window graphically displays the Measured Value, Set value and Controller O/P.

Control settings buttons

Following are the remaining buttons on the panel with their respective functions.

i) **Auto/Start:** This buttons is used to start On-Line PC based PID Control after configure of all Parameter.

ii) **Manual/Stop:** In auto mode Stop button used to Stop On-Line PID Control to change the parameter or end the Process.

In manual mode, on click set point value will be output passing through forward reverse action selected on main PID window i.e. x or 100-x etc as the controller output (Un) on DAC. This facility therefore may be used to control valve position manually.

☞ **Note:-** If you need then emergency stop button should be provided on the setup & can't expect software to take care of emergency e.g. use EMT1 stop button etc.

iii) **Auto tune:** To facilitate learning, auto tune process has been split in two steps. Student is expected to determine values of PID parameters by following Ziegler Nichols tuning methods (I or II) after plotting graphs then finding out slopes or time period. The same will have to be saved in file named as process I, Process II etc. Their sequence is same as 9 nos. of spin buttons on the panel starting from left (Integral time) to Right then next line etc. Now whenever you press Auto tune the same is copied into 9 nos. of spin buttons. Of course real life feel is given through appropriate messaging on screen which is to be understood in the context of above auto tuning trainer. Even pressing load setting button will also simulate same function if you specify same file name.

iv) **Forward /Reverse Action (S)**

a) Reverse action- MV increase o/p increases and SP increases o/p decreases.

b) forward action - MV increase o/p decreases & SP decreases o/p increases

v) **Details:** This button used to watch the intermediate result during On-Line Calculation.

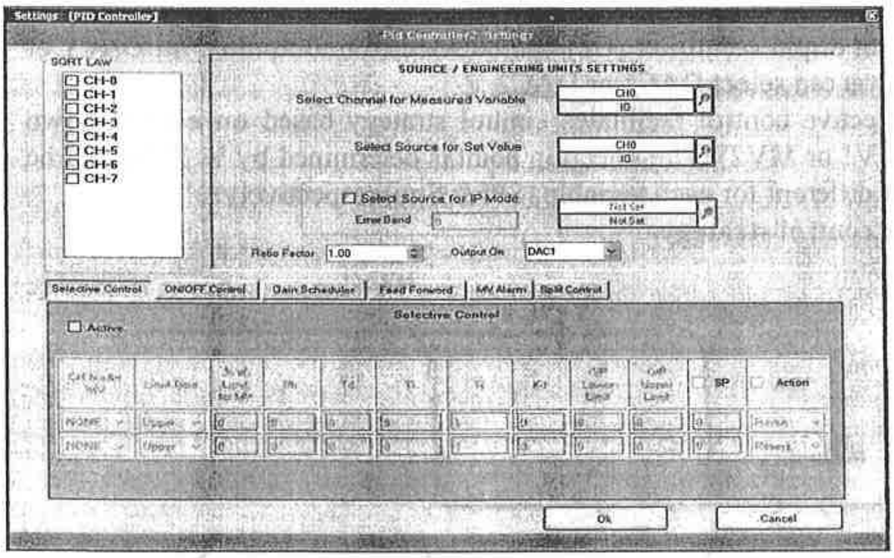
vi) **Save Setting:** This button used to save all parameter at desired path in <u>*. xml</u> File.

vii) **Load Setting:** This button used to Load saved Setting, from *<u>.xml</u> File

viii) **Setting:**

When this button is pressed following window will appears.

Fig. B.11: PID Settings Window



This **button** is used to Set the several parameter as follows:

a) **Select Source for Set value (SP):** SP or set point for pid controller can be selected from Channel or From Panel Set value Window or from another PID controller or internal FG.

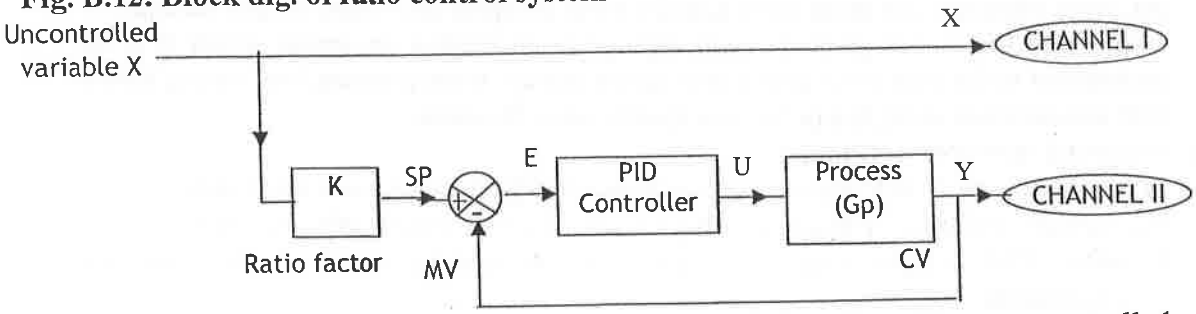
b) **Select Channel for Measured Variable (MV):** Measured variable can be selected from channels or from another pid controller or internal FG.

c) **Sqrt Law**: when DPT flow sensor (Orifice plate) is used, this option must be selected to extract the square root of MV.

d) **Select source for IP mode:** - This mode is used for inverted pendulum experiment only. When this mode is selected it enables the selection of source i.e. FG for inverted pendulum when the MV is within the given band of error as specified in box next to it. Herein when MV values lies beyond error band then FG o/p (set elsewhere) is output to DAC until MV returns to within specified error band and then controller takes over.

e) **Ratio factor: -** This is used for the digital ratio control. The ratio factor will vary from 0 to 2. It will be multiplied to your set value. Set value can be either from panel or from any one of the channels. By default it should be 1. The ratio factor will get multiplied to whatever will be your set point & further it will be fed to the PID controller. This is typically used when a channel is reading a wild variable which is fed to main PID as SP after scaling up/down.

Fig. B.12: Block dig. of ratio control system



The block diagram of ratio control system is as shown below. Here X is a uncontrolled variable. K is the ratio factor. Y is set to follow the X in a given ratio. This is called as a ratio control. Rn (set point) for the ratio based PID controller is = K * X.

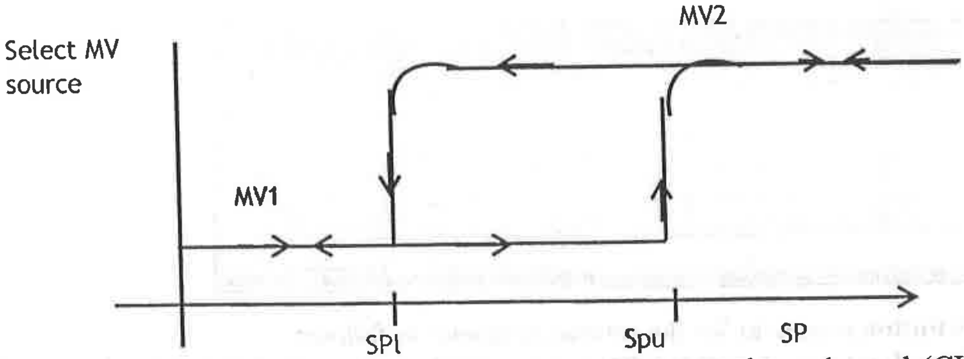
Y will try to follow Rn i.e KX ⇒ Rn = KX

Therefore Y =KX ⇒ K = Y/X = constant ratio.

f) **Output on:** Here output of pid controller (Un) can be selected to outputted on DAC1 or DAC2 or None. Here you can select DAC1 or DAC2.

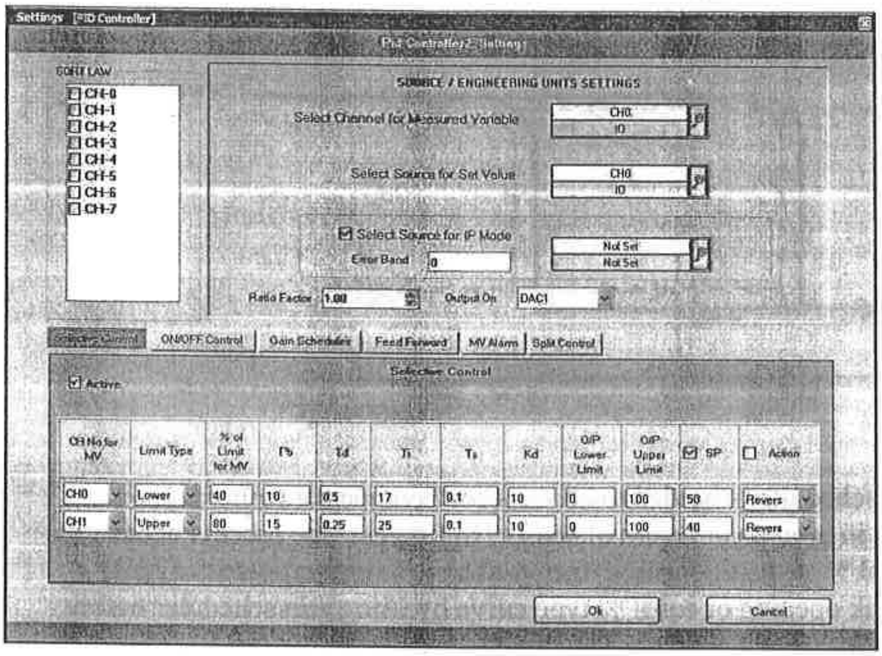
g) **Selective control:** Selective control facilitates control strategy based on either of two feedback variabkes (MV1 or MV2). The selection point is determined by % SP. It can be either same for both or different for each variable.(SPl & Spu) respectively.

Fig. B.13: Selective control strategy.



The source of SP can be either from main PID control window or from channel (CIP). Once source of MV is swapped along with it the set of PID parameters too are swapped as set in the selective control window. To enable selective control strategy you need to tick on active button.

Fig. B.14: Selective control window.



h) **ON/OFF control:** The button when selected enables the controller to output on/off action depending on ± % error band which user has to specify in box next to it. Do not enter ± or % sign, these are assumed. During this PID action is suspended. Error band facilitates creation of hysteresis so that output may not oscillate around threshold.

Fig. B.15: ON-OFF control window

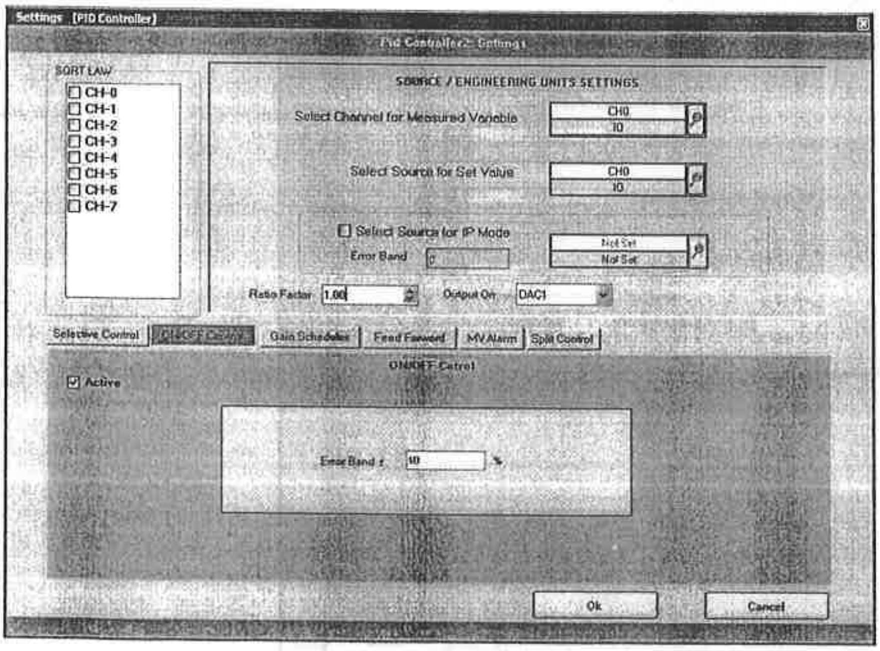
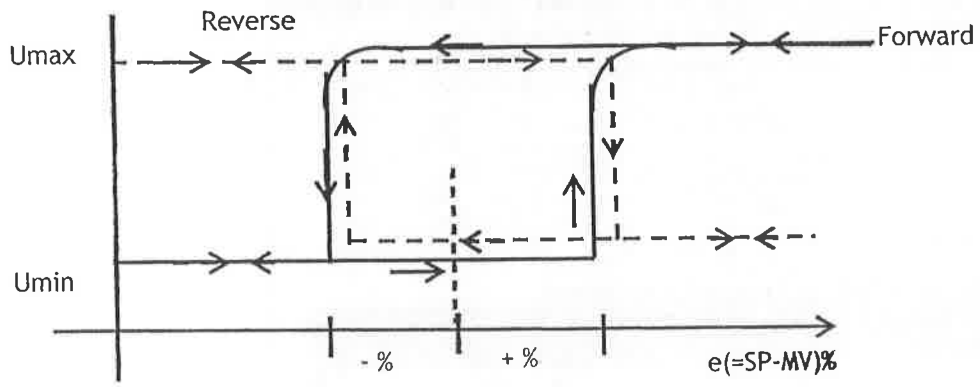


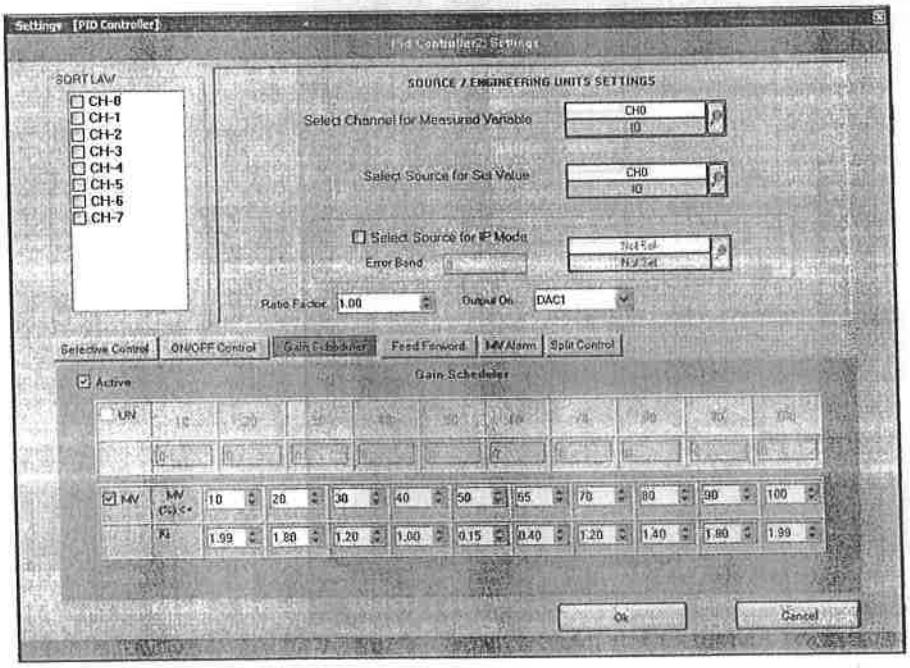
Fig. B.16: ON-OFF control strategy



i) **Gain scheduler:** Gain scheduler is needed to account for / compensate inherent non linearity either inherent in process or nature of sensor. In first case the process needs non linear actuator e.g. equal % or quick opening, then you have to convert output of PID which is linear into quick opening or equal % type curve by using gain scheduler before driving the output (DAC).

In second case, the feedback sensor is non linear as in case of PH sensor which is very sensitive around 7 to 8 PH but as you move away, sensor becomes sluggish in response. In that case many times it is desirable to attenuate PID output (Un) when MV is around 7-8 PH while you can choose to amplify Un as MV moves away say in the region around 12 PH or 4 PH.

Fig. B.17: Gain scheduler window



j) Under feed forward function block exits two options- FF(feed forward) manipulation of Un o/p & KF (Kalman filter) manipulation of MV I/P as shown.

I) Feed forward: - This radio control button is used to select digital feed forward control. Feed forward control is the method of canceling the effect of disturbance on the system.

This is advantageous because, in usual feedback control system, the corrective action starts only after the output has been affected. Consider the system shown in fig. below. However the process should be a known process with its model known.

Fig. B.18: Feed forward control window

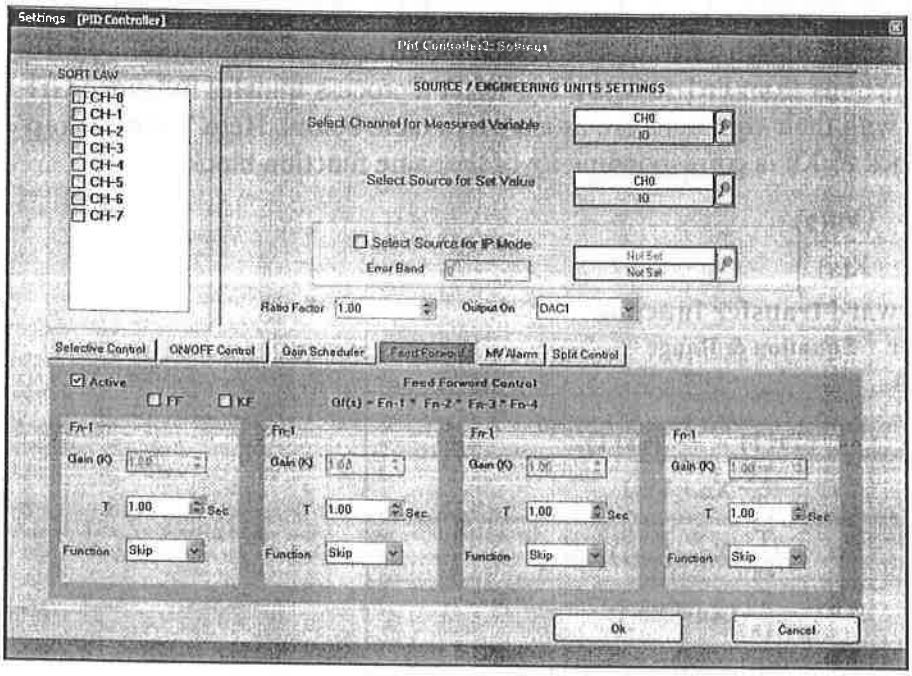
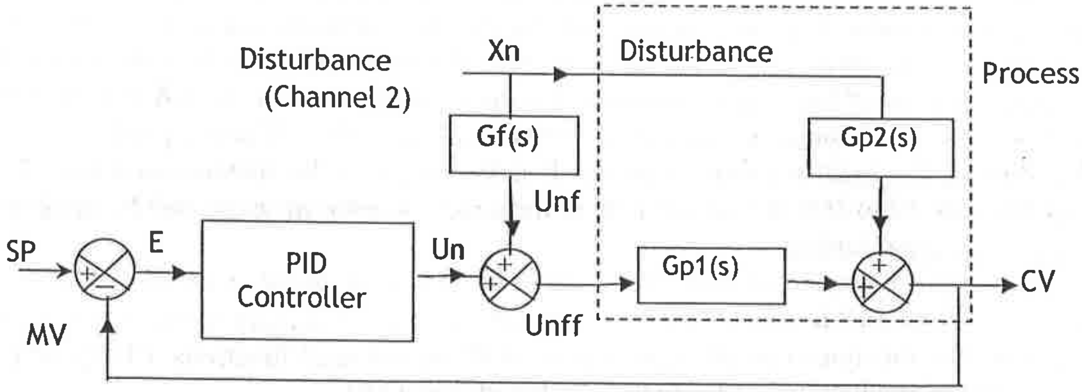


Fig. B.19: Block diagram of feed forward control



The disturbance feed forward transfer function Gf(s) is determined such that effects of disturbance are eliminated in the process o/p Cv. Therefore

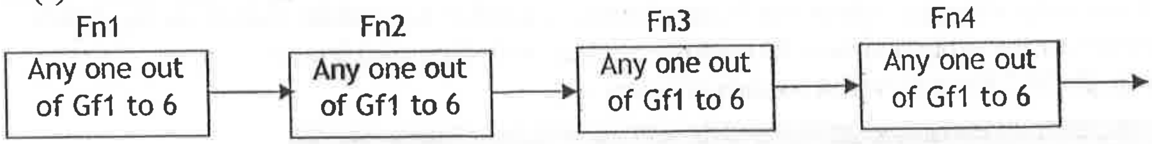
$Gf(s) * Gp1(s) + Gp2(s) = 0.$ ----------- (e1)

Where Gp1 & Gp2 constitute the process which you are supposed to know a priori.

$$Gf(s) = -\frac{Gp2(s)}{Gp1(s)} \quad \text{--------} \quad (e2)$$

There are 4 functions Fn-1 to 4, which will select the feed forward transfer function for your process. The digital feed forward transfer function Gf(s) will be

Gf(s) = Fn1* Fn2* Fn3* Fn4



These functions are accessible to user only when clicked on Feed Forward button. From any one of the selected functions from Fn1 to 4 you can select 6 process transfer functions Gf1 to Gf6. These functions with their equations are as shown in table below. Here Yn is n^{th} o/p of particular function block & Xn is corresponding i/p of the same function block.

Thus

$$Gf(s) = \frac{Y(s)}{X(s)} \quad \text{or} \quad \frac{Unf(s)}{X(s)}$$

Table B.4: Feed forward transfer functions

Function name	Transfer function	Equation & Range
GF1(s)	1/(Ts+1)	$Yn = \frac{T}{(Ts+T)} Yn\text{-}1 + \frac{Ts}{(Ts+T)} Xn$
GF2(s)	1/Ts	$Yn = \frac{Ts}{T} Xn + Yn\text{-}1$
GF3(s)	(Ts+1)	$Yn = \frac{T}{Ts}(Xn - Xn\text{-}1) + Xn$
GF4(s)	Ts	$Yn = \frac{T}{Ts}(Xn - Xn\text{-}1)$
GF5(s)	e^{-Ts}	Yn = Xm where m = n-T/Ts
GF6(s)	K	Yn = K*Xn where K = ± 0.2 to 20

T on the feed forward window is the time constant of the process as you see it from the equations of above table. For our processes on the process simulator panel T is 1Sec. The sampling time (Ts) for these fast processes is 0.1Sec. Therefore T/Ts = 1/0.1=10. Your real time processes will be of large time constants. For these processes your Ts will be large like 10Sec. Therefore T/Ts range is selectable between 10 & 100. Whatever will be your sampling time on the main window, T on the feed forward is to be selected such that T/Ts should be between 10 to 100. If it is not with in the range the error message will be displayed & you can not proceed further.

Fn1 will be the function selected from Gf1-6. O/p of Fn1 will be given as an i/p to Fn2 & so on. Gain (K) will be enable when Gf6(s) is selected. The gain will vary from (+/-) 0 to 20. You can select the functions one after another & SKIP for not used functions. CHANNEL 2 of CIA card is by default assigned for to take in disturbance (Xn).

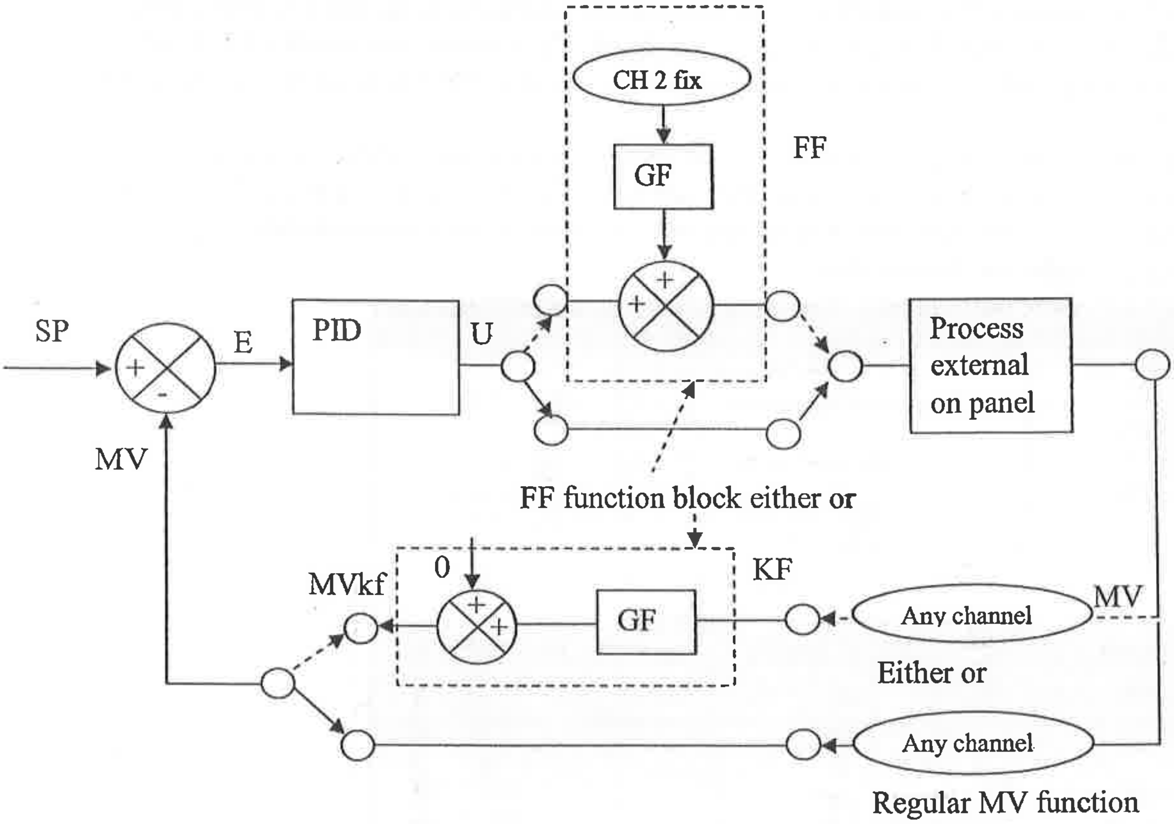
II) Kalman Filter: Kalman filtering, also known as linear quadratic estimation (LQE), is an algorithm that uses a series of measurements of MV observed over time, containing statistical noise and other inaccuracies, and produces estimates of unknown variables (MV) that tend to be more precise than those based on a single measurement alone.

KF radio control button is used to select KF filter. KF is the method of removing disturbance in MV of the system.

The same functions GF1 to GF6 can be applied to MV using kalman filter.

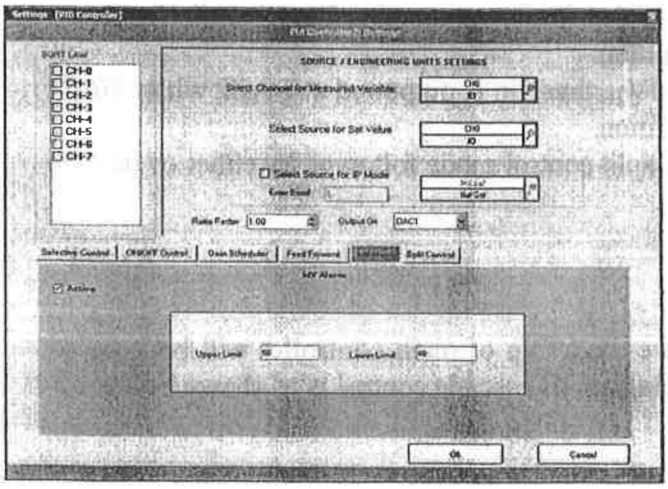
The block diagram of the KF is as shown below.

Fig. B.20: Block diagram of Kalman filter



k) **MV alarm limit**: - the button when selected enables the lower & upper limits of MV. When MV goes below than lower limit & above upper limit the sound will be generated on your system speaker if connected.

Fig. B.21: MV alarm window



l) **Split control:**

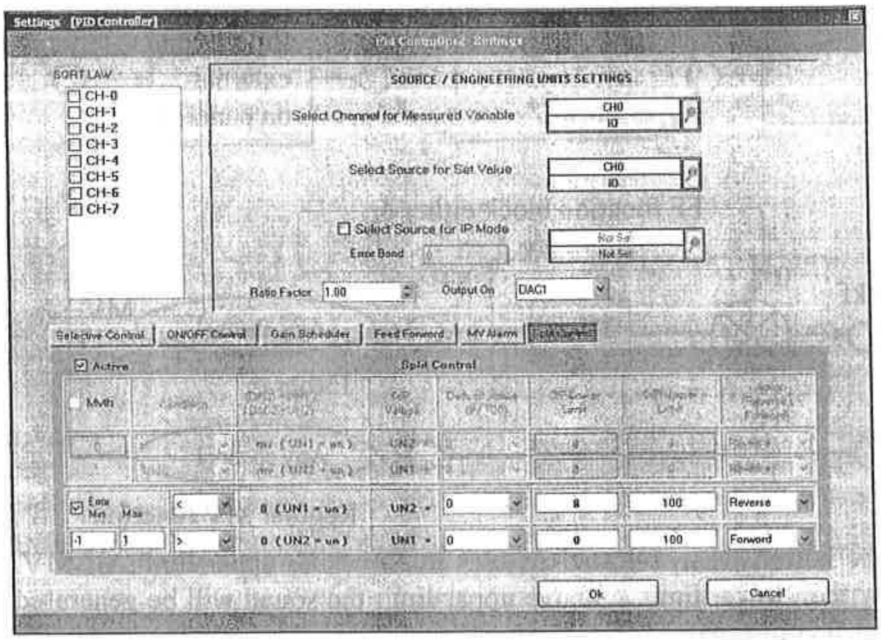
Split control can be either MV based or error based i.e. error sign is needed to be detected.

i) In error based split control either of two outputs (DACs) needs to be driven from PID while other DAC remains in off state depending upon error sign.

e.g. PH process has two dosing pumps one for acid solution & other for base solution. If you wish to increase PH towards 14 then base solution needs to be added & if you want to decrease towards 0 PH then acid needs to be added. The upward movement of PH needs forward acting PID controller while downward movement of PH needs reverse acting PID control.

Inactive (error) band is sometimes needed to prevent continuous shifting between the two PID outputs which appears as oscillatory behavior on MV graph. Once MV is within error band of SP then both outputs are kept off / to default values, thus stability.

Fig. B.22: Split control window



ii) In MV based Split control facilitates control strategy based on MV_{TH} (MV threshold) value which is settable.

a) When actual MV is less than MV_{TH} then Un is outputted at DAC1 while DAC2 should be at 0 or 2.5V at this condition.

b) When actual MV is greater than MV_{TH} then Un is outputted at DAC2 while DAC1 should be at 0 or 2.5V at this condition.

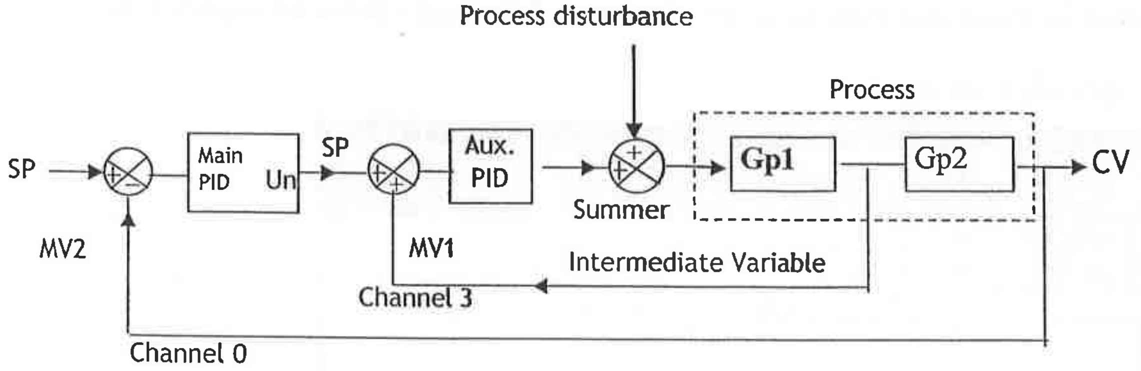
Note: You will have to activate on screen split control mode followed by either of the two options as above.

B) Multiple PID use:

I) Cascade control:

In cascade control two PID controllers are used. O/p of main controller will become set point for the auxiliary controller. The block diagram of cascade control is as shown below.

Fig. B.23: Block diagram of cascade control



For cascade control to be feasible intermediate variable of the process should be available for measurement. The process used in the block diagram is divided in two parts – Gp1 & Gp2. Here MV1 is the intermediate variable available for measurement (channel 3).

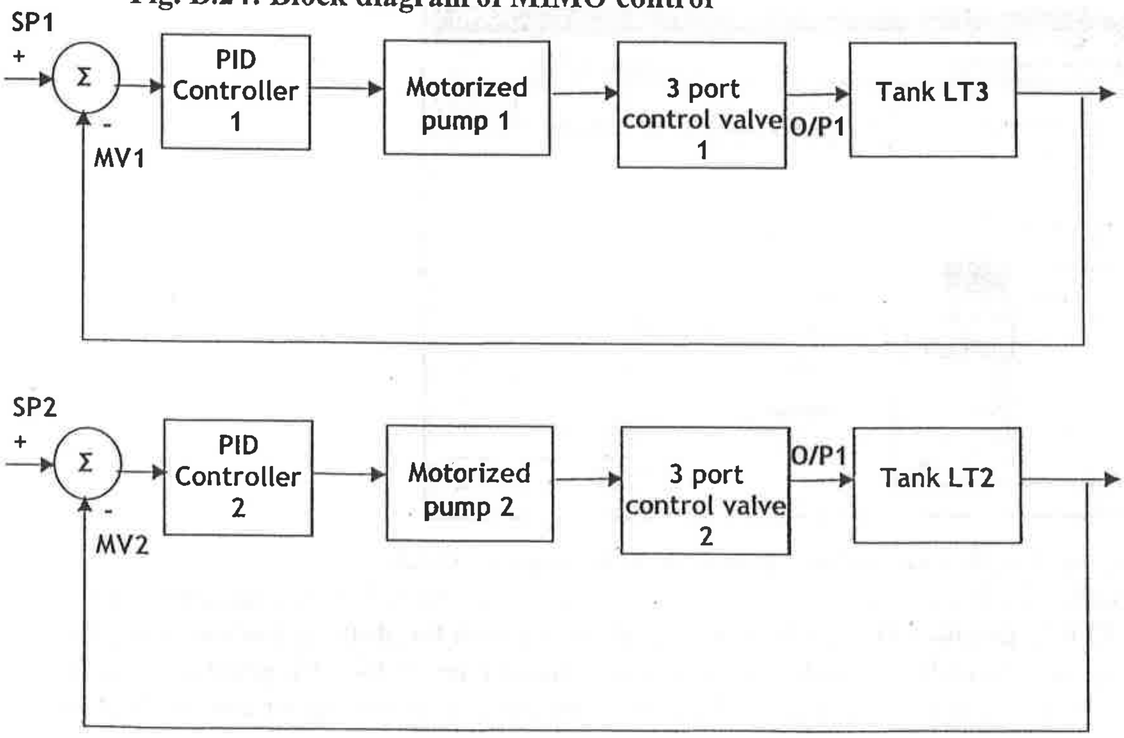
To perform digital cascade control our main pid will be first PID & Auxillary PID will be the second. For cascade control we have to create 2 identical PIDs namely main PID & Auxillary PID. In setting window of Auxillary PID we have to select Un from main PID as SP.

II) MIMO controller:

In this version11.1 software package, user could create multiple instances but concurrently running instances of PIDs obviously will need its I/P channels & O/P DAC channels without overlap i.e. use of CIPII panel.

For example in XPO-PCT/4T we have to use two PID controllers working independently to control the level of two different tanks with two different set points. The two controllers operate independently; controller o/p of each is given to two motorized pumps which control flow in the tank through settable 3 port control valves.

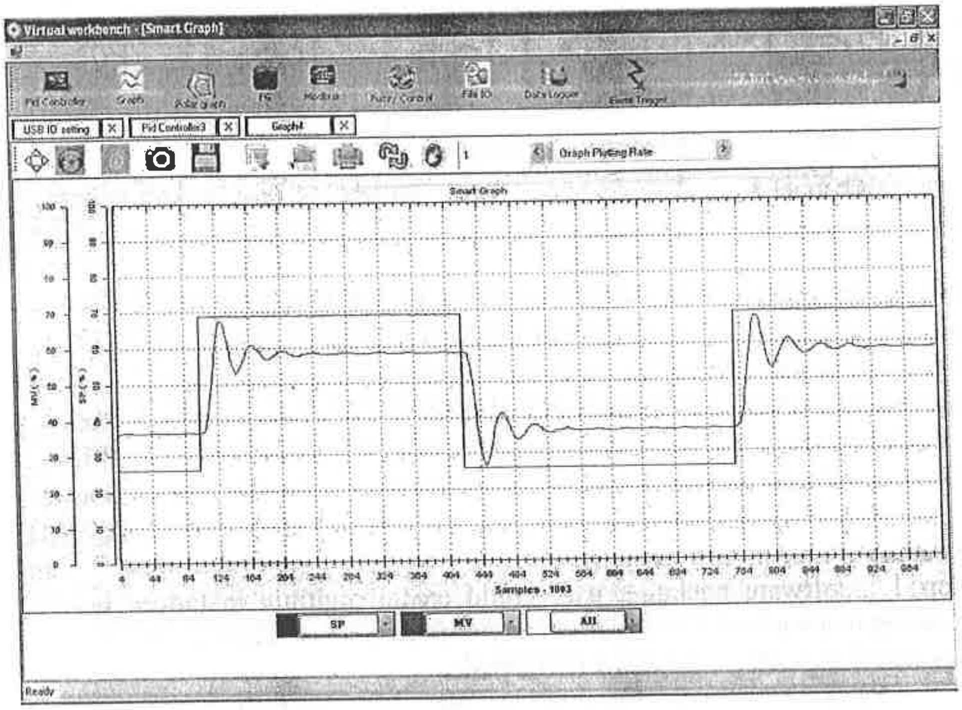
Fig. B.24: Block diagram of MIMO control



3) Graph plotting :

When click on Graph menu button on the main panel, following window of graph will be shown.

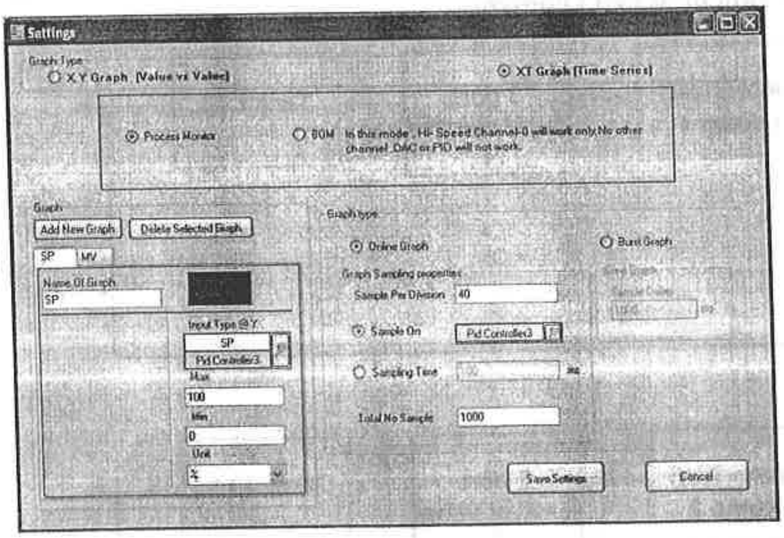
Fig. B.25: Graph window



This window consists of following buttons:

i) **Setting:** When click on this button located at left hand corner of graph window it shows graph setting window as shown below.

Fig. B.26: Graph setting window



At the bottom half of the window consist of following two blocks

a) **Graph:** This block consist of two buttons i.e. add new graph & delete selected graph

Add new graph: This button is used to add new graph for plotting, you can also give name to new added variable. You can select 'Input type' Y (for XT graph) or X & Y (for XY graph) by clicking on drop down window You can select colour to your graph, can give minimum (0%) / maximum (100%) setting for graph, select unit for graph i.e. %, °C, Rpm, V, mm, LPH, Kg/cm2, PH, Usi/cm, Degree etc.

Delete Selected graph: This button is used to remove old graph from the plotting.

b) **Graph type:** This block consists of following selection buttons.

Online graph: When this button is selected online graph of selected channels or parameters is plotted.

Burst Graph: When this mode is selected **'Sample Delay"** box is enabled & you can set time in milliseconds (1ms to 100sec) to plot burst graph. In this graph a burst graph of 1000 samples are plotted at a time interval of time set in 'Sample Delay'.

Sample per division: This box is used to enter the samples / div on graph display. It can be from 3 to 100. For high speed processes using digital PID it will be 3 & for normal process monitoring it will be 40 and for very slow process you may set 100. The graph scale will be divided into the samples / div you selected. But even if you select 3 or 40 every time when you save the graph, total 1000 samples will be saved in the file. This will be helpful when you will plot the graph in 3 samples / div especially when Ts = 0.01sec (Hi-speed) but will be opened later with 40 samples/div. The current sample number will be continuously running & updated at the bottom of the graph under no. of samples.

Sample on: When this button is selected you will get a drop down window displaying IO, PID controller1, PID controller 2 etc. Here you select sample rate for plotting of graph matching with the given list.

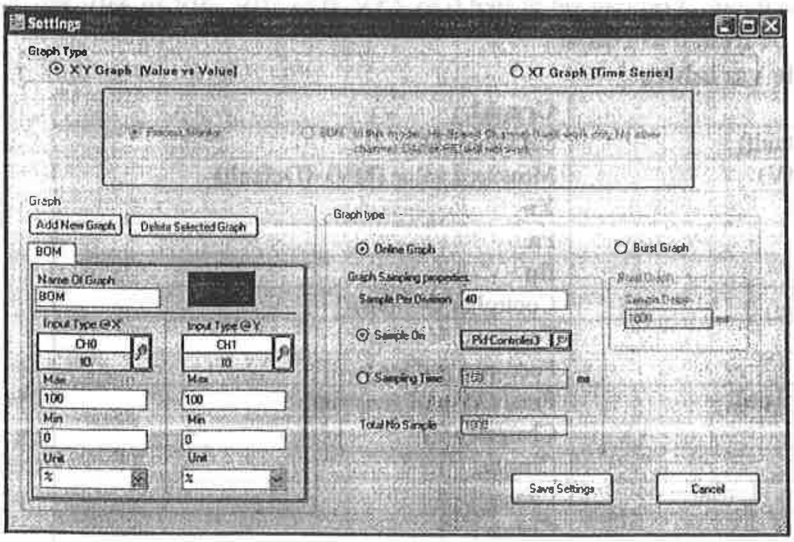
Sampling time: Here you can directly enter the sampling rate of graph plotting in milliseconds from 1msec to 99.9 sec. When this button is selected **'sample on'** button will be disabled.

Total No of sample: Here you have to enter total number of samples to be plotted on the graph. Here you can enter from 1 to 1000 samples in a graph.

In this setting window there are 2 options for graph plotting

c) **XY Graph:** In this mode you can plot various parameters vs another parameters from PID parameters or FG or File IO or Data logger or Modbus or Fuzzy logic etc. In this mode both X & Y selection is user selectable.

Fig. B.27: Graph setting window XY mode



Since you can use data logger to source formulae processed parameters, it will be easy to plot XY graph Online as the signal conditioned sensor info is being manipulated through formulae which can be directly plotted e.g. Q= $\sqrt{\Delta P}$ This is famous formulae specifying flow through orifice in terms of square root if differential pressure across it. This square root can be processed using formula pad / calculator in data logger & resultant output directly used for plotting graph.

d) **XT Graph (Time series):** In this mode X-axis is fixed for time & Y-axis is user selectable. Thus you can plot time Vs channels, PID parameters, FG, modbus parameters etc. The setting window is as shown in fig. In this XT graph mode there are 2 options:

I) **Process Monitoring**

Typically once CIA/CIP-II translates real life voltages (0-2.5V) into numbers, % representation (0- 100%) w.r.t full range of sensor o/p , controller o/p become a very convenient method of representing reality. Hence you observe Un (Controller O/P) & MV (Measured Value) in % terms. Typically 50% line serves as reference line. As the real world varies about 0V within ±9V, the variables on screen are observed to vary about 50% reference line. However during process monitoring since you are observing actual voltage waveforms, you will see 1.25V as reference line & all waveforms seen to vary around it within 2.5V.

Typically you have two or more X axis left side vertical lines representing variables designed on Gaph1 (Left/thick / block) & Graph2 (Right / thin / Red)

This option is used to draw the graphs for the ADC input channels or pid parameters etc. This in the online process monitoring. At a time two or more Channels Graph can be drawn. You can add or delete channel for plotting.

Generally process monitoring can be done at 40 samples/div & digital PID graphs can be plotted on 3 samples /div settings.

Note: In case your PC is of slower speed, then the OS overheads will force the data acquisition s/w miss samples and therefore you will observe reduced width of square wave on the scrolling graph. In such case you are requested to select 3 samples / div in place of 40 samples / div or whatever is deemed appropriate. This will prevent sample loss and therefore graph will appear of constant width.

The basic scale on Y axis in this mode is in %. The min. & max. value can be set from setting window on the panel. You can set at like 0 to 2.5V, 0 to 10V, -9V to +9V etc. by default the range will be from 0 to 100%.

Table B.5: Table of plottable variables

Sr. No.	Graph1	Graph2
1	Set value (SP) (Default)	Set value (SP)
2	Measured value (MV)	Measured value (MV) (Default)
3	Xn	Xn
4	Fn	Fn
5	Bn	Bn
6	Controller O/P (un)	Controller O/P (un)
7	Feedfrwd MV (cn)	Feedfrwd MV (cn)
8	Feedfrwd unf (cn)	Feedfrwd unf (cn)
9	Final O/P unff (unp+un)	Final O/P unff (unp+un)
10	Channel - 0	Channel - 0
11	Channel - 1	Channel - 1
12	Channel - 2	Channel - 2
13	Channel - 3	Channel - 3
14	FG Output	FG Output

II) **BOM:** When this mode is selected all other control like PID, FG will be disabled. This mode will automatically select only single channel graph of channel 0 with respect to time (highest speed) with the sampling rate of 1Khz & in burst mode of 1000 samples acquire then plot in one burst then again acquire and go on continuously until stopped.

ii) **Start Graph:** This button is used to start drawing different graphs.

iii) **Stop Graph:** This button used to stop the graph drawing. In case of digital PID this button will stop only the graph plotting but still the PID is working.

iv) **Take Snap:** This button is used to take photo of the screen graph & save it in .emf file as image file.

v) **Save to Disk:** This button is used to save the points of graphs in a file. Whenever you click on the save option only the points visible on the screen will be saved. Thus max. 1000 samples. No other task should be done while saving graph of process. Doing any other operation while scrolling may disturb your graph due to missed samples.

vi) **Save data to Disk in text format**: This button is used to save the graph data in .CSV file which can be open using note pad or excel format to see readings.

vii) **Open Saved Graph**: This button is used to reopen the previous saved file on the disk & redraw it with all its setting like unit, min/max value etc.

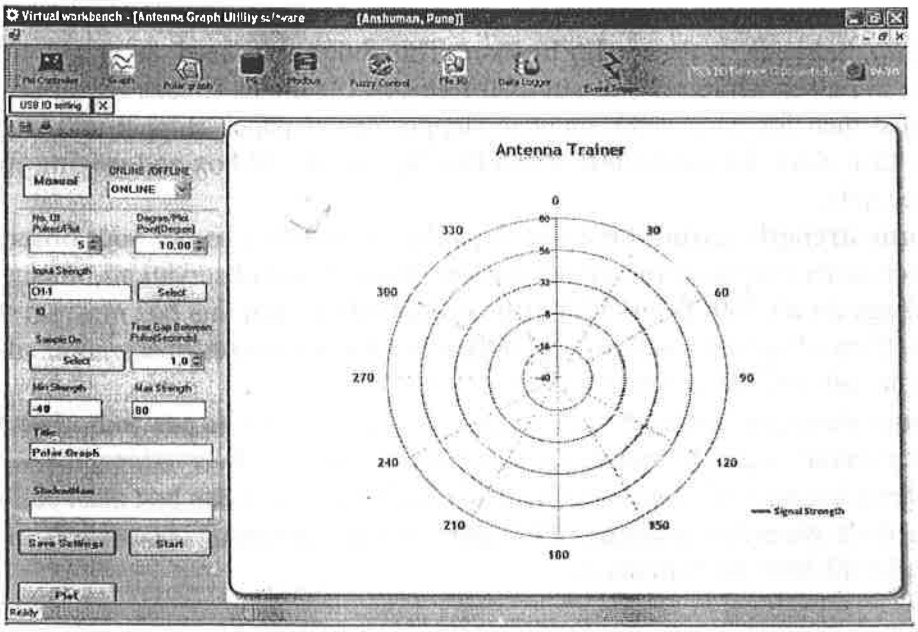
viii) **Print**: This button used to print graph drawn on the screen to printer. If the plotted graph line is overlapping the grid line on the graph sometimes it get suppressed.

ix) **Refresh Button**: This button is used to clear the graph present on the screen. It will not clear setting but clear screen.

4) **Polar Graph:** This option is used predominantly in plotting antenna characteristics (Model XPO-ANT) curve in polar form (360° response). However if PID is concurrently enabled you may try to plot its polar plots if found useful. Mostly in PID you will need time series (XT) graph.

When click on 'Polar Graph' menu on the main panel following window of polar graph will be shown.

Fig. B.28: Polar Graph window



The polar graph software (VWB 11.x) option may be used either in ONLINE mode or OFFLINE mode, for this a drop-down button is provided on the software. Use this button to select the mode of operation as per your experiment. Above is the complete polar graph utility software window shown & also described below the functions of each buttons/boxes.

a) **ONLINE/OFFLINE mode selection drop-down button:** By using this button, you can select Antenna software mode of operation either in ONLINE or OFFLINE. If you wish to plot antenna pattern directly by controlling stepper driver panel to PC & acquiring data from RF power meter, then select the ONLINE mode, while if you have collected data manually for all 360^0 AUT rotation, then use OFFLINE mode & fill the table to plot pattern.

b) **AUTO/MANUAL indicator:** The ONLINE mode is separated into two sections, one is AUTO & other is MANUAL. For this, a toggle switch is provided on the hind side of power meter, use this switch to select either ONLINE-AUTO mode (if at DOWN position) or ONLINE-MANUAL mode (if at UP position, this is default position). In AUTO mode, the indicator changes to GREEN colour & in MANUAL, it changes to YELLOW colour and also text changes either Auto or Manual as per selection.

c) **Degree/plot point edit button:** It is used to set Degree steps for AUT to capture strength in these angle steps, while in ONLINE-AUTO mode. And in OFFLINE mode, set this Degree as per your observations, means if you have taken readings at 10^0 angle steps then set this edit box to 10^0. It is a Floating-point edit box to set angle as per your selections of pulses/plot button; it is ranging from 1.00^0 to 99.00^0

d) **No. of pulses/plot edit button:** This button is useful for capturing signal strength as per the settings used in ONLINE-AUTO mode only. For example if you set this edit box to 3, then antenna software will create 3 clock-pulses for stepper driver by this AUT will rotate to 3 steps & then strength at this last step will be captured & displayed on the polar chart automatically. It is an Integer edit box and ranging from 1 to 99.

e) **Input strength (ADC channel) selection button:** This drop-down button is used for selection of ADC channel, only one channel is to be selected at a time. Internally Channel-1 is selected by hardware itself, by default it is already selected to ADC channel-1, so no need to select while in use. It is ranging from Channel-0 to Channel-4.

f) **Time gap between pulses edit button:** This button is used to create time-gap between to pulses while software in ONLINE-AUTO mode. Means if you set this as 2 seconds, then for each clock input to stepper driver panel, stepper will stop for 2 seconds then clock for next pulse. It is a Floating-point edit box and ranging from 0.1 to 9.9 seconds.

g) **Minimum strength setting box:** Set the value of this box as per your observations for power meter output as minimum strength from all the observations, means if you got readings for all 360^0 from -50.0 dBm to -30.0 dBm, then this box must set to -50.0 because from observed readings -50.0 dBm is the minimum observation of signal strength for all 360^0 AUT rotation.

h) **Maximum strength setting box:** Set the value of this box as per your observations for power meter output as maximum strength from all the observations, means if you got readings for all 360^0 from -50.0 dBm to -30.0 dBm, then this box must set to -30.0 because from observed readings -30.0 dBm is the maximum observation of signal strength for all 360^0 AUT rotation.

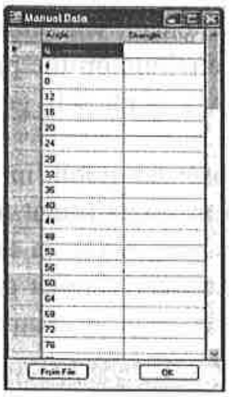
i) **Title text box:** This box is used to write name of antenna for which you are going to take radiation pattern, by writing on this box, the same text will automatically displayed on top of the polar graph. Suppose you are taking readings of Folded-dipole antenna, then write "Folded-dipole antenna radiation pattern", then automatically this will displayed on the polar graph area.

j) **Student name text box:** This box is used to write name of student who are going to take experiments. By writing in this text box, the same will be displayed on the save page (in .doc file).

k) **Start/Stop push button:** In ONLINE-AUTO mode, use this push button to start acquiring of polar graph. If you want to stop the plotting sequence, then click on the same button to stop the plotting of polar graph.

l) **Plot push button:** When clicking this push button, a table will pop-up with columns Angle & Strength, fill the table for all 360^0 and click the OK button to plot antenna pattern, this button is only used in OFFLINE mode.

Fig. B.29: Table of Angle versus signal strength in OFFLINE mode



NOTE:

i) A "From-File push button" is provided on the OFFLINE manual data entry table for directly filling the data from a specific file (i.e. data from temp-file, as discussed below).

Temp Data File: If you are observing data by using ONLINE mode, then observed signal strengths at each angle will also be saved automatically at software setup path as **tempdata.ans** (i.e. where the setup file is stored in your PC), generally this will saved in the following path;

C:\Program Files\STS\SetupPolar\Polar graph\ tempData.ans

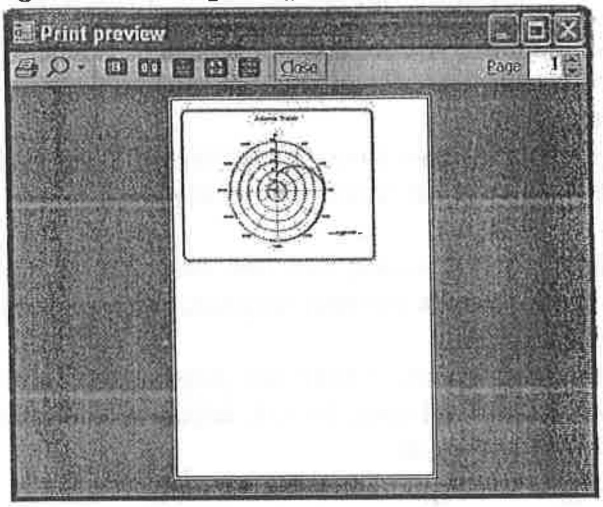
Use "Notepad" to read this file by using open-with icon & select Notepad.

Importing File: You can also import file from the saved temp-data.ans file, whatever observed in ONLINE-mode by clicking on the "**From-File button" of** Manual data entry table.

ii) While entering signal strengths on the above table, if somewhere, your observed readings is out-of the maximum & minimum strength settings, then data of that angle position will be automatically truncated to either maximum or minimum set value & also the pattern is out-of the polar graph. Then at this condition, again click the setting button, and change the strength settings to appropriate value.

m) **Print Graph icon:** This icon is used for printing of observed polar graph by simply clicking on it. First it shows the print preview window as shown below;

Fig. B.30: Polar print preview window



By using this window, you can zoom out the graph to check your observed readings and also can select no. of pages to print. And finally clicking on the print icon of this preview window (provided at top-left corner of window), graph will get printed out by the default printer connected to the PC.

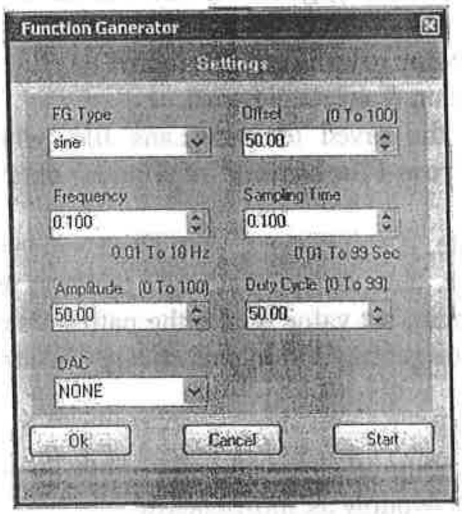
n) **Save Graph icon:** This icon is used to save your observed graph in .doc format by directly clicking on this icon. The file will be saved as, experiment name (whatever you wrote in title text box), student name (whatever you wrote in name of student name text box) and signature of class teacher with the observed polar graph.

o) **Close/Minimize/Maximize icons:** If you wish to minimize or maximize or close this software window click on the appropriate icon (as usual).

5) **Function Generator (FG):**

To set FG click on 'FG' menu on the main panel of virtual work bench, you will get following FG window:

Fig. B.31: Function generator

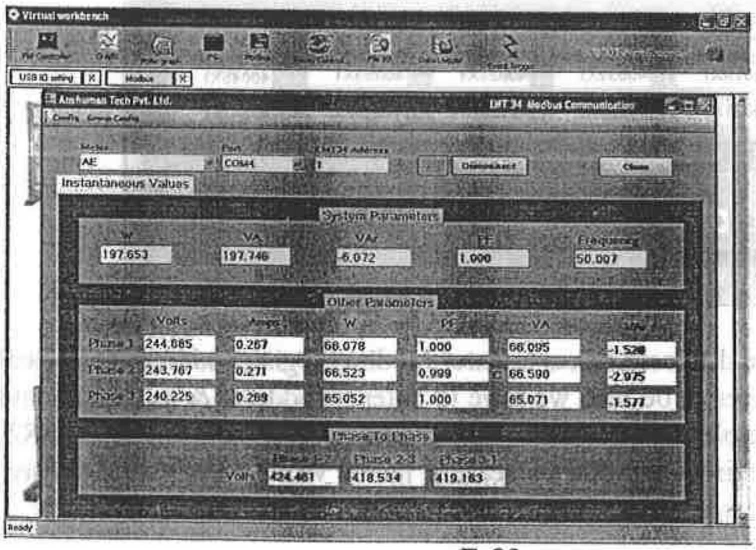


This FG panel consists of various parameters setting buttons which we have to set for operation. This is a software generated FG used to give SP change in PID.

a) **FG type (Wave selection):** This is the drop down window when pressed; it will display Sine, triangular & square or Ramp through use of duty cycle control setting. We have to select any one the three waves.
b) **Offset:** This is a increment/decrement button used to add offset to the selected waveform. You can enter the offset from 0 to 100%.
c) **Frequency:** This is also an increment/decrement button used to set or enter the frequency of selected wave. You can set the frequency from 0.001 to 10Hz.
d) **Amplitude:** This is also a increment/decrement button used to set or enter the amplitude of selected wave. You can set the amplitude from 0 to 100%.
e) **Duty cycle:** This is also an increment/decrement button used to set or enter the duty cycle of selected wave. You can set the duty cycle from 0 to 100%. This will enable you to construct Ramp out of triangular wave.
f) **DAC:** This is a drop down window when pressed it will display None, DAC1 & DAC2. We have to select any one these three outputs. When DAC1 is selected FG output will be available on the DAC1 for the control of external world. When 'None' is set, FG O/P is not brought out but it can be internally used for internal SP manipulation.
g) **OK:** This button is used to accept the entered data in FG block. After entering or changing any above setting we have to press this button to accept the new value.
h) **Stop/Start:** This button is used to start or stop the FG block.

6) **Modbus:** This is modbus RS485 interface of different types of multifunction meters useful to read all parameters of the meter. You have to use Rs485 to Rs232 (or Rs485 to USB) converter to interface meter with PC USB port & connect the multifunction meter. Typically the data over modbus gets updated every 1 sec.
Note:
1) Under this menu you can only read modbus data & cannot write to modbus device.
2) To use Modbus facility, it does not need any hardware module other than your meter & converters as above.
To set modbus interface click on 'Modbus' menu on the main panel of virtual work bench, you will get following EMT34 modbus communication window

Fig. B.32: Modbus interface



This Modbus panel consists of various setting buttons which we have to set for operation as below.

a) **Meter (Selection):** This is drop down button when pressed will display three meters i.e. AE, Krycard PLM cube 415 & Rishab delta energy. We have to select the meter which we have connected to the USB port though RS485 to USB converter.

b) **Port (Selection):** This is also a drop down window when clocked will display list of com ports like COM1, COM2 etc. We have to select the comport where our meter is connected.

c) **EMT34 address:** Here we have to enter the device/meter ID from 1 to 255.

d) **Connect/Disconnect:** This button is used to make or break communication with the device/meter. When the communication with the device is succeeded the indicator just on the left of this button will becomes green otherwise it will be red i.e. communication failed.

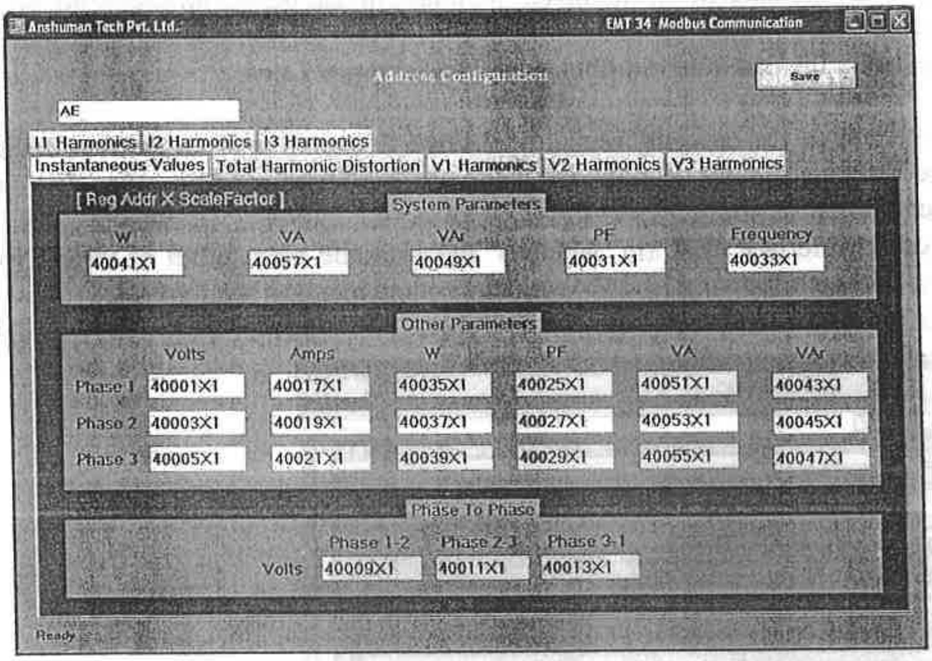
e) **Close:** This button when pressed will minimize the Modbus window.

f) **Instantaneous values:** When click on this button it will display all instantaneous parameters of the meter for all 3 phases like voltage, current, Watts, PF, VA, Var, phase to phase voltages & system parameters like total watts, VA, Var, system PF & Frequency.

g) **Total Harmonic Distortion:** When click will display total harmonic distortion in % for voltage & current for all three phases.

h) **Configuration (Config) :** This button is used to set the configuration of device/ meter to be connected. When click on this button following window will open.

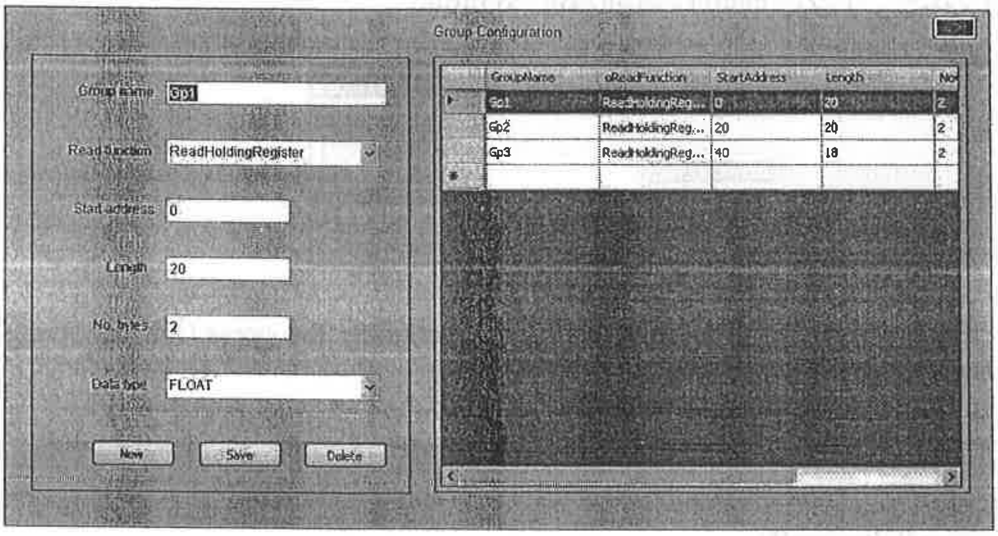
Fig. B.33: Modbus Configuration window



In this window there are different boxes to enter modbus register address & its scaling factor. For each parameter to be read we have to enter its address & its corresponding scaling factor. For example in krycard meter, System PF register address is 41820 & PF value in modbus register is 1000 so scaling factor will be 0.001. Therefore we have to enter in PF box as 42820X0.001.

i) **Group configuration:** This is use to create different groups of modbus register to be read from device/meter. When click on 'Group config' you will get following window.

Fig. B.34: Modbus group Configuration window



This window consists of following buttons & boxes:

i) **Group name:** Here we have to enter some group name like GP1, GP1 etc which we have creating

ii) **Read function:** This is drop down window, when click will display three options i.e. Read Holding register, Read coil and Read input register. We have to select any one of this depending upon the modbus register of meter which we are going to read. Mostly we have to select read holding register or input register.

iii) **Start address:** Here we have to enter starting address of modbus register from which we star to read. For example if 42816 is the star address of register then we have to enter 2816 in the box of star address, the initial 4 stands for holding register so neglect it.

iv) **Length:** Here we have to enter the length of register we are reading i.e. how many register we want to read from the device for that group. So here we enter numbers like 10, 20 etc. Typically longer string lengths >20 causes reading problems with the meter.

v) **No. of bytes:** Here we have to enter no. of bytes to be read from that register. Typically it will be 1 or 2 bytes.

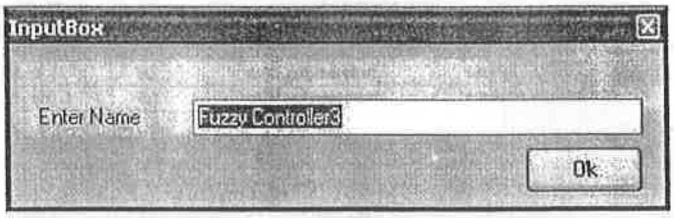
vi) **Data type:** This is drop down button when click will display 5 numbers of data types i.e. LONG (long integer), INT (Integer), SINGNED_INT (Signed integer), FLOAT (floating point), SWAPPED_FLOAT (swapped floating point). Here we have to select any one of the above data types depending upon data type used in the device/meter for modbus register.

vii) **New:** This button is used to create new group. When click on this button new blank window with above parameters will come which we have to fill as above.

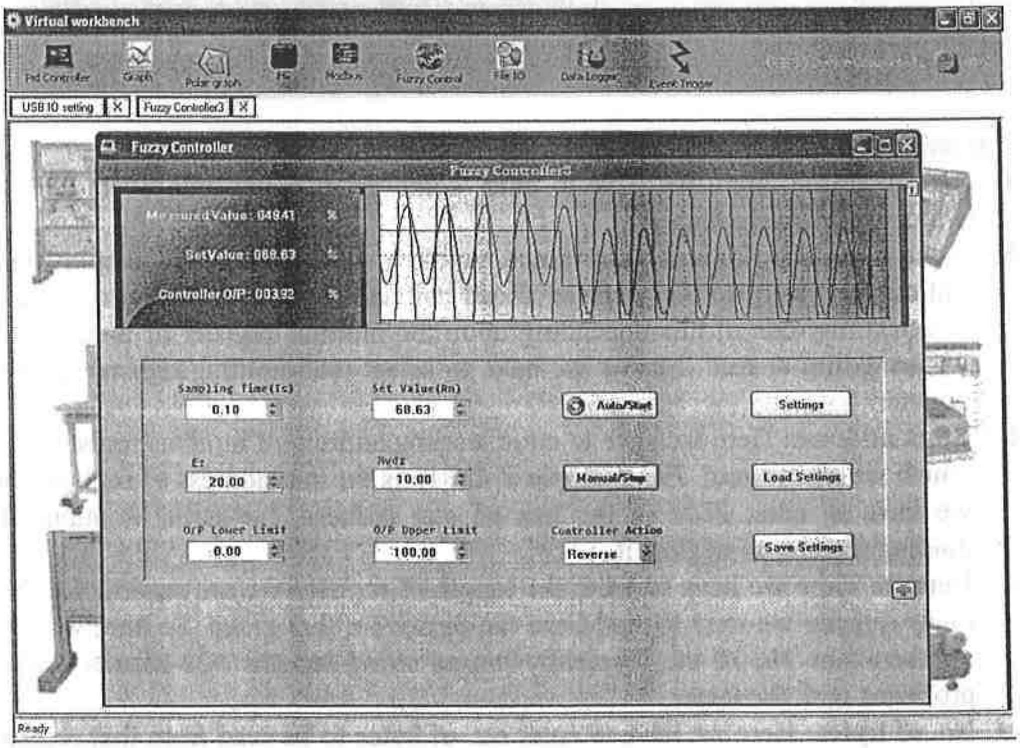
viii) **Save:** This button is used to save the new created group.

ix) **Delete:** This is used to delete any group from the list.

7) **Fuzzy Control:** This is an alternate control strategy similar to PID controller but works on fuzzy logic principle.
For Fuzzy control experiment click on 'Fuzzy control', menu you will get input box as shown below.
Fig. B.35: Fuzzy control Input Box Window



In this box you can give name your fuzzy controller then press OK following fuzzy controller window will open.
Fig. B.36: Fuzzy control Window



This is your main control panel of the Fuzzy controller.
This control panel includes various fuzzy controller parameters as shown in the table below that you will have to set. ADC sampling time can be set from 0.01sec to 99.9sec. However even if you set 0.01sec or below, windows OS due to its overheads may not actually allow you that conversion rate but slow down the sampling time by margin of around 20%. This % will decrease as you set higher & higher Ts time. This is the interval at which ADC is triggered for conversion. It will always convert data from any 2 out of 4 channels at every Ts rate, as set by the channel select button under settings.
These Parameters can set by directly entering values into particular window or by clicking up and down arrow button. If the value entered is not within the specified limit then it will take minimum or maximum value depending on entry.

Table B.6: Parameters & their ranges

Symbol	Parameter	Range	Resolution
Ts	Sampling Time	0.01-99.9 sec	0.01 sec
Rn	Set Value	0 - 99.9	0.1 %
Ez	Error	0.1 – 99.9	0.1%
MVdz	Error dot	0.1 - 999	0.1
Ul	O/P Lower Limit	0-100%	0.1 %
Uh	O/P Upper Limit	0-100%	0.1 %

Two display windows on the panel are

a) **Numeric Value Display** -This window displays the measured value, set Value and Controller O/P. These are display independently.

b) **Bar Graph Display** - This window graphically displays the Measured Value, Set value and Controller O/P.

Control settings buttons

Following are the remaining buttons on the panel with their respective functions.

i) **Auto/Start:** This buttons is used to start On-Line PC based Fuzzy Control after configure of all Parameter.

ii) **Manual/Stop:**

a. **Stop**: In auto mode Stop button used to Stop On-Line fuzzy Control to change the parameter or end the Process.

b. **Manual:** In manual mode, on click set point value will get output directly as the controller output (Un) on DAC. This facility therefore may be used to control valve.

iii) **Save Setting:** This button used to save all parameter at desired path in *. xml File.

iv) **Load Setting:** This button used to Load saved Setting from *.xml File

v) **Controller action:** This is a drop down window when click will show following two options.

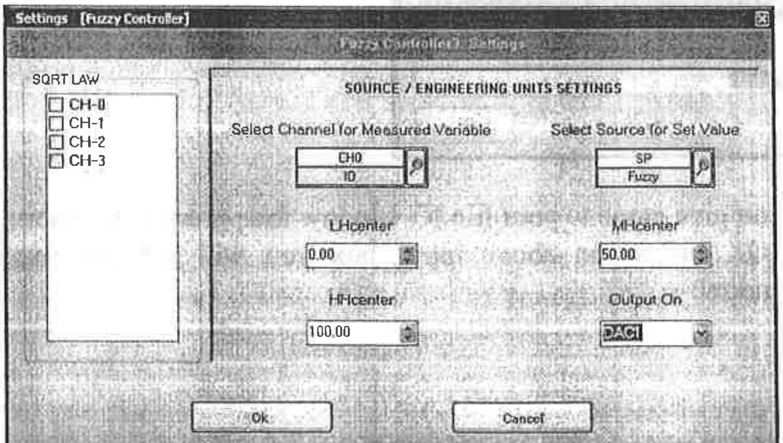
a) Reverse action- MV increase o/p increases and SP increases o/p decreases.

b) Forward action - MV increase o/p decreases & SP decreases o/p increases

vi) **Details (+ symbol):** This button used to watch the intermediate result during On–Line Calculation. When click on + symbol at right side below of the panel, it will display values of R1 to R9.

vii) **Setting:** When this button is pressed following window will appears:

Fig. B.37: Fuzzy setting window



This window consists of various parameters as below which we have to set

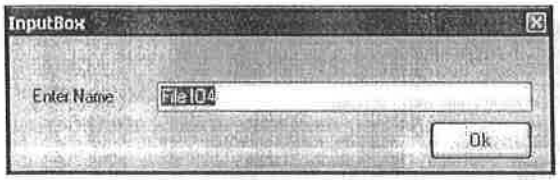
a) **Select Source for Set value: SP** or set point for fuzzy controller can be selected from Channel or from panel set value window or from another fuzzy controller or from Internal FG.
b) **Select Channel for Measured Variable (MV):** Measured variable can be taken from any one channel or from another fuzzy controller or internal FG.
c) **Sqrt Law**: when DPT flow sensor (Orifice plate) is used, this option must be selected to extract the square root of MV.
d) **LH/MH/HH centres**: Here we have to define centers for LH/MH/HH. Default set is LH=0%, MH = 50% & HH = 100%.
e) **Output on**: Here output of fuzzy controller (Un) can be selected to outputted on DAC1 or DAC2 or None. Here you can select DAC1 or DAC2.
f) **OK**: This button is used to save the settings & exits from the setting window.
g) **Cancel**: This button is used to exit from setting window without saving the setting.

8) **File IO:** This option is used to plot simulated graph of different variables using a .CSV file.
For this option first we have to create a .CSV file using excel or notepad. File should be of maximum 4 columns separated using commas on each line (3 commas per line) when observed in notepad.

Fig. B.38: File IO preview

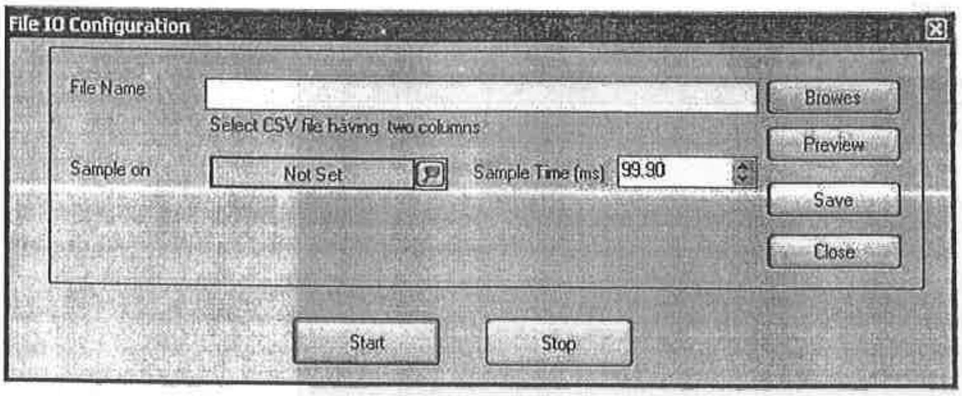
For file IO experiment click on 'File IO' menu on the main panel of the virtual work bench you will get following input box window.

Fig. B.39: File IO input box



In this box you can give name to your file IO window then press 'OK' button.
Now click on OK button on above input box you will get following file IO configuration window:

Fig. B.40: File IO configuration window



The above window consist of following buttons

a) **Brows:** This button is used to load the file you have created. When click it will ask for file name, you will have to select file & press open. The file path is displayed in file name text box.

b) **Preview:** This button is use to view the file contain. When click it will display preview of selected file contain.

c) **Sample On:** When this button is selected you will get a drop down window displaying IO, file IO etc. Here you select sample rate for plotting of graph matching with the given list.

d) **Sample time:** Here you can directly enter the sampling rate of file IO in milliseconds from 1msec to 99.9 sec. When **'sample on'** is selected then sample time entered in this window will be ignored & not work.

e) **Save:** This button is used to save changes made in file IO figuration & to save selected file.

f) **Start:** This button is used to start the file IO sampling.

g) **Stop:** This button is used to stop the file IO sampling.

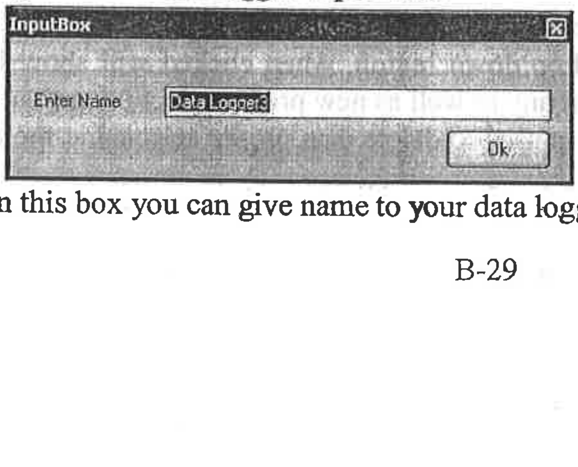
h) **Close:** This button is used to close the file IO configuration window.

Note: To see file IO working, you have to open the graph window as described at point no 3 under (D) section.

9) **Data logger:** Data logger is used to acquire / save data or readings during experiments in .CSV file for later journal printing / entry by students by using USB IO module. Typically use of this functional block is for filling torque- speed observation table & plotting its graph. Of course to read data from modbus, you don't need USB IO module. However the readings of torque & speed will enter PC through USB IO module & attached signal conditioning circuit (0-2.5V range).

To set data logger click on 'Data logger' menu on the main panel of virtual work bench, you will get following input box as shown below.

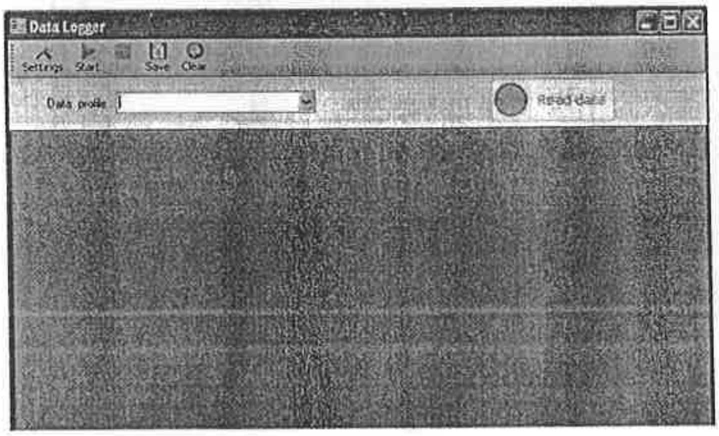
Fig. B.41: Data logger input box.



In this box you can give name to your data logger window then press 'OK' button.

Now click on OK button on above input box you will get following data logger window:

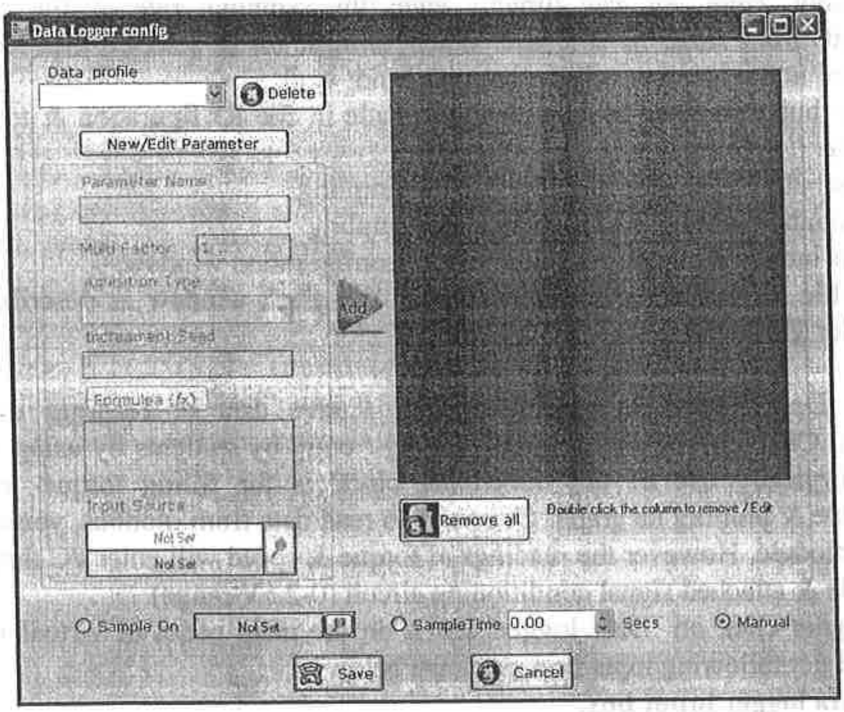
Fig. B.42: Data logger window



This is the main data logger window. This window consists of various buttons as shown below.

a) **Setting button:** This setting button is used to create new data profile or to delete /edit previous stored data profile. When clicked on this button following configuration window will open.

Fig. B.43: Data logger configuration window



This window includes various setting buttons as below.

i) **Data profile:** This is the drop down button, when clicked will show list of data profiles created before if any as well as new profile selection option.

ii) **Delete button:** This button is used to delete data profile selected at the above button.

iii) **New/Edit parameters button:** This button is use to create new profile or to modify previous profile. To create new profile, first we have to select 'New profile' in above Data profile drop down button then click on this 'New /Edit parameters' button, different parameters setting window will be visible as below.

Parameter name: Here we have to enter the name of your first column parameter of the observation table.

Multi factor: Here you can enter any multiplying factor to your first column of observation table. Default it will be 1, if you enter say 0.1 then first column reading will be multiply by 0.

Acquisition type: This is a drop down window, when clicked will display 4 options i.e. Device, manual, Auto increment & Formulae

Here we have to select any one of the above 4 options

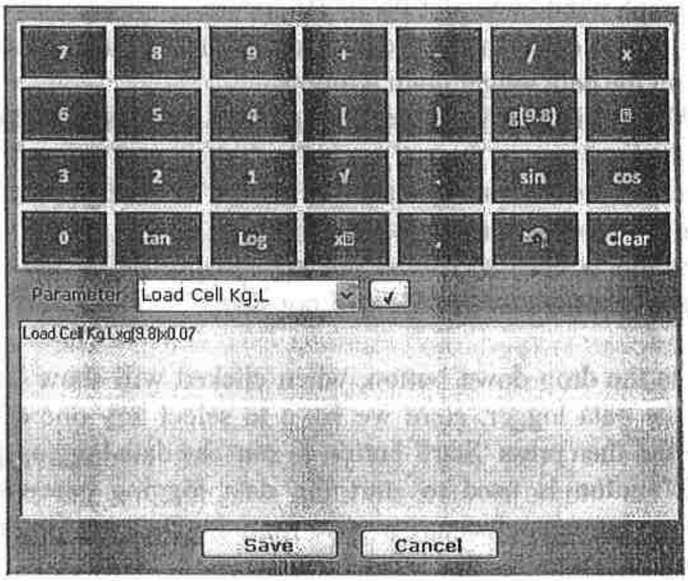
Device: When 'Device' is selected then 'input source' drop down window will be enabled. Now we have to select input source for first column of your observation table. When click on input source list will be display like IO channels, modbus etc, we have to select any one from the list.

Manual: When manual is selected then during data acquisition it will ask for value to enter by manually.

Auto increment: When this selected then 'increment seed' entry box will be enabled. Here we have to enter value to be incremented by. Suppose you enter 1 then during data acquisition the first column reading is incremented by 1 for each data acquisition button pressed.

Formulae: When this is selected then formula entry radio button will be enabled. When clicked on this 'Formulae' button following formula pad will be displayed.

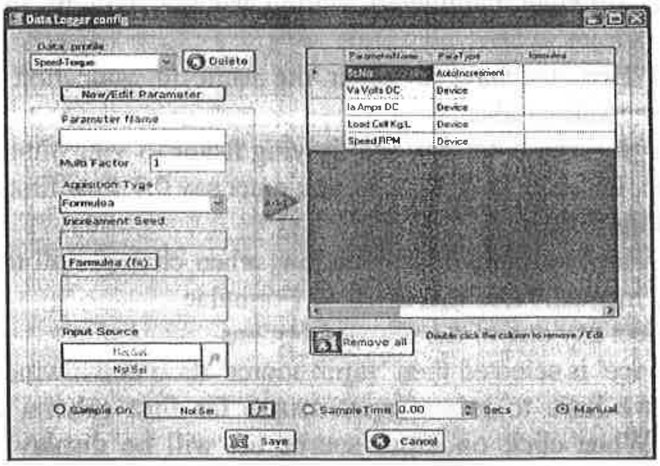
Fig. B.44: Data logger Formulae pad / Calculator



Using above pad you can create any scientific formulae.

After creating formulae, you have to press 'Save' button. After pressing this button formulae pad window will close. Now to add above created first column of your observation table, press "Add' button then the first column is added into the right side blank window.

Fig. B.45: Data logger configuration window with data profile added.



iv) **Sampling time:** Here you can enter sampling time for your data profile from 0.01 to 100 sec. When this sampling time is selected then it will read data at a interval of sampling time & then display.

Sample On: Here you can also use sampling time from PID or any other active components like FG or event trigger or fuzzy control etc. However observe that with extensive mathematical formulae processing available in formulae pad for practical parameters (columns), smaller sampling time below 1 sec may be compromised due to delay in output availability without affecting working of other active components like PID. E.g. You can sample I(t) & V(t) of solar PV output & plot P(t) [=I(t)*V(t)] power verses voltage curve to identify MPP. The resultant variable like P(t) so created in data logger can be used by graph window to plot PV or IV curves.

Manual: When this selected then for data acquisition we have to press 'Data acquire' button on the data logger main window.

v) **Remove all:** When this button is pressed all the profiles will be deleted /removed from the list.

vi) **Save:** This button is used to save the profile created or changes made. While saving new data file it will ask name to save the file.

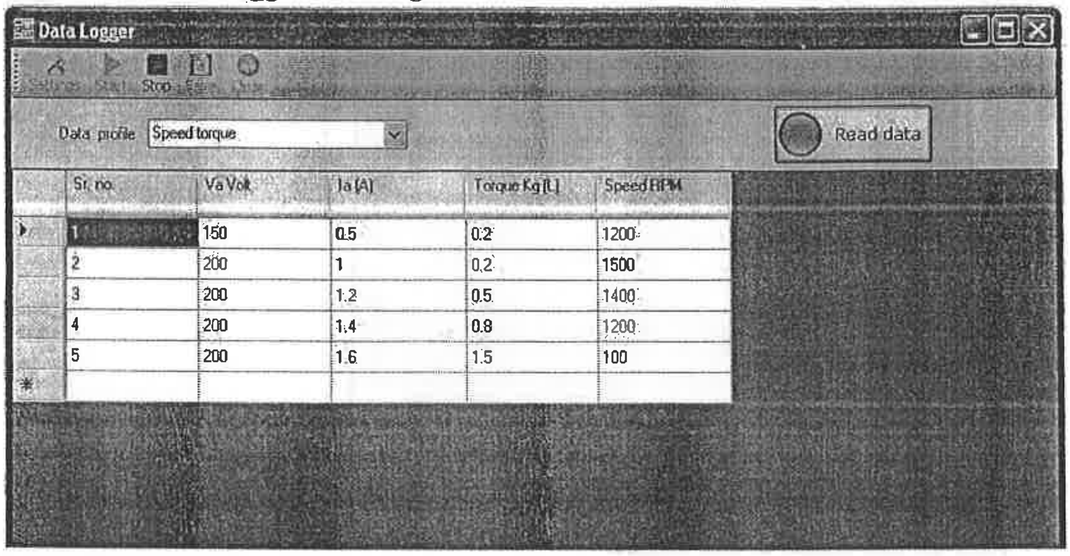
vii) **Cancel:** This button is used to cancel the created profile. If we press this button the changes made or new profile will not save.

b) **Data profile:** This is the drop down button, when clicked will show list of data profiles present in the data logger. Here we have to select any one of the data profile from the list and then press 'Start' button to start the data logging process.

c) **Start Button:** This button is used to start the data logging process. Before pressing this button we have to select any profile from the Data profile drop down box below this button followed by 'Read data' button.

d) **Read data:** This button is used to read the data from the device for the selected profile manually. When this button is pressed the required data is read for the selected data profile & entered in the table which is simultaneously displayed on the screen first reading. For 2nd reading we have to press the 'Read data' button again. For each reading we have to press the 'Read data' button.

Fig. B.46: Data logger running window



e) **Stop**: This button is used to stop the data logging process.

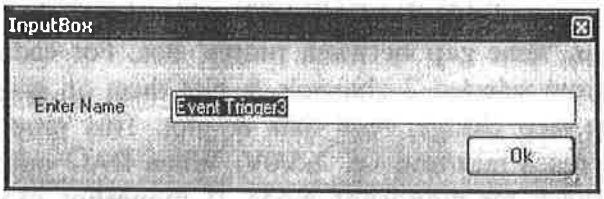
f) **Save:** This button is used to save read data file to .CSV file format. It will ask file name to be saved. Then using excel facility, you can draw graph.

g) **Clear:** This button is used to clear the data table present on the screen for selected profile data.

10) **Event trigger:** Event trigger is used to give step change to output from DAC, read data from ADC & plot the graph of one or two variables (XT or XY) for each step change. For example if we connect DAC o/p to EMT9 socket no 1 which in turn controls the armature voltage to a DC motor while speed & torque of the motor are read through channels of ADC then for each step change manually or automatically we can plot the graph of speed verses torque. Thus using event trigger speed torque characteristics can be obtained. The polar graph plotting is used in XPO-ANT does not need Event trigger but equivalent function is built in into polar graph function block it self.

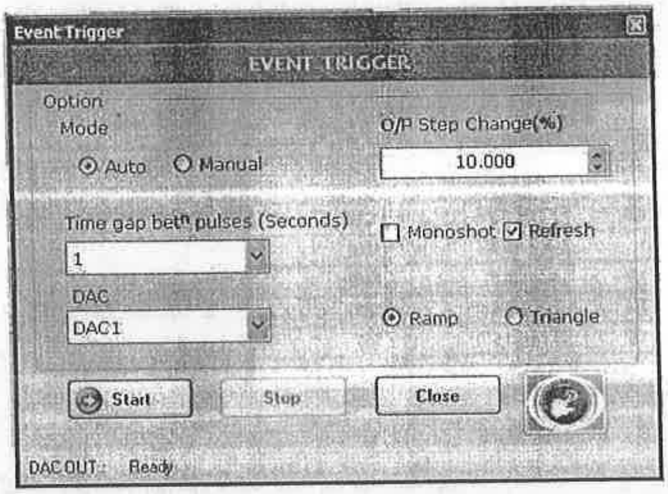
To set event trigger click on 'Event trigger' menu on the main panel of virtual work bench, you will get following input box as shown below.

Fig. B.47: Event trigger input box.



In this box you can give name to your event trigger window then press 'OK' button. Now click on OK button on above input box you will get following event trigger window:

Fig. B.48: Event trigger window



This is the main event trigger window. This window consists of various setting buttons as shown below.

i) **O/P step change:** Here we have to enter the value between 1 to 50 %. The entered value is outputted on corresponding DAC as selected in DAC drop down selection box.

ii) **Time gap bet^{n} the pulses:** Here we have to enter the value between 1 to 20 sec. The output step change is executed after this time gap.

iii) **Ramp:** This is the selection button for 'Ramp'. If ramp is selected the outputted DAC value is reset to zero after maxima reached.

iv) **Triangle:** This is the selection button for 'Triangle'. If this button is selected the outputted DAC value is decremented to zero after maxima reached. You can select either Ramp or Triangle, both can't be selected.

v) **Monoshot:** If this button is selected then above ramp or triangle is executed for a single time only & then it will stop. If this button is not selected then it will continue to plot above ramp or triangle again & again still stop button is pressed.

vi) **DAC:** Here you can select DAC1/DAC2 depends on hardware connected i.e. CIPI/CIPII etc.

vii) **Start:** This button is used to start the event trigger block

viii) **Auto mode (Online):**

When **Auto mode** is selected, it will give step change of min 1% (0.025V) as entered in **'O/P step change'** box to DAC (DAC1/DAC2) with a interval of time gap (1 to 20 sec) as entered in **'time gap between pulses'** box. For each step change it will read the data from selected 2 channels & plot them on graph as Cartesian XY, again give the step change, read data & plot. This process is continuing until DAC output reach max/min i.e. 2.5/0V. When DAC output is reached at max/min it will check **for monoshot** mode, if **monoshot** mode is selected then it will stop & we have to save the file. Otherwise it will check for **clear** button set or not set, if set then it will clear the screen, if not will continue without clearing the screen then it will check for **ramp** or **triangle**, if **ramp** is selected then DAC is directly reset to zero & continue to step change, if **triangle** is selected then DAC is decremented to zero & continue to step change.

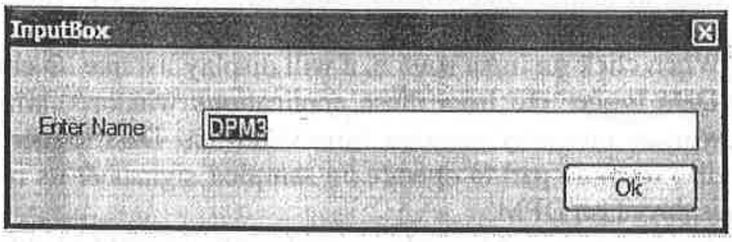
ix) **Manual mode (Offline): When Manual** is selected click of 'Acquire data' button on the front graph window is used to acquire data & plot while external changes in setting to be made manually e.g. knob to change voltage in EMT9 etc

x) **Stop:** This button is used to stop the event trigger block.

xi) **Close:** This button is used to close the event trigger window.

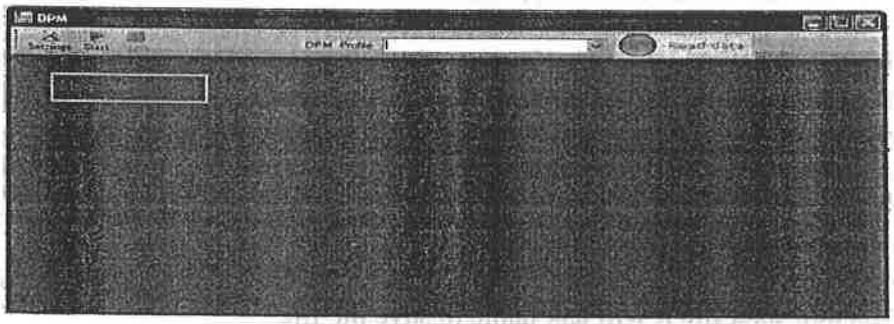
11) **DPM:** The DPM block is used to monitor different parameters from PID, Modbus, Fuzzy control, IO channels, Data logger etc. Maximum 7X6 DPM windows can be displayed on the screen. You can create multiple pages of such DPM screens.
To open DPM window click on 'DPM' menu on the main panel of virtual work bench, you will get input box window as shown below.

Fig. B.49: DPM input box window



In this box you can give name to your DPM window then press 'Ok' button.
Clicking on 'OK' button you will get following DPM window.

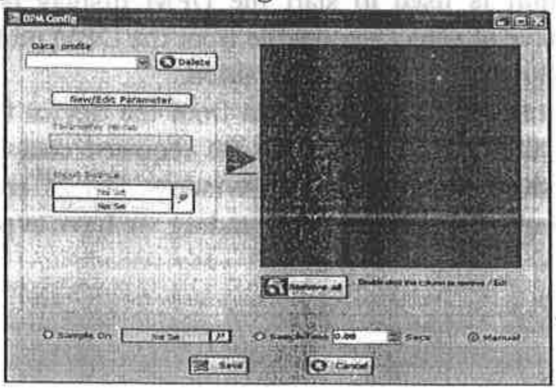
Fig. B.50: DPM main window



This is the main window of DPM panel. This window consists of various buttons as shown below.

a) **Setting button:** This setting button is used to create new data profile or to delete /edit previous stored data profile. When clicked on this button following configuration window will open.

Fig. B.51: DPM setting window



This window includes various setting buttons as below.

i) **Data profile:** This is the drop down button, when clicked will show list of data profiles created before if any as well as new profile selection option.

ii) **Delete button:** This button is used to delete data profile selected at the above button.

iii) **New/Edit parameters button:** This button is use to create new profile or to modify previous profile. To create new profile, first we have to select 'New profile' in above Data profile drop down button then click on this 'New /Edit parameters' button, different parameters setting window will be visible as below.

iv) **Parameter name:** Here we have to enter DPM name indicating which parameters you want to display like voltage, current, SP, MV etc which will display on the top of the DPM.

v) **Input source:** When click on input source, it will display list like IO channels, modbus, PID, Data logger etc from these applications windows, which are open already, we have to select any one from the list. Data logger option enables you to use formula pad to operate on sampled signals & its resultant output can be displayed on DPM.

vi) **Add button:** This button is used to add created profile of DPM in the right side window. For each DPM profile created we have to press Add button.

vii) **Sampling time:** Here you can enter sampling time for your data profile from 0.01 to 100 sec. When this sampling time is selected then it will read data at a interval of sampling time & then display on the DPM panel.

Sample On: Here you can also use sampling time from PID or any other active components like FG or event trigger, Fuzzy etc.

Manual: When this selected then for DPM display we have to press 'Read data' button on the DPM main window.

viii) **Remove all:** When this button is pressed all the profiles will be deleted /removed from the list.

ix) **Save:** This button is used to save the profile created or changes made. While saving new data file it will ask name to save the file.

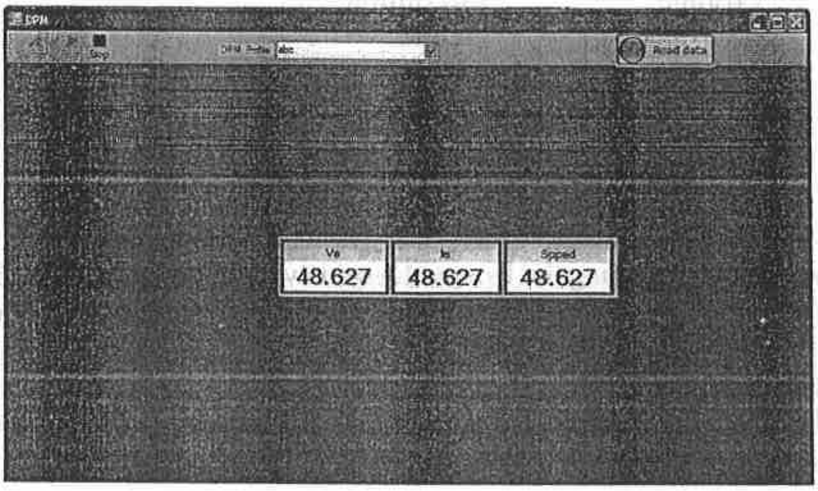
x) **Cancel:** This button is used to cancel the created profile. If we press this button the changes made or new profile will not save.

b) **DPM profile:** This is the drop down button, when clicked will show list of DPM profiles present in the DPM panel. Here we have to select any one of the DPM profile from the list and then press 'Start' button to start the DPM display process.

c) **Start Button:** This button is used to start the DPM display process. Before pressing this button we have to select any profile from the DPM profile drop down box below this button followed by 'Read data' button.

d) **Read data:** This button is used to read the data from the device for the selected profile manually. When this button is pressed the required data is read for the selected DPM profile & displayed on the DPM window. For 2nd reading we have to press the 'Read data' button again. For each reading we have to press the 'Read data' button.

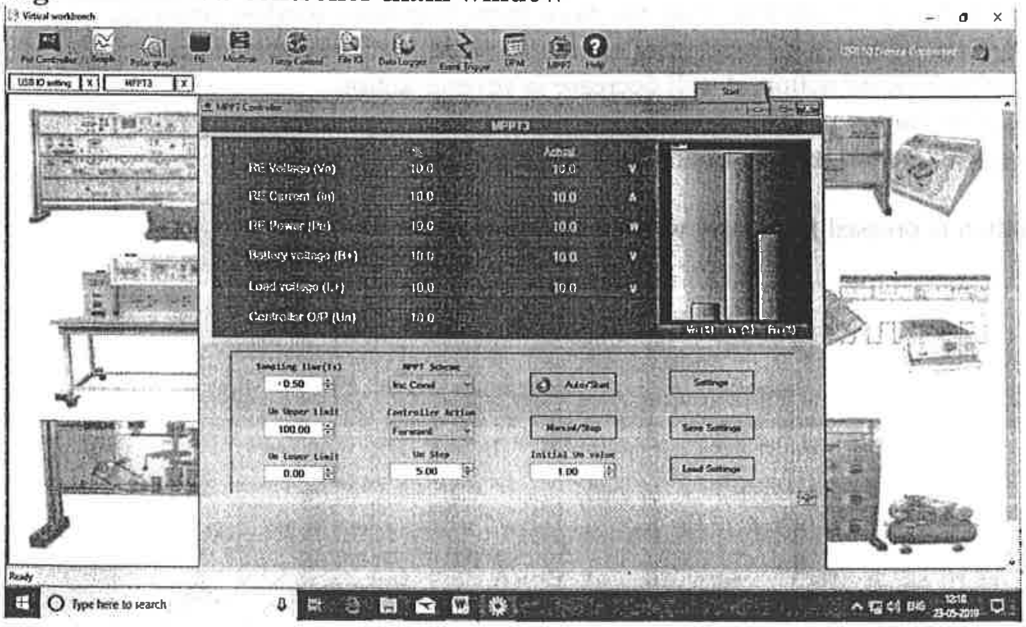
Fig. B.52: DPM running window



e) **Stop button:** This button is used to stop monitoring the DPM process.

12) **MPPT controller:-** Abbreviation of MPPT is Maximum Power Point Tracking. This function block is used to control maximum power point (MPP) using 3 schemes i.e. incremental conductance (Inc Cond), Perturb and Observe (P&O) and 75% of Voc algorithms for battery charging. This facility is also used for plotting IV & PV curves of renewable energy sources like solar or wind etc.
The main window of MPPT controller is as shown below

Fig. B.53: MPPT controller main window



This control panel includes various MPPT schemes & respective controller parameters as shown in the table given below that you will have to set.
RE = Renewable Energy

Table B.7: **Parameters & their ranges**

Parameter	Range	Resolution
Sampling Time (Ts)	0.01-99.9 sec	0.1 sec
Un Lower Limit	0-100%	1 %
Un Upper Limit	0-100%	1 %
Un Step	1-99.9	1 %
Initial Un value	1-99.9	1 %

These Parameters can set by directly entering values into particular window or while by clicking Up and Down arrow button, or using the Up and Down key on keyboard where only discrete steps are allowed. The error message will be displayed for any erroneous entry of no. or if the value entered is not within the specified limit.

Two display windows on the screen are

Numeric value display:- This window displays RE voltage (Vn), RE current (In), RE power (Pn), Battery voltage (B+), Load voltage (L+), Controller DAC O/P (Un) in percentage (%) and actual form.

Bar graph display:- This window graphically displays the RE voltage (Vn), RE current (In), RE power (Pn)

Control settings buttons

Following are the remaining buttons on the panel with their respective functions.

Auto/Start: This buttons is used to start On-Line PC based PID Control after configure of all Parameter.

Manual/Stop: This buttons is used to Stop On-Line PID Control to change the parameter or end the Process.

MPPT scheme:- There are 3 schemes of MPPT i.e. incremental conductance (Inc Cond), Perturb and Observe (P&O) and 75% of Voc. You can chose from drop down window provided.

Controller Action:- There are 2 controller actions forward and Reverse action

If Un increases in forward action, it will decrease in reverse action.

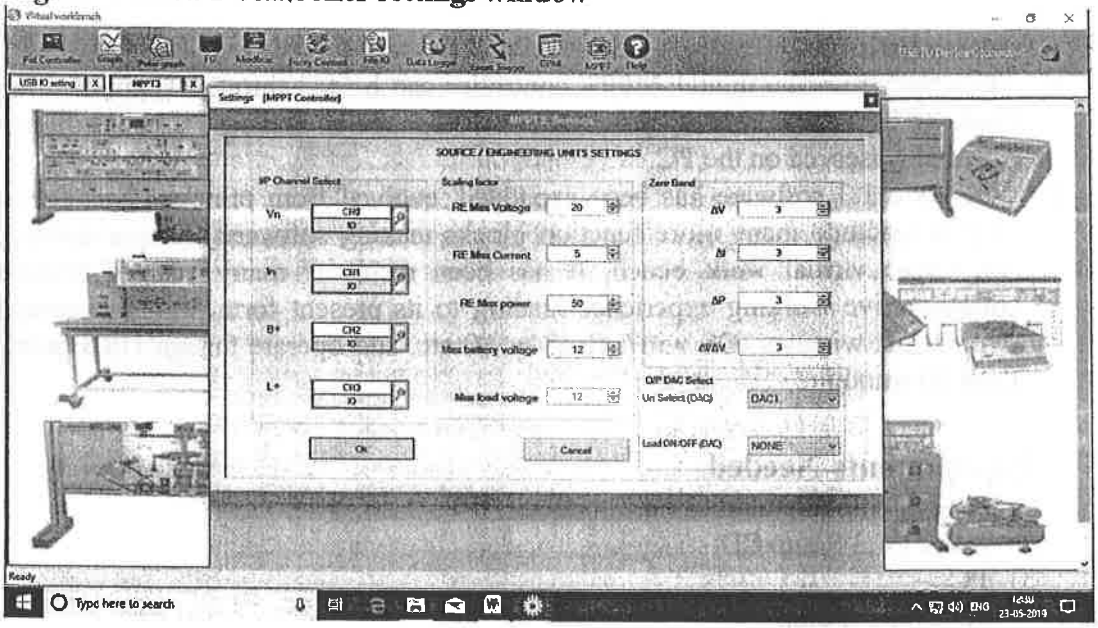
Save Setting: This button used to save all parameter at desired path in ***. xml** File.

Load Setting: This button used to Load saved Setting, from ***.xml** File

Setting:

When this button is pressed following window will appear

Fig. B.54: MPPT controller settings window



I/P channel select:- Drop down window is provided for RE voltage (Vn), RE current (In), Battery voltage (B+) and Load voltage (L+) to select channels from CH0, CH1, CH2, CH3
Scaling factors:- Window is provided to set RE Max voltage, RE Max current, RE Max power, Max battery voltage, Max load voltage. You can set from 0 to 100.
Zero band:- Window is provided to set ΔV, ΔI, ΔP, ΔI/ΔV. You can set from 0 to 100.
O/P DAC select:- Drop down window is provided for Un Select, Load ON/OFF to select DAC1 or DAC2. User can select DAC1 or DAC2 for Un select and load ON/OFF.
OK:- After filling all parameters click on this button.

☞ Keywords.

- **USB Port** : Universel serial bus
- **COM Port** : Communication Port
- **PC** : Personal Computer
- **ADC** : Analog to Digital Converter
- **DAC** : Digital to Analog Converter
- **SPV** : Solar PhotoVoltaic
- **MPPT** : Maximum Power Point Tracking
- **Inc Cond** : Incremental Conductance
- **P & O** : Perturb and Observe
- **Voc** : Open Circuit Voltage
- **RE** : Renewable Energy
- **Vn** : RE Voltage
- **In** : RE Current
- **Pn** : RE Power

☞ Conclusion

1) The O/P from the digital MPPT controller can be fed through Computer Interface Card (CIP) to control any process. Also response of analog PID controller can be directly observed on the PC.
2) Version 11.3 software has been expanded, evolved from previous package version 11.2 to include many more function blocks making software more pervasive hence the name virtual work bench. It has been result of many years of research & collaborative working experience leading to its present form making it compatible with latest windows OS win7, win8 or 10 etc. and operate through USB port using USB IO module.

☞ Equipments Needed

1) USB IO module with cable Connector.
2) VWB 11.3 Setup CD
3) PC
4) XPO-STT Setup

APPENDIX - C
Conversion Tables

1) dBm - Watts - Volts conversion Table:

A) Conversion of Watt (W) to dBm:

a) First convert Watt (W) value to 'mW' by simply multiplying this watt value to 10^(+3).

b) Then convert it to dBm using the following equation;

dBm = 10 * Log(mW).

Where, Log = Logarithm by base 10.

For example;

If power in mW = 25 mW,

Then in dBm = 10*Log(25) = 13.9 dBm.

c) If you want to convert dBm to Watt (W),then use Anti-log of dBm value as given,

For example;

If power in dBm = 12.

Then in mW = Anti-Log (12/10) = 15.8 mW.

B) Conversion of dBm to volts (V):

a) First convert dBm to mW using the same above equation as given;

dBm = 10 * Log(mW).

Where, Log = Logarithm by base-10.

b) Then convert mW value to Watts (W) by simply multiplying it to 10^(-3).

c) Then use the following standard equation to convert Watts to volts as given;

Volts (V) = SQRT (W * R) [$\therefore$ Power (W) = V^2 / R].

Where,

R = Resistance of system in ohms (i.e. 50 ohms).

W = Watts value to be converted to volts.

For example;

If power in dBm = 12.

Then in mW = Anti-Log (12/10) = 15.8 mW.

In Watts = 15.8 mW * 10^(-3) = 0.0158 Watts.

Then, in volts (V) = SQRT (0.0158 * 50)

= SQRT (0.79)

= 0.88 volts (in RMS).

NOTE: Below is a table is provided with conversions from dBm to volts and then to watts in different column.

Table C.1 dBm - volts - watts conversion table

dBm	V	W	dBm	V	mW	dBm	mV	µW	dBm	µV	pW
53	99.9	200	0	0.224	1.00	-49	0.79		-98	2.8	
50	70.7	100	-1	0.199	0.79	-50	0.71	.01µW	-99	2.51	
49	63.0	79	-2	0.178	0.63	-51	0.63		-100	2.24	.1pw
48	56.2	63	-3	0.158	0.50	-52	0.56		-101	2.0	
47	50.1	50	-4	0.141	0.40	-53	0.50		-102	1.8	
46	44.6	40	-5	0.126	0.32	-54	0.45		-103	1.6	
45	39.8	32	-6	0.112	0.25	-55	0.40		-104	1.41	
44	35.4	25	-7	0.100	0.20	-56	0.35		-105	1.26	
43	31.6	20	-8	0.089	0.16	-57	0.32		-106	1.12	
42	28.2	16	-9	0.079	0.126	-58	0.282		**dBm**	**nV**	
41	25.1	12.6	-10	0.071	0.10	-59	0.251		-107	999	
40	22.4	10	-11	0.063		-60	0.224	.001µW	-108	890	
39	19.9	8.0	-12	0.056		-61	0.199		-109	793	
38	17.8	6.3	-13	0.050		-62	0.178		-110	707	.01pW
37	15.8	5.0	-14	0.045		-63	0.158		-111	630	
36	14.1	4.0	-15	0.040		-64	0.141		-112	562	
35	12.6	3.2	-16	0.0354		**dBm**	**uV**		-113	501	
34	11.2	2.5	**dBm**	**mV**		-65	126		-114	446	
33	10.0	2.0	-17	31.6		-66	112		-115	398	
32	8.9	1.6	-18	28.2		-67	100		-116	354	
31	7.9	1.26	-19	25.1		-68	89		-117	316	
30	7.07	1.0	-20	22.4	.01mW	-69	79		-118	282	
dBm	**V**	**mW**	-21	19.9		-70	71	.1nW	-119	251	
29	6.30	794	-22	17.8		-71	63		-120	224	.001pW
28	5.62	631	-23	15.8		-72	56		-121	199	
27	5.01	501	-24	14.1		-73	50		-122	178	
26	4.46	398	-25	12.6		-74	45		-123	158	
25	3.98	316	-26	11.2		-75	40		-124	141	
24	3.54	251	-27	10.0		-76	35		-125	126	
23	3.16	200	-28	8.9		-77	32		-126	112	
22	2.82	158	-29	7.9		-78	28		-127	100	
21	2.51	126	-30	7.1	.001mW	-79	25		-128	89	
20	2.24	100	-31	6.30		-80	22.4	.01nW	-129	79	
19	1.99	79	-32	5.6		-81	19.9		-130	71	.1fW
18	1.78	63	-33	5.0		-82	17.8		-131	63	
17	1.58	50	-34	4.5		-83	15.8		-132	56	
16	1.41	40	-35	4.0		-84	14.1		-133	50	
15	1.26	32	-36	3.5		-85	12.6		-134	45	
14	1.12	25	-37	3.2		-86	11.2		-135	40	
13	1.00	20	-38	2.82		-87	10.0		-136	35	
12	0.89	16	-39	2.5		-88	8.9		-137	32	
11	0.79	12.6	-40	2.24	.1µW	-89	7.9		-138	28	
10	0.71	10	-41	2.0		-90	7.1	.001nW	-139	25	
9	0.63	8.0	-42	1.8		-91	6.3		-140	22	.01fW
8	0.56	6.3	-43	1.6		-92	5.62				
7	0.501	5.0	-44	1.4		-93	5.0				
6	0.446	4.0	-45	1.26		-94	4.5				
5	0.398	3.2	-46	1.12		-95	4.0				
4	0.354	2.5	-47	1.00		-96	3.54				
3	0.316	2.0	-48	0.89		-97	3.2				
2	0.282	1.6									
1	0.251	.26									

2) Return Loss - Reflection coefficient (Γ) - VSWR conversion Table:

The relationship of Reflection coefficient, Return Loss & VSWR is given below, which is already discussed in unit-18 / point-C /b;

$$\text{Return Loss } (R_L) = -(P_F - P_R) \quad \text{dBm}$$

Where,

P_F = Forward/Incident power observed in dBm.
P_R = Reflected power observed in dBm.

Relationship with Reflection co-efficient & VSWR;

$$\text{Reflection co-efficient } (\Gamma) = \text{Antilog } (R_L / 20)$$
$$\text{And VSWR} = (1 + \Gamma) / (1 - \Gamma)$$

Below table shows the complete relationship of Return Loss (ranging from infinite to 0 dBm) with Reflection co-efficient & VSWR;

Table C.2 Return Loss - Γ - VSWR conversion table

Sr. No.	Return Loss (in dB)	VSWR	Reflection co-efficient (Γ)
1.	- Infinite	1.00	0
2.	-26.02	1.11	0.05
3.	-20.00	1.22	0.1
4.	-16.48	1.35	0.15
5.	-13.98	1.50	0.2
6.	-12.04	1.67	0.25
7.	-10.46	1.86	0.3
8.	-9.12	2.08	0.35
9.	-7.96	2.33	0.4
10.	-6.94	2.64	0.45
11.	-6.02	3.00	0.5
12.	-5.19	3.44	0.55
13.	-4.44	4.00	0.6
14.	-3.74	4.71	0.65
15.	-3.10	5.67	0.7
16.	-2.50	7.00	0.75
17.	-1.94	9.00	0.8
18.	-1.41	12.33	0.85
19.	-0.92	19.00	0.9
20.	-0.45	39.00	0.95
21.	0.00	Infinite	1

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APPENDIX - D
Content of Accompanying CD

Directory of H:\

Volume in drive H is XPO ANT (SOFTWARE)

03/28/2012	04:59 AM	<DIR>	.
03/28/2012	04:59 AM	<DIR>	..
02/18/2012	01:52 PM	1,270,272	SetupPolar.msi
05/03/2010	06:28 PM	2,585,872	WindowsInstaller-KB893803-v2-x86.exe
01/08/2010	05:13 PM	242,743,296	dotnetfx35.exe
02/18/2012	01:51 PM	466,944	setup.exe

4 File(s) 247,066,384 bytes

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Appendix - E
Impedance matching using Smith Chart

☞ Unit Objective

At the completion of this unit, you will be able to form/construct matched network to match source with load having different impedances by the use of Smith chart, a graphical matching network tool.

☞ Discussion on Fundamentals

1) About History of Smith Chart:

The Smith chart, invented by **Phillip H. Smith**, is a graphical aid to use in RF engineering in solving problems with matching circuits. The Smith chart can be used to represent many parameters including impedances, admittances, reflection coefficients, scattering parameters, noise figure circles, constant gain contours and regions for unconditional stability etc. The Smith chart is most frequently used at or within the unity radius region.

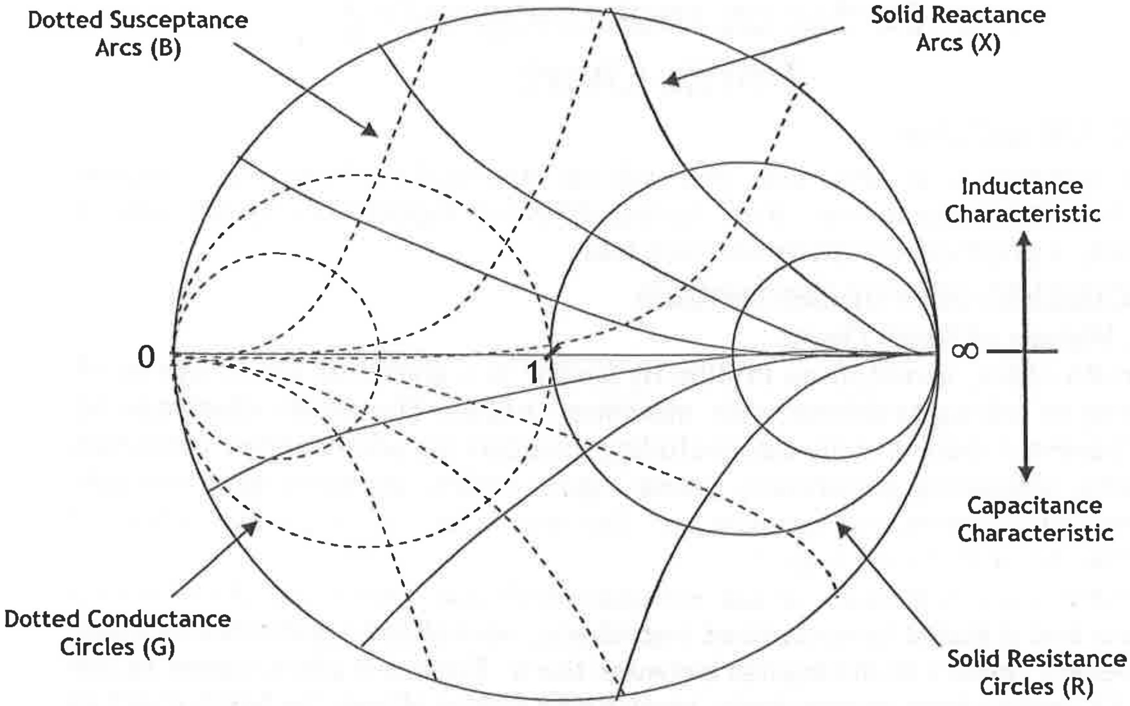
The Smith chart is plotted on the complex reflection coefficient plane in two dimensions and is scaled in normalized impedance, normalized admittance or both, using different colours to distinguish between them. These are often known as the Z, Y and ZY Smith charts respectively. Normalized scaling allows the Smith chart to be used for problems involving any characteristic or system impedance which is represented by the center point of the chart. The most commonly used normalization impedance is 50 ohms (or, source impedance, whatever). Once an answer is obtained through the graphical constructions described below, it is straightforward to convert between normalized impedance (or normalized admittance) and the corresponding unnormalized value by multiplying by the characteristic impedance (admittance).

2) Introduction on "How to use Smith Chart":

A ZY smith chart (or, combined smith chart), which is comprised by impedance smith chart and admittance smith chart. The center point denotes the resistance 50Ω for the source having impedance of 50Ω. The impedance at the left and right extremities of the chart are 0 Ω (i.e. short circuit) & infinity (i.e. open circuit) respectively. We can separate the smith chart into Top and Bottom semicircles with the impedance characteristic of the Top semicircle is inductance, i.e. $Z = R + jX$ or $Y = G - jB$ and the impedance characteristic of the Bottom semicircle is capacitance, i.e. $Z = R - jX$ or $Y = G + jB$.

From Smith chart, the Solid Circle indicates constant Resistance circle (R), the Solid Arc indicates constant Reactance circle (X), the Dotted Circle indicates constant Conductance arc (G), the Dotted arc indicates constant susceptance Circle (B) and Real-line semicircle indicates constant Q-contours as shown below;

Fig E.1 General combined Smith chart diagram



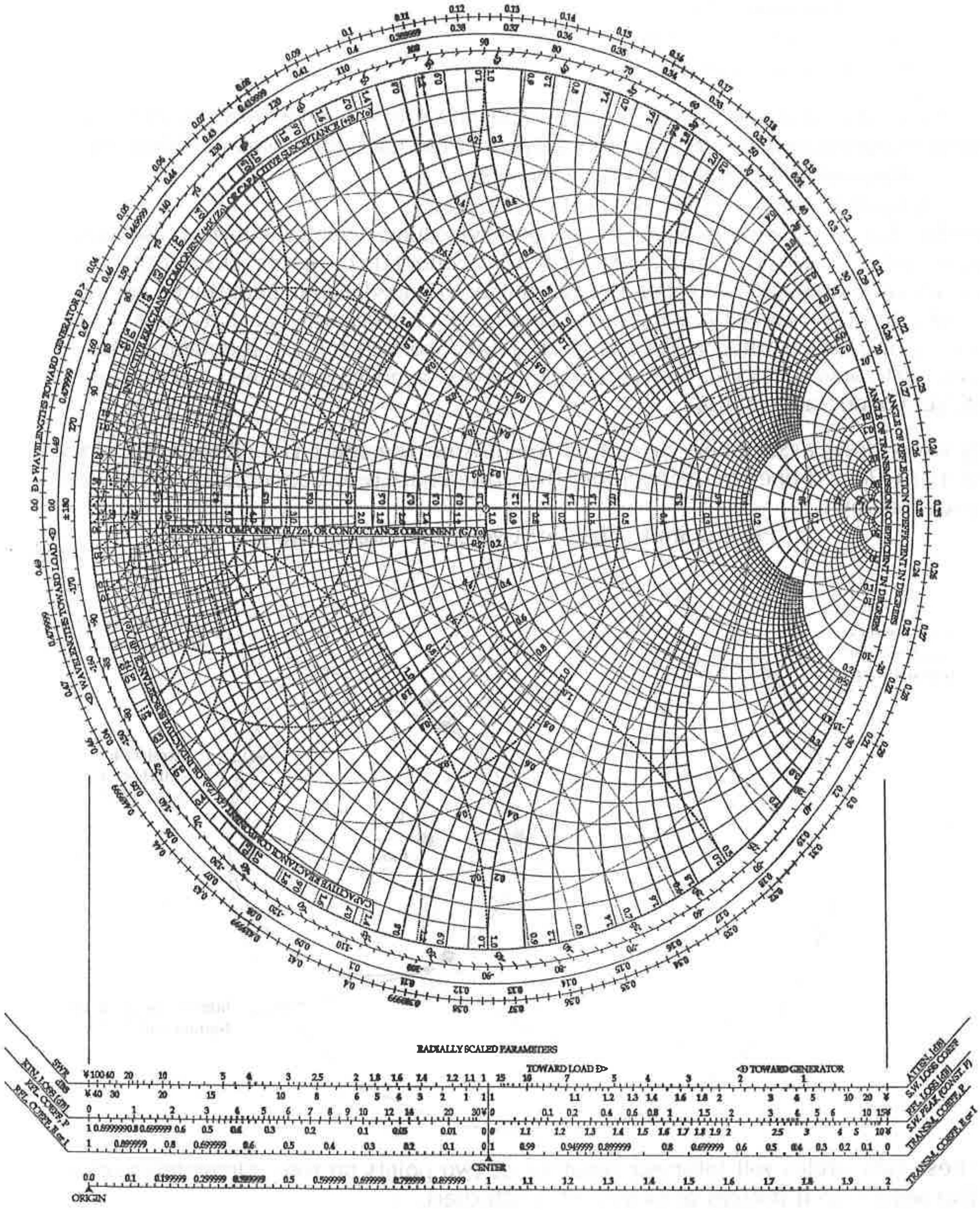
Method of finding the matched network components:

If any point moves along the constant resistance circle, that point indicates a series component of matched network (inductor: if CW & capacitor: if CCW) & if any point moves along the constant conductance circle, that point indicates a shunt component (inductor: if CCW & capacitor: if CW), refer the table below;

Table E.1 Matched component selection table

Sr. No.	Component placement in Matched network	Moving Path (in which circle)	Moving Direction
1.	Series Inductor	Resistance Circle	Clock-wise (CW)
2.	Series capacitor	Resistance Circle	Counter Clock-wise (CCW)
3.	Shunt Inductor	Conductance Circle	Counter Clock-wise (CCW)
4.	Shunt capacitor	Conductance Circle	Clock-wise (CW)

Fig. E.2 Combined Impedance & Admittance Smith Chart



☞ Procedure

Impedance matching using Smith Chart at frequency 500 MHz with different Impedances of Source (Z_S) & Load (Z_L) is illustrated below in step-by-step procedure;

Source Impedance (Z_S) = 50 Ω

Load Impedance (Z_L) = 75 Ω

At frequency (f) = 500 MHz.

1) First normalize the source & load impedances by dividing these numbers by source impedance (i.e. 50 Ω, in this case), so as to locate them on Smith chart as;

Normalized Z_S = 50 Ω / 50 Ω = 1 (No unit).

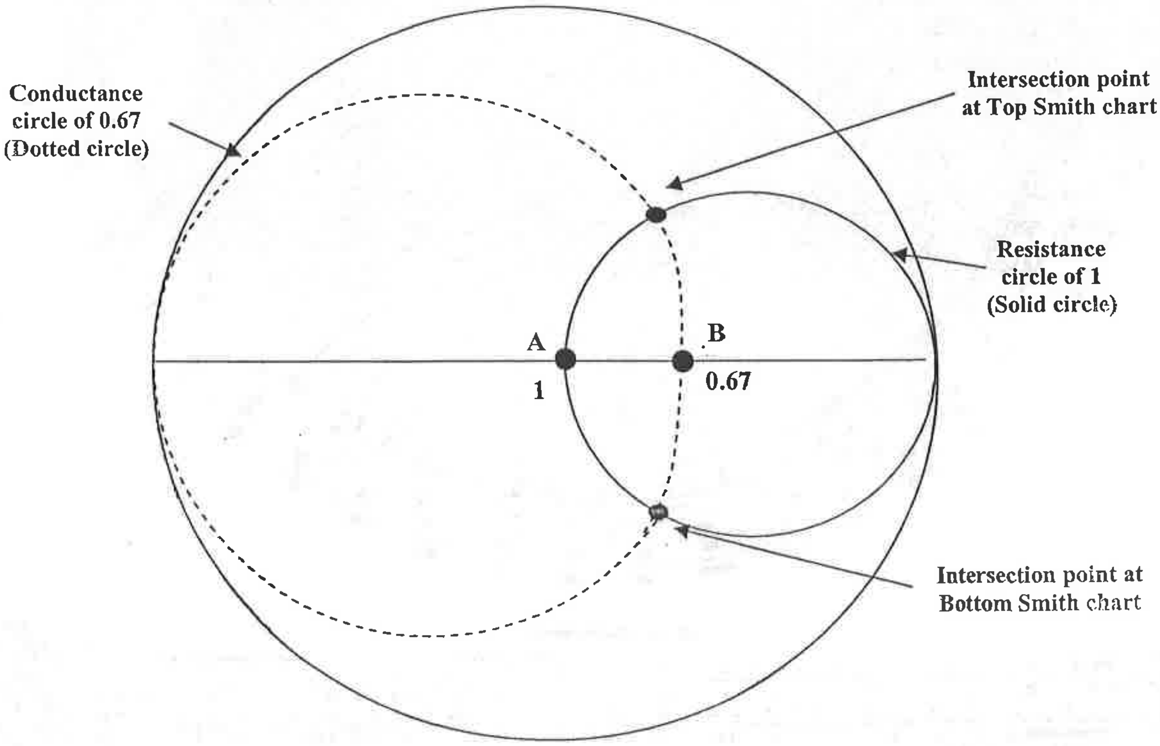
& Normalized Z_L = 75 Ω / 50 Ω = 1.5 (No unit).

NOTE: For ease in getting matching network values, you will have to use both Resistance circle (i.e. Solid-line circle) & Conductance circle (i.e. Dotted-line circle) on Combined Smith chart containing both Impedance & Admittance Locii.

Hence after normalization, mark these points on Smith chart as point-A for normalized source having resistance of 1. And point-B for 1.5 (normalized load), but first convert 1.5 into conductance by simply inverting itself then mark at point-B i.e. conductance of 0.67.

2) Now draw a Solid-line circle from point-A on the chart (i.e. Resistance circle of 1) & Dotted-line circle from point-B on the chart (i.e. Conductance of 0.67) as shown below;

Fig E.3 Smith chart of two circle intersections



These two circles will intersect together at two points on their circumferences at Top semicircle & Bottom semicircle of Smith chart.

NOTE: i) For matching between impedances of source & load, you will have to move from normalized load value to normalized source value on Smith chart by tracing the path of Circles only (either Solid-line or Dotted-line).

ii) While you are moving from load (point-B) to source (point-A); series/parallel Inductors & series/parallel Capacitors will come in picture from one intersection point to another of circles. And after complete movement, the final matched circuit will be made by observing movement by tracing direction on each path of circle intersections.

iii) For each matching case, you are going from load to source by following on circle circumferences to match the impedances of source & load. Hence, there are two possible matching networks in each case, because you can move either from Top semicircle of smith chart or from Bottom half of circle.

But these two matching networks (collection of inductors & capacitors) will have different values of components & also their placement will be interchanged (i.e. from series to parallel & vice-versa), but the matching behavior will be same in each case.

Hence for above example, we will explain both the method of matching by considering circles path on Top & Bottom half of Smith charts separately;

METHOD-I (By considering Bottom Smith Chart):

3) Now name the intersection point of both circles on Bottom chart as point-C. Hence resistance at point-C is 1 & conductance at point-C is 0.67.

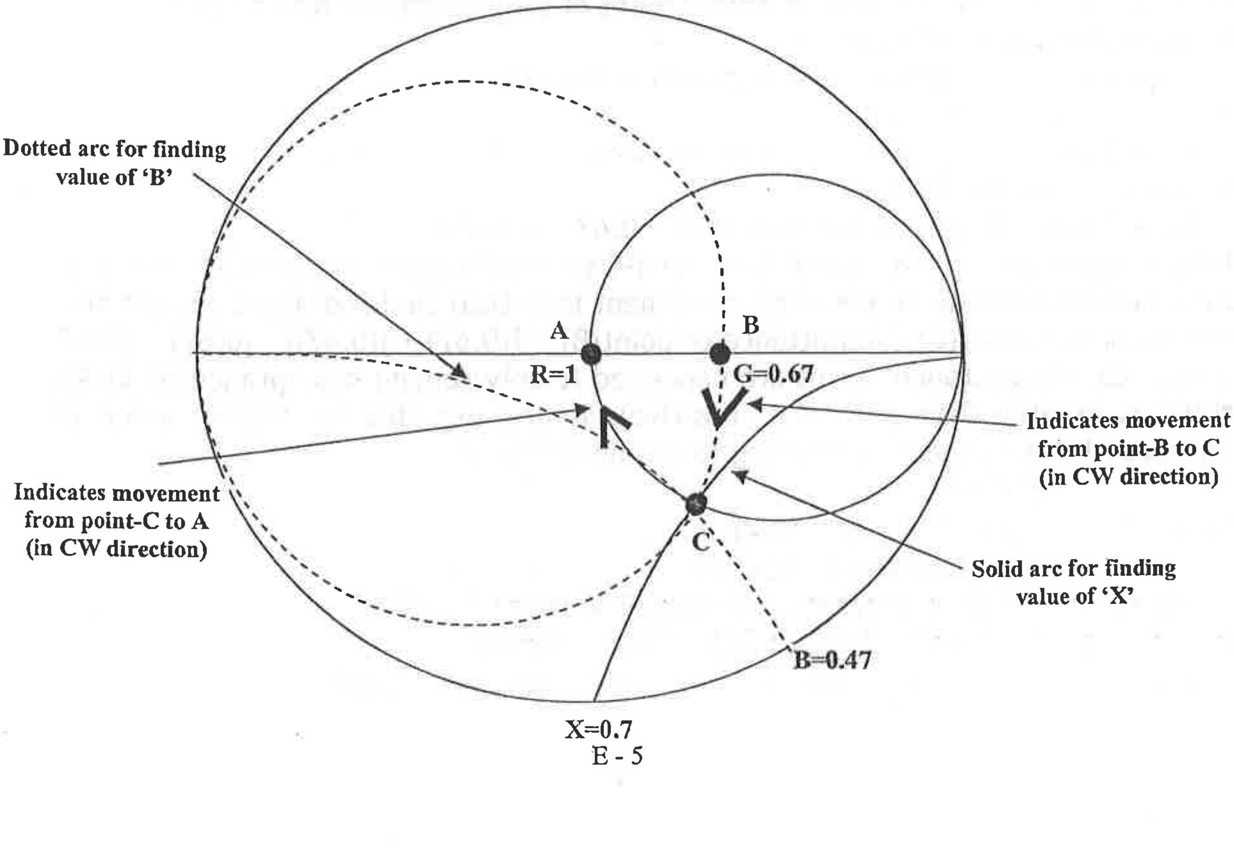
i.e. At point-C, Resistance (R) = 1 & Conductance (G) = 0.67.

For bottom smith chart, the Impedance & Admittance are given as below;

i.e. $Z = R - jX$ & $Y = G + jB$.

Now for finding Impedance & Admittance of point-C, you will have to know the values X (i.e. Reactance) & B (i.e. Susceptance) of point-C. For finding these two values of point-C, identify arcs passing through point-C as shown below (Dotted for finding 'B' & Solid for 'X');

Fig E.4 Impedance matching using Bottom Smith chart

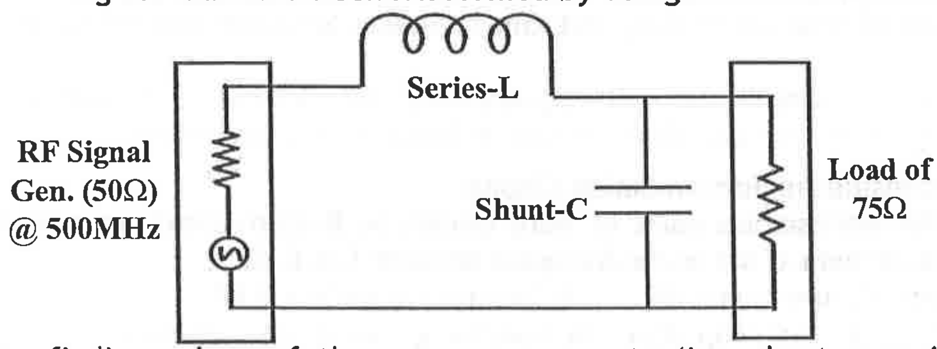


Now Impedance & Admittance of point-C are given below;
Impedance (Zc) = R - jX = 1 - j(0.7)
Admittance (Yc) = G + jB = 0.67 + j(0.47).

4) There are some pre-defined process for finding matched components (i.e. Inductors & Capacitors) are either in series or parallel in matched network as given in above table.

Now we can conclude, using guidelines given in table above & observing your movement on Smith chart, the moving clockwise direction from point-B to point-C in Conductance circle indicates **"a Shunt Capacitor"** and moving clockwise direction from point-C to point-A in Resistance circle indicates **"a Series Inductor"**. And finally you moved from Load to Source by tracing the above path & finally the matched network is formed with a shunt capacitor in Series with an inductor as shown below;

Fig E.5 Matched network formed by using Bottom Smith Chart



5) For finding values of these two components (i.e. shunt capacitor & series inductor) go through the following procedure;

i) Check for values of jB & jX by subtracting Admittances & Impedances of two circle intersection points respectively from which components will be decided as;
If jB > 0, component is 'Capacitor (C)' & if jB < 0, component is 'Inductor (L)'.
If jX > 0, component is 'Inductor (L)' & if jX < 0, component is 'Capacitor (C)'.
Following are the impedances & Admittances of each point on chart as given;

At point-A (Source value, given):
Impedance = 1 + j(0) = 1 & Admittance = 1 + j(0) = 1.

At point-B (Load value, given):
Impedance = 1.5 + j(0) = 1.5 & Admittance = 0.67 + j(0) = 0.67.

At point-C (Observed value):
Impedance = 1 - j(0.7) & Admittance = 0.67 + j(0.47).

ii) Now while moving from point-B to point-C on conductance circle in CW direction the resultant admittance (because movement in dotted circle) of the path will be;
Admittance of point(C) - Admittance of point(B) = [(0.67) + j(0.47)] - [0.67] = j0.47
Hence, the conductance terms are cancelled & only remain susceptance of j0.47, which is greater than zero (i.e. positive), hence use this for finding value of normalized shunt capacitor by using following formula;

$$jB = jwC_N$$

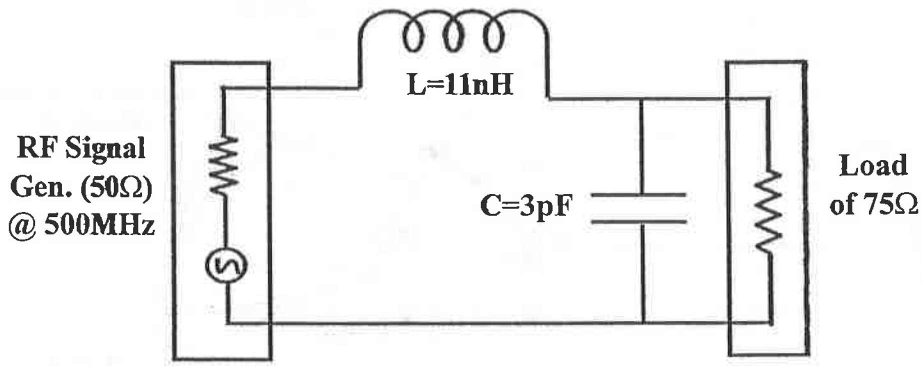
Where, $w = 2 * (\pi) * f$, (f = 500 MHz).
C_N = Normalized shunt capacitor.
And jB = resultant susceptance of point-B to point-C = j0.47.
Now, $C_N = B / (2\pi f) = (0.47)/(2\pi * 500 * 10^6) = 150$ pF.
The actual value of shunt capacitor = $(C_N)/50 = 150 / 50 =$ **3 pF.**

iii) And while moving from point-C to point-A on Resistance circle in CW direction the resultant Impedance (because movement in solid circle) of the path will be;
Impedance of point(A) - Impedance of point(C) = [1] - [(1) - j(0.7)] = j0.7
Hence, the resistance terms are cancelled & only remain reactance of j0.7, which is greater than zero (i.e. positive), hence use this for finding value of normalized series inductor by using following formula;

$$jX = jwL_N$$

Where, $w = 2 * (\pi) * f$, (f = 500 MHz).
L_N = Normalized series inductor.
And jX = resultant reactance of point-C to point-A = j0.7.
Now, $L_N = X / (2\pi f) = (0.7)/(2\pi * 500 * 10^6) = 0.22$ nH.
The actual value of series inductor = $(L_N)*50 = 0.22 * 50 =$ **11 nH.**
Hence complete circuit with the matched network element is shown below;

Fig E.6 Final Matched network with values



METHOD-II (By considering Top Smith Chart):

6) Same as above Method-I, do the same procedure as given. Name the intersection point of both circles on Top chart as point-D. Hence resistance at point-D is 1 & conductance at point-D is 0.67.

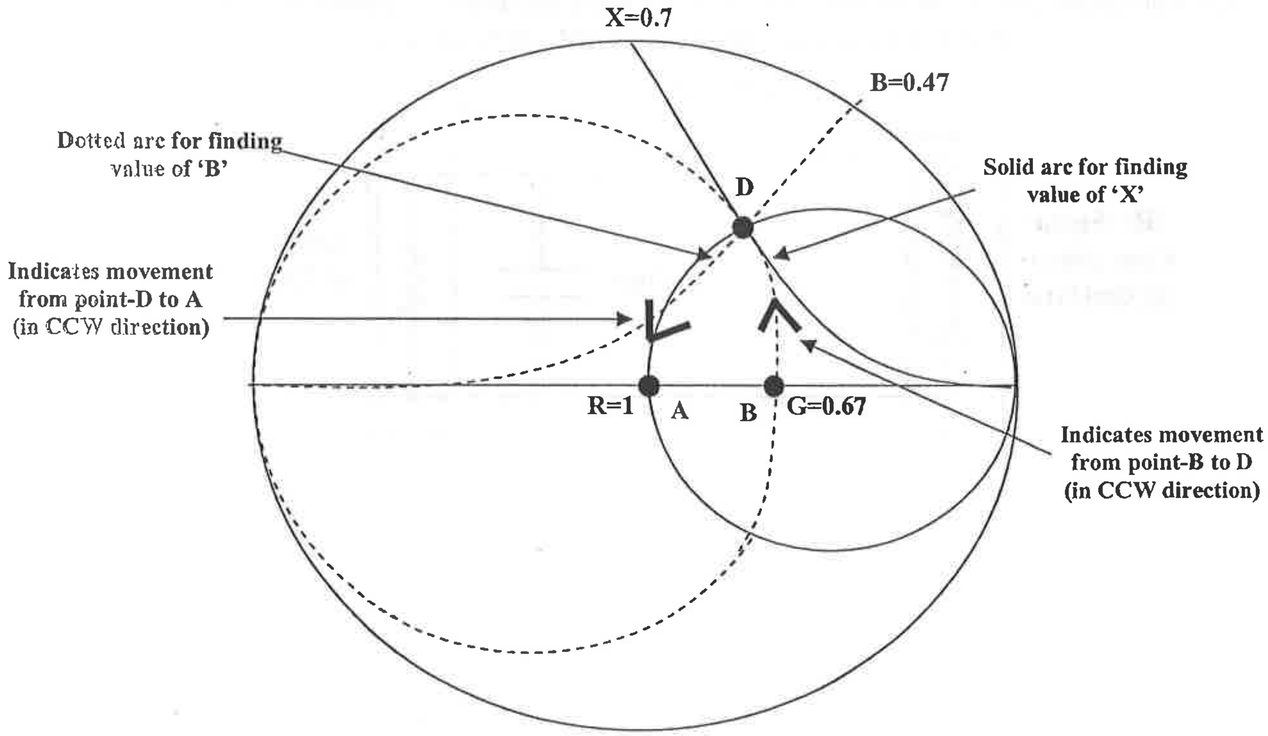
i.e. At point-D, Resistance (R) = 1 & Conductance (G) = 0.67.

For Top smith chart, the Impedance & Admittance are given as;

i.e. $Z = R + jX$ & $Y = G - jB$.

Now for finding Impedance & Admittance of point-D, you will have to know the values X (i.e. Reactance) & B (i.e. Susceptance) of point-D. For finding these two values of point-D, identify arcs passing through this point as shown below (Dotted for finding 'B' & Solid for 'X');

Fig E.7 Impedance matching using Top Smith chart



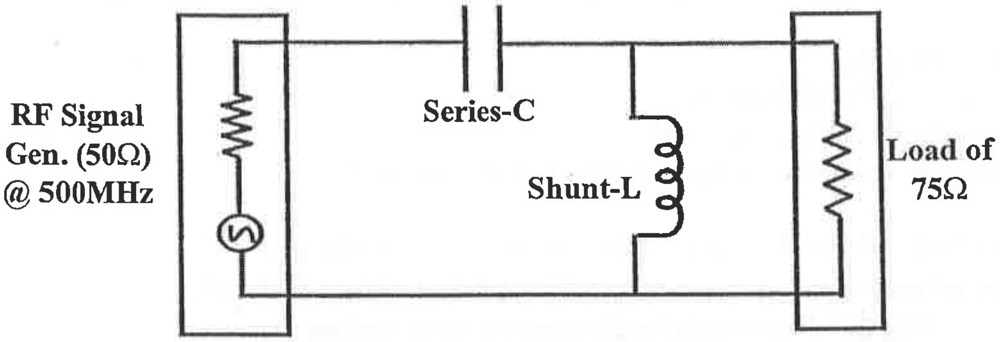
Now Impedance & Admittance of point-D are given below;

Impedance (Z_D) = $R + jX = 1 + j(0.7)$

Admittance (Y_D) = $G - jB = 0.67 - j(0.47)$.

7) Now by observing the movement on smith chart & referring above table, the moving counter-clockwise direction from point-B to point-D in Conductance circle indicates **"a Shunt Inductor"** and moving counter-clockwise direction from point-D to point-A in Resistance circle indicates **"a Series Capacitor"**. And finally you moved from Load to Source by tracing the above path & finally the matched network is formed with a shunt Inductor in Series with a capacitor as shown below;

Fig E.8 Matched network formed by using Top Smith Chart



8) For finding values of these two components (i.e. shunt inductor & series capacitor) go through the following procedure;

i) Check for values of jB & jX by subtracting Admittances & Impedances of two circle intersection points respectively from which components will be decided as;
If jB > 0, component is 'Capacitor (C)' & if jB < 0, component is 'Inductor (L)'.
If jX > 0, component is 'Inductor (L)' & if jX < 0, component is 'Capacitor (C)'.
Following are the impedances & Admittances of each point on chart as given;

At point-A (Source value, given):
Impedance = 1 + j(0) = **1** & Admittance = 1 + j(0) = 1.

At point-B (Load value, given):
Impedance = 1.5 + j(0) = 1.5 & Admittance = 0.67 + j(0) = 0.67.

At point-D (Observed value):
Impedance = 1 + j(0.7) & Admittance = 0.67 - j(0.47).

ii) Now while moving from point-B to point-D on conductance circle in CCW direction the resultant admittance (because movement in dotted circle) of the path will be;
Admittance of point(D) - Admittance of point(B) = [(0.67) - j(0.47)] - [0.67] = -j0.47
Hence, the conductance terms are cancelled & only remain susceptance of -j0.47, which is less than zero (i.e. negative), hence use this for finding value of normalized shunt inductor by using following formula;

$$jB = 1 / (jwL_N)$$

Where, w = 2 * (π) * f, (f = 500 MHz).
L_N = Normalized shunt inductor.
And jB = resultant susceptance of point-B to point-D = -j0.47.
Now, L_N = (1) / (2πf) * (B) = (1) / (2π * 500 * 10^6) * (0.47) = 0.67 nH.
The actual value of shunt inductor = (L_N) * 50 = 0.67 * 50 = **33.5 nH.**

iii) And while moving from point-D to point-A on Resistance circle in CCW direction the resultant Impedance (because movement in solid circle) of the path will be;
Impedance of point(A) - Impedance of point(D) = [1] - [(1) + j(0.7)] = -j0.7
Hence, the resistance terms are cancelled & only remain reactance of -j0.7, which is less than zero (i.e. negative),

hence use this for finding value of normalized series capacitor by using following formula;

$$jX = 1 / jwC_N$$

Where, $w = 2 * (\pi) * f$, ($f = 500$ MHz).

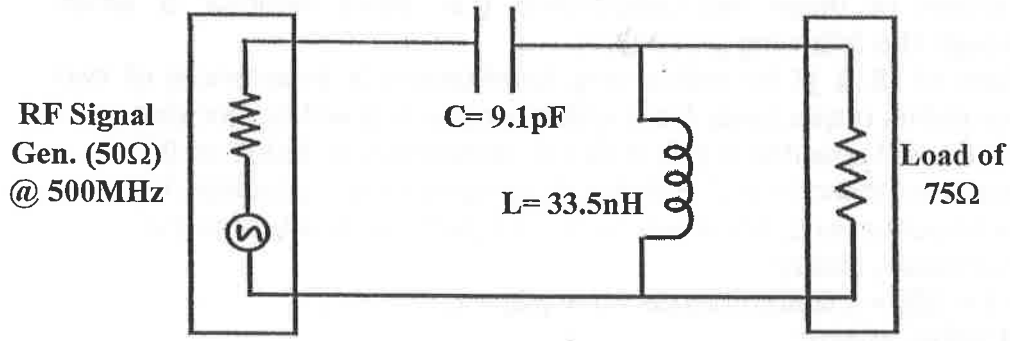
C_N = Normalized series capacitor.

And jX = resultant reactance of point-D to point-A = $-j0.7$.

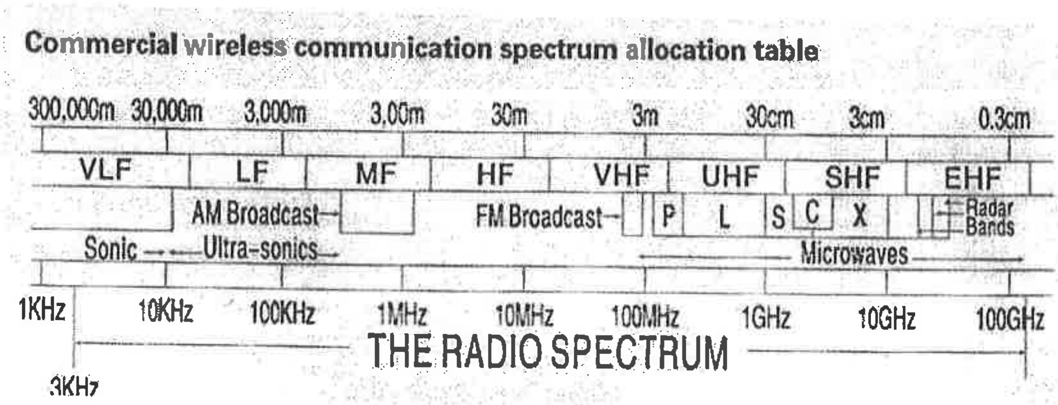
Now, $C_N = (1) / (2\pi f) * (X) = (1) / (2\pi * 500 * 10^6) * (0.7) = 455$ pF.

The actual value of series capacitor = $(C_N) / 50 = (455) / (50) =$ **9.1 pF.**

Fig E.9 Final Matched network with values



Appendix - F
Frequency spectrum



Sr No	Spectrum	Freq Band MHz	Wave Band (m)	Application Radio	Use area (country)
1	HF	3-30	100-10	HF Armateur Radio	Global
2	HF	26-28	11.54-10.71	CB radio	Eropean, North & South American
3	AM	0.525-1.7	571.4-176.5	Radio	Global
4	FM	88-108	3.4-2.78	Radio	Global
5	VHF	136-174	2.2-1.72	VHF Radio	Most countries
6	VHF	136-174	2.2-1.72	Marine Radio	Most countries
7	VHF	46-68	6.52-4.41	T-DAB I	Most countries
8	VHF	174-240	1.72-1.25	T-DAB II	Most countries
9	VHF	40-87	7.5-3.45	TV I	Global
10	UHF	174-230	1.72-1.3	TVII	Global
11	VHF	470-862	0.64-0.35	TV Ill	Global
12	VHF	174-230	1.72-1.3	T-DMB	Korea
13	UHF	174-230	1.72-1.3	DVB-T I	European
14	UHF	P470-860	0.64-0.35	DVB.-T II	European
15	UHF	403-40	0.71-0.68	UHF Radio	Most countries
16	UHF	420-470	0.71-0.64	UHF Radio	Most countries
17	UHF	806-866	0.37-0.35	Cluster radio	European TETRAN0rth American APCO25
18	GSM 900	880-960	0.34-0.31	GSM Phone	Most countries
19	GSM1 800	1 710-1880	0.18-0.16	GSM Phone	Most countries
20	CDMA800	824-894	0.36-0.35	CDMA Mobile phone	Most countries
21	CDMA2000	1920-2125	0.16-0.14	CDMA Mobile phone	Most countries
22	WCDMA	1940-2145	0.16-0.14	3G Mobile phone	Few Countries
23	TD-SCDMA	1880-2025	0.16-0.15	TDMA Mobile phone	North American
24	GPS	1227.6-1575.42	0.24-0.19	GPS	Most countries
25	Wireless access	45-49	6.67-6.12	Cordless public phone	Most countries
26	Wireless access	900-930	0.33-0.32	Cordless public phone	Most countries
27	Wireless access	1900-1920	0.16-0.16	Cordless phone	Most countries
28	Wireless access	2400-2483	0.13-0.12	LAN	Most countries

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APPENDIXG

Troubleshooting Procedure

Q.1)Not able to detect/connect USB IO Module with software?

Ans:-

1)Remove USB cable from pc

2)Make the module RF power meter (RF6) supply off.Then connect USBmodule to PC port.

3)Open the software," Connection succeed "message will bedisplayed on PC.

4) Connect USB I/O module to RF Power meter(RF6).

5)Click on s/w & make power supply on,so that operating system will detect presence ofUSB module.

6)This sequence should be followed correctly.

7)Indicator on software changes to green color in AUTO mode & yellow in MANUAL mode by changing switch present at back side of power meter which ensure proper connectivity with software.

Q.2)If motor not rotate by giving data through software?

Ans:-

1)Install software by following procedure given on page C.2 in manual.

2)Connect CLK &GND output of RF power meter present at back side of power meter to P25 panel at socket 5 (CLK) & 14 (GND) respectively.

3)Switch on P 25 panel& RF power meter .Motor will rotate as per setting.

4) If motor doesnot rotate by above procedure ,Switch off RF power meter .You need to open power meter very precisely by removing side screws as all setting & connections are factory set & not advise to open without consulting .Check continuity between powermeter GND present at back side & power meter module GND .check that brown wire on power meter module is properly soldered at module to ensure proper grounding.

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Revision History

Ver./ CD No.	Date	Affected Chap.	Type of change	Engr. Name
V1.0/644	01/03/10	-----	New released.	
V1.1/644	11/02/12	All chapters	Added new antennas and their parameter measurements with separate chapters.	
V1.2/644	05/03/12	CH-3 to CH-15 & IG.	Added antennas: Half & Quarter wave, 3□/2 simple dipoles, Half-wave folded with reflector, End-fires, Broad-side, Co-linear and their measurements.	
	23/03/12	CH-16 to CH-18 & All Appendix.	Added Slot & Discone antennas and Antenna VSWR measurements. In Appendix, added step-by-step procedure & VSWR conversion table in separate appendix.	
	06/04/12	Appendix-E	New appendix as content of Accomp. CD.	
V1.3/644	13/06/12	CH-18 & CH-19 & Appendix-F	Added parabolic reflector & Patch antennas. Added appendix for Smith chart.	
		CH-20	Added Antenna resonance experiment using variable length simple dipole antenna.	
V1.4/644	12/3/15	CH-2,1	1Added software setting at page 2-15 2.Modified picture of Anteena holder box at page 1-5	
V1.5/644	16/4/15	CH-1	Added reciprocity note at page 1-14	
V1.6/644	10/1/16	Appendix-G	Added Frequency spectrum	
V1.7/644	25/8/16	Appendix-H	Added troubleshooting procedure	
V1.8/644	1/4/17	CHAP.-2	Added Antenna graph utility software for WIN-7 & 8	
V1.8/644	5/12/17	Important precautions	Note added in point 4. Page IV	
V1.9/644	13/06/20	CH2, App-B, C CH3 to CH19	Modified Appendix B as VWB software & removed App-C which is repeated in CH2. Added to plot radiation pattern using VWB in CH2. Modified note in each chapter from CH3 to 19	NB