This chapter describes in detail the design and fabrication procedures, the facilities utilised and the measurement techniques of various antenna characteristics.

3.1 DESIGN AND FABRICATION OF ANTENNAS

The work presented in this thesis is on antennas operating in the frequency range of 800 - 2500 MHz. This low frequency band is selected mainly due to the ease and convenience in fabrication of the antennas. It is well-known that the size of printed antennas become smaller as we go to higher frequencies. The physical dimension of the printed antennas will further be reduced by the use of high dielectric constant substrate.
The substrate used for the antenna fabrication is double-side copper cladded glass-epoxy, having dielectric constant 4.5 and thickness 1.6 mm, which is readily available in the market. Selection of such a substrate, for the above frequency band gives the freedom to neglect the fabrication tolerance, which will be a very small fraction of wavelength. Also this frequency band is of particular interest because it is most commonly used in land mobile satellite communication systems and for IFF applications.

The antennas are fabricated using photolithographic technique. The chart shown in Fig. 3.1 describes the step-by-step procedure of photolithographic etching technique.

3.1.1 Printed dipole

Experiments are started with the fabrication of ordinary rectangular printed dipoles, as shown in Fig. 3.2. The arm shown by dotted line is etched on the other side of the substrate.

As a modification of this structure, flaring is given to the dipole arms. Fig. 3.3 shows the sketch of such an antenna. Experimental observations indicate that the impedance bandwidth can be improved considerably by this modification. Optimisation of the design is done by exhaustive experimental observations.

Further investigations revealed that enhancement of impedance bandwidth is possible by end-loading of dipole arms. A number of printed dipoles with different end-load shapes, like triangular, circular, parallelogram, square etc. are fabricated. The conclusions drawn from these experiments are that the triangular and parallelogram shapes are most suitable for bandwidth optimisation of the printed dipoles. Fig. 3.4 and Fig. 3.5 show the antennas with triangular and parallelogram end-loading respectively.
Fig. 3.1 Photolithographic design procedure
Fig. 3.2 Ordinary rectangular printed dipole

Fig. 3.3 Flared printed dipole
Fig. 3.4 Triangular end-loaded printed dipole

Fig. 3.5 Parallelogram end-loaded printed dipole
Apart from this, studies are carried out to optimise the triangular and parallelogram end-loaded dipoles with cavity backup. This is done by placing a large ground plane at the optimum distance from the dipole.

### 3.1.2 Microstrip dipole

The triangular end-loaded printed dipole antenna design is extended to develop a wideband microstrip dipole antenna. The design requires two dielectric substrates. In one substrate, the dipole structure is etched as discussed in Section 3.1.1. The other substrate, which acts as the ground plane, is a single-side copper cladded glass-epoxy. The substrate having the dipole structure is placed on the other substrate in such a way that the dipole arm connected to the main feedline is sandwiched between the two substrates. Fig. 3.6 shows the complete structure. The interfacing layer is made air-tight by means of four screws at the corners of the substrate. The feedline for this dipole is stripline because the main feedline is in between the two substrates with top and bottom metallised.

To avoid double photographic exposure and the requirement of two substrates, a new type of triangular microstrip dipole antenna, shown in Fig. 3.7, is developed and optimised. Here both arms are etched on the same side of the substrate and the other side of the substrate is kept completely metallised. This design gives almost the same impedance bandwidth as that of the previous design.

### 3.2 ANTENNA FEEDING

It is clear from Fig. 3.2 to 3.5 that the electromagnetic energy is fed to the arms of the printed dipoles through microstrip line. To match the low input impedance of the antenna
Fig. 3.6 Triangular end-loaded microstrip dipole

Fig. 3.7 Triangular microstrip dipole
with system impedance (i.e. 50 Ω), an impedance transformer and a stub is used. Initial studies showed that the 42 Ω line impedance for impedance transformer is the best choice. Thus, for all further designs the line impedance of the impedance transformer is kept 42 Ω. To optimise the impedance bandwidth for a particular antenna, the stub is not etched along with the dipole and the impedance transformer, rather they are cut from thin copper foil and pasted using very thin layer of conducting flux, so that the length, width and position of the stub from the antenna, can be varied easily.

For microstrip dipoles, shown in Fig. 3.6, the feedline is stripline. Like printed dipoles, the input impedance of microstrip dipole is less than the system impedance. Here matching is achieved with a single impedance matching transformer. The dipole arms are etched along with 50 Ω stripline and the optimisation of impedance transformer is done by cutting and pasting thin copper foil of different length and width.

In the case of triangular microstrip dipoles with microstrip feed (Fig. 3.7), antennas are etched along with 50 Ω line. Matching is achieved by adjusting the matching balun length.

The planar transmission lines, for printed and microstrip dipoles are coupled to coaxial line through SMA connectors. The SMA connector is screwed to a rectangular aluminum block. Four holes are made in the block to tighten it with the antenna substrate. Fig. 3.8 shows the side-view of the same.

For printed dipoles, the microstrip line is soldered to the center conductor of the SMA connector and the antenna substrate plate is screwed with the aluminum block. Thus, the outer conductor of SMA connector is coupled to the other dipole arm.
The same connector and the base is used for feeding triangular end-loaded microstrip dipole antenna. The center conductor of the SMA connector is soldered to the center-line of the stripline. Then the other substrate is placed over it and both the substrates are screwed together with the base block. Thus, the ground plane and the top metallised portion are electrically coupled to the outer conductor of the SMA connector.

The feeding mechanism for triangular microstrip dipole is entirely different from the earlier ones. The outer conductor of the SMA connector is connected to the ground plane and the inner conductor comes out through a hole made in the substrate and is soldered to the microstrip feedline. The side-view is shown in Fig. 3.9.

3.3 FACILITIES UTILISED

The main facilities used for antenna characterisation are:

1. Anechoic chamber
2. HP 8510B Network Analyser
3. Scientific Atlanta positioner-controller

3.3.1 Anechoic chamber

The most important antenna characteristics are the radiation patterns. Hence, proper care has to be taken while plotting the radiation patterns. For indoor pattern measurements, the reflections from the surrounding walls, objects and external radiations may create errors in the measurements. Hence the resultant pattern may deviate from the actual one. For avoiding such spurious reflections during pattern measurements, *anechoic (no-echo) chamber*
Fig. 3.8 Side-view of the SMA connector and the base

Fig. 3.9 Cross-sectional view of triangular microstrip dipole with feed mechanism
is used. The philosophy is to have a non-reflecting environment like the outer space except that the walls are at ambient (\(\sim 300 \text{ K}\)) temperature instead of 3 K.

The walls of the chamber are covered with good RF absorbers. Instead of flat sheet absorbers, pyramidal and wedge shaped absorbers are used to reduce the reflection further [137]. To avoid external electromagnetic signal interference, a metallic lining is also provided in between the absorbers and the walls of the chamber. The measured return-loss of the chamber is found to be better than -35 dB.

Out of two basic types (rectangular and tapered) of anechoic chamber design, the tapered one is preferred for radiation pattern measurement, because it straighten the E-field faster than rectangular chamber.

In the present test set-up, the test antenna, whose radiation characteristics have to be measured, is mounted on a Scientific Atlanta turn-table which is kept in the quiet zone of the chamber. The antenna is aligned in such a way that the plane of the radiating edge is exactly along the axis of rotation of the turn-table. The turn-table is controlled from outside the chamber, through the controller, which can be automated using HP 9000/300 series computer. A schematic representation of the anechoic chamber is shown in Fig. 3.10.

### 3.3.2. Network Analyser

All antenna measurements have been taken using HP 8510B Vector Network Analyser. In this section, a brief description of microwave network analyser is given.

The description of parameters like impedance or transfer function of both the active and passive networks through stimulus response testing is referred as network analysis. Thus, using network analyser, the transmission and reflection characteristics of a test device
Fig. 3.10 Schematic representation of the microwave anechoic chamber
can be measured. A network analyser consists of a sweep oscillator, a transducer, a harmonic frequency converter (receiver) and a display unit, as shown in Fig. 3.11.

The transducer, which is the transmission/reflection test unit, is connected between the signal source and the receiver. It has a three-fold function. The first is to split the incoming signal into the reference and test signals. Secondly, it provides an extension capability for the electrical length of the reference channel, so that the distance travelled by the test and the reference signal are equal. Finally, it connects the system properly for transmission or reflection measurements.

In the receiver, the harmonic frequency converter mixes the RF signal with the output of a local oscillator and the resulting signal is given to the display unit.

The present configuration of HP 8510B Network Analyser is capable of measuring the transmission and reflection characteristics of active and passive networks in the form of gain, reflection coefficient, S-parameters and normalised impedance over 110 dB spurious free dynamic range in the frequency band of 10 MHz to 26.5 GHz. The measurements can be executed in any one of the two independent channels. The channels can be displayed individually or simultaneously in coupled or uncoupled channel mode. This provides the facility of simultaneously observing both transmission and reflection characteristics of the network under test. The measured results can be presented in logarithmic or linear magnitude, phase or group delay format on rectangular or polar coordinates. Direct measurement of normalised impedance or admittance is possible with Smith-Chart or Inverted Smith-Chart format. The value and frequency of any data can be read directly with the help of one of the five independent markers. The measurement can be done either in Ramp mode or in Step mode. In Step mode, measurements can be performed in 801 points with a maximum averaging of 4 K. The sweep rate can also be adjusted depending upon
Fig. 3.11 Block diagram of a network analyzer
with a maximum averaging of 4 K. The sweep rate can also be adjusted depending upon
the need. The main advantage of HP 8510B Network Analyser from its earlier versions is
its capability of time domain measurements. This gives more accuracy in measurement by
knowing the precise point of reflection and by removing it (if unwanted) using time domain
gating technique.

In the present measurement set-up, HP 8510B is interfaced with HP 9000/300 series
computer and a HP 7475A plotter, so that depending upon the need, the displayed output
can be saved in floppy through computer or the hard copy can be taken out directly using
the plotter.

3.3.3 Antenna positioner and controller

For plotting the radiation patterns, the test antenna can be used either as a receiver or as
a transmitter, whichever is convenient. In the present work, the radiation patterns are
measured in the receiving mode. In this mode of pattern measurement, the test antenna has
to be rotated about a vertical axis in the azimuth plane. For this, an antenna positioner
(turn-table) with remote control facility is required.

The positioner-controller used for the measurement is Scientific Atlanta 4131
positioner-controller. The model 4131 is a microprocessor based unit designed to move
about a single axis and simultaneously display the angular position. The controller can be
interfaced to a computer and various setting parameters like range, speed of rotation,
direction of rotation etc., can be controlled from the front panel of the controller or through
the computer. The accuracy of the system is 0.01 degree.
3.4 METHOD OF MEASUREMENTS

The various antenna characteristics measured are:

1. Impedance
2. Radiation pattern
3. Gain

3.4.1 Impedance

The knowledge of input impedance of an antenna is of prime importance, because input impedance directly effects the efficiency with which the energy is transferred to and from the antenna. When the microwave signal is fed to the antenna, if the antenna input impedance is not properly matched with the source impedance, part of the signal will be reflected back towards the source. This results in a standing wave pattern in the transmission line. The reflection is accounted by the parameter reflection coefficient ($\rho$) and is defined as the voltage/current ratio of the energy reflected to the incident energy. The mismatch of the device can be measured by another parameter called VSWR. It is related to $\rho$ by the relation, $\text{VSWR} = (1+\rho)/(1-\rho)$. For perfect match, the VSWR is unity which is an ideal case.

The input impedance measurement of the antennas are carried out using HP 8510B Vector Network Analyser. Before taking any measurement, one port calibration has been done using 3.5 mm cal-kit and the calibration is stored in the memory, so that it can be revoked at any time. Recalling the proper calibration, the test antenna is connected to Port 1 of the S-parameter test set. Using FORMAT menu, the measured values can be
displayed in any one of the numerous possible formats. In the present investigation, plots are taken in Smith-Chart and VSWR formats.

Since the characteristic impedance of the network analyser is set to 50 Ω, the center of the Smith-Chart corresponds to 50 Ω. The trace shows the variation of complex input impedance of the test antenna with frequency. By selecting the MARKER, the complex impedance in R + jX format can be read directly from the display for any frequency value.

In VSWR format, the trace represents the variation of VSWR with frequency. In this format, value of VSWR for a particular frequency can be displayed using MARKER. The impedance bandwidth of the antenna can be obtained directly by noting the frequency band over which the VSWR value is less than 2. Then the percentage bandwidth is given by \((\Delta f / f_0) \times 100\%\), where \(f_0\) is the central frequency of the band and \(\Delta f\) is the frequency band where VSWR is less than 2.

### 3.4.2 Radiation pattern

The radiation pattern of an antenna is the spatial variation of the received/transmitted field intensity/power by the antenna. A complete representation of the radiation pattern requires a three dimensional plot. For simplicity, the radiation pattern can often be described in terms of principal E and H-planes. According to the reciprocity theorem, the radiation pattern can be measured by either of the two methods: (i) test antenna as receiver and (ii) test antenna as transmitter. In the present investigation, the radiation pattern measurements of the antennas are carried out inside an anechoic chamber, using the first method. The set-up used for pattern measurement is shown in Fig. 3.12.
Fig. 3.12  Experimental set-up used for radiation pattern measurement
The HP 8510B Network Analyser system is used for pattern measurement. The network analyser is interfaced to HP 9000/300 series computer and Scientific Atlanta positioner-controller. An automatic pattern measurement software [138] is used for measuring and plotting the radiation patterns of the test antennas. The software incorporates all the facilities of network analyser like averaging, time domain capabilities etc. Flow chart of the programme is given in Fig. 3.13.

In the experimental set-up, the standard transmitting antenna (wideband ridged horn, 1 GHz - 18 GHz) is connected to Port 1 and the test antenna is connected to Port 2 of the network analyser. The test antenna can be rotated along the azimuth plane using a Scientific Atlanta positioner-controller, which is also connected to the computer. The computer automatically controls both the network analyser and the positioner-controller and acquires and stores data in it. In sweep mode, it can collect information about 801 frequency points in one rotation itself. The HP 7475A plotter, interfaced with the computer, gives the hard copy of the radiation pattern.

3.4.3 Gain

The ability of the antenna to concentrate radiated power in a direction, or conversely to absorb the incident power efficiently from that direction is termed as its gain.

In this thesis, a comparative measurement of gain of new antennas is made with standard antennas. For printed dipoles, gain is compared with standard half wave wire dipole resonating at the central frequency of the band of interest. The gain of microstrip dipoles is compared with standard rectangular patch etched on same dielectric substrate and resonating at the central frequency of the band of interest of test antenna.
Start

Start frequency, Stop frequency, Step frequency
Start angle, Stop angle, Step angle
Source power, Averaging & Smoothing

Calibration

Yes
Bore-sight the antenna

No

Instrumental state

No

Response calibration

Yes

Time domain analysis

No

Bore-sight the antenna

Yes

Time domain mode

No

Proper window

Gate

Frequency domain mode

A

61
Fig. 3.13 Flow chart for radiation pattern measurement procedure using HP 8510B network analyser
For measurement, the reference antenna (wire dipole for printed dipole and rectangular microstrip patch for microstrip dipole) is kept on the turn-table and connected to the Port 2 of the network analyser. The Port 1 is connected to a wideband transmitting horn. The turn table is rotated so as to receive maximum power. Then the network analyser is calibrated ie., the $|S_{21}|$ is made 0 dB in the frequency band of interest. Now, the reference antenna is replaced by the test antenna and the trace of $|S_{21}|$ gives the gain of test antenna with respect to the reference antenna.