CHAPTER - II

CHAPTER II

EXPERIMENTAL WORK

2.1 Introduction

The designing and fabrication of EMC patch antenna was completely done at the thick and thin film laboratory, Shivaji University, Kolhapur. The ferrite prepared in the laboratory was used as an overlay over the EMC patch antenna to study its effect on the antenna parameters. The parameters like resonance frequency, bandwidth, beam width, radiation patterns, directivity and gain were investigated. The following experimental work was carried out.

1) Designing and fabrication of EMC patch antenna.
2) Synthesis and characterization of ferrite.
3) Microwave studies using X band microwave bench.

2.2 Designing of Electromagnetically Coupled Patch Antenna (EMCPA).

According to skin depth condition the thickness of the conductor must be

$t > 3\delta$

δ is the skin depth given by,

$$\delta = \sqrt{\frac{\rho}{\pi f_r \mu_o \mu}} \qquad 2.1$$

ρ = Specific electric resistivity. = $0.01639344 \times 10^{-5}\ \Omega$ for Ag

$\pi = 3.142$

f_r = Resonance frequency.

μ_o = Permeability of free space = 1.256637 x 10^{-8} H/cm

μ = 1 H/cm

According to this, in the X band the thickness of the conductor should be approximately greater than 3-4 μm. Since in this work Ag thick film was used as a conductor, the thickness was approximately 8-10 μm, which satisfies the skin depth requirement.

For any microstrip component design it is necessary to derive d/h for a specific value of characteristics impedance, assuming that the substrate permittivity is known, where d is dimension of the element and h is the thickness of the substrate.

2.2.1 Design of microstrip feed line.

In this work open-ended microstripline was used as a feed line. The aim of designing it is to get width W_f of microstrip line with better accuracy for Z_0 and low loss in order to achieve maximum power coupled to the patch on top of it. The empirical formula for synthesis by Wheeler [77, 78] was used here, which is given below.

$$\frac{W_f}{h} = \frac{8\left(\left\{\frac{7\varepsilon_r + 4}{11\varepsilon_r}\right\} A + \frac{\varepsilon_r + 1}{0.81\varepsilon_r}\right)^{1/2}}{A} \qquad 2.2$$

$$\text{Where} \quad A = \exp\left\{\frac{Z_0}{42.4}\sqrt{\varepsilon_r + 1}\right\} - 1 \qquad 2.3$$

ε_r = 9.8 Relative permittivity of the substrate.

Z_0 = 50 Ω Characteristic impedance.

h = 0.0635 cm Thickness of the substrate.

This is the formula for a strip with zero thickness. Practically strip lines have a finite thickness that must be accounted [79]. Equivalence is established between a practical line with parameters (W_f', h, t) and zero thickness line with parameters (W_f, h, 0).

$$\frac{W_f'}{h} = \frac{W_f}{h} + \left(\frac{1.25\,t}{\pi h}\right)\left(1 + \ln\left\{\frac{4\pi W_f}{t}\right\}\right) \qquad 2.4$$

Equation 2.4 is for $W_f / h \leq 1 / 2\pi$

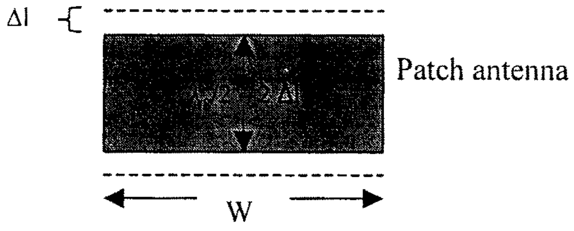
$$\frac{W_f'}{h} = \frac{W_f}{h} + \left(\frac{1.25\,t}{\pi h}\right)\left(1 + \ln\left\{\frac{2h}{t}\right\}\right) \qquad 2.5$$

Equation 2.5 is for $W_f / h \geq 1/2\pi$ which has been used in our design.

2.2.2 Design of rectangular patch antenna

At resonance the patch antenna launches electromagnetic waves (received from feedline) to the free space by matching the antenna impedance with the free space characteristics impedance at output and to the feed line at input.

The patch can be represented by two slots of width W, separated by spacing L that is λ/2, with radiation from these slots being in phase.



2.2.2.1 Element width

Patch element radiating edge W based on transmission line model is given by [80],

$$W = \frac{C}{2\,f_r}\left(\frac{\varepsilon_r + 1}{2}\right)^{-1/2} \tag{2.6}$$

Where

$C = 3 \times 10^8$ m/s, is the velocity of the light.

f_r is desired resonance frequency.

$\varepsilon_r = 9.8$ is the relative permittivity of the free space for alumina

h = 0.127 cm, is the thickness of the substrate below the patch.

(Since thickness of the single substrate is 0.0635 cm, here for EMC patch antenna two substrates were taken one on another.)

Other widths may be chosen, but for widths smaller than those selected according to equation 2.6, radiation efficiency is lower while for larger widths the efficiency is greater, but higher order modes may result, causing field distortions [80].

2.2.2.2 Element length.

Length is a critical parameter because of the narrow bandwidth of the resonance element [79].

$$L = \frac{C}{2\,fr\sqrt{\varepsilon_r}} - 2\,\Delta l \tag{2.7}$$

Δl is the extension length of the patch element L. It is required for better accuracy [81]. It is calculated by,

$$\frac{\Delta l}{h} = \frac{\zeta_1\zeta_3\zeta_5}{\zeta_4} \tag{2.8}$$

Where

$$\zeta_1 = 0.434907 \times \frac{\varepsilon_{eff}^{0.81} + 0.26}{\varepsilon_{eff}^{0.81} + 0.189} \times \frac{(w/h)^{0.8544} + 0.236}{(w/h)^{0.8544} + 0.87} \tag{2.9}$$

$$\zeta_2 = 1 + \frac{(w/h)^{0.371}}{2.35\,\varepsilon_r + 1} \tag{2.10}$$

$$\zeta_3 = 1 + \frac{0.5274 \text{ arc tan } [0.084\,(w/h)^{1.9413/\zeta_2}]}{\varepsilon_{eff}} \tag{2.11}$$

$$\zeta_4 = 1 + 0.0377 \text{ arc tan } [\,0.067\,(w/h)^{1.456}\,] \times \{\,6 - 5\exp(\,0.036(1-\varepsilon_r))\} \tag{2.12}$$

$$\zeta_5 = 1 - 0.218 \exp(-7.5\,(w/h)) \tag{2.13}$$

Where ε_{eff} is effective relative permittivity.

Electric field is not completely in free space but present both in air and in free space, so effective relative permittivity can be expressed in terms of an effective filling factor q [77, 82].

$$\varepsilon_{eff} = 1 + q\,(\varepsilon_r + 1) \tag{2.14}$$

To calculate effective filling factor first characteristics impedance is calculated knowing w/h and ε_r [83, 84].

$$Z_0 = \frac{42.4 \times \ln(1+A)}{\sqrt{\varepsilon_r + 1}} \tag{2.15}$$

A is positive root of following equation,

$$A^2 - \left\{ \frac{7\varepsilon_r + 4}{11\varepsilon_r} \; \frac{8h}{W} \right\} A - \frac{\varepsilon_r + 1}{0.813\,\varepsilon_r} \left(\frac{8h^2}{W} \right)^2 = 0 \qquad 2.16$$

Effective filling factor q is obtained by [82, 84],

$$q = \sum_{i=0}^{6} \sum_{j=0}^{3} R_{ij} X^i Y^j \qquad 2.17$$

Where

$$X = \{\ln(\sqrt{\varepsilon_r}\; Z_0) - 4\} \qquad 2.18$$

$$Y = 1 - \frac{1}{\varepsilon_r} \qquad 2.19$$

The R_{ij} coefficients with power of 10 are tabulated below.

	j →			
i	**0**	**1**	**2**	**3**
0	**7.80057 (-1)**	**-1.34226 (-3)**	**-3.01251 (-3)**	**-1.06181 (-3)**
1	**-1.35581 (-1)**	**4.04927 (-3)**	**3.48945 (-3)**	**-3.92521 (-4)**
2	**-1.36989 (-2)**	**-2.73642 (-3)**	**3.98886 (-3)**	**2.89673 (-3)**
3	**1.30331 (-2)**	**-1.38608 (-3)**	**-2.61336 (-3)**	**-3.16976 (-3)**
4	**6.31324 (-3)**	**2.14458 (-3)**	**-1.17603 (-3)**	**-1.59925 (-3)**
5	**-1.54467 (-3)**	**-4.56127 (-4)**	**1.17440 (-3)**	**1.9418 (-3)**
6	**-2.64802 (-4)**	**-1.67567 (-4)**	**-2.15831 (-4)**	**-3.3567 (-4)**

Value of q is such that $0.5 < q < 1$. It is related to the portion of the electrostatic energy stored in the substrate region and is a function of w/h and ε_r.

$q \rightarrow 1$ as $w/h \rightarrow \infty$ and

$q \rightarrow 0.5$ as $w/h \rightarrow 0$.

Using this q, ε_{eff} is calculated which is used in equation 2.8, for Δl calculations. The Δl is the extension length for calculating element length L. From these equations the dimensions of the patch for various frequencies is generated by means of C++ programming language.

2.3 Fabrication of EMC patch antenna.

2.3.2 Artwork.

Layout of pattern sketched on a plain paper is called as an "artwork". After calculations of dimensions of patch and feedline, the ink diagrams were drawn on paper. Drawing should be more accurate; otherwise small error causes large error in the final circuit. For accuracy, Auto CAD was used for drawing.

2.3.2 Mask Forming.

Photo masks are films or glass plates upon which the required conductor structure is produced as a negative or positive in size ratio 1:1, with precision. Photopositives are used as a mask for thick film fabrication process.

2.3.3 Preparation of stencil.

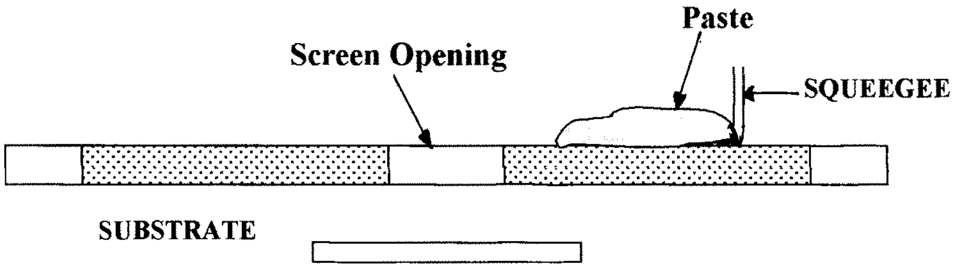
First screen was cleaned. Chromaline paper with photopositive material is placed on the face of the screen. PVA (Poly Vinyl Acetate or Poly Vinyl Alcohol) and positive sensitizer, with proportion 5 ml PVA to 4 drops of sensitizer were applied on the opposite side of the screen. The screen is dried for 10 minutes. When PVA was dried the chromaline paper was removed. Masks (Photopositives) were placed on the face of screen and exposed to yellow light for 10 minutes. In the exposed area material was polymerized rendering it insoluble and the material in the unexposed area remains soluble and which can be washed out to leave open meshes (which is the circuit pattern). The screen was dried to remove all the trace of water and small particles of emulsion. The screen stencil was examined thoroughly for pinholes and open areas, and was blocked out by emulsion.

2.3.4 Substrate cleaning.

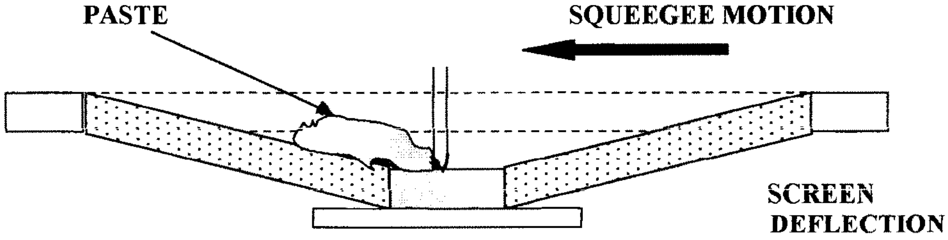
Potassium dichromate was dissolved in 250 ml of distilled water, in which 2-3 drops of sulfuric acid are added to prepare chromic acid. Substrates were kept in this solution for 15-20 minutes. Then substrates were kept in liquid sop solution with distilled water for 10-15 minutes. The substrates were washed with distilled water.

2.3.5 Screen-printing through stencil.

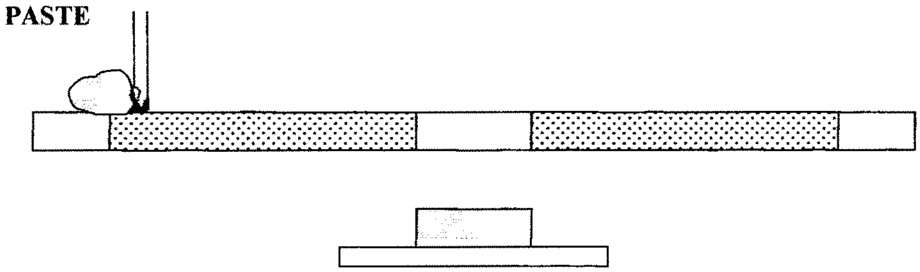
The stencil of the required pattern of the EMC antenna was fitted on the screen holder with a C shaped clamp. The pre cleaned alumina substrate was fixed and aligned bellow the circuit pattern on the screen. The substrate was fixed such that it did not disturb the aligned position. The finished screen had open mesh over the circuit pattern area. The appropriate quantity (~ 2 gm/ circuit) of paste was placed on the screen stencil. Using the square edge squeegee, the silver paste (ESL USA) was made to traverse on the screen under pressure bringing it into contact with the substrate and at the same time driving the paste through the opening of the screen. The angle of squeegee blade was adjusted at 45 ^{0}. The snap-off setting was adjusted such that it occurred immediately behind the squeegee blade. The screen-printing process is as shown in Figure 2.1. All the affecting parameters in the screen printing process such as squeegee attack angle, squeegee hardness, edge shape, down pressure, traverse speed, snap-off setting, and volume of ink/paste on the screen were standardized for the present work. The thickness of the screen-printed thick film antenna was 10-15 μm range.



1. START



2. DURING STROKE



3. SNAP BACK

FIGURE 2.1 : SCREEN PRINTING PROCESS

2.3.6 Drying and firing of antenna

The thick film printed antenna and feed line on the substrate was allowed to settle for few minutes. After the settling of the films, they were dried at 150^0 C for 15 minutes under IR lamp. The resulting thick films were set to permit handling. The high temperature firing is designed to remove the remaining organic binders, to develop the electrical properties of the circuit element to the substrate. Firing takes place between the paste components themselves. During firing as temperature increases particle to particle sintering and solid state alloying occurs and this gives rise to decrease in resistivity of the components. Total firing cycle was of 60 minutes. 20 minutes heating time, 20 minutes residence time at the peak temperature and 20 minutes cooling time. The burning of organic vehicle takes place up to 200^{0}C. Then various chemical reactions take place from200^{0}C to 500^{0}C, which gives required physical and electrical properties. The microstructure development begins at about 450^{0}C to 500^{0}C. Adhesion between the film and the substrate develops at 700^{0}C to 900^{0}C. Here the wet bonding material is absorbed by alumina to establish continuous bond between conducting film and the substrate. The furnace is switched off and cooling takes place after which firing cycle is completed. The patch and feed line had acquired good surface finish and sharp edges after firing. The adhesion was also good.

As already mentioned another aspect of the work was use of ferrite as an overlay on the fabricated antenna. The ferrite synthesis was done by wet chemical method. Details of which are given in the next articles.

2.4 Synthesis of ferrite

Single ($MgFe_2O_4$) and mixed ($Mg_{0.4}Mn_{0.5}Zn_{0.1}Al_{0.8}Fe_{1.2}O_4$) ferrite was prepared by wet chemical method. Basic materials used were magnesium sulphate, manganese sulphate, zinc sulphate, aluminum sulphate and ferrous sulphate.

Sulphates were accurately weighed to obtain desired proportion and dissolved in distilled water. A4 M solution of NaOH was prepared as a precipitant. The starting sulphate solutions were added to the NaOH solution slowly with continuous stirring. A suspension containing green intermediate precipitate was formed. It was heated at a temperature of 60^0 with continuous stirring to promote oxidation reaction until all the green intermediate precipitate changed into dark brownish precipitate and then allowed to settle down. The precipitate was filtered and washed with distilled water until Na and S ions are removed. To check their complete removal following tests were carried out on the filtrate obtained.

Flame test for Na - A glass rod was dipped in a filtrate and kept over the burner or spirit lamp. The liquid drop on glass rod burns with typical golden colored sodium flame indicating presence of sodium.

Precipitation test for SO_4 - Barium chloride or calcium chloride solution was prepared. Drop of it was poured in filtrate. A white coloured precipitate of barium sulphate or calcium sulphate formed showing presence of SO_4 ions.

Washed and filtered precipitate was dried. The dried powders were decomposed at 250^OC for two hours and then presintered at 500^OC for 4 hours. Presintered powder was mixed thoroughly and binder PVA was added if necessary. The pellets and torroid of this powder were made with a die by pressing it with pressure of 6-8 tons/sq. inch for about 3-5 minutes, under the hydraulics press. Pellets of thickness ranging from 1 mm to 5 mm were made from both the samples. The pellets were placed on clean platinum foil and sintered at 950^{O}C in air medium for 12 hours in furnace. Samples were furnace cooled and removed from furnace after it nearly reached room temperature.

In order to ascertain the proper formation of ferrite some of its properties were studied. The following properties were investigated.

1) Structural analysis by X-Ray diffraction and IR spectra studies.
2) Quantitative analysis by EDAX and granular spectral analysis by SEM.
3) Magnetic moment and saturation magnetization by hysteresis method.
4) Curie temperature by permeability measurements.

2.5 Microwave system for antenna characterization.

The X-Band (8-12 GHz) measurements were taken using a wave system consisting of the following components.

1) Gunn power supply.
2) Gunn oscillator.
3) Isolator.
4) Attenuator
5) Co-axial to waveguide adapter
6) SMA connectors/launchers
7) Pyramidal Horn antenna
8) Detector

The functioning of the each component is given below in brief.

1) Gunn power supply:

It consists of a DC power supply and a square wave generator designed to operate between DC voltage ranging from 0-15 Volts.

2) Gunn oscillator:

It is a solid-state microwave generator consists of waveguide cavity flanged at one end and micrometer driven plunger fitted on the other end. A Gunn diode is mounted inside the waveguide with BNC (f) connector for DC bias and connected to Gunn power supply. The manufacture supplies the calibration chart of frequency verses micrometer reading with each oscillator.

3) Isolator:

It is three port ferrite circulator converted into isolator by terminating one of its port into the matched load. It is a nonreciprocal transmission device used to isolate one component from reflections of the other components in the transmission line.

4) Attenuator:

In microwave terminology, any dissipative element inserted in the energy field is called attenuator. It consists of resistive or lossy surface in the form of card placed in the center of the waveguide through a slot. On increasing penetration of the card it absorbs more energy and increases attenuation. Card is moved outwards to decrease the attenuation resulting less absorption of energy.

5) Waveguide to co axial adapters:

The adapter consists of a section of a waveguide whose one end is terminated with a smooth polished flat. This works as a loss less transmission line from rectangular waveguide to co axial line or vice a versa.

6) SMA connectors / launchers:

Microstrip line circuits being in a miniaturized form, special miniaturized connectors and adapters have to be used. The connectors and adapters used for this work are of SMA type (from OSM, USA). The microstrip line has to be connected through specialized launchers. The dimensions for SMA connectors are 0.26 inch diameter for male (jack) and 0.182 inch diameter for the female (plug).

7) Pyramidal Horn antenna:

It consists of a section of waveguide joined to a pyramidal section fabricated from brass sheet. Due to this shape the horn has directional characteristics. Waveguide horns are used as a pick up antenna for receiving microwave power. The energy emitted from flared end gets concentrated in a specified beam and effectively increases the power output in comparison with non-concentrated beam. This was attached to antenna rotating stand (shown in photograph)

8) Detector:

The detector used was a diode detector having square law characteristics. The energy flow in the detector is only in one direction. Ge or Si is commonly used as the material in construction for the crystals. 1N21 and 1N23 are the suitable diodes for the microwave frequency. The output of the detector was connected to a voltmeter.

Block diagram and photograph of the system is shown in the Figure. 2.2 and 2.3 respectively.

2.6 Characterization of EMC using X-Band microwave bench.

In this part of experimental work resonance frequency, bandwidth, polar plot, radiation pattern, lobe width (half power beam width $\Delta\theta$), amplitude of the main lobe (antenna beam), directivity and gain were studied for rectangular electromagnetically coupled microstrip patch antenna.

In this study microstrip line was used as a feed line to antenna. Microstrip patch antenna was used as a transmitter and waveguide horn antenna was used as a receiver in the far field region.

The substrate of the feed line was kept on the substrate holder. On the feed line the substrate containing the patch was kept in such a way that the metallization section was on the top and backside of the substrate was touching the feed line. The feed line was adjusted in such a way that antenna

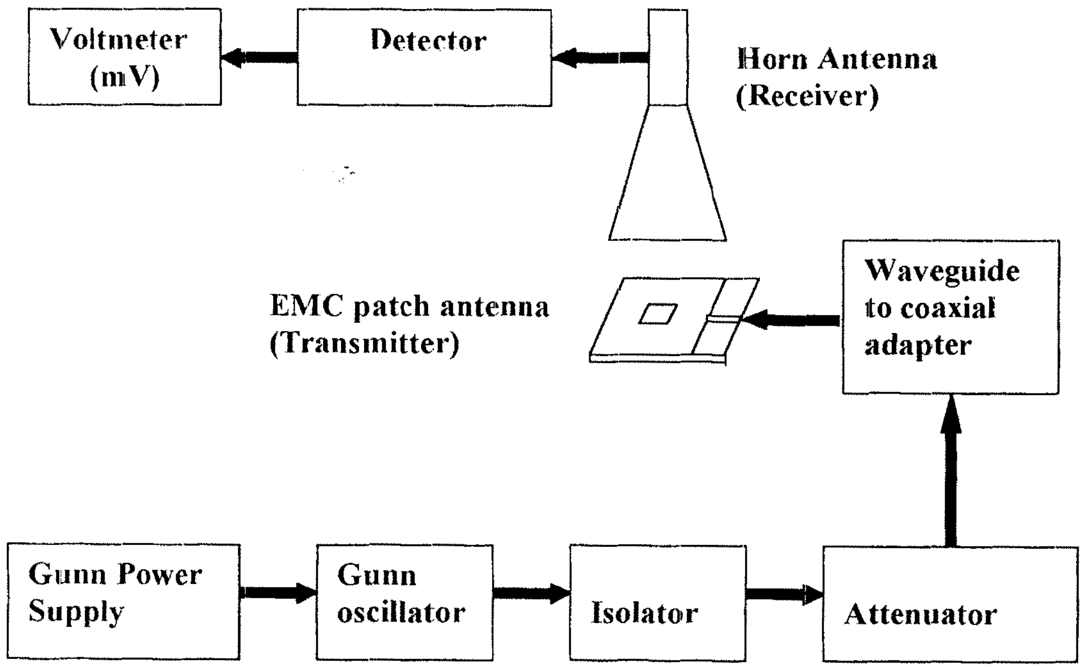
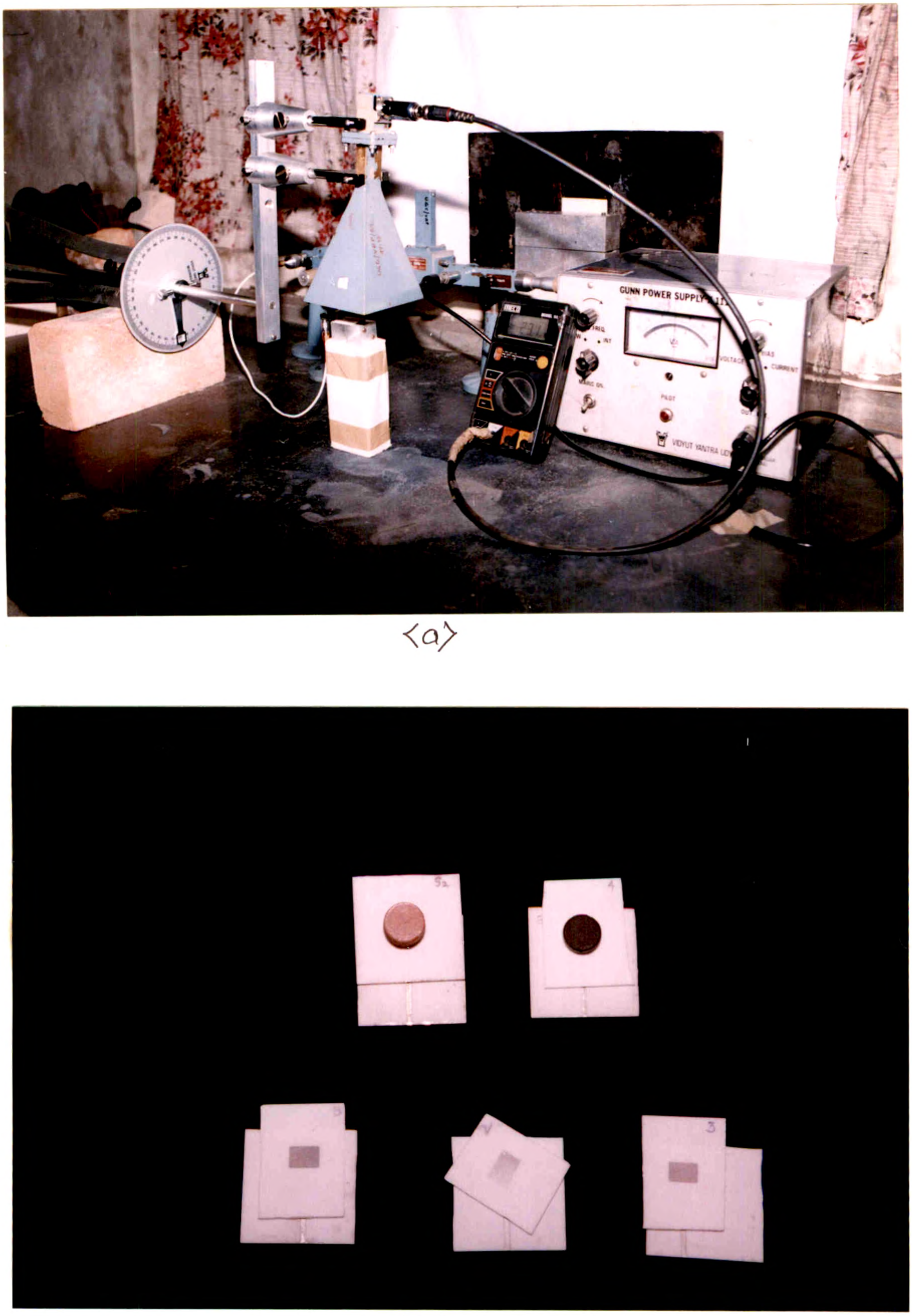


FIGURE 2.2: Block diagram of X – Band Microwave system used for characterization of EMC patch antenna



<a>

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Fig.2.3: Photographs of <a> X-band microwave system & <b> Actual circuits used for characterisation.

was fed at the center. During the experimentation the rectangular patch was fed from three feeding positions as shown in Figure 2.4.

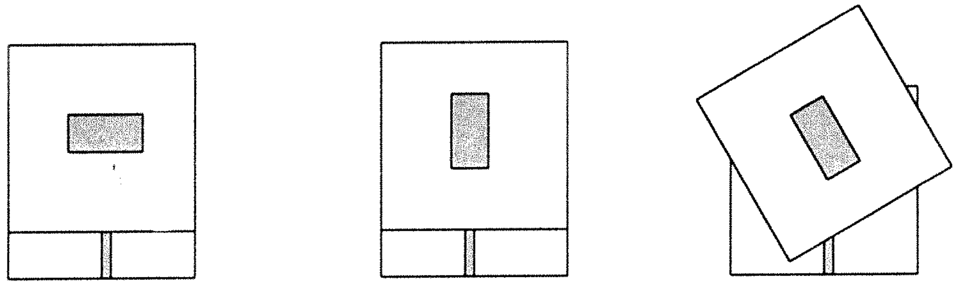


FIGURE 2.4 Change in feeding positions viz. Long Side Fed (LSF), Short Side Fed (SSF), Diagonally Fed (DF).

The feed line was connected to the flexible cable through SMA connector. Other end of flexible cable was connected to the microwave source through co axial to waveguide adapter.

2.6.1 Resonance frequency and Bandwidth

To determine resonance frequency and bandwidth: EMC patch antenna without overlay and with overlay was scanned for frequency from 8-12 GHz. Both the antennas were investigated for three feeding positions viz. Long Side Fed (LSF), Short Side Fed (SSF) and Diagonally Fed (DF). In these measurements output in mV was recorded. Square law detector was used which detects power proportional to square of voltage.

In these measurements, the patch antenna (transmitter) and the horn antenna (receiver) were kept in such a way that the radiation maxima is along $\theta = 0^{o}$ direction at resonance frequency.

2.6.2 Radiation pattern

For radiation-pattern, measurement the horn antenna was rotated as described below. The microstrip patch antenna kept fixed and horn antenna was fixed to the antenna-rotating stand. Horn antenna was rotated around patch antenna through 180^0 keeping the distance between them constant. Z is direction of propagation.

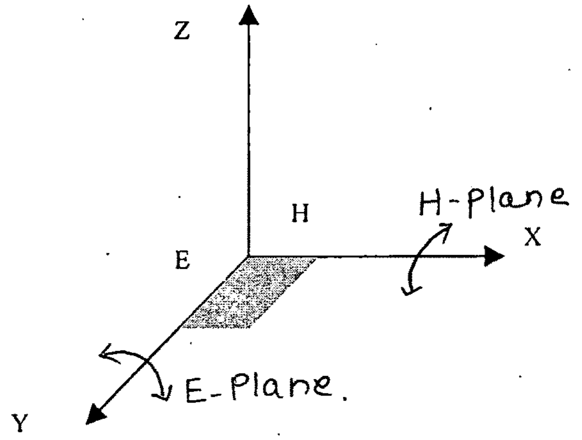


FIGURE 2.5 : Axis of rotation of E & H plane radition Pattern.

For H plane radiation pattern horn was rotated in ZY plane and for E plane radiation pattern horn was rotated in ZX plane. Power was recorded for every 10^0 angle for both E and H pane radiation pattern.

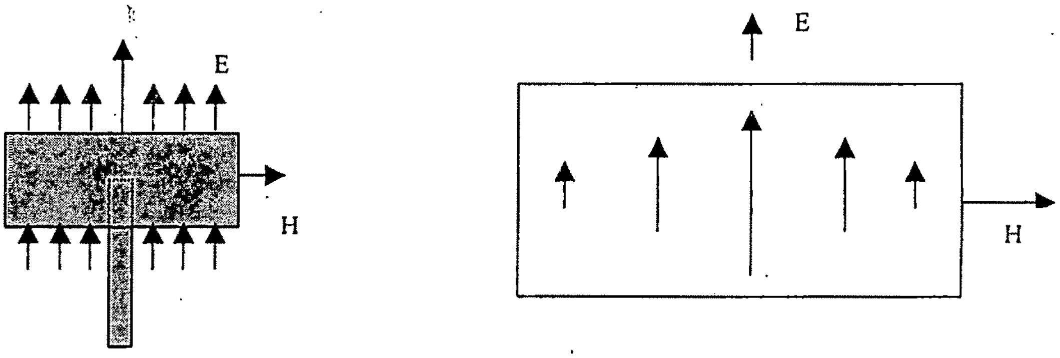
Horn antenna was kept such that E planes of both the horn antenna and MPA were parallel to each other; hence, electric field was also parallel. This gave co polar patterns. H plane radiation pattern (in YZ plane) was obtained by rotating the microstrip antenna (or horn) around X-axis (hence the direction of feed line). Where as to obtain E plane radiation pattern (in XZ plane) microstrip antenna (or horn), was rotated around Y-axis. In practice for both radiation patterns horn antenna was rotated through 180^0. Radiation patterns were recorded for the three feeding positions for both the patches.

Figure 2.5 shows the axis of rotation for E and H plane radiation patterns.

2.6.3 Polar plots

Frequency was kept fixed.

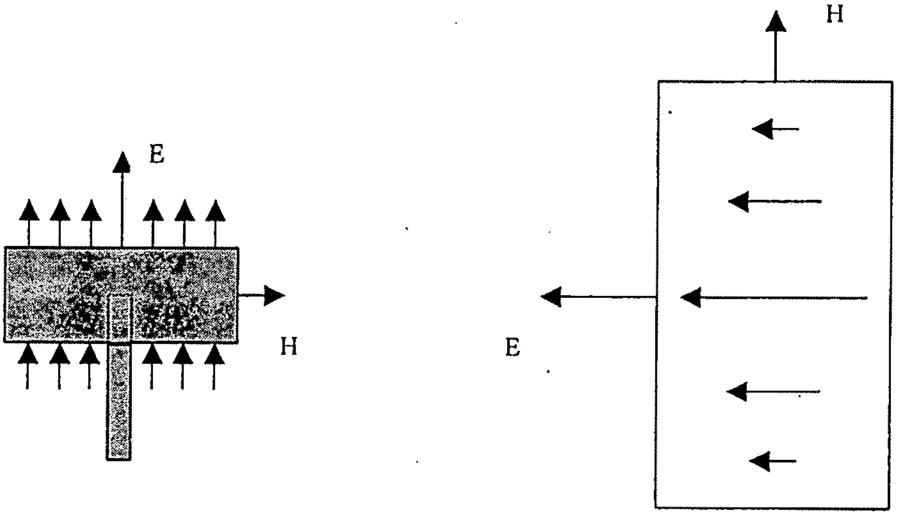
The position of horn antenna and microstrip patch antenna are as shown Figure. 2.6. Where the electric field directions are shown by using arrows.



LSF MPA

Horn in TE_{10} mode

(a) Co-polar



(b) Cross polar

FIGURE 2.6: Co-polar and Cross-polar situations.

When E plane of the patch is parallel to E plane of the horn that is electric field is parallel to each other, it is called co-polar situation that is at polarization angle 0^0. When E plane of the patch is perpendicular to E plane of the horn then it is called as cross polar situation.

Patch was rotated through 360^O in the plane of the patch. If Z is the direction of propagation then patch is rotated in XY plane with the difference of 10^0. The received power is recorded for each angle. Power in dB across each plot was plotted which gives polar plots. Thickness, composition, feeding positions dependent polar plots were recorded for various frequencies (resonance and off resonance)