CHAPTER - IV

CHAPTER IV
DISCUSSION

4.1 Introduction:

The results described in chapter III have been discussed in this chapter. As already indicated thick film silver electro magnetically coupled patch antenna has been studied in detail for the first time. The effect of ferrite loading over the antenna has also been studied for all feeding positions for the first time. To our knowledge there are no reports available of thick film EMC patch antenna with ferrite loading in the absence of external magnetic field. The microstrip antenna, with microstrip line EMC feed system is not completely understood and particularly the flexibility aspect of it is not fully explored even experimentally.

The metallisation of the antenna patch and also the feed line is an important aspect in the efficiency of the EMC patch antenna. Silver thick film has proved to be cost effective and comparable in properties to thin film for metallisation purpose [94 - 96]. In this work the metallisation for the patch and feedline was achieved using thick film technology with silver as the conductor.

Most of the reports available are for microstrip patch antenna with low dielectric constant substrate ($\varepsilon_r \sim 2.5$) and at lower microwave frequencies namely the S band and C band. There is a need to study microstrip patch antenna on high dielectric constant substrate at higher frequencies. The study on high dielectric constant substrate is justified because for MMIC, phased array application especially for satellite space born experiments, the GaAs substrate used has a dielectric constant of the order of 10 is therefore suitable for these studies.

4.2 Antenna without overlay.

Though both the antennas show resonance characteristics at the designed frequency the % power efficiency is quite low for long side feeding. When the patches were designed they were for frequencies corresponding to dominant TE_{10} mode for long side fed system. The EMC antenna configuration is as follows. The open-ended microstrip feedline and ground plane is fabricated on one substrate and the radiator on the covering substrate, being located immediately on the open-ended feedline. This results in the top patch being excited by the field either at the open end or at the side of the open-ended microstrip EMC feedline. Since the microstrip feedline has fringing fields present all over the line length, this side field will tend to interfere with the normal end field. This might result in the lowering of radiated power from the antenna. There are very few reports available for short side feeding and diagonally feeding. As per the design these positions are non-radiating sides. This might be the reason for lower % power efficiency when the antenna is fed from short side and diagonally. The radiation observed in short side feeding is mainly from side field feeding of the misrostrip feedline. Since the fringing fields are of very low intensity, the coupling to the upper surface is poor. When antenna is fed diagonally as far as fields are concerned, the situation becomes very complex. Analysis of fieids when patch is fed diagonally is not available in literature. In the EMC antenna, reasonably accurate alignment between upper substrate containing patch and lower substrate containing feedline is required for the efficient coupling of feedline to the patch for radiation. It has at least two degrees of freedom, the length of the feeding stub and the patch width to line width ratio. The capacitive nature of this coupling method has a capacitor in series with a parallel RLC resonator that represents the patch [23]. Since Ag thick film has been used for metallization of the patch and feedline, the inherent problems of thick film technology alters the values of R, L and C. The cross section is not rectangular because of the ink slump after printing gives rounded profile. The thick film microstripline and the patch have higher surface roughness as compared to the thin film version [96]. The rough and porous surface morphology of the thick film component contribute to the losses. There is also slight spreading of the thick film at the edges of the patches and also microstripline. Excessive rounding of the edges results in increased losses [97].

The thick film due to the very process of its manufacture is porous complex system with random distribution of metal patches and oxide spaces. Due to this the film would present extra impedance to the microwaves.

Due to the irregular surface and edges of microstrip feedline, the upper EMC may not be efficient. The upper substrate with the radiator patch may not be positioned evenly on the feedline. These irregularities tend to increase spurious feed radiation, surface wave generation and also feed inductance. These factors add to the losses in the antenna.

It has been reported [98] that finite sized ground planes influence the radiation pattern of patch antenna. Diffraction/ Scattering from the edges of the finite ground planes have a significant impact on the far field radiation from patch antennas. These edges diffracted / scattered fields arise due to surface waves, space waves and leaky waves. These waves contribute to the loss mechanism of the antenna. Since the edges of the thick film structures are not smooth and also the thick film substrates have rough surfaces, they form discontinuities. Diffraction from these discontinuities can degrade the antenna radiation pattern or polarization characteristics. The minor resonance peaks observed for LSF (patch 2) might be due to irregularities in the antenna structure. The peak obtained around 8.5 GHz and below seems to be the resonant frequency corresponding to the non-resonant side rather than the designed side of the patch that is $L = \lambda_g/2$. Higher order mode excitation also tends to give additional resonance frequency. Double peaks may be due to splitting of the resonant peaks due to over coupling.

The radiation patterns have been measured both for $\theta = 0^0$ and $\theta = 90^0$ planes that is for E and H plane. The EMC microstrip antenna element exhibited satisfactory and nearly symmetrical H plane radiation pattern. The E plane pattern was not symmetrical. For the diagonal feed position greater asymmetrical properties were observed. The figures show some important scan observations. The potential scanning range in H plane is large as no blindness is present for a large range of angles. A poor scan performance is observed in E planes for angles greater than $+40^0$ and -40^0. All these radiation patterns are co-polar radiation patterns. The presence of double unequal lobes about $\theta = 0^0$ unequal E, H lobe value at $\theta = 0^0$ may be due to secondary radiation due to launcher. Since the receiving horn antenna was rotated for E plane pattern, the launcher effects are more prominent after 50^0. Ideally the radiation pattern of microstrip element should be hemispherical, both in the E plane and H plane and they should have null in horizontal plane at $+90^0$ and -90^0. Most of the H plane pattern shows this behavior as the radiated power in most cases is lesser than –60 dB. The E plane pattern does not show this behavior. This indicates that the radiated power in this plane is affected by the presence of surface waves.

According to Kara [99] the diffraction from the edges of the ground plane has the profound effect on the radiation pattern above $+60^0$ and -60^0. In the main beam region, the ideal patch pattern is modulated by diffracted fields. Diffraction effect have also been observed due to imperfect ground planes. According to Kara even variations below $+60^0$ and -60^0 are possible and can be caused by surface waves and diffraction at the ground plane edges. The far field radiation patterns in the E and H planes are also affected by factors such as physical and effective dimensions of the antenna element, its feed point location, and its operational frequency. The feeding and construction discontinuities can cause asymmetry in radiation patterns. The diagonally fed antenna due to its complex field configuration shows very bad radiation pattern in the E plane. The H plane patterns are slightly better. The exact reason has to be investigated in details.

4.3 EMC patch antenna with ferrite pellet loading.

As already mentioned most of the known applications of ferrite on microstrip antenna are when ferrite is used as a substrate. The use of ferrite as overlay gives an additional degree of flexibility to the antenna properties. All the measurements were taken in the absence of external DC magnetic field. When ferrite pellet is kept on the patch as overlay, the configuration consists of perfect reflector (metallic substrate holder) on top of which another reflector (antenna patch). Since two substrates are used, possibility of air gap (dielectric layer) between the two exists. All the power efficiency data have been taken for $\theta = 0^0$. The ferrite $MgFe_2O_4$ (S1) and $Mg_{0.4}Mn_{0.5}Zn_{0.1}Al_{0.8}Fe_{1.2}O_4$ (S2) used as overlay has been obtained by co-precipitation method. These ferrites have the easy axis randomly oriented [100]. The magnetization direction is not fixed along any of the easy axes. It fluctuates among the easy axis of magnetization when there is no external magnetic field. Since no external magnetic field is applied these ferrites are magnetically non saturated and as such multi domains are nucleated in the ferrite materials. The ferrite overlay is in touch with the patch. In the close proximity of the antenna, the radiation fields exhibits complex characteristics, because of reactive component due to the electrostatic zone in the close proximity of antenna in addition to radiated fields.

It has been reported by many workers [38,47,101] that dielectric superstrate loading on the antenna causes considerable shift in the resonance frequency.

The basic characteristics pattern of the antenna does not change. The changes in the resonance frequency is attributed to the changes in the effective relative permittivity ε_{eff} which results in changes in Z_{in} of the microstrip patch antenna and therefore there are more mismatches between feedline and patch feed point.

The ferrite loading being used in the absence of external magnetic field there is a possibility of permittivity related effects being more prominent than permeability related effects. If it were only permittivity related effects like pure dielectric overlay the resonance frequency should shift to lower frequency side. This effect is not observed on our antenna due to ferrite. It appears that the magnetic properties of the ferrite also contribute to the effects observed. Due to ferrite overlay both S1 and S2, no specific shift in resonance frequency is observed due to LSF both on patch 1 and patch 2. Nothing much can be discussed about resonance frequency for SSF and DF. It appears that at the original resonance frequency of the antenna (9.2 GHz for patch 1 and 10.4 GHz for patch 2) the % power efficiency decreases. The power efficiency enhances at about 8.1 GHz for both patches and at 9.2 GHz for patch2. The driven patch with superstrate behaves as an RL as well as RC network. Where as EMC antenna with superstrate behaves as an RL network [101]. The overlay is in the electrostatic zone of the antenna. There will be a considerable change in the ε_{eff} due to this. The radiation from the patch passes directly through overlay, particularly from the sides of the overlay. In the first case power transmits by multiple internal reflections in the thickness of the overlay depending on $d/\lambda m$. In the second case the waves diffracts at the edges of the overlay and in the third case the waves passes without disturbance from overlay. The transmitted power depends on the size of the overlay and relative thickness. The overlay behaves as a secondary parasitic radiator fed by the patch. The characteristics of the overlay are bound to affect the radiation of the patch. This might be in the form of absorption.

Since the overlays used are ferrites the propagating modes in a ferrite may be strongly or weakly affected by the magnetic properties of the ferrite. It has been reported [102] that ferrite supports dielectric and magnetic type of modes. The dielectric modes are analogous to surface waves on a dielectric substrate. Due to dielectric constant of ferrite being high they give rise to mode conversion even in the absence of dc magnetic field. There is zero field magnetic loss, which makes the radiated power less. The presence of higher order modes causes erratic variations in the radiated power of the antenna. Wang et al [103] have observed electromagnetic interference effects due to loading of superstrate. According to them the interfering external electric and magnetic fields on the surface of the patch antenna could trigger or excite the antenna to mal function. The magnetic field intensity causes more interference than the electric field intensity. These effects may be more prominent where ferrite is used as superstrate as in our case. The field pattern due to SSF and DF is very complex and beyond the scope of this thesis. Not much can be said about them at this junction.

The off resonance magnetic loss seems to be very less, since in both the patches the ferrite increases the off resonance peak considerably. This effect is observed even for SSF and DF. Insertion loss is an outstandingly important performance parameter. The thickness dependent characteristics are more prominent with S2 as overlay especially with SSF and DF on patch 1. The metallisation being Ag thick film the in touch overlay may produce air gaps between antenna and superstrate. The system becomes more like a multilayer structure. The configuration of the electric flux in the multilayer structure becomes complicated since the radiated wave meets different dielectric constant medium. Considerable shifts in resonance frequency for air gaps of the order of tenth of a free space wavelength have been observed. According to Reza et al [47], where dielectric superstrate is used in touch with a patch an optimized thickness of $\leq 0.14\ \lambda_m$ is suggested for optimum performance.

The splitting observed at the resonance frequency due to the ferrite overlay might be due to the coupled oscillatory phenomena related to over coupling. The exact reason is not known. There might be multiple reflection interference in the thickness of the overlay pellet. This gives maximum wave reflection to patch from overlay.

4.3.1 Effect of ferrite pellet overlay on the radiation pattern of the EMC patch antenna.

As already explained in chapter III, the radiation pattern due to overlay generally follows the same shape as that of without overlay antenna except when the antenna is fed from diagonal side. The beam width of H plane pattern is almost not affected by ferrite loading of both compositions and their thicknesses, whereas the E plane pattern shows increase in beam width in most of the cases. According to Wang et al [104] due to dielectric superstrate loading, the beam width of E plane pattern decreases and H plane is almost not affected. They have also found beam width of E plane pattern decreasing with increasing superstrate thicknesses.

When the antenna is fed from short side there is slight dip in the E plane pattern at $\theta = 0^0$. This might be due to the excitation of mode on the patch conductor. The extent of decrease in magnitude is dependent on the relative position on feed with respect to center of the patch. This dip gets smoothened out due to ferrite overlay. The ferrite might be suppressing the spurious modes on the antenna.

Radiation intensity not deteriorating over the steering angle in most of the H plane patterns and also in many E plane patterns indicates the non occurrence of impedance mismatch due to ferrite.

When the antenna is fed from diagonal side, there is a splitting of lobe and also broadening even in the H plane due to ferrite overlay splitting of lobe is not obtained for LSF and SSF.

The increase in radiation power at some frequencies may be due to the fact that in these directions all rays, which pass through the overlay layers into free space, have nearly the same phase. According to Shen et al [48] this is possible when the resonance condition corresponds to $\varepsilon_r >> 1$ and $\mu_r >> 1$. Ferrites have $\varepsilon_r >> 1$ and also $\mu_r >> 1$. The ferrite due to their magnetic non homogeneity tend to have local free magnetic poles at air spaces and other nonmagnetic inclusions creating an additional magnetic field distribution, a disturbing influence of material magnetic field and antenna field occurs. This disturbance is highly θ dependent.

The polar plots (Figure 3.23- 3.25) as already described have been plotted by changing the angle of the patch antenna keeping the horn antenna position fixed.

These plots give an idea about the polarization aspect of the radiated beam. At the resonance frequency the LSF antenna shows broadside radiation pattern (maximum at $\theta = 0^0$). The ferrite does not change the polarization of the radiated power. At off resonance 8.1 GHz without overlay it appears that the radiation of the antenna is elliptically polarized waves, which becomes linearly polarized due to ferrite overlay. When the antenna is fed from short side, at the frequencies studied again there is a tendency for maximum relative power to be away from $\theta = 0^0$. Due to ferrite this does not come to 0^0. For the case of diagonally feeding as the frequency increases the polarization changes from elliptical to circular and again elliptical. The overlaid antenna also follows the same pattern.

More detailed investigation has to be done to understand the various aspects of these patterns.