

## **PERTURBATION OF EMC MICROSTRIP PATCH ANTENNA FOR PERMITTIVITY AND PERMEABILITY MEASUREMENTS**

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**Abstract**—The complex permittivity and permeability of barium hexaferrite in the 8–12 GHz range was determined by using perturbation of electromagnetically coupled Ag thick film patch antenna due to overlay. In this technique even minor change in the overlay material properties changes the antenna response. The power gain of the EMC patch antenna was enhanced by 50% due to barium hexaferrite overlay. Barium hexaferrite was synthesized by co precipitation method and their fritless thick films were fabricated by screen printing technique. The properties were found to depend on the synthesis conditions such as Fe/Ba molar ratio, pH of the solution.

### **1. INTRODUCTION**

Microstrip antennas are popular choice for a range of military and commercial applications because of their conformability to surfaces, ease of manufacture and durability [1]. The work in our lab on overlay technique [2, 3] has shown that the same antenna can be operated at different resonant frequencies due to in-touch overlay of NiZn ferrite. This is a very simple and cost effective method for the perturbation of resonance of microstrip circuits. It has the flexibility to change the strength of perturbation by changing permittivity, permeability, width and thicknesses of the overlay material. In the present paper the microwave properties of barium hexaferrite in thick film and bulk form were investigated using overlay on EMC Ag thick film microstrip antenna. EMC patch antennas are of interest due to their flexibility of feed position which provides flexibility of resonance frequency.

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Ferrite materials have found application in microwave components [4–6]. The magnetodielectric substrates also been used to achieve impedance matching [7–9]. It has been challenging in achieving magnetic materials with high  $\mu$  and  $\varepsilon$  at microwave frequencies suitable for antenna applications, hexaferrite being one of those [10]. Though thick film technology is attractive for planarization, it is not widely used till now.

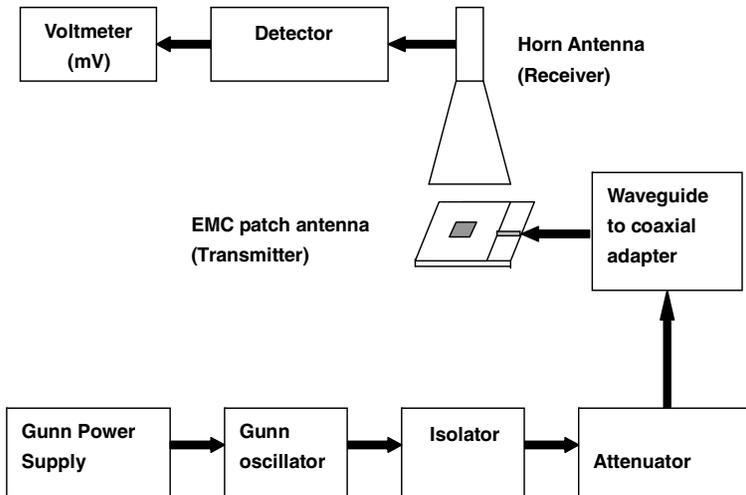
In the present paper, the response of the Ag thick film electromagnetically coupled microstrip patch antenna (EMCPA) to thick film and bulk barium hexaferrite overlay is reported. The effect of Fe/Ba molar ratio and pH of barium hexaferrite on the microwave properties of EMCPA are also studied. From the perturbations the *X* band (8–12 GHz) permittivity and permeability of overlay material is obtained. To the authors knowledge there are no reports on the microwave properties of bulk and fritless thick film barium hexaferrite using perturbation due to overlay technique. All the *X* band studies have been undertaken in the absence of external dc magnetic field.

## 2. EXPERIMENTAL PROCEDURE

The Electromagnetically Coupled Patch Antenna (EMCPA) was used as resonant circuit. The rectangular patch and microstrip feed line were designed by using standard equations and delineated on two separate alumina substrate by screen printing technique. The antenna was fired at 925°C for 1 hour. The thickness of the screen printed thick film antenna was 10–15  $\mu\text{m}$ . The M type barium hexaferrite powder was synthesized by co precipitation method. The materials were weighed for 11:1 and 14:1 Fe/Ba molar ratio and desired pH of 11, 12, 13 was maintained. The powder was pelletized by hydraulic press to a thickness of 1 mm for obtaining bulk samples. The sintered powder was used for the formulation of thick film paste. The paste was deposited on to alumina substrate using screen printing technique and fired. The thickness of the thick film was 60  $\mu\text{m}$ . The saturation magnetization, remanence and coercivity of powder and thick film barium hexaferrite were measured using vibrating sample magnetometer (Lakeshore 7307).

The design of the antenna was for the frequency corresponding to the dominant mode for long side fed system. The *X* band output was measured point by point by using a system consisting of Gunn source, isolator, attenuator, pyramidal horn and detector. SMA connectors were used for contact to antenna. The patch antenna was used as the transmitting antenna and the horn as the receiver. The barium hexaferrite bulk and thick films was kept as in-touch overlay on the

patch.

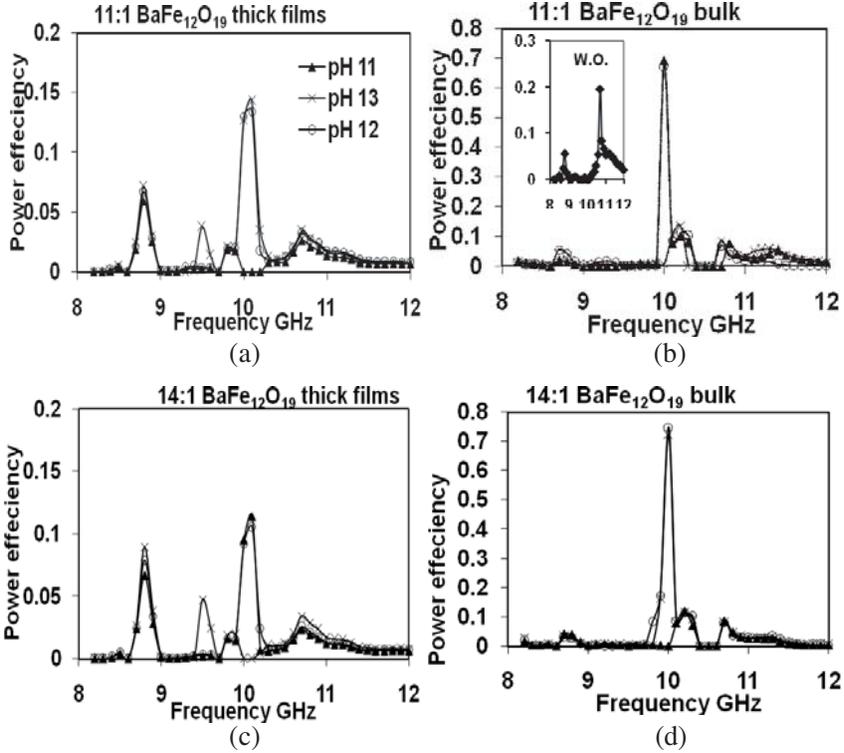


**Figure 1.** Schematic of microwave measurement set up for overlay technique.

### 3. RESULTS AND DISCUSSIONS

The microwave power gain of microstrip patch antenna with barium hexaferrite bulk and thick film overlay is plotted in Fig. 2. The power gain of EMCPA without overlay (W.O.) is shown in inset of Fig. 2(b). The resonant frequency of patch antenna without overlay is 10.7 GHz. The minor resonance peak observed at 8.6 GHz might be due to irregularities in the antenna structure. Due to the barium hexaferrite thick films of 11:1 Fe/Ba ratio (Fig. 2(a)) of pH 12 and 13 and of 14:1 Fe/Ba ratio (Fig. 2(c)) of pH 11 and 12 overlay the resonant frequency shifts to 10.1 GHz with power reduction by 5%. The thick film of pH 11 of 11:1 Fe/Ba and pH 13 of 14:1 Fe/Ba ratio overlaid on EMCPA shifted the resonant frequency to 9.9 GHz with no change in the power gain as compared to antenna without overlay. The small irregularity at 8.8 GHz was enhanced by the thick film  $\text{BaFe}_{12}\text{O}_{19}$  overlay. The resonant frequency of EMCPA at 10.7 GHz is shifted to 10 GHz by barium hexaferrite (of 11:1 Fe/Ba ratio of pH 11 and 12) bulk overlay (Fig. 2(b)) with increase in power gain by 40% whereas the resonant frequency shifted to 10.2 GHz due to the sample of pH 13 with decrease in power gain by 5%. With the overlay of barium hexaferrite pellets (bulk) of 14:1 Fe/Ba ratio (Fig. 2(d)) of pH 12 and

13, the resonant frequency shifts to 10 GHz with increase in power gain by 50% whereas BaFe<sub>12</sub>O<sub>19</sub> bulk of 14:1 Fe/Ba ratio and pH 11 shifts the resonant frequency to 10.2 GHz with gain reduction by 7%.



**Figure 2.** Microwave power efficiency of EMCPA with BaFe<sub>12</sub>O<sub>19</sub> bulk and thick film overlay.

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.

The driven patch with superstrate (overlay) behaves as an RL as well as RC network, where as EMC antenna with superstrate behaves as an RL network [11]. The overlay is in the electrostatic zone of the antenna. There will be a considerable change in the  $\epsilon_{eff}$  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. 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 also. Wong et al. [12] 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 ferrites are used as superstrate as in our case. The domain walls in the barium hexaferrite vibrates as the electromagnetic waves are incident on it. These vibrations may produce magnetostatic interference either in a constructive or destructive manner. It may result in the increased power gain of EMCPA due to bulk ferrite overlay and decreased power gain due to thick film ferrite overlay.

The band width and quality factor of the Ag thick film EMCPA with barium hexaferrite bulk and thick film overlay is given in Table 1. The  $\text{BaFe}_{12}\text{O}_{19}$  bulk overlay reduces the band width and quality factor whereas thick films overlay increases the quality factor.

The complex permittivity and permeability of barium hexaferrite was calculated from the frequency shift of the microstrip antenna due to barium hexaferrite overlay [2, 3] using following equations,

$$\varepsilon' = 1 + \frac{C_0}{K} \left\{ \left( \frac{f_a}{f_r} \right)^2 - 1 \right\} \quad \text{and} \quad \varepsilon'' = \frac{N'}{f_r r_0} \quad (1)$$

where, the ratio  $\frac{C_0}{K}$ , is a constant term related to the standard alumina sample (substrate) given as,

$$\frac{C_0}{K} = \frac{\varepsilon'_s - 1}{\left( \frac{f_a}{f_s} \right)^2 - 1} \quad (2)$$

where,  $\varepsilon'_s$  is the permittivity of the standard sample and  $f_a$ ,  $f_r$  &  $f_s$  are the resonant frequencies without overlay, with overlay of thick films and standard alumina samples respectively.

$$N' = \varepsilon'_s f_s r_{0s} \quad (3)$$

$r_0$ ,  $r_{0s}$  — is the reflection coefficient of ferrite thick film and standard sample respectively.

**Table 1.** The band width and quality factor of EMCPA with barium hexaferrite bulk and thick film overlay.

Overlaid material	Fe/Ba molar ratio	pH	Band width GHz	Quality factor
Without overlay	–	–	0.18	59.4
Thick film BaFe <sub>12</sub> O <sub>19</sub>	11 : 1	11	0.11	90.0
		12	0.15	67.3
		13	0.16	63.1
	14 : 1	11	0.14	72.1
		12	0.15	67.3
		13	0.11	86.3
Bulk BaFe <sub>12</sub> O <sub>19</sub>	11 : 1	11	0.15	64.0
		12	0.10	96.0
		13	0.20	49.0
	14 : 1	11	0.17	57.0
		12	0.12	80.0
		13	0.10	96.0

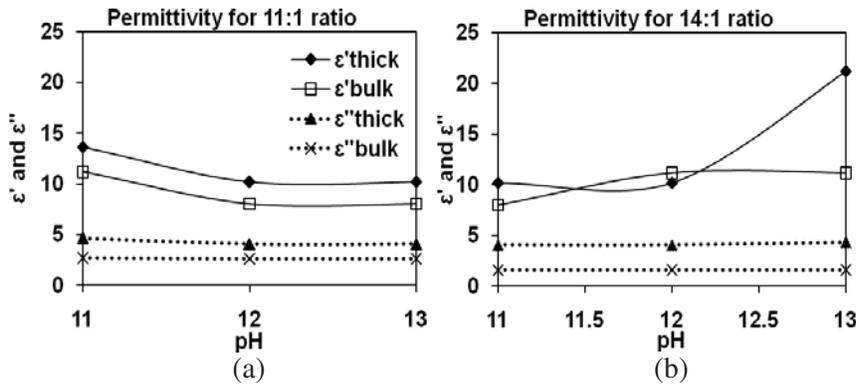
For calculating the permeability the following equations were used [14]. Since the antenna is a resonant circuit the cavity perturbation technique can be used for such structures.

$$\mu' = \frac{(\lambda_g)^2 + 4a^2}{8a^2} \frac{f_0 - f_r}{f_r} \frac{V_0}{V_r} + 1 \quad (4)$$

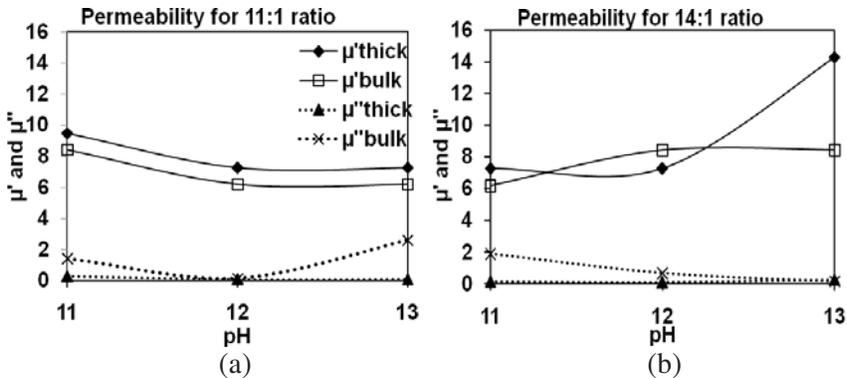
$$\mu'' = \frac{(\lambda_g)^2 + 4a^2}{16a^2} \frac{V_0}{V_r} \left( \frac{1}{Q_r} - \frac{1}{Q_0} \right) \quad (5)$$

where  $V_r$  and  $V_0$  are the volume of cavity and sample respectively,  $f_r$  and  $f_0$  are the resonant frequencies of the patch with and without overlay,  $\lambda_g$  is the guided wavelength and  $Q_r$ ,  $Q_0$  are the Q factors of the patch with and without sample. The microwave permittivity and permeability calculated from these equations plotted against pH of the barium hexaferrite bulk and thick film is shown in Figs. 3 and 4.

The  $\varepsilon'$  and  $\mu'$  both are higher for these thick films of both Fe/Ba ratio of all pH except for pH 12 of 14 : 1 Fe/Ba ratio. For 11 : 1 Fe/Ba ratio of both bulk and thick film,  $\varepsilon'$  and  $\mu'$  decreases with increase in pH. Whereas for 14 : 1 Fe/Ba ratio,  $\varepsilon'$  and  $\mu'$  increases with increase in pH for thick films and inverse for bulk barium hexaferrite. The



**Figure 3.** Permittivity of BaFe<sub>12</sub>O<sub>19</sub> bulk and thick films of (a) 11 : 1 and (b) 14 : 1 Fe/Ba ratio.

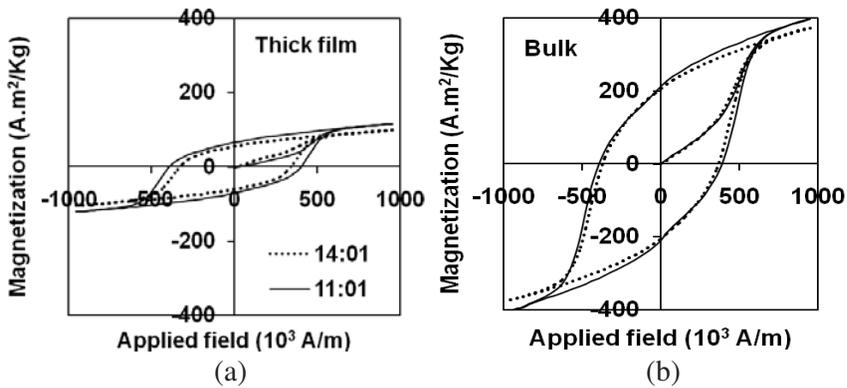


**Figure 4.** Permeability of BaFe<sub>12</sub>O<sub>19</sub> bulk and thick films of (a) 11 : 1 and (b) 14 : 1 Fe/Ba ratio.

permittivity of bulk and thick films lies in the range 8 to 13 for 11 : 1 Fe/Ba ratio and 8–21 for 14 : 1 Fe/Ba ratio.

Permeability lies in the range 6 to 9.5 for 11 : 1 and 6 to 14 for 14 : 1 Fe/Ba ratio. This increase in permittivity and permeability may be attributed due to increased grain size for 14 : 1 Fe/Ba molar ratio. The high permeability of barium hexaferrite bulk and thick film is related to the high saturation magnetization at dc magnetic fields as shown in Fig. 5.

Thick films show saturation magnetization of 115 A · m<sup>2</sup>/kg for 11 : 1 and 98 A · m<sup>2</sup>/kg for 14 : 1 Fe/Ba ratio at 954 kA/m applied field. The saturation magnetization of bulk barium hexaferrite is about 397 A · m<sup>2</sup>/kg for 11 : 1 and 373 A · m<sup>2</sup>/kg for 14 : 1 Fe/Ba ratio.



**Figure 5.** Magnetization of BaFe<sub>12</sub>O<sub>19</sub> of (a) thick film and (b) bulk.

The synthesis condition dependant saturation magnetization may be attributed to the grain size variation with synthesis conditions. The lower saturation magnetization for thick films than the bulk might be due to high porosity. The saturation magnetization of the fritless thick film obtained is larger than that of the bulk barium hexaferrite reported by others [13]. Such a high magnetization may be responsible for the high microwave permeability obtained.

The dielectric loss  $\epsilon''$  is higher for thick films of both molar ratio and all pH than bulk. The permeability loss  $\mu''$  is higher for bulk of both molar ratio of pH 11. pH 12 of both bulk and thick film of 11 : 1 Fe/Ba ratio shows same lowest  $\mu''$  of 0.17. pH 13 of 11 : 1 Fe/Ba ratio show high loss of 2.61. pH 13 of both bulk and thick film of 14 : 1 Fe/Ba ratio shows same lowest  $\mu''$  of 0.17 whereas pH 11 show highest loss of 1.91. At microwave frequencies, the loss is due to effects on the atomic scale. In this frequency range, the major contribution to the electric losses comes from the finite conductivity of the material, whereas for most magnetic absorbers, the main loss mechanism is magnetization rotation within the domains.

The increase in  $\epsilon'$  of the overlay, the fringing field lines gets concentrated, thus increases the fringing field capacitance. It effectively results in decrease in resonating frequency of the resonator. The region of high dielectric constant material with low loss above the resonant circuit confines the fringing field to substrate and thus enhancing the power gain of the antenna. With increase in  $\epsilon''$  and  $\mu''$  of the overlay, i.e., when overlay becomes more lossy, the fringing field will be more damped/attenuated by the overlay which results in reduction of output power gain. The thick films attenuate the fringing field as they are lossier (high  $\epsilon''$ ). Bulk BaFe<sub>12</sub>O<sub>19</sub> of pH 13 of 11 : 1

and pH 11 of 14:1 Fe/Ba ratio show high  $\mu''$  and hence reduces the power gain.

Thus, the overlay technique provides frequency agility for resonant circuits by overlaying materials with different  $\epsilon^*$  and  $\mu^*$  and can prove to be an efficient tool capable of detecting the changes in microwave properties due to minor changes in the synthesis conditions of the bulk and thick film BaFe<sub>12</sub>O<sub>19</sub>.

#### 4. CONCLUSION

The output power gain of microstrip patch antenna was increased by 50% due to bulk BaFe<sub>12</sub>O<sub>19</sub> whereas quality factor was enhanced due to thick film barium hexaferrite overlay. It is felt that the quality factor and power gain of the EMCPA can be improved with the overlay of barium hexaferrite having thickness in between thick film and bulk. The molar ratio and pH dependent resonant frequency shift of the EMCPA due to overlay of barium hexaferrite may provide frequency agility for the EMCPA. The thick film hexaferrite overlaid EMCPA having planar structure appropriate for cost effective miniaturization not only provides frequency agility but also agility in feed position. The overlay technique was successfully implemented for the calculation of complex permittivity and permeability of the overlaid material and it is an efficient tool capable of detecting the changes in microwave properties due to minor changes in the synthesis conditions of the bulk and thick film BaFe<sub>12</sub>O<sub>19</sub>.

#### ACKNOWLEDGMENT

One of the authors Dr. Vijaya Puri is gratefully acknowledged to UGC for the award of research scientist 'B' and financial assistance under UGC-DRS-SAP II.

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