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Study of X-band Microwave properties of Polyaniline overlay on Microstrip patch Antenna

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Abstract:

This paper reports the percentage power efficiency of microstrip patch due to overlay of electropolymerised polyaniline thin films on stainless steel and silver substrate in X-Band (8-12GHz). The overlay method has been used for the microwave studies. The PANI films are overlaid on centre and feed line of patch antenna. The behavior of thick film microstrip patch antenna changes more due to polyaniline thin films overlay on centre than feed line. Due to overlay of PANI thin films resonance peak of microstrip patch antenna was shifts from 8.9GHz to 10.5GHz. The larger changes are observed in radiation pattern. The thickness dependent properties are not very prominent but the frequency dependent changes are observed.

Key words: Polyaniline thin film; thick film microstrip patch antenna; radiation pattern; bandwidth; Q-factor; Directivity gain.

I. INTRODUCTION:

Conducting polymers have created at great interest due to their wide variety of properties and technological applications. In particular, variation of their conductivity with the frequency of an incident radiation suggests their use for microwave absorption applications [1]. Polyaniline (PANI) is well known conducting polymers used for different applications such as contact layer in organic light emitting diode, sensors, battery electrodes [2] due to its excellent features such as high stability under ambient conditions, change in conductivity [3] and interesting electrical, electrochemical, optical characteristics along the excellent environmental stability and its raw material can be obtained easily [4-12]. Our lab has been working on thick film microstrip passive components and its response to various types of in-touch dielectric overlay [13]. The microstructure of the conducting PANI can vary with the conditions of synthesis. Electropolymerisation is a simple method for deposition of nano structured PANI thin films. The structure can be granular [14-15], fibular [16-17] or flakey [18]. This paper reports the response of the Ag thick film electromagnetically coupled patch antenna (EMCPA) to electropolymerised PANI thin films overlay. The PANI thin films deposited by electropolymerisation on stainless steel and silver substrate. The percentage power efficiency of thick film microstrip patch antenna due to PANI overlay in X-Band is reported. The radiation pattern both E-plane and H-plane of thick film patch antenna due to polyaniline thin film overlay is also reported. The Peak Amplitude, Bandwidth and Q-factor of Ag microstrip patch antenna and directivity gain is reported. For this studies overlay technique has been used.

II. EXPERIMENTAL:

The PANI thin films were deposited by Electropolymerisation method using three electrode galvanostatic cells. A saturated calomel electrode was used as a reference electrode and high density and high surface area graphite rod was used as the counter electrode. The PANI thin films were deposited on the stainless steel and silver substrate at constant current in a conventional three electrode cell [19]. The electrolyte solution contained 1M aniline and 2M H₂SO₄, 2M HCl. The PANI thin films SS-A, SS-B, SS-C, SS-D are synthesized in 2M H₂SO₄ on stainless steel (SS) substrate, SS-1, SS-2, SS-3, SS-4 are synthesized in 2M HCl on SS substrate and Si-1, Si-2, Si-3 Si-4 are synthesized in 2M HCl on silver (Si) substrate with thicknesses of 2.5, 5, 10 and 15µm respectively. The size of substrate was 1x1cm. The thickness of PANI films was measured by gravimetric method [15].

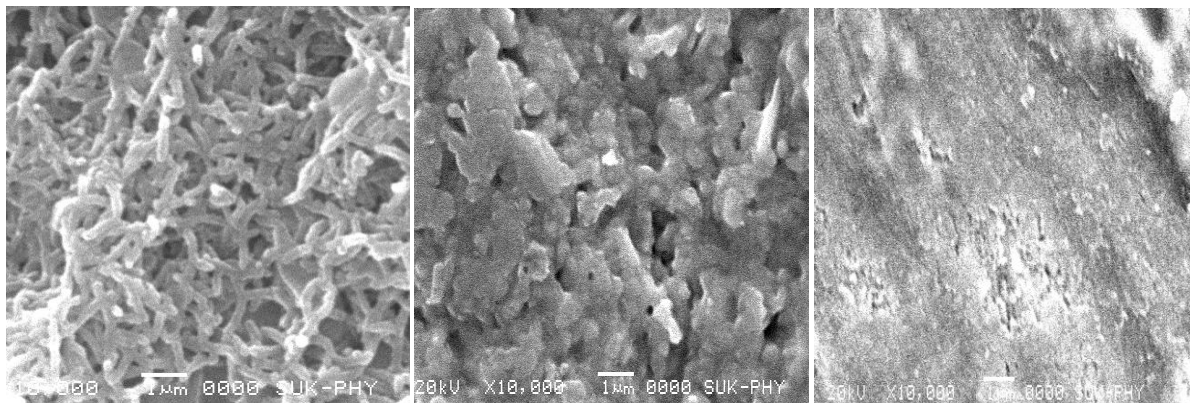
The thick film microstrip patch antenna was fabricated using screen printing technology. The metallization was Ag and the substrate was alumina (Kyocera, Japan) for thick film microstrip patch antenna. The Electromagnetically Coupled Patch Antenna (EMCPA) was used as resonant circuit. The design of the antenna was for the frequency corresponding to the dominant mode for long side feed system. 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 X-band output was measured point by point and finding its resonance peak by using a system consisting of Gunn source, isolator, attenuator, pyramidal horn and detector. SMA connectors were used for contact to antenna. The thickness of the screen printed thick film antenna was 10–15 μm . The patch antenna was used as the transmitting antenna and the horn as the receiver. The PANI thin films were kept as in-touch overlay on the patch.

III. RESULTS AND DISCUSSION:

A. Morphology using SEM:

The SEM surface morphology of polyaniline thin films was imagined by [SEM, JEOL- JSM 6360] scanning electron microscopy. Fig.1 shows the SEM images of polyaniline thin films. Differences are observed between the polyaniline films deposited in the two acids with different substrates. All the films show porous morphology. Fig.1 (a) shows SEM micrograph of polyaniline prepared in H_2SO_4 with 1M aniline. The striking feature of these micrographs is the presence of fibrils throughout the polymer surface. Such fibril like structure has been reported. [20]. Polymerization in sulfuric acid leading to granular morphology has been also reported in literature [21]. Fig. 1 (b) and (c) shows the SEM micrograph of polyaniline prepared in HCl on SS and Silver substrate respectively. The morphology of polyaniline on SS in HCl shows more granular like structure but it is structureless on silver substrate in same HCl concentration. The structure of polyaniline and its homogeneity in H_2SO_4 is better than HCl and its porosity is in $\text{HCl} < \text{H}_2\text{SO}_4$.



(a) PANI in H_2SO_4 on SS

(b) PANI in HCl on SS

(c) PANI in HCl on Silver

Fig 1. Surface morphology of PANI in different acids .

B. Optical Absorption Studies:

The visible absorption spectra of polyaniline were recorded with UV-VIS-NIR 300, HITACHI, JAPAN spectrometer. From the fig.2, the absorption peaks near 400nm and over 800 nm is responsible for green colour emeraldine form of polyaniline films which is conducting in nature The intercept of this plot on the photon energy axis gives the band gap (Eg) of the polyaniline.

The polyaniline thin film on SS in H_2SO_4 acid had a band gap of ~ 2.4 eV. The band gap of pure polyaniline is 3.04 eV [22]. The absorption peaks at 1.5 and ~ 3.3 eV has been reported for bulk polyaniline obtained from HCl. [23]

The FTIR spectra in the range of 450-4000 cm^{-1} of the polyaniline sample shows the major peaks expected of polyaniline are present. Also the main vibration bands are observed from polyaniline in H_2SO_4 and HCl can be identified on the basis of normal vibration modes of polyaniline.

C. Microwave Characteristics:

1. Effect of polyaniline thin films on thick film microstrip patch antenna:

Thick film rectangular patch antenna showed single resonance peak characteristics. In the antenna, metallization of the patch and feedline is an important aspect in the power efficiency of the antenna. Due to this the rectangular thick film patch antenna was investigated for their resonance frequency for two positions of overlay 1) On centre of patch antenna and 2) On feedline of patch antenna.

a. Measurement of Resonance frequency of antenna without overlay:

Fig.3 shows the graph of output as a function of frequency for microstrip patch antenna. From figure it is seen that the % power efficiency is more ($\sim 13\%$) at 8.9 GHz frequency. The resonance frequency of the microstrip patch antenna was 8.9 GHz. This study was done only X-band region. The transmittance of patch antenna due to overlay of polyaniline thin films on it is depicted as % power efficiency.

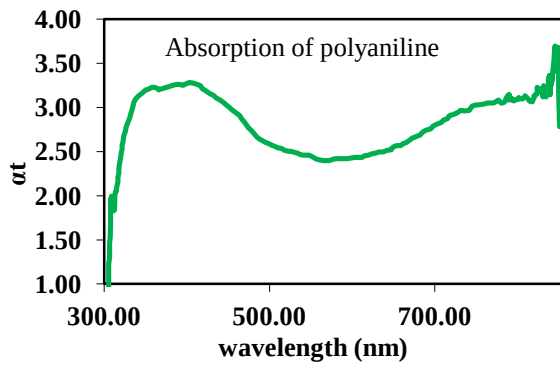


Fig. 2. The optical absorption of polyaniline thin film.

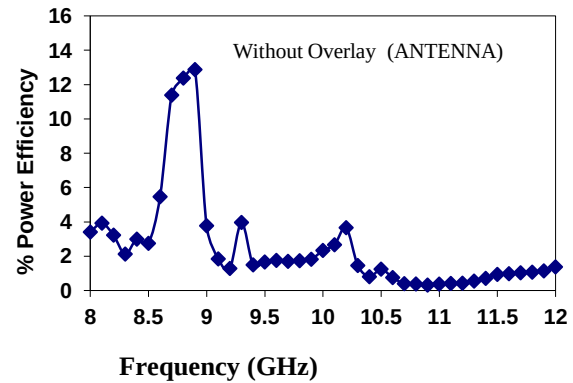


Fig. 3. % power efficiency in X-band.

b. Effect of polyaniline thin films overlay placed at centre and feedline of patch antenna:

The variations of % power efficiency as a function of frequency due to polyaniline thin film overlay at centre of patch antenna is given in fig. 4 (a). From the figure the important result obtained is that, for all polyaniline thin films peak frequency changes from 8.9 GHz to 10.5 GHz.

The % power efficiency of patch antenna becomes ~ 5 to 6% due to overlay of polyaniline and bare substrates as compared to ~1% without overlay. The % power efficiency of antenna decreases from ~13% to 0.5% at the response frequency 8.9 GHz. The % power efficiency due to bare substrate is slightly higher than due to PANI films. Due to overlay of PANI deposited in HCl, the response peak tends towards asymmetric nature. Some thickness dependent effects are observed.

The fig.4 (b) shows the variation of % power efficiency as a function of frequency due to polyaniline overlay on feedline of patch antenna. From the figure it is seen that here also shift in resonance frequency to 10.5 GHz occurs. When bare substrate is kept as overlay on the feedline, the output is lower as compared to PANI deposited substrate. This effect is opposite to that obtained when overlay is kept at the centre of patch. Acid dependent and substrate dependent changes are prominent here. The small spikes become prominent peaks due to the PANI overlay. Due to PANI deposited in HCl on SS, thickness dependent effects are more. The antenna almost losses its resonance characteristics due to PANI deposited on silver. Beyond 11 GHz the output is very low similar to that obtained without overlay.

c. Effect of polyaniline thin films on H-plane and E-plane patterns of thick film microstrip patch antenna:

Fig.5(a) gives the H-plane radiation pattern due to overlay of polyaniline thin films from H_2SO_4 , HCl overlay on thick film microstrip patch antenna. The H plane radiation pattern of the patch without overlay is quite symmetrical with peak amplitude at 0° . Due to overlay a large increase in output at 0° is observed with not much change in the shape of the pattern. At around 30° – 50° a slight symmetry is obtained due to film deposited on SS. The symmetry is more pronounced and thickness dependent when film deposited from HCl is kept as overlay. When PANI-Ag is used as overlay the asymmetry appears at -30° .

The E plane radiation pattern of thick film microstrip patch antenna due to polyaniline thin films overlay is given in fig.5.(b) From figure it is seen that the output in the E plane is smaller than that obtained in the H plane. Larger symmetry is obtained here. Due to PANI overlay the E plane output also increases at 0° . Highly thickness dependent effects are observed. Appearance of secondary lobe is evident where PANI-Ag is used as overlay. The increase in output at 0° are lesser than those obtained for PANI – SS.

2. Radiation pattern of thick film patch antenna due to polyaniline thin film overlay:

The H plane and E plane radiation pattern were observed by keeping the patch antenna fixed and rotating the receiving antenna in proper direction. The % power efficiency versus frequency graph (fig.5) showed larger power at 10.5 GHz after overlay. This frequency was chosen and kept constant for both the H plane and E plane radiation pattern measurements. The patch antenna was kept at a fixed position and receiving horn antenna was turned from 0° to 90° and -90° in H and E planes. These studies were done with overlay placed at centre of patch antenna.

3. Measurement of peak amplitude, Bandwidth, Q- Factor of microstrip patch Antenna and Beam width due to PANI overlay:

The data of band width and Q factor [24] of the antenna is tabulated in table 1 and data from radiation pattern in

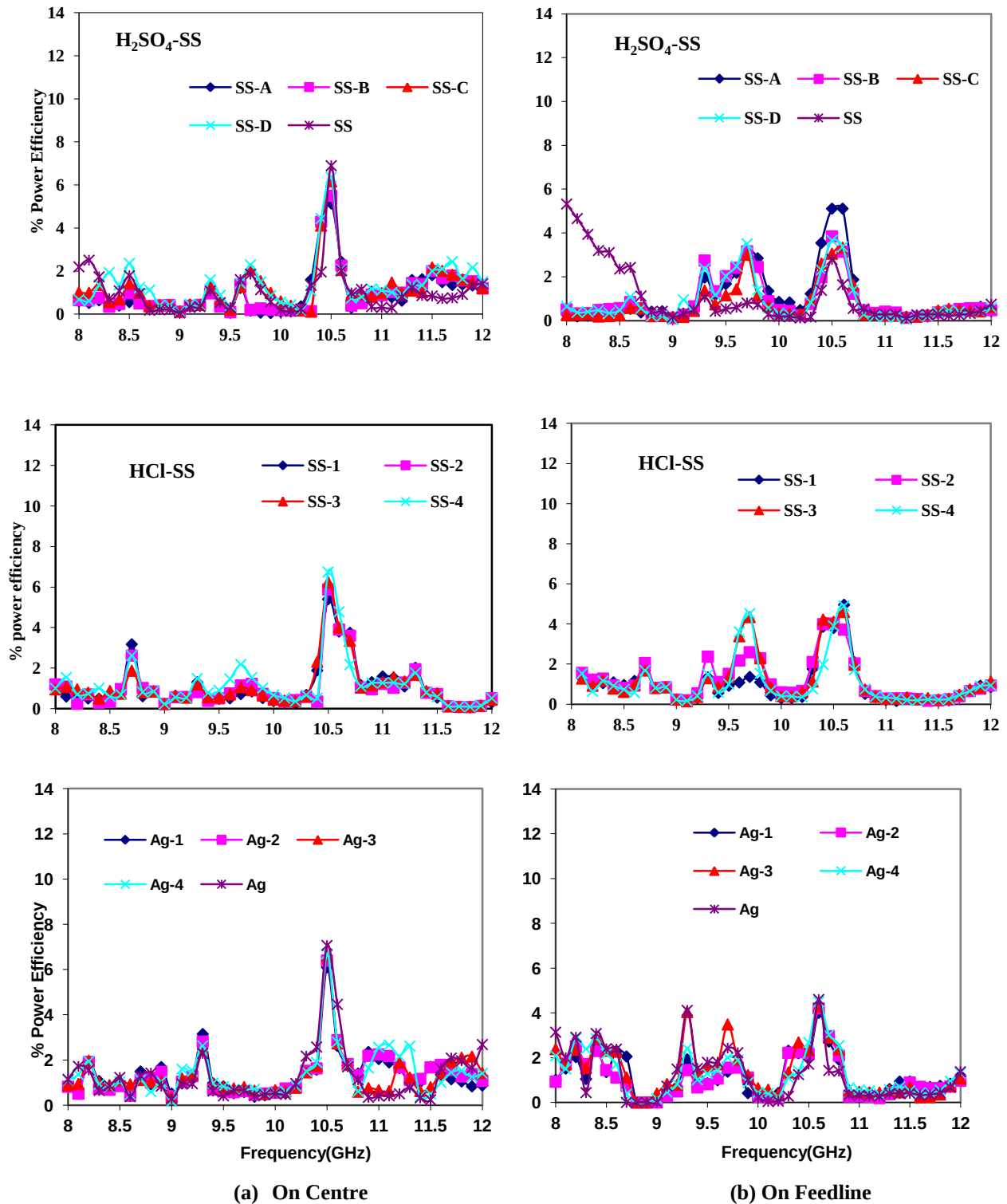


Fig. 4. Variations of % power efficiency as a function of frequency in X-band.

table 2. From the table it is seen that due to overlay of PANI the bandwidth decreases and a factor increases. Also it is observed that the Q-factor increases with increase in thickness of PANI thin films.

Larger increase in a factor is observed due to PANI-Ag overlay. The beam width (table 2) in the E-plane decreased and in the H plane increased due to PANI overlay. There is no definite thickness or type of deposition dependent effects.

4. Measurement of Directivity gain.

The semitherotical gain calculations can be done from the lobe width product formula. The directivity gain can be calculated from formula[25].

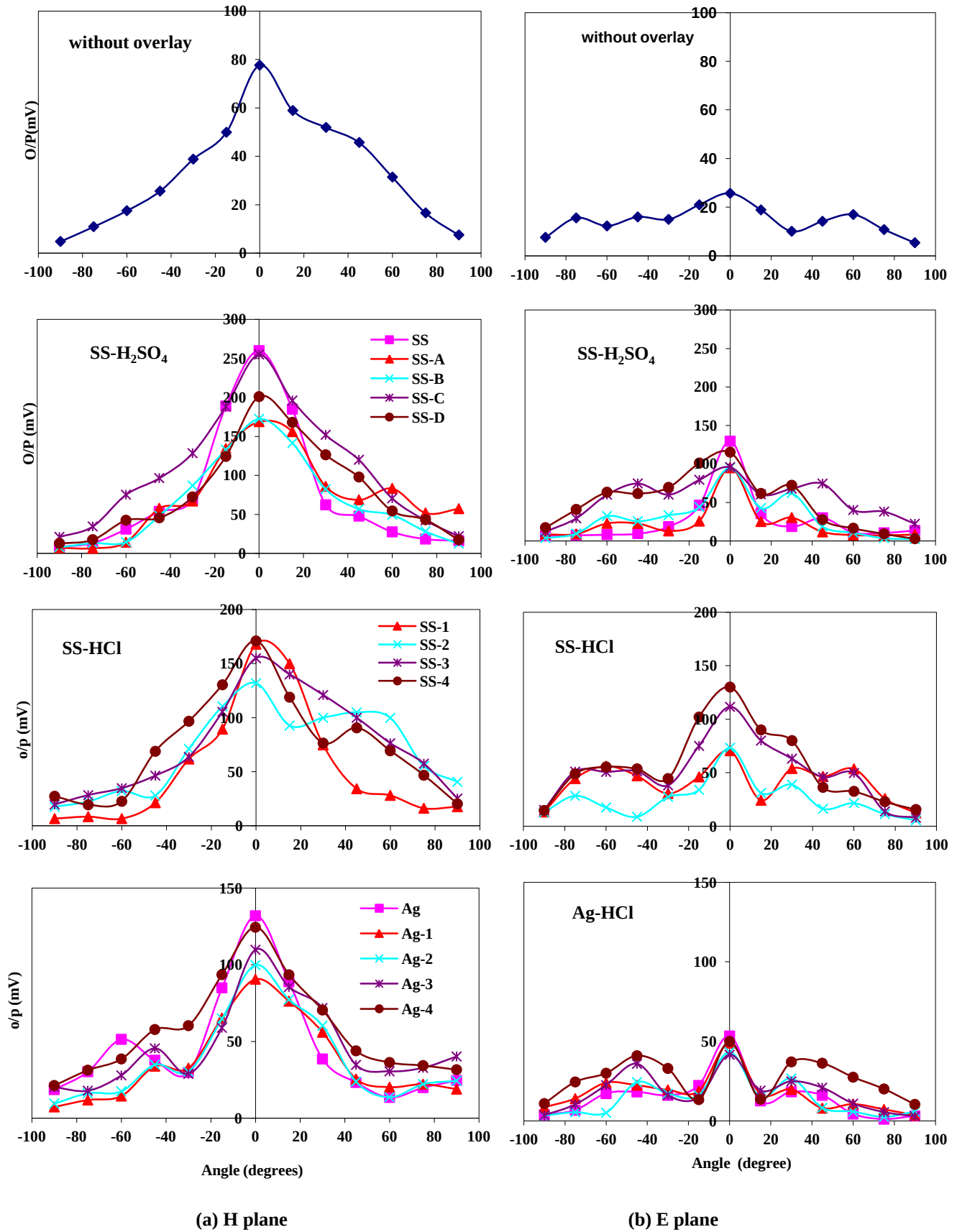


Fig 5. Radiation pattern due to polyaniline thin films on thick Film Microstrip patch antenna.

Sr. No.	Antenna Condition	Sample	Thickness (μ)	Peak frequency (GHz)	Peak of Amplitude %PE	Bandwidth (GHz)	Q-Factor
1	Without overlay	-	-	8.9	12.86	0.3	29.6
2	With overlay PANI in H ₂ SO ₄	SS	-	10.5	6.9	0.14	75
		SS+ PANI	2.5		5.14	0.21	50
		SS+PANI	5		5.5	0.20	52.5
		SS+PANI	10		6.17	0.19	55.3
		SS+PANI	15		6.35	0.15	70
3	With overlay PANI in HCl	SS+ PANI	2.5		5.39	0.12	87.5
		SS+PANI	5		5.87	0.13	80.7
		SS+PANI	10		6.24	0.13	80.7
		SS+PANI	15		6.73	0.15	70
4	With overlay PANI in HCl	Ag	-		7.06	0.18	58.3
		Ag+PANI	2.5		6.1	0.10	105
		Ag+PANI	5		6.4	0.08	131.25
		Ag+PANI	10		6.6	0.09	116.6
		Ag+PANI	15		6.7	0.07	150

Table 1. Data of Peak Amplitude, Bandwidth and Q-factor of Ag microstrip patch antenna.

Sr. No	Sample	Peak of Amplitude (mV)		Beam width (deg.)	
		E plane	H plane	E plane	H plane
1	-	25.7	77.6	39	32
2	SS	39.5	101.3	19	48
	SS+ PANI	50	168.9	20	46
	SS+PANI	70	172.5	25	44
	SS+PANI	95.8	201	30	58
	SS+PANI	115.2	255	33	57
3	SS+ PANI	70.5	108	27	48
	SS+PANI	73.3	132	18	36
	SS+PANI	115.5	155	34	54
	SS+PANI	130	171	36	36
4	Ag	11.4	80	16	31
	Ag+PANI	26.3	90.6	20	37
	Ag+PANI	23.3	99.8	23	35
	Ag+PANI	31.6	109.8	18	28
	Ag+PANI	50	123.5	13	32

Frequency = 10.5 GHz.

Table 2. Data of E and H plane Peak amplitude and Beam width.

$$D.G = 10 \log \frac{26000}{Q_E \times Q_H}$$

Where Q_E and Q_H are the 3db down (half power) lobe width in E and H plane respectively. The directivity gain data is tabulated in table 3. From the data, it is seen that, the directivity gain increases due to overlay of PANI exception being some cases. The increase is more due to PANI deposited on Ag. Thickness of PANI or acid dependent effects is not observed.

Sr. No	Sample	Thick ness (μ)	Directivity Gain (db)
1	-	-	13.8
2	SS	-	14.54
	SS+ PANI	2.5	14.57
	SS+PANI	5	13.73
	SS+PANI	10	11.14
	SS+PANI	15	11.40
3	SS+ PANI	2.5	13.02
	SS+PANI	5	16.03
	SS+PANI	10	11.51
	SS+PANI	15	13.02
4	Ag	-	17.19
	Ag+PANI	2.5	15.54
	Ag+PANI	5	15.09
	Ag+PANI	10	17.12
	Ag+PANI	15	17.95

Table 3. Data of Directivity gain.

IV. CONCLUSION:

For the fabrication of MIC the metallization is a very important aspect to be taken into consideration. The function of the circuit depends on the extent of power loss, adhesion, geometry, definition of the metallic conductors. The microstripline have been fabricated according to the dimensions achieved by design equations for components with air as dielectric at the top. When overlay is used this parameter will change.

From the above results on the studies undertaken using in-touch overlay technique on microstrip patch antenna it can be said that all the PANI films studied show changes in the microstrip component properties. The response of thick film microstrip patch antenna is more prominent. Type of PANI dependent changes are obtained in the patch antenna characteristics.

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