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Micromachined Microstrip Rectangular Antenna On RT Duroid in-S, X and Ku Band

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Abstract:- A comparative study of micromachined and regular rectangular patch microstrip antennas at three frequencies i.e. 3,10 and 18 GHz in microwave frequency range on low and high RT Duroid substrate is presented. The promising micromachining technique is uses for improving the overall radiation performance of such antenna systems. In the present work the RT Duroid material is removed laterally underneath the patch antenna to produce a cavity that consists of a mixture of air and substrate with equal or unequal thickness. This paper presents the design of three types of antennas – the conventional regular patch antennas (type I), antennas of type II, in which the substance is removed just below the patch and the antennas of type III, those printed on mixed air-duroid cavity. Results are presented on bandwidth, input impedance, gain and radiation patterns for purposed antenna geometry.

I. INTRODUCTION

Microstrip antennas have been applied to variety of systems such as high flying aeroplane, satellite missiles, modular designs and integrated circuits due to their unique properties and easy fabrication technique [1-5]. As system requirements for faster data transmission in lighter compact designs drive the technology area, higher frequency design solution with large density layouts require - integration of microwave devices, circuitry and radiating elements that offer light weight, smaller size and optimum performance. Compact circuit designs are typically achieved in high index materials, which is in direct contrast to the low index substrate imposed by antenna performance requirement. Thus the ideal solution requires the capability to integrate the planar antenna on electrically thick low-index regions while the circuitry remains on the high-index regions in the same substrate. Microstrip antenna designs show significant performance degradation due to the pronounced excitation of surface waves in high-index materials. As a result of this the antenna has lower efficiency, reduced bandwidth and degraded radiation patterns. Optimum antenna performance depends on the choice of feeding network. Such microstrip designs are typically fabricated on electrically thick low-index materials and characterized by maximum antenna bandwidth and efficiency as reported by several investigators.

Katehi et al. developed a novel concept of micromachined patch antennas in order to improve radiation performance of rectangular microstrip patch antennas printed on high index wafers [6-7]. In the present paper emphasis is laid to create broad band antenna system following the promising micromachine approach and by varying the substrate height at three frequencies 3, 10 and 18 GHz in microwave frequency range. In this study, RT duroid material is removed underneath the antenna by using selective etching technique and the excitation of surface wave is suppressed by creating a micromachined cavity that produces a low permittivity environment for the patch antenna.

II. MICROMACHINED PATCH ANTENNAS

The geometry of the micromachined patch antenna is shown in Fig.1 [5]. The micromachined antenna configuration consists of a rectangular patch centred over the cavity, sized according to the effective index of the cavity region, and fed by a microstrip line. Most specifically, the antenna is printed on a cavity region that is comprised of two dielectric sections: (1) air and (2) high dielectric substrate. Using micro-machining techniques, substrate is laterally removed from the cavity region producing a substrate area that has thickness less than or equal to 50% (i.e. amount of substrate removed varies from 50 to 80%) of the original substrate thickness and an air region that is created by the removal of material. The walls of the hollowed cavity are in general slanted due to the anisotropic nature of the chemical etching.

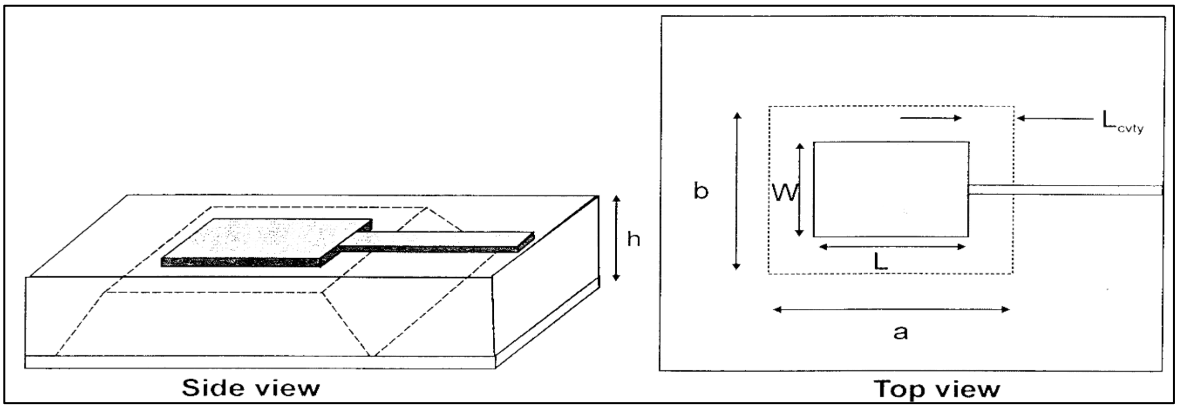

Fig. 1: Geometry of the micromachined patch antenna

A cavity model is used to predict the effective dielectric constant of the mixed air-substrate region for varying thickness ratios underneath the patch antenna.

For simplicity the walls of the cavity are assumed to be vertical and the effective dielectric constant εeff=εreffε0 is estimated by the following expression [9-10]

$$\varepsilon_{reff} = \varepsilon_{cavity}\left[\frac{L+2\Delta L\frac{\varepsilon_{fringe}}{\varepsilon_{cavity}}}{L+2\Delta L}\right] \quad ...(1)$$

$$\frac{\varepsilon_{fringe}}{\varepsilon_{cavity}} = \frac{\varepsilon_{air}+(\varepsilon_{sub}-\varepsilon_{air})x_{air}}{\varepsilon_{air}+(\varepsilon_{sub}-\varepsilon_{air})x_{fringe}} \quad ...(2)$$

Where $\varepsilon_{cavity} = \frac{\varepsilon_{air}\varepsilon_{sub}}{\varepsilon_{air}+(\varepsilon_{sub}-\varepsilon_{air})x_{air}}$ ...(3)

In the above expressions, ε_{cavity} represents the relative dielectric constant of the mixed substrate region and ε_{fringe} represents the relative dielectric constant in the fringing field region. Eq.(1) includes the open end effect extension length ΔL to the antenna, whereε_{fringe} is the permittivity used for the calculation of ΔL. Hence, the dimension of the patch are calculated as

$$W = \frac{c}{2f_r}\left[\frac{\varepsilon_{cavity}+1}{2}\right]^{-\frac{1}{2}} \quad ...(4)$$

$$L = \frac{c}{2f_r\sqrt{\varepsilon_r}} - 2\Delta L \quad ...(5)$$

$$\varepsilon_e = \frac{(\varepsilon_{re}+1)}{2} + \frac{(\varepsilon_{re}-1)}{2}\left[1+10\frac{h}{b}\right]^{-1/2} \quad ...(6)$$

The thickness parameters xair and xfringe are ratios of the air to full substrate thickness in the mixed and fringing field regions respectively. Xfringe is taken as zero for micromachined case showen in Fig. [2(b)], Xfringe , whereas for the case of Fig. [2(c)], xfringe= xair.

III. DESIGN OF MICROMACHINED PATCH ANTENNAS

In this investigation we consider three types of antennas as shown in Fig. 2.[12]

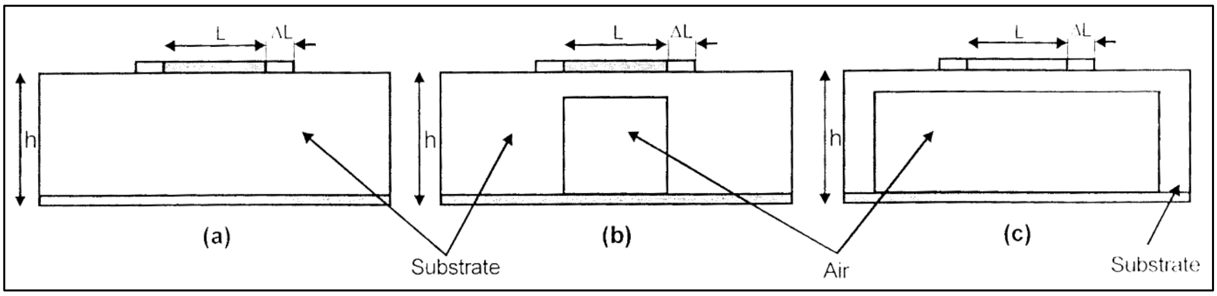

Fig. 2: Geometry for the (a) regular patch antenna-Type I, (b) micromachined patch antenna with radiating edges into the substrate-Type II, (c) radiating edges over the mixed air substrate cavity-Type III.

- The conventional regular patch antenna type I, on low (εr=2.33) and high 10.8) index material [Fig. 2.(a)]. In this antenna no substrate is removed.
- Antennas of type II, in which the substrate is removed (80%) just below the patch by using isotropic or anisotropic etching techniques, such that the radiating edges are into the substrate of low (εr=2.33) or high (εr=10.8) index [Fig.2(b)]. Thus, the separation Lcvty =0
- Antennas of type III, those printed on a mixed air-duroid cavity, such that the radiating edge is over the mixed air-substrate cavity [Fig.2(c)]. In this case the cavity has been created by etching 80% duroid at 2h (up to 6h) away from the edge of patch and only 20% of the Duroid remains to support the antenna. Hence, the separation Lcvty=2h (upto 6h), this is so because the fringing fields usually extend one to two times the thickness h beyond the radiating edges of the antenna into the substrate environment. The final geometry is similar to those shown in Fig. 1 without the sloping side walls i.e. the side walls are vertical. This antenna too is constructed once by taking low (εr=2.33) dielectric constant Duroid and than by taking high (εr=10.8) dielectric constant Duroid.

Several rectangular patch antennas (type I, II and III) fed by a 50 ohm microstrip line are designed on Duroid substrates of low (ε_r=2.33) and high (ε_r=10.8) index constants (dielectric loss tangent tan δ = 0.00066) with varying substrate thickness ‘h’. In the antennas of type II and III the amount of Duroid removed is 80% of the original substrate thickness underneath the patch and a cavity model is used (Eq. 1-6) to estimate the various important antenna parameters. For simplicity the walls of the cavity are assumed to be vertical.

A comparative study is carried for antennas of type I, II and III in low (ε_r=2.33) and high (ε_r=10.8) dielectric constant Duroid at three different frequency range 3GHz , 10GHz and 18GHz respectively for various fundamental parameters of antenna.

For the antennas (type I, II and III), the dimensions (Eq. 5 and 6) are calculated at operating frequencies 3, 10 and 18GHz respectively and the comparative study is done on bandwidth (BW), input impedance at the edge Z_a, total resistance R_T(=R_c+R_d+R_r) and gain G_g. The results have been tabulated in Tables 1-4.

From Table 1, we observe that antennas of type II (ε_r=2.33) and type III (ε_r=2.33) have more bandwidth than antennas of type I (ε_r=2.33). More precisely bandwidth of antenna type II (ε_r=2.33) is slightly more than antenna type III (ε_r=2.33). Hence, by selectively removing the substrate material underneath the radiating patch element, the bandwidth can significantly be improved. Now, if the low (ε_r=2.33) dielectric substrate is replaced by high (ε_r=10.8) dielectric substrate to improve the antenna performance, we observe from Table 1 to 4 that there is a good agreement between the antennas of type III (ε_r=2.33) and antennas of type III (ε_r=10.8) in respect to bandwidth, input impedance at the edge of the patch, total resistance, and gain. Hence, antennas of type III (ε_r=10.8) can easily replace antennas of type III (ε_r=2.33). Thus, apart from significantly improving bandwidth, other antenna properties are also improved by using the antennas of type III (ε_r=10.8).

The radiation properties have also been studied [11]. The H patterns for antenna type I (ε_r=2.3 and ε_r=10.8) antenna II (ε_r=2.3 and ε_r=10.8) and antenna type III (ε_r=2.3 and ε_r=10.8) are plotted in Fig. 3. [12]. We observe that the patterns are similar in all cases. The E plane patterns are studied and sketched for some antenna geometries (in frequency range 3, 10 and 18 GHz) in Fig.3 to Fig. 9. [12]Comparing the patterns of regular high index patch [type I (ε_r=10.8)] to micromachined patch [type III (ε_r=10.8)], we observe that the regular high index [type I (ε_r=10.8)] patterns are spread. In contrast, the micromachined patch [type III (ε_r=10.8)] show improved patterns in E plane. We thus conclude that micromachined substrate has improved E-plane radiation patterns compared to the patch design in high index material and can suppress the surface wave excitation. On studying the efficiency of regular patch and micromachined patch antenna, we observe that the micromachined patches are more effective.

Table 1: Comparative study on bandwidth of regular and micromachined patch antennas with ε_r=2.33 and ε_r=10.8

h (cm)	(ε_r=2.33)			(ε_r=10.8)		
	Bandwidth (%) of Antenna Type I	Bandwidth (%) of Antenna Type II	Bandwidth (%) of Antenna Type III	Bandwidth (%) of Antenna Type I	Bandwidth (%) of Antenna Type II	Bandwidth (%) of Antenna Type III
f=3GHz						
0.159	1.6	1.9	2.1	0.9	1.2	2.0
0.559	6.6	8.1	8.0	4.5	4.6	7.9
0.959	13.6	17.4	15.6	11.0	1.8	15.4
1.359	22.1	28.3	24.0	18.4	-	23.8
f=10GHz						
0.059	2.0	2.4	2.6	1.2	1.8	2.5
1.159	6.6	7.6	7.5	4.1	4.5	7.4
0.359	18.6	23.9	20.7	15.8	-	20.4
f=18GHz						
0.559	31.9	37.2	32.4	-	-	-
0.059	3.8	4.6	4.8	2.3	3.2	4.7
0.159	13.5	17.3	15.6	10.9	1.9	15.3
0.259	26.3	32.8	27.7	19.7	-	27.5
0.359	35.2	37.3	35.1	-	-	-
0.459	34.1	22.8	35.6	-	-	-

Table 2: Input impedance characteristics on regular and micromachined patch antennas at low ε_r=2.33 and high ε_r=10.8 index materials

	(ε_r=2.33)			(ε_r=10.8)		
h (cm)	Input Impedance (ohms)of Antenna Type I	Input Impedance (ohms)of Antenna Type II	Input Impedance (ohms)of Antenna Type III	Input Impedance (ohms)of Antenna Type I	Input Impedance (ohms)of Antenna Type II	Input Impedance (ohms)of Antenna Type III
f=3GHz						
0.159	171-j1.7	219.9-j2.6	152.5-j1.9	258.6-j1.4	469.1-j3.4	153-j1.9
0.559	153.5-j6.4	182.7-j9.1	154.3-j7.6	214.5-j5.8	269.7-j7.6	153.9-j7.4
0.959	146.7-12.2	148-j15.8	152-j14.6	176-j11.9	1057-j11.8	150-j14.2
1.359	143-j19.3	134-j23.3	158-j23.2	181-j20.4	-	155-j22.6
f=10GHz						
0.059	164.8-j2.1	214.9-j3.2	153.5-j2.4	253-j1.8	365.5-j3.9	152.9-j2.4
0.159	159.2-j6.0	185.3-j8.6	154.3-j7.1	217.7-j1.8	265-j7.3	153.9-j6.9
0.359	143-j16.3	137.2-j20	154-j19.5	172-j16.6	-	152-j18.9
0.559	158-j30.8	152-j34.7	188-j37.3	-	-	-

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f=18GHz						
0.059	164-j3.9	202.8-j5.7	154.6-j4.5	239-j3.4	146-j2.8	154.6-j4.4
0.159	146.6-j12	149-j15.7	152-j14.5	176-j11.8	997-j11.7	150.5-j14
0.259	145-j23.4	136-j27.3	165.7-j28	215.7-j26	-	162-j27.4
0.359	183-j39.4	189.7-j43	223-j47.9	-	-	-
0.459	313-j65.3	507.6-j71	365-j79.6	-	-	-

Table 3: Total resistance on regular and micromachined patch antennas at low εr=2.33 and high εr=10.8 index materials. vc

	$(\varepsilon_r=2.33)$			$(\varepsilon_r=10.8)$		
h(cm)	R_r (ohms) of Antenna Type I	R_r (ohms) of Antenna Type II	R_r (ohms) of Antenna Type III	R_r (ohms) of Antenna Type I	R_r (ohms) of Antenna Type II	R_r (ohms) of Antenna Type III
f=3GHz						
0.159	300.7	192.6	192.3	1064.9	202.9	200.7
0,559	299.9	191.8	191.8	1062.4	200.4	200.1
0.959	299.8	191.6	191.7	1062.1	204.2	200.0
1.359	299.8	191.6	191.6	106.1	-	-
f=10GHz						
0.059	300.6	192.4	192.2	1064.5	203.1	200.6
0.159	299.9	191.8	191.8	1062.4	200.4	200.1
0.359	299.76	191.6	191.7	1062.1	-	200
0.559	299.7	191.6	191.6	-	-	-
f=18GHz						
0.059	300.1	192	191.9	1062.9	200.7	200.3
0.159	299.8	191.7	191.7	1062	203.6	200
0.259	299.7	191.6	191.6	1062.1	-	200
0.359	299.7	191.6	191.6	-	-	-
0.459	299.7	191.7	191.7	-	-	-

Table 4: Comparative study on gain for regular and micromachined patch antennas at low εr=2.33 and high εr=10.8 index materials.

	$(\varepsilon_r=2.33)$			*$(\varepsilon_r=10.8)$*		
h(cm)	Gain (dB) of Antenna Type I	Gain (dB) of Antenna Type II	Gain (dB) of Antenna Type III	Gain (dB) of Antenna Type I	Gain (dB) of Antenna Type II	Gain (dB) of Antenna Type III
f=3GHz						
0.159	8.1817	8.1730	8.1794	8.1834	8.1307	8.1796
0.559	8.1929	8.1918	8.1922	8.1938	8.1864	8.1923
0.959	8.1943	8.1941	8.1939	8.1949	8.1051	8.1939
1.359	8.1949	8.1947	8.1944	8.1952	-	8.1944
f=10GHz						
0.059	8.1826	8.1767	8.1812	8.1851	8.1482	8.1814
0.159	8.1925	8.`913	8.1918	8.1937	8.1861	8.1919
0.359	8.1946	8.1945	8.1942	8.1951	-	8.1943
0.559	8.1949	8.1948	8.1945	-	-	-
f=18GHz						
0.059	8.1896	8.1871	8,1887	8.1915	8.1789	8.1888
0.159	8.1943	8.1940	8.1938	8.1949	8.1179	8.1888
0.259	8.1949	8.1948	8.1945	8.1951	-	8.1945
0.359	8.1949	8.1946	8.1944	-	-	-
0.459	8.1945	8.1919	8.1938	-	-	-

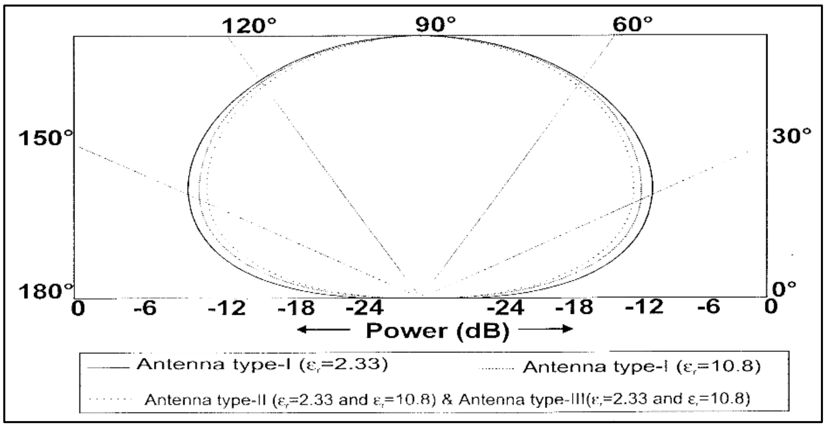

Fig. 3: H-plane pattern of micromachined patch antenna (type I, type II and type III) at f= 3GHz, 10 GHz and 18 GHz.

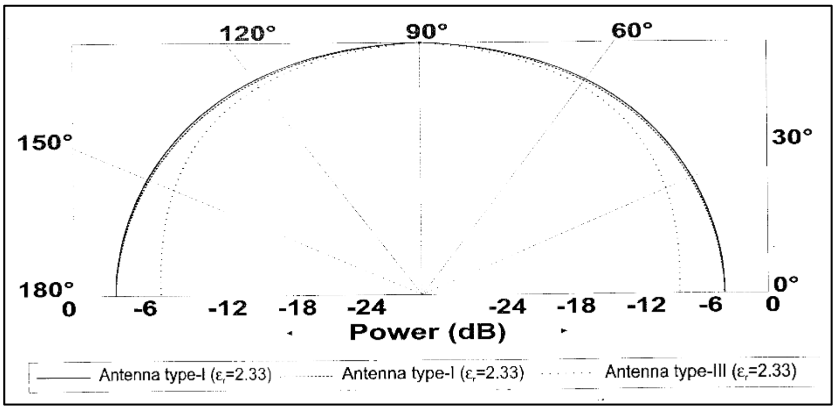

Fig. 4: E-plane pattern of micromachined patch antenna (type I, type II and type III) at f= 3GHz, $\varepsilon_r = 2.33$, h=0.959 cm

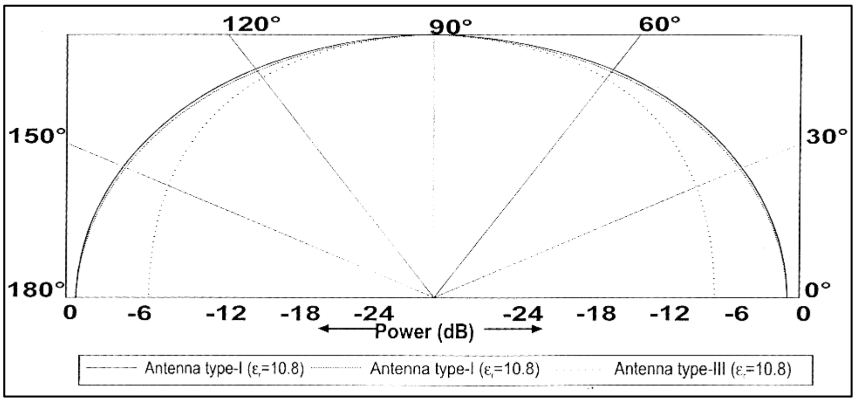

Fig. 5: E-plane pattern of micromachined patch antenna (type I, type II and type III) at f= 3GHz, $\varepsilon_r = 10.8$, h=0.959 cm

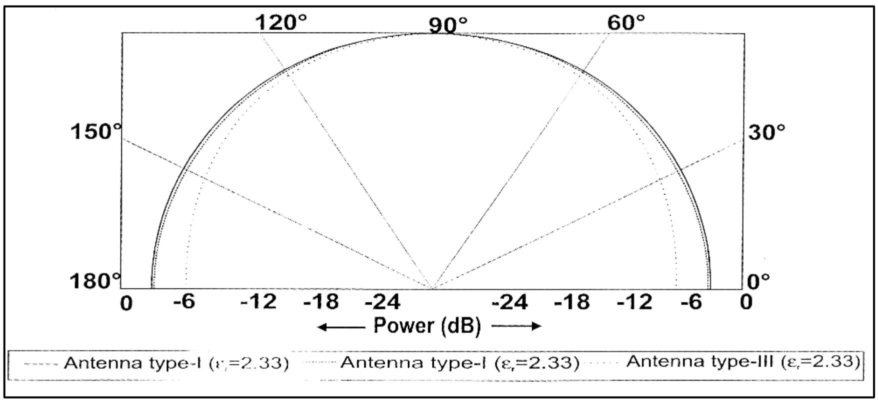

Fig. 6: E-plane pattern of micromachined patch antenna at (type I, type II and type III) f= 10GHz, $\varepsilon_r = 2.33$, h=0.359 cm

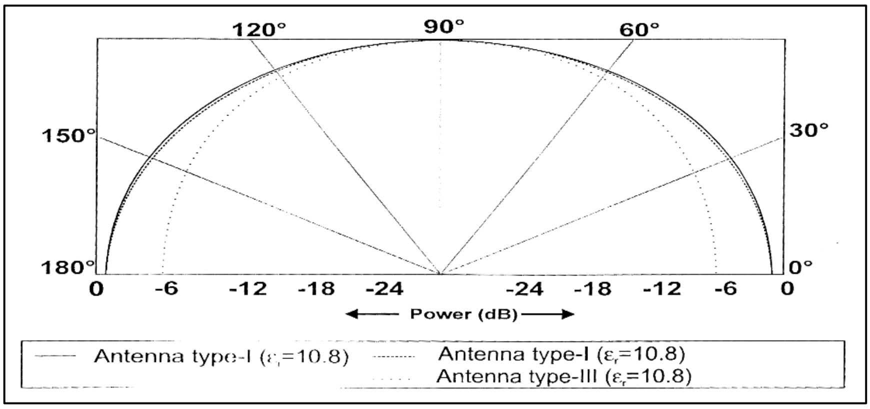

Fig. 7: E-plane pattern of micromachined patch antenna at (type I, type II and type III) f= 10GHz, $\varepsilon_r = 10.8$, h=0359 cm

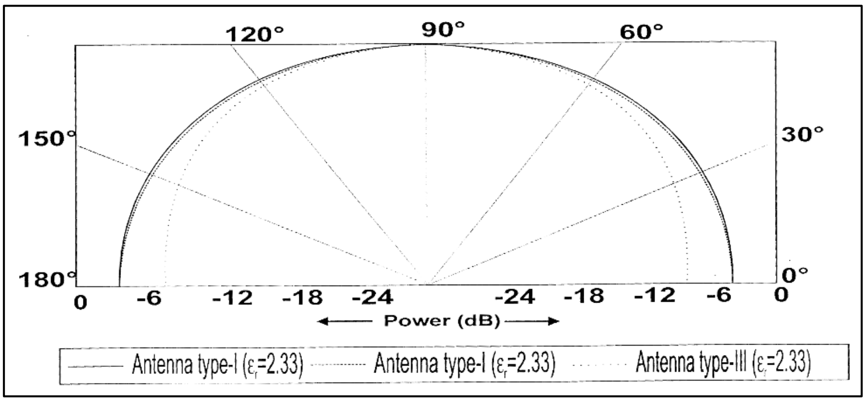

Fig. 8: E-plane pattern of micromachined patch antenna (type I, type II and type III) at f= 18GHz, $\varepsilon_r = 2.33$, h=0.159 cm

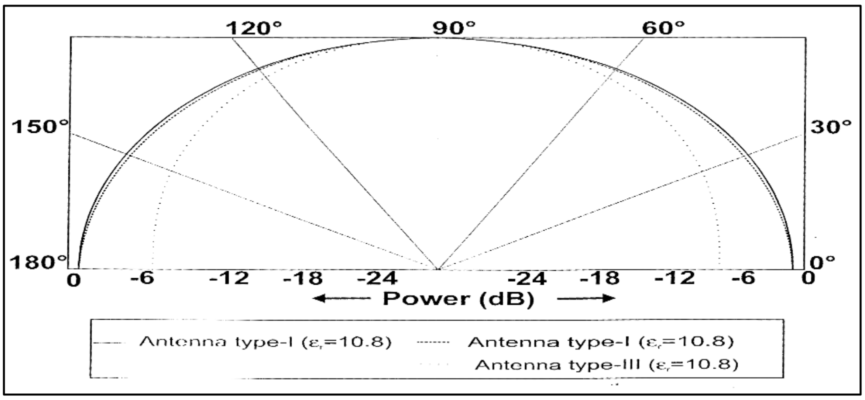

Fig. 9: E-plane pattern of micromachined patch antenna(type I, type II and type III) at f= 18GHz, $\varepsilon_r = 10.8$, h=0.159 cm.

IV. CONCLUSIONS

The micromachined patch antenna has been studied in three frequencies 3, 10 and 18 GHz. The micromachined patch antennas type II and III have been studied for various fundamental parameters of antenna and the results are compared to regular patch antenna (type I) in table 1-4. It is observed from the radiation patterns of these geometries (Figs. 3-9) that the H-plane patterns are similar in all cases and E-plane patterns of the type III (ε_r=2.33) and type III (ε_r=10.8) are comparable. Thus, the comparison between the high index patch and the micromachined patch antennas of type III(ε_r=10.8) show not only bandwidth improvement by a large factor but improvement in other antenna properties too. Thus we achieve our goal to integrate the planar antennas on electrically thick low-index region and circuit on high-index region in same substrate.

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