ENHANCED BANDWIDTH MICROSTRIP PATCH ANTENNAS LOADED WITH HIGH PERMITTIVITY DIELECTRIC RESONATORS

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ABSTRACT: *A novel technique for the bandwidth enhancement of conventional rectangular microstrip antenna is proposed in this paper. When a high permittivity dielectric resonator of suitable resonant frequency was loaded over the patch, the % bandwidth of the antenna was increased by more than five times without much affecting its gain and radiation performance. A much more improved bandwidth was obtained when the dielectric resonator was placed on the feedline. Experimental study shows a 2:1 VSWR bandwidth of more than 10% and excellent cross polarization performance with increased pass band and radiation coverage almost the same as that of rectangular microstrip antenna.* Microwave Opt Technol Lett 35: 327–330, 2002; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.10597

Key words: *dielectric resonator; microstrip antenna; DR-loaded antenna; bandwidth enhancement*

1. INTRODUCTION

The recent rapid progress in the field of wireless communication demands simple, reliable, economical, small, low profile and lightweight antennas for application in mobile and satellite communication, phased array, electronic warfare, radar, missile telemetry, space and airborne microwave remote sensing systems etc. Since microstrip patch antennas posses the above-mentioned unique properties they are considered as a potential candidate for these purposes. But the fields of application of these antennas are limited by their inherent disadvantage of relatively low-impedance bandwidth (BW). Several techniques are available in literature for improving the bandwidth of microstrip antennas such as use of thick substrates [1], addition of parasitic patches [2] etc. However these methods will also increase the complexity of the system and will adversely affect the gain of the antenna. In 1998, J. George et al. proposed that the BW of a microstrip patch antenna could be increased by loading a DR on the patch surface [3]. This envisages a novel technique for the purpose without much affecting other antenna radiation properties. In this paper we report optimization of the position of DR on the patch surface and the effect of its dielectric constant and resonant frequency on the antenna properties. We also studied the effect of loading DR on the feedline after fixing the position of the microstrip patch. In both the cases the antenna exhibited excellent properties with an impedance bandwidth of more than 10%.

2. ANTENNA GEOMETRY

The geometry of the proposed antenna is shown in Figure 1. Rectangular patch antenna of dimension $L \times W$ is etched on a substrate of thickness $h_2 = 1.6$ mm and permittivity $\varepsilon_{r2} = 4.28$. The patch is electromagnetically coupled by a 50Ω microstrip feed fabricated on a substrate of thickness $h_1 = 1.6$ mm and permittivity $\varepsilon_{r1} = 4.28$. The antenna is loaded with a cylindrical DR of diameter d, height H and dielectric constant ε_{dr}.

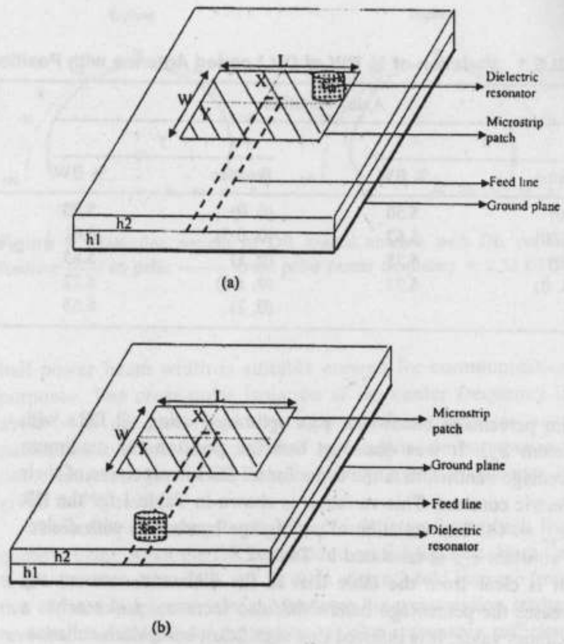

Figure 1 Geometry of DR loaded microstrip patch antenna. (a) DR over the patch. (b) DR on the feedline $h_1 = h_2 = 1.6$ mm, $\varepsilon_{r1} = \varepsilon_{r2} = 4.28$, $L \times W = 30 \times 39$ mm^2 $\varepsilon_{dr} = 48$, $H = 6.81$ mm, $d = 24.15$ mm, $f_r = 2.4$ GHz

3. EXPERIMENTAL RESULTS

3.1 DR Over the Patch Surface

A rectangular microstrip antenna of $L \times W = 30 \times 39$ mm^2 resonating at 2.3 GHz is fabricated on a dielectric substrate of permittivity $\varepsilon_{r1} = 4.28$ and height $h_1 = 1.6$ mm as described in Figure 1(a). Dielectric resonator materials of different dielectric constant (11 − 92) were prepared by solid-state ceramic route. Their dimensions were so chosen to have different resonant frequencies.

The impedance BW of the rectangular microstrip patch was noted first. The BW of the antenna was found to be 2.77% at 2.3 GHz. The DR is fixed at different locations on the patch. The corresponding bandwidth is noted in each position. Along x and y direction the percentage bandwidth increases when the DR is moved from the center to the edge of the patch. The change in percentage bandwidth along the diagonal is more significant than any other intermediate position. It is clear from Table 1 that along the diagonal the percentage bandwidth reaches a maximum at a position (1.5, 1.5). At this position, the DR is at the corner of the patch but it is completely within the boundary of the patch. The DR is also moved along the edges of the microstrip patch to study the variation in percentage bandwidth. It is observed that the percentage bandwidth increases and reaches a maximum value at (1.5, 1.5) position and then decreased at the extreme corner. It was also noted that the maximum percentage bandwidth observed at the same position on all quadrants of the patch, as it is symmetrical. For all other intermediate positions of the DR on the microstrip patch the percentage bandwidth was less than that at the (1.5, 1.5) position. In a similar manner the optimum position for max-

TABLE 1 Variation of % BW of DR Loaded Antenna with Position of DR on the Microstrip Patch. (ε_{dr} = 48)

Axial Variation							
x		y		Diagonal Variation		Variation Along the Edges	
Position	% BW	Position	% BW	Position	% BW	Position	% BW
(0, 0)	5.50	(0, 0)	5.50	(0, 0)	5.50	(1.5, 0)	5.93
(0.5, 0)	5.62	(0, 0.5)	5.61	(0.5, 0.5)	6.31	(1.5, 0.5)	6.21
(1, 0)	5.75	(0, 1)	5.85	(1, 1)	8.48	(1.5, 1)	7.39
(1.5, 0)	5.93	(0, 1.5)	6.22	(1.5, 1.5)	10.57	(1.5, 1.5)	10.57
		(0, 2)	6.65			(1.5, 2)	8.33

imum percentage bandwidth was optimized using all DRs with different ε_{dr}. It was observed that the position for maximum percentage bandwidth is the same for all DRs irrespective of their dielectric constant. This variation is shown in Table 1 for the DR of $\varepsilon_{dr} = 48$. The variation of percentage bandwidth with dielectric constant ε_{dr} is tabulated in Table 2.

It is clear from the table that as the dielectric constant ε_{dr} increases the percentage bandwidth also increases and reaches a maximum value. It is inferred that significant bandwidth enhancement occurs when the dielectric constant of the DR is in the range 40 to 50. The maximum % BW is 10.57 for the material $Ca_5Nb_2TiO_{12}$ [4]. This material has a dielectric constant of 48, with a quality factor $Q_u \times f > 26\,000$ and low temperature variation of resonant frequency τ_f. This confirms that the system is stable with temperature variations. More over the relatively low density (4.19 g/cm^3) of the material ensures that the weight and hence the complexity of the antenna system will not be much increased by DR loading. It is also to be noted that the resonant frequency of the antenna is almost unaffected by loading a DR on it. A very small decrease in resonant frequency occurs when the value of ε_{dr} suites for maximum enhancement of % BW. The variation of percentage bandwidth with dielectric constant of the DR ε_{dr} is given in Figure 2.

To study the effect of resonant frequency of the DR on the antenna properties we prepared $Ca_5Nb_2TiO_{12}$ samples of different dimensions so as to have different resonant frequencies (2 GHz to 6 GHz). These samples were placed at the optimized position for maximum BW and measured the % BW of the antenna in each case. It is inferred that the DR loaded microstrip antenna attained a maximum BW of 10.57% at 2.27 GHz when the resonant frequency (f_r = 2.4 GHz) of the DR approaches that of the rectangular microstrip patch alone. The variation of % BW with resonant frequency of DR is given in Figure 3.

TABLE 2 Variation of % BW of DR Loaded Antenna with Dielectric Constant of DR

Sl.No	Dielectric Material	ε_{dr}	Resonant Frequency of the DR Loaded Antenna (in GHz)	% BW
1	$Mg_5Nb_4O_{15}$	11	2.30	3.41
2	$Mg_{4.5}Zn_{0.5}Nb_4O_{15}$	13	2.30	3.52
3	$YTiTaO_6$	18	2.30	4.61
4	$LaTiTaO_6$	20	2.30	4.92
5	$Zn_5Nb_4O_{15}$	22	2.30	5.02
6	$Ba(Mg_{1/3}Ta_{2/3})O_3$	25	2.30	5.56
7	$Ba(Zn_{1/3}Ta_{2/3})O_3$	29	2.30	6.48
8	$EuTiTaO_6$	36	2.29	7.21
9	$Ca_5Ta_2TiO_{12}$	38	2.28	7.95
10	$TbTiTaO_6$	42	2.28	8.63
11	$SrLa_4Ti_4O_{15}$	44	2.27	9.43
12	$Ca_5Nb_2TiO_{12}$	48	2.27	10.57
13	$CaLa_8Ti_9O_{31}$	50	2.27	9.94
14	$CaLa_4Ti_5O_{17}$	54	2.28	8.86
15	$Ba_{0.4}Sr_{0.6}InTi_5O_{14}$	62	2.28	7.90
16	$BaPr_2Ti_4O_{12}$ (+Bi_2O_3)	73	2.29	7.05
17	$BaNd_2Ti_4O_{12}$	84	2.30	6.13
18	$BaPr_2Ti_4O_{12}$	92	2.30	5.02

The typical E-plane and H-plane radiation patterns of the DR loaded antenna at the center frequency are given in Figure 4. At the center frequency, the E-plane half-power beam width is 66° and the H-plane half-power beam width is 64°. This confirms that the antenna is working like a conventional Microstrip Antenna with enhanced bandwidth. The cross polarization studies show that the cross-polar isolation is better than −20 dB, which is also a desirable characteristic for communication antennas. The return loss plot of the DR loaded antenna is given in Figure 5.

The % BW is increased by more than five times than that of microstrip patch alone. It is also observed from the transmission studies that the gain of the antenna is not deteriorated much by DR loading. From the experimental studies it is observed that the antenna is exhibiting excellent radiation performance in the entire band.

3.2 DR on the Feedline

The microstrip patch antenna with resonant frequency 2.3 GHz and % BW 2.77 is fixed on the feedline. The dielectric resonator material of $\varepsilon_{dr} = 48$ and f_r = 2.4 GHz is placed over the feedline at different positions (See Fig. 1(b). The % BW and return loss is measured in each case. It is observed that as the DR moves away

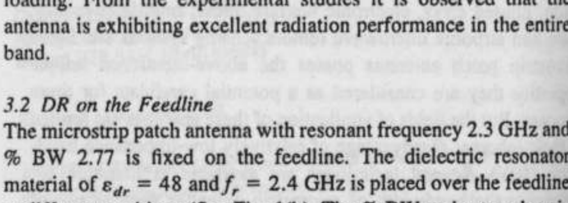

Figure 2 Variation of % BW of the DR loaded antenna with dielectric constant of DR

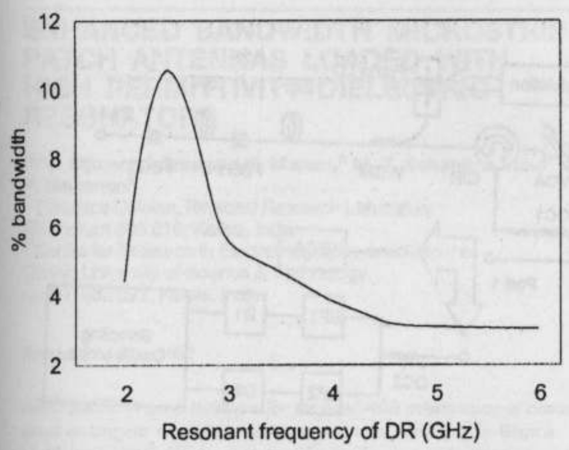

Figure 3 Variation of % BW of the DR loaded antenna with resonant frequency of DR (ε_{dr} = 48)

from the patch and approaches the feed point, the % BW increases along with slight increase in the resonant frequency of the resultant antenna. Near the feed point the BW reached a maximum of 13.79% at 2.32 GHz with a negligible reduction in gain. The DR is fixed at this point on the feedline and the E-plane and H-plane radiation characteristics are studied. Typical E-plane and H-plane radiation patterns at the central frequency (2.32 GHz) are given in Figure 6.

The radiation pattern reveals that the antenna is exhibiting excellent properties in the entire band. The E- and H-plane

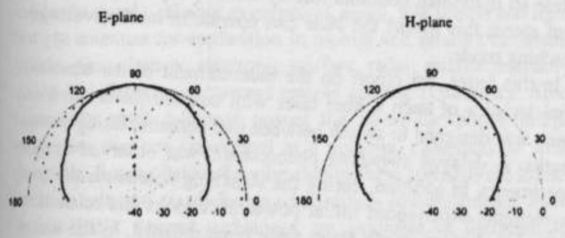

Figure 4 Radiation pattern of DR loaded antenna with DR over the patch. —— co polar -------- cross polar center frequency = 2.27 GHz

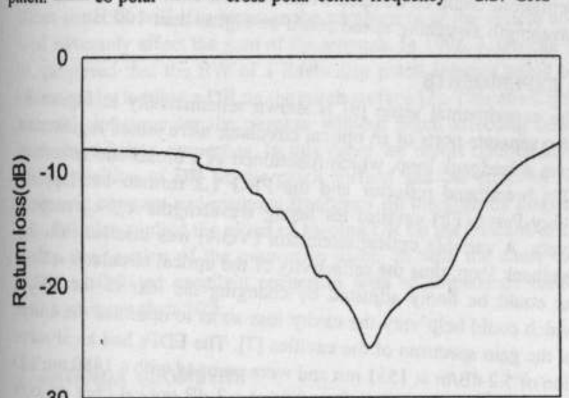

Figure 5 Variation of return loss with frequency with DR over the patch

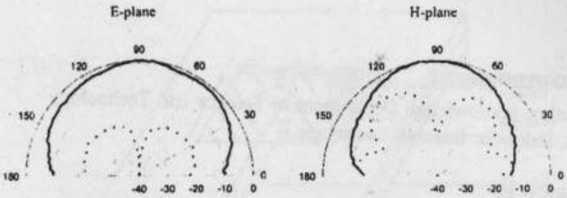

Figure 6 Radiation pattern of DR loaded antenna with DR on the feedline —— co polar -------- cross polar center frequency = 2.32 GHz

half-power beam width is suitable enough for communication purposes. The cross-polar isolation at the center frequency is about −30 dB and it greatly supports these antennas as a potential candidate for broadband applications in communication. The return loss of the antenna plotted against frequency is given in Figure 7.

The center frequency is slightly shifted towards the high frequency region when the DR was loaded on the feedline. Here the % BW reaches about 14% at 2.32 GHz with a 7-fold increase from that of microstrip patch alone. Moreover the transmission studies revealed that the gain of the antenna is also reasonably sufficient for applications in communication field.

4. CONCLUSIONS

The cylindrical dielectric resonator loaded microstrip antenna for enhancing the impedance bandwidth of a conventional microstrip patch antenna is proposed. The position of DR on the patch surface as well as the value of dielectric constant and resonant frequency of DR needed for maximum percentage bandwidth is optimized. In addition we studied the effect of fixing a high permittivity DR on the feedline. In both cases the increase in BW of microstrip patch antenna is achieved with excellent radiation characteristics. The studies also revealed that these methods will not adversely affect other properties of the antenna especially its gain and efficiency. These characteristics point towards the possibility of using these antennas for practical applications. A bandwidth of more than 10% is achieved by loading a dielectric resonator of ε_{dr} = 48 over the patch and about 14% by loading the same DR on the feedline.

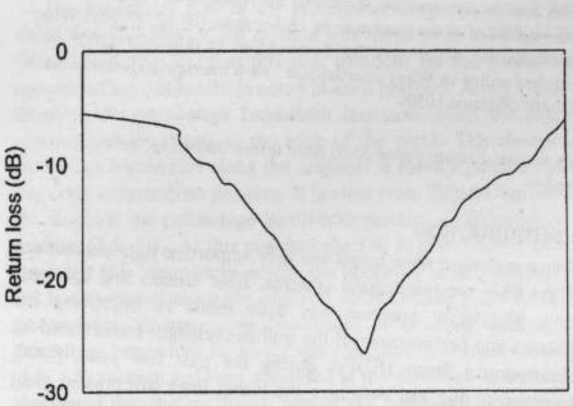

Figure 7 Variation of return loss with frequency with DR on the feedline

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