Progress In Electromagnetics Research C, Vol. 11, 11–19, 2009

A NOVEL SLOT FOR ENHANCING THE IMPEDANCE BANDWIDTH AND GAIN OF RECTANGULAR MICROSTRIP ANTENNA

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Abstract—This paper reports the design and development of rectangular microstrip antenna comprising a novel slot for enhancing the impedance bandwidth and gain. By incorporating a slot of optimum geometry at suitable location on the radiating patch, the antenna provides 78.08% (3.39–7.73 GHz) of impedance bandwidth and 3 dB of gain without changing the nature of broadside radiation characteristics when compared to conventional rectangular microstrip antenna. The proposed antenna may find applications in mobile WiMax, IEEE802.11a, HIPERLAN/2, cordless phones, fixed wireless etc. Design concept of antennas is given, and experimental results are discussed.

1. INTRODUCTION

In current communication systems, the use of microstrip antennas (MSAs) has become widespread because of their attractive properties such as planar, light weight, low profile, low production cost, etc. But the main limitations of MSAs are their narrow impedance bandwidth and lower gain. Several promising techniques are available in the literature for the enhancement of impedance bandwidth of MSAs such as use of stacked antenna [1], additional resonators [2], aperture coupling method [3], etc. But, these methods are effective for the antenna with a thick substrate. In conjunction many techniques are available to enhance the gain of MSAs, such as the uses of parasitic patch [4], array antenna [5], etc. These methods are effective at the cost of increased size of the antenna. In this study, a novel slot microstrip antenna is proposed after the different slots on the conducting patch

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for wide impedance bandwidth and adequate gain response without any change in height or size of the antenna are studied.

2. DESIGNING

The proposed antennas are designed using low cost glass epoxy substrate material of thickness, $h = 1.66$ mm and dielectric constant $\varepsilon_r = 4.2$. The artwork of proposed antennas is developed using computer software Auto CAD-2006 to achieve better accuracy. The antennas are fabricated using photolithography process.

Figure 1 shows the geometry of conventional rectangular microstrip antenna (RMSA). The antenna is designed for the resonant frequency of 4 GHz. It consists of radiating patch of length L and width W, quarter wave transformer of length L_t and width W_t used for better impedance matching between the patch and 50 Ω feed line of length L_f and width W_f.

A wide slot is loaded horizontally at the suitable place on the radiating patch of RMSA as shown in Figure 2. This antenna is termed as wide slot rectangular microstrip antenna (WRMSA). The dimension of slot is taken in terms of λ_0, where λ_0 is the free space wavelength in cm. The thickness of slot W_h is taken as $\lambda_0/75$. The optimized length L_1 of wide slot is $\lambda_0/10.7$, and it is placed 0.49 cm ($\lambda_0/15.3$) inside from the upper radiating edge (W) and 0.81 cm ($\lambda_0/9.3$) inside from the non-radiating edges (L) of the patch. This slot is considered as wide slot as its width is comparable to its length. The wide slot is selected because it is more effective in enhancing the impedance bandwidth when compared to narrow slot [6].

Figure 3 shows the geometry of inverted L-slot rectangular

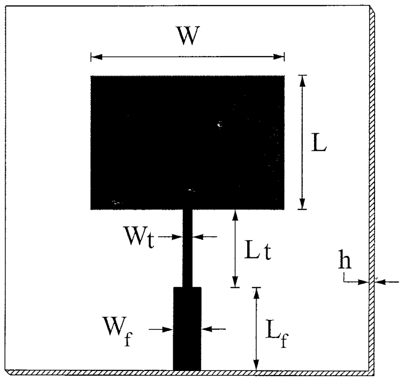

Figure 1. Geometry of RMSA.

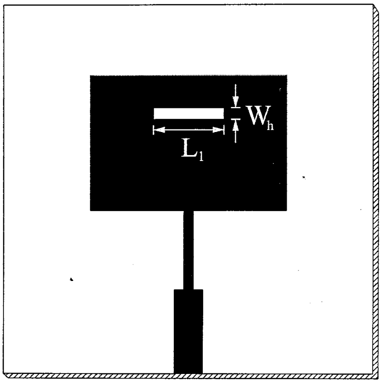

Figure 2. Geometry of WRMSA.

microstrip antenna (ILRMSA) which is derived from WRMSA. In this figure, the slot is used in the form of inverted L. The optimized length L_2 of the slot is $\lambda_0/1.5$, and width is W_h. The dimension of horizontal arm of inverted L-slot remains the same as that of Figure 2.

Figure 4 shows the geometry of C-slot rectangular microstrip antenna (CRMSA). In this figure, the lower end of the vertical slot in ILRMSA is extended horizontally in order to have the 'C' shaped slot. The length of the extended horizontal slot is L_1, and its width is W_h.

Figure 5 shows the geometry of G-slot rectangular microstrip

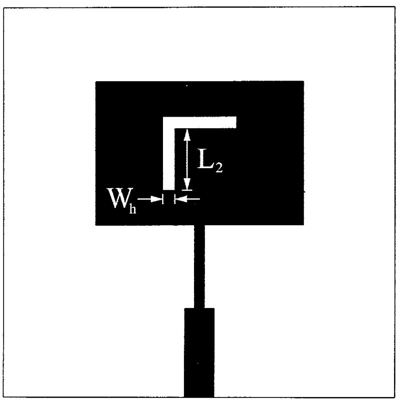

Figure 3. Geometry of ILRMSA.

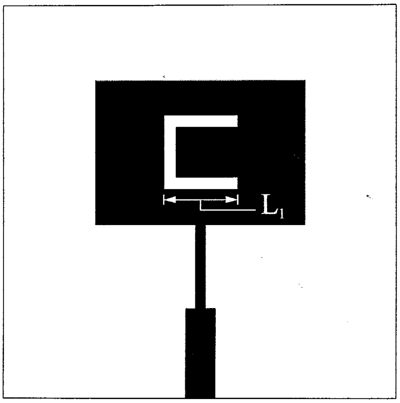

Figure 4. Geometry of CRMSA.

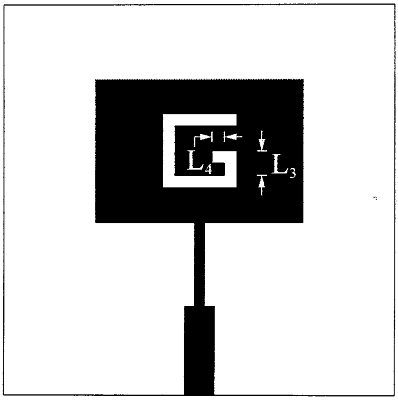

Figure 5. Geometry of GRMSA.

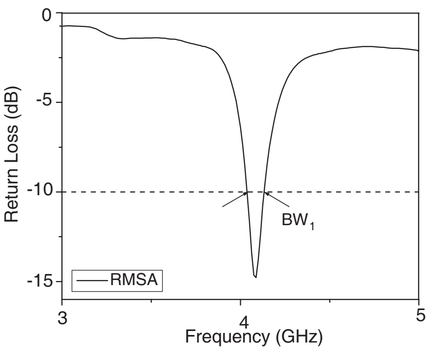

Figure 6. Variation of return loss versus frequency of RMSA.

Table 1. Designed parameters of RMSA, WRMSA, ILRMSA, CRMSA and GRMSA.

$L = 1.68\,\text{cm}$	$W = 2.32\,\text{cm}$
$L_t = 0.96\,\text{cm}$	$W_t = 0.05\,\text{cm}$
$L_f = 0.96\,\text{cm}$	$W_f = 0.32\,\text{cm}$
$L_1 = 0.70\,\text{cm}$	$L_2 = 0.50\,\text{cm}$
$L_3 = 2.00\,\text{cm}$	$L_4 = 0.10\,\text{cm}$
$W_h = 0.10\,\text{cm}$	$h = 0.16\,\text{cm}$

antenna (GRMSA). In this figure, the C-slot of CRMSA is extended from its lower arm in order to have the 'G' shaped slot. The lengths L_3 and L_4 are $\lambda_0/3.75$ and $\lambda_0/75$ respectively. The widths of L_3 and L_4 are W_h. The designed parameters of RMSA, WRMSA, ILRMSA, CRMSA and GRMSA are listed in Table 1.

3. EXPERIMENTAL RESULTS

Since the designed frequency of conventional RMSA is 4 GHz, the impedance bandwidth over return loss less than −10 dB is measured from S (2–4 GHz) to C (4–8 GHz) band of frequencies. The measurements are taken on Vector Network Analyzer (Rohde and Schwarz, Germany make ZVK model 1127.8651). The variation of return loss versus frequency plot of RMSA is as shown in Figure 6.

From this figure, it is seen that the RMSA resonates at 4.08 GHz of frequency which is close to the designed frequency of 4 GHz. From this graph the experimental impedance bandwidth is calculated using the formula:

$$\text{Impedance Bandwidth } (\%) = \left[\frac{f_2 - f_1}{f_r}\right] \times 100 \tag{1}$$

where, f_2 and f_1 are upper and lower cut-off frequencies of the band BW_1 respectively when its return loss reaches −10 dB, and f_r is the centre frequency between f_1 and f_2. The impedance bandwidth of conventional RMSA is found to be 2.26%.

The theoretical impedance bandwidth of this antenna is calculated using [7],

$$\text{Impedance Bandwidth } (\%) = \left[\frac{A \times h}{\lambda_0\sqrt{\varepsilon_r}}\right] \times \sqrt{\frac{W}{L}} \tag{2}$$

where, A is the correction factor, which is found to be 180 in [7]. The theoretical impedance bandwidth of RMSA calculated using

Equation (2) is 2.2% which is in good agreement with the experimental result.

Figure 7 shows the variation of return loss versus frequency of WRMSA. The antenna resonates at two bands of frequencies BW_2 and BW_3. This is due to independent resonance of patch and wide horizontal slot [8]. The overall impedance bandwidth is found to be ($BW_2 + BW_3$) 4.57% (i.e., 230 MHz). If the horizontal slot is replaced by inverted L-slot, i.e., ILRMSA, the antenna resonates at three bands of frequencies BW_4, BW_5 and BW_6 as shown in Figure 8. The third band BW_6 is due to additional resonance of vertical slot used in ILRMSA. The overall impedance bandwidth is found to be 9.05% (i.e., 537 MHz). However, if inverted L-slot is replaced by C-slot in CRMSA, the antenna resonates at one band BW_7 as shown in Figure 9. The magnitude of BW_7 is 34.46% (i.e., 2145 MHz). The merging of three bands BW_4, BW_5 and BW_6 of ILRMSA into a single band BW_7 in CRMSA is due to the effect of lower horizontal slot which resonates in between BW_4 and BW_6 [9]. It is clear that slot can be either resonant or non-resonant. If it is resonant, the current along the edges of the slot introduces an additional resonance. If these additional resonances are near the patch resonance, adding them together causes enhancement in impedance bandwidth.

Further, when the C-slot is replaced by G-slot, i.e., GRMSA, the antenna resonates again at a single band BW_8 as shown in Figure 10 and gives the highest impedance bandwidth of 78.08% (i.e., 4345 MHz) which is 34.54 times more than the impedance bandwidth of conventional RMSA. This further enhancement in impedance bandwidth when compared to CRMSA is due to the insertion of slots L_3 and L_4 used for the construction of G-slot in GRMSA. The current

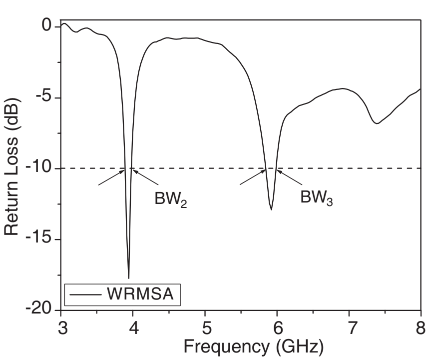

Figure 7. Variation of return loss versus frequency of WRMSA.

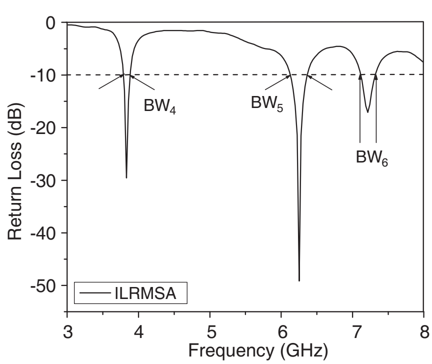

Figure 8. Variation of return loss versus frequency of ILRMSA.

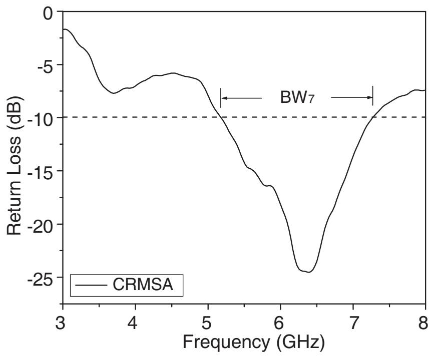

Figure 9. Variation of return loss versus frequency of CRMSA.

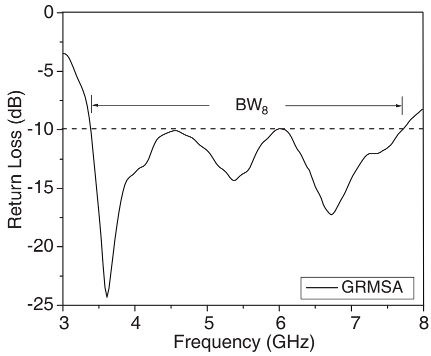

Figure 10. Variation of return loss versus frequency of GRMSA.

along the edges of the slot induces an additional resonance, which adds to the fundamental resonance of radiating element that helps to increase the impedance bandwidth [10].

For the measurement of radiation pattern, the antenna under test (AUT), i.e., the proposed antennas and standard pyramidal horn antenna are kept in far field region. The AUT, which is the receiving antenna, is kept in phase with respect to transmitting pyramidal horn antenna. The power received by AUT is measured from $-90°$ to $+90°$ with the steps of $10°$.

The co-polar radiating patterns of RMSA, WRMSA, ILRMSA, CRMSA and GRMSA are measured at the frequencies 4.08, 3.94, 3.83, 6.39 and 3.61 GHz respectively, as shown in Figure 11 to Figure 15. From these figures, it can be observed that the co-polar patterns are broadside and linearly polarized. The -3 dB half power beamwidth (HPBW) of RMSA, WRMSA, ILRMSA, CRMSA and GRMSA are

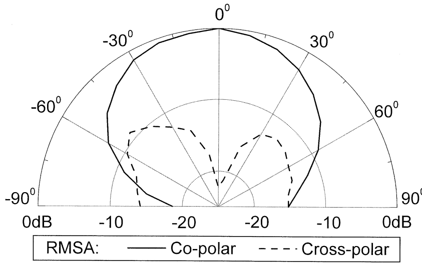

Figure 11. Radiation pattern of RMSA.

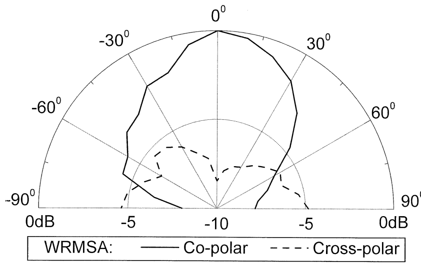

Figure 12. Radiation pattern of WRMSA.

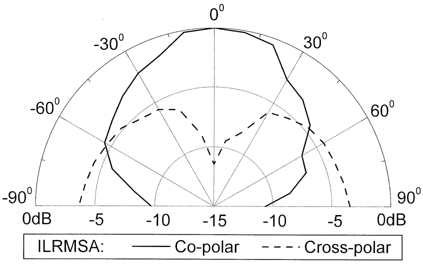

Figure 13. Radiation pattern of ILRMSA.

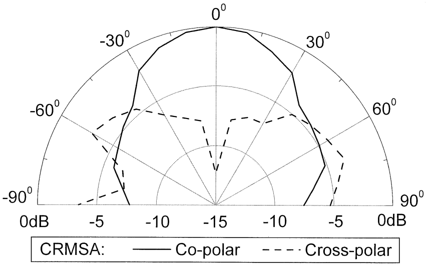

Figure 14. Radiation pattern of CRMSA.

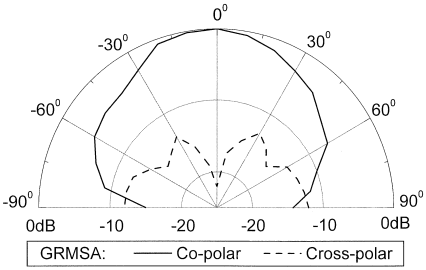

Figure 15. Radiation pattern of GRMSA.

71°, 78°, 74°, 70° and 61° respectively. Hence, it is also clear that the GRMSA improves the sharpness of the beam when compared to conventional RMSA by reducing the HPBW from 71° to 61°. This is because the G-slot suppresses the maximum back radiations among the proposed slots, which in turn sharpens the beam and hence improves the radiation pattern [11].

For the calculation of gain of proposed antennas, the power transmitted 'P_t' by pyramidal horn antenna and power received 'P_r' by AUT are measured independently. With the help of these experimental data, the gain G dB of AUT is calculated using the absolute gain method [12],

$$(G)\,\text{dB} = 10\log\left(\frac{P_r}{P_t}\right) - (G_t)\ \text{dB} - 20\log\left(\frac{\lambda_0}{4\pi R}\right)\ \text{dB} \tag{3}$$

where, G_t is the gain of the pyramidal horn antenna, and R is the distance between the transmitting antenna and the AUT. Using (3), the gains of RMSA, WRMSA, ILRMSA, CRMSA and GRMSA are found to be 0.86, 0.48, 0.66, 1.15 and 3 dB respectively. Since the gain of reference antenna G_t is taken in dB, the calculated gain G (dB) of

Table 2. Experimental results.

Antenna	No. of Bands	Overall BW (%)	Gain (dB)
RMSA	1	2.26	0.86
WRMSA	2	4.57	0.48
ILRMSA	3	9.05	0.66
CRMSA	1	34.46	1.15
GRMSA	1	78.08	3.00

AUT using (3) gives gain in dB. It is seen that the gain is maximum in case of GRMSA. Hence GRMSA enhances the gain from 0.86 to 3 dB when compared to the gain of conventional RMSA. However, this gain could be expected more by using the area of ground plane more than twice of the area of the patch [13]. Experimental results of these antennas are given in Table 2.

4. CONCLUSION

From the detailed experimental study, it is found that the impedance bandwidth of conventional RMSA can be enhanced from 2.26 to 78.08% by loading G-slot on the conducting patch. The insertion of G-slot also enhances the gain from 0.86 to 3 dB. The single band of RMSA can be converted into dual and triple bands by loading horizontal and inverted L-slots on the patch respectively. The triple band can be converted into single band by loading C-slot on the patch. The highest impedance bandwidth and gain is achieved by replacing C-slot by G-slot. Enhancement of impedance bandwidth and gain does not affect the nature of broadside radiation characteristics. The proposed antennas are simple in their geometry and are fabricated using low cost glass epoxy substrate material. These antennas may find applications in mobile WiMax (3.4 to 3.6 GHz), IEEE802.11a (5.15 to 5.35 GHz), HIPERLAN/2 (5.725 to 5.825 GHz), cordless phones (5 GHz), fixed wireless (5 GHz), etc.

ACKNOWLEDGMENT

The authors thank the Dept. of Science & Technology (DST), Government of India, New Delhi, for sanctioning Network Analyzer to this department under FIST project.

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