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Development of microstrip array antenna for wide band and multiband applications

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The paper presents the design and development of an X-band linearly polarized microstrip array antenna. The array elements are fed by corporate feed network, which improves the impedance bandwidth of the two element rectangular microstrip array antenna (2RMSAA) by 15.38%. By increasing the array elements from two to four and eight, multiband operation can be achieved with improved impedance bandwidth. These multiband array antennas may provide an alternative to large bandwidth planar antennas in applications where large bandwidth is needed for operating at two separate transmit-receiver frequencies. When the two operating frequencies are far apart, a multiband antenna can be used to avoid the use of separate antennas. Experimental results for the array antennas in term of return loss, radiation pattern, -3dB beam width, and gain are presented.

Keywords: Microstrip array antenna, Corporate feed network, Rectangular array antenna

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1 Introduction

In many wireless communication systems, there is a requirement for light, low-profile antennas. These antennas are less obtrusive than traditionally used parabolic reflectors. In addition, snow, rain or wind has less affect on their performance. A planar antenna, incorporating an array of microstrip patches, is one example of a low weight, low-profile antenna. In order to make this array an effective radiator, each individual patch has to be suitably fed[1,2]. Different methods can be used to achieve this goal.

The conventional approach to the design of feed network aims at division of power from input port to patch element with the ideal match at any level within the network up to the patch element. The patch element impedance bandwidth is known to depend on the substrate thickness. Conventional impedance bandwidth enhancement approaches aim at broadening the bandwidth by employing multilayer construction using parasitic elements and electromagnetic coupling or by employing a matching filter network attached to each element. The latter approach requires additional circuit area for every patch element, which often is in conflict with the required circuit area for the feed network[3].

One very popular choice is a corporate feed network, in which two-way power divider or T-junctions are arranged in a rectangular matrix[4]. The advantages are as follows:

1. The process of photo etching hundreds or thousands of microwave components in one process results in a low-cost array antenna.
2. The resulting printed circuit board is thin, its performance is unaffected by mounting to a metallic surface such as an aircraft or a missile.
3. Microstrip arrays have high performance because a large variety and quantity of antenna elements, power dividers, matching sections, phasing sections, etc. can be added to the printed circuit board without any cost impact. This gives the design engineers the components that are not commercially available in separate packages.
4. The microstrip array is reliable since the entire array is one continuous piece of copper. Other types of antennas, most commonly, have failed at interconnections within the antennas and at their input connectors[5].

Konda *et al.*, in 2006, presented an experimental study carried out on two-elements rectangular microstrip array antenna (TRMSA) fed by corporate feed technique with the impedance bandwidth of 220 MHz, i.e. 2% (ref. 6). In 2008, Konda *et al.*

proposed the design of four element rectangular microstrip array antenna (FRMSA) and eight element rectangular microstrip array antenna (ERMSA), which are also fed by corporate feed arrangement. The experimental result of FRMSA shows that the antenna operates at three bands of frequencies and the overall impedance bandwidth is found to be 10.61% whereas the experimental impedance bandwidth of ERMSA is found to be 12.31%, which resonates for two bands[7].

The present study provides a new approach of feed network design in which the network is used for the power division and at the same time for broad banding of the impedance match of the array antenna.

2 Antenna configurations

The proposed antennas are designed using low cost FR4 material having dielectric constant ϵ_r = 4.4 and thickness h = 0.166 cm. The geometry of 2RMSAA is shown in Fig. 1. The elements of array are designed for 9.2 GHz frequency with dimensions L and W. The length (L_g) and width (W_g) of the ground plane of antenna is calculated using $L_g = 6h + L$ and $W_g = 6h + W$ (ref. 8). The elements of this array antenna are excited through simple corporate feed arrangement. This feed arrangement consist of matching transformer, quarter wave transformer, coupler, and power divider for better impedance matching between feed and radiating elements[9]. A two-way power divider, made up of 70Ω matching transformer of dimension (L_{70}, W_{70}), is used between 100Ω microstrip line of dimension (L_{100}, W_{100}) and 50Ω microstrip line of dimension (L_{50}, W_{50}). A coupler of dimension (C_L, C_W) is used between 50Ω microstrip lines to couple the power[10,11]. This coupler has been used in the present study instead of microstrip bend (M_b) used by Konda *et al.* This feed network is simple as compared to feed network used by Konda *et al.* The 50Ω microstrip line is connected at the center of the driven element through a quarter wave transformer of dimension (L_t, W_t) for better impedance matching. At the tip of microstrip line feed of 50Ω, a coaxial SMA connector is used for feeding the microwave power. The array elements are kept at a distance of D = 0.856λ_0 from their center point, where λ_0 is the free space wavelength in centimeters. This optimized distance is selected in order to achieve minimum side lobes in the radiation pattern and to add the radiated power in free space[12]. The various dimensions mentioned in Fig. 1 are given in Table 1. Further, the study is carried out for four element rectangular microstrip array antenna (4RMSAA) and eight element rectangular microstrip array antenna (8RMSAA).

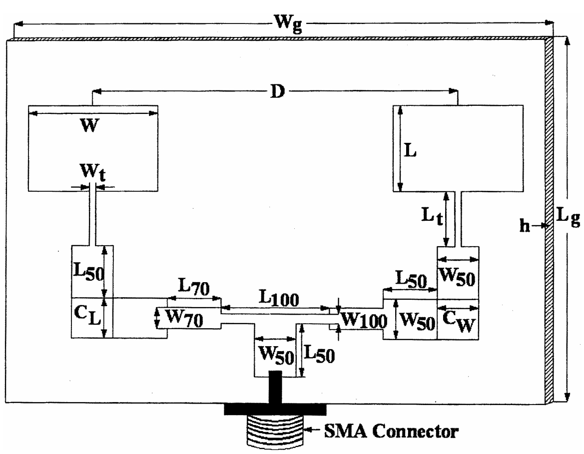

Fig. 1 — Geometry of 2RMSAA

3 Experimental results and discussion

The impedance bandwidths for the proposed antennas are measured at X-band frequencies. The measurements are taken on Vector Network Analyzer (Rohde & Schwarz, German make ZVK Model No. 1127.8651). The variation of return loss *vs* frequency of 2RMSAA, 4RMSAA and 8RMSAA are shown in Figs 2, 3 and 4, respectively.

From Fig. 2, it is clear that the experimental impedance bandwidth of 2RMSAA (BW_1) is found to be 1340 MHz, i.e. 15.38%, which is 5.009 times more as compared to single radiating element (3.07%) and

Table 1 — Various dimensions of patch, ground plane and corporate feed line network

(a) Patch dimensions:	
Length of the patch (L)	0.68 cm
Width of the patch (W)	0.99 cm
Distance between two driven elements (D)	2.79 cm
(b) Ground Plane dimensions:	
Length of the ground plane (Lg)	3.06 cm
Width of the ground plane (Wg)	5.70 cm
(c) Corporate feed line dimensions:	
Length of 50 Ω line (L_{50})	0.41 cm
Width of 50 Ω line (W_{50})	0.31 cm
Length of 100 Ω line (L_{100})	0.83 cm
Width of 100 Ω line (W_{100})	0.07 cm
Length of 70 Ω line matching transformer (L_{70})	0.41 cm
Width of 70 Ω line matching transformer (W_{70})	0.16 cm
Length of coupler (C_L)	0.31 cm
Width of coupler (C_W)	0.31 cm
Length of quarter wave transformer (L_t)	0.41 cm
Width of the quarter wave transformer (W_t)	0.05 cm

7.68 times more as compared to the experimental impedance bandwidth of TRMSA (ref. 6). It is also seen that the graph has two peaks which shows that both the elements are resonating at their own frequency and the closer resonance of each element results in improvement of impedance bandwidth[13].

The experimental result of 4RMSAA is shown in Fig. 3 and it is observed that the antenna operates at three bands of frequencies (BW_2, BW_3 and BW_4), each of magnitude 850 MHz (8.35%), 480 MHz (3.93%) and 700 MHz (4.95%). The improvement in impedance bandwidth of BW_2 is due to the closer resonance of first two elements[13] and the BW_3 and BW_4 are due to the independent resonance of other two elements[14]. Further, from the graph, it is clear that the overall impedance bandwidth of 4RMSAA is 17.23%, which is 1.624 times more as compared to the overall impedance bandwidth of FRMSA (ref. 7).

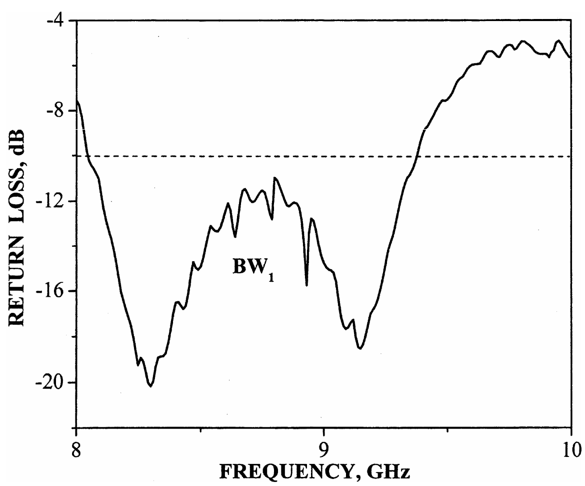

Fig. 2 — Variation of return loss versus frequency of 2RMSAA

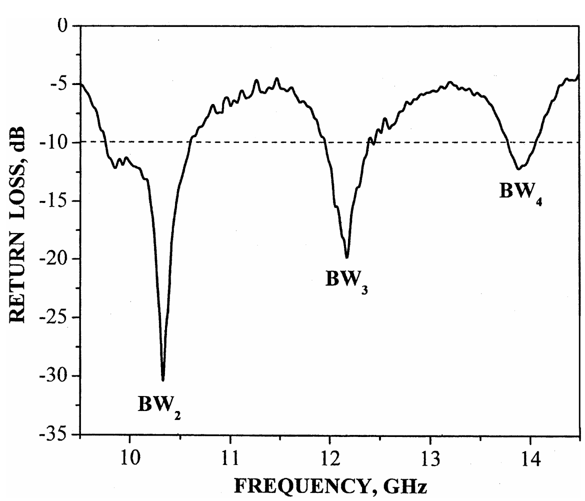

Fig. 3 — Variation of return loss versus frequency of 4RMSAA

Figure 4 shows the variation of return loss *vs* frequency of 8RMSAA and it is observed that the antenna is resonating for four bands (BW_5, BW_6, BW_7 and BW_8) with BW_5 = 180 MHz (2.22%), BW_6 = 1260 MHz (13.78%), BW_7 = 760 MHz (7.08%) and BW_8 = 370 MHz (3.1%). The first band BW_5 is due to the independent resonance of first element of 8RMSAA. The enhancement in the impedance bandwidth of BW_6 is due to the closer resonance of the second, third, fourth and fifth element of 8RMSAA. The bandwidths of BW_7 and BW_8 are due to closer resonance of sixth and seventh elements and individual resonance of last element of 8RMSAA[14,15]. The overall impedance bandwidth of 8RMSAA is found to be 26.18% which is 2.126 times more as compared to the overall bandwidth of ERMSA (ref. 7).

The array factor (AF) for all the proposed antennas is calculated using the equation[12]:

$$AF = \left[\frac{\sin\left(\frac{N}{2}\right)\Psi}{\frac{\Psi}{2}} \right]$$

where, $\psi = k d\cos\theta+\beta$; N = number of array elements; $k = 2\pi/\lambda$; θ = polar angle; and β = difference of phase between any two successive elements forming the array. From the analysis, it is found that for all the proposed arrays, $AF = 1$.

The X-Y plane co-polar and cross-polar radiation patterns of 2RMSAA, 4RMSAA and 8RMSAA are measured at their resonating frequencies and are shown in Figs (5-13). From these figures, it is clear that all the antennas show broad side radiation

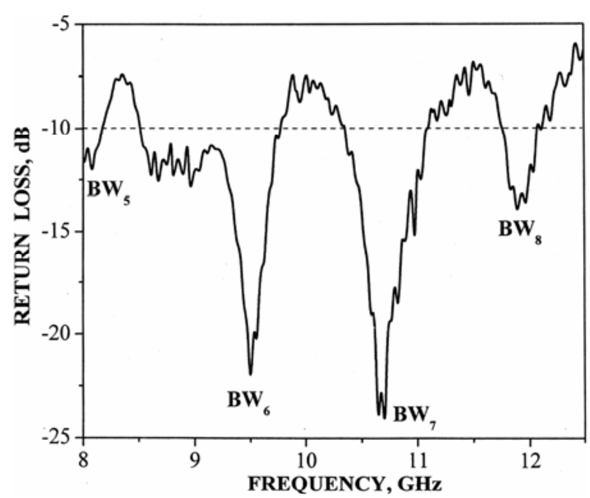

Fig. 4 — Variation of return loss versus frequency of 8RMSAA

characteristics. The side lobe levels and cross polarization levels of these antennas for their resonating frequencies are mentioned in Table 2 for the sake of comparison. Figure 8 shows the radiation pattern of 4RMSAA measured at 12.1 GHz. At this frequency, antenna shows split beam characteristic, which is useful in SAR for generating a pair of forward and backward squinted beams and provide simultaneous measurement of both the along-track and the cross-track velocities[16]. Figures 11 and 13 show the radiation patterns of 8RMSAA measured at

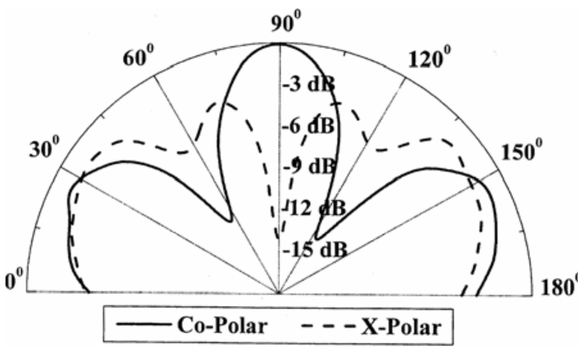

Fig. 5 — Variation of relative power versus azimuth angle of 2RMSAA at 8.29 GHz

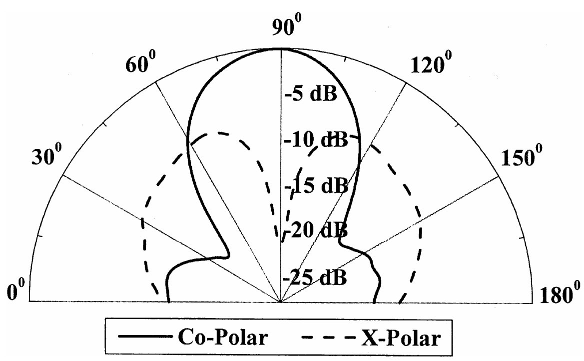

Fig. 6 — Variation of relative power versus azimuth angle of 2RMSAA at 9.14 GHz

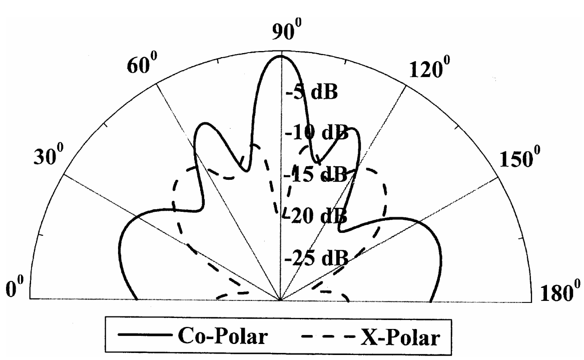

Fig. 7 — Variation of relative power versus azimuth angle of 4RMSAA at 10.3 GHz

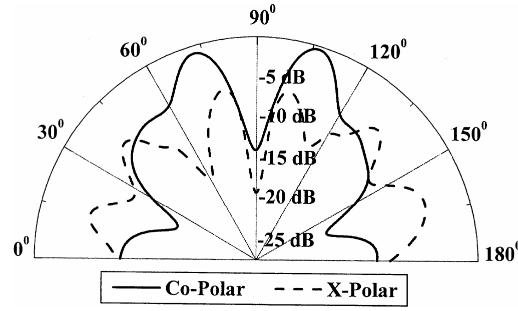

Fig. 8 — Variation of relative power versus azimuth angle of 4RMSAA at 12.1 GHz

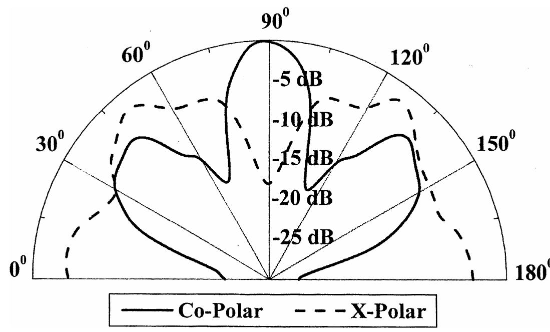

Fig. 9 — Variation of relative power versus azimuth angle of 4RMSAA at 13.85 GHz

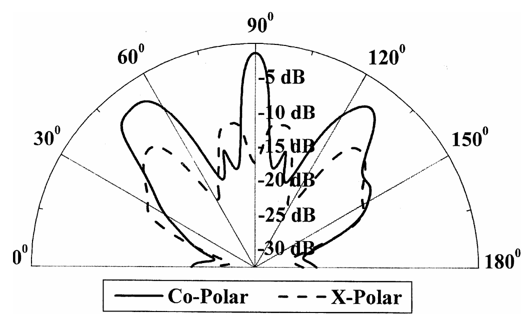

Fig. 10 — Variation of relative power versus azimuth angle of 8RMSAA at 8.09 GHz

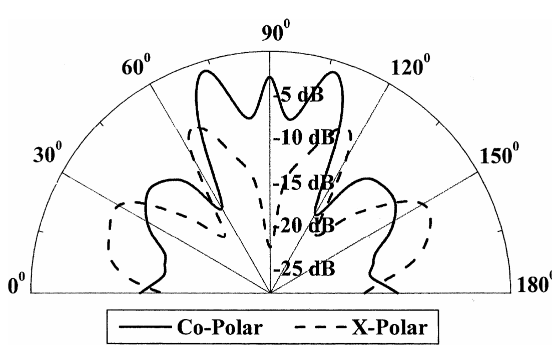

Fig. 11 — Variation of relative power versus azimuth angle of 8RMSAA at 9.53 GHz

9.53 GHz and 11.90 GHz, and the antenna shows mutual coupling of array elements. This oscillatory behavior of the mutual coupling is supposed to be a consequence of the interference between the surface waves and the space waves, which vary for different substrate materials, caused due to equal current distribution in the array elements[17-19].

The half power beam width (HPBW) of 2RMSAA, 4RMSAA and 8RMSAA is calculated for their resonating frequencies and is tabulated in Table 2.

In order to calculate the gain, the power received (P_S) by the pyramidal horn antenna and the power received (P_t) by 2RMSAA, 4RMSAA and 8RMSAA are measured independently. With the help of experimental data, the gain of antenna under test (G_T) in dB is calculated using the formula:

$$(G_T)_{dB} = (G_S)_{dB} + 10 \log (P_t/P_S)$$

where, G_S, is the gain of pyramidal horn antenna. The obtained gain of the proposed antennas is mentioned in Table 2, which indicates that the gain of antenna can be increased by array configuration[20]. When compared with 4RMSAA, the gain of 8RMSAA is decreased. This may be due to higher side lobe level and mutual coupling effect in 8RMSAA.

The 8RMSAA gives multiple frequencies and wider impedance bandwidth among the proposed antennas. The input impedance of 8RMSAA, shown in Fig. 14, has multiple loops at the center of Smith chart that validates its wide band and multiple frequency behavior.

4 Conclusions

From the detailed experimental study, it is clear that the proposed corporate fed network antennas are quite simple in design and fabrication and quite good in enhancing the impedance bandwidth and give better gain with broadside radiation pattern at X-band frequencies. These antennas are superior due to the use of low cost substrate material. These antennas may find application in modern communication system and in radar systems like monopulse tracking radar and SAR.

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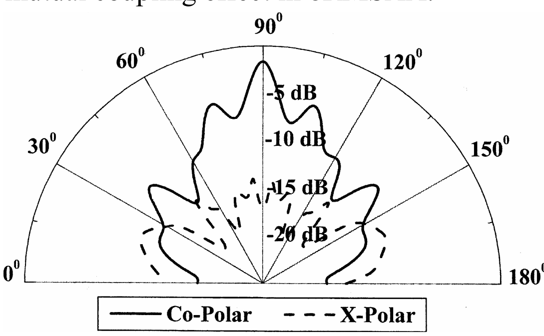

Fig. 12 — Variation of relative power versus azimuth angle of 8RMSAA at 10.73 GHz

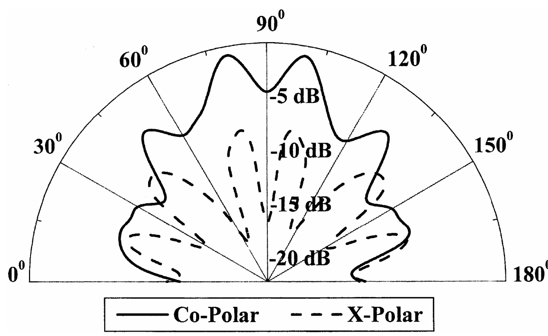

Fig. 13 — Variation of relative power versus azimuth angle of 8RMSAA at 11.90 GHz

Table 2 — Measured return loss, side lobe level, X-polar level and calculated HPBW and gain with respect to resonating frequencies

Antenna	Frequency (GHz)	Minimum return loss (dB)	Side lobe level (dB)	X-polarization level (dB)	HPBW	Gain (dB)
2RMSAA	8.29	-20.1719	-9	-4	32°	1.08
	9.14	-18.5158	-21	-9	38°	4.25
4RMSAA	10.3	-32.9953	-9	-11	11°	6.61
	12.1	-20.7221	-24	-7	Split beam	—
	13.85	-12.2351	-12	-7	18°	2.13
8RMSAA	8.09	-12.0441	-8	-11	8°	2.33
	9.53	-21.1794	Mutual coupling	-9	Mutual coupling	1.55
	10.73	-24.3441	-6	-14	6°	5.21
	11.90	-13.9578	Mutual coupling	-8	Mutual coupling	1.61

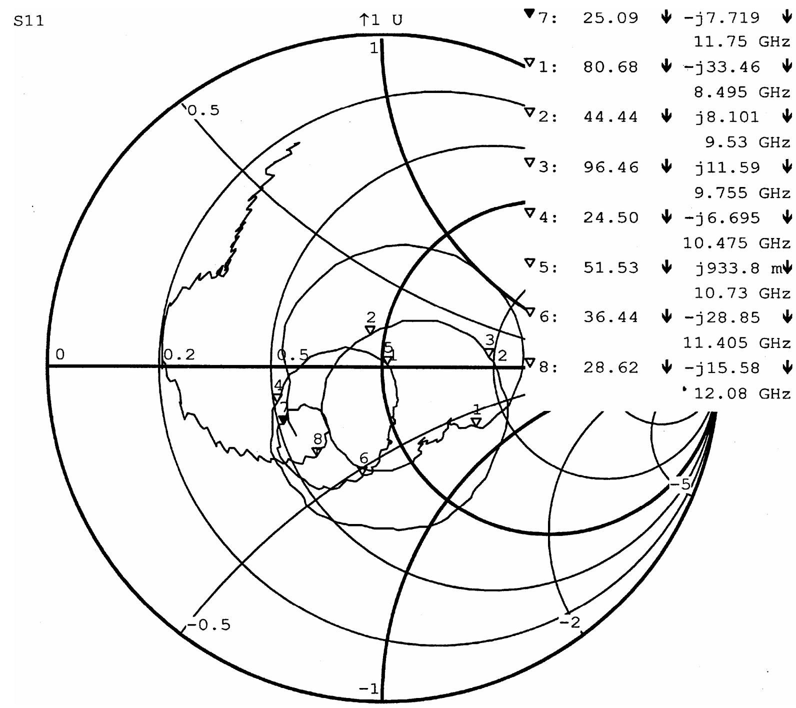

Fig. 14 — Input impedance profile of 8RMSAA

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