A Novel Design of Two Element Slot Loaded Square Microstrip Array Antenna for Wide Band Operation

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Abstract: A novel design of two-element identical unequal length right angle slot loaded square microstrip array antenna (TIURSAA) is presented for triple band operation with a magnitude of each operating bandwidth is 54.39%, 4.09% and 3.36% and a maximum gain of 11.83 dB. If the slots used on the patches are also placed in the ground plane the antenna converts triple bands to dual bands. Further, when equal length right angle slots are placed on top of the patches and equal length right angle slot and H-slot in the ground plane dual bands merges into single band. The antenna gives highest bandwidth of 95.93% and gain 13.10 dB retaining the nature of broad side radiation characteristics. The design concepts of antennas are described and experimental results are discussed.

Keywords: Right angle slot, Triple band, Dual band, Ground plane, Bandwidth.

1. INTRODUCTION

A square patch antenna consists of a radiating patch on one side of a dielectric substrate with a ground plane on the opposite side. Conventional microstrip patch antenna radiator shapes are usually rectangular, triangular, circular, elliptical etc. [1]. The microstrip antennas are becoming one of the most dynamic field in the antenna theory because they are low-cost, planar, compact, can be housed easily on the moving vehicles and they show the properties of linear and circular polarization. But the main disadvantage of microstrip antennas is narrow bandwidth, sensitivity to environment factors such as temperature and humidity, dielectric and conductor losses of patches, resulting in poor antenna efficiency [2].

The conventional microstrip antenna has low gain between (2 to 3 dB) and narrow bandwidth around 2%. In the modern communication systems antennas of larger gain and wider bandwidth are more effective. The bandwidth and gain of the antenna is normally improved by using a thick substrate material or by constructing the patch antennas in the form of array [3]. Dual, triple and multi band antennas are realized by many techniques like gap-coupled, complementary-symmetry, stubs or spur lines etc. [4, 5, 6]. The antennas operating more than one band of frequencies are more useful as they avoid the use of two separate antennas for transmit and receive applications. In view of this a simple array technique has been used to construct the antenna which gives the triple band. A study is conducted to convert triple to dual band and single band by using slot on the patch and on the ground plane. This technique also enhances the gain without changing the nature of broad side radiation characteristics.

2. ANTENNA CONFIGURATION

The artwork of the proposed antennas is sketched by using computer software Auto-CAD 2006. The antennas are fabricated using photolithographic process using low cost glass epoxy substrate material of thickness h = 3.2 mm and dielectric constant ε_r = 4.2.

Figure1 shows the geometry of TIURSAA designed on a substrate area of $A \times B$. The length and width (L) of the square patch is designed for the resonant frequency of 9.4 GHz, using the equation available for the design of square patch [7]. The unequal length right angle slot (URAS) of identical in geometry is placed on each element of TIURSAA. The dimension of URAS is taken in terms of λ_o, where λ_o is the free space wavelength in cm corresponding to the designed frequency of 9.4 GHz. The vertical length (L_v) and horizontal length (L_h) of URAS are taken as $\lambda_o/12$ and $\lambda_o/6$ respectively. The horizontal width (W_h) and vertical width (W_v) of URAS are taken as 1mm. The URAS is placed at a distance of 1mm from the length and width of square patch. The two radiating elements are placed at a distance of $D = \lambda_o/1.3$ from their center in order to add the radiated power in free space by individual elements [8]. However, the distance between two radiating elements should be $\lambda_o/2$ for minimum side lobes [8]. But for $D = \lambda_o/2$, the length of 100 Ω microstripline L_{100} shown in Fig. 1 becomes smaller than the width of 50 Ω microstripline W_{50} and hence two way power divider is not possible to construct. The length of quarterwave transformer L_t is taken as $\lambda_g/4$ which cannot be reduced lesser than this. Hence D is selected as $\lambda_o/1.3$. However, the length of D may be selected even larger than $\lambda_o/1.3$ but feedline should be kept as compact as possible for minimum feedline loss. The corporate feed arrangement shown in Fig. 1 consists of a 50 Ω microstripline of length L_{50} and width W_{50} which is connected to a 100 Ω microstripline of length L_{100} and width W_{100} to form a two way power divider. A matching quarter wave transformer of length L_t and width W_t is connected between 100 Ω feedline and mid point of the radiating elements in order to ensure perfect impedance matching.

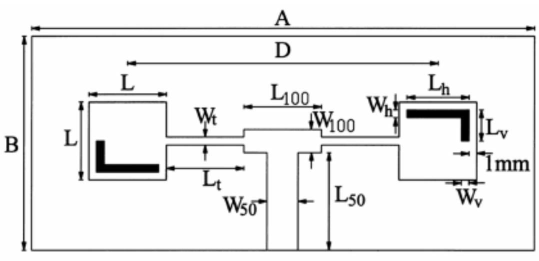

Fig. 1: Geometry of TIURSAA

Figure 2 shows the ground plane geometry of two-element identical unequal length right angle slot square microstrip array antenna (GTIURSAA). The top view geometry of this antenna remains same as that of Fig 1. In the ground plane the two URAS are placed exactly below the top URAS. The dimension of URAS on top and ground plane remains identical with each other.

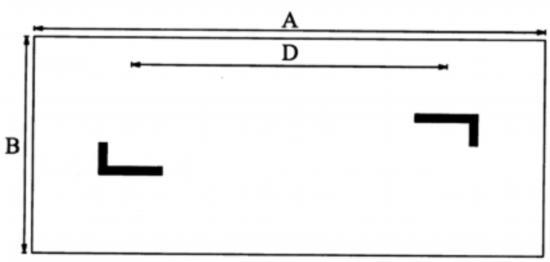

Fig. 2: Ground Plane Geometry of GTIURSAA

Figure 3 (a) shows the top view geometry of two-element identical equal length right angle slot square microstrip array antenna (TIERSAA). In this figure, the vertical length L_v of URAS used in Fig. 1 is extended to L'_v (*i.e.*, $\lambda_o/6$). The slot appears in the form of equal length right angle slot (ERAS). The other geometries of Fig. 3 (a) remain same as that of Fig. 1. In the ground plane of TIERSAA as shown in Fig. 3 (b), two slots are placed exactly below the top patches of Fig. 3 (a). One is ERAS and other is H-slot. The dimensions of ground plane ERAS remains same as that top ERAS. The various dimensions of H-slot are as shown in Fig. 3 (b). Table 1 shows the designed parameters of the proposed antennas.

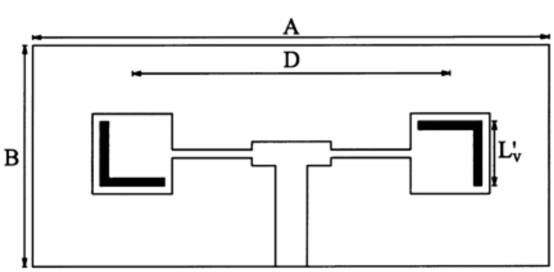

Fig. 3: (a) Top view Geometry of TIERSAA

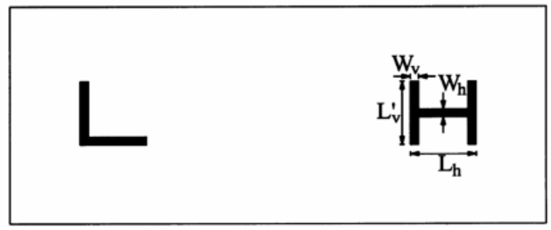

Fig. 3: (b) Ground Plane Geometry of TIERSAA

Table 1
Design Parameters of Proposed Antennas

A	40	L_h	5.3
B	20	L_v	2.6
L	7.6	W_v	1.0
L_t	4.1	W_h	1.0
W_t	0.3	L'_v	5.3
L_{50}	4.0	λ_0	31.9
W_{50}	6.3	D	24.5
L_{100}	8.2	W_{100}	1.4

3. EXPERIMENTAL RESULTS

The bandwidth over return loss less than 10 dB for the proposed antennas is measured on Vector Network Analyzer (Rohde & Schwarz, Germany make ZVK model 1127.8651). The variation of return loss versus frequency of TIURSAA is as shown in Fig. 4. The bandwidth is calculated using the formula [5],

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

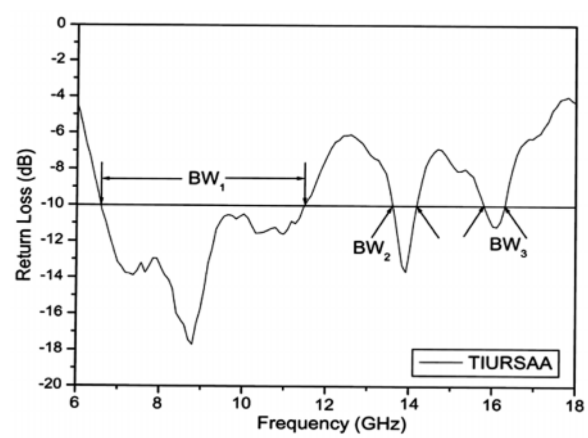

Fig. 4: Variation of Return Loss Versus Frequency of TIURSAA

where, f_1 and f_2 are the lower and upper cut-off frequencies of the band respectively, when its return loss becomes –10 dB and f_c is the center frequency between f_1 and f_2. From this figure it is seen that, the TIURSAA resonates for triple band of frequencies BW_1, BW_2 and BW_3.

The magnitude of each operating band is found to be 54.39%, 4.09% and 3.36% respectively. The triple band operation is due to the independent resonance of square patch elements and slots inserted in the driven elements of TIURSAA [9].

The variation of return loss versus frequency of GTIURSAA is as shown in Fig. 5. It is clear from this figure that, the antenna resonates for dual band of frequencies BW_4 and BW_5. The two operating bands BW_2 and BW_3 shown in Fig. 4 are merges together in this case and give BW_5. The magnitude of BW_5 is found to be 64.42%. But the magnitude of BW_4 decreases to 19.07% when compared to BW_1 as shown in Fig. 4. Hence use of slots in the ground plane is quite effective in widening the upper band.

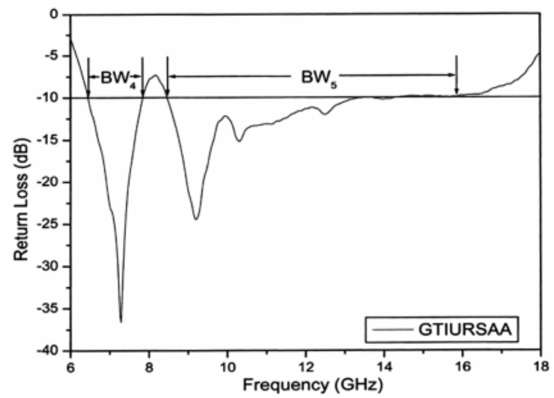

Fig. 5: Variation of Return Loss Versus Frequency of GTIURSAA

Figure 6 shows the variation of return loss versus frequency of TIERSAA. It is clearly seen from this figure that, the antenna resonates for single band of frequency BW_6. The dual bands obtained in TIURSAA are merged into a single band and antenna gives highest bandwidth of 95.93%. The merging of bands is due to the current along the radiating edges of square patch elements and the slots on the top and in the ground plane which introduces an additional resonance [5], results in the enhancement of bandwidth.

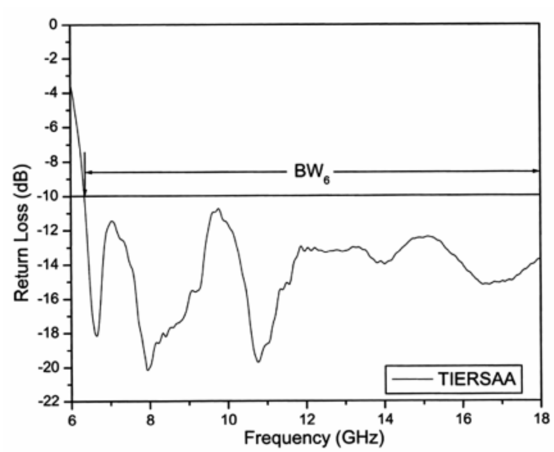

Fig. 6: Variation of Return Loss Versus Frequency of TIERSAA

The gain of the proposed antennas is measured by absolute gain method. The power transmitted P_t by pyramidal horn antenna and power received P_r by antenna under test (AUT) is measured independently. With the help of these experimental data, the gain (G) in dB of AUT is calculated by using the formula,

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

where, G_t is the gain of the pyramidal horn antenna and R is the distance between the transmitting antenna and the AUT. Using above equation the maximum gain of the proposed antennas measured in their operating bands BW_1, BW_5, and BW_6 are found to be 11.83, 11.12 and 13.10 dB respectively. It is clear that TIERSAA gives highest gain among the proposed antennas.

Figure 7-9 shows the co-polar and cross-polar radiation pattern of TIURSAA GTIURSAA and TIERSAA measured at 8.79, 9.29 and 10.77 GHz respectively. From these figures, it is clear that, the patterns are broad sided and linearly polarized. Hence it is clear that the TIERSAA shows the nature of radiation pattern same as that of TIURSAA and GTIURSAA in spite of enhancement in the bandwidth and gain.

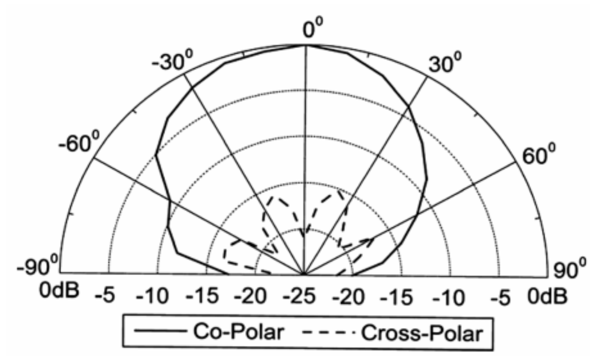

Fig. 7: Variation of Relative Power Versus Azimuth Angle of TIURSAA at 8.79 GHz

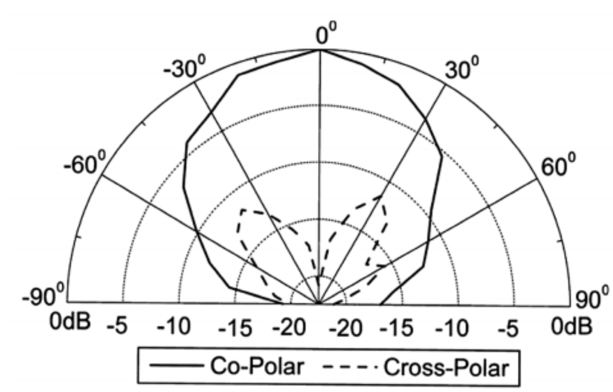

Fig. 8: Variation of Relative Power Versus Azimuth Angle of GTIURSAA at 9.29 GHz

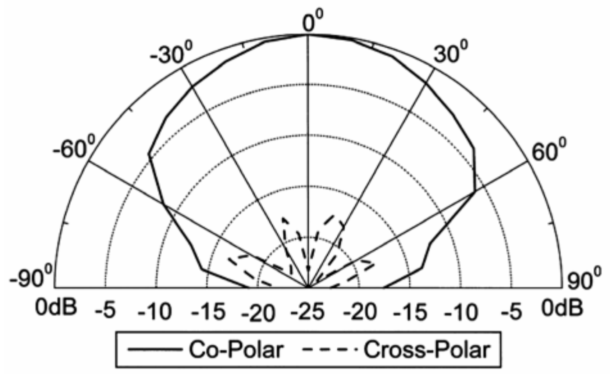

Fig. 9: Variation of Relative Power Versus Azimuth Angle of TIERSAA at 10.77 GHz

4. CONCLUSION

From the detailed experimental study it is concluded that, the triple band operation obtained from the novel design of TIURSAA can be converted into dual bands by placing URAS in the ground plane. These dual bands can be converted into single band by placing the ERAS slot on the patches of array element and by placing ERAS and H-slot in the ground plane. The maximum 95.93% of bandwidth and 13.10 dB of gain are achieved without changing the nature of broad side radiation characteristics. The proposed antennas are simple in their design and construction and they use low cost substrate material. These antennas may find application for the microwave systems operating at *C* to *Ku* bands of frequencies.

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