

AN ARRAY OF BROADBAND DUAL POLARIZED ELECTROMAGNETICALLY COUPLED MICROSTRIP ANTENNAS

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Abstract—In this paper, design of broadband dual polarized electromagnetically coupled antenna array is proposed to achieve high isolation between two orthogonal ports. A dual polarized electromagnetically coupled microstrip antenna is designed with a suspended radiating element placed in inverted microstrip configuration and excited by two orthogonal microstrip line feeds to achieve broad bandwidth and high isolation. The antenna is designed for 5.8 GHz frequency band. The antenna design is extended to 2×2 antenna array, with top layer radiating elements electromagnetically coupled to the open microstrip feed line network. The 6×6 antenna array is designed using 2×2 sub arrays with power divider network. The power divider network is integrated on the back side of the feed network to feed 2×2 antenna sub arrays. The 6×6 antenna array achieves VSWR < 2 bandwidth of 26% for Port 1 and 28% for Port 2. The 6×6 antenna array has measured gain of 22 dBi at 5.8 GHz with isolation between two orthogonal ports > 30 dB.

1. INTRODUCTION

The increase in demand of high data rates for mobile communication systems requires an efficient utilization of available resources. With recent advances in wireless communication systems for commercial and strategic applications, the polarization diversity achieved by dual polarized antenna is explored to improve the channel capacity and link

Received 9 September 2013, Accepted 10 October 2013, Scheduled 11 October 2013

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reliability [1, 2]. The analysis of the uses of dual polarized antenna concludes that the polarization diversity is best suited for the urban environment with Rayleigh multipath fading channels [3, 4]. The dual polarized antennas have advantage in terms of space requirement and overall system cost as compared to traditional space diversity technique. Due to these advantages, the dual polarized antennas are used in multiple input multiple output (MIMO) systems for Wi-Max application, mobile backhaul systems, RADAR systems and in strategic communication systems.

Primary requirement of antenna for these applications is to achieve high isolation between two orthogonal ports and broad bandwidth. In order to achieve high isolation between two orthogonal ports, various design techniques such as aperture coupled, hybrid feed, feeds on two different layers and gap feed have been used. Most common techniques to improve the bandwidth for a microstrip antenna are planar or stacked multi-resonators and aperture coupled antennas with different slot shapes cut in the ground plane [5]. The aperture coupled dual polarized antennas are designed either with two offset slots cut in the ground plane or using a cross slot with orthogonal feed technique. Different slot shapes are proposed to increase the port-to-port isolation for aperture coupled antenna design [6–11]. A dual polarized antenna with two dog bone shaped offset slots are proposed in [6]. The dog bone shaped slots result in smaller slot dimension which increases the spacing between two slots achieving port-to-port isolation > 30 dB. A dual polarized aperture coupled antenna is proposed using C-shaped coupling slot for second port to improve isolation between orthogonal ports [7]. The antenna achieves an isolation > 28 dB between two orthogonal ports. Broadband dual polarized antennas with two H shaped slots placed in T configuration to the edge [8] and corner [9] of the patches are reported achieving an isolation > 30 dB. The modified H-shaped slot antenna with two legs of H shaped slot bent inwards results in to better isolation as compared to conventional H-shaped slot [10]. The dual polarized antenna with I-shaped slot is reported in [11] achieving isolation > 34 dB. The antenna with centralized cross-slot and two orthogonal feeds on two substrates achieves better isolation as compared to offset fed slot [12]. However, the aperture coupled antennas have higher back lobe radiation and dual polarized antenna with cross-slot is difficult to extend for the design of higher gain array.

The antenna designs with dual-probe feed and hybrid feed having combination of aperture coupled and probe feed have been proposed with port-to port isolation of 25–30 dB [13–17]. However, these approaches add complexity to the overall antenna design. The dual

polarized antenna with gap-fed and inset-fed technique have been proposed in [18, 19], where two microstrip lines are placed near to the two edges of microstrip patch elements. The antenna achieves isolation > 30 dB with impedance bandwidth of 5%.

In this paper, a novel approach for the design of high gain dual polarized antenna array using electromagnetic coupling is presented. The suspended radiating element in an inverted microstrip configuration is electromagnetically coupled to two orthogonally placed open microstrip lines to achieve dual orthogonal polarization and broad bandwidth. The antenna design can be easily extended for higher gain antenna arrays. The 2×2 and 6×6 antenna arrays are proposed using electromagnetically coupled antenna and corporate feed network for two orthogonal polarizations. The 6×6 antenna array is designed with 3 substrate layers using 2×2 sub arrays and power divider networks to feed the open microstrip feed lines for dual polarization followed by experimental verification.

2. DUAL POLARIZED ELECTROMAGNETICALLY COUPLED ANTENNA DESIGN

The dual polarized electromagnetically coupled (EMCP) antenna is designed for 5.8 GHz frequency band. The configuration of dual polarized electromagnetically coupled antenna is shown in Figure 1. The antenna consists of two substrate layers 1 and 2, placed with an air gap between them. A substrate of $\epsilon_r = 2.55$, $h = 0.762$ mm and $\tan \delta = 0.0015$ is used for the bottom layer to minimize the losses due to feeds. The glass epoxy substrate of $\epsilon_r = 4.4$, $h = 0.8$ mm and $\tan \delta = 0.02$ is used for top layer to reduce overall cost of antenna. The

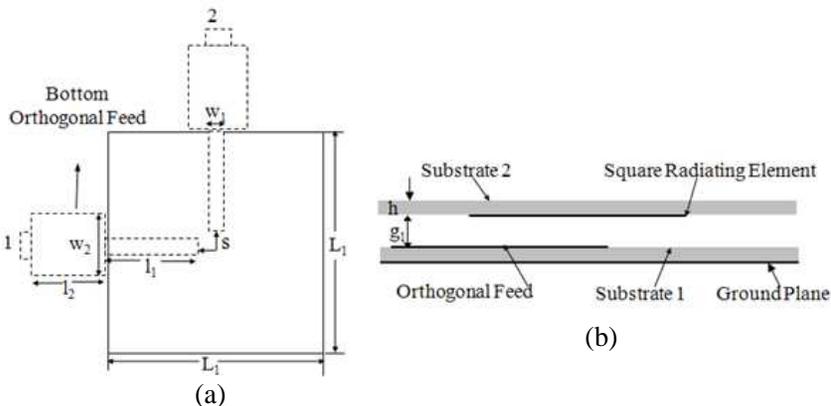


Figure 1. Dual polarized electromagnetically coupled antenna design. (a) Top view and (b) side view.

bottom substrate layer consists of two orthogonal microstrip line feeds of dimension $l_1 = 7.3$ mm, $w_1 = 2$ mm with an offset of $s = 1.9$ mm from center. Each microstrip feed line is connected to a quarter wave transformer of dimension $l_2 = 9$ mm, $w_2 = 9.2$ mm to achieve 50Ω impedance matching for individual ports. The top substrate layer is placed with an air gap of $g_1 = 2$ mm from bottom substrate layer. A square microstrip antenna of dimension $L_1 = 17.1$ mm is placed in inverted microstrip configuration so that the top substrate also acts as a protective layer for antenna.

The square microstrip patch is electromagnetically coupled to the orthogonal microstrip line feeds. The suspended radiating patch has lower effective dielectric constant and larger height, which results in higher impedance bandwidth and higher gain of antenna. The overall antenna configuration is symmetric for both the ports resulting in similar gain and radiation pattern for two orthogonal ports. In order to optimize the antenna design for high isolation between two orthogonal ports, a detailed parametric analysis of dual polarized EMCP antenna was carried out using method of moments based software IE3D [20].

3. DUAL POLARIZED ANTENNA ARRAY DESIGN

The dual polarized EMCP antenna is used for the design of higher gain 2×2 and 6×6 arrays for 5.8 GHz frequency band as described below.

3.1. 2×2 Dual Polarized EMCP Antenna Array Design

A 2×2 antenna sub array is designed with electromagnetically coupled radiating elements and dual open microstrip lines for orthogonal

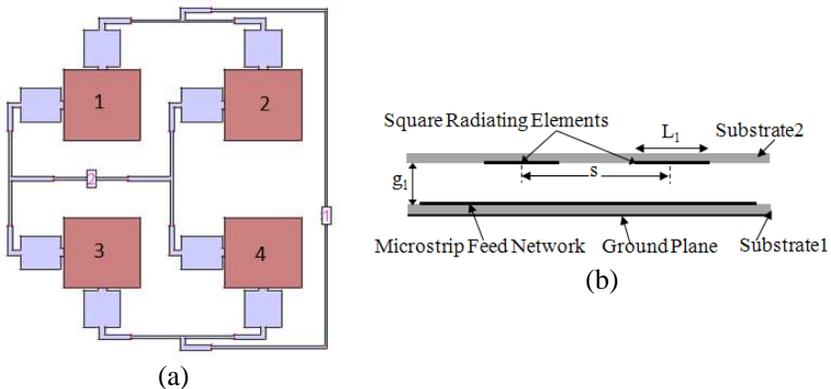


Figure 2. 2×2 dual polarized EMCP antenna array design. (a) Top view and (b) side view.

polarizations. The configuration of 2×2 antenna array is shown in Figure 2. Top substrate layer has four square radiating elements of length $L_1 = 17.1$ mm. The radiating elements are placed with an equal inter-element spacing of $s = 36$ mm ($\approx 0.7\lambda_0$). The top substrate layer has been placed in inverted configuration with an air gap of $g_1 = 2$ mm from bottom substrate. The bottom substrate consists of two open microstrip lines to excite the radiating elements on the top substrate layer. A corporate feed network for 2×2 antenna array, with quarter wave transformers on each open microstrip line is used to achieve 50Ω impedance matching. For Port 1 of 2×2 antenna array, elements 1 & 2 in comparison with elements 3 & 4 are fed at opposite edges. To compensate for phase reversal due to opposite edge feeding, additional $\lambda/2$ line length is used for elements 1 & 2 of 2×2 antenna array. For Port 2 of 2×2 antenna array, all four elements are fed in phase using corporate feed network.

The simulated S -parameters vs. frequency plot for 2×2 antenna array is shown in Figure 3. The 2×2 antenna array has VSWR < 2 bandwidth of 13% and isolation > 40 dB for two orthogonal ports. The simulated radiation pattern plots for two orthogonal ports of 2×2 antenna array are shown in Figure 4. The radiation pattern for two ports especially the cross polar levels are slightly different because of different feed network. The side lobe levels for both the ports are < 15 dB and cross-polar levels are < 25 dB.

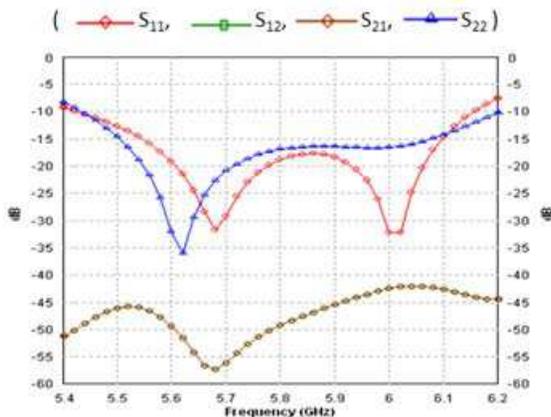


Figure 3. S -parameters vs. frequency plot of 2×2 dual polarized EMCP antenna array.

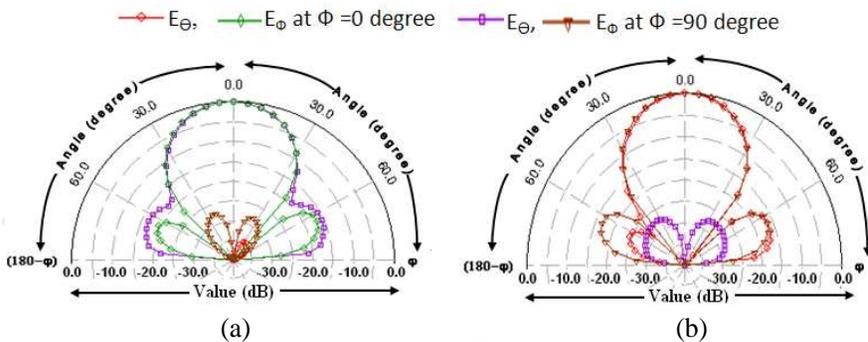


Figure 4. Radiation pattern plots of 2×2 dual polarized EMCP antenna array for (a) Port 1 and (b) Port 2 at 5.8 GHz.

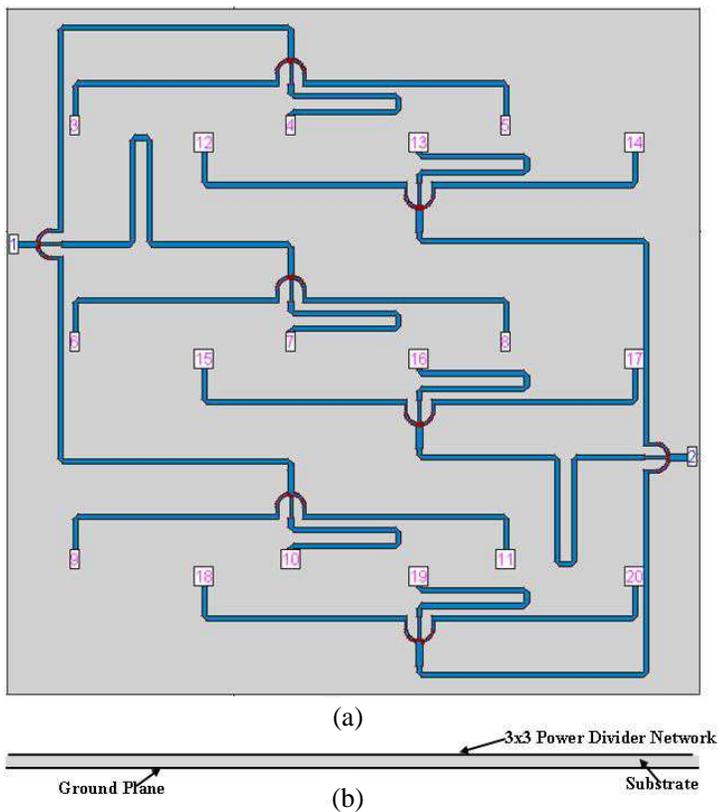


Figure 5. 3×3 power divider network for two orthogonal ports of 6×6 dual polarized EMCP antenna array. (a) Top view and (b) side view.

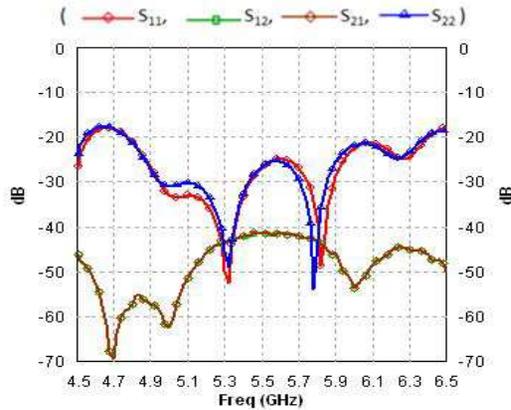


Figure 6. S -parameters vs. frequency plot of 3×3 power divider network.

3.2. 6×6 Dual Polarized EMCP Antenna Array Design

The 6×6 dual polarized antenna array is designed with three substrate layers to accommodate large feed network without criss-crossing each other. The 6×6 antenna array is designed using 2×2 sub arrays and a 3×3 power divider network placed at the bottom layer to feed the middle layer microstrip line feed network of 2×2 sub arrays.

The configuration of 3×3 power divider is shown in Figure 5. The 3×3 power divider is designed with each of the three arms of the power divider of equal length achieving equal amplitude and phase for each arm. The quarter wave transformers are used on each arm of power divider network to achieve 50Ω impedance matching. Two 3×3 power dividers are placed together to feed dual orthogonal polarized ports for 2×2 sub arrays. The simulated S -parameters plot of the 3×3 power divider network is shown in Figure 6. The 3×3 power divider network has $VSWR < 1.2$ from 4.8 GHz to 6.4 GHz which corresponds to $> 27\%$ bandwidth. The isolation between the two power dividers for two orthogonal ports is > 40 dB for entire frequency band.

The configuration of 6×6 EMCP dual polarized antenna array is shown in Figure 7. The radiating elements are designed on the top substrate layer in inverted configuration. The top substrate layer is placed with an air gap of $g_1 = 2$ mm from the middle layer. The square radiating elements have dimension $L_1 = 17.1$ mm. The elements of 2×2 antenna sub array are placed with an inter-element spacing of $s = 36$ mm. However, in order to accommodate feed network for 6×6 antenna array and to reduce the mutual coupling effects between the

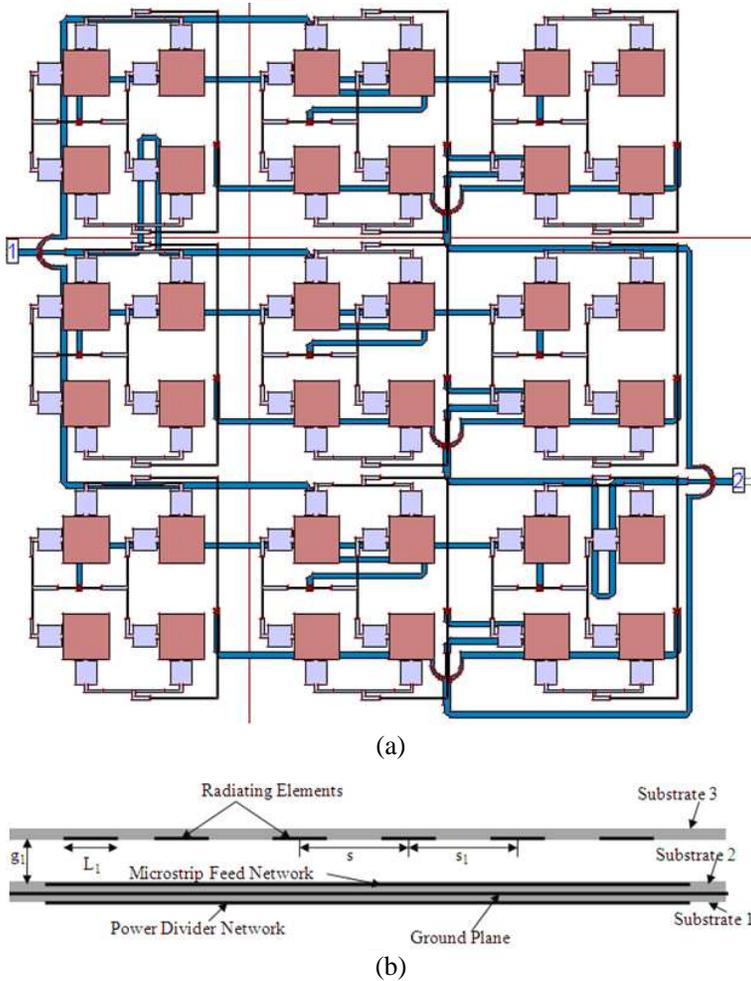


Figure 7. 6×6 dual polarized EMCP antenna array design. (a) Top view and (b) side view.

feed networks of two orthogonal ports, the spacing between adjacent elements of two 2×2 subarrays is $s_1 = 51$ mm. Thus, the 2×2 sub-arrays are placed with a spacing of 87 mm among them. The microstrip line feed network for electromagnetic coupling of radiating element is placed at the middle layer substrate. Each element is excited by two orthogonal open microstrip feed lines to achieve dual polarization. In order to provide maximum physical separation between the feed networks for two orthogonal ports, the 2×2 sub-arrays are fed using

a 3×3 power divider network designed on the bottom substrate layer. The power divider networks at the bottom substrate are connected to the 2×2 antenna sub arrays using conical vias. The ground plane of the antenna is placed between the middle and bottom substrate layer acting as a common ground plane for microstrip feed network and power divider network. The overall dimension of 6×6 dual polarized antenna array is $275 \text{ mm} \times 275 \text{ mm}$ including finite ground plane.

4. 6×6 ANTENNA ARRAY MEASURED RESULTS

The three layers of 6×6 antenna array are fabricated individually and integrated with an air-gap between middle layer substrate and top layer substrate as shown in Figure 8. The top layer is placed in inverted configuration. The middle layer and bottom layer substrate are placed such that the copper layers of two substrates form common ground plane. The bottom layer power divider network is connected

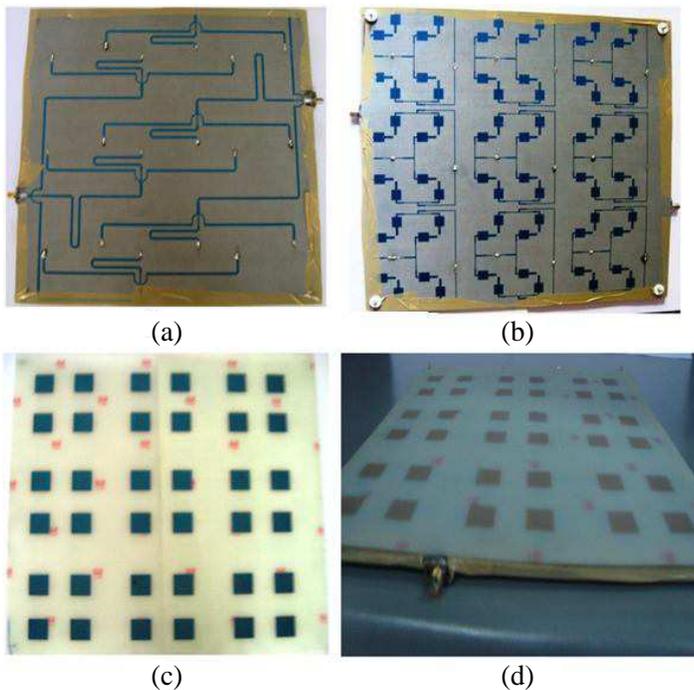


Figure 8. Fabricated 6×6 EMCP dual polarized antenna array. (a) Bottom substrate: power divider network, (b) middle substrate: feed network, (c) top substrate: radiating elements, and (d) integrated 6×6 antenna array.

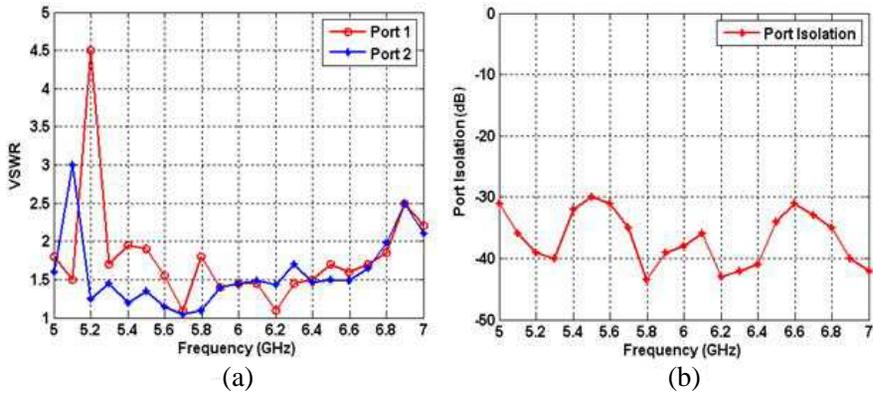


Figure 9. Measured (a) VSWR vs. frequency and (b) S_{21} vs. frequency plot of 6×6 dual polarized EMCP antenna array.

to middle layer feed network using vias.

Measurements of VSWR and isolation between two orthogonal ports have been carried out using vector network analyzer (VNA). Measured VSWR vs. frequency and plot for two orthogonal ports of 6×6 antenna array is shown in Figure 9(a). The measured bandwidth for $VSWR < 2$ for Port 1 is from 5.3 GHz to 6.81 GHz (26% BW) and for Port 2 is from 5.18 GHz to 6.8 GHz (28% BW). The measured $VSWR < 2$ Bandwidth for 6×6 antenna array is more than that for 2×2 antenna array due to formation of multiple loops after integrating the power divider network with 2×2 antenna sub arrays. Measured isolation vs. frequency plot for two orthogonal ports of antenna is shown in Figure 9(b). The 6×6 antenna array has isolation > 30 dB for entire bandwidth with maximum isolation of 43.9 dB at 5.8 GHz.

The antenna gain measurement for both the orthogonal ports is done by comparing with a standard gain antenna in the desired frequency band. The total efficiency of antenna is determined by comparing the measured gain with respect to directivity of 6×6 array. The total efficiency accounts for the impedance mismatch losses and feed network losses of 6×6 antenna array. The total efficiency vs. frequency plot for two orthogonal ports of 6×6 array is shown in Figure 10(a). The antenna has maximum efficiency of 82% for Port 1 and 77% for Port 2. The total efficiency of antenna is better than 50% for frequency band of interest. Measured gain vs. frequency plot for two orthogonal ports of 6×6 array is shown in Figure 10(b) The measured gain of 6×6 antenna array is 22.1 dBi for Port 1 and 22 dBi for Port 2 at 5.8 GHz. The total efficiency and gain for two ports of

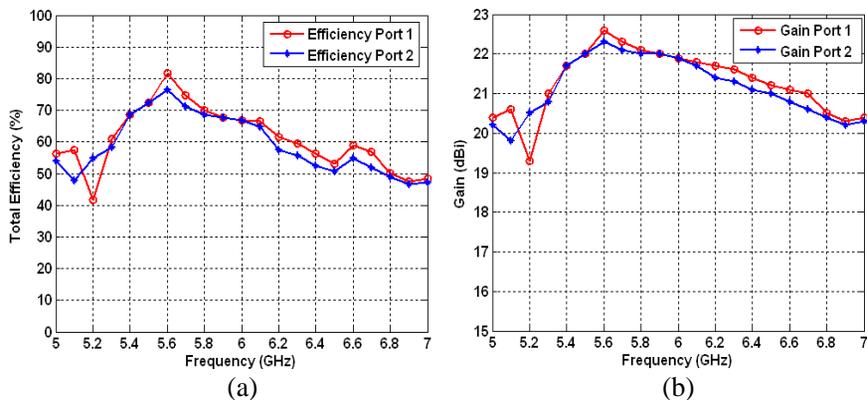


Figure 10. Measured (a) efficiency vs. frequency and (b) gain vs. frequency plot of 6×6 dual polarized EMCP antenna array.

antenna are slightly different due to different feed configuration for the two ports.

5. CONCLUSION

The dual polarized electromagnetically coupled microstrip antenna arrays with broad bandwidth and high isolation between two orthogonal ports are designed. The 2×2 dual polarized EMCP antenna array is designed and its simulated results are presented. The 6×6 dual polarized EMCP antenna array is designed using 2×2 sub array and 3×3 power divider network. The 6×6 antenna array is fabricated and measurements are carried out. The 6×6 antenna array configuration achieves $> 26\%$ impedance bandwidth for both the orthogonal ports. The 6×6 antenna array has maximum gain of 22 dBi and symmetrical radiation pattern for both the ports. The 6×6 antenna array has isolation > 30 dB for entire frequency band. This antenna array design approach can be easily extended to higher gain dual polarized antenna array design with broad bandwidth and high isolation between two orthogonal ports.

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