Aperture Coupled Microstrip Antenna with Different Feed Sizes and Aperture Positions

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Abstract – The aperture coupled is one of the feeding techniques in micrsotrip antenna. The main mechanism of power transfer between its feed line and patch is the coupling mechanism. This paper describe two different designs of an aperture coupled microstrip patch antenna fabricated using different feed width, aperture size and position. In both proposed structures, the feed width of aperture coupled microstrip antennas (ACMAs) and aperture position are varied, while keeping tight to the three layer structure visible in conventional ACMAs (feed line at bottom most layer, ground plane with aperture in middle layer and patch layer at the top). The fabricated antenna produced better return loss and impedance bandwidth, while maintaining comparable radiation performance compared against simulation. All antennas produced maximum E-and H-plane co- and cross-polarization difference in the magnitude of -20dB and half-power beam widths (HPBW) of 90^{o}.

Keywords: Aperture-Coupled Microstrip Antenna (ACMA), Microstrip Antennas, Methods of Moment, wide bandwidth

1. Introduction

Microstrip patch antenna (MPA) is one of the excellent candidates for portable wireless devices nowadays, simply because of its low profile, light weight and low cost. However, the requirement of frequency bandwidth is becoming greater in present wireless communications systems. This contradicts the inherent narrow impedance bandwidth (BW) of patch antennas. Hence many researchers are focusing on the development of impedance bandwidth enhancement techniques for patch antennas. To satisfy large volume and high speed data transfer requirements, antennas with a high radiation efficiency and gain are desirable. The aperture-coupled patch has more design parameters than the direct contact fed patches and therefore has more flexibility or degrees of freedom for the antenna designer. Despite its somewhat complex appearance, the aperture-coupled microstrip patch antenna is relatively easy to accurately model [1]. The reason for this is that unlike for the direct contact fed patches, there are no abrupt current discontinuities. Thus, it is relatively simple, accurate, and computationally fast to model. In its original form the aperture-coupled patch has similar bandwidth and gain responses as the direct fed patches; however, it is very easy to significantly enhance the impedance bandwidth of this antenna. Independent optimization of the feed and antenna substrates can be achieved.

A common aperture coupling microstrip antenna (ACMA) in its basic form consists of two substrates separated by a ground plane. Two substrates increase the volume of the antenna and the complexity in fabrication processes. Another drawback is that a multilayered substrate structure with the coupling slot on the ground plane can result in coupled surface-wave modes. These modes can lead to distorted radiation patterns and reduced radiation efficiency [2].

2. Antenna Structure and Design

The main objective of this work is to design a rectangular-shaped, aperture coupled microstrip patch antenna operating at the frequency of 2.4 GHz. Since a suitable and similar substrate must be chosen in order to provide a general platform for all structures to be simulated, the chosen substrate is FR-4, which has a dielectric constant (ε_r) of 4.5, dielectric loss tangent ($tan\delta$) of 0.019 and substrate height (h) of 1.6mm.

To account for the fringing of the electric field above the microstrip (where air is the medium), an effective dielectric constant is defined; which allows the microstrip to be modeled as if it a homogeneous dielectric medium of ($\varepsilon_{r,eff.}$). Thus the parameter values in Table 1 have been calculated as an initial value, using design frequency of 2.4GHz.

A significant upwards shift in resonant frequency has been reported in [3]. Thus before designing the patch, a lower design frequency must be determined experimentally to compensate for the amount of upward shifts. A batch of prototype with different feeds has been fabricated and its amount of shift calculated so that it could be taken into consideration when designing for the actual prototypes.

Other than Microwave Office, antenna CAD program was also used in verification of calculated parameters. It provides an approximate value of the resonant parameters. The software is necessary to achieve optimal simulation results at desired resonance.

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Table 1: Initial calculated values in designing a rectangular patch.

Feed Method	Calculated (2.4 GHz)	*W (mm)*	*L (mm)*
ACMA A	Calculated (2.4 GHz)	37.663	29.097
	Actual	37.000	28.000
ACMA B	Calculated (2.4 GHz)	37.663	29.097
	Actual	37.000	29.000

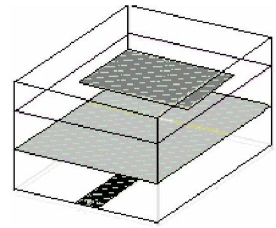

Figure 2: 3D view of 8mm aperture coupled-fed antenna

2.1 ACMA-A (8mm Feed Aperture Coupled Microstrip Antenna)

The design of ACMA-A is almost similar with the conventional aperture-coupled antenna. The dimension of the patch for resonant frequency at 2.4 GHz is 37mm x 28mm. The only different is at the feed width. Normal feed width in FR-4 for aperture coupled antenna is 3mm so that it can match 50 ohm line. But the new designed feed width is 8mm. The feed line has structure has a width and length of 8mm x 57.5mm, where 28.75 mm of the length is overlapped under the AMCA patch. The antenna's full dimension is shown in Fig. 1.

The aperture slot is 1.5 mm x 11 mm and is centered at the patch of the antenna. However, this design is a two substrate design. Both substrates are from the same material which is FR-4 as to provide substrate standardization for comparison with another antenna. The patch is at the top most of the first substrate and the aperture at the top most of the second substrate while the feed is at the bottom of the second substrate. A clearer illustration is shown in Fig 2

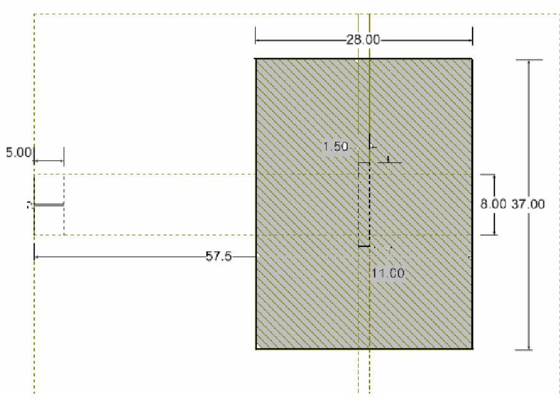

Figure 1: 8 mm feed Aperture Coupled fed antenna dimensions

2.2 ACMA-B (6mm Feed and Aperture Shifted Aperture Coupled Microstrip Antenna with 3 substrate)

The second design ACMA-B considers a wider feed width, while shortening its length to about a quarter of the wavelength. Its aperture is also not centered relative to the radiating patch, but instead centered relative to the whole ground plane. For this ACMA to resonate at 2.4GHz, optimized values of W = 37 mm and L = 29 mm is used. Its dimension is shown in Fig. 3 and 4. The patch is fed using a 50Ω SMA connector with 1mm inner conductor's diameter; while outer conductor is soldered to the ground plane

Contrary to different substrate usage for each of the layers as proposed in [4] for increased radiation efficiency, the antenna designed here uses the same substrates which is the FR-4 for all layers, as to provide a substrate standardization for comparison. The feed line structure has a width and length of 6 mm x 26 mm, where 11.5 mm of the length is overlapped under the AMCA patch. The width of the feed is centered on the patch's width, which also happens to be the radiating edge. The aperture slot is 2 mm x 10 mm sized, and is centered in the center of the whole structure instead of in the patch's center in conventional ACMA. However, this structure maintained the conventional structure, where the patch is etched at the top most layer, slot in the ground plane (located in between top and bottom layers) and feed line etched at the bottom layer.

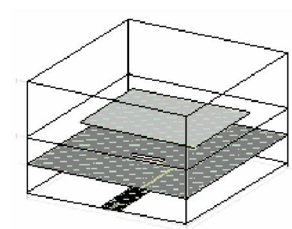

Figure 3: The 3D view of the aperture coupled-fed antenna

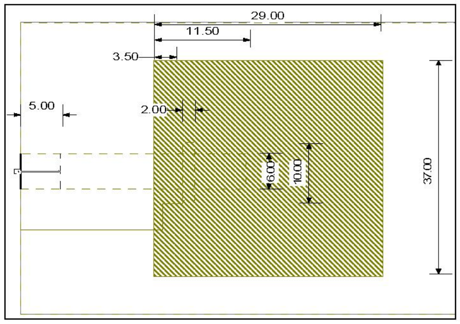

Figure 4: Aperture position shifted Aperture coupled-fed antenna dimensions

3. Results

3.1 ACMA-A (8mm Feed Aperture Coupled Microstrip Antenna)

The simulated and measured numerical data of AMCA-A are shown in Table 2. From the simulation and measurement results, the bandwidth (BW) differences are 3.373%. It shows that a poor approximation of the designed and simulated AMCA in its real performance in the operational environment. However, the return loss between the simulated and the measured are differs by 27% which is a large differences.

The radiation patterns measurement are shown in Fig. 5 for H-plane and Fig. 6 for E-plane. The fabricated antenna showed a large isolation (>20dB) and half power beamwidth in both E and H plane.

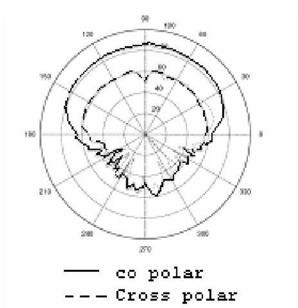

Figure 5: H Plane radiation pattern for ACMA-A.

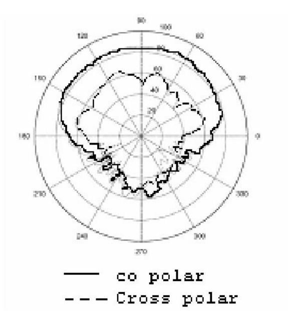

Figure 6: E plane radiation pattern for ACMA-A.

Comparison between HPBW simulated and measured results generally shows that variances between both are only up to 4% for both E and H planes.

3.2 ACMA B (6mm Feed and Aperture Shifted Aperture Coupled Microstrip Antenna with 3 substrate)

The simulated and measured numerical results for ACMA-B are shown in Table 3. The bandwidth (BW) difference between simulation and measurement results which is less than 2 %, shows an excellent approximation of the designed and simulated ACMA against its real performance in the operational environment. However, the return loss (RL) between simulated and measured which differs about 5% is the highest among the three ACMAs, and shows a poor approximation of the proposed layout design against the real hardware. It will be discussed more in the discussion part.

The radiation patterns measurement are shown in Fig 7 for E plane and Fig. 8 for H plane. The fabricated antenna produced satisfactory isolation on both E and H plane (HPBW > 20dB). It also shows a large isolation and half-power beamwidth (HPBW) on the H Plane. Comparison between HPBW simulated and measured results generally shows that variances between both are only up to 4% for both E and H planes.

Table 2: Measured Return Loss, bandwidth and resonant frequency.

Feed Type	Model	Return Loss dB	Resonance frequency GHz	Bandwidth %
ACMA-A	Simulation Measurement	-25.72 -18.77	2.41 2.43	7.938 4.527
ACMA-B	Simulation Measurement	-25.53 -24.090	2.350 2.474	3.82 3.890

Table 3: Radiation Pattern Measurement.

Feed Type	ACMA-A E Plane	ACMA-A H-Plane	ACMA-B E-Plane	ACMA-B H-Plane
Max Co polar	-0.064	-0.322	-10.55	-10.83
Max cross polar	-20.945	-18.772	-29.43	-33.17
Isolation (dB)	25.382	28.948	18.88	22.34
HPBW (degree)	98	117	81	95

From the results, the gain is more influenced by the E plane isolation rather than the H plane isolation.

The higher the isolation is, the better its gain and directivity values produced [5]. It is also shown in this analysis that the aperture coupled technique has a better efficiency in producing a closer gain value from certain directivity value.

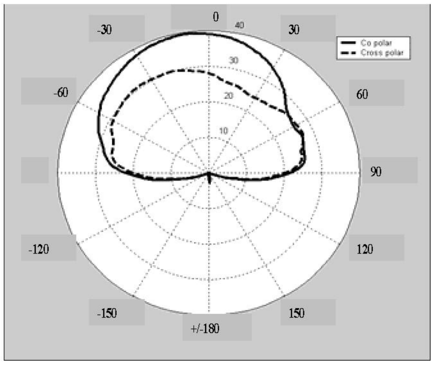

Figure 7: E plane measurement radiation pattern for aperture coupled-fed patch antenna

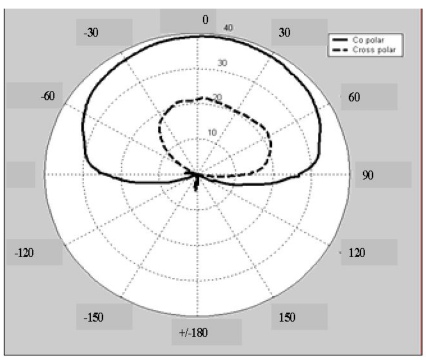

Figure 8: H plane measured radiation pattern aperture coupled-fed patch antenna.

4. Discussion

The variation of simulated and measured return loss is due to the difficulty in modeling the circuit which is already mentioned in [3]; has been caused by the substrate definition in simulation, which assumes a constant value of dielectric constant throughout the simulation structure. In practice, this definition is unrealistic, as the dielectric constant has certain amount of variation along the length, width and even thickness of the structure. Moreover, this is due to the different definition in the software and hardware. In the Microwave Office, 3-layer substrate is defined due to the software constraint. In the hardware, only 2-layer of substrate is used. The other reason is caused by the substrate definition in simulation, which assumes a constant value of dielectric constant throughout the simulation structure. In practice, this definition is unrealistic, as the dielectric constant has certain amount of variation along the length, width and even thickness of the structure. Besides that, variation of this is contributed by Method of Moments (MoM) in the simulation assumes an infinite ground plane in layout structure as to simplify the calculation. This also contributes to the variation.

Electromagnetic coupling to the environment is also not modeled in the simulation, whereas while measuring the RL of an ACMA even in the “cleanest” environment, there will always exists a level of coupling to surrounding objects or even parts of the human body. This fact is made even more difficult where the main operational mechanism of the ACMA is centered on the power coupling methodology, and will contribute further to variations that exist between simulation and measurement.

In the radiation pattern, H plane HPBW grows inversely proportionate with larger patch width (*W*); while the smaller the substrate thickness (*h*) the broader E plane HPBW will be [6]. Since all patches has about the same *W* value, the H plane HPBW produced is about of the same values; while a similar *h* value produced narrow E plane HPBW. Smaller value of E plane isolation also proves the extensiveness of the spurious radiation affecting this technique due to the exposed feed line, in contrary to other feeding techniques such as the proximity coupled feed, which feed line is buried under the patch.

5. Conclusion

A method of comparative simulation and measurement between two new techniques applied to a similar rectangular patch ACMA and conventional ACMA is presented. Each parameter that is being changed to influence the enhancements is also described in detail. Simulated results are also compared with fabricated hardware’s measurement. All designs of ACMAs achieved the best return losses at the desired frequency region, which is 2.4 GHz. For increased accuracy in simulations, some percentage of design frequency shifts is introduced. This is to accommodate the resonant frequency shift when the hardware is fabricated, due to the difference of physical hardware’s dielectric constant from ideal software definitions [7]. Although hardware measurements indicated acceptable level of variation, it will help to reflect the true property of the ACMAs in practice.

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