Analysis of an Aperture-Coupled Microstrip Patch Antenna having an Asymmetric Cross Slot

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1. Introduction

Aperture-Coupled Microstrip Patch Antennas (ACMPAs) have plenty of advantages like no spurious radiation from the feed network, high radiation efficiency, and performance optimization of the feed part and the radiation part independently by choosing the different permittivities and thicknesses of the corresponding substrates [1]. For these reasons, many practical and theoretical studies have been performed to design and analyze ACMPAs [2][3]. To obtain dual-frequency operation, ACMPA with a cross slot could be used [4] and it is possible to provide more degrees of freedom in antenna design for dual-frequency characteristics than the ACMPA having an inclined slot [5]. In this paper, we suggested the analysis and the modeling of an ACMPA having an asymmetric cross slot for dual-frequency operation using improved transmission line model [2] based on the reciprocity theorem [6] and the spectral domain immittance approach [7]. With this modeling, we can achieve the easy way to predict the input impedance of the antenna and faster simulation time with good accuracy when compared with measurement results.

2. Antenna analysis and modeling

Figure 1 shows the geometry of the ACMPA having an asymmetric cross slot fed by a microstrip line. L_{p1}, L_{p2}, L_{s1}, L_{s2}, W_{s1} and W_{s2} represent the lengths and the widths of the patch and cross slot for the 1st and 2nd resonance frequencies, respectively. W_f and L_f are the width of the feed line and the length of the extended open stub. The substrate of the patch has a thickness h_p and a permittivity ε_{rp}, while the substrate of the feed has a thickness h_f and a permittivity ε_{rf}. Because the ratio of slot length to width is typically 1/10 [1], the slot widths, W_{s1} and W_{s2}, rarely contribute to the resonances. In addition, coupling between the orthogonal slots is negligible. Taking these characteristics into account, the modeling of the ACMPA having an asymmetric cross slot can be expressed as shown in Figure 2. The turn ratios (n_{p1}, n_{p2}, n_{f1}, and n_{f2}) of these transformers, which reflect various structure parameters, could be efficiently calculated via the improved transmission-line model [2]. The slot electric fields for 1st and 2nd resonance frequencies could be represented as (1) and (2), where the x' and y' expressed the centre position of the antenna.

$$e_{s1} = \left[\cos \frac{\pi}{L_{s1}} (x - x') \right] \Big/ \left[\pi \sqrt{(W_{s1}/2)^2 - (y - y')^2} \right] \tag{1}$$

$$e_{s2} = \left[\cos \frac{\pi}{L_{s2}} (y - y') \right] \Big/ \left[\pi \sqrt{(W_{s2}/2)^2 - (x - x')^2} \right] \tag{2}$$

The input impedances of the slot lines and the microstrip patch lines for 1st and 2nd resonance frequencies could be also expressed as (3) and (4).

$$Z_{ins1,2} = jZ_{os1,2} \tan\left[\beta_{s1,2} \left(L_{s1,2}/2 + \Delta L_{s1,2} \right) \right] \tag{3}$$

$$Z_{inp1,2} = Z_{op1,2} \frac{\left(1/G_{r1,2}\right) + jZ_{op1,2} \tan\left[\beta_{p1,2}\left(L_{p1,2}/2 + \Delta L_{p1,2}\right)\right]}{Z_{op1,2} + j\left(1/G_{r1,2}\right)\tan\left[\beta_{p1,2}\left(L_{p1,2}/2 + \Delta L_{p1,2}\right)\right]} \tag{4}$$

Taking the transformers into account, the input impedance of the two slots can be represented as (5).

$$Z_{in1,2} = n_{f1,2}^2 \left[\frac{1}{\left(n_{p1,2}^2 / 2Z_{inp1,2}\right) + \left(2/Z_{ins1,2}\right)}\right] \tag{5}$$

The two orthogonal slots can be expressed by their series connection, thus the total input impedance of the ACMPA having an asymmetric cross slot is given by

$$Z_{in} = Z_{in1} + Z_{in2} - jZ_{of} \cot\left[\beta_f\left(L_f + \Delta L_f\right)\right] \tag{6}$$

3. Results

To validate the suggested modeling, the ACPMA having an asymmetric cross slot operating at 3 GHz and 5 GHz was designed. The design parameters of Figure 1 are in Table 1. The antenna was fabricated as shown in Figure 3, and the return loss was measured using an Agilent 8722ES network analyzer. Figure 4 shows the result of comparison between the computed and measured return losses of the fabricated antenna. The error for the 1st resonance frequency of 3 GHz is less than 0.7 % and the error for the 2nd resonance frequency of 5 GHz is less than 0.6 %. This indicates the validity and the accuracy of the suggested modeling. The lengths L_{p1} and L_{p2} control the 1st and 2nd resonance frequencies of the antenna, respectively. As the length L_{p1} increases, the 1st resonance frequency of the antenna decreases without change in the 2nd resonance frequency. Similarly, as the length L_{p2} increases, the 2nd resonance frequency decreases with no change in the 1st resonance frequency. The slot lengths, L_{s1} and L_{s2}, can adjust the coupling levels between the feed and the patch to satisfy impedance matching for the 1st and 2nd resonance frequencies. As the lengths, L_{s1} and L_{s2}, increase, the coupling levels for the 1st and 2nd resonance frequencies also increase, respectively. Therefore, the desired dual resonance frequencies can be obtained by adjusting the lengths L_{p1} and L_{p2}, and then impedance matching can be achieved by changing the lengths L_{s1} and L_{s2}. This is convenient when designing the ACMPA for dual-frequency operation.

4. Conclusion

The analysis and modeling of an ACMPA having an asymmetric cross slot for dual-frequency operation was proposed using improved transmission line model. To achieve the 1st resonance frequency of 3 GHz and 2nd resonance frequency of 5 GHz, an ACMPA having an asymmetric cross slot was designed using the proposed modeling. The computed result from the suggested modeling agrees very well with the measured result of the fabricated antenna. Because of its efficiency and simplicity, the proposed modeling approach is useful for the analysis and design of the ACMPA for dual-frequency operation.

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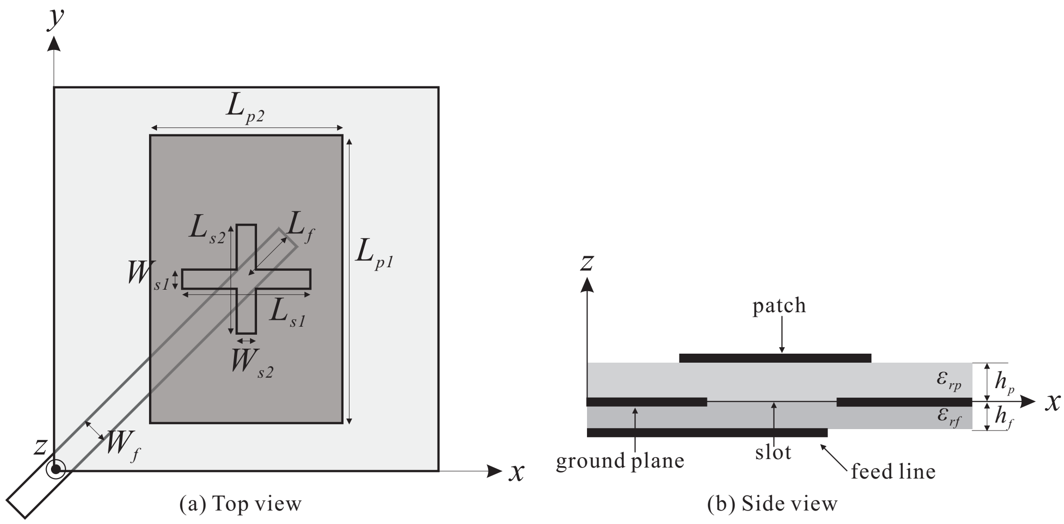


Figure 1: The geometry of the ACMPA having an asymmetric cross slot

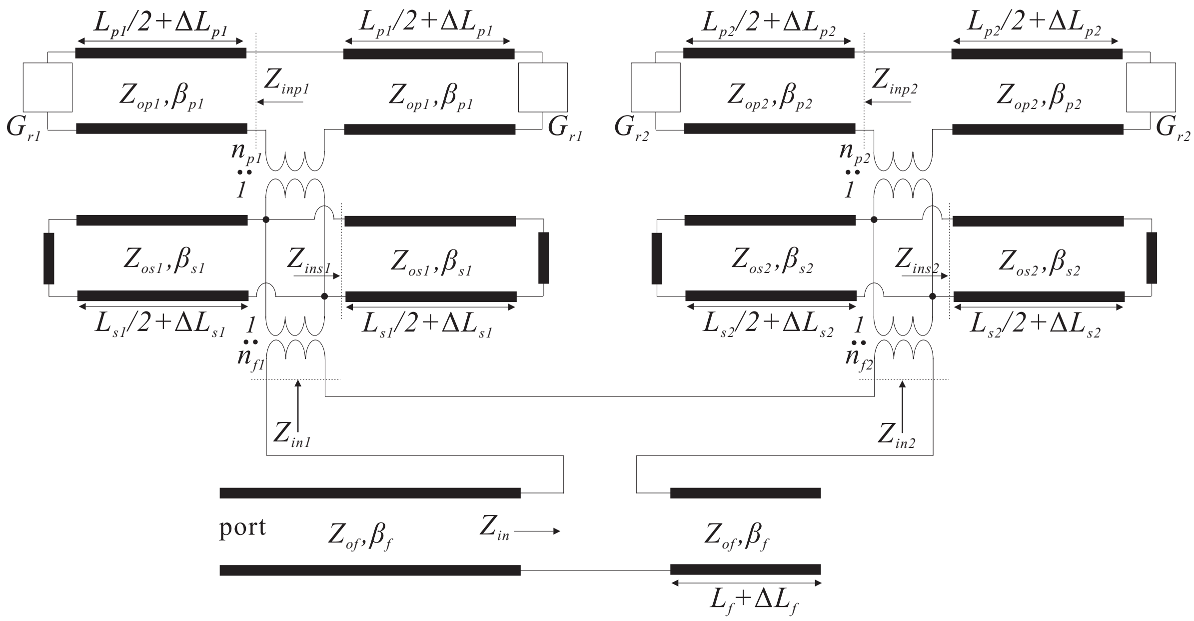
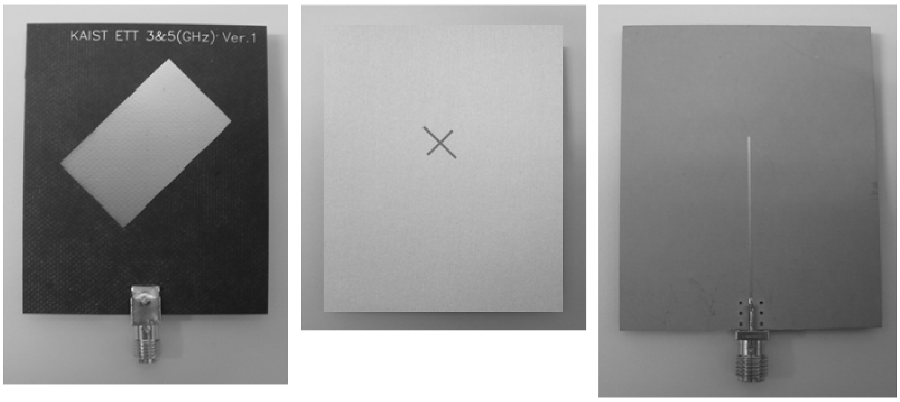


Figure 2: The equivalent model of the ACMPA having an asymmetric cross slot

Table 1: Design parameters

Parameter	Size (unit)	Parameter	Size (unit)	Parameter	Size (unit)
L_{p1}	31 (mm)	L_{s1}	9 (mm)	h_p	0.7874 (mm)
L_{p1}	18.4 (mm)	L_{s2}	7 (mm)	h_f	0.635 (mm)
W_{s1}	0.5 (mm)	W_f	0.6 (mm)	ε_{rp}	2.2
W_{s1}	0.5 (mm)	L_f	2.16 (mm)	ε_{rf}	10.2



(a) Top view (b) Asymmetric cross slot (c) Bottom view

Figure 3: Fabricated ACMPA having an asymmetric cross slot

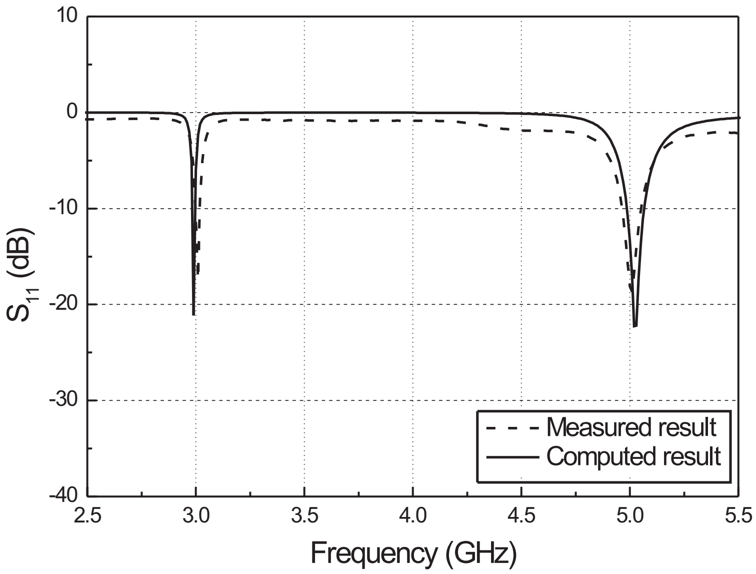


Figure 4: Return loss of the ACMPA having an asymmetric cross slot

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