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NOVEL IMPEDANCE MATCHING SCHEME FOR PATCH ANTENNAS

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Abstract—Aiming at the bandwidth enhancement for patch antennas, a new impedance matching scheme is presented. In this design, open-ended microstrip-lines are used as the matching resonators; the gaps between the lines are used as the J inverters. Numerical and experimental studies are executed to demonstrate this new structure. The measured and predicted results are in good agreement. The measured data show that the bandwidth of a sample antenna is increased by a factor of 3.3 after adding two matching resonators. The proposed matching structure is good in performance, and smaller in size than traditional matching structures.

1. INTRODUCTION

Microstrip patch antennas have attracted much attention due to many useful features, such as light weight, low profile and easy fabrication. A main drawback of conventional patch antennas is the narrow operating bandwidth (BW). To widen the BW of patch antennas, a variety of techniques have been proposed and developed in the past five decades [1, 2]. In general, those approaches could be classified into three types. The first way is to reduce the quality factor of the radiating patch directly. For example, a wider BW may be obtained by using a thicker substrate with lower permittivity. The second is to use the multiple-radiator or multiple-mode configurations. In this case, the BW improvement may be realized by adding radiators [3, 4] or using modified patches [5–8]. The third is to use an impedance matching (IM) circuit [9–14]. In comparison with each other, the IM technique has some unique features. For example, the radiating patch needs not to be altered by using an IM circuit; so the radiation properties could

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be retained [9]. In addition, the use of IM technique is independent of the choice of the patch substrate.

The IM technique for patch antennas was first proposed by Pues and Van de Capelle in 1989 [9]. After that, much effort has been made to develop this technique [10–14]. However, as a main drawback of this technique, additional area is required to place the matching circuit. Therefore, the antenna size will be increased. In this paper, a new IM scheme for patch antennas is presented. In this design, IM network is realized by using several parallel-coupled microstrip-lines. Comparing with the reported IM schemes, the present one is smaller in size whereas good matching performance is retained.

2. ANTENNA DESIGN

Figure 1 shows the basic schematic of a traditional IM network [9]. From the figure, it is clear that an n-stage IM network consists of n matching resonators and $n+1$ J inverters. Because of the single resonance nature, a radiating patch could be simply equivalent to an RLC circuit near its resonant frequency. In [15], the matching procedure for an RLC load is introduced. First, the resonant frequencies of the matching resonators shown in Figure 1 are tuned to be the same as that of the patch radiator. Second, a new parameter is defined as

$$\delta = \frac{1}{WQ_A} \tag{1}$$

W, Q_A are the fractional bandwidth of the goal circuit and radiator's Q-factor, respectively. Finally, the values of the J inverters could be

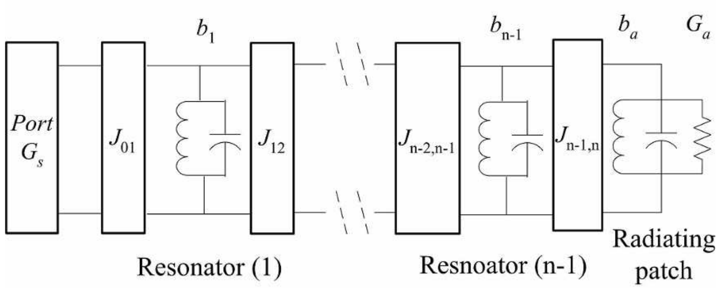

Figure 1. Circuit model of IM network.

obtained:

$$J_{01} = \sqrt{\frac{G_s b_1 W}{g_0 g_1}} \tag{2}$$

$$J_{k-1,k|k=2\sim n-1} = W\sqrt{\frac{b_k b_{k+1}}{g_k g_{k+1}}} \tag{3}$$

$$J_{n-1,n} = \sqrt{\frac{G_a b_{n-1} W}{g_{n-1} g_n \delta}} \tag{4}$$

b_i $(i = 1 \sim n-1)$ stands for the susceptance slope parameter of the i-th matching resonator. Moreover, the values of g_i $(i = 0 \sim n)$ also could be obtained from [15], they depend on δ and the matching degree of the goal.

Figure 2 depicts the configuration of the proposed IM scheme. It may be seen the novel scheme consists of a side-coupled feed microstrip-line and several $\lambda_g/2$ open-ended microstrip-lines. The open-ended lines are used as the matching resonators, and the gaps are used as the J inverters. The whole structure is similar to a pseudocombline filter [16]. Therefore, compact design could be realized.

For comparison, Figure 3 depicts two traditional IM schemes. In [9], open-ended $\lambda_g/2$ stubs are used as the matching resonators, $\lambda_g/4$ microstrip-lines are used as the J inverters (Type A in Figure 3). In [12], an alternative design is developed (Type B in Figure 3). Parallel-coupled $\lambda_g/2$ microstrip-lines are used as the matching resonators. The structure is similar to a patch-loaded parallel coupled-line filter. Both the two schemes are good in matching performance.

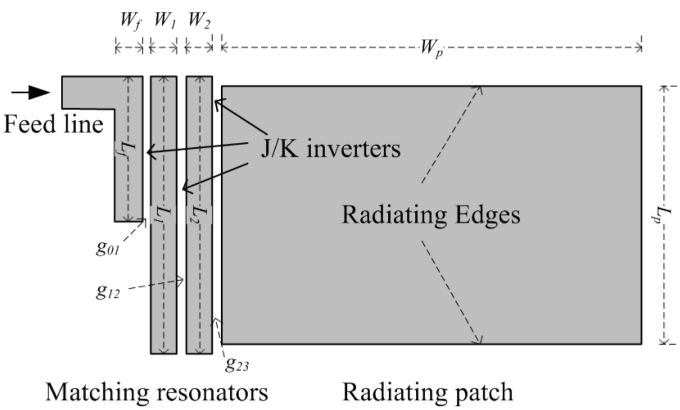

Figure 2. Proposed IM scheme for patch antennas (two-stage).

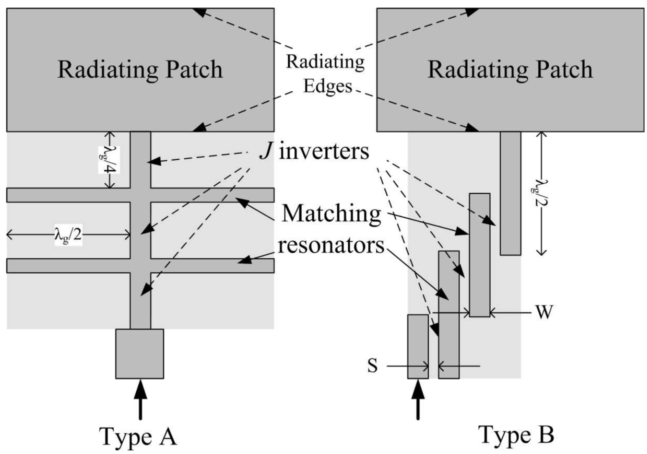

Figure 3. Two IM schemes for patch antennas (Type A: [9], Type B [12], both are two-stage).

Table 1. Size comparison of different IM schemes.

Number of Stages	Size of IM circuit					
	[9]		[12]		This work	
	Width	Length	Width	Length	Width	Length
1	λ_g	$0.50\lambda_g$	$3W+2S$	$0.75\lambda_g$	$2W+2S$	$0.50\lambda_g$
2	λ_g	$0.75\lambda_g$	$4W+3S$	$1.00\lambda_g$	$3W+3S$	$0.50\lambda_g$
3	λ_g	$1.00\lambda_g$	$5W+4S$	$1.25\lambda_g$	$4W+4S$	$0.50\lambda_g$
4	λ_g	$1.25\lambda_g$	$6W+5S$	$1.50\lambda_g$	$5W+5S$	$0.50\lambda_g$

*λ_g is the guided wavelength at the resonant frequency of the radiating patch
*W and S are the maximum width and spacing of the coupled microstrip-lines, respectively
*$W, S \ll \lambda_g$

Table 1 illustrates the detailed size of the above three IM schemes under different matching stages. It may be seen that the proposed is smaller in size than the two reported ones.

The numerical simulations are carried on simulator IE3D. The substrate is with $\varepsilon_r = 2.94$ and a thickness $h = 1.27$ mm. The characteristic impedance of the feed microstrip-line is taken to be 50 Ohm. After carefully adjusting, three antennas with different matching-stages are obtained. The antenna dimensions are given in Table 2. The radiating patches of those three antennas are the same in size ($30 \times 20\,\text{mm}^2$).

Table 2. Dimensions of proposed antennas.

Unit: mm	Original	One resonator	Two resonators
W_p	30.0	30.0	30.0
L_p	20.0	20.0	20.0
L_f	11.8	8.6	10.8
W_f	0.4	1.0	1.5
g_{01}	0.2	0.3	0.5
W_1	N/A	1.0	0.7
L_1	N/A	23.6	24.0
g_{12}	N/A	0.5	2.3
W_2	N/A	N/A	0.7
L_2	N/A	N/A	24.0
g_{23}	N/A	N/A	1.5

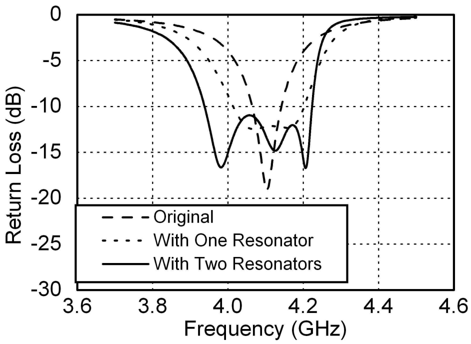

Figure 4. Simulated $|S_{11}|$ of patch antennas with different numbers of matching resonators (antenna dimensions are listed in Table 2.

The simulated S parameters of the adjusted antennas (dimensions are listed in Table 2) are illustrated in Figure 4. It may be seen that the fractional BW of the original patch antenna is 1.9%. The central frequency is 4.1 GHz. The BWs of those with one and two matching resonators are 4.6%, 7.0%, respectively. They are 2.4 and 3.7 times as wide as that of the original. The simulated results validate the proposed IM scheme is good in matching performance.

Antenna samples were fabricated for verification, using the standard PCB process. The photographs of the samples are shown in Figure 5. The dimensions of the fabricated antennas (#2, #3) are given in Table 2. In addition, a patch antenna with traditional feed (#1)

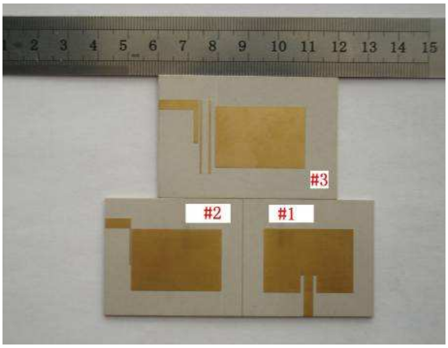

Figure 5. Photograph of fabricated samples. #1: Direct feed scheme, #2: Side coupled scheme, #3: Proposed IM scheme (two-stage).

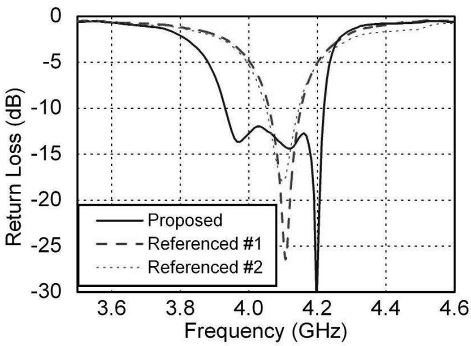

Figure 6. Measured return loss of samples shown in Figure 5.

is fabricated for comparison purpose. The return loss measurement is performed on network analyzer (HP 8720). The measured return loss is given in Figure 6. It could be seen that antenna #1 and #2 are nearly the same in performance. The measured BWs (2.2%, 2.1%) validate that the quality factor is stable using different feeding schemes. The measured fractional BW of antenna #3 is about 7.0% (from 3.92 GHz to 4.21 GHz), 3.3 times wider than that of antenna #2. The measured data agrees well with the predicted.

The measured radiation patterns of antenna #3 are shown in Figure 7. The measured data show that the radiation patterns are stable within the operating band. The measured antenna gain is better than 4.5 dBi in the frequency range between 3.92 to 4.21 GHz.

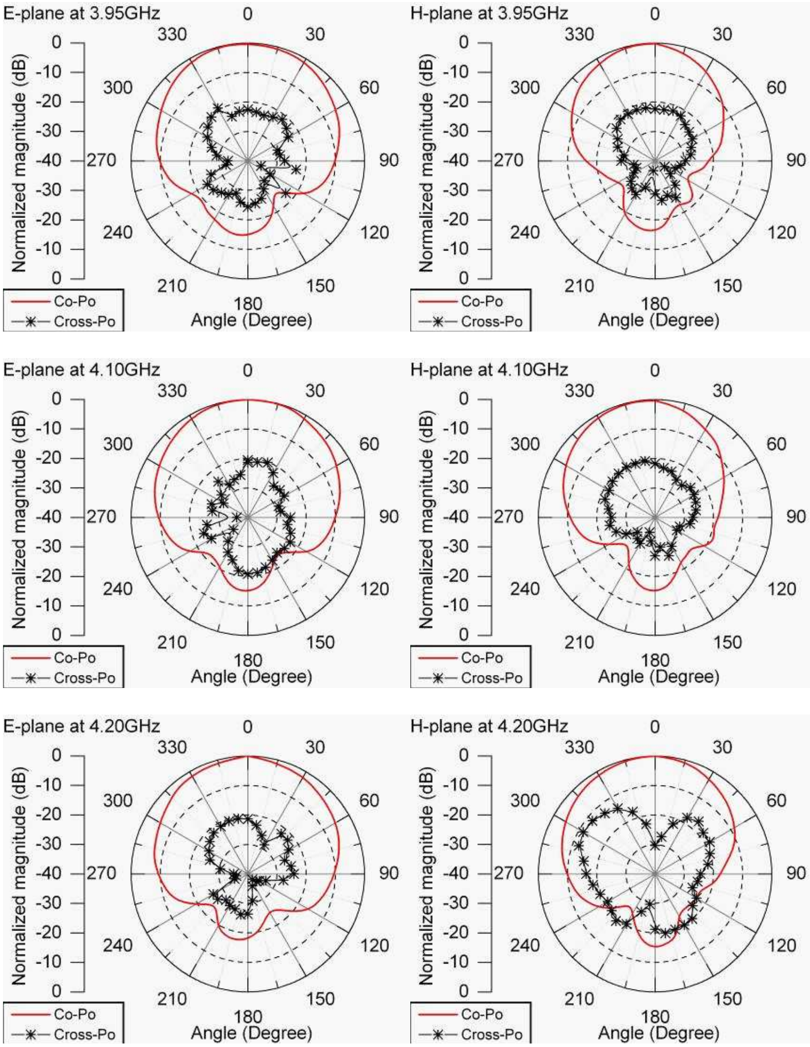

Figure 7. Measured radiation patterns of antenna #3 (shown in Figure 5.

3. CONCLUSION

In this study, a novel IM scheme for patch antennas is introduced. $\lambda_g/2$ open-ended microstrip-lines are used as the matching resonators; the gaps between the lines are used as the J inverters. The structure is similar to a pseudocombline filter. Compared with the traditional IM schemes, the proposed one is smaller in size. Antenna samples were designed, fabricated and measured. The measured and predicted data are in good agreement. Both the measured and simulated results show the novel scheme is good in matching performance. As a result, the operating BW of a two-staged sample is 3.3 times as wide as that of the initial one.

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