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QUASI-METALLIC-WALL TECHNIQUE FOR INCREASING THE EFFICIENCY OF CB-CPW ANTENNAS

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Abstract—This paper presents a new quasi-metallic-wall technique for improving the gain of CB-CPW single antenna and arrays. This technique allows reducing the surface wave losses of the CB-CPW antennas, which decreases the antenna radiation efficiency. It consists on including pins as quasi-metallic wall between the upper and lower ground planes in the CB-CPW antenna structure. To validate the proposed approach, a CB-CPW-slot antenna fed through an inductive coupled CPW-line operating at 5.8 GHz is considered. This approach allows to increase the antenna efficiency from 70% to 95% around the operating frequency. The antenna gain achieves then an improvement of 2 dBi. Also, an antenna array is designed and the pins technique is also applied to prove its applicability for the array case. An efficiency increase from 64% to 95% was achieved. Both single antenna and antenna array with pins were fabricated and measured. A good agreement between numerical and experimental results was obtained.

1. INTRODUCTION

Recently, wireless communications represent one of the highest growing markets, especially on the development of mobile communications and wireless local area networks (WLANs), where high capacity transmission systems are required. These concern new wideband RF wireless components such as antennas, filters and so on. Especially for antenna issue, planar broadband antennas using coplanar waveguide CPW feed lines have been proposed as an alternative for microstrip feed lines [1]. Indeed, CPW feed lines have several useful design characteristics, a low radiation loss, less dissipation, and uniplanar configurations. Particularly for antenna applications, CPW-fed antennas have long been popular for various applications because of their low cost, low profile, light weight, and compatible with integrated circuits [2–7]. In practice, additional conducting planes are often placed below the substrate in order to electromagnetically separate the circuit from its environment [8]. The main drawback of this approach is the presence of parallel-plate modes, which are considered as unwanted bulk modes [9]. Therefore, the CB-CPW structure suffers from radiation leakage, which makes it less efficient. This leakage is caused by is the surface wave losses, which decreases considerably the antenna performance.

To overcome this problem, various techniques have been proposed. For instance, we can quote: Jahagirdar et al. [10] have proposed non-leaky conductor backed coplanar waveguide with emphasis on avoiding the leakage of power. Lan et al. [11] have used parallel-plate mode leakage to radiate through the slot array etched on both sides of the ground plane. In [12], twin broadside slots with half guided wavelength are used to reduce the undesired propagating power. However, all these design are more complex and expensive to be implemented. Furthermore, these approaches deal only with a single element, and they have not been investigated yet for antenna arrays. In this paper, a new efficiency-enhancement technique using an appropriate via density to create a quasi metallic wall in CB-CPW technology is proposed. These via connectors join the upper and lower CB-CPW (Conductor Backed CPW) ground planes to eliminate the unwanted parallel plate modes and to create the cavity effect in the antenna by stopping the propagation of surface wave between the upper and lower ground planes. First, a parametric study of the pin inclusion effect in CB-CPW lines was carried out. Second, this technique was applied to a single element antenna case [13]. Third, a serial array of three elements was also designed using this approach. To validate the proposed approach, numerical simulations and experimental measurements were carried out on a single antenna and then on antenna array. The obtained results show a good performance in terms of radiation efficiency.

The paper is organized as follows. After this introduction, the quasi metallic wall technique is described in Section 2. In Section 3, an antenna element with via shorting pin is presented. Section IV, presents the proposed technique for an antenna array case. Finally, the last section presents the conclusion.

2. QUASI METALLIC WALL TECHNIQUE

Figure 1 shows the structural view of CB-CPW line, where the two top ground planes and the center conductor form a CPW line. In this structure, a parallel-plate mode is formed between the top and bottom

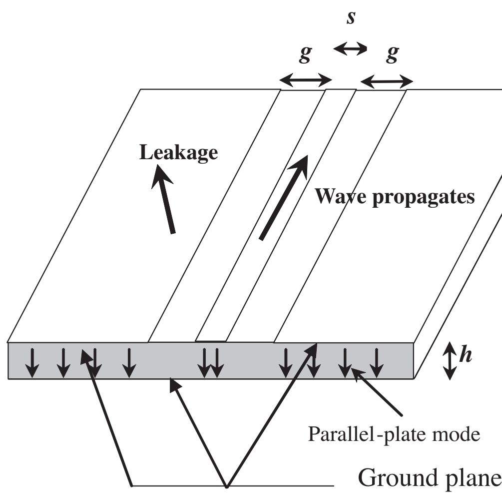


Figure 1. CPW electromagnetic field leakage.

ground planes. The energy will leak along a particular angle once the wave is launched. It is apparent that this leakage can be stopped if a guard ring type method is used along the signal propagation as reported in [9].

It is well known that periodic structure exhibits a stopband phenomenon, which can be used to stop wave propagation at this band. For our application, we are interested in using via technique in regards to its compactness and its simplicity. To implement this technique, the coupling effect between two CB-CPW lines as illustrated in Fig. 1 was simulated. This CB-CPW lines is built on a substrate with a relative permittivity $\varepsilon_r = 2.2$ and a thickness $h = 3.175$ mm. The CPW line is designed in order to achieve a 50 input impedance for matching the characteristic impedance measurement system feed line. Dimensions of the CPW line are calculated using LineCalc software of Agilent [14]; the parameters at 5.8 GHz are $s = 0.4$ mm, $g = 3.88$ mm.

First, the case of opposite line disposition as described in Fig. 2 was investigated. The study consists on observing the effect of including pins in the structure. Figure 3 shows simulated results for the transmission coefficients S_{12} of the structure with and without pins. Inclusion of pins produces a quasi metallic wall effect that reaches 17 dB of relative stop-band at 5.8 GHz. The optimal value of the pin step distance is 8 mm. The pin diameter is found to be 0.6 mm.

To make our study more complete, the case of parallel line

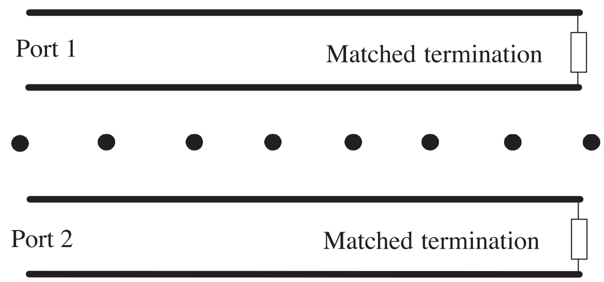


Figure 2. Opposite CPW line pins disposition.

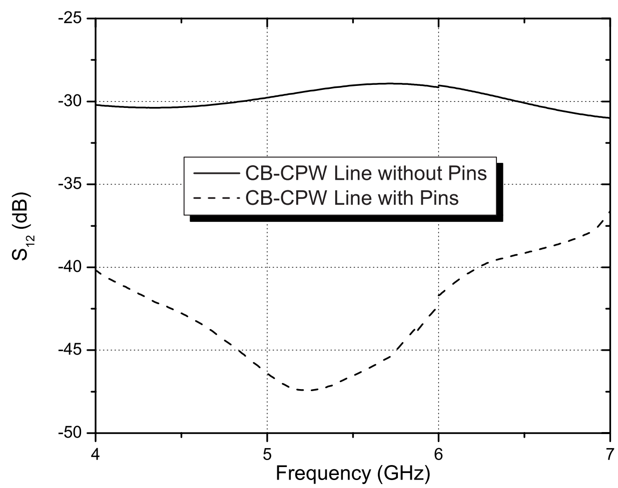


Figure 3. Transmission coefficient decrease for opposite lines disposition.

disposition has also been introduced as shown in Fig. 4. All ports are matched. The simulation results shown in Fig. 5 reveal a stop-band effect of 17 dB at maximum. The optimal value of a pin-step distance is 8 mm. From these results, it can be concluded that the pins act like metallic wall, which confirms our approach. This technique is commonly used to forbid high mode propagation.

The purpose of this section has been to investigate the proper pin dimension and distance in order to include them in an antenna prototype. In the next section, these pins are added to antenna global structure (antenna + pins), and the overall performance is simulated and measured.

3. ANTENNA ELEMENT WITH SHORTING VIAS

3.1. Design

As mentioned, the proposed technique was first applied to a single CB-CPW antenna. For this issue, a new antenna using inductively fed slot was designed. The inductively fed slot antenna geometry is shown in Fig. 6.

This type of feeding technique corresponds to a short-circuited excitation slot [13]. The antenna is composed of one substrate, which has a relative permittivity $\varepsilon_r = 2.2$ and a thickness $h = 3.175$ mm.

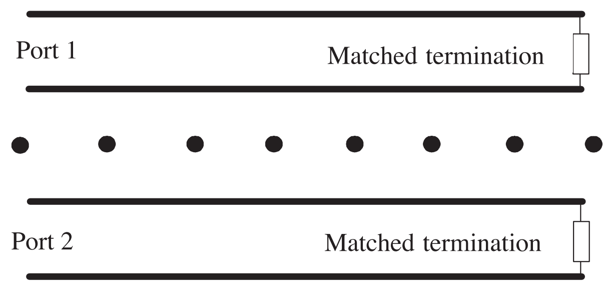


Figure 4. Parallel CPW line pins disposition.

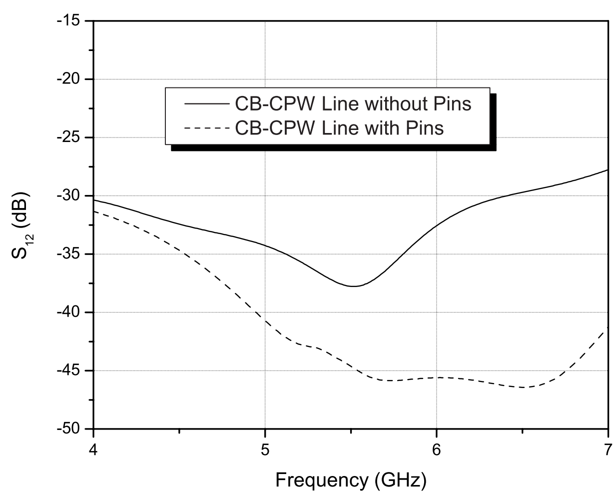


Figure 5. Transmission coefficient decrease for parallel lines disposition.

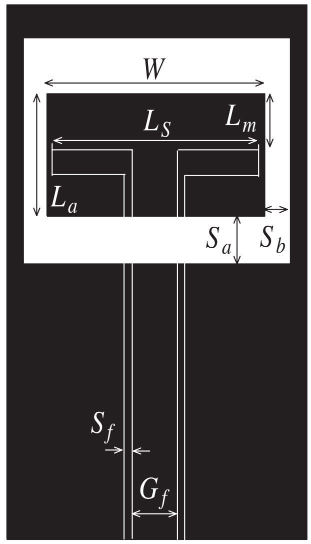


Figure 6. Configuration of single element CPW inductively fed slot antenna.

The parameters of this antenna are the followings: $S_f = 0.4\,\text{mm}$, $G_f = 3.88\,\text{mm}$, $L_a = 13.72\,\text{mm}$, $W = 17.74\,\text{mm}$, $S_a = 3.7\,\text{mm}$, $S_b = 1\,\text{mm}$, and $L_s = 17.48\,\text{mm}$. The major problem in this design is the surface wave loss. Even if the structure is optimized to reduce the surface wave loss, there is still some non radiated energy of about 30% of the overall energy. This energy is dissipated as leaky waves due to the parallel plate modes that are inherent and undesired feature of CB-CPW structures.

Fig. 7 shows, through simulations carried out with HFSS-Ansoft [15], how the electrical field is distributed around the radiating slots. From this figure, it can be seen that a part of energy is lacked into the substrate between the upper and lower ground planes. In order to recover the lacked energy, the proposed quasi-metallic wall technique was applied to this design. To ensure antenna performance enhancement, the proper dimensions of this antenna were investigated. Figure 8 shows the antenna structure with surrounded pins. Both distances between the upper radiating element and the pins and between the antenna sides and the pins are taken into a count; these parameters affect grandly the antenna performance.

The effect of the distance between the upper radiating slot and the pins location (a) and effect of the distance between the antenna

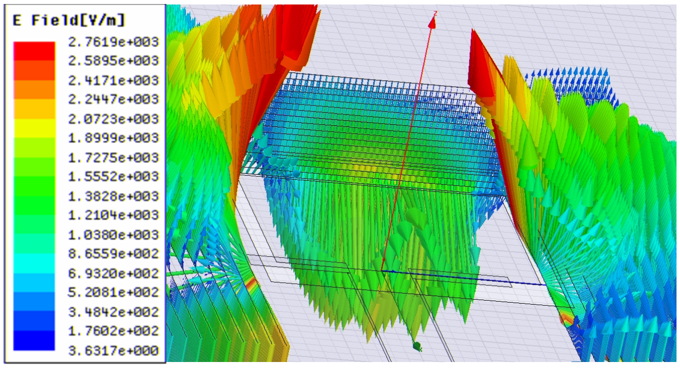


Figure 7. Electric field distribution in the space around the antenna without pins.

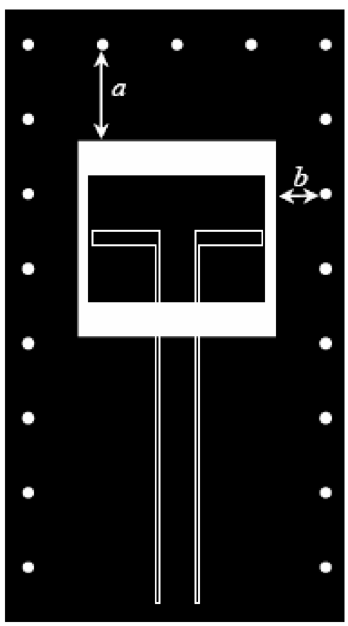


Figure 8. Configuration of single element CPW antenna with pins.

sides and the pins location (b) were studied and both are shown in Fig. 9. It is been found that the first parameter affects the antenna efficiency. It can be observed that this parameter does not affect the resonance frequency (Fig. 9 (a)). The optimum value is obtained for $a = 9.94$ mm, which corresponds approximately to quarter wavelength. This is due to the fact that the radiating edges are the upper and lower slot edges. The pins row behaves like an electric wall. Combining phase inversion due to the image reflection and the 180 phase introduced by the half wavelength path (go to and come from with quarter wavelength), the sum is then constructive. The effect of the distance between the antenna sides and the pins location affects highly the impedance matching (Fig. 9(b)). This can be explained by the fact that the current distribution is out of phase for the lateral edges. Thus, if the current is disturbed by the proximity of an electric wall, the overall input impedance is also disturbed. The optimal distance is $b = 8.326$ mm. Fig. 10 illustrates the behavior of the magnetic current in the radiating slot. The distribution of magnetic current in the slot radiating element without and with pins (case $b = 8.326$ mm) is almost the same, which confirm that the optimum case does not affect the current distribution of the antenna. However, when, the distance

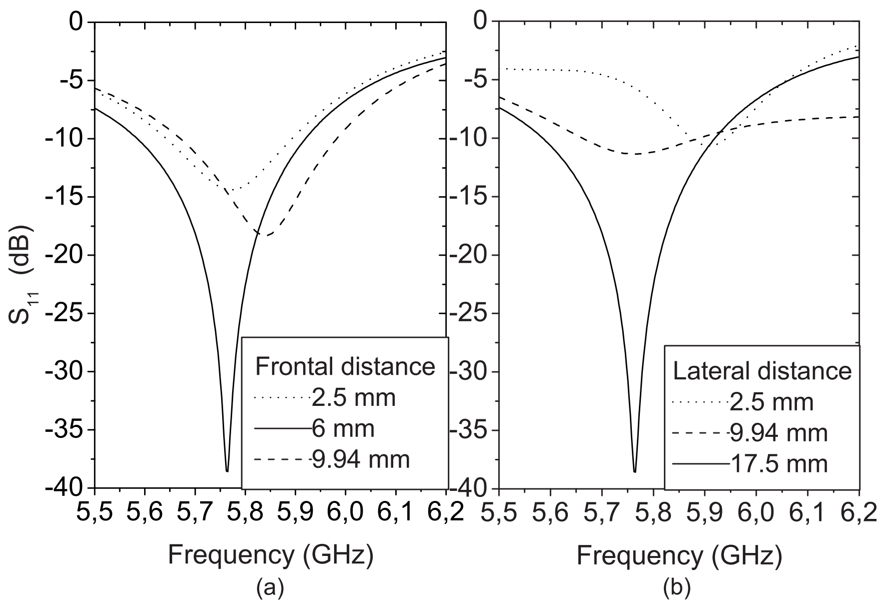
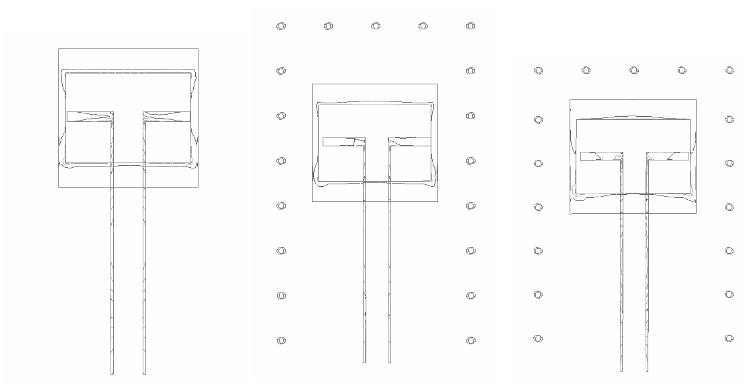


Figure 9. Return loss versus pins distance effect: (a) frontal distance (b) lateral distance.

b, for example, changes to $b - 5$, the magnetic current distribution is degraded.

3.2. Results and Discussion

To validate the proposed design, a prototype was fabricated using above parameters, and measured by HP8772 network analyzer with TRL calibration technique. Also, a prototype of antenna element without pin has been fabricated for comparison purposes.



(a) (b) (c)

Figure 10. Current distribution on the radiation slot: (a) without pin (b) optimal value (c) pins shifted by 5 mm.

The simulated and measured return loss coefficients for both antennas are shown in Fig. 11. A good agreement between simulation and experimental results was obtained. Furthermore, it can be seen that there is no discrepancy between the return loss of the two antennas. It can be noted that the bandwidth of 300 MHz (6.5%) for a −10 dB return loss level is observed at 5.8 GHz operating frequency. The major difference between the antennas is their efficiency. Fig. 12 describes the efficiency for both cases. Whereas, the simple antenna element shows an efficiency of 75% at 5.8 GHz, the introduction of pins leads to reach 94%.

To verify this approach in terms of propagation of electrical field inside the antenna, the antenna with pins was simulated with HFSS. Simulation results of propagation of electrical field id plotted in Fig. 13. From this figure, it can be shown, that electrical fields are not propagating beyond the pins lattice, compared to the distribution observed in Fig. 7, which confirm that the most part of lacked energy

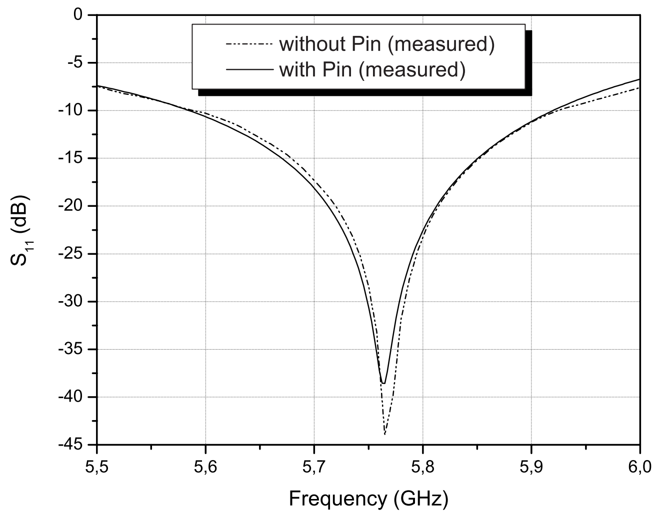


Figure 11. Simulated and measured return loss for single element antennas with and without pins.

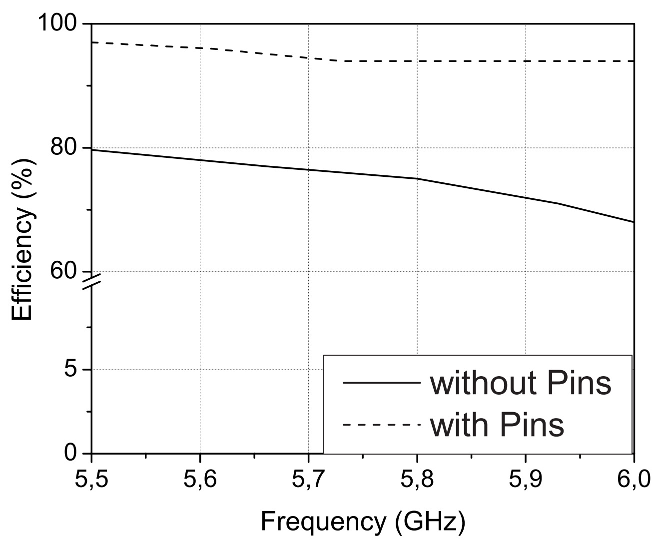


Figure 12. Comparison of radiating efficiencies for single element antennas with and without pins.

is recovered by using the quasi metallic wall. A measurement of this increase was carried out. For this purpose, a network analyzer HP8772 is used to measure the transmission coefficient (S_{12}) between a reference antenna, which is a wideband horn antenna from Antcom Corp., and our prototypes. The distance between the antennas respects the far field condition. It is known that the antenna gain and the directivity are relied as follow

$$G = \eta D \tag{1}$$

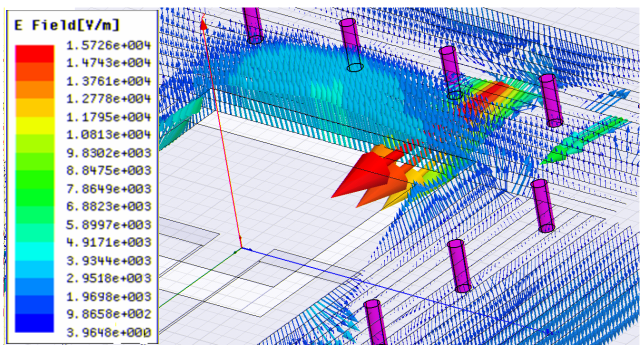


Figure 13. Electric field distribution in the space around the antenna with pins.

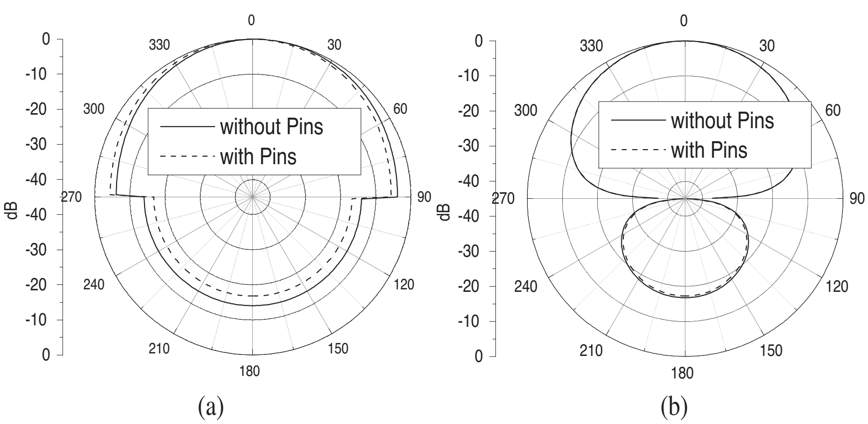


Figure 14. Simulated radiation pattern at 5.8 GHz for single element antennas with and without pins: (a) E-plane (b) H-plane.

where η is the antenna efficiency, G is the gain and D is the directivity. From Fig. 14, it can be noted that the radiation patterns of both antennas with and without pins are sensitively the same; their directivities are then also similar. This can be justified by the magnetic current distribution within the radiation which remains mainly identical. Since that, the ratio between the gains and the efficiencies is the same, then it is possible to write

$$\frac{G_2}{G_1} = \frac{\eta_2}{\eta_1} \tag{2}$$

G_1 and G_2 are the gains of the antennas without and with pins, respectively. For measured powers, the following formula can be used:

$$P_{received} \propto G P_{transmitted} \tag{3}$$

or simply,

$$G \propto S_{21}^2 \tag{4}$$

Comparing the transmission coefficient for both cases of antennas without and with pins permits to write

$$\frac{\eta_2}{\eta_1} = \frac{G_2}{G_1} = \frac{S_{21,2}^2}{S_{21,1}^2} \tag{5}$$

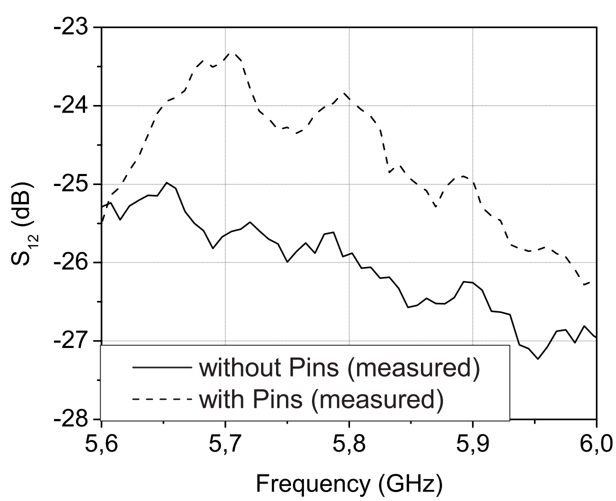


Figure 15. Relative received power of single element antennas with and without pins.

where $S_{21,i}$ is the transmission coefficient associated to the gain G_i. This ratio is illustrated in Fig. 15. This figure shows that by including pins in the structure the received power and then the gain are increased. Around 5.8 GHz, a maximum of 2.3 dB improvement is noted. The measured ratio is then 1.44. The simulation reports a ratio of 1.27. Moreover, the enhancement of efficiency is wideband.

The radiation patterns of the antenna were also measured in anechoic chamber with Antcom corp. Figure 16 shows theoretical and measured radiation patterns in principal planes, and a good agreement is observed. The pin introduction does perturb neither the antenna bandwidth nor its radiation pattern.

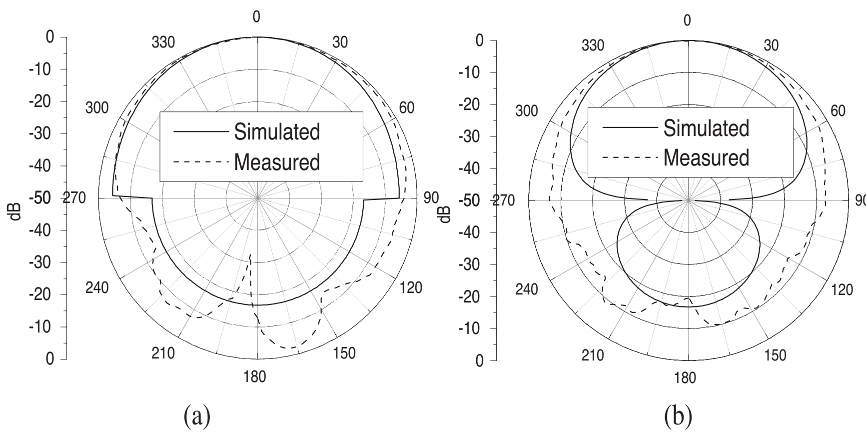


Figure 16. Simulated and measured radiation pattern at 5.8 GHz of single element antenna with pins: (a) E-plane (b) H-plane.

The next section deals with antenna arrays. To verify that the quasi-metallic wall technique of pins inclusion is exportable to an array structure, an arrays of three elements are presented.

4. ANTENNA ARRAY

Usually, the radiation pattern of a single radiating element is relatively wide with low directivity. In many applications, antennas with very directive characteristics are needed and this can be done by enlarging their electric dimensions. A way to do this without increasing the size is to form an array. In most arrays, antenna elements are identical because this convenient, simple, and practical.

Few works about improving the performances of antenna array have been reported in literature [16, 17]. These works were mainly focused on decreasing mutual coupling between array elements. The case of the efficiency enhancement has never been studied yet. To demonstrate, that the proposed enhancement efficiency technique is suitable for series fed arrays, a linear three elements array was designed with this approach.

Using the single antenna design presented previously, a three element array was built. The proposed antenna element is an inductively fed one; this allows controlling easily input impedance of the antenna. Thus, serial feeding is a suitable choice for our array design.

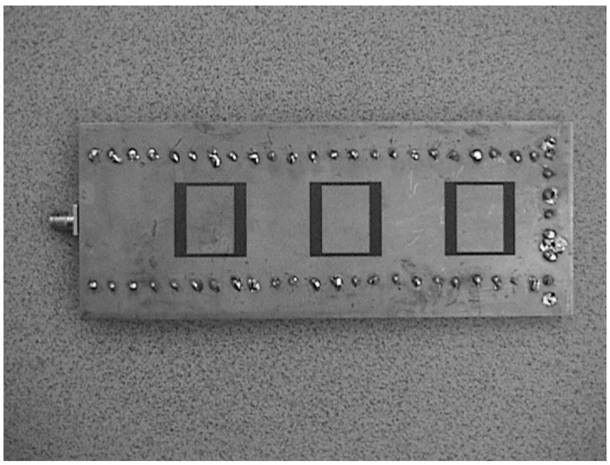


Figure 17. Photograph of three elements CPW array with pins.

Figure 17 shows the layout of the antenna array. The elements are identical, excited in phase (broadside array) since the electrical length in the CPW line between exciting slot corresponds to a wavelength at 5.8 GHz. The antenna can be electrically modeled as RLC serial circuit [18]. To achieve 50Ω as input impedance for the global array, each element should be designed with 50Ω/3 input impedance ($Z_{in}/3$). For this purpose, the chosen dimensions for the elements are: CPW feed line: $S_f = 0.4$ mm, $G_f = 3.88$ mm; Slot radiating element: $L_a = 13.94$ mm, $W = 19.25$ mm, $S_a = 3.7$ mm, $S_b = 1$ mm; Exciting slot: $L_s = 18.38$ mm. The distance between the via and the upper radiating slot is 10 mm and 7.33 mm from each radiating slot side to lateral one.

First, the prototype of an array without via was fabricated. For comparison purposes, the measured and simulated results are shown in Figs. 18 and 19. A good agreement between simulation and measurement is noted. The E-plane radiation pattern is clearly more directive.

As reported in Section 2, however, the structure has a poor radiating efficiency which is about 64%. To overcome this undesired feature, via are included. The antenna structure with pins was simulated and fabricated. Settings are sensitively the same that those

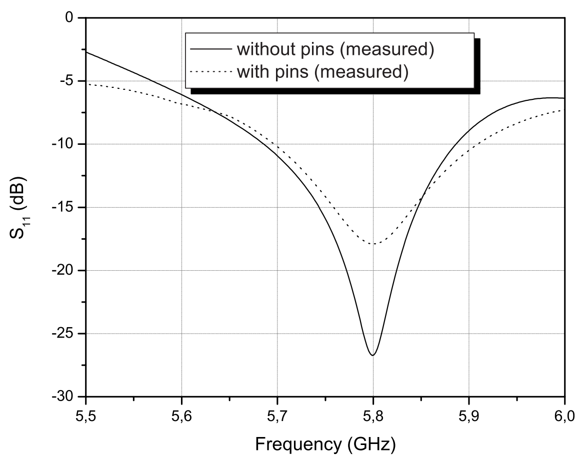


Figure 18. Simulated and measured return loss coefficients for three elements arrays with and without pins.

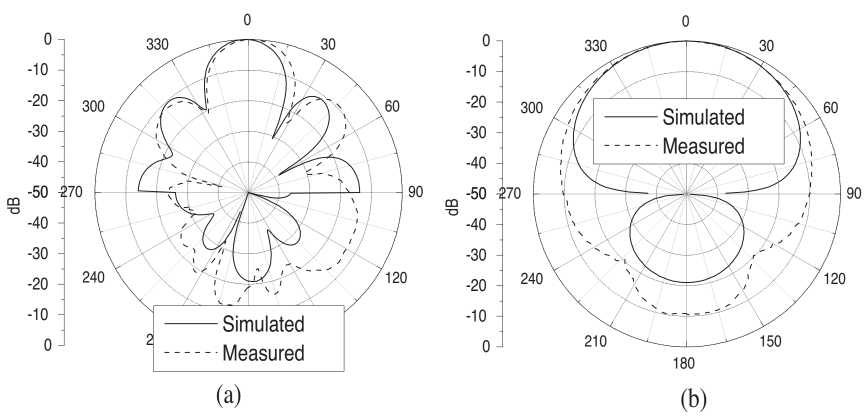


Figure 19. Simulated and measured radiation pattern at 5.8 GHz of three elements array without pins: (a) E-plane (b) H-plane.

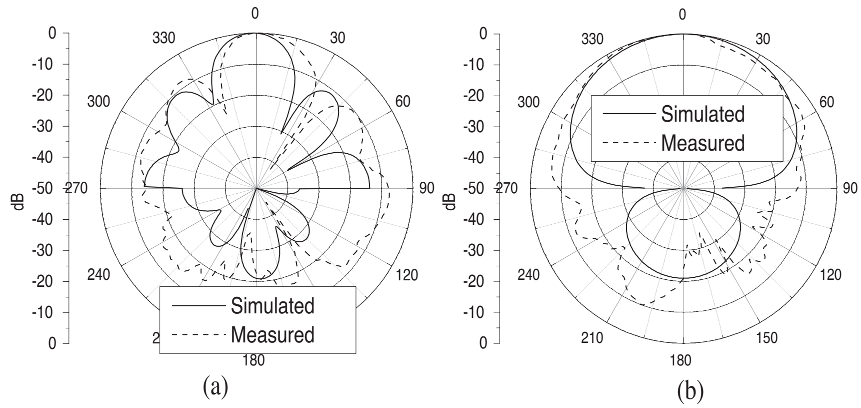


Figure 20. Simulated and measured radiation pattern at 5.8 GHz of three elements array with pins: (a) E-plane (b) H-plane.

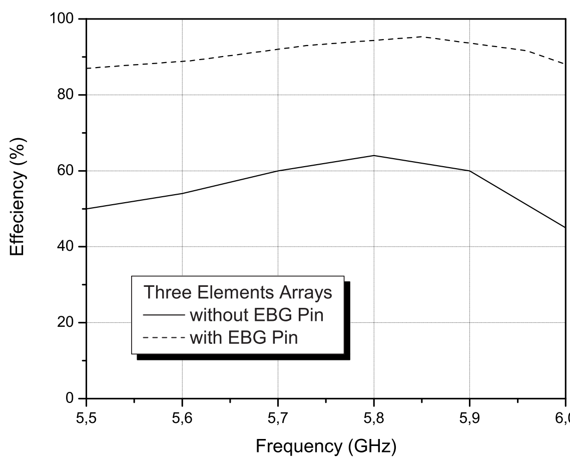


Figure 21. Comparison of radiating efficiencies for three elements arrays with and without pins.

encountered for the single element case.

Figures 18 and 20 display simulation and measurement results of the return loss and the radiation pattern. The bandwidth is still relatively the same, and the radiation pattern does not suffer from any perturbation. Fig. 21 reports the radiating efficiency. It is clear that, at 5.8 GHz, the efficiency climbs form 64% to 95%. This enhancement has been verified by measurements using the same transmission coefficient

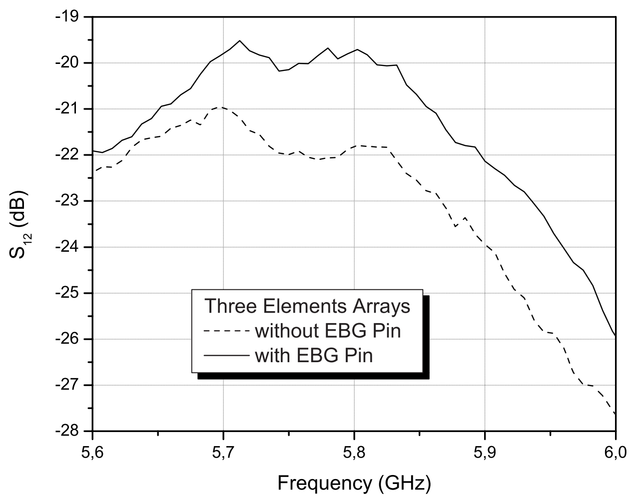


Figure 22. Relative received power comparison of three elements arrays with and without pins.

method described above as shown in Fig. 21. A gain enhancement of 2 dB can be observed at 5.8 GHz.

5. CONCLUSION

In this paper, a quasi-metallic wall technique has been introduced to CB-CPW antenna technology to suppress surface wave losses and to increase the radiation gain. This technique was originally applied to a CB-CPW single element slot antenna to raise the radiating efficiency from 74% to 94%. In addition, using the same technique, a three-element array has been designed and measured. The radiation efficiency of this array is increased from 60% to 95% which corresponds to 2 dB gain enhancement. With these features, these high gain structures are useful for wireless communication systems as WLAN.

ACKNOWLEDGMENT

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