Broadband Double-Layered Coplanar Patch Antennas for Microwave / Millimeter-Wave Wireless Communications

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In this paper, we have presented the double-layered coplanar patch antennas of enhanced impedance bandwidth and adjustable conductor-backed coplanar waveguide feed lines. The proposed structure retains the advantage of laying the coplanar patch and CPW feed line on the same surface, which makes direct integration with other devices easier. Besides the substrate thickness of the radiating patch can be adjusted for wider impedance bandwidth while the dimensions of the CPW feed line was kept unchanged. Simulation has been done by using commercial EM simulation software. A parametric study of the gap distance between the coplanar patch and the top ground, and the width at the feeding point was carried out. Four testing antennas, which operate at 10GHz, were designed and the characteristics of the antennas were compared. The four testing antennas had same total thickness, but different thickness combinations. The measured return loss, gain, and radiation patterns of the antennas demonstrated that different thickness combinations do not affect the characteristics of the antennas seriously. Therefore, the dimensions of the CPW feed lines of the antennas can be adjusted for different applications.

Keywords: planar antenna, broadband, multi-layered structure, coplanar patch antenna, coplanar waveguide fed

1. Introduction

High speed, large capacity, and mobility are the basic requirements of today's communications systems. Wireless systems, which use optical fibres to transmit radio wave, fulfils the above conditions have been reported recently[1][2]. These systems consist of fibre network in which optical wave is the carrier and the wireless system in which radio wave is the major communication media. The conversions between optical wave and radio wave are done by photonic devices (such as light modulators and photodetectors). Antennas, which connect to the photonic devices, will transmit / receive the radio wave to / from the users. The terminals (both input and output) of photonic devices are usually in the form of coplanar waveguide (CPW). For this reason, CPW fed antennas, which can directly connect to the CPW terminals of photonic devices, will be good candidates for simple and low loss integration.

CPW fed antennas[3][4] also have the advantages such as low radiation loss, less dispersion and uni-planar configuration. Coplanar patch antennas (CPAs), which enjoy the above advantages, have been proposed[5][6]. The geometry of a coplanar patch antenna looks like a loop slot antenna with a ground plane at the backside. However, both simulation and experimental

results demonstrated that the electric field distribution of a CPA is similar to that of a microstrip patch antenna. Second, the patch length (about half of a guided wavelength) of a CPA primarily determines the resonant frequency, not the perimeter of the slot[5][7]. Finally, the input impedance of a CPA can be controlled by the width of the coplanar patches. These results lead us to consider CPAs as a new kind of patch antennas, not loop slot antennas. However, coplanar patch antennas inherit one of the characteristics of microstrip patch antennas - narrow impedance bandwidth (return loss < -10dB). It is only a few percentages (about 3.4%), which may not be enough for communication systems nowadays.

As we have confirmed the resonant mechanism of a CPA is similar to that of a microstrip patch, it can be predicted that the bandwidth of the antenna can be widened simply by increasing the thickness of the dielectric substrate. However, if we want to retain the advantage of keeping the CPW feed line and the radiation patch on the same surface, we will need to increase the substrate thickness of the feed line as well. This will result in a problem that the dimensions of the CPW feed line may be impractical for real applications. For example, if we want to design a CPA, which will operate at about 10 GHz and have an impedance bandwidth of about 10%, the thickness of the dielectric substrate ($\varepsilon_r = 2.17$) will be about 2.032 mm. Moreover, as shown in Fig. 1, the slots and centre conductor of the 50Ω conductor-backed coplanar waveguide (CBCPW) feed line will be 0.7 and 4.8 mm respectively. However, the diameter of dielectric core of a

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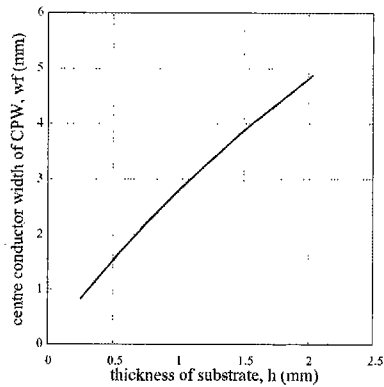4-2-1 Nukuikitamachi, Koganei-shi, Tokyo 184-8795

Fig. 1. Substrate thickness vs. centre conductor width of CPW(ε_r = 2.17, h = 2.032mm).
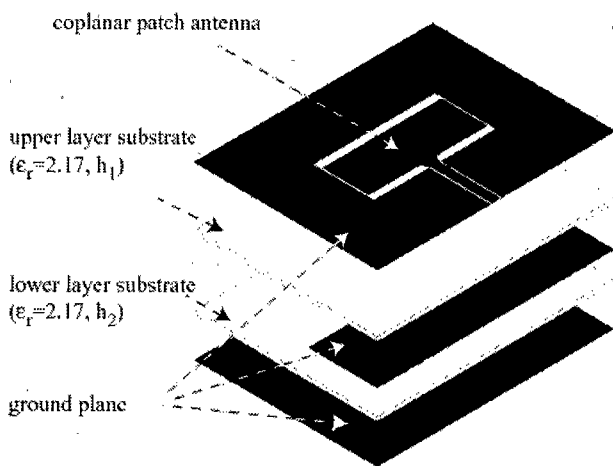

Fig. 2. Geometry of broadband double-layered coplanar patch antenna.

conventional SMA connector is only about 4.5 mm. It will be difficult to connect the antennas and the connectors without shorting the ground and centre conductor.

In this article, we have investigated a new kind of double-layered geometry (as shown in Fig. 2) that can increase the impedance bandwidth of the antennas and provide flexibility in the dimensions of the CPW feed lines at the same time. The double-layered structure allows the coplanar patch and CBCPW feed line to have different layer thickness. This advantage keeps the substrate thickness of the CBCPW feed line thin, i.e. lower centre strip conductor width to the total CBCPW feed line width ratio and lower dispersion. On the other hand, it does not limit the layer thickness of the coplanar patch, so wider impedance bandwidth can be achieved. Moreover, we can retain the uni-planar structure of the feed line and patch surface.

Then a parametric study of the gap distances between the coplanar patch and the top ground plane, and the width at the feed point will be presented. Finally, we proceed to the investigation to the characteristics of the CPAs that consist of different layer thickness combinations. The total thickness of the antennas was kept unchanged. The variations of the thickness combination provide convenience for circuit integrations, as the ratio R_{ws} can be controlled by changing the thickness of upper layer (h_1). Simulation was done by a commercial package Ansoft Ensemble.

h = h_1+h_2	0.508 + 0.508	W, L	28.6 x 9.15
s_f w_f s_f	1.0·1.6·1.0	L_f	17

2. Antenna Geometry and Design

2.1 Geometry The geometry of a broadband double-layered CPA was shown in Fig. 2. The antenna composed of two layers of DICLAD 880 dielectric substrate (ε_r = 2.17m tan δ = 0.00085@10GHz). The thickness of the upper and lower substrate was denoted as h_1 and h_2, respectively. A coplanar patch was located on the top of the upper layer. Energy from the input was fed to the coplanar patch thru the conductor-backed coplanar waveguide (CBCPW) connected to one of the radiating edge. Between the two substrates, there was a copper layer. The length of this middle copper layer equalled to the length of the feed line (L_f). The primary role of this copper layer was to provide a ground plane for the CBCPW feed line, so the substrate thickness of the feed line (h_1) could be different from that of the coplanar patch (h_1+h_2). Moreover, the antenna retained its own uni-planar structure. This extra ground plane could also control ratio of the centre strip conductor width to the total CBCPW feed line width (w_f / (wf+2_{sf})) by changing the thickness of the upper layer. At the back of the lower layer, there was the third ground plane, which was the ground plane of the coplanar patch. The three ground planes were connected by the left, right and bottom sidewalls of the antennas.

2.2 Parametric Study of the Gap Distances The unique parameters of a CPA were the gap distances (vertical: Ls and horizontal: Ws) between the coplanar patch and the top ground plane, so a parametric study have been carried out to investigate the effect caused by adjusting these two parameters first. Then the study of another parameter, the width of the feeding point (f) was carried out. The parametric study was based on the antenna of basic dimensions listed in Table 1. Before any adjustment, the width of Ls, Ws and f were 1.0, 1.0, 1.6 mm respectively, then the parameters were altered one by one, while the rest two remained at the original value.

In Fig 3, the effect of impedance by changing the vertical gap distance Ls was shown. The impedance of the CPA was decreased, as Ls was increased. In Fig. 4, we could see that the gain of the CPA was increased with Ls. There were two points worth mentioning here. First, when the gap distance Ls was smaller than the substrate thickness h, the gain of the antenna was unusually low.

Second, when Ls was increased beyond about 1.5 times of the substrate thickness, the gain of the CPA did not further increase.
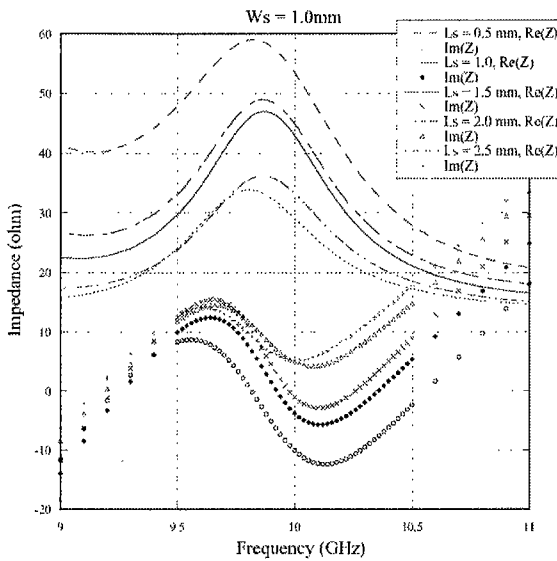
Fig. 3. Impedance of the CPA vs. frequency of different Ls. Ws = 1.0mm.

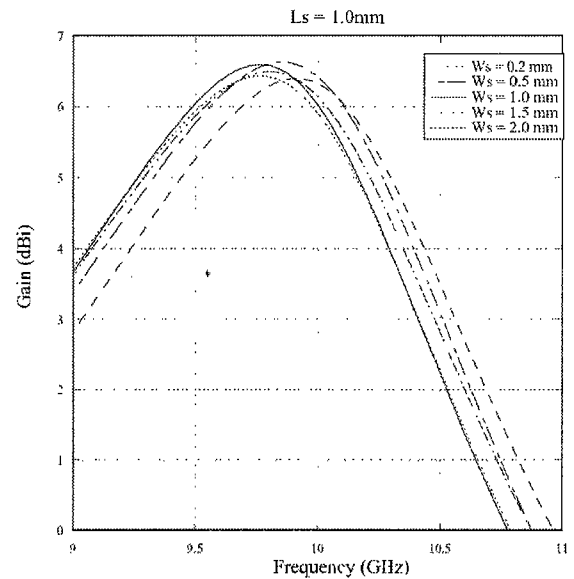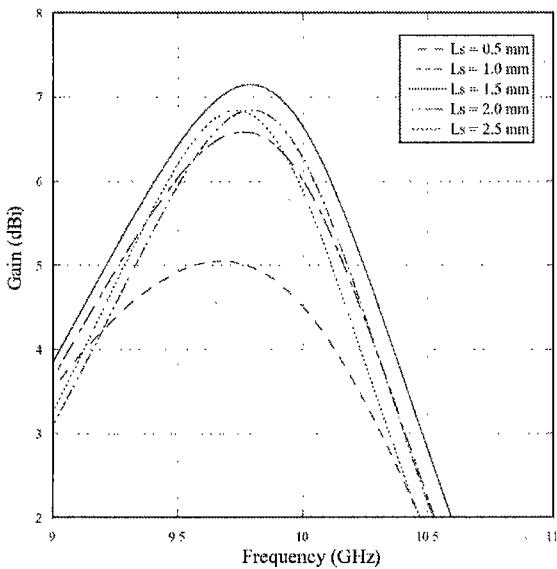Fig. 4. Gain of the CPA vs. frequency of different Ls. Ls = 1.0mm.

Fig. 5. Impedance of the CPA vs. frequency of different Ws. Ls = 1.0mm.
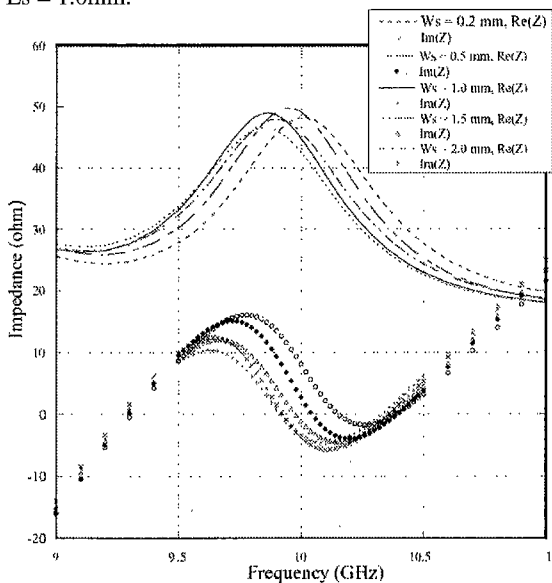

Fig. 6. Gain of the CPA vs. frequency of different Ws.

Moreover, the impedance was sensitive to Ls; it suffered a large fluctuation when Ls was changed, so in our design, the gap distance Ls, which gave the optimal gain, was investigated first.

Fig. 5 and 6 showed the variations of the impedance and gain caused by different horizontal gap distance Ws. Ws was useful for fine-adjusting the resonant frequency of the CPA, while the resonant frequency of the CPA was preliminary based on the length (L) of the coplanar patch. The resonant frequency of the CPA shifted to lower frequencies, when Ws was increased. On the other hand, Ws did not affect the gain of the CPA much.

The effect caused by the third parameter – the width of the feed point f was shown in Fig. 7 and 8. When the gap distances Ls and Ws of the CPA have been determined, the width f could be used for adjusting the impedance matching of the CPA. The impedance of the antenna was increased by increasing the width f, while the resonant frequency of the CPA can be kept unchanged (Fig 7). Furthermore, the width f can also been used to achieve the optimal impedance bandwidth of the antenna. Simulation result showed that the change of the width f has little effect on the gain of the antenna and the corresponding graph was not included for the conciseness of the article.

2.3 Investigation of Layer Thickness Combinations

Based on the knowledge of the different characteristics caused by the gap distance and the width f. Four test antennas (AUT A to D) were designed and fabricated to investigate the effect caused by different layer combinations. The total thickness h (= h_1+h_2) of the four antennas was all kept to 1.016 mm. The layer thickness combinations of AUT A to D were (0.254+0.762), (0.508+0.508), (0.762+0.254) and (1.016+0) mm respectively. AUT D actually was a single-layered coplanar patch antenna, which substrate thickness equalled 1.016 mm. The purpose of AUT D was to evaluate the effect caused by the double-layered structures. The other dimensions of the double-layered CPAs were tabulated in Table 2.

The antenna patterns were fabricated by using wet etching process. Less than 50 micrometer tolerance in dimension might be introduced during the fabrication process. Reflection coefficient S11 of the antennas was measured on a vector network analyser (HP8510C). Coaxial-to-CPW test fixture was used to
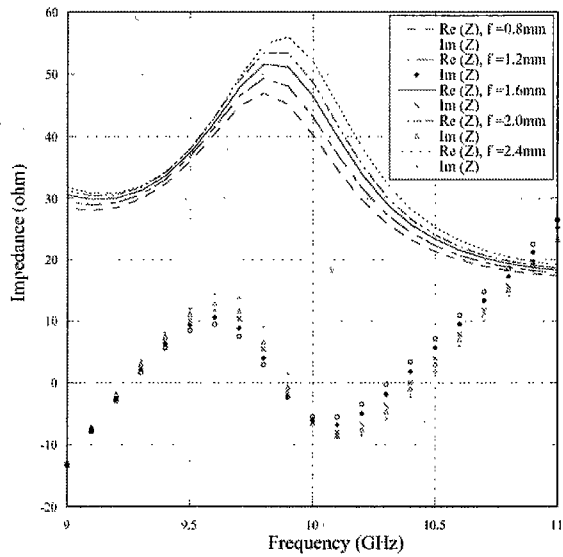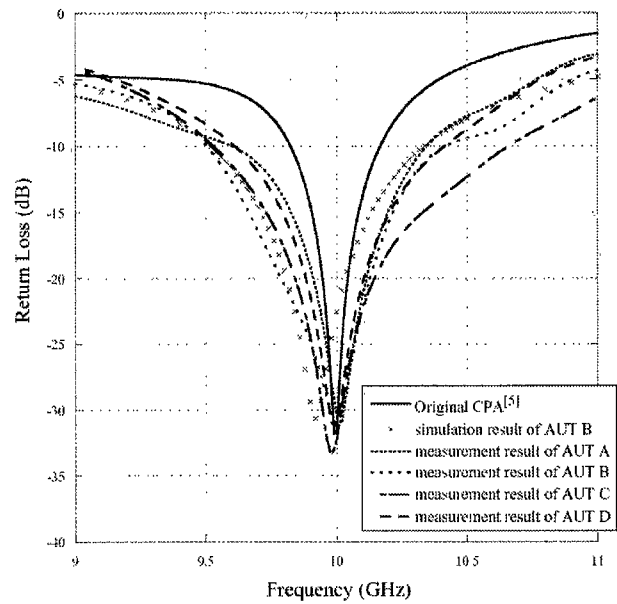
Fig. 7. Impedance of the CPA vs. frequency of different f.

Fig. 9. Return loss of the double-layered CPA.

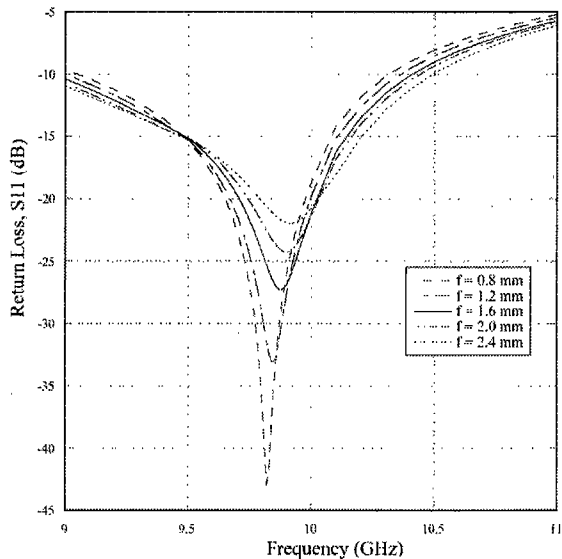
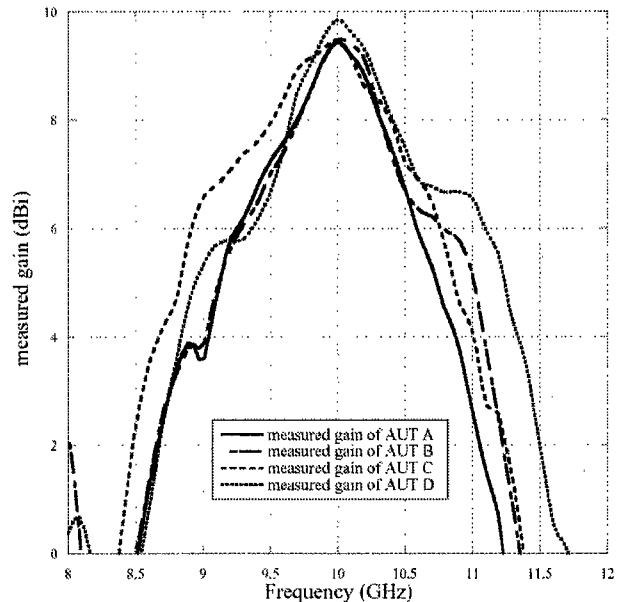Fig. 8. Return Loss of the CPA vs. frequency of different f.

Fig. 10. Gain of the double-layered CPA.

Table 2. Dimensions of the four testing antennas (in mm).

	AUT A	AUT B	AUT C	AUT D
h = h₁+h₂	0.254 + 0.762	0.508 + 0.508	0.762 + 0.254	1.016 + 0.0 (single-layered)
s_f·w_f·s_f	0.2-0.7-0.2	0.2-1.3-0.2	0.2-1.7-0.2	0.2-2.1-0.2
W, L	27, 9.1	27, 9.1	27, 9.1	27, 9.1
W_s, L_s	0.5, 2.0	0.5, 2.0	0.5, 2.0	0.5, 2.0
f	3.8	3.8	3.8	3.8
L_f	17.0	17.0	17.0	17.0

mount the testing antennas.

In table 2, we could see that the centre conductor width of AUT D equals 2.1 mm, while that of the coaxial-to-CPW test fixture was 2.2 mm. When doing the measurement, special attention has been paid on connecting the test fixture to the antennas. This was

also the reason that the total thickness of the antennas was fixed at 1.016 mm. The text fixture could not be used if we further increased the substrate thickness of the antennas, even wider impedance bandwidth would be achieved.

3. Results and Discussion

The measured return losses of the four test antennas were shown in Fig. 9. The resonant frequencies of the antennas were about 10.0 GHz. The impedance bandwidths were about 8.5%. The return loss of the ordinary single-layered coplanar patch antenna[5] was also shown for comparison (solid line). The substrate thickness of the original CPA was 0.508 mm. We could see that the bandwidths of the double-layered designs were about twice as large as the ordinary single-layered one, when we increased the thickness of the antennas from 0.508 mm to 1.016mm. From Fig. 9, we could also see that the derivation resonant frequency and impedance bandwidth between the

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(a)

(b)

(c)

(d)

—— H-plane co-polarization
✕✕✕✕ H-plane cross-polarization
- - - - E-plane co-polarization
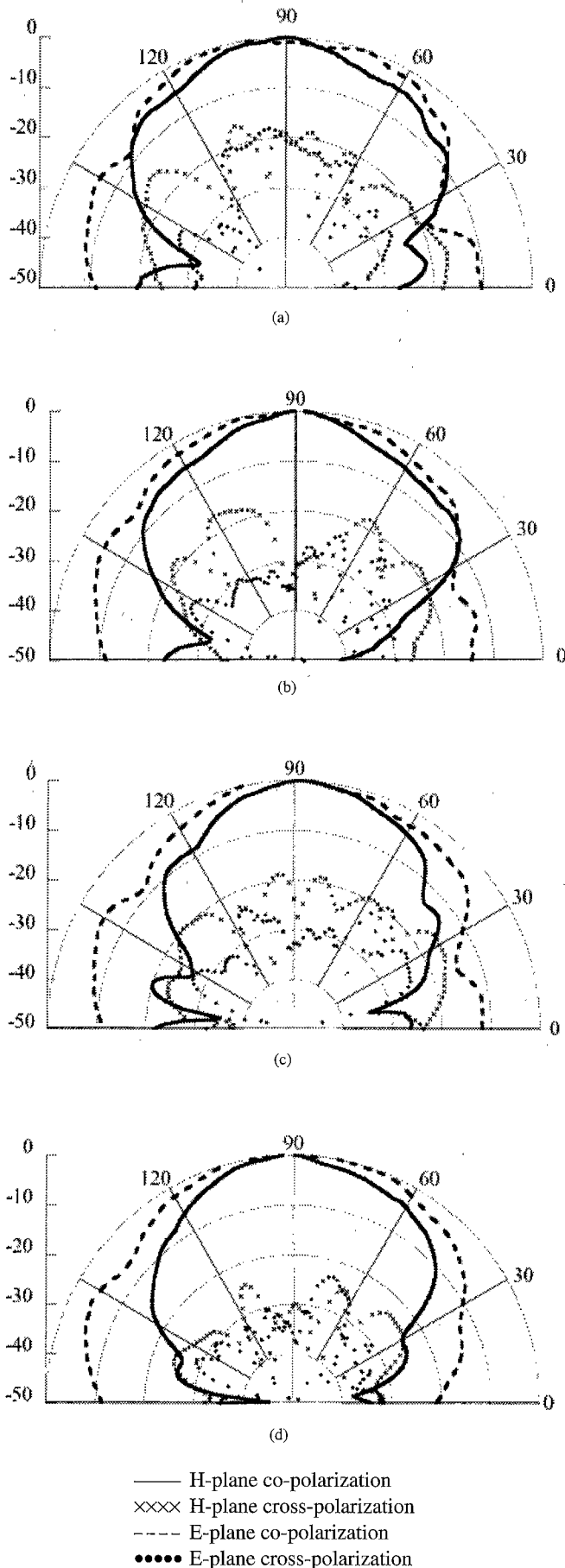●●●●● E-plane cross-polarization

Fig. 11.   Radiation patterns of the double-layered CPAs at
10 GHz (a) AUT A (b) AUT B (c) AUT C (d) AUT D

simulation and measurement results of AUT B were about 0.8%
and 9% respectively, which were considered reasonable.

Fig. 10 showed the gains of the antennas. For AUT A, B and C,
a maximum gain of 9.4 dBi was obtained at 10.0 GHz. The gain
of AUT D was 0.4 dBi higher than that of other three antennas
under test.

The radiation patterns of the antennas at 10 GHz were shown in
Fig. 11. The half-power beamwidths of the antennas were about
$40°$ and $67°$ in H-plane and E-plane respectively. The cross-
polarization levels were less than -18dB in both planes. The
asymmetry of E-plane radiation patterns were caused by the
connectors and the CBCPW feed lines connected to one of the
radiating edges of the antennas.

From Fig. 9, 10 and 11, we could observe that different
thickness combinations of the antennas changed the
characteristics of the antennas slightly, but it offered large
freedom in the input CBCPW feed line design and retained the
uni-planar structure of the antenna surface. It was an advantage
especially for circuit integrations.

4.   Conclusions

This article has presented a simple broadband method for
coplanar patch antennas. The double-layered structure allows
different layer thickness of the CBCPW feed line and the coplanar
patch. An extra ground plane was inserted between the two layers
plane, which controls the dimensions of the CBCPW without
affecting the performance of the antennas seriously. The
proposed structure can preserve the advantage of laying the CPW
feed line and the coplanar patch on the same surface, which make
the circuit integrations easier. A parametric study has been
carried out to provide useful information of the coplanar patch
antennas design. The impedance bandwidth of the antenna is
about 8.5%. The maximum gain of the antennas was 9.4 dBi
within the pass band. The radiation patterns were stable and the
maximum cross-polarization level of the antenna was about $-$
18dB.

(Manuscript received June 24, 2003, revised Sep. 24, 2003)

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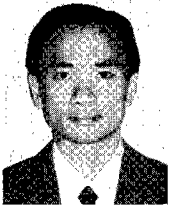
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