# Edge-Fed Patch Antennas With Reduced Spurious Radiation

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***Abstract*—In this paper, a technique to reduce the spurious feed radiation from edge-fed patch antennas by using a dual thickness substrate is presented. A thin microwave substrate is employed for the feed network, and then a transition is made to a thick substrate for the patch antenna element. The new feeding procedure allows the feed network and antenna elements to be optimized independently. Measured results on a single element prototype exhibit a reduction in the level of cross-polarized fields and decreased pattern distortion whilst preserving a reasonable impedance bandwidth. The technique is also proven to be beneficial in an array environment, as an extensive transmission line feed network is required. We present the theoretical and experimental results of a 1 × 8 edge-fed patch array that utilizes the dual thickness substrate configuration. Significant improvement in the radiation patterns and gain are observed for the new array compared to a standard edge-fed patch array.**

***Index Terms*—Cross polarization, microstrip arrays, microstrip patch antennas.**

## I. Introduction

EDGE-FEEDING a microstrip patch has several advantages over other direct contact and noncontact feeding techniques [1], [2]. One of the key attributes of this power distribution scheme is its ease of fabrication, as the feed network and radiating patches can be etched on the one board. Many large planar arrays have been developed using edge-fed patches due to this characteristic (for examples, see [3] and [4]). However, edge-fed microstrip patches typically have relatively narrow impedance bandwidths, in the order of a couple of percent of the resonant frequency. An established means of enhancing the bandwidth of an edge-fed patch is to use thicker substrates. Unfortunately this relatively simple method does have its drawbacks. An increase in the thickness of the microwave substrate results in an expansion in the width of the microstrip feed lines. Consequently, the structure generates additional spurious radiation (or feed radiation). This results in elevated levels of cross-polar radiation from the patch radiator, which can limit the performance of the antenna especially when it is configured in an array. For example, increasing the thickness by a factor of 2 can increase the bandwidth by a similar factor but also degrades the cross-polar radiation levels significantly [5]. The issues associated with arrays of co-planar fed patches have also been investigated [4]–[7]. In [6] it was shown that the mitered bends are significant contributors to cross-polarization levels [8] and that electrically thin arrays give better radiation performance. In [7] balanced feeding and using high impedance lines with tapered transitions were proposed to alleviate some of the cross-polarization issues associated with the feed network.

In this paper, a technique to alleviate this spurious radiation problem with edge-fed patches on thick substrates is investigated. Specifically, two variations of the same principal are explored: using a thinner grounded feed substrate and making a transition to a thicker substrate near the radiating patch; and an extension of this structure, where under the thin substrate a metal block is incorporated to improve ground plane continuity. It was found that the later method was required to prevent trapped energy beneath the ground plane of the thinner layer that decreased the radiation efficiency. Experimental verification of the proposed techniques is presented and compared to a conventional edge-fed patch etched on a thick, grounded substrate. To determine the behavior of the dual layer configuration in an array environment, an eight element linear array is also evaluated and compared to an equivalent edge-fed patch array on a thick microwave substrate. Significant improvement in the radiation performance of the dual thickness array was achieved compared to a conventional edge-fed array. The gain was increased by approximately 10 dB.

## II. Edge-Fed Patch Configurations

It is well known that the conflicting substrate requirements for increasing the bandwidth and mitigating unwanted feed radiation from edge-fed patch antennas present a design dilemma. A thick, low dielectric constant microwave laminate can be employed to achieve reasonable bandwidth (∼5%). However as the thickness of the substrate increases, the microstrip feed line must be broadened in order to maintain a 50 Ω impedance. This gives rise to elevated feed radiation, causing pattern distortion. To illustrate this phenomenon, we undertook a theoretical performance comparison of two edge fed patches on thin (1.575 mm) and thick (3.125 mm) Rogers RT/Duroid 5880 substrates. The antennas were analyzed using Ensemble 6.0. The results confirm that the use of a thick substrate can increase the impedance bandwidth to 3.4% (defined as being $< -10$ dB return loss) from approximately 2% when using the thin substrate. However, the level of H-plane cross-polarized radiation for the thick substrate case is about 6 dB higher for that of the thin substrate. The E-plane cross-polar radiation levels were negligible for both cases. Distortion of the E-plane co-polar pattern (>6 dB) for the thick case was observed, which is another consequence of the elevated level of spurious radiation. This form

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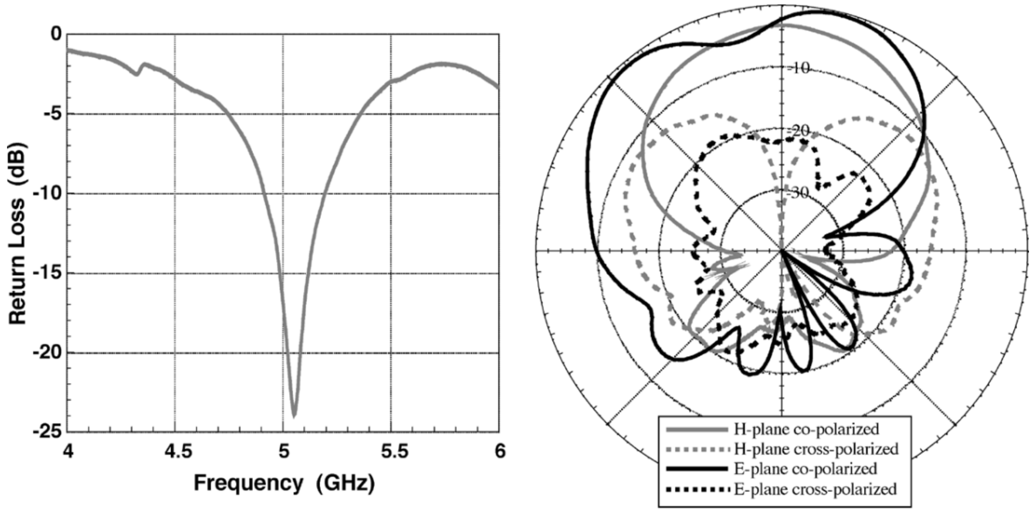


(a) (b)

Fig. 1. Measured performance of edge-fed patch antennas on a thick substrate: (a) return loss and (b) radiation patterns.

of pattern distortion is particularly evident when truncated substrates are used to realize the antenna.

To validate the simulated results, the edge-fed patch on a 3.125 mm thick substrate was fabricated and tested. The microstrip patch element dimensions were 20.3 $\times$ 20.3 mm. The microstrip feed line had a width of 9.4 mm, and was inset into the patch element a distance of 7.1 mm. The ground plane and substrate measured approximately 100 $mm^2$. Fig. 1 displays the measured performance of the antenna. The return loss plot in Fig. 1(a) shows that the antenna exhibits an impedance bandwidth of approximately 5%. This exceeds the simulated result that predicted a bandwidth of 3.4%. In the analysis, dielectric losses were not included, which can contribute to the observed discrepancy. As was the case in the theoretical examination, the radiation results for the edge-fed patch antenna on a thick substrate in Fig. 1(b) show severe distortion in the E-plane co-polarized pattern caused by excessive feed radiation. Highly elevated levels of cross polarization are also evident in both the E- and H-planes.

To alleviate the predicament of increased feed radiation when designing these antennas on thick substrates, we propose an edge-fed patch with a dual thickness substrate. The majority of the microstrip feed line resides on thin dielectric layer with a ground plane directly underneath, requiring a thin track to achieve 50 $\Omega$ characteristic impedance. A transition is then made to a thick substrate for a short section microstrip line and the patch antenna element.

One of the original concerns of the new edge-fed antenna design was the transition from the thin microstrip transmission line to the thicker substrate line required to feed the patch antenna. Because of the physical discontinuity associated with the different transmission line widths, it was assumed that this could dramatically degrade the cross-polarization levels of the new antenna. To circumvent this, the impedance of the feed line directly connected to the patch element was made larger (100 $\Omega$ was selected) thereby allowing for a thinner width line, and in the process, reduce the physical discontinuity. A quarter-wave transformer was incorporated on the thin substrate material to

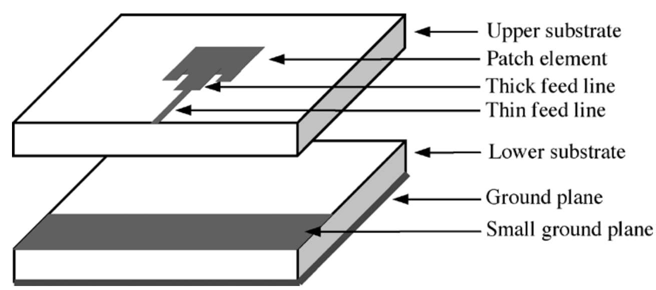


Fig. 2. Initial dual thickness edge-fed patch antenna structure.

match this higher impedance to the 50 $\Omega$ microstrip line on the thin material. The insert of the patch was also adjusted to ensure the impedance of the antenna at the operation frequency was 100 $\Omega$. Interestingly, it was found that the cross-polarization levels for the quarter-wave transformer case were of the same order as when the physical discontinuity was ignored. This could be attributed to the quarter-wave transformer contributing to the radiated fields. As there was little to gain using the transformer, the straight transition was utilized due to the smaller area required to realize the antenna.

Initially, the new edge-fed antenna was realized using two sheets of 1.575 mm thick Rogers RT/Duroid 5880 measuring approximately 100 $mm^2$, as shown in Fig. 2. The lower substrate consisted simply of a ground plane spanning the entire bottom surface. The upper substrate supported the patch element, and the two sections (thin and thick) of feed line on the top surface, and a small ground plane under the thin section of feed line on the reverse side. The two ground planes were joined together by the flange of an SMA connector mounted at the edge of the substrates. One issue that arises with the ground planes connected in this way is that it is difficult to equalize their potential, particularly at the transition. This can cause excessive field diffraction at the transition, and excite parallel plate modes between the two ground planes. Another consequence is the likelihood of coupling diffracted energy from a truncated substrate to the parallel plate mode decreasing the overall efficiency of the radiator.

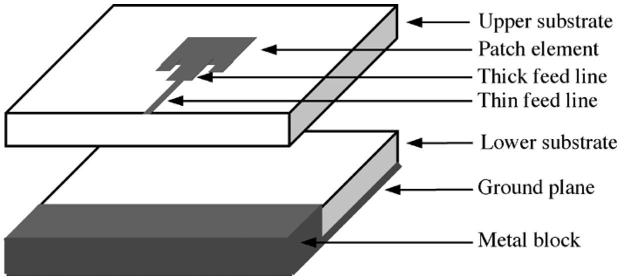


Fig. 3. Dual thickness (with metal block) edge-fed patch antenna structure.

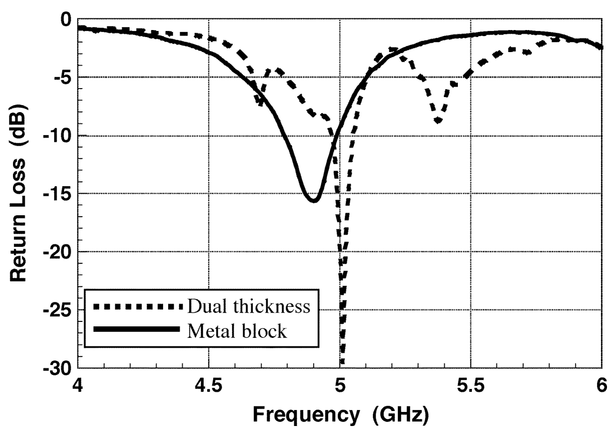


Fig. 4. Measured return loss of the different dual thickness configurations.

To improve the continuity of the ground plane at the transition, the second prototype had a metal block inserted below the small ground plane (see Fig. 3). The lower substrate was trimmed to accommodate the metal block. The two ground planes and the SMA connector were affixed to the metal block with solder, forming a three-dimensional (3-D) ground plane. This configuration also removes the parallel plate structure between the ground planes of the previous design.

## III. Measured Performance of the Dual Thickness Edge-Fed Patch

Fig. 4 compares the measured return loss of the two dual thickness edge-fed patch configurations (with and without the metal block). The initial dual thickness edge-fed patch antenna shows a diminished bandwidth ($\sim$2%), and spurious resonances are observed due to parallel plate mode generation and field diffraction at the feed line transition. However, when the metal block was inserted below the small ground plane and the antenna parameters were optimized, a clean impedance response was observed with a bandwidth in excess of 4%.

The measured far field radiation patterns for the two dual thickness architectures are given in Fig. 5. Both plots have been normalized to the same gain level. For the initial dual thickness antenna in Fig. 5(a), the field diffraction at the transition produces acute deformation of the co-polarized patterns and highly elevated levels of cross-polarization. With the metal block under the small ground plane [Fig. 5(b)] substantially lower cross-polarization is observed in the E- and H-planes, and the front to back ratio is improved.

## IV. Dual Thickness Array

The performance of patch antenna arrays can greatly benefit from a reduction in spurious feed radiation, and hence, lower cross-polarization levels. To illustrate this, two $1 \times 8$ patch antenna arrays were evaluated using Ensemble. The first array is a conventional edge-fed patch array on a 3.125 mm thick Rogers RT/Duroid 5880 substrate. The dimensions of the microstrip patch elements were $20.3 \times 20.3$ mm, and the inter-element spacing was 48 mm (0.8 $\lambda_o$ at 5 GHz). The 50 $\Omega$ sections microstrip feed line had a width of 9.5 mm, and the inset into the patch element a distance of 7.1 mm. The 100 $\Omega$ and impedance transformation sections in the array feed network has widths of 2.73 and 5.38 mm, respectively. The ground plane and overall array size was $405 \times 150$ mm.

An array of dual thickness edge-fed patch elements was also developed. The array uses the dual thickness (with metal block) antenna from Section III as a unit element. The patch dimensions, inter-element spacing, and overall size are similar to those of the conventional array. The 50 $\Omega$ patch feed line extends 8.9 mm past the edge of the patch, before making the transition to the thin substrate 50 $\Omega$ line that has a width of 4.9 mm. The 100 $\Omega$ and impedance transformation sections on the thin substrate have widths of 1.41 and 2.78 mm, respectively. First we looked at the current distribution on both arrays. We found that for the new configuration the maximum current densities were confined to the patch elements, whereas for the traditional feeding procedure 'resonant effects' were associated with the physically wide feed lines.

The predicted far field radiation patterns at 5 GHz for the $1 \times 8$ edge-fed patch arrays on a thick substrate are given as Fig. 6(a). The 3 dB beamwidth in the H-plane of the antenna is approximately 10°, with a gain of 9.5 dBi. The cross-polar pattern in the H-plane shows a null at broadside, but increases to considerable levels away from broadside. The cross-polar radiation in the E-plane is negligible. The predicted radiation patterns in Fig. 6(b) for the $1 \times 8$ array at 5 GHz with a dual thickness substrate show superior results to those of Fig. 6(a). The 3 dB H-plane beamwidth is approximately 9°, and the gain is 15.0 dBi. The increased gain is brought about by the efficient delivery of power to the patch elements by the feed network, as stated previously. The H-plane cross-polar radiation is also significantly reduced away from broadside by around 10 dB. At broadside, the H-plane cross-polar level is still very low ($\sim -35$ dB). The E-plane cross-polarized fields are higher than those in Fig. 6(a) due to low levels of diffracted fields at the ground plane transition between the thin and thick substrates. However, the cross-polarized fields are still more than 30 dB below the broadside co-polar level. Note that the sidelobes in the H-plane have also been reduced, particularly the second and third sidelobes.

The microstrip arrays were fabricated and tested. The measured return loss responses for the conventional and the new dual thickness edge-fed arrays are shown in Fig. 7. The 10 dB return loss bandwidth for the conventional array is 5.6% centered at approximately 5 GHz. The bandwidth for the new array is 12%. A broadening of the impedance bandwidth is a common characteristic of incorporating 'resonant style' antennas into an array [5].

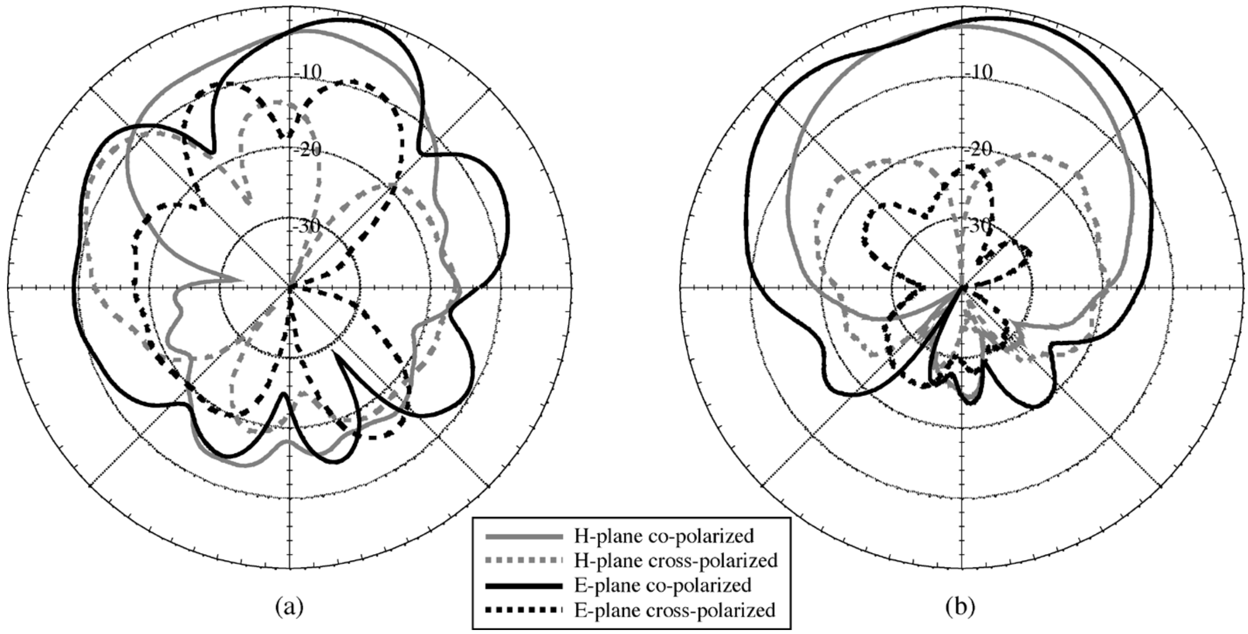


Fig. 5. Measured radiation patterns of the different configurations: (a) dual thickness and (b) metal block.

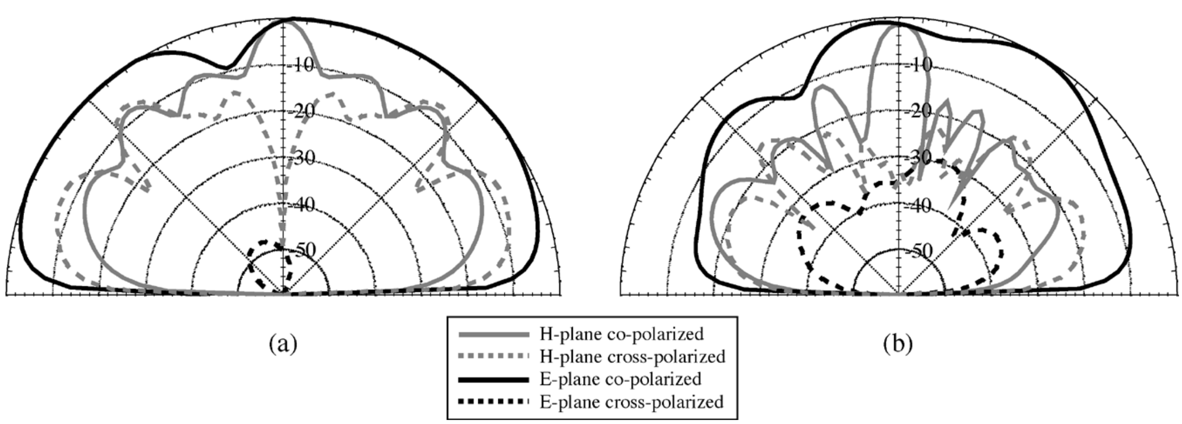


Fig. 6. Theoretical radiation patterns of the 1 × 8 array configurations: (a) thick substrate and (b) dual thickness substrate array.

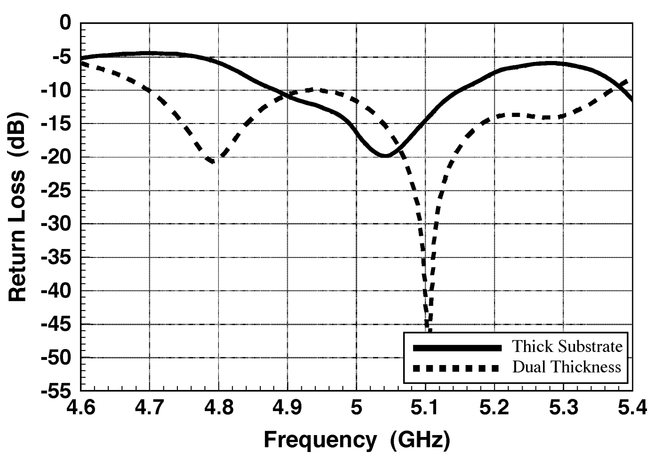


Fig. 7. Measured return loss of the conventional array and the new dual thickness array.

The measured H-plane radiation patterns of the conventional array and the dual thickness edge-fed array are shown in Fig. 8 at 5.0 and 5.1 GHz, respectively. These patterns are normalized with respect to 14.5 dBi; the maximum measured gain of the dual thickness array. As can be seen from the measured patterns, the dual thickness edge-fed array has dramatically improved the radiation performance. The discrepancy in the measured and theoretical results for the conventional array can be attributed to the finite ground-plane (405 mm × 150 mm) not being modeled in the analysis. As stated previously and also evident in Fig. 8, there is significant interaction between the truncated substrate edges and the wide feed lines used to excite the array. As the dual thickness array configuration reduces the radiation from the feed lines and therefore any interaction between the feed and the truncated substrate, the predicted results are in closer agreement with the measured response. The measured gain is within 1 dB of the predicted value. The measured E-plane patterns are shown in Fig. 9, once again normalized to 14.5 dBi. As was the case for the single element patterns shown in Fig. 5, there is significantly less pattern scalping for the new feed arrangement.

The ideal directivity of a 1 × 8 patch array at approximately 5 GHz with the given element spacing is 17.6 dB. Taking into consideration surface wave losses of the material (1 dB), for the new antenna the total loss attributed to the feed network, diffraction and input impedance mismatch, is approximately 2.1 dB.

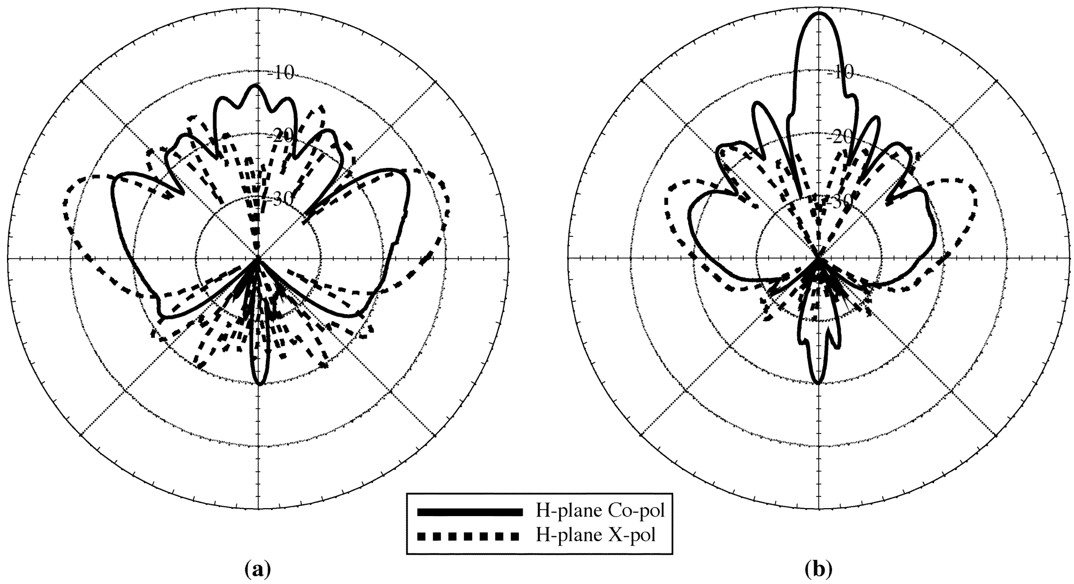


Fig. 8. Measured H-plane radiation patterns of the: (a) conventional array and (b) dual thickness array.

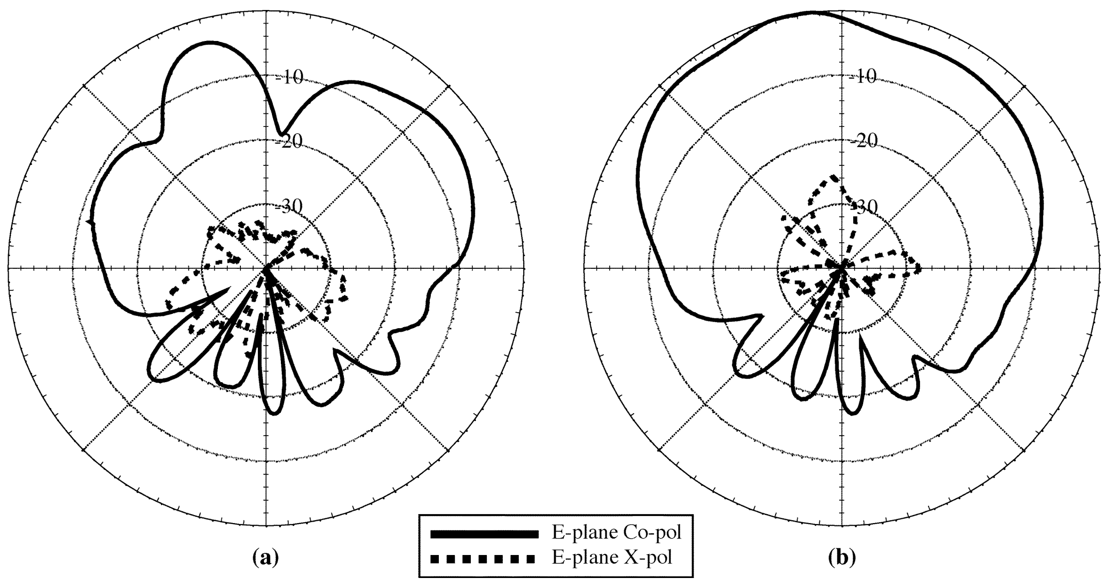


Fig. 9. Measured E-plane radiation patterns of the: (a) conventional array and (b) dual thickness array.

The conventional feeding technique is significantly worse: the equivalent loss is greater than 8 dB, highlighting the usefulness of our proposed procedure.

## V. Conclusion

A method to reduce the spurious feed radiation from edge-fed patch antennas by using a dual thickness substrate is presented. The technique utilizes a thin microwave substrate for the feeding transmission line network, and then makes a transition to a thick substrate for the patch antenna element. Measured results on single element patches show decreased pattern distortion and diminished cross-polarized fields whilst maintaining a reasonable impedance bandwidth.

Also presented in this paper are theoretical and experimental results of the new dual thickness substrate edge-fed patch array. Due to the extensive feed network of these arrays, this technique has been shown to be extremely beneficial in reducing the overall level of cross-polarized fields and sidelobes, and enhancing the gain. It is worth noting that although the spurious feed radiation, which contributes to cross-polarization and side-lobe levels, has been reduced; it cannot be completely eliminated because spurious radiation from a coplanar feed circuit is an unavoidable problem [5], [6].

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