A Novel Technique for Increasing the Scanning Range of Infinite Arrays of Microstrip Patches

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Abstract—**A novel technique to reduce the magnitude of the active reflection coefficient at large scan angles for microstrip patch arrays is proposed. The method involves loading each element of the array with a varactor diode and then varying the bias to the varactor in order to reduce the impedance mismatch at the appropriate scan angle. A rigorous full-wave analysis in conjunction with an equivalent circuit model of the varactor diode was implemented to analyze the proposed loaded patch array. Significant improvement in the scan performance of the array was predicted using this technique.**

I. Introduction

Microstrip patches are the new generation of antennas due to their many attractive features [1]. A simple but effective means of increasing the inherent narrow bandwidth of microstrip patch resonators is to use thick substrate material. However this method also increases the likelihood of scan blindnesses in large arrays of microstrip elements and also increases the mutual coupling between the elements.

In this paper, a novel technique that reduces the effect of mutual coupling on the scanning range of probe-fed microstrip patches is presented. Each element of the infinite array is loaded with a varactor diode, which in turn is biased to reduce the reactive impedance mismatch caused by the coupling between elements at large scan angles. The rigorous full-wave spectral domain analysis presented in [2] was implemented to accurately analyze the loaded patch array. A comparison of the scan active reflection coefficients for the unloaded and loaded case for different substrate relative permittivities and thicknesses are presented. The efficiency of the radiators when loaded with a varactor diode is also investigated.

II. Scan Impedance Behavior of Probe-Fed Patch Array

A thorough understanding of the scan behavior of a microstrip array of probe-fed patches can be obtained by examining the input impedance variation of the element considered in the infinite array as a function of the scanning angle, θ. This requires accurate knowledge of the current variation on the probe feed and the currents generated by the discontinuity between the feed and the patch [3]. Fig. 1 shows the real and imaginary components of the input impedance of two infinite arrays when scanning in the E-plane, using the analysis presented in [3]. The size and probe position of the microstrip patch in each array have been optimized for 50 Ω resonance (the figure caption gives the dimensions for both cases and the reader is referred to [2] and [3] for the array layout). The probe-fed patch array mounted on the substrate of dielectric constant, $\epsilon_r = 2.55$ and thickness, $d = 0.06\lambda_0$ (case A) exhibits a poor scan performance for angles greater than 72° while the array etched on the substrate of dielectric constant, $\epsilon_r = 12.8$ and height, $d = 0.05\lambda_0$ (case B) has limited scanning potential for $\theta > 54°$. The poor scan impedance behavior of both arrays at large scan angles is primarily due to the large reactance component of the input impedance (see Fig. 1).

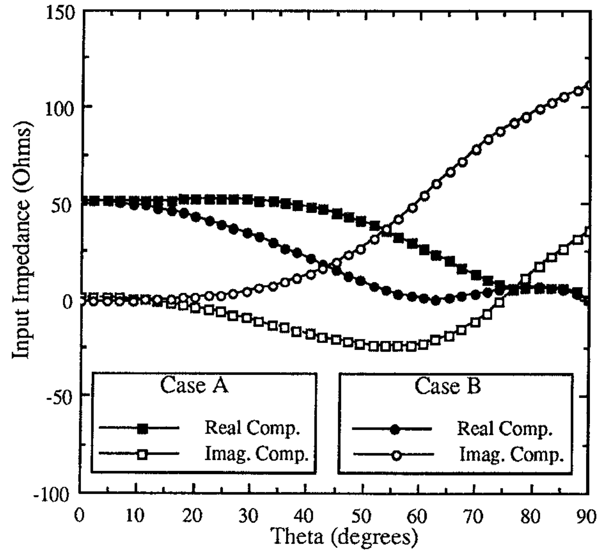

Fig. 1. Scan impedance variation for two infinite arrays of probe-fed patches (parameters: Case A: $\epsilon_r = 2.55$, $d = 0.06\lambda_0$, $L = 0.29\lambda_0$, $W = 0.28\lambda_0$, $x_p = 0.081\lambda_0$, $y_p = 0$, $r_0 = 0.015\lambda_0$; Case B: $\epsilon_r = 12.8$, $d = 0.05\lambda_0$, $L = 0.113\lambda_0$, $W = 0.15\lambda_0$, $x_p = 0.034\lambda_0$, $y_p = 0$, $r_0 = 0.0004\lambda_0$; for both cases $a = b = 0.5\lambda_0$) (note: comp. represents component)

III. Technique for Extended Scan Performance

Consider an infinite array of probe-fed patches each loaded with a varactor diode. Fig. 2 shows the unit cell of this loaded array and also the equivalent circuit of the varactor diode. To analyze such an array, the rigorous full-wave spectral domain analysis presented in [2] was implemented. In this analysis the diode is replaced by a metallic pin of the same radius and the pin is subsequently loaded by the equivalent impedance of the diode. Details of the analysis can be found in [2].

Fig. 3 shows the real and imaginary components of the input impedance of two infinite arrays of loaded probe-fed

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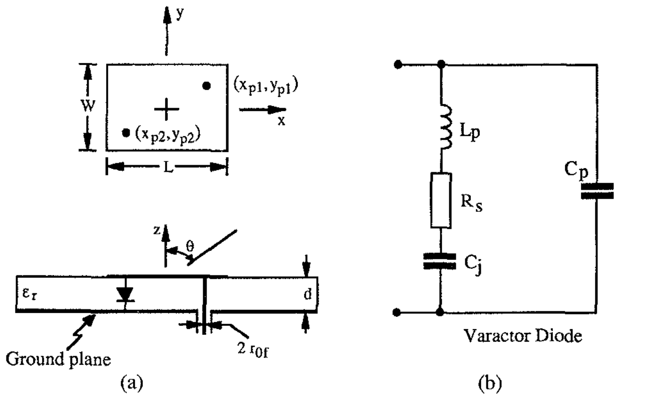

Fig. 2. (a) Schematic illustration of probe-fed rectangular microstrip patch loaded with varactor diode and (b) Equivalent circuit diagram of varactor diode

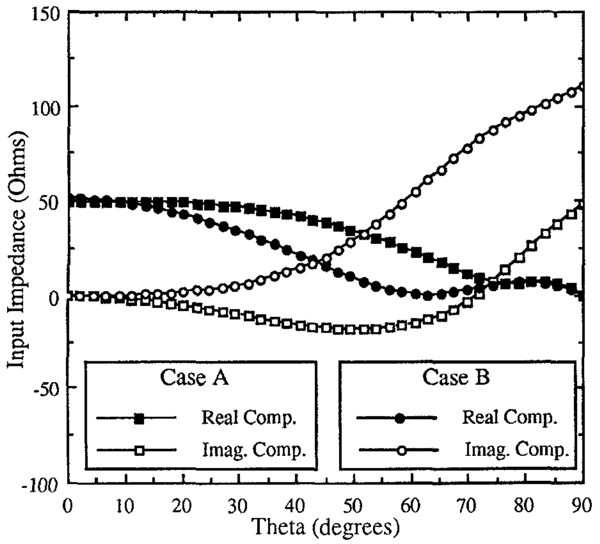

Fig. 3. Scan impedance variation for two infinite arrays of probe-fed patches loaded with varactor diodes (array parameters, Case A: $\epsilon_r = 2.55$, $d = 0.06\lambda_0$, $L = 0.287\lambda_0$, $W = 0.28\lambda_0$, $x_{p1} = -x_{p2} = 0.085\lambda_0$, $y_p = 0$, $r_0 = 0.0004\lambda_0$; Case B: $\epsilon_r = 12.8$, $d = 0.05\lambda_0$, $L = 0.11\lambda_0$, $W = 0.15\lambda_0$, $x_{p1} = -x_{p2} = 0.0325\lambda_0$, $y_p = 0$, $r_0 = 0.0004\lambda_0$; for both cases, $a = b = 0.5\lambda_0$; diode parameters : $f = 7.0$ GHz, $R_s = 7.0\Omega$, $L_p = 0.1$ nH, $C_p = 0.2$ pF) (note: comp. represents component)

patches mounted on the substrates given in Fig. 1. The frequency of operation is 7.0 GHz and the varactor diode is positioned symmetrically opposite the coaxial feed to reduce the cross polarization levels [2]. The diode parameters used in the calculation are given in the figure caption. The bias to each diode is quite high, corresponding to a junction capacitance of 0.06 pF. As can be seen from Fig. 3, the parameters of each array have been optimized for 50 Ω resonance and the scan impedance behavior for both arrays are similar to those presented in Fig. 1. However one distinct advantage of this configuration becomes evident, namely that the load impedance can now be varied and thus the impedance mismatch at large scan angles can be reduced.

Fig. 4 shows a comparison of the active reflection coefficient for cases A and B when the patches are unloaded (see Fig. 1 caption for dimensions) and when each patch is loaded with

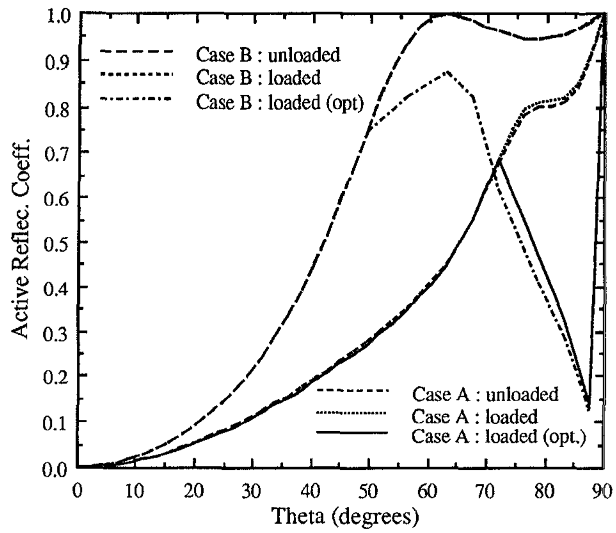

Fig. 4. Comparison of E-plane active reflection coefficient for arrays presented in Figs. 1 and 3 and also the loaded cases optimized (opt.) to reduce the active reflection coefficient after a particular scan angle

a varactor diode (see Fig. 3 caption for dimensions). Also shown in this figure are the active reflection coefficients for the two loaded cases where the bias level to the diode is kept constant until a particular scan angle, after which the bias is optimized to both minimize the magnitude of the reflection coefficient and ensure that the power dissipated in the diode is not too large. For the optimized loaded case A, the varactor diode is biased such that the junction capacitance is 0.06 pF for scan angles less than 72°. For angles greater than this, the bias to the diode is optimized to minimize the reflection coefficient at the particular scan angle. A similar technique is incorporated for case B, with the scan angle (where the junction capacitance is varied to minimize the reflection coefficient) set to 50°. As can be seen from Fig. 4, the overall scan performance for both cases has been significantly improved, particularly at large scan angles.

As described in the previous paragraph, not only is the scan impedance behavior of the array important, but the power dissipated in the diode to achieve improved scan behavior must also be considered. For example, the active reflection coefficient at a scan angle of 58° for the loaded case B can be reduced to 0.1 if the junction capacitance is set to 1.0 pF; however, the efficiency of the radiator would be less than 40%, as a significant amount of power is dissipated in the diode. For the results presented in the Fig. 4, the maximum junction capacitance used was 0.6 pF. Using the definition of antenna efficiency due to the diode provided in [2] and [4], the efficiency of each loaded patch in case A was greater than 88% for scan angles less than 75° and no less than 85% for scanning at $\theta > 78°$ (until endfire). For case B, at all scan angles (with the exception of endfire and near the scan blindness) the efficiency of each loaded patch was greater than 95%. These results indicate that there is less power dissipated in the diode for the high dielectric constant case due to the large reactive nature of the impedance

TABLE I
ANTENNA EFFICIENCIES FOR OPTIMIZED LOADED CASES A AND B (NOTE: θ_{SB} REPRESENTS THE SCAN BLINDNESS ANGLE FOR THE PARTICULAR ARRAY CONFIGURATION)

	$\eta < \theta_{SB}$	$\eta > \theta_{SB}$
Case A	$> 88\%$	$> 85\%$
Case B	$> 95\%$	$> 95\%$

mismatch. It is important to note that at scan angles near the potential blindness ($\theta \approx 76^\circ$ and $\theta \approx 63^\circ$ for cases A and B respectively), the antenna efficiency is very low (less than 20%). This is due to the TM_0 surface wave mode coupling to the diode in a similar manner to the way in which it couples to the probe feed [3], resulting in considerable power being dissipated in the diode, even for high bias levels. To overcome this effect, the technique proposed in [2] to improve the array performance at potential scan blindness angles could be implemented. Table I summarizes the antenna efficiencies for both cases.

IV. CONCLUSIONS

A novel method for improving the scanning range of infinite arrays of probe-fed microstrip patches has been presented. The technique involves involves loading each element with a varactor diode. A full-wave analysis to simulate infinite arrays of varactor diode loaded patch elements was implemented and significant improvements in the scan impedance behavior of such arrays have been predicted.

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