for the phases of a small number of elements, Electron Lett 37 (2001), 1495–1497.
3. P. López, J.A. Rodríguez, F. Ares, and E. Moreno, Low sidelobe level in almost uniformly excited arrays, Electron Lett 36 (2000), 1991–1993.
4. J.F. Deford and O.P. Gandhi, Phase-only synthesis of minimum peak sidelobe patterns for linear and planar arrays, IEEE Trans Antennas Propagat AP-36 (1988), 191–201.
5. R.L. Haupt, Optimum quantised low sidelobe phase tapers for arrays, Electron Lett 31 (1995), 1117–1118.

WIDEBAND DIELECTRIC RESONATOR-LOADED SUSPENDED MICROSTRIP PATCH ANTENNAS

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ABSTRACT: *Experimental investigations of rectangular and circular suspended microstrip patch antennas with dielectric resonator loading at X-band are reported. With loading, enhanced impedance bandwidth to about 18% is achieved in a single circular patch as compared to 13% for a single rectangular patch. In both cases, with loading, there is practically no change in the respective 3-dB beam widths of the radiation patterns in E- and H-planes.* © 2003 Wiley Periodicals, Inc. Microwave Opt Technol Lett 37: 300–302, 2003; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.10900

Key words: *suspended microstrip; rectangular and circular patch antennas; dielectric resonator loading*

1. INTRODUCTION

Microstrip patch antennas, particularly with rectangular and circular patches, are widely used in airborne systems, mobile radio, and a variety of other wireless communications devices for which small size, light weight, and low profile are the main considerations. As is well known, a major attribute that has limited their application capability is their inherent narrow impedance bandwidth (typically 2% to 3%). In certain applications, such as high data-rate wireless transmission, this low bandwidth is not adequate. In order to meet the demand for larger bandwidth, several techniques have been reported [1–6]; the most commonly employed technique is increasing the height of the patch above the ground plane by using a multi-layer dielectric [1]. The simplest and most widely used structure in this category is the suspended microstrip which, in view of the air gap next to the ground plane, offers improved efficiency. The suspended microstrip patch antennas offer a bandwidth of about 5% to 6%. Preliminary investigations by the authors on a single rectangular patch with recessed feed in suspended microstrip have shown an impedance bandwidth of about 12% with dielectric resonator (DR) loading [7]. In this paper, we present an experimental study to compare the effect of DR loading on rectangular patch antennas with that on circular patch antennas, both in suspended microstrip configurations with identical parameters.

2. DESIGN AND EXPERIMENT

Figure 1 shows the geometry of dielectric resonator-loaded rectangular and circular patch antennas in suspended microstrip configuration. The suspended microstrip uses a substrate (GML1000) of thickness $d = 0.508$ mm and relative dielectric constant $\varepsilon_r = 3.05$. The air gap between the substrate and the ground plane is $a = 0.25$ mm. The parameters of the suspended microstrip were kept fixed for all the antennas. Two different disk-shaped dielectric resonators (from Trans-Tech) were used in the experimentation. Their dimensions and resonant frequencies (f_{dr}) are as follows: for dielectric resonator 1 (DR1), $D = 5$ mm, $H = 3.1$ mm, and $f_{dr} = 10.26$ GHz; for dielectric resonator 2 (DR2), $D = 5$ mm, $H = 3.37$ mm, and $f_{dr} = 10$ GHz.

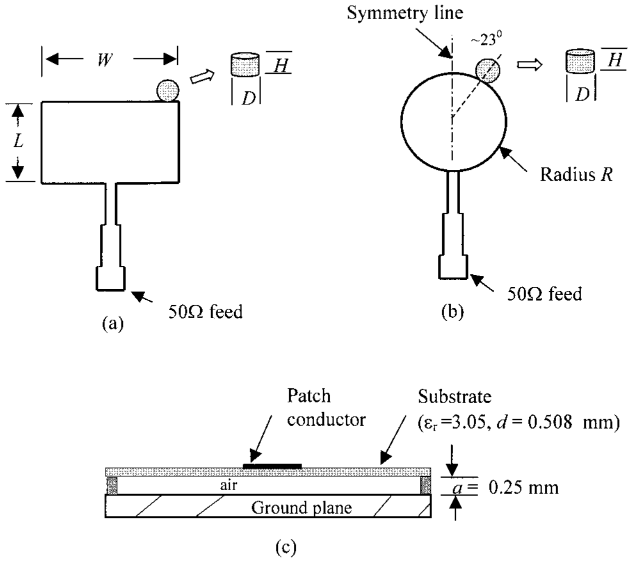


Figure 1 Geometry of DR-loaded suspended microstrip antennas: (a) layout of rectangular patch showing position of DR; (b) layout of circular patch showing position of DR; (c) cross section of suspended microstrip

For holding the dielectric resonator at the experimentally optimized position, a thin layer of conducting epoxy was used. A two-section binomial matching transformer was used to match to the 50Ω feed line, so that the matching transformer does not limit the bandwidth of the antenna when loaded with the dielectric resonator.

2.1. Rectangular Patch Antenna

Keeping the suspended microstrip parameters d, ε_r, and a fixed, several rectangular patch antennas were designed corresponding to different resonant frequencies in the range 9–11 GHz. The resonant length of the patch was calculated using the standard formula

$$L = \frac{v_0}{2f_0\sqrt{\varepsilon_{eff}}} - 2\Delta, \tag{1}$$

where $\varepsilon_{\mathrm{eff}}$ is the effective dielectric constant of the suspended microstrip, f_0 is the resonant frequency of the antenna, v_0 is the free space velocity and Δ is the end correction. The expression for end correction is given by [8]:

$$\frac{\Delta}{h} = 0.412\left(\frac{\varepsilon_{eff} + 0.3}{\varepsilon_{eff} - 0.258}\right)\left(\frac{\frac{w}{h} + 0.262}{\frac{w}{h} + 0.813}\right), \tag{2}$$

TABLE 1 Measured Parameters of Rectangular and Circular Patch Antennas in Suspended Microstrip with DR Loading and with DR Removed

	Rectangular Patch		Circular Patch	
	L = 11 mm, W = 10.18 mm, With DR1	With DR1 removed	R = 6.13 mm, With DR2	With DR2 removed
Res. freq. (GHz)	10.36	10.5	9.14	9.98
10-dB return loss bandwidth (GHz)	1.3 [13%]	0.38 [3.6%]	1.65 [18%]	0.28 [2.8%]
3-dB beamwidth in E-plane, H-plane	55°, 70°	55°, 70°	65°, 70°	62°, 70°

Refer to Fig. 1(c) for suspended microstrip.

where $h = (a + d)$ is the height of the patch above the ground plane. The resonant frequencies were measured for several antennas and the experimentally deduced correction was then used to redesign and fabricate the antennas.

Return loss and impedance characteristics were studied by taking measurements on a Network Analyzer for several patch antennas with and without the DR loading. The optimum position of the DR that gave the best return loss and maximum bandwidth was located. The E- and H-plane radiation pattern measurements were also made on the antennas with and without the DR.

2.2. *Circular Patch Antenna*

Keeping the same set of suspended microstrip parameters (d, ε_r, and a) as given in Figure 1, several circular patch antennas were designed for operation in the frequency range 9–11 GHz. The radius R of the circular patch is calculated by extending the standard cavity model formula, reported for microstrip [9], to the suspended microstrip configuration, given by

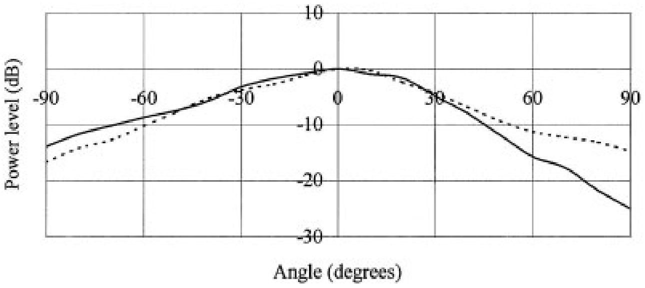
$$R = F\left[1 + \frac{2h}{\pi\varepsilon_{eff}F\left\{\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right\}}\right]^{-1/2}, F = \frac{8.791 \times 10^9}{f_0\sqrt{\varepsilon_{eff}}}, \tag{3}$$

where h is in cm and f_0 is in Hz. For a specified resonant frequency, the radius R (in cm) and the effective dielectric constant ε_{eff} are calculated in an iterative manner. The value of ε_{eff} is calculated by approximating the patch diameter $2R$ as a square of side $2R$.

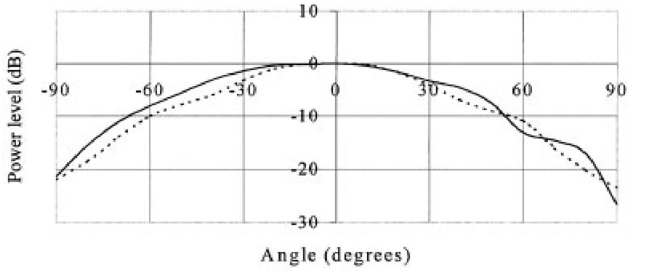
Experimental studies were carried out on the return loss and impedance characteristics of a number of antennas with and without the DR. The position of the DR that gave maximum bandwidth and best return loss was experimentally determined. The E- and H-plane patterns of the antenna were measured with and without the DR.

3. RESULTS

In all the rectangular and circular patch antennas, the effect of dielectric resonator loading was found to lower the resonance frequency and improve the return loss (equivalently, impedance) bandwidth. For the rectangular patch, the optimum position for achieving maximum bandwidth and best return loss was found to be at the right (or left) corner of the radiating edge, away from the feed line as shown in Figure 1(a). For the circular patch, the optimum position was at the rim of the patch approximately +23° (or −23°) away from the vertical symmetry line passing through the center of the patch [Fig. 1(b)]. In both rectangular and circular patches, when the DR was removed from the patches, the 10-dB

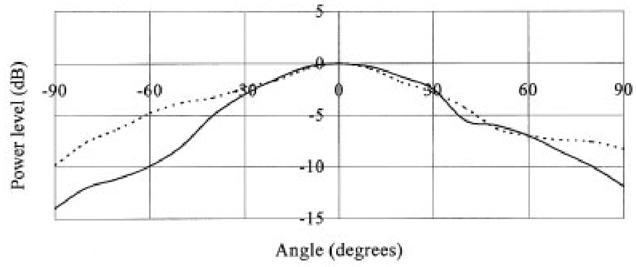


(a) E- Plane

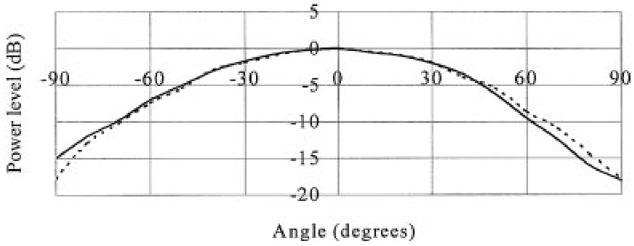


(b) H-plane

Figure 2 E- and H-plane patterns of rectangular patch antenna (W = 11 mm, L = 10.18 mm) loaded with DR1 and without loading (- - - - - unloaded, — loaded with DR1)



(a) E-plane



(b) H-plane

Figure 3 E- and H-plane patterns of circular patch antenna (R = 6.13 mm) loaded with DR2 and without loading (- - - - unloaded, — loaded with DR2) return loss bandwidth reduced to about 3% instead of to about 5% to 6%. This is expected, because with the removal of the DR, the input impedance of the patch changes and the transformer does not offer the best match.

Table 1 shows a typical set of experimental results for rectangular and circular patch antennas with and without DR loading. In the case of the rectangular patch, a 10-dB return-loss bandwidths on the order of 12% to 13% could be achieved. As compared with the rectangular patch, the circular patch offered higher bandwidth on the order of 18% with DR loading. Figure 2 shows typical *E*- and *H*-plane patterns of the rectangular patch antenna with and without DR loading. Figure 3 shows similar patterns for the circular patch. In both the antennas, the 3-dB beam width remains nearly the same with and without the DR loading.

Measurements of gain showed that the DR-loaded matched rectangular patch antennas offer a mean gain of about 1–2 dB over the corresponding unloaded matched antennas. On the other hand, no such improvement in gain was observed in DR-loaded matched circular patches over the corresponding unloaded matched antennas.

4. CONCLUSION

The impedance bandwidths of rectangular and circular patch antennas in suspended microstrip configurations are shown to increase by a factor of nearly two and three, respectively, through dielectric resonator loading. In both cases, the dielectric resonator loading showed practically no effect on the 3-dB beam widths of either the *E*-plane or the *H*-plane.

REFERENCES

1. H. Iwasaki and Y. Suzuki, Electromagnetically coupled circular-patch antenna consisting of multilayered configuration, IEEE Trans Antennas Propagat AP-44 (1996), 777–780.
2. S.D. Targonski, R.B. Waterhouse, and D.M. Pozar, Design of wide-band aperture-stacked patch microstrip antennas, IEEE Trans Antennas Propagat AP-46 (1998), 1245–1251.
3. D.M. Pozar and B. Kaufman, Increasing the bandwidth of a microstrip antenna by proximity coupling, Electron Lett 23 (1987), 368–369.
4. K.S. Fong, H.F. Pues, and M.J. Withers, Wideband multilayer coaxial-fed microstrip antenna element, Electron Lett 21 (1985), 497–499.
5. J. George, C.K. Anandan, P. Mohan, K.G. Nair, H. Sreemoolanathan, and M.T. Sebastian, Dielectric resonator loaded microstrip antenna for enhanced impedance bandwidth and efficiency, Microwave Opt Technol Lett 17 (1998), 205–207.
6. K.F. Lee, K.M. Luk, K.F. Tong, S.M. Shum, T. Huynh, and R.Q. Lee, Experimental and simulation studies of coaxially fed U-slot rectangular patch antennas, IEE Proc Microwave Antennas Propagat 144 (1997), 354–358.
7. V. Gupta, S. Sinha, S.K. Koul, and B. Bhat, Suspended microstrip patch antenna with dielectric resonator loading for enhanced bandwidth, Proc Asia Pacific Microwave Conf Dec. 2000, pp. 1330–1334.
8. I.J. Bahl and P. Bhartia, Microstrip Antennas, Artech House, MA, 1981.
9. C.A. Balanis, Antenna Theory-Analysis and Design, 2nd Edition, John Wiley & Sons, 1997.

APPLICATION OF THE SN-PRECONDITIONING METHOD TO THE INTEGRAL EQUATIONS FOR A SLOT-ARRAY ANTENNA

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ABSTRACT: *In this paper, a novel preconditioner scheme slot neighbour (*SN*) preconditioner is applied to dense matrix equations derived from integral equations for a slot-array antenna in order to improve the convergence of iterative integral-equation solvers, such as the conjugate-gradient (*CG*) method. The preconditioner accounts for expansion-function–testing-function interactions in the vicinity of a given slot, requiring an order of $N_s \times N_b$ complexity for each N_s* slot and each slot with *N_b expansion unknowns. A typical slot-array antenna is analyzed and good results demonstrate the validity of the proposed algorithms.*

Key words: *slot-array antenna; preconditioning scheme; conjugate-gradient technique*

1. INTRODUCTION

Waveguide slot arrays have found wide applications in many radar and communication systems. A method of moments (MoM) characterization of an isolated slot doublet had been described in [1], a full-wave analysis of a linear array had been presented in [2], and rectangular waveguide longitudinal slot arrays were analyzed using MoM in [3]. The formulation involves the solution of a set of simultaneous integral equations to obtain the unknown tangential fields in all slots, while taking into account both the external and internal mutual coupling between slots. This approach yields accurate results, but is computationally intensive in the case of larger arrays. In particular when radiation pattern optimization of a larger array is carried out, the amount of computation is extremely large.

As far as the iterative method is applied for solutions, its iteration number largely depends on the spectral properties of the integral operator or the matrices of discrete linear systems. To reduce the number of iterations, various preconditioning techniques have been used [4–11]. One widely used preconditioner is the incomplete LU (ILU) decomposition of the coefficient matrix and its block variants [7–8]. Another one is based on the factorization of the approximated inverse of the coefficient matrix [9, 10]. However, to form these preconditioners, prohibitively large additional computing time is required, depending on the preconditioning algorithm. Therefore, to

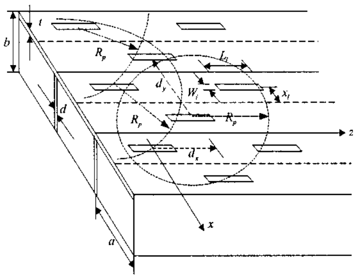

Figure 1 Configuration of a longitudinal waveguide slot array