ALPSS: A millimetre-wave aperture-coupled patch antenna on a substrate lens

G.V. Eleftheriades, Y. Brand, J.-F. Zürcher and J.R. Mosig

Indexing terms: Antennas, Microstrip antennas

The feasibility of millimetre-wave (mm-wave) aperture-coupled patch antennas, printed at the back surface of substrate-lenses is demonstrated and the corresponding radiation characteristics are investigated. A specific realisation of such an air-lens-patch-slot-strip (ALPSS) antenna on a low-permittivity $\varepsilon_r = 4.0$ extended hemispherical lens substrate is theoretically and experimentally characterised at 70GHz. It is demonstrated that the ALPSS antenna exhibits clean, axially symmetric patterns of low cross-polarisation (–26dB), a directivity of 30.4dB and the 3dB pattern full-beamwidth remains within 6°–5° between 60–80GHz. In addition, a very-high front-to-back (F/B) ratio, of the order of 50dB is measured at 70GHz, despite the absence of a backing ground-plane. The ALPSS antenna is well suited for low-cost broadband point-to-point communications and collision avoidance applications.

Introduction: In recent years there has been an increased interest in the development of mm-wave planar-antennas for communication and collision avoidance applications [1]. A very efficient way to avoid surface-wave losses in such planar antennas is to utilise a substrate lens [2]. In this Letter, the feasibility of mm-wave aperture-coupled patch antennas on low permittivity substrate lenses is demonstrated. The use of low permittivity lenses is attractive for low-cost applications, based on hybrid technology and plastic materials. The main advantages of aperture coupled patch antennas for mm wave operation [3] are that (i) the circuit and radiation functions are well separated and thus the antenna patterns are immune to parasitic radiation, (ii) a great flexibility is available in choosing the material and geometrical parameters in order to meet design specifications, (iii) a reasonable bandwidth of 15% can be achieved, (iv) circular polarisation can easily be generated, and (v) a high F/B ratio can be obtained without a backing ground-plane.

A specific ALPSS antenna has been built at 70 GHz and characterised both theoretically and experimentally with an excellent agreement between the two approaches. The theoretical analysis for the input-impedances is based on a full-wave mixed-potential-integral-equation (MPIE) formulation and the method of moments (MoM) [4], whereas the radiation patterns through the lens are computed using a geometrical-optics approach [5, 6]. To measure the radiation patterns, a subharmonic mixer is hybridly integrated with the ALPSS antenna based on an ALPHA beam-lead Schottky diode [6].

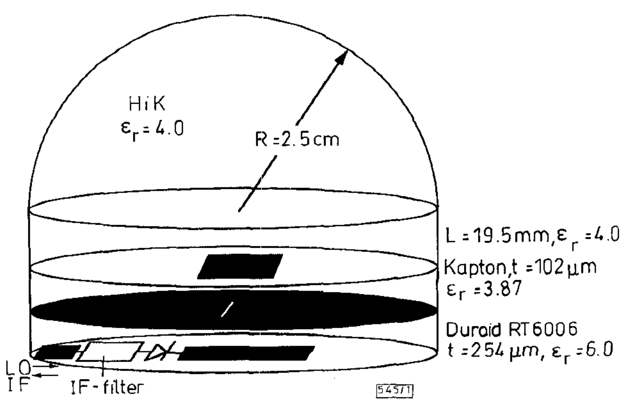

Fig. 1 *ALPSS antenna configuration operating at 70GHz*

Metallisation dimensions given in text

ALPSS antenna configuration and design: A schematic diagram of the constructed ALPSS antenna is shown in Fig. 1. Apart from the indicated nominal layers, two additional layers have also been accounted for in the analysis: An 'adhesive' film (t = 22µm, ε_r = 2.28) just above the slot ground-plane and an 'air' layer (t = 24µm) just above the patch. Because of the low-permittivity ε_r = 4.0 of the lens, an anti-reflection coating is not judged necessary which is advantageous for low-cost applications. The lens extension-length, L, is chosen at the elliptical-position in order to achieve maximum directivity [5]. In Fig. 1, the built-in subharmonic mixer, operating at the 16th-harmonic of the LO-signal, which is used to measure the radiation patterns is also shown schematically. The microwave frequency local-oscillator (LO) signal is injected from a HP8563E spectrum analyser and the generated intermediate-frequency (IF) signal is extracted through a diplexer and detected by the spectrum analyser [6]. The IF-filter is a simple five-stage stepped-impedance microstrip filter with a cut-off frequency at 45GHz. A bond-wire from the microstrip-line to the ground-plane acts as the DC-return but is not shown in Fig. 1 for clarity. With this configuration a dynamic-range of 50dB for the pattern measurements is readily achieved.

The ALPSS antenna was designed to resonate at 70GHz using the MPIE/MoM fullwave analysis approach [4]. For this purpose, the lens is modelled as an infinite halfspace of ε_r = 4.0 [7]. Special care is taken to maximise the F/B ratio and to illuminate the lens uniformly in order to achieve diffraction limited patterns. Based on these design requirements, the final metallisation dimensions are a rectangular patch of size 860 × 700µm and an aperture size of 180 × 480µm. The corresponding microstrip feed-line is 150µm wide which yields a characteristic impedance of 75Ω. The length of the open ended microstrip line from the centre of the slot is determined to be 330µm.

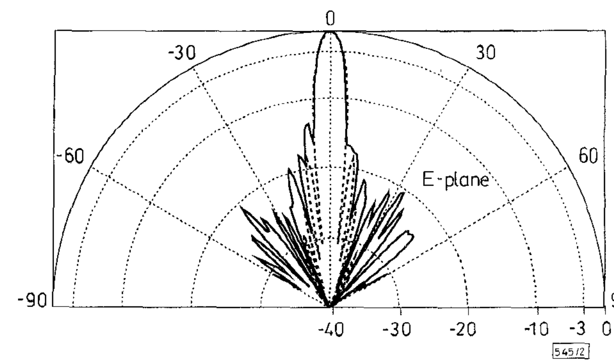

Fig. 2 *E-Plane computed and measured patterns at 70GHz*

– – – – computations
——— measurements

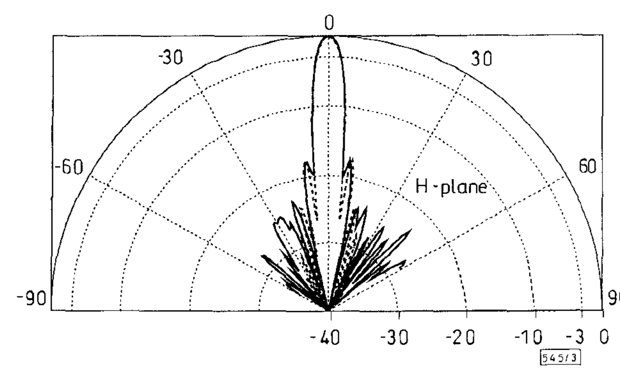

Fig. 3 *H-Plane computed and measured patterns at 70GHz*

– – – – computations
——— measurements

Computational and experimental results: In Figs. 2 and 3 the simulated and measured E- and H-plane radiation patterns of the ALPSS antenna at 70GHz are depicted. As shown, very clean, rotationally symmetric patterns are measured which agree well with simulations. As demonstrated by the measurements, the shielding effect of the slot ground-plane results only in a small perturbation of the pattern symmetry (mainly in the E-plane), despite the presence of the integrated mixer configuration. The 3dB full-beamwidth is measured and computed to be 5.5° in the E-plane and 5.6° in the H-plane. Those beamwidths remain within 6°–5° between 60–80GHz. The computed antenna bandwidth based on a SWR ≤ 2:1 is 12%. The directivity at 70GHz as computed from a far-field integration is 30.4dB. The corresponding coupling to a fundamental Gaussian beam is calculated to be 85% [5] which is still acceptable for quasi-optical applications (although the antenna has not been optimised for this purpose). The measured cross-polarisation level in the main axes is better than –26dB at 70GHz. Also shown in Fig. 4 is the estimated total antenna-mixer loss when aperture-coupling efficiency, dielectric and metallic losses as well as the conversion-loss of the 16th-harmonic mixer are all taken into account. This antenna-mixer loss is estimated based on the calibrated power radiated by the Gunn-oscillator used for the RF source, the Friis transmission equation and the power-level recorded by the spectrum analyser. As shown from this graph, the antenna-mixer loss is minimised at the design frequency of 70GHz, thus implicitly validating the antenna design. Once more it should be made clear that despite the high conversion-loss of the Schottky diode when operated as a 16th-harmonic mixer, the dynamic range of the pattern measurements is still 50dB. The corresponding measured F/B ratio is also reported in Fig. 4. As shown, the F/B level exhibits a peak of 50dB at the design frequency, even without a backing ground-plane for the microstrip feed-line. This indicates the strong coupling between the slot and the patch which is optimised to result to unidirectional patterns.

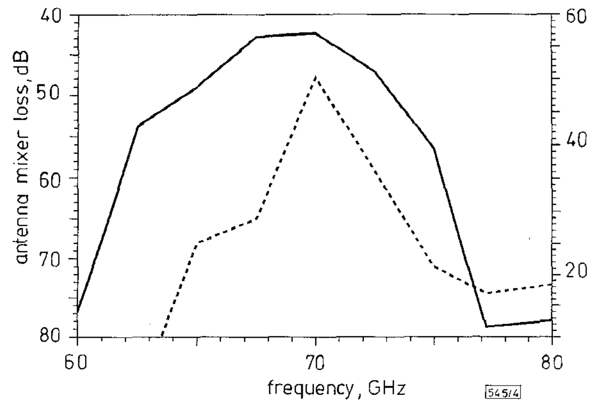

Fig. 4 *Estimated (from measurements) 16th-harmonic antenna-mixer loss and measured F/B ratio against frequency*

——— loss, dB
– – – – front/back, dB

Conclusion: A mm-wave aperture-coupled patch antenna composed on an extended hemispherical lens has been constructed and characterised both theoretically and experimentally. It is demonstrated that the ALPSS antenna exhibits clean, axially symmetric patterns of low cross-polarisation (–26 dB), a directivity of 30.4dB, and the 3dB pattern full-beamwidth remains within 6°–5° between 60–80GHz. In addition, a very-high front-to-back (F/B) ratio of the order of 50dB is measured at 70GHz. A major advantage of the ALPSS antenna is that it is not sensitive to parasitic radiation effects which can become significant at millimetre-wave frequencies. The presented ALPSS antenna is well suited for low-cost broadband point-to-point communications and collision avoidance applications.

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Corporate feed in nonradiative dielectric waveguide

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Indexing terms: Dielectric waveguides, Antenna feeds

The development of a corporate feed for application to antennas fed from a nonradiative dielectric (NRD) waveguide is described. A feed was constructed and tested, and its performance evaluated by allowing the unterminated circuit to radiate as an antenna.

Introduction: The use of nonradiative dielectric (NRD) waveguide in a large number of applications has been described, and the waveguide finds application in lowloss circuits at microwave and millimetre-wave frequencies. A variety of antennas make use of the leakage properties of the NRD guide [1], but all arrays described thus far are based on the principle of radiation through slots in the NRD guide sidewalls [2 – 5] or from the unidirectional radiator [6]. In this Letter the development of a corporate feed in NRD guide, is described. The feed finds application in feeding radiating NRD elements in array.

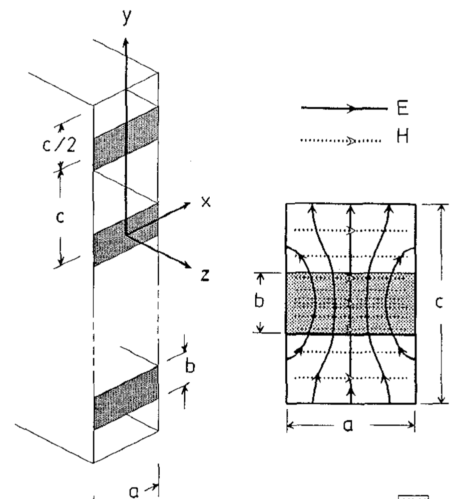

Fig. 1 *Fields in even-sum mode coupled NRD guide*

LSM modes in coupled NRD waveguides: The fundamental operating mode in the NRD guide is an LSM mode which has been described in detail elsewhere [2]. In principle, the main electric field component lies parallel to two conducting plates that are closer together than one half free space wavelength, so that the guide is below cutoff in the air-filled regions. In the dielectric-filled region the guide is, however, above cutoff, and the LSM mode can propagate. The propagation constant in the axial direction, β_z, must be the same for both regions, and consequently

$$\beta_z^2 = k^2 + \alpha_y^2 - (\pi/a)^2 = k^2\epsilon_r - \beta_y^2 - (\pi/a)^2 \quad (1)$$

where the separation between the plates is a, the thickness of the dielectric is b, and the fields in the two regions vary as $\exp[-\alpha_y(b/2 - |y|)]$ and $\cos(\beta_y y)$, respectively. Application of the transverse resonance method gives the transcendental equation

$$\alpha_y = \frac{\beta_y}{\epsilon_r}\tan(\beta_y b/2) \quad (2)$$