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A 30 GHz PLANAR ARRAY ANTENNA USING DIPOLE-COUPLED-LENS

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Abstract—Measurements of the radiation patterns from a planar array of bow-tie slot antennas coupled through an extended hemispherical lens are reported. The design operates over 10% bandwidth centred at 30 GHz with a return loss of 10 dB. A moderate directivity from the integrated lenses of 13 dB with half-power beamwidth (HPBW) of 10° is achieved. The reduced size of this design is suitable for the integration with millimetre wave circuits.

1. INTRODUCTION

Nowadays, dipole-coupled-lenses made of low permittivity materials as dielectrics are frequently used in designs of planar antennas for imaging, wireless communication systems, astronomy, and many low-cost applications [1], which are playing an increasingly important role due to the facilities for their incorporation to systems composed by the emerging front-end monolithic microwave integrated circuits (MMIC). One of the main advantages of using dipole-coupled-lenses in planar antennas is the increase of gain and directivity. They can be designed in compact models within a mechanism for pointing the antenna's main lobe at the target or source, thus acting as a directional antenna system. Moreover, whether the design includes a collimator to focus the incoming electromagnetic signal, the operation of the dielectric lens

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is analogous to the operation of optical lenses in an optical system, since dielectric lenses convert planar phase fronts to spherical phase fronts and focus the radiation into a narrow beam.

In this report, we present a 30 GHz linear array composed of four elements of bow-tie slot antennas coupled through an extended hemispherical lens made of Plexiglas®. The design is fed by a microstrip feed line (MFL) joined to a combination of three Wilkinson power dividers (WPD), which is followed by transitions to coplanar wave guides (CPW). The characterization of this array consists in measurements of the S-parameters, the radiation pattern and gain. We have obtained a moderate directivity of 13 dB and side lobe levels lower than 13 dB below the main lobe, using a collimating lens over the experimental setup. Our main goal of this investigation is to achieve optimal structures that can be integrated with millimetre wave integrated circuits.

2. EXPERIMENTAL SETUP

The geometry of the antenna array joined to the WPD is depicted in Fig. 1. The inset shows the parameters for a single element. All dimensions are in mm. The experimental setup is shown in Fig. 2(a). The extended hemispherical lens was fabricated as a single piece of Plexiglas® ($\varepsilon_r = 3.4$). It is composed of a cylinder of 22 mm of diameter, 4.5 mm of height, and is joined to a hemisphere of 11 mm of radius. The lens is glued to a dielectric substrate, Arlon 25N® ($\varepsilon_r = 3.28$) of $22 \times 22\,\text{mm}^2$ with an etched copper patch of $2 \times 8\,\text{mm}^2$ on the top which in turn is glued to the antenna array structure. The second lens acting as collimator and placed over the setup is a concentric spherical lens of radius 60 mm made also of Plexiglas®. A previous step to the lens assembly is shown in Fig. 2(b), and a detail of the printed circuit can be seen in Fig. 2(c), which was produced by chemical etching on an Alumina substrate of $36 \times 36\,\text{mm}^2$ with 3 µm-thick electroplated gold, 0.254 mm of thickness, relative permittivity of 9.9, and loss tangent of 0.0001. The substrate has a modified ground plane, since it has a centred square cavity of $22 \times 22\,\text{mm}^2$ without backside metallization fitting it with the CPW line and bow-tie structure. The antenna array metallization has an area of $36 \times 28\,\text{mm}^2$, while for the feeding section (MFL and WPD) is $8 \times 36\,\text{mm}^2$. The widths of the MFL and gaps of the CPW were calculated as reported in the previous work [2] to provide characteristic impedances of around $Z_0 = 50$ ohms respectively, to reduce mismatch losses in the transition from MFL to a 50 ohms 2.4 mm coaxial connector. Each WPD has a resistor of 100 ohms realized by means of an additional Ni-Cr layer

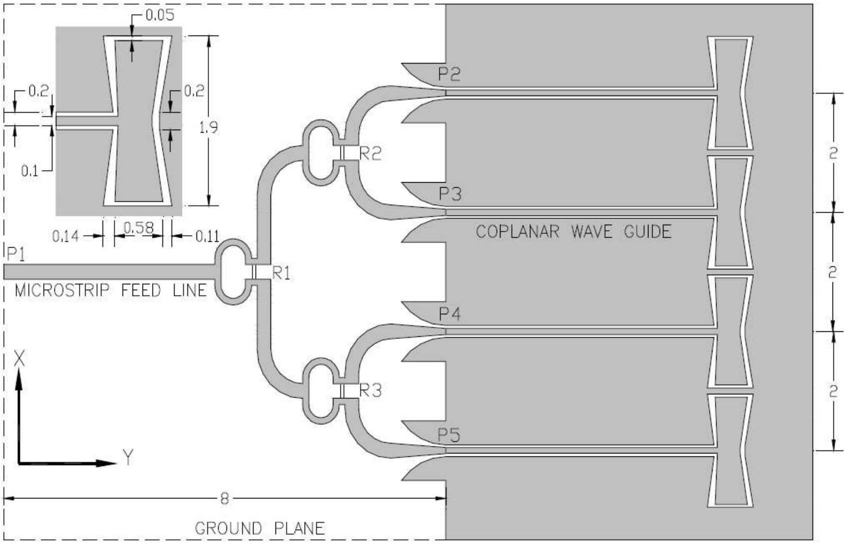


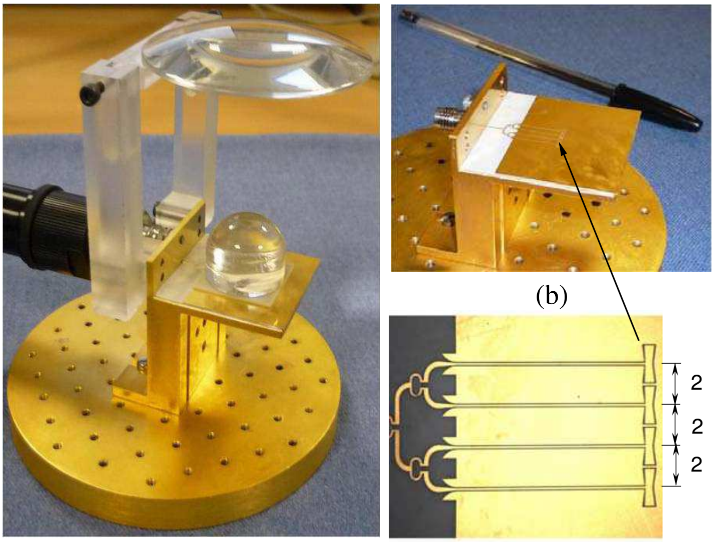
Figure 1. Antenna array geometry (not to scale) and parameters. All dimensions are in mm.

existing on the Alumina substrate whose resistance is 20 ohms/square. The structure is assembled on a metallic mount by attaching its ground plane with Epo-Tek H20E®.

3. MEASUREMENTS RESULTS

All measurements were made using a PNA-E8364A vector network analyzer, considering that the experimental setup was completely assembled and including a reflector plane placed at a distance of $\lambda/4$ below the metal base where the antenna array was glued. The gain of the antenna array was measured according to the standard horn method explained in [3], thus giving a maximum value of 13 dB around the central frequency of 30 GHz.

Far field radiation patterns were manually measured, taking values of the radiated power every three degrees in a scanned angle interval from -60° to 60° for the E-H planes. We observed that the focusing property of the collimator provides moderate directivity and symmetry to the E-plane, with HPBW of 10° in the main lobe, and side lobe levels lower than 13 dB below the main lobe. However, the measurements for the H-plane did not match as well as we expected, because very large and asymmetric side lobes appear. These irregularities may be caused mainly by the field reflection produced by the top edge of the metal



(b)

(a) (c)

Figure 2. (a) Experimental setup. (b) Previous step to the lens assembly, and (c) Detail of the printed circuit showing the element spacing (dimensions in mm).

mount, on which the collimator support and the 2.4 mm connector are screwed. In addition, the collimator is glued to a transversal bar which in turn is also screwed to the support. We assume that the asymmetry and those irregularities can be corrected, improving the fixed collimator's supporting system by providing mobility in the E-H plane directions.

Test results at 30 GHz for E-plane and H-plane patterns are shown in Fig. 3 and Fig. 4, respectively. It should be noted that the simulation results in Fig. 4 do not take into account the real geometry of the setup, as the supporting and mechanical structures, coaxial connector, soldering and gluing, etc.

The measurements of return losses were also taken with the experimental setup assembled as explained above. The results are shown in Fig. 5. They exhibit a narrow bandwidth of 10% from 28.5 to 31.5 GHz achieved with a return loss of 10 dB. The appearance of the second resonance around 25 GHz and the others could be caused by the finite size ground plane and the 2.4 mm connector, as well as all the artifacts involved in the setup.

Similar results were obtained in a second measurement by

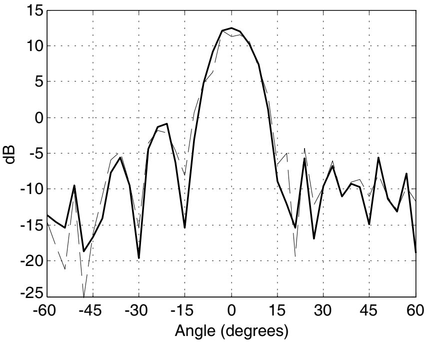


Figure 3. E-plane measured radiation patterns at 30 GHz. Dark line and dashed line correspond to measurements taken with the collimator made of Plexiglas® and Teflon® respectively.

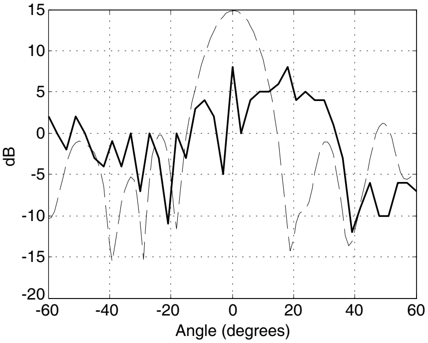


Figure 4. H-plane simulated (dashed line) and measured (dark line) radiation patterns at 30 GHz, taken with the collimator made of Plexiglas®.

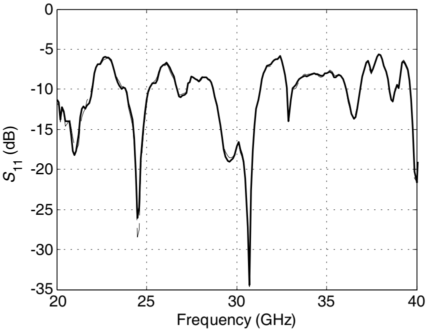


Figure 5. Measured return losses taken with the collimator assembled. Plexiglas® (dark line), and Teflon® (dashed line).

replacing the collimator of Plexiglas® by one made of Teflon® ($\varepsilon_r = 2.1$). In both plots, we observe very good similarity. The small differences presented in Fig. 3 may be produced because of the manual measurement technique. Both Teflon® and Plexiglas® are materials that can be easily machined and commonly used in large variety of low temperature experiments, for instance in cryostat windows wherein the collimator can be machined in the same plate as the window, thus avoiding the mechanical supporting and reducing the losses during the radiation pattern measurements, since the development of our design could also be operated under cryogenic environments.

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4. CONCLUSION

We have designed and characterized an array of bow-tie slot antenna with dipole-coupled-lens for operation at 30 GHz. The presented design is the first step towards the development of multiple arrays to study their feasibility and use at room temperature and under cryogenic environments. Even though the collimator supporting system can be improved, the measurements showed good radiation patterns, which demonstrate that the antenna array and optical system are suitable for use in applications where the moderate directivity is required.

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