FOAM AND MEMBRANE TECHNOLOGY FOR MILLIMETER-WAVE ANTENNA APPLICATIONS

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ABSTRACT

With the increasing demand for multimedia services and therefore higher bit rate equipments, research activities are focused today on the development of millimeter waves modules. If MMICs are available up to 60 GHz, antennas remain external critical functions for which efforts still have to be produced concerning both technologies and design methodologies. This paper describes recent advancements in the design of original antennas where technological constraints as well as electrical conditions are considered for optimizing performances. Emerging technologies, entirely designed, built and tested at the LEST site, based upon foam waveguide or/and membrane configurations are presented. Hybrid structures are proposed for improving gain and/or bandwidth while controlling cost and reliability. Simulation and measurement results are shown and demonstrate the feasibility of the above-mentioned technologies for applications up to 76 GHz.

INTRODUCTION

Requirements generally specified for antennas used in mm-wave systems concern gain and radiation efficiency as well as operating bandwidth, technological reliability, cost and compatibility with other RF modules. Significant efforts have been made during the past few years for designing and implementing efficient miniaturized antennas for mobiles or radio communications equipments. This results in a quasi-generalization of microstrip antennas, with some original features about feeders, shapes and supporting material. This has also contributed to a better understanding of operating properties and constraints of such radiating elements, with respect to materials, design methodology, electromagnetic compatibility.

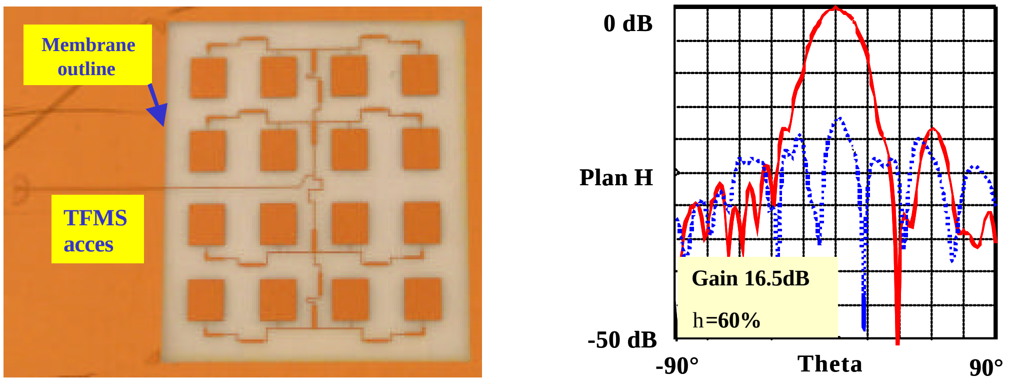
In this paper, main difficulties related to the design of microstrip antennas at high frequencies will be discussed. If convenient behaviours can be achieved by using appropriate materials (foam substrates for instance) and designs, great difficulties are encountered for reaching high gain and/or wide operating bandwidth.

MEMBRANE TECHNOLOGY FOR PLANAR ARRAYS

Preliminary solutions were proposed through the well-known uniplanar technology, which is recommended for mm-wave applications. We investigate on the design of “Vivaldi” and slot antennas, then accessing to quite wide operating bandwidth. This requires unfortunately 3D interconnections for suppressing parasitic coplanar modes and has some incidence on cost and reproducibility as well as packaging.

Therefore, we developed alternative and original low-cost solutions based upon the membrane technology [1]. Instead of considering a thin-film process on Si or GaAs materials, we proposed the use of thin polymer dielectric film (polypropylene, BCB) spread on a copper plate [2]. A standard photo-etching procedure is employed for removing the copper and creating inner cavities nearby the desired membrane regions, while implementing the circuit pattern on the upper side. This is an innovative technological proposal for developing cheaper membrane structures, by means of well-known industrial process. The radiation efficiency of an antenna on a membrane section is increased as expected thanks to this equivalent ideal medium (radiation efficiency of about 60 % measured at 40 and 60 GHz). Figure 1 illustrates an example of antenna array fed by Thin Film MicroStrip (TFMS) lines. The H-plane radiation characteristic is also shown in fig. 1.

We have also proposed hybrid architectures for optimal association of membrane antennas and feeding networks. The solution based upon individual electromagnetic coupling with a lower microstrip network (Fig. 2) can be considered as a convenient solution for interconnection facilities (with MMICs). In addition, some radiation pattern improvement can be achieved as parasitic coupling between adjacent antennas and lines can be reduced.



a) Array with feeding network b) H-plane pattern (x-pol.: dot line)

Fig. 1. Membrane 4x4 antenna array at 41.5 GHz – H plane characteristics

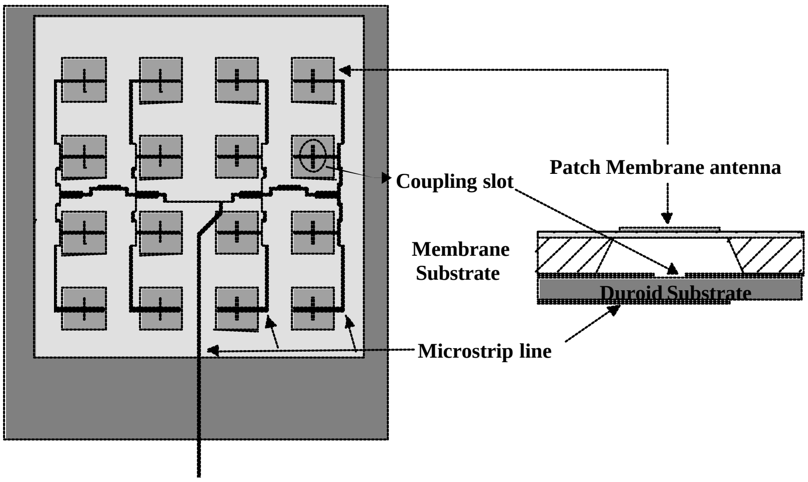
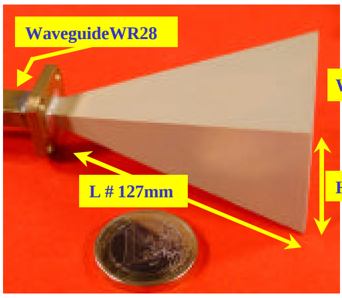


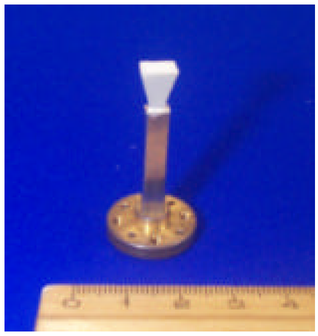
Fig. 2. Membrane 4x4 antenna network with slot feeding

Nevertheless, some drawbacks can be encountered with the membrane technology, like mechanical robustness or deviation of performances with temperature in specific environment, and complementary solutions have been consequently investigated.

3D TOPOLOGIES AT MM-WAVE FREQUENCIES

In the millimetre-wave range, great difficulties with planar implementation (e.g. etched sensitivity due to the reduced dimensions) can be encountered. Consequently, 3D architectures become feasible. Indeed, a rectangular or circular horn recovers quite small dimensions beyond 30 GHz, in agreement with the bearable size and shapes of mm-wave sensors and front-ends. In order to overcome cost limitations, we rather develop horns based upon foam materials instead of metallic milled or electro-formed structures. The technological challenge lies on the control of the dimensions, the accuracy in the physical delimitation of shapes and outlines, and mostly the metalization procedure. We select the Rohacell HF71 foam in accordance with its electrical characteristics (ε_r=1.07 / tan δ = 0.001 at 40 GHz), its robustness, reduced weight and porosity. Unfortunately, this material cannot be injected (like conventional plastic injected techniques proposed by [3] for moulding waveguides) but can be accurately press-moulded or milled by means of multi-axial milling machines. We investigate on the design of rectangular and circular horns, and compared results with those obtained with commercial products. The gain deviation do not exceed 0.5dB with respect to the classical solution for the different experimentations made on 32 and 76 GHz antennas with standard feeders. This can be attributed to the foam dispersion (# 0.15 dB/cm for a rectangular waveguide at 40 GHz) and the metalization quality (# 100µm thickness silver spray painting). This is undoubtedly a good compromise between cost and electrical performances, the critical point lying in the metalization procedure.





a) Pyramidal horn (32 GHz) b) Pyramidal horn (76 GHz)

Fig. 3. Illustrations of horns based upon metalized milled-foam materials

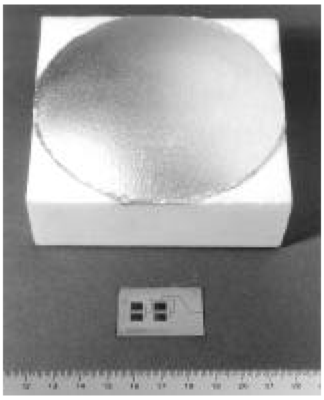
Only 0.3 dB additional loss was measured for the horn illustrated in fig. 4b as compared to commercial equipment. Another techniques based upon electrolytic deposition techniques were also tested, but with significant difficulties in term of adhesion, losses and oxidation

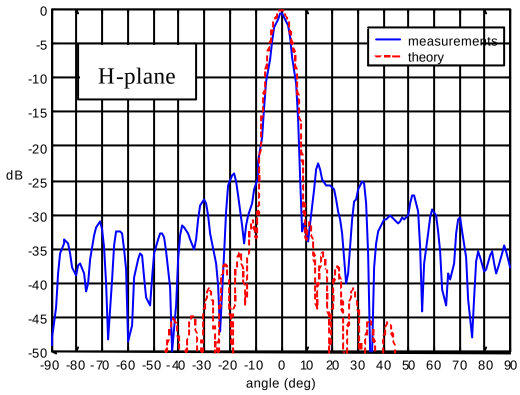
COMBINATION OF VOLUMIC AND PLANAR STRUCTURES

The 3D Foam-structure is a convenient solution for recovering antennas with extended but well-defined radiating areas, and consequently high gain values with respect to planar configurations for which the efficiency is reduced because of dielectric and conductive losses in the feeding network. On the other hand, reaching gains greater than 30dBi would require excessive radiating aperture dimensions, mostly when using waveguide topologies. Hybrid volumic antennas were investigated by considering membrane or horn antennas as offset primary sources for reflectors or artificial lenses with applications to anti-collision radar antennas [4], [5]. The foam material acts as a semi-transparent spacer between the focal source and the reflector, and simultaneously allows an accurate relative positioning with appropriate angle.

Reflector antenna

Some investigation was carried out at 32 GHz with a parabolic profile (see fig. 4) fed by a 2x2 patch antenna in membrane technology (visible in fig. 4a). The corresponding measurements and simulation results are presented in fig. 4b. The theoretical model is based on GTD.





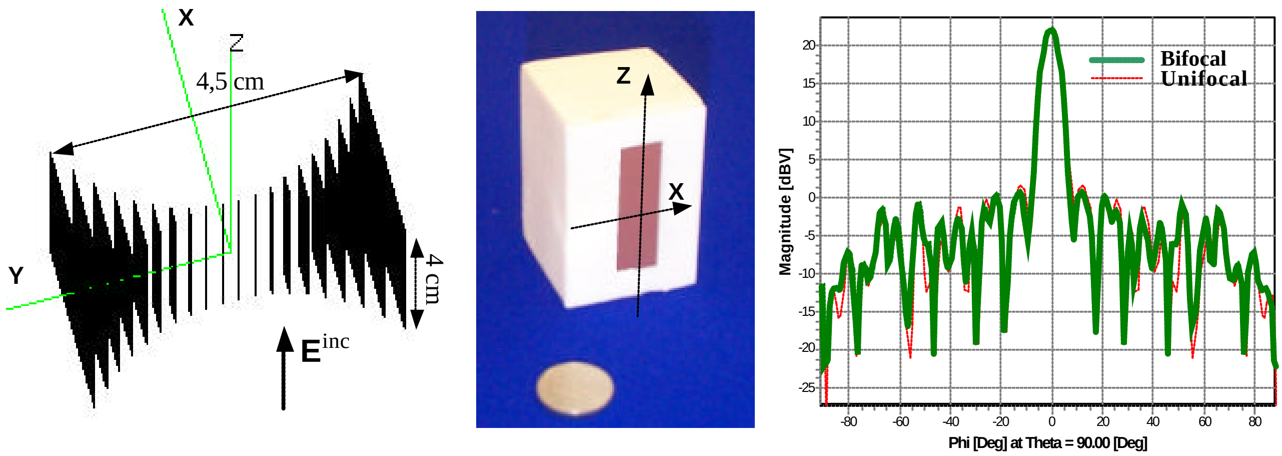
a) Metalized parabolic reflector with planar primary source b) H-plane radiation pattern

Fig. 4. Reflector antenna system in foam technology (32 GHz)

Some good agreement is obtained for the radiation pattern as far as the main lobe is concerned. However, the model underestimates side lobe levels. Lower values are obtained with more directive primary source. A 4x4 patch arrays can be used in this case. Extension for operation at 76 GHz was investigated and theoretical simulations showed very good results [4]. However, the lack of efficient guide-to-microstrip transition at that frequency has prevented measurements. Such transition compatible with membrane and foam technologies is actually under test.

Artificial lens

Keeping in mind low-cost and compactness criteria, a system based on artificial lenses shows some potential advantages. For instance, the primary source and the focusing system can be implemented into the same block of foam, which facilitates their positioning (as for reflector systems). The focusing element consists of stacked parallel-plate waveguides of various lengths. To obtain focalization, the TE_1 mode of the parallel plates, that has the electric field transverse and parallel to the plates, i.e; in the Z-direction, is required (see fig. 6a). Consequently, the primary source polarization should be also transverse and parallel to the conducting plates. Various lens configurations (unifocal, bifocal) can be implemented with this approach [5]. Simulations were performed for the structure illustrated in fig. 6b illuminated by a pyramidal horn at 76 GHz. The lens consisted in 20 plates whose length (along X) varied from 0.1 to 23 mm. Simulation results are shown in fig. 6c.



a) Artificial lens Metalized plates b) Lens foam block c) H-plane computed radiation pattern

Fig. 4. Artificial lens antenna system (76 GHz)

Very good performances can be observed in terms of gain (> 30 dB) and side lobe-levels (lower than –22 dB). Also, no major differences are predicted between bifocal lens (f = 31 mm, elliptic profile) and unifocal lens (f = 30 mm, spherical profile, Abbé's sinus condition). Implementation of the structure for measurements is being carried out.

CONCLUSION

The association of volumic and planar antennas for developing high performance radiating networks at mm-wave frequency is undoubtedly an attractive approach, for which constraints about reliability, compatibility with active MMIC's are strongly minimized and partially reported on the primary source only. Various applications are presented: Planar arrays and horns using membrane and foam technology, respectively. Combination of both technologies can provide very interesting solutions for compact antenna with high gain. 3D focusing systems are presented namely, reflector and artificial lens in foam technology that use planar array as primary source implemented in membrane technology. This allows some efficient positioning between focusing element and primary source. Good performances are reported in terms of gain and side-lobe levels at 32 and 76 GHz..

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