Recent and Future Research Trends in Planar Multi-beam Antennas in the Millimeter Wave Range at IETR-France

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***Abstract* - A review of some flat multi-beam antennas developed at IETR during the last 5 years (2010-2015) is reported. These antennas are based on quasi-optical and circuit-based beam forming networks (BFNs). The enhanced scanning capabilities of the proposed solutions will be shown. In addition, some antennas integrate antenna functions like monopulse techniques to enhance the angular resolution for tracking applications. The main concepts and features of the developed antennas will be reported. These antennas operate in different frequency band in the millimeter wave range and are realized with different fabrication processes.**

***Index Terms* — Multi-beam antennas, BFNs, SIW (Substrate Integrated Waveguide) technology, Diffusion Bonding technique, LTCC, CTS (Continuous Traveling Stub) antennas.**

1. Introduction

In multi-beam antennas, the same radiating aperture is used to create multiple beams in free space. The advantages of such antennas are the possibility to achieve high gain and wide coverage simultaneously, with a single antenna. These features are very attractive for communication applications involving a mobile user (e.g. SATCOM communications). Generally speaking, operations of these antennas are based on BFNs that provide the amplitude and phase distribution to steer and shape the radiated beam in a given direction.

BFNs can be classified into two categories. *i) Quasi-optical BFN* such as Rotman and Luneburg lens, BFN based on reflectors and pillbox concepts, etc. They allow flexible design with a large bandwidth and wide scanning range. *ii) Circuit based BFN* such as Butler, Nolen and Blass matrices [1].

In the last five years, the antenna group at IETR has been very active in proposing new low-cost antenna concepts for planar multi-beam antennas with enhanced radiation performances. This paper reviews some of them and reports only their main features for space limitation. However, more details can be found in the provided references.

2. Multi-beam antennas with quasi-optical BFN

(1) Pillbox coupler

The proposed pillbox architecture is shown in Fig. 1 [2]. It is a double-layer structure and is composed of three parts; *i) a feeding systems* in the lower layer (Sub.1), *ii) a radiating part* in the upper layer (Sub.2); *iii) a parabolic reflector and several coupling slots* connecting the two layers. The ideal pillbox structure is a passive and lossless BFN. The generated beams are all mutually orthogonal for a single radiation aperture [3]. Therefore, it is not possible to specify the side lobe levels (SLLs) and the crossover level amongst the radiated beams. In order to overcome this limitation the "*Split aperture decoupling*" method has been applied in Ref. [3] where SLLs lower than -24dB for the central beams and high beam crossover around -3dB have been obtained in the full scanning range of ±40°.

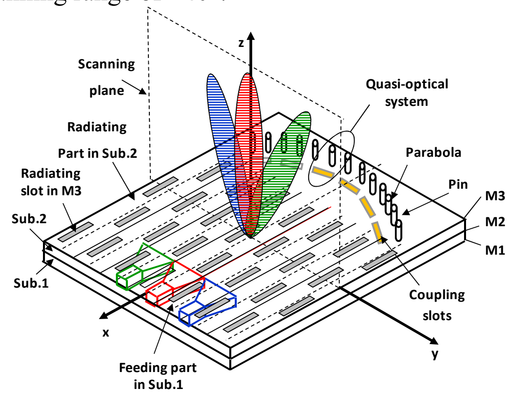

Fig. 1 Multi-beam pillbox antenna with slotted waveguide radiating part.

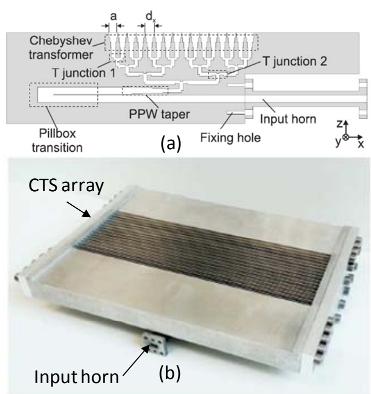

Fig. 2 Multibeam pillbox antenna with a CTS array. (a) Artistic representation (Cross section view). (b) Realized prototype.

Pillbox architectures are suited to low-cost SIW [4] and LTCC technology [5]. They have also been implemented in high efficient hollow waveguide technology with a CTS radiating part (Fig. 2) in Ka band [6].

(2) Integration of Antenna Functions

The same pillbox architecture has been used to realize antenna operation like monopulse tracking [7] to enhance the angular resolution in the E-and H-planes [8], [9]. These two monopulse antennas are amongst the first solutions in the open literature that combine a beam switching operation to a monopulse operation. In addition, they avoid the mechanical orientation of the antenna as usually done in monopulse systems with a slow time response due to mechanical inertia.

(3) Rotman Lenses

The possibility to reduce the footprint of Rotman lenses has also been investigated. This is a key for integration purposes in applications scenarios as automotive radars. A multi-layer technique has been adopted to fold the Rotman lens over its main reflector [10]. An antenna (Fig. 3) has been designed and fabricated at 24 GHz. It is composed of three layers with a total thickness of 1.6mm. The size reduction is 50% for the lens and 33% for the overall antenna compared to the single layer case. The SLL is lower than -12dB over the entire field of view of ±32°.

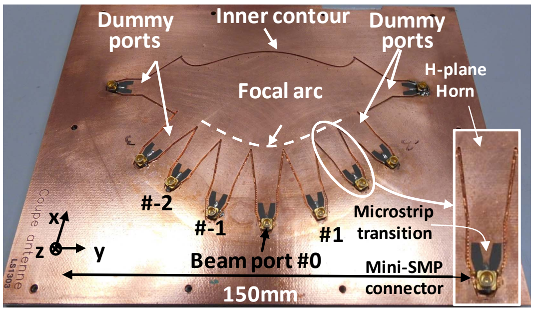

Fig. 3 Bottom view of the multilayer Rotman lens. The top view is a slotted waveguide array of 15×20 radiating slots.

3. Muti-beam antennas with circuit based BFN

In the last years, we consider the possibility to improve the performance of the Butler matrix. The main limitations of Butler matrix are its size and limited radiation performance in terms of achievable SLLs.

In order to reduce the size, a compact design has been proposed where the couplers and the crossovers of the matrix were designed with lumped elements [11]. The size of the realized 4×4 matrix is 25 times smaller than typical transmission-line-based Butler matrices.

In addition, the Butler matrix produces a uniform tapering at its output ports limiting the SLLs of the radiating beams to about -13dB. In order to reduce the SLLs, an additional passive circuit has been designed and connected to a 4×4 Butler matrix [12]. An antenna in hollow waveguide technology has then been designed in the 60-GHz band for fixed wireless access applications (FWA) and fabricated with the Diffusion Bonding technique. The antenna (Fig. 4) is a dual-layer structure with a total thickness of 4mm. The SLLs are lower than -17.5dB over the entire field of view (±43°).

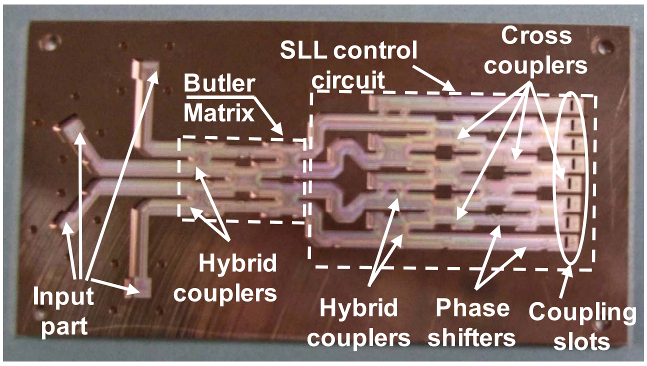

Fig. 4 Some details of the realized Butler matrix with SLL control circuit (Bottom view). The top view is an array of 8 slotted ridged waveguides.

4. Conclusion

In this paper we reviewed some planar multi-beam antennas in the millimeter wave range developed at IETR, France over the last five years. Some of them define the state-of-the-art in the open literature. During the conference, the designs will be detailed and more numerical and measured results shown. We will also give some research trends of our group for the future.

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