Planar, Volumetric and Integrated Millimetre-Wave Antennas

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***Abstract*- In this paper we review various kinds of antenna technologies for millimetre wave applications. This includes multilayer planar antennas (small antennas and large antenna arrays) in PCB (Printed Circuit Board), SIW (Substrate Integrated Waveguide) and LTCC (Low temperature co-fired ceramic) technology, and volumetric and large aperture antennas (dielectric and discrete lenses).**

I. Introduction

The millimetre-wave (mm-wave) band (30-GHz ~ 300-GHz) is about ten times broader than the centimetre wave one (3-GHz ~ 30-GHz). This large available bandwidth is thus favourable for many high data rate or high resolution communication and radar systems like: i) broadband high data-rate indoor (smart home, gigabit offices) and outdoor wireless communication systems around 38 GHz and 60 GHz [1]-[3], ii) Wireless Personal Area Networks (WPANs) in the 60-GHz band [4],[5], iii) Radio over Fiber (RoF) systems [6], iv) Intelligent Transport Systems (ITS) (short range / long range / multi-function automotive radars at 77 GHz and, in the near future, from 77 GHz to 81 GHz for ultra wide band (UWB) high-resolution short range radars [7],[8]), v) Passive and active imaging / sensing, security and surveillance systems in public areas (airports, stations, etc.) at mm and sub-mm waves, vi) or instrumentation (time-domain or frequency-domain spectroscopy, quasi-optical receivers and systems).

One of the most promising applications boosting nowadays the research in the lower part of the mm-wave spectrum is based on the wide unlicensed frequency band around 60 GHz. The recent developments in CMOS technology allow designing cost-effective antenna terminals for WLAN with high data rate (up to 2~4 Gbps, for transfer of uncompressed video signals) or the emerging millimetre-wave identification systems. Moreover, the 71-76 and 81-86 GHz bands (widely known as "E-band") are permitted worldwide for ultra high capacity point-to-point communications, up to 10 Gbps in the future over the distances of several miles.

Due to this very wide diversity of applications, many different kinds of mm-wave passive, active and integrated antennas and systems (systems on chip (SoC), systems in package (SiP)) have been introduced over the last decade.

In this paper, we review some recent achievements for planar (Section II) and volumetric (Section III) antennas at millimetre waves, with emphasis on operating frequencies below 100 GHz.

II. Planar Antennas

The LTCC (Low-temperature cofired ceramic) multilayer technology is very attractive to integrate passive components with MMICs in a single, cost-effective package. Passive structures (filters, transitions, antennas) can be integrated on different layers, leading to 3-D miniaturized integrated modules. Cavities and metallized vias can be also processed. On of the main challenges for LTCC technology at millimetre waves is the fabrication accuracy (conductors and spacing) because LTCC tapes shrink by about 10-15% during sintering, and shrinking effects have to be taken into account at the early stages of the design process. The manufacturing reliability of LTCC circuits and the associated tolerances have been studied in [9].

Many different kinds of LTCC antennas ranging from simple radiating elements up to large antenna arrays have been proposed recently. In the first case, low-gain (from 5 to 7 dBi) aperture-coupled patch antennas [10], Yagi antennas [11] or tapered slot antennas [12] have been published for 60-GHz applications.

Due to the relatively high dielectric constant of LTCC materials, patch antennas on LTCC may suffer from a narrow bandwidth and a reduced antenna efficiency (due to surface wave loss). One solution to overcome this limitation consists is accommodating an air cavity inside the patch substrate to reduce the effective permittivity, broaden the bandwidth and increases the gain. Solutions have been proposed in Ka-band [13] and more recently in V-band (16-element antenna array with corporate feed network [14], grid array antenna [15] for Antenna-in-Package solutions [16]).

To provide higher antenna gain, microstrip antenna arrays on LTCC have been proposed (e.g. a 4×4 array integrated in a compact System-on-Package (SoP) transmitter module in [17]). EBG-based solutions can be also implemented to reduce mutual coupling between antenna elements [18].

The SIW (Substrate Integrated Waveguide) approach [19],[20] is also very promising to build effective beam forming networks for antenna arrays at millimetre waves. If we focus our attention on multiple-beam passive antennas [21]-[30], three main configurations have been studied over the last two years: i) beam forming networks with T-junctions [21] for beam switching applications [24],[26], ii) R-KR [23], Rotman [25], Butler [26], Blass [27], Nolen [28] lenses, and

finally iii) integrated reflectors [22],[29],[30]. These solutions will be discussed during the presentation. Recent results obtained with pillbox antennas will be presented at 24 and 77 GHz.

III. Volumetric Antennas

For high-gain applications, electrically large antennas are often needed. We briefly review below three antenna solutions, namely integrated lens antennas (ILAs), discrete lenses / transmit-arrays, and folded reflect-arrays.

Existing focusing systems based on lens antennas are summarized in Fig. 1. During the presentation, we will focus our attention on recent achievements on integrated lens antennas, including shaped lenses for beam shaping applications (e.g. [32]-[34]), reconfigurable lenses [35] and ultra wide band configurations [36],[37].

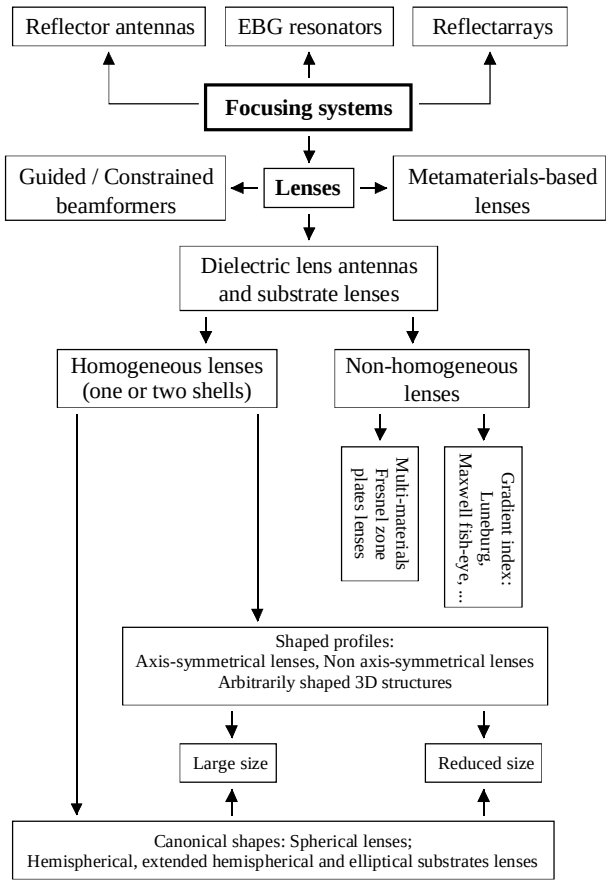

Figure 1: Mm-wave focusing systems and relevant lens technologies [31].

Dielectric lens antennas can be viewed as "analogue" phase correcting devices. Their "digital" counterpart is often referred to as "discrete lens antennas" or "flat lens antennas" [38],[39]. Alternative terminologies have been also employed like transmit-array antennas [40],[41] or antenna-filter-antenna systems [42]. One of the first demonstrations of the performance of passive transmit-arrays in the 60-GHz band is available in Ref. [43]. Some of these results will be presented. Active transmit-arrays have been also studied in Ka-band for beam scanning applications [44].

Finally, the main features of transmit-arrays will be compared to folded reflect-arrays [45] at millimeter-waves.

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