Millimeter-Wave Radar for Civil Applications

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***Abstract*— This contribution gives an overview of civil state-of-the-art and also some novel applications of radar sensors in the millimeter-wave frequency range, together with some general principles and a number of examples of such radar systems.**

I. INTRODUCTION

In the recent 10 or 20 years, the application of millimeter-wave radar sensors in civil areas has grown significantly; maybe the most noticeable application being in the automotive area where the first commercial radar for adaptive cruise control (ACC) has been introduced by Mercedes in 1999. While military developments had started much earlier, even based on metal waveguide circuits together with Gunn elements and IMPATT diodes, and later on with hybrid planar circuits, it took a much longer time for civil systems, although many researchers were convinced about system maturity much earlier [1], [2]. The main reason for such a delay has been the immense cost pressure for most of the civil applications, so critical development steps had to be achieved first, including

- transistors with sufficiently high cut-off frequencies
- planar circuits with surface mounted devices (including automatic assembly)
- reliable millimeter-wave MMICs at reasonable cost
- novel multilayer, multifunctional circuits.

MMICs firstly were based on GaAs, but SiGe and CMOS circuits are developed with potentially reduced cost. Quite complex circuits are also possible today combining printed circuit boards for DC supply, IF, baseband and digital circuits with microwave substrates hosting the mm-wave MMICs, passives, transmission lines, and partly even antennas [3].

Simple CW sensors in the 24 GHz ISM band have found already widespread consumer applications, e.g. [4], [5], but today, much more advanced mm-wave radar systems are under development or already in use including scanning/ imaging functions, operating partly at much higher frequencies and bandwidths with range resolutions in the centimeter range.

II. APPLICATION OVERVIEW

A tabular overview of typical civil mm-wave radar applications, certainly not complete, is given in Table I. The frequency range considered here starts with the 24 GHz ISM band for many of the consumer/commercial applications, includes the bands of 76 – 77 GHz for long range (ca. 200 m) and the two bands 21.65 – 26.65 GHz and 77 - 81 GHz for short range automotive applications (up to about 50 m), [9], [10], and partly goes up to the lower THz range for concealed weapon detection [22] or research applications [23]. Typical radar principles are CW for motion detection or speed measurement, FMCW or frequency-stepped CW, and pulsed systems, often with correlation receivers which operate in an equivalent time sampling mode to reduce final evaluation frequency and bandwidth.

Concerning obstacle detection, an interesting application is emerging due to the Concorde accident in 2000 which was probably caused by a piece of metal lost by another plane on the runway. Millimeter-wave radar could be a tool to detect such debris immediately [7], [8].

In the automotive area, Mercedes just equipped their E-class cars with four broadband 24 GHz sensors and the advanced medium/long range 77 GHz ARS 300 radar fabricated by Conti [24] which is able to scan over a wide angle and can fine-adjust the elevation angle. This radar also is offered for a range of other applications, e.g. area surveillance or different industrial applications. The latter also shows a general trend – with the increasing availability of automotive radar sensors, these are finding more and more potential applications in other areas as well [20].

Already in the 1980s, efforts had been done to improve the safety of helicopters by radar detecting high voltage lines or cable car ropes [11]; this topic has been addressed again recently [12]. Another problem for helicopters, both in the military as well as in the civil area, is loss of visibility during landing on dusty or snowy ground (brown- or white-out), this also has gained increasing interest [13], [14].

TABLE I
APPLICATION OVERVIEW

Consumer appl.	Door opener, sanitary applications (water faucets, flushing), …	[4], [5]
Traffic (general)	Speed over ground, speed surveillance, traffic statistics, debris detection on airport runways, …	[6] – [8]
Automotive	Adaptive cruise control, parking aid, blind angle control, or assistance systems for stop-and-go, breaking, lane keeping, lane changing , ...	[9], [10], [24], [25]
Helicopters	Obstacle detection (e.g. high voltage transmission lines), landing aid (brown-out/white-out)	[11] – [14]
Industrial	Level measurement, contour mapping, autonomously guided vehicles, vibration detection, ...	[15] – [21], [26]
Security	Intrusion detection, body scanners (weapon detection), …	[4], [5], [22]
Research	Vulcaneological surveillance, space missions (docking, landing), …	[23]