Design Challenges for Millimeter Wave Active Imaging Systems

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Abstract — **Due to the atmospheric absorption in W-band, especially the spectrum around 94 GHz has been the frequency of choice for radar applications in reconnaissance and metrology, but more recently also for indoor security applications. However, for indoor security applications the propagation environment and scale of the application is quite different as compared to the long-range military and scientific applications. In this paper we report on the work performed at the research group ESAT-TELEMIC on modelling and designing indoor millimeter wave imaging systems that employ coherent multi-parametric illumination in a "flash"-like configuration. We discuss trade-offs between certain system parameters and present two examples of multi-parameter imaging. We show that a 2.5D simulator is a good compromise between computational cost and ability to analyse interference effects such as speckle. We also elaborate on challenges in terms of hardware implementation, and demonstrate experimentally the potential of using printed antennas for millimeter wave security applications.**

Index Terms **— Active millimeter wave imaging, Hadamard, speckle, method of moments, Huygens.**

I. Introduction

For many years now various types of 94 GHz airborne radar systems have been deployed both for military applications (fire-control radar, surveillance [1]), scientific applications (cloud profiling [2]), and civilian applications such as aircraft landing systems [3]. In addition, a number of passive imaging systems have been reported [4].

Over the last decade, millimeter wave imaging systems for security applications have experienced a great deal of media interest under the term "body scanners", although it should be mentioned that most of the body scanners deployed nowadays actually use low-level X-ray backscattering. The frequency range of 94 GHz is an excellent compromise between resolution and penetration depth for the detection of objects concealed underneath clothing [5]. Nearly all mm-wave systems today are of the portal type where the person to be scanned needs to stand in a cabin for a few seconds while the system acquires a millimeter wave image. This type of system is clearly superior to existing metal detectors in terms of the range of detectable objects.

Indoor imaging using millimeter waves is difficult because of the limited natural temperature contrast available in the scene, which can be as low as 4K. To deal with this, two strategies can be used: either use very sensitive receivers to distinguish between parts of the scene or illuminate the object and measure the backscattered radiation [4]. The portal systems deployed today mostly use a radar-based approach using a linear array of transceivers [6].

A different type of millimeter wave imager is the standoff type, whereby the object or person does not need to be confined to a volume but instead can be imaged from a distance, still having the possibility to detect hidden objects. The problem for these kinds of systems is again a problem of low temperature contrast available for imaging, necessitating some form of active illumination.

An important difference with optical imaging is that at millimeter-wave frequencies truly incoherent illumination sources are difficult to realize. The use of a coherent source causes images resulting from wave interference. Moreover, since reflections at millimeter wave frequencies are primarily specular in nature as opposed to diffuse reflection at optical frequencies, glint will be present in the image.

Essentially what is needed is a millimeter noise source which floods the room with low-power radiation, enough to increase temperature contrast.

An alternative to mm-wave noise sources is to use multi-parameter illumination and to use multiple images to construct an averaged image which suffers less from interference [7]. One possible incarnation of this concept is shown in Fig. 1 and shows a switchable reflectarray (diffuser) that spatially modulates the illuminating wave front before it reaches the object. At the detector side an image with reduced interference can then be reconstructed using the different partial images.

When designing a complex system such as this, a fast way of estimating the influence of various system parameters such as frequency, system geometry, lens/mirror parameters, diffuser settings, object shape/materials, etc. on system performance is essential. Since a full-wave 3D calculation on system level is not practical, a simplified 2.5D approach based on Huygens ' Principle is presented in the second section of this paper. In the third section we will show results which illustrate the various types of interference that will occur in practical situations. In the fourth section results will be summarized on the modeling of two types of multi-parameter illumination: the first employing spatial modulation (Hadamard diffuser), the second using multi-angle