Millimeter-wave antennas for 5G

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***Abstract*—The fifth generation (5G) wireless communications systems have brought a growing need for various antennas, electrically small and large, low-gain and large-gain, also at millimeter wavelengths, and in many cases with beam steering or switching capability. Frequencies of 28 GHz, 38 GHz, 58 GHz, 60 GHz, 71-86 GHz, 140-150 GHz, and some even higher window frequencies are of interest in 5G and subsequent generations. Different parts of the systems need different kinds of antennas. In this presentation, we discuss two antenna types that we have recently studied, namely high-gain lenses with beam switching capability and lower gain printed antennas that suit very well for mass production.**

Keywords—millimeter waves, lens antennas, printed antennas

I. Introduction

In the fifth generation (5G) of wireless communications systems, the consumers are looking forward to faster connectivity, faster browsing and even "unlimited" data. Such characteristics require from the system heterogeneous coverage and use of millimeter-wave frequency bands.

In back haul or access point antennas, high antenna gain is needed, and often beam steering capability is desirable. A lens antenna with an integrated feed antenna network can provide those characteristics. In mobile user devices, the antenna must be of low cost and light weight, in addition low gain and flexibility are preferred characteristics. Printed antennas provide these characteristics. Even with the printed antennas, the price strongly depends on the fabrication method.

In this paper, we discuss first integrated lens antennas and then a specific fabrication method of printed antennas that is supposed to suit best for mass production of mm-wave printed antennas, namely reverse offset roll-to-roll printing.

II. Beam Steerable Integrated Lens Antennas

The integrated lens antenna enables beam steering when it is equipped with a switchable feed antenna array on the back surface. Each low-directivity antenna of the feed array corresponds to one beam. The lens antenna provides a large aperture and, by collimation of the feed illumination, highly directive beam is produced.

The basic shape of the integrated lens antenna is elliptical providing the highest directivity for the boresight beam. However the scan loss is also high, i.e., the directivity decreases when the beam is steered further away from the lens axis. The extended hemispherical lens antenna provides a better solution in terms of scan loss while suffering from lower maximum gain. In [1] the eccentricity of the integrated lens antenna is varied and intermediate shapes between the elliptical and extended hemispherical are studied in order to find the optimal shape to maintain high gain and low scan loss. It is found out that tuning of a single parameter, the eccentricity, gives easy means to optimize the lens performance. Also, the optimal shape depends on the required beam steering range.

The integrated lens antenna suffers from the spillover loss, especially lenses made of low permittivity material. The spillover energy hits the extension part of the lens and reflections cause spurious signals deteriorating the performance of the lens. Mitigation of the reflection effects have been studied in [2] proposing the shaping of the extension part of the lens and adding absorbers around the extension part in order improve the performance of the lens.

Electronic beam steering necessitates switchable feed array. The dedicated switching network tends to be lossy at millimeter wavelengths because of the rather high insertion loss of the switches. Also, for large feed arrays the transmission lines may introduce significant losses. A practical implementation of two-dimensional feed array and switching network for beam steering is demonstrated with 64 beams at the lower E-band in [3].

The mass markets require the antennas to be of low cost. In addition to the material cost, the manufacturing cost is relevant and, e.g., injection molding instead of the conventional machining is seen advantageous. Low loss plastic materials such as HDPE, Rexolite, Teflon, have been used in practical experiments of high gain lens antennas. In order to realize extremely high gain antennas, low losses are required, because increasing the lens size further does note necessary improve the gain as the dielectric losses increase more rapidly than the gain through the increased antenna aperture [4]. The optimal relative permittivity of the lens antenna is about 3-5 [4]. The low permittivity results in the large lens height and the increase of the spillover loss thus the overall efficiency is poor. On the other hand, for the high permittivity the material losses tend to be cause of high overall loss although the lens height is small. As an example of the lens in the optimal permittivity range, a lens of the Preperm plastic material has been designed, fabricated and measured.

Fig. 1. Machined Preperm lens. The diameter of the lens is 64 mm.

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Fig. 1 shows the machined lens. The extension is shaped in order to reduce internal reflections and it is covered with absorbers during the measurements. The measured relative permittivity of the used material is 5.0 and the loss tangent is 0.004. The lens diameter is 64 mm and it provides a gain of 27.8 dBi at 73.5 GHz when fed with a WR-10 open-ended waveguide. Fig. 2 shows the measured gain in the E- and H-planes.

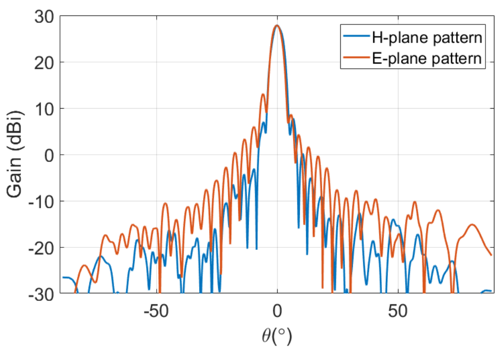

Fig. 2. Measured gain of the 64-mm Preperm lens at 73.5 GHz.

III. Printed Antennas

Printed electronics may be produced with methods used also in printing of newspapers and journals. Fast printing methods used in printing of electronics and antennas are: screen printing, flexography, gravure printing, inkjet printing, offset, and reverse offset printing (RO). However, printing resolution (<1 μm) needed in mm-wave antennas seems to be achievable only by using reverse offset printing.

We have studied reverse offset roll-to-roll (RO-R2R) printing in case of antennas and absorbers at 70-100 GHz [5], [6], [7]. Silver nanoparticle ink has been printed on a flexible polyethylene naphtalate (PEN) substrate of 125-μm thickness. Submicron accuracy has been achieved in edges of various structures ranging from patch antennas to various transmission lines with printing thicknesses of about 300 nm (measured after sintering 60 minutes at 180 °C). However, the square resistance of such printed conductors is > 1 Ω which is somewhat high for mm-wave antennas but very good for absorbers designed using the theory of electromagnetic metasurfaces [6].

Fig. 3 shows an 80-GHz patch antenna printed with the RO-R2R techniques described above. The antenna gain was measured in the on-wafer probe station environment using one-antenna gain measurement method [8], and the measurement result is shown in Fig.4.

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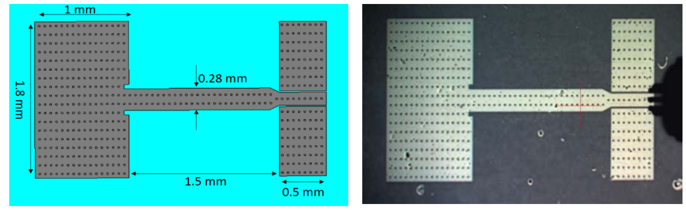

Fig. 3. An 80-GHz RO-R2R printed microstrip patch antenna with GSG probe feed.

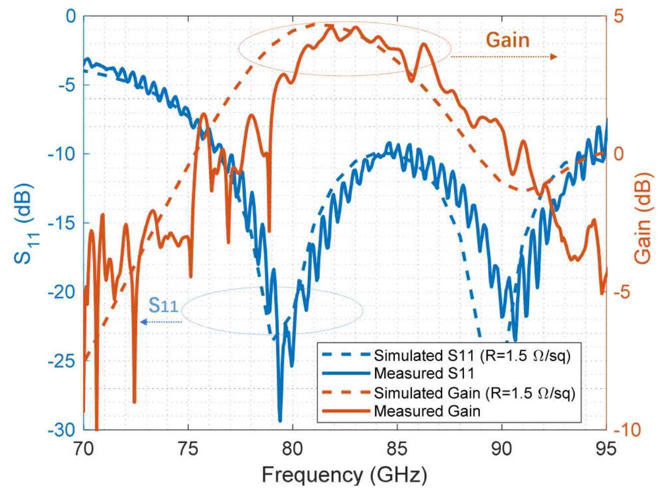

Fig. 4. Measured and simulated antenna matching and gain. Gain measured using the 1-antenna method.

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