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7th European Conference on Antennas and Propagation, EuCAP 2013, Gothenburg, Sweden, 8-12 April 2013

Citation for the published paper:
Yang, J. (2013) "The SWE Antenna – A New Wideband Thin Planar Antenna for 60GHz Communications". 7th European Conference on Antennas and Propagation, EuCAP 2013, Gothenburg, Sweden, 8-12 April 2013

The SWE Gapwave Antenna – A New Wideband Thin Planar Antenna for 60GHz Communications

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***Abstract*—The 60GHz short-range wireless communication system has gained a lot of attention because it can offer high rate data communications with the free-licensed band. Development of wideband, high gain, compact 60GHz antennas is a crucial issue in the system. We present a concept of a new wideband thin planar antenna, the Sheet Waveguide Element (SWE) antenna with gap waveguide technology, for 60GHz communication systems in the paper. This antenna can operate over a wideband with a very thin configuration and have a potential to have very low manufacture cost.**

***Index Terms*—60GHz communication, planar array antenna, wideband**

I. INTRODUCTION

The 60GHz wireless communication systems have gained a lot of attention due to its unique characteristics, such as license-free, wideband (7GHz), high data-rate communication, high oxygen absorption and therefore high security advantages. The high-gain, narrow beam 60GHz antenna is a crucial issue in the development of the 60GHz systems.

Among many types of 60GHz antennas, planar array antennas have many advantages: low-profile, light weight and easy installation. The SIW (substrate-integrated waveguide) planar array [1]–[3] and hollow waveguide slot array antenna [4] are important examples of 60GHz planar array antennas. However, the SIW antennas may have a high dielectric loss and hollow waveguide slot array has narrow bandwidth and difficulties to manufacture.

We propose a new concept for planar array antennas - the Sheet Waveguide Element (SWE) antenna in the paper, integrated with gap waveguide [5]–[7]. The gap waveguide technology was introduced in 2009 [5] and later validated experimentally [6] and applied to packaging of microstrip circuits [8], [9], MMIC amplifier chains [10], and in particularly for improving microstrip filters [11] and other components [12]. There has previously been published 3 different gap waveguide types: ridge, groove and microstrip gap waveguides [13]. The groove gap waveguide was used to realize high Q filters in [14]. We have not yet realized gap waveguide antennas, except for the initial work in [15] before the invention of the general gap aveguide technology, and the related phased array antenna design in [16], and some single slot antenna design. We propose a new concept for planar array antennas in this paper the Sheet Waveguide Element (SWE) antenna in the paper, integrated with a new type of gap waveguide, prohibiting higher order modes in very wide parallel-plate waveguides. The antenna's architecture was inspired by CTS (Continuous Transverse Stub) antenna [17], [18]. In the SWE antenna, we introduce a new type of waveguide – the sheet gap waveguide, in order to 1) suppress the higher order modes in the very wide sheet waveguide, able to design E-band power divide with a very thin profile and have better radiation performance in H-plane; 2) have different matching mechanism without problem of exciting higher order modes; 3) have a very low manufacture cost.

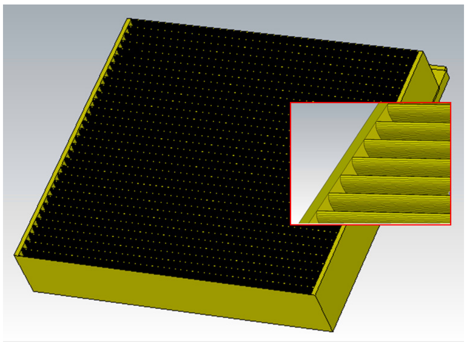

Fig. 1. CST modeling of the SWE antenna.

In the SWE antenna, The tapered aperture distribution over H-plane can be achieved by a parallel plate waveguide (PPW) reflector or lens antenna. The tapered aperture distribution over E-plane can be achieved by thin E-bend power dividers, which was used in CTS antenna. However, the overmode waveguide in CTS antenna has a drawback: the E-bend power divider should be cylindrical structure – no variation along the width, otherwise higher order modes will be created. This imposes a difficulty on manufacture, and limits the matching methods to design a good E-bend power divider when the power divider is very thin.

The purpose of this paper is to present the concept of SWE antenna and show some preliminary results [19].

II. SHEET GAP WAVEGUIDE

Several waveguide technologies have been proposed for millimeter and sub millimeter waves up to Terahertz in order to reduce both the ohmic loss of the wave transmission and the manufacture cost. The SIW (Substrate Integrated Waveguide) has lower loss than microstrip line but the dielectric loss may still lead to unacceptable ohmic loss.

In the SWE antenna, we need to use a very wide waveguide. The ohmic loss, due to the finite conductivity, of a very wide waveguide is much lower than a standard waveguide. Fig. 2 compares the simulated insertion loss, using CST Microstudio [20], between the standard waveguide WR15 ($3.759 \times 1.88\text{mm}^2$) and the overmode waveguide ($140 \times 1.88\text{mm}^2$) (referred to as the Sheet Waveguide). Both waveguides are modeled by copper ($\sigma = 5.8 \times 10^7$S/m). The simulations indicate clearly that the sheet waveguide has much low ohmic loss when only the dominate mode propagates, and much wider band performance.

Reducing the height of a waveguide will increase the ohmic loss in general. Fig. 3 shows the CST simulated insertion loss between sheet waveguides with different heights. It can be concluded the followings. If the height of the sheet waveguide is very thin, such as 0.05 mm, the ohmic loss will be 1.5 dB per 50 mm at 60 GHz (10 wavelength), an unacceptable value in most application cases. However, when the height is larger than 0.2 mm, the ohmic loss will be in an acceptable range. For example, the ohmic loss is about 0.15 dB per 50 mm at 60 GHz when the height is 0.3 mm, ten times less than that when the height is 0.05 mm.

As mentioned, the sheet waveguide can have higher order modes propagating in it. Fig. 4 shows the simulated dispersion diagram of the first 8 modes in the sheet waveguide, which means that all these modes can propagate in the sheet waveguide. In order to avoid this problem, a sheet gap waveguide is introduced, as shown in Fig. 5: on the bottom plate of the sheet waveguide, two rad periodic pin structure is implemented with a certain spacing along the width of the waveguide. By doing so, the waves will be stopped in the area of the pin structure. The height of the pin is chosen as 1.25 mm, a quarter wavelength at 60 GHz. This height can be reduced by several means, which we will not discuss here. Fig. 6 shows the simulated dispersion diagram of the 8 modes, which states that 7 modes are stopped by the pin structure and only one mode can propagate now in the sheet gap waveguide. We will investigate more on this issue.

The simulated insertion loss of the sheet gap waveguide is shown in Fig. 7, where the losses of the sheet waveguide without pin structure and a rectangular waveguide of $3.76 \times 0.3\text{mm}^2$ are also shown as references. From the figure, it can be seen that i) the sheet gap waveguide has a similar ohmic loss as the sheet waveguide does, which is much lower than a normal rectangular waveguide with the same height; ii) since the propagation mode has very low cut-off frequency, the insertion loss is almost flat over 50–70 GHz, while the normal thin rectangular waveguide has a large insertion loss at 50 GHz.

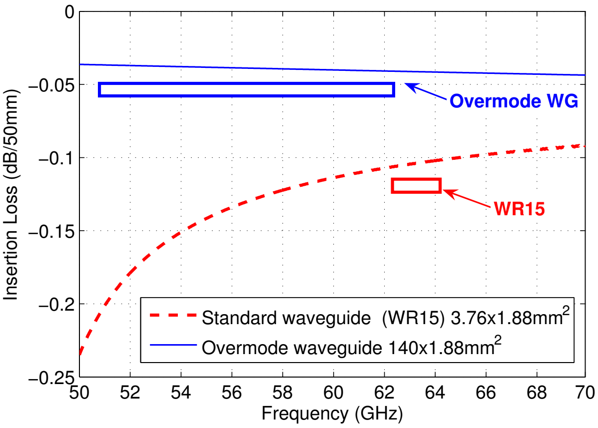

Fig. 2. Insertion loss of standard waveguide WR15 ($3.76 \times 1.88\,mm^2$) and overmode waveguide ($140 \times 1.88\,mm^2$).

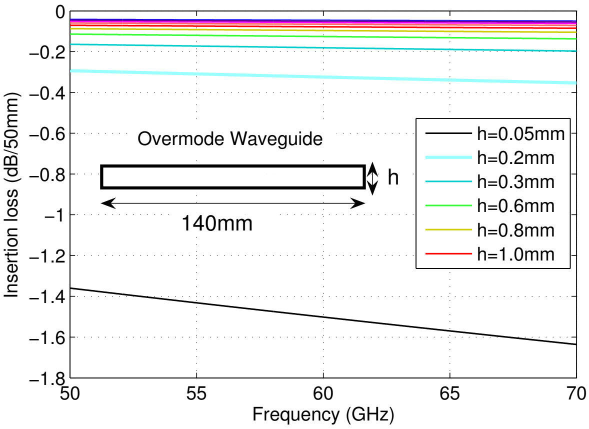

Fig. 3. Insertion loss of overmode waveguide ($140 \times 1.88\,mm^2$) with different height h.

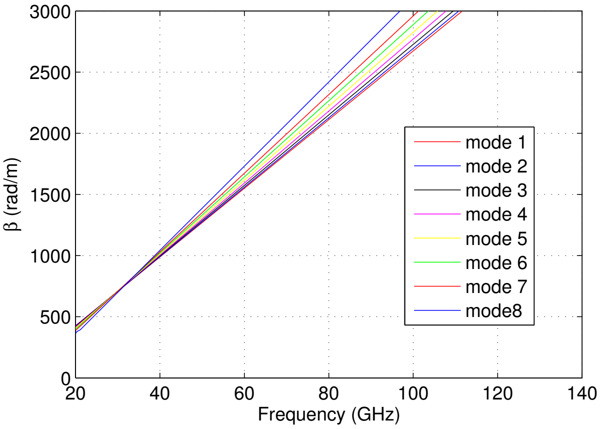

Fig. 4. Dispersion diagram of the sheet waveguide (140×0.3 mm^2).

III. SHEET WAVEGUIDE ELEMENT ANTENNA

We have not completed the design of 60GHz antenna with sheet gap waveguide. We present here the preliminary design with sheet waveguide without pin structure, in order to show the potential of this type of antenna.

Fig. 1 shows the configuration of the Sheet Waveguide

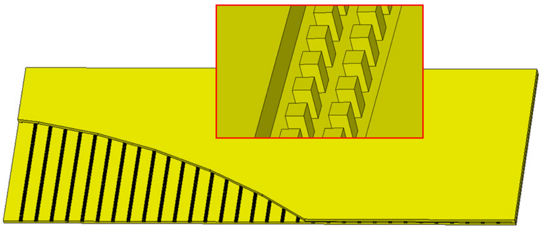

Fig. 5. Geometry of sheet gap waveguide (SGWG) ($140 \times 0.3\,mm^2$ + gap).

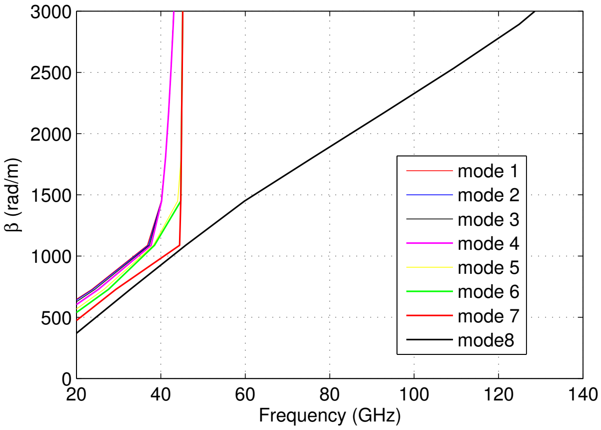

Fig. 6. Dispersion diagram of sheet gap waveguide ($140 \times 0.3\,mm^2$ + gap).

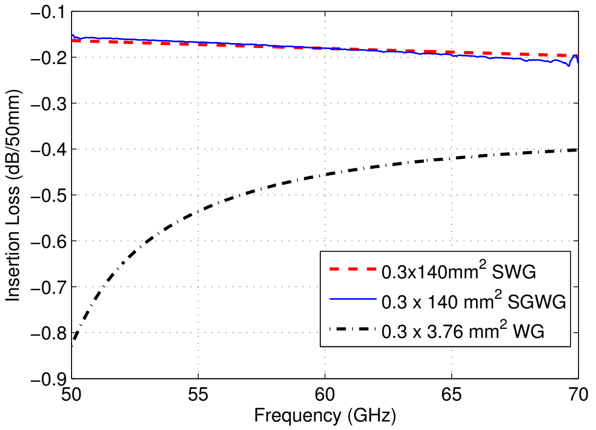

Fig. 7. Insertion loss of sheet gap waveguide ($140 \times 0.3\,mm^2$ + gap), overmode sheet waveguide ($140 \times 0.3\,mm^2$) and thin WR15 waveguide ($3.76 \times 0.3\,mm^2$).

Element (SWE) array antenna, which consists of 32 overmode waveguide horns with a size of 140×5 mm^2. The size of the whole antenna is $140 \times 140 \times 30$ mm^3. The input port is a standard WR-15 rectangular waveguide. Fig. 8 shows the compact feeding network using E-bend power dividers for the aperture distribution over the E-plane, and Fig. 9 shows that we use a parallel plate waveguide reflector to achieve the tapered aperture distribution over the H-plane.

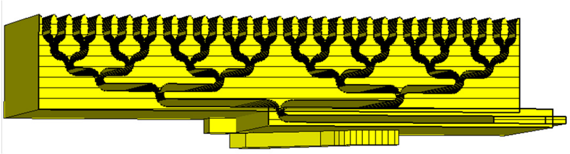

Fig. 8. Feeding network.

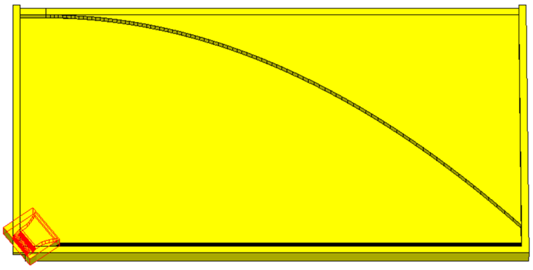

Fig. 9. Reflector in parallel plate waveguide for tapered field distribution in H-plane.

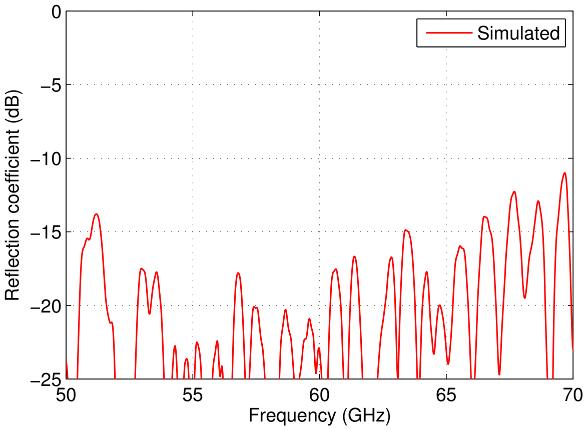

Fig. 10. Simulated reflection coefficient of the SWE antenna.

IV. SIMULATED RESULTS

The design has be carried out by an optimization scheme – so-called Social Civilization algorithm [21]. The simulated reflection coefficient of the whole antenna is shown in Fig. 10, below -12 dB over 50–70 GHz. Simulated radiation patterns in 45° plane are shown in Fig. 11. It can be observed that the sidelobe levels in this plane are under the ETSI class 3B envelop. Fig. 12 shows the simulated radiation patterns in E- and H-plane at 60 GHz. From the figure we see that the sidelobe levels do not satisfy the ETSI class 3B requirements. For E-plane, we can design the E-bend power dividers to have an optimal tapered aperture distribution. For H-plane, we believe that the sheet gap waveguide feeding network will solve the problem.

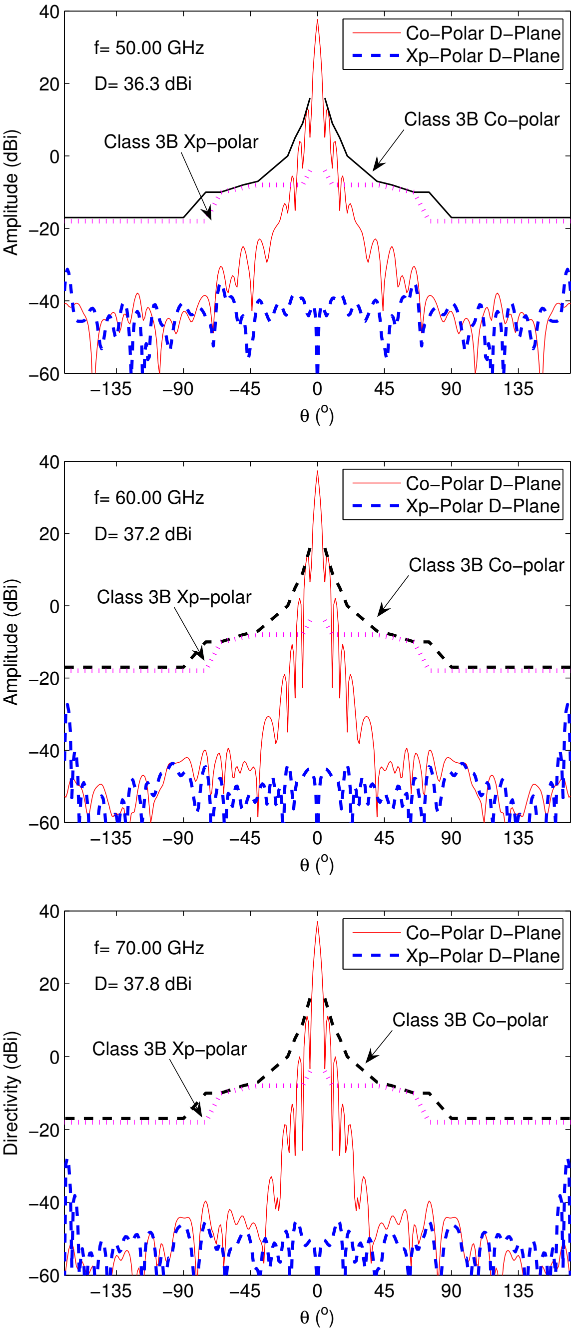

Fig. 11. Simulated radiation patterns in 45° plane.

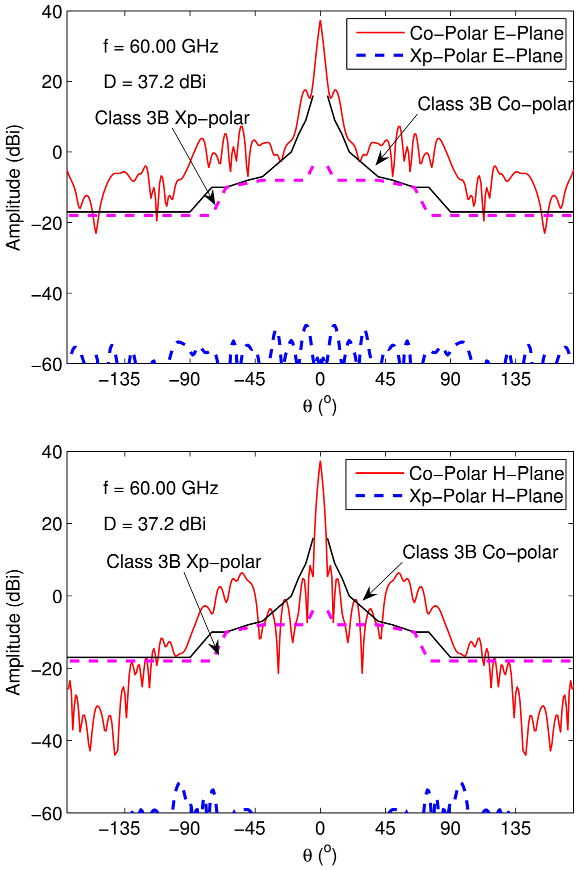

Fig. 12. Simulated radiation patterns in E- and H-plane at 60 GHz.

V. CONCLUSION

A concept of a new 60GHz planar antenna has been presented in the paper. Simulation results show that the antenna has a wideband performance, good impedance match at input port and low sidelobes.

A patent application of this antenna has been submitted [19].

ACKNOWLEDGEMENT

I would like to express my appreciation to Prof. Per-Simon Kildal from Chalmers and Orjan Eriksson from Gapwaves AB for their comments and discussions on this work.

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