Waveguide Fed Broadband Millimeter Wave Short Backfire Antenna

#Shi-Wei Qu[1], Kung Bo Ng[2], and Chi Hou Chan[2]
[1] School of Electronic Engineering, University of Electronic Science & Technology of China (UESTC), Chengdu 611731, China (dyon.qu@gmail.com)
[2] Dept of Electronic Engineering, City University of Hong Kong
83 Tat Chee Ave., Kowloon, Hong Kong (kubong@cityu.edu.hk, eechic@cityu.edu.hk)

Abstract—A broadband millimeter (mm)-wave short backfire antenna (SBA), excited by a bowtie dipole and fed by an E-band rectangular waveguide, is presented in this paper. Its subreflector is replaced by two simple strips printed on the same supporting substrate of the exciter for ease and accuracy of fabrication. Measurements and simulations show that the proposed antenna can feature an improved operating bandwidth and broadside gain compared to reported conventional SBAs. Finally, high illumination efficiency of the bowtie exciter to the antenna aperture is highlighted by comparisons with an SBA excited by a straight dipole.

1. Introduction

SBAs were firstly proposed by Ehrenspeck in 1960s [1], and from then on they have been investigated by many researchers due to their various advantages, and extensively applied in different systems from land-based point-to-point communications, maritime rescue to satellite applications in space. Generally, this kind of antennas consists of a cavity as a main reflector, a small subreflector to improve the illumination efficiency of the antenna aperture, an exciter, and its corresponding feeding structure. The total dimensions of SBAs are commonly around two wavelengths in diameter and over one half wavelengths in height, and their leaky-wave properties ensure their excellent radiation performances, e.g. a maximum aperture efficiency of around 80%, a back lobe level of -30 dB and a side lobe level (SLL) of -15 dB [1]-[4]. However, their operating bandwidth is limited to a small value, and at frequencies out of the narrow operating band, poor impedance matching, rapidly increased side lobes and sharp drop of broadside gain make them unusable. Generally, their impedance bandwidth can be enhanced to a maximum value of 20% by reconstructing cavity shapes, employing different kinds of exciters, and optimizing the antenna dimensions [1], [5]-[6]. Since 2000, many developments on the SBA have been published [2]-[4], [7]-[9], in which the maximum bandwidth of 30% and a simulated peak gain of 16 dBi are individually realized in microwave frequency bands by various combinations of different exciters and cavities but at different kinds of costs.

On the other hand, mm-wave communication systems, e.g. 60-GHz wireless local network (WLAN), are currently becoming one of the hottest topics in antenna and array research. Different from microwave-band operation, electrically large dimensions of the SBAs become one of the merits in mm-wave bands, which can reduce fabrication difficulties and sensitivity to the fabrication error. However, both small solid structures and installation of the subreflectors make their realization much more difficult in mm-wave bands. Even in some cases, very fine dimensions of the mm-wave SBA, especially the feeding structure, cannot be put into reality even if it shows perfect electrical performances. Therefore, only a handful of publications can be found on SBAs operating at around 30 GHz [11]-[12], and scarcely little work in V band or above. In this paper, a waveguide-fed E-band SBA, excited by a bowtie dipole, is proposed for ease of fabrication, broadband and high-gain operation, and its available bandwidth will depend on SLL requirements.

2. Geometry

Fig. 1 shows the proposed broadband mm-wave SBA. The antenna consists of a rounded sectorial bowtie dipole as an exciter, two parallel strips as the subreflectors, an elliptical composite cavity built in a copper block, and two transitions as a feeding structure. The exciter, subreflectors, and transitions are etched on both sides of a substrate with a relative permittivity of 2.2 and a thickness of 0.127 mm, which is centrally arranged with respect to the rectangular waveguide in the yz plane. For presentation clarity, this substrate is depicted in Fig. 1 (a) as transparent. To practically build the antenna, the copper block can be symmetrically cut into two parts along the yz plane, and the substrate can be clamped between them without obvious influences on the antenna electrical performances, because it is equivalent to a longitudinal slot at the center of wide sidewalls of the waveguide. It is fed by a standard waveguide WR12 which can be easily connected to the Agilent Network Analyzer E8361A. At the joint of the waveguide and the cavity, there are two tapered parts for better impedance matching. The composite cavity is determined by three ellipses, as given in Fig. 1 (b), and the axial lengths of the bottom, middle and top ones along y axis are D_b, D_m, D_t, respectively, and a minor-to-major axis ratio R_a is shared by all of them. Thus, the aperture size of the proposed SBA can be tuned by changing the parameters of D_t and R_a. Meanwhile, two subreflectors, placed back to back on both sides of the substrate as shown in Fig. 1 (c), will dominate the antenna performances in a similar manner to that of conventional SBAs. However, they can be printed on the same substrate layer with the exciter, instead of parallel arrangement to the aperture, avoiding difficulties of installation and interferences of mounting or supporting components to antenna radiation at mm-wave frequencies. Meanwhile, Transition I is used to convert the rectangular waveguide mode first into an antipodal finline mode and then into a parallel strip line mode, and Transition II is actually an impedance transformer to connect the exciter for good impedance matching. Height of the exciter (h_e) dominates the antenna impedance matching to a large extent, and its design procedure can be referenced to our previous work [13]. Note that the impedance matching can be achieved by carefully tuning of the two transitions and the exciter.

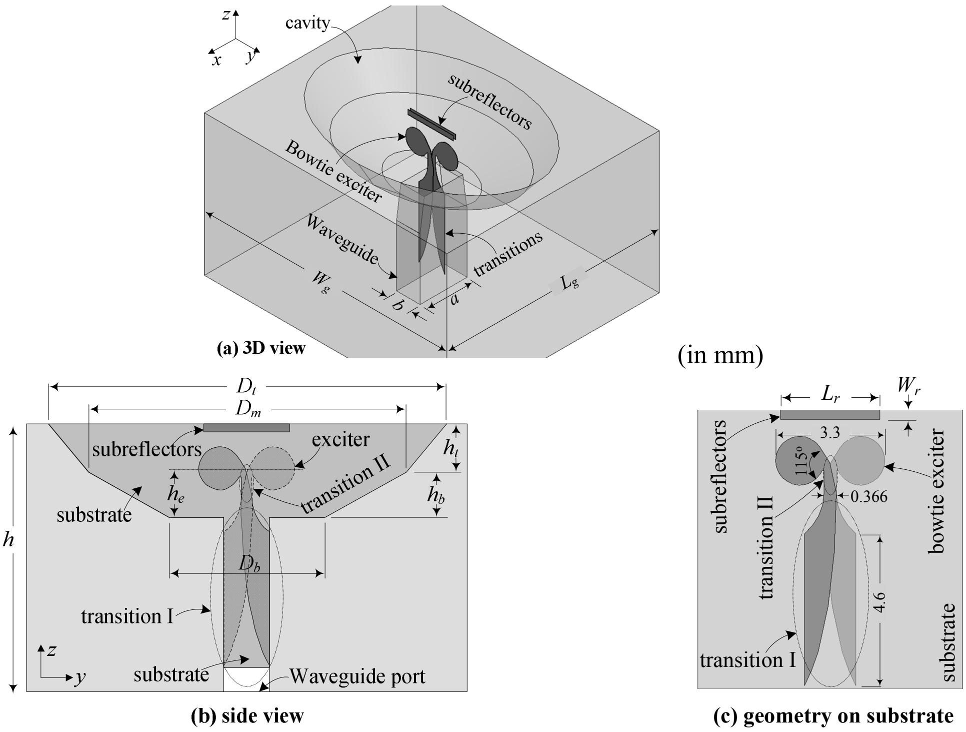

Figure 1: Geometries of the proposed mm-wave SBA. W_g = L_g = 20, h = 9.243, a = 3.0988, b = 1.5494, R_a = 0.7, L_r = 3, W_r = 0.3, D_t = 14, D_m = 11, D_b = 5.4, h_t = 1.8, h_b = 1.57, and h_e = 1.57.

3. Simulated and Measured Results

To verify the simulations, an antenna prototype was built and measured after optimizations. Standing-wave ratio (SWR) was measured by Agilent Network Analyzer E8361A in two separated bands, i.e. 50 ~ 75 GHz and 75 ~ 100 GHz, calibrated by V-band and W-band waveguide calibration kits, respectively. The simulated and measured SWRs are shown in Fig. 2 (a) along with simulated broadside gain, where they agree reasonably well with each other. The simulated impedance bandwidth for SWR ≤ 2 is over 54%, covering from 57.5 to over 100 GHz, and comparatively the measured results are from 55.7 to over 100 GHz. Meanwhile, the simulated broadside gain is between 14.2 and 18.7 dBi over the simulated impedance bandwidth, and a maximum appears at 86.2 GHz. Simulated and measured H(xz)-plane radiation patterns at 60, 65, 70, and 75 GHz are shown in Fig. 3, and measurements agree well with simulations. Similar agreements are obtained for the E-plane patterns which are not shown here due to limited space. Note that the radiation pattern measurement system in our lab can only operate up to 75 GHz at the present time. It can be seen that the antenna can achieve symmetrical radiation patterns at all the frequencies shown. Actually according to our numerical investigations, the E-plane SLL is always kept small up to 90 GHz, and the H-plane SLL is a little higher, going up to -7.7 dB at 90GHz. Thus, the bandwidth will depend on the SLL in practice, but it still features a notable available bandwidth.

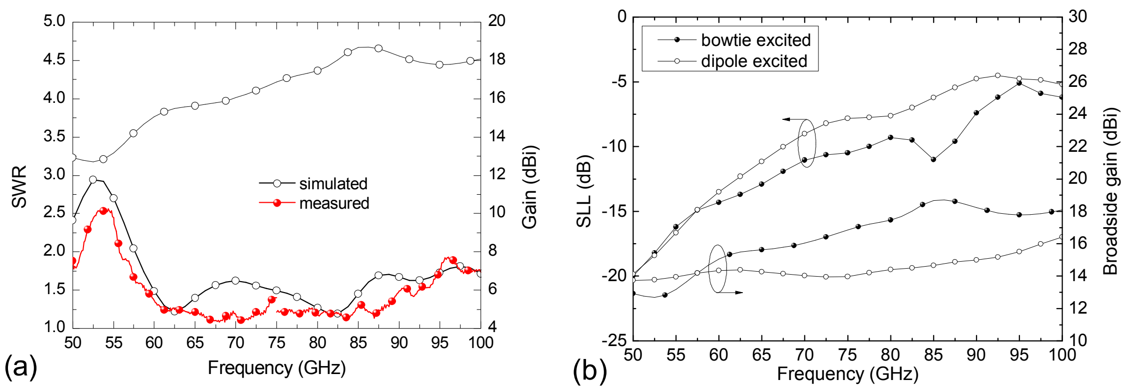

Figure 2: Simulated and measured SWRs and broadside gain of the fabricated antenna prototype.

To show the high illumination efficiency of the bowtie exciter, the same SBA excited by a straight dipole (0.3 mm in width and 2 mm in length) is referenced. As given in [10], the radiation performances of the SBA will be changed only in a small range by the dipole position, but dominated by the dipole length to some extent according to our investigations. Fig. 2 (b) gives comparisons of the SBAs with the bowtie exciter and a straight dipole, in terms of the SLL and broadside gain. It is obvious from the figure that the broadside gain of the dipole-excited SBA is in a range of 13.94 ~ 14.67 (16.41) dBi from 57.5 to 85 (100) GHz, 1 ~ 4dBi lower than that of the bowtie-excited one, meanwhile its SLL is also 1 ~ 5 dB poorer. Furthermore, for the dipole-excited SBA, the highest gain and the best SLL cannot be simultaneously achieved, e.g. a longer dipole (3.3 mm) results in a better SLL and comparatively a shorter one (2 mm) will cause a higher gain.

4. Remarks

An mm-wave SBA is studied in this paper for broadband and high-gain operation. Parametric studies and measurements are done for purposes of verification and providing guidance for practical designs. Comparisons between the proposed SBA excited by the RSBD and a straight dipole prove high illumination efficiency of the bowtie exciter. Furthermore, more investigations show that it is easy to design the proposed antenna with variable electrical performances. For example, if a low SLL is expected, the parameters of R_a, D_m, and D_b can focused on our efforts, and comparatively, R_a, D_t, D_m and h_b should be emphasized on for a high gain.

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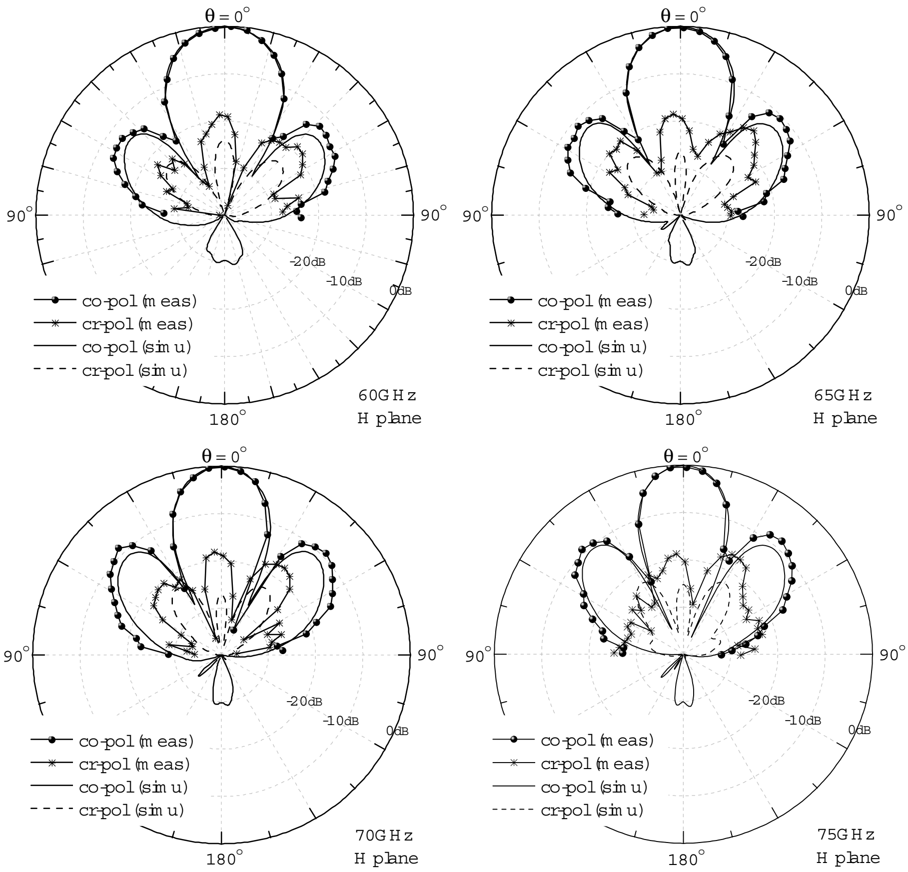

Figure 3: Simulated and measured H-plane radiation patterns at 60, 65, 70, and 75 GHz.

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