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Investigation and experiment of a symmetrically unidirectional patterns antenna

***Abstract**. An investigation of symmetrically unidirectional beam antenna accomplished by a probe-feed open-rectangular waveguide with two-stacked-coupling aperture is proffered. The proposed antenna is capable to adjust the asymmetrically bidirectional beam to a symmetrically unidirectional beam by mean of the impact of two-stacked-coupling aperture. The geometry of the proposed antenna consists of a radiating rectangular waveguide (at the middle) vertically jointed to the two one-open-end waveguides of an identical widthwise on top and underneath the radiating section. The radiating open rectangular waveguide is stimulated by a probe together with a matching circular disc. All parameters of the presented antenna are analyzed by using an electromagnetic microwave simulator. Apparently, it produces symmetrical unidirectional beam over the 15 dB return loss frequency band of 2.4–2.5 GHz with maximum gain of 7.09 dBi. The experiment was set and performed to verify the simulation. Obviously, experimental results are reasonably in excellent agreement with the simulation ones.*

Streszczenie.** Zaproponowano badanie anteny z symetryczną wiązką jednokierunkową, zrealizowanej za pomocą otwartego prostokątnego falowodu zasilanego sondą z aperturą sprzęgającą z dwoma stosami. Proponowana antena jest w stanie przestawić wiązkę asymetrycznie dwukierunkową na wiązkę symetrycznie jednokierunkową za pomocą uderzenia dwupiętrowej szczeliny sprzęgającej. Geometria proponowanej anteny składa się z promieniującego prostokątnego falowodu (w środku) pionowo połączonego z dwoma falowodami z jednym otwartym końcem o identycznej szerokości na górze i pod sekcją promieniującą. Promieniujący, otwarty prostokątny falowód jest stymulowany przez sondę wraz z dopasowanym okrągłym dyskiem. Wszystkie parametry prezentowanej anteny są analizowane za pomocą symulatora mikrofal elektromagnetycznych. Najwyraźniej wytwarza symetryczną jednokierunkową wiązkę w paśmie częstotliwości strat powrotnych 15 dB w zakresie 2,4–2,5 GHz z maksymalnym wzmocnieniem 7,09 dBi. Eksperyment założono i przeprowadzono w celu weryfikacji symulacji. Oczywiście wyniki eksperymentalne są w miarę doskonale zgodne z wynikami symulacyjnymi.* (Badanie i eksperyment symetrycznie jednokierunkowej anteny pattern***)

Keywords: Symmetry unidirectional antenna; Open-rectangular waveguide; Coupling aperture.
Słowa kluczowe: Antena symetryczna, falowód

Introduction

Over decades years, the point-to-point communications systems have promptly continued for long distance communications such as, microwave radio relay link, long length Wi-Fi, wireless WAN/LAN link, satellite communication, and home satellite television etc. [1]- [4]. A pencil beam producing high gain antenna is required for improving overall performance of point-to-point communication [1], [3]-[5]. To achieve the pencil beam, a parabolic reflector antenna is one of good candidates producing a sharp beam. For parabolic reflector antenna, symmetric E/H-plane radiation pattern can improve the total gain of antenna system [5]-[10]. In addition, an illuminating symmetrical radiation pattern source (primary feed) is required for the reflector (secondary) antenna to generate the pencil beam with high gain. Nevertheless, because of the asymmetric structure leading to asymmetrical beamwidths between the E - and H -planes, thus generating symmetrical radiation pattern at the primary feed is not easy [8]. To improve overall antenna performance system, various research on symmetrical beam antenna for the primary feed of the reflector antenna have been continuously proceeded, such employing corrugate horn, planar array, planar spiral with conical spiral and using coupling aperture etc. [11]- [16]. In the midst of symmetrical radiation pattern antenna in the recent literatures, applying stacked-coupling aperture (SCA) is one of desirable techniques to accomplish the symmetrical radiation pattern due to its simple structure and ease of manufacture [13]-[14], [17]. Apart from that, unidirectional feeds are desirable to accumulate the reflector performance by productively directing most of the feed radiation toward the reflector surface, thus diminution the overflow power. Therefore, the symmetrically unidirectional pattern antenna is required. A probe-fed open- rectangular waveguide with two-stacked-coupling-aperture antenna (PFORWWTSCAA) was preliminary studied for designing a symmetrical unidirectional beam antenna in 2018 [14]. It was found that the influence of TSCA could convert the asymmetrical beam to be symmetry at -3 dB beamwidth. Nevertheless, an equal beamwidth of both E- and H-planes at -10 dB could not achieved yet. Consequently, this article intends to incessantly improve the TSCA for progressive symmetrically unidirectional radiation pattern at -10 dB beamwidth. Applying the microwave simulation tool, all antenna appropriate parameters are achieved. The organization of the article is as follows: Section 2 presents the antenna structure and its design. Next, the simulated and measured results of the proposed antenna are investigated in section 3. Finally, section 4 informs on conclusions.

Antenna structure and its design

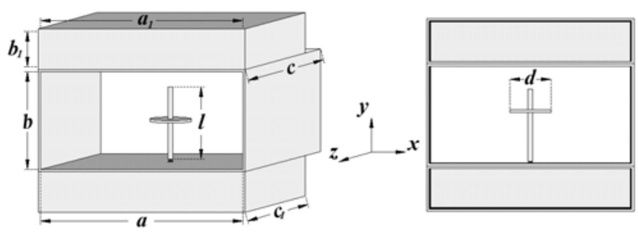
A fabric of a PFORWWTSCAA is depicted in Fig. 1. It consists of the open ended-rectangular waveguide as the radiating section located at the middle, which is vertically attached by two identical coupling apertures on top and underneath the radiating section. For the radiating section, it is fed by a linear probe of length l located at the center of an open-rectangular waveguide (ORW) of width a, height b and length c, respectively. For TSCA, they have the same width a_1, height b_1, and length c_1, where its closed-end aperture directs to the forward plane, while the open-end turns to the opposite direction. In the process, the ORW is designed to propagate the dominant mode (TE_{10}) [18] operating at the center frequency (f_c) of 2.45 GHz by applying (1). Consequently, the width and height of ORW a=0.69λ (84 mm) and b=0.33λ (40 mm) are obtained. In addition, for a compact size of radiating section and good return loss, the length c is selected at 0.26λ (35 mm). To excite the ORW, a linear probe of length 0.25λ (30 mm) with a matching circular disc of radius d of 8.5 mm [19] is applied. These values are kept constant throughout the paper.

$$f_c = \frac{\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}}{2\pi\sqrt{\mu\varepsilon}}, \quad (1)$$

where, f_c is the cut off frequency, μ is permeability, ε is permittiity, m = 1 and n=0.

Note that the PFORW without SCA produces the asymmetrically bidirectional pattern (half-power beamwidths (HPBWs) in E- and H-planes are 94° and 66°, respectively) with maximum gain of 5.17 dBi. Therefore, the influence of vertical SCAs consequently impact and reform the asymmetrical beam and to be symmetry by rearranging number of SCAs, height b_1 and length c_1 [14], [17]-[18]. In our previous work [17], symmetrically bidirectional beam was accomplished by using four SCAs, where two SCAs are attached on top and others are underneath the radiating section. Remarkably, reducing number of SCA from four to two, a nearly symmetrical beam unidirectional beam was produced [14], but it was not finished yet. In this paper, the PFORWWTSCAA is demonstrated to further complete our previous work in [14]. For this work, the width a_1 of TSCA is kept as the same value as width a of radiating section, since the beamwidth in vertical plane has more effect to the symmetrical pattern in this case. The optimized parameters of the proposed PFORWWTSCAA are reported in Table 1.

a)



b)

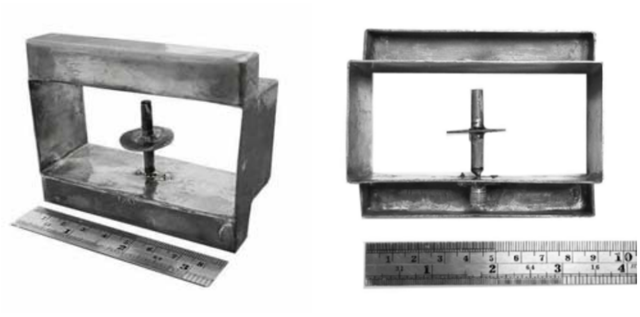


Fig.1. Geometry of the PFORWWTSCAA: (a) model and (b) prototype

Table 1. The parameters of the designed antenna

Parameters	Physical size (mm)	Electrical size (λ)
a	84	0.69
b	40	0.33
c	35	0.26
l	30	0.25
a_1	84	0.69
b_1	15	0.12
c_1	12	0.10
d	8.5	0.07

Simulation and measured results

In this section, the simulated and measured results of PFORWWTSCAA are shown and discussed. Figures 2 and 3 show the effect of length c_1 followed by height b_1 of TSCA to the radiation pattern of PFORWWTSCAA. Apparently, as the longer length c_1 produces the widen -3 dB and -10 dB beamwidths for both E- and H-planes. Moreover, an identical -3 dB beamwidth is obtained at c_1 about 0.12λ and 0.20λ. Nevertheless, the -10 dB beamwidth trends to be more dissimilar for longer length c_1. Taking into consideration of both -3 dB and -10 dB beamwidths simultaneously, the nearly identical beamwidths are achieved at c_1 of 0.1λ; it provides the smallest divert at -10 dB beamwidth. Therefore, the length c_1 of 0.1λ is selected and fixed. Afterward, effect of height b_1 is investigated and plot in Fig. 3. Obviously, the further height provides a narrower HPBW for E-plane, in contrast to H-plane. They provide the same HPBW when the height is 0.12λ. For -10 dB beamwidth, slightly increasing beamwidths are produced for both planes. Note that, the -10 dB beamwidth of E-plane cannot achieve when b_1 > 0.125λ, because the field strength is higher than -10 dB. In this paper, b_1 of 0.12λ is selected, since it offers an identical -3 dB beamwidth and nearly similar -10 dB beamwith for both planes. Consequently, the symmetrical unidirectional pattern of the -3 dB and -10 dB beamwidths of 64° and 120° (with $\pm 2^{\circ}$) respectively, are achieved covered frequency from 2.4-2.45 GHz.

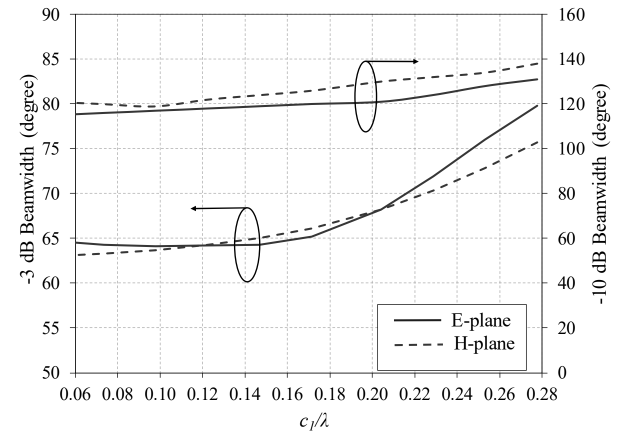


Fig.2. Simulated beamwidths of the PFORWWTSCAA for various length c_1.

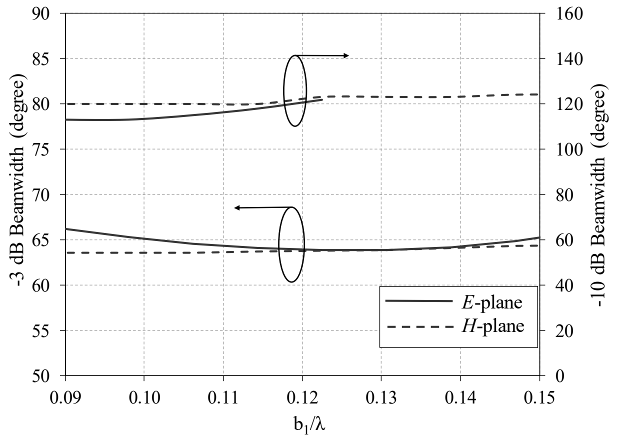


Fig.3. Simulated beamwidths of the PFORWWTSCAA for various height b_1.

In addition to its beamwidths, the return loss and gain of the proposed PFORWWTSCAA are plot in Fig. 4. This proposed antenna provides the minimum and maximum gains of 5.79 dBi and 7.01 dBi respectively for 15 dB return less over the frequency range of 2.38–2.66 GHz, which also covers the WLAN frequency. Note that the the minimum and maximum gains of 6.78 dBi and 7.01 dBi, respectively over the interested operating frequency of WLAN. Also, back lobe level (BLL) is taken into consideration as depicted in Fig. 5. Obvious that as the increasing frequency as the decreasing BLL is achieved until it reaches the lowest value at the center frequency of 2.45 GHz, then it increases again. Unfortunately, the BLL of the PFORWWTSCAA is quite high; the lowest BLL is -7.9 dB.

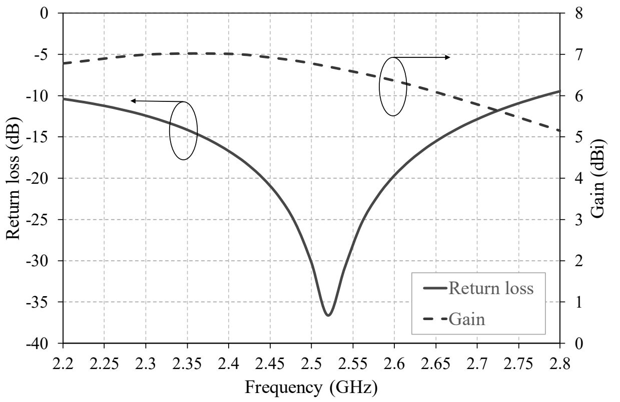


Fig.4. Simulated return loss and gain of the proposed antenna.

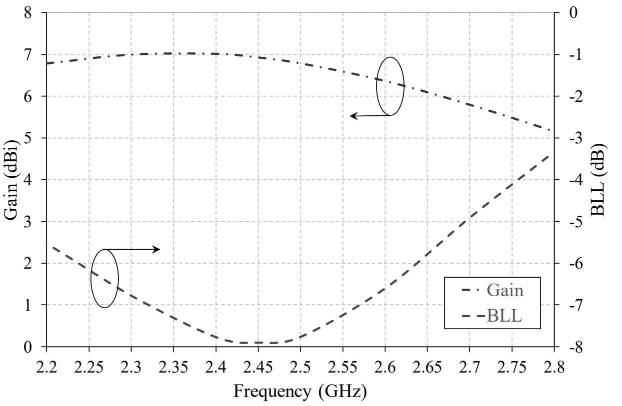


Fig.5. Simulated gain and BLL of the proposed antenna.

In the validation, a prototype antenna was fabricated from copper with the designed dimensions as in Table 1. A photograph of the prototype antenna including coaxial feeding port connected via SMA 50-ohm connector is shown in Fig. 1 (b). Using an E5071C network analyzer, impedance and radiation characteristics of the presented antenna are measured and discussed. Figure 6 shows the comparison between simulated and measured return loss versus the frequency ranging from 2.2 GHz to 2.8 GHz. Apparently, the similar trend of measured and simulated 15 dB return loss over the interested band 2.4 GHz to 2.5 GHz are achieved; the simulated and measured 15 dB return loss bandwidth are 2.38-2.66 GHz and 2.34-2.66 GHz, with the resonance frequencies of 2.52 GHz and 2.5 GHz, respectively.

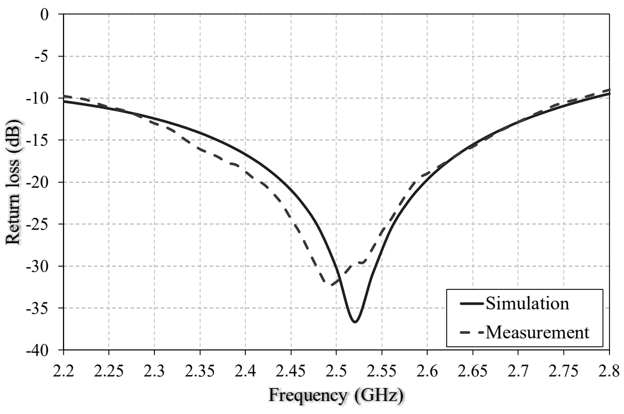


Fig.6. Simulated and measured return loss of the proposed antenna.

Beside the impedance characteristics, the radiation pattern is also demonstrated. Figure 7 shows the simulated and measured radiation patterns of the proposed PFORWWTSCAA for both E-and H-planes at the operating frequency of 2.4, 2.45 and 2.5 GHz. Obviously, it provides the symmetrical unidirectional pattern with simulated and measured maximum gains of 6.92 dBi and 7.09 dBi, respectively.

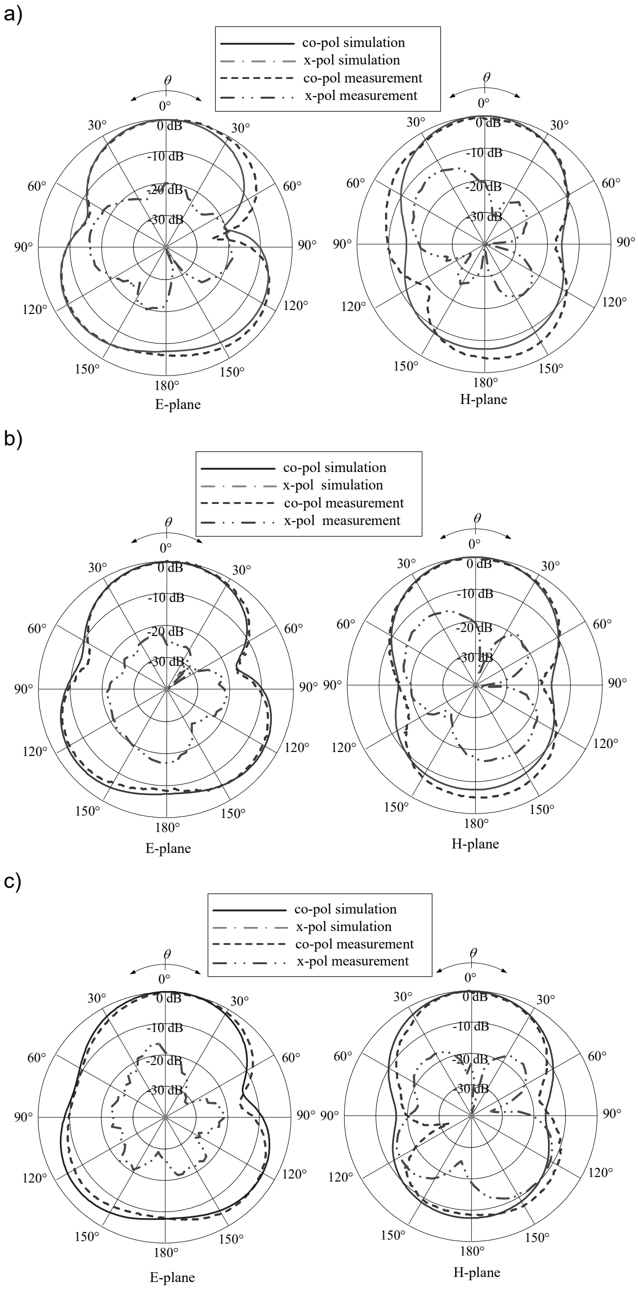


Fig.7. Radiation pattern in E-and H-plane at a) 2.4 GHz, b) 2.45 GHz and c) 2.5 GHz

Within the operational bandwidth, the simulated and measured -3 dB and -10 dB beamwidths are identical values of 64° and 120° (with $\pm 2^{\circ}$) for both E- and H-planes, respectively. The simulated cross polarization was not obtained, but the measurements resulted in a value of less than −20 dB (in the forward direction) for both E- and H-planes. The measured radiation efficiency of the antenna was not obtained, but the simulations resulted in a high value of greater than 97% at 2.4–2.5 GHz. Unfortunately, it's BLL is quite high. Nonetheless, this weakness point can be suppressed by modifying a partial reflector at one-end of the radiating ORW. It should be noted that the slight discrepancy between the measurement and simulation could be attributed to the effects of the SMA connector and cable in the experiment setting.

Conclusions

A probe-fed open rectangular waveguide with two-stacked-coupling aperture antenna producing a symmetrically unidirectional pattern is discovered. This proposed antenna is capable to tailor the asymmetrically bidirectional beam to be the symmetrically unidirectional beam within the mastery of two stacked-coupling apertures. It provides the 15 dB returnloss with the simulated and measured maximum gains of 6.92 dBi and 7.09 dBi, respectively over the frequency band of 2.4–2.5 GHz. In addition, the simulated and measured half-power beamwidths in both *E*-and *H*-planes are equal to 64°, while the -10 dB beamwidth of both planes are equal to 120° (with tolerance $\pm 2^\circ$). To validate the simulation, antenna prototype was fabricated and measured. As the results, both simulation and experimental results are in great agreement. From these results therefore, this symmetrical beam PFOWWTSCAA is one of good choices for applying to be the primary feed of parabolic reflector antenna, which is one example of its applications.

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