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Theoretical Investigation of a Parabolic Reflector Illuminated by a Probe-Fed Rectangular Waveguide with Coupling Apertures

***Abstract**. In this study, a design of high gain reflector antenna for point to point communications is reported. A probe-fed waveguide aperture with four-stacked-coupling aperture is employed to be a primary illuminated parabolic reflector antenna. By varying distance between the primary and secondary antennas, its gain can be raised. An EM simulator has been used in the process. It is found that this proposed antenna provides an excellent symmetrical sharp beam with a low side lobe level as well as low cross-polarization. In addition, this proposed antenna produces a high gain of 26.9 dBi with S_{11} < -15 dB from $0.88f_c$ to $1.06f_c$. All simulation results are reported and discussed in the paper.*

Streszczenie.** Przedstawiono projekt anteny z reflektorem o dużym wzmocnieniu do komunikacji point to point. Zastosowano falowód z czterema sprzężeniami oraz reflektor paraboliczny. Przez zmianę odległości między antenami wzmocnienie może się zmieniać. Ten problem rozwiązuje symulacja. **Teoretyczna analiza parabolicznego reflektora z prostokątnym falowodem ze sprzężoną apertura.

Keywords: Symmetrical beam antenna; Reflector antenna; Rectangular waveguide; Sharp beam antenna.
Słowa kluczowe: antena symetryczna, reflektor anteny, falowód

Introduction

Large parabolic reflector antennas are vastly employed in radar, navigation, direct broadcast, high-gain wireless communications, and space and satellite systems [1]-[4]. With various types of paraboloids, the single reflector has become in demand [5]-[11]. Nevertheless, due to the asymmetry of the offset reflector geometry, it inflicts undesirable effects, resulting in low cross-polarization discriminations and squinted main beams for the linearly and circularly polarized waves, respectively, at the asymmetry plane [7]-[9]. Therefore, the requirement of an illuminating source, also called a primary feed, with symmetrical radiation pattern properties [3]. The aforementioned shortcomings of the offset reflector antenna, there are many techniques have been addressed such as using the conjugate match technique, multimode operation, using metasurfaces, phased arrays, polarization diversity and coupling apertures as primary feeds to improve radiation properties of reflector antenna [3], [8]-[10].

This paper presents a sharp beam with high gain and low cross-polarization employed by a primary probe-fed rectangular waveguide aperture with four-stacked-coupling apertures fed the secondary parabolic reflector. This probe-fed rectangular waveguide aperture provides a symmetrical pattern beam within the operation of four-stacked-coupling apertures [12]-[13]. By applying this primary fed reflector antenna, a focal distance is varied to investigate appropriate parameters by using the CST microwave studio [14]. All numerical results will be discussed and reported in this paper.

Antenna structure and its design

In this work, the proposed probe-fed waveguide aperture with four-stacked-coupling apertures as depicted in Fig. 1 (a) is employed for the primary fed reflector with the distance d_f as shown in Fig. 1 (b). For the primary fed antenna, it was designed to provide symmetrical pattern and presented in our previous works [12]-[13]; all optimum parameters of a primary fed and secondary antennas are summarized as shown in Table 1. Note that, this proposed probe-fed rectangular waveguide aperture with four-stacked-coupling apertures provides the maximum gain of 7.04 dBi. In the study, the dimension of the secondary parabolic reflector is set as the same size of commercial one as follows: its diameter of reflector d_0 is $12\lambda_c$ (where λ_c is wavelength of center frequency at 10.25 GHz), the deep and focal length of parabola are denoted as d and d_f., respectively as depicted in Fig. 1(b).

a)

b)

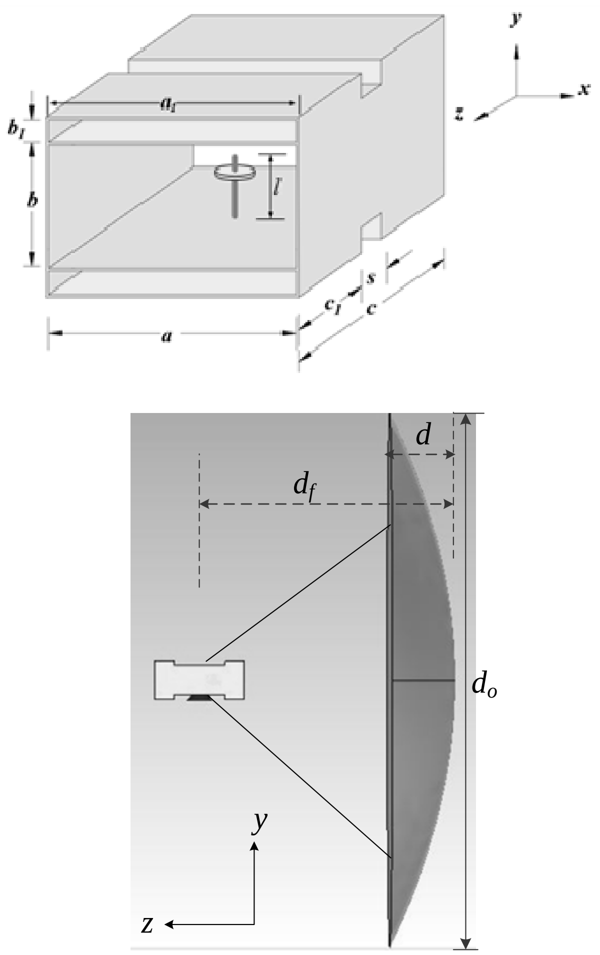

Fig.1. Geometry of the proposed antenna: (a) primary fed antenna, (b) reflector antenna

To achieve a sharp beam with high gain, the focus distance d_f is varied. Next section, simulation results are shown and discussed.

Table 1. The parameters of the primary fed [13] and secondary antennas

Parameters	Electrical size (λ_c)
a	0.76
a_1	0.76
b	0.35
b_1	0.05
c	1.11
c_1	0.20
l	0.22
s	0.70
d	1.54
d_0	12

Simulation and measured results

In this section, a distance between a primary fed and secondary antenna is varied as function of d_f /d_0 as shown in Figs. 2 and 3, where d_0 is a diameter of parabolic reflector. It is found that the antenna gain is slightly increased as the further distance until d_f /d_0 is equal to 1, then its gain is slightly decreased. For the side lobe level (SLL), it increases as the further distance and provides the highest SLL of -15 dB at d_f /d_0 equals to 0.97; then it reduces. The maximum gain of 26.9 dBi with the lowest side lobe level of -20 dB is achieved when d_f equals to d_o as shown in Fig. 2. Furthermore, back lobe level (at θ = 180 degree) is also considered as plotted in Fig. 3. Apparently, back lobe level alters and tends to increase as the further distance during 0.93d_0-0.96d_0 and 0.97d_0-1.03d_0. The highest level occurs at 1.03d_0 with BLL of -23.88 dB. For the focal distance d_f /d_0 of 1, this presented antenna provides an acceptable BLL of -28 dB as depicted in Fig. 3.

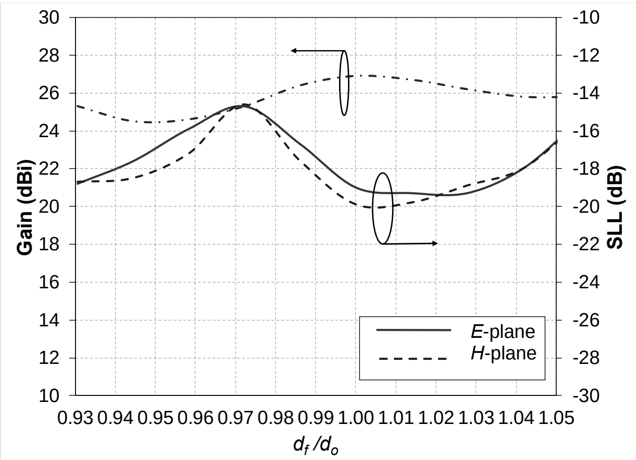

Fig.2. Gain and SLL for various distances.

In addition to the radiation properties as a function of the focal distance, gain and S_{11} in the function of frequency ranging from 0.88f_c to 1.06f_c are also investigated and plotted as shown in Fig. 4. Obvious that this probe-fed waveguide aperture with four-stacked-coupling apertures fed parabolic reflector provides S_{11} better than -15 dB with the minimum and maximum gains of 24.5 dBi and 26.9 dBi respectively over the interested frequency; the maximum gain is achieved at the center frequency. In addition, the efficiency of this presented antenna is higher than 98%.

Figure 5 shows the radiation pattern of the proposed probe-fed waveguide aperture with four-stacked-coupling apertures as the primary fed of paralabolic reflector antenna. Apparently, this proposed antenna provides a symetrical sharp beam with the HPBW (-3 dB beamwidth) of 6 degree and the -10 dB beamwidth of 10 degree for E-, H-, and diagonal-planes. It produces a very sharp beam with the first-null beamwidth (FNBW) of 16 degreee. Moreover, this presented antenna provides a low SLL in E- and H-planes of -19 dB and -20 dB, respectively, as low as back lobe level of -27 dB for both E- and H-planes. In addition, the unwanted cross-polarization is less than -40 dB. It should be pointed that this proposed antenna provides a linear polarization with an axial ratio of 40 dB at the operating frequency.

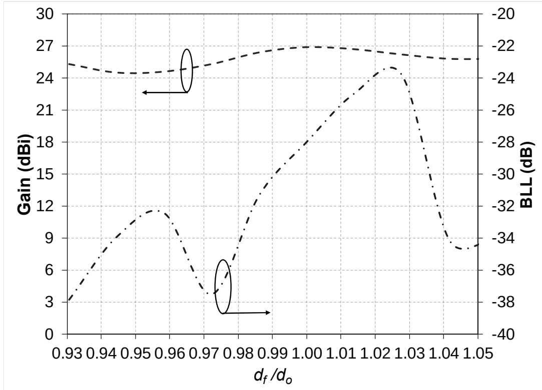

Fig.3. Gain and BLL for various distances

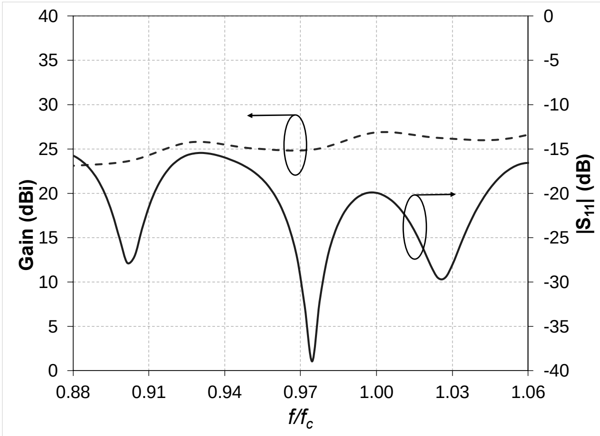

Fig.4. Gain and S_{11} for various frequencies (d_f/d_0=1).

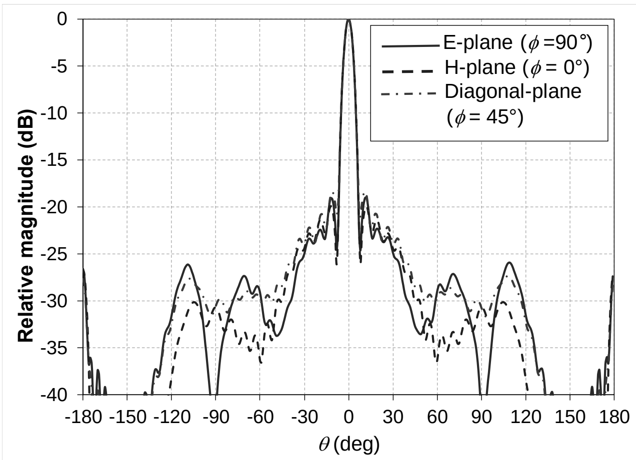

Fig.5. Radiation pattern of the proposed antenna (d_f/d_0=1).

Conclusions

A primary probe-fed rectangular waveguide aperture with four-stacked-coupling aperture illuminated secondary parabolic reflector antenna is proposed to provide high gain for point to point communication. This presented antenna produces an excellent symmetry sharp beam with a very low SLL of -20 dB as well as BLL of -28 dB. It provises S_{11}

better than -15 dB ranging from $0.88f_c$ to $1.06f_c$ and maximum gain of 26.9 dBi. In addition, this antenna provides a linear polarization with low cross-polarization level less than -40 dB. With its simple structure, compact size, cost effectiveness, sharp beam and producing high gain, therefore, this presented antenna is capable a good candidate for a primary-fed parabolic reflector antenna as proposed.

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