Testing Strips and Quarter Wavelength Monopole Antennas using Computerized Simulations

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ABSTRACT: *X-band operation is improved with the help of the horn antenna, and the exercises carried out in this study use computerised simulation and measurements. The antenna aperture with 60 degrees is fixed to expand the strips by linear expansion. In the strips, the four-quarter wavelength monopole antennas are placed. The strips have an array fabricated with 20 mm and 1 mm thicknesses. The horn arms specification is fixed at 60 mm long, and the aperture angle is 60 degrees. The SMA connector pins are placed at a quarter-length distance from the strip circuits.*

Keywords: Microwaves, Microwave Antenna Arrays, Horn Antennas, Strip Horn

Received: 18 November 2022, Revised 4 February 2023, Accepted 14 February 2023

DOI: 10.6025/jdp/2023/13/2/31-37

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1. Introduction

Horn antennas [1-3] represent the oldest forms of microwave antennas (1897 - Jagadish Chandra Bose). Owing to their simple design, low-cost fabrication and wide operating range (typically 10:1) they are often used in various applications: microwave telecommunications, radars, radar weapons, automatic door systems, distance measurements, alarm sensors, etc.

There are three basic types of horn antennas: sectoral, pyramidal and conical. All of them are characterized by the gradual widening of the waveguide aperture creating the gradual transition from the characteristic impedance of the waveguide to the impedance of the free space (around 377Ω), thus reducing the reflection at the horn input. Excitation of sectoral and pyramidal horns is usually realized with rectangular waveguide with dominant wave type TE_{10} [1] (and only one component of the electric field $E_y = E_0 cos(\pi x/a)$, [2]). The horn antenna aperture size varies from around 1.5 wavelengths for small-sized to around 6 wavelengths for medium-sized horns [2].

According to [2], an array with N identical elements with identical amplitudes but each succeeding element has a β progressive phase lead current excitation relative to the preceding element is referred to as a uniform array.

The array factor (AF) of an N-element linear array of isotropic sources is [4]:

$$AF = 1 + e^{j(kdcos\Theta+\beta)} + e^{j2(kdcos\Theta+\beta)} + ... + e^{j(N-1)(kdcos\Theta+\beta)} \tag{1}$$

Equation (1) can be written as:

$$AF = \sum_{n=1}^{N} e^{j(n-1)\psi} \tag{2}$$

where $\psi = kdcos\ \Theta + \beta$

Multiplying both sides of the expression (2) by $e^{j\psi}$, and after some manipulations, the array factor can be rewritten as:

$$AF = \left[\frac{e^{jN\psi}-1}{e^{j\psi}-1}\right] = e^{j[(N-1)/2]\psi}\left[\frac{\mathrm{Sin}\left(\frac{N}{2}\ \psi\right)}{Sin\left(\frac{\psi}{2}\right)}\right] \tag{3}$$

When the reference point is in the physical center of the antenna array, (3) can be reduced to:

$$AF = \frac{Sin\left(\frac{N}{2}\ \psi\right)}{Sin\left(\frac{\psi}{2}\right)} \tag{4}$$

To obtain the maximum of the AF of a uniform linear array in the broadside direction, ψ has to be zero, i.e. $\beta = 0$ — namely, all the elements must have the same phase excitation.

The normalized array factor for the four element array ($N = 4$) is

$$AF = \frac{Sin\,[2\psi]}{Sin\left[\frac{\psi}{2}\right]}$$

and is shown in Figure 1.

2. Design of the Strip Horn Antenna Array

The linear array [1-2] of strip horns that are fed in-phase can be realized in two ways – as individual strip horns [5-11] positioned along the straight line at the mutual distance of $\lambda_0/4$ or with the common reflector system with radiating elements spaced $\lambda_0/4$ apart, where λ_0 is the free space wavelength at the center frequency (f_c=10 GHz) of the frequency range of interest. Figures 2a and 2b display both concepts of the design.

The excitation of the individual radiating elements in the array is performed through the feed network [3, 6-7] realized in microstrip technology on the RO4003C dielectric substrate with permittivity $\varepsilon_r = 3.38$, and thickness $h = 0.2$ mm. The microstrip lines' widths and lengths are calculated at the center frequency (f_c=10 GHz) of the X-band. The radiating elements – monopole antennas – are realized with the SMA connectors' pins. Figures 3 and 5 display the photographs of the separate array feeding network and its integration with the linear array of strip horn antennas, respectively.

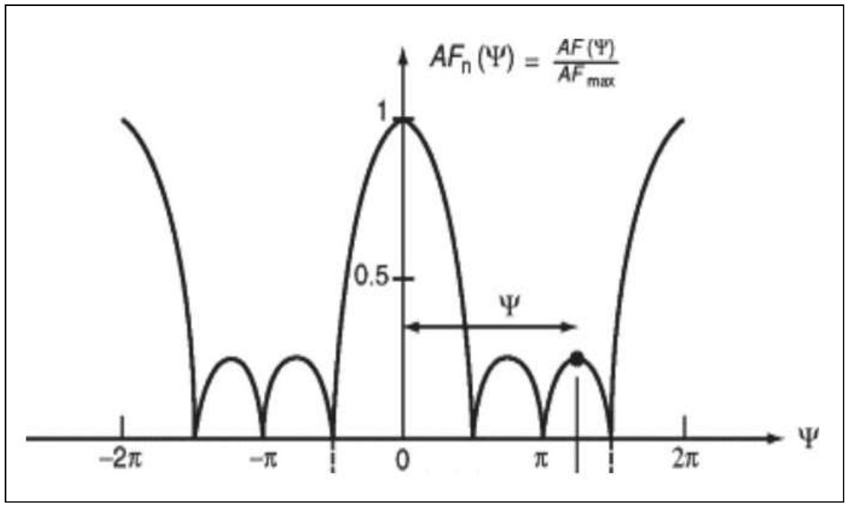
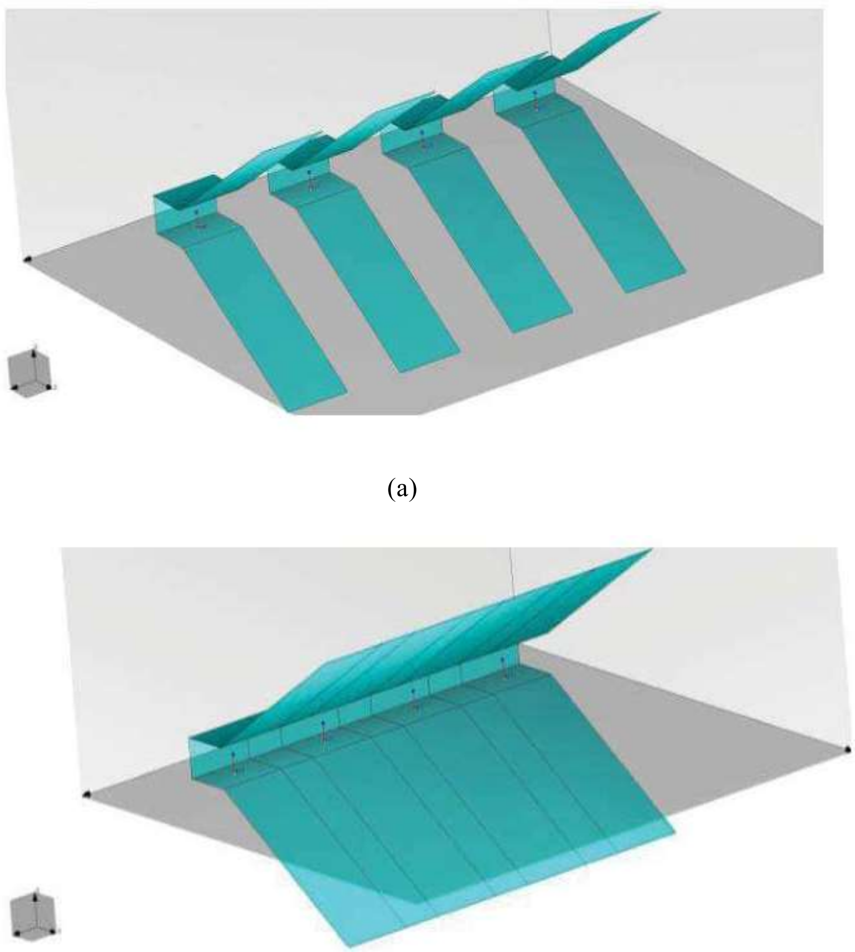


Figure 1. Graphical representation of the normalized array factor of the 4-element array as a function of ψ



(a)

(b)

Figure 2. Linear array of strip horn antennas: (a) Linear array of 4 individual horn antennas, (b) Linear array of 4 radiating elements in the common reflector system

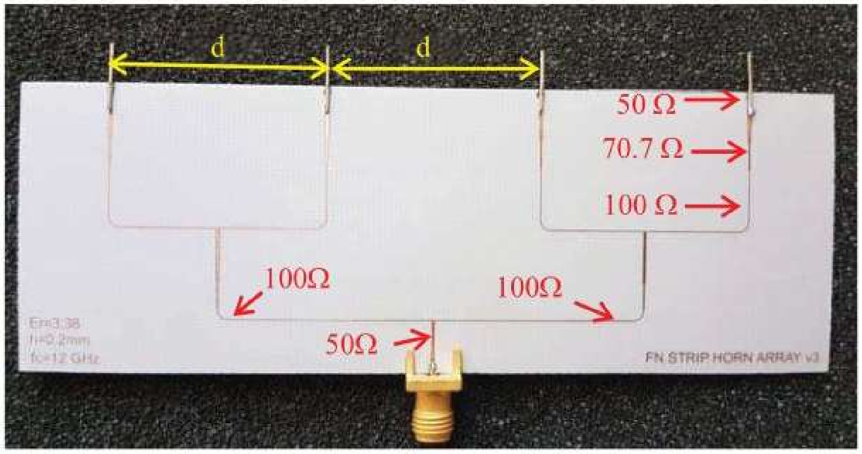


Figure 3. Photograph of the microstrip feed network for the linear array of strip horn antennas (with indicated impedances)

3. Analysis and the Simulated Results

In the first step, an array composed of four individual strip horns is simulated and analyzed using the program package WIPL-D [12]. The distance between two neighboring horns (d) is equal to the odd number of quarter wavelengths at the center frequency f_c. In our case, this distance is chosen to be $5\lambda_0/4$. Next, the same array of radiating elements is placed into the common reflector and simulated.

Simulated radiation patterns in *x0y*- plane of both models – with individual strip horns and with the common reflector – at the center frequency, are shown in Figure 4. It can be seen that the compact array model has a slightly lower gain (~ 17.2 dBi) than the model with separated strip horn antennas. The 3D radiation pattern of the compact array is displayed in Figure 5.

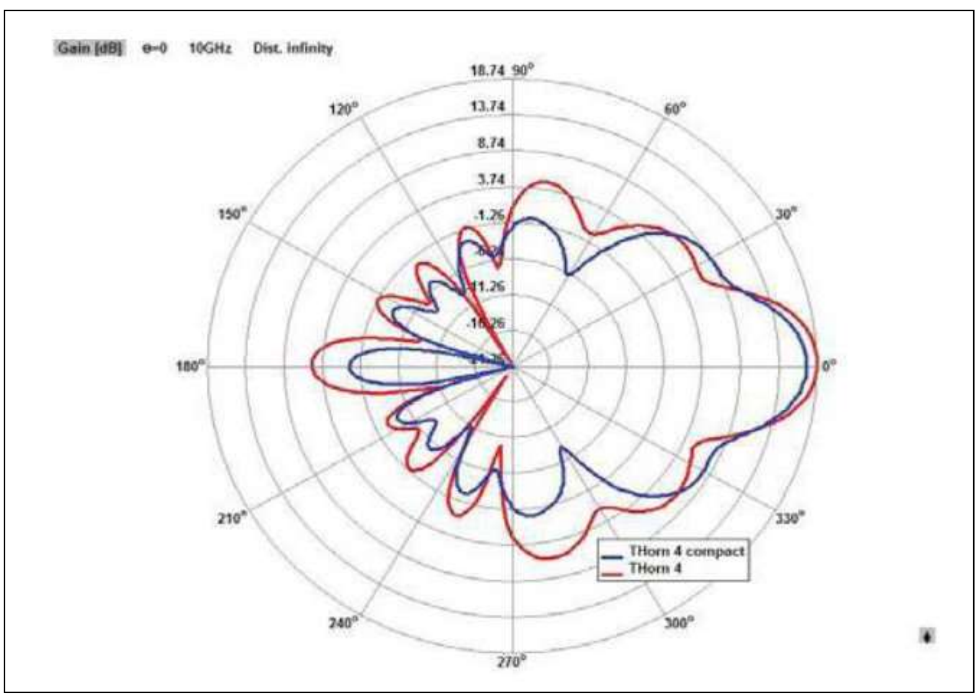


Figure 4. Radiation patterns of the linear array of strip horn antennas in *x0y*-plane: individual horns (red line) and with the common reflector (blue line)

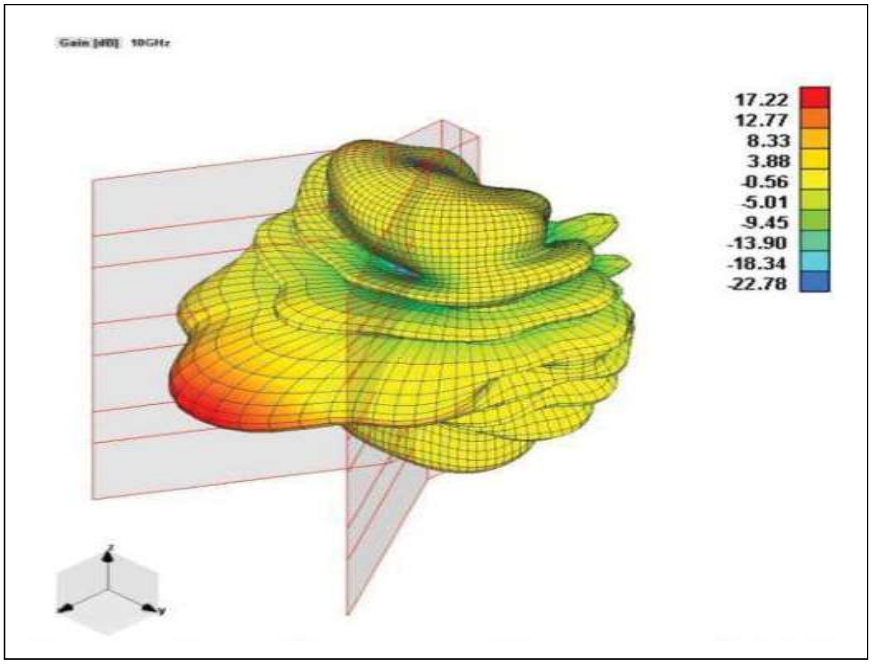
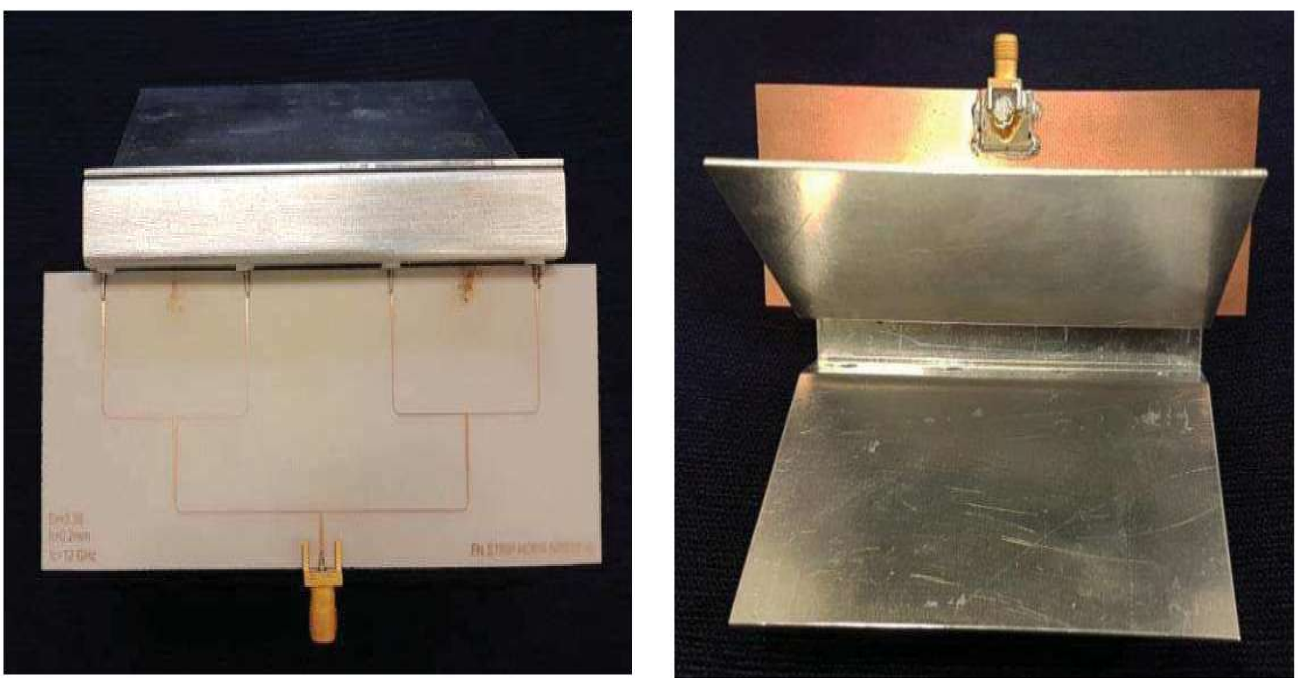


Figure 5. 3D radiation pattern of the proposed linear array of strip horn antennas

4. Realization and the Measured Results

The realization of the complete antenna system which consists of the metallic strip horn with the array of four quarter-wavelength monopole antennas and the feed network is shown in Figures 6 (a, b).



(a) (b)

Figure 6. Photograph of the realized linear array of strip horn antennas: (a) rear view, (b) front view

The measured reflection coefficient S11 of the realized antenna array, Figure 7, is less than – dB in about 9% of the bandwidth around the center frequency.

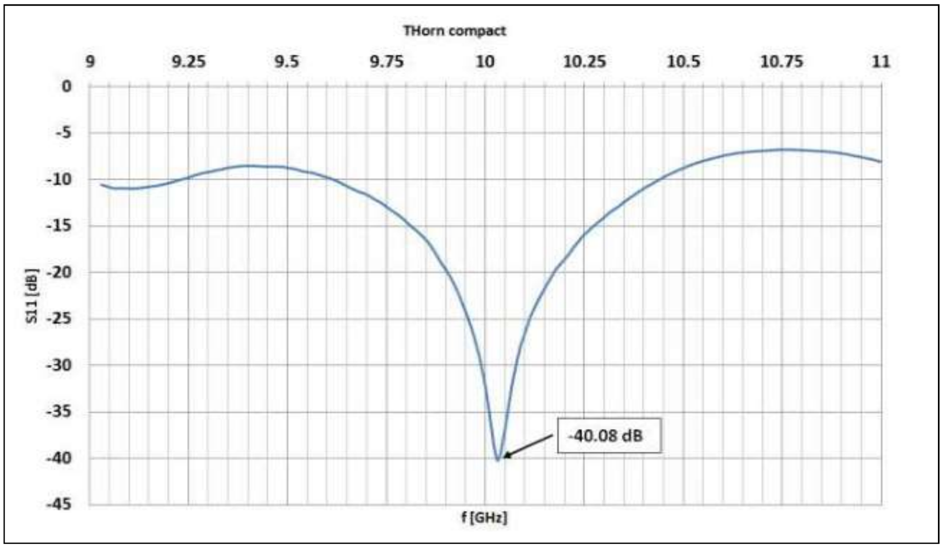


Figure 7. Measured reflection coefficient S11 of the realized strip horn antenna array

The antenna gain measurement is performed using the gain comparison technique which requires two sets of measurements. The standard gain horn antenna for operation in the range (8.2-12.4) GHz is used as a transmitting antenna. In the first measurement, the test antenna is used as a receiving antenna and the received power is measured. In the second set, the test antenna is replaced by the standard gain horn antenna. The difference between these two sets of measured results gives us the gain of the antenna under test, shown in Figure 8.

The discrepancies between the measured and the simulated array gains, especially at higher frequencies of the range, can be attributed to the insertion loss of the microstrip feed network.

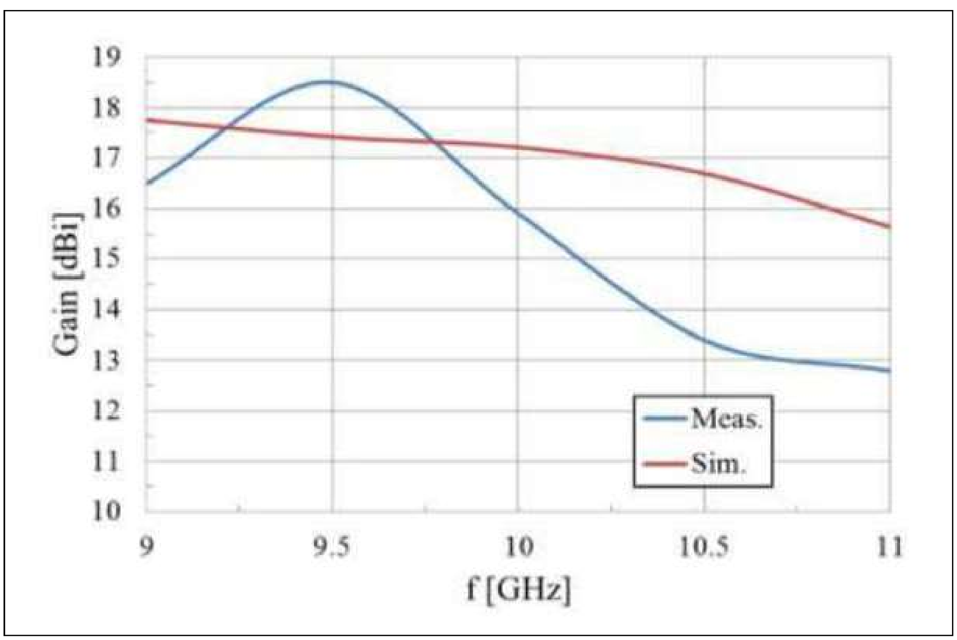


Figure 8. Measured and simulated gains of the realized strip horn compact antenna array

Acknowledgement

This work was supported by the Serbian Ministry of Education and Science within the Technological Development Project TR 32052.

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