INTERNATIONAL JOURNAL OF Telecommunications
AIR DEFENSE COLLEGE

# Methodology and Laboratory Measurements of Miniaturized and Improved Antenna Loaded With Circular Spiral-Line Structures (CSLS) Linear and Triangular Planar Arrays for Radar Applications.

**Citation:** Miligy, Aahmed F.; Taher, F., Abo Sree, M.; Mohammad T. Haweel ; Morsy, M. *Inter. Jour. of Telecommunications, **IJT'2024**, Vol. 04, Issue 01, pp. 01-15, 2024.*
***Editor-in-Chief:*** *Youssef Fayed.*
*Received: 02/04/2024.*
*Accepted: 01/05/2024.*
*Published: 01/05/2024.*
*Publisher's Note: The International Journal of Telecommunications, IJT, stays neutral regard-ing jurisdictional claims in published maps and insti-tutional affiliations.*



**Aahmed F. Miligy*[1], Fatma Taher [2] , Mohamed Fathy Abo Sree [3], Mohammad T. Haweel[4], and Mohamed E. Morsy [5]**

[1]Communication and Electronic Department, ADC, Alexandria University, Alexandria, Egypt; ahmed_miligy73@yahoo.com, [2] College of Technological Innovation, Zayed University, P.0. Box 19282, Dubai, UAE; fatma.taher@zu.ac.ae , [3] Department of Electronics and Communications Engineering, Arab Academy for Science, Technology and Maritime Transport, Cairo 11799, Egypt; mohamed.fathy@aast.edu, [4] Electrical Engineering Trainer, National Maritime Academy, BAE Systems, jubail, KSA: Mohamed.haweel@nma.edu.sa, [5] Communication and Electronic Department, ADC, Alexandria University, Alexandria, Egypt; dr.mohamedmorsy.6829.adc@alexu.edu.eg.

**Abstract:** This paper presents the introduction of a miniaturised and enhanced horn antenna that is loaded with a linear or triangular planar array of Circular Spiral-Line Structures (CSLS). A CSLS array was placed inside the horn aperture in order to reduce the size of the suggested horn antenna.The antenna's resonance frequency when loaded with CSLS array is 6.3 GHz, and when it is not loaded, it is 8 GHz.The dimensions of the antenna aperture and axial length would be 150×138×103 mm$^3$ if it were intended for 6.3 GHz.However, by loading the CSLS array, the 8 GHz antenna's dimensions are reduced to 90×57×130 mm$^3$, and a shift in resonance frequency from 8 GHz to 6.3 GHz results in a 68.7% miniaturisation in size.With the CSLS array put into the suggested antenna, the antenna's Bandwidth Improvement percentage (BWI) increases to 8.7%, the Enhanced Return Loss Ratio (ERLR) increases to 26.2 , maximum power intenisity Umax= 1.8 W/Str., directivity D= 25.8 dB, gain G=24.6 dB, radiated power Pr=0.92 for one watt input power Pin and radition efficiency $e_0$ reaches to 95% for the proposed horn loaded with CSLS arrays compared with the horn without arrays .The SLSM linear array was designed and manufactured with a Rogers of $\varepsilon_r$=10.2 and thickness of 0.635 mm.An introduction and analysis are given to the laboratory test and measurement for the CSLS linear array loaded in the WR90 rectangular waveguide.Finite Element Method (FEM) based, HFSS, is used for the design and analysis of the proposed structures.

**Keywords:** Improved Antenna, Horn Antenna, Metamaterials and Spiral Structures.

## 1. Introduction

Active research has been done on miniaturized and improved antenna parameters in microwave system applications.A high gain and wided bandwidth antennas are necessary for these applications for high effective radiated power.Traditionally, helical, horns, and reflectors antennas have been investigated for use in microwave and radar systems.These antennas have sturdy constructions that can handle extremely high power [1-3]. The horn antenna, which has high-gain qualities and a huge size, is one of them.The Wideband applications are now more necessary than ever. As the primary source for any communication system, there have been numerous research projects on the design of antenna systems in recent years.The horn antenna is frequently used in wireless communications for the transmission and reception of RF microwave signals. It is also employed in

biomedicine, nondestructive testing, and nondestructive assessment, as well as electromagnetic sensing and heating.Horn antennas have a conical, pyramidal, E-plane, H-plane and two plate's horn on one end and a waveguide on the other.There are many different types of horn antennas, such as sectored, conical, and pyramidal horn antennas [4-7]. Pyramidal Horn Antenna is the one that the designers favor among these due to its straight forward design, high directivity and wide bandwidth, little return loss, low VSWR, and positive outcomes.These antennas provide various benefits, including ease of construction, strong directional performance for microwave purpose, and outstanding peak power handling capacity [8-12].
Horn antennas operate at a wide variety of frequencies and have a large bandwidth since they lack any resonant features. Additionally, they act as a global reference for the calibration and gain evaluation of other antennas. Creating horn array antennas for commercial and military use at microwave and millimetre wave frequencies has gained popularity recently.An antenna array is to obtain the required magnitude, phase, the radiation pattern and gain that the design calls for. These antennas can be made in a number of sizes and forms to suit a wide range of real world applications such the radar applications. They can also be used as feed elements for other antennas such reflector, compound, and lens antennas. These antennas are made to achieve the required result depending on the application, such as satellite communication, radar, radio astronomy, feed elements of parabolic and dish antennas, etc [13-17].
Here, the operating frequency and gain are crucial design factors.The feed methods used by communication and radar antennas are extremely advanced. Due to its great power handling capacity and minimal RF loss, waveguide is a frequent transmission medium at higher microwave frequencies. The RF energy at microwave frequencies is transmitted through waveguides. Due to their low attenuation, waveguides are favored as feeders for microwave antennas.These days; rectangular waveguides are mostly employed as feeders for UHF waveguides as well as short connecting segments, bends, and twists [18-24].
Electromagnetics has advanced tremendously, notably in antenna structures. This can be attributed mostly to the introduction of metamaterial (MTMs), or artificial negative index medium.MTMs are synthetically electromagnetic materials composed of metallic components organised in periodic patterns, smaller than the wavelength of the incident electromagnetic (EM) wave [25-30].There is a huge need for MTM because of the importance of size miniaturisation and mutual coupling reduction of antennas in modern communication devices, microwave, and radar applications.Various techniques have been employed to reduce the size and improve the characteristics of antennas [31-35].The antenna may be more compact with a reactive dielectric constant.The use of MTMs is the most current development in antenna downsizing.Planner MTMs are frequently utilised for minimizing the antenna size and enhance its parameters [33-36].
In the present paper,a miniaturised and enhanced horn antenna that is loaded with a linear or triangular planar array of CSLS is introduced and analyzed. The antenna's resonance frequency when loaded with CSLS array is 6.3 GHz, and when it is not loaded, it is 8 GHz.A shift in resonance frequency from 8 GHz to 6.3 GHz results in a 68.7% miniaturisation in size.With the CSLS array BWI= 8.7%, and ERLR= 26.2 for radar applications.The SLSM linear array was designed, manufactured and tested in microwave Lab. with a Rogers of εr=10.2 and thickness of 0.635 mm using HFSS.
The paper is organized as follows. Section II introduces an analysis and the design methodology for the horn antenna without metamaterial array including apperture, feeding, and radiation element and simulation results. In Section III, presents the circular CSLS unit cell, linear and triangular planar array design and simulation results.Section IV, introduces analysis of miniaturized and improved horn antenna loaded with CSLS triangular array, Lab. test and measurement for the CSLS linear array loaded in WR90 rectangular waveguide.The comparison with recent related works, and finally concludes the research work is presented in section V.

## 2. Horn Antenna without CSLS Array

A waveguide is a hollow conducting tube that transmits electromagnetic energy from one place in space to another in an effective manner. Various guiding structures exist, including common coaxial cable, two-wire and microstrip transmission lines, hollow conducting waveguides (rectangular & cylindrical), and optical fiber. The preferred operating frequency band, the quantity of power to be transmitted, and the level of transmission losses that may be allowed all influence the choice of structure. Rectangular waveguides are one of the waveguide forms that are used to transmit enormous quantities of microwave power at extremely high frequencies

[20-23]. Waveguides are still necessary in many applications, including high-power systems, millimetre wave systems, feeding antennas, horn antennas and several precision test applications. Since there is only one conductor, the hollow rectangular waveguide can only propagate TM and TE waves; TEM waves cannot [21].
The horn antenna is one of the most extensively antenna used and most basic type of microwave antenna belongs to the aperture antenna family. An antenna that is used to send electromagnetic waves from a waveguide into space or receive electromagnetic waves through a waveguide is known as a horn antenna. Between the waveguide feeder and free space, it could alternatively be thought of as the impedance matching device. A waveguide and a conical or pyramidal, E-plane, H-plane and the supported two plates horn are the components of this type of antenna [15-17]. These types of antennas consist of a flare and a rectangular waveguide. The horn antenna should have a big aperture to produce high gain. On the other hand, directivity and aperture size are dependent on gain and operating frequency, respectively. One of the metrics that is frequently used as a measure of merit to define an antenna's performance is directivity. By forming the highest radiation, directivity is discovered.The Waveguide, aperture, and flared angle designs are all part of the design of various horn antennas [5-8]. The antenna was simulated using the HFSS to acquire results once all parameters had been established and all components had been designed.

### *2.1 Aperture Design Methodology*

The pyramidal horn is also referred to as a standard gain horn because it is frequently used as a benchmark to assess the gain of other antennas. The intended gain $G_0$ and the dimensions a, b of the rectangular feed waveguide are often known when designing a pyramidal horn. The design's goal is to identify the final dimensions shown in Figure1 (a1, b1, a, b, L, Pe, and Ph) that will result in the greatest gain [37-38].

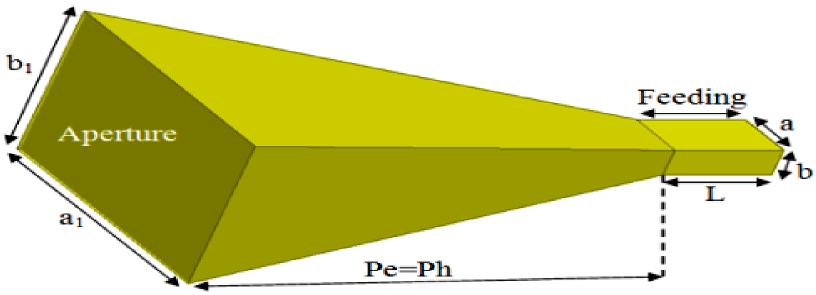



**Figure 1.** Pyramidial Horn Antenna Without CSLS Dimensions

The horn antenna design structures using mathematical calculation for the proposed antenna according to the horn antenna design procedures in [38].For a pyramidal horn to be physically realizable, Pe and $P_h$ shown in Figure1 must be equals.In order to improve antenna directivity and match the impedance between the waveguide aperture and free space, the flare is used. The total flare angle of the horn should be equal to 2ψ.

### 2.2 Feeding and Radiating Element

Pyramidal TE and TM wave functions can be used to describe the fields inside the horn. In a rectangular waveguide, radio waves can propagate in a variety of distinct modes. The predominant method of transverse electromagnetic propagation is chosen for our purposes. The TE10 mode in a rectangular waveguide has the lowest attenuation of any mode, and its electric field is vertically polarized [18-21]. To determine the waveguide's dimensions, we must determine the cut-off frequency for the dominant mode of propagation [21-24]. For maximum power transfer, the width of the rectangular waveguide must be twice that of its height (a=2b), and the total length of the waveguide L=0.75 $\lambda g$ as shown in Figure2 where the cutoff wavelength and the guided wavelength calculated [21-24].
For waves to propagate inside the waveguide, the cutoff frequency must be lower than the mode of propagation. This is why the operating frequency must be one and a half of the cutoff frequency. The radiating element's design and fabricated shown in Figure2 is a crucial component of the overall scheme. [21] were used in the design of this component to determine the radiating element's length, distance from the waveguide's back side, and overall waveguide length.The fabricated horn with feeding waveguide connection is shown in Figure2 and the main dimensions of horn, feeding and radiating elements are tabulated in Table 1.

**Table 1.** Pyramidal Horn Dimensions [mm] and Parameters

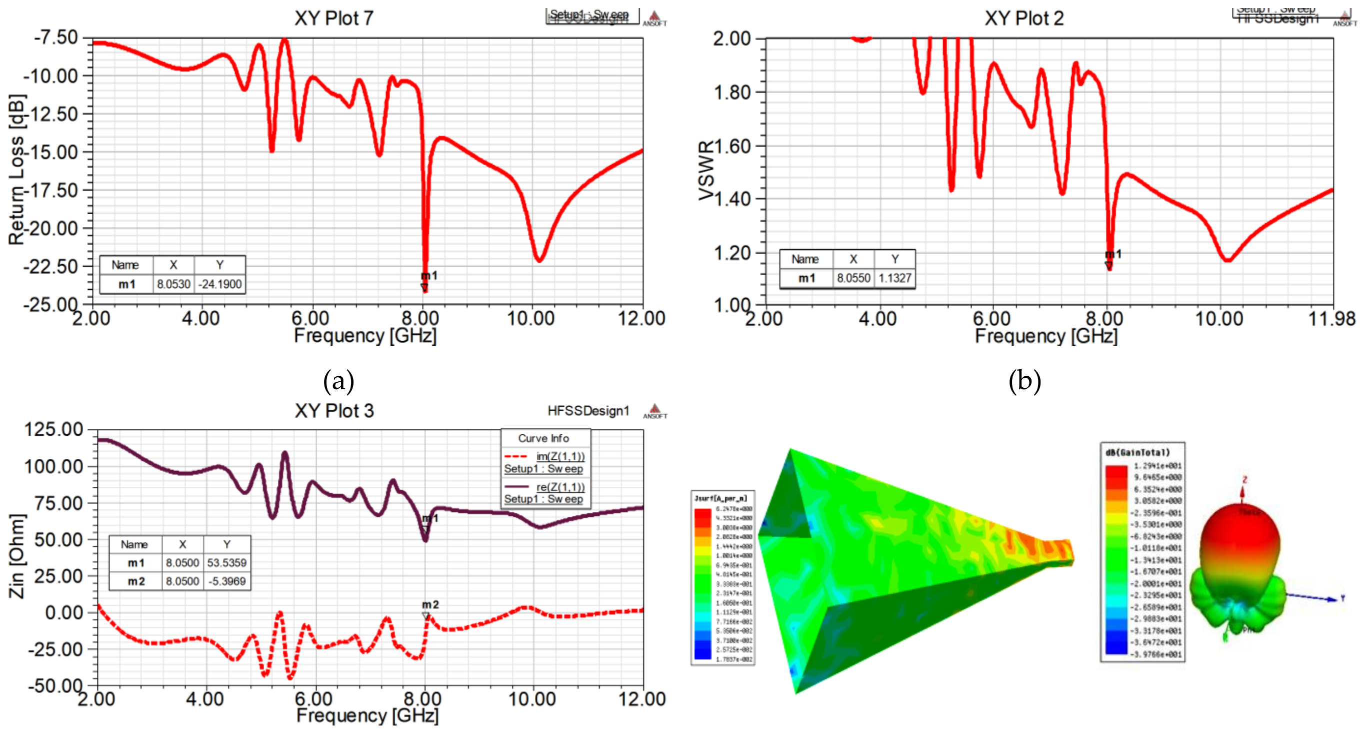
| Pyramidal Horn Dimensions and Parameters | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **a** | **b=a/2** | **a1** | **b1** | **L=3λg/4** | **Pe, Ph** | **l=λg/4** | **d=λ/4** | **λ** | **λc** | **λg** | **2Ψ [deg.]** | |
| 20.4 | 10.27 | 90 | 57 | 27.44 | 130 | 9.14 | 6.818 | 27.3 | 40.9 | 36.5 | E(24) | H(29) |


(a) (b) (c)

**Figure 2.** Horn With Waveguide Feeding Connection: (a) Design Dimensions;(b) Fabricated; (c) Connector

2.3 *Horn Without Metamaterial Array Simulation Results*

Figure 3 shows the simulation results for the suggested pyramidal horn without loaded metamaterial structures, includingthe RL, VSWR, Js, Zin, and radiation pattern, which are introduced to determine the performance of antennas.




(c) (d) (d)

**Figure 3.** Horn Without CSLS Array Simulation Results: (a) RL [dB]; (b) VSWR; (c) Zin [Ω] (d) Js[A/m]; (e) Radiation [dB].

Based on the simulation findings displayed in Figure 3, the suggested structure adds a matching antenna parameter of -24.19 dB return loss with 1.13 VSWR at the 53 ohm real component of the input impedance with a bandwidth of 6.44 GHz.The results presented in Table 2 are introduced by the proposed pyramidal horn.

**Table 2.** Horn Without CSLS Array Simulation Results

| Horn Without CSLS Array Simulation Results | | | | | |
|---|---|---|---|---|---|
| **Frequency [GHz]** | **RL[dB]** | **VSWR** | **Zin [Ω]** | | **B.W [GHz]** |
| | | | **Real Part (Rin)** | **Imaginary Part (Xin)** | |
| 8.05 | -24.19 | 1.132 | 53.5 | -5.3 | 6.44 |

## 3. Metamaterials

Metamaterials are new materials that are made up of the arrangement of metal structures on the surface of dielectric substrates. Therefore, the physical properties of metamaterials depend on their structures more than the component that makes up them.The effects created by the metamaterials can be observed during the transmission of electromagnetic waves such as wave propagation.This phenomenon occurs due to an antiparallel group and the phase velocity leads to the inversion of the wave fronts, while its energy is moving away from the source.Metamaterial can be used for microwave fields in devices such as antennas, filters, integrated network sensors, or new superlayers that can improve some of the parameters of equipment in the different field of science and technology.In this medium, the poynting vector has the opposite direction to the propagation vector, so that it can support backward waves, i.e., the energy and wave fronts travel in opposite directions [39-41].

### *3.1 Metamaterials in Antenna Design and ImprovingPparameters*

Because metamaterials have unusual properties, so we can create antennas with novel characteristics, which cannot be obtained with traditional materials. The metamaterial antenna is one or more layers of metamaterials that are used as substrates or in addition to the configuration of the antenna to improve its performances. From scientific research shows that the application of metamaterials in the antenna design can enhance the radiated power, improve antenna parameters and reduce the size of the antenna [39-41].

In this section, the applications of metamaterials in design to enhance antenna parameters are presented. The metamaterials can be applied as an environment of the antenna or as part of the antenna. Depending on the parameters of the desired antenna to improve, the metamaterials can be applied in different methods. The metamaterials can be applied to improve bandwidth, power gain, or to create compact, multifrequency-band antennas. In addition to the benefits of using metamaterials to design the antennas mentioned above, it is also used to enhance the antenna frequency bandwidth. To achieve this goal, the metamaterials are used as components of the antenna or a superstrate placed above the radiation surface.Unit cells of metamaterials can be placed on top or under bottom of the superstrate. The bandwidth of this antenna depends on the number of unit cells as well as the distance of the superstrate to the radiation surface [39-41].

### *3.2 Analysis of CSLS Unit Cell and Array*

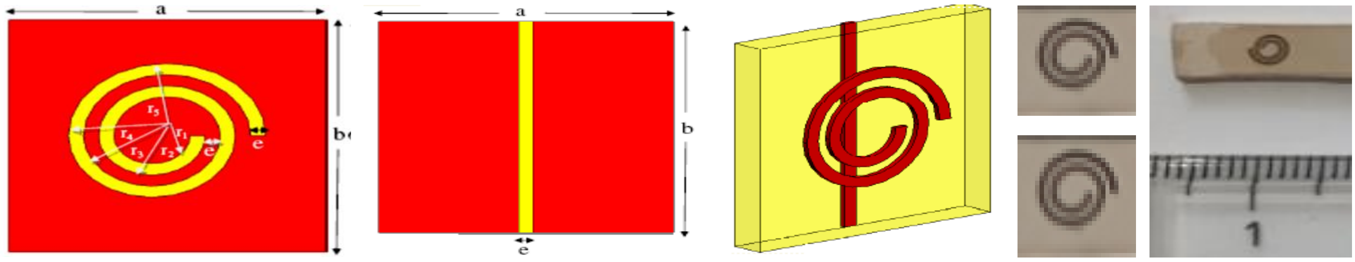
The metamaterials applied in the antenna design can be in the form of a unit cell or multiple unit cells assembled together into an array. Thus, the first step in designing the antenna metamaterials is to design and analyze the main factors affecting the resonance frequency, permittivity, and permeability of its unit cell. The design of unit cells of metamaterials is based on the calculation of size and simulation of unit cells, so that the parameters $\varepsilon$ and $\mu$ of these unit cells will satisfy the requirements at the expected resonant frequency. Depending on the structure and size of each unit cell, we can obtain different ε, μ, and resonant frequencies f. For each unit cell type, the dimensions of unit cell can be adjusted to satisfy condition at resonant frequency fr [39-41].The methodology for unit cell and array can be introduced as follow:

- The width of transmission line spiral is calculated for Roger substrate of $\varepsilon_r$=10.2 and thickness of 0.635 mm using microstrip transmission line design equations [42].
- Total length of spiral equals n $\lambda$g of the WR90 [42].
- A unit cell is usually smaller than 1/10 of the operating wavelength, depending on the shape of the metamaterial, but the unit cell size is different.
- The array composed of four unit cells separated by $\lambda$g/4 of WR90 rectangular waveguide [42].
- Numerical simulations of unit cell and array performed to obtain the scattering parameters.
- Using scattering parameters obtain $\varepsilon_{eff}$ and $\mu_{eff}$ [41].
- In many cases, the numerical simulations of unit cells and arrays, according to calculations, do not fully achieve the desired results [41].
- Thus, the sizes of the unit cells need to be adjusted iteratively, until the simulation results satisfy the requirements of the metamaterial structure [41].

- For simulation results to be satisfied in the shortest possible time, the size of unit cells can be determined using an optimization computational algorithm. In Ansoft HFSS software, we can use the optimization method to save time and get the results as expected and build the proposed array.
- Simulate the CSLS array in WR90.
- We can build the structure and do experiments to see what the performance is as antenna substrate, or we can do numerical simulations.

In order to improve the antenna characteristics and minimise its dimensions, a circular CSLS unit cell, linear, and triangular planar array structures are designed and analysed using Rogers 3010, which has a thickness of 0.635 mm, a dielectric constant of εr = 10.2, and a tanδ of 0.0035.The metamaterial uses the metallic mesh of thin wires (Line), for obtaining negative value of ε,where the mu-negative (MNG) material, the most popular structure has been using is circular spiral resonator structures (CSRS).The combination of both constructed the CSLS unit cell.The size of an effective homogeneous structure to form a unit cell of metamaterials must be much smaller than the guided wavelength.

By loading the CSLS array, the planned X-band antenna will resonantly operate in the C-band. The Rogers and HFSS simulators are used to simulate the circular CSLS unit cell and array.Figure 4 displays the unit cell CSLS based substrate dimensions and fabrication, whereas Table 3 lists the CSLS unit cell dimensions.



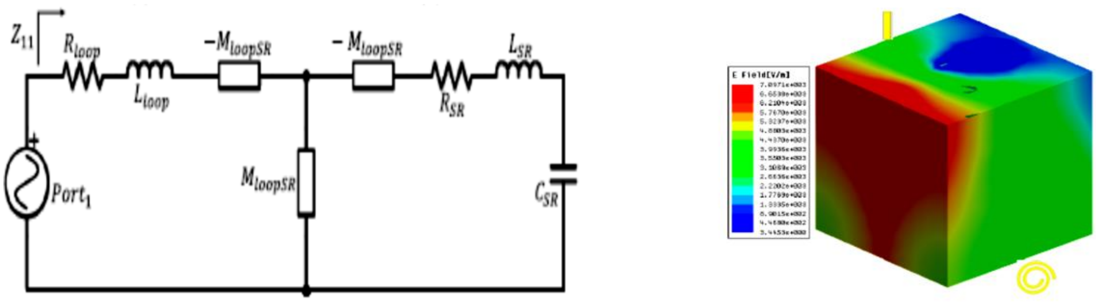

(a) (b) (c) (d)

**Figure 4**. The CSLS Unit Cell Dimensions and Fabrication: (a) Front View; (b) Back View; (c) 3-D View; (d) Fabricated View;

**Table 3.** CSLS Unit Cell Dimensions [mm]

| CSLS Unit Cell Dimensions | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **a** | **b** | **e** | **r1** | **r2** | **r3** | **r4** | **r5** |
| **Value [mm]** | 5 | 5 | 3.12 | 0.6 | 0.84 | 1.08 | 1.32 | 1.56 |

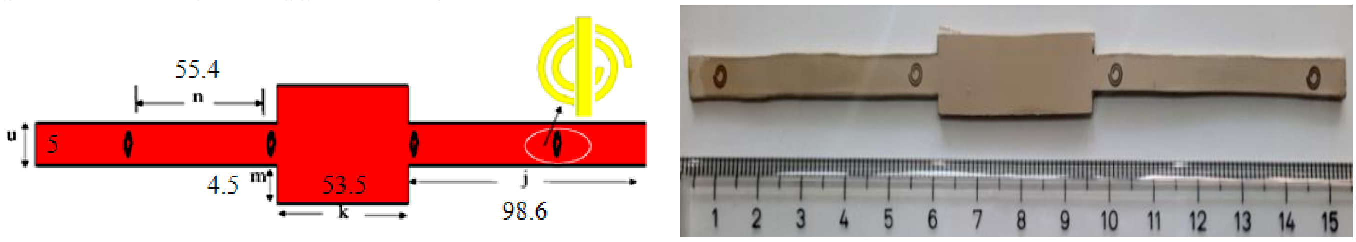
The CSLS has been classified as a metamaterial structure using the S-parameter retrieval techniques. The objective is to achieve the modification of ε and μ by specifically including metal in dielectrics in order to characterise the CSLS unit cell and array. In order to produce the best radiation characteristics, this is done to achieve the desired substrate qualities. Figure 5 displays the electric field distribution and the CSLS unit cell equivalent circuit.




(a) (b)

**Figure 5**. The CSLS Unit Cell: (a) Equivelent Circuit; (b) E-Field [V/m].

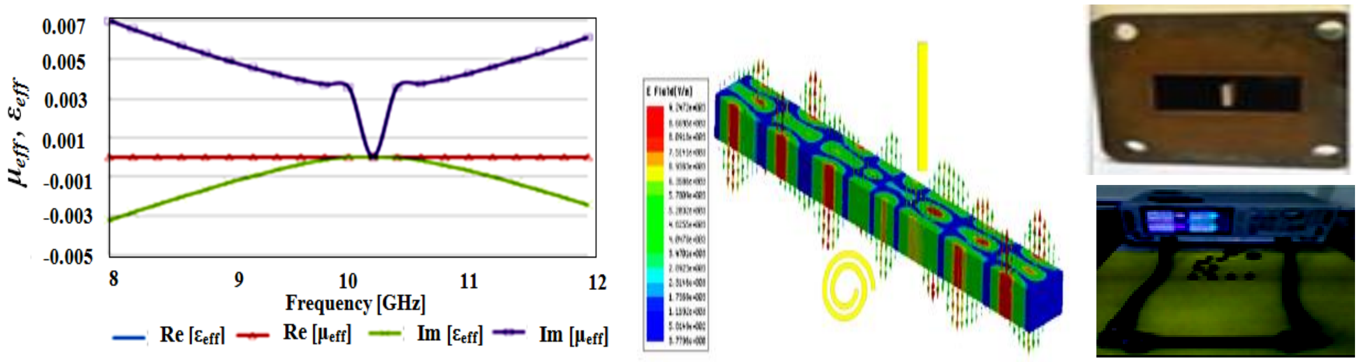
Figure 6 (a) depicts the arrangement of the CSLS unit cell's linear array, while Figure 6 (b) shows the fabricated array. As illustrated in Figure 6, four CSLS unit cells are arranged in a linear distribution and spaced 55.4 mm apart, with a length of approximately 150 mm.




(a) (a)

**Figure 6**. The CSLS Linear Array (a) Dimension [mm]; (b) Fabrication.

Based on the modelling of scattering parameters in a WR90 rectangular waveguide, as seen in Figure 7, the optimal circular CSLS linear array has the best simulation results. Figure 7(b) displays the CSLS linear array's electric field distribution.

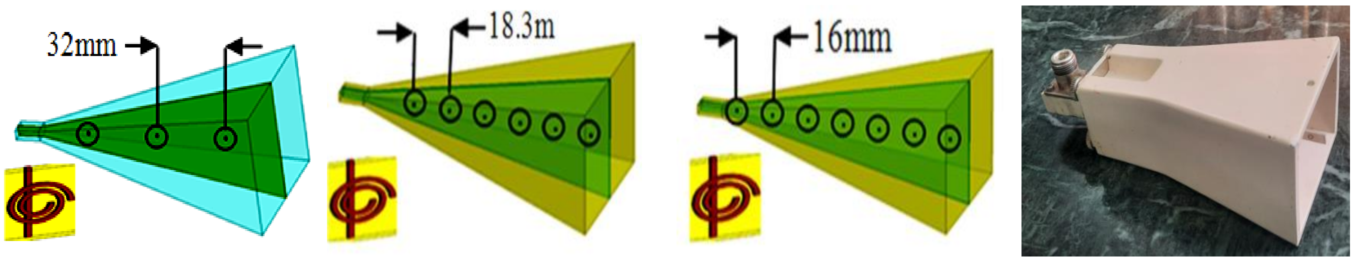



(a) (b) (c)

**Figure 7.** CSLS Linear Array Results: (a) Re. and Im. Parts of ε and μ; (b) The E-Field [V/m]; (c) Laboratory Measurement.

Simulation results indicate that for the TE10 mode, the real parts of εeff and↑ μeff are closest to zero and neff ≈ 0 with the least amount of losses, as shown in Figure 7(a). As seen in Figure 7(c), a laboratory test and measurement of the linear CSLS array loaded in WR90 rectangular waveguide are presented.When effective permitivity and/or effective permeability approach zero, the CSLS unit cell and array structures experience n ≈ zero. To get the desired qualities, the CSLS unit cell and array were ideally optimised.

There are three varieties of horn antennas that are equipped with CSLS linear arrays. A linear array with three CSLS unit cells makes up the first variation. As seen in Figure 8, the second has six CSLS unit cells, while the third has seven.The faricated design loaded with CSLS linear array is shown in Figure8 (d).

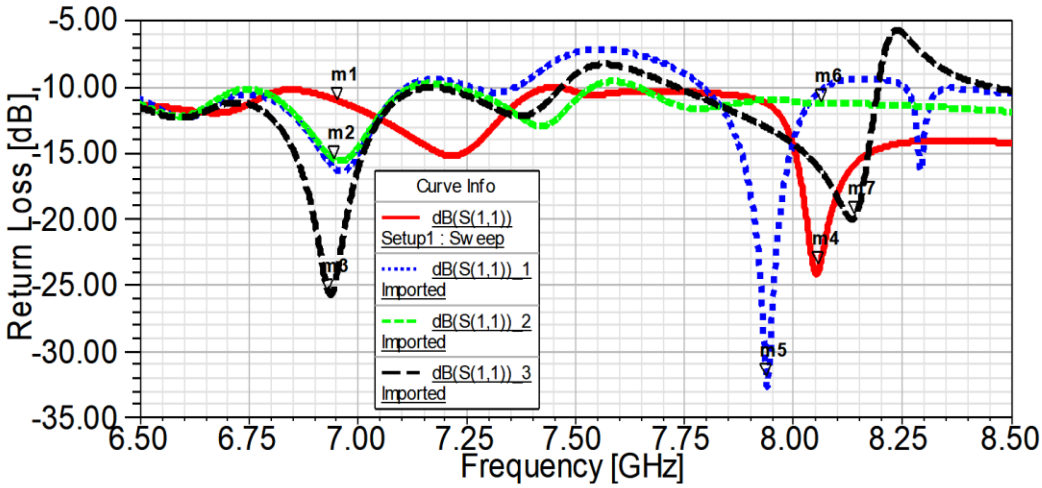



(a) (b) (c) (d)

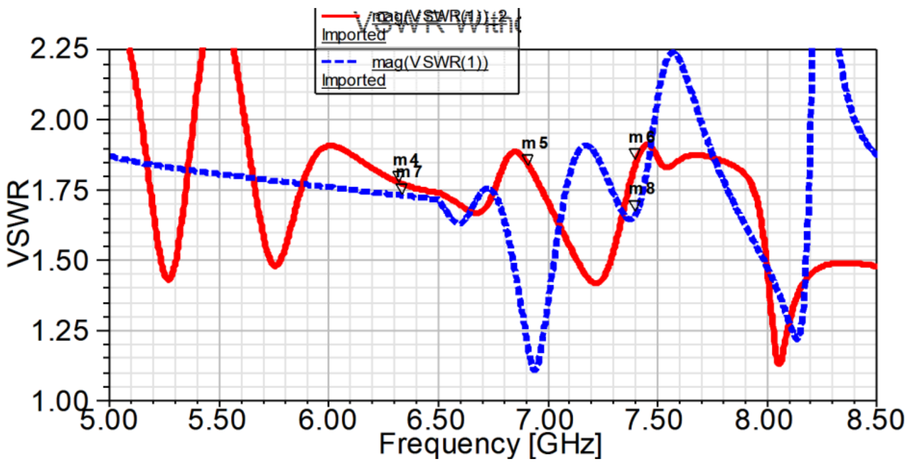
**Figure 8.** Horn Loaded With CSLS Linear Array: (a) Three Unit Cells; (b) Six Units; (c) Seven Unit Cells; (d) Fabricated.

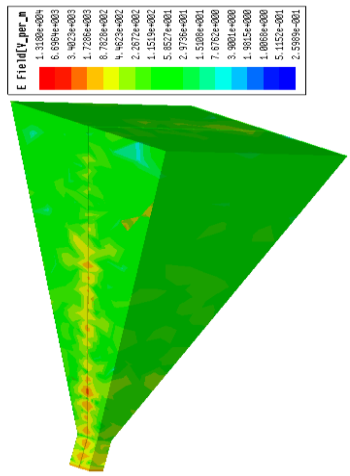
The CSLS linear array has been characterised as a metamaterial structure loaded in the proposed horn antenna using the S-parameter retrieval techniques. Figure 9 shows the horn antenna loaded with the CSLS linear array variation simiulation findings.

Figure 9 (a) shows the return loss in dB comparision of horn antenna loaded with the CSLS three, six and seven linear array simiulation results.
The comparison between the VSWR of a horn without a CSLS array and a horn loaded with a seven-element CSLS linear array is presented in Figure9 (b).According to simulation results, the minimum VSWR reached by the seven-element linear array is 1.1 when compared to the horn without the CSLS linear array.Figure9 (c) depicts the distribution of electric fibres across the surface of the suggested horn loaded with the seven-element linear array. According to Table 4, the suggested structure introduces ERLR = 14.6 and 11 at f = 6.9 GHz and 8 GHz, respectively.




(a): dB(S(1,1)),Horn Without Arrays; dB(S(1,1))_1,Horn With 3 Elements L.A; dB(S(1,1))_2,Horn With 6 Elements L.A; dB(S(1,1))_3,Horn With 7 Elements L.A.



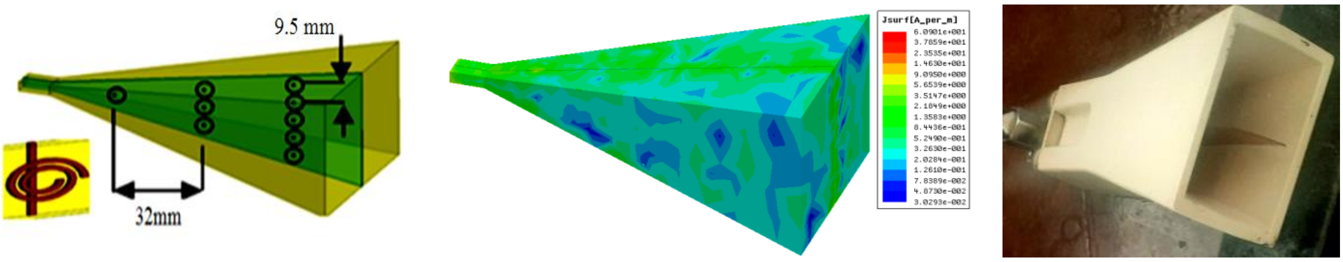
(b) VSWR (1)_2,Horn Without Arrays; VSWR (1),Horn With 7 Elements L.A. (c)

**Figure 9.** Horn Loaded Linear Array Results: (a) Comparision RL [dB; (b) Comparision VSWR of Horn Without CSLS and Loaded With Seven Elements Array; (c) CSLS Seven Elements Linear Array E-Field [V/m].

**Table 4.** Comparision RL [dB] and ERL for Horn L oaded With CSLS Linear Array at f=6.9 GHz and f=8 GHz

| Parameter | RL[dB] | ERLR | RL[dB] | ERLR |
|---|---|---|---|---|
| **Frequency [GHz]** | **6.9 GHz** | | **8 GHz** | |
| **Without CSLS Array** | -11 | Comparision With | -23 | Comparision With |
| **Three Elements Array** | -15.5 | 4.5 | -34 | 11 |
| **Six Elements Array** | -15.5 | 4.5 | -12 | -11 |
| **Seven Elements Array** | -25.6 | 14.6 | -20 | -3 |

The CSLS triangular planar array, which is intended to be installed in the horn antenna's aperture for miniaturisation and the improvement of antenna parameters, is made up of nine CSLS unit cells arranged in an a triangular shape, as illustrated in Figure 10(a). Electric resonators in the CSLS triangular array aid in the production of magnetic resonance frequency through electric resonance. Figure10 (b) displays the E-field distribution and Figure 10(c) shows the fabrication.

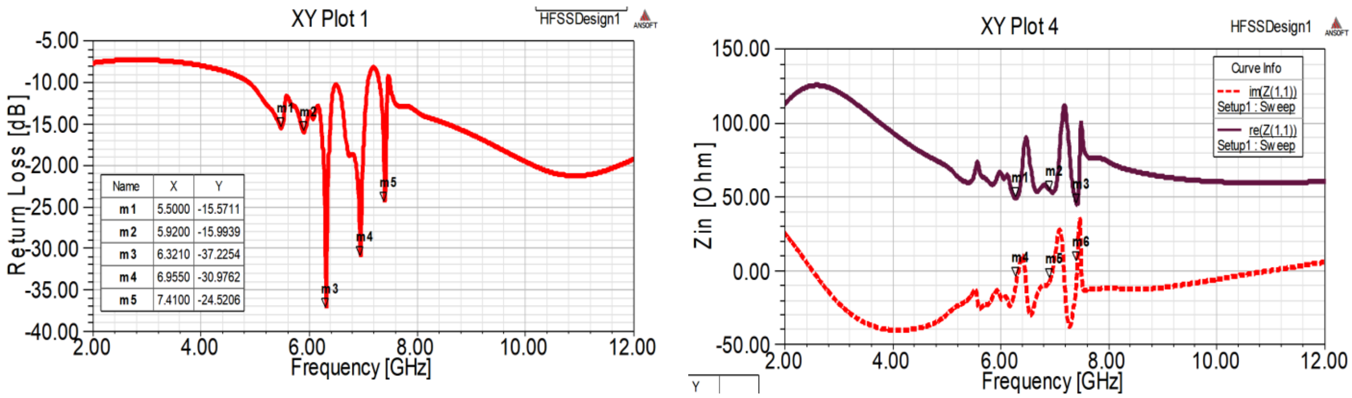



(a) (b) (c)

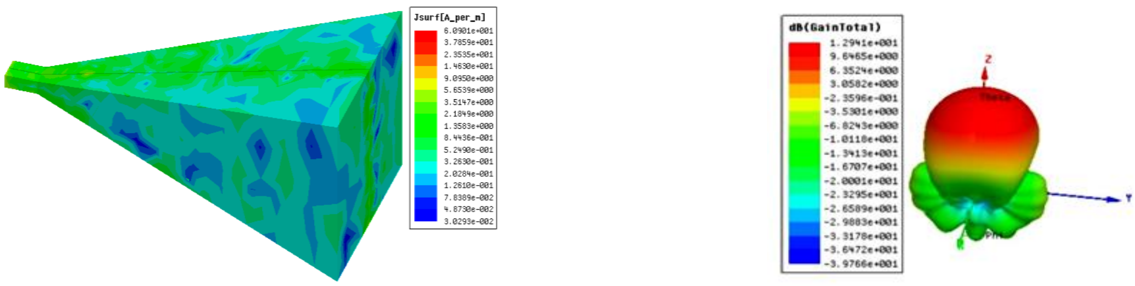
**Figure 10.** Horn Loaded With CSLS Triangular Array: (a) 3D View; (b) Electric Field Distribution [V/m]; (c) Fabrication.

## 4. Miniaturized and Improved Antenna Loaded With CSLS Triangular Planar Array

An improved and miniature horn antenna with a CSLS arrays is shown in this section. For radar applications, the CSLS array is loaded into the horn antenna's aperture. It consists of nine triangle-shaped, circular spiral-line unit cells.This part presents the design, analysis, and introduction of the CSLS triangular planar array that is depicted in Figure 10(a). A simulation and construction of the proposed antenna structure with the CSLS triangular planar array structure have been completed. The simulated findings, which offer an intuitive view of how the structure operate with enhanced performance in both the C-band and the X-band, are contrasted with the S-parameter characteristics of the structures.Figure11 depicts the performance of antennas loaded with CSLS triangular planar arrays for the suggested pyramidal-loaded horn. Simulation findings such as RL, VSWR, Js, and Zin are introduced.



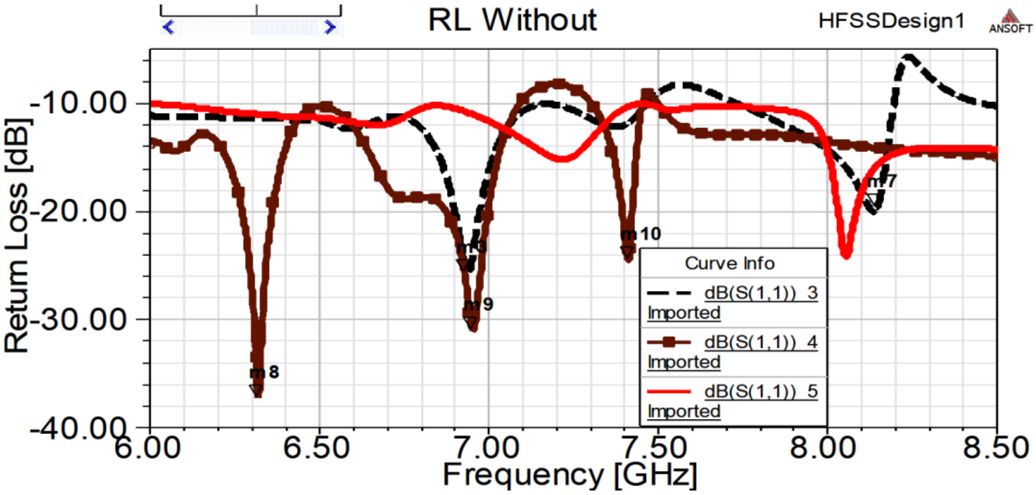

(a) (b)



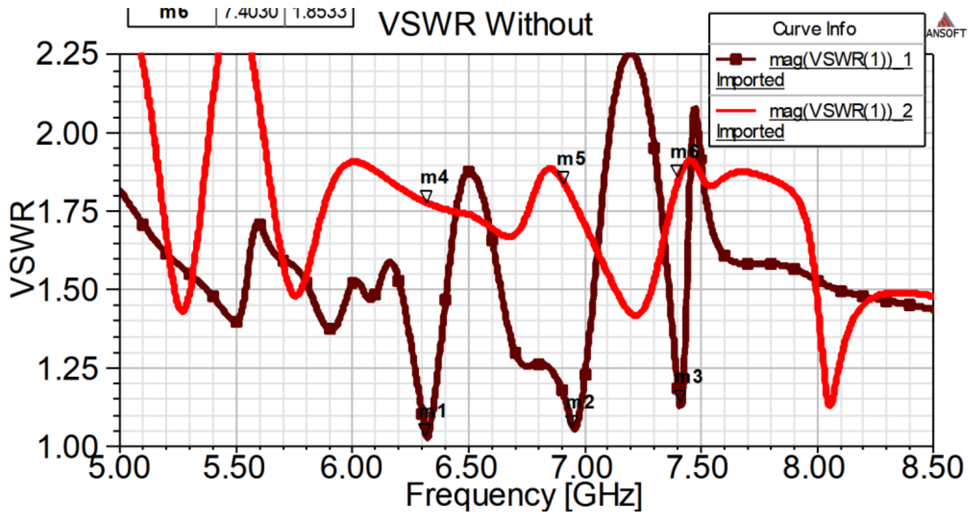

(c) (d)

**Figure 11.** Horn Loaded With CSLS Triangular Array Simulation Results: (a) RL [dB]; (b) Zin [Ω] (c) Js[A/m]; (d) Radiation [

The horn antenna loaded with the CSLS triangular planar array RL simulation results is shown in Figure11 (a). These results show five operating frequencies, moved from the 8 GHz of the horn without array for the miniaturised antenna loaded with CSLS triangular array,at 5.5, 5.9, 6.3, 6.9, and 7.4 GHz with RL=-15.5,-15.9,-37.2,-30.9, and -24.5 dB, respectively at 6.3 GHz.
The horn antenna loaded with the CSLS triangular planar array input impedance simulation results is shown in Figure 11(b). The suggested configuration presents input impedance for impedance matching that is close to 50 ohm based on simulation findings.
The 3D radiation and Js are displayed in Figure 11(c) and 14(d).
The results of a comparison between the horn loaded with a CSLS liner and a triangular array and the horn without an array are presented in Figure12




(a) dB(S(1,1))_5,Horn Without Arrays; dB(S(1,1))_3,Horn With 7 Elements L.A; dB(S(1,1))_4,Horn With Triangular Array.




(b) VSWR (1)_2,Horn Without Arrays; VSWR (1)_1,Horn With Triangular Array

**Figure 12.** Comarision Results: (a) RL [dB] of Horn Without and With CSLS Linear and Triangular Array; (b) VSWR of Horn Without and With CSLS Triangular Arry.

The miniaturisation procedure results in a shift in resonance frequency from 8 GHz to 6.9 GHz or 6.3 GHz utilising a seven-element CSLS linear array or a nine-element CSLS triangular planar array, respectively. Figure 11(a) shows the RL comparison of the suggested structure without and with CSLS arrays.
The VSWR comparison of the suggested structure with and without CSLS arrays for the miniaturisation process is shown in Figure 11 (b). For the triangular array, the minimum VSWR reaches 1.1 at 6.3 GHz. The antenna's ERLR climbs to 26.2 when the CSLS tringular array is loaded, as shown in Table 5.

**Table 5.** Comparision RL [dB] and ERL for Horn Loaded With CSLS Triangular Array at f=6.3 GHz and f=6.9 GHz

| Comparision RL [dB] and ERL for Horn Loaded With CSLS Triangular Array | | | | |
|---|---|---|---|---|
| **Parameter** | **RL[dB]** | **ERLR** | **RL[dB]** | **ERLR** |
| **Frequency [GHz]** | **6.3 GHz** | | **6.9 GHz** | |
| **Without CSLS Array** | -11 | Comparision With | -12 | Comparision With |
| **Loaded CSLS Triangular Array** | -37.2 | 26.2 | -31 | 19 |

The CSLS linear array loaded in the WR90 rectangular waveguide is tested and measured in a laboratory. Using a network analyzer HP8719ES, measured S-parameters of WR90 with and without a circular CSLS array structure have been introduced, as shown in Figure 13, to validate the CSLS array's performance. The CSLS has been classified as a metamaterial structure using S-parameter retrieval techniques. Here, the objective is to characterise the CSLS array and achieve ε and μ modification through targeted metal inclusion in dielectrics.

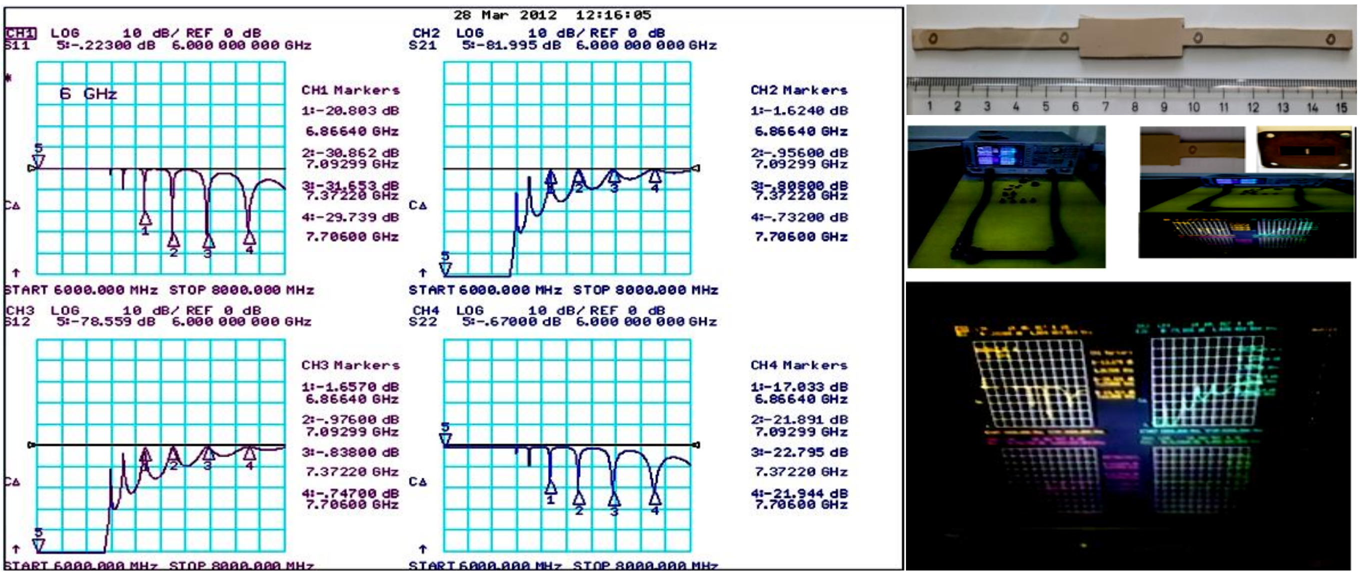



**Figure 13.** The Measured Results of CSLS linear Array Loaded in WR90 Rectangular Waveguide

A comparison of the horn antenna parameters loaded with a CSLS linear or triangular planar array and those without is shown in Table 6. These variables include BW, RL, and VSWR. At 6.9 GHz, the CSLS seven-element linear array-loaded structure introduces ERLR = 14.6, VSWR = 1.05, and BIW = 8.7%. The CSLS triangular planar array-loaded structure exhibits ERLR = 26.2, VSWR = 1.02, and BIW = 8.7% at 6.9 GHz as antenna parameters enhancement.

**Table 6.** Comparision Horn Without CSLS and With CSLS Linear and Triangular Array

| | **Frequency [GHz]** | **RL [dB]** | **SWR** | **BW [GHz]** | **ERLR** | **BWI [%]** |
|---|---|---|---|---|---|---|
| **Without CSLS Arrays** | 6.3 | -11 | 1.7 | 6.44 (5.56:12) | Compared With | |
| | 6.9 | -12 | 1.77 | | | |
| | 7.4 | -10 | 1.85 | | | |
| **With CSLS Linear Array** | 6.3 | -11 | 1.7 | 7 (5:12) | 0 | 8.7 |
| | 6.9 | -25.6 | 1.05 | | 14.6 | |
| | 7.4 | 10 | 1.6 | | -1 | |
| **With CSLS Triangular Array** | 6.3 | -37.2 | 1.02 | 7 (5:12) | 26.2 | 8.7 |
| | 6.9 | -31 | 1.05 | | 20 | |
| | 7.4 | -24.4 | 1.13 | | 13.4 | |

**Table 7.** Comparision Antenna Parameters Without and With CSLS Arrays

| Parameters | Umax[W/Str.] | D[dB] | G[dB] | Pin[W] | Pacc.[W] | Prad.[W] | e0[%] |
|---|---|---|---|---|---|---|---|
| **Horn Without CSLS** | 1.15 | 14.25 | 15.3 | | 0.94 | 0.92 | 0.97 |
| **Horn With Linear Array** | 0.83 | 11.59 | 12.25 | 1 | 0.9 | 0.85 | 0.94 |
| **With Triangular Array** | 1.8 | 25.8 | 24.6 | | 0.96 | 0.92 | 0.95 |

From Table 7 as a comparision results betweeen horn without and with CSLS arrays, it wase found that there is an improvement in the radiated power intenisity, directivity,gain ,radiated power and the radiation efficiency for the array loaded with CSLS arrays compared without structures.

Photographs of the horn measurements without and with CSLS arrays at the microwave Lab. are shown in Figure 14 (a), Figure14 (b) and Figure14 (c).The comparision between simulated and measured results are shown in Figure 14 (d) with an agreement between them and the little different because of the effect of fabrication process includes the connector welding and practical design accuracy.

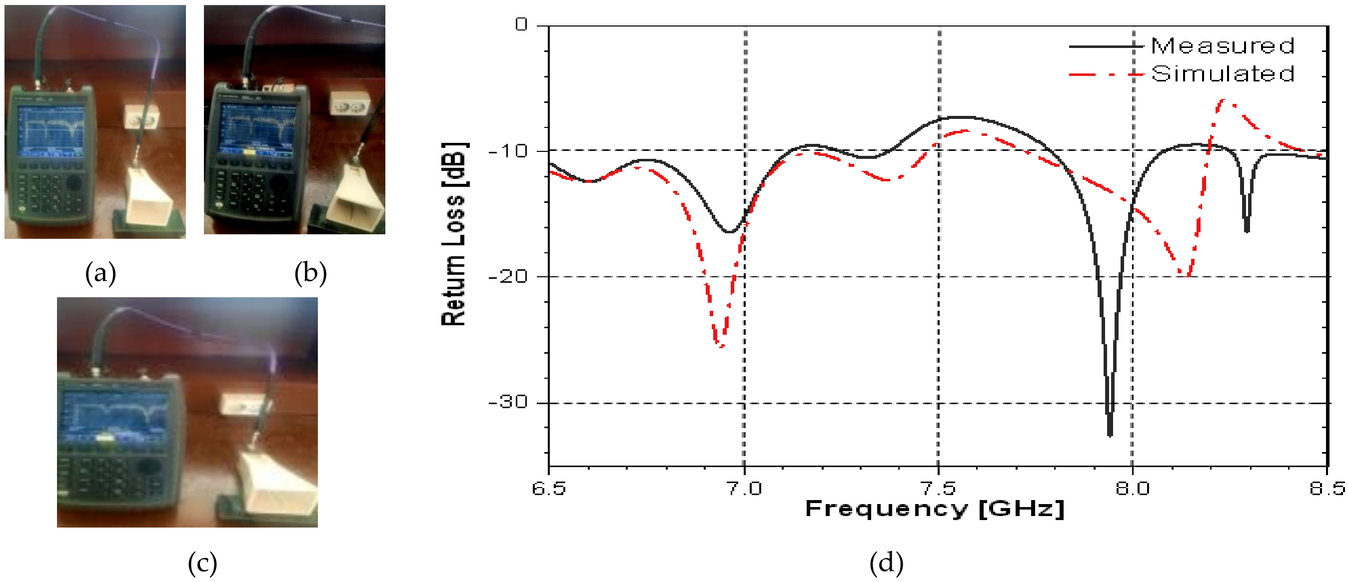
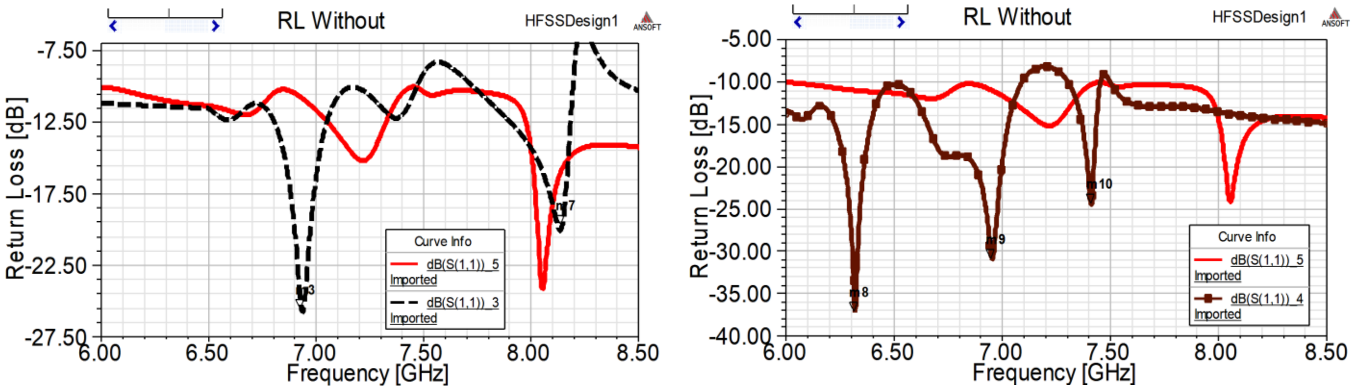



**Figure 14.** Laboratory Measurements and Comparision: (a) Horn Without CSLS Array; (b) Horn With CSLS Linear Array; (c) Horn With CSLS Triangular Array; (d) Comparision Between Simulation and Implementation Results.

## 5. Conclusions

A horn antenna's miniaturisation through the use of a CSLS linear or triangular planar array has been presented, designed, and examined. As illustrated in Figure15, loading the CSLS array causes a 68.7% reduction in size and a shift in resonance frequency from 8 GHz to 6.9 GHz, or 6.3 GHz, utilising a seven-element CSLS linear array or a nine-element CSLS triangular planar array respectively.As illustrated in Figure 15(b), the VSWR for a horn loaded with a linear or triangular planar array and without a CSLS arrays has been introduced. At the operating frequency listed in Table 8, loading the CSLS arrays causes the antenna's BWI to increase to 68.7% and the ERLR to increase to 14.6 and 26.2 for each array.HFSS is used to analyse the suggested design for radar applications.
A comparison with ten current research models is presented in Table 9. It is clear that the antenna parameters offered by this paper such as RL, BW, gain, and miniaturisation in size are improved.




(a) (b)

**Figure 15.** Horn Comarision Results: (a) Without and With 7-Elements Array ; (b) Without and With Triangular Array

**Table 8.** Comparision Horn Loaded With CSLS Linear and Triangular Array

| Comparision Horn Loaded With CSLS Arrays | | |
|---|---|---|
| | **CSLS Linear Array** | **CSLS Triangular Array** |
| **Frequency [GHz]** | 6.9 | 6.3 |
| **ERLR** | 14.6 | 26.2 |
| **BWI [%]** | 8.7 | |
| **Miniaturization [%]** | 68.7 | |

**Table 9.** Comparision with Related Recent Research References

| Comparision with Related Recent Research References | | | | |
|---|---|---|---|---|
| **References** | **RL[dB]** | **Gain [dB]** | **BW [GHz]** | **Reduced [%]** |
| **Ref [25]** | -35 | 4 | 18 | NF |
| **Ref [26]** | -45.36 | 1.37 | 0.2 | 44.82 |
| **Ref [27]** | -30 | 11.5 | 0.75 | NF |
| **Ref [28]** | -40 | 4.5 | 2.5 | NF |
| **Ref [29]** | -18.59 | 10 | 3.9 | NF |
| **Ref [1]** | -35 | 19.7 | 3.5 | NF |
| **Ref [5]** | -20 | 13 | 3 | NF |
| **Ref [14]** | -23 | 15 | 4.5 | NF |
| **Ref [17]** | -22 | 25 | 1.5 | NF |
| **Ref [30]** | 35 | 15 | 2.5 | 60 |
| **This Paper** | -37.2 | 24.6 | 7 | 68.7 |

## References

1. Yoon-Seon Choi , Ji-Hun Hong , Jong-Myung Woo" Array Synthesis Horn Antenna with an Extended Horn and a Stepped Corrugated Structure for High-Power Microwave Applications"JOURNAL OF ELECTROMAGNETIC ENGINEERING AND SCIENCE, VOL. 20, NO. 2, 110~114, APR. 2020.
2. Shao, J., G. Liu, Y. Ji, et al., "UWB TEM horn antenna for the asphalt pavement investigation," Journal of Electronics (China), Vol. 31, No. 1, 24–28, 2014.
3. Li, Y., X. Yin, H. Zhao, et al., "Radiation enhanced broadband planar TEM horn antenna," IEEE Microwave Conference (APMC), 2014 Asia-Pacific, 720–722, 2014.
4. P. Gowtham Kumar, P. Chandrasekhar, S.B. Sai Rama Raju (2015). "Study on Slotted Waveguide Pyramidal Horn Antenna with Enhanced Directivity". IPASJ International Journal of Computer Science (IIJCS).Volume 3, Issue 3 (2015).
5. U. C. Gope,S. Rana, N.K. Das (2019). "Design, Fabrication and Simulation of Pyramidal Horn Antenna at 950 MHz Frequency". International Journal of Engineering and Applied Sciences (IJEAS) ISSN: 2394-3661, Volume-6, Issue-1, January 2019.
6. R. Kiran Chand, Dr. M V Raghavendra, K.Sathyavathi (2013). "Radiation Analysis and Design of Pyramidal Horn Antenna". International Journal of Engineering Research & Technology (IJERT). Vol. 2 Issue 10 (2013).
7. G.Abhignya, B.Yogita, C.Abhinay, B.Balaji, MBR Murthy (2015). "Design, "Fabrication and Testing of Pyramidal Horn Antenna". International Journal of Engineering and Applied Sciences (IJEAS) ISSN: 2394-3661, Volume-2, Issue-4 (2015).
8. Shital Pramod Kapade, Prof. A.S. Deshpande (2017). "Review of Horn Antenna". IJARIIE-ISSN (O)-2395-4396 ,Vol-3 Issue-4 (2017).
9. KirpalSingh, AjaySiwach, Lovleen Kaur (2013). "Advancement in Designing of Wideband Horn Antenna". International Journal of Engineering Trends and Technology (IJETT). Volume4,Issue4(2013).
10. S. Bassam and J. Rashed-Mohassel (2006)."A Chebyshev Tapered TEM Horn Antenna". PIERS ONLINE, VOL. 2, NO. 6:pp (2006).
11. Daniyan O.L., Opara F.E., Okere B.I., Aliyu N., Ezechi N., Wali J., Adejoh J., Eze K., Chapi J., Justus C.10, Adeshina K. O.11" Horn Antenna Design: The Concepts and Considerations" International Journal of Emerging echnology and Advanced Engineering Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4, Issue 5, May 2014).
12. S. Gowri Shankar, K. Viswavardhan Reddy and K. ishnuvardhana eddy "Design and Simulation of Horn Antenna in x-Ku Band for Satellite Communications " International Journal of Research in Science & Technology,2014.
13. Chen, Z. and Z. Shen, "Broadband and low-profile H-plane ridged horn antenna," Proc. IEEE International Sym. on Antennas and Propag. & USNC/URSI National Radio Science Meeting, 2319–2320, Jul. 19–24, 2015.
14. Fadhil Mukhlif , "Analysis and Design Pyramidal Horn Antenna in X-Band"International Conference on Communication, Electrical and Computer Networks (ICCECN 2020) Kuala Lumpur, Malaysia, 1 – 2 February 2020.
15. Yogesh G S, Chandrappa D N, Anita R, Rajendra Soloni "DESIGN AND SIMULATION OF HORN ANTENNA AT 2GHZ WITH HFSS "International Journal of Advanced Research in Computer and Communication Engineering Impact Factor 7.39◎◎Vol. 11, Issue 1, January 2022.
16. Barik, B.R., Kalirasu, A. "Design of a UHF pyramidal horn antenna using CST" Int.J.PureAppl. Math. 114, 447–457 (2017). ISSN 1311-8080 (printed version); ISSN 1314-3395(on-lineversion).
17. Girish, K.: Electrical Engineering Department, IIT Bombay. https://nptel.ac.in/courses/ 108101092/ Week-10-Horn-Antennas-Part-1.pdf. Last accessed 12 Jul 2018.
18. Sezgin ORDEK, Ahmet KIZILAY"Horn Array Antenna Design for Ku-Band Applications"Electrical and Computer Networks (ICCECN 2020) Kuala Lumpur, Malaysia, 1 – 2 February 2020.
19. Inductive Diaphragm in Rectangular Waveguide Using Integral Equation Method``, Vol. 64, No. 2, pp. 94–107. Radioelectronics and Communications Systems, 2021, February, 2021.
20. M. Moradian, et.al., "Application of Wiggly Ridge Waveguide for Design of Linear Array Antennas of Centered Longitudinal Shunt Slot," Wiley Int. J. RF and Microwave, July 2009.
21. David M. Pozar "Microwave Engineeriing", Second edition. JOHN Willey & Sons,INC.New York.
22. "Waveguide basics tutorial," RF Wireless World, waveguide basics- tutorial.html.
23. Southworth, G.E, "Principles and applications of waveguide transmission".Chapter 8. Van Nostrand company, Princeton,N.J.
24. Samuel Y. Lio, "Microwave devices and circuits", Third edition
25. Manish Varun Yadav , and Jaume Anguera "A Miniaturized Antenna forMillimeter-Wave5G-IIBandCommunication"Technologieshttps://doi.org/gies12,2024.
26. Abdel-Ali Laabadli, Youssef Mejdoub, Abdelkebir El Amri1 and Mohamed Tarbouch "A miniaturized rectangular microstrip patch antenna with negative permeability unit cell metamaterial for the band 2.45 GHz" https://doi.org/10.1051/itmconf/20235203002, ITM Web of Conferences 52, 03002 (2023).
27. Ashraf S. Abdel Halim · Mohanad Mostafa , Omnia Hamdy "Design and Implementation of 3.2-GHz Co-Planar Miniaturized Antenna for S-Band Communication and Wireless Applications" Wireless Communications,(2023)132:1887–897https://doi.org/10.1007/s11277-023-10686-9,springer,2023

28. Humam Hussein , Ferhat Atasoy and Taha A. Elwi "Miniaturized Antenna Array-Based Novel Metamaterial Technology for Reconfigurable MIMO Systems", Sensors 2023, 23, 5871. https://doi.org/10.3390/s23135871,2023
29. Abdullah Baza, Deval Jansarib, Sunil P. Lavadiyac, Shobhit K. Pateld, "Miniaturized and high gain circularly slotted 4×4 MIMO antenna with diversity performance analysis for 5G/Wi-Fi/WLAN wireless communication applications" journal homepage: www.sciencedirect.com/journal/results-in-engineering, Publishedby Elsevier B.V,2023.
30. Halim, A. S. A., Mostafa, M., & Hamdy, O. (2022). Miniaturized antenna verified with diffuse optical measurements for native and oiled adipose tissue differentiation. Scientific Reports, 12(15035), 1–13. https:// doi. org/ 10. 1038/ s41598- 022-19430-y
31. P. T., Taryana, Y., Paramay, K., Prawara, B., "Design of flexible 3.2 GHz rectangular microstrip patch antenna for S-Band communication". Jurnal Elektronika dan Telekomunikasi (JET), 21(2), 140–145. https:// doi. org/ 10. 14203/ jet. v21. 140-145,2021
32. Haleem, M.; Elwi, T.A. Circularly Polarized Metamaterial Patch Antenna Circuitry for Modern Applications. Int. J. Emerg. Technol.
33. Adv. Eng. 2022, 12, 44–50.
34. Al-Hadeethi, S.T.; Elwi, T.A.; Ibrahim, A.A. A Printed Reconfigurable Monopole Antenna Based on a Novel Metamaterial
35. Structures for 5G Applications. Micromachines 2023, 14, 1.
36. M. Z.S.; Ali. M.; Elwi, T.A.; Hassain, "Photonic controlled metasurface for intelligent antenna beam steering applications including 6G mobile communicationsystems". AEU Int. J. Electron. Commun. 2023, 166, 15–25.
37. "Antenna Theory & design" by Robert S.Elliot.
38. . A. Balanis, Antenna Theory: Analysis and Design, John wiley & sons 3rd Edition. 3rd ed., Wiley-Interscience, 2015.
39. Hafid Griguer, Eric Marzolf, Hicham Lalj, Fatima Riouch, M'hamed Drissi, "Patch Antenna Bandwidth Enhancement through the Use of Metamaterials" Authorized licensed use limited to: Government of Egypt - SPCESR - (EKB). Do3w2n4loaded on April 19,2024 at 16:19:39 UTC from IEEE Xplore.
40. Huthaifa A. Al Issa, Yahya S. H. Khraisat (□), Fatima A. S. Alghazo" Bandwidth Enhancement of Microstrip Patch Antenna by Using Metamaterial", iJIM – Vol. 14, No. 1, 2020, http://www.i-jim.org
41. "Metamaterials in Application to Improve Antenna Parameters"Book, WRITTEN BY Wojciech Jan Krzysztofik and Thanh Nghia Cao Reviewed: 31 July 2018 Published: 05 November 2018 DOI: 10.5772/intechopen.80636,https://www.intechopen.com/chapters/63993
42. David M. Pozar "Microwave Engineering" Third Edition