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The Design of a Superstate NZIM-Antenna Array for WLAN Application

A. Khairy[1], Islam Mohammed[1], Mohamed I. Ahmed[2] and M. M. Elsherbini[1,3,]*

[1]Department of Electrical Engineering, The Egyptian Academy for Engineering and Advanced Technology (EAEAT), Egypt
[2]Department of Microstrip, Electronic Research Institute, Egypt
[3]Shoubra Faculty of Engineering, Benha University, Egypt

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ABSTRACT

With the development of telecommunications and its applications, the design of compact antennas with high performance has become a great necessity. Among the important requirements is a high gain. In this article, a microstrip patch antenna using near zero-index metamaterial (NZIM) is proposed. This prototype is designed with the designing parameters of a rectangular microstrip patch antenna. The substrate material is FR-4. Simulation results show that this antenna operates at 5.8 GHz for a wireless local area network (WLAN). The proposed single antenna element achieves side-lobe suppression better than -13 dB. The 4×4 proposed antenna array is designed using 16 single elements and a T-shaped power divider to split power for each element. By covering a single-layer NZIM coating with a 4×4 array over a microstrip antenna, a gain enhancement of 14 dB is achieved in comparison with the single element. Over the operating band, the antenna prototype demonstrates steady radiation patterns. These characteristics are in good agreement with the simulations, rendering the antenna a good candidate for 5G applications. These antennas are designed, optimized, and simulated using CSTMWS2020.

Keywords: Antenna Array, Microstrip Antenna, CST, NZIM, Gain, Side Lobes Level.

1 Introduction

Microstrip or patch antennas are becoming increasingly useful because they can be printed directly onto a circuit board and have a low profile and low cost. High speed, broadband, and high capacity in or outside WLANs are becoming increasingly common nowadays, so it's worth getting acquainted with some of the difficulties of wireless design that must be addressed and overcome. Because of their advantages, microstrip antennas are an excellent choice for wireless local area network (WLAN) applications [1]. Despite these drawbacks, like a lower gain, narrow bandwidth, and large ohmic losses in the feed structure of arrays. The microstrip patch antennas can be adapted for use in new high-speed broadband WLAN systems as well as other applications like PCS, Bluetooth, RFID, and so on. The purpose of this paper is to use a near-zero-index metamaterial as a single- or double-layer superstrate hung above a microstrip patch antenna operating at 5.8 GHz for gain enhancement. The metamaterial layer superstrate is composed of a periodic arrangement of Jerusalem cross-unit cells and has the properties of a homogeneous medium with a refractive index close to zero [2]-[4]. This metamaterial characteristic enables the collection of radiated waves from the antenna and collimates them in the direction of the superstrate normal [5]. Many metamaterial-based patch antennas have been built and thoroughly explored in recent years. Moreover, near zero-index of refraction metamaterials have been widely studied to enhance antenna performance [6]. Due to their ability to control the radiation pattern and the convergence energy, near-zero-index metamaterials can be used to improve the gains of the antennas.

2 Antenna Design

The single element of the antenna is designed using an FR4 substrate with a relative permittivity of 4.3 and a thickness of 1.57 mm to operate at 5.8 GHz, achieving -10 dB, 300 MHz bandwidth. The single element has an overall realized gain of 3.58 dB. A single layer NZIM with 43 cells is covered over a microstrip antenna at a height of 4.62 mm operating at 5.8 GHz with broadband characteristics to improve its performance. As a result, a gain enhancement of 14 dB is achieved for the antenna.

2.1 Antenna Structure

A microstrip antenna is an antenna that is primarily a two-dimensional flat structure, as shown in Fig. 1. In its most basic form, it employs a one-half wavelength long conducting "patch," with the metal surface acting as a resonator, similar to half-wave dipole antennas. It is frequently constructed simply by mounting or constructing an appropriately dimensioned metal sheet or surface on an insulating dielectric substrate, such as a printed circuit board. The opposite side of the PC board substrate is also cladded and so forms a ground plane, or another conductive surface is added on the other side of the dielectric [7]. The dimensions of the rectangular microstrip patch antenna are shown in Table 1. The substrate material is FR-4 with a relative permittivity of 4.3 and a thickness of 1.6 mm. The following equations are used for microstrip antenna design [8].

$$w = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{w}\right)^{\frac{-1}{2}} \tag{2}$$

$$\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \tag{3}$$

*Corresponding Author Email Address: m.moustafa@eaeat-academy.edu.eg Published by: SciEn Publishing Group

$$Re = \frac{\rho V d}{\mu} \qquad (4)$$

$$L = \frac{c}{2 f_r \sqrt{\varepsilon_{r_{eff}}}} - 2\Delta L \qquad (5)$$

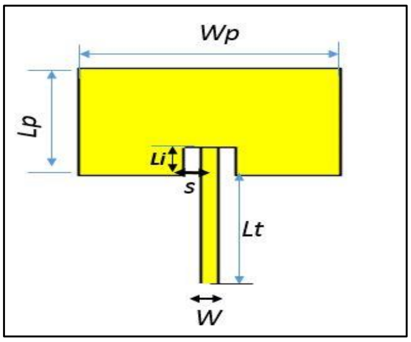
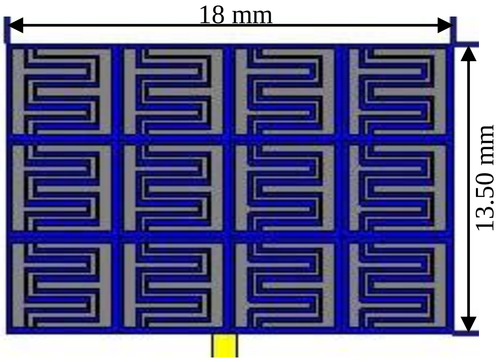
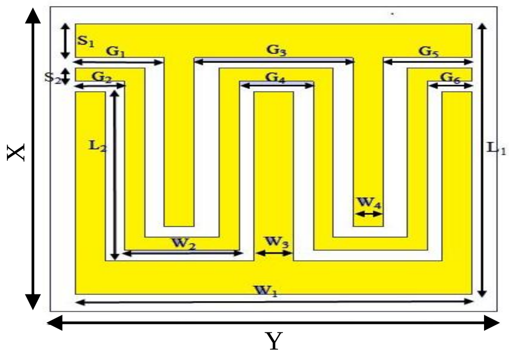


Fig. 1 Microstrip Structure.



(a)



(b)

Fig. 2 NZIM Structure. (a) The geometry of unit cell (b) The schematic diagram of NZIM unit cell.

Table 1 Microstrip Antenna Parameters.

Parameter	Value
Lp	15
Wp	15
Wf	3
Lt	17
S	1

2.2 NZIM Unit Cell Design

Metamaterials are synthetic structures with electromagnetic properties which are not present in natural materials. Since their initial experimental realization, metamaterials have been utilized to increase the performance of different microwave devices, particularly antennas. Researchers have recently proposed various metamaterial-resonator-based techniques for achieving multiband, multi-polarized, and band-notched ultra-wideband antenna features [9]-[10]. Fig. 2 shows an NZIM structure for a unit cell with a width of 18 mm, a length of 13.50 mm, and a distance of 4.62mm from the patch. The full dimensions of NZIM are illustrated in Table 2. The frequency range corresponding to near-zero refractive index can be this factor is easily modifiable by adjusting these variables [11].

Table 2 NZIM Parameters

X	Y	W1	W2	W3	W4	L1	L2
4.5 mm	4.5 mm	4 mm	11.5 mm	0.4 mm	0.3 mm	4 mm	2.5 mm
G1	G2	G3	G4	G5	G6	S1	S2
1 mm	0.5 mm	1.6 mm	0.75 mm	1 mm	0.5 mm	0.5 mm	0.2 mm

2.3 Antenna Array Design

The schematic diagram of the proposed antenna array with NZIM superstrate is shown in Fig. 3. The 4 x 4 array is designed using 16 single elements and a T-shaped power divider to split power for each element. The antenna array elements are separated by λ/2 to avoid mutual coupling between each element. The proposed array is designed to increase the realized gain. The realized gain is increased by using the array to 14 dB.

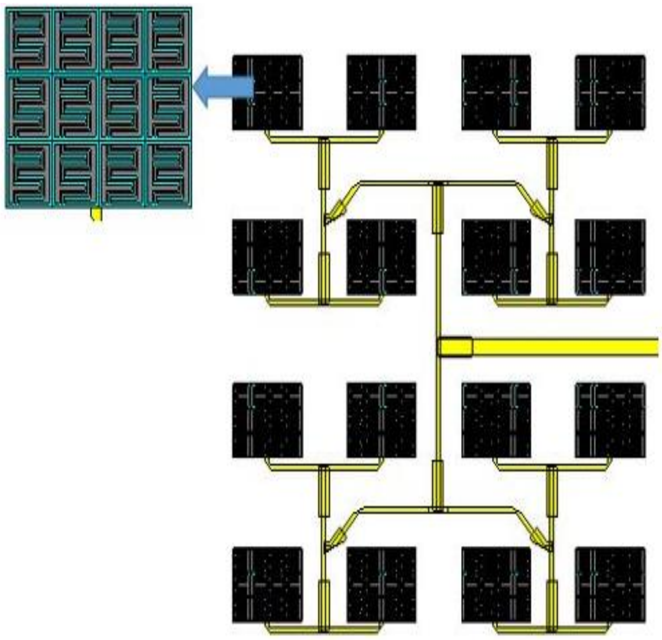


Fig. 3 The proposed antenna array with NZIM Superstrate.

3 Results and Discussion

In CSTMWS2020, the NZIM is designed using an FR4 substrate with a relative permittivity of 4.3 and a thickness of 1.57 mm. The unit cell NZIM is simulated with PEC and PMC border conditions. The PEC and PMC boundary conditions are constructed in such a way that an electric field exists along the yaxis and a wave propagates along the z-axis. The effective medium parameters are derived from the scattering parameters. The extracted permittivity, permeability, and refractive index are presented in Fig. 4, Fig. 5, and Fig. 6 respectively.

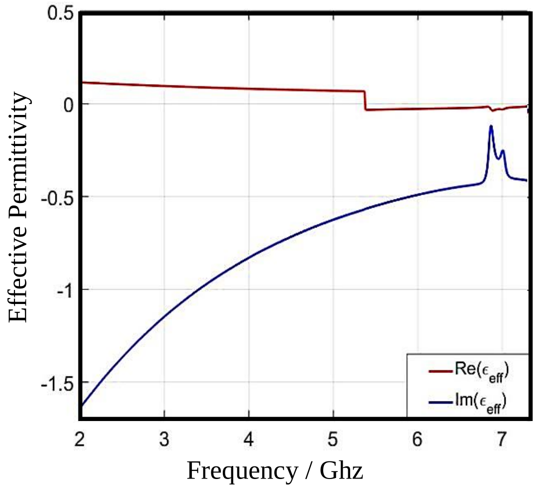


Fig. 4 NZIM Permittivity.

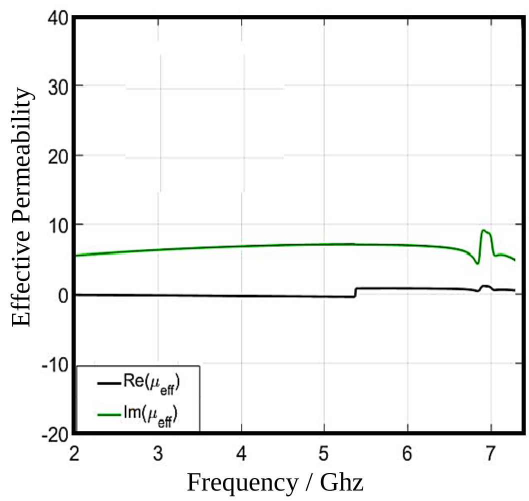


Fig. 5 NZIM Permeability.

The Fig. 4, the effective permittivity is extracted from the S12 parameter of the NZIM unit cell. The value of relative permittivity is near zero. Fig. 5 shows the real and imagine effective permeability of NZIM is near zero.

Fig. 6 shows the value of the refractive index is near zero at operating frequency, which leads to an increase in the overall realized gain of the antenna. The NZIM collimates the radiated beam of the antenna. Fig. 7 shows the variation of S11 of the patch antenna with frequency for a single element and the 4 × 4 arrays without NZIM.

In Fig. 7, the reflection coefficient shows the return loss due to the mismatch in impedance of the fed line and antenna. So, the lower value of the reflection coefficient is preferred, and -10 dB is the standard value for calculating impedance bandwidth. The proposed single-element design has a return loss of –48.8 dB. The variation of S11 of the patch antenna with frequency for a single element and the 4 × 4 arrays without NZIM has a return loss of -40 dB with the resonance at 5.8GHz with a bandwidth of 300 MHz for a single element. However, the bandwidth is 1 GHz for the antenna array illustrated.

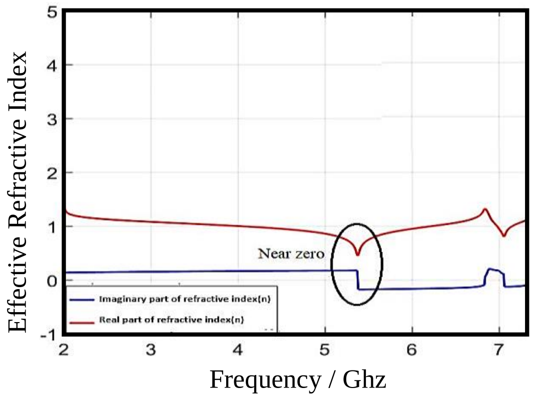


Fig. 6 Extracted real and imaginary parts of the refractive index for the proposed NZIM unit cell.

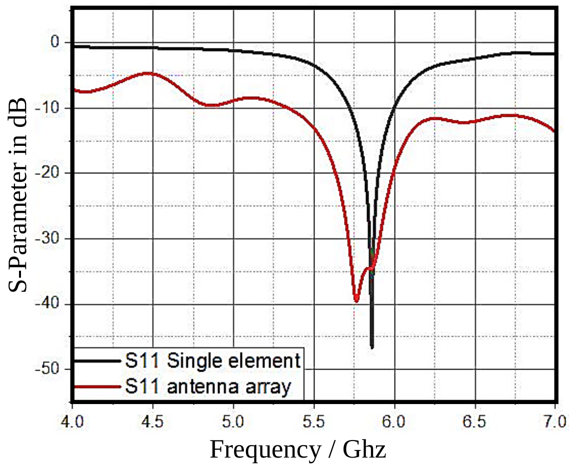


Fig. 7 The reflection coefficient of single element and antenna array.

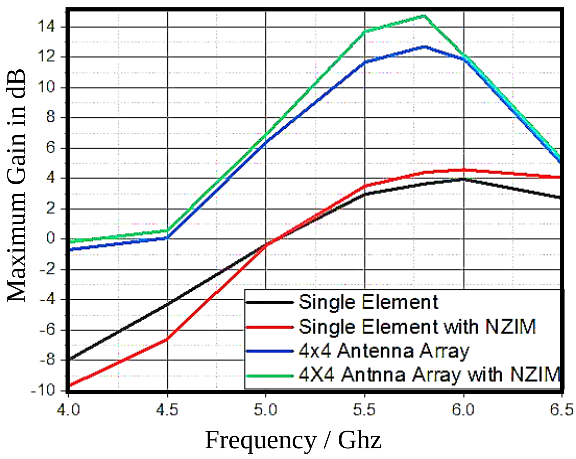


Fig. 8 High gain patch antenna with and without the NZIM superstrate.

The single-element design provides a gain of 3.7 dBi without NZIM and 4.41 dBi with NZIM at two resonating frequencies. The 4×4 array without NZIM increased the gain by 12 dBi, and the overall realized gain for the array with NZIM was enhanced to 14.22 dBi. The single element side lobe level without NZIM is -12.15 dB and the single element with NZIM achieves a -13.2 dB side lobe level. The 4×4 antenna array without NZIM side lobe level is 8.95 dB, and the 4×4 antenna array with NZIM is -9.4 dB, as illustrated in Fig. 8.

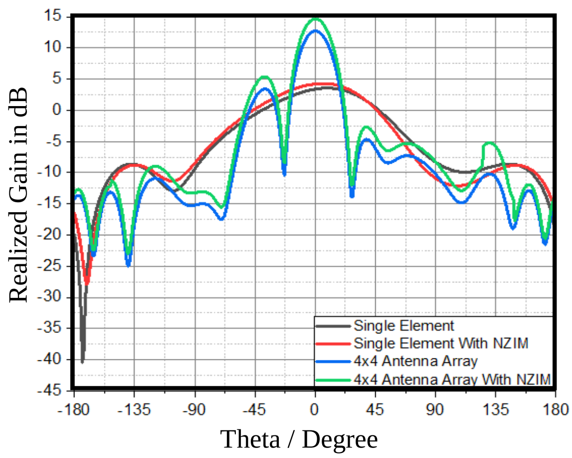


Fig. 9 The realized gain at operating frequency 5.8 GHz is simulated at constant phi = 90° versus theta.

Fig. 9 shows that the single element side lobe level without NZIM is -12.15 dB and a single element with NZIM achieves a -13.2 dB side lobe level. The 4×4 antenna array without NZIM side lobe level is 8.95 dB, and the 4×4 antenna array achieves with NZIM -9.4 dB, and the overall realized gain for the array is 14 dB.

4 Conclusion

The MS- arrays are the best way to design low-profile antennas with high-performance parameters like gain and directivity, mutual coupling between elements of the array, and low side lobes. The necessity of high gain and protection from path loss will be necessary considering the expansion of modern technology in WLAN systems. This paper proposed a microstrip patch antenna to operate at a resonant frequency of 5.8 GHz. Moreover, it has also been deduced that numerous parameters of the antenna model have been the radiation pattern and antenna gain of the proposed antenna are studied and presented. Simulations using CSTMWS2020 verify several advantages, such as high antenna gain, stable radiation pattern, and good SLLs in both E- and H-planes. The proposed antenna is designed to operate for WLAN applications with high gain to cover the huge demand for data transferring rates with high performance. The NZIM unit cell increased the gain by increasing the directivity of the antenna. The 4×4 antenna array achieved an overall realized gain of 14 dB approximately by using the NZIM superstrate technique. The side lobe level is reduced to below -13 dB. All elements are designed using FR4 substrate to reduce the cost of implementation and fabrication because WLAN applications are commercial.

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