 https://doi.org/10.1051/itmconf/20224801003

Wideband meta-material-inspired reconfigurable antenna using Infinity Split Ring Resonator

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Abstract. In this article, a reconfigurable antenna inspired by the broadband meta-material using the Infinity slotted ring resonator (I-SRR) is designed and computer-based for wireless communication. Antenna takes an infinitely split ring resonator as a radiator powered by a coplanare wave guide (CPW). The procedure for extracting parameters of the meta-material property of the I-SRR is discussed in detail, by which the existence of negative permeability and the new resonance frequencies are verified. The proposed antenna has advantages of simple design, miniaturisation that can be used for wireless mobile communication system.

Index terms – frequency reconfigurable, meta-material, negative permeability, split ring resonator (SRR), wideband antenna, coplanar waveguide (CPW)

1 introduction

Over the past few years, there has been a remarkable development in the field of communication, notably in wireless communications. There is an increasing need for innovative materials to improve the performance of antennas, which are components that transmit and receive electrical signals. Since the first demonstration on the negative of electric permittivity and magnetic permeability by V.G.Veselago in 1968 [1], and its manufacture by Smith and his team [2], Meta-data have a strong interest in the area of antennas due to their properties, that are not found in nature. Synthesized meta-materials are classified into three categories: the first one is the meta-material with negative permittivity, the second one is the meta-material with negative permeability, and the last one is the meta-material with both are negative, the permittivity and the permeability [3].

Bandwidth is a very important parameter for transmitting data via the antenna. The multi-band antenna covers millimeter waves for 5G technology was presented in [4-5]. In [6-7], a compact coplanar waveguide (CPW)-fed meta-material inspired multi-band is designed to cover WLAN, C-band, UMTS and WiMax. A multi-band reconfigurable antenna inspired hexagonal meta-material was presented in [8]-9]. A wideband antenna of a monopole type for frequency reconfiguration using varactor diode was illustrated in [10]. Complementary Split Ring Resonator is a kind of meta-materials that have a negative epsilon. In [11] the four rectangular Split Ring Resonator was printed in ground plane for improve gain value with a rectangular patch. In [12], the Infinity Split Ring Resonator was loaded in ground plan improve gain and efficiency.

In this work, we focus on developing the shape of meta-materials and using it as a primary resonator to perform broadband reconfiguration. The simulator used is CST MICROWAVE STUDIO

2 Extraction of negative permeability

The electromagnetic response of that material is determined by electric permittivity and magnetic permeability. In conventional materials, these parameters are positive, but in artificial materials, the two are negative or one of them is negative. The most commonly used techniques to extract negative permittivity or negative permeability are the Nicholson-Ross-Weir (NRW) [13] and Robust [14] methods. These techniques are based on parameters S: render in the coefficient of reflection S11 and the coefficient of transmission S21.

The permeability expression is given by the following equation

$$\mu = z * n \tag{1}$$

Where n is the refractive index and z is the wave impedance.

According the NWR and Robust methods, the expression of n and z are given by the following equation:

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$$z = \left(\frac{(1+S_{11})^2 - S_{21}^2}{(1-S_{11})^2 - S_{21}^2}\right)^{1/2} \quad (2)$$

$$n = \frac{1}{kd} cos^{-1}\left[\frac{1-S_{11}^2+S_{21}^2}{2S_{21}}\right] \quad (3)$$

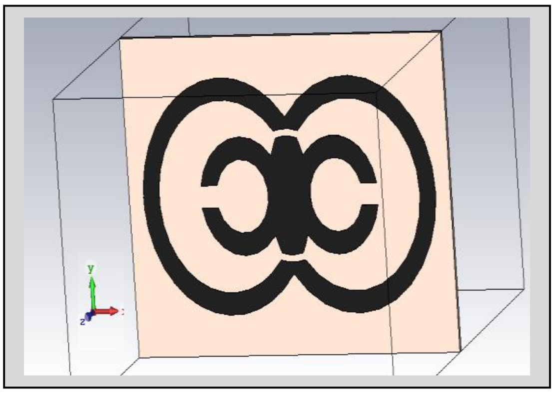

Fig.1. Infinity-SRR unit cell

The proposed infinity split ring resonator is located between two waveguide ports on the right and left of the z-axis. The wave is excited from the positive Z axis (port1) to the negative Z axis (ports2) to calculate the parameter S11 (reflected from port 1) and the parameter S21 (transmission to port 2 due to 1**).**
Fig.1. shows the photographs of the improved infinity SRR cell. Scattering parameters are essential to extraction of negative permeability. The S11 and S21 parameters are extracted from CST Microwave Studio. The simulated results presented in Fig.4. are consistent.

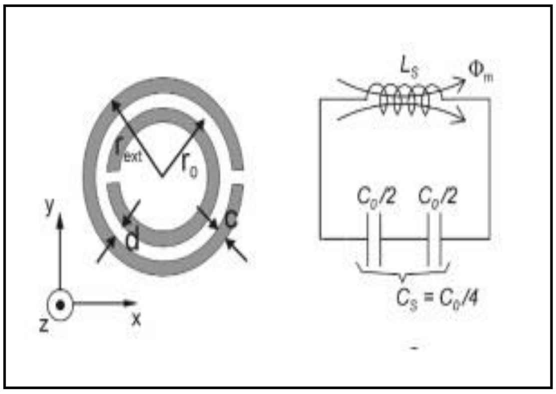

Fig.2. circular split ring resonator and its equivalent circuit [15]

The combination of two circular split ring resonators (Fig.2) results an infinitely shaped split ring resonator whose resonance frequency is given by the following formula[16],[17] :

$$f = \frac{1}{2\pi\sqrt{L_T C_{eq}}} \quad (4)$$

Where

$$C_{eq} = \left(2a_{avg} - \frac{g}{2}\right)\frac{\sqrt{\varepsilon_e}}{c_0 Z_0} + \frac{\varepsilon_0 ch}{2g} \quad (5)$$

And

$$L_T = 0.00508l(2.303log_{10}\frac{4l}{d} - 2.451) \quad (6)$$

C_{eq} is the equivalent capacitance and L_T is the total inductance
The development of the structure leads to the final structure presented in **Fig.1** and its electrical equivalent is given in **Fig.3**

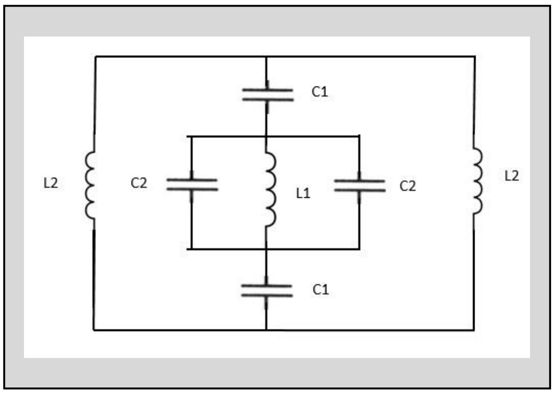

Fig.3.equivalent circuit of Infinity-SRR

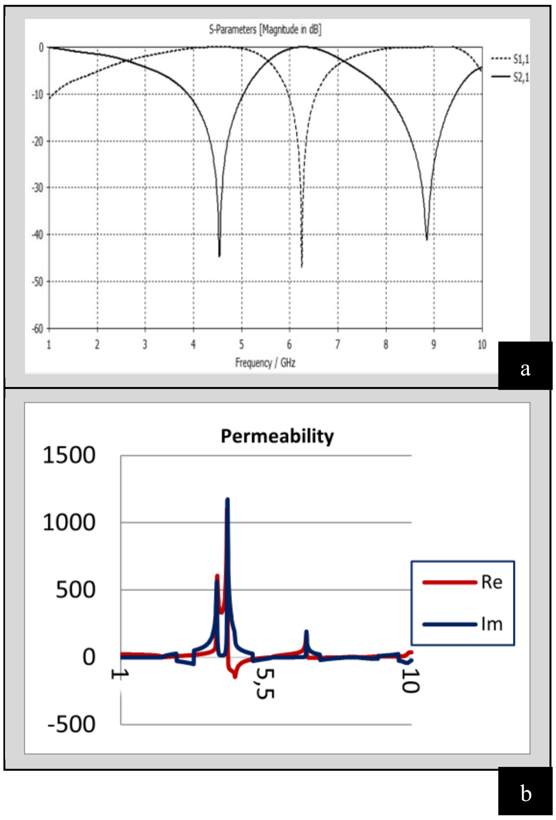

Fig.4. (a) S11&S21 parameters vs frequency and (b) real and imaginary permeability plot vs frequency

3 Antenna design

3.1 antenna configuration

The suggested antenna has infinity shape which CPW-ground planes as presented in Fig.1. Its design is imprinted on a 32 x 35.56 x 0.381 mm3 low –cost

Rogers RO3003 substrate ($\boldsymbol{\varepsilon_r = 3}$, $\boldsymbol{tan\delta = 0.001}$). This proposed antenna has infinity split ring radiating element to create wideband reconfigurable for wireless communication. The radiating area consists of pairs of infinite metal rings, which are one inside another. Top and side views of the antenna are presented in Fig.5.

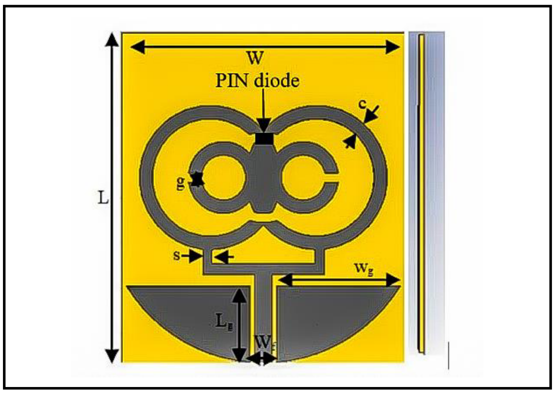

Fig.5. Geometry of proposed reconfigurable antenna

The parasitic inner infinity is connected to the outer infinity ring using one PIN diode in the higher gap between them. After numerous optimization runs using the CST simulator that have based on the finite integration technique (FIT). It is the most used solver due to ease in simulations. Final geometry of the proposed infinity meta-material is illustrated in Fig.5. The optimised dimensions obtained for the reconfigurable antenna inspired by the proposed meta-material are summarized in Table 1.

Table 1. Design Parameters of the proposed antenna

parameter	Dimension (mm)
L	36.56
W	32
Wf	3
Lf	9.78
Lg	8.49
Wg	14
g	1
c	1.5

3.2 Equivalent circuit model of PIN diode:

PIN diode is one of the electronic switching components that have been widely used to reconfigure antennas thanks to their speed of switching and its simple integration within antennas. PIN diode used in this work is MPP4203 from Microsemi.[18]

Fig.6. shows the corresponding circuit for a PIN diode. ON state is replaced by a resistor of 3 Ω, and OFF state is replaced by a resistor of 25 KΩ simultaneously with a capacitor of 0.08 pF.

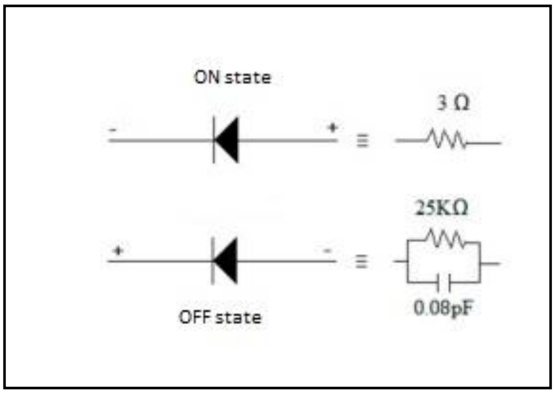

Fig.6. Equivalent circuit of PIN diode

3.3 Parametric Study

3.3.1 the effect of substrate

Parameter S11 (Reflection coefficient) is simulated for different substrate types Three substrates chosen for this study are FR-4 (dielectric permittivity constant of 43, dielectric loss tangent of 0.025), Rogers RT5880 (dielectric permittivity constant of 2.2, tangent dielectric loss of 0.009), and Rogers RO3003 (dielectric permittivity constant of 3, dielectric loss tangent of 0.001). The results are plotted in Fig.7. The impedance bandwidth of the proposed antenna is observed to remain stable and frequency resonances are offset. The Rogers RO3003 substrate gives the good results.

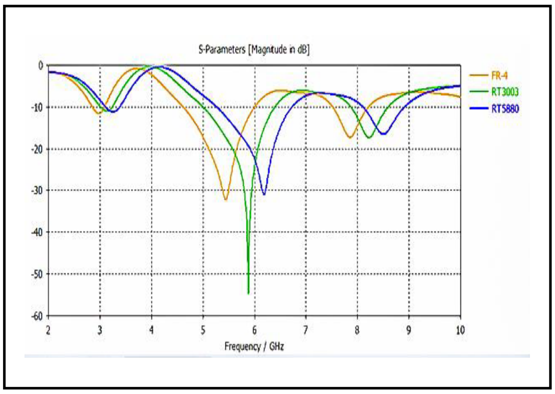

Fig.7. S11 for different types of substrate

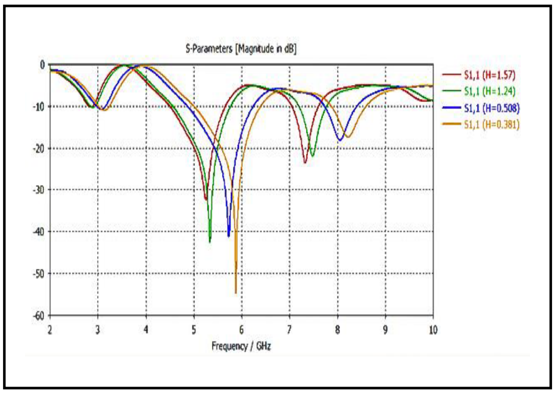

Fig.8. S11 for four values of substrate thickness

3.3.2 the effect of substrate thickness

Fig.8. presents the simulation reflection coefficient for different values of substrate thickness h. It has been observed that the impedance bandwidth of recommended antenna stay unchanged and that frequency resonances are significantly affected. When H=0.381 mm, the antenna fits better.

3.3.3 the effect of width of the rings

The width of the rings has a direct effect on inductance and capacity. The increase in this width decreases the value of the inductance and the value of the capacity. Therefore, rings with low thickness have a small frequency. The optimal thickness value is c=1.5mm in order to reach the desired frequency. Fig.7. shows to obtained results with the other dimensions remains fix (Table1).

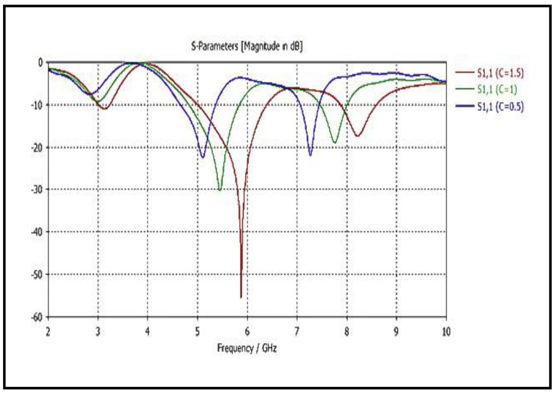

Fig.9. S11 for different values of width of rings c

4 results and discussion

4.1 reflection coefficient

The simulation reflection coefficient S11 results for the both configurations are presented in Fig.10. PIN diode ON configuration resonates at 4.832 GHz in the simulation with -10 dB impedance bandwidth of 2.268 GHz, and OFF configuration resonates at 5.84 GHz and 7.8 GHz in the simulation with -10 dB impedance bandwidth of 1.65 GHz and 687 MHz, respectively.

The results obtained for the coefficient of reflection presented in Table 2 demonstrate that the proposed antenna is suitable for CPW.

There is an advantage to the reconfigurable antenna, it is bandwidth improvement. In this work the bandwidth gets larger. The antenna covers the 2.5 GHz range.

Another parameter is very interesting than S11 parameter; it is the Voltage Standing Wave Ratio (VSWR) which determines the reflected power. Depending on the results presented in Table 2, for the both configurations, the value of VSWR is optimal, which means that most of the power is provided to the antenna.

Table 2. Diodes configurations, S11and VSWR values

	Fr(GHz)	S11 (dB)	BW(%)	VSWR
Configuration 1(ON)	4.832	-26.28	44.68	1.1
Configuration 2 (OFF)	5.84	- 40,87	28.3	1.01
	7.8	- 28.1	8.79	1.08

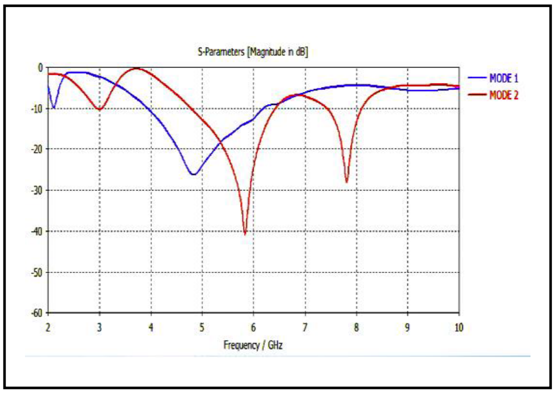

Fig10. Simulated S11 value of the proposed antenna

4.2 Gain and efficiency

The gain of the proposed reconfigurable antenna for the observed operating frequencies are simulated namely the CPW monopole antenna with PIN diode ON/OFF as dipected in Fig.10. and the Fig.11. shows the simulated gain over frequency.

The peak gain for CPW monopole antenna inspired meta-material goes up to 3 dB at 4.832 GHz with diode ON, and 3.58 dB at 5.84 GHz and 4.53 dB at 7.8 GHz with diode OFF.

In this work, the CPW monopole reconfigurable antenna inspired infinity SRR is wideband antenna. It covers the frequencies defined under the C-band (4-8GHz). The most important appears is Industrial, Scientific and Medical (ISM) band at 5.84 GHz.

One of the major parameters is the efficiency of radiation. It describes how such an antenna transmits and receives RF signals. It has defined as the relation between the total power radiated by the antenna and the total power input received from generator. Radiation efficiency value simulated is 92.97% at 4.83 for the configuration 1, and for configuration 2 its value for the bi-band are 94.32% and 98.27% at 5.84 GHz and 7.8 GHz respectively. The gain and radiation efficiency are presented in Table 3.

The simulated surface current distribution for the both configuration at 4.832 GHz, 5.84 GHz, and 7.8 GHz are shown in Fig. 13 respectively.

The recommended antenna is successful in terms of gain and efficiency. Finally, the proposed reconfigurable antenna settings are compared to other references in Table 4.

Table 3. Simulated Gain and Efficiency

	Fr(GHz)	GAIN (dB)	EFFICIENCY (%)
Configuration 1	4.832	3	92.97
Configuration 2	5.84	3.58	94.32
	7.8	4.53	98.37

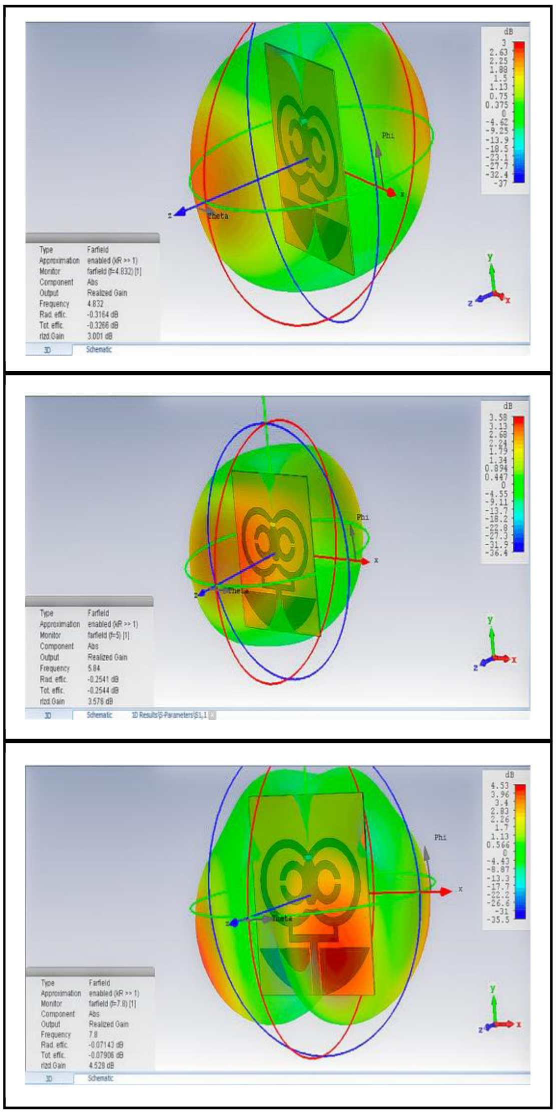

Fig.11. the simulated gain for the three bands and proposed antenna position

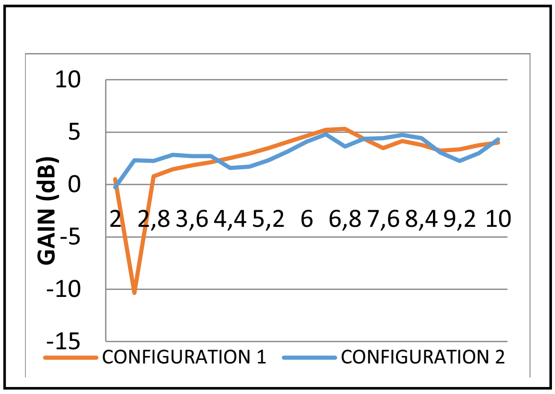

Fig.12. gain vs frequency for the both configurations

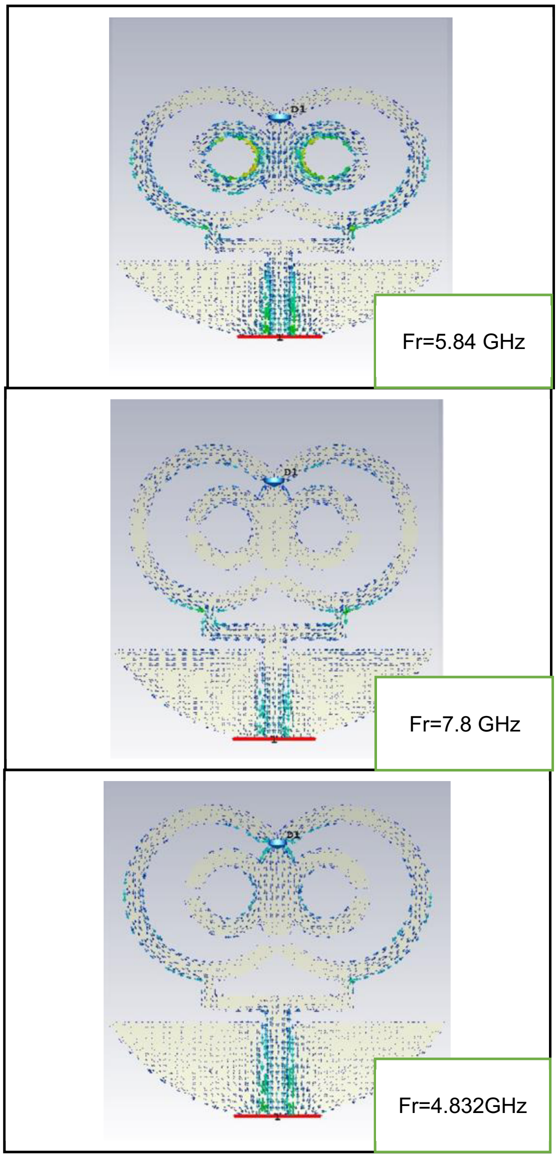

Fig.13. the current distribution at different resonating frequencies.

Table 4. Comparison of the proposed antenna with other works

Ref.	Patch	Dimension(mm^2)	EFFICIENCY (%)	Gain (dB)	Meta-proposerty
[6]	Penta-rings	40 x 40	Not virified	1.5-6.5	yes
[7]	Hexagonal	27.38 x 29	55-81	0.634-3.75	no
[8]	hexagonal	26.5 x 30	Not virified	2.6 – 3.8	no
This work	**I-SRR**	**36.56 x 32**	**92.97 – 98.27**	**3-4.58**	**yes**

5 Conclusion

In this article, a new broadband meta-material based on the reconfigurable antenna using Infinity Split Ring Resonator (I-SRR) was introduced. The proposed antenna has developed for C-band wireless communications. A PIN diode was used as an ON and OFF switch. The proposed antenna covers three bandes, one of them is wideband range that appears in configuration 1. One of the benefits of reconfiguring is to increase the bandwidth of this antenna. The antenna resonates effectively, with gains and efficiencies presenting better values. The proposed antenna introduces a new structure usable in wireless networks.

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