American Journal of Engineering Science and Technology Research
Vol. 1, No. 1, February 2013, PP: 01 - 09
Available online www.ajestr.com

Research Article

Ameliorated RMPA using 'Squares surrounded by Hexadecagon' shaped Double Negative Metamaterial structure in Ultra High Frequency (UHF) Band

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Abstract

Authors analyzed and explored a significant concept of rectangular microstrip patch antenna configured by double negative left handed metamaterial which have dielectric permittivity & magnetic permeability both negative simultaneously. Metamaterials are artificial structures exhibits double negative properties. They can control Electromagnetic radiations by quantum mechanics. This work deals with miniaturisation of patch antenna using metamaterial. Rectangular microstrip patch antenna without proposed metamaterial is designed to resonate at 2.322 GHz. The antenna with metamaterial is proposed and analyzed at a height of 3.276 mm from the ground plane. The antenna along with the proposed metamaterial is designed to resonate at 0.909 GHz frequency. Main work in this design process is reduce the size of the antenna, and this target has been achieved by reducing the size of antenna up to 85% and also reduce the return loss from -10.269 dB to -46.06dB and increases the efficiency of the antenna from 47% to 72%. In this paper authors have used the computer simulation technology microwave studio (CST-MWS) simulation software for designing and simulation, and MS-Excel for metamaterial proving.

Index Terms: Double negative left handed metamaterial, rectangular microstrip patch antenna (RMPA), permittivity, permeability, Nicolson-Ross-Weir (NRW) approach.

1. INTRODUCTION

The progress in wireless communication systems and wireless applications have remarkably increase the demand of compact antennas with smaller dimensions than conventionally possible. This has initiated antenna research in various directions; one of which is by using metamaterial. Stutzmann and Thiele define an antenna [1] as a device that provides a means for radiating or receiving radio waves. An antenna is basically a transducer that converts electric current into electromagnetic waves and vice versa. The microstrip patch is generally square, rectangular, circular, triangular, and elliptical or some other common. Among these the rectangular patch is the most extensively used patches. It is very easy to analyze a rectangular microstrip antenna using transmission and cavity model [2, 3]. The compact design of antenna also reduces bandwidth.

Microstrip antennas based on photolithographic technology are seen as an engineering breakthrough. Microstrip antenna has its remarkable advantages over conventional antennas, such as small size, low weight, simplicity of manufacturing, compatibility to planar and non planar surfaces, ease of being integrated with circuits, simplicity of creating antenna arrays, mechanically robust when mounted on rigid surfaces, compatible with MMIC designs and suitable for multi frequency operation. They are finding applications in aircraft, spacecraft, satellite, wireless, mobile communication, missile and military. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate In order to simplify analysis and performance prediction, the patch is rectangular. For are rectangular patch, the length L of the patch is usually $0.3333\lambda o < L < 0.5\lambda o$, where λo is the free-space wavelength. The patch is selected to be very thin such that $t << \lambda o$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\lambda o \leq h \leq 0.05\lambda o$.The dielectric constant of the substrate (ε_r) is typically in the range $2.2 \leq \varepsilon_r \leq 12$ [4].

Compactness is important aspect in wireless communication in addition with the other parameters improvement like return loss, directivity, efficiency, Bandwidth [5]. These characteristics can be achieved by covering of microstrip patch antennas with metamaterial structures [6, 7]. In 1967 Victor Georgievich Veselago, a Russian physicist was the first to introduce the theoretical concept of metamaterial which exhibit negative permittivity and permeability [8] left handed material [9-10]. In metamaterial the phase velocity would be anti-parallel to the direction of Poynting vector. In 1999 split rings resonator (SRR), originally proposed by Pendry [11, 12] have attracted a great interest for the design of negative permeability, negative permittivity and left-handed (LH) metamaterials.

2. DESIGN METHODOLOGY

All the design work and simulation work has been done on the computer simulation technology microwave studio (CST-MWS). Initially dimensions were calculated for the operating resonant frequency i.e. 2.322 GHz by using formulas shown below. The proving of the metamaterial which used to enhance the property of RMPA, Microsoft excel software is used.

For calculation of width and length of the patch antenna-

A. Desired Parametric Analysis [1, 4]

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{C}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad \text{.... (1)}$$

$$L = Leff - 2\Delta L \qquad \text{.... (2)}$$

Where,

$$Leff = \frac{C}{2f_r\sqrt{\varepsilon_{eff}}} \qquad \text{.... (3)}$$

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \qquad \text{.... (4)}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{w}}}\right) \qquad \text{.... (5)}$$

In above used formulas the symbols have their usual meanings.

c = Velocity of light in free space,

ε_r = Substrate Dielectric constant,

ε_{eff} = Effective dielectric constant,

L= Actual length of the patch,

W= Width of the patch,

L_{eff} = Effective length.

After dimension calculation design work has been done. Perfect electric conductor (PEC) was used to make the patch antenna over the ground which also having the same material with substrate of dielectric constant 4.3 between patch and ground. RMPA at 2.322 GHz frequency is shown in figure 1.

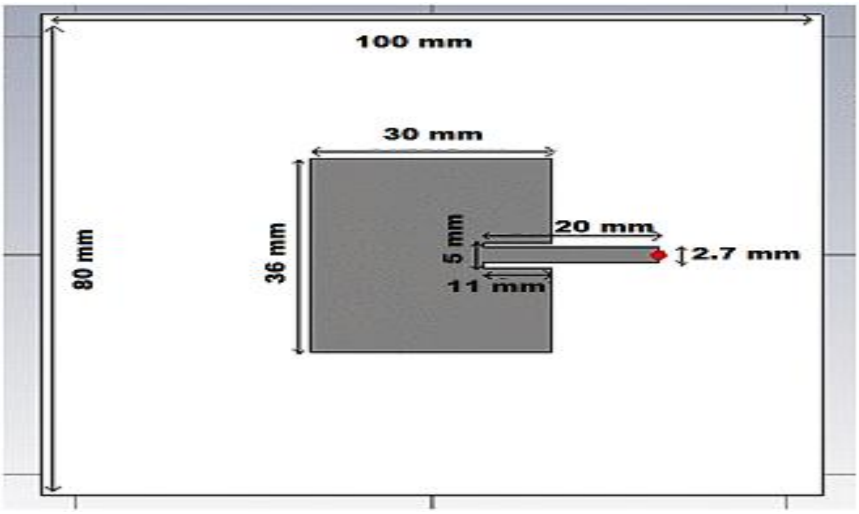

Figure1: RMPA at height of 1.6mm from ground of 2.322GHz.

The simulation result of the patch shown in figure 1 is in graphical form shown in figure 2, with the return loss and bandwidth of -10.269 dB and 13.8 MHz respectively.

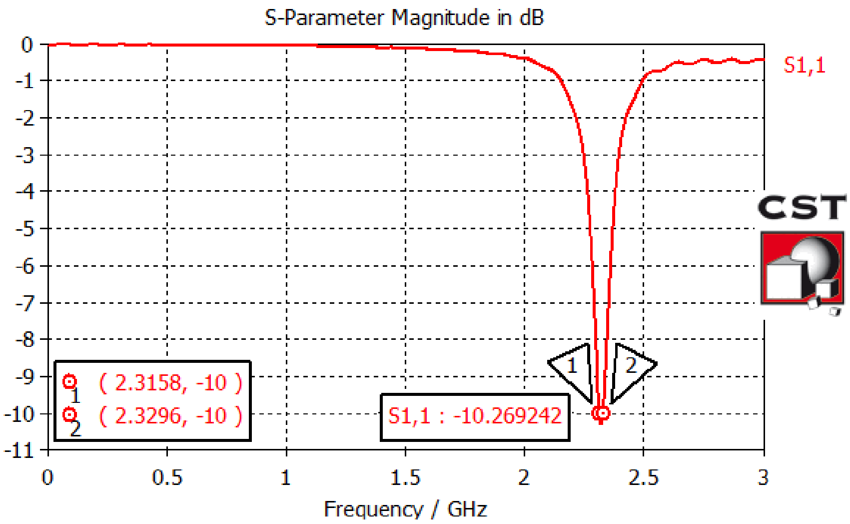

Figure 2: Simulation result of the RMPA with return loss of -10.269 dB and bandwidth of 13.8 MHz.

Three Dimensional Radiation Pattern of Rectangular Microstrip Patch Antenna is shown in Figure 3.

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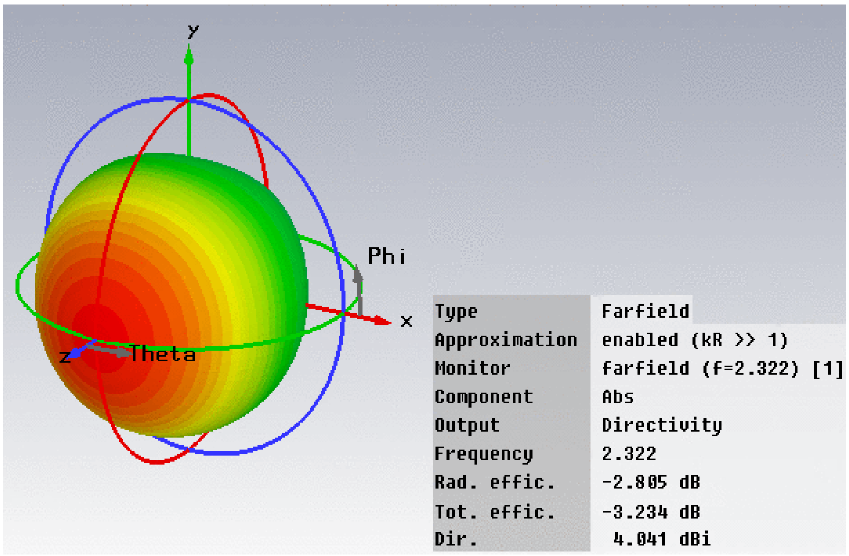

Figure 3: Radiation Pattern of a Rectangular Microstrip Patch Antenna

After the RMPA simulation the metamaterial is implemented over the patch antenna at the height of 3.267 mm from the ground. The proposed metamaterial structure implemented with its dimension used in the proposed design is shown in figure 4.

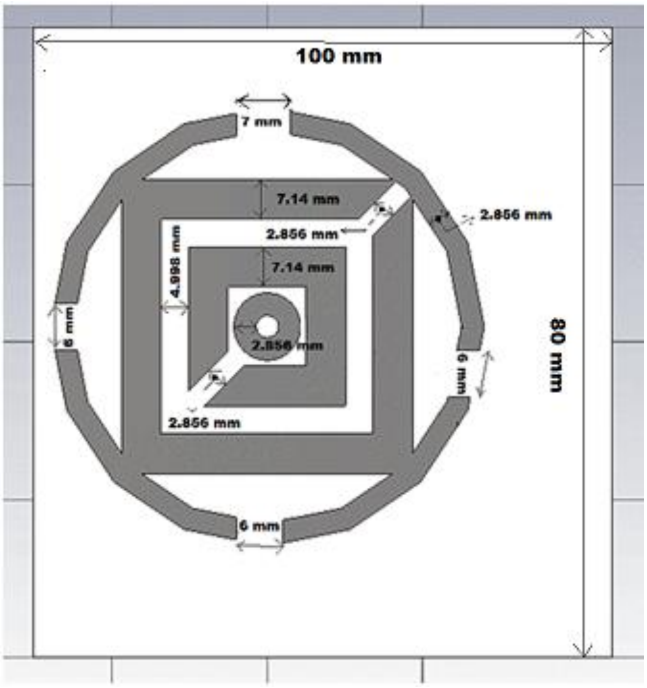

Figure 4: Proposed metamaterial structure at the height of 3.267 mm from ground.

The simulation result after the implementation of the metamaterial over the rectangular microstrip patch antenna at the height of 3.267 mm from the ground enhance the property of the RMPA alone and reduces the size of the antenna by shifting the lowest dip to a frequency other than the operative frequency i.e. at 0.909 GHz. The size is being reduced to 85%. The simulation result with the metamaterial is shown in figure 5.

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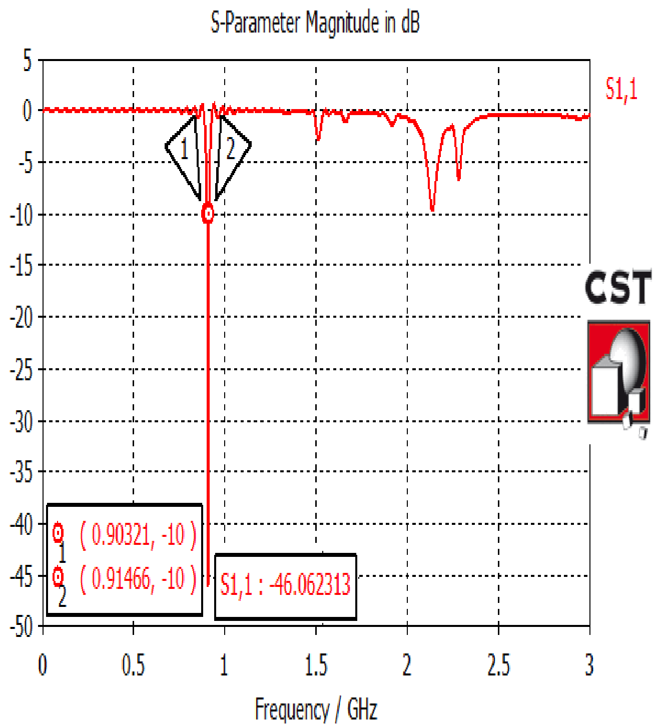

Figure 5: This simulated result is showing the return loss of –46.06 dB and bandwidth of 11.45 MHz.

Three Dimensional Radiation Pattern of Rectangular Microstrip Patch Antenna with proposed metamaterial structure is shown in Figure 6.

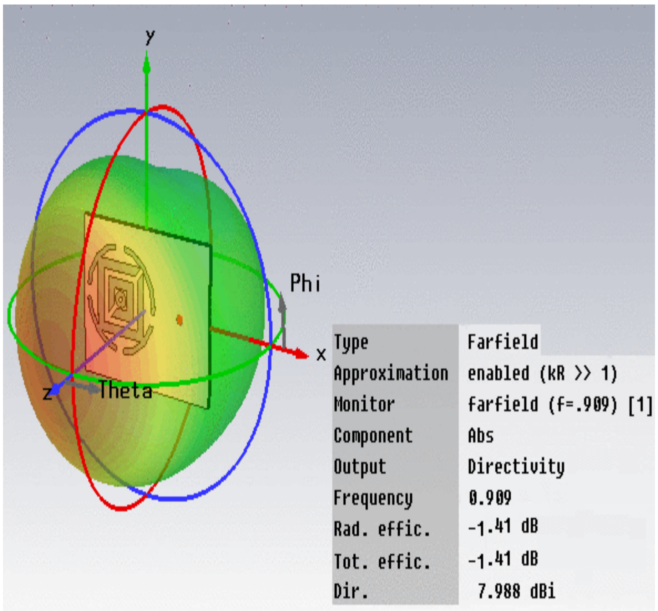

Figure 6: Radiation Pattern of RMPA with proposed metamaterial structure.

Comparison of dimensions between reduced patch antenna using proposed metamaterial structure at operating frequency 2.322 GHz and RMPA alone at 0.909 GHz is in tabular form below.

TABLE 1: COMPARISON OF DIMENSIONS

Parameters	Dimensions of RMPA alone at 0.909 GHz	Dimensions of RMPA using Metamaterial works on 0.909 GHz	Unit
Length	79.383	30.799	mm
Width	101.368	39.683	mm
Cut width	16	5	mm
Cut length	26	11	mm
length of feed	76.684	20	mm
Width of feed	12	2.7	mm

After comparing it is necessary to prove that the material here used to reduce the size of RMPA is Meta, NRW (Nicolson Ross Weir) approach [16, 17] is used to prove it. The following formula belongs to NRW approach.

$$\mu_r = \frac{2.c(1-v2)}{\omega.d.i(1+v2)} \qquad \text{.... (6)}$$

$$\varepsilon_r = \mu_r + \frac{2.S11.c.i}{\omega.d} \qquad \text{.... (7)}$$

Where,

V_2 = S21 - S11
ω = Frequency in Radian,
d = Thickness of the Substrate,
c = Speed of Light,
V_2 = Voltage Minima.
μ_r = Relative permeability
ε_r = Relative permittivity

In NRW approach, proposed design of patch antenna having metamaterial structure placed between two waveguide ports on both sides of antenna on X-axis to calculate S11 and S21 parameters. ‘Y’ and ‘Z’ planes are defined as the perfect electric and magnetic boundary respectively. Following that, the wave was excited toward the port 2 from port 1 or left to right.

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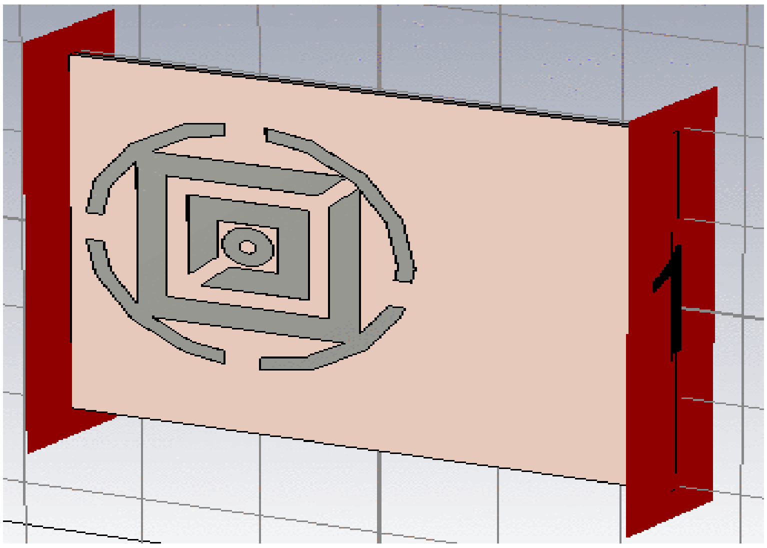

Figure 7: Proposed metamaterial structure between waveguide ports.

After the simulation in CST-MWS software the S11 and S21 parameters were exported to MS Excel software for proving of metamaterial. In MS Excel equation no. (6) & (7) were used for proving of structure that it is metamaterial. The result of NRW approach, showing negative permeability and permittivity in figure 8 & 9 respectively.

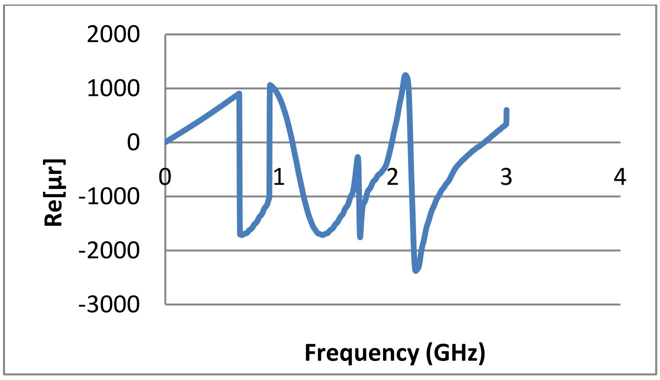

Figure 8: Permeability versus frequency graph obtained from Excel software.

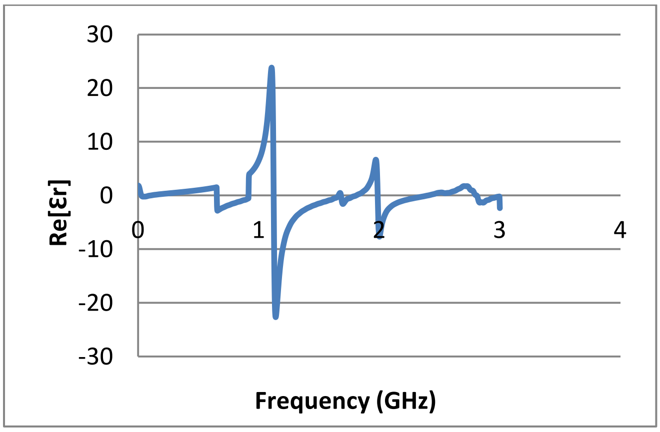

Figure 9: Permittivity versus frequency graph obtained from Microsoft Excel software.

The Table generated for permittivity and permeability by using MS-Excel Software was too large, therefore the Table 2 & 3 shows the negative value of permittivity and permeability only in the frequency range 0.8969999-0.912 GHz.

TABLE 2: SAMPLED VALUES OF PERMEABILITY AT 0.909 GHZ CALCULATED ON MS EXCEL SOFTWARE.

Frequency [GHz]	Permeability [μr]	Re[μr]
0.8969999	-1141.9429597594-128.693933001594i	-1142
0.9	-1123.67174184324-125.133733210449i	-1124
0.903	-1103.37209832053-123.858740463905i	-1103
0.9059999	-1082.05744203275-125.377808507957i	-1082
0.909	-1060.80577077854-129.759423882227i	-1061
0.912	-1040.6597268626-136.669775724973i	-1041

TABLE 3: SAMPLED VALUES OF PERMITTIVITY AT 0.909 GHZ CALCULATED ON MS EXCEL SOFTWARE.

Frequency [GHz]	Permittivity [Ɛr]	Re[Ɛr]
0.897	-0.733225111112916-0.155264929773749i	-0.7
0.9	-0.698854853268743-0.150786069795711i	-0.7
0.903	-0.661610383745311-0.151008049731378i	-0.7
0.906	-0.623285516413551-0.156722665671922i	-0.6
0.909	-0.585893531846821-0.167998349996369i	-0.6
0.912	-0.551467474967669-0.18405121449957i	-0.6

3. RESULT

By emphasizing RMPA with ‘Squares surrounded by Hexadecagon’ Metamaterial structure of RMPA, the frequency on which it shows lowest return loss is 0.909GHz whether the operating frequency was 2.322 GHz. Table 1 shows the comparison of patch antenna designed at the frequency of 0.909 GHz and at 2.322 GHz with metamaterial. RMPA at 0.909 GHz acquire a large area instead of RMPA at 2.322 GHz. Due to the large difference between both the operating frequencies RMPA of 2.322 GHz could not be used at the former frequency. By using metamaterial it became possible that the antenna at 2.322 GHz operating frequency be able to work at 0.909 GHz frequency with 85% lesser area and more accurate results [13,14]. Like low return loss, high directivity and high efficiency where bandwidth is almost constant. Figure 2 & 5 shows the comparison of return loss; Figure 3 & 6 shows the comparison of directivity and efficiency of the RMPA alone and with the metamaterial. It has been found that the return loss is reduced by 35.791 dB, directivity is increased by 3.947 dB & the efficiency is increased by 25% of the proposed structure. The Figure 8 & 9 obtained from Microsoft Excel Software shows the negative value of permittivity & permeability [16] at the operating frequency of 0.909 GHz, and Table 2 & 3 shows the numeric value of corresponding figure at the required operating frequency [15]. This proves that the proposed Design of media with a negative refractive index is a Metamaterial Structure.

4. CONCLUSION

Authors presented a new design methodology in this paper for creating highly miniaturized patch antennas, by adding a single layer that contains a combination of Squares surrounded by Hexadecagon like structure. That has been proved as a metamaterial. The size of the antenna can be reduced significantly. Because the construction is simple, the miniaturized antennas can be produced with little effort at low cost & low space. In this paper it is found that the implementation of metamaterial structure on a RMPA at a height of 3.276 mm from the ground plane shows significant reduction in size of the Patch Antenna as compare to calculated patch antenna at 0.909 GHz. The purpose of this work is to produce a small, low cost Antenna that can be used for UHF band (0.3-3GHz) applications. An even smaller antenna is possible by this proposed design, but with further miniaturisation comes lacking in radiation efficiency and bandwidth that may prove undesirable.

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