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Artificial Magnetic Conductor based Composite substrate Antenna for Low Frequency Wireless Underground Sensor Networks

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***Abstract*—In the current era of Wireless Internet of Things, developing low frequency planar antennas for underground communication is a challenging task. For underground electromagnetic wave propagation, low frequencies in the range of 300 MHz to 900 MHz are optimal. As the frequency drops, the size of the planar antenna grows, making design more difficult. This paper describes a planar antenna with shorting vias and an air-AMC composite substrate that operates at 385 MHz and has a peak gain of 1.3 dB. This study lays the groundwork for the development of low frequency planar antennas with positive gain and a comparably compact construction.**

***Index Terms*—composite substrate, Low frequency antenna, underground prorogation, shorting vias.**

I. Introduction

Wireless underground sensor networks are becoming increasingly important in sensing applications such as agriculture, mining, and ground penetrating radar (GPR). According to the published research [1]–[3], low frequencies in the range of 300 MHz –900 MHz are better for subsurface Electromagnetic wave propagation. As the frequency of operation decreases, the size of the planar microstrip antenna increases since the length of the patch antenna is inversely proportional to operating frequency. Few antennas constructed at low frequencies that are useful for Underground propagation have been documented [4]–[9]. In [4], a partial ground plane using meander line and employing array of metamaterial with vias resonating at 455 MHz is presented Another structure with slot loading rectangular patch [5] working at 500 MHz-600 MHz achieves 1.4 dB gain. In [6] a simple patch antenna at 900 MHz is constructed for underground monitoring applications utilizing a concrete grounded plane, providing a poor gain of -3 dB to -6 dB. Vivaldi circular patch antennas with -12.9 dB and 0 dB are given for Ground Penetrating Radar applications at 500 MHz [7], [8]. A recent study [9] used an artificial magnetic conductor as a composite substrate to achieve a gain of 3.1 dB at 413 MHz.According to the available literature, few studies have attempted to construct an antenna below 400 MHz. This study extends the work of [9] by making the structure resonate at a lower frequency of 385 MHz with a positive gain of 1.3dB.

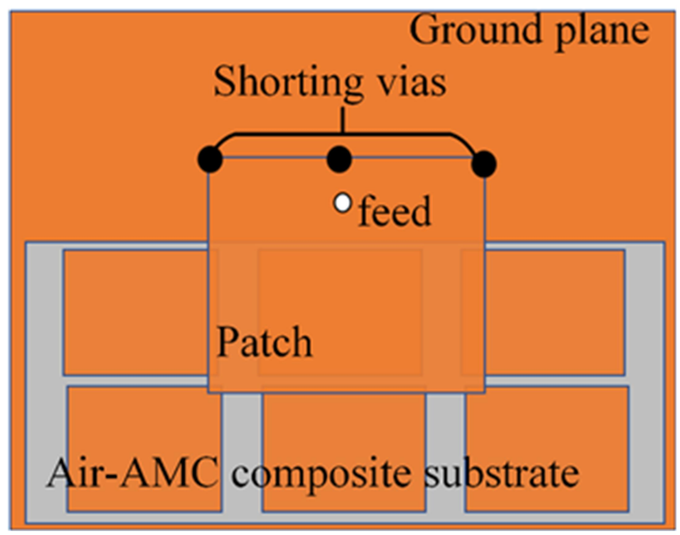

Fig. 1. Schematic diagram of Proposed Antenna

II. Evolution of Structure

A. Antenna Design

A conventional Rectangular Microstrip Antenna (RMA) with dimensions of $120mm \times 150mm$ on a ground plane of $320mm \times 320mm$ resonates at 1.1 GHz. Miniaturization meth-

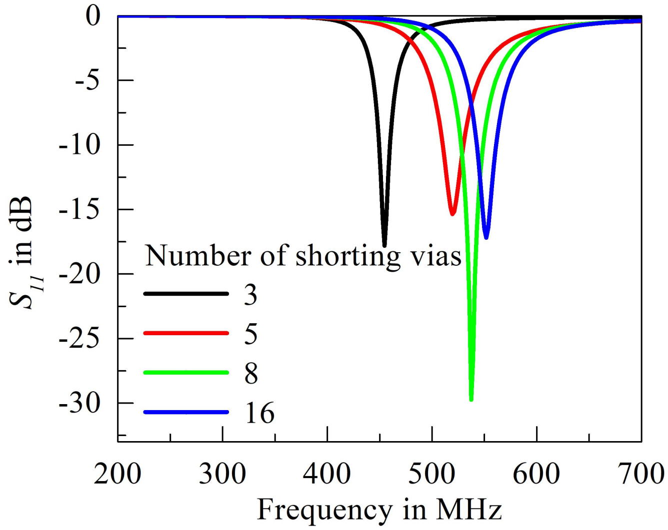

Fig. 2. Variation in the frequency with number of shorting vias

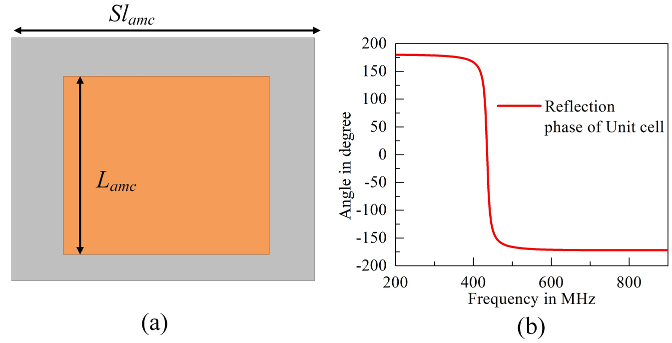

Fig. 3. AMC structure(a) unit cell (b)reflection coefficient

TABLE I
PARAMETERS USED IN AMC UNIT CELL

Parameter	Value
L_{amc}	100 mm
Sl_{amc}	104 mm

ods with shorting vias and an air-AMC composite substrate are used for this typical RMA. In the next sections, the Quarter Wave Patch (QWP) idea and the use of AMC as a composite substrate are thoroughly addressed. The schematic diagram of the proposed antenna is depicted in Fig. 1

B. Quarter wave patch with shorting vias

A patch of length 250 mm is required for a typical antenna to resonate at 385 MHz. To miniaturize the structure, the length is reduced to less than half and shorting vias are provided at the patch's radiating edge. This type of patch is known as a Quarte wave patch (QWP). The number of shorting vias at the radiating edge of such QWP is critical in downsizing. As the number of shorting vias drops, so does the operating frequency.Fig. 2 depicts the variation in the frequency with number of shoring vias. As a result, the downsized version that resonates at 454 MHz is QWP of $L \times W(120mm \times 150mm)$ with three shorting. The structure is miniaturized using this shorting vias, yielding a very low gain of 0.7 dB. AMC array has been included to improve the gain even further.

C. AMC Unit cell

AMC unit cell and array are designed in a view to enhance the gain of the QWP which is resonating at 454 MHz. This is accomplished by designing a square AMC unit cell of $L_{amc} \times L_{amc}$ (100 mm × 100 mm) on alumina dielectric of $Sl_{amc} \times Sl_{amc}(104mm \times 104mm)$ with thickness h_1=3.2mm and ϵ_r=10.2. This AMC unit cells has reflection coefficient at 440 MHz which matches the frequency of QWP antenna. The AMC unit cell and its reflection phase characteristics are shown in Fig. 3(a) and 3(b). A 2× 3 array of such unit cells are constituted and composite substrate is formed as shown in Fig. 1. The AMC on a dielectric substrate of height h_1 from the ground plane with characteristic impedance can be represented as series R - L - C circuit on a grounded dielectric of impedance Z_d [9]. The equivalent circuit diagram of proposed AMC unit cell is shown in Fig. 4.

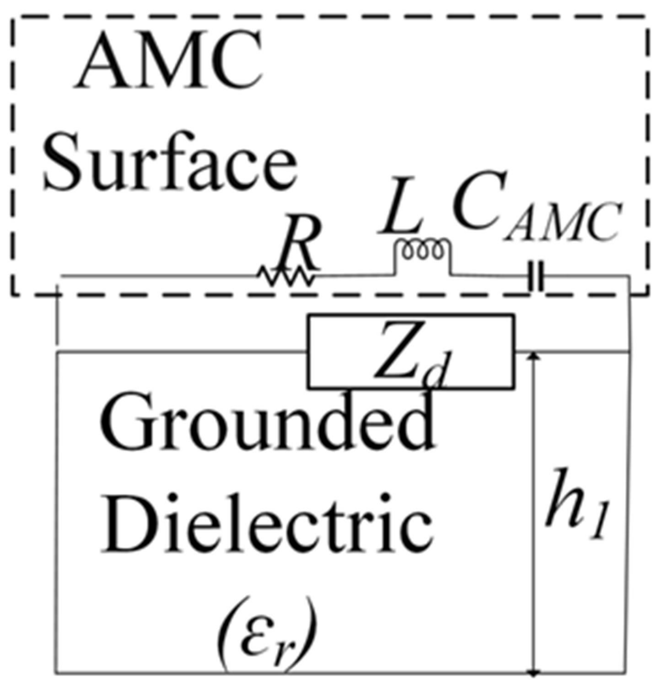

Fig. 4. Equivalent circuit of AMC unit cell

D. Proposed Antenna

The techniques discussed in the previous sections are integrated to form the present antenna structure. As mentioned, earlier the AMC unit cell forms a series R - L - C circuit, when embedded with the QWP with three shorting further reduces the frequency of operation for the proposed antenna.

The proposed Antenna with $120mm \times 150mm$patch on a $320mm\times320mm$ ground plane resonates at 385 MHz yielding a positive gain of 1.3 dB. The reflection coefficient graph and the gain of the proposed structure is shown in Fig. 5 and Fig. 6 respectively.

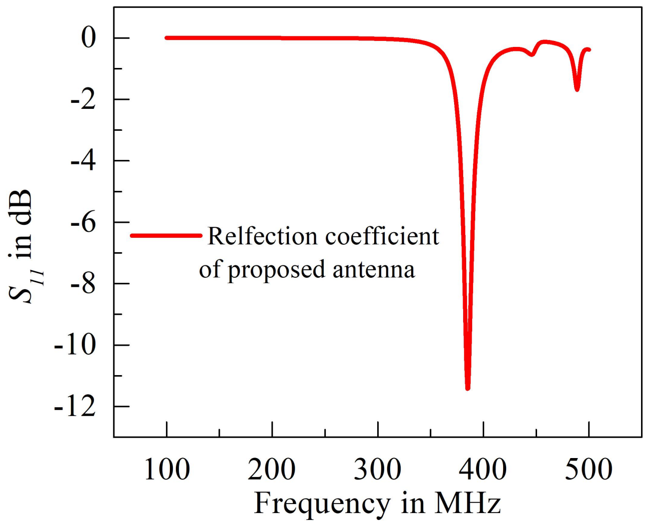

Fig. 5. Reflection Coefficient of proposed antenna

III. RESULTS AND DISCUSSION

The proposed structures operate at low frequency which will be suitable underground applications. The reflection coefficient characteristics depicted in Fig. 5 justifies the fact that the structure is resonating at 385 MHz with desirable matching.

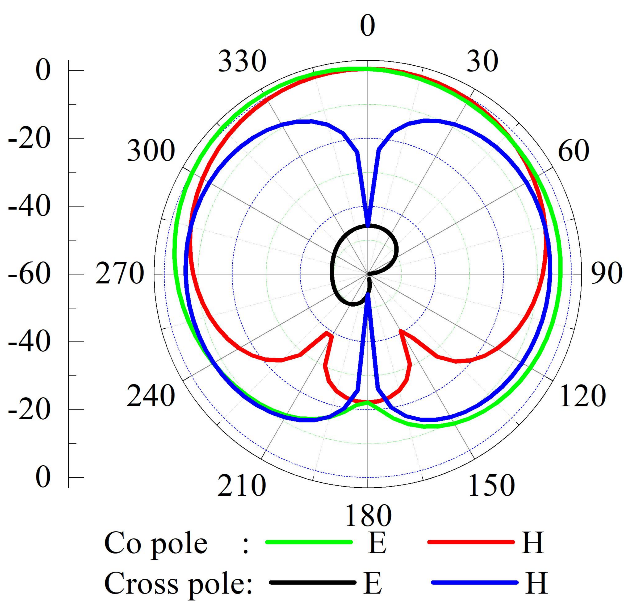

Fig. 6. Radiation Pattern of proposed antenna at 385 MHz

Judicious use of AMC with the property of in phase reflection, further enhances the gain to 1.3 dB at -250. The radiation pattern of the proposed antenna is depicted in Fig. 6. Hence the usage of shorting vias to miniaturize the structure and AMC for enhancing the gain is clearly exploited and presented in the present work. As the proposed structure resonates at low frequency of 385 MHz, it can be clearly applied to fields such as underground sensing, GPR and other low frequency applications.

IV. CONCLUSION

A basic Patch antenna with positive gain and a reasonably tiny construction that operates at a low frequency of 385 MHz is given. This study lays the way for the scientific community working on low frequency planar antenna design. Low frequency antennas are utilized in satellite applications, ground penetrating radar (GPR) applications, land slide monitoring, agricultural and defence applications. This paper describes the concept and execution of low-frequency metamaterial embedded antennas.

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