Patch Antenna over RIS Substrate: A Novel Miniaturized Wideband Planar Antenna Design

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1. Problem Statement

Smaller physical size, wider bandwidth, and higher efficiency are three desired characteristics of antennas for mobile systems. Antenna miniaturization utilizing a patch antenna printed on a metal-backed high dielectric substrate has been attempted previously[1]. The drawbacks of this approach are twofold: 1) there is a strong electromagnetic coupling between the patch and the PEC surface backed the high permittivity medium, which traps a significant portion of EM energy in the near-fields resulting in a low antenna efficiency, narrowband characteristics, and in some cases an unwanted radiation pattern caused by surface and leaky waves, 2) the characteristic impedance in a high permittivity medium is rather low which creates difficulty in impedance matching of the antenna. We propose that challanges can be successfully circumvented by the novel design of patch antenna over a Reactive Impedance Surface (RIS) [2]. The RIS has the minimum interaction with the patch and dramatically enhances antenna performance metrics, namely, size, bandwidth, and efficiency.

2. Patch Antenna over the RIS Substrate

It is demonstrated in [2] that a reactive impedance plane with $\eta = j\nu$ has the minimum interaction with the antenna located above it. To artificially design the RIS substrate a periodic surface of FSS patches printed on a metal-backed dielectric material as illustrated in Fig. 1 is used. The PEC plane after the distance d (thickness of substrate) shows an inductive property, which is in parallel with the existence capacitors between the patches. Thus, the composite periodic structure is equivalent to a parallel LC circuit providing the desired impedance property. The Finite Difference Time Domain (FDTD) technique with PBC/PML boundary conditions [3] is applied to characterize the structure and the impedance behavior of the surface is presented in Fig. 2. The results are compared very well with the circuit model formulation. The unique variation of the impedance plane between the PEC and PMC allows one to successfully miniaturize the antenna size and enhance the bandwidth.

Fig. 3(a) depicts the geometry of a patch antenna over the RIS substrate. The frequency variation of RIS tunes the resonance frequency of the patch to around $f_0 = 1.86\,GHz$ (Fig. 4(a)) where the longest patch dimension is about $\lambda_0/10$. Additionally, since the interaction between the antenna and RIS substrate is minimized the EM waves cannot be trapped beneath the patch as in a traditional patch antenna and the bandwidth is enhanced dramatically to $BW = 4.96\,\%$. According to FDTD simulation the directivity of is antenna is $D = 4.8\,dB$ and a $5.6\,dB$ front-to-back ratio is achieved as shown in Fig. 4(b). Notice that, using the conventional high dielectric substrate shown in Fig. 3(b) the trapped EM waves inside in the high permittivity material prevent proper matching of the antenna as illustrated in Fig. 3(b).

Therefore, the unique property of RIS presents a novel substrate for miniaturized wideband planar antenna design with high efficiency performance.

3. Fabrication

Two independent layers are fabricated, metalized, and bonded to form the compete patch antenna over RIS substrate system.

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The dielectric material used for the patch antenna was Trans-Tech's D-6, magnesium silicate (ε_r=6), commonly known as forsterite. The RIS substrate was Trans-Tech's MCT-25, magnesium calcium titanate composition (ε_r=25). Both materials were fabricated by reacting the individual chemical constituents at high temperature to form a powder. Blocks were formed and subjected to another high temperature firing to achieve the desired dielectric properties. These blocks are shown in Fig. 5(a) From these blocks, substrates were machined to the desired size.

Using a thick film silver paste and Trans-Tech's screen printing process, the array of FSS patches, corresponding metal backing, and patch were generated. Both substrates were heat treated to form an intimate bond of the silver to the dielectric material. This intermediary stage is diagrammed in Fig. 5(b). Using a two part, low loss dielectric adhesive, the substrates were assembled in a fixture to ensure alignment. The feed-hole was then drilled into the assembly. Finally, the feed-thru pin was machined from hardened brass and soldered to the silver patch. The completed antenna structure is shown in Fig. 5(c).

4. Measurement

The return loss of the patch antenna over RIS substrate is shown in Fig. 6(a). The antenna resonance was found to be 1.92 GHz and it exhibited matching far superior to 'traditional' patch antennas, with better than 25dB input matching and a -10dB impedance bandwidth of 6.71%. This validates the FDTD model based design resonant frequency of 1.86 GHz, 22 dB matching, and a -10dB impedance bandwidth of 6.99%.

The radiation pattern was measured in an anechoic chamber at the University of Michigan Radiation Laboratory, Fig 5(d). Two calibrated standard gain antennas were employed to characterize the path loss and radiation environment of the chamber at the antenna operating frequency. The standard gain antenna in transmitting mode in the anechoic chamber 'quiet region' was replaced with the patch antenna to be measured while the receiving antenna was kept fixed at the chamber far end. When the patch was oriented for optimal reception by the standard gain antenna, the signal level had dropped relative to the standard gain antenna configuration to a level indicating a patch antenna absolute gain of 4.5 dB.

The patch antenna was rotated along its E and H planes and the received signal power was recorded as a function of patch orientation angle. Figure 6(b) indicates the radiation pattern observed.

Radiation pattern measurement yielded 4.5dB gain, 5.6 dB front/back ratio, and an efficiency of 93%. This validates the model designed parameters of 4.8 dB gain and 5.6 dB front/back ratio.

References

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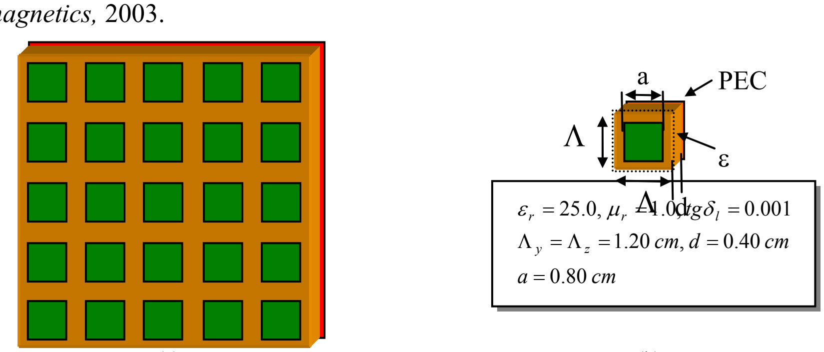
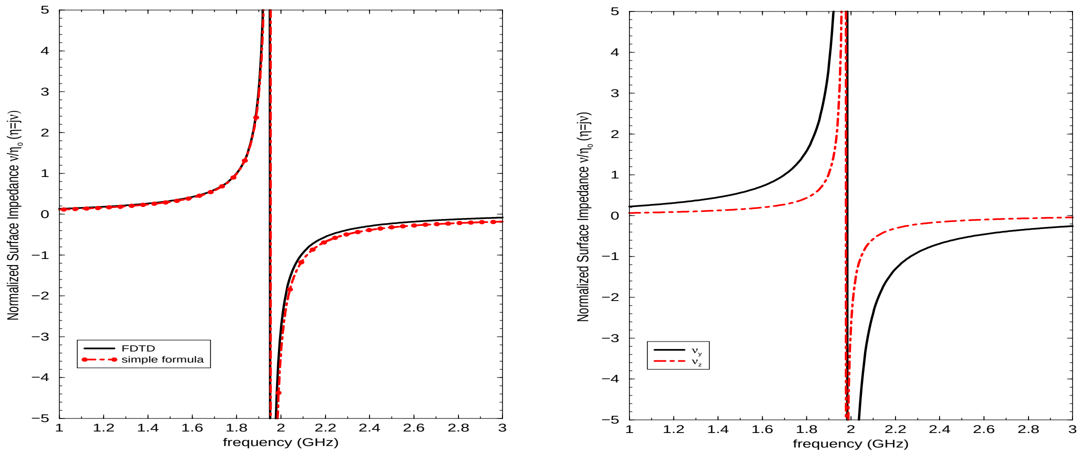


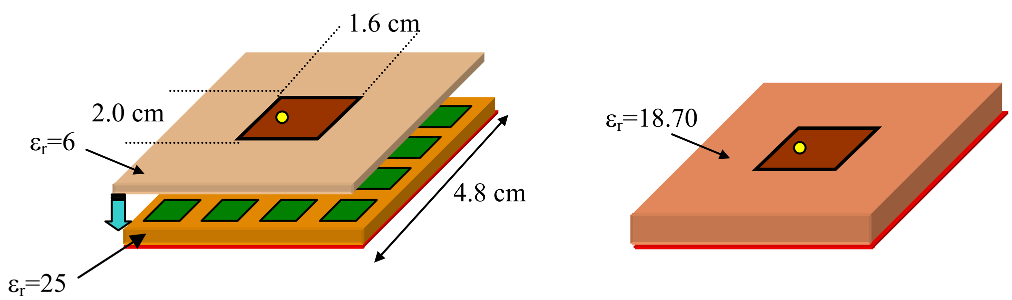
(a) (b)

Fig. 1. RIS artificial surface. (a) Periodic structure, (b) Building block unit cell.



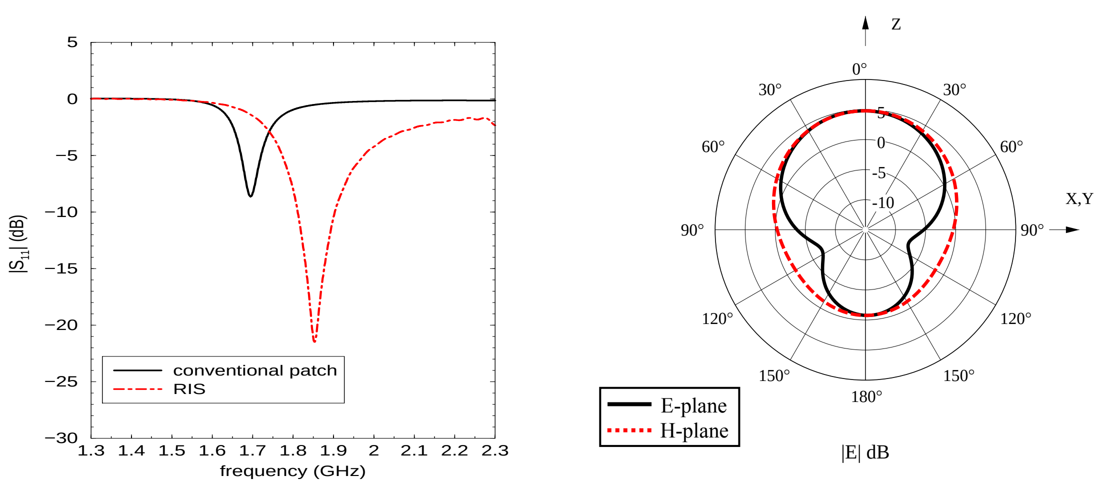
(a) (b)

Fig. 2. Impedance behavior of the RIS plane. (a) Normal incidence (notice the excellent agreement between the circuit model and FDTD method), (b) Oblique incidence ($\theta^i = 90^\circ$, $\phi^i = 120^\circ$, $\psi^i = 50^\circ$).



(a) (b)

Fig. 3. Patch antenna over the (a) RIS and (b) conventional substrates.



(a) (b)

Fig. 4. FDTD modeled performance of patch antenna, (a) Return loss, (b) Radiation pattern.

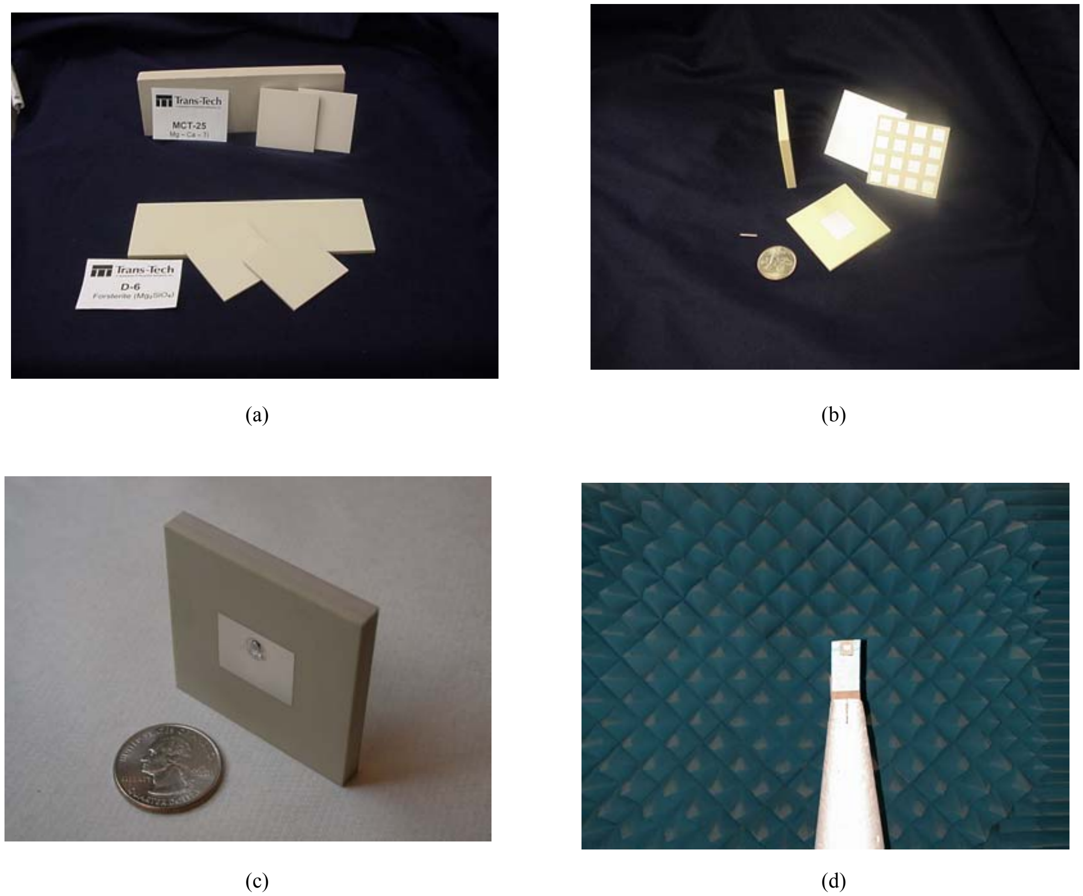


Fig. 5. Fabrication&Measurement:(a) magnesium silicate and magnesium calcium titanate blocks
(b) metalized and etched RIS and patch
(c) assembled patch antenna over the RIS substrate (d) measurement in anechoic chamber

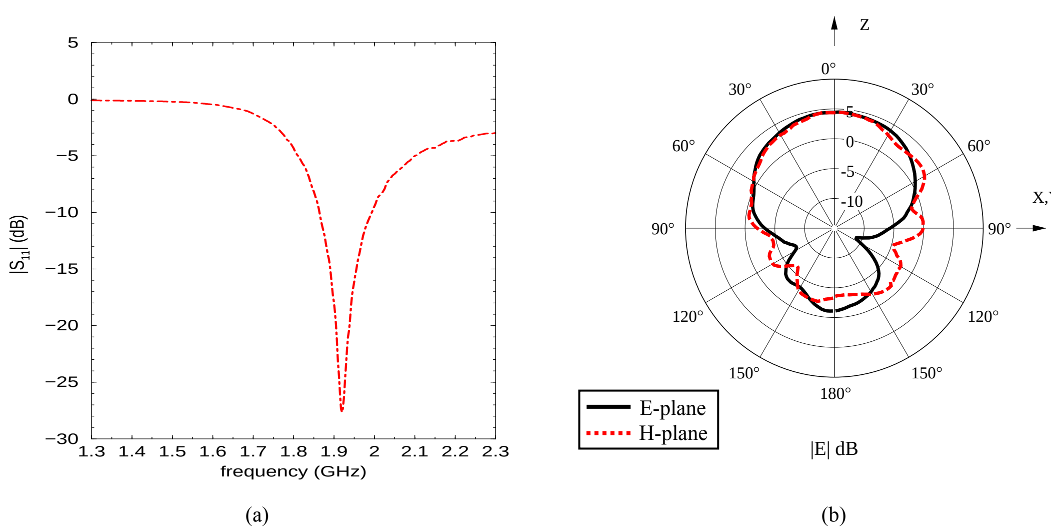


Fig. 6. Measured performance of patch antenna, (a) Return loss, (b) Radiation pattern.