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Compact Wideband UHF Patch Antenna on a Reactive Impedance Substrate

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***Abstract*— The goal of this paper is to design a compact, planar UHF antenna operating over the frequency range 420-450 MHz. A microstrip patch antenna is selected as the elementary radiating structure because it has a low profile and is simple to fabricate. Compact size and enhanced bandwidth are simultaneously achieved through the use of a Reactive Impedance Surface (RIS) in place of a PEC ground plane. The inherently limited bandwidth of the patch is overcome by incorporating a U-shape resonant slot radiator within the patch area. The design, fabrication, and measurement results are presented. It is shown that a patch with a U-shape slot whose dimensions are only 0.136λX0.228λ at the lowest frequency of operation can provide more than 20% bandwidth, covering a frequency range of 410-485 MHz.**

***Index Terms*—Reactive Impedance Surface, Microstrip Patch Antenna, U-slot**

I. Introduction

A compact, low-profile, UHF antenna with high radiation efficiency operating over the frequency range 420-450 MHz is desired for terrestrial communication. As the antenna will be mounted on vehicles, its radiation characteristics must be immune to platform effects. Hence a microstrip patch is selected as the elementary radiating structure because it is low profile and has unidirectional radiation characteristics. It is also simple to fabricate as well as integrate with the other electronic components of a communication system. The primary drawback of microstrip patch antennas is limited bandwidth and relatively large dimensions (λ/2, with λ being the wavelength in the substrate).

Recent research efforts have been devoted to improving the bandwidth of patch antennas. Oftentimes additional resonances are incorporated into the design; however, in most cases this step increases the area or height of the antenna. One successful technique, which does not increase the size of the patch, is the inclusion of a U-shaped slot on the patch surface. As described in [1] and [2], this configuration produces an additional resonance, at which the polarization and pattern of the original patch are maintained.

The second design goal, after wide bandwidth, is reduced size. A high permittivity substrate could be used but this approach increases the coupling between the antenna and the ground plane. The result is a large amount of energy trapped inside the substrate, which significantly reduces the bandwidth at each resonance and makes a wideband response difficult to achieve. Furthermore, this approach degrades the antenna's radiation efficiency. To overcome these problems a reactive impedance surface (RIS) is used in place of a PEC ground plane [3]. The RIS is an engineered meta-substrate that allows miniaturization while reducing coupling between the antenna and its ground plane. Therefore, an antenna printed on an RIS is capable of providing a wideband response while maintaining compact size and high radiation efficiency. These characteristics have successfully been demonstrated with a patch antenna operating at 1.8 GHz [4].

The antenna design and fabrication process are reviewed in Sections II and III, respectively. Measurement results are provided in Section IV.

II. Design

A. *Reactive Impedance Surface*

Reactive impedance surfaces can be designed to have the ability to reflect total power like PEC or PMC surfaces and at the same time be able to store magnetic or electric energy. It is shown that the latter property can be exploited to tune a resonant antenna below its natural resonance frequency [3]. Miniaturization is achieved by combining the reactive characteristic of the RIS with the capacitive (inductive) behavior of the antenna input impedance below its natural resonance in order to tune the resonance to a lower frequency. It is also shown that RISs have the capability to minimize interaction between the antenna and its substrate (antenna image in the RIS), which simplifies matching and allows wideband operation. In addition, it provides a significant front to back ratio, which is similar to that obtained using a PEC ground plane.

An RIS is a printed capacitive layer separated from a metallic ground plane by a dielectric substrate layer. The resonant frequency of the surface depends on the value of the capacitive elements, the distance between the capacitive layer and the metallic surface, and the permittivity of the dielectric layer. An RIS designed to operate at UHF band with a relatively low layer thickness and moderate dielectric constant, requires high capacitance values. This can be accomplished using interdigitated capacitors laid out in a periodic fashion. Figure 1 depicts the periodic array of crossed dipoles, which couple through the interdigitated capacitors at their ends. The dipoles are printed on a dielectric material backed by a PEC. The structure is equivalent to a parallel LC circuit whose input impedance is always reactive. The normalized impedance of the surface, shown inset in Figure 1, indicates that below resonance the surface behaves inductively, as expected. Therefore, when the surface is combined with a capacitive radiating element, the element radiates at a lower frequency.

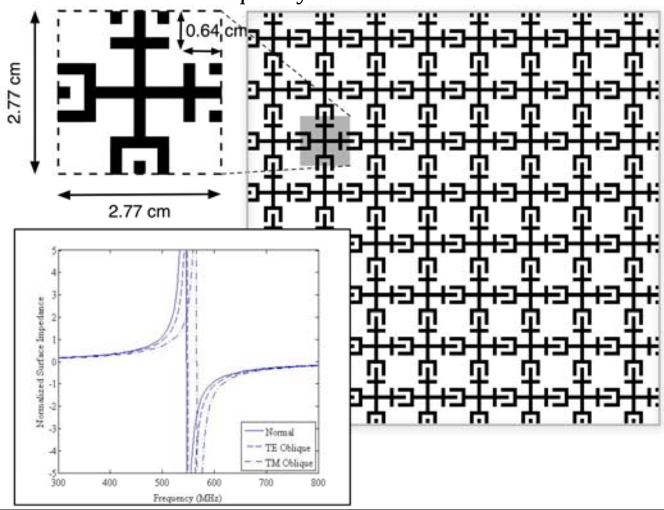


Figure 1: The periodic interdigitated capacitors of the RIS. The inset at lower left shows the normalized surface impedance of the RIS.

B. Microstrip Patch

The dimensions of the patch antenna with U-shaped slot and the RIS are shown in Figure 2. This antenna produces a double resonant return loss response. The first resonance is due to the lowest order mode of the patch and the second resonance is due to the U-slot. FDTD and FEM (HFSS) numerical tools were used to determine the physical dimensions of the proposed U-Patch antenna on the RIS. The amplitude of the currents on the surface of the patch at the lower and higher resonant frequencies are shown in Figures. 3 and 4, respectively. The surface current at the lower resonance flows from patch edge-to-edge with a maximum value in the middle, similar to a regular patch antenna. However, at the upper resonance, most of the surface current circulates around the U-shaped slot, with little current on the remaining patch area. As will be seen in Section IV, the same radiation pattern and polarization are produced at each resonance.

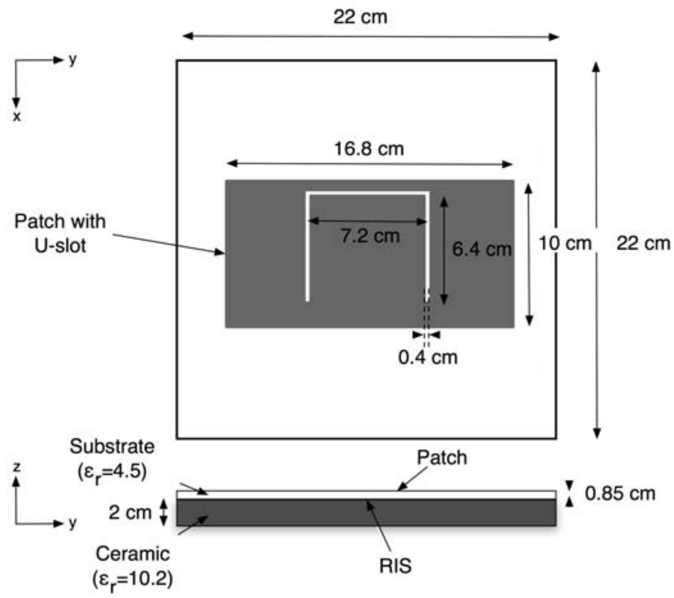


Figure 2: A patch with U-shaped slot for increased bandwidth.

The design has numerous free parameters that need to be optimized to meet the desired bandwidth and size goals. The final antenna has a compact size occupying a volume of 22 cm square by 2.85 cm tall. It is noted that without the RIS the length of the patch itself is on the order of 20 cm, not including the requisite ground plane and surrounding substrate. Also with a substrate thickness of 2.85 cm at 435 MHz, a traditional patch can only provide about 8 MHz of bandwidth.

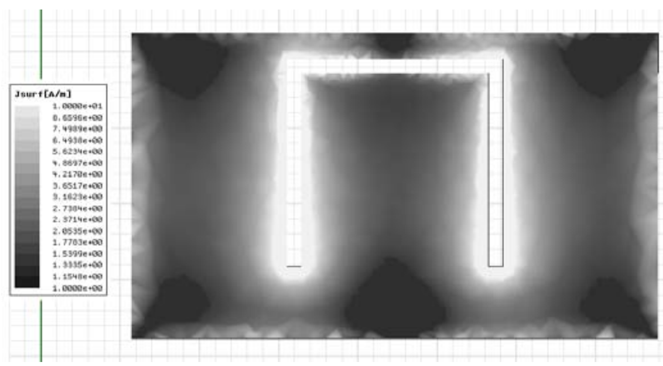


Figure 3: Simulated currents on the surface of the patch near 425 MHz, the lower resonance.

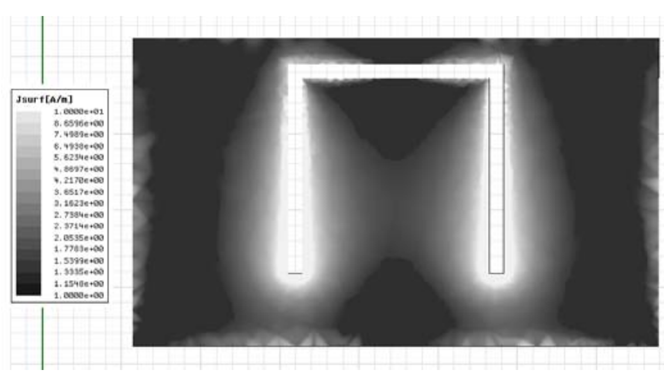
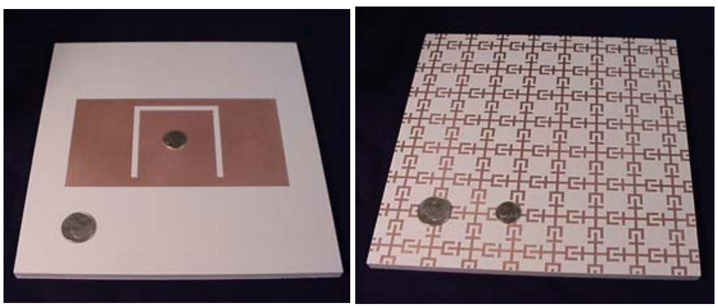


Figure 4: Simulated currents on the surface of the patch near 475 MHz, the upper resonance.

III. Fabrication

The patch and RIS pattern are etched on each side of Rogers TMM4 substrate (ε_r=4.5, tanδ_e=0.002) using chemical lithography. The substrate is 0.85 cm thick and 22 cm square. Photographs of the patch and RIS sides of the substrate are shown in Figures 5(a) and 5(b), respectively. To assemble, the substrate is glued to a high quality ceramic dielectric layer with a permittivity of 10.2 and a thickness of 2cm. The ceramic is fabricated in two pieces and glued together. In the middle of the ceramic layer a hole is drilled for the patch antenna probe feed. The ceramic layer is then glued to a copper sheet that acts as the ground plane for the RIS.



(a) (b)

Figure 5: (a) Fabricated patch antenna with U-shaped slot and (b) fabricated RIS on high permittivity (eps-r=10.2), low loss ceramic made by TransTech.

Measurement

The return-loss of the prototype antenna is measured using a calibrated Agilent 8722ES vector network analyzer. Minor tuning is required to obtain return loss below -10dB over the desired band of operation. Figure 7 shows the measured return loss results, which indicate operation between 410 MHz and 490 MHz, or 20% fractional bandwidth for a patch whose dimensions are only 0.136λX0.228λ at the lowest frequency of operation.

Radiation patterns are measured at three frequencies within the operational frequency band. Results for co- and cross-polarized radiation in both principle planes at 420 MHz, 450 MHz, and 485 MHz are given in Figures 7 and 8. As expected, consistent radiation patterns are obtained. The ratio of co- to cross-polarized radiation is measured to be better than 22 dB over the entire band of operation. An average front-to-back ratio of about 7 dB is also observed. The value of the front-to-back ratio can be improved significantly if the size of the ground plane behind the RIS is increased. The gain of the UHF patch is also measured at three frequencies using a dipole as the reference antenna. Table 1 summarizes the values, which are close to the theoretical values, indicating high radiation efficiency.

Frequency MHz	Gain dBi
420 MHz	5.2
450 MHz	5.2
485 MHz	5.9

Table 1: Gain measurements using a dipole antenna as a reference.

IV. Conclusion

A miniaturized, UHF microstrip patch antenna with a U-shaped resonant slot and placed above an RIS is designed and measured. Both the patch and U-slot are resonant structures, resulting in wide bandwidth. The RIS simultaneously enhances the bandwidth at each resonance and allows for miniaturization. The fabricated antenna whose overall dimensions are as small as 0.3λX0.3λ has better than 20% bandwidth, high efficiency, consistent patterns, and low cross-polarization levels.

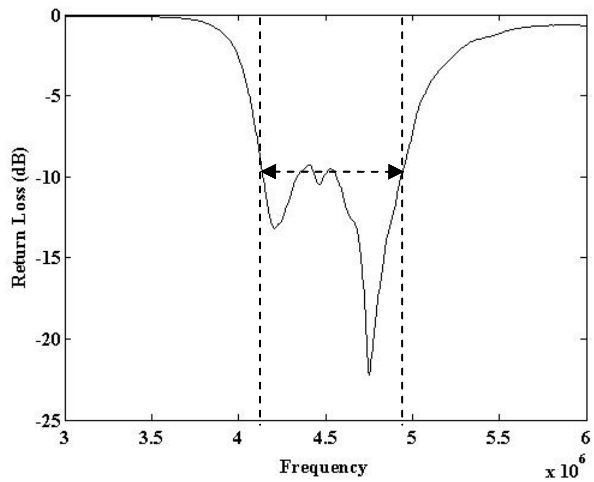


Figure 6: Measured return loss of the UHF patch over RIS substrate.

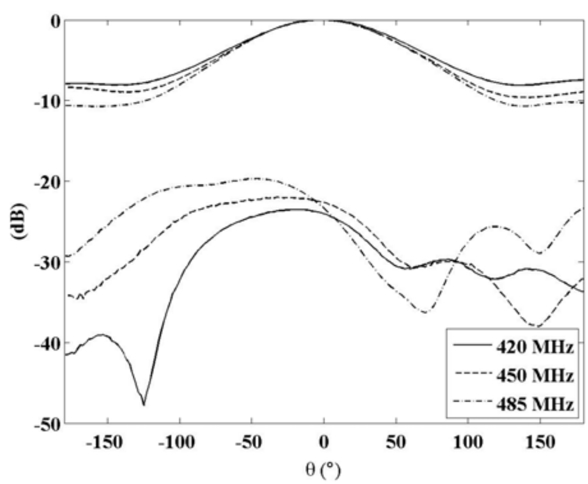


Figure 7: Co- and cross-polarized E-plane radiation patterns at 420, 450, and 485 MHz.

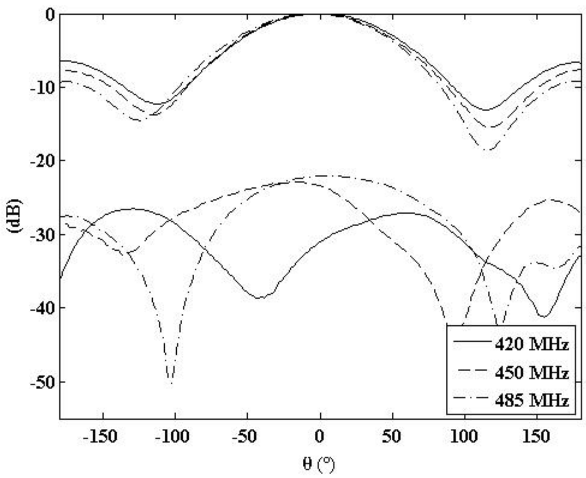


Figure 8: Co- and cross-polarized H-plane radiation patterns measured at 420, 450, and 485 MHz.

ACKNOWLEDGMENT

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