Designing Wideband Patch Antenna by Fusion of Complementary-Split Ring Resonator, Inter-Digital Capacitor and Slot Cutting Technique

[1]S. Anwar, [1]S. A. Niazi, [2]M. I. Malik, [1]A. Aziz
[1]Department of Electrical Engineering, University College of Engineering and Technology, Islamia University of Bahawalpur.
[2]Department of Electrical Engineering, University College of Engineering and Technology, Bahauddin Zakariya University, Multan
[1]summeya_anwar@yahoo.com

Abstract-An electrically small wideband patch antenna loaded with meta-material unit cell is proposed in this thesis. Meta-material unit cell is constructed by inter-digital capacitance (IDC) and rectangular slot on the patch and complementary split ring resonator (CSRR) etched on ground plane. The parametric analysis reveals that the electrical size of antenna becomes small by increasing inter-digital finger length, due to increase in series capacitance. The circulating current distribution across CSRR slot induces second radiation mode. The radiation modes resulting due to CSRR and inter-digital capacitor, overlaps by introducing rectangular slot, without any pattern distortion. This yields a wideband property regardless of small electrical size of the proposed antenna. We achieved a wide bandwidth of 780MHz, directional radiation pattern and moderate gain.

Keywords-Wideband antennas, Microstrip Patch Antennas, Metamaterials, Inter-digital Capacitance (IDC), Complementary Split-Ring Resonators (CSRR).

I. INTRODUCTION

Meta-material based patch antenna have attracted many researchers as it offers certain desirable characteristics such as increase in bandwidth and reduction in electrical size [i] as compared to conventional patch antenna. In 1968, the innovative theoretical model claiming negative permittivity and permeability of material that results in negative index medium was proposed by [ii]. After 30 years of experimentation it is verified that medium with artificial negative index exists [iii]. The materials with negative refractive index were categorized as Left-handed materials [iv]. Meta-materials are specifically engineered to produce electromagnetic properties that are unavailable in natural resources [v] . Meta-materials have drawn broad interest in many electromagnetic applications both in microwave and optical regime [vi,vii] due to permittivity, permeability, and index of refraction [viii-ix].

Antennas are used to increase radiation efficiency [x]. Meta-material based antennas can enhance radiation efficiency quite appreciably. Microstrip patch antennas are low profile antennas that are compatible with integrated circuitry due to their small size, simple structure and low cost. Theoretically, the size of patch antenna can be less than half of its resonance frequency. Therefore, many schemes have been proposed for the reduction of size [xi] and enhancement of radiating bandwidth of patch antenna [xii] . These schemes involve modification of geometry [xii, xiv], using multilayered substrate [xv] and cutting slots of different shaped on ground plane and patch [xvi, xvii]. Moreover, composite right/left handed (CRLH) properties of meta-materials can be achieved by coupling transmission line or waveguides with CSRR [xviii].

An electrically small wideband patch antenna which is loaded with planar meta-material unit cell is proposed and simulated. For shunt admittance, the unit cell consists of complementary split-ring resonators (CSRR), for series capacitance inter-digital capacitors [xix] are used and a rectangular slot for wide bandwidth characteristic. For small antenna applications, its dispersion characteristics are analyzed. Increase in inter-digital finger length results in TM01 radiations due to circular current distribution around CSRR. The wideband can be achieved by combining TM10 and TM01 mode without any pattern distortion. As compare to conventional antenna the proposed antenna have wide bandwidth characteristic, small electrical size and reasonable gain.

II. MATERIALS AND METHODS

An electrically small wideband microstrip patch antenna which is loaded with planar metamaterial unit cell is proposed. The proposed antenna is designed and simulated in Computer Simulated Technology (CST) Microwave studio. In this section the design geometry of proposed antenna is discussed.

Choice of Substrate

Choosing a substrate is as critical as the configuration itself. The substrate itself is a part of the antenna and contributes altogether to its radiative properties. A wide range of components are considered in choosing a substrate, for example, dielectric constant, thickness, firmness and in addition loss tangent. The dielectric constant must be as low as could reasonably be expected to energize bordering and radiation. A thicker substrate is additionally picked as it expands the impedance bandwidth. In any case, utilizing a thick substrate would bring about a loss in accuracy since most microstrip antenna models utilize thin substrate estimation in the analysis. Substrates which are lossy at higher frequencies should not be utilized for clear reasons. The decision of a hardened or soft board essentially relies on upon the current application.

III. MODELING

Basic Geometry

The proposed antenna is designed in CST Studio Suit based on Finite Integration Technique (FIT). The radiating element is constructed on 1.57mm thick Teflon substrate, with relative permittivity (εr=2.1) and loss tangent (tan δ = 0.001). Following steps are involved in the designing of proposed wideband patch antenna.

Designing a Simple Patch Antenna:

The first step in designing the proposed antenna is to design a simple patch antenna. Figure 1 shows the design geometry of patch antenna. A 19mm × 19mm patch is constructed on Teflon substrate of dimensions 40mm × 35mm and the thickness of substrate is 1.57mm.

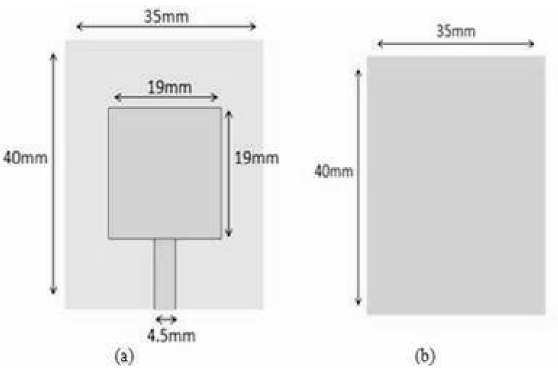

Fig. 1: Structure of Simple Patch Anteena
(a) Top view and (b) Bottom view

A square radiating patch is constructed on the top of Teflon substrate. The radiating element is excited by a 4.5 mm wide microstrip feed line having a reference impedance of 50 Ω.

Inserting Inter-digital Capacitor in Patch:

Inter-digital capacitor is inserted in patch to introduce the capacitive effect. Capacitance increases as the finger length increases and gaps decreases. The inter-digital finger length is optimized to 6.5mm. Figure 2 shows the top view of patch antenna after insertion of IDC of optimized finger length of 6.5mm.

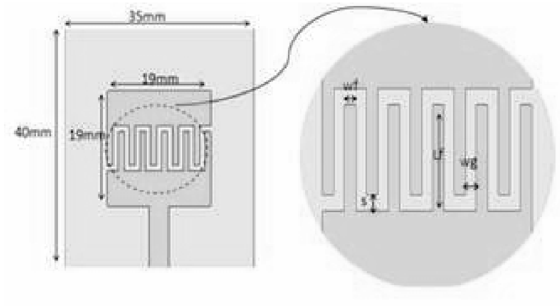

Fig. 2: Inter-digital capacitor loaded patch antenna

Dimension of IDC loaded patch antenna is given in Table I. Inter-digital finger length is denoted by Lf, width of inter-digital finger is wf and wg is the gap between two fingers.

Table I
DIMENSIONS OF IDC LOADED ANTENNA

Lf	6.5mm
wf	1mm
wg	1mm
s	1mm

By varying inter-digital finger length, electrical size of antenna can be varied. Our goal is to design an antenna that have wideband characteristics and electrically small in size as compare to the conventional patch antenna. By increasing inter-digital finger length, capacitance increases thus the resonance frequency is decreased. By adding capacitance, resonance frequency is reduced by keeping antenna size same. So actually, the size of antenna is reduced for low resonance frequency by adding capacitance.

Etching CSRR in Ground plane:

Ground plane is loaded with CSRR for shunt admittance. Figure 3 shows the ground plane of proposed antenna that is loaded with inter-digital capacitor. List of all the dimensions is given in Table 2.

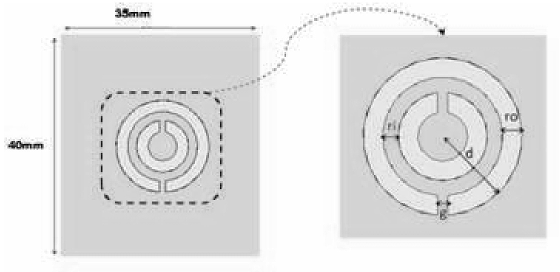

Fig. 3: CSRR etched on ground plane

Table II
DIMENSIONS OF CSRR

d	8mm
ro	2mm
ri	1.5mm
g	1mm

As shown in Figure 3, CSRR is pair of enclosed loops. These loops have splits at opposite ends in them .These splits supports resonant wavelength. These wavelengths are much higher than the diameter of the rings. These splits in the rings are responsible for excitation second resonant mode. To get required device performance they are electrically coupled with different microstructures.

Design of Proposed Antenna:

Figure 4 shows design of proposed antenna. In addition to inter-digital capacitor, patch is also loaded with rectangular slot. This rectangular slot is responsible for wideband characteristic in patch antenna. Different shapes of slots are cut on the surface of a path in antenna for enhancement of bandwidth. A rectangular slot is incorporated to the patch to perturb surface current. Complete dimensions of proposed antenna are given in Table 3.

Table III
DIMENSIONS OF PROPOSED ANTENNA

L	40mm	W	35mm
lp	19mm	wp	19mm
ws	14mm	ls	14mm
Lf	6.5mm	wm	4.5mm
d	8mm	g	1mm
ro	2mm	ri	1.5mm

It is interesting to note that when a rectangular slot is inserted in the patch, operating frequency bands which results due to inter-digital capacitance and CSRR overlaps. Because of phase difference they do not interfere with each other. Therefore wide bandwidth is achieved for proposed antenna.

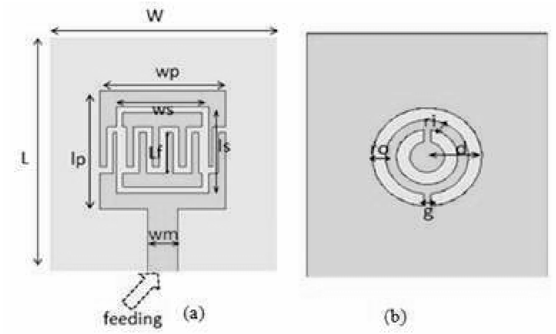

Fig.4: Geometry of proposed antenna
(a) Top view and (b) Bottom view

IV. RESULTS AND DISCUSSIONS

The parametric analysis and simulation of designed antenna is done in the CST Microwave Studio in order to get the following parameters.

Return loss (S11) Parameter:

In a system, the relationship between input- output terminals (ports) is represented by its S-parameters. S11-parameter is also known as return loss or reflection coefficient as it describes amount of power that is reflected by antenna. If the value of S11= 0 dB, it means that all of the power is reflected by antenna and no power is radiated. And if the value of S11=-10 dB, this infers power delivered to antenna is 3dB and then the reflected power will be -7dB.

Figure 5 shows S11-parameter of simple patch antenna of dimensions (40mm × 35mm × 1.57mm). Bandwidth of simple patch antenna of given dimension is 310MHz. The resonant frequency occurs at 6.7GHz. The plot below shows the return loss or S11-parameter (dB) vs frequency (GHz) curve.

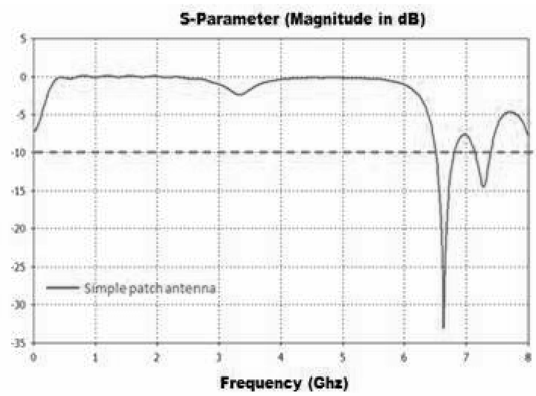

Fig. 5: S11-parameter of simple patch antenna

Figure 6 shows S11-parameter of antenna when it is loaded with IDC. The resonant frequency occurs at 4.6GHz, when an inter-digital capacitor is loaded in the patch.

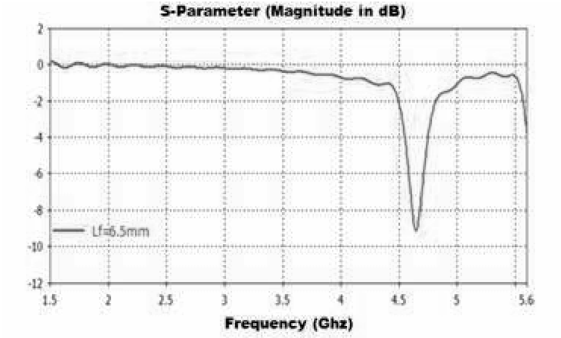

Fig. 6: S11 parameter of IDC loaded antenna when Lf=6.5 mm

Parametric study reveals that by varying finger length (Lf) electrical size of the antenna can be varied. Figure 7 shows the parametric study of antenna by varying Lf. It can be seen, by increasing Lf resonance frequency decreases as the capacitance increases. Thus the

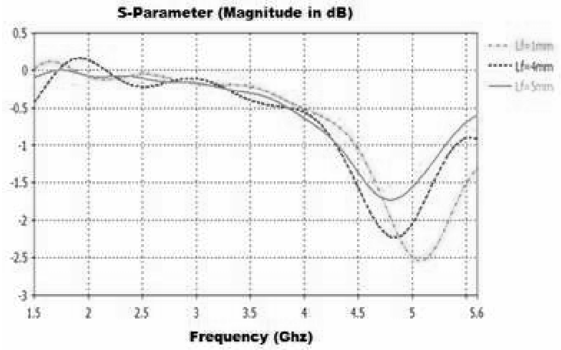

Fig. 7: S11 performance comparison by varying LF

After etching CSRR in ground plane another resonance frequency appears. This resonance frequency appears due to circulating current distribution across CSRR. Figure 8 shows the S11-parameter after inserting CSRR in the ground plane. First resonance frequency appears at 4.05GHz having 103MHz bandwidth and second resonance frequency appears at 5.7GHz having bandwidth of 155MHz.

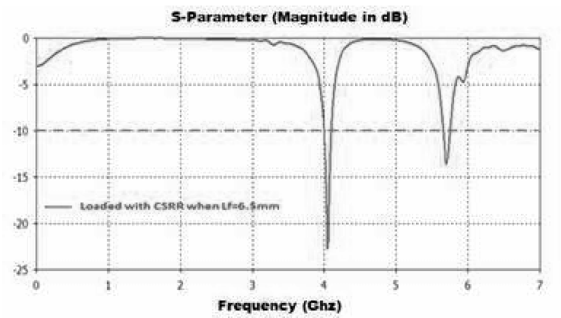

Fig. 8: S11 parameter ofAntenna loaded with CSRR

Figure 9 shows the parametric study of antenna loaded with CSRR by varying Lf. It can be seen, by increasing Lf resonance frequency decreases. The first resonance frequency decreases from 4.9GHz to 4.05GHz as Lf increases from 1mm to 6.5mm.

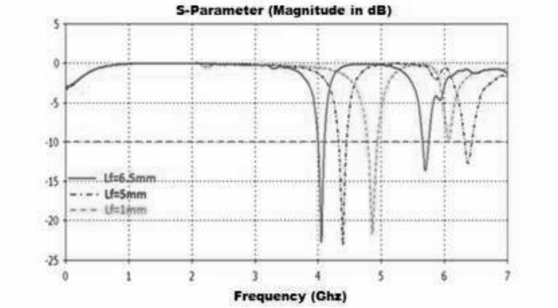

Fig.9: S11 performance comparison by varying Lf with CSRR loading

Figure 10 shows the simulated S11 parameter of proposed antenna. Bandwidth of proposed antenna extends from 5.2GHz to 6.02GHz. As compare to conventional patch antenna operating at same frequency, proposed antenna bandwidth is approximately three times wider because of combination of two radiation modes. Because when a rectangular slot is inserted in the patch, frequency bands which results due to inter-digital capacitor and CSRR overlaps. Bandwidth of designed antenna is 780MHz.

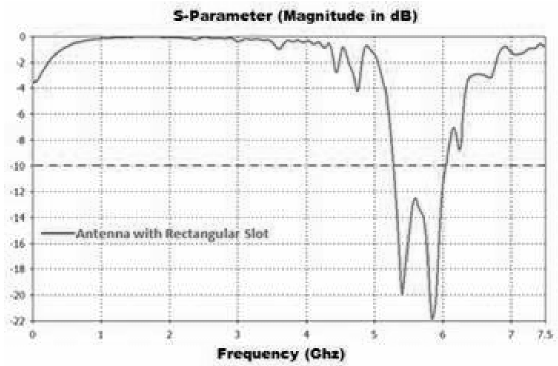

Fig. 10: S11 parameter of Proposed Antenna

To see the impact of rectangular slot on the bandwidths and resonant frequencies, a parametric study is performed for proposed antenna. Figure 11 shows the effects of variation in the width of the rectangular slot. As ws (width of slot) is decreased from 3mm to 1mm, two modes are overlapped efficiently and the bandwidth is increased but after it at ws = 0.5mm there is decrease in bandwidth.

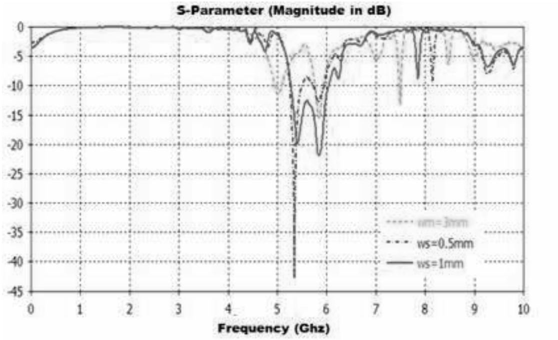

Fig. 11. S11 performance comparison of proposed antenna by varying ws

Surface Current Distribution:

An antenna is a structure conveying or carrying an electrical current and the electrical properties of the antenna relies on the distribution of that current in size (magnitude) and phase. At the point when the current distribution of the antenna is transformed, it likewise changes its attributes.

From Figure 8 it can be seen that another resonant frequency appears after etching CSRR in ground plane, one at 4.05GHz and the other at 5.7GHz. Figure 12 shows the current distribution at 4.05GHz and 5.7GHz respectively.

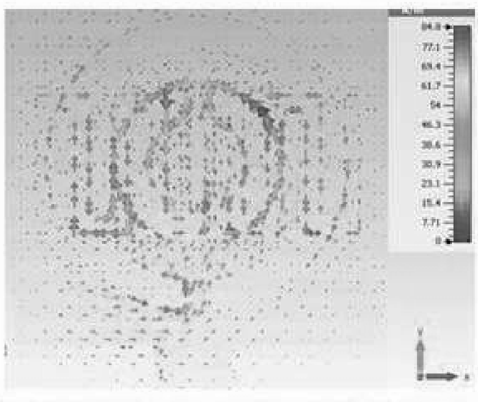

Fig 12 (a): Surface current distributions at 4.05 GHz

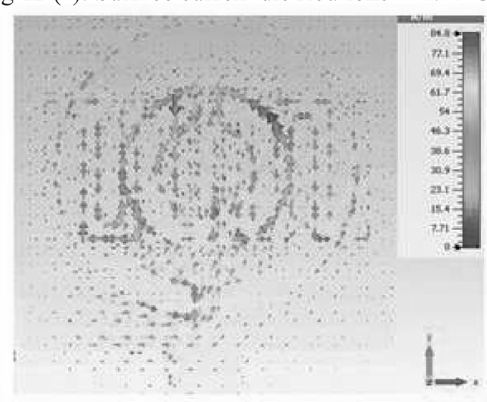

Fig. 12 (b): Surface current distributions at 5.7GHz

It can be seen from Figure 12 that maximum current distribution at 4.05GHz and 5.7GHz is across CSRR and IDC respectively. Figure 13 shows the surface current distribution of proposed antenna at the central frequency of 5.6GHz. It can be seen that maximum current is distributed across the rectangular patch which is responsible for widening bandwidth.

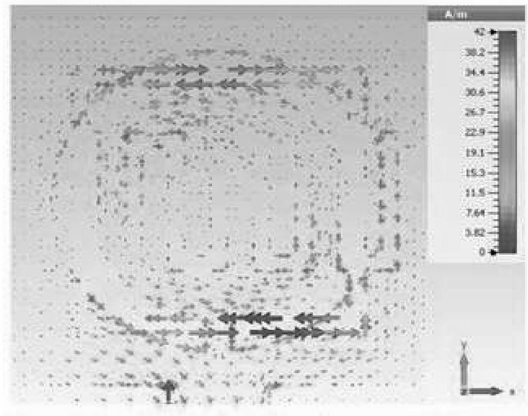

Fig. 13: Surface current distribution at 5.6 GHz

Radiation Pattern:

Figure 14 shows 2-D radiation patterns in polar E-plane and H-plane at the resonant frequency 5.6GHz. The radiation pattern shows that the antenna is directional with directivity (7.43dBi).

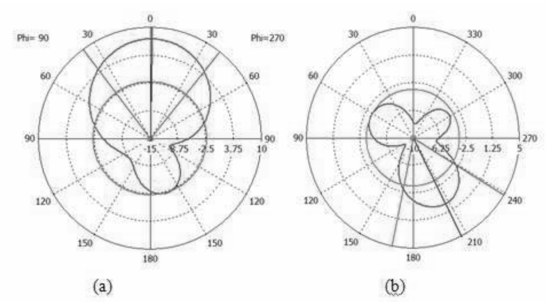

Fig. 14 2-D Radiation patterns of proposed antenna (a) Azimuth or H-Plane (b) Elevation of E-plane

VSWR vs Frequency plot

Figure 15 shows Voltage Standing Wave Ratio (VSWR) vs frequency plot of proposed antenna. Curve below VSWR=2 represents the bandwidth of antenna. It can be seen for proposed antenna the value of VSWR is less than 2 for frequency range 5.2GHz to 6.02GHz. Thus bandwidth of proposed antenna is 780MHz.

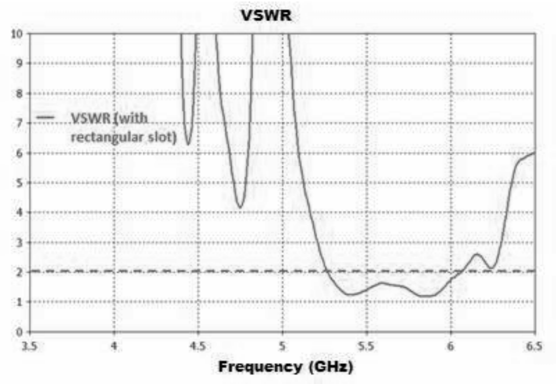

Fig. 15: VSWR vs frequency curve (antenna with rectangular slot loading)

CONCLUSION

A novel wideband antenna loaded with CRLH unit cell is proposed. In proposed antenna, CRLH unit cell consists of inter-digital capacitor and rectangular slot on patch and CSRR etched on ground plane. By increasing inter-digital finger length series capacitance increases due to which electrical size of proposed antenna is reduced. 30% reduction in patch size of proposed antenna is achieved as compare to conventional patch antenna. Due to circulating current distributing along CSRR, resonance frequency is observed which generates TM01 mode. Rectangular slot on patch combines the TM01 mode generated by circulating current across CSRR and normal TM10 mode. A wider bandwidth from 5.2 GHz – 6.05 GHz is achieved by combination of these two modes.

The proposed antenna has a wide bandwidth and moderate gain regardless of its size as compare to that of conventional patch antenna of same dimensions, operating at same frequency. Based on performance of proposed antenna such as moderated gain and wide bandwidth of 780MHz. Due to wide bandwidth characteristic proposed antenna can be used in WLAN and due to directional radiation patterns it can be used in RFID applications.

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