FREQUENCY RECONFIGURABLE TWIN DFILA ANTENNA WITH VARACTOR-LOADED BC-SRR FOR 5G APPLICATIONS

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Abstract

The design of a miniaturized frequency-tunable circularly polarized twin dual folded inverted-L antenna with varactor-loaded Broadside Coupled split-sing resonator(BC-SRR) structure is proposed in the paper. The design integrates two linearly polarized inverted-L antenna elements with double-folded arms and with a varactor-loaded Broadside Coupled split-sing resonator(BC-SRR) structures on both sides. To improve the impedance matching and radiation characteristics the double-folded structure plays a significant role. Although the use of BC-SRRs to the dual inverted-L antenna elements achieves compact volume, the antenna's radiation efficiency rapidly decreases around the SRR's resonant frequency. The decrease is avoided by employing a variable capacitance diode loaded on both BC-SRR structures (VLBC-SRR). The antenna is structure is minimized is to be about 66 mm in length, 10 mm width, and 1 mm in height (66 x 10 x 1mm^3).The configuration is simplified by using wave feeding, The better values are obtained between the theoretical calculations and simulated results, which validate the design concept and has a wide varactor tuning bandwidth. The simulated and measured results show that the proposed antennas resonate at multi-band frequencies, The band-1 (1.87 – 2.51GHz) with varactor tuning of 645MHz,the band-2 (3.72 – 4.22GHz) with varactor tuning of 500MHz, the band-3 (5.27 – 6.03GHz) with varactor tuning of 760MHz and The band-4 (7.42-8.44GHz) with varactor tuning of 1020MHz. With the impedance bandwidth of 6%, VSWR < 2, and 3-dB axial ratio (AR) <3 across the entire operating bands.

Index Terms: DFILA, VLBC-SRR, axial ratio, gain, radiation efficiency, FBR,Impedance Bandwidth percentage.

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1. Introduction

Nowadays, many existing communication services require antenna with multi-band or wideband characteristics of electronic gadgets [1]–[8]. There is also a requirement for small antennas operating on required frequency bands. The reports have also been published on a broadband technique arranging a coupling feed structure in an inverted-F antenna, also as on a compact structure comprising a planar printed strip monopole antenna and a closely coupled parasitic shorted strip [9], [10]. A compact internal coupled loop antenna with two branch lines in [11] and a wideband dual loop antenna with a coupled feeding structure using two resonance modes in [12] have also been reported as a means for covering the frequency bands.

The small internal antenna that has a region of 15 x30 mm^2 with a conductor wall of 3 mm height has been reported [13]. Frequency tunable antennas have been examined as a means of decreasing antenna volume. Techniques reported as means of acquiring wideband characteristics include an inverted-F antenna with a switchable feed employing a PIN diode and a tunable antenna with a variable capacitance diode[14], [15].

The split-ring resonator (SRR) is known as a structure exhibiting an efficient negative permeability [1], [2]. This structure has been utilized in a variety of antenna miniaturization and multiband operation approaches [3]–[9]. Dual-frequency printed dipoles are fabricated by loading a dipole with SRRs [3] and an antenna size reduction technique has been reported during which a pair of SRRs is employed because of the antenna's radiating element [4]. Design of compact patch antennas loaded with complementary SRRs and a reactive impedance surface was reported with [5] and a compact microstrip patch antenna using just one unit of a double SRR acting because the radiating element was reported in [16-20]. A report has also been published on the utilization of a frequency tunable waveguide antenna with a varactor-loaded SRR to realize size reduction and wideband characteristics [7]. A Tunable Inverted L Antenna (TILA) that operates at LTE, LTE-A and LTE-U frequency bands which range from 2250 MHz to 2700 MHz and from 5000 MHz to 5800 MHz is proposed[21-24].Tuning is achieved by using the varactor diodes, and the antenna is aimed for Multiple-Input Multiple-Output (MIMO) application[28]. Ferroelectric films are added to the substrate of the SRRs and the magnetic tunability is achieved by controlling the electric permittivity of the ferroelectric films with the change of temperature[29-32]. SRRs provide a negative effective permeability to the structure in a certain frequency band above their resonance frequency, whereas CSRRs make the structure to behave as a negative permittivity medium in a frequency band below resonance[33-38].

In the applications, a straight quarter-wavelength wire monopole has largely been modified due to its high profile and narrow bandwidth[39]. Typically, the top-loading technique is used to reduce the height, for example, as reported. Of them, the simplest configuration is an inverted-L antenna ILA, whose low-profile feature very attractive for many applications, although low input impedance is an inherent drawback[40]. On the ground of the ILA in its basic form, many practical antennas, typically, the inverted-F antenna have been developed using various matching techniques, as mentioned[41-43].This paper reports the author's use of a BC-SRR structure to develop a compact inverted-L antenna. This structure, initially designed for mobile phones, enables the antenna to acquire a complex magnetic permeability that greatly changes around the SRR's resonant frequency.

It is by using a variable capacitance diode loaded in the BC-SRR gaps (VLBC-SRR);

the material characterization is acquired by turning around the required frequency bands. The author has also developed a tunable inverted-L antenna by using a BC-SRR structure tuned by the variable capacitance diode loaded in the gap (VLSRR).This compact (66 x 10 x 1mm^3) volume antenna formed on the front and backside of a dielectric substrate not only avoids decreased radiation efficiencyaround the SRR's resonant frequency but also increases the radiation efficiency from 10% to 40% or more. It achieves wideband and multi-band characteristics that enable to cover the author's target frequency bands.

It is by using a variable capacitance diode loaded in the BC-SRR gaps (VLBC-SRR); the material A thin inverted-L antenna is well known for its low profile and small in size. Due to its poor impedance matching and irregular radiation patterns greatly limit its use. Much exertion has been committed to enhance its impedance performances [25]–[27], but no circular polarized antenna using the inverted L antenna as the element has been developed. In the proposed work, a modified dual inverted L antenna with VLSRR structures on both sides is developed, simulated and measured. To differentiate from the conventional dual inverted L antenna, it can call as dual folded inverted L antenna(DFILA) with VLSRR structures. Two double folded inverted L antennas are appropriately arranged to operate with broad bandwidth and broadside radiation.

The rest of this paper is organized as follows. In Section 2, the author describes the antenna design of the proposed dual inverted-L antenna, Section 3 discussion is made with simulated and measured results of the proposed Frequency-Tunable circularly polarized dual Inverted-L Antenna With Varactor-Loaded Split-Ring Resonator Structure and as well as comparison. Section 4 concludes the paper.

2. Antenna Geometry and Design

For designing a microstrip patch antenna, we have to select the resonant frequency and a dielectric medium for which the antenna is to be designed. The parameters to be calculated are as under. Width (W): The width of the patch is calculated using the following equation [22]

$$W = \frac{C_o}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (1)$$

Where, W = Width of the patch

C_0 = Speed of light

ε_r = value of the dielectric substrate

f_c = Centre frequency of the antenna.

Effective refractive index: The effective refractive index value of a patch is an important parameter in the designing procedure of a microstrip patch antenna. The radiations traveling from the patch towards the ground pass through the air and some through the substrate (called as fringing). Both the air and the substrates have different dielectric values, therefore in order to account for this we find the value of effective dielectric constant. The value of the effective dielectric constant (ε_{reff}) is calculated using the following equation [22].

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2} \frac{W}{h} > 1 \quad (2)$$

Length: Due to fringing, electrically the size of the antenna is increased by an amount of (ΔL). Therefore, the actual increase in length (ΔL) of the patch is to be calculated using the following equation [22]

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \quad (3)$$

Where 'h'= height of the substrate

The length (L) of the patch is now to be calculated using the below mentioned equation[22]

$$L = \frac{C_0}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (4)$$

Where L=Effective length of the antenna

C_0 =speed of light (3 x10^8 m/sec)

f_r = resonant frequency

ε_{reff} =effective dielectric constant.

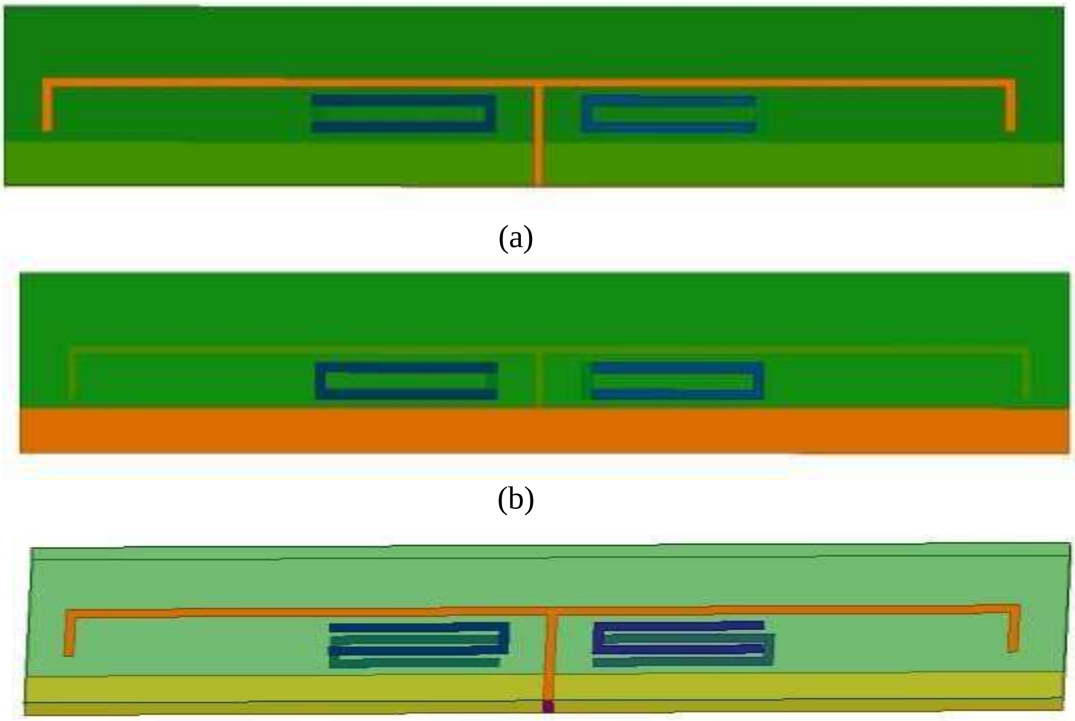
ΔL =length extension

Length (L_g) and width (W_g) of ground plane: Now the dimensions of a patch are known. The length and width of a substrate is equal to that of the ground plane. The length of a ground plane (Lg) [22] and the width of a ground plane (W_g)[22] are calculated using the following equations

$$L_g = 6h + L \quad (5)$$

$$W_g = 6h + W \quad (6)$$

The geometry of the proposed circularly polarized dual folded inverted-L antenna with varactor-loaded split-ring resonator structures is shown in Figure.1. The Figure 1(a) shows the front view of the proposed antenna which clearly shows the inverted L shape with dual folded arm antenna, varactor diode loaded split ring resonator structures on both sides, a rectangular ground plate, substrate and wave feeding element. Figure 1(b) and 1(c) shows the Backside view and Top of the proposed antenna. The Range of frequency used to simulate the proposed antenna is from 1GHz to 10 GHz. The solution frequency used to simulate is 5GHz, with 99 passes and with the maximum delta S of about 0.02



(a)

(b)

(c)

Figure 1.Geometry of the Proposed Antenna (a)Front View (b)Backside View and (c)Top View

The proposed antenna consists of two arms of inverted L; the inverted L arms are formed by folding the ends of the patch in inverted L shape on both sides of the antenna. It is clearly noted that, by folding the ends of the antenna, the size will become compact and the radiation resistance will increases.

In this section, it is to investigate the performance of the proposed antenna. The proposed antenna is made to simulate at different resonant frequencies with different frequency setups. The BC-SRRs are arranged between the inverted-L element and the ground. Comprising two open metallic rings, it can be considered an LC resonant circuit that effectively consists of the inductance due to the ring conductor and the capacitance due to the interval of two rings. The induced current flows on the rings when an electromagnetic field with a vertical magnetic field for the plane including the rings is generated. However, the induced current flow is interrupted by the gap between the rings, and the electric charge accumulates between the rings. One characteristic of the SRR structure is that the effective permeability greatly changes in the vicinity of the resonant frequency. It is not the negative value but the greatly changed value of the complex magnetic permeability is useful for the design because the antenna characteristic can be tuned by changing the material characteristic. The BC-SRR structure's material characteristics can be extracted from S-parameters. The complex electric permittivity and the complex magnetic permeability are

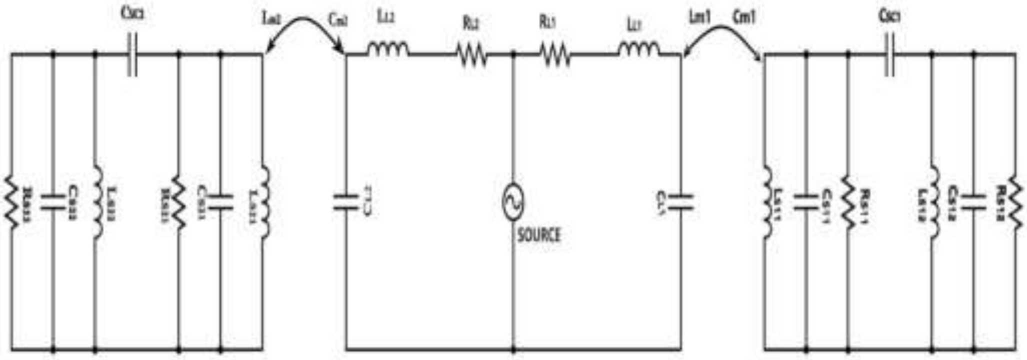


Figure 2: Equivalent circuit of the DFILA antenna with the VLSRR structures

defined as follows

$$\mathcal{E}^* = \Upsilon/\Upsilon_o \, (1-\tau|1+\tau) \quad (7)$$

$$\mu^* = \Upsilon/\Upsilon_o \, (1+\tau|1-\tau) \quad (8)$$

Where τ is the reflection coefficient

The proposed antenna combines two dual folded inverted-L antennas and with the VLBC-SRR structures on both sides that resonate in the multi-band frequencies of 2.19GHz,3.97GHz, 5.65GHz, and 7.93GHz. Adjusting the conductor length of the inverted-L elements and the VLSRR ring lengths enable the antenna to achieve the required frequency bands. The VLBC-SRR structures are formed on the top side of an FR-4 dielectric substrate ($\mathcal{E}r$ =4.4 and tan δ=0.02). The FR-4 dielectric substrate is 1mm thick. The antenna volume is 66 x 10 x 1mm^3 (0.66cm^3) and the ground plane dimensions are 75 x 4 mm^2 . The conductors of both the inverted-L element and the SRRs are 1mm wide. The end of the inverted-L element is bent in order to store in the volume of 66 x 10 x 1mm^3. As the antenna elements are folding on both sides with will improves the impedance and radiates in circular polarization. The antenna was simulated using Ansoft HFSS 15.0.

Figure.2 shows the equivalent circuit of the dual folded inverted-L antenna with the VLBC-SRR structures on both sides of the antenna. In this figure R_{L1}, $L_{L1}$and $C_{L1}$are the resistance, inductance, and capacitance of the dual folded inverted-L antenna1 (DFILA$_1$), R_{L2},$L_{L2}$and $C_{L2}$are the resistance, inductance, and capacitance of the dual folded inverted-L antenna2(DFILA$_2$),R_{S11}, L_{S11} & C_{S11} are the resistance, inductance, and capacitance of the inner ring of the VLSRR of DFILA1, R_{S12}, L_{S12} & C_{S12} are the resistance, inductance, and capacitance of the outer ring of the VLBC-SRR of DFILA1, R_{S21}, L_{S21} & C_{S21} are the resistance, inductance, and capacitance of the inner ring of the VLBC-SRR of DFILA2, R_{S22}, L_{S22} & C_{S22} are the resistance, inductance, and capacitance of the outer ring of the VLBC-SRR of DFILA2. C_{SC1} is the capacitance between the rings of VLBC-SRR1 and C_{SC2} is the capacitance between the rings of VLBC-SRR2. L_{m1} and C_{m1} are the mutual inductance and capacitance between the DFILA1 and the VLBC-SRR1. L_{m2} and C_{m2} are the mutual inductance and capacitance between the DFILA2 and the VLBC-SRR2.If $R_{L1}=R_{L2}=R_{S11}=R_{S12}=R_{S21}=R_{S22}=0$ Then the DFILA antenna and VLBC-SRRs conductors are treated as lossless, then the total inductance and the total capacitance of the VLBC-SRRs are L_s and C_s. In the case that the DFILA antenna and VLBC-SRRs are on the same medium, the relation $L_{L1}C_{L1}=L_{S11}C_{S11}$ and $L_{L2}C_{L2}=L_{S21}C_{S21}$, it can be written as $L_LC_L = L_SC_S$ and the resonant frequencies are defined as follows[23]

$$fL1 = \frac{1}{2\pi\sqrt{(Ls11 \pm Lm1)\,Cs11}} \quad (9)$$

$$fc1 = \frac{1}{2\pi\sqrt{(Cs11 \pm Cm1)\,Ls11}} \quad (10)$$

$$fL2 = \frac{1}{2\pi\sqrt{(Ls21 \pm Lm2)\,Cs12}} \quad (11)$$

$$fc1 = \frac{1}{2\pi\sqrt{(Cs21 \pm Cm2)\,Ls21}} \quad (12)$$

Where **f_{L1}** is the frequency due to mutual inductance of DFILA1 and VLBC-SRR1.

f_{c1} is the frequency due to mutual capacitance of DFILA1 and VLBC-SRR1.

f_{L2} is the frequency due to mutual inductance of DFILA2 and VLBC-SRR2.

$\mathbf{f_{c2}}$ is the frequency due to mutual capacitance of DFILA2 and VLBC-SRR2.
If it is considered to be a parallel circuit, the resonance frequencies are expressed as follows[23]

$$f11 = \frac{1}{2\pi\sqrt{(Ls11+Lm1)(Cs11+Cm1)}} \quad (13)$$

$$f12 = \frac{1}{2\pi\sqrt{(Ls11-Lm1)(Cs11-Cm1)}} \quad (14)$$

$$f21 = \frac{1}{2\pi\sqrt{(Ls21+Lm2)(Cs21+Cm2)}} \quad (15)$$

$$f22 = \frac{1}{2\pi\sqrt{(Ls21-Lm2)(Cs21-Cm2)}} \quad (16)$$

Where f_{11} & f_{12} are high and low frequencies of DFILA1 and f_{21} & f_{22} are high and low frequencies of DFILA2.

Therefore, the resonant frequency is divided into the high-frequency side and low-frequency side by adding the VLBC-SRRs to the DFILA antenna as shown in Figure.1.

The mutual coupling has been also proven to be a useful mechanism to improve the bandwidth for mobile antennas when an extra antenna element is coupled to the driven element [27], [28].

The current is strongly distributed on the outer ring of the VLBC-SRR conductor and the DFILA element at the resonant frequency on the low-frequency side and on the inner ring of the VLBC-SRR conductor at the resonant frequency on the high-frequency side.
Each resonant frequency can be changed by adjusting the bias voltage of varactor diodes loaded on the VLBC-SRR structures. The antenna can achieve multi-band characteristics in the vicinity of the resonant frequency of the original DFILA.
In order to get the circular polarization and better radiation characteristics, two dual folded inverted-L antennas are used. One DFILA1 covers Left side Circular polarization and DFILA2 covers Left side Circular polarization. Double folded arms play a significant role in improving Impedance matching and Radiation characteristics of the proposed antenna.

3. Results and Discussions

The previous section described the antenna design of the dual folded inverted L antenna with varactor diode loaded VLSRR structures. This section describes the proposed antenna, which combines DFILA with VLSRR structures by using different switch cases like

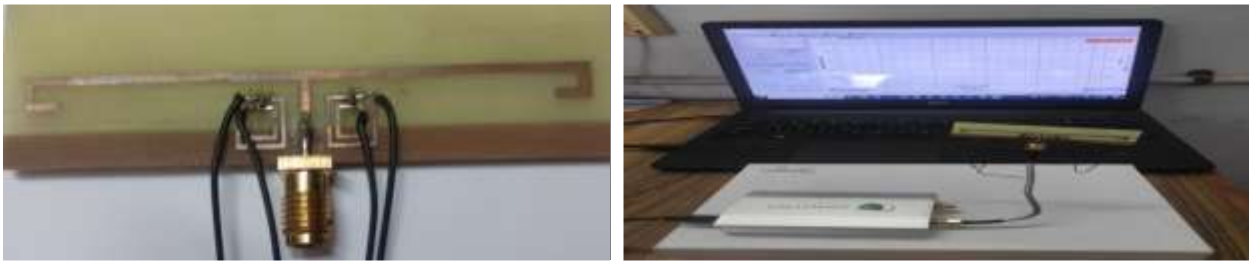
(a).Switch case-1(OFF OFF):DFILA with VLSRR structures with varactor diode1(VD1) and varactor diode2(VD2) OFF & OFF.

(b).Switch case-2(OFFON):DFILA with VLSRR structures with varactor diode1(VD1) and varactor diode2(VD2) OFF & ON.

(c).Switch case-3(ONOFF):DFILA with VLSRR structures with varactor diode1(VD1) and varactor diode2(VD2) ON & OFF.

(d).Switch case-4(ONON):DFILA with VLSRR structures with varactor diode1(VD1) and varactor diode2(VD2) ON & ON.

The proposed antenna combines the DFILA antenna with the VLSRR structure. It is by switching the varactor diodes ON and OFF VLSRR enables the antenna to achieve the required malty frequency band tuning. A prototype has been built DFILA antenna with VLSRR structure; Figure.3(a) shows the Proto type model of Proposed DFILA with VLBC-SRR Structure and (b) shows the Proto type model connected with Pocket Vector Network Analyser[44]. Its volume is 66 x 10 x 1mm^3 and the ground plane dimensions are 75 x 4mm^2.



(a) **(b)**

Figure 3: Proto type model of DFILA with VLSRR Structure

The FR-4 dielectric substrate is 1mm thick. The conductors of both the inverted-L element and the SRRs are 1mm wide.The each DFIAL length is 40mm in order to increase the impedance and to get circular polarization the arms of both folded twice, with folding on both ends volume 80x10x1mm^3 is reduced to 66x10x1mm^3. The DFILA with VLSRR structures is loaded with two varactor diodes, varactor diode1(VD$_1$) and varactor diode2(VD$_2$) on the VLSRR structures of DFILA$_1$ and DFILA$_2$ respectively. **SMV2019** varactor diode is used in the proposed model.

(a) Switch Case-1(OFF OFF):

The switch case-1 describes the VD1 is OFF & VD2 is OFF, where applied external bias voltage for the both Varactor Diodes VD1 and VD2 is at 0v.

Figure.4 Shows the Reflection Coefficient vs. Frequency plot for switch case -1(OFF OFF). The solid line represents the simulated results and the dotted line represents the measured results.

The Proposed antenna is resonating with four Bands of Frequencies.Band-1 is resonating at 1.92GHz, with Tuning range and Tuning bandwidth of 1.88 to 2.056GHz and 176MHz ,Band-2 is resonating at 3.88GHz, with Tuning range and Tuning bandwidth of 3.76 to 4.22GHz and 460MHz, Band-3 is resonating at 5.66GHz, with Tuning range and Tuning bandwidth of 5.44 to 5.93GHz and 488MHz and Band-4 is resonating at 8.30GHz, with Tuning range and Tuning bandwidth of 8.16 to 8.44GHz and 280MHz Respectively.

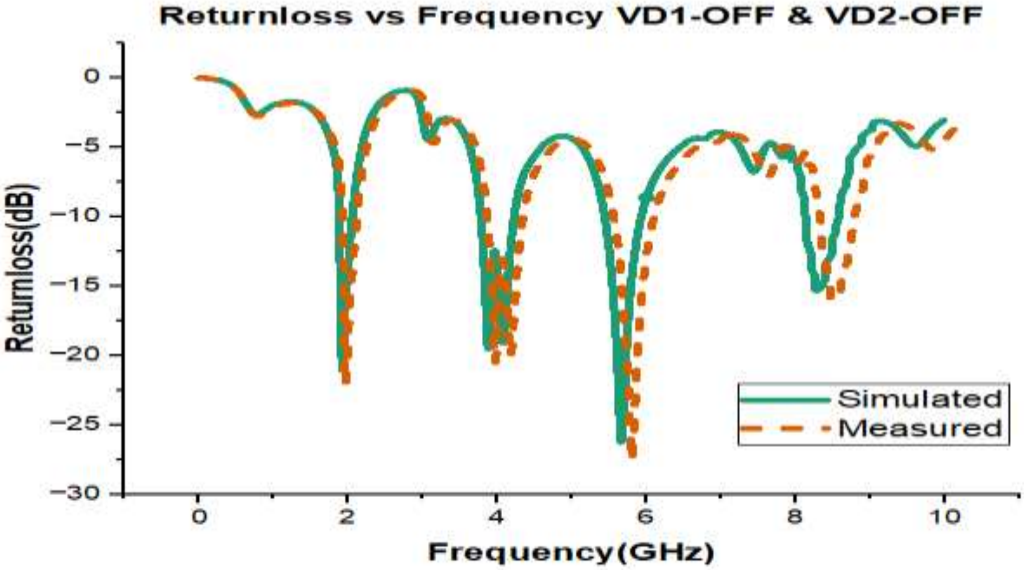


Figure 4: Reflection Coefficient (S11 (dB) vs. Frequency (GHz) for switch case -1(OFFOFF)

The Simulated results with Ansys HFSS and Measured results with Pocket Vector Network Analyzer(PVNA) like Resonant Frequency, S11, VSWR, Varactor Tuning Range, Tuning Bandwidth , Functional Bandwidth and Axial Ratio of the proposed antenna is Tabulated in the Table.1. The Solid Line Represents the Simulated Results and Doted Line represents the VNA Measured Results.

Table.1 S11,VSWR,Varactor Tuning, Bandwidth of switch case-1(OFFOFF)

Valves		Resonant Frequency (GHz)	S11 (dB)	VSWR	Varactor Tuning (GHz)	BW (MHz)	FBW %	AR
Band-1	Simulation	1.92	-21.07	1.11	1.88-2.056	176	9.16	1.8
	Measured	1.90	-24.7	1.12	1.84-1.94	100	9.01	1.2
Band-2	Simulation	3.88	-19.5	1.15	3.76-4.22	460	20.36	1.2
	Measured	3.80	-18.7	1.18	3.72-4.10	380	18.60	1.1
Band-3	Simulation	5.66	-26.22	1.43	5.44-5.92	488	8.62	2.1
	Measured	5.56	-26.1	1.25	5.38=5.84	460	6.12	1.9
Band-4	Simulation	8.3	-10	1.27	8.16-8.44	280	3.37	1.7
	Measured	8.2	-10	1.32	8.12-8.34	220	5.4	1.6

(b). Switch Case-2(OFFON):

The Switch Case-2 describes the VD_1 is OFF & VD_2 is ON, where applied external bias voltage for the both Vatactor DiodesVD_1 is 0V and VD_2 is at 20V. Figure.5 Shows the reflection coefficient vs. Frequency plot for switch case -2(OFFON). The solid line represents the simulated results and the dotted line represents the measured results. The Proposed antenna is resonating with four Bands of Frequencies.Band-1 is resonating at 1.98GHz, with Tuning range and Tuning bandwidth of 1.82 to 2.09GHz.and 270MHz,Band-2 is resonating at 3.83GHz, with Tuning range and Tuning bandwidth of 3.73 to 4.11GHz and 380MHz, Band-3 is resonating at 5.68GHz, with Tuning range and Tuning bandwidth of 5.28 to 5.97GHz and 690MHz and Band-4 is resonating at 7.65GHz, with Tuning range and Tuning bandwidth of 7.55 to 7.76GHz and 210MHz Respectively.

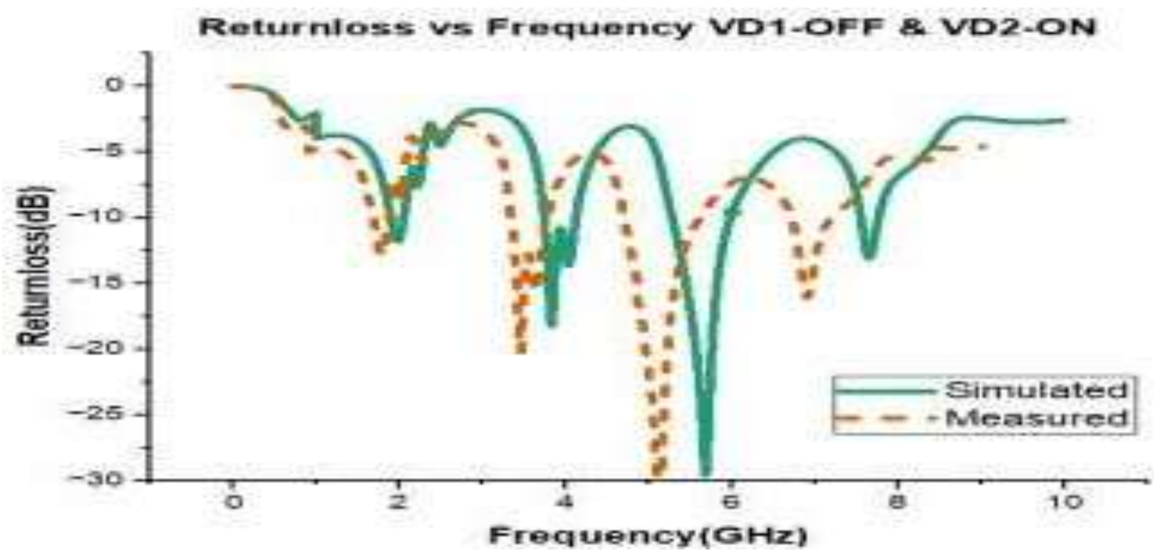


Figure 5: Reflection Coefficient(S11(dB) vs Frequency(GHz) for switch case -2(OFFON)

The Simulated results with Ansys HFSS and Measured results with Pocket Vector Network Analyzer(PVNA) like Resonant Frequency, S11, VSWR, Varactor Tuning Range, Tuning Bandwidth , Functional Bandwidth and Axial Ratio of the proposed antenna is Tabulated in the Table.2. The Solid Line Represents the Simulated Results and Doted Line represents the VNA Measured Results.

Table.2 S11,VSWR,Varactor Tuning, Bandwidth of switch case -2(OFFON).

Valves		Resonant Frequency(GHz)	S11 (dB)	VSWR	Varactor Tuning (GHz)	BW (MHz)	FBW %	AR
Band-1	Simulation	1.98	-10	1.17	1.82-2.09	270	13.63	1.8
	Measured	1.99	-12	1.15	1.81-2.09	280	12.6	1.5
Band-2	Simulation	3.83	-18.21	1.21	3.73-4.11	380	9.92	1.4
	Measured	3.85	-20.15	1.11	3.72-4.12	400	8.42	1.1
Band-3	Simulation	5.68	-29.58	1.48	5.28-5.97	690	12.14	2.2
	Measured	5.72	-32.15	1.14	5.26-5.99	730	12.18	1.9
Band-4	Simulation	7.65	-13.01	1.74	7.55-7.76	210	2.74	2.1
	Measured	7.84	-12.45	1.85	7.57-7.82	250	2.54	1.8

(c).Switch Case-3(ONOFF):

The Switch Case-3 describes the VD_1 is ON & VD_2 is OFF, where applied external bias voltage for the both Varactor Diodes VD_1 is 20V and VD_2 is at 0V. Figure.6 shows the reflection coefficient vs frequency plot for switch case - 3(ONOFF). The solid line represents the simulated results and the dotted line represents the measured results. The Proposed antenna is resonating with four Bands of Frequencies.Band-1 is resonating at 2.00GHz, with Tuning range and Tuning bandwidth of 1.91 to 2.08GHz and 170MHz ,Band-2 is resonating at 3.82GHz, with Tuning range and Tuning bandwidth of 3.72 to 4.11GHz and 390MHz, Band-3 is resonating at 5.69GHz, with Tuning range and Tuning bandwidth of 5.40 to 6.03GHz and 613MHz and Band-4 is resonating at 7.67GHz, with Tuning range and Tuning bandwidth of 7.54 to 7.76GHz and 220MHz Respectively.

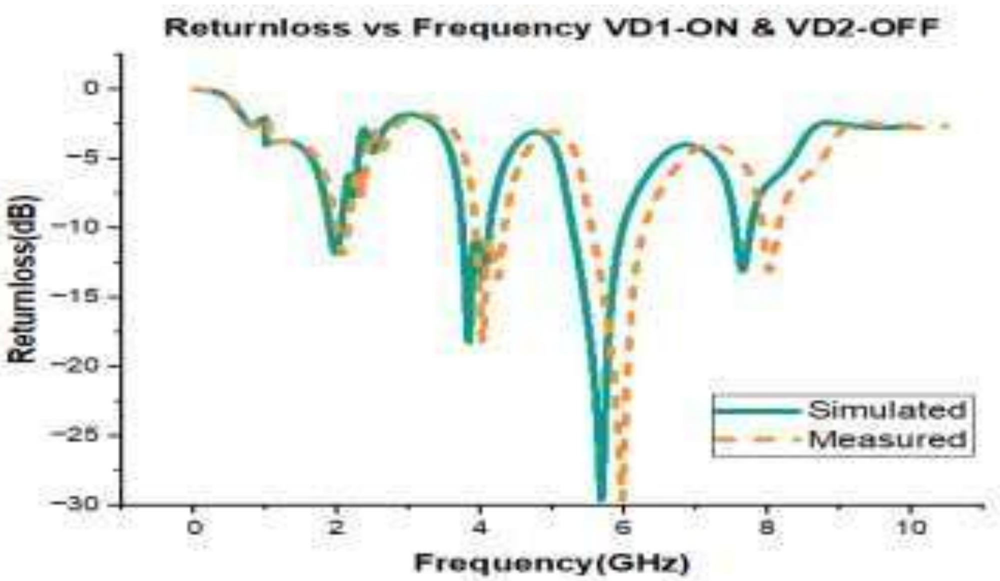


Figure 6: Reflection Coefficient S11(dB) vs. Frequency(GHz) for switch case -3(ONOFF)

The Simulated results with Ansys HFSS and Measured results with Pocket Vector Network Analyzer(PVNA) like Resonant Frequency, S11, VSWR, Varactor Tuning Range, Tuning Bandwidth , Functional Bandwidth and Axial Ratio of the proposed antenna is Tabulated in the Table.3. The Solid Line Represents the Simulated Results and Doted Line represents the VNA Measured Results

.Table.3 S11,VSWR,Varactor Tuning, Bandwidth of switch case -3(ONOFF).

Valves		Resonant Frequency(GHz)	S11 (dB)	VSWR	Varactor Tuning (GHz)	BW (MHz)	FBW %	AR
Band-1	Simulation	2.00	-22.62	1.34	1.91-2.08	170	8.5	1.9
	Measured	1.99	-25.20	1.21	190-208	180	6.9	1.8
Band-2	Simulation	3.82	-20.19	1.48	3.72-4.11	390	10.20	2.1
	Measured	3.81	-19.18	1.05	3.69-4.10	410	9.8	2.0
Band-3	Simulation	5.69	-24.22	1.54	5.40-6.03	613	10.77	2.2
	Measured	5.70	-23.45	1.8	5.42-6.03	610	9.70	2.1
Band-4	Simulation	7.67	-13.21	1.79	7.54-7.76	220	2.86	1.6
	Measured	7.80	-12.22	1.80	7.55-7.80	250	2.85	1.3

(d) Switch Case-4(ONON):

The Switch Case-4 describes the VD_1 is ON & VD_2 is ON, where applied external bias voltage for the both Varactor Diodes VD_1 and VD_2 is at 20V. Figure.7 shows the reflection coefficient vs. frequency plot for switch case -4(ONON). The solid line represents the simulated results and the dotted line represents the measured results.

The Proposed antenna is resonating with four Bands of Frequencies.Band-1 is resonating at 2.10GHz, with Tuning range and Tuning bandwidth of 1.99 to 2.20GHz and 210MHz ,Band-2 is resonating at 4.01GHz, with Tuning range and Tuning bandwidth of 3.74 to 4.14GHz and400MHz, Band-3 is resonating at 5.72GHz, with Tuning range and Tuning bandwidth of 5.44 to 6.03GHz and 600MHz and Band-4 is resonating at 7.65GHz, with Tuning range and Tuning bandwidth of 7.52 to 7.78GHz and 230MHz RespectivelyThe Simulated results with Ansys HFSS and Measured results with Pocket Vector Network Analyzer(PVNA) like Resonant Frequency, S11, VSWR, Varactor Tuning Range, Tuning Bandwidth , Functional Bandwidth and Axial Ratio of the proposed antenna is Tabulated in the Table.4. The Solid Line Represents the Simulated Results and Doted Line represents the VNA Measured Results. To detect the frequency tuning of DFILA with VLSRR comparison of the four switch cases, need to be done. The table.5 shows the comparison of four switch cases with Simulated and Measured Results.The Proposed antenna in Band-1 is obtained with the tuning range of 1.87 to 2.51GHz with tuning bandwidth of 645MHz

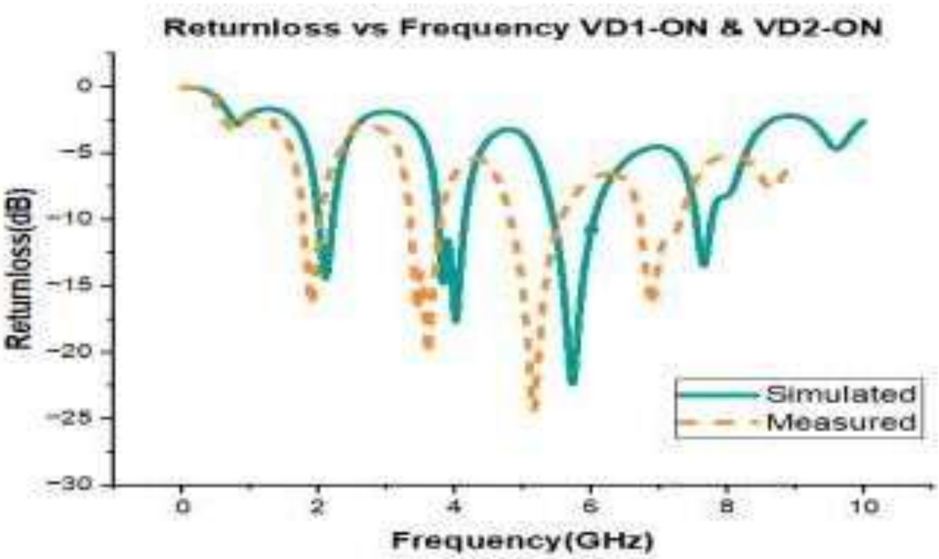


Figure 7: Reflection Coefficient (S11(dB) vs. Frequency(GHz) for switch case -4(ONON)

Band-2 is obtained with the tuning range of 3.72 to 4.22GHz with tuning bandwidth of 500MHz, Band-3 is obtained with the tuning range of 5.27 to 6.03GHz with tuning bandwidth of 760MHz and The Band-4 is obtained withthe tuning range of 7.42 to 8.44GHz with tuning bandwidth of 1020MHz. Figure.8 shows the combined results of four switch cases, which clearly represents the resonant frequency shifting from lower order frequency to higher order frequency.

.Table.4 S11,VSWR,Varactor Tuning, Bandwidth of switch case -4(ONON).

Valves		Resonant Frequency (GHz)	S11 (dB)	VSWR	Varactor Tuning (GHz)	BW (MHz)	FBW %	AR
Band-1	Simulation	2.10	-14.4	1.1	1.99-2.20	210	10	1.2
	Measured	2.07	-15.45	1.3	1.98- 2.22	220	9.0	1.1
Band-2	Simulation	4.01	-17.64	1.2	3.74-4.14	400	9.7	2.1
	Measured	3.99	-16.45	1.5	3.75-4.14	390	9.1	1.9
Band-3	Simulation	5.72	-22.39	1.1	5.44-6.03	590	10.31	2.0
	Measured	5.69	-22.58	1.1	5.43-6.03	600	9.10	1.8
Band-4	Simulation	7.65	-13.46	1.3	7.53-7.76	230	3.0	1.4
	Measured	7.64	-12.56	1.2	7.52-7.78	260	3.1	1.3

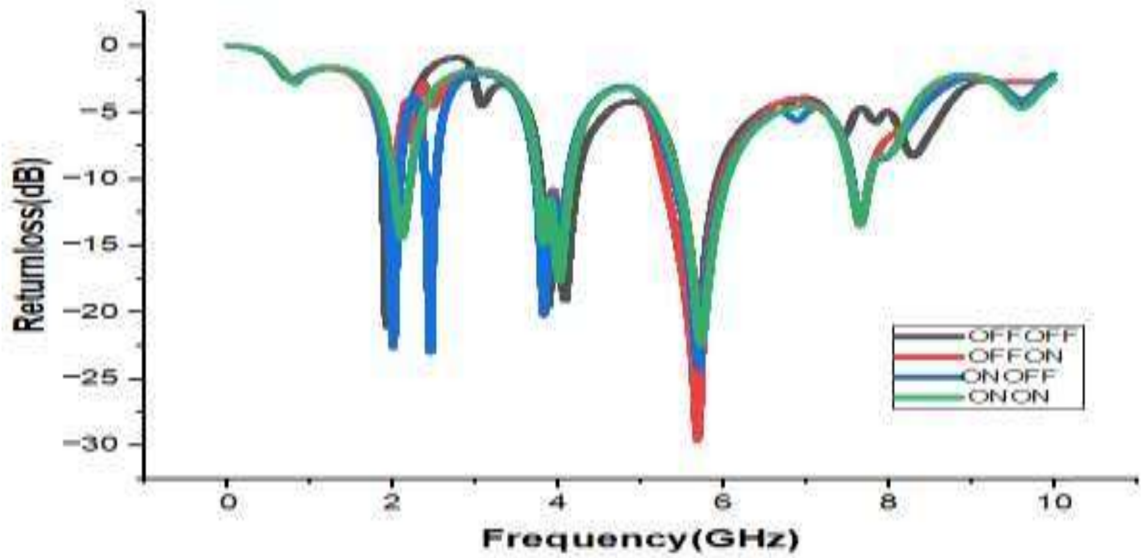


Figure 8: combined results of four switch cases.

Table 5: comparison of four switch cases with Simulated and Measured Results.

Switch Case	Band -1		Band -2		Band -3		Band -4	
	Resonant Frequency (GHz)		Resonant Frequency (GHz)		Resonant Frequency (GHz)		Resonant Frequency (GHz)	
	Simulate	Measured	Simulated	Measured	Simulate	Measured	Simulated	Measured
Switch case-1 (OFFOFF)	1.92	1.90	3.88	3.80	5.66	5.56	8.33	8.20
Switch case-2 (OFFON)	1.98	1.99	3.83	3.85	5.68	5.72	7.65	7.84
Switch case-3 (ONOFF)	2.0	1.99	3.82	3.81	5.69	5.70	7.67	7.80
Switch case-4 (ONON)	2.1	2.07	4.01	3.99	5.72	5.69	7.65	7.64
Tuning Range (GHz)	1.87 - 2.51		3.72 - 4.22		5.27 - 6.03		7.42 - 8.44	
Tuning Bandwidth (MHz)	645		500		760		1020	

The Proposed Design is compared with the Existing models of DFILA with VL-SRR Stuructures and SRR Structures, Thetable.6 shows the comparison Proposed Design with Existing Models. The possible application of the proposed antenna is Electronic warfare, Band-1 is used for Electronics surveillance, Band-2 used for Electronic Identification, Band-3 used for Electronic attack and. Band-4 used for Electronic Counter attack.

Table 6: Comparison Proposed Design with Existing Models.

Band Name		**Proposed Antenna**	**DFILA with VLSRR (Existing Model)[19]**	**DFILA with SRR (Existing Model)[23]**
Band-1	Varactor Tuning (GHz)	1.87 - 2.51	1.75 to 2.58	3.28 to 3.70
	Band width (MHz)	645	828	425
	Impedance bandwidth%	6.12	11.62	4.2
Band-2	Varactor Tuning (GHz)	3.72 - 4.22	3.45 to 4.23	6.42 to 6.75
	Band width (MHz)	500	775.2	331
	Impedance bandwidth%	8.42	18.07	7.5
Band-3	Varactor Tuning (GHz)	5.27 - 6.03	5.43 to 6.44	13.75 to 14.21
	Band width (MHz)	760	1001	460
	Impedance bandwidth%	6.9	21.86	4.8
Band-4	Varactor Tuning (GHz)	7.42 - 8.44	7.13 to 8.15	Band Not Exist
	Band width (MHz)	1020	1020	
	Impedance bandwidth%	9.16	17.17	

4. Conclusion

A novel twin frequency tenable circularly polarized twin dual folded inverted-L antenna (DFILA) with varactor loaded split-ring resonator structures (VLSRR) is developed in the proposed paper. The proposed antenna consists of two DFILA elements with dual folding arms on both side lengths and with a varactor loaded split-ring resonator (VLSRR) the structure on both DFILA antennas that was made tunable by loading a variable capacitance diode in the SRR gap. The antenna structure is minimized is to be about 66 x 10 x 1mm^3(0.66cm^3). This paper described the antenna characteristics and showed that it achieved the multi-band characteristicsof Four bands, The band-1 (1.87 – 2.51GHz) with varactor tuning of 645MHz,the band-2 (3.72 – 4.22GHz) with varactor tuning of 500MHz, the band-3 (5.27 – 6.03GHz) with varactor tuning of760MHz and The band-4 (7.42-8.44GHz) with varactor tuning of 1020MHz. With the impedance bandwidth of 6%, VSWR < 2, and 3-dB axial ratio (AR) <3 across the entire operating bands. The tunable antenna makes it possible to avoid decreases in radiation efficiency in the frequency bands.

5. References

B. Pendry, A. J. Holden, D. J. Robbins, and W. J. Stewart, "Magnetism from conductors and enhanced nonlinear phenomena," IEEE Trans. Microw. Theory Tech., vol. 47, no. 11, pp. 2075–2084, Nov.1999.

Choi, E.-C., J. W. Lee, and T.-K. Lee, "An axial ratio beamwidth enhancement of S-band satellite antenna with parasitic elements and its arrays," IEEE Antennas Wireless Propag. Lett., Vol. 13, 1689–1692, 2014.

D. Daniel, "A circularly polarized planar antenna modified for passive UHF RFID," in Proc. IEEE Int. Conf. RFID, 2009, pp. 265–269.

Deshmukh, A. A. and K. P. Ray, "Broadband proximity-fed square-ring microstrip antennas,"IEEE Antennas Propag. Magazine, Vol. 56, No. 2, 89–107, 2014.

E. Ozbay, K. Aydin, S. Butun, K. Kolodziejak and D. Pawlak, "Ferroelectric based tuneable SRR based metamaterial for microwave applications," in Proceedings of the 37th European Microwave Conference, 497-9 (2007)

Gao, S., Q. Luo, and F. Zhu, Circular Polarized Antenna, John Wiley & Sons Ltd, 2014.

H. See, R. A. Abd-Alhameed, D. Zhou, and P. S. Excell, "Dualfrequency planar inverted F-L-antenna (PIFLA) for WLAN and short range communication systems," IEEE Trans. Antennas Propag., vol. 56, no. 10, pp. 3318–3321, Oct. 2008.

Ha, K. Kwon, Y. Lee, and J. Choi, "Hybrid mode wideband patch antenna loaded with a planar metamaterial unit cell," IEEE Trans. Antennas Propag., vol. 60, no. 2, pp. 1143–1147, Feb. 2012.

J. Herraiz-Martínez, L. E. García-Muñoz, D. González-Ovejero, V.González-Posadas, and D. Segovia-Vargas,"Dual-frequency printed dipole loaded with split ring resonators," IEEE Antennas Wireless Propag. Lett., vol. 8, pp. 137–140, 2009.

J. D. Baena, J. Bonache, F. Martín, R. Marqués, F. Falcone, T. Lopetegi, M. A. G. Laso, J. García, I. Gil, and M. Sorolla, "Equivalent circuit models for split ring resonators and complementary split rings resonators coupled to planar transmission lines," IEEE Trans. Microw. Theory Tech., vol. 53, no. 4, pp. 1451–1461, Apr. 2005.

JUN ZHANG, JIANXING LI AND JUAN CHEN "Mutual Coupling Reduction of a Circularly Polarized Four-Element Antenna Array Using Metamaterial Absorber for Unmanned Vehicles" 2019. Digital Object Identifier 10.1109/ACCESS.2019.2913552

Kim and V. V. Varadan, "Electrically small, millimeter wave dual band meta-resonator antennas," IEEE Trans. Antennas Propag., vol. 58, no. 11, pp. 3458–3463, Nov. 2010.

Kumar, B. A., & Rao, P. T. (2015, July). Overview of advances in communication technologies. In Electromagnetic Interference and Compatibility (INCEMIC), 2015 13th International Conference on (pp. 102-106). IEEE.

Li, M. and K.-M. Luk, "Wideband Magnetoelectric Dipole antennas with dual polarization and circular polarization," IEEE Antennas and Propagation Magazine, Vol. 57, No. 1, Feb. 2015.

Ling Sun*, Baohua Sun, He Wu, Jiangpeng Yuan, and Wending Tang "Broadband, Wide Beam Circularly Polarized Antenna with a Novel Matching Structure for Satellite Communications" Progress In Electromagnetics Research C, Vol. 59, 159–166, 2015

Luo, Y., Q.-X. Chu, and L. Zhu, "A miniaturized wide-beamwidth circularly polarized planar antenna via two pairs of folded dipoles in a square contour," IEEE Trans. Antennas Propag., Vol. 63, No. 8, 3753–3759, Aug. 2015.

Li, X. Q. Lin, J. Y. Chin, R. Liu, and T. J. Cui, "A novelminiaturized printed planar antenna using split-ring resonator," IEEE Antennas Wireless Propag. Lett., vol. 7, pp. 629–631, 2008.

Liu, J. Guo, L. Zhao, X. Shen, and Y. Yin, ''A meta-surface decoupling method for two linear polarized antenna array in sub-6 GHz base station applications,'' IEEE Access, vol. 7, pp. 2759–2768, 2018.

Kumar, P. P., & Rao, P. T. (2021). Frequency- tunable circularly polarized twin dual folded inverted- L antenna with varactor- loaded split- ring resonator structures. *International Journal of Communication Systems*, e4715.

Nesic, S. Jovanovic, and I. Radnovic, "Wideband printed antenna with circular polarization," in Proc. IEEE AP-S Int. Symp., 1997, vol. 3, pp. 1882–1885.

Nesic, I. Radnovic, and M. Mikavica, "Printed antenna and array with circular polarization," Electron. Lett., vol. 32, no. 9, pp. 785–786, 1996.

Nakano, Y. Sato, H. Mimaki, and J. Yamauchi, "An inverted FL antenna for dual-frequency operation," IEEE Trans. Antennas Propag.,vol. 53, no. 8, pp. 2417–2422, Aug. 2005.

P C Praveen Kumar, P Trinatha Rao " Design of Reconfigurable Circularly Polarized Double Folded Inverted-L Antenna with Rectangular Ground Plane using HFSS"IET networks, NET-2019-0218.R1,2020.

Quevedo-Teruel,M. N.Mou Kehn, and E. Rajo-Iglesias, "Dual-band patch antennas based on short-circuited split ring resonators," IEEE Trans. Antennas Propag., vol. 59, no. 8, pp. 2758–2765, Aug. 2011.

PC Praveen Kumar, P.Trinatha Rao, "Dual Staircase Shaped Microstrip Patch Antenna"ICPC-2015, IEEE Xplorer Digital Library, ISBN: 978-1-4799 6272-3,DOI:10.1109/PERVASIVA.2015.7086964.

Praveen Chenna, Trinatha Rao , "Design of Twin inverted L Microstrip Antenna using HFSS Software for sustainable systems" International Journal of Computer Aided Engineering and Technology(IJCAET) DOI: 10.1504/IJCAET.2021.10023552.

Ping Jack Soh, Azremi Abdullah Al-Hadi, Mohd Faizal Jamlos ,"A Tunable Inverted-L Antenna (TILA) for LTE Mobile Terminals Surentiran Padmanathan", 978-1-5386-0465-2017 IEEE ISAP2017, Phuket, Thailand.

Rakesh Nath Tiwari, Prabhakar Singh and Binod K. Kanaujia"Butter Fly Shape Compact Microstrip Antenna for Wideband Applications", Progress In Electromagnetics Research Letters, Vol. 69, 45–50, 2017.

R.Marqués, F.Mesa, J.Martel, and F.Medina, "Comparative analysis of edge- and broadside-coupled split ring resonators for metamaterial design-theory and experiments," IEEE Trans. Antennas Propag., vol. 51, no. 10, pp. 2572–2581, Oct. 2003.

R. Lee, H. K. Ryu, S. Lim, and J. M. Woo, "A miniaturized, dualband, circularly polarized microstrip antenna for installation into satellite mobile phones," IEEE Antenna Wireless Propag. Lett., vol. 8, pp.823–825, 2009.

Sharma, Anuj Kumar & Sharma, Vipul & Singh, Shiv & Garg, Tanuj & Singh, Sanjay & Kumar, Anuj. (2023). Fractal Array Antenna: A Review of the State of the Art. European Chemical Bulletin. 1460-1474.10.48047/ecb/2023.12.7.11020 23.13/06/2023.

Soras, M. Karaboikis, G. Tsachtsiris, and V. Makios, "Antenna printed on aPCMCIA card for the 2.4 GHz ISM band," IEEE Antennas Propag. Mag., vol. 44, no. 1, pp. 37–44, Feb. 2002.

Takemura, "Inverted-FL antenna with self-complementary structure," IEEE Trans. Antennas Propag., vol. 57, no. 10, pp. 3029–3035, Oct. 2009

W.-K. Park, S.-S. Oh, Y.-H. Lee, and H.-D. Park, "Frequency-tunable waveguide antenna with minitaturized aperture using a varactor-loaded split-ring resonator," IEEE Antennas Wireless Propag. Lett., vol. 9, pp. 1233–1236, 2010.

W. S. Chen, C. K. Wu, and K. L. Wong, "Novel compact circularly polarized square microstrip antenna," IEEE Trans. Antennas Propag.,vol. 49, no. 3, pp. 340–342, Mar. 2001.

W. S. Yoon, S. M. Han, J. W. Baik, S. Pyo, J. Lee, and Y. S. Kim,"Crossed dipole antenna with switchable circular polarisation sense,"Electron. Lett., vol. 45, pp. 785–786, 2009.

W. Baik, K. J. Lee, W. S. Yoon, T. H. Lee, and Y. S. Kim, "Circularly polarised printed crossed dipole antennas with broadband axial ratio," Electron. Lett., vol. 44, pp. 785–786, 2008.

X. F. Peng, S. S. Zhong, S. Q. Xu, and Q. Wu, "Compact dual-band GPS microstrip atnenna," Microw. Opt. Technol. Lett., vol. 44, pp.58–61, 2005.

X. L. Bao and M. J. Ammann, "Dual-frequency dual circularly-polarized patch antenna with wide beamwidth," Electron. Lett., vol. 44, no. 21, pp. 1233–1234, 2008.

Y. Dong, H. Toyao, and T. Itoh, "Design and characterization of miniaturized patch antennas loaded with complementary split-ring resonators," IEEE Trans. Antennas Propag., vol. 60, no. 2, pp. 772–785, Feb. 2012.

Y. J. Zhou, C. C. Chen, and J. L. Volakis, "Single-fed circularly polarized antenna element with reducedcoupling for GPS arrays," IEEETrans. Antennas Propag., vol. 56, no. 5, pp. 1469–1472, May 2008.

Z. Qamar, U. Naeem, S. A. Khan, M. Chongcheawchamnan, and M. F. Shafique, ''Mutual coupling reduction for high-performance densely packed patch antenna arrays on finite substrate,'' IEEE Trans. Antennas Propag., vol. 64, no. 5, pp. 1653–1660, May 2016.

Z. Liu et al., ''Enhancing isolation of antenna arrays by simultaneously blocking and guiding magnetic field lines using magnetic metamaterials,'' Appl. Phys. Lett., vol. 109, no. 15, Sep. 2016, Art. no. 153505.

Z. N. Chen, "Note on impedance characteristics of L-shaped wire monopole antenna," Microw. Opt. Technol. Lett., vol. 44, pp. 58–61,2005.

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