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An Inter digital- Poison Ivy Leaf Shaped Filtenna with Multiple Defects in Ground for S-Band bandwidth Applications

Ch. Amarnatha Sarma[1], Syed Inthiyaz[2], B T P Madhav[3], P Sree Lakshmi[4]
[1]Research Scholar, Department of ECE, Koneru Lakshmaiah Education Foundation, Andhra Pradesh, India.sarma.chakrala@gmail.com
[2]Faculty, Department of ECE, Koneru Lakshmaiah Education Foundation, Andhra Pradesh, India.syedinthiyaz@kluniversity.in
[3]Faculty, Department of ECE, Koneru Lakshmaiah Education Foundation, Andhra Pradesh, India, btpmadhav@kluniversity.in
[4]Associate Professor, Department of ECE, Audisankara Institute of Technology, Gudur, Andhra Pradesh, India, sree1612@gmail.com

Abstract:

The proposed work, a filtenna for s band application is implemented. It is designed by embedding an Interdigital band pass filter (IDBPF) and leaf shaped antenna which are operated in S band. The IDFBPF is having seven resonators with one end shorted through dual vias. It offers a bandwidth of 1.3GHz from 1.65GHz to 2.95GHz. A Dumbbell shaped DGS (Defected Ground Structure) provided in ground to improve the filter characteristics. Measured pass (BRL) band return loss (S_{11}) & insertion loss (S_{12}) are -18dB & -4.6dB correspondingly. Further, leaf shaped antenna is designed based on modified polar transformation equation; it has 2.7 GHz bandwidth from 1.3 GH to 3 GHz and has a gain of -5.45dBi, and return loss (S_{11}) of -19.5 dB. The filtenna is obtained by integrating the IDBBPF in the fodder line of the leaf designed antenna**.** The final model has 1.2 GHz operating bandwidth from 02.30 GHz to 03.50 GHz with peak arrival damages at 2.4GHz and 3.1GHz with -20dB and-24dB respectively. The designed filtenna has a pass band gain of -5.3dBi. The shift in operating band is due to combining the filter with antenna. The proposed model is invented on FR4 substrate having a wideness of 01.60 mm and having a dimension of $0.25\times 0.58\ \lambda_0^2$. In this final model two complementary slip ring resonators (CSRR) are used in addition with four dumbbell structures as defects in the ground plane to avoid ripples in return loss (S_{11}) graph. A high degree of concordance exists between empirically measured and simulated outcomes. The radiation band is showing its application in S band wireless mobile communications, Wi-Fi and ISM 2.4GHz band.

Keywords: IDBPF, CSRR, DGS, vias, Polar transformation, Leaf shaped antenna

1. Introduction

Now-a-day demand for wireless communications are increased rapidly, predominantly for the S-band (2 – 4 GHz) of micro waves is increased to satisfy the need of end users. This demand made a great in growth in usage of RF wireless communication systems and also settled few challenges like compactness, economical, quality of service etc., for the researchers. If any RF system is considered, the final block in transceiver unit called RF front end system is combination of sub systems like an air interference unit, micro wave filter, and followed by switching unit that communicate with transmitter and receiver units. The air interference unit converts electrical signal to EM signal and vice-versa. The electrical signals are passed through micro wave filtering unit (usually (BPF) band pass filter), (LAN) low noise amplifier, (PA) Power amplifier, and other RF modules. One way to decrease the range of the RF front end system is combining some of these sub systems to one unit without degrading the performance of the system. One of such approach is embedding the filter unit into antenna that results FILTENNA [1].In this work an interdigital bandpass filter (IDBPF) is designed and installed in a leaf shaped antenna feed line. This arrangement performs as both filtering function and antenna function and its pass band gain has enhanced rejection characteristics when compared to conventional antenna. This filtenna structure reduces signal transmission path losses, avoids the interference of antenna with filter, cost and complexity. The major design challenge is filter and antenna both are designed such that the filter pass band and the antenna radiating band both operate at same frequency. There are two approaches to design filtenna, one is designing filter and antenna separately and combining and the other method is incorporating filtering characteristics to antenna. The first approach is less complex and easy to get required parameters but not compact when compared to second approach. Whereas the compact size can get in second approach, but the design complexity is high.

For the intelligent transportation system and Global positioning system [2], an adaptive band pass filter (BPF) is suggested and constructed for the feed line of a MSPA

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(micro strip patch antenna). It is an end fire radiating system and in this work the filter, antenna, and filtenna all are designed. The filtenna designed in [3] is linearly polarized, its insertion loss suffered due to direct insertion of stepped impedance band pass filter in to SIW antenna. Frequency shifting characteristics provided in filtenna by tuning the filter [4] or by tuning the antenna [5]. The filter elements are controlled by PIN diodes which are made using grapheme whereas the antenna tuning in is by both filter and antenna fabricating using malty layer technique on liquid crystals. The filtenna proposed in [6] is fabricated using ink jet technology and it has wide band coverage. In this the filtering function obtained by providing slots on the silver coated patch antenna. The filtenna in [7] is a compact circular shaped co-design angular slot antenna in connected with band pass filter. An arch shaped thee concentric tightly coupled resonators are used to have band pass operation. The resultant filtenna offer narrow band operation. The authors in [8] proposed an artificial material popularly known as Meta material is used in the design filtenna. In this work slip ring resonator is connected in the feed line of rectangular patch. The SRR radiated at on frequency and acts as band pass filter. Two electrically small planar monopole filtennas are designed in [9]. In these planar design structures, the filter part is obtained using capacitive loaded loop (CLL) in one design and slots along with CLL in other design and hence the band of operation is improved form one design to another. A MIMO filtenna proposed in [10], in which slip ring resonator is used to achieve the filtering action and the antenna is simple circular patch with multiple inputs. A monopole antenna with integrated BPF is discussed in [11]. In this coupled line BPF is used. Flower shaped filtenna [12] can offer high gain by providing slots. It offers ultra wide band radiation. Here, filter and antenna both flower shaped and the filtenna is obtained from combining them. The filtenna proposed in [13] is obtained by combining omega shaped band pass filter (BPL) with an antenna of non-regular structure. It shows its applications in 5G communication. Most of the filtenna works are used band pass filters (BPFs) and patch antennas. The BPF are either stepped impedance or coupled line structures and patch antennas are mostly circular or rectangular structures. An Interdigital filter (IDF) structure is a slow wave structure that very much suitable for BPF operation. It is suitable because it has low profile, good band pass band characteristics used only for BPF, and considerable spacing makes the design flexible and the stop band cutoff increased with number of resonators [14][15]. Its unique feature is for band pass filter its another pass band will be at three times of its first middle frequency which escapes the design complexity for required band. In [16][17] discussed exact design steps for Inter digital filter. They are designed to have s-band application [18] or ultra wide band applications [19] or with greater out of band elimination. Its bandwidth can be developed by adding vias, DGS and adding radiators. For single band operation the filter with vias and DGS is proposed in [20], it offers flat pass band and good out band rejection. Modified structures of this IDF, hairpin, asymmetrical shaped, without vias, with vias [21][23] can be designed. The works of [24][26] are discussed about the improvement in the filter characteristics and bandwidth enhancement by with DGS. Various periodic, non-periodic DGS structures are reviewed in [27]. From the literature it is observed that rectangular and circular antennas are popularly used for mobile application. But the feeding of circular patch is not so easy due to impedance matching difficulty. Elliptical PA is implemented to avoid the feeding problems [28]. The Antenna area can be reduced by using bio inspired models such as trees, leaf, and flower shaped and any bio other structure are used in the design [29][30]. These structures may fallow polar transformation, advanced elliptical formula or any perturbation technique in the design [31][32].

Consolidating the literature, a novel filtenna structure that embed Interdigital Band pass filter in the feed path of leaf structured antenna is proposed [33][34]. In this work CSRR and dumbbell shaped defects in ground are provided [35]. The work is divided in to 4 sections. Section 1 covers the literature and outline of the work. Section 2 is gives detailed steps of design, simulation and simulation results of filter, antenna and filtenna. Section 3 presents the final constructed proto type model, together with the associated data and analysis. In the end, Section 4 wraps everything up.

2. Design of Inter Digital Filtenna:

2.1. Inter Digital Band Pass Filter (BPL):

A BPL allows only specified Band of frequencies. In this work Inter digital filter (IDF) structure is used as BPF because of its slow wave structure provides good signal characteristics at set of frequencies. It also provide good band. The basic IDF with symmetric feed of ‘n’ number resonator structure is shown in Figure 1. As shown in fug ‘l_n’ and ‘W_n’ is length and width values of nth resonator.

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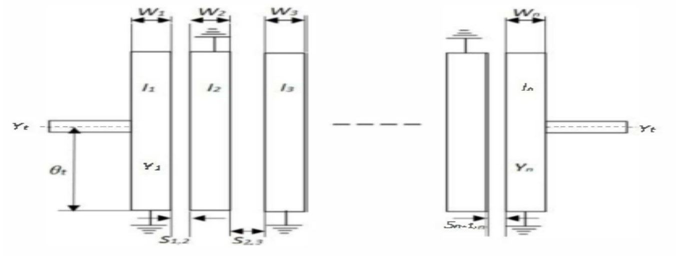


Figure: 1. IDF structure with 'n' number of resonators

The scheme steps for inter digital band-pass filter (BPF) with detailed input/output lines will start by calculate electrical length θ for a bandwidth (BW) using

$$\theta = \frac{\pi}{2}\left(1 - \frac{BW}{2}\right) \quad (1)$$

And the characteristic admittance is Yt of tapped line is

$$Y_t = Y_1 - \frac{Y_{12}^2}{Y_1} \quad (2)$$

Yi, i+1calculated by using, $Y_{i,i+1} = \frac{Y_1}{\sqrt{g_i g_{i+1}}} \cos\theta$ fori $= 1$ ton $- 1$ (3)

Where gi, gi+1 are component parameters of prototype low pass ladder-type filter with controlled frequency ωc= 01

The short circuited end of resonator has its electrical length of θ t is given by

$$\sin\theta_t = \sqrt{\frac{Z_0}{z}}\, \mathrm{sinc}\theta \quad (4)$$

At very high frequency the electrical length is low, above equation can be

$$\theta_t = \sqrt{\frac{Z_0}{Z}} \quad (5)$$

The width 'W_n' of the micro strip line can be calculated by using

$$\frac{w}{h} = \frac{8\left(\frac{7\varepsilon_r+4}{11\varepsilon_r}A + \frac{\varepsilon_r+1}{0.81\varepsilon_r}\right)^{0.5}}{A} \quad (6)$$

Where, $A = \exp\left(\frac{Z_1}{42.4}\sqrt{\varepsilon_r + 1}\right) - 1$ (7)

εr represent substrate dielectric constant & h is its thickness.

After finding width and spacing of resonator its equivalent length li will be obtained using

$$l_i \cong \frac{\lambda_{g0i}}{4} - 2\Delta l_i \quad (8)$$

Where λgoiis guided wave length and is given by

$$\lambda_{g0i} = \frac{\lambda_0}{\sqrt{\varepsilon_{re}}} \quad (9)$$

ε_{re} Represent substrate effective dielectric constant followed by

$$\varepsilon_{re} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1 + 12\frac{h}{w}\right)^{-\frac{1}{2}}, \qquad \text{for } \frac{w}{f} \geq 1$$

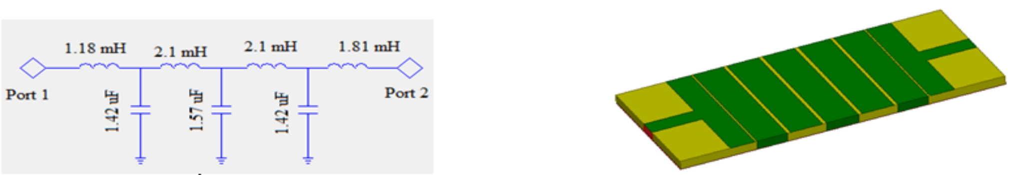
(10)

The length of electrical resonator is maximum value of λ/2 and all resonators are shorted at one end alternatively. In this work, a seven resonator inter-digital structure is designed with middle frequency at 02.60 GHz & its elemental values are identified using ANSYS HFSS software as g1=g7=1.18178, g2=g6=1.4228, g3=g5=2.09667, g4=1.5734 and the dimensions of the inter-digital structure shown in Figure 1 with 7 resonators in given in Table 1.

Table1. IDF design values

Parameter	**Dimensions in Millimeter(mm)**
$l_1 = l_2 = l_3 = l_4 = l_5 = l_6 = l_7$	*16*
$W_1 = W_7$	*2.944*
$W_2 = W_6$	*3.603*
$W_3 = W_5$	*3.788*
θ_t	*7.5*
$S_{12} = S_{67}$	*0.2297*
$S_{23} = S_{56}$	*0.434*
$S_{34} = S_{45}$	*0.478*

The equivalent lumped model of proposed Inter Digital Band Pass Filter (IDBPF) is shown in Figure 2(a). The micro strip model is formed on FR4 substrate having εr = 04.20 has substrate height of 01.60 mm. The proposed structure shown by 2(b) figure.



(a) (b)

Figure 2(a) Lumped model of proposed IDBPF (b). Micro strip IDBPF

Instead of shorting one end of resonator, Vias with 1 mm diameter are used for shorting alternate opposite ends of each resonator. The first and last resonator lengths are increased at both ends give smooth stop band characteristics

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(14). Hence length of resonators l1and l7are increased by 0.5mm each side to insert zeros at stop band. To improve filter characteristics dumbbell shaped etching in the ground plane provided. A dumb bell shaped DGS and its equivalent to LC tank network is shown in figure 3((a), (b) & approximation of inductance (Ld), capacitance (Cd) vales are fallow Eq. 11, 12 respectively.

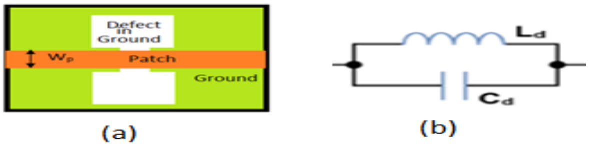


Figure 3(a). Dumb bell shaped defect in ground; (b). Equivalent of DGS structure.

The parameters Ld & Cd are calculated by using the equations.

$$C_d = \frac{5 f_c}{\pi (f_0^2 - f_c^2)} \quad (11)$$

$$L_d = \frac{250}{\pi^2 f_0^2 c} \quad (12)$$

Where, f_c & f_0 are cutoff & resonant frequency of stop band correspondingly.

In Figure 4 the IDBPF simulated model with via and DGS is shown; it's step by step simulation result and the consolidated S-parameter simulated outcomes are shown in figure 5 on same scale.

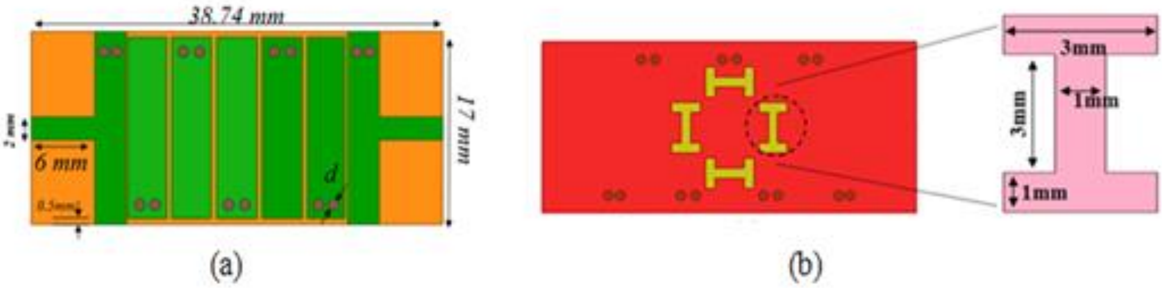
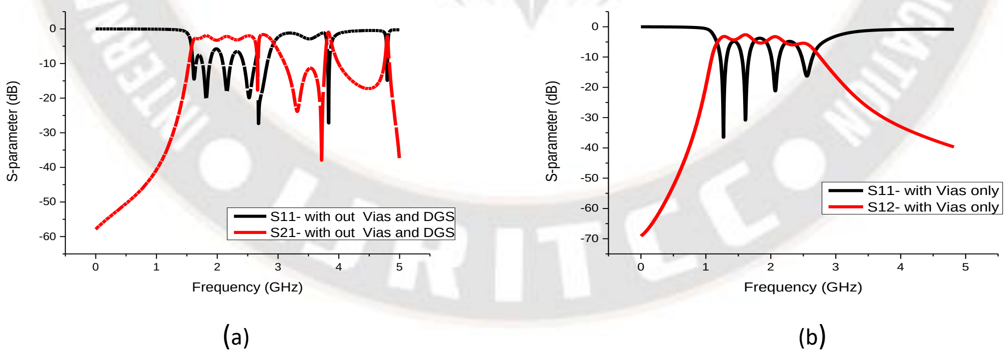


Figure 4. IDBPF with via and dumb bell shaped DGS: (a). Upper outlook (b) lowest outlook



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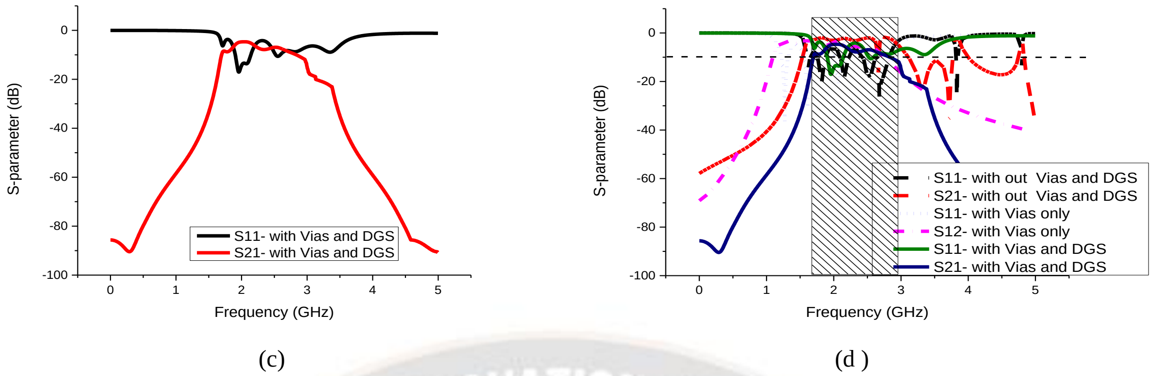

Figure 5. Return loss (S_{11}) & insertion loss (S_{12}) of IDPF: (a) Without vias and DGS ;(b) with Vias ;(c) With vias and DGS (d) Consolidated S-parameter simulation results of (a),(b) and (c)

It is evident that adding vias and defects in ground plane, the filter offer betters characteristics than without Vias, DGS and with vias only.

2.2 Antenna design:

The design of leaf antenna is starts by design of rectangular antenna and the patch area is removed to shape of leaf. The rectangular patch antenna can be designed using the design equations given below. The width of the rectangular parch in millimeter (mm) is obtained by

$$W = \frac{212}{f_r\sqrt{\varepsilon_r+1}}\ mm \quad (13)$$

Where fr is in GHz, and εr represent substrate Dielectric constant

The length is calculated by

$$L = L_{eff} - 2\Delta L \quad (14)$$

Where, $L_{eff} = \frac{150}{\sqrt{\varepsilon_{eff}}}$ (15)

$$\Delta L = 00.412\ h\ \frac{(\varepsilon_{eff}+00.3)\left(\frac{W}{h}+00.264\right)}{(\varepsilon_{eff}-00.258)\left(\frac{W}{h}+00.8\right)} \quad (16)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{2h}{w}\right)^{-1/2} \quad (17)$$

The ground is removed till feed line so that Omni directional radiation pattern is obtained. The patch area can be reduced by using the leaf model which is designed by using the polar transformations Equation (18). Different shapes using above formula depends on 'k' values are shown in the Figure 6.

$$\vec{P} = \left(1+\frac{\cos(t)}{2}\right)\left(\mathrm{Cos}\left(\frac{2t-\sin(2t)}{k}\right), \mathrm{Sin}\left(\frac{2t-\sin(2t)}{k}\right)\right), 0 \le t \le k\pi \quad (18)$$

The new antenna design fallow which is developed from modified polar transformation equation given by Equation (19) and the shapes are shown in Figure 7.

$$\vec{P_M} \rightarrow f(\vec{P} \cup \vec{M}) \quad (19)$$

Where, $\vec{M} = \left(0.2 + q0.8\mathrm{Cos}\left(\frac{2t-\sin(2t)}{k}\right), 0.4 + q0.8\mathrm{Sin}\left(\frac{2t-\sin(2t)}{k}\right)\right), \quad 0 \le t \le k\pi$ (20)

$$m = \left(1+\frac{\cos(t)}{2}\right) \quad (21)$$

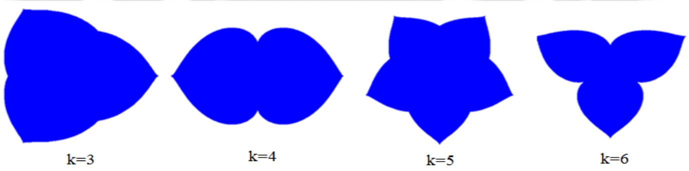

Figure 6. Nature inspired models from different values of 'k' from equation 18

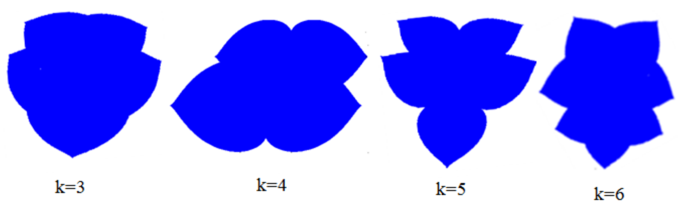

Figure 7. Nature inspired models from different values of 'k' from equation 19

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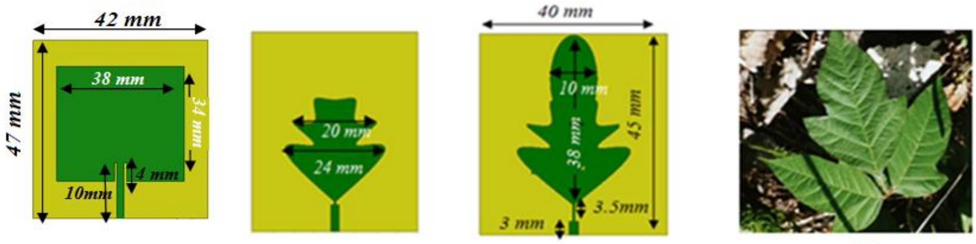
In this work the shape of the antenna inspired from "Poison ivy" leaf shape. The shape is obtained using Eq. 20 with k=5 and an elliptical patches. The dimensions are approximated y trial and error method, but it is noted that this antenna occupies less area when compared to conventional rectangular patch antenna for the same operating frequency. Figure.8. constructional details of leaf shaped antenna from rectangular patch is shown. It shows two antenna designs, Antenna design 1 is based on Eq.18 and Antenna 2 is based and Eq.19 added with elliptical patch. These antennas return loss and their compression shown by figure 9.



(a) (b) (c) (d)

Figure 8. (a) Rectangular patch (b) Antenna-1 (c) Antenna-2 (d) "Poison ivy" Leaf

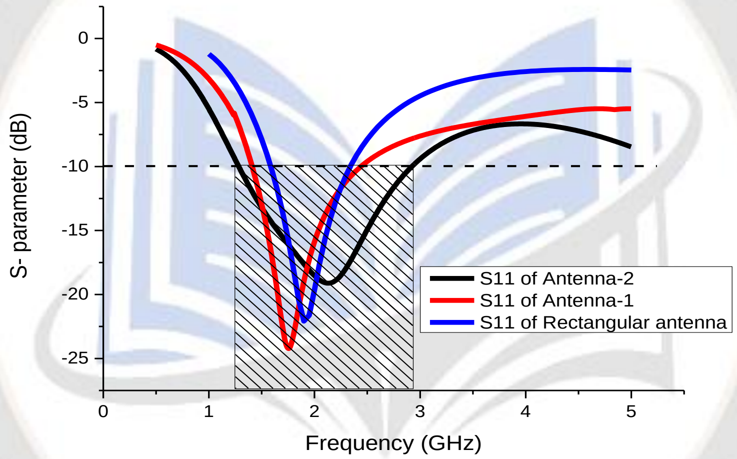


Figure 9. Comaprission of S11 of Antenna 2 with Antenna 1 and rectangular antenna

From the simulation results of three designs shown above, the Antenna-2 i.e leaf shaped antenna offer good return loss with comparatively wide and less space.

2.3 Filtenna design

The Interdigital Band Pas Filter shown in Figure 10 and leaf shaped antenna model shown Figure 10(c) are combined to get Inter digital Filtenna (IDF) Design. The Filtenna design is optimized in three steps using commercial EM tool HFSS simulation. In first step is IDF Design 1, in this the IDBPF is embedded in the feed line of leaf shaped antenna. In step is IDF Design 2, in this two CSRR defects near the feed line in ground is provided to reduce the ripples in pass band. The IDF Design 3 is last step, in this the patch modified ad anchor shape to have non rippled return loss curve. The Figure 8 shows the IDF top and bottom planes with dimensions. The Table 2 explains the design structures of Design 1, 2 &3.

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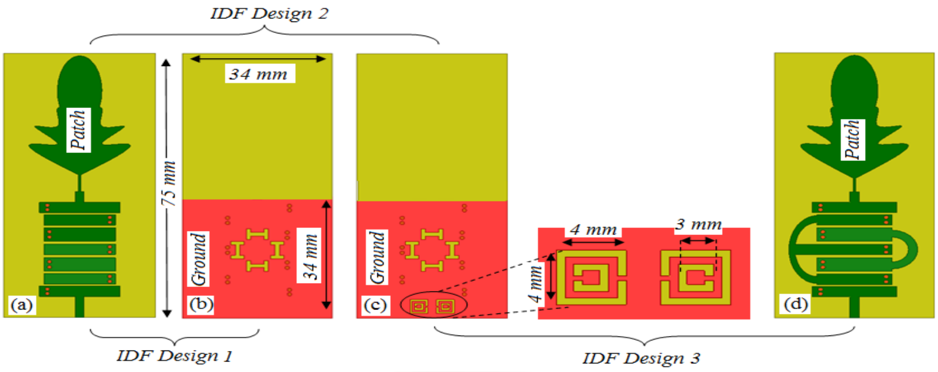
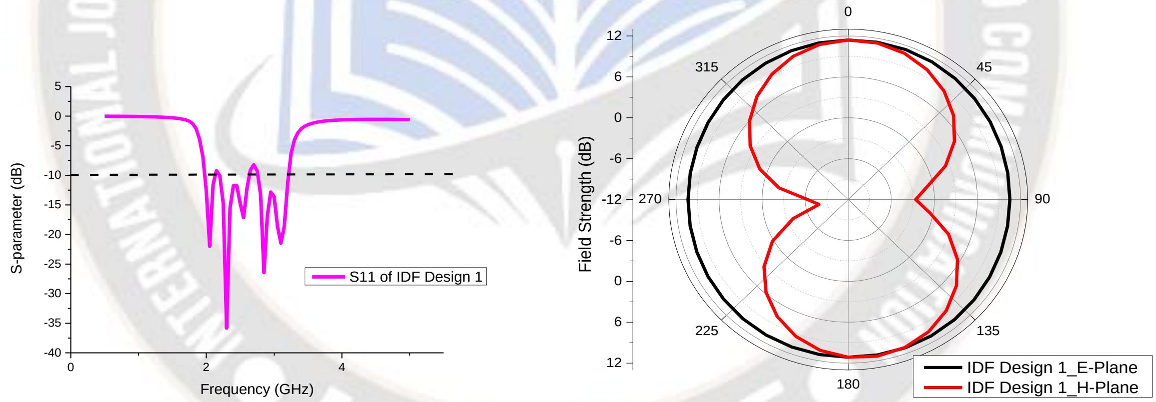


Figure.10. Interdigital Filtenna design: (a) Patch Filtenna (b) Etched ground with DGS (c) Etched ground with DGS and SRR (d) Modified Patch Filtenna

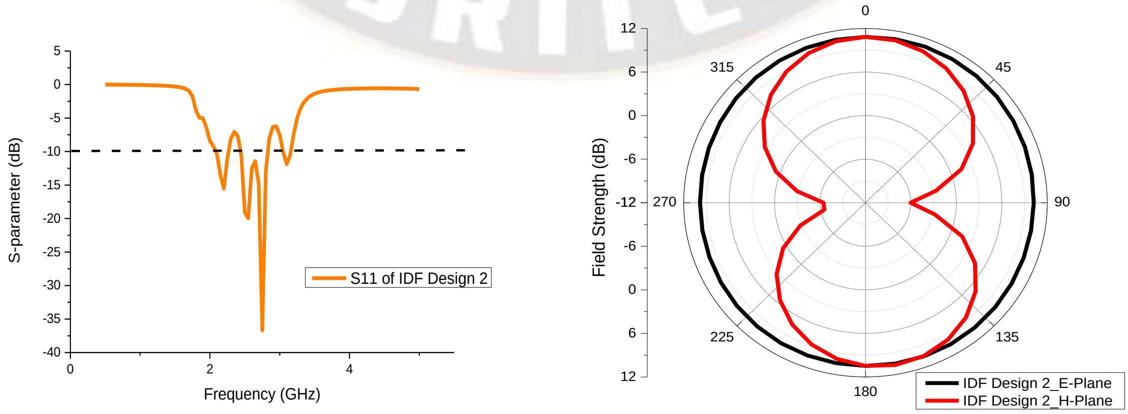
Table 2: Inter Digital Filtenna designs

Design Type	Top view	Bottom	Remarks
IDF Design 1	(a)	(b)	Etched ground and Dumb-ell shaped DGS
IDF Design 2	(b)	(c)	Etched ground and Dumb-ell shaped DGS and CSRR
IDF Design 3	(d)	(c)	Etched ground and Dumb-ell shaped DGS and CSRR and modified patch on top

Their simulation S-parameter and radiation results of all three designs are plotted in Figure 11(a) shown below



(a)



(b)

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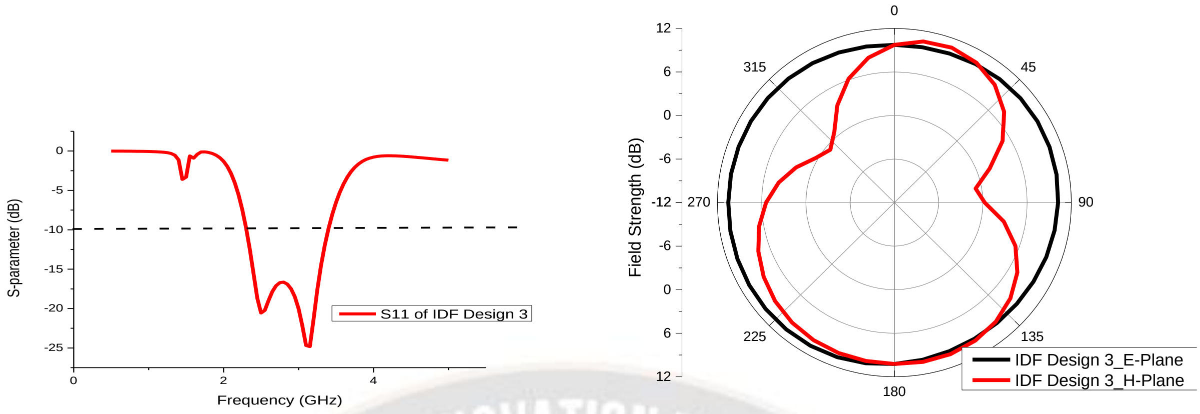


(c)

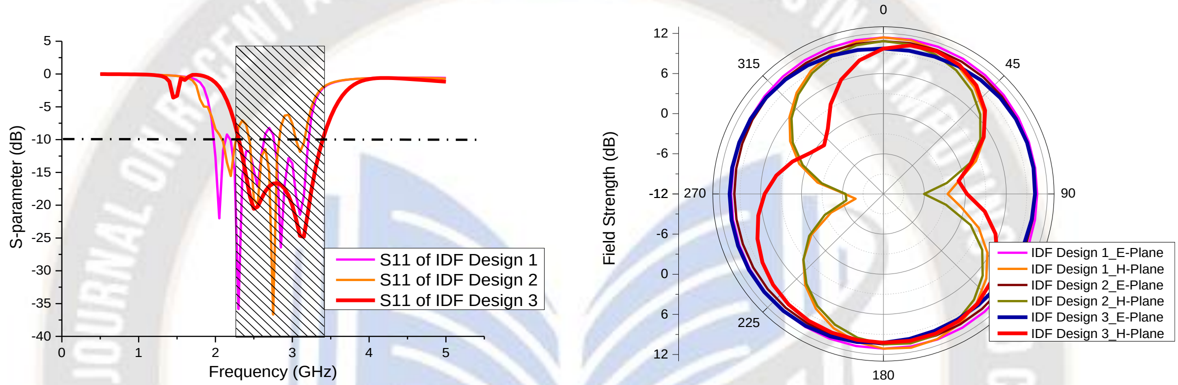
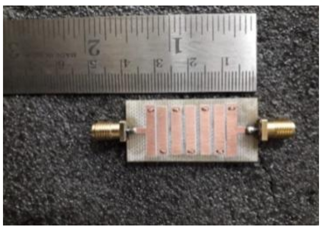


Figure 11. Interdigital Filtenna designs simulation results: (a) Return loss (S11) radiation pattern on IDF Design 1; (b) Return loss (S11) radiation pattern on IDF Design 2; (c) Return loss (S11) radiation pattern on IDF Design 3; (d) Comparisons of results between three designs

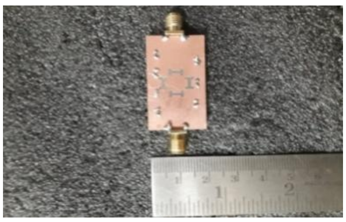
3. Results and Discussions:

From those simulated results given in Figure 11, Design 1 has frequency waves in pass band i.e. poor S11 parameter response. In Design 2 a pair of CSRR defects in the ground is added that shows an improvement in the parameter S11 below -10dB but its waves in pass band are not reduced. The waves in the pass band further reduced significantly in Design 3. Likewise the when the radiation patters of filtenna designs inspected, the radiation patterns of Design 1 and 2 are offer similar properties. Design 3 having little narrow beam width of radiation pattern in one direction and greater beam width in other direction when compared to Design 1 and 2. Consolidating these simulation results the Design 3 gives better performance in both reflection loss and radiation pattern.

The Inter digital filter shown in Figure is fabricated on 1.6 mm thickness FR4 substrate. Its ground has dumb bell shaped DGS. The prototype, measurement setup and its measurement result *Vs* simulation result plots shown by figure 12 (a), (b), & (c) respectively.



(a)



(b)

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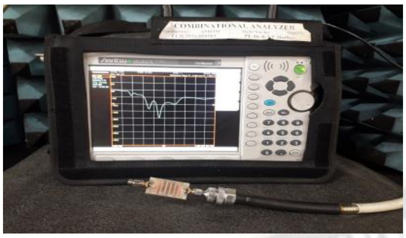

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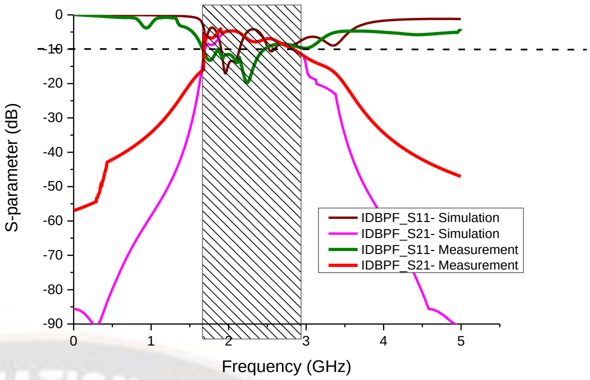
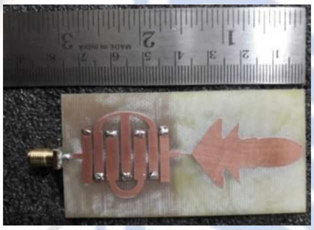


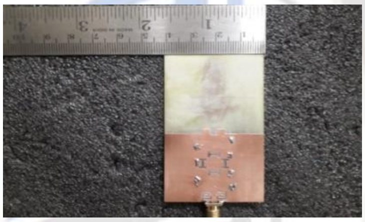
(d)

Figure 12 (a) Prototype of proposed IDBPF top view ;(b) bottom view; (b) S- Parameter Measurement setup; (c) S- Parameter of IDBPF measurement result Vs simulation result

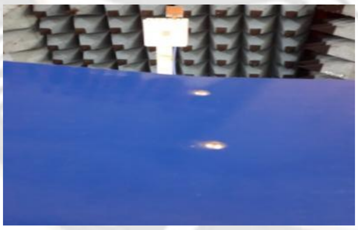
The Figure 13 shows the proto type of final design, IDF Design 3 i.e. Interdigital- leaf shaped Filtenna top view, bottom view, measurement setup for S11 calculation and radiation pattern is shown. The Figure 14 shows measured & simulated results and their comparison.



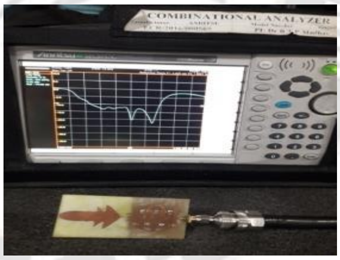
(a)



(b)



(c)



(d)

Figure.13. Interdigital Filtenna prototype: (a) Upper view; (b) Lowest view; (c) Radiation Measurement setup; (d) Return loss measurement

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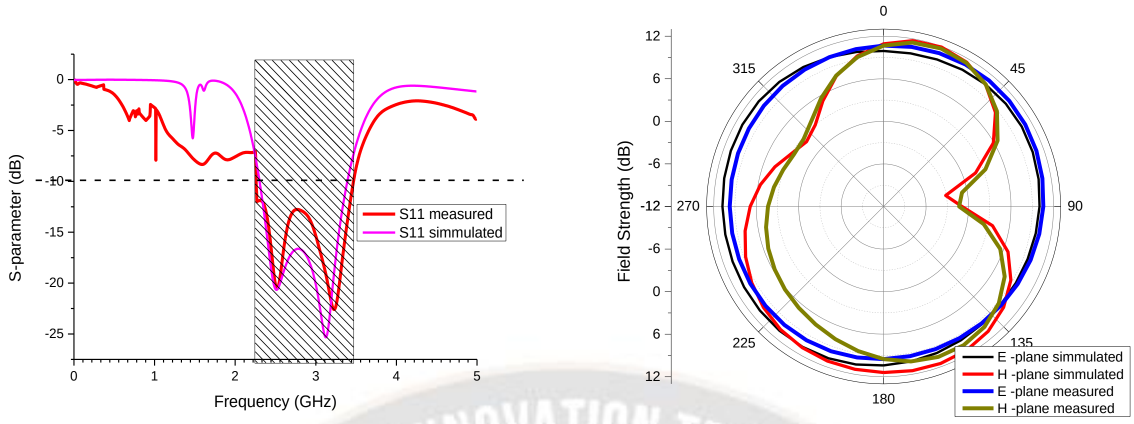

(a) (b)

Figure14. Interdigital Filtenna prototype simulation, and measured results comparison
(a) Reflection loss (S11) ; (b) Radiation pattern

The reflection losses are below -10 dB for the band same as simulated one. But the stop band ripples and the radiation pattern is also having deviation from simulated. These variations are due to the physical errors, which can be tolerable.

4. CONCLUSION:

In this work an Inter digital band pass filter, “Poison ivy” leaf shaped antenna and the embedding them a filtenna structure is the is proposed and fabricated. This reduces the hardware requirement in the transmitter and receiver units that results the leaf shaped antenna reduces the size and unnecessary signal loss front end of transceiver unit. The measured results are slightly deviated from simulated results in its radiation pattern. The reflection losses measured and simulated are same for the operating band 2.3 to 3.5 GHz which is 1.2 GHz bandwidth. This covers maximum applications in S band inkling ISM 2.4 GHz band also. Its maximum radiation gain 3.3 GHz and the reflection loss is about -25dB.

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