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FSS Integrated High Gain Broadband Antenna

Tapas Tewary[1], Smarajit Maity[2], Arindum Mukherjee[3], Avisankar Roy[4], Sunandan Bhunia[5,*]

[1] *Department of ECE, Academy of Technology, Hooghly, West Bengal, India*
[2] *Department of AEIE, Academy of Technology, Hooghly, West Bengal, India*
[3] *Department of ECE, Central Institute of Technology, Kokrajhar, Assam, India*
[4] *Department of ECE, Haldia Institute of Technology, Haldia, West Bengal, India*
[5] *Department of ECE, Central Institute of Technology, Kokrajhar, Assam, India*

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This research work represents hybrid shape microstrip patch broadband antenna for wireless communication application. This hybrid shaped antenna exhibits broadband characteristics (2.27 GHz – 5.55 GHz) with 84 % fractional bandwidth and 3.96 dBi peak gain at 3.93 GHz. An elliptical shaped reference patch is loaded with another elliptical shaped slot to design the final patch of the proposed antenna. Full rectangular ground plane is first reduced along the width and two rectangular slots are loaded in proper position to design the ground plane of the presented antenna. The antenna resonates at 2.6 GHz, 3.4 GHz and 5.15 GHz. So the antenna can be suitably used for Wi-Fi (2.4 GHz, 5 GHz), WiMAX band (3.4), Bluetooth (2.4 GHz) applications and other short range communication. Further gain improvement is achieved by incorporating 6 × 6 FSS (Frequency Selective Surface) structure with the antenna at optimal position without hampering broadband characteristics. Maximum gain enhancement of 5.1 dBi at 2.6 GHz and peak gain of 7.3 dBi at 2.6 GHz are achieved for composite structure of the FSS and antenna. Physical size of only antenna is 30 mm × 40 mm × 1.6 mm and FSS integrated antenna's overall dimension is 96 mm × 96 mm × 40 mm. Electrical size of only antenna is $0.227\lambda \times 0.3\lambda \times 0.012\lambda$ and overall electrical dimension Proposed antenna is $0.67\lambda \times 0.67\lambda \times 0.28\lambda$. Proposed antenna, unit cell FSS and composite structure are constructed using FR-4 substrate (1.6 mm thick, loss tangent ~ 0.02, dielectric constant ~ 4.4) and simulated by CST software. FSS integrated antenna can be utilized for long range communication.

Keywords: Broadband, Hybrid, FSS, High gain.

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1. INTRODUCTION

In the present day world, various kinds of electronic gadgets are all around us. These electronic gadgets, which often overlap with each other, require a standard technology with fast data rates. This can be achieved by increasing channel capacity (bandwidth dependence) and signal to noise ratio (SNR). In this situation broadband technology appears to be a promising solution for high capacity channel. For this reason, researchers are pursuing a variety of different ways to develop broadband antennas that are capable of resonating at many frequencies and having applications across several frequency bands.Modern communication systems make extensive application of microstrip patch antennas due to their many advantages like tiny size, light weight, and support for many resonant frequencies. But, the main drawbacks of this type of antenna are narrow bandwidth and low gain. Researchers are looking into a variety of techniques, including slots loading in radiating patches and ground planes, use of parasitic patches, use of metamaterial, the application of various types of dielectric substrate, augmentation of substrate width through the use of air gaps, use of defective ground structures and shorting pin technique, hybrid shaped patches, modification of path geometry etc. In recent times in place of normal structures such as square, rectangular, circular, triangular, elliptical, etc., hybrid structures like 'bloom shaped', 'flower shaped', 'dumbbell shaped', 'skirt shaped',' inverted sigmoid-shaped' radiating patches and ground planes are being researched as a means of achieving improved impedance matching. Because of the improved impedance matching, the bandwidth has been increased [1-14]. Integration of FSS with the suggested antenna offers the greatest gain boost compared to other approaches [15-18].

This article introduces an inset fed thin hybrid shape broadband microstrip patch antenna that is obtained by altering the reference structure's ground plane and radiating patch by adding slots of proper dimension in proper location. At 3.93 GHz, a maximum gain of 3.96 dBi is attained. By loading an elliptical slot in an elliptical-shaped radiating patch, it is possible to achieve broad characteristics between 2.27 and 5.5 GHz with 84 % fractional bandwidth. To increase antenna gain, a single layer 6 × 6 FSS (96 mm × 96 mm × 1.6 mm) is placed beneath the suggested patch antenna at a reasonable distance (37 mm). This improvement occurs without affecting the antenna's original bandwidth.The reported antenna may be suitably used short range and long range communications etc.

* s.bhunia@cit.ac.in

2. ANTENNA CONFIGURATION, ANTENNA DESIGN ANTENNA RESULT

Fig. 1(a) shows radiating patch and Fig. 1(b) shows ground plane structure of the proposed antenna. An elliptical shaped reference patch is loaded with another elliptical slot to design the final patch. Full rectangular ground plane is first reduced along the width and two rectangular slots are loaded in proper position to design the ground plane. Table 1 tabulates values of all variables of proposed antenna and unit cell FSS structure. Fig. 2(a) illustrates designed steps of presented antenna and Fig. 2(b) shows reflection coefficients of all six design steps. Step 1 illustrates reference antenna having elliptical patch for radiating and finite ground plane. But impedance matching is not so good for this finite ground plane. So reference antenna resonates at 7.6 GHz. Then an elliptical slot is loaded in patch to create multiple frequency bands as shown in step 2. From reflection coefficient corresponding to step 2 it is seen that at 6.6 GHz the antenna resonates. But still impedance matching is poor and broadband characteristic is not achieved. To obtain impedance matching within a large frequency band, ground plane is modified by loading rectangular shaped slots of optimum length and width. In step 3 ground plane width is reduced and due to this step two frequency bands are obtained. One is 2.3 GHz to 2.7 GHz and other is 6.4 GHz to 6.6 GHz. In step 4 only left slot is loaded in reduced ground plane. Reflection coefficient corresponding to step 4 shows again two frequency bands. One frequency band is 2.4 GHz to 2.8 GHz and the other is 5.7 GHz to 7.4 GHz. In step 5 only right slot is loaded to obtain three frequency bands as can be seen from Fig. 2(b). First band is 2.4 GHz to 2.6 GHz, second is 3.6 GHz to 4.7 GHz; the third is from 5.2 GHz to 5.6 GHz. When two slots are loaded at the same time as per step 6, very close multiple frequency bands are created and due to stagger tune phenomenon broadband characteristics (2.27 GHz – 5.55 GHz) is achieved [19].

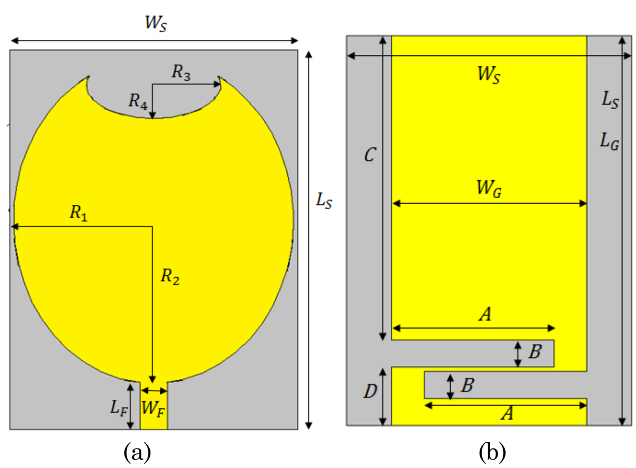


Fig. 1 – Proposed antenna (a) Radiating plane (b) Ground plane

Table 1 – Antenna and unit cell FSS variables and their value in mm

Variable name	Optimum Value (mm)	Variable name	Optimum Value (mm)
W_S	30	W_G	20.6
L_S, L_G	40	A	17.1
W_F	2.92	B	2.8
L_F	4.8	C	31.2
R_1	14.6	D	6
R_2	17.2	W_{FSS}, L_{FSS}	16
R_3	7	d	12.2
R_4	3.5	g	0.2

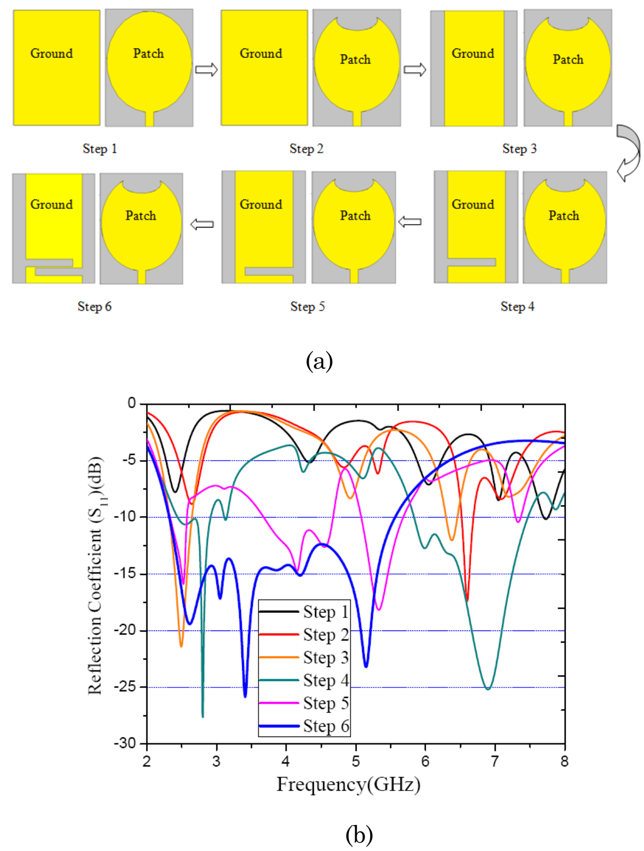


Fig. 2 – (a) Evolution Steps and (b) Reflection coefficients of evolution steps of the proposed antenna

Fig. 3 represent proposed hybrid shaped antenna's simulated reflection coefficient and simulated peak gain.

Fig. 4(a) shows equivalent RLC model circuit of the presented antenna which consists of five sections of RLC circuit connected in parallel corresponding to five resonant frequencies. The simulated S_{11} of this circuit obtained by ADS software is assessed with the simulated S_{11} from CST software and is given in Fig. 4(b). *R-L-C* values of each section corresponding to each resonant frequency are calculated by the following formulas (i-iii). All resonant frequencies and corresponding values of the values of inductor (L), resistor (R) capacitor(C), 3 dB B.W. and quality factor (Q_F) are tabulated in Table 2.

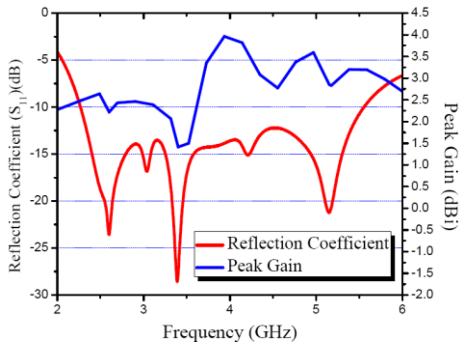


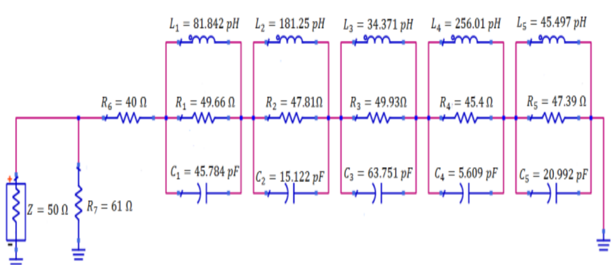
Fig. 3 – Reflection Coefficients and Peak Gain

$$Q_F = \frac{f_r}{3\text{ dB BW}}\ldots\text{(i)}\quad Q_F = 2\pi f_r C\ldots\text{(ii)}\; f_r = \frac{1}{2\pi\sqrt{LC}}\ldots(iii)$$

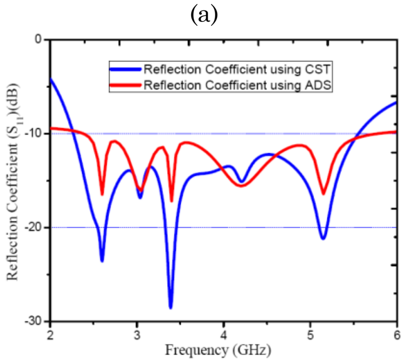
Where Q_F = Quality Factor and f_r = Resonant Frequency

Table 2 – Values of inductor (L), resistor (R), capacitor (C) for each section

Frequency (GHz)	3 dB B.W.	Q_F	R (Ohm)	L (pH)	C (pF)
$f_1 = 2.6$	0.07 GHz	37.143	49.66	81.842	45.784
$f_2 = 3.04$	0.22 GHz	13.81	47.81	181.25	15.122
$f_3 = 3.4$	0.05 GHz	68	49.93	34.371	63.751
$f_4 = 4.2$	0.625 GHz	6.72	45.4	256.01	5.609
$f_5 = 5.15$	0.16 GHz	32.19	47.39	45.497	20.992



(a)



(b)

Fig. 4 – (a) Equivalent RLC circuit model using ADS Software (b) Simulated (Both CST and ADS) S_{11}

3. GAIN IMPROVEMENT USING PROPOSED FSS

To increase antenna gain without compromising the impedance bandwidth, the antenna has been integrated with single layer band reject FSS structure which stops the band frequency from 2.1 GHz to 6 GHz. First, a FSS unit cell of square shaped is taken as the reference cell with a feature size of 16 mm × 16 mm. A circular slit with diameter of 12.2 mm is then removed from the center. A 16 mm × 0.2 mm rectangular slit was cut from each end of the unit cell, as shown in Fig. 5. When 6 × 6 FSS is placed in far field zone at a distance of 37 mm from the antenna in the bottom then gain is enhanced without hampering the broadband characteristics [20]. Fig. 6(a) shows reflection coefficient of FSS integrated antenna. This structure exhibits impedance bandwidth of 2.11 GHz to 5.55 GHz. The FSS integrated antenna structure is simulated with the help of CST studio software and the simulated gain is shown in Fig. 6(b) and this gain is compared with the gain of antenna alone. Peak gain for FSS embedded antenna from the simulated result is found 7.3 dBi at 2.6 GHz and maximum gain improvement of 5.1 dBi at 2.6 GHz is obtained and shown in Fig. 6(b).

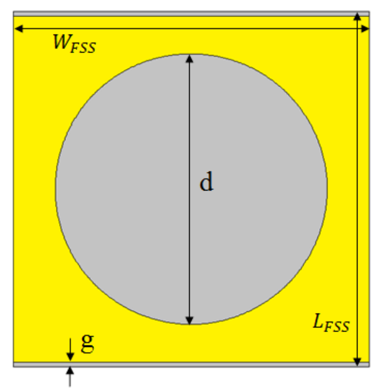
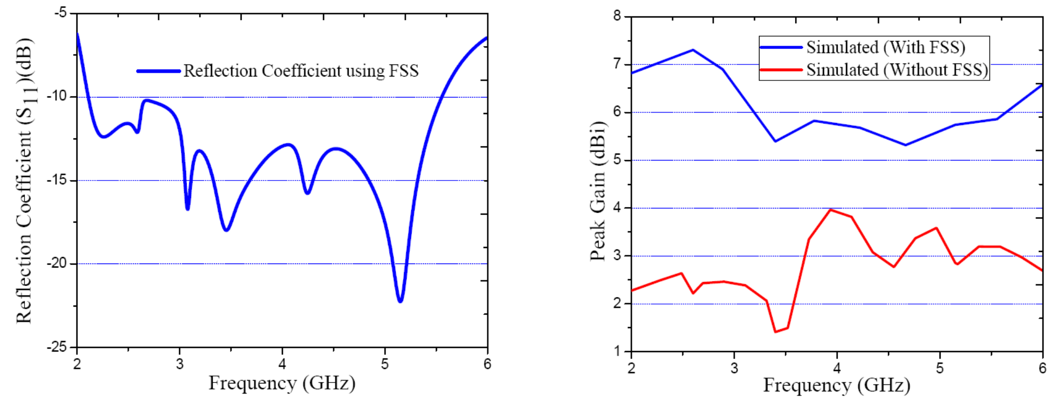


Fig. 5 – FSS Unit Cell

Fig. 7 and 8 show normalized simulations of the co-pol & cross-pol patterns of radiation for the FSS coupled antenna in *E*- & *H*- plane respectively. It can be noticed from Fig. 7-8 that radiation patterns for FSS integrated antenna are highly directive and front lobe to back lobe ratio is also large. As a result high gain is achieved throughout the band of interest.

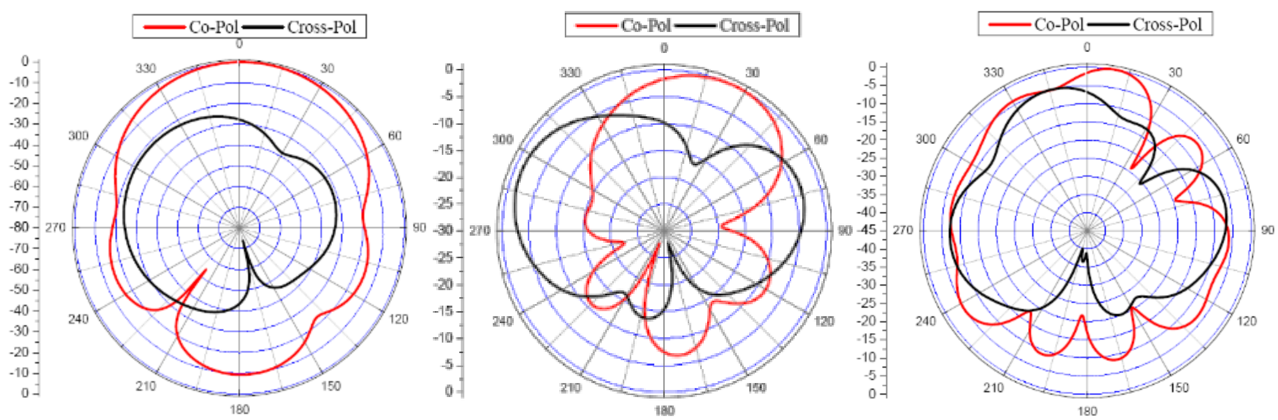
4. CONCLUSION

This article introduces line fed microstrip broadband high gain patch antenna having hybrid radiating patch with slot loaded ground plane surface. Presented antenna displays bandwidth of 2.27 GHz to 5.5 GHz with 84 % fractional bandwidth and maximum realized gain 3.39 dBi. Further improvement of the antenna gain is made by utilizing Frequency Selective surface (FSS). Maximum gain 7.3 dBi has been achieved with a maximum improvement in gain of 5.1 dBi at 2.6 GHz for FSS embedded structure. For short-range communications applications the proposed antenna without FSS structure may be used and for long-range communication applications the presented FSS integrated antenna may be used successfully. From this, we can conclude that this antenna can be used in his IoT applications, wireless communications, satellite communications, satellite services, etc.



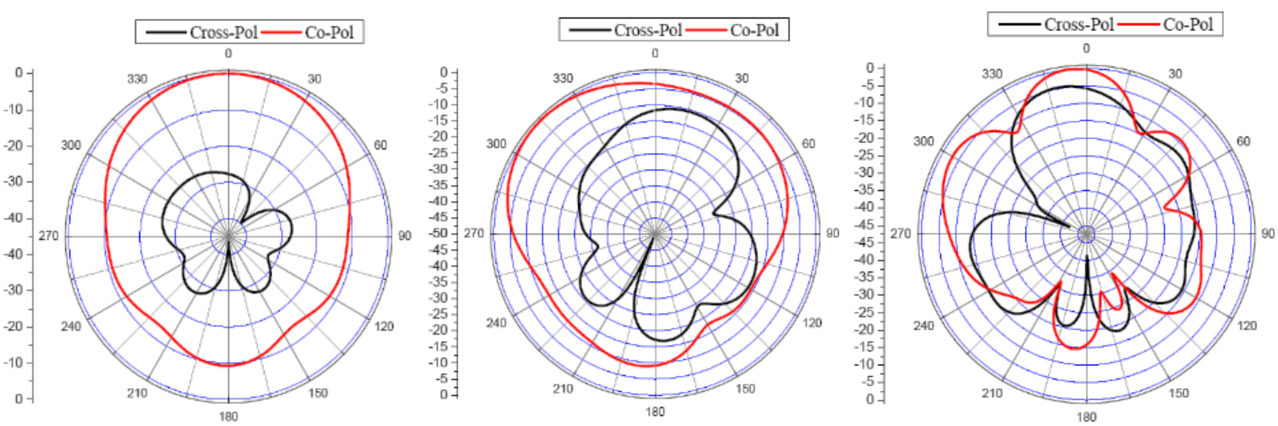
(a) (b)

Fig. 6 – (a) Simulated S11 using FSS; (b) Gain Improvement using FSS



(a) (b) (c)

Fig. 7 – *E*- plane patterns (a) at 2.6 GHz (b) at 3.4 GHz (c) 5.15 GHz using FSS



(a) (b) (c)

Fig. 8 – *H*- plane patterns (a) 2.6 GHz (b) 3.4 GHz (c) 5.15 GHz using FSS

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Інтегрована широкосмугова антена високого коефіцієнта підсилення

Tapas Tewary[1], Smarajit Maity[2], Arindum Mukherjee[3], Avisankar Roy[4], Sunandan Bhunia[5]

[1] *Department of ECE, Academy of Technology, Hooghly, West Bengal, India*
[2] *Department of AEIE, Academy of Technology, Hooghly, West Bengal, India*
[3] *Department of ECE, Central Institute of Technology, Kokrajhar, Assam, India*
[4] *Department of ECE, Haldia Institute of Technology, Haldia, West Bengal, India*
[5] *Department of ECE, Central Institute of Technology, Kokrajhar, Assam, India*

Ця дослідницька робота представляє мікросмужкову широкосмугову антену гібридної форми для застосування бездротового зв'язку. Ця гібридна антена демонструє широкосмугові характеристики (2,27 – 5,55 ГГц) з 84 % часткової смуги пропускання та піковим посиленням 3,96 дБі на 3,93 ГГц. Еталонний патч еліптичної форми завантажується іншим слотом еліптичної форми для розробки остаточного патча пропонованої антени. Повна прямокутна площина заземлення спочатку зменшується вздовж ширини, а два прямокутні щілини завантажуються в належне положення для розробки площини заземлення представленої антени. Антена резонує на частотах 2,6 ГГц, 3,4 ГГц і 5,15 ГГц. Тому антену можна використовувати для додатків Wi-Fi (2,4 ГГц, 5 ГГц), діапазону WiMAX (3,4), Bluetooth (2,4 ГГц) та іншого зв'язку на короткій відстані. Подальше покращення підсилення досягається за рахунок використання структури 6 × 6 FSS (частотно-селективна поверхня) з антеною в оптимальному положенні без перешкод для широкосмугових характеристик. Максимальне посилення 5,1 дБі на 2,6 ГГц і пікове посилення 7,3 на 2,6 ГГц досягаються для композитної структури ФСС і антени. Фізичний розмір однієї антени становить 30 мм × 40 мм × 1,6 мм, а загальний розмір інтегрованої антени FSS становить 96 мм × 96 мм × 40 мм. Електричний розмір лише антени становить $0{,}227\lambda \times 0{,}3\lambda \times 0{,}012\lambda$, а загальний електричний розмір запропонованої антени становить $0{,}67\lambda \times 0{,}67\lambda \times 0{,}28\lambda$. Запропонована антена, елементарна комірка FSS і композитна структура побудовані з використанням підкладки FR-4 (товщина 1,6 мм, тангенс втрат ~ 0,02, діелектрична проникність ~ 4,4) і змодельовані за допомогою програмного забезпечення CST. Інтегровану антену FSS можна використовувати для зв'язку на великі відстані.

Ключові слова: Широкосмуговий, Гібридний, FSS, Високий коефіцієнт підсилення.