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Compact Dual Wideband Open-Ended Ring Shaped Slot Loaded Printed Monopole Antenna for X Band Applications

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A low cost dual band offset fed monopole microstrip antenna is proposed in this paper. The suggested antenna is designed using an inexpensive 1.6 mm thick fr-4 substrate of relative permittivity 4.4. The design and analysis of the proposed antenna model have been performed using HFSS software. By inserting a square slot loaded with an inverted metallic structure in the patch and the presence of a partial ground plane, dual band operation with an extremely wide bandwidth for the higher band can be obtained. A comprehensive analysis of characteristics parameters (S_{11}, gain, radiation patterns) including distribution of surface current of the suggested antenna is furnished in this paper. The prototype of the fabricated antenna has an attractive compact dimension of only 22 × 19 × 1.6 mm^3. The reported measured bandwidths are 800M Hz (4.2-5.0 GHz) and 4200 MHz (8.0-12.2 GHz) for the lower and upper bands, respectively. The measured peak gains across the two operating bands are 3.0 and 4.3 dBi, respectively. The measured results are well accepted and verify the simulated results and hence validates the appropriateness of the design concept. The proposed antenna covers the bandwidth requirements for INSAT (4.4-4.8 GHz) and microwave X-band (8-12 GHz) systems. The compact size, low cost, simple monopole configuration, dual band resonance characteristics, wide bandwidth, good gain, and stable radiation patterns are the advantages of the designed antenna.

Keywords: Compact, Monopole antenna, Dual band, Broadband, Wireless applications.

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1. INTRODUCTION

In the last decade, a significant transformation has been observed in the domain of wireless communication systems. The endless increasing demand for data communication and broadcasting services leads to the progressive growth of wireless communication systems. In order to support rapidly growing multiple wireless applications, antennas must be capable of resonating at multiple frequencies. Accordingly, dual band/multiband/broadband antennas became an essential part of many communication systems. The design challenge of creating multi-resonance antennas opened a new window to the researchers working in this antenna technology domain. The design challenges set to the researchers are the requirement of an antenna with compact size, simple structure, easy fabrication, low cost, low profile, enhanced operating bandwidth with dual band/multiband operation. To be specific, in the simplest form, dual-band antennas with broad impedance bandwidths became popular since they allow operation in multiple frequency bands, thus eliminating the need for a separate antenna for each application. Recently, researchers have proposed different techniques for the design of dual band antennas with improved bandwidths [1-9] and bandwidth enhanced antennas [9-11] to overcome narrow bandwidth problem of the microstrip antenna. The design ideas include incorporation of protruding stubs [1], rectangular projection strip [2], stepped impedance structure [3], inverted-U-shaped driven element [4], h-shaped stub [5], U-shaped slot with a paired strips [6], U-shaped modified ground plane [7], U-shaped DGS [8], ohm shaped DMS and semi-circular DGS [9], open loop resonator [9], slotted patch with modified ground plane [10, 11].

In this paper, A low cost dual band offset fed monopole microstrip antenna is designed using fr-4 substrate and presented. The suggested antenna successfully covers some design requirements of modern communication systems such as miniaturized size, broad bandwidth, dual band operation, etc. The proposed antenna structure offers dual band operation with an extremely wide bandwidth for the higher band due to the insertion of a square slot loaded with an inverted metallic structure in the patch with a partial ground plane. The proposed antenna has an attractive compact size of only 22 × 19 × 1.6 mm^3. The reported measured bandwidths are 800 MHz (4.2-5.0 GHz) and 4200 MHz (8.0-12.2 GHz) for the lower and upper bands, respectively. The designed antenna supports INSAT (4.4-4.8 GHz) and microwave X-band (8-12 GHz) systems.

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2. ANTENNA DESIGN

The geometry of the proposed antenna is shown in Fig. 1.The suggested antenna is designed using an inexpensive 1.6 mm thick fr-4 substrate of relative permittivity 4.4 and loss tangent 0.002. The proposed antenna is formed by using the combinations of a modified rectangular patch fed via an off-set microstrip line and a partial rectangular ground plane. The structure of the radiating patch is designed by incorporating an inverted monitor shaped metallic structure loaded within a square shaped slot (SSL). The structural parameters are optimized through parametric analysis using HFSS software. The suggested monopole antenna resonates at dual band with enhanced operating bandwidth. The overall dimension of the structure is very compact and occupies a small physical footprint of only 22 × 19 mm^2. The dimensional parameters of the proposed antenna as labeled in Fig. 1 are given as follows: $W = 22$ mm, $L = 19$ mm, $W_1 = 12$ mm, $L_1 = 15$ mm, $W_g = 10$ mm, $W_f = 3$ mm, $L_f = 10$ mm, $W_2 = 7$ mm, $L_2 = 7$ mm, $L_p = 1$ mm, $L_s = 1$ mm. The step-wise design analysis of the proposed antennas is discussed in the next section.

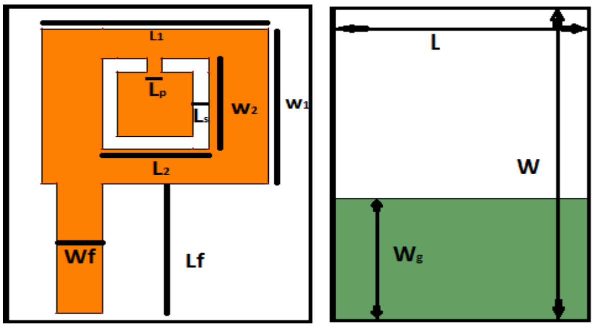

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Fig. 1 – The geometry of the designed antenna: (a) top view, (b) bottom view (partial ground plane)

3. STEP WISE DESIGN ANALYSIS OF THE PROPOSED ANTENNA

In this section, the step-wise design evolution of the suggested antenna is presented and discussed. The incorporated shape in the patch, off-set feeding and the utilization of the partial ground plane play a key role in obtaining the desired resonance and radiation characteristics. Fig. 2 depicts the different design steps opted to reach out the final proposed structure. The simulated reflection coefficient (S_{11}) characteristics for the various design cases are shown in Fig. 3.

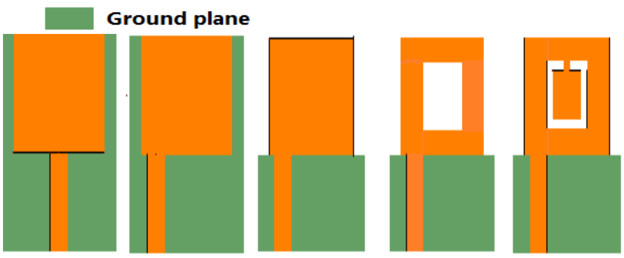

Fig. 2 – Design steps of the proposed dual band antenna

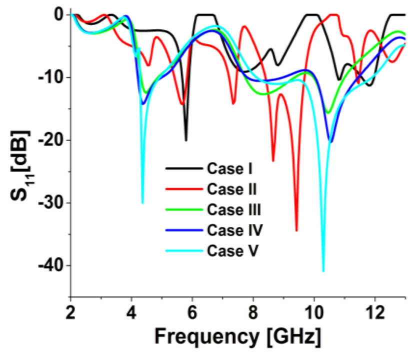

Fig. 3 – Simulated S_{11} parameters for different design steps

In case I, the antenna resonates at 5.8 GHz with a reflection coefficient of – 20 dB, covering an operating bandwidth from 5.68 GHz to 5.86 GHz. In case II, the antenna shows multiband resonance (5.46-5.8 GHz, 7.2-7.45 GHz, 8.43-9.65 GHz, and 11.40-11.46 GHz) due to change in feed position but the obtained operating bands are not useful to cover the bandwidth requirements of the intended X (8-12 GHz) band applications. In case III, the presence of a partial ground plane offers two advantages, namely, it enhances the operating bandwidth and shifts the resonant frequency to lower resonance. The first operating band is obtained from 4.36 to 4.86 GHz, the second band covers 7.77 GHz to 9.31 GHz, and third operating band exists from 10 GHz to 10.96 GHz for – 10 dB level of the reflection coefficient. So, to further enhance the operating bandwidth, modification has been done in the radiating patch by introducing a square slot [case IV]. In this case IV, the antenna operates from 4.25 to 4.97 GHz, 7.83 to 9 GHz, and 10 to 11.40 GHz for a – 10 dB reflection coefficient. So, both for case III and IV, impedance matching problems are observed in the higher band to offer continuous bandwidth in between lower operating frequency and upper operating frequency. These design steps (case I to IV) do not fulfill the objective of the proposed work,i.e., to cover the whole microwave X band ranging from 8 to 12 GHz. Finally, in case V (proposed), the incorporation of an inverted monitor-shaped metallic structure improved the resonance characteristics of the antenna by offering much better impedance matching and operating bandwidth. In case V, the antennas offer a reflection coefficient of about – 30 dB at 4.36 GHz and – 41 dB at 10.30 GHz, respectively, for the dual band operation. The lower operating band ranges from 4.27 to 4.93 GHz and the upper operating band extends from 8 to 12 GHz covering the bandwidth requirements of INSAT (4.4-4.8 GHz) and microwave X-band (8-12 GHz) system. The surface current distributions of the proposed antenna at dual band operations are shown in Fig. 4. As shown in Fig. 4a, the surface current is strongly present and circulating around the modified parts (both square slot and metallic parts) of the patch. For 11.5 GHz operation, the surface current is much dense around the arms of the incorporated inverted monitor-shaped metallic structure only for which the resonances after 11 GHz are generated and excited. This clears the working mechanism of the proposed antenna.

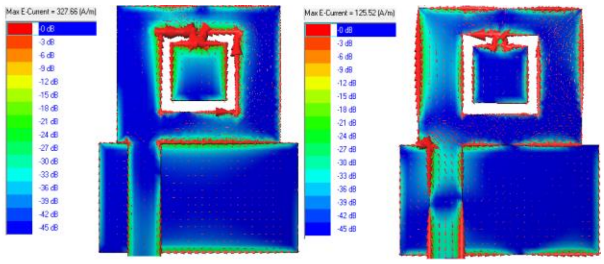

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Fig. 4 – Surface current distributions at (a) 4.36 GHz and (b) 11.5 GHz

4. RESULTS AND ANALYSIS

To validate the designed model and simulation results, the prototype of the antenna is fabricated using an fr-4 substrate. The fabricated antenna model is shown in Fig. 5. The S_{11} parameter of the antenna is measured using Anritsu MS20038C VNA. The simulation and measured reflection coefficient (S_{11}) are depicted in Fig. 6. The simulated and measured results demonstrate good agreement and confirm the validity of the suggested antenna model. The measurement results confirm dual band characteristics of the proposed antenna with – 10dB impedance bandwidths of 800 MHz (4.2-5 GHz) and 4200 MHz (8-12.2 GHz) for the lower and upper bands, respectively. The simulated and measured gain variations are depicted in Fig. 7. According to the measurement results, the maximum peak gain of the antenna is recorded as 4.32 dBi at 12 GHz. The radiation pattern characteristics of the proposed antenna are shown in Fig. 8. The antenna offers bi-directional patterns at the *E*-plane and nearly omni-directional patterns at the *H*-plane.

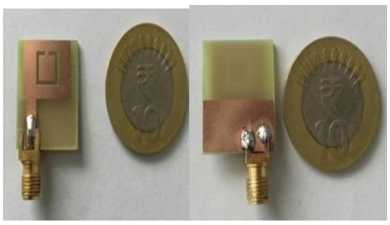

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Fig. 5 – Fabricated prototype of the proposed antenna

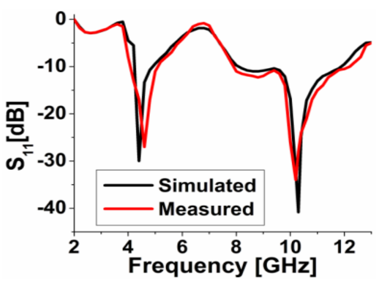

Fig. 6 –Comparison of simulated and measured reflection coefficient (S_{11} in dB) characteristics

The performance of the proposed antenna is compared with some other reported dual-band planar antennas in terms of their sizes, the total area occupied, and operating frequency bands. The analyzed results are presented in tabular form in Table 1. It is evident from the comparison table that the proposed dual band annntenna provides the maximum – 10 dB impedance bandwidths at both the dual operating frequency bands. It is also evident from the comparative dimension analysis that the proposed antenna occupies the smallest area compared to other reported dual-band antennas. So, the designed antenna offers superior performance in terms of miniaturaization and bandwidth enhancement compared to some other reported dual-band antennas.

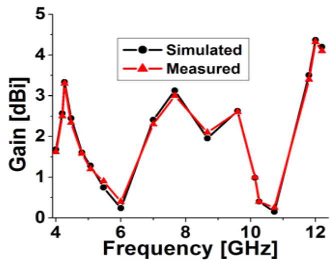

Fig. 7 – Variations of simulated and measured gains of the proposed antenna

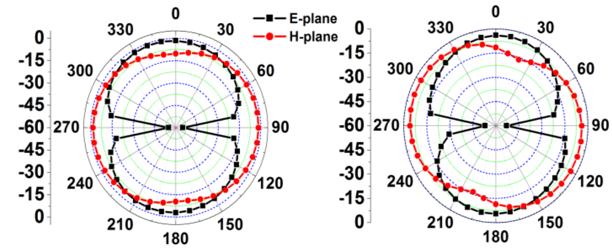

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Fig. 8 – *E* and *H* plane radiation pattern characteristics at (a) 4.36 GHz and (b) 10.30 GHz

5. COMPARATIVE STUDY WITH OTHER REPORTED DUAL BAND ANTENNAS

Table 1 – Comparison with other reported antennas

Reference work	Antenna size (mm × mm)	Total occupied area (mm^2)	Operating frequency bands (GHz)
[1]	50 × 35	1750	2.05-2.86, 5.55-6.14
[2]	48 × 14	672	2.325-3.47, 5.075-6.4
[3]	60 × 50	3000	2.4-2.5, 5.725-5.875
[4]	100 × 60	6000	0.881-1.280, 1.7-2.568
[5]	28 × 20	560	2.36-2.58, 4.53-6.38
[6]	38 × 38	1444	2.40-2.48, 5.15-5.825
[7]	25 × 20	500	2.39-2.52, 4.97-6.07
[8]	25 × 18	450	2.92-3.6, 4.12-6.42
Proposed	22 × 19	418	4.2-5.0, 8.0-12.2

6. CONCLUSIONS

This paper presents a compact printed antenna for microwave X band and INSAT applications. The proposed antenna is designed using a modified patch and partial ground plane structure. The proposed antenna shows dual band (4.2-5 GHz and 8-12.2 GHz) resonance characteristics. Furthermore, good gain and stable radiation pattern characteristics are observed at dual band operation. The simulation studies have been carried out using HFSS software. The structure of the presented antenna is very simple and it is easy to be fabricated on a commercially available low-cost fr-4 substrate with a small area of 22×19 mm².

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Компактна подвійна широкосмугова відкрита кругова несиметрична друкована антена з щілинним завантаженням для додатків X-діапазону

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У роботі розглядається малобюджетна подвійна несиметрична мікросмугова антена зі зміщеним живленням. Пропонована антена розроблена з використанням недорогої підкладки з матеріалу fr-4 товщиною 1,6 мм і відносною діелектричною проникністю 4,4. Проектування та аналіз запропонованої моделі антени було виконано з використанням програмного забезпечення HFSS. Вставивши перевернуту металеву структуру в квадратну щілину у патчі і частково її заземливши, можна отримати дводіапазонну антену з надзвичайно високою пропускною здатністю верхньої смуги. У роботі представлений комплексний аналіз характеристичних параметрів (S_{11}, коефіцієнта підсилення, діаграми спрямованості), включаючи розподіл поверхневого струму запропонованої антени. Прототип виготовленої антени має привабливі компактні розміри 22×19×1,6 мм³. Отримані смуги пропускання складають 800 МГц (4,2-5,0 ГГц) та 4200 МГц (8,0-12,2 ГГц) відповідно для нижньої і верхньої смуг. Виміряні пікові коефіцієнти підсилення в двох робочих діапазонах становлять 3,0 та 4,3 дБі, відповідно. Результати вимірювань є загальноприйнятими і узгоджуються з результатами моделювання і, отже, підтверджують доцільність концепції дизайну. Запропонована антена задовольняє вимогам до смуг пропускання для систем INSAT (4,4-4,8 ГГц) та мікрохвильових X-діапазонів (8-12 ГГц). Компактні розміри, низька вартість, проста несиметрична конфігурація, дводіапазонні резонансні характеристики, широка смуга пропускання, гарний коефіцієнт підсилення та стабільні діаграми спрямованості є перевагами розробленої антени.

Ключові слова: Компактний, Несиметрична антена, Дводіапазонний, Широкосмуговий, Бездротові додатки.