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Parasitic Loaded Shorting Pin Based Compact Multi-slot LoRa Antenna for Military Application

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Abstract

In this paper, work on a compact multi-slot patch antenna with a parasitic load and shorting-pin has been presented for its use in long range (LoRa) defense applications. Initially the antenna is designed and simulated using HFSS and a parametric study has been carried out for achieving an optimized antenna configuration. This is followed by the fabrication of antenna prototype based on the optimal performances obtained from the simulated results. Further, the return loss along with free space co-polar and cross-polar radiation pattern measurements has been carried out for the fabricated antenna. The experimental results show a good comparison with that of the simulated one. The proposed antenna resonates at an operating frequency of 866 MHz, providing a -10 dB bandwidth from 856 MHz-877 MHz, which covers the wireless standard used for LoRa technology. Finally, a comparative analysis of the proposed antenna with the recently reported works is presented.

Keywords

compact, shorting pin, parasitic strip, LoRa

1 Introduction

Long Range (LoRa) band is specially defined for an efficient communication range that ascertains a good connectivity among the different module of IoT network. Undoubtedly, antenna design and its working in the LoRa band plays a vital role in this communication field [1]. Moreover, reported works show that the use of antenna in the defense system has gained a lot of interests among the researchers [2–5]. In the diverse IoT environment such as in the battle fields, the major demand for an antenna is the compactness in size. Microstrip patch antennas with the features like compatibility, low profile and easy to integrate are hence preferred for such IoT applications. In recent years, a lot of antennas working in different IoT environment as well as LoRa technology have been reported [6–14]. An inverted F-antenna for IoT devices using LoRa technology is designed for a single resonating frequency band in [6]. A CubeSat microstrip antenna with metamaterial structure is proposed for LoRa communication in [7]. In [9], a dual-band conductive textile-based wearable antenna operating at LoRa and Bluetooth range is proposed for application in accurate geolocation, tracking and communication in the military and telemedicine industries. In [10] various techniques for miniaturization of antenna are reported with a proposed inset fed rectangular microstrip antenna resonating at LoRa band. In [11], a dual-band footwear textile antenna is presented for off-body network communication, which can be applicable for LoRa applications covering 433 MHz, 868 MHz and 915 MHz bands. However, the size of the antenna is still a factor to be concerned. Many techniques have been explored in the literature for the miniaturization of multi-band antennas such as defected ground structure [15–17], slotting [18–23] and parasitic loading [24, 25] etc. The use of shorting pins is one of the favorite techniques used for antenna design because of their planar profile, ruggedness and ease of fabrication. In recent years, it has been used extensively for reducing the size of the patch [26–29].

In this work, we propose a compact microstrip patch antenna for its possible use in wearable defense application working in the LoRa band. The proposed antenna has an impedance bandwidth of 21 MHz (856–877) MHz that covers LoRa band. Three simple techniques of size reduction such as shorting pin, slot loaded patch and parasitic element have been adopted altogether for this design

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where a reduction of 93% has been achieved. Further, being miniature in size the proposed antenna is suitable to be integrated with the bullet proof armor of the soldier.

2 Antenna design and parametric analysis

The working of the proposed antenna is based on the effective shunt inductance property of shorting pin and effective electrical length property of slot to reduce the frequency of operation. At first, the antenna is designed and simulated using HFSS where the final geometry of the antenna evolves out after a few succeeding steps and thereby it is targeted to achieve a better matching result in the required band of operation. FR-4 material of thickness 1.5 mm is used as the dielectric substrate for the design where a linear array of slots at equidistant position has been introduced over a rectangular patch of length 46 mm and width 13 mm. This is followed by incorporation of a shorting pin near to the co-axial probe feed location of the patch. Afterwards, the array of slots is made inclined downward at angle of 30° without changing the feed point and the shorting pin position of the antenna. Subsequently, the opening edge of the slots has been truncated which are finally shorted via a parasitic microstrip line, as shown in Fig. 1.

Fig. 2 shows the simulated matching performances at the various steps of the antenna design.

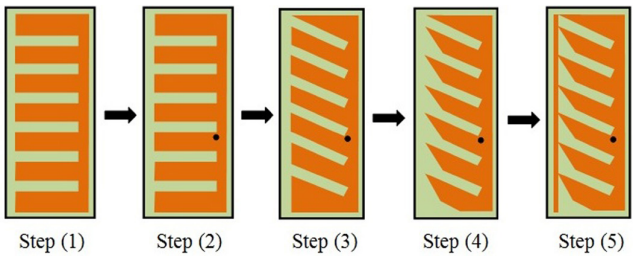


Fig. 1 Step by step procedure for designing the antenna

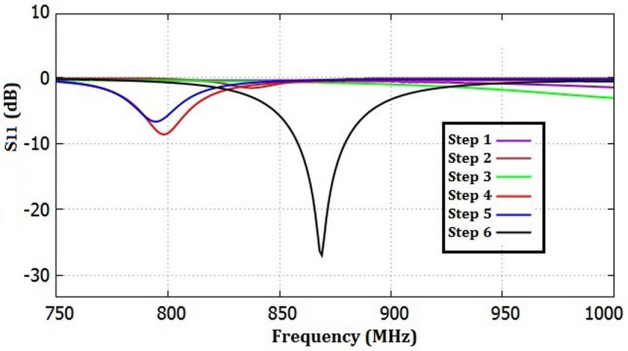


Fig. 2 Simulated return loss plots at different steps of the antenna design

It can be seen that the introduction of the shorting pin in the rectangular patch having inclined array of slots shows a trend of matching nearby 800 MHz. Further, the addition of the parasitic line on the truncated open edge of the slots allows the antenna to have a good matching at the frequency of interest at around 870 MHz. A parametric analysis has been carried out via simulation for obtaining an optimal antenna configuration that aims for its operation in the required band. This analysis is also opted to have an insight of the effect on the antenna matching performances due to change in its different design parameters by keeping the feed point location fixed throughout the analysis. Fig. 3 shows the schematic diagram of the final design of the proposed antenna.

2.1 Effect of shorting pin location (x_p, y_p) and the parasitic linewidth (p)

The effect of the shorting pin positions along with the parasitic line width on the matching performance has been observed by keeping the feed point constant (x_f = 37.5 mm, y_f = 3 mm) and the dimension of the slot length (S_L) and width (S_W) at a fixed value of 11 mm and 2 mm respectively. To maintain the compactness of the proposed design, the ground plane dimension is initially maintained at L_g = 48 mm and W_g = 15 mm. The simulated return loss performances for different feed position (x_p, y_p) and the parasitic line width (p) are shown in Fig. 4 (a, b, c).

It can be seen that, for the opted feed point location and the dimension of S_L and S_W, a better matching performance is obtained for the shorting pin location at x_p = 31 mm and y_p = 3 mm for all the antenna configurations having different parasitic line width (p). However, amongst the three different parasitic line width configurations, a suitable result is seen for p = 0.5 mm and x_p = 31 mm and y_p = 3 mm with a S11 value of −40.10 dB at 866 MHz.

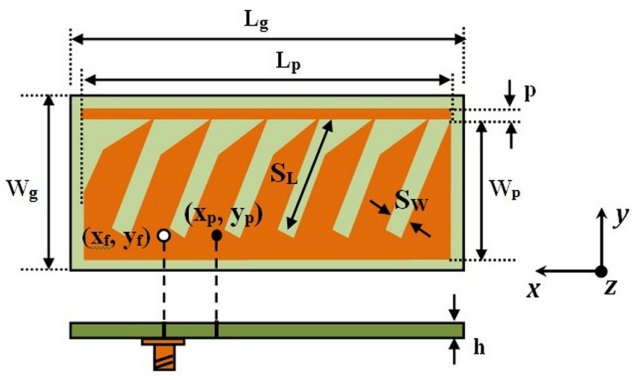
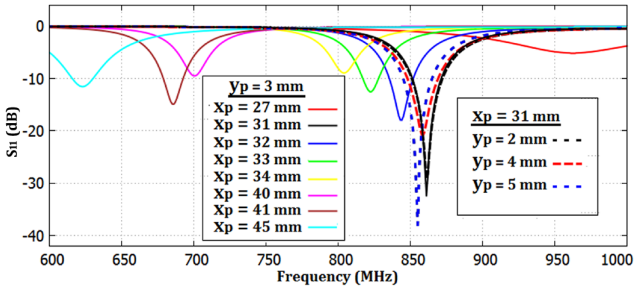
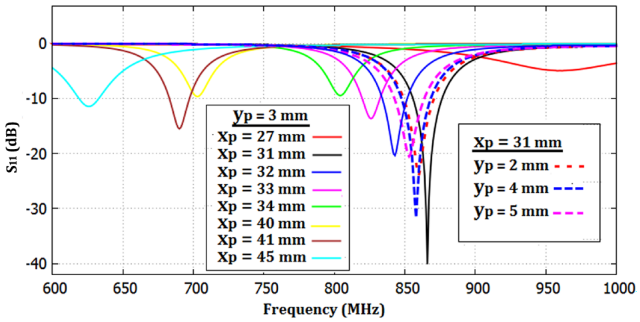


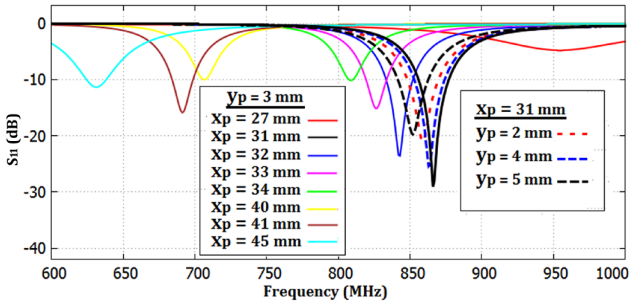
Fig. 3 Schematic diagram of the final design of the proposed antenna



(a)



(b)



(c)

Fig. 4 (a) Simulated S11 plot for different feed position (x_p, y_p) with the parasitic line width (p = 0.3 mm); (b) Simulated S11 plot for different feed position (x_p, y_p) with the parasitic line width (p = 0.5 mm); (c) Simulated S11 plot for different feed position (x_p, y_p) with the parasitic line width (p = 0.8 mm)

2.2 Effect of slot length (S_L) and slot width (S_W)

To have an insight of the effect of S_L and S_W on the antenna matching performance, simulations are carried out by varying its dimensions whereas the other parameters are maintained at a value that provides the best matching performance in the preceding analysis. The slot length S_L is varied from 10 mm to 12 mm in steps of 1 mm whereas the slot width is varied from 1 mm to 2.5 mm in steps of 0.5 mm. The simulated S11 plots for different values of S_L and S_W are shown in Fig. 5.

From the obtained simulated results, it can be seen that the slot width S_W has a greater impact on the operating frequency of the antenna whereas an increase in S_W shift the resonating frequency to the lower side of the RF spectrum. Apart from the slot length S_L = 2.5 mm, rest

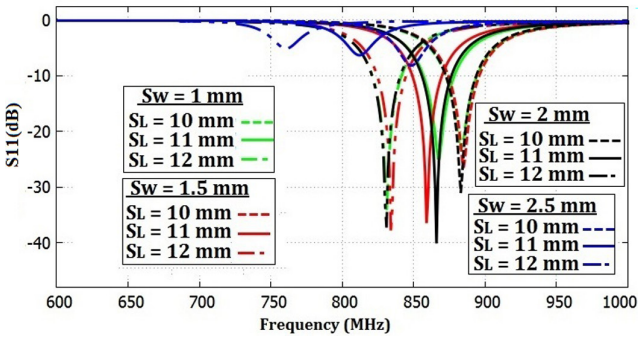


Fig. 5 Simulated S11 plots for different values of S_L and S_W

shows a minimum variation in the resonant frequencies and in their corresponding S11 values. However, the best matching is obtained for the antenna configuration having S_L = 11 mm and S_W = 2 mm.

2.3 Effect of ground plane ($L_g \times W_g$)

Simulations are carried out by varying the ground plane dimension ($L_g \times W_g$) of the antenna to have an insight of its effect on the antenna matching performances where the rest of the parameters are fixed at their optimal dimensions obtained from the preceding observations. The simulated return loss plots are shown in Fig. 6 with three different values of L_g and W_g.

As can be seen, with the increase in the ground plane width W_g, the resonant frequency of the antenna is shifted to lower side of the RF spectrum. Further, it has been observed that for a given dimension of W_g, the resonant frequency of the antenna shifts towards the higher side of the RF spectrum with increment in the ground plane length L_g. Among all the variations, simulated results show a better matching for the antenna configuration having L_g = 48 mm and W_g = 15 mm.

3 Experimental results

From the parametric analysis that has been carried out, the antenna prototype is fabricated using the optimal

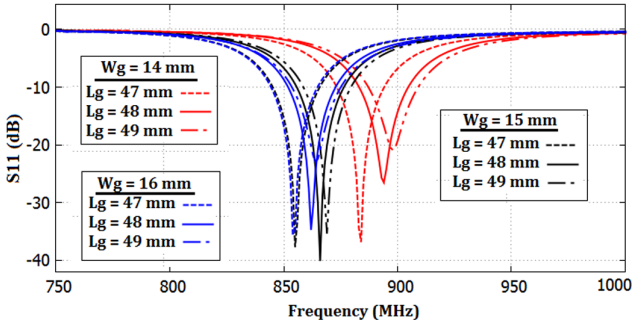


Fig. 6 Simulated S11 plots for different values of L_g and W_g

dimensions as shown in Table 1 and the fabricated antenna is shown in Fig. 7. Return loss and radiation pattern measurements are carried out and the results are compared with that of the simulated one.

3.1 Return loss measurement

The return loss measurement of the fabricated antenna is carried out by using a vector network analyzer (Rohde & Schwarz ZNB20). The measurement is also taken by mounting the antenna on a Kevlar material to have an insight of its effect on the matching performances when shall be mounted on the military tactical vest in the battle ground. Moreover, the antenna is covered with radome like material to eliminate the environmental effects and this is followed by the return loss measurement to observe the effect of the material on the antenna performance. The simulated and measured return loss plots for the proposed antenna are shown in Fig. 8. It is observed that the simulated and measured results are in good agreement.

Although, a small shift in the resonant frequency for the antenna mounted on the Kevlar material is observed which may be due to the fabrication tolerances but the operational −10 dB bandwidth lies in the required LoRa band of operation. Also, there are no significant changes in its return loss value and −10dB bandwidth when the designed antenna is covered by plastic radome like material. However, the radome material must be chosen carefully as it may reduce the radiation efficiency of the antenna. Table 2 shows the simulated and the measured return loss values at their corresponding resonant frequencies.

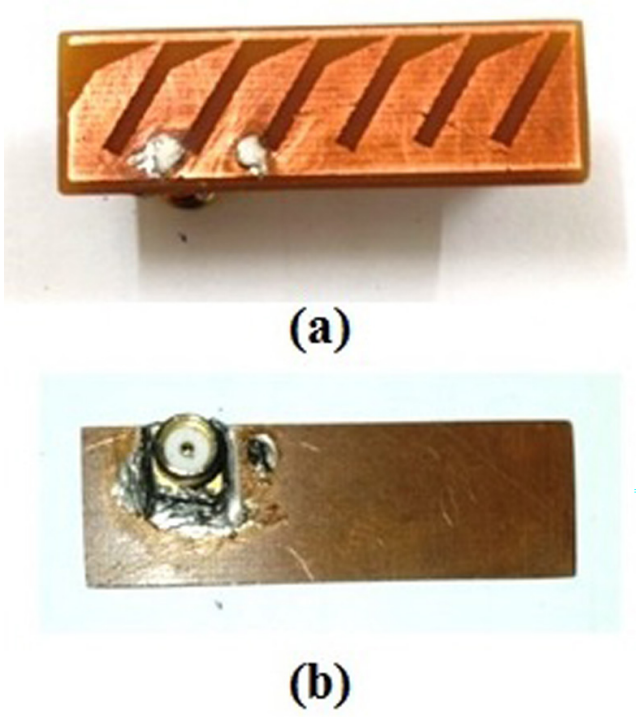


Fig. 7 Fabricated antenna (a) top and (b) bottom view

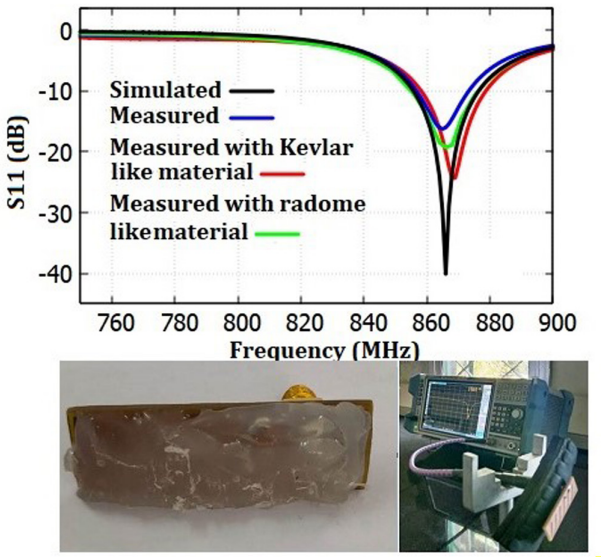


Fig. 8 Simulated and measured return loss plots of the proposed antenna

3.2 Radiation pattern measurement

The free space co-polarization and cross-polarization radiation pattern measurements of the single antenna are carried out using DAMs antenna measurement setup where the vector network analyzer is interfaced with a computer along with an automated turn table. The measured and simulated radiation patterns at their corresponding resonant frequencies are shown in Fig. 9 (a, b).

It can be seen that both the x-z and y-z plane show a broadside radiation pattern whereas the cross-polarization levels lie below -10 dB at its corresponding co-polar maximum. The measured gain at the resonant frequency of the proposed antenna comes out to be around 1.5 dBi as provided by the DAMS antenna measurement setup. The radiation pattern so obtained can also be verified from the surface current distribution at 866 MHz which is shown in Fig. 10.

Table 1 Optimized designed parameters of the proposed antenna

Ref [Fig 3]	Parameters	L_g	W_g	L_p	W_p	p	S_L	S_W	(x_f, y_f)	(x_p, y_p)
	Value (mm)	48	15	46	13	0.5	7	2.7	(37.5, 3)	(31, 3)

Table 2 Simulated and measured S11 values at their corresponding resonant frequencies

Antenna configuration		S11 (dB)	Frequency (MHz)
Simple	Simulated	−40.10	866
	Measured	−16.25	865
Measured with Kevlar material		−24.35	868
Measured with radom like material		−18.82	865

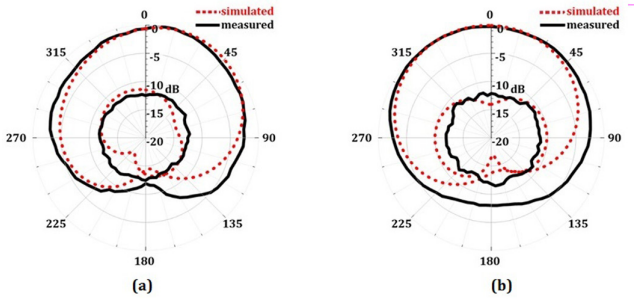


Fig. 9 Simulated and measured radiation pattern in (a) x-z plane; (b) y-z plane

3.3 Antenna size reduction calculation

The dimension of a conventional rectangular patch working in the LoRa band (856−877 MHz) designed on FR-4 substrate having thickness of 1.5 mm generally has a dimensional area of 105 × 82 mm^2 whereas this proposed design has an overall occupied patch area of 46 × 13 mm^2. The total size reduction thus can be found by the Eq. (1),

$$\left(A-B\right)/A\times 100\%, \tag{1}$$

where A is the original dimension and B is the reduced dimension. By placing the values $A = 105 \times 82$ mm^2 and $B = 46 \times 13$ mm^2 an overall size reduction of 93% has been achieved.

4 Discussions and conclusion

A compact antenna loaded with shorting pin, slot and parasitic patch is presented in this paper. The proposed antenna has an overall dimension of 48 ×15 × 1.5 mm^3 including the ground plane. The antenna shows an impedance bandwidth of 21 MHz covering the LoRa band for long range communications. Geometrically, the truncated inclined slots along with the shorting pin and the parasitic line for the chosen feed position provides the overall size reduction of around 93% than the conventional rectangular patch dimension by

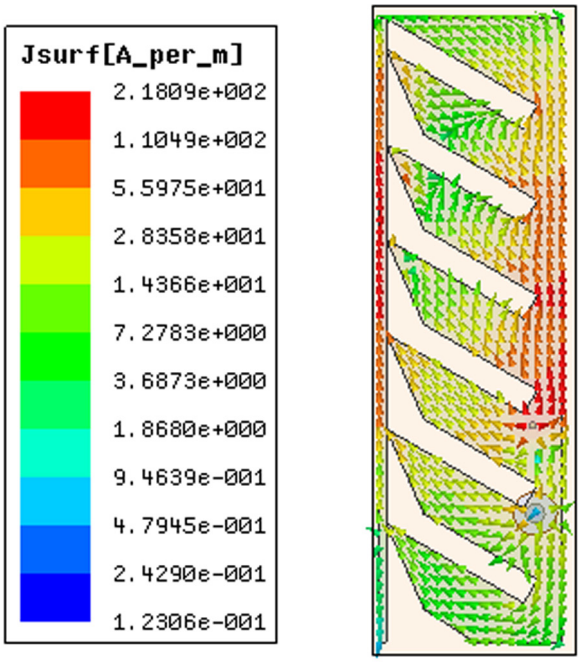


Fig. 10 Surface current distribution of the proposed antenna at 866 MHz

increasing the electrical length. Being miniature in size and the obtained measured results, the proposed antenna can be a potential candidate in LoRa communication system. Further, it can also be mounted on military armor for sharing information such as data obtained from mine detectors among the military troops and their headquarters. This will help the military to decide the future movement of troops from the area; mines removing missions and marking the areas as landmine danger zones. The antenna is also found to be satisfactory in its performance whenever covered with radome like materials to protect it from external environmental effects. A performance comparison has been carried out between the proposed antenna and others related works as shown in Table 3. It shows that that the proposed antenna is satisfactory one in terms of impedance bandwidth and size.

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Table 3 Comparative analysis of the proposed antenna with reported work

Ref.	Substrate	Size (in mm^3)	Bandwidth (in MHz)	Technique used
[6]	FR-4	34× 80× 0.8	847-873	IFA
[7]	FR-4	250 × 250 × 19.6	758-983	Metamaterial
[8]	FR4	120 × 120 × 0.8	791-1123	Meander line
[9]	Neoprene	150 × 150 × 3.2	863-870	Aperture coupled
[10]	FR4	67.74 × 55 × 1.58	857-885	Inset fed, ground etching
[11]	Metal and wool	95 × 65 × 25	433, 868 and 915	flexible textile
Proposed antenna	FR-4	48 × 15 x 1.5	856-877	Shorting Pin, parasitic element

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