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Optimized PIFA with Improved Bandwidth and Gain for Bluetooth Devices and Wearable Appilications

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Abstract- The designed antenna is proposed by Bluetooth energy communication which is commonly used in modern devices at 2.44 GHz. Considering it is to be used for a wearable device, it must be small in size and resistant to mechanical and temperature variations. An optimized planar inverted-F antenna (PIFA) with parasitic element is used to broaden the antenna bandwidth. The parasitic element's end is shorted to reduce the patch size to 22 × 7.25 mm2, making it suitable for wearable devices such as Smartwatches. Also, the ground layer of antenna allows it to radiate well externally while interfering minimum with the internal medium behind it. As a result, the reflection coefficient is not affected by the changes in the internal medium. The maximum gain of the proposed antenna is 13.4 dBi, and its impedance bandwidth ranges from 1-2.7 GHz. Finally, the antenna can be fabricated into a wearable electronic device.

Keywords- PIFA, Parasitic Element, Shorting pin, Bluetooth Devices, Wearables

I. INTRODUCTION

In recent years, the use of Bluetooth technology plays a vital role in wireless communication. This technology is enhanced due to its major security and performance factors. Wearables of Bluetooth technology like smart watches, fitness trackers and health monitoring devices are of compact size, consume low power, portable and extends the battery life. For implementing the Bluetooth devices in the desired way PIFA antennas are commonly used because of their low profile and ease of integration on Printed Circuit Boards (PCB). The design consists of a ground plane, shorting pin and a radiating element which creates a low-profile structure. This configuration allows PIFA antenna to make impedance matching, reduce interference and enhances the signal strength by minimizing the signal loss while transmitting and receiving of signal. A compact PIFA antenna with a parasitic element is shorted to minimize its size and enhances outward radiation with minimal interference is designed in [1]. To enhance the antenna performance, new resonant modes are excited by cutting the rectangular slot. A capacitive coupled feed is provided using small rectangular strip and attached to feed to optimize impedance matching is carried out in [2]. The increase in number of antennas for 5G technology is putting pressure on the frames of 5G devices. when multiple antennas are placed close to each other there can be electromagnetic coupling between them which effects the isolation and performance. To overcome this issue a cross line connecting four antennas is designed in [3]. A dual-band antenna that supports MIMO is designed for WIMAX and WLAN based applications for minimizing signal interference is discussed in [4]. Between the ground and patch, a shorting metal is introduced. Thereby [5] presents the design of PIFA for biotelemetry applications. It also uses biocompatible materials in its substrate to ensure low SAR and safety in medical uses. [6] discusses the use of PIFA in Microsatellites for omnidirectional communication by creating a system with two antennas that can receive signals from satellites without any interference. [7] refers to the antenna used in medical applications such as medical monitoring equipment's like continuous glucose monitors (CGM) and Electromyography (EMG) which has the ability to work at two frequencies and track signals like heartbeat, blood pressure and oxygen levels. A phased array antenna designed for 5G wave communication which offers faster data transfer rates, lower delays and higher capacity. This antenna consists of multiple antenna elements that work together to send the signal in a specific direction. When these elements are placed together a mutual coupling may occur affecting antenna radiation and reducing efficiency [8] explores various methods to decouple the elements and implementing beamforming algorithms. [9] describes about a multiband PIFA designed for cars and development of V2X (Vehicle to Everything) communication over a wide frequency range. Transmitting the signal to target frequency bands [10] uses two modes, the basic TM11 mode and combination of higher order modes which result better performance for MIMO applications.

Table 1: Dimensions of the Optimized PIFA

Parameter description	Parameter	Dimension (in mm)
Substrate	Ls	25mm
	Ws	10.8mm
	Ws1	1.3mm
	c	1.25mm
Ground	Lg	25mm
	Wg	10.8mm
	Ls1	5.95mm
	Ws1	1.3mm
	a	4mm
	b	4.5mm
Radiating Patch	Lp	22mm
	Wp	7.25mm
	Lf	6mm
	Wf	1.3mm
	Lpe	23.6mm
	Wpe	0.5mm
	d	0.3mm
	e	1mm
	f	1.7mm
	g	1.05mm
	h	6mm
Feeding pin	R	0.6mm
	h1	8.5mm
Shorting pin	r	0.1mm
	h2	8.5mm

II. ANTENNA DESIGN

The designed antenna is made up of three layers-Ground, Substrate and Patch. The dimensions of ground layer are Lg x Wg mm2. A rectangular slot of a x b mm2 is added to the ground layer and a part of Ls1 x Ws1 mm2 is removed from the slot.

The dimensions of substrate layer which is made up of FR4 material is 25 x 10.8 mm2 and a part of Ws1 x c mm2 is removed. The radiating patch is designed along with parasitic element and feed. The dimensions of patch are Lp x Wp mm2, parasitic element is Lpe x Wpe mm2 and feed is Lf x Wf mm2.

A cylindrical feeding pin of radius R is placed on the feed connecting the patch with a height h1. To establish connection between patch and ground a shorting pin of radius r mm is placed at height h2.

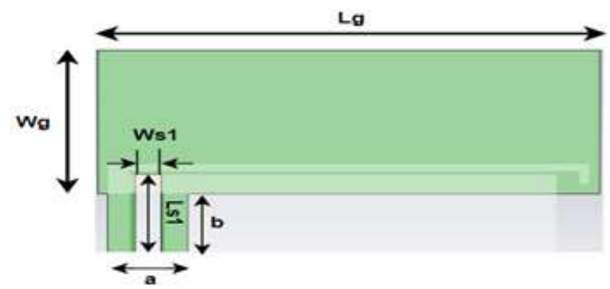


Fig 1: Ground Layer

Fig (1) represents the bottom ground layer which is made up of copper material with the dimensions Lg x Wg mm2 and a rectangular slot of a x b mm2 is added to it. Then some part of the ground layer of Ls1 x Ws1 mm2 is removed that helps to match the impedance by altering current flow, allowing for ideal power transmission.

The slot also increases bandwidth by enabling several frequencies to resonate, extending the range of operation. The ground layer also influences the radiation pattern which is required for successful signal direction. In systems with several antennas the ground plane eliminates signal interference among them, enhancing overall performance.

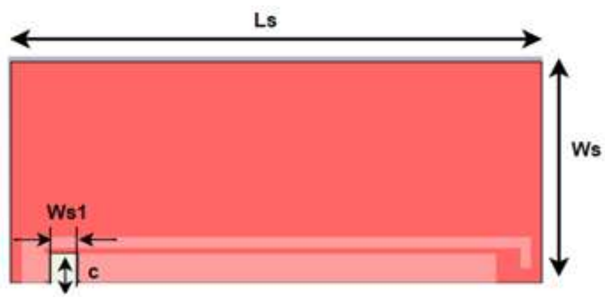


Fig 2: Substrate Layer

Fig (2) represents the substrate layer between the ground and radiating element, which is built of FR4 dielectric material with dimensions of Ls x Ws mm2.A cut at the bottom end of the substrate of size Ws1 x c mm2 helps in tuning the antenna to the required frequency by changing the current distribution on the antenna's surface. It may also reduce the size of the antenna without affecting efficiency, allowing the design to be easily integrated into modern devices supporting many forms of communication such as 4G,5G and Bluetooth, while improving electrical properties and minimizing the signal losses.

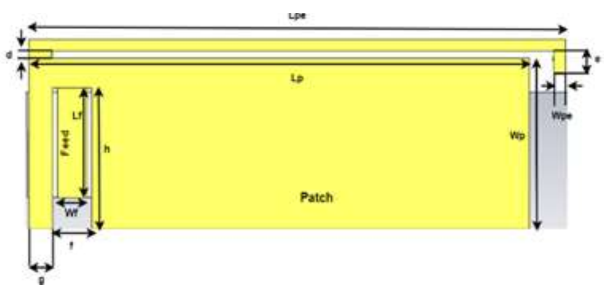


Fig 3: Radiating patch

Fig (3) represents the top radiating patch which is made up of Perfect Electric Conductor (PEC) material with the dimensions of Lp xWp mm2.The patch is mainly responsible for transmitting and receiving the electromagnetic waves effectively. The parasitic element of size Lpe x Wpe mm2 is another conductive component that is close to the main patch but not directly linked to the feed. Its objective is to improve antenna performance and gain. The parasitic element can resonate at different frequencies than the main patch, allowing the antenna to work more efficiently over a wider frequency range. The signal is fed into the antenna through feedline of dimensions Lf x Wf mm2. The position and design of the feed line is important for ensuring better impedance matching and increasing antenna efficiency.

Proposed Pifa

The proposed antenna is of compact size which is designed to use in Bluetooth wearable devices. The design of this proposed PIFA has additional conducting parasitic element attached to the main patch in order to increase the gain and bandwidth ranges. A shorting pin of radius r is placed to connect ground and patch thereby improving the power transfer efficiency of PIFA. The feeding pin placed between feed and patch is of radius R transfers RF energy and ensures excitation of patch for radiation.

Fig 4: Top View

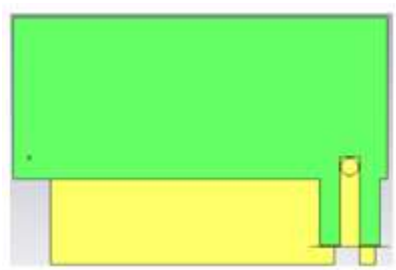


Fig 5: Bottom View

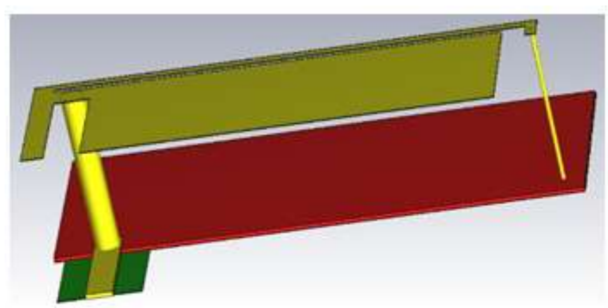


Fig 6: Overall View

III. FIELD ANALYSIS

Simulations allow for the calculation of the antenna's reflection coefficient, gain, co- and cross-polarizations, and surface currents. The suggested antenna operates between 1.07 GHz and 2.7 GHz. The S11 parameter ensures that the impedance spectrum is well-matched. Figures 7, 8, 9, and 10 show measured E and H field radiation patterns for the antenna designed at 2.44 GHz. Radiation gain is observed at 13dBi. Theta 'Θ' and phi 'Φ' are spherical coordinates for co- and cross-polarizations that range from 0 to 360 degrees in the Eplane and 0 to 90 degrees in the H-plane.

1. Electric-Field

The electric fields of antennas expand horizontally. The patch and antenna feed line provide the maximum electric field. This is measured in Volts per meter. Fig 7 represents 2888 V/m electric field observations at resonate frequencies of 2.44 GHz.

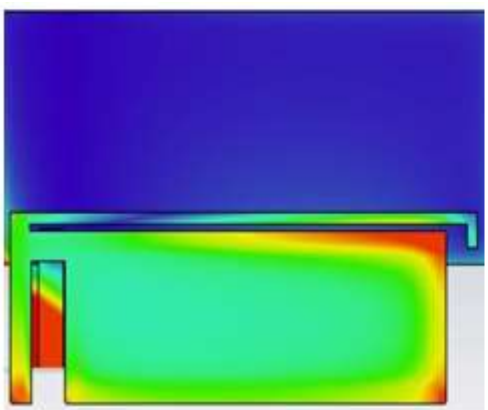
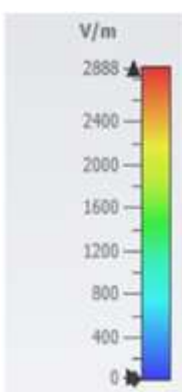


Fig 7: (a) E-field at 2.44 GHz



(b) E-field scale

2. Magnetic-Field

The magnetic and electric fields are usually perpendicular to each other. The magnetic field of an antenna increases vertically. The antenna's feed line and patch generate the strongest magnetic field. It is measured in Amperes per meter. Fig 8 shows 0.81 A/m magnetic field observations at resonance frequencies 2.44 GHz.

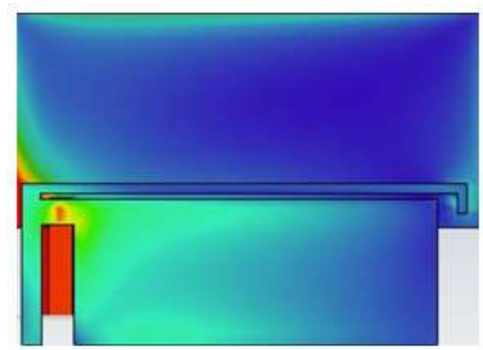
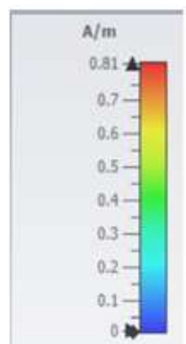


Fig 8: (a) H-field at 2.44 GHz



(b) H-field scale

3. Surface Current Field

The Patch receives surface current from the feedline. We measure the surface current in units of Amperes per meter. Surface current of 3.55A/m is developed at 2.44 GHz which is shown in Fig 9.

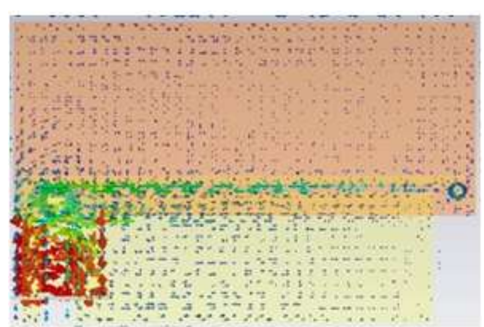
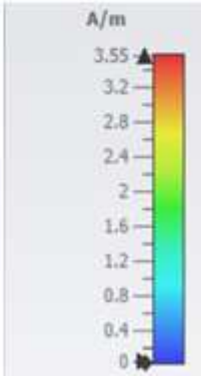


Fig 9: (a) Surface current field at 2.44 GHz



(b) Surface current field scale

4. Far Field

An antenna has a far field radiation pattern. Main, minor, side, and adjacent lobes exist. The radiation pattern shows where the maximum gains occur. The far field radiation pattern is observed at 2.44 GHz resonant frequency, with gain of 13.4 dBi. Which is observed at Fig 10.

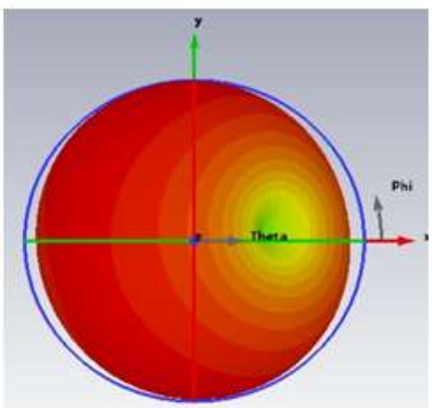
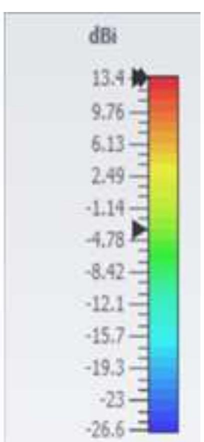


Fig 10: (a) Far field at 2.44 GHz



(b) Far field scale

IV. RESULT

The performance of the optimized PIFA is evaluated by simulating the design. Fig 11 discusses about the reflection coefficient and Fig 12 represents the VSWR value.

The readings of VSWR and reflection coefficient match well at a particular resonant frequency. The gain and efficiency of antenna is measured in Fig 13,14 which demonstrates that the antenna operates well with minima signal losses and can be easily integrated into the modern devices.

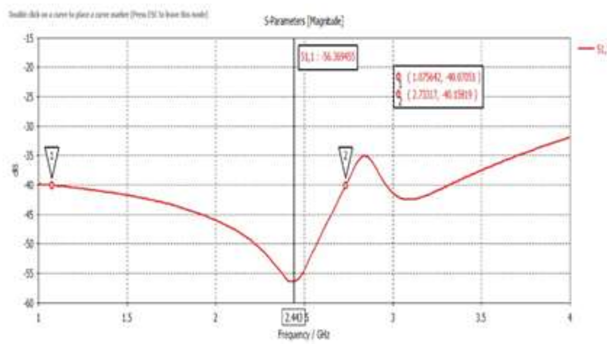


Fig 11: Frequency Vs Reflection Coefficient

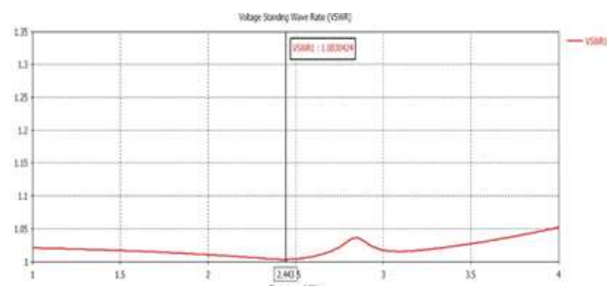


Fig 12: Frequency Vs VSWR

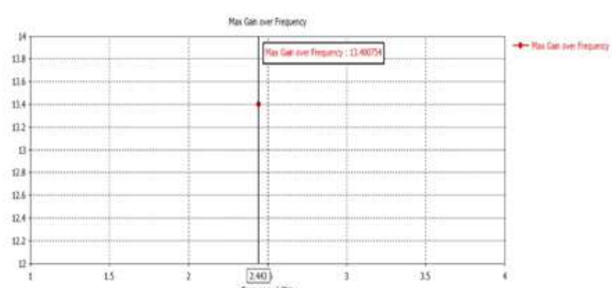


Fig 13: Maximum Gain Over Frequency

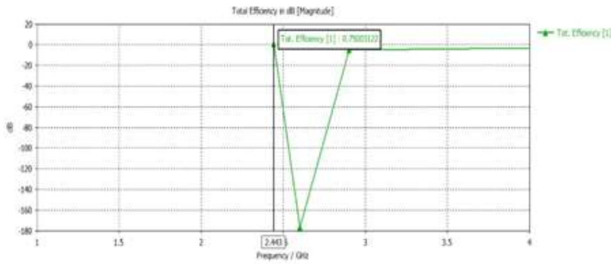


Fig 14: Frequency Vs Total Efficiency

Table 2: Comparison Table

Ref no	Antenna Size (mm2)	Dielectric material used	Bandwidth of Antenna (GHz)	Resonance Frequency (GHz)	Gain(dBi)	Radiating Patch
1	25*10.8	FR4	2.4-2.48	2.45	3.62	Rectangular
2	53*36	RO5880	5-7	5.46,5.88,6.42	8.4 -10.82	Rectangular
3	30.6*2	FR4	3.25-4.21	3.34,4.03	2.5-3.48	Slotted Quasi-Quarter circle
4	32*44	FR4	2.6-3.08 5.42-6.18	2.84,5.8	2.5-3.48	Stepped L, Inverted F
5	10*10	Alumina	2.34-2.52	2.45	-4.5	Inverted F
6	85*85	Polyimide	392.8-410.8MHz	401.8MHz	5.37	Serpentine / Zigzag
7	27.7*16	FR4	2.14-2.62 8.42-9.04	2.24,8.8	3.5	Stepped Rectangular
8	30.68*6.46	Rogers RO4350B	47.726-50	48.836	14.53	Square
9	54*38	FR4	950MHz-6GHz	5.5,5.2,5.9	7.08,6.81,6.65	Inverted F
10	39.4*1.2	FR4	3.4-3.6 4.8-4.9	3.5,4.85	0.5,0.7	Quarter circle
Proposed antenna	22*7.25	FR4	1.07-2.7	2.43	13.4	Rectangular

V. CONCLUSION

A PIFA with dimensions of 25 x 10.8 mm2 and a completely covered ground made of copper was simulated. The structure is fed by a microstrip line feed. Because of its compact size, improved radiation efficiency, E-field, H-field, and surface current resonant frequency it is suitable for Bluetooth wearables like Smart watches and various medical applications. This antenna has bandwidth of 1.07 GHz to 2.7 GHz. The calculated gain of PIFA is 13.4 dBi The VSWR and reflection coefficient characteristics simulated are found to be quite accurate.

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