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Compact Flexible Wearable Loop Antenna for Enhanced WBAN Performance across Multiband Frequencies

Mr. Pradipkumar V. Lokhande*[1], Dr. Yuvraj K. Kanse [2]

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Abstract: This paper demonstrates the compact flexible wearable loop antennas structures for Wireless Body Area Network (WBAN) applications for various frequency bands. Also, examining the performance of loop antenna, loop monopole antenna and loop monopole antenna with smaller ground structure. All these antennas are designed by FR4 epoxy material with 0.2 mm thin flexible substrate thickness and 0.035mm copper strip as radiating element using microstrip feed techniques. The deformed geometries are reanalyzed using High frequency structure simulator (HFSS v18) software. Initially, proposed two antennas design as per the dimensions as 60×20× 0.2 mm^3. Proposed two antennas (loop and loop monopole) are operating from 2.1723 GHz to 3.6200 GHz without change in dimensions, which provides resultant bandwidths are 56.36 % and 59.30 % respectively. Finally, compact loop monopole antenna with smaller ground structure dimension reduced as 50.5 × 20 × 0.2 mm^3which operating from 1.1135 GHz to 3.72 GHz, improves bandwidth as 106.38 % under the industrial, scientific and medical (ISM) band. Also facilitating multi-band functionally at 1.13, 2.45 and 3.53 GHz. Finally, comparison and improvement in various antenna performance parameters such as bandwidth, return loss, VSWR, gain and antenna efficiency under ISM band for various WBAN applications using paper based (thin substrate) flexible wearable antenna.

Keywords: *Flexible material, thickness, ISM Band, Multi-band Antenna, WBAN applications*

1. Introduction

The development and utilization of wearable antenna has been increased due to the recent reduction of wireless devices. An antenna that is worn inside clothes that is used for the transmission and reception of wireless signals for a variety of uses, such as public safety, tracking, navigation, and mobile computing. WBAN has many health surveillance applications in real-time. Designing wearable antenna for WBAN applications provides the facilities such as sense, communicate, transfer and exchange the data through IoT.

Various human physiological indicators, including as body temperature, blood pressure, respiration rate, ECG, and EMG/EEG, are measured by a WBAN sensor [1]. Numerous sensors are positioned on the patient's body to gather medical data, allowing for quick service for older citizens [2]. Flexible conductive materials for the radiating patch, ground plane, and substrate material can be used to design the wearable microstrip patch antenna [3-4].Additionally, utilizing the Ultra-Wideband (UWB), Medical Impact Communication System (MICS), and Industrial Scientific Medical (ISM) bands, many antennas have been modelled for WBAN applications.

Among the research issues in antennas for body-centric (in/on/off body) communications is wearable, textile or fabric-based antennas. All contemporary applications demand wearable antennas, which must be lightweight and inexpensive. There are a wide range of uses for wearables in our daily lives. They apply

for body-centric communication systems in a variety of specialized industry segments, including entertainment, medical, and military.

2. Literature Review

Flexible wireless sensor node operating at 2.4 GHz with a single-layer monopole polyimide substrate antenna for wearable applications on-body capabilities using patch and meandering line [5-6]. Highly efficient wireless power system with a compact design reach > 80% efficiency with 60 mm range for wearable applications [7-8]. Low-profile segment with a small form factor that is a result of a seamless combination of a bandpass filter and a patch radiator in a compact circularly polarized co-designed filtering antenna which integration into diverse wireless systems for wearable off-body communications [9-10]. Utilizing a metamaterial structure, a wearable antenna with bidirectional patterns allows for configurable resonance in both modes. Antenna exhibits the unique absorption rate associated with European standard thresholds [11]. Represents with antenna wearable antenna challenges, requirement for conformity, flexibility, and low-profile structures integration with the human body in 5G. Provide information related to materials and fabricating methods, highlighting how difficult it is to achieve ideal

[1]*Research Scholar, RIRD Satara & Shivaji University,*
Assistant Professor, TKIET Warananagar, Kolhapur, Maharashtra, India
ORCID ID: 0009-0004-0330-5675
[2] *Research Guide, RIRD Satara & Shivaji University,*
Associate Professor, KBP Satara, Maharashtra, India
** Corresponding Author Email: pvlokhande21@email.com*

performance while preserving compact size and minimizing the impacts of body coupling and structural deformation [12]. Hybrid structure of triangular patch antenna with defective ground structure and Koch fractal geometry on a flexible substrate made of inexpensive vinyl polymer which provides specific form factor, impedance bandwidth, peak gain and maximum radiated efficiency while operating in the 2.45 GHz ISM band [13-14]. Dual-band antenna in the 2.45 and 5.8 GHz ISM bands uses in off-body and on-body communications with circular patch uses silver fabric is integrated into a flexible polydimethylsiloxane (PDMS) substrate [15-16]. Electromagnetic band-gap (EBG) structure of a wearable circular ring slot antenna design for wireless body area networks (WBAN). Antenna exhibits dual band monopole antenna for improvement in various wearable antenna parameters [17-18]. For WBAN at the 2.4 GHz ISM band, compact and flexible circularly polarized (CP) wearable antenna is made by utilizing a low-loss composite made of silver nanowires (AgNWs) and polydimethylsiloxane (PDMS) [19-20].

Wearable button antenna consists of a button with a small diameter with patch on top of a dielectric textile substrate for 2.4 GHz and 5 GHz band. Also, Substate-Integrated Waveguide (SIW) technology used significantly higher efficiency [21-22]. Antenna is performed effectively at UWB with a larger frequency range of 3 GHz - 10.5 GHz for early breast cancer detection and WLAN and LTE-A applications with thin flexible cotton material substrate was used in the design wearable textile antenna. By bending the structure to various degrees, the antenna's performance is examined in terms of emission patterns, gain, and reflection coefficients improvement using line slot is employed at the ground level [23-24]. A novel wearable textile antenna is designed to operate in the 2.45 GHz and 5.8 GHz Industrial, Scientific, and Medical (ISM) bands using Jeans textile material. It is designed to be used in future wireless systems that require omnidirectional radiation patterns. Antenna performance parameters are investigated on human bodies and in open space [25-26]. Researching wearable technology with antenna applications and digital health care systems. The use of antennas in healthcare is covered in this thorough systematic review. In addition, it offers a cutting-edge summary of recent advancements in healthcare, emphasizing design, monitoring tools, diagnostic implants, early detection processes, control and future aspects [27-28]. Inverted E-shaped antenna is made by effectively loading a rectangular slot with a strip line inserted in a miniature textile antenna. The antenna is smaller than a typical antenna in size. As a wearable antenna, the antenna demonstrates an improvement in size reduction with impedance bandwidth of more than 15%, and an efficiency of more than 78% in the ISM band [29]. Antenna is a dual-band, flexible, self-grounding semi-circular gap antenna made of polyimide. The antenna construction with slit structure provides higher gain and efficiency. Offers two frequency bands that include typical communication frequency bands as WLAN, 4G, 5G, Bluetooth, ISM etc. [30]. Different flexible textile-based materials were used to design of proximity-fed antennas, which increased bandwidth and decreased footprint [31].Designed smart bandage with battery-free, inexpensive, durable and easy to use electrochemical wound monitoring and sensing. The low-cost textile embroidery onto fabric substrate manufacturing process was used to create the electronics and biotelemetry linkages. A bedsheet featuring an innovative Elektrisola-7 corrugated crossed-dipole stitched onto gauze fabric textile served as the transmitter's representation in large area for RF power harvesting system [32-33].

Designed compact single-layer textile MIMO antenna with good isolation for wearable applications. The wearable antenna fabricated on a flexible felt for bending condition [34]. Designed MIMO antenna with horizontal and vertical mode of the ground plane and the phase difference between them controlled by utilizing an inductor-loaded metal strip in the ground plane [35]. Design fully textile integrated antenna with slotted short circuited microstrip line for automobile sector. The antenna fabricated using an industrial loom with laser prototyping machine which working at 5.9 GHz and a 9.3% bandwidth [36].

Wearable textile patch antenna with a varactor-loaded with highly flexible and conductive nickel-copper-silver plated polyamide fabric for dual band for ISM band [37]. Fabrication of wearable circular ring slot antenna with EBG structure for WBAN application at 2.4 GHz under ISM band for bandwidth improvement. Antenna meets the specific absorption value which less than the limitations [38]. Provides effects of bending conditions for cylindrical surfaces for wearable patch antennas [39].Dual-mode wearable textile antenna compared with textile patch antenna with different scenarios on human body [40]. A compact flexible circularly polarized (CP) wearable antenna is designed for WBAN by using a lowloss composite of polydimethylsiloxane and silver nano wires [41]. A miniaturized textile antenna designed by denim fabric under different bending condition [42].Designed single band wearable antenna with on-body and off body that two integrated antennas are fed separately but share a common ground for felt substate [43]. Demonstrates serviceable effects of the multilayered low dielectric constant substrate for radiating elements [44]. Performance analysis of a flexible and stretchable wearable antenna on a 3D printed substrate for details 3-D printing of the substrate, brush painting of the antenna, results and antenna limitations for wireless on body application for ISM band [45-46].Wearable antenna with truncated patch integrated into a military beret circular ring patch with four conductive threads for the higher-order resonance mode of indoor positioning systems, both for outdoor and indoor applications. The antenna has been incorporated into a military beret and is made of felt substrate materials [47]. Designed planer monopole antenna with EGB 2 by array structure at ISM band. Antenna designed with semi-flexible RT/duroid 5880 substrates provides low SAR, compact size, high gain etc. [48]. EBG structure used to antenna for improves FBR, gain, SAR reduction to wearable technology [49].Design wearable antenna for a GPS with anti-theft tracking system [50].Under the right working conditions, polyester fabric prints various designs on active materials using a nickel electroless bath. Textile antenna designed having a conductive nickel fabric and tested at different angles[51]. Comparative analysis of multilayer stacked substrates microstrip patch for antenna performance improvement [52]. Fabric demin gens used as dielectric material which gives very good result for wearable antenna simulated within 1 GHz to 10 GHz frequency range resultant antenna useful for various applications [53].Lower resonating frequency with increasing tension strain with increasing dielectric constant for leveraging laser-induced graphene printed flexible microstrip antenna [54].

3. Design and Methodology

The suggested antenna's design and simulation study were carried out utilizing High Frequency Structure Simulator (HFSS v18) software. The proposed flexible wearable antennas were designed by FR4 epoxy material with 0.2 mm thin flexible substrate thickness with dielectric constant of 4.4 and loss tangent of 0.02. Also, 0.035 mm copper loop as radiating element using microstrip feed techniques. Standard copper cladding was used to create the antenna's shape on the substrate's top side. A rectangular patch was designed using two parts as LHS & RHS. First design, loop antenna has been designed on both sides i.e. LHS & RHS. The loop patch structure is exactly same on LHS and RHS as shown in figure. Proposed loop antenna design length (Lg) of antenna is 60 mm, width (Wg) is 20 mm also antenna's flexibility and stability are balanced by the FR4 substrate's 0.2 mm thickness. Figure 1 shows proposed flexible wearable antenna. Also, table 1 provides all the design parameters of flexible wearable loop antenna.

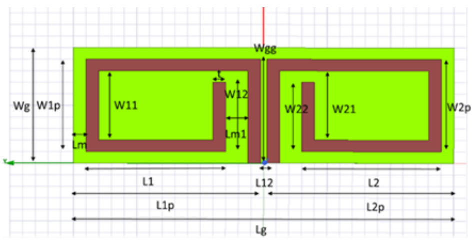

Fig.1. Proposed Flexible Wearable Loop Antenna

Table. 1. Proposed Flexible Wearable Loop Antenna Parameters

Parameter	Value (mm)	Parameter	Value (mm)
Wg	20	W1p=W2p	16
Lg	60	L1P=L2P	29.5
Wgg	18	W11=W21	12
T	2	W12=W22	12
Lm1	3.5	L1=L2	22
L12	1	Lm	2

Second design, monopole loop antenna has been designed at only LHS side. The flexible monopole antenna has been modified version of loop antenna with RHS loop side is absence in structure. Monopole antenna parameters are similar to loop antenna. Proposed loop monopole antenna design length (Lg) of antenna is 60 mm, width (Wg) is 20 mm and FR4 substrate thickness is 0.2 mm as shown in figure 2. Also, table 2 provides all the design parameters of flexible wearable loop antenna.

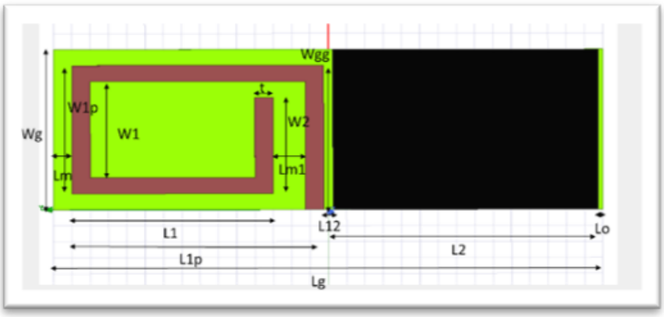

Fig. 2. Proposed Flexible Wearable Loop Monopole Antenna

Table 2. Proposed Flexible Wearable Loop Monopole Antenna Parameters

Parameter	Value (mm)	Parameter	Value (mm)
Wg	20	W1p	16
Lg	60	L1P	29.5
Wgg	18	W1	12
t	2	W2	12
Lm1	3.5	L1	22
L12	1	Lm	2
L2	29	L0	0.5

Finally, third design, loop monopole antenna with small ground structure which is modified version of loop monopole antenna. The RHS side is acts as a ground plane also reduction in antenna length. Proposed loop monopole antenna with small ground design length (Lg) of antenna is 50.5 mm, width (Wg) is 20 mm and FR4 substrate thickness is 0.2 mm as shown in figure 3. Also, table 3 provides all the design parameters of flexible wearable loop antenna with small ground structure.

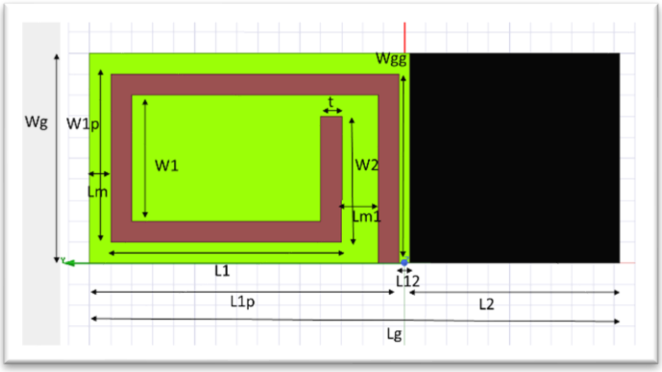

Fig.3. Proposed Flexible Wearable Loop Monopole Antenna with Smaller Ground

Table. 3. Proposed Flexible Wearable Loop Monopole Antenna with Smaller Ground Parameters

Parameter	Value (mm)	Parameter	Value (mm)
Wg	20	W1p	16
Lg	50.5	L1P	29.5
Wgg	18	W1	12
T	2	W2	12
Lm1	3.5	L1	22
L12	1	Lm	2
L2	29		

4. Result Discussion and Experimentation

Proposed flexiblewearable antennas were simulated on HFSSv18 and obtain the antennas different parameters. Reflection coefficient (S11) provides the antenna's functioning bandwidth. i.e. minimum-maximum and resonant frequency of antenna with reflection coefficient's magnitude is less than -10 dB.. Figure 4 indicates loop antenna is optimized for the targeted band spectrum of 2.44 GHz and 3.28 GHz with impedance bandwidth of 2.26-3.60 GHz. Loop monopole antenna is optimized for the targeted band spectrum of 2.34 GHz and 3.26 GHz with impedance bandwidth of 2.18-3.56 GHz. Loop monopole antenna with smaller ground structure is optimized for the targeted band spectrum of 1.44, 2.46 and 3.56 GHz with impedance bandwidth of 1.11-3.72 GHz. Resultant flexiblewearable antenna structures provide bandwidths as 1.26 GHz, 1.38 GHz and 2.46 GHz respectively.

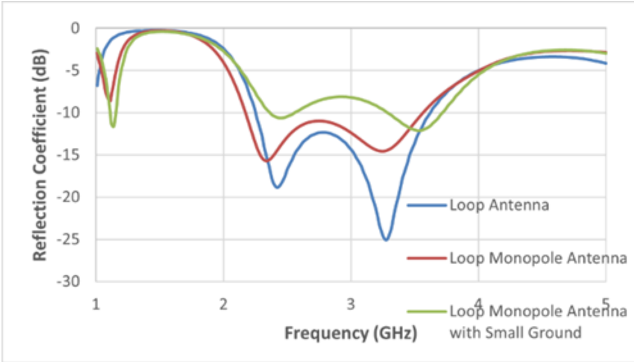

Fig. 4. Reflection Coefficient Vs Frequency

Also, the efficiency with which radio frequency is transferred from a power source over a transmission line and into a load is measured by the voltage standing wave ratio. The usual acceptable range of VSWR is 1 to 2. Figure 5 indicates all flexiblewearable antenna structures resonates in acceptable range.

Frequency Vs gain plot provides information about how antenna provides gain for resonating frequency. Figure 6 indicates all the flexible wearable antenna structure obtains more than 2.5dB gain in operating band. It's observed that for flexible wearable loop, loop monopole and loop monopole with small ground antenna structure provides 2.30 dB, 2.47 dB and 1.90 dB gain respectively for ISM band.

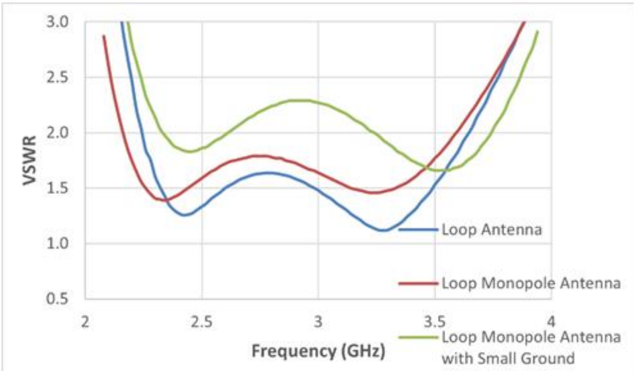

Fig. 5. VSWR Vs Frequency

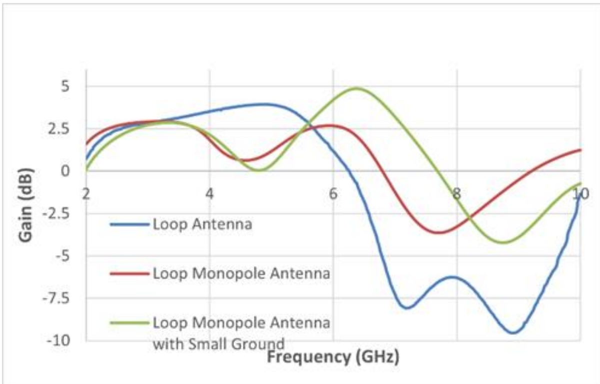

Fig. 6. Gain Vs Frequency

Antenna efficiency Vs frequency plot provides information about antenna efficiency at particular resonant frequency. Figure 7 indicates flexible wearable loop and loop monopole and loop monopole with small ground antenna structure achieves total efficiency up to90%, 88%, 88 % at 1.26 GHz.

Also, up to 98 %at 2.46 GHz for all antenna structure. But, for 3.56 GHz achieves up to 102% for loop antenna and 99% for loop monopole and loop monopole with small ground antenna structure.

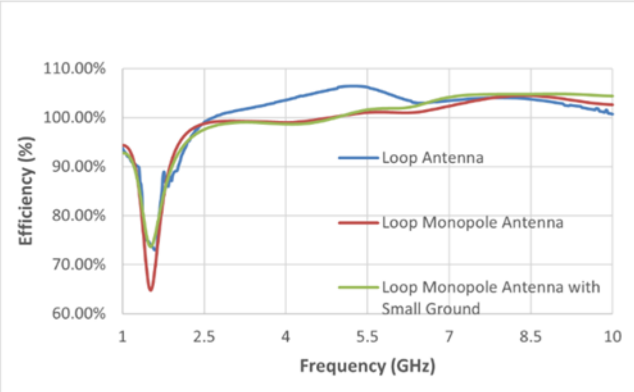

Fig.7. Antenna Efficiency Vs Frequency

Antenna radiation pattern is a graphical depiction of the antenna's radiation characteristics which describes how symmetrical it radiates or adsorbs electromagnetic radiation in E & H plane. Figure8, for both Phi 0 and 90 degrees, the normalized radiation patterns are displayed. For both planes, the antenna exhibits a bidirectional radiation pattern.

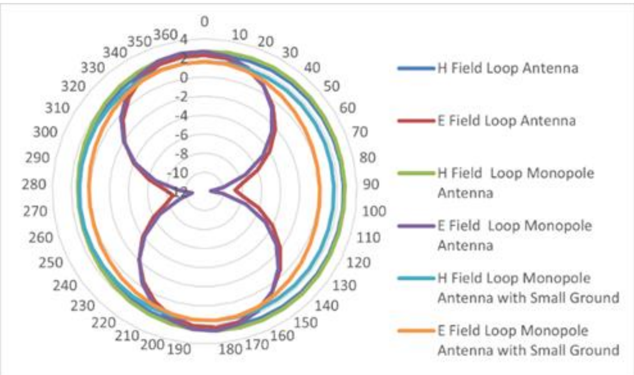

Fig.8. Radiation Pattern (E & H Field)

Table 4 and 5 provides comparative analysis of proposed antenna structure with physical size, substrate material, operating band, number of bands and antenna design techniques.

Table. 4. Comparison of Proposed Flexible Wearable Antenna w.r.t. Material and Operating Band

Ref. No.	Physical size (mm^3)	Wearable Antenna Material	Operating Band (GHz)
[55]	60×60×5.14	Resin-coated Paper	0.8 to 1.1
[56]	120×120×3.5	Jeans	2.4 to 2.5
[57]	38×38×3	FR4	2.40 to 2.48
This work	50.5×20×0.2	FR4	1.11 to 3.72

Table. 5. Comparison of Proposed Flexible Wearable Antenna w.r.t. No. of bands and Design Techniques

Ref. No.	Physical size (mm3)	No. of Bands	Design Technique
[58]	122.5×122.5×1.8	Single	AMC
[59]	64.36×76.96×4.06	Dual	Aperature coupled
[60]	60×60×4.52	Triple	Two Layered Substrate
This work	50.5×20×0.2	Tripple	Strip line feed

Proposed antenna structure with 0.2 mm FR4 substrate thickness useful for many application under1.11-3.72 GHz operating band. It is also useful for Wireless Body Area Network (BAN) due to its material properties like lightweight, flexibility, printed electronics, low cost etc.

5. Conclusion

This paper presents an investigation of the performance and unique design structures of a FR4 epoxy substrate flexible wearable loop antenna with 0.2 mm thickness. Analysis of all loop antennas under ISM band. The different antenna performance parameters are found to be satisfactory for WBAN a application which resonates in tri-band as 2.23-3.60 GHz, 2.18-3.56 GHz and 1.11-3.72 GHz frequency band. Simulated antenna results provide maximum resultant bandwidth as 2.46 GHz for loop monopole antenna with small ground structure. Also provides maximum gain as 2.47 dB for loop monopole antenna. As tri-band resonating frequency band, loop monopole antenna with small ground structure provides 102 % radiating efficiency for 1.11-3.72 GHz. All flexible wearable antennas show VSWR and input impedance in acceptable range. Reflection coefficient, VSWR, bandwidth, gain and radiation efficiency etc. are useful for effective health monitoring for Wireless Body Area Network (WBAN) applications for various frequency bands. Measured parameters in HFSS shows good agreement with the modeling and conform that such antennas can be successful used for flexible wearable applications. Simulation results shows the proposed flexible wearable compact monopole antenna with small ground structure can be useful for applications such as ISM, mid-band spectrum, Wi-Max, WLAN, Wi-Fi etc. Future work is underway to develop the fabricated antenna with multiple substrate material layers for human phantom for specific absorption rate for flexible wearable antenna.

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