Design and Realization of Microstrip Circular Patch Antenna Using Textile Material with 2.4 GHz Frequency for Telemedicine Application

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***Abstract*— Telemedicine is a technological innovation that use wireless communication within the human body to facilitate the provision of health care over large distances. The utilization of wireless communications for remote monitoring can offer advantageous outcomes for wearable antenna systems. Wearable antennas have the potential to be employed in Wireless Body Area Networks (WBANs), facilitating the transmission of health-related information and addressing telemedicine requirements. The wearable antenna under consideration employs a microstrip antenna, which possesses several noteworthy attributes like compact size, low weight, flexibility, cost-effective manufacturing, and the ability to operate within specific frequency ranges. Hence, the author formulated the title with the objective of facilitating the utilization of this antenna in health-related contexts.**

In this study, the antenna is affixed to the arm's surface and functions at a frequency of 2.4 GHz, specifically within the Industrial, Scientific, and Medical (ISM) range. The antenna design employed in this final project incorporates the insertfeed method, which is anticipated to enhance the return loss and VSWR values. Additionally, the Defected Ground Structure (DGS) method is utilized to improve the gain and bandwidth values, thereby enabling the antenna to operate within the ISM frequency range. The chosen material for this application is CORDURA, which possesses a thickness of 0.5mm. The supply of the Microstrip feedline is utilized in this context.

The objective of this final research project was to build a microstrip antenna with a circular patch. The performance of the antenna was evaluated by software simulation, yielding the provided results. At a frequency of 2.4 GHz, the measured return loss value is -30,923 dB. The bandwidth of the system is determined to be 775 MHz. The Voltage Standing Wave Ratio (VSWR) is calculated to be 1.058. The gain of the system is determined to be 2,239 dBi. The resulting radiation pattern is observed to be bidirectional. The findings of the measurement conducted are as follows. At a frequency of 2.4 GHz, the measured return loss was -16,019 dB. The bandwidth of the system was found to be 296.7 MHz. The Voltage Standing Wave Ratio (VSWR) was determined to be 1,376. Additionally, the antenna exhibited a gain of 2.0887 dBi and a bidirectional radiation pattern.

***Keywords*— Telemedicine, Microstrip, Wearable Antenna, Cordura, WBAN, DGS, ISM**

I. INTRODUCTION

Telemedicine is one of the technologies that uses wireless communication in the human body to provide long-distance health services [1]. Telemedical technology is defined as technology that provides medical services to persons who can be monitored remotely [2]. since Indonesia has a very diversified geographical position, including islands, enormous landmasses, and much that cannot be reached quickly, and the presence of medical workers is not fairly dispersed in each part of Indonesia And because of the restricted number of doctors in certain areas, as well as the lack of medical facilities in certain areas, health services in Indonesia are undoubtedly a severe concern. From these issues, can be concluded as a proposes methods for employing wireless communication on the human body, sometimes known as a Wireless Body Area Network (WBAN).

WBAN is typically used to make it easier for doctors, medical workers, or the patient's family to monitor the patient's health in real time [3]. WBAN is made up of on-body and off-body sensors that can be employed in applications. Typically, a chip device sensor can be used to obtain data in the form of body temperature, blood pressure, respiration, heart rate, glucose levels, and signal waves via Electro Cardio Gram (ECG) [4]. The sensor chip gadget is attached to or embedded in the body of the patient. The sensor chip will communicate data through the transmitting antenna, which will be received by a receiving device. As for the antenna, it must be flexible and lightweight in order to be comfortable for users to use. This is referred to as a wearable antenna.

An antenna is a radio-frequency device that converts electrical signals into electromagnetic waves that flow across free space or air, and vice versa. The microstrip antenna is a popular choice for wireless communication. Microstrip antennas have various advantages, including their small size, simple manufacturing process, ease of installation, and low cost. The downside of microstrip antennas is their limited bandwidth. Wearable antennas are microstrip antennas that can be connected to garments or placed directly on the human skin. Wearable antennas have various advantages, including small size, light weight, ease of manufacture, and the ability to perform in a relatively wide frequency range. Because of the flexible substrate material, wearable antennas can also be bent.

Wearable antennas have various advantages, including their compact size, light weight, ease of construction, and ability to work across a wide frequency range [5]. Because the substrate material is a flexible and thin substance, wearable antennas can also be bent or curved. With such flexibility, the antenna can adjust to changes in the shape of the body and continue to function correctly. However, wearable antennas have a disadvantage in their use since they have a thin substrate and hence a narrower bandwidth than the others. In general, this antenna is utilized in the Industrial, Scientific, and Medical (ISM) band because it is the most suited band for WBAN because it is license-free and has sufficient bandwidth.

Therefore, in this final project, the design of a wearable antenna at ISM 2.4 GHz frequency with flexible materials will be uses a textile-based substrate that is different from the usual microstrip antenna substrate. This antenna will be applied to the health sector, especially telemedicine and can make it easier and at the same time get comfort when used. Testing of this antenna will be carried out on the arm to support WBAN (Wireless Body Area Network) applications with good SAR (Specific Absorption Rate) values and also get a very wide bandwidth. And a flexibility test will be carried out on the antenna.

The aspects discussed are VSWR parameters, bandwidth, gain, and radiation pattern.

II. THEORITICAL STUDY

A. Utilization Scenario

The microstrip antenna fabricated exhibits a resonant frequency of 2.4 GHz. The microstrip antenna is fabricated in conjunction with an amplifier on the antenna groundplane with the objective of enhancing the antenna's gain.

B. Specification

The frequency utilized in this observation was recorded within the spectrum of 2-2.8 GHz, with a designated operational frequency of 2.4 GHz. The antenna's substrate material is Cordura 600D, while copper is utilized for both the patch and groundplane materials.

Table 2.1 Antenna Specification

No	Parameters	Details
1.	Work Frequency	2.4 GHz
2.	*Gain*	> 2 *dBi*
4.	*Return Loss*	≤ -10 dB
5.	*Bandwidth*	> 234.5 MHz
6.	VSWR	VSWR ≤ 2
7.	Substrate dielectric constant	1.6
8.	Substrate Thickness	0.5 mm
9.	Copper Thickness	0.1 mm

C. Antenna Textile

Textile antennas are an excellent option to be used in wearable antennas. Because of its lightweight and flexible material, this antenna is highly comfortable to wear when placed on the patient's body or clothing. Textile substrate materials usually have a very low dielectric constant which reduces surface wave losses and improves antenna's bandwidth [6].

D. Wireless Body Area Network (WBAN)

WBAN can be applied in the healthcare field; the placement of WBAN on the human body can be classified into three groups, including [7]:

1. In-Body Centric
   The WBAN devices are implanted inside the human body.
2. On-Body Centric
   The WBAN devices is mounted to one area of the body and communicates with body tissues.
3. Off-Body Centric
   The WBAN devices are typically linked for long-distance communications via a wearable antenna.

E. Industrial, Scientific and Material (ISM)

The frequency used in this study is Industrial, Scientific and Medical (ISM), which is one of the unlicensed bands approved by the Federal Communication Commission (FCC) in 1985 and is included in the Unlicensed National Information list. As shown in the following Table 2.2 [8].

F. Specific Absorbtion Rate (SAR)

SAR is a measurement of the amount of energy absorbed into the body when exposed to electromagnetic wave radiation emitted by wireless devices or Radio Frequency (RF), in this example the SAR induced by the antenna wearable. The SAR in this example is measured in watts per kilogram (W/kg) [9]. The safe limit for the SAR value given by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) of Europe is 2.0 W/kg, whereas the Federal Communication Commission (FCC) of USA set it at 1.6 W/kg based by International ANSI/IEEE standard [16].

G. Phantom

Phantom which is a modeling of the human body. Phantoms must be designed according to the shape and characteristics of human body parts, whether from their physical appearance such as skin thickness, fat, muscle or from their special characteristics (electrical properties) such as permittivity, permeability and conductivity values [8]. Table (2.2) describes the Electrical Properties of Phantom Components.

Table 2.1 Electrical Properties of Phantom Components

Layers	Permittivity Value	Conductivity Value (S/m)	Density (km/m^3)
Skin	38.01	1.46	1090
Fat	5.28	0.1	930
Muscle	52.73	1.74	1050
Bone	18.55	0.8	1920

III. METHODE

Microstrip antennas are fabricated via the feed line distribution technique. The utilization of the Defected Ground Structure (DGS) technique or the implementation of a cut ground plane antenna can be employed to enhanc both the gain and bandwidth efficiency.

A. Dimension Calculation for Antenna

When incorporating microstrip antennas, it is imperative to ascertain the dimensions and initial configuration of the antenna for the purpose of design. The process of determining the size of the microstrip antenna at a frequency of 2.4 GHz involves doing calculations to ascertain its dimensional characteristics.

1) Determine the patch radius.

$$F = \frac{8.791\times10^9}{fr\sqrt{\varepsilon r}} \tag{3.1}$$

$$F = \frac{8.791\times10^9}{2.4\times10^9\sqrt{2.05}} = 2.558$$

$$a = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon rF}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{\frac{1}{2}}} \tag{3.2}$$

$$a = \frac{2.558}{\left\{1+\frac{2\cdot0.5}{\pi\cdot2.05\cdot2.558}\left[\ln\left(\frac{\pi\cdot2.558}{2\cdot0.5}\right)+1.7726\right]\right\}^{\frac{1}{2}}} = 3.302$$

$$r = a\left\{1+\frac{2h}{\pi\varepsilon rF}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{\frac{1}{2}} \tag{3.3}$$

$$r = 3.302\left\{1+\frac{2\cdot0.5}{\pi\cdot2.05\cdot2.558}\left[\ln\left(\frac{\pi\cdot2.558}{2\cdot0.5}\right)+1.7726\right]\right\}^{\frac{1}{2}}$$

$$r = 2.558\, mm$$

2) Determine the Ground plane (Gp) and Substrate.

$$Gp = 6h + 2a \tag{3.4}$$

$$Gp = 6\cdot0.5 + 2\cdot3.302 = 18.604\, mm$$

3) Determine Width Feedline.

$$A = \frac{z_o}{60}\sqrt{\frac{\varepsilon r+1}{2}} + \sqrt{\frac{\varepsilon r-1}{2}}\left(\frac{\varepsilon r-1}{\varepsilon r+1}\right) \tag{3.5}$$

$$A = \frac{50}{60}\sqrt{\frac{2.05+1}{2}} + \sqrt{\frac{2.05-1}{2}}\left(\frac{2.05-1}{2.05+1}\right) = 1.278$$

$$W_f = \frac{w}{d} = \frac{8e^A}{e^{2A}-2} \tag{3.6}$$

$$W_f = \frac{8e^{1.278}}{e^{2\cdot1.278}-2} = 2.638\,mm$$

4) Determine Length Feedline.

$$\varepsilon_{eff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left(1 + 12\frac{h}{wf}\right)^{-\frac{1}{2}} \tag{3.7}$$

$$\varepsilon_{eff} = \frac{2.05+1}{2} + \frac{2.05-1}{2}\left(1 + 12\frac{0.5}{2.638}\right)^{-\frac{1}{2}} = 0.642$$

$$\lambda g = \frac{\lambda o}{\sqrt{\varepsilon_{eff}}} \tag{3.8}$$

$$\lambda g = \frac{\frac{1}{8}}{\sqrt{0.645}} = 0.1556$$

$$L_f = \frac{\lambda g}{4} \tag{3.9}$$

$$L_f = \frac{0.1556}{4} = 3.89\,mm$$

B. Antenna Design

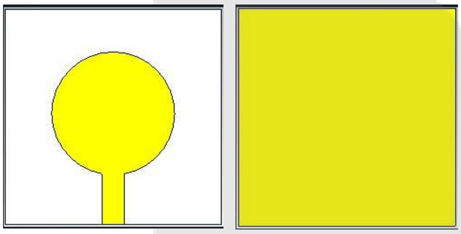


Figure 3.1 Front View (a) and Back View (b) Antenna Design

The simulation of microstrip antenna design is conducted subsequent to performing calculations. The initial dimensions of the antenna parameters are presented in Table 3.1.

Table 3. 1 Intial Antenna Dimensions

Parameters	Values
Radius patch (r)	2.558 mm
Width Ground Plane (W_g)	18.604 mm
Length Ground Plane (L_g)	18.604 mm
Width Substrate (W_S)	18.604 mm
Length Substrate (L_g)	18.604 mm
Width Feedline (Wf)	2.638 mm
Length Feedline (Lf)	3.89 mm
Copper Thickness (t)	0.1 mm
Substrate Thickness (h)	0.5 mm

Upon doing a simulation of the dimensional antenna the initial antenna settings acquired did not meet the desired standards. Next, the optimization process will be conducted in order to get the desired antenna parameters. The dimensions characteristics of the optimized antenna are presented in Table 3.2.

Table 3.2 Optimization Antenna Dimensions

Parameters	Values
Radius patch (r)	14.3 mm
Width Ground Plane (W_g)	46.604 mm
Length Ground Plane (L_g)	54.604 mm
Width Substrate (W_S)	46.604 mm
Length Substrate (L_g)	54.604 mm
Width Feedline (Wf)	4.038 mm
Length Feedline (Lf)	27.302 mm
Width Slot (x)	1.5 mm
Length Slot (y)	2.5 mm
Copper Thickness (t)	0.1 mm
Substrate Thickness (h)	0.5 mm

C. Alteration in Ground Plane Dimension

The use of the ground plane discontinuity or the commonly known defected ground structure (DGS) technique results in a modification of the bandwidth and voltage standing wave ratio (VSWR), leading to favorable outcomes. The visual representations of the data can be observed in Figure 3.2.

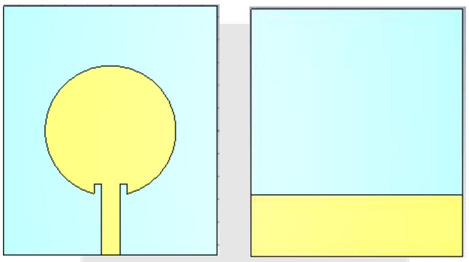


Figure 3.3 Front View and Back View Optimization Antenna Design

D. Comparison of Simulation Result

Once the simulation has concluded, a comparison is made between the antenna parameters of the initial antenna and the optimized antenna. Table 3.3 presents a comparison based on the outcomes obtained from the conducted simulations.

Table 3. 3 Simulation Results

Products	Initial Antenna	Optimization Antenna
Return Loss (dB)	-0.245	-30.971
VSWR	70.771	1.058
Bandwidth (MHz)	-	775
Gain (dBi)	-17.96	2.239

E. Antenna on Wrist Phantom

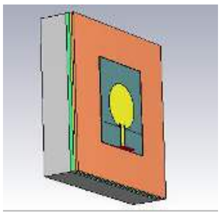


Figure 3. 2 Phantom Wrist Simulation

Upon completion of the antenna design in accordance with the specified requirements, the antenna underwent testing under on-body conditions using a wrist phantom. The outcomes of the antenna parameters are presented in Table 3.4.

Table 3.4 Parameter Values of Antenna with Wrist Phantom

Frequency (GHz)	Distance (mm)	VSWR	Gain (dB)	SAR (W/kg)	Bandwidth (MHz)	Radiation Pattern
2.4	0	1.903	-5.848	12.577	-	Bidirectional
	15	1.758	5.577	2.488	385	Bidirectional
	20	1.626	6.190	1.397	489	Bidirectional
	30	1.471	6.228	0.595	721	Unidirectional

F. Comparison of Simulation Results in On and Off-Body Condition

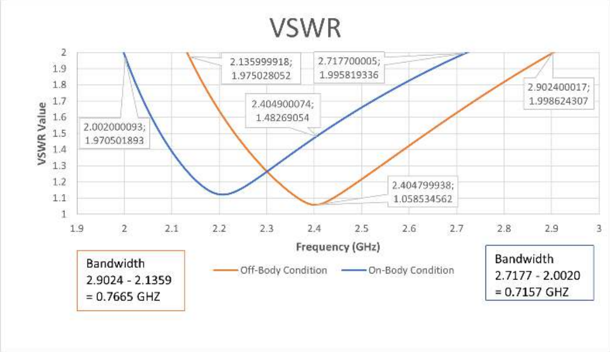


Figure 3.4 Comparison Results in On and Off-Body Conditions

The simulation findings indicate disparities in the values of VSWR and Bandwidth between Off-Body conditions and On-Body scenarios. The graph Figure 3.20 illustrates that under Off-Body conditions, the VSWR value is 1.0585, accompanied by a bandwidth of 766.5 MHz. Conversely, when the On-Body condition is taken into account, the VSWR value increases to 1.4827, with a corresponding bandwidth of 715.7 MHz. The presence of a Phantom in the vicinity of an antenna can lead to changes in impedance values, resulting in impairments to Voltage Standing Wave Ratio (VSWR) and bandwidth.

Table 3.5 Comparison Simulation Value in On and Off-Body Conditions

Conditions	VSWR	Bandwidth	Gain
Off-Body	1.0585	766.5 MHz	2.239 dB
On-Body	1.4827	715.7 MHz	6.234 dB

IV. RESULTS AND DISCUSSION

A. Fabrication of Antenna

Figure 4. 1 Front View and Back View Fabrication Antenna

B. Measurement Result in Off and On-Body Condition

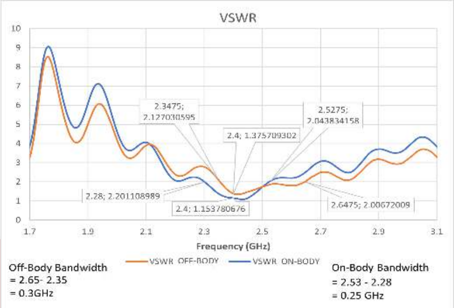
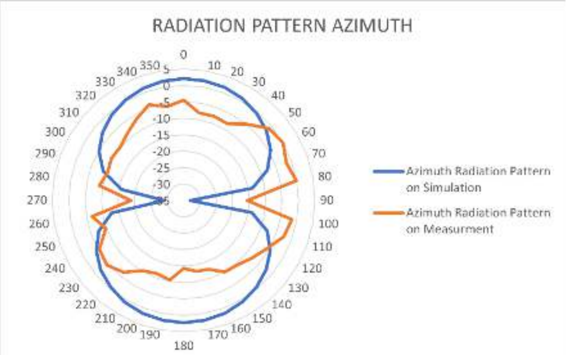


Figure 4. 2 Measurment Comparison in Off and On-Body Condition

The VSWR graph depicted in Figure 4.2 illustrates the measurement outcomes obtained under two conditions: Off and On-Body state, specifically by measuring the wrist. In the absence of Phantom, the Voltage Standing Wave Ratio (VSWR) exhibits a value of 1.376, accompanied by a bandwidth of 296.7 MHz, under typical circumstances. The VSWR data for the wrist in the on-body state yielded a value of 1.539, accompanied by a bandwidth of 248.7 MHz. In comparison to the simulation results, the observed measurements indicate a reduction in bandwidth and an elevation in the VSWR value. The reduction in bandwidth can be attributed to the discrepancy between the utilization of body parts in the measuring process and the corresponding simulation. Additionally, there exist inadequacies in the manufacturing aspect. The rise in Voltage Standing Wave Ratio (VSWR) can be attributed to the manual manufacturing process of antennas, which results in imperfections that deviate from the ideal performance simulated in theoretical models. The measured parameter values are inferior to the simulated findings yet, the constructed antenna remains usable since it still meets the anticipated parameters.

C. Measurement Result of Gain, Radiation Pattern and Polarization



The provided Figure 4.3 depicts the outcome of a radiation pattern measurement conducted on the azimuth plane at a frequency of 2.4 GHz. The maximum power is observed at an angle of 100 degrees, while the smallest power angle is recorded at 90 degrees. The obtained measurement findings indicate that the radiation pattern is bidirectional. The blue graph represents the outcome of a simulation conducted on an antenna design. In the simulation, the maximum power is observed at an angle of 180 degrees, while the minimum power is observed at an angle of 90 degrees.

Figure 4. 3 Results of Elevation Field Radiation Pattern Measurements

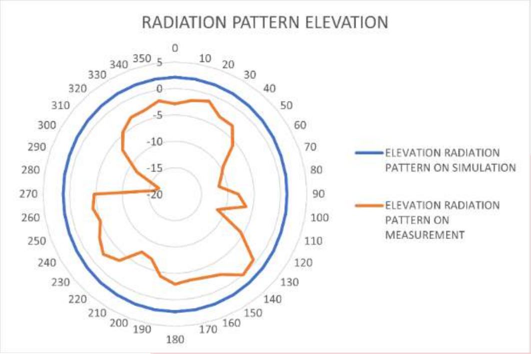


Figure 4. 4 Results of Elevation Field Radiation Pattern Measurements

The figure 4.4 depicts the collected data, which consist of measurements of the radiation pattern in the elevation plane. The pattern exhibits bidirectional characteristics, with the highest intensity observed at an angle of 140 degrees and the lowest intensity observed at an angle of 280 degrees. The simulation findings indicate that the highest value is observed at a corner angle of 180 degrees, while the lowest value is observed at an angle of 210 degrees.

Table 4. 1 Acquire Gain Measuring Results

Condition	Frequency	Gain Value
Simulation	2.4 GHz	2.239
Measurement	2.4 GHz	2.0887

The table 4.1 displays the measurement results of the simulation gain settings and other measurements. There are other factors that influence the outcomes of gain measurement, specifically the suboptimal condition of the textile antenna and the presence of internal attenuation due to ambient conditions outside the measuring chamber.

Table 4. 2 Azimuth Polarization Measurement Result

Axis	Power (dB)	Power (watt)
Mayor	-33.85	$4.12\ x\ 10^{-7}$
Minor	58.06	$1.5\ x\ 10^{-9}$

$$Axial\ Ratio = \sqrt{\frac{P\ mayor\ watt\ x\ 377}{P\ minor\ watt\ x\ 377}} \tag{4.1}$$

$$Axial\ Ratio = \sqrt{\frac{4.12\ x\ 10^{-7}\ x\ 377}{1.5\ x\ 10^{-9}\ x\ 377}} = 16.25123269\ (numberic)$$

$$10\log(16.25123269) = 12.109\ dB$$

The azimuth measured axial ratio value of 12.109 dB or 3 ≤ AR < 40 dB indicates the presence of elliptical polarization.

Table 4. 3 Elevation Polarization Measurement Result

Axis	Power (dB)	Power (watt)
Mayor	-35.08	$3.1\ x\ 10^{-7}$
Minor	-52.65	$5.43\ x\ 10^{-9}$

$$Axial\ Ratio = \sqrt{\frac{P\ mayor\ watt\ x\ 377}{P\ minor\ watt\ x\ 377}}$$

$$Axial\ Ratio = \sqrt{\frac{3.1\ x\ 10^{-7}\ x\ 377}{5.43\ x\ 10^{-9}\ x\ 377}} = 7.555808323\ (numberic)$$

$$10\log(7.555808323) = 8.783\ dB$$

The measurement of elevation polarization involved determining the axial ratio value, which was found to be 8.783 dB. This result falls within the range of 3 ≤ AR < 40 dB, indicating the level of axial ratio. The circular antenna constructed from textile material exhibits elliptical polarization as a result of its polarization type. The simulation results indicate that the circular textile antenna initially possessed linear polarization, however the tests conducted post-fabrication revealed a shift towards elliptical polarization. The fluctuations in the polarization of the measurement stem from ambient noise present in the measuring environment. Additionally, suboptimal conditions of the equipment utilized throughout the measurement process hinder the optimal transmission and reception of the signal.

D. Final Examination

The test findings involve a comparison between the antenna parameters and the specified values indicated in Table 4.4.

Parameters	Simulation Antenna	Fabrication Antenna Measurement
Return Loss	-30.923 dB	-16.019 dB
VSWR	1.058	1.376
Bandwidth	775 MHz	296.7 MHz
Gain	2.239 dBi	2.0887 dBi
Radiation Pattern	Bidirectional	Bidirectional
Polarization	Linear	Ellipse

Table 4.4 presents a comprehensive comparison between the original requirements set in the simulation and the actual results obtained through measurements. The ultimate outcome attained is nearly attainable with the exception of the polarization specification. The simulated values exhibit varying polarization parameters, as depicted in Table 4.4, which presents the final outcomes. The observed variations in polarization outcomes can be attributed to the elliptical polarization induced by the truncation of the antenna's ground plane. The failure to achieve the polarization target has consequences such as the occurrence of cross polarization in the antenna when either the transmitting or receiving target possesses linear polarization. This leads to suboptimal transmission and reception of signals, as well as the introduction of various external noise variables during the measurement process.

V. CONCLUSION

The final outcomes of the comprehensive analysis and simulation design procedure conducted on the antenna software, focusing on a circular patch antenna utilizing Cordura Delinova 600 textile material as a substrate for health-related purposes, can be summarized as follows:

1. A wearable circular patch microstrip antenna has been conceived and implemented to meet the predetermined parameters for healthcare applications.
2. The VSWR measurement outcomes obtained from a circular patch antenna integrated into a wearable device, using Cordura Delinova 600 as the substrate material, exhibit a value of 1.3757. Furthermore, the antenna

demonstrates a bandwidth of 296.7 MHz. The obtained data exhibit disparities when compared to the simulated results, wherein the VSWR value was recorded as 1.058.

3. The disparities observed in simulation outcomes and measurement findings can be attributed to the utilization of a homemade antenna, which may include imperfections in its production process. Additionally, the measurements were conducted outside of a controlled environment, lacking the use of a dedicated measurement room.
4. The bandwidth experiences an increase when structures such as the groundplane are cut.
5. The performance of an antenna can remain satisfactory when subjected to bending tests. The bending radii considered for the antenna in this study are 40 mm, 80 mm, 120 mm, 180 mm, and 240 mm.
6. In general, the outcomes of the antenna parameters align with the stipulated requirements for healthcare applications inside the Industrial, Scientific, and Medical (ISM) frequencies, specifically at 2.4 GHz. The antenna, which operates at a frequency of 2.4 GHz, can be readily integrated into telemedicine technologies used in health applications.

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