Wearable antenna dual band with EBG structure for health applications

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ABSTRACT

The wearable antenna can work for Wireless Body Area Network (WBAN) using the Industrial, Scientific, and Medical (ISM) band. Wearable antenna are small, lightweight, easy to make, and others. The thin substrate limits the bandwidth for this antenna. This research will create a wearable planar monopole antenna circular patch that can operate at 2,4 and 5,8 GHz. The suspended line method can create a band gap and produce dual bands. This method tests the antenna with and without UC-EBG and analyzes the effect of UC-EBG on the antenna performance. Simulation of the antenna without UC-EBG at 2,4 and 5,8 GHz shows return loss -1,520 dB and -25,314 dB, VSWR 1,504 and 1,180, bandwidth 17,906 GHz, and gain of 2,671 dBi and 4,663 dBi. The addition of UC-EBG can affect the antenna parameters so that the return loss -15,269 dB and -17,491 dB, VSWR 1,417 and 1,308, Bandwidth 1,48 GHz and 9 GHz, and gain 2,869 dBi and 5,208 dBi. In the measurement realization antenna, the return loss -13,134 dB and -18,421 dB, VSWR 1,566 and 1,273, bandwidth 2 GHz and 0,98 GHz, and gain is 2,198 dBi and 4,81 dBi. The radiation patterns for simulation and measurement are omnidirectional.

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1. INTRODUCTION

Health care is a problem that numerous nations have to face. Information and communication technology (ICT) has the potential to be a problem-solver in providing affordable, efficient, and high-quality healthcare services. Telemedicine is a technique for remotely delivering medical services that use ICT to gather accurate data. ICT in telemedicine can improve patient circumstances and increases access to medical care and information [1]. The usage of WBAN technology in healthcare applications has increased the impact of technology on patient health. In addition to diagnosing and treating diseases, WBAN technology can keep medical personnel up-to-date on the patient's condition. Based on a 2012 publication, the IEEE 802.15.6 standard for WBAN technology defines it as a protocol for short-range wireless communication devices worn on or near the human body. Rather than invent new frequency bands, WBAN technologies use the Industrial, Scientific, and Medical (ISM) frequency band and those bands approved by local regulators [2].

A wearable antenna can work in wireless body area network (WBAN) communications, which is essential for wearable networks as they can receive and send signals to or from implanted devices. Wearable antennas are capable of functioning in the ISM band. This antenna can operate while worn on the human body and has several advantages, such as small size, lightweight, ease of manufacture, and ability to work at a wide range of frequencies. However, this antenna has a narrow bandwidth due to the thin substrate [3], [4]. Wearable antennas have some drawbacks that must be considered. It is because the human body can absorb a significant amount of the transmitted power, which can decrease the gain, change the antenna's radiation pattern, and have a narrow bandwidth [5]. Textile material can make the antenna flexible and comfortable to wear. Since this material is usually made from porous material, their constant electrical values are relatively low, somewhere between 1 and 2. The low dielectric value can increase bandwidth and gain. The increased efficiency and thicker substrate will make the gain higher. Then, the reduced loss tangent can improve antenna performance [6]. The uniplanar compact EBG is best for wearable applications because they are inexpensive, not used via, etc. The structure of the EBG reflects all electromagnetic waves in the stopband region. The EBG performs as an LC circuit to stop surface waves from spreading and can lower the amount of potentially harmful radiation that can be absorbed by the human body [7].

Research [8], shows a microstrip-type wearable antenna with an EBG structure for body wireless communication. The patch antenna has a rectangular shape, and the EBG has a mushroom-like shape. The EBG structure aims to improve efficiency and the radiation pattern while decreasing mutual coupling effects and radiation effects on the body. The experiment was carried out by testing antennas without EBG and antennas with additional EBG at the 5G band frequency of 3.5 GHz. Based on previous research, this research will design and simulate a wearable antenna that can operate at dual band frequencies using a planar monopole antenna with a circular patch. The Uniplanar Compact Electromagnetic Band Gap, or UC-EBG structure, is added to the planar monopole antenna design. The antenna can operate at 2.4 GHz and 5.8 GHz frequencies. This research will examine the effect of the UC-EBG structure on antenna performance using the suspended line method on a planar monopole antenna.

2. METHOD

The research aims to create a wearable antenna with good specifications when placed around the body. Antenna specifications are required to determine the antenna's performance. Table 1 lists the various specifications of a planar monopole antenna.

Table 1. Antenna Specifications

Parameter	Specification
Frequency	2,4 GHz and 5,8 GHz
Gain	> 1 dB
VSWR	≤ 2
Bandwidth	≥ 500 MHz
Input Impedance	50 Ω
Return Loss	≤ 10 dB

The dual-band monopole planar antenna materials are cordura for the substrate and copper for the patch, ground plane, and feedline materials. Details about the material characteristics are summarized in Table 2 [8].

Table 2. Material Characteristics

Component	Material	Thickness (mm)	Relative Permittivity (ε_r)	Density $\left({kg}/{m^3}\right)$
Patch, groundplane, and feedline	Copper Tape	0,1	-	-
Substrate	Cordura Delinova 2000	0,5	1,6	0,037

The design and realization of a dual-band wearable antenna with the addition of UC-EBG for health applications requires several steps, as shown in Figure 1 literature study is the first step to understanding concepts and theories. Following this step, the specifications for the antenna parameters, including VSWR, bandwidth, return loss, and gain, will be established. The antenna dimension will be determined in the following step. After knowing the antenna dimension, 3D simulation software can be used to design and simulate the antenna. An optimization process is required if the simulation results do not match the established antenna specifications. Uniplanar Compact Electromagnetic Band Gap, or UC-EBG, is then designed and simulated using the suspend line method. The UC-EBG can be simulated and installed on a planar monopole antenna if the specifications are good. The fabrication of the antenna and its measurement are the final steps. Antenna fabrication measurement results will be compared to simulated results.

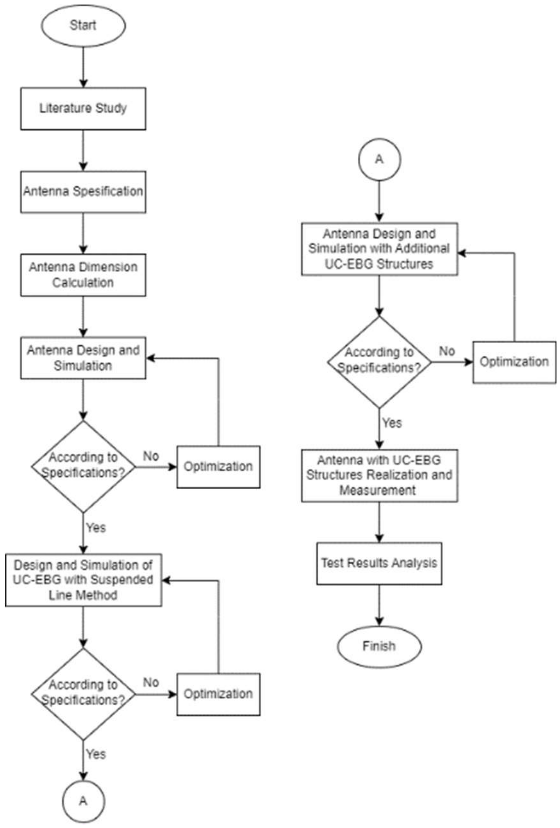


Figure 1. Flowchart for the research

2.1. Planar Monopole Antenna

A planar monopole antenna is like a microstrip antenna but has a gap between the ground plane and the patch. Planar monopoles have a wide bandwidth, good azimuth radiation, low profile, small size, ease of fabrication, and inexpensive. One of the most common patches, in addition to the rectangular patch, is the circular patch. The formula for calculating the dimensions of an antenna with a circular patch is given below [9], [10].

$$L = 2A \tag{1}$$

$$r = \frac{A}{4} \tag{2}$$

$$k = \sqrt{\frac{\varepsilon_r + 1}{2}} \tag{3}$$

$$f_L = \frac{7,2}{(L + r + p) \times k} \tag{4}$$

Where L is the diameter of the circular patch monopole planar antenna in cm, A is the radius of the patch in cm, r is the effective radius in cm, k is the effective dielectric constant, p is the length of the gap between the patch and the ground plane, and f_L is the lower frequency in GHz [9], [10]. To get the width (W_g) and length (L_g) of the ground plane and the substrate can be calculated using the following equation.

$$W_g = 6h + L \tag{5}$$

$$L_g = 6h + L \tag{6}$$

The feed width (W_f) can be calculated using the microstrip line equation. The input impedance (Z_0) can influence the value of B in the W_f calculation. The following formula shows the equation for calculating the values of W_f and B [3].

$$W_f = \frac{2h}{\pi}\left\{B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln(B - 1) + 0,39 - \frac{0,61}{\varepsilon_r}\right]\right\} \tag{7}$$

$$B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}} \tag{8}$$

2.2. Antenna Design

This research uses a planar monopole antenna with a circular patch shape that can operate at frequencies of 2.4 and 5.8 GHz. Equations (1) to (4) can be used to calculate the dimensions of a planar monopole. Table 3 shows the dimensions of a conventional planar monopole antenna. An optimization is performed based on the calculation results to obtain an antenna with good specifications. Table 4 and Figure 2 show the dimensions of the optimization antenna.

Table 3. Conventional Antenna Dimensions

Dimension	Symbol	Size (mm)
Diameter Patch	L	36,4
Radius Patch	A	18,2
Relative Permittivity	k	1,14
Radius Effective	r	4,55
Distance Between Patch and Ground Plane	p	1,17
Ground Plane and Substrate Width	W_g	39,4
Ground Plane and Substrate Length	L_g	39,4
Feed Width	W_f	1,87

Table 4. Optimization Antenna Dimensions

Dimension	Symbol	Size (mm)
Radius Patch	A	20
Distance Between Patch and Ground Plane	p	1
Ground Plane and Substrate Width	W_g	54
Ground Plane and Substrate Length	L_g	66
Feed Width	W_f	1

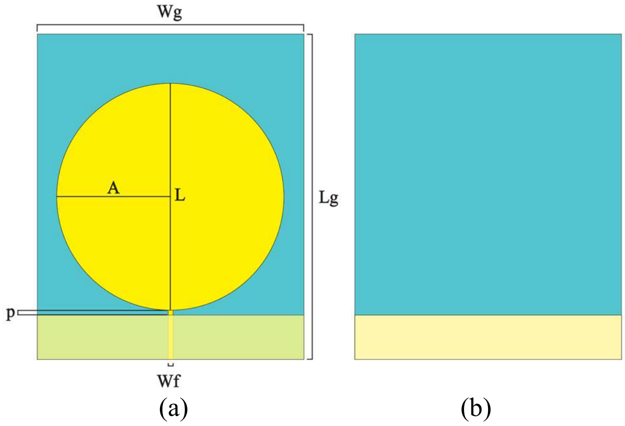


Figure 2. Optimization Antenna (a) Front View and (b) Back View

2.3. Electromagnetic Band Gap (EBG)

Electromagnetic Band Gap or EBG is an artificial object, either periodic or aperiodic, that also blocks or increases the transmission of electromagnetic waves in a specific frequency range. Perfect magnetic conductors (PMC) do not occur naturally, but EBG can resemble their characteristics. EBG materials, in their basic form, are made up of alternating high and low dielectric areas that repeat at regular intervals to generate a band gap. Uniplanar Compact Electromagnetic Band Gap is a type of EBG structure without vias. Removing the via can make the fabrication process easier. The UC-EBG is preferred for wearable antennas because it is easy to make and inexpensive [5]. The capacitance (C) comes from the edge of the connection between two UC-EBG next to each other. Because the EBG structure does not use vias, the inductance (L) is a thin microstrip line in the layer that connects one UC-EBG to another [11]. In Figure 3 there is a unit cell form of UC-EBG.

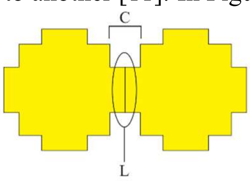


Figure 3. Unit Cell Form of UC-EBG

2.4. Suspended Line Method Design

The suspended line method validates the EBG structure's operating frequency. This method can inhibit the current of electromagnetic waves in a specified frequency band so that this method can create dual band frequencies [5]. The suspended line will have two designs. The first design is a suspended line that uses a UC-EBG unit cell with a long copper or wire on top. The second design is a suspended line without a unit cell, and the design will use a ground plane and substrate with a long copper or wire. This wire or copper acts as a feedline, allowing the current to flow from electromagnetic waves. Suspended line have two ports, unlike planar monopole antenna. Thus, port 1 will transfer power to port 2. Table 5. and Figure 4. show the shape and dimensions of the UC-EBG that will be used.

Table 5. UC-EBG Dimensions

Dimension	Symbol	Size (mm)
EBG Square	a	6
EBG Plus Width	b	3
EBG Plus Length	c	8

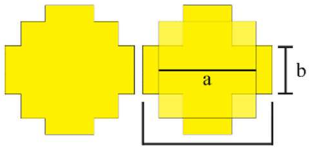
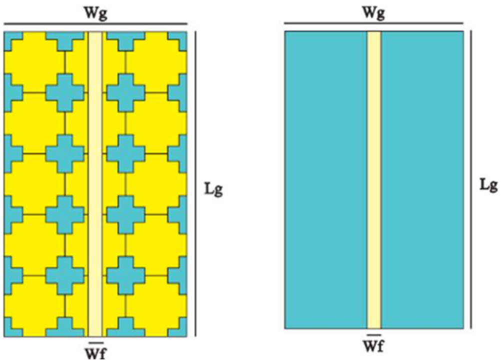


Figure 4. UC-EBG Shape and Dimensions

The suspended line method with UC-EBG will be created by arranging columns and rows of 5x3 unit cells with a 1 mm gap between the feedline and the UC-EBG. The suspend line method is used without the UC-EBG to ensure that the UC-EBG can stop electromagnetic waves in a specified frequency range. This method has a 1.1 mm thickness, the sum of the feedline gap and the UC-EBG thickness. Dimensions of the suspended line with and without UC-EBG are shown in Table 6, and the suspended line shape is illustrated in Figures 5 and Figure 6.

Table 6. Dimensions of the suspended line with and without the UC-EBG

Dimension	Symbol	Size (mm)	
		UC-EBG	Without UC-EBG
Gap between Patch and Feedline	*gap*	1	1,1
Distance Between Patch and Ground Plane	p	1,87	1,87
Ground Plane and Substrate Width	W_g	24	24
Ground Plane and Substrate Length	L_g	40	40
Feed Width	W_f	1	1



(a) (b)

Figure 5. Suspended Line Method (a) with UC-EBG and (b) without UC-EBG

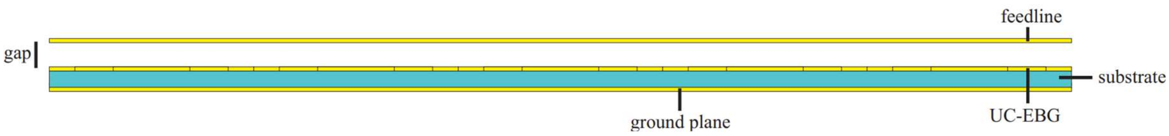


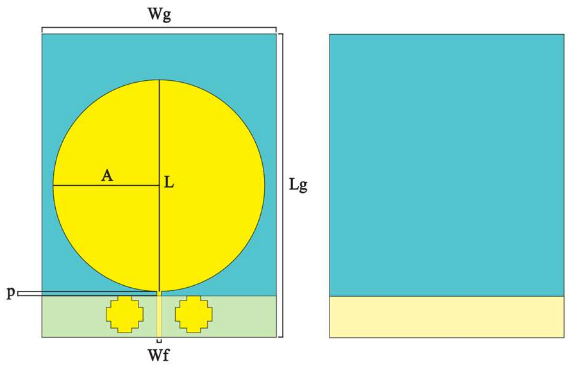
Figure 6. Suspended Line Method with UC-EBG Side View

2.5. Antenna Design with UC-EBG Structure

In this section, we will create a planar monopole antenna with UC-EBG. The patch and feedline will be paralleled by UC-EBG unit cells. This design will use two unit cells, which will be placed close to the feed line. The UC-EBG dimensions used are the same as the previous design. Table 7. and Figure 7. show the dimensions of a planar monopole antenna with the addition of the UC-EBG structure.

Table 7. Antenna with UC-EBG Dimensions

Dimension	Symbol	Size (mm)
Radius Patch	A	21
Distance Between Patch and Ground Plane	p	1
Ground Plane and Substrate Width	W_g	51
Ground Plane and Substrate Length	L_g	66
Feed Width	W_f	1



(a) (b)

Figure 7. Antenna with UC-EBG (a) Front View and (b) Back View

3. RESULTS AND DISCUSSION

This section discusses the simulation and measurement results of the planar monopole antenna. Simulation results for the optimized conventional antenna and the antenna with additional UC-EBG. Measurement results for the antenna with the addition of UC-EBG that has been realized.

3.1. Simulation Results for Antenna Optimization

The results of return loss, VSWR, bandwidth, and gain for the optimized conventional planar monopole antenna at 2.4 GHz and 5.8 GHz are shown in Table 8.

Table 8. Parameters of the Antenna Optimization

Frequency (GHz)	Return Loss (dB)	VSWR	Bandwidth (GHz)	Gain (dBi)
2,4	-13,520	1,504	17,906	2,671
5,8	-25,314	1,180		4,663

3.2. Simulation Results for Suspended Line Method

This section presents simulation results of suspended lines using UC-EBG and without UC-EBG. This graph shows simulation results for S21 in decibel (dB). The following figure compares the S21 graph of the suspended line with UC-EBG and without UC-EBG. Figure 8 shows the effect of UC-EBG on band rejection at frequencies of 2,7 GHz, 4,2 GHz, and 5,4 GHz.

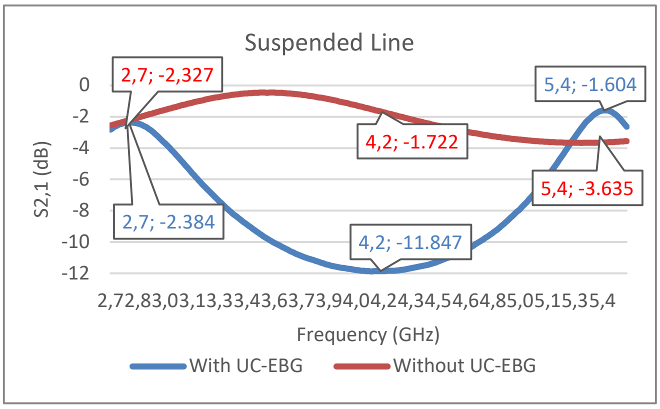


Figure 8. Comparison of Suspended Line Method Simulation Results

Based on these data, at a frequency of 4.2 GHz, the attenuation loss is less than −10 dB, and a band gap occurs. In the frequency range of 2.7-3.5 GHz and 4.8-5.5 GHz, the value of S2.1 is above -10 dB, so there is no band gap in that frequency range. Table 9 shows the results of the S21 graph for the suspended line with UC-EBG and without UC-EBG.

Table 9. Suspended Line Results (dB)

Frequency (GHz)	Without UC-EBG (dB)	With UC-EBG (dB)
2,7	-2,327	-2,384
4,2	-1,722	-11,847
5,8	-3,635	-1,604

From the value of S21 in dB, the receiving power can be determined using equations (9)–(10). Based on this equation, the yield results for suspended lines with UC-EBG and without UC-EBG are shown in Table 10 below.

$$S_{21(numeric)} = 10^{\frac{S_{2,1(dB)}}{20}} \quad (9)$$

$$S_{21(dB)} = 20 \log S_{21(numeric)} \quad (10)$$

Table 10. Suspended Line Receiving Power

Frequency (GHz)	Without UC-EBG (numeric)	With UC-EBG (numeric)
2,7	0,765	0,760
4,2	0,820	0,256
5,4	0,658	0,832

If the value of S21 is numerically 1, the power transmitted from port 1 to port 2 is 100%. Meanwhile, if the result is 0, then the transmitted power is 0% or nothing. For a suspended line without UC-EBG, the receiving power is 76,5% at 2,7 GHz, 82% at 4,2 GHz, and 65,8% at 5,4 GHz. For a suspended line with UC-EBG at a frequency of 4,2 GHz, the receiving power is only 25,6%. Then at a frequency of 2,7 GHz and 5,4 GHz, the receiving power is 76% and 83,2%. Therefore, the suspended line method with the addition of UC-EBG is proven to inhibit electromagnetic waves in that frequency band.

3.3. Simulation Results for Antenna with Additional UC-EBG Structures

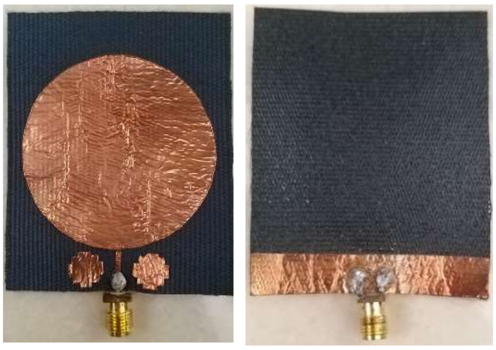
A planar monopole antenna with additional UC-EBG unit cells can affect the antenna simulation results. The simulation results of return loss, VSWR, and antenna gain can be seen in Table 11.

Table 11. Parameters of Antennas with Additional UC-EBG Structures

Frequency (GHz)	Return Loss (dB)	VSWR	Bandwidth (GHz)	Gain (dBi)
2,4	-15,269	1,417	1,48	2,869
5,8	-17,491	1,308	9	5,208

3.4. Antenna Realization

After designing and simulating planar monopole antenna with operating frequencies of 2.4 GHz and 5.8 GHz, the next step is to realize or fabricate the antennas. The antenna is made from the materials listed in Table 2. The antenna realization is shown in Figure 9. Once an antenna has been fabricated, it must be measured to determine its characteristics and parameters.



(a) (b)

Figure 9. Antenna Realization (a) Front View and (b) Back View

After performing the measurement process, the next step is to compare the return loss and VSWR values from the measurement and simulation results for the planar monopole antenna with an additional UC-EBG. The comparison of simulation and measurement results for dual-band planar monopole antenna is in Figure 10 and Figure 11. The return loss in Figure 10 shows that at a frequency of 2,4 GHz, the planar monopole antenna has a value of -13,134 dB for measurement result and -15,269 dB for simulation result using UC-EBG. Then at a frequency of 5,8 GHz, the antenna has a return loss value of -18,421 dB for measurement result and -17,491 dB for simulation resuls using UC-EBG.

Figure 11 shows VSWR values at frequencies of 2,4 GHz and 5,8 GHz for results from measurement and simulation using UC-EBG. At a frequency of 2,4 GHz, the VSWR value is 1,566 for measurement result and 1,417 for simulation result using UC-EBG. At a frequency of 5,8 GHz, the VSWR value is 1,273 for measurement result and 1,308 for simulation results using UC-EBG. The bandwidth value of the planar monopole antenna is seen based on the VSWR results. At a frequency of 2,4 GHz, the bandwidth value is 2 GHz for measurement result and 1,48 GHz for simulation result using UC-EBG. At a frequency of 5,8 GHz, the bandwidth value is 0,98 GHz for measurement result and 9 GHz for simulation result using UC-EBG.

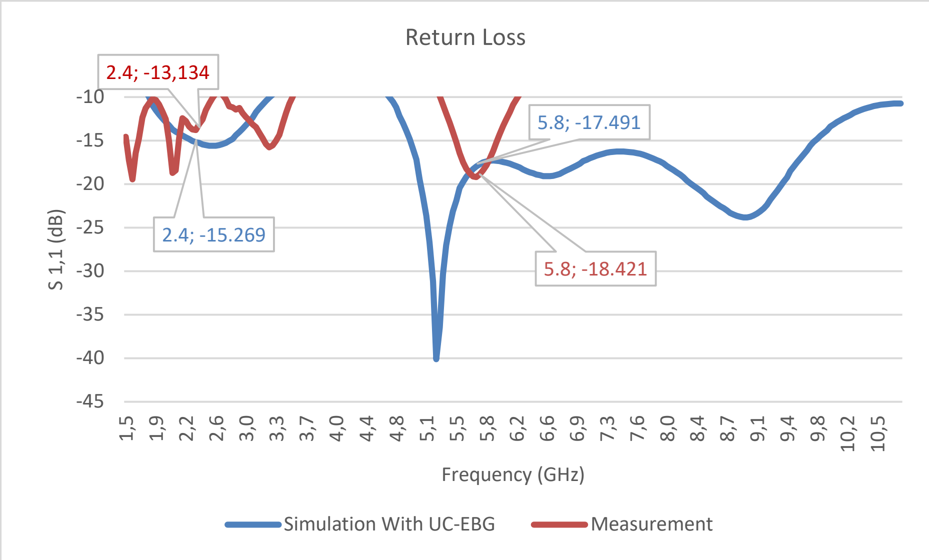


Figure 10. Return Loss Results

The gain value can be calculated using the results of the radiation pattern measurement by taking the average of 10 samples of the radiation pattern measurement. The antenna cable loss and Free Space Loss (FSL) impact the gain measurement. The gain at 2.4 GHz has a value of 2.198 dBi for the measurement result and 2.869 dBi for the simulation result using UC-EBG. At a frequency of 5.8 GHz, it has a value of 4.981 dBi for measurement result and 5.208 dBi for simulation result using UC-EBG.

To determine the radiation pattern of a planar monopole antenna, the masting or the place to put the antenna is rotated every 10 degrees from 0 to 360 degrees. The azimuth and elevation angles are the direction of rotation of the antenna during measurement. Figure 12 shows the azimuth and elevation radiation patterns at 2.4 GHz, while Figure 13 shows the azimuth and elevation radiation patterns at 5.8 GHz.

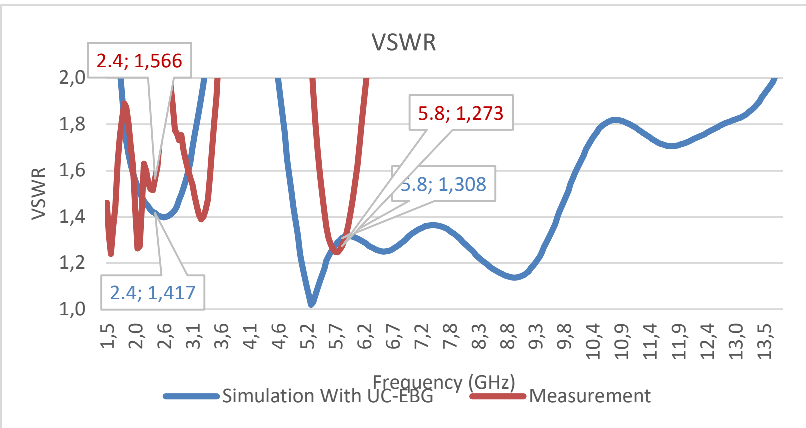
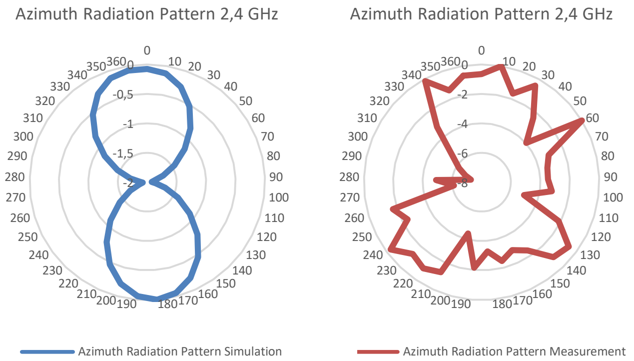
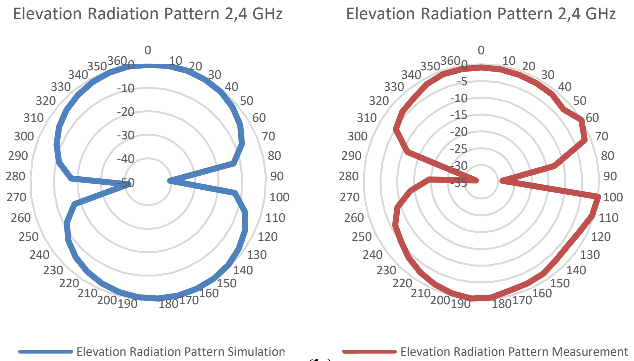


Figure 11. VSWR Results



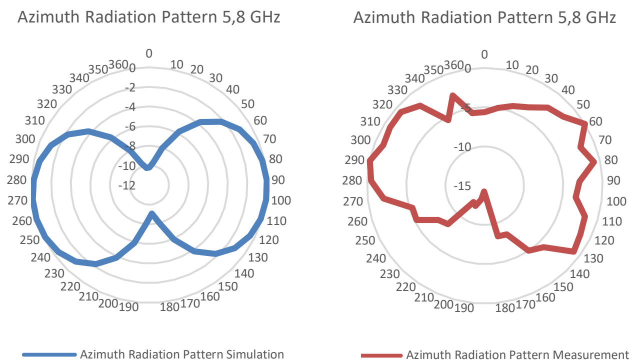
(a)



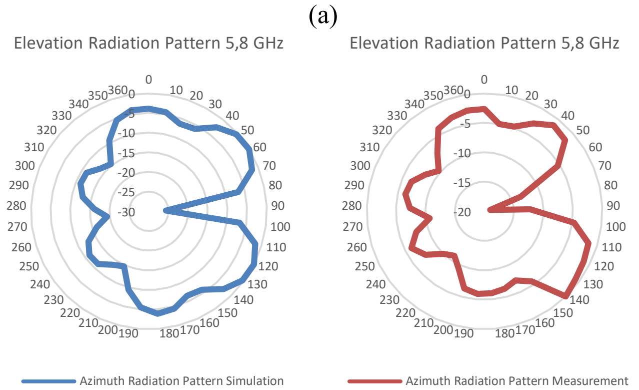
(b)

Figure 12. Antenna Radiation Pattern at 2.4 GHz for (a) Azimuth and (b) Elevation

Based on Figure 12, there are results of azimuth and elevation radiation patterns at a frequency of 2,4 GHz, which is an omnidirectional radiation pattern.



(a)



(b)

Figure 13. Antenna Radiation Pattern at 5,8 GHz for (a) Azimuth and (b) Elevation

Based on Figure 13 above, there are results of azimuth and elevation radiation patterns at a frequency of 5,8 GHz, which is an omnidirectional radiation pattern.

After designing, simulating, and measuring the planar monopole antenna, there is a comparison between the measurement and simulation results. The following Table 12 compares the parameter results of the dual band planar monopole antenna with the addition of UC-EBG. The difference between parameter results for measurement and simulation can occur due to several factors. The first factor is the manual fabrication process, so the results of the antenna component pieces may be less accurate. Then there are cable losses that can affect the measurement results. The last factor is the influence of the situation and conditions of the place when measuring the antenna.

Table 12. Comparison of Measurement and Simulation Results

Parameter	Measurement		Simulation	
Frequency (GHz)	2,4	5,8	2,4	5,8
Return Loss (dB)	-13,134	-18,421	-15,269	-17.491
VSWR	1,566	1,273	1,417	1,308
Bandwidth (GHz)	2	0,98	1,48	9
Gain (dBi)	2,198	4,981	2,869	5,208

4. CONCLUSION

Planar monopole antenna with EBG structures were designed and simulated in 3D applications. Cordura Delinova 2000 is used for the antenna substrate, and copper tape is used for the ground plane, patch, feedline, and EBG. The antenna simulation and measurement results met the specifications, with a return loss of less than -10 dB, VSWR less than 2, and gain of more than 1. The suspended line method on the conventional antenna has been proven to inhibit the flow of electromagnetic waves in specific frequency bands. The UC-EBG unit cell in the suspended line method has been shown to have a lower transmit power than the suspended line method without the UC-EBG unit cell. As a result, planar monopole antennas with UC-EBG can work well at working frequencies of 2.4 GHz and 5.8 GHz and can be used in health applications. Further research on the UC-EBG structure using the suspended line method for testing the Specific Absorption Rate (SAR) and bending of circular planar patch wearable monopole antenna is suggested to improve antenna performance.

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