Textile Antenna with Electromagnetic Band Gap Structure at Frequency 3.5 GHz 5G Band

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***Abstract*— The Microstrip textile antenna is a form of wireless communication for human monitoring purpose that can be integrated with clothing while maintaining user comfort. However, microstrip antennas have several disadvantages such as low gain and efficiency, narrow bandwidth and surface waves that can damage the radiation pattern. The use of textile antennas also allows a mutual coupling effect between the body and the antenna that can change the resonance frequency, reduce antenna performance, and radiation hazard to the body. Based on these problems, an Electromagnetic Band Gap (EBG) structure is used with a unit cell in the shape of a Mushroom-like EBG and a via in the middle of the EBG. The use of the EBG structure can increase efficiency, reduce the effect of mutual coupling, create a better radiation pattern, and reduce radiation hazard to the body. Tests were carried out on antennas with and without EBG structures in the bandwidth range of 10–100 MHz for the 5G Band operating frequency of 3.5 GHz (n78 3500 MHz). In the 0 mm SAR test, the conventional antenna SAR is 2.4264 W/Kg, and the modified EBG antenna SAR is 1.082 W/Kg, there is a 55% reduction in SAR when the EBG structure is added. Thus, it is proven that the addition of EBG with modifications in this study can produce a minimum SAR value..In addition, there is an increase in bandwidth of 92% with the Conventional Antenna bandwidth of 27.30 MHz and the Modified EBG Antenna bandwidth and 52.50 MHz DGS with the test object on Hand. In the radiation parameters, the radiation pattern is unidirectional, linear polarization, and gain is 8.32 dBi.**

Keywords*— *Textile antenna, microstrip, unit cell, mushroom-like, electromagnetic band gap.

I. Introduction

The use of wireless communication technology for monitoring human body purposes has been carried out in recent years. One of the components used is a textile antenna that can be integrated with clothing. The IEEE 802.15 WBAN's standardization group has set standards in Antenna and Propagation research for communication systems both in the body, inside the body and outside the body [1].

The type of antenna used for the textile antenna is a microstrip antenna because its dimensions are small so it will be easy to integrate into clothes and maintain user comfort. However, this antenna has a number of disadvantages such as low gain and efficiency, narrow bandwidth and surface waves that can damage the radiation pattern [2]. A textile antenna for monitoring the human body makes the antenna close to the human body. Positioning the antenna near the body can cause a mutual coupling effect between the human body and the antenna which can change the working frequency and decrease the performance of the antenna. In addition, the efficiency of the antenna radiation beam is reduced due to the absorption of radiation by body tissues. The absorption of electromagnetic wave radiation by the body is considered harmful to the health of human body tissues [3]. Therefore, the Specific Absorption Rate (SAR) value has been determined by the international standard ANSI/IEEE (United States), that the safe SAR value for the human body is 1.6 W/Kg [4].

The performance of the Electromagnetic Band Gap (EBG) structure on a communication device in suppression of waves which can reduce back radiation to produce a better radiation pattern [5]. Interest in [6] it was also explained that the use of EBG can improve antenna performance on radiation parameters such as polarization, radiation pattern and beam width of an antenna. Similarly with [7] also shows several things that are appropriate, that the use of EBG which is proven to increase bandwidth and produce a minimum SAR value.

Based on the explanation above, the authors propose the use of an EBG structure that can increase efficiency and gain, reduce the effects of mutual coupling and SAR.

II. Theory

A. Textile Antenna

A textile antenna is a type of antenna that can be used because of its uniqueness that can be integrated with clothing. One of the uses of this type of antenna is for remote monitoring purposes as described in [1]. The structure of the antenna of this type is basically the same as the usual microstrip antenna, which consists of a patch, substrate, and ground plane. However, in order to allow the antenna to be comfortable on the body, the material of the patch and the substrate used is different from that of typical microstrip antennas. The substrate and patch materials used can be seen in Table 1 [8].

TABLE 1. Substrate and patch materials for textile antenna.

Dielectric Material			**Conductive Material**	**Performance**
Material	***h (mm)***	***Relative Permittivity***		
Unspecified material	0.236	3.29	-	Acceptable
Fleece fabric	3	1.04	Knitted copper fabric	Acceptable
Cordura	0.5	1.1-1.7	Copper tape	Good
Fleece fabric	2.56	1.25	Flectron	Acceptable to good
Polyurethane protective foam	11	1.16	Flectron	Acceptable
Felt	1.1	1.3	Zelt	Acceptable
Cotton/ polyester	2.808	1.6	Flectron/ conductive ink	Acceptable
PDMS	-	3.0-13	Embroidered conductive fibres	Good
Polyamide spacer fabric	6	1.14	Silver-copper-nickel-plated woven fabric	Good
Woollen felt	3.5	1.45	Silver-copper-nickel-plated woven fabric	Good

B. Body Phantom

A textile antenna for monitoring the human body makes the antenna close to the human body. Because of that, it is necessary to model the body phantom where the antenna will be placed. Body phantom modelling will be added to the antenna design as a test object in analyzing the antenna performance. The body phantom model consists of skin, fat, muscle and bone tissue with characteristics based on Table 2 [9].

TABLE 2. Dielectric constants of body tissues.

Tissues	**Relative permittivity**	**Conductivity (S/m)**	**Density (Kg/m^3)**	**Thickness (mm)**
Skin	37.005	2.0249	1090	1.5
Fat	5.1739	0.15553	930	1.5
Muscle	51.444	2.5575	1050	2.5
Bone	11.41	0.38459	1920	7

C. Spesific Absorption Rate

The use of textile antennas can cause the absorption of electromagnetic wave radiation by the body. The absorption of electromagnetic wave radiation is harmful to the health of human body tissues [3]. To protect the human body from the dangers of electromagnetic wave radiation, the Specific Absorption Rate (SAR) value is determined by the international standard ANSI/IEEE (United States), that the SAR value which is safe for the human body is 1.6 W/Kg [4]. The following is the equation of the SAR:

$$SAR = \frac{\delta|E|}{\rho} \quad (1)$$

When δ is constant dielectric value of material, $|E|$ is vector magnitude value of electric field, and ρ is density value of material.

D. Electromagnetic Band Gap

The electromagnetic band gap (EBG) is an innovation in RF and microwave communication systems with unique band gap characteristics and a certain frequency range.

Based on research in [10], EBG is known to improve the performance of microstrip antennas. In this case, the EBG structure is used to improve the performance of microstrip textile antennas [11].

The EBG structure used is a Mushroom-like EBG, as shown in Figure 1, and there is a via in the middle of the EBG that connects it to the ground plane. The EBG structure can be interpreted as an LC resonance circuit that arises the value of inductance L and capacitance C. There is an electric current in the EBG metal which arises an inductor L. There is also a capacitance C that arises due to the gap between parts of the EBG both between parts in one unit cell and between parts unit cells with each other [12].

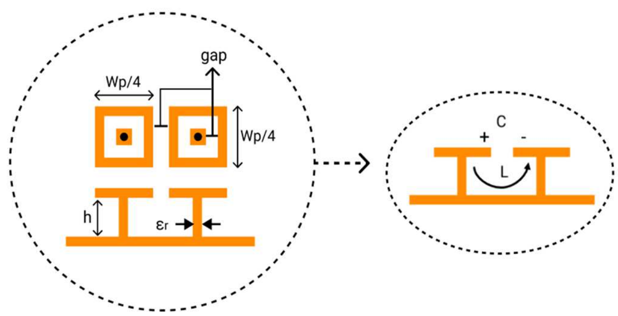

Fig 1. Mushroom-like EBG.

E. 3.5 GHz 5G Band

3.5 GHz 5G Band (n78 3500 MHz) or commonly referred to as C-band 5G is the working frequency that is widely used in testing the development of 5G technology. In this case, the 3.5 GHz frequency is used for simple wireless communication on the 3.3 GHz - 3.8 GHz spectrum with several supported channel bandwidths including 10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100 in MHz [13].

III. DESIGN AND SIMULATIONS

The antenna design and simulation process were carried out on the CST Studio Suite 2019 simulation software with the parameters used are antenna dimensions based on calculations that refer to specifications.

A. Design Spesification

TABLE 3. Proposed antenna specification.

Parameter	Specification
Resonant Frequency	3.5 GHz 5G Band
Gain	>1 dB
VSWR	<2
Radiation Pattern	Unidirectional
Bandwidth	50 MHz
SAR	<=1.6 W/kg

This microstrip type textile antenna is designed to use cordura as a substrate and copper tape as a patch and ground plane with the characteristics of the materials in Table 4.

TABLE 4. Properties of patch, ground plane, and substrate.

Component	Materials	Relative Permittivity	Density (Kg/m^3)	Thickness (mm)
Patch and ground plane	Copper tape	-	-	0.1
Substrate	Cordura Delinova 200	1.6	0.0370	0.5

B. Design of Conventional Antenna

Conventional antennas are antennas that are designed before adding the EBG structure. The structure of the conventional antenna consists of a patch, a substrate and a groundplane. Based on the calculations that have been done, the antenna parameter values are obtained in Table 5 to be designed and simulated.

TABLE 5. Proposed antenna dimension without EBG

Parameter	Value (mm)	Description
Wp	37.58	Width of patch
Lp	33.53	Length of patch
Wg	75.16	Width of substrate and ground
Lg	67.06	Length of substrate and ground
Wf	2	Width of feedline
Lf	17	Length of feedline
t	0.1	Thickness of patch
h	0.5	Thickness

Antenna performance measurement simulations are performed on the calculated antenna design by measuring the performance of the antenna simulation results on-body phantom conditions and off-body phantom conditions.

After obtaining the simulation results from the design in Figure 2, the EBG structure was added with the following design modifications.

Figure 2 show the entire front view of the conventional antenna with a rectangular patch with inset feed, then Figure 3 is the overall shape of the conventional antenna ground plane before using the DGS method and for last, Figure 4 which is a side view of the conventional antenna that consists of patch, substrate and ground plane.

C. Design of Antenna with EBG

EBG antenna is arranged parasitic with a conventional antenna which aims to obtain the minimum SAR value and DGS on the ground plane of conventional antenna to increase the bandwidth value. Furthermore, the body-phantom design is carried out to test the SAR value generated when the antenna is close to the body after the addition of the EBG structure as shown in Figure 5.

The designed EBG antenna consists of a patch, a substrate, and a ground plane. This EBG patch antenna is an arrangement of the EBG structure with several unit cells and a via in the center of the unit cell as shown in Figure 6 which is connected to the ground plane as shown in Figure 5. Then, the ground plane is cut with a pattern in the shape of the EBG unit cell on the ground plane of a conventional antenna as shown in Figure 8. Figure 6 and figure 7 are EBG antennas that are designed in stages, at the initial stage the EBG was designed with a 5x5 configuration as in figure 6 and then modified the configuration so that the configuration model is obtained as in figure 7.

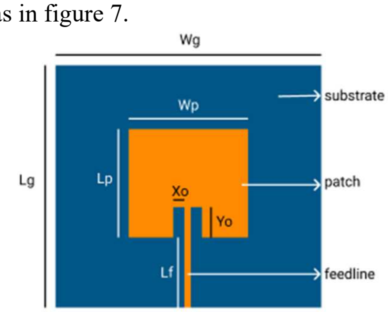

Fig 2. Conventional antenna front view.

Fig 3. Conventional antenna rear view.

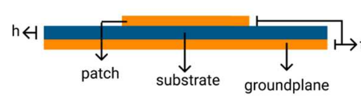

Fig 4. Conventional antenna side view.

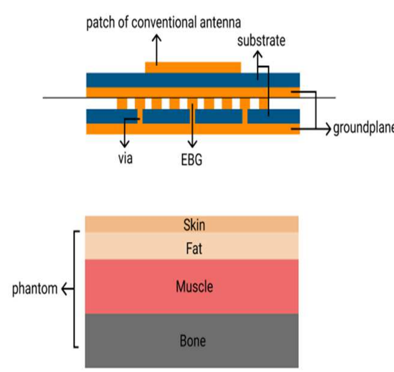

Fig 5. Simulation of Conventional antenna with EBG structure and DGS with phantom.

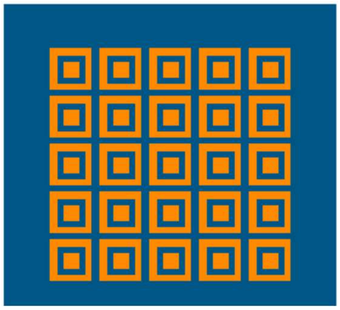

Fig 6. 5x5 EBG antenna.

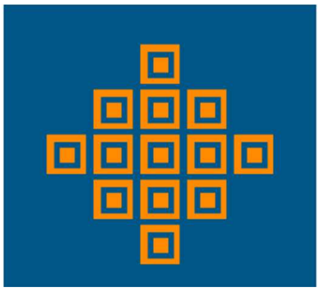

Fig 7. Modified EBG antenna.

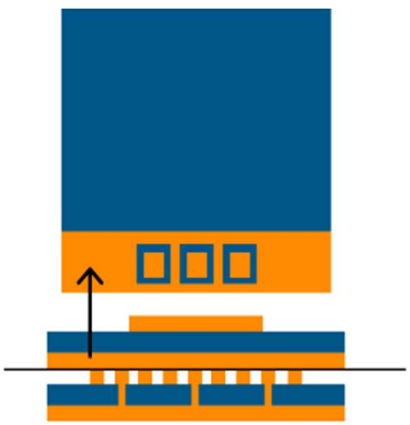

Fig 8. DGS in ground plane of conventional antenna.

After designing the antenna with and without the EBG antenna, the antenna design is simulated with off-body and on-body phantom conditions, respectively, to determine the achievable specification values as shown in Table 6.

TABLE 6. Simulated result comparison between conventional antenna and antenna with EBG

Specification	Conventional Antenna		EBG Antenna		Antenna with Modified EBG	
	Off body	***On body***	***Off body***	***On body***	***Off body***	***On body***
Return loss (dB)	- 31.73	- 43.48	- 35.23	-20.06	- 31.28	- 28.76
Bandwidth (MHz)	27.90	27.30	28.1	31	52.50	53.10
Gain (dBi)	7.62	8.00	7.71	3.42	8.43	8.07
SAR (W/kg)	-	2.426		1.562	-	1.082

The first specification is for the return loss value, both conventional antennas and antennas with the addition of EBG antennas produce values $S_{11} < -10\ dB$ for each off-body and on-body phantom conditions. Next is the bandwidth value, the antenna with EBG and DGS in off-body and on-body phantom conditions produces a greater bandwidth and almost doubles the bandwidth produced by conventional antennas in both off-body and on-body phantom conditions. Same with the case in gain value which has increased for antenna simulation with EBG compared to conventional antennas both in off-body and on-body phantom conditions. which are considered harmful to the body. The last is SAR value which has decreased significantly when simulating the antenna with modified EBG compared to the SAR value of 5x5 EBG antenna and conventional antenna which is considered harmful to the body.

D. Antenna Realization

The antenna realization is carried out after the design and simulation results achieve the target specifications. The fabricated textile antenna is made of Cordura Delinova 200 with dimensions of $67mm \times 75mm$ which consists of two antennas arranged in parasitic stacks, namely a conventional antenna and an EBG antenna as shown in the Figuren 9, 10, 11 and 12.

Fig 9. Fabrication of conventional antenna front view.

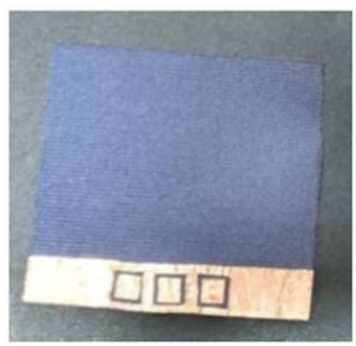

Fig 10. Fabrication of conventional antenna with DGS rear view.

Fig 11. Fabrication of EBG antenna front view.

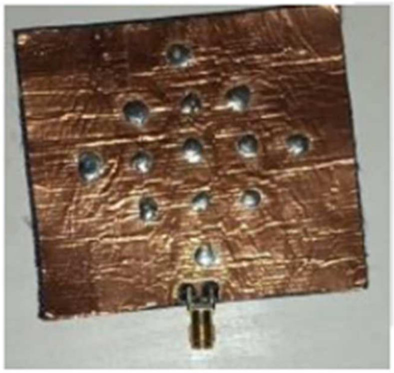

Fig 12. Fabrication of EBG antenna rear view.

IV. MEASUREMENT AND ANALYSIS

Antenna testing is carried out in the Laboratory and produces CSV data from VNA-T5280 (300-8000 MHz) which is processed and attached below. Testing of the printed EBG antenna was carried out in 2 conditions on body and off body. The measurement of on body condition are shown in the Figure 13. The test results in the form of data processed using excel as evidence that this research has succeeded in achieving the objectives and specifications.

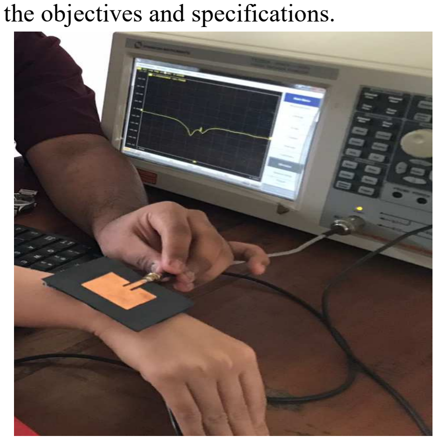

Fig 13. Measurement on Hand.

The object of measurement in the on-body condition measurement process used is the hand. Several other body objects were also tested, such as the chest and thighs, but the maximum gain value produced was in the hands as shown in the Figure 14.

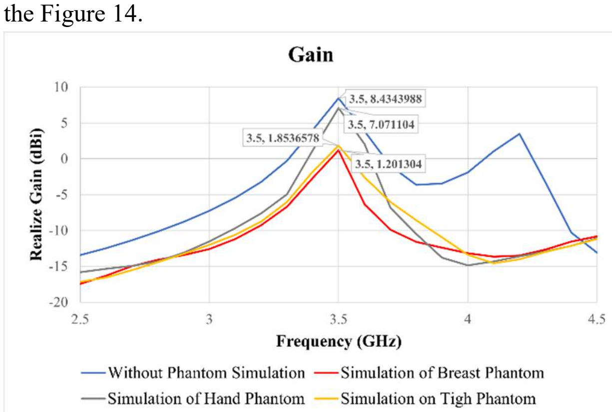

Fig 14. Comparison of body phantom based on gain value.

A. Measurement Result of Return Loss and Bandwidth

The return loss measurement was carried out twice, namely the measurement off-body phantom condition and the on-body condition brought closer to the hand. Thus, a comparison of the return loss and gain of the simulated antenna and the fabricated antenna is carried out for off body and on body conditions as shown in Figure 15.

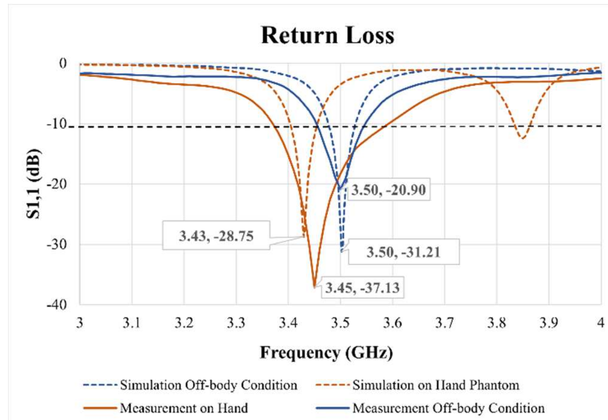

Fig 15. Return loss value between simulation and measurement.

In the simulation antenna off-body conditions, the return loss value is -31.20 dB with a bandwidth of 52.40 MHz, while the simulation antenna on-body conditions (hand phantom) return loss value is -28.74 dB with a bandwidth of 52,20 MHz. Furthermore, for the off-body condition antenna, the return loss value is -20.90 dB with a bandwidth of 77.60 MHz, while the on-body simulation antenna produces a return loss of -37.13 with a bandwidth of 217.90 MHz.

B. Measurement Result of Gain

Gain measurements are carried out using the Signal Generator RF Explorer (24 MHz – 6 GHz) at the Transmitter Antenna (Tx) and a Spectrum Analyzer (SA) in the form of Signal Hound s/n 03000379 (100 KHz – 12.4 GHz) at the Receiver Antenna (Rx). The received power from SA is processed using Power Link Budget to obtain the undertest antenna gain value with the parameters in Table 7.

Table 7. known Parameter value of gain measurement

Known Parameter	Value
Gain Tx	11 dB
Loss Cable Tx	-1.5 dB
Loss Cable Rx	-1.5 dB
Distance of Tx and Rx	2.5 m
FSL	51.3 dB
Gain Rx	8.32 dBi

The gain generated after performing the next measurement is compared with the gain generated in the simulation. The measured gain value is different from the simulation gain with the measurement gain of 8.32 dBi, while the gain of the simulation result is 8.43 dBi.

C. Measurement Result of Radiation Pattern

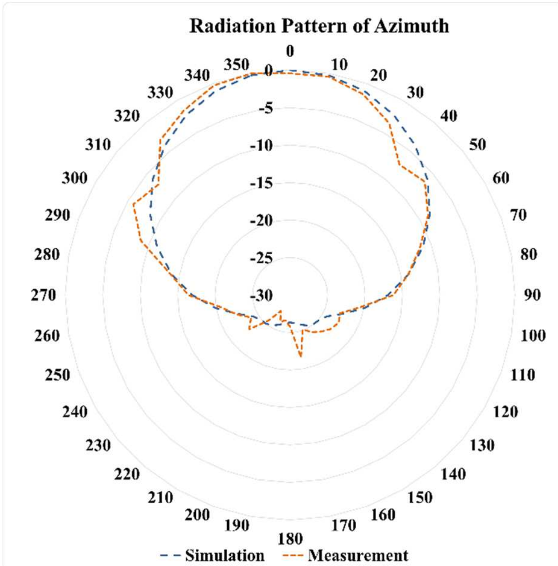

Fig 16. Radiation pattern of azimuth.

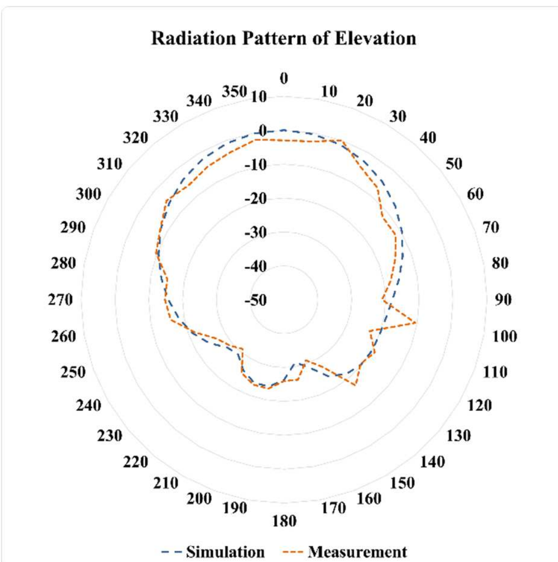

Fig 17. Radiation pattern of elevation.

Based on Figure 16 and Figure 17 above, the radiation pattern obtained is a type of unidirectional radiation pattern with the emission focused in one direction only.

CONCLUSION

The conclusion from the design and simulation process as well as antenna fabrication with a substrate made from Cordura Delinova 200 fabric that works at a frequency of 3.5 GHz 5G Band, namely the addition of the EBG structure to the antenna is proven to increase bandwidth and gain and reduce the resulting SAR value, then modified the number of EBG unit cells and get the minimum SAR value, maximum bandwidth increase is obtained after performing DGS on a conventional antenna ground plane. Antenna specifications for circuit parameters, Conventional Antenna produces a bandwidth of 27.30 MHz, while EBG Antenna and DGS produce a bandwidth of 52.50 MHz in on body conditions. For radiation parameters, both Conventional Antenna and EBG Antenna and DGS produce unidirectional radiation pattern parameters and linear polarization. However, the gain value produced is different from the conventional antenna gain of 7.62 and for the EBG antenna and DGS which is 3.41 in the on-body condition. SAR Conventional Antenna is 2.4264 W/Kg, while the EBG Antenna and DGS is 1.08 W/Kg on the body part of the hand.

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