Characterization of Artificial Magnetic Conductor, Electromagnetic Band Gap and Frequency Selective Surface

M. Abu, S. A. M. Ali, H. Hassan and I. M. Ibrahim
Centre of Telecommunication Research and Innovation (CeTRI),
Faculty of Electronic and Computer Engineering (FKEKK),
Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya 76100, Melaka, Malaysia
maisarah@utem.edu.my

Abstract— **This paper investigates the characteristics of Artificial Magnetic Conductor (AMC), Electromagnetic Band Gap (EBG) and Frequency Selective Surface (FSS) at 5.8 GHz. Reflection magnitude and phase are characterized both AMC and EBG meanwhile, the band gap is specially characterized by the EBG structure. Besides that, transmission and reflection coefficients are used to characterize the FSS structure. Three different flexible substrates are considered which are Fast Film, Arlon AD350 and Rogers RO3010. Then, angular stability is analyzed for each structure. In order to design AMC, EBG and FSS by using thin substrate, the highest dielectric constant is needed to develop a compact structure with the highest bandwidth. Later, AMC, EBG and FSS structures can be used to improve the radiation pattern apart from enhancing the realized gain of a low profile antenna such as dipole antenna.**

***Index Terms*—Flexible, Artificial Magnetic Conductor (AMC), Electromagnetic Band Gap (EBG), Frequency Selective Surface (FSS).**

I. Introduction

Metamaterial is defined as a macroscopic composite having synthetic; three dimensional and periodic architecture designed to produce as an optimized combination, not available in nature [1-3]. The metamaterial structures include the Frequency Selective Surface (FSS), Artificial Magnetic Conductor (AMC) and Electromagnetic band Gap (EBG). The use of metamaterial structures gives advantages in communication electronic components such as antenna [4-9], filter [10] and microwave couplers [11].

The research activities in the field of flexible metamaterials are focused on the design of the light-weight, conformable and compact structure. The flexible metamaterials are then can be integrated with flexible antennas thus experience performance degradation when placed on the human body. Moreover, the radiation that penetrates into the human cells is a major health concern. To improve the overall performance of the antenna is to enhance the gain of a system at receiver end that can be achieved using AMC, FSS and EBG.

Additionally, in 2013, a journal published titled "Bandwidth Widening, Gain Improvement and Efficiency Boost of an Antenna using AMC Ground Plane" by R. Dewan et al., the realized gain is improved up to 2.1 dBi [12]. While "Dual- Band Wearable Antennas over EBG Substrate" by Zhu and Langley (2007) conclude that placing the EBG behind the antenna considerably reduces back radiation by at least 13 dB while improving gain by up to 3 dB in a direction away from the body [13]. Furthermore, in the analysis of "A Super Wideband Printed Antenna with Enhanced Gain using FSS structure", by Aqeel and Farooq (2015) found that maximum gain enhancement is around 7.5 dB and the average gain enhancement is more than 4 to 5 dB for the complete operational band [14].

This paper explains the characteristics of AMC, EBG and FSS. Reflection magnitude and phase characterized both AMC and EBG while the band gap is specially characterized by the EBG structure. While transmission and reflection coefficients are characterized the FSS structure. All of them are characterized by using 3 different types of flexible substrates which are Fast Film, Arlon AD350 and Rogers RO3010. It is followed by analyzing the effect of different incidence angle to determine the angular stability of the structure.

II. Artificial Magnetic Conductor

Artificial Magnetic Conductor also known as Perfect Magnetic Conductor (PMC) is categorized as metamaterial structure that exhibits novel electromagnetic properties that do not exist in nature. It is called "artificial" magnetic conductor because it is an "artificial engineered material" with a magnetic conductor surface at certain frequency range where it has zero tangential magnetic fields. Thus, the AMC is a high impedance surface (HIS) structure, a lossless and can approximate an open circuit due to the very high surface impedance it has at the resonant.

Generally, the AMC is realized within a limited frequency range. It is characterized when its reflection phase and magnitude is zero and +1 at the resonant. In recent years, there has been growing interest in investigating compact AMC structures to address the needs of various communication devices that are gradually being miniaturized.

Figure 1 shows the patch layout of AMC. There are 8 branches connected to the main square and each 4 of them has a corner square connected at the end of the branch. All the branches are designed alternately between the basic branches with the connected corner square branches. AMC consists of 3 layers configuration which is patch, substrate and ground planes.

AMC substrate is used 3 different types of flexible substrates which are Fast Film (thickness of 0.13 mm and dielectric constant of 2.17), Arlon AD350 (thickness of 1.016 mm and dielectric constant of 3.5) and Rogers RO3010 (thickness of 1.28 mm and dielectric constant of 10.2). Table 1 shows the parameter of the AMC patch for 3 different types of flexible substrates.

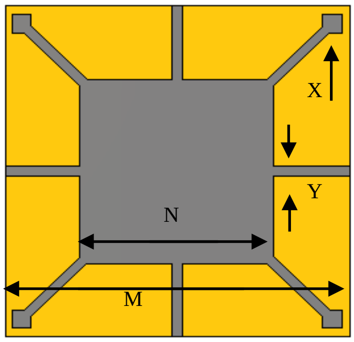

Figure 1 Patch layout of AMC

Table 1
Parameter of the AMC patch for 3 different of flexible substrates

	Fast Film	AD350	RO3010
M	21.71	16.56	9.36
N	12.06	9.20	5.20
X	1.21	0.92	0.52
Y	0.60	0.46	0.26

Reflection magnitude and phase characterize the AMC structure. Figure 2 illustrates the reflection phase for 3 different substrates. All of the reflection phases varies from 180^{o} to -180^{o} and at 5.8 GHz, the reflection phase is 0^{o}. While the reflection magnitude is -26.74 dB, -1.27 dB and -0.87 dB for Fast Film, AD350 and RO3010 respectively.

In order to improve the antenna performances, the AMC structure should be good reasonably reflector. Thus the reflection magnitude is close to zero. RO3010 substrate evaluates -0.87 dB reflection magnitude which is almost close to zero is considered the best reflector. Furthermore RO3010 substrate with 1.28 mm thickness produced the smallest size of the unit cell according to the highest dielectric constant as compared to the others. Based on ±90^{o} of reflection phase, the frequency is laid between 5.67 GHz to 5.93 GHz thus contributes to 4.48% of bandwidth.

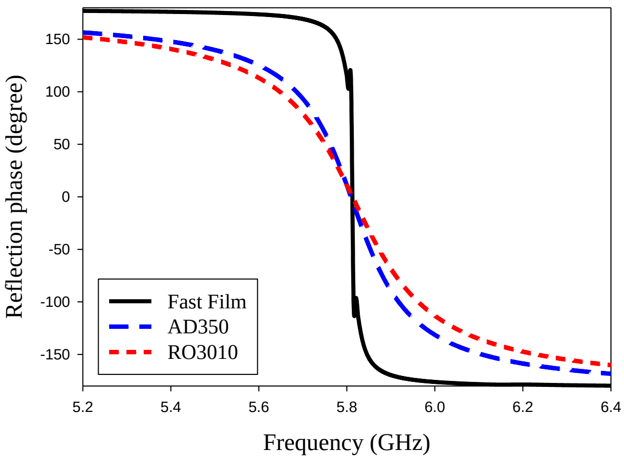

Figure 2 Reflection phase and magnitude of AMC for 3 different substrates

Then, the angular stability of the substrate is analyzed. The structure has angular stability whenever the resonant frequency does not affect as the incidence angle is varied. Figure 3 is the reflection phase of AMC with the RO3010 substrate at different incidence angle. The incidence angle is varied from 0^{o} up to 80^{o}. The graph shows that different incidence angle doesn't affect much the resonant frequency of the structure. Thus the AMC with the RO3010 substrate has high angular stability.

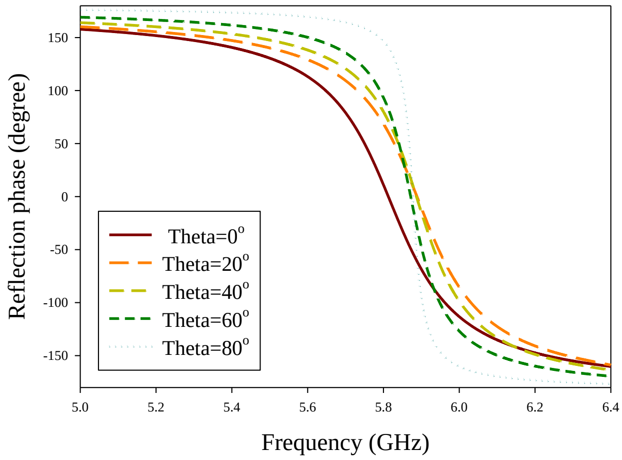

Figure 3 Reflection phase of AMC with the RO3010 substrate at a different incidence angle

III. ELECTROMAGNETIC BAND GAP

Generally, Electromagnetic Band Gap (EBG) structures are defined as non-periodic objects that prevent the propagation of electromagnetic waves in a specified band of frequency for all incident angles and polarization states. EBG structures are usually realized by the periodic arrangement of dielectric materials and metallic conductors.

EBG structures also consider as a sub-class of metamaterials, thus includes various periodic structures with non-existing properties in nature. There are certain energy bands that electrons can occupy and forbidden bands that cannot occupy. Hence, electromagnetic (EM) waves with a frequency inside the forbidden band cannot propagate through the EBG material, regardless of their angle of incidence.

Planar EBG is of particular interest at microwave frequencies, due to ease of fabrication [15-17]. This EBG is usually the only periodical a 2D plane and does not exhibit band gap for all angles of incidences of an EM wave, but just for all angles in that one plane. The uniplanar compact (UC-EBG) and mushroom type EBG are within the group of EBG.

Basically, the AMC and EBG layers configuration are same. In this paper, the patch layout of EBG is same as the AMC. EBG is characterized by reflection phase and magnitude same goes for the AMC, but band gap is specially characterized the EBG. Then, this part only focuses on the band gap of the EBG.

The band gap for the structure is investigated by using the 50 Ω transmission line method [18-21]. The initial work started by designing a 50 Ω transmission line on the supporting substrate thus same with the substrate material. The proposed geometry of the transmission line is shown in Figure 4. The band gap frequency is defined based on –20 dB of the transmission coefficient [22-23].

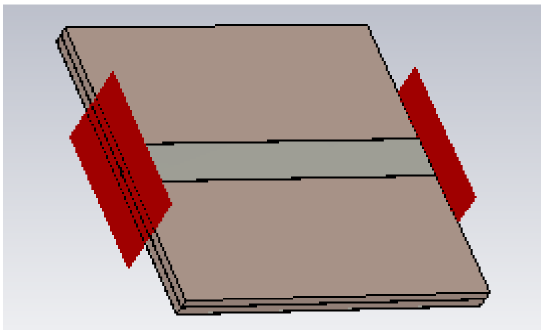

Figure 4 Geometry of the transmission line

Figure 5 shows the transmission coefficients of designed EBG with 3 different types of substrate. As can be seen, more than one frequency band gap is produced at different frequencies. The band gap around 2.45 GHz and 5.8 GHz are observed with Fast Film EBG. While the EBG with AD350 illustrates the best transmission coefficient which is almost close to the operating EBG frequency which is 5.8 GHz and there is no band gap at 2.45 GHz.

The antenna which is resonated closed or within the EBG band gap contributes to the improvement of antenna performance while working together. While the antenna which is resonated out of the EBG band gap will be rejected as its work together. Therefore, the EBG structure does not only help to improve the antenna performances but at the same, it also works as a filter to removed unwanted harmonics.

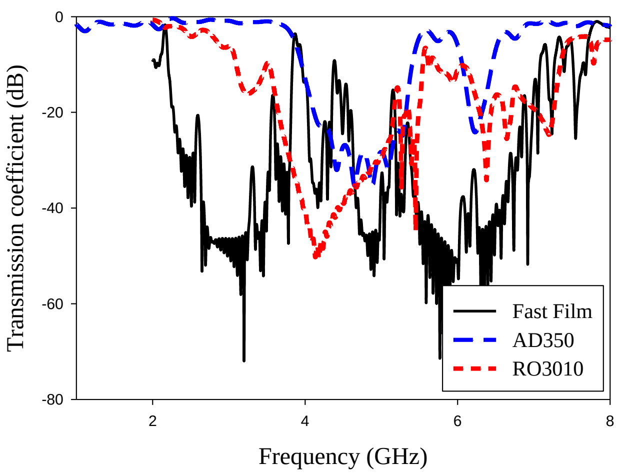

Figure 5 Transmission coefficients of EBG with 3 different types of substrate

Therefore, EBG with AD350 is the best substrate to be incorporated with antenna later on. The reflection magnitude is -1.27 dB which is also close to zero in order to be good reasonably ground plane for the antenna. Besides, the frequency band gap is close to 5.8 GHz.

Then, the angular stability of the EBG is analyzed. Either the structure has high angular stability thus the resonant frequency does not affect by the different of incidence angle or the structure has low angular stability whenever the changes in incidence angle change the resonant frequency of the structure. Figure 6 is the reflection phase of EBG with AD350 substrate at different incidence angle. From the observation, the difference of incidence angles effected the resonant frequency of the structure around 5.5 GHz up to 5.7 GHz. Thus the EBG with AD350 has low angular stability.

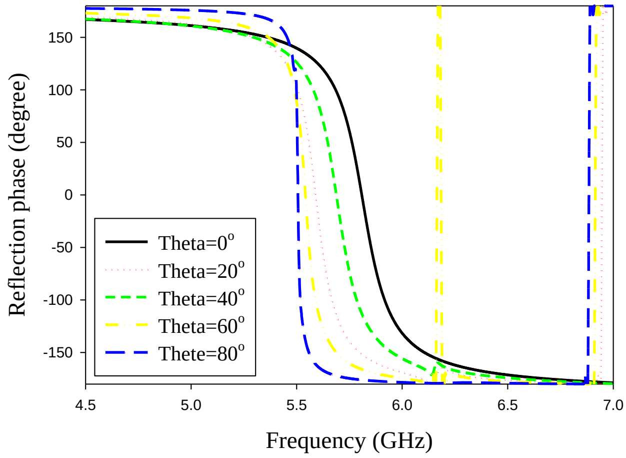

Figure 6 Reflection phase of EBG with AD350 substrate at a different incidence angle

IV. Frequency Selective Surface

A frequency selective surface (FSS) is a spatial electromagnetic filter, consists of one or two dimensional periodic array of wire or slot elements etched on a dielectric substrate. Basically, FSS works as a filter, designed to reveal different reflection and transmission properties as a function of frequency. Normally the FSS consists of slot element is composed of arbitrarily shaped perforations in a metallic screen which support magnetic currents. Surfaces comprised of wire elements act as band stop filters and surfaces comprised of slot elements act as band pass filters

FSS consists of patch and substrates layers configuration only. FSS was known as AMC or EBG without ground plane while AMC and EBG known as FSS with the ground plane. For this paper, the patch layout of EBG is same as the AMC and EBG. FSS is characterized by transmission and reflection coefficients. It is also being analyzed using 3 different types of substrates. Table 2 is the parameter of the FSS patch for 3 different types of flexible substrates.

Table 2
Parameter of the FSS patch for 3 different of flexible substrates

	Fast Film	AD350	RO3010
M	30.96	24.12	15.41
N	17.20	13.40	8.36
X	1.72	1.34	0.84
Y	0.86	0.67	0.42

Figure 7 illustrates the transmission and reflection coefficients of FSS for 3 different types of substrates. The operating frequency for FSS is at 5.8 GHz. All the substrates show the best reflector behavior where the reflection coefficient (RC) is almost zero. While the transmissions coefficient (TC) are -58.67 dB, -54.76 dB and -57.71 dB for Fast Film, AD350 and RO3010 respectively. Based on -10 dB of transmission, the evaluated bandwidths are 34.74% for Fast Film, 40.27% for AD350 and 51.65% for RO3010. FSS with Fast Film substrate evaluates the highest transmission with almost zero reflection is to proceed.

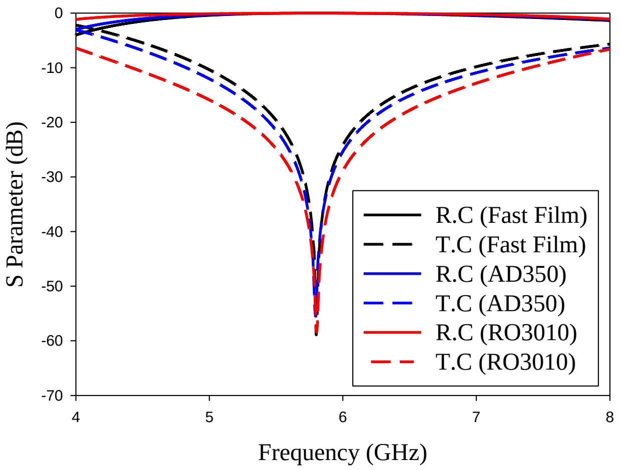

Figure 7 Transmission and reflection coefficients for 3 different types of substrates

Next, the angular stability of the structure is analyzed. Figure 8 is the transmission coefficient of FSS with Fast Film substrate at different incidence angle. The operating frequency is varied from 5.30 GHz up to 5.70 GHz, thus the structure has low angular stability.

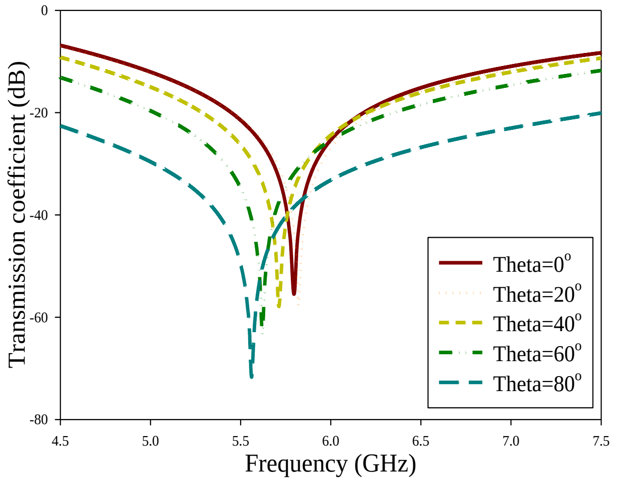

Figure 8 Transmission coefficients of FSS with the RO3010 substrate at a different incidence angle

The thickness and dielectric constant of the substrate influence the structure size for all types of AMC, EBG and FSS. The thicker of the substrate evaluates the bigger size of the unit cell while the higher dielectric constant contributes to the smaller size of the unit cell. So that, designing the AMC, EBG and FSS while considering the thin substrate, the high dielectric constant is needed in order to develop the compact structure.

Table 3 shows the bandwidth of AMC, EBG and FSS for 3 different types of substrate. Noted that the bandwidth for AMC and EBG were same which evaluated by reflection phase graph. The thin substrate with the lowest dielectric constant produces the smallest bandwidth and vice versa. Then, designing AMC, EBG and FSS while considering the thin substrate, the high dielectric constant is needed in order to develop the largest bandwidth.

Table 3
Bandwidth for AMC, EBG and FSS for 3 different types of substrate

	Fast Film	AD350	RO3010
AMC/EBG	0.05	3.27	4.48
FSS	34.74	40.27	51.65

V. CONCLUSION

The characteristics of the AMC, EBG and FSS are successfully characterized at 5.8 GHz. Reflection magnitude and phase are characterized both AMC and EBG meanwhile, the band gap is specially characterized by the EBG structure. Besides that, transmission and reflection coefficients are used to characterize the FSS structure. Three different flexible substrates are considered which are Fast Film, Arlon AD350 and Rogers RO3010. Then, angular stability is analyzed for each structure. In order to design AMC, EBG and FSS by using thin substrate, the highest dielectric constant is needed to develop a compact structure with the highest bandwidth. Later, AMC, EBG and FSS structures can be used to improve the radiation pattern apart from enhancing the realized gain of a low profile antenna such as dipole antenna.

ACKNOWLEDGMENT

The authors wish to thank the Ministry of Science, Technology and Innovation (MOSTI), Center for Research and Innovation Management (CRIM) of Universiti Teknikal Malaysia Melaka (UTeM) for the support of this work under the grant number PJP/2015/FKEKK (2B)/S01406.

REFERENCES

[1] Cui, T.J., Smith, D., and Lin, R.P., 2009. *Metamaterial: Theory, Design and Application*, Springer Sciences & Business Media, pp. 2.

[2] S. A. M. Ali, *et al*., "Dipole Antenna backed by 8-CBU AMC-EBG and 8-CBU FSSat 5.8 GHz," Journal of Telecommunication, Electronic and Computer Engineering, 2016, Vol. 8, pp. 108-114.

[3] O. Ayop, M. K. A. Rahim, M. Abu, and T. Masri, "Slotted Patch Dual Band Electromagnetic Band Gap Structure Design," *3rd European Conference on Antenna and Propagation (EUCAP)*, 2009, pp. 2618-2621.

[4] M. Abu, and M. K. A. Rahim, "Single-band and Dual-band Artififcial Magnetic Conductor Ground Planes for Multi-band Dipole Antenna," *Radio Engineering*, 2012, Vol. 21, No. 4.

[5] S. Zhu, and R. Langley, "Dual-Band Wearable Antennas over EBG Substrate," *Electronic* Letters, 2007, Vol. 43, No. 3.

[6] H. N. Aqeel, and A. T. Farooq, "A Super Wideband Printed Antenna with Enhanced Gain using FSS structure," *Proceedings of 12th International Bhurban Conference on Applied Science & Technologhy (IBCAST)*, 2015, 978-1-4799-6369-0/15.

[7] D. Cara, D. Trajkovikj, J. Torres-sánchez, R. Zürcher, and J. Skrivervik, "A Low Profile UWB Antenna for Wearable Applications : The Tripod Kettle Antenna (TKA)," *European Conference on Antennas and Propagation (EuCAP)*, 2013, pp. 3257–3260.

[8] J. Choi, J. Tak, and K. Kwon, "Low-Profile Antennas for On-Body Surface Communications," *International Workshop on Antenna Technology*, 2014, pp. 288–29.

[9] P. Duangtang, P. Krachodnok, and R. Wongsan, "Gain Improvement for Conventional Conical Horn By Using Mushroom-like Electromagnetic Band Gap," *Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*, 2014, pp. 3–6.

[10] K. Herbertz1, S. Lucyszyn, " Two-Dimensional Metamaterials for Dual-Band Filter Applications," *Proceedings of the 38th European Microwave Conference*, 2008.

[11] S. Telikepalli, M. Swaminathan, D. Keezer, " An Alternate Power Distribution Scheme with Superior Noise Suppression Characteristics than EBG," *Electrical Performance of Electronic Packaging and Systems (EPEPS)*, 2014.

[12] R. Dewan, S. K. A. Rahim, S. F. Ausordin, D. N. A. Zaidel, B. M. Sa'ad, and T. Purnamirza, "Bandwidth Widening, Gain Improvement and Efficiency Boost of an Antenna using AMC Ground Plane," *Jurnal Teknologi*, 2014, pp. 2180-3722.

[13] S. Zhu, and R. Langley, "Dual-Band Wearable Antennas over EBG Substrate, " Electronic Letters, Vol. 43, N0. 3, 2007.

[14] H. N. Aqeel, and A. T. Farooq, "A Super Wideband Printed Antenna with Enhanced Gain using FSS structure, " Proceedings of 12th International Bhurban Conference on Applied Science & Technologhy (IBCAST), 978-1-4799-6369-0/15, 2015

[15] B. Ivsic, G. Golemac, and D. Bonefacic, "Performance of Wearable Antenna Exposed to Adverse Environmental Conditions," *Apllied Electromagnetics and Communications (ICECom)*, 2013, pp. 978-953.

[16] Z. H. Jiang, D. E. Brocker, P. E. Sieber, and D. H. Werner, "A Compact , Low-Profile Metasurface-Enabled Antenna for Wearable Medical Body-Area Network Devices," *IEEE Transaction on Antennas and Propagation*, 2014, pp. 4021–4030.

[17] K. Kamardin, M. K. A. Rahim, and P. S. Hall, "Textile Diamond Dipole and Artificial Magnetic Conductor Performance under Bending , Wetness and Specific Absorption Rate Measurements," *Radio Engineering*, 2015, pp. 729–738.

[18] Kwon, J.H., Sim, D.U. & Kwak, S.I, "Study on Triangular EBG Unit Cell Structures for Suppression of SSN in Power / Ground Planes," *IEEE International Symposium of Microwave Conference (EuMC)*, 2015, pp.290–1293.

[19] Chen, Z., "A Compact Electromagnetic Bandgap Structure based on Multi-layer Technology for 7-Tesla Magnetic Resonance Imaging Applications," *Proceedings of the 9th European Microwave Integrated Circuis Conference*, 2014, Vol. 1, No. 1, pp.632–635.

[20] Siya, M. & Lee, Y.H., "Design of a Compact Patch Antenna Using UC-EBG Structure," *Antenna and Propagation Society International Symposium (ASPURI)*, 2013, pp.1384–1385.

[21] M. Abu, *et al*., "Design of Single-Band Star Geometric Pattern Artificial Magnetic Conductor," *ARPN Journal of Engineering and Applied Sciences*, 2015, Vol. 11, pp. 3184-3187.

[22] R. F. Munawar, *et al., "*8 Connected Branches AMC-EBG and FSS for Circle Connected Dipole at 5.8 GHz," International Journal of Applied Engineering Research, 2016, Vol. 11, pp. 6932-6939.