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PROXIMITY COUPLED ANTENNA WITH STAR GEOMETRY PATTERN AMC GROUND PLANE

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ABSTRACT

In this paper, a conventional proximity coupled microstrip antenna operating at 2.45 GHz is firstly designed as a reference antenna. Then, the proximity coupled microstrip antenna is incorporated with a star geometry pattern artificial magnetic conductor (AMC) as the ground plane. Performance comparison is analyzed between the conventional antenna and the antenna with the AMC ground plane. The proximity antenna with star geometry pattern AMC ground plane successfully enhances the efficiency and gain by 8 % and 3 % as compared to the conventional antenna. In addition, the size of the proximity antenna with star geometry pattern AMC ground plane is reduced by 13 % as compared to conventional antenna. It shows that AMC as a ground plane to the antenna are able to reduce the size, enhance the gain and efficiency of the antenna.

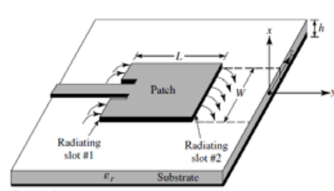
Keywords: artificial magnetic conductor, star geometry pattern, proximity coupled microstrip antenna, efficiency, gain.

INTRODUCTION

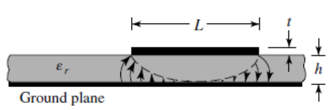
Microstrip antenna

In application of aircraft, spacecraft, satellite and missile application, they require a low profile antenna, lower cost and size, ease of installation and aerodynamic profile (Constatine A. Balanis, 2005). Recently, most of government and commercial applications, such as mobile radio and wireless communication meet these specifications (Constatine A. Balanis, 2005). Therefore, microstrip antennas are used.

As shown in Figure-1, Microstrip antennas have a very thin $(t << \lambda_0)$, where (λ_0) is the free space wavelength and a metallic strip (patch) where a small fraction of a wavelength $(h << \lambda_0)$ usually $(0.003\lambda_0 \leq h \leq 0.05\lambda_0)$ is located above a ground plane (Constatine A. Balance, 2005).



(a) Top View



(b) Side View

Figure-1. Microstrip antenna (Constatine A. Balanis, 2005).

Microstrip antennas have many advantages compared to conventional microwave antennas and covered the broad frequency range from ~100 MHz to 100 GHz ~ (R. Garg, P. Bhartia, I. Bahl, and A. Ittipiboon, 2001).These included lightweight and low volume, low profile planar configuration which can be easily made conformal to hose surface and low fabrication cost. The limitations of microstrip patch antenna are narrow bandwidth, low efficiency, low gain and low power handling capacity (R. Garg, P. Bhartia, I. Bahl, and A. Ittipiboon, 2001)

However, these limitations can be minimized by using many methods. For example, bandwidth can be increased by using fed methods. One of the most popular fed methods is proximity coupling. The multilayer proximity-coupling or electromagnetically-coupling technique consists of two-layer substrate as shown in Figure-2. The upper substrate used for the radiator (patch) and the bottom substrate used for feedline. There is a contact which provided between the patch and the microstrip line in order to increase the bandwidth of the patch.

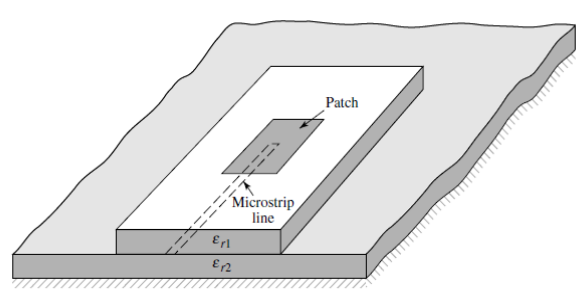


Figure-2. Proximity-coupled fed (Constatine A. Balanis, 2005).

The substrate parameters can be chosen separately. The upper substrate on which the antenna is printed requires a relatively thick substrate with a low relative dielectric constant to enhance radiation and increase bandwidth, whereas the lower guideline substrate requires a thin substrate with a high relative dielectric constant to prevent radiation.

The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth as high as 13%, due to an overall increase in the thickness of the microstrip patch antenna (Preeti Sharma and Shubham Gupta, 2014),(Shubham Gupta, and Shilpa Singh, 2012).

One of the disadvantages of using this feeding method is the difficulties to fabricate due to the existence of two substrates which need the proper alignment. Other than that, this method will increase the overall thickness of the antenna (Preeti Sharma and Shubham Gupta, 2014), (Shubham Gupta, and Shilpa Singh, 2012).

Different configuration of proximity coupled antenna is designed in order to enhance the important antenna parameters. P.Sharma and S.Gupta design a proximity coupled microstrip antenna array in order to enhance bandwidth and gain (Preeti Sharma and Shubham Gupta, 2014). 2×1 microstrip antenna array, 4×1 microstrip antenna array and 4×2 microstrip antenna array design for simultaneous improvement of bandwidth, gain, directivity in 4×1 and 4×2 microstrip antenna array using a dielectric substrate FR4 for 8GHz frequency applications (Preeti Sharma and Shubham Gupta, 2014).

M. Shaker, E. A.F. Abdallah, H. Taher, H. El-hennawy proposed a design of high isolation proximity coupled dual polarized rectangular microstrip patch antenna with two orthogonal feeder lines. There are two types of DGS-integrated with microstrip transmission lines are presented, namely, the spiral- shaped DGS and the dumb-bell shaped DGS. The dumb-bell shaped DGS is etched on the ground plane underneath the microstrip antenna feed the transmitting port (2.5GHz antenna port).The spiral DGS is etched on the ground plane underneath the antenna feeding line at the receiving port (2.0GHz antenna port) (M. Shaker, E. A.F. Abdallah, H. Taher and H. El-hennawy, 2010).

Dan Sun and Lizhi You present a method in order to achieve broadband impedance matching for proximity-coupled microstrip antenna by narrow cavity backed configuration. The narrow cavity is used to afford effective coupling to the patch with a thick substrate, and the increase of the coupling is beneficial for the enhancement of the bandwidth (Dan Sun and Lizhi You, 2010).

Pritam Singh Bakariya, Santanu Dwari, Manas Sarkar, Mrinal Kanti Mandal proposed a novel proximity-coupled multiband microstrip patch antenna operates at Bluetooth (2.4-2.485 GHz), WiMAX (3.3–3.7 GHz), and WLAN (5.15–5.35 and 5.725–5.85 GHz) bands with consistent radiation pattern and uniform gain. The antenna is designed with a V-shape of the patch and the parasitic structure in ground plane in order to improve antenna characteristics (Pritam Singh Bakariya, Santanu Dwari, Manas Sarkar, and Mrinal Kanti Mandal, 2015).

Back-to-back, multilayered, dual frequency, dual polarized antenna has been proposed by P. R. Prajapati, A. Patnaik, and M. V. Kartikeyan, Two DGSs (spiral shape and dumbbell shape) are incorporated in order to get benefits like realization of dual polarization, good impedance matching, and reduction in cross polarization at boresight and patch size reduction (P. R. Prajapati, A. Patnaik and M. V. Kartikeyan, 2014).

This work presents a design of proximity coupled microstrip antenna with star geometry pattern artificial magnetic conductor (AMC) as a ground plane at a frequency of 2.45 GHz. Two different substrates are chosen which FR-4 with $\varepsilon_r = 5.4$ and $\varepsilon_r = 1.6$ as a patch substrate while RO3010 with $\varepsilon_r = 10.2$ and $h = 1.28$ as a feed substrate. The main objective of this design is to enhance the gain and efficiency. The other objective is to reduce the size of the antenna. Firstly, a conventional proximity coupled antenna which operated at 2.45 GHz is designed. Then, a star GP AMC structure is designed and simulate at 2.45 GHz with a reflection coefficient $|\Gamma| = 1$ and $\angle\Gamma = 0°$. Finally, these two structures are incorporated and simulated at a frequency of 2.45 GHz. Performance comparison is analyzed between the conventional antenna and the antenna with the star geometry pattern AMC ground plane.

AMC structure

There are many attentions of an artificial magnetic conductor (AMC) structures due to their special characteristics in controlling the propagation of electromagnetic waves which can be used in order to overcome the antenna problems (M[a] Elena de Cos, Yuri Álvarez, Ramona Hadarig and Fernando Las-Heras, 2011). Artificial magnetic conductor AMC (Maisarah Abu, Mohamad Kamal A. Rahim, 2012) (M. Abu, M. K. A. Rahim, O. Ayop, And F. Zubir, 2010) is a member of high impedance surface (HIS) family and it is designed in order to simulate the performance of a PMC. Thin layers of AMC perform as a perfect magnetic wall at resonance or operating frequency. The form of AMC is obtained by the frequencies where the magnitude and phase of the reflection coefficient $|\Gamma| = 1$ and $\angle\Gamma = 0°$ respectively (M[a] Elena de Cos, Yuri Álvarez, Ramona Hadarig and Fernando Las-Heras, 2011). Besides that, the reflection phase of AMC surface varies continuously from +180˚to -180˚ relative to the resonant as shown in Figure-3 (Chahat Jain, Navneet Kaur, Gurpurneet Kaur, 2012).

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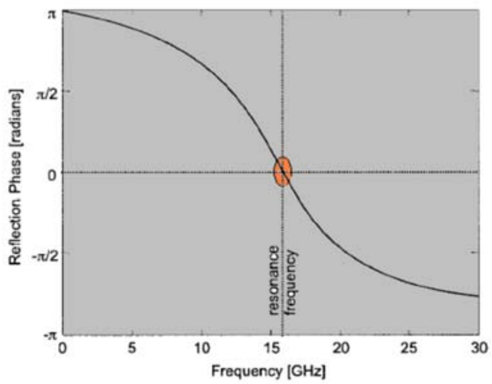

Figure-3. Reflection phase of the high impedance. (Chahat Jain, Navneet Kaur, Gurpurneet Kaur, 2012).

There are two crucial and interesting characteristics of AMC surfaces. These characteristics does not happen in nature and applicable to a wide range of microwave circuit applications.

Firstly, AMC surfaces have a forbidden frequency band over which therefore surface waves and currents cannot be transmitted. This property is useful for them as ground planes and planar or waveguide type filters. Therefore, it will present a good radiation pattern without unwanted ripples based on suppressing the surface wave propagation within the band gap frequency range (J. R. Sohn, K. Y. Kim, and H.-S. Tae, 2006).

Secondly, there is very high surface impedance in AMC surfaces within a specific limited frequency range. Even though with a large electric field through the surface, the tangential magnetic field is small. For that reason, AMC surface is able to have a reflection coefficient of +1 (in-phase reflection) (J. R. Sohn, K. Y. Kim, and H.-S. Tae, 2006).

There are many designs of antennas that implemented AMC as a ground plane. Mustafa Cekingen, Cevdet Isik and Bahattin Turetken presented a new broadband microstrip monopole antenna with artificial magnetic conductor (AMC) ground plane in order to minimize antenna size and decrease the resonant frequency to lower frequencies (E. Carrubba, S. Genovesi, A. Monorchio, G. Manara, 2007), (D. N. Elsheakh, H. A. Elsadek, 2009), (D. Nashaat, H. A. Elsadek, E. Abdallah, 2009). Therefore, one of the advantage of this new antenna is lower distortion in its omni-directional radiation pattern at higher operating frequencies (Mustafa Cekingen, Cevdet Isik, Bahattin Turetken, 2011).

Maisarah Abu, Mohamad Kamal A. Rahim presented the design and development of a multi-band dipole antenna employing HIS structure in order to increase the gain of the antenna. The purpose of this design is to develop a versatile antenna and AMC which can be operated in multiple frequency band. The gain of dipole antenna is increased due to the unique characteristic of the AMC that has an in-phase reflection with the antenna current (Maisarah Abu, Mohamad Kamal A. Rahim, 2012)

DESIGN METHODOLOGY

Conventional proximity coupled antenna (without star GP AMC ground plane)

The basic calculation of rectangular patch microstrip antenna is based on the transmission-line method. Firstly, the value of width, w can be obtained by using equation (1).

$$w = \frac{c}{2 f_0 \sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{1}$$

where, f_o is operating frequency, ε_r is dielectric substrate and c is the speed of light. Then, the value of effective relative permittivity ε_{eff} for microstrip line of rectangular patch antenna is calculated as in equation (2).

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + 12h/w}}\right) \tag{2}$$

Therefore, with the value of ε_{eff}, the fringe factor ΔL can be determined by using the equation (3).

$$\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)(w/h + 0.264)}{(\varepsilon_{reff} - 0.258)(w/h + 0.8)} \tag{3}$$

Next, the value of effective length L_{eff} can be obtained through the equation (4).

$$L_{eff} = \frac{c}{2 f_o \sqrt{\varepsilon_{reff}}} \tag{4}$$

By calculating the value of ΔL and L_{eff}, the value of actual length L can be obtained as in equation (5).

$$L = L_{eff} - 2\Delta L \tag{5}$$

Lastly, the witdh and length of ground plane can be calculated by using equation (6) and (7) below.

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

$$w_g = 6h + w \tag{7}$$

Figure-4 shows a design of conventional proximity coupled microstrip antenna by using CST software at operating frequency of 2.45 GHz.

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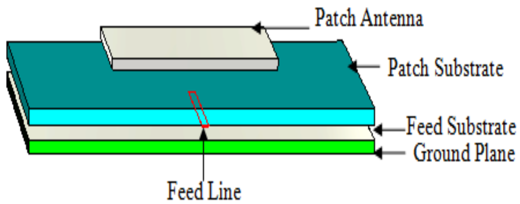

Figure-4. A design structure of conventional proximity coupled microstrip antenna.

RO3010 is chosen as a feed substrate with $\varepsilon_r = 10.2$ and $h = 1.28$ while FR-4 is chosen as a patch substrate with $\varepsilon_r = 5.4$ and $h = 1.6$. The dimension of the ground plane, feed substrate and patch substrate are adjusted to 53 mm x 53 mm x 2.95 mm. The parameters of this antenna were simulated and optimized in order to make sure that the results are resonating at a frequency of 2.45 GHz.

Design of AMC structure

The operating frequency and the bandwidth of an AMC design structure depends on the unit cell geometry together with substrate's relative dielectric permittivity and thickness. The AMC design structure consists of three parts which are patch, substrate and ground. Starting with tetragon shape design, AMC is designed by using Rogers RO3010 as a substrate, with dielectric permittivity ε_r = 10.2, loss tangent = 0.0023 and thicknesses = 1.28 mm. Frequency operates at 2.45 GHz with a dimension size of 28 mm x 28 mm as shown in Figure-5(a).

Then, by combining the same size of tetragon and square shape, the design right now can be called as basic star pattern as shown in Figure-5(b). The basic star AMC design is resonated at 2.45 GHz with 25 mm x 25 mm size.

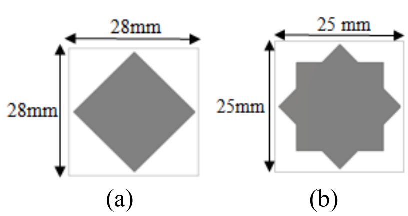

Figure-5. (a) Tetragon shape AMC design (b) Basic Star AMC design; resonated at 2.45 GHz

In Star GP AMC design as shown in Figure-6, there are four triangle slots and four arrow slots in the basic star AMC design. Through the slots combination, there is another basic star pattern appear at the center of the Star GP AMC.

By inserting four triangle slots and four arrow slots to the actual size of basic star AMC also makes the resonance frequency has been decreased. Hence, to increase the frequency back to 2.45 GHz, the size of Star GP AMC has to be reduced. After the optimization process, the new size of the Star GP AMC is 23 mm x 23 mm.

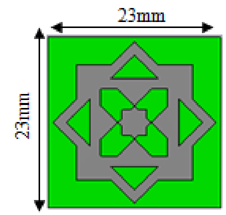

Figure-6. Top view of unit-cell star GP AMC structure.

Proximity coupled antenna with star GP AMC ground plane

Figure-7 shows a design of 2x2 Star GP AMC with a dimension of 46 mm x 46 mm x 1.315 mm. Figure-8 presents a design of proximity coupled antenna with 2x2 Star GP AMC structure ground plane. The AMC structure is located at the bottom of feed substrate. The dimension is adjusted to 46 mm x 46 mm x 4.3 mm.

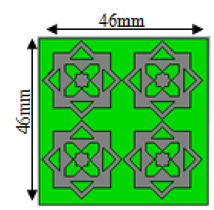

Figure-7. 2x2 Star GP AMC design structure.

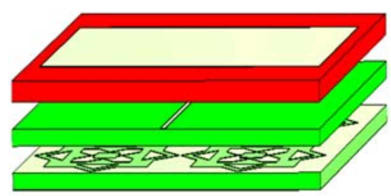

Figure-8. A design structure of proximity coupled antenna with Star GP AMC ground plane.

RESULTS AND DISCUSSIONS

AMC structure

From the simulation results as shown in Figure-9 below, the reflection phase bandwidth of tetragon shape AMC is relatively small compared to the basic star AMC design. The reflection phase of Star GP AMC falls from 2.4022 GHz to 2.4938 GHz at ± 90^0 respectively as in Figure-9 and the bandwidth percentage is 3.74 %. Meanwhile the tetragon shape AMC has given 3.01% bandwidth of reflection phase.

The operating bandwidth of an AMC structure is normally described as +90° to - 90° on upper and lower frequencies. This is because of these phase values would

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not cause destructive interference between direct and reflected waves (Shruti Karkare and Kavita Tewari, 2014).

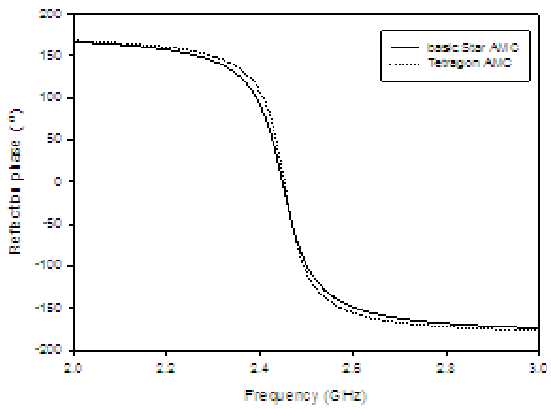

Figure-9. Reflection phase of tetragon and basic star AMC design.

In order to determine the frequency band in which the periodic structure performs as an AMC, its reflection coefficient for a uniform incident plane wave is simulated. Figure-10 shows the simulated reflection coefficient of the designed AMC structure. It is observed that the $\angle\Gamma = 0°$ and the reflection phase of AMC surface varies continuously from +180˚to - 180˚ relative to the resonant frequency of 2.45 GHz. The AMC operating bandwidth is 3.27%

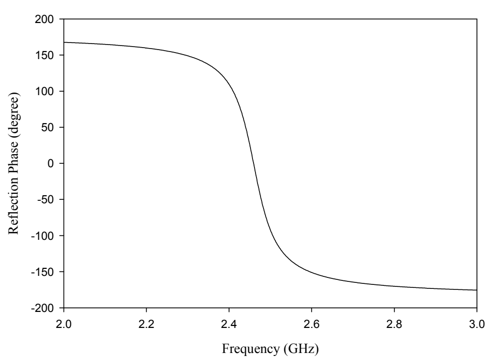

Figure-10. Reflection phase of unit cell Star GP AMC structure.

Proximity coupled microstrip antenna with and without star GP AMC ground plane

Figure-11 and Figure-12 show the simulated return loss of both antennas operating at a frequency of 2.45 GHz. The return loss is one of the ways to determine mismatch. Refer to Figure-11, it shows that the antenna without star GP AMC ground plane has a return loss of -27.47 dB with an operating bandwidth of 2.48 %, while the antenna with star GP AMC ground plane has a return loss of -22.52 dB as shown in Figure-12. However, the operating bandwidth of the antenna with star GP AMC ground plane became narrower in comparison to the conventional antenna which about 1.92%. This may be due to the form of AMC itself which affects the narrower bandwidth of the antenna.

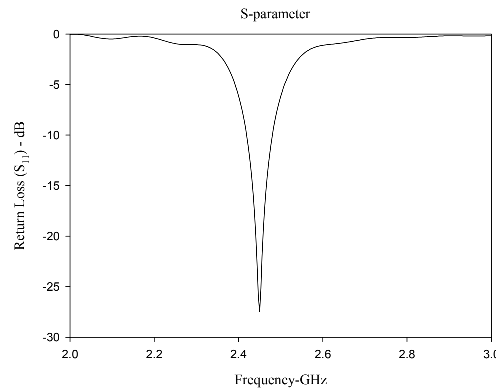

Figure-11. Return Loss (S_{11}) simulation result of a conventional proximity coupled microstrip antenna (without Star GP AMC ground plane).

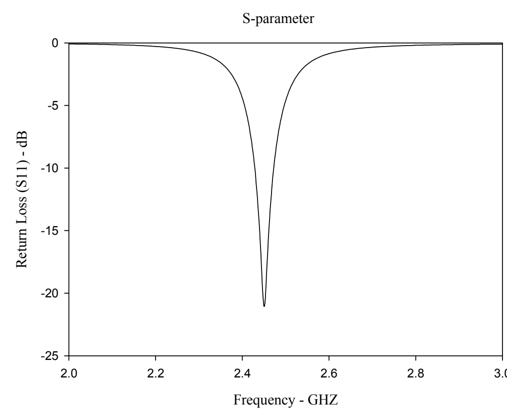

Figure-12. Return Loss (S_{11}) simulation result of a proximity coupled microstrip antenna with start GP AMC ground plane.

Figure-13 and Figure-14 show a farfield pattern of a conventional proximity coupled antenna and proximity coupled antenna with Star GP AMC ground plane. The total efficiency and a realized gain of conventional antenna is -0.5464 dB (88%) and 5.461 dB respectively. The total efficiency and realized gain of the proximity antenna with star GP AMC ground plane is -0.1801 dB (96%) and 5.653 dB respectively. Therefore, the increasing efficiency and gain of the proximity antenna with star GP AMC ground plane is by 8 % and 3 % respectively.

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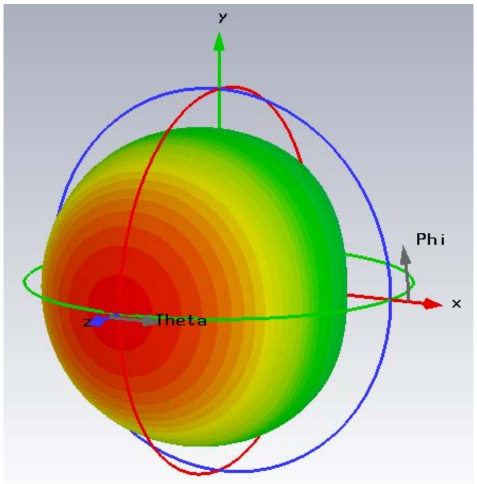

Figure-13. Farfiled pattern of conventional proximity coupled antenna (without Star GP AMC ground plane).

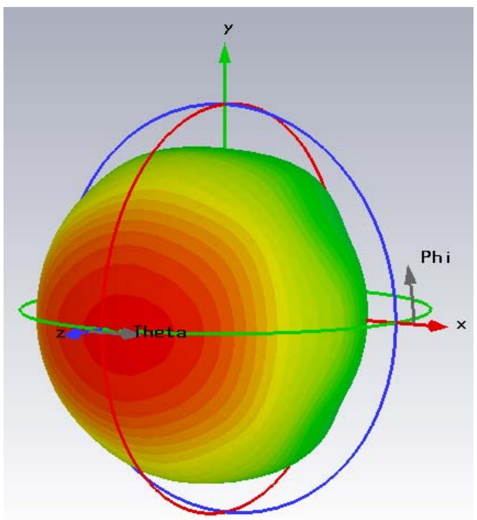

Figure-14. Farfiled pattern of proximity coupled antenna with start GP AMC ground plane.

Figure-15 and Figure-16 show a directional radiation pattern of both antenna designs. The directivity D of an antenna is known as a ratio of power density in the main beam to the average power density whiles the gain $G = eD$ (Kai Fong Lee, Kwai Man Luk, 2011). The directivity of the antenna is determined by the design pattern of the antenna.

Refer to Figure-15 and Figure-16, it shows that the conventional antenna is more directivity compare to the antenna with star GP AMC ground plane. Both values of directional radiation pattern are 6.01 dBi and 5.79 dBi respectively. However, the directivity of the antenna with star GP AMC ground plane still accepted and can be assumed in the range of patch microstrip antennas.

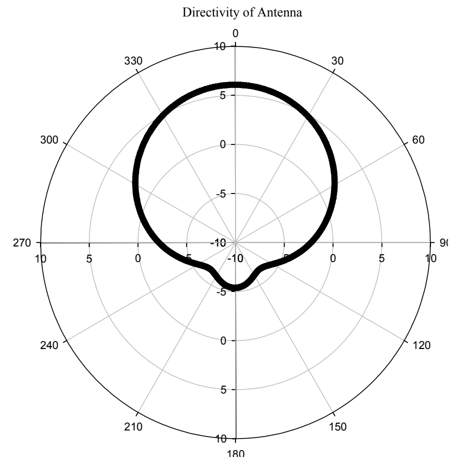

Figure-15. Directivity of a conventional proximity coupled microstrip antenna (without Star GP AMC ground plane).

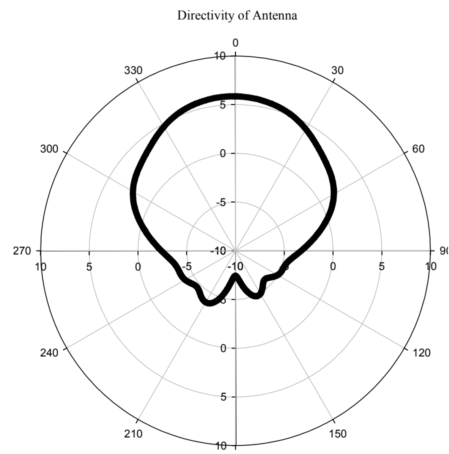

Figure-16. Directivity of a proximity coupled microstrip antenna with star GP AMC ground plane.

CONCLUSIONS

The proximity coupled microstrip antenna with Star GP AMC ground plane has been designed. Performance comparison has been analyzed between the conventional proximity coupled microstrip antenna and proximity coupled microstrip antenna with star GP AMC ground plane. It is discovered the incorporated AMC to the antenna successfully enhanced the efficiency by 8 %. Other than that, it is also observed that the gain of the antenna with the AMC ground plane increased by 3 %. In addition, the size of the proximity antenna with star GP AMC ground plane is reduced by 13 % as compared to reference antenna the proximity coupled microstrip antenna with star GP AMC ground plane operates at a frequency of 2.45 GHz as conventional antenna.

FUTURE WORK

For future work, the proximity coupled microstrip antenna with AMC structure will be designed with different form of a radiated patch. Other than that,

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different form of AMC structure will be designed in order to implement together with proximity coupled microstrip antenna or other designs of antennas.

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REFERENCES

Chahat Jain, Navneet Kaur, Gurpurneet Kaur. 2012. Artificial magneticconductor for miniaturized antenna applications-A Review. International Journal of Emerging Technology and Advanced Engineering (ISSN 2250-2459, Volume 2, Issue 7.

Constatine A. Balanis. 2005. Antenna Theory, Analysis and Design, 3rd Edition. A John Wiley & Sons, Inc., Publication.

Dan Sun and Lizhi You. 2010. A Broadband Impedance Matching Method for Proximity-Coupled Microstrip Antenna. IEEE Transactions on Antennas and Propagation, Vol. 58, No. 4.

D. N. Elsheakh, H. A. Elsadek. 2009. Ultrawide Bandwidth Umbrella-Shaped Microstrip Monopole Antenna Using Spiral Artificial Magnetic Conductor. IEEE Antennas and Wireless Propagation Letters, vol. 8, pp. 1-4.

D. Nashaat, H. A. Elsadek, E. Abdallah. 2009. Enhancement of Ultra-Wide Bandwidth of Microstrip Monopole Antenna by Using Metamaterial Structures. IEEE Antennas and Wireless Propagation Letters.

E. Carrubba, S. Genovesi, A. Monorchio, G. Manara. 2007. AMC-based Low Profile Antennas for 4G Communication Services. IEEE Antennas and Wireless Propagation Letters. pp. 3364-3367.

J. R. Sohn, K. Y. Kim, and H.-S. Tae. 2006. Comparative Study on Various Artificial Magnetic Conductors for Low-Profile Antenna. Progress in Electromagnetics Research, PIER 61, pp. 27-3.

Kai Fong Lee, Kwai Man Luk. 2011. Microstrip Patch Antennas. Imperial College Pres.

M.Abu, M.K.A. Rahim. 2012. Single-band and Dual-band Artificial Magnetic Conductor Ground Planes for Multi-band Dipole Antenna. Radioengineering, Vol. 21, No. 4.

M. Abu, M. K. A. Rahim, O. Ayop and F. Zubir. 2010. Triple-Band Printed Dipole Antenna with Single-Band Amc-His. Progress in Electromagnetics Research B, Vol. 20, pp. 225-244.

Mª Elena de Cos, Yuri Álvarez, Ramona Hadarig and Fernando Las-Heras. 2011. Flexible Uniplanar Artificial Magnetic Conductor. Proceedings of the 5th European Conference on Antennas and Propagation (EUCAP). IEEE. pp. 1218-1221.

M. Shaker, E. A.F. Abdallah, H. Taher and H. El-hennawy. 2010. Modern Isolation of Dual-Band Proximity Coupled Microstrip Antenna Front-End Transceiver, (c) 2010-IEEE APS, Middle East Conference on Antennas and Propagation (MECAP), Cairo, Egypt, pp. 1-6.

Mustafa Cekingen, Cevdet Isik, Bahattin Turetken. 2011. Design of a Broadband Microstrip Antenna with Artificial Magnetic Conductor Ground Plane. ELECO 2011 7th International Conference on Electrical and Electronics Engineering. pp. 226 - 229.

Preeti Sharma and Shubham Gupta. 2014. Bandwidth and Gain Enhancement in Microstrip Antenna Array for 8GHz Frequency Applications. Engineering and Systems (SCES), 2014 Students Conference On, IEEE. pp. 1-6.

Pritam Singh Bakariya, Santanu Dwari, Manas Sarkar, and Mrinal Kanti Mandal. 2015. Proximity-Coupled Microstrip Antenna for Bluetooth, WiMAX and WLAN Applications. IEEE Antennas and Wireless Propagation Letters, Vol. 14.

P. R. Prajapati, A. Patnaik and M. V. Kartikeyan. 2014. Design of Single Feed Dual Band Dual Polarized Microstrip Antenna with Defected Ground Structure for Aeronautical and Radio Navigation Applications. General Assembly and Scientific Symposium (URSI GASS), 2014 XXXIth URSI. pp. 1-4.

R. Garg, P. Bhartia, I. Bahl, and A. Ittipiboon. 2001. Microstrip Antenna Design Handbook. Boston-London: Artect House.

Shruti Karkare and Kavita Tewari. 2014. Design of a Rectangular Microstrip Antenna with Artificial Magnetic Conductor Ground Plane. International Journal on Recent and Innovation Trends in Computing and Communication Volume: 2 Issue: 11. 3433 – 3436.

Shubham Gupta, and Shilpa Singh. 2012. Bandwidth Enhancement in multilayer microstrip proximity coupled Array. International Journal of Electronics and Computer Science Engineering, vol. 1, no. 2.