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Effects of Dielectric Substrate on Performance of UWB Archimedean Spiral Antenna

A. M. Shire * and F. C. Seman§
Wireless and Radio Science Centre (WARAS)
Faculty of Electrical and Electronic Engineering
University Tun Hussein Onn Malaysia
86400 Parit Raja, Johor Malaysia
shire_288@hotmail.com*, fauziahs@uthm.edu.my§

Abstract— **This paper presents the design of the Archimedean Spiral Antennas (ASA) backed by a metal plate. The dimension of the spiral arm was designed to operate between 3.1 – 10.6 GHz and different permittivity of the dielectric substrate was employed between the spiral arm and the backing plate with specified electrical thickness of $\lambda_g/4$ at the lowest frequency range. The CST simulated results shows that when the dielectric permittivity, ε_r increases, the performance of the ASA in terms of return loss, axial ratio, efficiency, pattern and gain deteriorates.**

Keywords-component; ASA; Backing Plate; UWB

I. INTRODUCTION

The Archimedean spiral antenna (ASA) which is categorized under frequency independent type antenna has received huge interest [1] due to the wideband operating range, unidirectional radiation pattern, high gain, high efficiency and circular polarization characteristics [2]. These characteristics make the ASA as a good candidate to be applied in useful applications in satellite communications, radar and remote sensing applications. In most cases a unidirectional pattern is preferable to minimize interference from transmitter structure such as satellite and radar transmitter. Due to this, a unidirectional beam is usually obtained by employing a lossy cavity [3], metal plate and other meta-material based devices. For most cases, the backing technique is chosen so that the device is low profile and able to function over wideband operating ranges [3]. Absorptive cavity-backed spiral radiators provide an effective solution for multiple SATCOM and SatNav services requiring consistent gain, uniformly matched input impedances and ≤3dB axial ratios across extremely wideband frequencies [4].

Most efforts, however, are relatively bandwidth limited and have not been able to address the needs of applications where bandwidths ≥ 10:1 are required with good circular polarization performance. This paper presents the simplest backing technique where a metal plate is employed to obtain a unidirectional ASA. This is performed by placing the metal plate $\lambda_g/4$ separation from the spiral arm. By employing different dielectric permittivity between the spiral arm and the ground plane, a lower profile (physically thinner) structure can be realised. Due to the deployment of different dielectric permittivity, the effect to important antenna parameters such as S_{11}, axial ratio and gain of the antenna will be investigated further in details. The simulated results were obtained by commercially available Computer Simulation Technology (CST) software. A relatively narrowband operation is expected from a metal plate backing technique but the outcome from this study is very important so that any further improvements on the design of ASA can be performed later.

II. CONFIGURATION OF ARCHIMEDEAN SPIRAL ANTENNA

Fig. 1 shows the configuration the ASA model employed in this study. For a UWB application operating over 3.1 – 10.6 GHz, the inner radius and the outer radius of the ASA is optimized using equation (1) and (2).

$$r_2 = \frac{1.5\lambda_L}{2\pi} \tag{1}$$

Where λ_L is the wavelength of the lowest design frequency. Frequency independent behavior is only achieved when $w = s$, s is the spacing width of the arm while w is the width of the arm. The inner radius is r_1, so the width can be calculated $w = s$ which is found in [5]:

$$r_1 = w = s = \frac{r_2}{2N+1} \tag{2}$$

Using equation (1) and (2), r_2 = 23 mm and $w = s$ = 1.4 mm but they are further optimized to 1.3mm and the inner radius is optimized to r_1 = 0.65mm. This ensures the active region for the highest and lowest frequencies of the desired bandwidth is located within the spiral arm as defined by $d = \lambda / \pi$ [6]. The configuration also includes the number of turns, N = 12 and the spiral arm is printed on 0.035 mm thick copper. In CST

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model, the spiral arm is fed at the centre of the structure by using discrete port. The spiral arm is backed by a metal plate at $\lambda_g/4$ (to the lowest operating range) separation of the dielectric substrate so that the in-phase condition is obtained [7]. The configuration of the variations of the dielectric substrate and the physical thickness is given as in Table I. The given dielectric substrates represent air cavity (ε_r = 1.0), Rogers Duroid (ε_r = 2.33), and FR4 substrate (ε_r = 4.3) respectively. However the loss tangents of all materials are simplified as zero so that the differences in the results are mainly contributed by the dielectric permittivity itself.

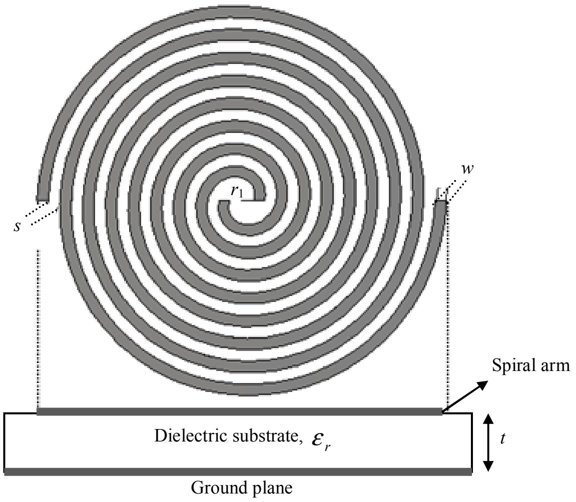


Figure. 1: Configuration of two arm ASA: Top and side view

TABLE I. PHYSICAL THICKNESS FOR VARIATION OF DIELECTRIC SUBSTRATE

Dielectric substrate, ε_r	**Physical thickness, t [mm]**
1	24.2
2.33	15.85
4.3	11.67

III. RESULTS AND DISCUSSION

Having variation configuration of dielectric permittivity versus physical thickness as shown in Table 1, the effects were investigated further from various parameters of the ASA characteristics; the return loss; S_{11}, axial ratio; AR, gain, radiation pattern and the antenna efficiency. Fig. 2 shows the return loss losses of the designed antennas simulated on different substrates. When ε_r increases, the S_{11} deteriorates significantly and strong mismatch can be observed in the return loss results. However, the S_{11} of lower dielectric permittivity of the antenna is still maintained at below −10 dB contributing to 109.5% at −10 dB bandwidth. This value is similar to 10:1 bandwidth of the antenna required for circular polarization [4]. Note that for ε_r = 1.0, the operating frequency range of the antenna is even wider between 3.1GHz and 10.6GHz. This explains most of the ASA designs presented previously [8], used air cavity as part of their backing techniques.

For circular polarized antenna, an axial ratio of less than 3 dB is an important consideration in order to provide RHC polarization since the antenna is fed at the centre [9]. Fig. 3 shows that an acceptable AR can only be achieved for low dielectric permittivity (ε_r = 1.0). On the other hand, as the permittivity increases; the axial ratio deteriorates. For example for the substrate of ε_r = 4.3; the axial ratio is higher than 3dB for most of the entire band where the AR is about 8.42 dB and 12 dB at 5.1 GHz and 10.6 GHz respectively.

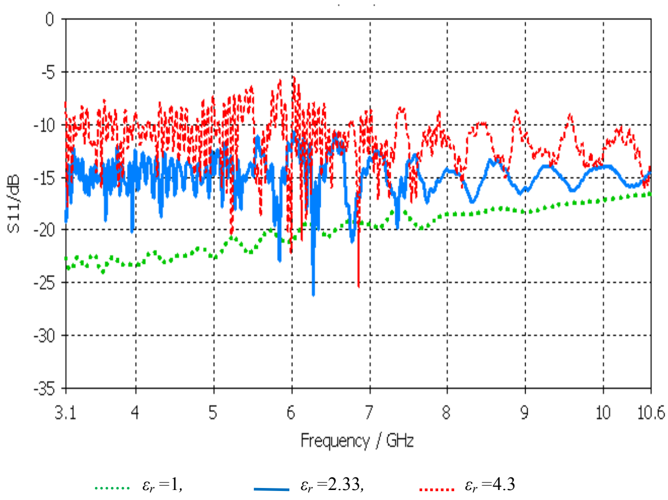


Figure.2: Comparison of S11 on different substrates.

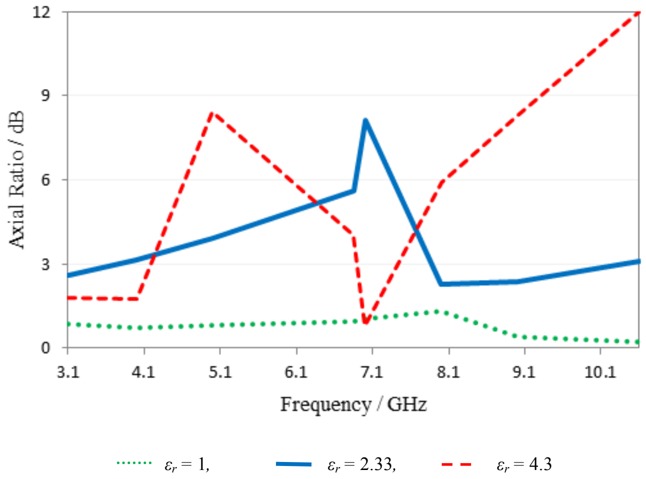


Figure.3: Comparison of axial ratio on a different substrates permittivity.

Fig 4 shows that the gain of the spiral antenna constructed with $\varepsilon_r = 1$, $\varepsilon_r = 2.33$, and $\varepsilon_r = 4.3$ at 3.1 GHz is 9.2 dB, 7.1 dB and 4.35 dB respectively. Note that the electrical thickness of the ASA is maintained at $\lambda_g/4$ at 3.1 GHz. Fig. 4 illustrates that for the dielectric substrate of $\varepsilon_r = 2.33$; the gain reduces from 7.1 dB at 3.1 GHz to 3.8 at 6.85 GHz because the electrical thickness increases to about $\lambda_g/2$ which lead to out of phase cancellation. When between 8 to 9 GHz the gain again increases up to 8 dB as the two waves are in-phase condition which is due to the electrical thickness of about $3\lambda_g/4$ [9]. The fluctuations that can be seen in the gain result are due to the electrical separation of the ground plane to the ASA where the reflected waves from the ground plane and the directly radiated waves from the spiral are repetitively out phase and in phase and this trend is also observed in the previous works [9, 11]. The same analysis goes to the other designs of $\varepsilon_r = 1$ and $\varepsilon_r = 4.3$. In general, the gain of the ASA is higher if a lower dielectric permittivity is used.

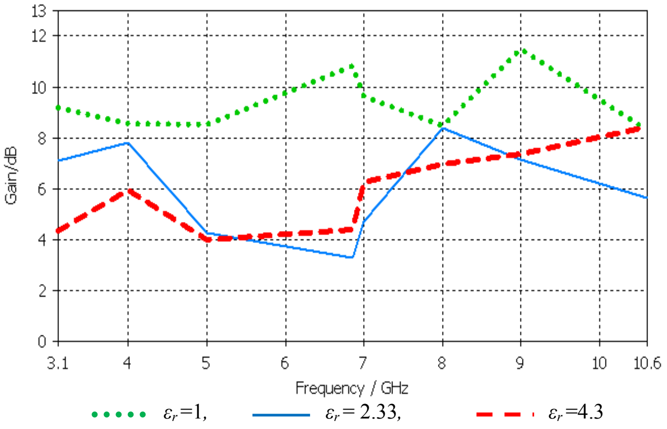
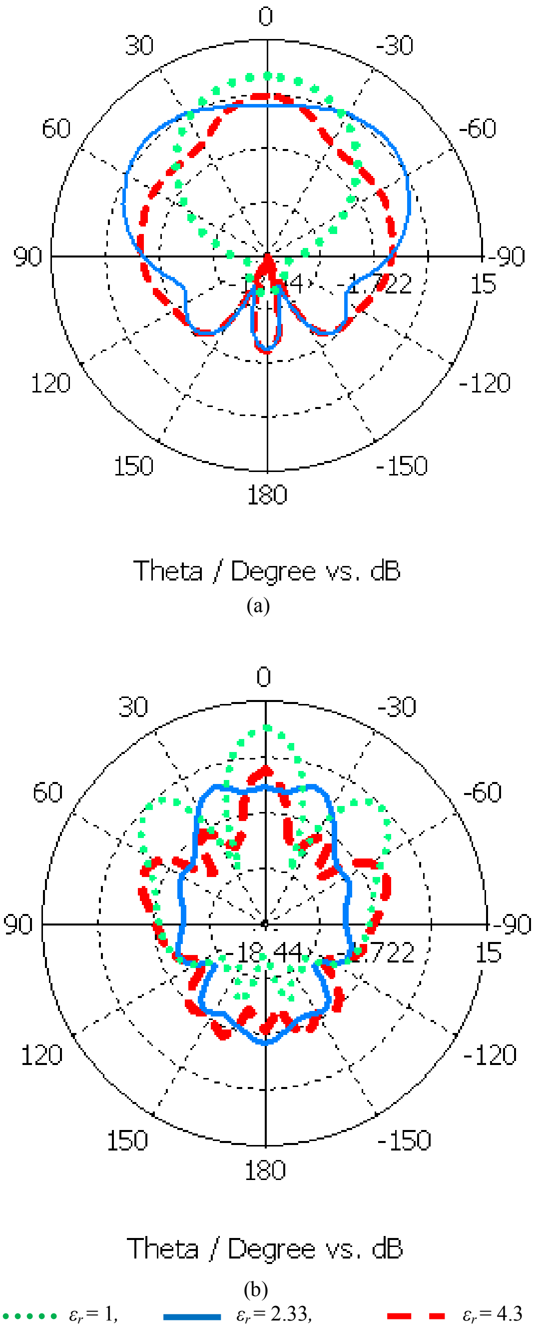


Figure. 4: Comparison of gain on a different substrate permittivity.

Fig. 5(a) shows the co-polarization radiation pattern of the spiral antennas at 3.1 GHz. For $\varepsilon_r = 1$, the gain for the front and back side lobe is 9.2 dB and -21.5 dB respectively. As the ε_r increases, the gain of the front side lobe reduces while the back side lobe increases. For example for $\varepsilon_r = 2.33$, the gain of the front and the back side lobe reduces to 7.3 dB and increases to -9.6 dB respectively. The best radiation pattern in terms of highest main lobe magnitude at boresight of the antenna and lowest side lobes are achieved when the spiral antenna is designed using lower substrate permittivity. This is because a higher dielectric permittivity slows the traveling wave [12] in the cavity and cause less radiation efficiency. As expected at 3.1 GHz, the pattern is for all dielectric permittivity configurations. The trend slowly changes when the electrical thickness of the dielectric cavity increases to about $\lambda_g/2$ as shown in Fig. 5(b). At 6.85GHz, the radiation pattern of the ASA distorts and the functionality of the ground plane to provide unidirectional pattern ASA is no longer valid. It is also observed that when the frequency increases, the back side lobes of the ASA increases where for $\varepsilon_r = 1$, $\varepsilon_r = 2.33$, and $\varepsilon_r = 4.3$ the gain of the back side lobe increases -4.7 dB, -5.9 dB and -3.5 dB respectively. This is due to that at higher frequencies the radiation takes place at the perimeter of the antenna [13].



(a)

(b)

Figure 5: Comparison of co-polarization radiation pattern on different substrate permittivity at (a) 3.1GHz (b) 6.85 GHz.

IV. CONCLUSION

In this paper the investigation on three configurations of ASA backed by different dielectric substrates and metal plate were presented. By employing a higher dielectric substrate, a lower profile structure can be realized. However, overall it degrades the performance of the ASA as shown in Table II. Since a wideband operating range is required in UWB applications, the BW of the ASA required criteria is differentiated by (i) when the S_{11} is less than -10 dB; (ii) when

TABLE II. SUMMARY OF THE EFFECTS OF DIELECTRIC SUBSTRATE

Parameters	**ε_r= 1**	**ε_r= 2.33**	**ε_r= 4.3**
Gain /dB	8 to 11.5	2 to 9.2	4 to 9
Physical thickness	24.2 mm	15.85 mm	11.67 mm
BW defined by S11	109.5% (3.1-10.6 GHz)	109.5% (3.1-10.6 GHz)	10.9% (9.5-10.6 GHz)
BW defined by AR	109.5%	22.2%	28.5%
BW defined by radiation pattern	47% (3.1 – 5GHz	25.35% (3.1-4GHz	25.35%(3.1-4GHz

the AR is less than 3 dB and (iii) the frequency range when a unidirectional pattern is observed. Based on these outcomes, a lower dielectric permittivity cavity will be employed in the later stage which might be focusing on the improvement of ASA backing technique. The improvement in terms of the unidirectional radiation pattern is possible by employing frequency selective surfaces. In summary, ASA is a good candidate for UWB application due to its frequency independent characteristics. However a careful arrangement is required especially in determining the dielectric permittivity because it can significantly alter its characteristics.

REFERENCES

[1]. Nakano, H; Igarashi, T; Oyanagi, H; Litsuka, Y; and Yamauchi, J "Unbalanced-Mode Spiral Antenna Backed by an Extremely Shallow Cavity" IEEE Transactions on Antennas and propagation, Volume: 57, 2009 pp. 1625-1633.

[2]. Yongwei Zhang; Brown, A.K. "Archimedean and equiangular slot spiral antennas for UWB communication" Microwave Conference, 2006. 36th European, pp. 1578 – 1581.

[3]. Chiu, C. N; Chuang, W.H "A Novel Dual-Band Spiral Antenna for a Satellite and Terrestrial Communication System" IEEE Antennas and Wireless Propagation Letters, Volume: 8, 2009 , pp. 624 – 626.

[4]. Afsar, M.; Rahman, N.; Cheung, R., "Design, characterization, and optimization of ultrawideband cavity-backed spiral antennas at microwave frequencies," European Radar Conference (EuRAD) pp.261,264, 12-14 Oct. 2011

[5]. Mohd Yusop, M.F.; Ismail, K.; Sulaiman, S.; Haron, M.A. "Coaxial feed Archimedean spiral antenna for GPS application" 2010 IEEE Asia-Pacific Conference on Applied Electromagnetics (APACE), , pp. 1-5.

[6]. McFadden, M.; Scott, W.R. "Analysis of the Equiangular Spiral Antenna on a Dielectric Substrate" IEEE Trans. Antennas Propagation. Vol. 55, pp. 3163 – 3171, Nov 2007.

[7]. Nakano, H.; Oyanagi, H.; Yamauchi, J. "Spiral antenna above a composite HIS reflector" APSURSI IEEE topics, , 2010, pp. 1-4.

[8]. Rao, P.H.; Sreenivasan, M.; Naragani, L., "Dual Band Planar Spiral Feed Backed by a Stepped Ground Plane Cavity for Satellite Boresight Reference Antenna Applications," *Antennas and Propagation, IEEE Transactions on* , vol.57, no.12, pp.3752,3756, Dec. 2009

[9]. Jung, Changwon W; Cetiner, Bedri Artug; De Fkaviis, Franco. " A single-arm circular spiral antenna with inner/outer feed circuitry for changing polarization and beam characteristics" IEEE Antennas and Propagation Society International Symposium, Volume: 4, 2003, pp. 474-477

[10]. Baixiao Wang; Aixin Chen "Design of an Archimedean spiral antenna" International Symposium on Antennas, Propagation and EM Theory, ISAPE 2008, 8th, pp. 384-351.

[11]. http://www.docstoc.com/docs/47541623/Chapter-2-Analysis-of-Archimedean-Spiral-Antenna, November 15 2012.

[12]. Dejan S. Filipovic and Tom Cencish "Antenna Engineering book, 4th ed. New York, MC GrawHill Companies 2007.

[13]. Müller, Dominikus J. ; Sarabandi, K. "Design and Analysis of a 3-Arm Spiral Antenna" IEEE Transactions on Antennas and Propagation, Volume: 55 , Issue: 2 , 2007, pp. 258 – 266.