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Original Article

Bandwidth and Return Loss Improvement Technique Using Double-Material Substrate Cylindrical Surrounding Patch Antenna:Part-I

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Abstract *- For the purpose of bandwidth enhancement, return loss improvement, and providing a solution to the negative effect of dimension inaccuracy, a Double Material Substrate (DMS) antenna composed of FR-4 (lossy), polyimide (lossy), and a partial ground plane of copper (annealed) has been presented in this work. The proposed antenna has been compared with a Single Material Substrate (SMS) antenna composed of FR-4 (lossy) and a partial ground plane of copper (annealed). Findings reveal that the cylindrical conformal antennas designed with DMS are significantly better in terms of bandwidth and return loss. The antenna with SMS presented a return loss and bandwidth value of -27 dB and 0.783 GHz (1962 MHz ~ 2745MHz), respectively, at a resonance frequency of 2.4 GHz. Also, at the same resonance frequency, the DMS antenna presented an enhanced return loss and bandwidth of -35.2 dB and 0.862 GHz (1844 MHz ~ 2700 MHz), respectively.*

Keywords — *Bandwidth, Returns Loss, WiMAX, WLAN, Cylindrical Surrounding Patch Antenna (CSPA).*

I. INTRODUCTION

Due to the lightweight, easy fabrication process, feeding techniques flexibility, implementation, and radiation properties. Capitalizing on these advantages, researchers have made different forms and dimensions of microstrip patch antennas for use in wireless communication systems [1]-[4]. One of such forms of the microstrip patch antenna is the Cylindrical Surrounding micro-strip fed Patch Antenna (CSPA). This form of antenna has been observed to have a better performance when compared with the regular rectangular patch antenna [2], [4].

Even though cylindrical surrounding patch antennas provide a series of advantages, they also have certain drawbacks, such as limited bandwidth, low gain, high return loss, and deteriorated radiation pattern. However, various researchers have used a variety of techniques to address challenges of limited bandwidth, high Return Loss (S_{11}) and, poor radiation pattern [5]-[8]. For the purpose of bandwidth enhancement of microstrip patch antenna, a Defected Ground Structure (DGS) consisting of an I-shape slot in the ground was presented by *Singh et. al*.[9]. Parameters such as bandwidth, return loss, and Voltage Standing Wave Ratio (VSWR) were much improved in the designed antenna than simple MPA without defected ground structure. The designed antenna was observed to resonate in the C-band at a frequency of *6.0718 GHz* with a bandwidth of *132.3 MHz* and a very good return loss of *-46.75 dB*.

In this present research work, bandwidth and return loss enhancement techniques have been analyzed. Also, this technique serves as a solution to the negative effects of inaccuracy in dimension resulting from the reduced size of antenna fabricated at high frequency using high dielectric permittivity materials.

To solve dimension inaccuracy during the fabrication process, a CSPA design with Double Material (DM) was proposed by *Omoru and Srivastava*[10]-[12]. However, the presented DMS antenna designs could suffer from phase impedance and resonance frequency errors resulting from mechanical tension effects (caused by compression and stretching of the dielectric substrates). The proposed antenna is also a solution to device fitting issues currently being experienced by mobile device design engineers. Thereafter, the proposed DMS CPA has been compared with SMS CPA using the *2.4 GHz* band. This paper has been structured as follows. Section II has an overview of DMS and SMS cylindrical patch antenna. Section III realized the performance analysis of DMS and SMS CSPA. Section IV gives a comparative analysis of DMS and SMS antennas. Finally, Section V concludes the work and recommends the future aspect.

II. OVERVIEW OF DMS AND SMS CYLINDRICAL PATCH ANTENNA

Most of the antenna design parameters are dependent on the effective dielectric constant of substrate materials used[13]-[15]. Here the effective dielectric constant has been computed as a function of the resultant dielectric constant of the two substrate materials used FR-4 ($\varepsilon_{r.fr\text{-}4}$) and dielectric constant for having polyimide ($\varepsilon_{r.pl}$)as shown in Eq. (1) to Eq. (3). A design frequency of *2.4 GHz* has been adopted for the modeling of the proposed antenna. The values for $\varepsilon_{r.fr\text{-}4}$ and $\varepsilon_{r.pl}$ are 4.3 and 3.5, respectively:

$$\varepsilon_{R.r} = \frac{\varepsilon_{r.fr-4} + \varepsilon_{r.pl}}{2} \quad (1)$$

$$W_p = \frac{V_0}{2F_r}\sqrt{\frac{2}{\varepsilon_{R.r}}} \quad (2)$$

From Eq. (1) and Eq. (2), the resultant dielectric constant and width of the patch have been calculated as *3.9* and *29.96 mm*, respectively. Also, the thickness of polyimide ($H_{s.pl}$), thickness of FR-4 ($H_{s.fr\text{-}4}$), height of the patch (H_p), height of the ground have been chosen as *2.0 mm, 2.8 mm, 0.8mm, and 0.8 mm,* respectively[16]-[18]. Substituting these values into Eq. (3), the effective resultant dielectric $\varepsilon_{r.eff}$ substrate has been calculated as *3.3.*

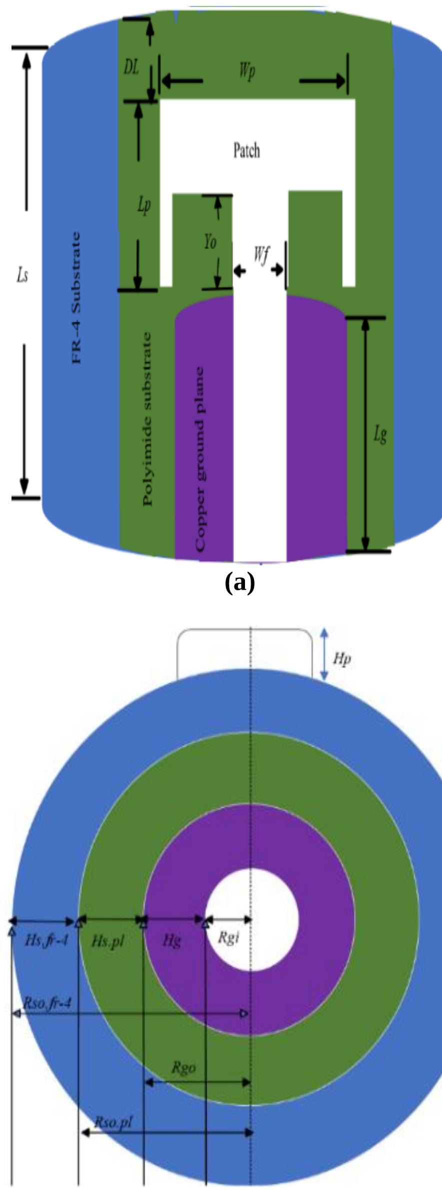
$$\varepsilon_{r.eff} = \frac{\varepsilon_{R.r}+1}{2} - \frac{\varepsilon_{R.r}-1}{2}\left(1+\frac{12\left(H_{s.pl}+H_{s.fr-4}\right)}{W_p}\right) \quad (3)$$

Using equations presented in [19]-[21] and known values of $\varepsilon_{R.r}$, $\varepsilon_{r.eff.}$, and W_p, other antenna design parameters have been calculated and recorded in Table I.

TABLE I.
DMS CSPA DESIGN PARAMETERS

Nomenclature	Symbol	Value (mm)
The outer radius of ground	R_{go}	13.4
Inner radius of ground	R_{gi}	14.2
The outer radius of polyimide substrate	$R_{so.pl}$	16.2
Outer radius of FR-4 substrate	$R_{so\text{-}fr\text{-}4}$	19.0
Length of ground	L_g	26.64
Length of substrate	L_s	50.28.
Substrate and patch top difference	ΔL	2.2
Inset feed length	Y_o	7.0

Using parameters in Table I, three distinct techniques have been used to produce the proposed Dual-Material Substrate (DMS) Cylindrical Surrounding Patch Antenna (CSPA) design, as shown in Fig. I. At first, using the electronic device simulator, a partly cylindrical copper ground plane with length (L_g), inner radius (R_{gi}), and outer radius (R_{go}) was initially created. Secondly, a cylindrical substrate composed of polyimide material of length (L_s), thickness ($H_{s.pl}$), and outer radius ($R_{so.pl}$) was constructed on the cylindrical copper ground plane. Also, on the first cylindrical substrate, an outer cylindrical substrate made of FR-4 material with length (L_s), thickness ($H_{s.fr\text{-}4}$), and outer radius ($R_{so\text{-}fr\text{-}4}$) was constructed. Finally, a copper patch of width (W_p) and length (L_p) was constructed and bent around the outer cylindrical substrate using the simulator bending functionality, thus providing a fully parameterized DMS CSPA conformal cylindrical patch antenna. A full design procedure, analysis, and mathematical modeling of the proposed DMS CSPA are presented in ref. [10].



(a)

(b)

Fig. 1. Proposed DMS cylindrical surrounding patch antenna (a) front view and (b) bottom view [10].

TABLE II

SMS CSPA DESIGN PARAMETERS

Nomenclature	Symbol	Value (mm)
The outer radius of ground	R_{go}	13.9
The inner radius of ground	R_{gi}	13.2
The outer radius of FR-4 Substrate	R	18.8
Thickness of substrate	H_s	4.8
Thickness of ground	H_g	0.8
Width of feed	W_f	7.5
Width of patch	W_p	28.8
Width of ground	W_g	59.6
Thickness of patch	H_p	0.8
Length of ground	L_g	26.6
Length of substrate	L_s	49.0
Substrate and patch top difference	ΔL	2.1
Inset feed length	Y_o	7.0

Similar design procedures have been adopted for the SMS CSPA and equations from the research work of *Umayah and Srivastava* [22], [23], have been used to calculate the design parameters of the SMS antenna. The SMS cylindrical surrounding patch antenna consists of a metallic radiating element (copper) conformed on a cylindrical dielectric FR-4 substrate and a partial metallic ground (copper) inside of the cylindrical substrate. The SMS and DMS antennas have been fed using a microstrip line feeding technology to easily integrate with other components. Unlike coaxial feed, which provides its feeding from below the patch [24]-[26].

III. PERFORMANCE ANALYSIS OF PROPOSED DMS CSPA AND SMS CSPA

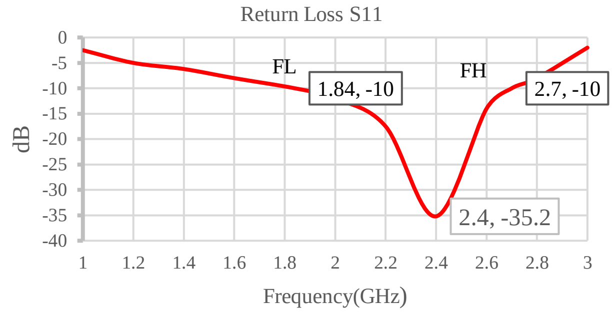
The microstrip antenna conformed on a cylindrical structure is shown in Table 3. The DMS CSPA performance parametersDMS and SMS surfaces with a microstrip feed have been simulated and performance analysis of both antennas is explained based on return loss and bandwidth. The simulated bandwidth and return loss characteristics of the proposed microstrip antenna conformed on cylindrical DMS, and SMS surface have been observed as *-35.2 dB* and *-27.5 dB* as illustrated in Fig. 2(a) and Fig. 2(b), respectively.

From the return loss plots, the bandwidth of the proposed design and SMS antenna has been calculated as *0.86 GHz*. and *0.76 GHz*, respectively. Also, percentage bandwidth for DMS and SMS antenna design have been calculated using the equation in [27],[28], and values have been recorded in Table III and Table IV, respectively:

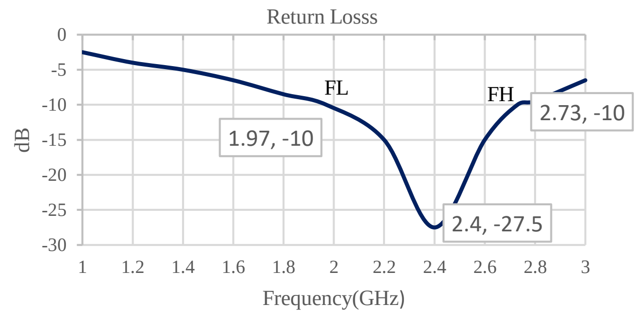
$$F_C = \frac{F_H + F_L}{2} \quad (4)$$

$$\%\ Bandwidth = \frac{F_H - F_L}{F_C} \times 100 \quad (5)$$

where F_H, F_L, and F_C are the highest, lowest, and center frequency, respectively.



(a)



(b)

Fig. 2. Return loss (S_{11}) plots for (a) DMS CSPA (b) SMS CSPA.

TABLE III
DMS CSPA PERFORMANCE PARAMETERS

Parameter	Value
Percentage bandwidth *(%)*	37.8
Return loss *(dB)*	-35.2
Bandwidth *(GHz)*	0.86

TABLEIV
SMS CSPA PERFORMANCE PARAMETERS

Parameter	Value
Percentage bandwidth *(%)*	32.3
Return loss *(dB)*	-27.5
Bandwidth *(GHz)*	0.76

IV. COMPARATIVE ANALYSIS OF DMS AND SMS CSPA

The effects of substrate combination on microstrip patch antenna performance have been studied and analyzed using two antenna performance parameters (return loss and bandwidth) plot for comparison is presented in Fig.3.

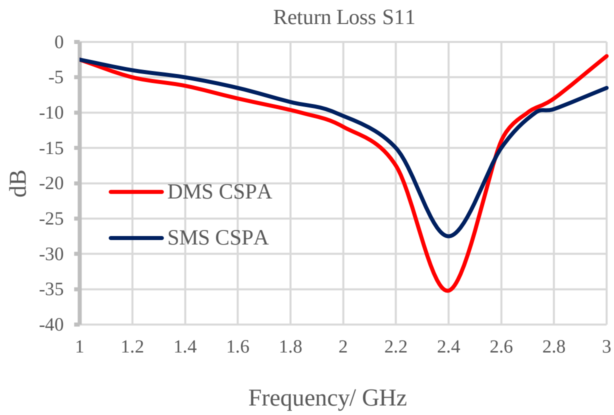


Fig. 3.The comparative plot of return loss for DMS CSPA and SMS CSPA.

Figure 3 compares the return loss of the designed DMS CSPA and the SMS CSPA at a resonance frequency of *2.4 GHz*. The return loss of the DMS CSPA and the SMS CSPA has been observed as *-35.2 dB* and *-27.5 dB* signifying a *7.7 dB* difference. Also, a *0.1 GHz* difference in bandwidth has been observed in Table III and Table IV. The bandwidth difference between the antennas is a result of the difference in the effective dielectric constants of the antennas presented in Section III; as reported in various microstrip patch antenna literature, lower effective dielectric constants result in increased width of the patch, thus providing a larger bandwidth [29], [30]. So to produce a substrate with a lower effective dielectric constant, a substrate material with a lower dielectric constant is combined with the FR-4 substrate, as shown in Section III. Thus, the combination reduces the effective dielectric constant of FR-4 from *4.3* to *3.9*. The reduced effective dielectric constant of combined substrate material increases the bandwidth from *0.76 GHz* (*1.97 GHz ~ 2.73 GHz*) to *0.86 GHz* (*1.84 GHz~ 2.7 GHz*). Also, when bandwidth increases, the return loss of the microstrip antenna becomes lower; this explains why there is a reduction in return loss from *-27.5 dB* to *-35.2 dB*.

Though both antennas presented a good return loss and bandwidth characteristics, the additional *100 MHz* bandwidth presented by the DMS CSPA will allow for usage in both integrated design for IEEE 802.11, Wireless Local Area Network(WLAN) standards of *2.4 GHz* (*2400 MHz ~ 2484 MHz*) standards, Worldwide Interoperability for Microwave Access (WiMAX) standards of *2.5 GHz* (*2.5 GHz ~ 2.69 GHz*), and Personal Communication Service (PCS) bands of *1.9 GHz* (*1850.2 MHz ~ 1989.8 MHz*). The DMS antenna can be very useful in Canada, Mexico, and the United States, where the *1.9 GHz* frequency band has been designated by the Industry of Canada and the United States Federal Commission for new wireless services to alleviate capacity caps inherent in the original Advanced Mobile Phone Systems (AMPS) and Digital AMPS (D-AMPS).

V. CONCLUSIONS AND FUTURE WORK

Though the two antennas presented have been observed to have good and acceptable values of return loss VSWR and bandwidth, the DMS CSPA displayed a better performance characteristic in comparison with the SMS CSPA. The better bandwidth characteristics presented by the DMS CSPA makes it suitable in integrated design for IEEE 802.11, Wireless Local Area Network(WLAN) standards of *2.4 GHz* (*2400 MHz ~ 2484 MHz*) standards, Worldwide Interoperability for Microwave Access (WiMAX) standards of *2.5 GHz* (*2.5 GHz ~ 2.69 GHz*), and Personal Communication Service (PCS) bands of *1.9 GHz* (*1850.2 MHz ~ 1989.8 MHz*), especially in Canada and United States where the *1.9 GHz* band has been allocated for PCS.

As a continuation of this work, physical implementation and comparative analysis of the proposed model will be presented, using gain, directivity radiation efficiency, and radiation pattern as a standard to verify the efficiency and usability of the proposed design in the 5G regime of frequencies.

REFERENCES

[1] J. Anguera, A. Andújar, and J. Jayasinghe, High directivity microstrip patch antennas based on TM_{odd-0} Modes, IEEE Antennas and Wireless Propagation Letters, 19(1) (2020) 39-43.
[2] A. S. Oluwole and Viranjay M. Srivastava, Design of smart antenna by circular pin-fed linearly-polarized patch antenna, International Journal of Wireless and Microwave, 3 (2016) 40-49.
[3] C. A. Balanis, Antenna theory analysis and design, 4th Edition, John Wiley & Sons, Hoboken, New Jersey, (2016).
[4] Y. Liu, L. M. Si, M. Wei, P. Yan, P. Yang, H. Lu,C. Zheng, Y. Yuan, J. Mou, L. Xin, and H. Sun, Some recent developments of microstrip antenna, International Journal of Antennas and Propagation, 2012 (2012) 1-10.
[5] A. Elrashidi, K. Elleithy, and Hassan Bajwa, The Performance of a cylindrical microstrip printed antenna for TM_{10} Mode as a function of temperature for different substrates, International Journal of Next-Generation, 3(3) (2011) 1-18.
[6] W. Geyi, A method for the evaluation of small antenna Q, IEEE Transactions on Antennas and Propagation, 51(8) (2003) 2124-2129.
[7] H. F. Abutarboush, W. Li, and A. Shamim, Flexible-screen-printed antenna with enhanced bandwidth by employing defected ground structure, IEEE Antennas and Wireless Propagation Letters, 19(10) (2020) 1803-1807.
[8] KwaiM. Luk and KaiF. Lee, Characteristics of the cylindrical-circular patch antenna, IEEE Transactions on Antennas and Propagation, 38(7) (1990) 1119-1123.
[9] Gurpreet Singh, R. Rajni, and Ranjit S. Momi, Microstrip patch antenna with the defected ground structure for bandwidth enhancement, International Journal of Computer Applications, 73(9) (2013) 14-18.
[10] Elliot O. Omoru and Viranjay M. Srivastava, MOSFET based absorber for reflected signal in 5G massive MIMO base station - A

circuit perspective, Journal of Communications, 15(11) (2020) 833-840.

[11] Elliot O. Omoru and Viranjay M. Srivastava, Simulation analysis of MOSFET based absorber for reflected RF signal in 5G massive MIMO base station, International Journal of Emerging Trends in Engineering Research, 8(251) (2020) 6488-6495.

[12] Elliot O. Omoru and Viranjay M. Srivastava., Parametric analysis of SiO2 MOSFET based absorber for 5G massive MIMO base Station, 6th International Conference on Material Engineering and Application, Jakarta, Indonesia, (2021) 20-22.

[13] L. C. Paul, M. S. Hossain, and S. Sarker, The effect of changing substrate material and thickness on the performance of inset feed microstrip patch antenna, American Journal of Networks and Communications, 4(3) (2015) 54-58.

[14] M. Karthigai Pandian and T. Chinnadurai, Design and optimization of rectangular patch antenna based on FR4, Teflon and Ceramic substrates, Recent Advances in Electrical & Electronic Engineering, 12(1) (2019) 1-6.

[15] N. Jayarenjiniand C. Unni, A novel microstrip slotted patch antenna using different dielectric substrates for multiple applications, International Journal of Applied Engineering Research, 13(16) (2018) 12591-12596.

[16] Dhawan Singh and Viranjay M. Srivastava., An analysis of RCS for dual-band slotted patch antenna with a thin dielectric using shorted stubs metamaterial absorber, International Journal of Electronics and Communications, 90 (2018) 53-62.

[17] S. K. Kundu, S. Jaiswal, and P. K. Singhal, Study and comparison of a planar and cylindrical patch antenna, 8th International Conference on Communication Systems and Network Technologies (CSNT), India, (2018) 10-16, 24-26.

[18] A. Elrashidi, K. Elleithy, H. Bajwa., Performance analysis of a microstrip antenna conformed on the cylindrical body at resonance frequency 4.6 GHz for TM_{01} mode, Procedia Computer Science, 10, (2012) 775-784.

[19] Ahmed I. Imran and Taha A. Elwi, A cylindrical wideband slotted patch antenna loaded with frequency selective surface for MRI applications, Engineering Science and Technology, an International Journal, 20(3) (2017) 990-996.

[20] Dhawan Singh, Aditi Thakur, and Viranjay M. Srivastava, Miniaturization and gain enhancement of microstrip patch antenna using defected ground with EBG, Journal of Communications,13(12) (2018) 730-736.

[21] A. Elrashidi, K. Elleithy, and H. Bajwa, Performance analysis of a microstrip antenna conformed on the cylindrical body at resonance frequency 4.6 GHz for TM_{01} mode, Procedia Computer Science, 10 (2012) 775-784.

[22] Erhiega N. Umayah and Viranjay M. Srivastava, Radiation pattern of novel cylindrical surrounding patch antenna for 2.4 GHz applications, International Journal of Electrical and Electronic Engineering and Telecommunications, 8(4) (2019) 213-220.

[23] Erhiega N. Umayah and Viranjay M. Srivastava, Comparative analysis of feeding techniques for cylindrical surrounding patch antenna, International Journal of Electrical and Computer Engineering, 10(5) (2020) 5377-5384.

[24] Zhijun Zhang, Antenna measurement, Antenna design for mobile devices, 2nd Ed, Wiley-IEEE Press, (2017) 229-275.

[25] Abdelmonem Abdelaziz, Bandwidth enhancement of microstrip antenna, Progress In Electromagnetics Research, 63 (2006) 311-317.

[26] S. Chakraborty and U. Mukherjee, Comparative study of microstrip patch line feed and coaxial feed antenna design using genetic algorithms, 2ndInternational Conference on Computer and Communication Technology, India, (2011) 203-208.

[27] C. L. Wen and Q. X. Chu, A Bandwidth enhanced broadband patch antenna for LTE700/GSM850/GSM900 applications, Cross-Strait Radio Science & Wireless Technology Conference (CSRSWT), China, 1-3 (2020) 13-16.

[28] P. Kumar Deb, T. Moyra, and P. Bhowmik, Return loss and bandwidth enhancement of microstrip antenna using defected ground structure, 2nd International Conference on Signal Processing and Integrated Networks (SPIN), India, 25(29) (2015) 19-20.

[29] A. A. Qureshi, M. U. Afzal, T. Tauqeer, and M. A. Tarar, Performance analysis of FR-4 substrate for high-frequency microstrip antennas, Joint Microwave Conference, China, 1(4) (2011) 20-22.

[30] S. B. Yeap and Z. N. Chen, Microstrip patch antennas with enhanced gain by partial substrate removal, IEEE Transactions on Antennas and Propagation, 58(9) (2010) 2811-2816.