Design of Compact Broadband Omnidirectional Canonical Sleeve Antenna covering UHF band

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Abstract

A novel compact broadband Canonical Sleeve Antenna (CSA) covering 500-3600 MHz with omnidirectional characteristics is presented in this paper. A new method is employed in which the radiating antenna structure is designed as combination of three different canonical structures: hemispherical, conical and cylindrical elements. To accomplish broad bandwidth with compact size, dipole antenna is designed by using cylindrical sleeve over the hemispherical dipole with conical extensions and cylindrical attachments. Performance characteristics of CSA is simulated and compared with BiConical Antenna (BCA) and other antenna configurations and found to be best antenna configuration with compact form factor. The antenna has height of 111.43 mm and diameter of 116.66 mm. Simulation studies are carried out using CST Microwave Studio. The simulated results are validated by fabricating CSA and evaluating its performance metrics. CSA has 7.2:1 bandwidth with measured VSWR <2.7:1 and gain varies from 0 to 3.6 dBi. The antenna finds use in wireless communication, spectrum monitoring and defense applications.

1. Introduction

The rapid spurt in communication and wireless industry has created a great demand for compact omnidirectional antennas for trans-receive applications. Half wave dipole and a quarter wave monopole antennas are the simplest omnidirectional antennas. The use of these antennas is restricted to narrow band applications due to their resonant behavior [1]. Biconical antennas and Monocone antennas have broadband omnidirectional characteristics. However, these antennas are bulkier and occupy large size, especially, when implemented in VHF/UHF band [2].

The bandwidth of monopole antennas can be increased by implementing sleeve concept. A wide-band sleeve cage monopole and sleeve helical antennas are reported covering 350-1550 MHz and 500-1750 MHz for a VSWR ≤ 3.5:1 respectively [3]. But, the sleeve monopole antennas require a very large ground plane of 5.5m x 6.7m. M.Ali et al. reported a dual meander sleeve antenna covering Personal Communication Network bands in 850-2050 MHz [4]. The antenna uses a square ground plane of 900mm x 900mm and achieves VSWR<3:1. But the radiation patterns and gain of the antenna are not reported in the published work. The requirement of large ground plane for sleeve monopole antenna often creates implementation problems. Bin Zhou et al. presented a sleeve antenna mounted on a metal cylinder covering 105-420 MHz which has a bandwidth ratio of 4:1 for VSWR of 3:1 [5]. However, the antenna has large size. The gain of the antenna is less than 0 dBi over certain operating frequencies. The bandwidth of the antenna is increased with inductance and capacitance matching networks to operate between 225-600 MHz with gain above 0 dBi. James L. McDonal et al. has designed a cylindrical dipole with biconically offset feed to operate between 200-2000 MHz. It is published in the paper, that the conical feed improved impedance and pattern bandwidths. But, the E-plane patterns have nulls in broad side direction above 400 MHz [6].

Chritz Duncan et al. reported a planar half disc dipole antenna with size reduced by half when compared to circular dipole antenna. The antenna has broadband characteristics from 2.016-6.38 GHz which gives a bandwidth ratio of 3.16:1 [7]. In general, application of shorting pins enhances the impedance bandwidth of monopole antennas. Fractal-shaped antenna has also been useful for broadband bandwidth covering from 800 MHz to 6 GHz [8].

A sleeve monopole antenna with cylindrical element having disc loading and shorting posts is reported over a frequency band of 350-1300 MHz. The antenna has impedance bandwidth ratio of 3.7:1 for 3:1 VSWR [9]. But the antenna requires a ground plane for its operation and also gain of the antenna is not mentioned.

An illustration is given on a 4:1 impedance bandwidth top loaded monopole antenna with open sleeve configuration, loaded with a series resistor and inductance elements. The antenna requires ground plane for its operation and the antenna gain varies from -7 to 1.5 dBi [10]. In practice, sleeve antenna configurations along with top loading and lumped matching networks are utilized to get small size broadband antennas. The main drawback of loaded antenna is reduction in efficiency due to losses in the circuit. Resistively loading of antenna for bandwidth improvement is established for monopole antenna [11]. The antenna is designed for 0.17-0.52 GHz frequency range and an efficiency of 23.85 % is obtained at 0.2 GHz. Hence, it can be shown that broad bandwidth is achieved at the expense of efficiency. This is a compromise to achieve broad bandwidth with resistive loading.

Waqas Mazhar et al. proposed a broadband sleeve monopole antenna with capacitive loads, matching network and impedance transformer [12]. The antenna operates a wide frequency range of 84-890 MHz. However, the E-plane patterns exhibit nulls along broadside direction of the order of 5dB which are not desirable and also gain of the antenna is not stated. K.George Thomas et al. demonstrated a dual sleeve top loaded monopole antenna for 0.5-2.1 GHz [13]. The return loss and radiation patterns of the antenna are presented, but gain of the antenna is not mentioned. A comparison of simulated and measured results is done for broadband rectangular sleeve dipole in 850-2500 MHz [14]. Tao Jian et al. designed a multiple sleeve dipole in 0.8-2.5 GHz for bandwidth ratio of 3.125: 1 [15].

Antenna structures other than cylindrical shapes are suggested for broad bandwidth and size reduction. In addition, various sleeve configurations can also be included in antenna design for better performance. S.L.Zuo et al. developed a conical radiator with cylindrical sleeve [16]. The antenna covers 750-2660 MHz, giving a bandwidth ratio of 3.54:1 with a circular ground plane of radius 150 mm. Z.-Y. Zhang et al. presented a conical sleeve monopole with shorting pins [17]. This low profile antenna covers 446-732 MHz giving a bandwidth ratio of 1.64:1. The antenna requires a ground plane of radius 200 mm.

In the present paper, the concept of shaped radiators using canonical shapes and cylindrical sleeve are used to design a compact omnidirectional antenna. The proposed antenna uses distributed loading impedance matching techniques and achieves an instantaneous bandwidth of 7.2:1 covering 500-3600 MHz.

2. Canonical Sleeve antenna (CSA)

2.1. Design approach and implementation

In the present paper, the concept of shaped radiators is applied for dipole using canonical shapes to design a compact omnidirectional antenna in UHF band. To accomplish broad bandwidth with compact size, CSA design is improved by employing cylindrical sleeves. In the antenna design distributed loading impedance matching techniques are adopted.

It is aimed to design a compact omnidirectional antenna covering 500-3600 MHz. To cover applications in UHF communications, the starting frequency for design is considered as 500MHz. By increasing the bandwidth of the antenna on the upper side, the antenna can be used over a wider spectrum.

A Solid BiConical Antenna (BCA) is first designed for an optimized diameter, height of Cone and feed gap. The structure of antenna is shown in fig. 1(a). BCA also serves the purpose of bench marking the performance of the proposed antenna. Bandwidth of Biconical antenna can be improved by varying the cone angle between 60° and 120°. The arrived angle of the cone is 112.16° for the proposed BCA. BCA meets the impedance matching goal. But, the gain of BCA is reduced at 1.5 GHz. The summary of results of BCA antenna is shown in Table 1.

The geometry of a Hemisperical Dipole Antenna (HDA) is shown in Fig. 1(b). HDA occupies more volume than BCA of same diameter and has smooth transition in its structure, leading to better design concept.

HDA is designed and the results given in Table 1. The performance of HDA is better than BCA with gain more than 0dBi over the frequency band 0.5-3.6 GHz. However, the dimension of HDA is more than BCA.

To realize a reduced size antenna, BCA structure is truncated from its tip to height of 22.18 mm and replaced with hemispherical dipole, leading to geometry of Hemispherical Dipole with Conical extensions (HDC) as shown in fig. 1(c).

The optimized dimensions of HDC are shown in Table 1. HDA has good impedance characteristics and gain varies from 0.7 to 3.2 dBi. To further improve the antenna performance, top loading concept is used by adding cylinders to HDC, leading to hemispherical dipole with conical extensions and Cylindrical top Loading (HDCCL) as shown in fig. 1(d).

Top loading increases capacitance and reduces the antenna height. HDCCL has good impedance characteristics and gain varies from 0.4 to 3.6 dBi. To improve the antenna radiation characteristics, a novel sleeve is designed. A conventional sleeve dipole has a cylindrical dipole with cylindrical sleeve over it as shown in fig. 1(e). In the proposed work, a cylindrical sleeve is used over HDCCL resulting in configuration of CSA as shown in fig. 1(f). The design concept used in this paper is to use a combination of canonical structures like hemisphere, cone and cylinder to replace the cylindrical dipole in a conventional sleeve dipole antenna. A sleeve length of 7.3 mm is designed. The sleeve is supported over the hemispherical elements using dielectric cylindrical supports made up of Poly Urethane Foam (PUF) having dielectric constant of 1.4.

CSA has the compact form among the antennas studied and good impedance and gain characteristics. The simulated gain varies from 0.25 to 4.4 dBi.

The optimised dimensions for the antenna configuration of BCA, HDA, HDC, HDCCL and CSA for best impedance match in 500-3600 MHz are given in

Table 1. It can be inferred that HDA has the largest dimensions. BCA has the lowest height and HDC has the lowest diameter. CSA has optimum dimensions with Height x Diameter : 111.43 mm x 116.66 mm. CSA occupies the lowest volume among all the antennas and hence has a compact form factor. CSA has height 11.77 % more and the diameter 21.32% less compared to the BCA.

The comparison of simulated VSWR of antenna configurations of fig. 1 (a) to 1(d) and 1(f) is shown in fig. 2. VSWR of all the antennas is less than 3:1. It can be inferred that the VSWR of HDA is improved by adding conical extensions to it (leading to HDC). HDC has the best impedance matching characteristics.

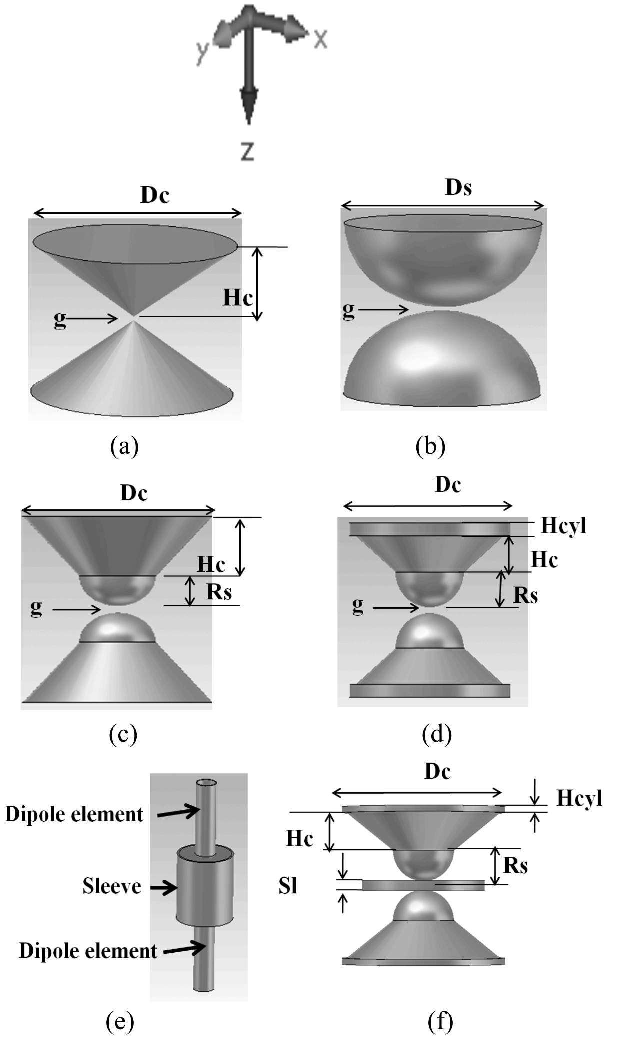


Figure 1: Various types of antenna configurations studied (a) Biconical Antenna (BCA), (b) Hemispherical Dipole Antenna (HDA) (c) Hemispherical Dipole with Conical Extensions (HDC) (d) Hemispherical Dipole with Conical Extensions and Cylindrical loading (HDCCL) (e) Geometrical configuration of sleeve dipole antenna (f) Canonical Sleeve Antenna (CSA)

VSWR of CSA is than BCA in low frequency region and both antennas have VSWR less than 2.5:1 from 0.525 GHz -3.6 GHz. The simulation studies of these antenna configurations are also carried out for three dimensional radiation characteristics. It is found that CSA has good radiation characteristics compared to other antenna configurations over the frequency band 0.5-3.6 GHz.

It is observed that the BCA has dough nut shaped pattern from 0.5-1 GHz and the pattern starts splitting above 1GHz up to 2 GHz. This leads to reduction in gain of the BCA in 1-2GHz at Horizon. (Please refer figure 1 for reference coordinate system. Horizon means is at 90 ° from Z-axis and in X-Y plane).

The dough nut shaped pattern is restored above 2 GHz up to 3.6 GHz, and as expected, beamwidth reduces as frequency increases. HDA, HDC and HDCCL also exhibits split in dough nut shaped radiation pattern in 1-1.75 GHz, 3-3.6 GHz and 1.5-2 GHz respectively. This split phenomenon is minimal for CSA and is observed around 1.5 GHz.

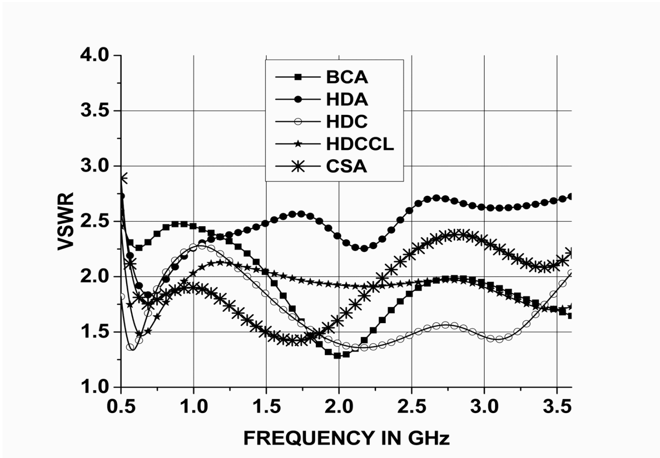


Figure 2: Comparison of Simulated VSWR of antennas

The comparison of Gain at Horizon for all the antenna configurations is shown in figure 3.

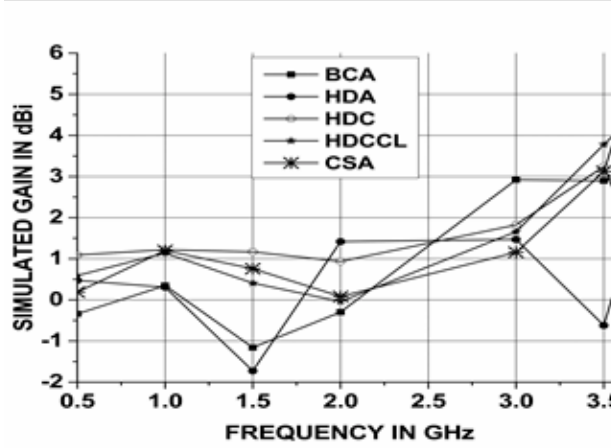


Figure 3: Simulated Gain of antennas at Horizon

It is observed that CSA exhibits over all good gain characteristics than other antennas despite its small dimensions. The gain of BCA is -0.3dBi at 0.5 GHz due to its low height of 99.69 mm (Gain is proportional to length of the antenna). Reduction in Gain of the order of 2 dB is found in BCA and HDA configurations around 1.5 GHz, which is undesirable. CSA antenna, though possessing low height exhibits a low intensity dip in Gain around 1.5 GHz and its gain increases with frequency. CSA has the highest gain of 4.2 dBi among the antennas at 3.6 GHz. It can be inferred that CSA is the best configuration among the antennas studied in broadband scenario. It has desirable impedance and radiation characteristics even though it has overall compact form factor. The impedance characteristics of CSA are shown in fig. 4.

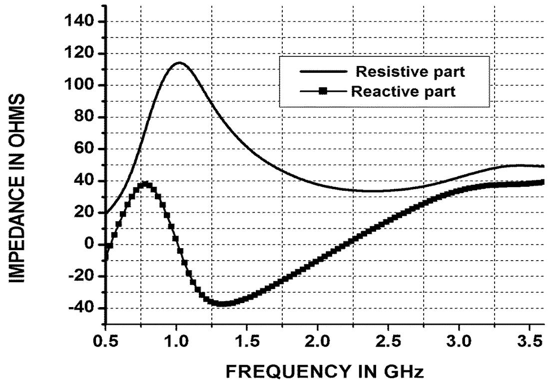
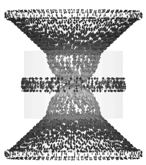
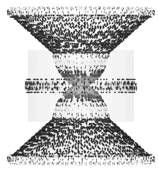


Figure 4: Impedance Characteristics of CSA

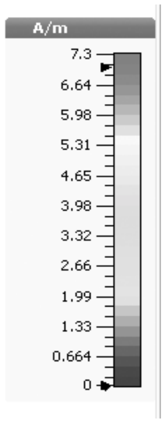
All the antenna design values are arrived at by carrying out simulations in CST Microwave Studio. The optimum configurations are arrived by keeping design goal of VSWR < 3:1 over the frequency band 0.5-3.6 GHz. The current distribution of CSA at 0.5GHz, 2GHz and 3.6GHz is shown in fig. 5. The superior performance of CSA compared to other antenna configurations can be attributed to its optimised geometry and suitable current distribution on it.

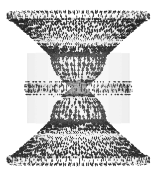


(a)



(b)

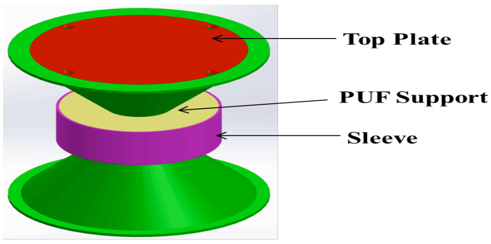




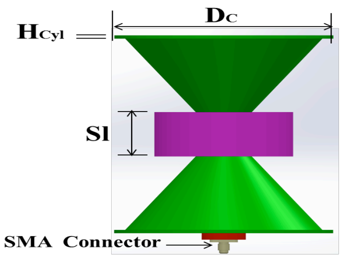
(c)

Figure 5: Simulated surface current distribution of Canonical Sleeve Antenna (CSA) at (a) 0.5 GHz (b) 2 GHz (c) 3.6 GHz

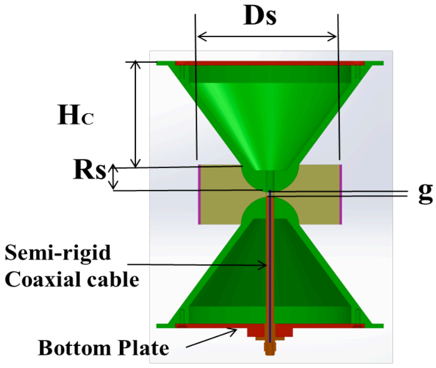
The geometrical configuration of CSA is given in fig. 6 showing its isometric, front and sectional views.



6 (a) Isometric View



6 (b) Front View



6 (c) Sectional View

Figure 6: Canonical Sleeve Antenna (CSA)
6(a) Isometric view, 6(b) Front view, 6(c) Sectional view

The CSA is fabricated as per design and photograph is shown in fig. 7.

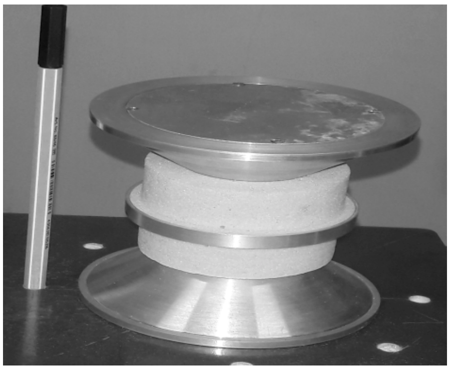


Figure 7: Photograph of Canonical Sleeve Antenna (CSA)

The antenna is fabricated by machining blocks of Aluminium alloy. CSA is fed using 0.141" semi-rigid coaxial cable. An SMA receptacle is assembled to 0.141" coaxial cable and is fixed to the bottom plate of CSA. The centre conductor of the coaxial cable is soldered to the upper hemisphere and the outer conductor to the bottom hemisphere of CSA. Upper and lower parts of CSA are supported using Poly Urethane Foam dielectric support embedded within cylindrical sleeve.

2.2. Measured results and discussion

The VSWR measurement of the CSA antenna is carried out using a Vector Network Analyser. The radiation characteristics are evaluated in an anechoic chamber. The comparison of simulated and measured VSWR of the antenna is given in fig. 8.

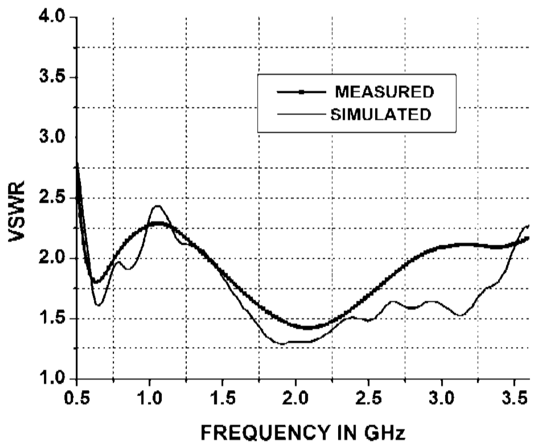
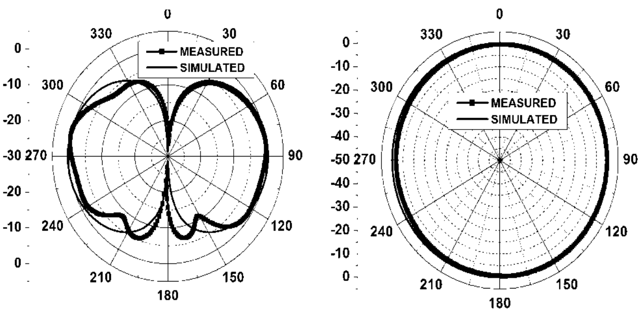
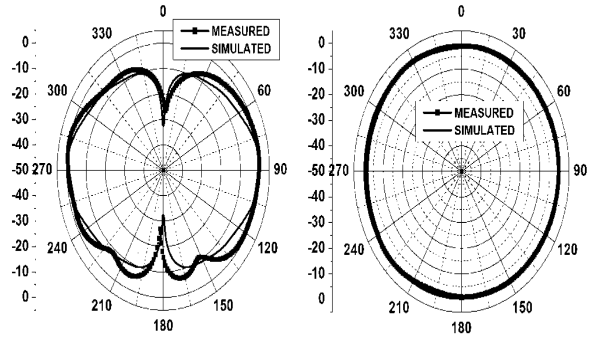


Figure 8: Simulated and measured VSWR of Canonical Sleeve Antenna (CSA)

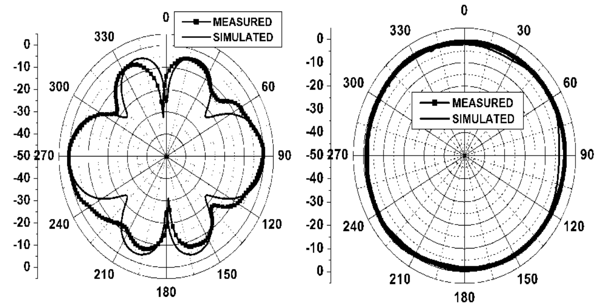
The results indicate good agreement between the measured and simulated profiles of VSWR. Measured VSWR of less than 2.7:1 is achieved throughout the band 500-3600MHz. The measured and simulated radiation patterns of the antenna are shown in fig. 9.



9(a) E-Plane Patterns H-Plane Patterns



9(b) E-Plane Patterns H-Plane Patterns



9(c) E-Plane Patterns H-Plane Patterns

Figure 9: Simulated and measured radiation patterns of CSA

(a) E-Plane and H-Plane patterns at 0.5 GHz
(b) E-Plane and H-Plane patterns at 3 GHz
(c) E-Plane and H-Plane patterns at 3.6 GHz

CSA antenna exhibits good radiation patterns with figure of eight patterns in E-Plane and omnidirectional patterns in H-Plane. The 3 dB beamwidth of the E-Plane patterns of antenna varies from 35º-66º. The maximum deviation from omnidirectionality in H-Plane patterns is within ± 1.5dB. Comparison of the simulated and measured gain of CSA is shown in fig. 10. The measured Gain varies from 0 to 3.6dBi.

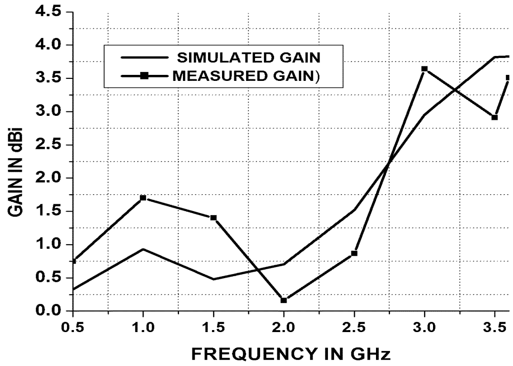


Figure 10: Comparison of measured and simulated Gain of CSA

Table 1: Results of Simulation of Antenna Configurations studied in this paper

Sl. No.	Type of Antenna	parameter values (mm)	Size (mm^2)	Simulated Results
1	BCA	Hc = 49.84, Dc = 148.28, g = 0.92	99.69 x 148.28	VSWR ≤ 2.57:1 Gain ≥ -1.15 to 3 dBi
2	HDA	Ds = 153.15, g = 4.43	157.59 x 153.15	VSWR ≤ 2.72:1 Gain ≥ 0.1 to 1.4 dBi
3	HDC	Hc = 44.64, Dc = 109.64, g = 4.82, Rs = 22.18	138.48 x 109.64	VSWR < 2.27:1 Gain ≥ 0.95 to 3 dBi
4	HDCCL	Hc = 25.62 Dc = 115.34 , g = 3.82, Rs = 24.68, Hcyl = 9.01	122.48 x 115.34	VSWR ≤ 2.45:1 Gain ≥ 0.37 to 3.64 dBi
5	CSA (Proposed Antenna)	Hc = 26.7, Sl = 7.3, Dc =116.66, g = 5.83, Hcyl = 4.23, Ds = 87.62, Rs = 21.85	111.43 x 116.66	VSWR ≤ 2.7:1 Gain ≥ 0.25 to 4.4 dBi

Table 2: Comparison of Results of Canonical Sleeve Antenna (CSA) with Published Literature

Sl. No.	Type of Antenna	Frequency Range and % Bandwidth	Size (mm^2)	Results (VSWR, Gain) and Remarks
1	Sleeve Helix Antenna [3]	500-1750 MHz; 111.11%	98x 60	VSWR<3.5:1. Gain not reported. Requires ground plane of 5500mm x 6700mm.
2	A Wideband Dual Meander Sleeve Antenna [4]	850-2050 MHz; 82.75%	66x 32.8	VSWR<3:1. Radiation patterns and Gain not reported. Requires ground Plane of 900mm x 900mm.
3	Low profile sleeve monopole antenna [15]	750-2660 MHz; 112.02%	29x 132	VSWR ≤ 2:1. Gain not reported. Requires a ground plane of 300mm diameter.
4	A novel multi-sleeve antenna [14]	0.8-2.5 GHz; 125.58%	104x 60	VSWR ≤ 2:1. Gain : 1.4 to 2.2 dBi. Good Gain and radiation Patterns.
5	CSA (Proposed Antenna)	500-3600 MHz; 151.21%	111.43 x 116.66	VSWR ≤ 2.7:1, Gain : 0 to 3.6 dBi. Requires no ground plane, has good Gain and radiation patterns.

3. Conclusions

A compact broadband Canonical Sleeve Antenna is designed and developed covering 500-3600MHz. The antenna configuration consists of hemispherical dipole with conical extensions, cylindrical top loading and cylindrical sleeve for accomplishing broad bandwidth. The antenna has good gain compared to Biconical antenna and other antenna configurations studied. The antenna can be used as base station for trans-receive roles, access point antenna, repeater antenna in wireless communication systems. This antenna also finds use for ISM applications, spectrum monitoring, law enforcement applications and EMI / EMC test applications. Electronic Warfare (EW) requires broadband antennas. For all the above mentioned applications, Canonical Sleeve Antenna can be used in trans-receive roles.

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