A Novel Coaxial Continuous Transverse Stub Antenna Array for High Frequency Satellite Applications

JOTHILAKSHMI.P[1*], RAJU.S[1#]
[1]*Department of Electronics and Communication Engineering
Sri Venkateswara College of Engineering, Chennai, Tamilnadu, India
jothi@svce.ac.in
[1#] Department of Electronics and Communication Engineering
Thiagarajar College of Engineering, Madurai, Tamilnadu, India

Abstract: - The need for antenna with multiband capability is miniaturization of design and improvement of bandwidth. Planar antennas suffer narrow bandwidth problem. This paper focuses on the implementation of multiband high gain antenna array for wireless satellite and aircraft applications with improved bandwidth. The proposed antenna structure consists of three pair of radial coaxial stubs in a zigzag manner. The stub pair consists of one large stub and another small one to radiate for multiple frequency bands. This cascaded structure offers high directivity and gain with minimum return loss. This proposed antenna structure covers the frequency range of 10 GHz to 26 GHz. The fabricated antenna of the proposed structure radiated for four frequency bands with minimum return loss. These frequencies are well suited to satellite, space craft and military applications.

Key-Words: - Coaxial antenna, Multiband, Omni directional radiation pattern, S-Parameter, Directivity and Gain.

1 Introduction

Multiband continuous transverse stub (CTS) technology developed in the early 1990's by Hughes Aircraft Company [10-14, 17]. This technology offers Omni-directional radiation pattern in the horizontal plane or perpendicular to the transmission line plane. CTS technology offers greater tunable bandwidth than waveguide or patch antennas. The different forms of CTS antenna include coaxial, coplanar and rectangular waveguide [2-4, 16]. This structure exhibits very low Q and impedance characteristics. CTS structure offers several advantages over planar CTS. The impedance matching is inherently easier in coaxial structures, providing higher efficiency and facilitating system integration with other coaxial structures. The designed antenna structure can cover the operating frequency range of 10 GHz to 26 GHz. There are three important methods used to improve the performance of coaxial CTS antenna array. The performance can be improved by varying the inclination between stubs, physical dimension alteration and adding terminal elements. This paper describes the physical dimension alteration property based performance improvement of CTS antenna array.

CST Microwave Studio® is used to analyze coaxial CTS antenna, which is electromagnetic simulation software based on finite integral method. The finite integration technique (FIT) is a spatial discretization [15] to solve electromagnetic field problems in time and frequency domain numerically. It preserves basic topological properties of the continuous equations such as conservation of charge and energy. This method covers the full range of electromagnetic spectrum, from static to high frequency and optic applications and is the basis for the commercial simulation tool CST Studio Suite. The basic idea of this approach is to apply the Maxwell's equations in integral form to a set of staggered grids. This method stands out due to high flexibility in geometric modeling and boundary handling as well as incorporation of arbitrary material distributions and material properties such as anisotropy, non-linearity and dispersion. Furthermore, the use of a consistent dual orthogonal grid in conjunction with an explicit time integration scheme leads to extremely high efficient algorithms referred to both computation time and memory requirements which are especially adapted for transient field analysis in RF applications.

2 Structure and Design Procedure

Design procedures for a coaxial CTS array includes selection of the following parameters [3-5] distance between two adjacent stub elements (L_2), width of the dielectric fill material (L_1), dielectric constant of filler dielectric (ε_r), diameter of inner conductor (D_1), diameter of the outer conductor (D_2), diameter of the stub (D_3). For the purpose of an illustrative design, the width of stub element L_1 has been selected to be of half a wavelength of dielectric material. The length of the transmission line segment L_2 and dielectric constant of dielectric material (ε_r) has been chosen to fulfil distance and phase demands between stubs. The diameter of the inner and outer conductor D_1 and D_2 of the coaxial transmission line can be adjusted to form the desired value of impedance, such as 50Ω or 75Ω in the case of a coaxial transmission line. The ratio between D_3 and D_2 determines the radiation pattern, voltage and the radiated power from each stub. The small value of D_3 /D_2 tends to lead to increased radiation, but more care must be taken to achieve impedance matching. Also, D_3 must be chosen so as to limit the level of mutual coupling between the stub elements in the coaxial CTS array. Control of mutual coupling between elements in the array can be generally achieved by meeting the condition D_3 greater than L_1.

Clearly, the diameters of the inner and outer conductors D_1 and D_2 do not need to be uniform along the transmission line, instead, they can be changed periodically to adjust the matching and phase relationship between elements. Actually, the coaxial CTS array structure offers are excellent self-matching. By properly controlling the ratio of D_3 and D_2 and the ratio of D_3 and L_1, it is possible to achieve low reflection stub elements. As one might expect, the design parameters D_2, D_3, L_1 and L_2 impact various aspects of the characteristics of the array including impedance matching, percentage of output power radiation, and radiation pattern. The value of coaxial transmission line impedance [1] is,

$$Z_0 = \frac{60}{\sqrt{\varepsilon_r}} \ln \frac{D_2}{D_1} \tag{1}$$

Another significant feature in the design is dependency of operation band and parameters L_1, D_3. To increase the value of D_3 or reduce the value of L_1, involves a shift in frequency of operation towards low frequency. The total length [1] of the array can be calculated using equation (2).

$$\text{LENGTH} = L_1 * N + L_2 * (N-1) \tag{2}$$

Fig.1 shows the existing, basic two element continuous transverse stub antenna arrays. Fig. 2 and Table.1 shows the physical structure and dimensions of proposed CTS antenna array which shows that the total length of the antenna is 135 mm only to operate a frequency range of 10 GHz to 26 GHz. The length of the stub should be reduced by 50mm compared to previous models [3-7]. For the previous designs the gap between two parallel plates are fully filled with dielectric material. This model fills dielectric material only in the gap between inner and outer conductors to reduce the weight of the entire antenna structure. This proposed antenna structure came under low cost low loss multiband category.

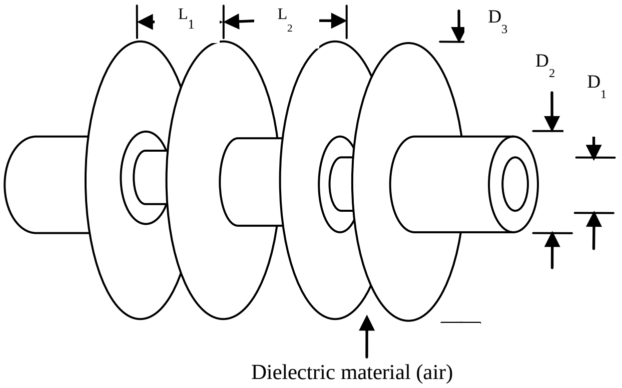

Fig.1. Geometry of basic continuous transverse stub (CTS) antenna array.

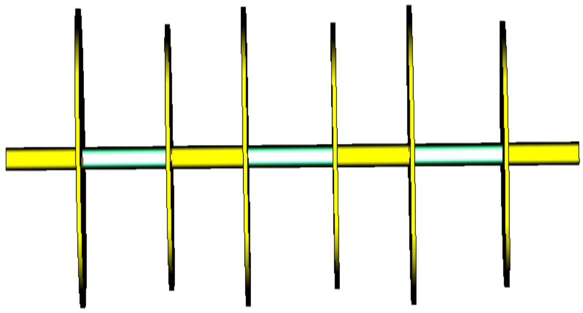

Fig.2. Geometry of proposed unevenly arranged stub CTS antenna array.

Table 1: Dimensions of proposed CTS antenna array

Component	Material Used	Dimension
Stub diameter (D_3)	Brass	80 mm
Stub thickness		1 mm
Distance between outer conductor and stub (L_2)		8 mm
Distance between two stubs (L_1)		6 mm
Length of inner conductor		135 mm
Diameter of outer conductor (D_2)	Brass	6.9 mm
Diameter of inner conductor (D_1)	Brass	3 mm
Total length of the proposed CTS antenna Array		135mm

3 Simulation Results and Discussion

The surface current distribution of proposed continuous transverse stub antenna structure has been shown in Fig.3, which shows that around the conductor the current flow is high. Fig.4 to Fig.11 shows the return loss (S_{11}), VSWR, gain and directivity plot of proposed CCTS antenna over the entire operating frequency range. The simulated result shows that for all operating frequency ranges the return loss and voltage standing wave ratio obtained is optimum. For a good antenna the VSWR value is 1:2. Here the VSWR value is within 1:2 and return loss values are above 10 (below 0 dB scale) which imply that the proposed antenna is an excellent radiator or receiver, to transmit and receive electromagnetic waves. These CTS antenna systems can be employed in numerous implementations due to its low profile. Fig.12 and Fig.13 shows the electric and magnetic field distribution of proposed antenna array in maximum of z direction. The low profile antenna systems of the present embodiments can be utilized on airplanes to provide direct communication with satellites and other stations or mobile communication platforms. The proposed antenna structure is primarily suitable for high frequency Satellite communication and Military applications. The obtained radiation pattern during CST software simulation shows that the designed antenna structure produced Omni-directional radiation pattern in the horizontal plane and end fire pattern in the vertical plane. These 2D and 3D radiation pattern show that the proposed antenna structure radiates for multiband frequency bands. The directivity and gain obtained are excellent with high radiation efficiency, above 90% for all bands.

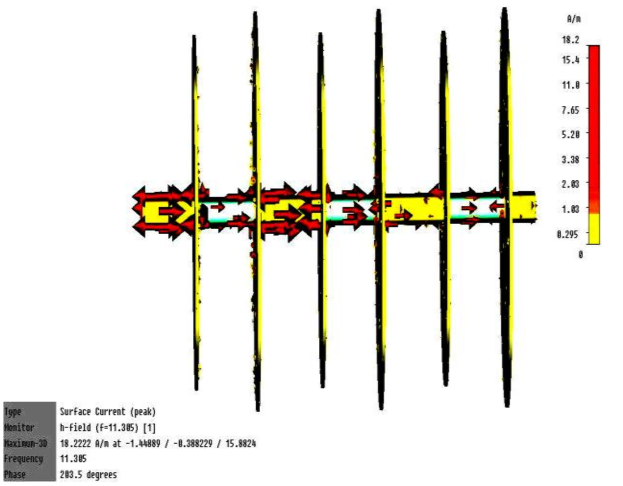

Fig.3.Surface current distribution in proposed CCTS antenna array.

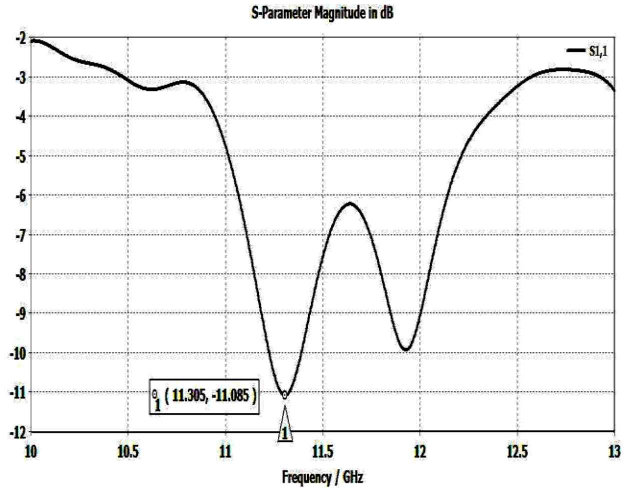

Fig.4.Return loss plot of proposed CCTS antenna array for 10 GHz to 13 GHz frequency range.

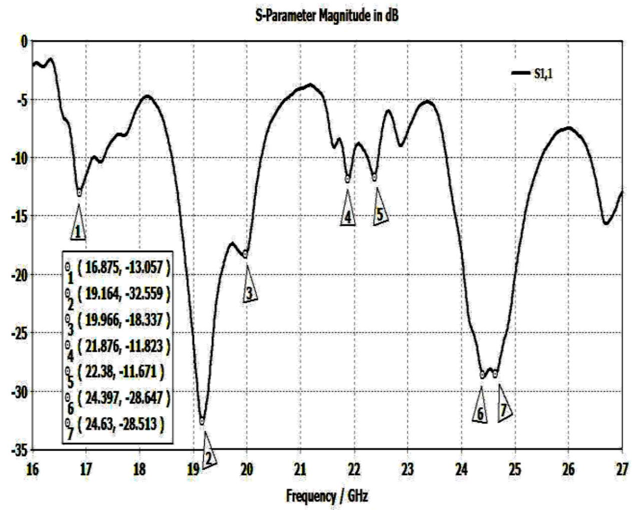

Fig.5.Return loss plot of proposed CCTS antenna array for 16 GHz to 27 GHz frequency range.

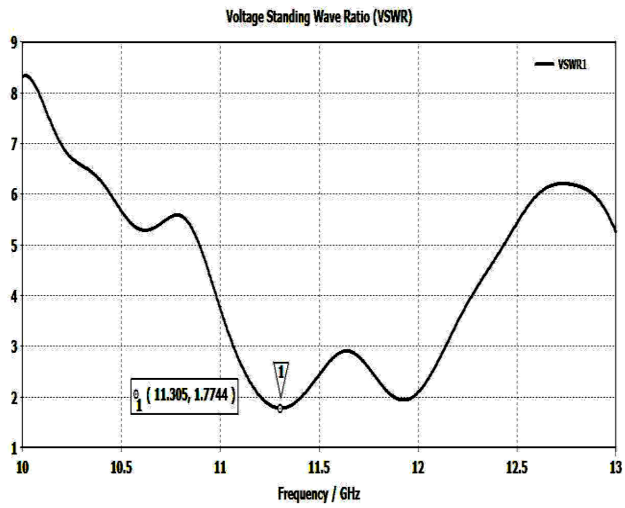

Fig.6. VSWR plot of proposed CCTS antenna array for 10 GHz to 13 GHz frequency range.

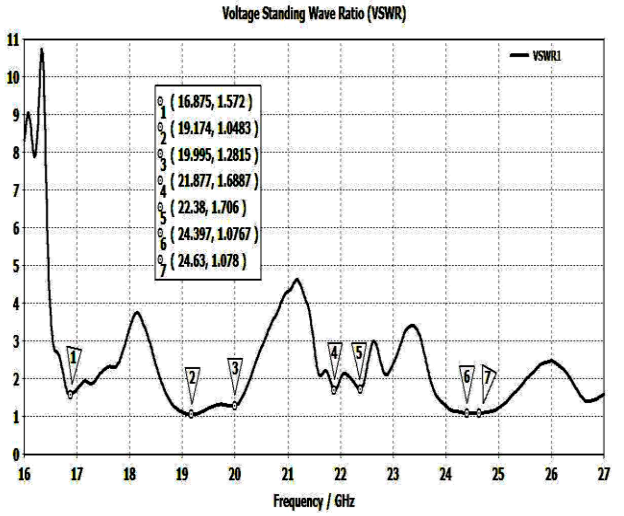

Fig.7.VSWR plot of proposed CCTS antenna array for 16 GHz to 27 GHz frequency.

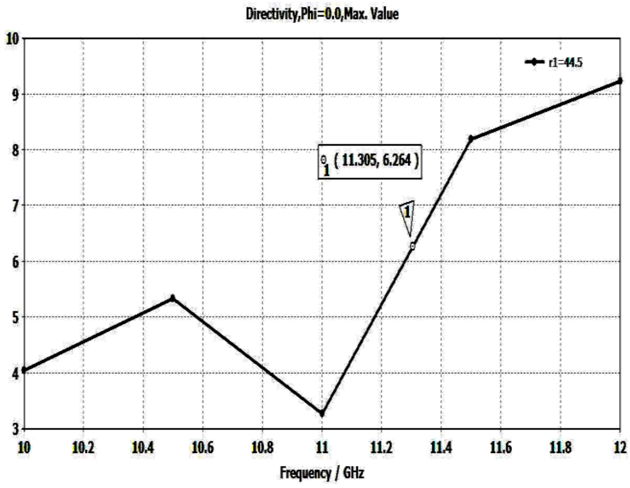

Fig.8.Directivity plot of proposed CCTS antenna array for 10 GHz to 12 GHz frequency.

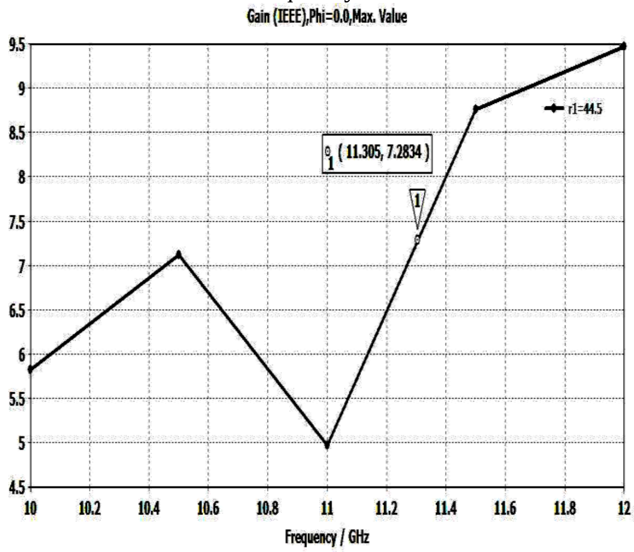

Fig.9. Gain plot of proposed CCTS antenna array for 10 GHz to 12 GHz frequency.

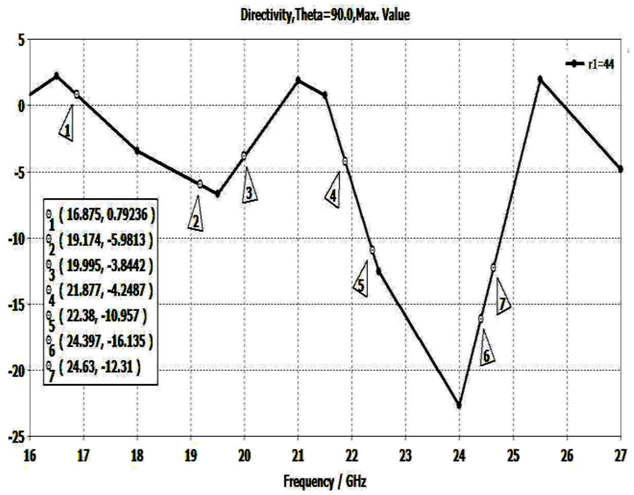

Fig.10.Directivity plot of proposed CCTS antenna array from 16 GHz to 27 GHz frequency.

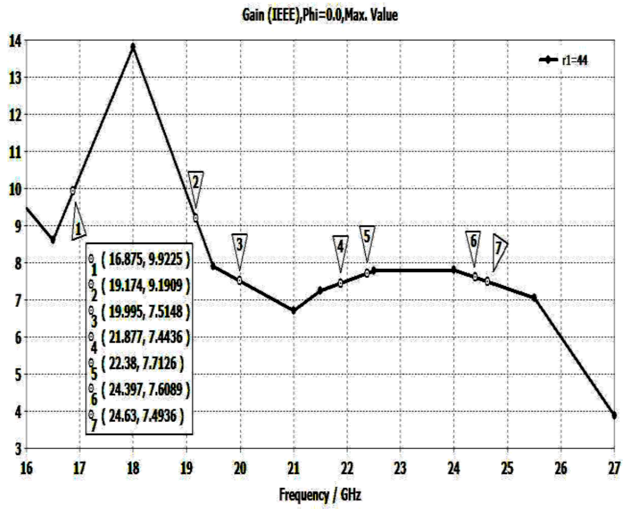

Fig.11.Gain plot of proposed CCTS antenna array from 16 GHz to 27 GHz frequency.

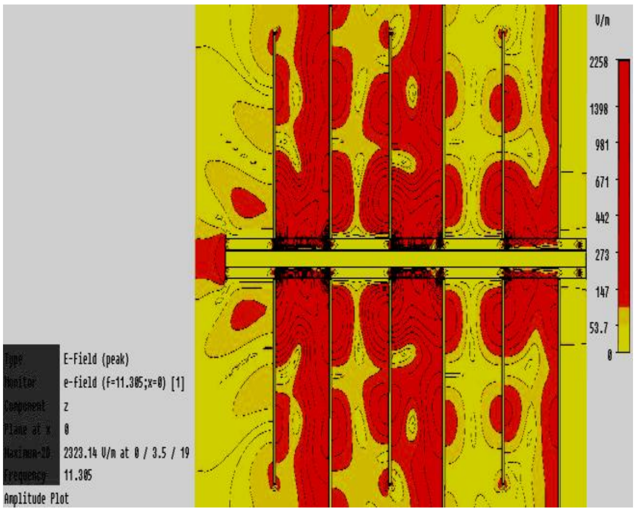

Fig.12.Electric field distribution in proposed CCTS antenna array in z direction.

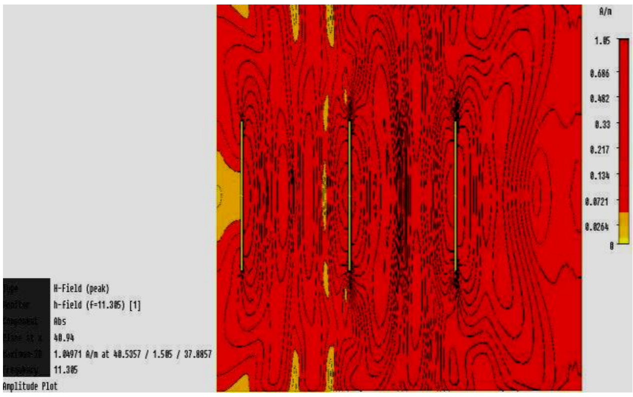

Fig.13.Magnetic field distribution in proposed CCTS antenna array in z direction.

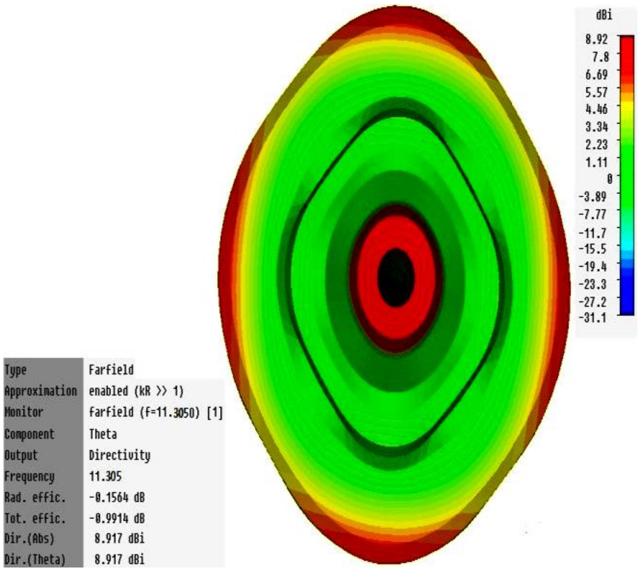

Fig.14.3-D radiation pattern of proposed CCTS antenna array at 11.305 GHz frequency.

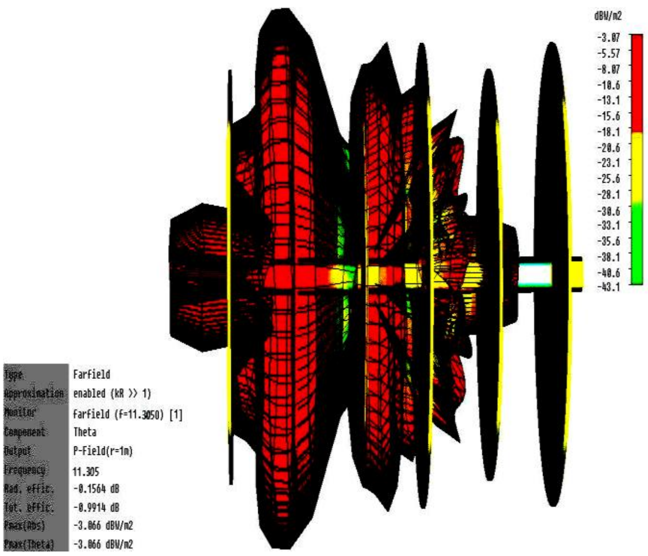

Fig.15.3-D power pattern of proposed CCTS antenna array at 11.305 GHz frequency.

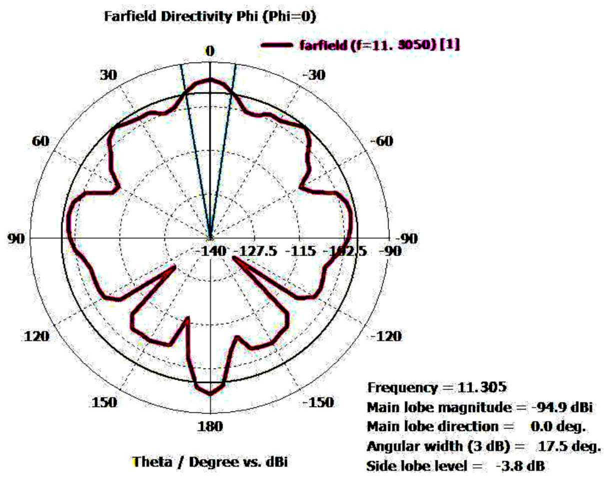

Fig.16.Far filed polar (phi plane when phi=0) plot of CTS antenna array at 11.305 GHz frequency (directivity).

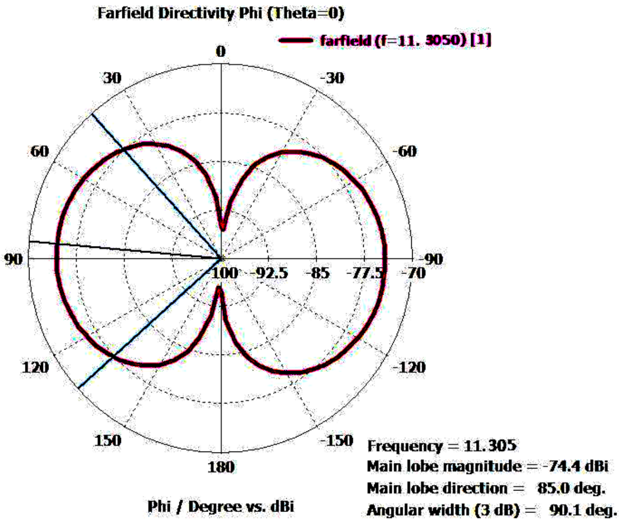

Fig.17. Far filed polar plot of (phi plane when theta=0) of CCTS antenna array at 11.305 GHz (directivity).

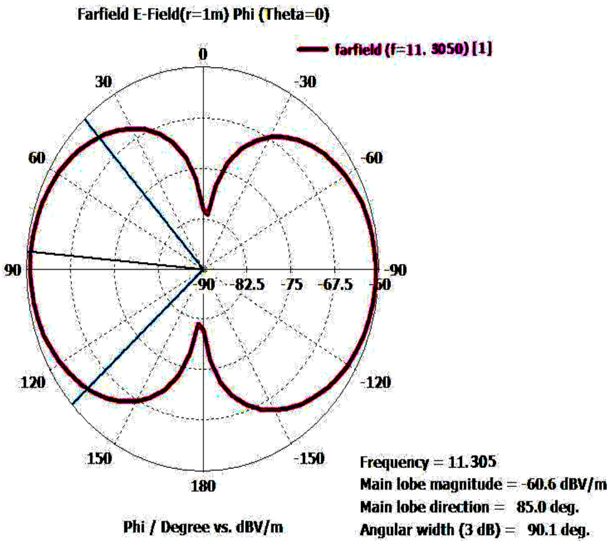

Fig.18. Far electric field polar (phi plane when theta=0) plot of CCTS antenna array (directivity).

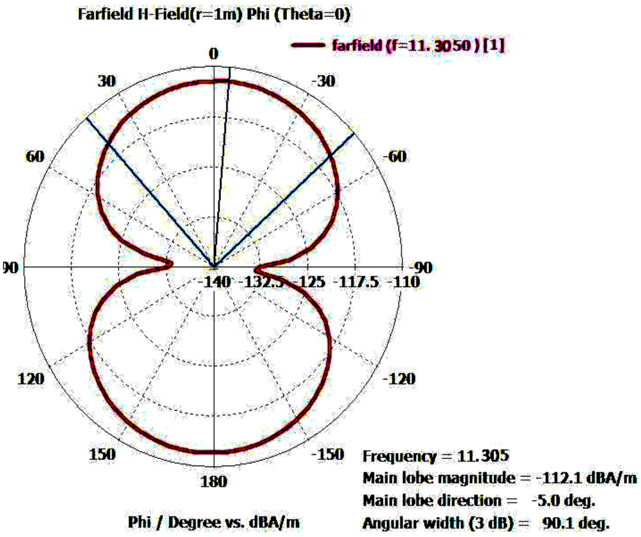

Fig.19. Far magnetic field polar (phi plane when theta=0) plot of CCTS antenna array (directivity).

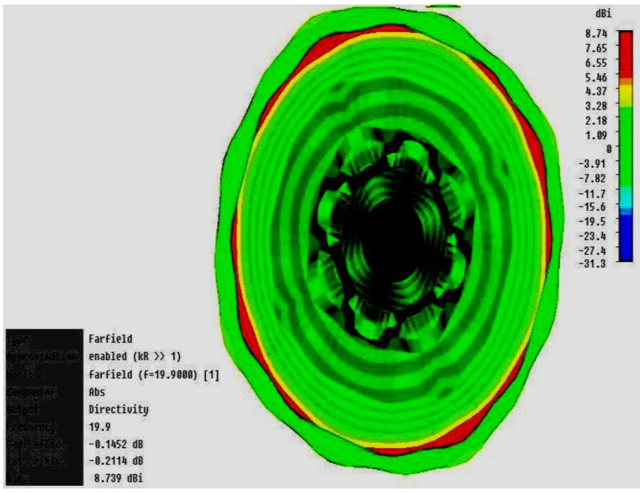

Fig.20. 3-D radiation pattern of proposed CCTS antenna array at 19.9 GHz frequency.

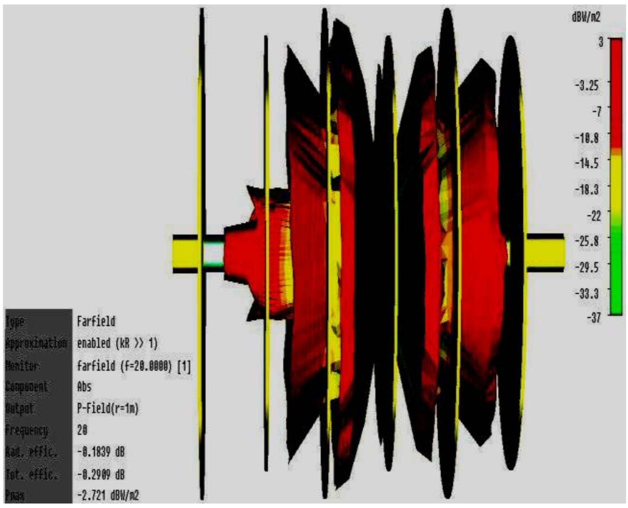

Fig.21.3-D power pattern of proposed CCTS antenna array at 11.305 GHz frequency.

It is very hard to achieve highly efficient antenna for multiband frequency range, so CTS antenna performs well for multiple bands of operation. The return loss and voltage standing wave ratio of the proposed antenna over entire operating frequency range is summarized in table 2 which shows that the values are optimum compared to previous results [3-9]. Fig.14 to Fig. 21 show the far field radiation pattern of proposed antenna structure for two different frequency bands. Results were observed for entire operating frequency range and have been summarized in Table.2.

Table 2: Extracted parameters of proposed CCTS antenna array for entire band of operation

Sl.No	Parameter	Frequency in GHz							
		11.305	16.875	19.164	19.966	21.877	22.38	24.397	24.63
1.	Return Loss (below 0 dB scale)	11.085	13.057	32.919	18.337	11.823	11.671	28.647	28.513
2	Voltage Standing Wave Ratio (VSWR)	1:1.774	1:1.572	1:1.048	1:1.282	1:1.689	1:1.706	1:1.077	1:1.078
3.	Radiation efficiency (%)	96.46	85.321	98.9	97.72	99.2	99.2	99.13	98.96
4.	Total efficiency (%)	79.59	57.18	97.5	95.79	77.41	77.41	98.99	98.83
5.	Gain (dB)	8.761	8.630	7.940	8.238	7.818	7.818	7.611	7.708
6.	Directivity (dBi)	8.917	9.319	7.866	8.338	7.199	7.199	7.649	8.917
7.	Electric field maximum (dBV/m)	29.68	21.95	22.05	22.95	21.29	12.73	22.15	21.69
8.	Magnetic field maximum (dBA/m)	-28.83	-29.57	-29.46	-29.66	-30.22	-29.42	-29.37	-29.83

4 Implemented Coaxial CTS Antenna Array, Results and Discussion

The front view and top view of the fabricated proposed coaxial continuous transverse stub antenna array with connector is shown from Fig.22 to Fig.24. The performance of antenna array was tested using network analyzer. The results were observed and comparison made between the simulated and fabricated structure. Fig. 25 to Fig. 27 shows the compassion of the return loss and voltage standing wave ratio results over the entire frequency range, these results show that the fabricated antenna structure supports four operating frequency ranges, with minimum loss and better impedance matching characteristics. There may be a slight deviation between simulated and measured results, due to material availability and machine cutting process during fabrication. The antenna structure can be fabricated using a single piece of conducting material, eliminates the structural deficiency. Fig. 28 to Fig.30 shows the measured vertical and horizontal plane radiation pattern of proposed coaxial CTS antenna, which shows that the proposed antenna produces figure of eight pattern on the vertical plane and omnidirectional pattern in the horizontal plane.

Fig.22. Prototype of Fabricated proposed continuous transverse stub antenna array (Front view).

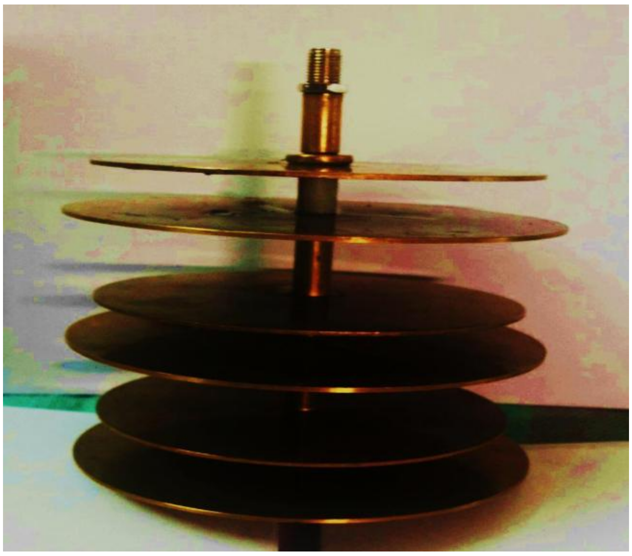

Fig.23. Prototype of Fabricated proposed continuous transverse stub antenna array (Top view).

Fig.24. Prototype of Fabricated proposed continuous transverse stub antenna array with connector.

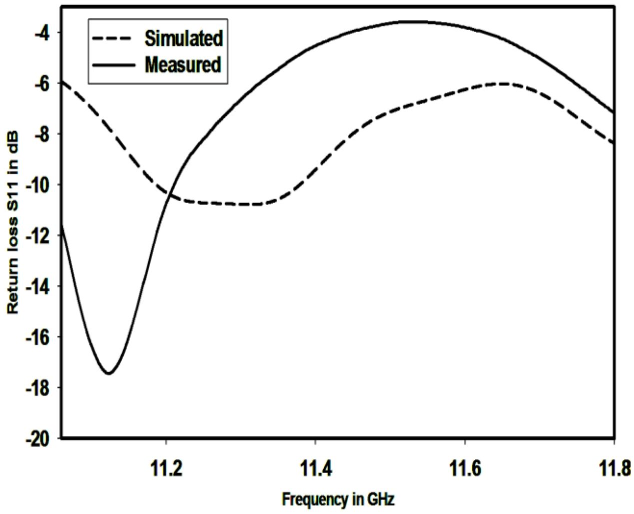

Fig.25. Return loss comparison plot of proposed CCTS antenna array for the frequency of 11.305 GHz.

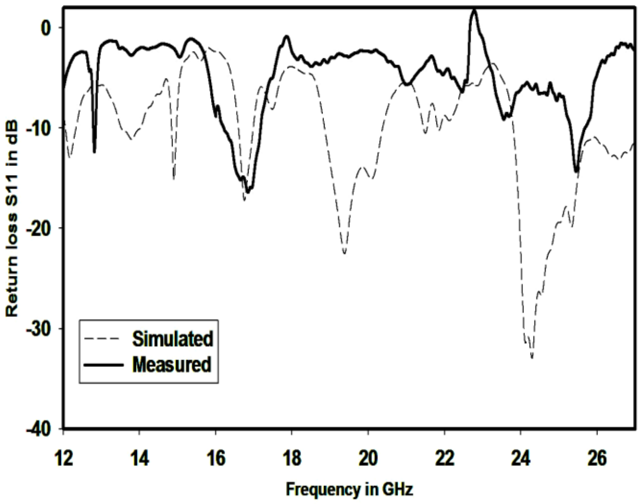

Fig.26.Return loss comparison plot of proposed CCTS antenna array for the frequency range of 12 GHz to 27 GHz.

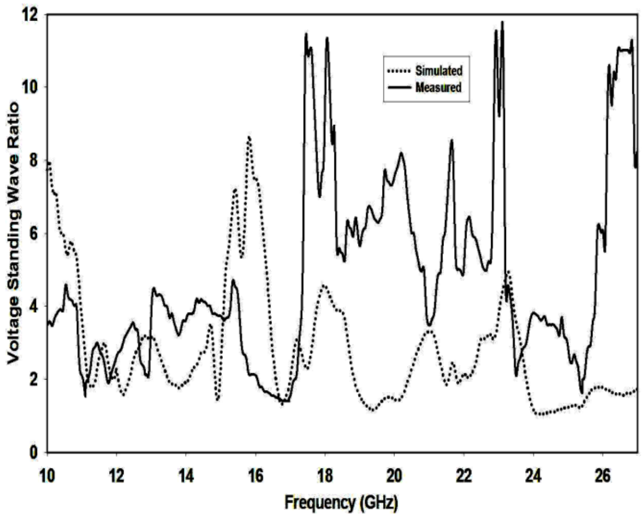

Fig.27. VSWR comparison plot of proposed CCTS antenna array from 10 GHz to 27 GHz frequency.

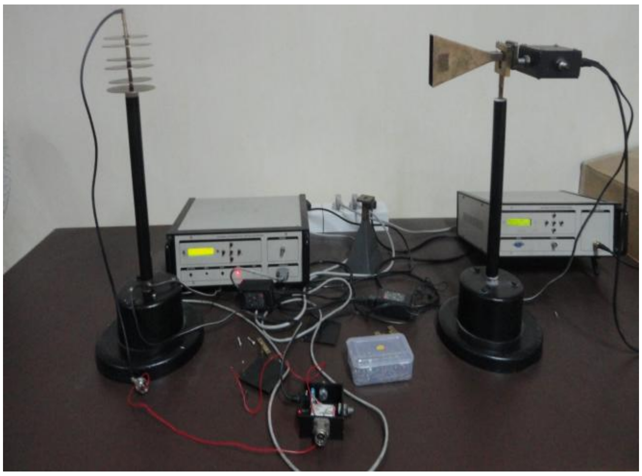

Fig.28.Photograph of radiation pattern measurement experimental setup.

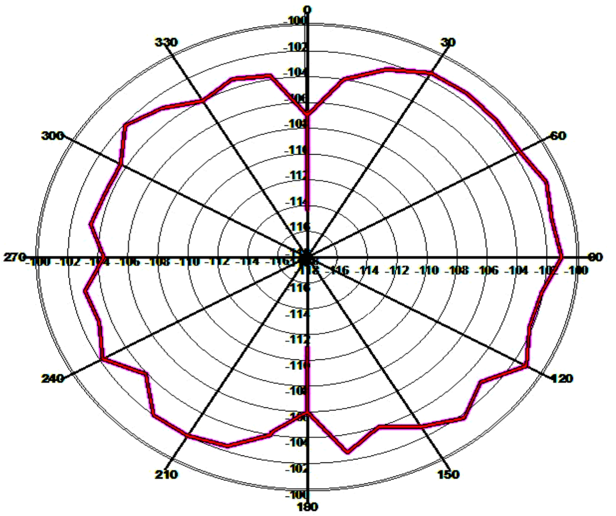

Fig.29. Measured vertical plane .polar radiation pattern at 11.305 GHz

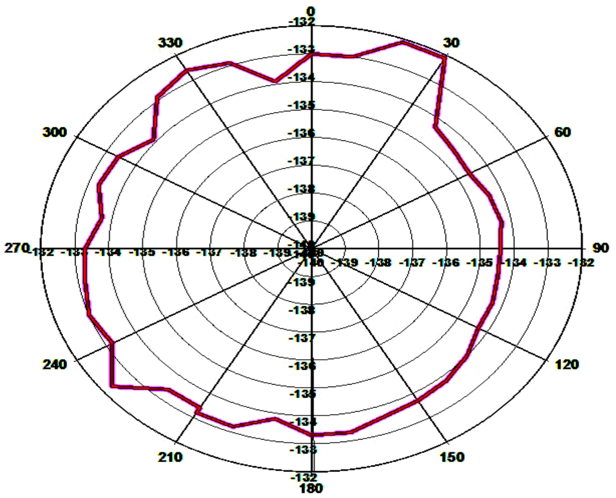

Fig.30 Measured horizontal plane polar radiation pattern at 11.305 GHz

Table 3: Comparison between simulated and measured return loss and VSWR

Simulated output			**Measured Output**		
Frequency (GHz)	Return loss S_{11}(dB)	VSWR	Frequency (GHz)	Return loss S_{11}(dB)	VSWR
11.305	11.09	1:1.774	11.1	-16.03	1:1.51
16.875	13.06	1:1.572	16.971	-15.49	1:1.39
24.63	28.51	1:1.078	25.41	-13.9	1:1.63

5 Conclusion

The simulated and measured result shows that the proposed CCTS antenna structure is well suited to radiate in microwave frequency bands. These frequency bands are suitable for satellite and RADAR applications. The proposed antenna structure offers good radiation efficiency for all the frequency bands with minimum side-lobe level. These results show that the same structure can be radiated over multiple high frequency bands. The structure can be further fine-tuned, in future, and fabricated using single piece of material to reduce the design mismatch effects. This work was not proposed by any one. This can be enhanced in future for practical applications.

6 Acknowledgement

I would like to thank my research supervisor Dr. (Mrs) S. Raju for her support and valuable suggestion for the successful completion of this research work. I would like to thank my husband and my children for their support and co-operation in completing this task within the stipulated time. I thank God almighty for the successful completion and submission of this research work in the referred Journal WSEAS Transactions on Communications.

References:

[1] Yip Loon Lee, Hyung-sun Youn, C.Tanaka and W. Kim, W, Design, development and experimental verification of voltage tunable ferroelectric coplanar phase shifters, *IEEE Antennas and Propagation Society International Symposium (APSURSI)*, Hawaii, Honolulu, HI, USA, 2010,pp.1-4.

[2] Seung-Yeup Hyun 2009, Se-Yun Kim & Young-Sik Kim, An Efficient FDTD Model for Resistively Loaded Cylindrical Antennas with Coaxial Lines, *IEEE Transactions on Antennas and Propagation*, vol.57.no.2, 2009, pp.484-490

[3] M.F.Iskander, Zhengquing Yun Celik, N.Bell and J.Kim, Antenna Arrays and Propagation Models for Advanced

wireless Systems, *IEEE International Conference on Electromagnetics in Advanced Applications*, 2007, pp.79-84.

[4] S.W.Yang , Y.K.Chen, and Z.P.Nie, Simulation of Time Modulated Linear Antenna Arrays Using the FDTD Method, *Progress in Electromagnetic Research*, vol.98, 2009 175-190.

[5] Bo Sun, Jinghui Qiu, Lingling Zhong and Xiaohang Xing, Design of Double Frequency Coaxial CTS antenna, *Progress In Electromagnetics Research Symposium*, Hangzhou, China, March 24-28, 2008, pp.875-877.

[6] N. Celik, W. Kim, M. Demirkol, M. Iskander and R.Emrick, Implementation and Experimental Verification of a Smart Antenna System Operating at 60 GHz Band, *IEEE Transactions on Antennas and Propagation*, vol. 56, no.9, 2008, pp. 2790- 2800.

[7] Dong Hailin, Xu Yunxue, Liu Ying, Zhang Pengfei and Yang Dong, A planar parallel plate fed Continuous Transverse Stub (CTS) array antenna, Proceedings of International Conference on Microwave and Millimeter Wave Technology', pp. 2012, 326-328.

[8] M.F. Iskander, N.Celik and W. Kim, Low Cost Phased Array Antennas using Analog and Digital Phase Shifters Technologies, *IEEE Antennas and Propagation Society International Symposium*, pp.37 – 40, 2007,9-15.

[9] J.M. Bell and M. F. Iskander, Ultra wideband Hybrid EBG/Ferrite Ground Plane for Low-Profile Array Antennas, *IEEE Transactions on Antennas and Propagation*, vol. 55,2007, pp.4-12.

[10] Jinghui Qiu, Xiaohang Xing and Lingling Zhong, A Novel Coaxial CTS Antenna Design, *IEEE 6th International Conference on Antenna Theory and Techniques*, 2007, pp 323-325.

[11] W. Kim, M. Iskander and C. Krowne, Modified Green's Function and Spectral Domain Approach for Analyzing Anisotropic and Multi-Dielectric Layers Coplanar Waveguide Ferroelectric Phase Shifters, *IEEE transactions on Microwave Theory and Techniques*, vol. 55, no.2, part 2,2007, pp.402- 409.

[12] N. Celik, W. Kim, M. Demirkol, M. Iskander and R.Emrick, Implementation and Experimental Verification of Hybrid Beam-forming Algorithm", *IEEE Antennas and Wireless Propagation Letters*, vol. 5, Issue 1, Dec 2006, pp. 280-283.

[13] Wayne Kim, Magdy F. Iskander and W.Devereux Palmer, An Integrated Phased Array Antenna Design Using Ferroelectric materials and the Continuous Transverse Stub Technology, *IEEE Transactions on Antennas and Propagation*, vol. 54, no.11, pp.3095-310, November, 2006.

[14] W. Kim, High Performance Phased Antenna Arrays Based on The Ferroelectric and Continuous Transverse Stub Technologies, *Ph.D Dissertation*, Univ. of Hawaii, HI, U.S.A, 2006.

[15] R. Isom, M. F. Iskander, Z. Yun, and Z. Zhang, Design and development of multiband coaxial continuous transverse stub (CTS) antenna arrays, *IEEE Transactions on Antennas and Propagation*, vol. 52, no. 8, 2004, pp. 2180-2184, 2004.

[16] Zhang, M. F. Iskander, Z. Yun and A. Host-Madsen, Hybrid Smart antenna system using directional elements – performance analysis in flat Rayleigh fading, *IEEE Trans. on Antennas and Propagation*,vol.51, no. 10,2003, pp.2926-2935.

[17] T. Sikina, D.McKay, K. Komisarek, and B.Porter, Variably Inclined Continuous Transverse Stub-2 Antenna, *IEEE International Symposium on Phased Array Systems and Technology*, 2003, pp.435 –440.

Mrs.P.Jothilakshmi has received her B.E. degree in Electronics and Communication Engineering from Madras University, India in 1996 and M.E degree from Madurai Kamaraj University, India in 2000. Currently working as an Assistant Professor in Electronics and Communication Engineering Department at Sri Venkateswara College of Engineering, Chennai, India. She has been a teacher for past 15 years and guided more than twenty five B.E and M.E Students. She has published more than thirty seven conference and Journal papers both National and International level. Pursuing Ph.D in the area RF antenna design under the supervision of Dr.(Mrs) S. Raju, Professor and Head, Department of Electronics and Communication Engineering, Thiagarajar College of Engineering, Madurai, India. She is a member in professional societies ISTE, IETE and IAENG.

Dr.(Mrs)S.Raju has B.E degree in Electronics and Communication Engineering from P.S.G college of Technology, India in the year 1982 and M.E in Communication systems in 1984 from Regional Engineering College Trichy, India. She obtained her PhD in the area of Microwave integrated circuits in the year 1996 from Madurai Kamaraj University. She was the first women Engineer to obtain Ph.D from Madurai Kamaraj University. India, currently working as a Professor and Head, Department of Electronics and Communication Engineering and as a Coordinator of TIFAC CORE in Wireless Technologies at Thiagarajar College of Engineering, Madurai, India. She has been a teacher for the past twenty eight years and has successfully guided eight Ph.D scholars and currently seven scholars are pursuing PhD under her supervision. She has guided more than fifty M.E and M.S Students. She has co-authored forty seven technical papers in international and national journals. She has published sixty papers in international and national conferences. She has successfully completed seven research projects for Defence Research Development Organization (DRDO) Laboratories, namely RCI, Hyderabad, DEAL Dehradun and ARDB, New Delhi. She has been awarded Career Award for Young Teachers in the year 1997 by AICTE, New Delhi and TCE Management Award. She has been research council member, Academic Council Member, Chairman Board of Studies of Electronics and Communication Engineering of Anna University, India.