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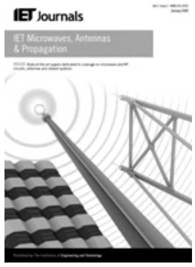

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Miniaturised multiband two-element coaxial continuous transverse stub antenna for satellite C-band applications

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Abstract: The continuous transverse stub (CTS) technology incorporates the use of coaxial lines to produce effective microwave antenna structures that radiate an omnidirectional pattern with high efficiency and low return loss. In this paper a two-element coaxial CTS antenna array is designed to operate in the C-band with improved efficiency and gain. The proposed prototype of the C-band antenna, with design operating frequencies –5.18, 6.536 and 7.42 GHz, finds numerous applications in C-band satellite communications. During simulation, the efficiency at these frequencies had been observed to be 89.5, 87.6 and 95.9% and their corresponding gains were observed to be 7.54, 5.24 and 7.51 dB, respectively. The measured results of the C-band antenna prototype for the above stated frequencies were observed to be 5.185, 6.845 and 7.313 GHz, respectively. This antenna can be used in INSAT/super extended C-band, fixed-satellite services which include space to earth, earth to space as well as mobile satellite services. The radiation of the designed structure is omnidirectional in the horizon plane, with minimum return loss. These simple and low-cost coaxial CTS structures can be adopted in wireless communication systems.

1 Introduction

The planar continuous transverse stub (CTS) was originally invented by W.W. Milroy at Hughes Aircraft Company in 1991. This represented a new category of low-cost antenna. This technology was adopted only recently in research. It offers traditional approaches to antenna design at microwave frequencies [1, 2]. A CTS element array structure exhibits coaxial geometry from a plurality of cylindrical segments. Each one of the cylindrical segments has a rim at the top and bottom end. Each rim extends transversely from the cylindrical segment with respect to a longitudinal axis to form a stub element and the individual cylindrical elements are aligned end-to-end to form a coaxial cable structure which surrounds a central core material. The series of these stubs form reactive or radiating elements for microwave, millimetre-wave and quasi-optical filter and antennas. The benefits of CTS structures include compact size, light-weight, decreased loss and high directivity. CTS technology also offers greater tunable bandwidth over waveguide or patch antennas. It is possible to obtain higher efficiency and polarisation isolation using this technology [3]. All the above facts are advantageous in the application of the coaxial geometries. The coaxial CTS structure provides omnidirectional radiation pattern, perpendicular to the transmission line. Another includes easier impedance matching, thereby providing higher efficiency and facilitating system integration with other structures.

The CTS technology can be used to design the antenna operating in a single band or in the multiband. The observation made from previous works [4–6] shows that the CTS antenna array can operate at high frequency and offers multiple frequency bands. There are three optimisation methods to improve the efficiency and the gain of the coaxial CTS antenna operating at the required band. These simple low-cost coaxial structures could be adapted to suit microwave frequency wireless communication applications, satellite application systems and could also be used in the Friend-or-Foe systems. The double frequency coaxial CTS antenna, operating in two different frequencies can be adapted to suit the base station applications in wireless communications. CTS antenna offers wide bandwidth. In the upper frequency region, it can also be used for satellite communication and personal communication systems [6]. CTS antenna [7] can be designed to serve as means of identification of Friend-or-Foe systems for the military. The proper separation between the arrays of different bands by the coaxial transmission line forms a single array antenna that can radiate at low and high frequency. Thus, the CTS antenna is capable of providing the multiband operation, thereby improving the band of operation with the reduced size of the antenna. Bo Sun *et al.* (2004) describes the structure and design of the double-frequency CTS structure with improved efficiency and gain. The use of different dielectric materials like Teflon, polypropylene that fills the stubs are thought to be customary in characterising the

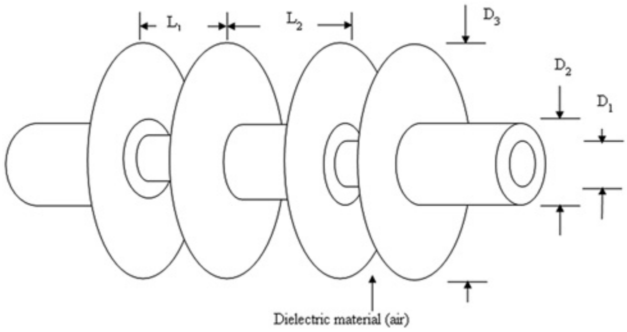

Fig. 1 *Geometry of two elements coaxial CTS antenna array*

performance of the antenna and to reduce the size of the antenna. The survey of Jinghui Qi *et al.* (2007) gives importance to a series of parameters that must be satisfied to get higher efficiency and gain of the antenna. The CTS antenna provides the advantage of the omnidirectional pattern in the horizon plane (perpendicular to the transmission line). An improvement in the performance of the antenna efficiency and the gain are obtained by varying the length of the transmission line segment, diameter of the stubs and the space between two stubs.

The coaxial line provides good impedance matching, with reduction in the reflection loss and greater tunable bandwidth that facilitates the integration of one coaxial structure with the other structures. The CTS antenna with multiple operating frequencies [7] that can be used for wireless communications and satellite applications can be designed through the inclination of the stubs. The applications include deep space communications, as well as terrestrial microwave communications. The proposed design is used

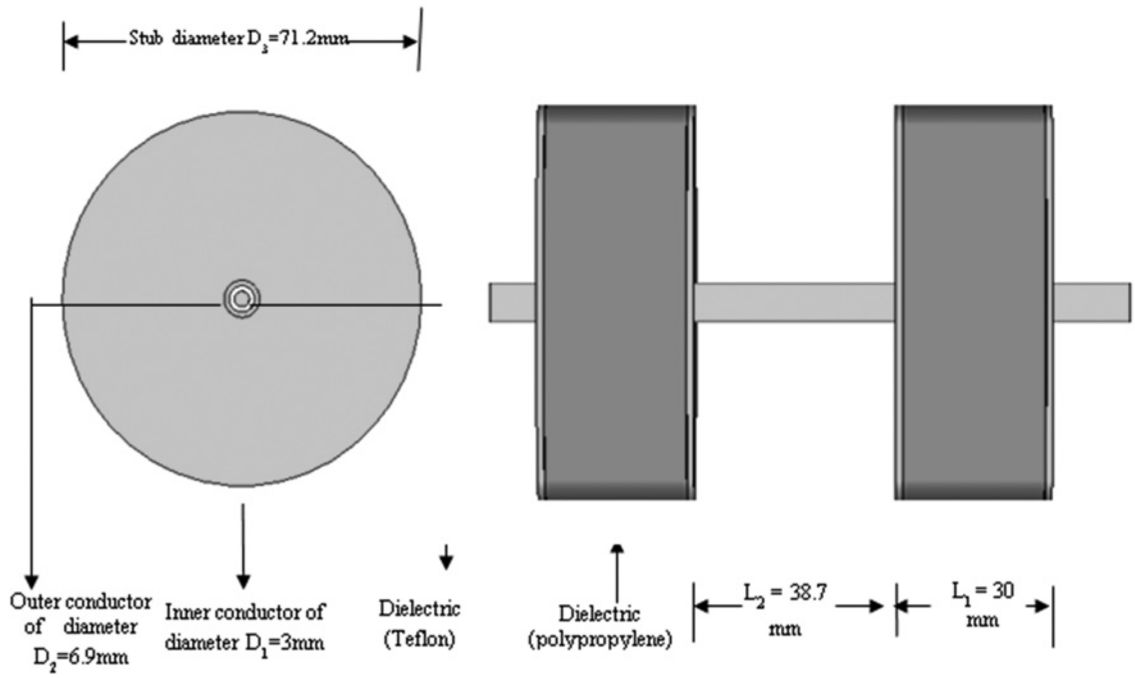

Fig. 2 *Geometry of two elements coaxial CTS antenna array during CST software simulation*

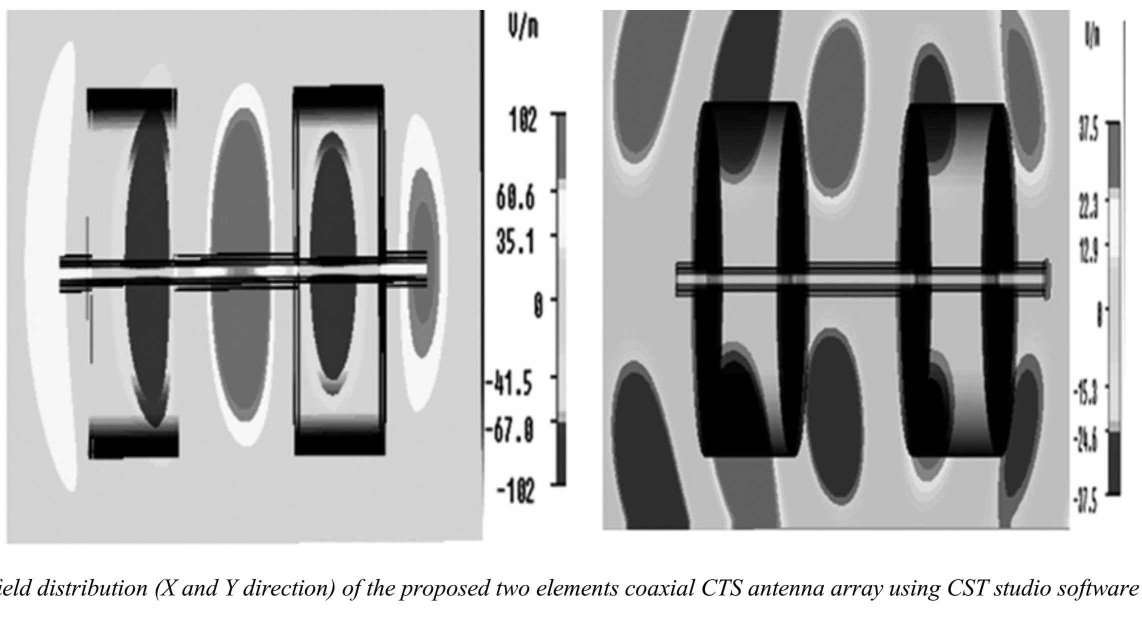

Fig. 3 *E-field distribution (X and Y direction) of the proposed two elements coaxial CTS antenna array using CST studio software simulation*

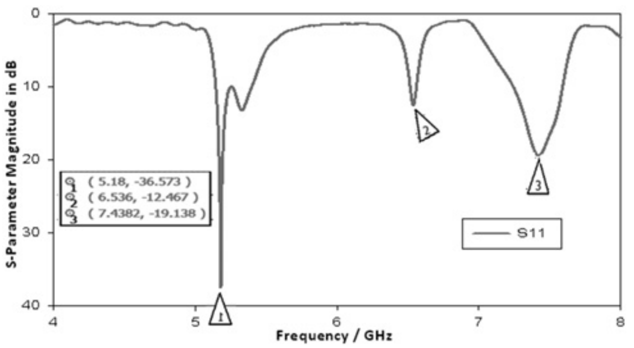

Fig. 4 *Return loss plot of the proposed two elements coaxial CTS antenna array using CST studio software simulation*

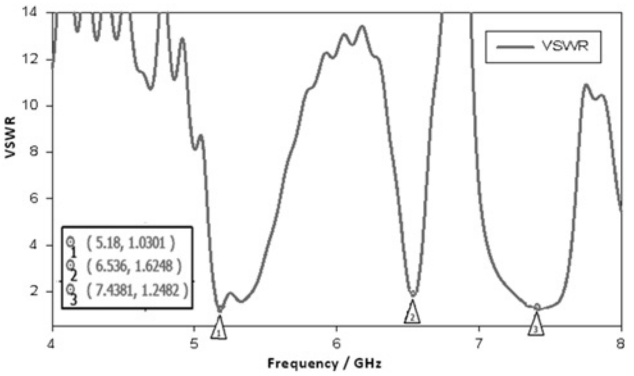

Fig. 5 *VSWR plot of the proposed two elements coaxial CTS antenna array using CST studio software simulation*

for satellite C-band and extended C-band applications. This design reduces the total size of the antenna significantly compared to previous models [6, 7]. In this design the length of the antenna used is 98.7 mm (to support three different frequency bands) whereas in the previous designs [8, 9] (producing two bands) the length of the antenna was 181 mm. This shows that the proposed CTS antenna array structure has miniaturised. The electromagnetic (EM) simulation software, CST Studio Suite, is used to optimise the antenna array in this design. This integrated design environment gives access to the entire range of solver technology, which comprises CST Microwave Studio as one of its modules. CST Microwave Studio is a special tool for the three-dimensional (3D) EM simulation of high-frequency (HF) components. It enables fast and accurate analysis of HF devices, such as antennas, filters, couplers, planar and multilayer structures, as well as SI and EMC effects [10–13].

2 Proposed antenna structure and design

The simple structure of the coaxial CTS array antenna with two elements is shown in Fig. 1. The coaxial CTS antenna generally consists of several stub elements, and each stub element includes cascade sections of standard coaxial transmission line and open-ended radiating stubs. It is proposed for the design of coaxial CTS array antenna with two elements separately to operate in C-band. One end of the array is fed by coaxial line, and the other end is connected with a matching load. The antenna can be terminated using a monopole. In the physical dimension optimisation method, the width of the stub L_1, the length of the transmission line segment L_2 or the diameter D_3 of the stub can be varied to achieve the desired radiation efficiency and the gain. In this design, the efficiency and gain of the proposed CCTS antenna is improved using the physical dimension alteration method. The other two methods refer to the addition of the terminal elements like monopole at the end of the line to improve the radiation and placing the stubs at an angle reference to the line. Usually, the width of the stub segment was selected to be a half wavelength in dielectric material that fills the stub. The

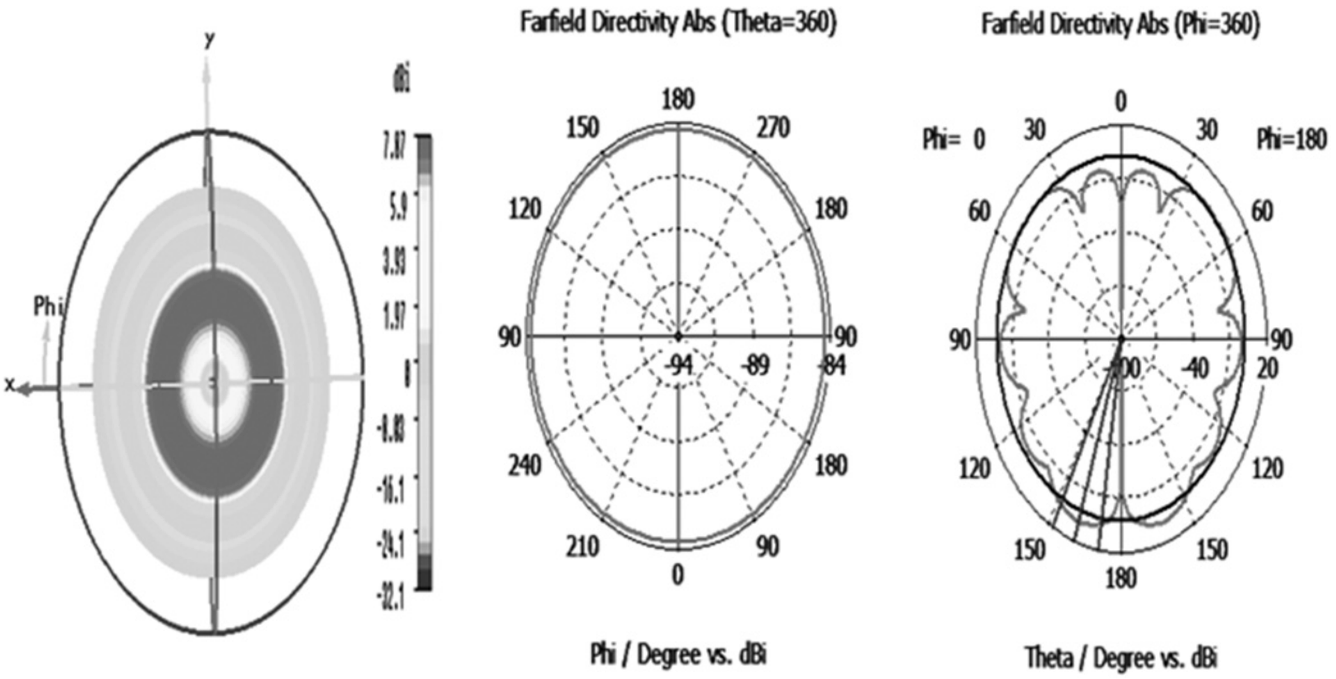

Fig. 6 *Three-dimensional and 2D (horizontal and vertical planes) radiation pattern plot of the proposed two-element coaxial CTS antenna array using CST studio software simulation at 5.18 GHz*

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commercially available Teflon and polypropylene can be used to fill the stubs.

The length of the transmission line segment L_2 and dielectric constant ε_r of dielectric material can be chosen to fulfil the distance and phase demands between the stubs. The diameter of the inner and the outer conductor (D_1 and D_2) of the coaxial transmission line can be adjusted to obtain the desired value of the impedance, such as 50 Ω or 75 Ω in some cases of coaxial transmission line. The ratio between D_3 and D_2 determines the radiation pattern, voltage across each stub and the radiated power from each stub. Smaller values of D_3 and D_2 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 above condition. It can be known that the diameters of the inner

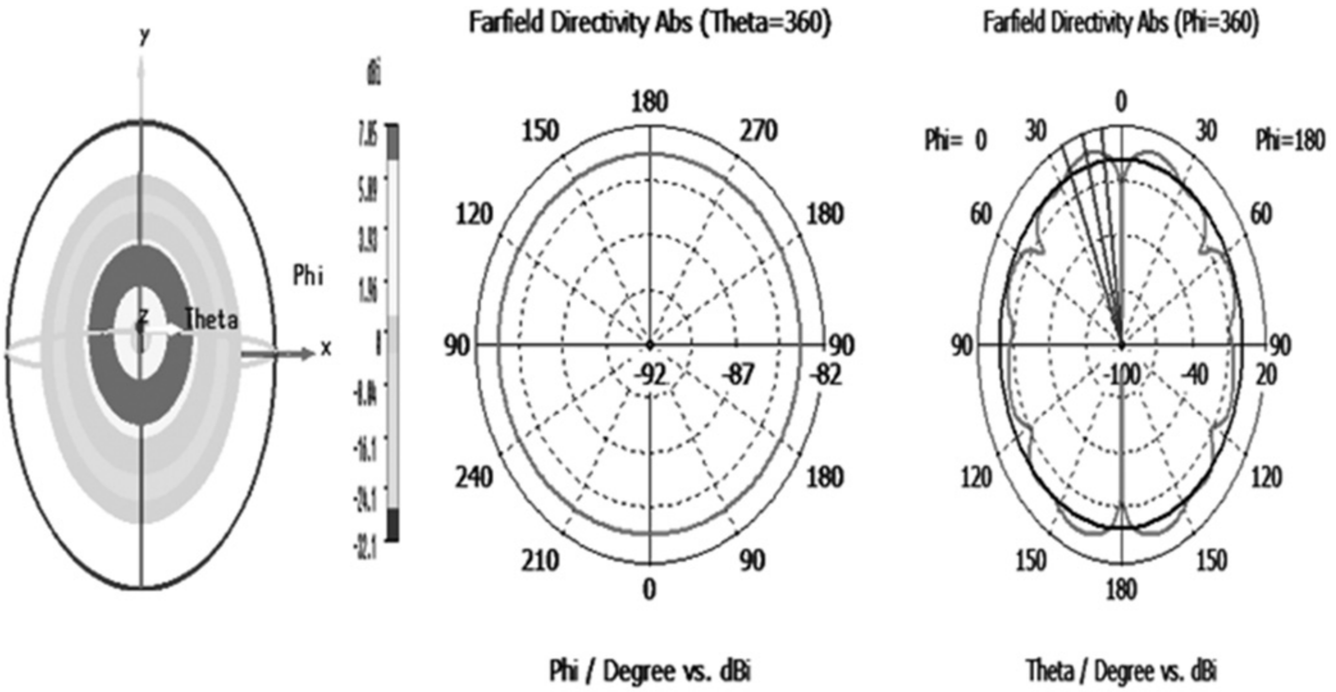

Fig. 7 *3D and 2D (horizontal and vertical planes) radiation pattern plot of the proposed two elements coaxial CTS antenna array using CST studio software simulation at 6.5 GHz*

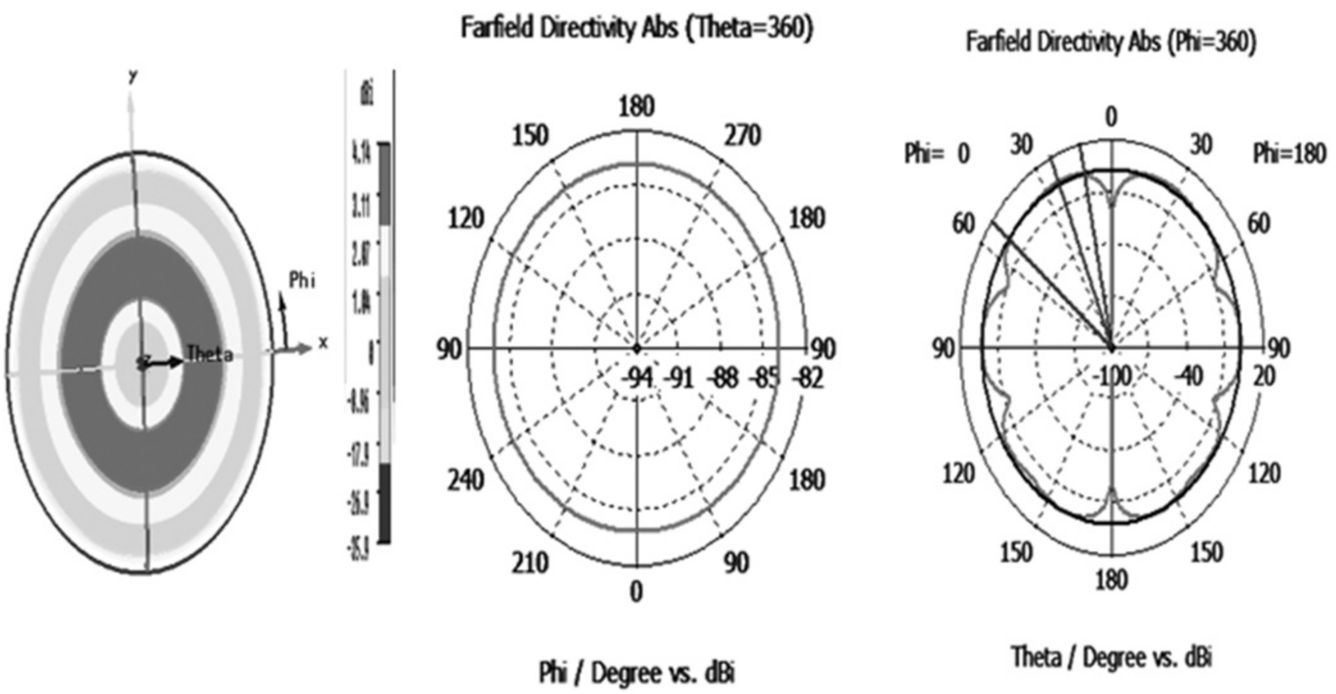

Fig. 8 *3D and 2D (horizontal and vertical planes) radiation pattern plot of the proposed two elements coaxial CTS antenna array using CST studio software simulation at 7.4 GHz*

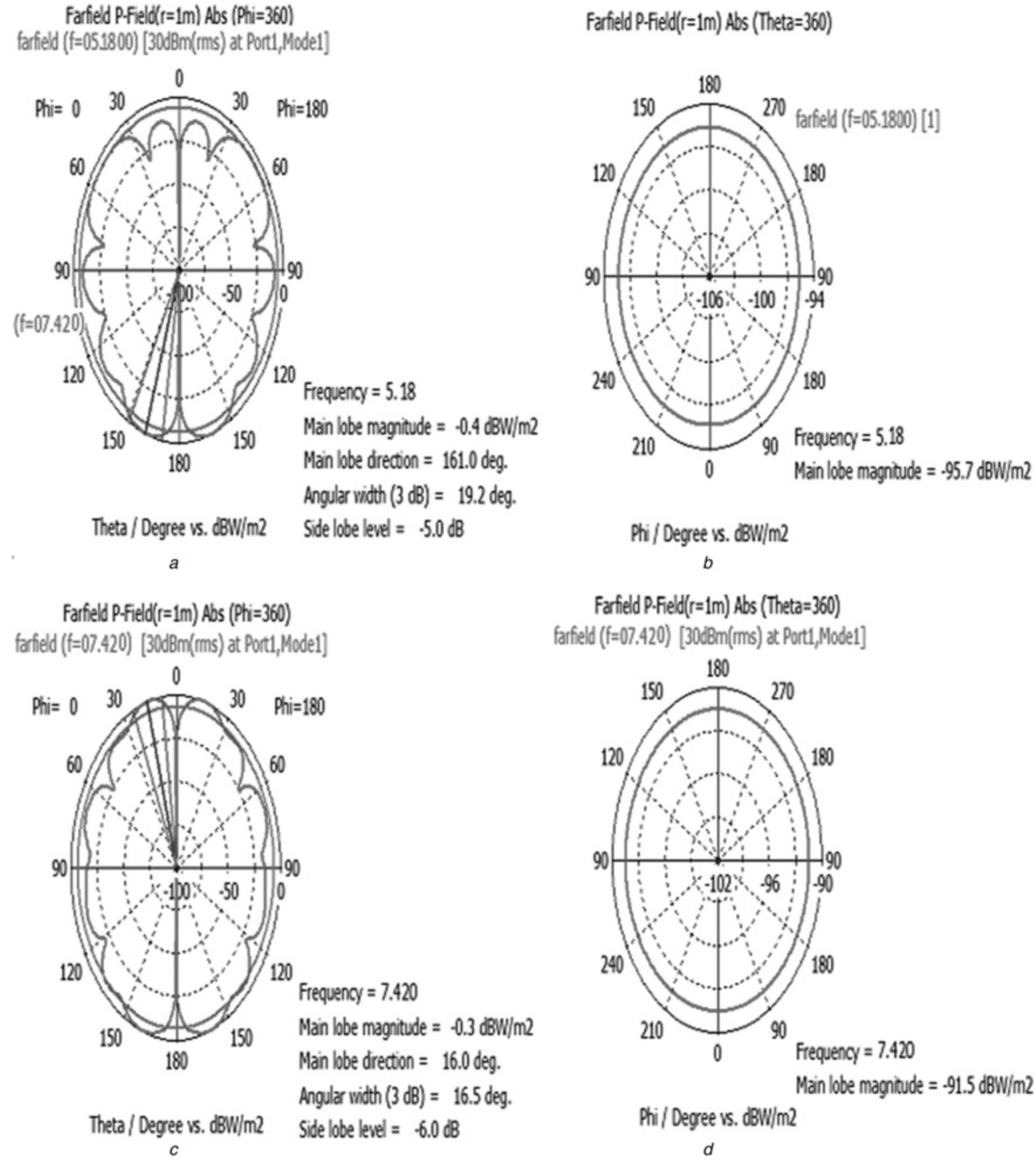

Fig. 9 *2D (horizontal and vertical planes) power pattern plot of the proposed two-element coaxial CTS antenna array using CST studio software simulation*

a 5.18 GHz (theta plane)
b 5.18 GHz (phi plane)
c 7.42 GHz (theta plane)
d 7.42 GHz (phi plane)

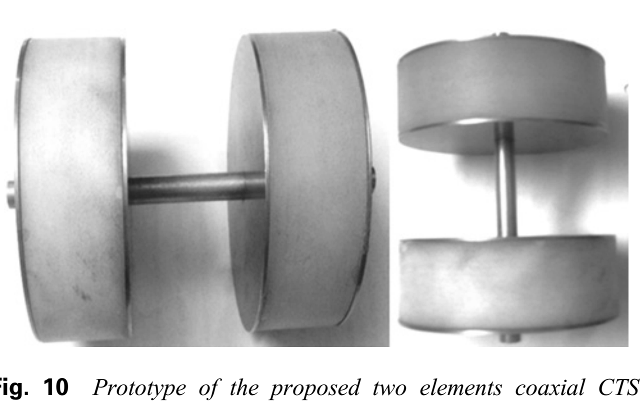

Fig. 10 *Prototype of the proposed two elements coaxial CTS antenna array for satellite C-band communication*

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 are excellent self-matching structures. 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.

The structural description for the C-band antenna with the desired number of stubs will determine the overall efficiency and the power radiated from each of the stubs. The proposed C-band coaxial CTS array antenna consists of two stubs. One end of the proposed antenna array is fed by coaxial line. The important parameters of coaxial CTS antenna are: (a) width of the stub segment L_1; (b) length of the transmission line

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segment between stubs L_2; (c) diameter of the inner conductor D_1; (d) diameter of the outer conductor D_2; (e) diameter of the stub D_3; and (f) dielectric constant ε_r of the fill material. The radiation efficiency and gain of the C-band coaxial CTS antenna can be improved by altering the physical dimensions. The physical dimensions, namely the width of the stub L_1, length of the transmission line segment L_2 or the diameter D_3 of the stub can be varied to achieve the desired radiation efficiency and the gain. The dielectric loading is used to improve the performance and to reduce the size of the antenna. The coaxial CTS array antenna is a type of travelling-wave antenna, so farther the position of the stub from the array input port, lesser the power received. This aspect of the array design may be adjusted depending on the location of each stub and the dimensions of the stub. The characteristic impedance of coaxial line and antenna array length can be calculated using (1) and (2).

According to the transmission line theory, the impedance of the coaxial line is measured by

$$Z_0 = \frac{60}{\sqrt{\varepsilon_r}} \ln\left[\frac{D_2}{D_1}\right] \tag{1}$$

where Z_0 is the impedance of the coaxial line, ε_r is the dielectric constant of fill material in stubs, D_1 is the diameter of the inner conductor of the coaxial line and D_2 is the diameter of the outer conductor of the coaxial line.

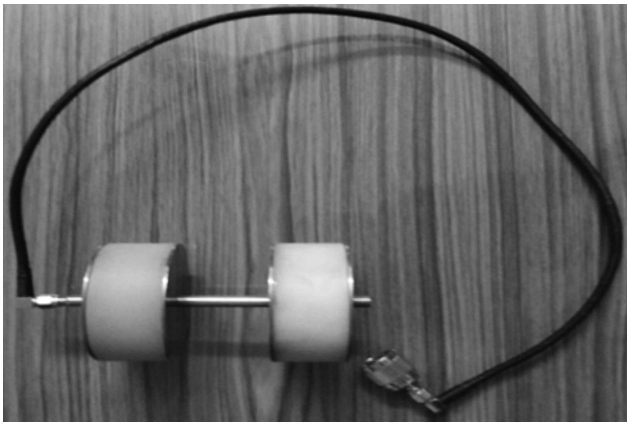

Fig. 11 *Prototype of the proposed two elements coaxial CTS antenna array with connector for satellite C-band communication*

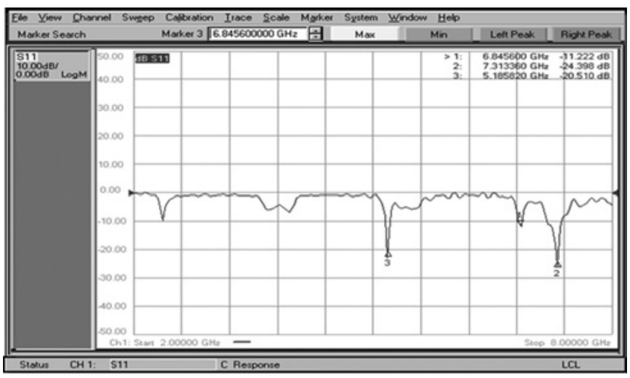

Fig. 12 *Measured return loss plot of the proposed two elements coaxial CTS antenna array using network analyser*

The length of the coaxial CTS array antenna can be calculated using the below formula

$$\text{Length} = L_1 \times n + L_2 \times (n - 1) \tag{2}$$

where L_1 is the width of the stub segment, L_2 is the length of the transmission line segment between the stubs, and n is the number of elements in the array.

3 Simulation results and discussion

From the design equation [2], the width of the stub segment, (L_1) is calculated as 30 mm, the length of the transmission

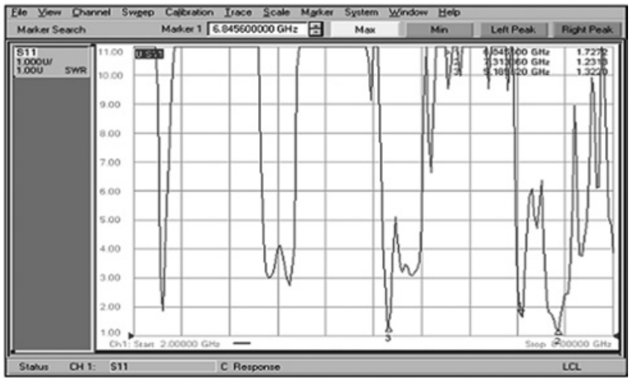

Fig. 13 *Measured VSWR plot of the proposed two elements coaxial CTS antenna array using network analyser*

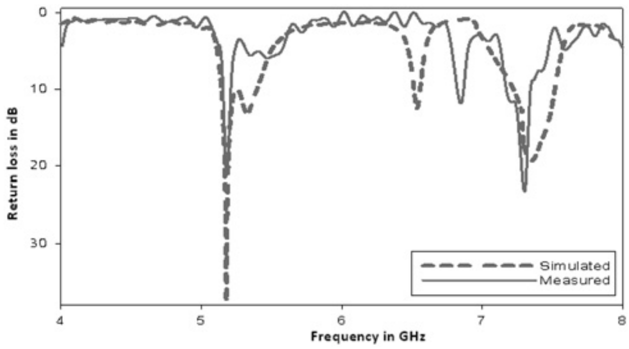

Fig. 14 *Comparison between simulated and measured return loss plot of the proposed two elements coaxial CTS antenna array*

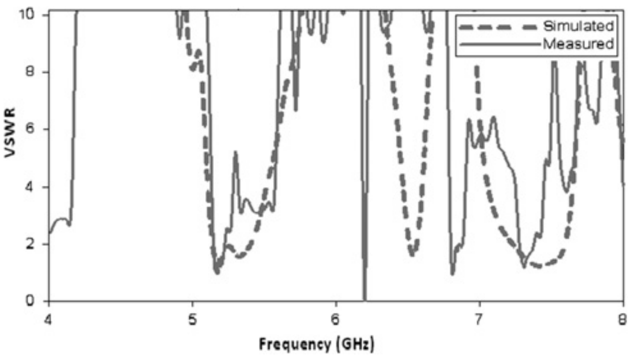

Fig. 15 *Comparison between simulated and measured VSWR plot of the proposed two elements coaxial CTS antenna array*

Table 1 Simulated parameters and comparisons between simulated and measured results of proposed CCTS antenna array for three operating frequency bands

Simulated output						Measured output		
Frequency, GHz	Return loss, dB	VSWR	Gain, dB	Directivity, dBi	Max. power dBW/m^2	Frequency, GHz	Return loss, dB	VSWR
5.18	36.573	1:1.03	7.656	7.865	– 0.436	5.185	20.51	1:1.32
6.536	12.467	1:1.62	3.732	4.143	– 11.9	6.845	11.22	1:1.72
7.42	19.42	1:1.24	7.674	7.851	– 1.99	7.313	20.39	1:1.23

line segment (L_2) is calculated as 38.7 mm, the diameter of inner conductor (D_1) and outer conductor (D_2) as 6.9 mm and 3 mm, respectively. The total length of the array antenna is calculated as 98.7 mm. These design values show that the length of the proposed continuous transverse stub antenna array has reduced when compared to previous designs [7, 8, 14, 15]. Fig. 2 shows the geometry of proposed continuous stub antenna array during software simulation. Fig. 3 shows the *E*-field distribution of proposed CTS antenna array in *X* and *Y* direction, and a very good field distribution has been observed in both directions. Figs. 4 and 5 show the return loss and voltage standing wave ratio (VSWR) plot of the proposed antenna structure, which shows that the antenna would radiate for three frequency bands at 5.18, 6.536 and 7.432 GHz with optimum return loss of −36.57, −12.467 and −19.138 dB, and VSWR of 1:1.03, 1:1.62 and 1:1.24, respectively. Figs. 6–9 show the 2D radiation pattern and 2D power pattern of proposed CTS antenna array for the entire three frequency bands with radiation efficiency of 89.5, 87.6 and 95.9%, which shows that the antenna should radiate with maximum efficiency in the HF range and produce omnidirectional radiation pattern in the horizontal plane and dipole pattern in vertical plane with minimum power requirement.

4 Prototype of the proposed antenna structure and its measured results and discussion

Figs. 10 and 11 show the fabricated two elements of CTS antenna array for C-band applications with Teflon as dielectric and Brass as stub material, and the dimensions are carefully chosen to work under three different operating frequency ranges. Figs. 12 and 13 show the return loss and VSWR plot measured in SAMEER (Electromagnetic Research Centre at Chennai, Tamil Nadu, India) using network analyser. Figs. 14 and 15 show the performance comparison between simulated and fabricated antenna structure. The corresponding return loss and VSWR for these operating frequencies, namely 5.185, 6.845 and 7.31 GHz are 20.51, 11.22 and 20.39 dB, respectively, with VSWR of 1:1.322, 1:1.7272 and 1:1.2313, respectively. From the result, it is observed that, at the interested frequencies, the return loss is got to be less than 10 dB. These values represent that much of the power fed at the antenna terminals is radiated effectively. A VSWR of 1:1 means that there is no power being reflected back to the source. This is an ideal situation that is rarely, if ever, seen. At a VSWR of 2.0, approximately 10% of the power is reflected back to the source. Not only does a high VSWR mean that power is being wasted, the reflected power can cause problems such as heating cables or causing amplifiers to fold-back. Table 1 shows the gain, directivity, maximum power, return loss and VSWR for three frequency bands. The observation made from Table 1 is that there may be a slight variation between simulated and measured results. This deviation is caused due to component proportion and machine design modelling, owing to slight deviation in the structural parameters because of its small dimensions. Some variation in manual cut and all leads to this frequency shifting. There is no provision here to combine two elements into a single piece. There is no major difference between the three frequency bands. Comparisons of these results show that the proposed antenna array structure will work under C-band and extended C-band satellite communication.

5 Conclusion

The simulated and measured results show that the proposed radial-shaped CTS structure is well suited to radiate in microwave frequency bands. These frequency bands are suitable for satellite and RADAR applications. This structure offers good radiation efficiency for all the bands with minimum side-lobe level. The *S*-parameters of the proposed structure and radiation pattern show that the operating frequency of the antenna is well suited for HF C-band satellite transmission and reception purpose. The results show that the same structure can be used to cover multiple frequencies.

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