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Design of Coaxial Continuous Transverse Stub Antenna Array for Mobile and Space Application

M.Kumaran

Abstract— Continuous Transverse Stub (CTS) technology with coaxial transmission line can be used for simple, light weight, low-loss microwave structures with omnidirectional radiation pattern in the horizon plane. The Coaxial CTS antenna provides low reflection with good input impedance and high radiation efficiency. This paper proposes the design of coaxial CTS antenna array operating at 2.238 GHz in S-band. The return loss (S_{11}) at this frequency is -47.481 dB. The corresponding gain and efficiency is 5.025 dB and 92.2%. This type of antenna can be used for fixed (line of sight), mobile (line of sight) and space operation. This paper also discusses the design of the CTS antenna array in X-band. Operating at 10.548 GHz this antenna can be used for radiolocation. Return loss (S_{11}) is got to be -34.642 dB. Radiation efficiency and gain at this frequency is 94.6% and 2.47 dB. The basic theory is analyzed. Design and optimization is done using CST Microwave Studio software. The simulation result shows the better performance in both S-band and X-band. The achieved impedance of 35 Ω doesn't worse the result obviously.

Index Terms— CTS array, mobile, radiolocation, space operation, S-band, X-band.

I. INTRODUCTION

The Planar CTS technology was originally invented by W.W. Milroy at Hughes Aircraft Company in 1991. It has attracted the research trends. This technology offers more advantages than the traditional approaches to the antenna design at microwave frequencies. Compact size, light weight, low loss and high directivity are the benefits of the CTS structure. Design of CTS structure as a multiband antenna is possible with coaxial transmission line [1], [2]. It was observed that the parallel-plate CTS arrays have achieved average gains of 39.7 dB over the bandwidth of 37-40 GHz with the relative dimensional insensitivity thus reducing the fabrication costs [3]. It is the category of low cost antenna with the characteristics of low dispersion and dimensional robustness. Other characteristics of Coaxial CTS antenna include greater tuneable bandwidth than waveguide or patch antennas, higher efficiencies, and polarization isolation. It provides the omnidirectional radiation pattern in the direction of the radiating stubs. With the coaxial transmission line as its feed, these are inherently easier to impedance matching thus providing higher efficiency and facilitate system integration with other coaxial structures.

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* Correspondence Author (s)
M.Kumaran*, Department of Electronics and Communication Engineering, Sri Venkateswara College of Engineering, Sriperumbudur, Chennai, India.

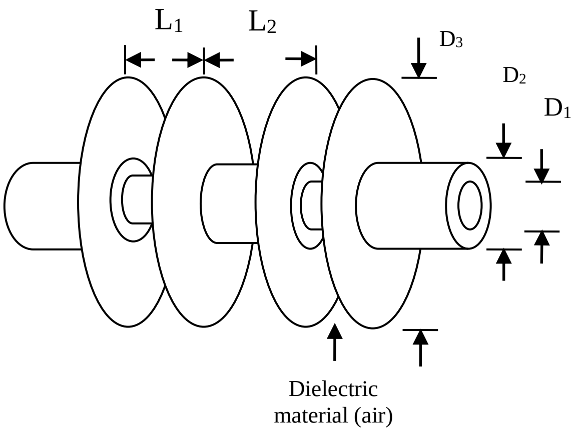

Fig.1. Two element Coaxial Continuous Transverse Stub (CTS) Antenna array

Brass is used as conductor. Teflon and polypropylene are used to fill between the inner and outer conductor of coaxial line and between stubs. The pattern and the array structure are the difference between the planar and the coaxial CTS version. In this paper, two separate antenna array operating in S-band and X-band is designed by simulating different structures using the CST Microwave Studio software. CST Microwave Studio is a specialized tool for the fast and accurate 3D EM simulation of high frequency problems.

II. COAXIAL CTS ANTENNA DESIGN PARAMETERS

Figure 1 shows the simple structure of the two element coaxial CTS antenna array. It consists of the coaxial transmission line, open ended radiating stubs and the dielectric filler material (air is chosen as dielectric) that fills the stub. Pure reactive elements can be realized through conductive terminating. Stubs of moderate height are opened to free space to form the radiating elements. Important Parameters of the CTS structure are (a) diameter of the inner conductor D_1; (b) diameter of the outer conductor D_2; (c) diameter of the stub D_3; (d) width of the stub L_1; (e) length of the transmission line segment between two stubs L_2; (f) dielectric constant of the filling material. In the design of the multiband antenna array as a single structure, the upper frequency stubs and the lower frequency stubs are separated by a distance (L), it is taken into account for the calculation of total length of the antenna array. The diameter of the inner conductor and the outer conductor of the coaxial line can be varied to achieve the desired impedance. The impedance of the coaxial line can be calculated using

$$z_0 = \frac{60}{\sqrt{\varepsilon_r}} \ln\left[\frac{D_2}{D_1}\right]$$

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where Z_0 is the impedance of the coaxial line and ε_r is the dielectric constant of the dielectric material. The dielectric material filled between the stubs is mandatory to improve the performance of the CTS antenna. The length of the CTS antenna array can be calculated using

$$length = L_1 \times n + L_2 \times (n-1)$$

where n in the number of elements in array. The width of the stub L_1 and the length of the transmission line L_2 between the stubs can be varied to achieve the desired radiation pattern. The width of the stub L_1 is chosen to be half the wavelength in dielectric that fills the stub. To fulfill the phase demands and the distance between the stubs, the dielectric constant of the material that fills the stub and the transmission line segment of

length L_2 are chosen appropriately. Radiated power from each stub is determined by the ratio between D_3 and D_2. This also determines the radiation pattern and the voltage across each of the stubs.

TABLE 1
PARAMETERS OF S-BAND COAXIAL CTS ANTENA

Band	D_1	D_2	D_3	L_1	L_2
S	3mm	6.9mm	50mm	35.3mm	40mm

Mutual coupling between the elements is possible if the diameter of the stub (D_3) is greater than the width of the stub (L_1). The constituent properties of the plates and stub dielectric mediums also control the mutual coupling between the plates of the stubs [8].

The Coaxial CTS antenna is an excellent self-matching structure. The design parameters D_3, D_2, L_2, and L_1 obviously determine the structure and properties of the antenna in terms of radiated power, impedance matching and radiation pattern. The farther the stub from the coaxial feed line, the less power is received by the stubs and if it is closer then more power is received.

III. DESIGN AND SIMULATION OF S-BAND COAXIAL CTS ANTENNA ARRAY

CST Microwave Studio is the electromagnetic simulation software used to analyze CTS antenna based on the finite integral method. After a series of calculation and optimization, the parameter chosen is shown in table 1. The impedance is calculated to 35 Ω that doesn't worse the simulation result obviously. The length of the antenna array becomes 150.6 mm. The designed S-band CTS array structure is shown in fig.2. The proposed antenna consists of three stubs operating at 2.238 GHz. Commercially available Teflon dielectric material of dielectric constant 2.1 is used to fill the space between the inner and the outer conductor of the coaxial line along the structure. Polypropylene material of dielectric constant 2.3 is used to fill the stubs. The uprising characteristics of Teflon material makes useful for this application are the resistance to chemicals, weather, UV resistance,

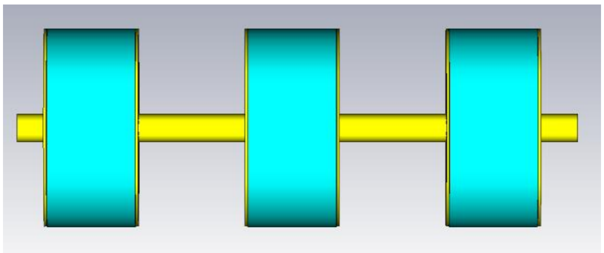

Fig.2 .Designed Structure of three element S-band Coaxial CTS antenna array

outstanding performance at extreme temperatures, low friction coefficient, low dissipation factor, high surface resistivity. As the same properties for polypropylene with the slight difference in the density, temperature and dielectric constant. To accomplish full transmission it is necessary to know the electrical dimensions of the antenna. The choice of the parameter D_3 is made to be greater than one third of the wavelength (λ/3 = 25 mm for 4GHz) or longer in case of S-band and 8mm for X-band. The optimization can be done by varying the distance between the stubs L_2, diameter of the stub D_3, and width of the stub L_1. More of the antenna performance and the reduction in overall size of the antenna can be achieved by using dielectric material. The antenna array provide low reflection and high-radiation efficiency at 2.238 GHz. Fig.3 shows the simulated reflection loss (S_{11}) of the S-band CTS antenna array. The plot shows the antenna radiates more efficiently at this frequency. Reflection loss (S_{11}) at this frequency is –47.481 dB. Simulated VSWR shown in Fig.4 is1.0085. Most of the power is radiated at this frequency. Fig.5 and fig.6 shows the 3D radiation pattern in gain mode and directivity mode. The gain and directivity is got to be 5.025 dB and 5.377 dBi. Fig.7 and fig.8 shows the obtained radiation pattern in theta plane and phi plane. Feed is from 0^o or 360^o in both the cases. The plot with the red marked circle shows the omnidirectional radiation pattern. More than 90% of the power is radiated by the antenna at this frequency.

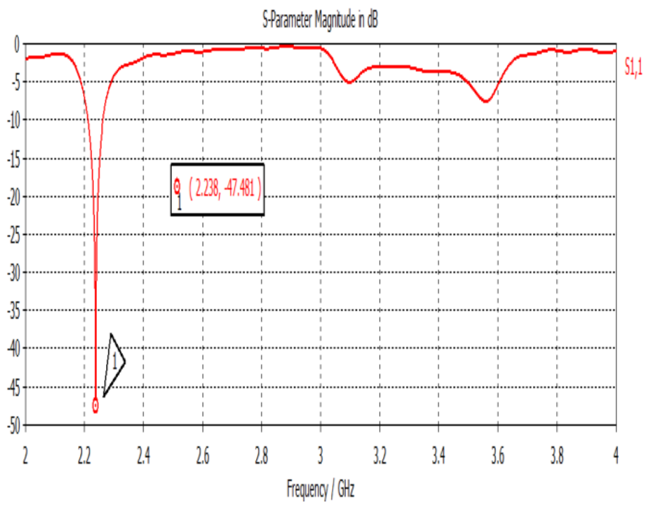

Fig.3. Simulated reflection loss (S_{11}) of S-band Coaxial CTS antenna array

The radiated power is the total power minus the power reflected back. The performance of the S-band antenna is improved in this range. The bandwidth at 2.238 GHz (S_{11} < -10 dB) is 51 MHz.

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As the coaxial line is travelling-wave-type array; for better performance the radiating stubs are placed close to the coaxial line feed to the possible extent so that the signals with more power will reach the stubs resulting in the maximum power radiation. The smaller the ratio between D_3 and D_2, refer the factor of stub coupling and radiation. If the array was designed such that each stub radiates a larger amount of power, then the array will effectively include a reduced number of stubs that can be used as a low gain antenna. On the other hand, if each stub was designed to radiate less power then more stubs can be used and a high gain antenna array may be designed. The metal plates used as stub determine the properties of the antenna.

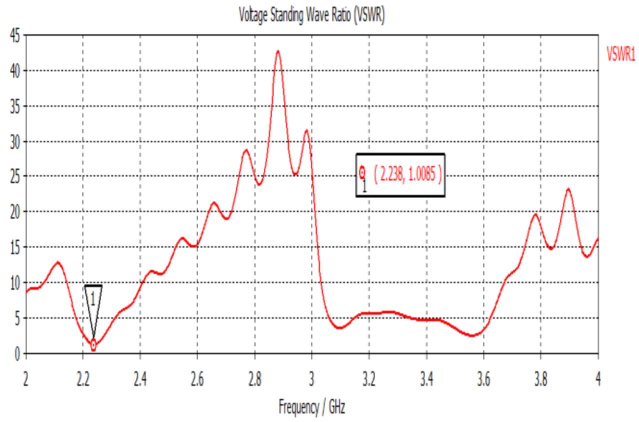

Fig.4. Simulated VSWR of S-band Coaxial CTS antenna array

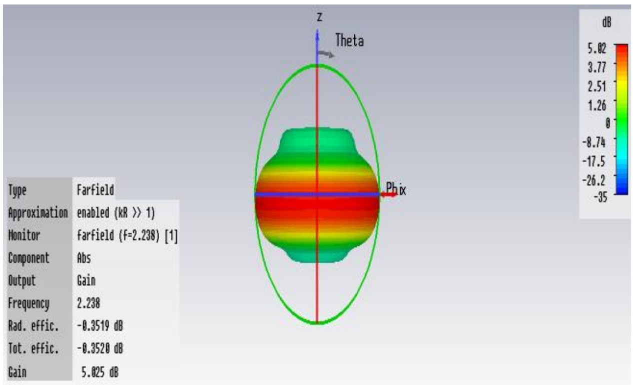

Fig.5. 3D radiation pattern in gain mode for the designed three element S-band CTS antenna array at 2.238 GHz

IV. DESIGN AND SIMULATION OF X-BAND COAXIAL CTS ANTENNA ARRAY

The design of X-band CTS antenna array follows the same procedure as the design of S-band CTS antenna array. After a series of optimization, the parameters shown in table 2 are chosen. Length of antenna array is 22 mm. The designed X-band (8-12 GHz) CTS array structure is shown in Fig.9. The operating frequency is 10.548 GHz as shown in Fig.10. The return loss at this frequency is -34.632 dB. The Bandwidth (S_{11}< -10 dB) in the operating region is 487 MHz respectively. The simulated VSWR in Fig.11 shows the better performance of the antenna. The corresponding VSWR value is 1.0378. The 3D radiation pattern in Fig. 12 and 13 are shown in gain mode and directivity mode at 10.548 GHz. Gain and radiation efficiency are 2.47 dB and 94.6%. Directivity at this frequency is 2.71 dBi. Thus the power feed at the antenna terminals are radiated efficiently. Teflon is used to fill the stubs. Obtained omnidirectional radiation pattern in

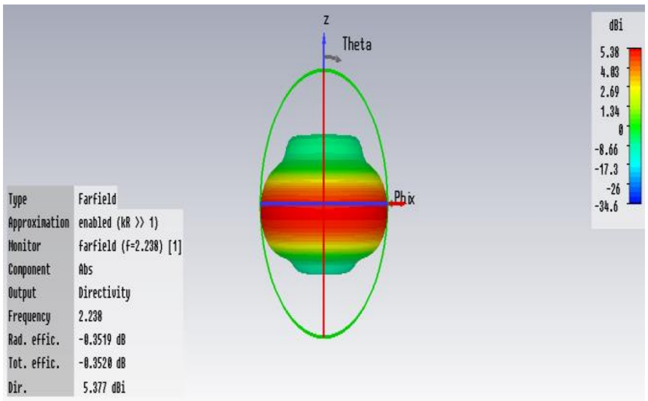

Fig.6. 3D radiation pattern in directivity mode for the designed three element S-band CTS antenna array at 2.238 GHz.

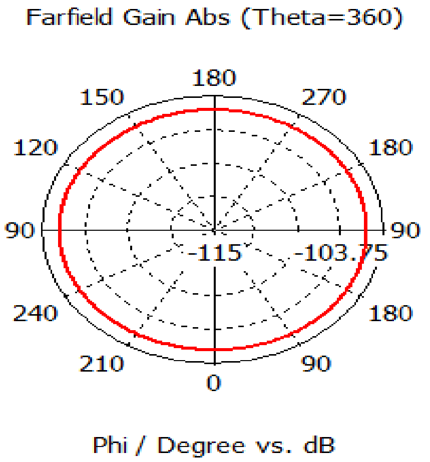

Fig.7. Radiation pattern in theta plane of the three element Coaxial CTS antenna array at 2.238 GHz. Feed is from 0° or 360°

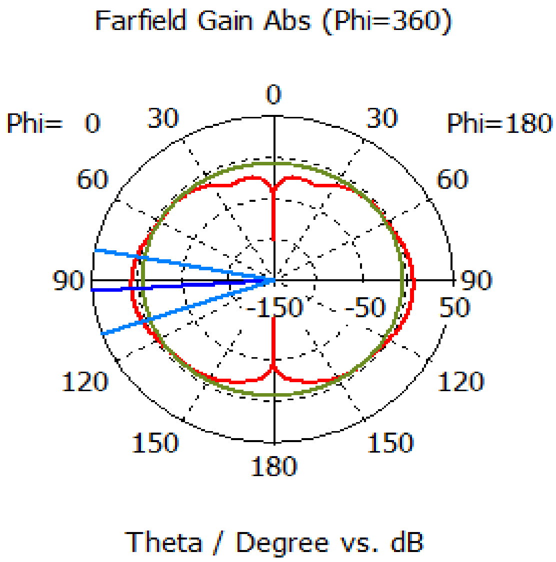

Fig.8. Radiation pattern in phi plane of the three element Coaxial CTS antenna array at 2.238 GHz. Feed is from 0° or 360°

the theta plane and the pattern in phi plane is shown in Fig. 14 and 15 at feed 0° or 360°. Fine tuning might eliminate the nulls at 0° and 180° in phi plane.

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TABLE 2
PARAMETERS OF X-BAND COAXIAL CTS ANTENA ARRAY

Band	D_1	D_2	D_3	L_1	L_2
X	3mm	6.9mm	19mm	7mm	8mm

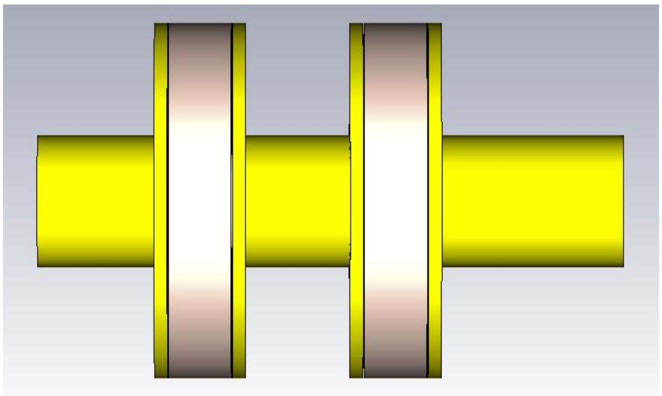

Fig.9 .Designed Structure of three element X-band Coaxial CTS Antenna array

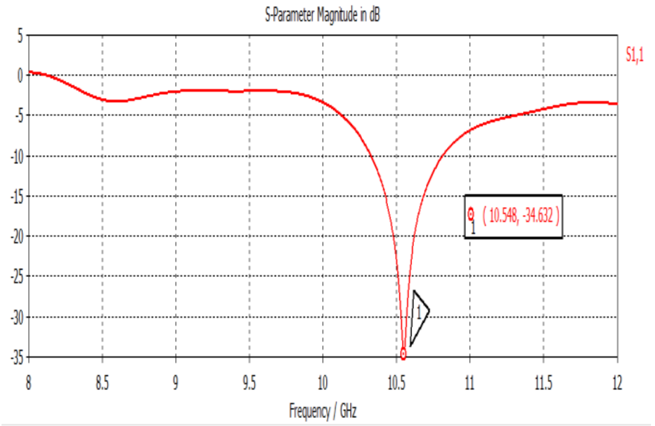

Fig.10. Simulated reflection loss (S_{11}) of X-band Coaxial CTS Antenna array

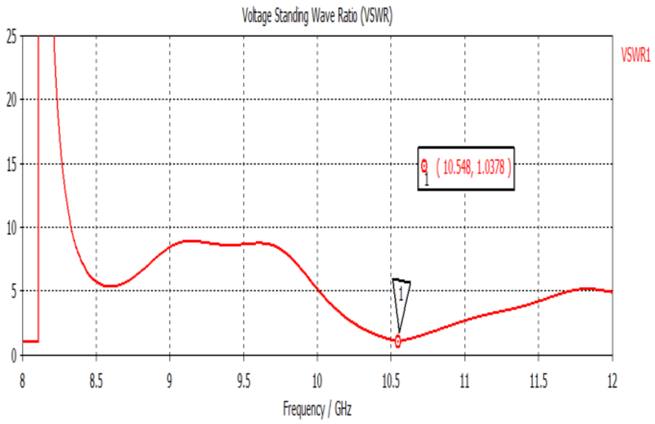

Fig.11. Simulated VSWR of X-band Coaxial CTS Antenna array

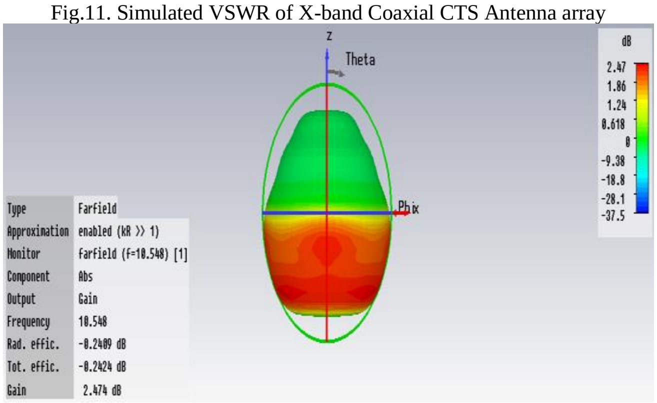

Fig.12. 3D radiation pattern in gain mode for the designed three element X-band CTS antenna array at 10.548 GHz

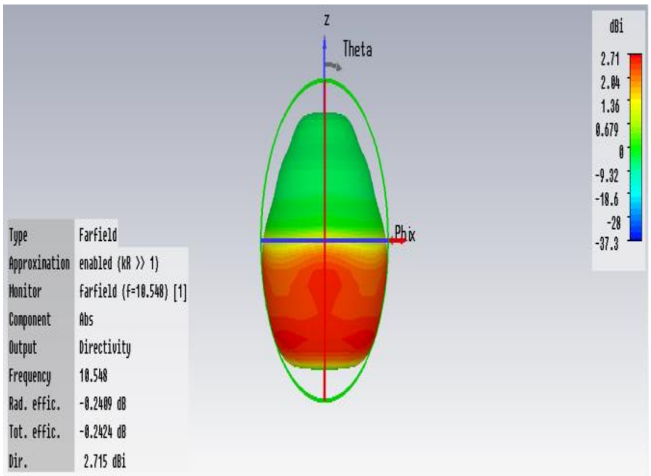

Fig.13. 3D radiation pattern in directivity mode for the designed three element X-band CTS antenna array at 10.548 GHz.

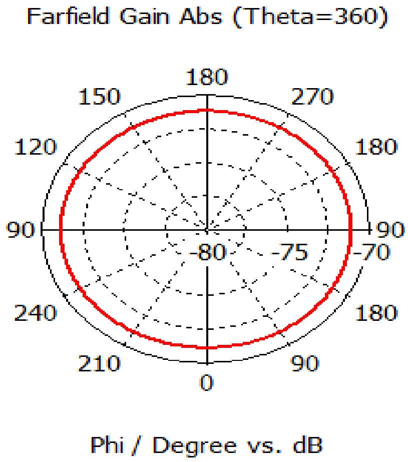

Fig.14. Radiation pattern in theta plane of the three element X-band Coaxial CTS antenna array at 10.548 GHz. Feed is from 0° or 360°

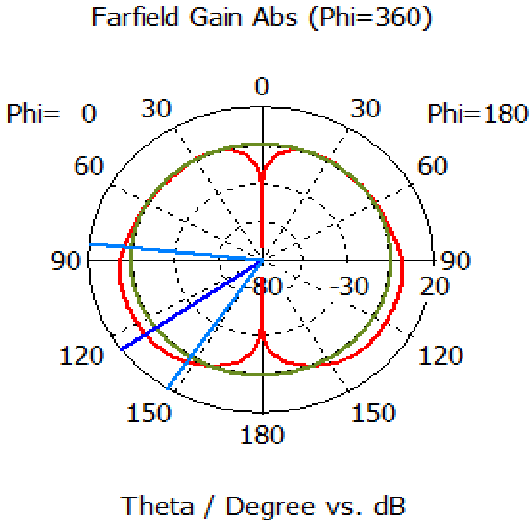

Fig.15. Radiation pattern in phi plane of the three element X-band Coaxial CTS antenna array at 10.548 GHz. Feed is from 0° or 360°

V. CONCLUSION AND FUTURE WORK

Coaxial CTS antenna provides omnidirectional radiation pattern with low loss and low reflection structures. The Coaxial CTS antenna array operating in S-band is designed to operate at 2.238 GHz.

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It can find applications in fixed (line of sight) service, mobile (line of sight) and space operation [13]. Simulation result shows the improved performance in the efficiency and gain. The design of the coaxial CTS antenna operating at 10.548 GHz in the X-band is discussed. The simulated return loss and VSWR shows good performance at this frequency. This type of antenna finds applications in radiolocation. Fine tuning might provide much narrow band for space operation. These two antenna arrays can be cascaded and tuned into a single structure array to operate at these frequency ranges as a multiband antenna. It might require sufficient spacing between these two antenna arrays and between stubs.

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