# Coaxial Continuous Transverse Stub (CTS) Array

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***Abstract*—A new coaxial continuous transverse stub (CTS) array is proposed, designed, constructed, and tested. It is an omni-directional low cost antenna array which provides good impedance matching characteristics and good tolerance to manufacturing errors. It can be simply fed by a coaxial connector and is particularly suitable for millimeter wave personal communication systems (PCS). It is shown that this type of radiating element provides high percentage of radiation, and for the simulated design of single- and multiple-element arrays, $S_{11}$ was below $-10$ dB across a 6 GHz frequency span at the Ka band. A three-element prototype Coaxial CTS antenna array was designed, constructed, and tested in the X-band. Experimental results were in good agreement with the simulated performance. Potential application of this new antenna array in multiband operation is also described.**

## I. INTRODUCTION

THE planar CTS was originally invented at Hughes Aircraft Company in 1991. It represents a unique class of low-cost antenna array, exploiting the low-loss, low-dispersion, dimensional robustness, and design flexibility of an open parallel-plate structure as both its transmission line and radiator bases [1]–[3].

The coaxial Continuous Transverse Stub array described in this paper, however, provides an alternative design that may provide additional advantages in feeding, impedance matching, and radiation characteristics [4]. It consists of a coaxial structure as its transmission line feed and parallel plate subs as the radiating elements. The difference between the coaxial CTS and the planar version is their array structure in the form of annular or sectoral stubs and the resulting omnidirectional radiation pattern. As in the case of planar CTS, beam steering may be achieved mechanically or by using Ferroelectric materials [4], [5].

## II. COAXIAL CTS DESIGN

Fig. 1 shows a two-element coaxial stub CTS antenna array, where it may be seen that it consists of a cascaded section of standard coaxial transmission lines and open-ended coaxial radiating stubs. Similar to the planar CTS case, short-circuited stubs may also be used and the coaxial CTS arrangement may be used as a filter in this case.

Design procedures for a coaxial CTS array include the determination of the following parameters: (1) width of stub segment $L1$; (2) length of transmission line segment $L2$; (3) dielectric constant of filler dielectric material: $\varepsilon_\tau$; (4) diameter of inner conductor $D1$; (5) diameter of outer conductor $D2$; and (6) diameter of stub $D3$.

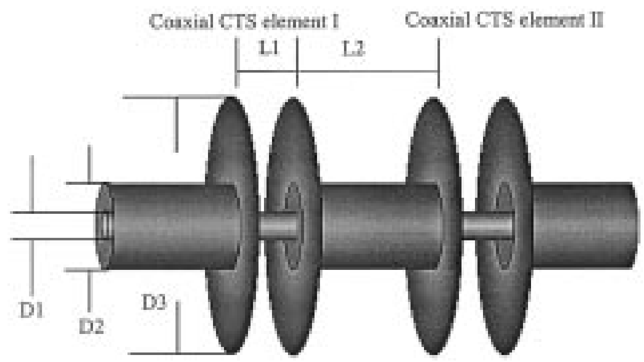


Fig. 1. Coaxial CTS array segment with two elements.

For the purpose of an illustrative design, the width of stub segment $L1$ was selected to be a half wavelength in dielectric material that fills the stub. The length of the transmission line segment $L2$ and dielectric constant of dielectric material $\varepsilon_\tau$ can be chosen to fulfill distance and phase demands between stubs. The diameters of the inner and outer conductors $D1$ and $D2$ of the coaxial transmission line can be adjusted to form the desired value of impedance, such as 50 Ω or 75 Ω in the case of a coaxial transmission line. The ratio between $D3$ and $D2$ determines the radiation pattern, voltage across, and the radiated power from each stub. Small values of $D3/D2$ tend to lead to increased radiation, but more care must be taken to achieve impedance matching. Also, $D3$ 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 $D3 > L1$.

Clearly, the diameters of the inner and outer conductors $D1$ and $D2$ 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 is an excellent self-matching structure. By properly controlling the ratio of $D3$ and $D2$ and the ratio of $D3$ and $L1$, it is possible to achieve low reflection stub elements. As one might expect, the design parameters $D2, D3, L1$, and $L2$ impact various aspects of the characteristics of the array including impedance matching $(S_{11})$, percentage of power radiated out, and radiation pattern. Detailed design curves will be developed and reported in a separate publication.

## III. SIMULATION RESULTS

Three different (three dimensional) 3-D electromagnetic simulation software packages (IE3D®, HFSS, and in-house FDTD codes) were used to simulate Coaxial CTS antenna

Manuscript received June 13, 2001; revised September 19, 2001. The review of this letter was arranged by Editor Dr. Samir El-Ghazaly.

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Publisher Item Identifier S 1531-1309(01)11122-0.

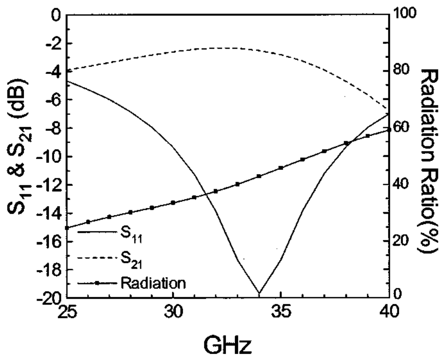


Fig. 2. $S_{11}, S_{21}$, and radiation of Coaxial CTS segment.

array structures. Fig. 2 shows the reflection $S_{11}$ and coupling $S_{21}$ of a one-element Coaxial CTS antenna. The coaxial fill material is air, $\varepsilon_r = 1, D1 = 1$ mm, $D2 = 2.3$ mm, $D3 = 10$ mm, $L1 = 5$ mm. The impedance of the air filled coaxial transmission line segment $(D2/D1 = 2.3)$ is 50 $\Omega$. As may be seen from Fig. 2, the bandwidth of $S_{11} < -10$ dB is more than 6 GHz. In this bandwidth, the radiation power ratio $[(\text{Total Power} - \text{Reflected Power} - \text{Transferred Power})/(\text{Total Power}) * 100\%]$ from the single stub is more than 30%, which supports the claim of a highly radiating structure. In the above equation, the total power was considered to include radiated power and the "transferred power" term represents the amount of power coupled to the load (end of the array). The numerator in the equation therefore quantifies the amount of radiated power from one specific stub.

Similar to the case of the planar CTS array, the coaxial CTS array is a traveling-wave-type array; so the farther the stub is from the array input port the less power it will receive. This aspect of the array design may be adjusted depending on the location of each stub and the dimension of the stubs' lengths and widths dimensions. 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 and the array will be used as a low gain antenna. On the other hand, if each stub was designed to radiate less power, more stubs can be used and a high gain antenna array may be designed.

The radiation pattern was calculated at the frequency of minimum $S_{11}$ (34 GHz) and was found to be split at broadside. Although this may be explained in terms of the excessively wide electrical width of the stub at this frequency $(L1/\lambda = 0.57)$, it is often desirable to achieve a radiation pattern with single main lobe. This was found to be possible to achieve at the slightly lower frequency of 30 GHz, which is still within the same operating frequency band of the array ($S_{11} < -9$ dB).

The radiation pattern at 30 GHz is shown in Fig. 3. The dotted line in Fig. 3 shows the radiation pattern of a one coaxial CTS stub segment with the same dimension and design parameters as described above. The solid line in Fig. 3 shows the radiation pattern at 30 GHz of a Coaxial CTS array formed by eight-stub elements. Here, $L2 = 3$ mm and it fulfills the demand of co-phase between stubs. Each stub radiates 33% power; hence, neglecting the mutual coupling effects, eight elements will be needed to radiate more than 95% of the incident power at a rate of 33% radiation from each stub.

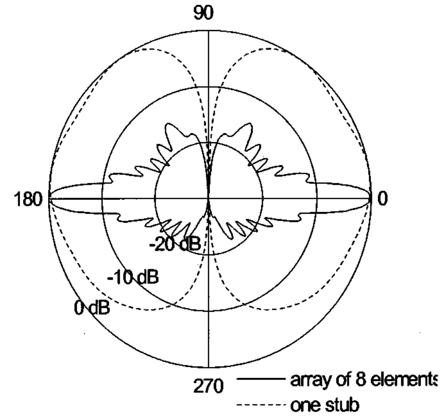


Fig. 3. Radiation patterns of single stub (dashed line) and a Coaxial CTS array (solid line).

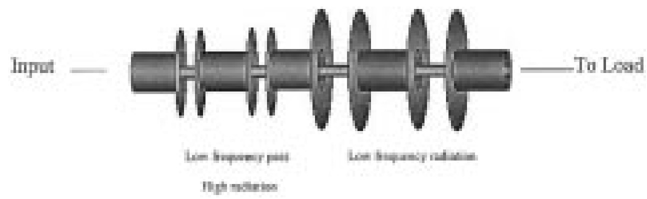


Fig. 4. Multiband CTS antenna array.

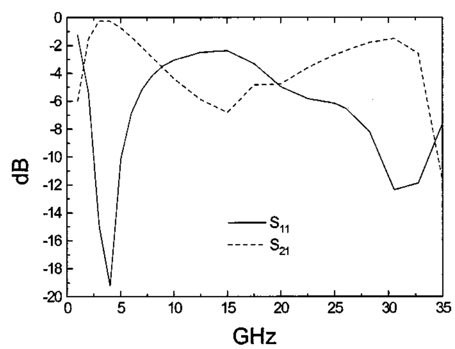


Fig. 5. $S_{11}$ and $S_{21}$ of transmission stub. At 4 GHz, $S_{11} < -19$ dB, $S_{21} = -0.24$ dB, $D1 = 1$ mm, $D2 = 2.3$ mm, $D3 = 20$ mm, $L1 = 5$ mm.

It is also of interest to examine the potential operation of such an array structure at multiband frequency ranges. A design that includes efficient radiators at higher frequencies near the antenna feed, and relatively lower frequency radiating stubs at the end, is shown in Fig. 4. To help examine the feasibility of this procedure two coaxial stubs were designed. The first is a high frequency radiating stub and is expected to exhibit a virtual short at the stub-coaxial line junction at the lower operating frequency. This means that the high frequency stubs will provide good transmission along the main coaxial line at the lower operating frequency. The design and the calculated $S$-parameters for this design is shown in Fig. 5. As it may be seen, almost perfect transmission and low reflection ($S_{11} = -19$ dB) were possible to achieve at 4 GHz. Fig. 5 also shows that this high frequency stub would radiate 29% of the power at 30 GHz. Alternatively, the stub dimension may be designed so as to enhance radiation at a lower frequency band. Such a design was simulated and the $S$-parameters results are shown in Fig. 6. Each stub can radiation 17% power at 4 GHz. Clearly combining these designs in a

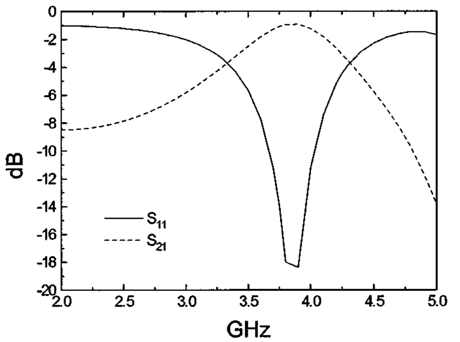


Fig. 6. $S_{11}$ and $S_{21}$ of radiation stub. At 4 GHz, $S_{11} < -11$ dB, $S_{21} = -1.24$ dB. $D1 = 1$ mm, $D2 = 2.3$ mm, $D3 = 90$ mm, $L1 = 40$ mm.

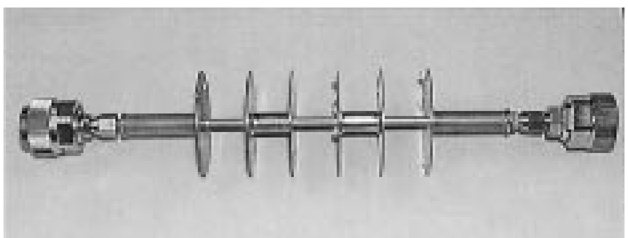

Fig. 7. Photograph of the prototype X-band three-element Coaxial CTS array.

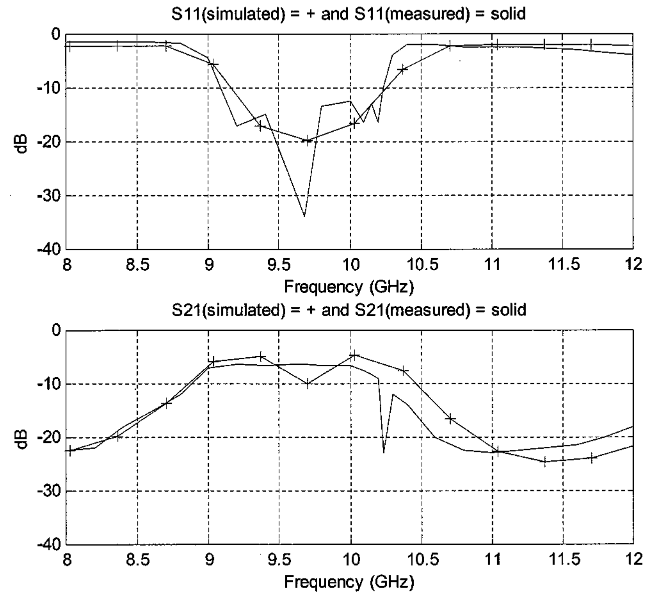


Fig. 8. Measured and calculated $S$-parameters of the prototype X-band three-element array.

single array will achieve the proposed multiband operation at 4 GHz and 30 GHz. This design may be varied and other possible frequency bands may be achieved.

## IV. Experimental Verification

It is critically important to verify the simulation results of the Coaxial CTS design with experimental measurements. For this reason, a three-element X-band Coaxial CTS antenna array was designed, fabricated, and tested at the University of Utah. A picture of the three-element array is shown in Fig. 7. The simulation was performed using an FDTD code and the design specifications are given as follows: $L1 = 18$ mm, $L2 = 17$ mm, $D1 = 3$ mm, $D2 = 6.9$ mm, $D3 = 40$ mm, and $\varepsilon_r = 1$. Nylon rings that were between the inner and outer conductors of the coaxial feed line for support were included in the FDTD model. This initial design was not synthesized for a particular radiation pattern with the simulation data, but instead for instead for $S$-parameter measurements and comparison.

$S$-parameter measurements of the three-element X-band coaxial CTS antenna array were taken using an HP-8510B Network Analyzer. The obtained experimental results (solid line) are shown in Fig. 8, together with the simulated data (solid line with +s). As may be seen from Fig. 8, excellent agreement may be observed, particularly in the operating frequency band of the array in the range from 9.2–10.3 GHz. One may also observe a sharp dip in the measured $S_{21}$ curve at about 10.2 GHz. This was attributed to the presence of a discontinuity in the junction at one of the end connectors. Much improvement was realized when the connectors were soldered to the antenna, but some discontinuity effects may be still be seen in Fig. 8.

## V. Conclusion

A New Coaxial CTS antenna array design was proposed. Unlike the planar CTS arrays, it provides significant impedance matching advantage and an omni-directional radiation pattern. Furthermore, by adjusting the dimensions of the center and outer conductors along the coaxial transmission line, significant impedance matching advantage may be achieved. The proposed low-cost coaxial CTS antenna array provides an excellent potential design for base stations for wireless communication systems at millimeter waves (LMDS). The potential use of this antenna array in multiband operation was also discussed.

Verification of the simulated results was obtained through simulating, building, and testing a three-element X-band Coaxial CTS antenna array. Good agreement was obtained between measured and simulated results from 8–12 GHz. Future work will include building and testing of a multiband design, the design of dielectrically loaded Coaxial CTS structures, and the use of ferroelectric materials to realize one-dimensional beamsteering [5].

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