

Advanced Broadband Access Applications of the Continuous Transverse Stub (CTS) Array

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Abstract -- The Continuous Transverse Stub (CTS) array represents a unique class of array antenna that exploits the low-loss, low-dispersion, dimensional robustness, and design flexibility of an open parallel-plate structure as both its transmission-line and radiator basis. Relative advantages of this array type include unusually high aperture efficiencies; precision sidelobe control; benign active impedance dependence on both frequency and scan angle; and inherently low cost. This paper will describe and illustrate recent wideband, dual-polarized and phased-array developments of the CTS array applied to fixed and mobile Terrestrial- and Satellite-Based Broadband Access applications at both microwave and millimeter-wave frequencies.

I. INTRODUCTION

SINCE its original invention in 1991 [1]-[2], the Continuous Transverse Stub (CTS) array has been successfully demonstrated in over 30 different embodiments, supporting specific applications spanning operating frequencies from 5 through 94 GHz [3]-[4] and continuous bandwidths in excess of two octaves.

A. Theory of Operation

The CTS array differs markedly from other planar array and Electronically-Scanned Array (ESA) implementations in terms of architecture, radiator realization, coupling mechanism(s), and transmission-line properties. Figure 1 illustrates the canonical architecture of a typical CTS antenna, realized as an array of broad *continuous transverse* radiating *stubs*, finite in height, extending from the upper conductive plate of an open parallel-plate transmission-line structure, and internally excited by a (generic) linear source. These transverse-oriented stubs interrupt longitudinal current components within the parallel-plate structure and in doing

so, efficiently couple and radiate propagating energy from the parallel-plate structure into free-space as a linearly-polarized wave. This simple architecture allows for a (typically) complex two-dimensional planar array to be instead realized as an “extrusion” of a one-dimensional (constant cross-section) geometry. This has the favorable effect of replacing a conventional “ $N \times N = N^2$ ” element structure (of discrete radiators, couplers, etc.) with a less complex “monolithic” array comprised of “ N ” integrated coupler/radiator features. The close proximity and parallel orientation of the radiating stubs typically equate to unusually strong (and interestingly, beneficial) mutual coupling, therefore requiring the rigorous simulation of the effective active impedance of each stub exploiting the periodicity of the structure [5].

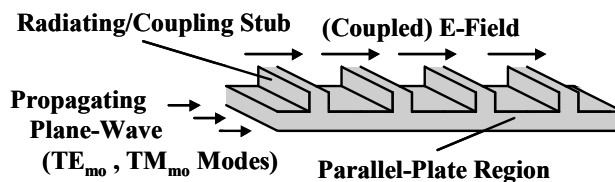


Fig. 1. Typical cross-sectional view of the Continuous Transverse Stub (CTS) Array.

The simple “tee” cross-section of the integrated CTS coupler/radiator forms an inherently low-“Q” (non-resonant) element which exhibits significant advantages (as compared to resonant slot or patch radiators) in terms of wide-angle scanning capability, polarization purity, bandwidth, and dimensional insensitivity. As an additional benefit, the utilization of a simple parallel-plate cross-section as the basis for the transmission-line structure fully exploits the low dissipative loss, dimensional insensitivity, wide operating bandwidth, and low-dispersion typical of

propagation within a parallel-plate structure. These favorable qualities contrast with the relative limitations of waveguide, microstrip, and strip-line transmission-line structures with respect to these attributes.

B. Line-Feed Options

A wide variety of continuous and discrete, fixed and scanning, line-feed implementations have been successfully integrated with the CTS array. Generically, these feeds excite a finite number of $TE_{m,0}$ or $TM_{m,0}$ modes (dependent on the width and edge-wall termination of the parallel-plate region). Some examples include: a sectoral (H-plane) horn; an electro-mechanical scanning line-feed; and an N-element linear phased array of Transmit/Receive (TR) modules. For cases in which an electronic scanning line-source is employed, the CTS array faithfully transforms the scanned *linear* phase-front emanating from the line-feed (typically a mode-limited finite Fourier Series representation of the imposed aperture taper and inclined phase-front) into a scanned plane-wave, oriented in the *H-plane* and radiating at an inclined angle with respect to the surface of the CTS array. Other potential scanning implementations include: *Digital Beam Forming* (DBF), *Rotman Lens*, *Butler Matrix*, and *Photonically-Controlled* scanning line-feeds. Figure 2 illustrates the applicable geometry for H-plane scanning typical with the CTS array.

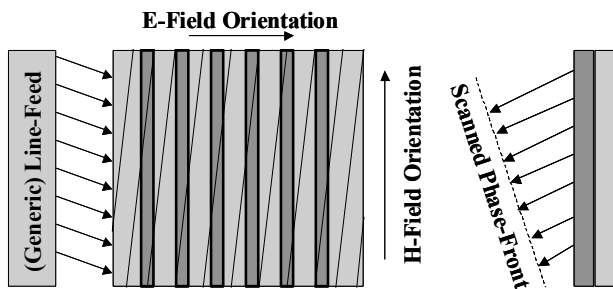


Fig. 2. H-Plane scanning phenomenology for the Continuous Transverse Stub (CTS) Array.

C. Electronic-Scanning Techniques

Electronic-scanning of the CTS array in the *E-plane* is accomplished through controlled variation of the propagation constant within the parallel-plate region. Various methods have been successfully devised and demonstrated for achieving this variation and include: controlled frequency variation (frequency-scanning); incorporation of non-linear Voltage-Variable Dielectrics (VVD) within the parallel-plate region [6]-[9]; and direct implantation of Varactor devices on and/or between the parallel-plate conducting planes [10].

II. WIDEBAND APPLICATIONS

The parallel-fed or True-Time-Delay (TTD) variant of the CTS array enables wideband antenna implementations that support multiple octaves of bandwidth [11]-[13]. Figure 3a illustrates such an implementation which supports a minimum aperture efficiency of 70% over the entire 5 to 20

GHz frequency band. A productized version of the TTD CTS array is currently in full-scale production (under license to Harris Corporation) in support of their 23, 26, and 38 GHz Point-to-Point (PTP) radio product line. This antenna is 50% wider in bandwidth, 20% higher in efficiency, 6 to 15 dB lower in sidelobes, 70% lower in profile, 40% lighter in weight, and 50% lower in cost than the shrouded- and steep taper-parabolic dishes it replaces [14]. Other broadband access sectors benefiting from the extremely low sidelobes, high efficiency, and low-cost of this design include Consumer Premises Equipment (CPE) and Business Premises Equipment (BPE) for Local Multipoint Distribution Service (LMDS) and Multi-channel Video and Data Distribution Service (MVDDS) applications.

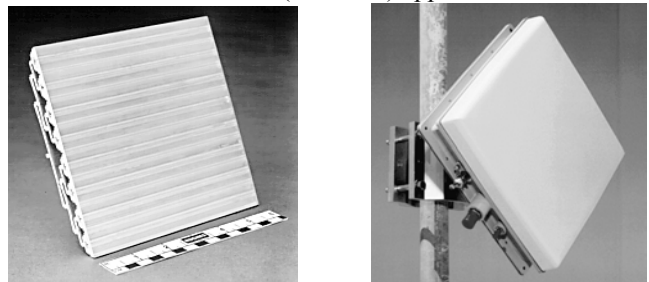
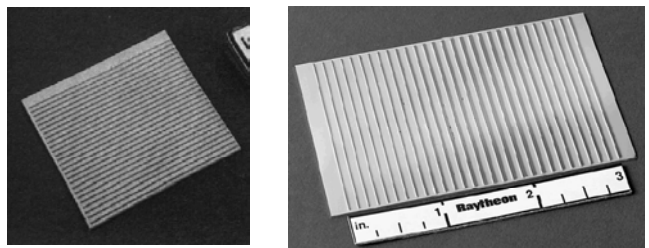


Fig. 3 (a) 15 cm x 15 cm Wideband CTS Array. (b) 28 cm x 28 cm x 4 cm 38 GHz Point-to-Point (PTP) CTS Array.

III. MONOLITHIC IMPLEMENTATIONS

Utilizing high-resistivity silicon as a substrate (parallel-plate and stub constituent material), Millimeter-Wave (MMW) CTS arrays have been successfully fabricated utilizing ion etching techniques. Figure 4a illustrates a 2.5 cm x 2.5 cm 94 GHz CTS array fabricated from silicon (utilizing ion-etching) which exhibited a total aperture efficiency of 87%. Figure 4b illustrates a larger 35 GHz silicon CTS array exhibiting a measured aperture efficiency



of 83%.

Fig. 4 (a) 2.5 cm x 2.5 cm 94 GHz Silicon CTS Array. (b) 5 cm x 8 cm 35 GHz Silicon CTS Array.

The CTS array, realized as an extremely low-loss high-performance aperture in low-resistivity silicon provides for the monolithic realization of active devices (MEM's switches, phase-shifters, LNA and HPA components, etc.) on a common substrate thereby uniquely enabling low-cost, fully integrated MMW antenna implementations.

IV. DUAL-POLARIZED APPLICATIONS

Specific variants of the basic CTS array represent a proven and effective solution for achieving single- and multi-band polarization diverse capability in a single, high-efficiency, low-profile, shared antenna aperture. These features are achieved by exploiting the unique “open” internal electromagnetic architecture of the basic (single-polarized) design through the distribution and subsequent radiation of two simultaneous orthogonal plane-wave (finite-mode) excitations. In terms of efficiency and performance as a radiator, the parallel-plate based radiating “stub” behaves (and models) similarly to a linear filamentary magnetic current source and therefore exhibits superior frequency-independent polarization purity (axial ratio) as compared to the band-limited (mode- and fringing-limited) performance of typical slot-, patch-, and/or waveguide-based radiator alternatives.

Figure 5a illustrates a 48 cm x 48 cm x 2 cm dual-polarized CTS array, suitable for Direct Broadcast Satellite (DBS) reception over the 12.20 to 12.70 GHz frequency band. This antenna exhibits 1 dB greater G/T, 10 dB lower sidelobes, and 50% less wind-/roof-loading than the 18” parabolic dish it is designed to replace. A minimum polarization isolation of 25 dB (AR < 1.0 dB) was realized for both RHCP and LHCP with a total dissipative loss of less than 0.6 dB. This antenna is fabricated exclusively utilizing low-cost commercially-available materials (aluminium, low-density foam, and plastic) and processes (stamping, extruding, and injection molding), requiring no supplemental conductive bonding, brazing, gasketing, or interconnects of any kind. Recurring manufacturing cost for this antenna, in its productized form, is estimated to be less than \$25 per unit.

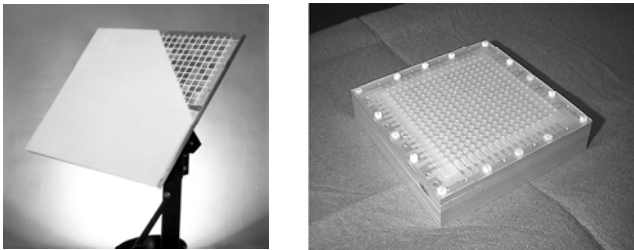


Fig. 5 (a) 48 cm x 48 cm Dual-Polarized DBS CTS Array. (b) 8 cm x 8 cm Dual-Polarized/Dual-Band CTS Array.

For applications requiring simultaneous dual-polarized operation over very broad and/or multiple frequency bandwidths (such as FSS VSAT antennas), the parallel-plate geometry of the CTS array may be further exploited to support this multi-functionality while preserving the simple low-cost attributes of the CTS structure. A CTS antenna exhibiting this broadband dual-polarization capability was successfully designed, fabricated, and demonstrated under funding from the United States Air Force (AFRL). Capable of supporting both the 17.7 to 21.2 GHz receive and 43.5 to 45.5 GHz transmit frequency bands simultaneously with dual-polarization (RHCP and LHCP) in both bands, this 8

cm x 8 cm x 1.7 cm aperture exhibited a minimum cross-polarization isolation of 22 dB (Axial Ratio < 1.4 dB) in a low-cost low-profile multi-layer form factor requiring no interconnects or RF critical joints. Figure 5b illustrates this dual-polarized/dual-band CTS aperture in subarray form (as tested), while Figure 6 illustrates an arrayed form of this antenna now being investigated for mobile broadband satellite communication applications.

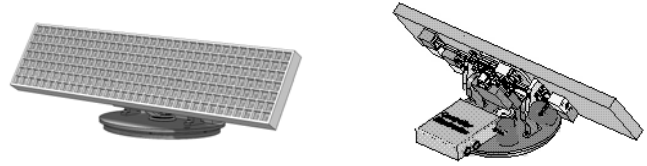


Fig. 6. Front and Rear Views of Airborne Dual-Band/Dual-Polarized CTS Array supporting polarization-diverse operation over 10.5 to 12.7 and 14.0 to 14.5 GHz frequency bandwidths.

V. DIRECTIVE PHASED ARRAY APPLICATIONS

As a direct extrapolation of the basic CTS array, the Variable Inclination Continuous Transverse Stub (VICTS) array employs a unique two-dimensional scan mechanism which is 100% mechanical, involving the simple rotation (common and differential) of two coplanar plates, one (upper) comprised of a one-dimensional lattice of continuous radiating stubs and the second (lower) forming the base of the parallel-plate region formed and bounded between the non-contacting (RF choked) upper and lower plates. This simple rotational geometry renders to the VICTS the unique ability to meet and even exceed the conformal low-profile and two-dimensional hemispherical scan features of a conventional electronically-scanned phased-array without the need (or cost) of any phase-shifting elements. In addition, because of its extremely high efficiency and well-behaved scan impedance, even at extreme scan angles, the VICTS array typically requires 40% to 75% less area than a conventional phased array in order to meet the same G/T (data bandwidth) performance.

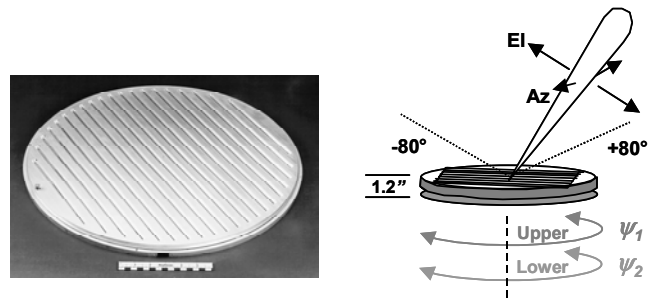


Fig. 7 (a) 51 cm Diameter Ku-band Variable Inclination Continuous Transverse Stub (VICTS) Array. (b) VICTS Scan Geometry and Mechanization.

VICTS designs at Ku-band (10.5 to 14.5 GHz), Ka-band (35 GHz) and W-band (94 GHz) have been designed, built, and successfully tested and a single VICTS aperture, capable

of simultaneous operation at both 20 GHz (receive) and 30 GHz (transmit) is currently under development. Applications of VICTS include fixed and mobile GEO and NGSO satellite terminal applications in support of broadband internet access. Figure 8 illustrates a measured antenna pattern for a 20" diameter VICTS array at 12.5 GHz and scanned to 63 degrees from broadside (normal).

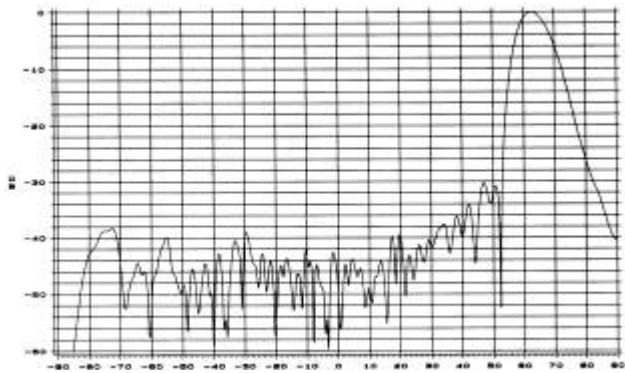


Fig. 8. Measured Elevation-Plane Pattern for 51 cm VICTS Array at 12.5 GHz (scanned to 63 degrees).

VI. SHAPED-BEAM APPLICATIONS

The unique open internal geometry of the CTS array makes it ideally suited for the realization of one- and two-dimensionally shaped patterns including null-filled, sectorized, and cosecant types. Exploiting this geometry and the resultant (natural) curvature of the CTS array's cardinal sidelobe planes, it is possible to uniquely map desired antenna patterns (equi-power footprints) to unique feed and CTS stub design attributes. Useful applications benefiting from such precision beamshaping include LMDS and MMDS node antennas as well as pico- and micro-cell nodes and repeaters for cellular, PCS, ITS, and satellite-based infrastructures.

VII. OMNI-DIRECTIONAL APPLICATIONS

Recent and evolving work by investigators at the University of Utah [15]-[17] have studied single- and dual-band omni-directional variants of the CTS array. Representing a cylindrical coordinate-based (coaxial and radial waveguide) dual of the original rectangular coordinate-based (parallel-plate) CTS, the Coaxial Continuous Transverse Stub (CTS) Array shows promise as a potential replacement for monopole, disc-cone, and wide-band patch antennas for communication applications.

VIII. CONCLUSION

The Continuous Transverse Stub (CTS) array represents a new and evolving antenna technology applicable to a broad range of Terrestrial and Satellite broadband access applications. The numerous described variants of the CTS, sharing in common unusual bandwidth, efficiency, and cost advantages as compared to competing planar and non-planar approaches, may reasonably be expected to positively

influence current and future commercial communication developments.

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