Wireless Communication Applications of the Continuous Transverse Stub (CTS) Array at Microwave and Millimeter Wave Frequencies.

W. H. Henderson W. W.Milroy*

ThinKom Solutions, Incorporated
3825 Del Amo Boulevard, Suite 200, Torrance, CA 90503 (USA)
BillH@thin-kom.com, BillM@thin-kom.com

***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 "$NxN=N^2$" 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].

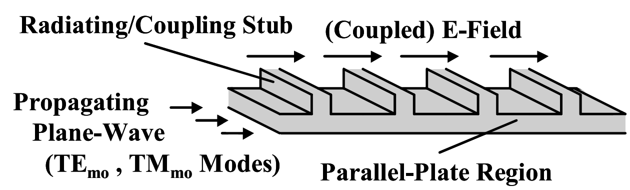

Fig. 1. Typical cross-sectional view of a Continuous Transverse Stub Array.

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,

0-7803-9068-7/05/$20.00 ©2005 IEEE

microstrip, and strip-line transmission-line structures.

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 $TE_{m,o}$ or $TM_{m,o}$ modes (dependent edge-wall termination of the parallel-plate). Some examples include: an 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 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 with the CTS array.

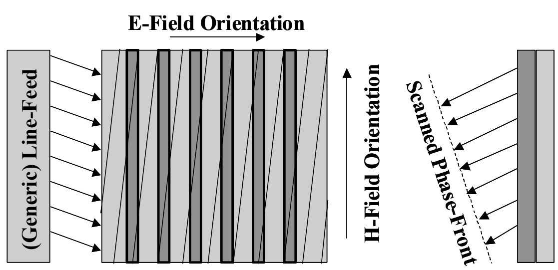

Fig. 2. H-Plane scanning phenomenology for the Continuous Transverse Stub (CTS) Array.

C. E-Plane Electronic-Scanning Techniques

Electronic-scanning of the CTS array in the *E-plane* can be accomplished through controlled variation of the propagation constant within the parallel-plate region. Various methods have been devised for achieving this variation: 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]. Unlike the travelling wave version shown in fig. 1, the TTD variant incorporates a corporate feed network in the parallel plate structure (see fig. 3). This structure can be fabricated at low cost with extruded and injection molded parts. Figure 4 illustrates 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].

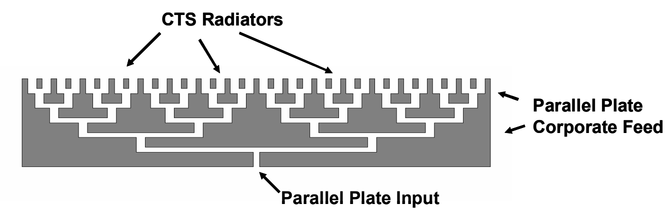

Fig. 3. Cross Sectional view of the True Time Delay CTS architecture.

A TTD CTS antenna which will cover the newly allocated millimeter wave communication bands from 71-76 GHz and 81-86 GHz is currently under development in collaboration with GigaBeam Corp. for a data link application. Achieving the relatively high gain (50 dBi) required for this with a parabolic dish necessitates the use of high cost manufacturing techniques. The TTD CTS architecture enables a design that can be fabricated at a small fraction of the cost of a dish and has better sidelobe performance and efficiency, as well as much smaller volume. Other broadband access sectors benefiting from the extremely low sidelobes, high efficiency, and low-cost of the TTD CTS architecture 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.

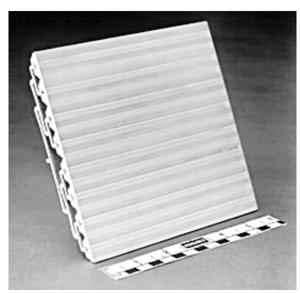

Fig. 4 15 cm x 15 cm Wideband CTS Array.

III. DUAL-POLARIZED APPLICATIONS

Specific variants of the basic CTS array are effective proven solutions for achieving single- and multi-band polarization diverse capability with a single, high-efficiency, low-profile, antenna. These variants exploit 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 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 radiators.

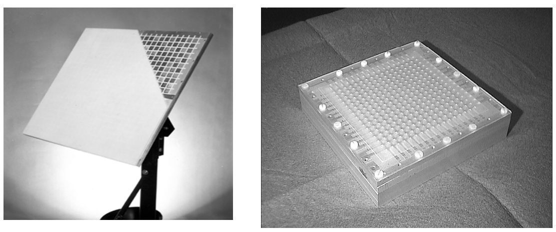

Fig. 5 (a) 48 cm x 48 cm Dual-Polarized DBS CTS Array. (b) 8 cm x 8 cm Dual-Polarized/Dual-Band CTS Array.

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 <$25 per unit.

For applications requiring simultaneous dual-polarized operation over very broad and/or multiple frequency bands (such as FSS VSAT antennas), the parallel-plate geometry of the CTS array may be further exploited while preserving the simple low-cost attributes of the basic 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.

IV. DIRECTIVE PHASED ARRAY APPLICATIONS

As a direct extrapolation of the basic CTS array, the Variable Inclination Continuous Transverse Stub (VICTS) array employs a unique 2D scan mechanism which is 100% mechanical, involving the simple rotation (common and differential) of two coplanar plates, one (upper) comprised of a 1D 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 2D 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 performance.

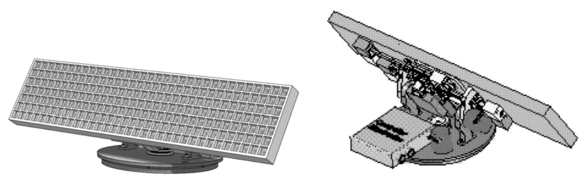

Fig. 6. Front and Rear Views of Airborne Dual-Band/Dual-Polarized CTS Array supporting polarization-diverse operation over 10.5 to 12.7 and 14.0 to 14.5 GHz frequency bandwidths.

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).

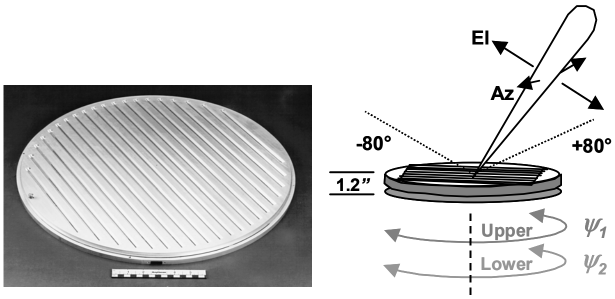

Fig. 7 (a) 51 cm Diameter Ku-band Variable Inclination Continuous Transverse Stub (VICTS) Array. (b) VICTS Scan Geometry and Mechanization.

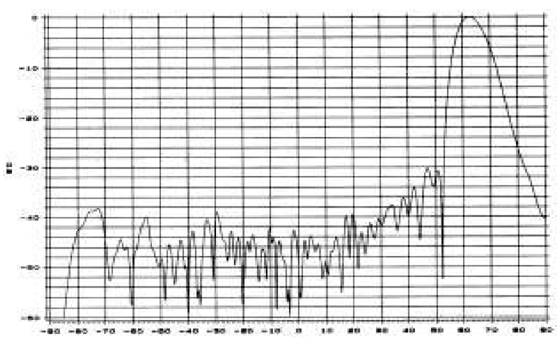

Fig. 8. Measured Elevation-Plane Pattern for 51 cm VICTS Array at 12.5 GHz (scanned to 63 degrees).

V. 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 many variants of the CTS, sharing in common unusual bandwidth, efficiency, and cost advantages as compared to competing approaches, may be expected to positively influence current and future commercial communication developments.

Acknowledgement

The authors wish to thank the Hughes Aircraft Company, GM/Hughes Electronics, the Raytheon Company, their employees, and our colleagues for their sponsorship and support in the development of the CTS Array.

References

[1] W. W. Milroy, "The Continuous Transverse Stub (CTS) Array: basic theory, experiment, and application," 1991 Antenna Applications Symposium, Allerton Park, IL, USA

[2] W.W. Milroy, "Continuous Transverse Stub element devices and methods of making same," United States Patent 5,266,961

[3] Alan Lemons, Robert Lewis, William Milroy, Ralston Robertson, Stuart Coppedge, and Todd Kastle, "W-Band CTS Planar Array," 1999 IEEE International Microwave Theory and Techniques Symposium, Los Angeles, CA, USA.

[4] W. W. Milroy, "Evolution of the Continuous Transverse Stub (CTS) Array in communication applications," (Classified Volume,) MILCOM 97 Symposium, Monterey, CA, USA

[5] Ruey-Shi Chu, "Analysis of Continuous Transverse Stub (CTS) Array by Floquet Mode Method," 1998 IEEE International Antennas and Propagation Symposium and USNC/URSI National Radio Science Meeting, Atlanta, GA, USA.

[6] W. W. Milroy, "Continuous Transverse Stub element antenna arrays using voltage-variable dielectric material," United States Patent 5,583,524.

[7] T. W. Bradley, W. W. Chen, J. R. Chow, S .B. Coppedge, T. K. Dougherty, S..A. Gabelich, N. H. Harris, N. T. Hrobak, R. T. Lewis, J. F. Linder, W. W. Milroy, B. M. Pierce, and R .J Wittmond, "Development of a Voltage Variable Dielectric (VVD), Electronic Scan Antenna (ESA)," 43rd Annual Tri-Service Radar Symposium (1997), Edinburgh, Scotland.

[8] M. Iskander, Z. Zhang, Z Yun, R. Isom, M. Hawkins, R. Emrick, B. Bosco, J. Synowczynski, B. Gersten, “New phase shifters and phased antenna array designs based on ferroelectric materials and CTS technologies,” 2001 IEEE International Microwave Theory and Techniques Symposium, May 20-25, Phoenix, AZ, USA.

[9] Magdy Iskander, Zhijun Zhang, Zhengqing Yun, “Low cost low loss antenna array with beam steering capability,” United States Patent application submitted.

[10] R. Robertson, “Electronically-Scanned semiconductor antenna,” United States Patent 6,064,349

[11] W. W. Milroy, "Planar antenna radiating structure having quasi-scan, frequencyi-independent driving-point impedance," United States Patent 5,995,055.

[12] W. W. Milroy, "Compact, ultrawideband matched E-plane power divider," United States Patent 5,926,077.

[13] W. W. Milroy, "Compact, ultrawideband, antenna feed architecture comprising a multistage, multilevel network of constant reflection-coefficient components," United States Patent 6,075,494.

[14] W. W. Milroy, "Application of the Continuous Transverse Stub (CTS) Array in Point-to-Point (PTP) communication systems" Unpublished.