Low-Profile CTS Array in PCB Technology for K/Ka-Band Applications

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***Abstract*—In this paper, an ultra-low-profile wideband continuous transverse stub (CTS) array is presented. The antenna module is fully realized in multilayer printed circuit board (PCB) technology, comprising 9 dielectric substrates. Particularly, the radiating part consists of long slots etched on the top of the eighth dielectric substrate. The slots are parallel-fed by a corporate feed network made of vertical parallel-plate waveguides (PPW), using via-fences. A pillbox system, embedded into two substrates, is employed to feed the slots with a line source. The antenna module is low cost and presents a very low form factor. A prototype was fabricated and measured in the K/Ka-band. The antenna array provides a pencil-beam radiation for angles of scanning as far as $\pm 24°$ along the azimuth plane parallel to the slots. The input reflection coefficient is below -10 dB in the frequency range 19-31 GHz (48% of relative bandwidth). The maximum realized gain is 21 dB at 29 GHz.**

***Index Terms*—Continuous transverse stub array, PCB technology, SatCom, pillbox system, ultra-low-profile, wideband.**

I. Introduction

The increasing demand of high-data-rate in satellite communications (SatCom) motivates the need of novel antenna solutions with wideband performance and low-form factor [1]. This device generation also requests to greater endeavors for increasingly antenna miniaturization. Reduced weight and encumbrance are, indeed, key assets to ease the integration into different vehicles, such as trains and aircrafts.

Continuous transverse stub (CTS) arrays [2] have received large attention for the past years, thanks to the wideband performance, wide-angle scanning capabilities, and low-profile. In 2015, the CTS array proposed in [3] was realized by assembling milled aluminum pieces and demonstrated wideband and wide-angle scanning capabilities for Ka-band applications. Moreover, recent contributions [6], [7], [8] have proposed a novel concept of CTS array attaining circular or dual-linear polarization, respectively.

Over the years, several research activities have led to important advancements in the field of compact CTS arrays. For instance, low-profile CTS arrays have been realized using multilayer modules in low-temperature co-fired ceramic (LTCC) technology at V-band [4] and printed circuit board (PCB) technology at E-band [5]. Leveraging on the vertical integration capabilities, multilayer modules in LTCC and PCB technologies have turned out to be very interesting in terms of size reduction and ease in integrating active components.

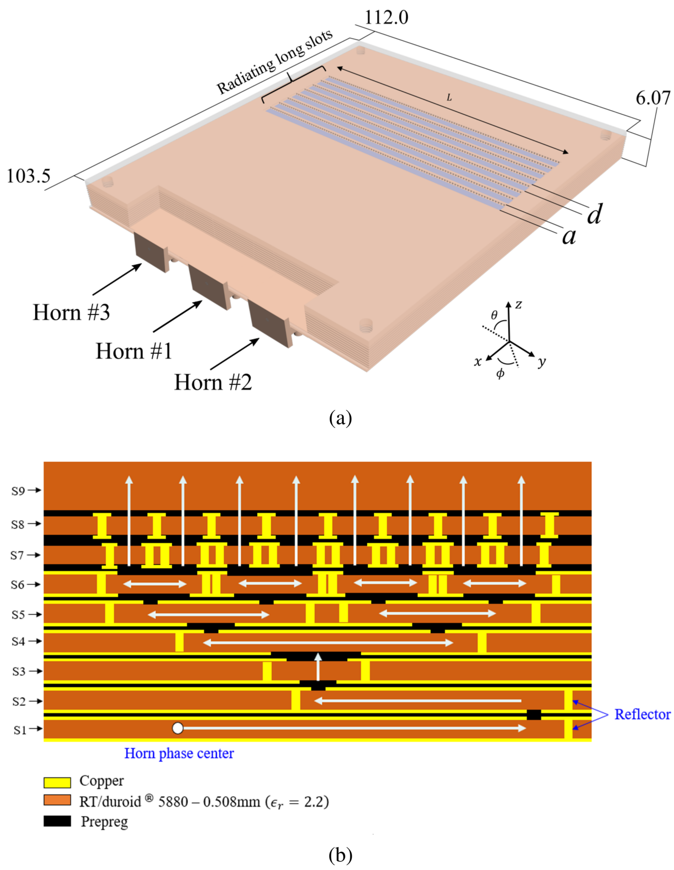


Fig. 1. (a) Perspective view of the antenna module. All dimensions are given in millimeters. (b) Sectional view along the xz-plane.

In this paper, we present the design of a wideband CTS array with an extreme low-profile at K/Ka-band. The antenna system is fully integrated and realized in PCB technology. A corporate feed network (CFN) is designed using parallel-plate waveguides (PPW) made of vertical via-fences and used to feed the radiating slots in parallel. The antenna is impedance-matched in the frequency band 19-31 GHz (48%) and performs scanning along the H-plane for polar angles as far as $\pm 24°$.

The paper is organized as follows. The antenna architecture is described in Section II. The measured results are shown in Section III. Finally, Section IV concludes the paper.

II. Antenna Architecture

A perspective view of the antenna architecture is depicted in Fig. 1(a), whereas the cross-sectional view along with the xz-plane is shown in Fig. 1(b). The antenna module comprises 9 dielectric substrates Rogers RT/duroid® 5880 ($\epsilon_r = 2.2, \tan\delta = 0.0009$ at 10 GHz). The CFN and the radiating slots are integrated in 8 dielectric substrates, i.e., S1-to-S8, as shown in Fig. 1(b). The substrate S9 is placed on the top of the radiating slots as matching layer to broad the operating bandwidth [see Fig. 1(b)]. The slots are etched on the upper face of the substrate S8. The width of the slots is $a \sim 0.22\lambda_{min} = 2.13$ mm, where λ_{min} is the free-space wavelength at 31 GHz. Furthermore, the array periodicity is $d \sim 0.28\lambda_{min} = 2.73$ mm. The condition $a < d < \lambda_{min}/2$ ensures the monomodal regime of the PPWs and guarantees that no grating lobes occur while scanning. The length of the slots along y-axis is $L = 102$ mm [see Fig. 1(a)]. The overall thickness of the antenna is 6.07 mm.

The slots are parallel-fed by a CFN made of 1-to-2 way T-junctions, whose architecture comprises vertical PPWs realized using via-fences, as shown in Figs. 1(a) and (b). A pillbox system [9] is employed to feed the CFN. It consists of a planar parabola of focal length 60 mm, embedded into the substrates S1 and S2 [see Fig. 1(b)]. The parabola is illuminated by a focal array of horns in substrate-integrated waveguide technology. The horns are arranged into the substrate S1 and their radiating aperture matches the focal plane of the parabola. Multiple slots are etched on the upper face of the substrate S1, in order to couple the electromagnetic field from the lower (S1) to the upper (S2) substrate. By means of the coupling slots, cylindrical waves traveling in the substrate S1 are converted into fields with planar wave-front in the upper substrate S2. The quasi-optical beamformer is thus employed to create a line source with a tapered amplitude and a progressive phase along the y-axis.

III. Experimental results

Each antenna building blocks has been designed separately through full-wave simulations in CST Microwave Studio [10]. Specifically, the unit cell of the array has been designed for broadside radiation. Scanning capability can be easily attained by displacing the feeding horn along the y-axis in the substrate S1. In this case, a focal array of horns (i.e., Horn #1, #2, and #3 in Fig. 1(a)) has been designed in such a way to achieve a multibeam radiation for polar angles θ equal to 0° and $\pm 24^\circ$ along with the azimuth plane $\phi = 90^\circ$. The antenna field-of-view can be further enhanced by displacing the input horns along the y-axis [see Fig. 1(a)].

As shown in Fig. 2, the measured reflection coefficient at the input connector of the antenna module is lower than -10 dB in the frequency range 19-31 GHz. The fractional bandwidth is 48%. The broadband capabilities of the CTS arrays are so

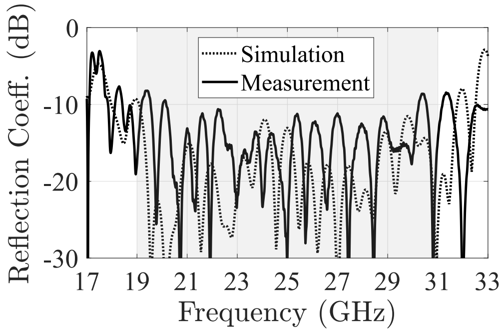
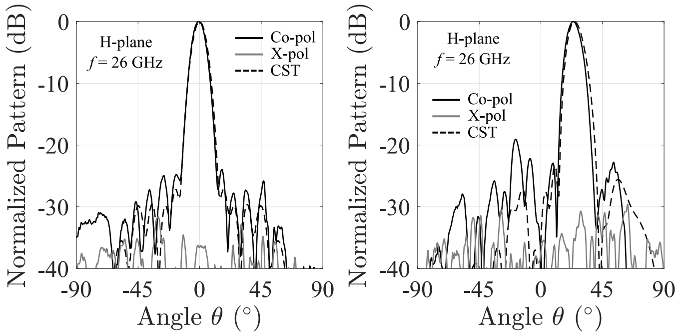


Fig. 2. Measured reflection coefficient at the input connector of the antenna (Horn #1).



(a) Horn #1. (b) Horn #2.

Fig. 3. Measured normalized patterns along the H-plane at 26 GHz. (a) Horn #1 excitation. (b) Horn #2 excitation.

confirmed, even for very compact antenna architectures. The measured results shown in Fig. 2 refer to broadside radiation, i.e., excitation from Horn #1 in Fig. 1(a).

The measured radiation patterns are depicted in Fig. 3. In particular, the normalized patters along the H-plane at 26 GHz are plotted in Figs. 3(a) and (b) for Horn #1 and #2 excitation, respectively. The side lobe levels (SLL) are below -25 dB at 26 GHz for broadside radiation and lower than -20 dB when the array is steering the main beam at $\theta = 24^\circ$ in the H-plane. The -3 dB beamwidth is about 15° at 26 GHz. A very good agreement is observed between measurements and full-wave simulations.

The antenna module guarantees a full coverage of the down- and up-link frequency channels of the K/Ka-band for SatCom applications. For this reason, it can be used in combination with a dual-band, linear-to-circular polarization (LP-to-CP) converter, in order to attain diverse circular polarization between the receive and transmit frequency bands [11].

IV. Conclusion

An ultra-low-profile, broadband CTS array has been proposed in this paper. The antenna array consists of long slots, parallel-fed by a pillbox system through a CFN in vertical PPWs, whose bounding walls are realized with via-fences. The antenna module is only 6.07 mm thin and entirely fabricated using a multilayer PCB process. The fractional bandwidth of operation is 48% (19-31 GHz). The maximum realized gain is 21 dB at 29 GHz. The broadband behavior of this antenna module and its extreme low-profile make it a valid candidate as a terminal antenna for modern SatCom on-the-move applications.

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