Full Duplex SATCOM ESA With Switchable Polarization and Wide Tunable Bandwidth Using a Tripleband Metasurface Aperture

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***Abstract*—A full duplex Ku Satcom user terminal using a metasurface antenna and holographic beamforming is presented. The shared-aperture metasurface combines multiple sub-arrays to integrate receive and transmit antennas in a single physical aperture. To cover the entire receive band with a high gain, two receive sub-arrays are implemented. These two receive sub-array along the transmit sub-array result in a Tripleband Metasurface Aperture (TMA). Each TMA sub-array can form and steer a beam independently and simultaneously, while switching the frequency channel and polarization in software. The reconfigurable TMA is manufactured using flat panel display technology with liquid crystal as the tunable dielectric. With a circular radiative aperture, 82cm in diameter, a maximum antenna gain of 35.9dBi in receive and 34.9dBi in transmit are achieved in full duplex mode. The user terminal provides a wide scan range of ±75° in 2D and fast tracking (~30°/sec) with antenna power consumption of only 35 W. Furthermore, an integrated multi-WAN 3G & LTE provides seamless connectivity between satellite and terrestrial networks.**

I. Introduction

A new age of satellite connectivity has emerged during the last few years and a new space race is on with advanced GEO and MEO satellites and large LEO constellations. Tens of thousands of satellites could be orbiting overhead in a few years if the proposed satellite internet plans become reality. Besides the technological advancements in spacecraft manufacturing and launch, the success of these ambitious plans hinges on innovations in Electronically Scanned Arrays (ESAs) to connect a massive number of users to these networks and provide the economies of scale. The metasurface antenna operated through holographic beam forming is an innovative solution that has been developed to meet performance, size, weight, cost and power requirements for mobile use cases. Kymeta has developed and commercialized a Ku band user terminal product based on this technology that will be discussed in this paper.

II. User Terminal

Figure 1 shows an image and exploded view of the user terminal. The metasurface and the feed assembly along with a wide-angle impedance matching network (WAIM) build the core of the antenna. The control electronics, RF chain and modems are integrated behind the feed assembly. The terminal is ruggedized and enclosed for environmental protection with a radome and backshell from the front and back. In the following, the characteristics of the metasurface is discussed and key antenna performance results are presented.

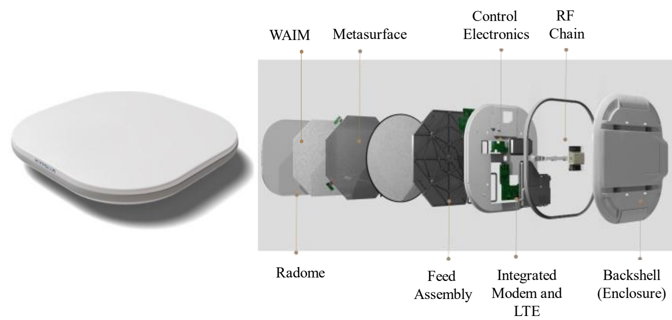

Figure 1. Image and exploded view of the MSA user terminal

III. MetaSurface Antenna Technology

A. Metasurface and Holographic Beam forming

A metasurface antenna is an aperture antenna that consists of resonant and scattering metamaterial elements with subwavelength spacing and size. A desired radiated field from the metasurface is generated by exciting the scattering elements with a field from a waveguide, and by modulating the metasurface. The modulation defines the impedance profile of the metasurface required to transform the feed wave into a radiated wave that results in a desired beam in farfield [1]. The desired beam is typically defined through its pointing angle, polarization, and frequency but can be extended to define other beam characteristics such as sidelobe profile and cross polarization discrimination. These attributes are implemented in the authors' metasurface antenna design and are controlled through software [2]. The modulation is calculated using a combination of Holographic Beam Forming (HBF) and Euclidean Modulation [3]. The HBF approach is predicated on the subwavelength scattering over the aperture, which can be conceptualized as continuous electric and magnetic current distributions.

B. Tripleband Metasurface Aperture

One of the key advantages of metasurface antenna technology compared to traditional ESA technologies is the design flexibility it provides when it comes to integrating multiple frequency bands within the same physical aperture. Due to the wideband nature of parallel plate waveguides as used in this work, the integration of multiple bands does not increase the complexity of the feed structure. The integration of multiple bands is done by interleaving multiple sub-arrays,

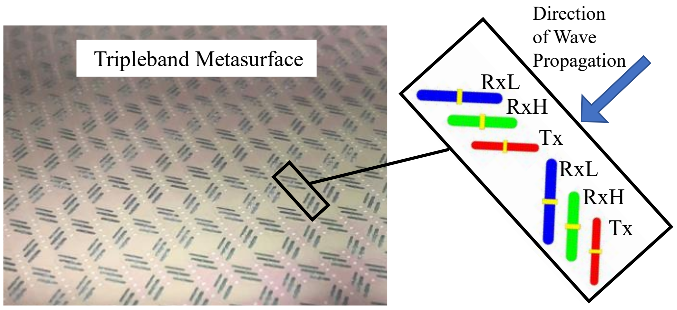

Figure 2. Photo of the TMA and the unit cell with three sub-bands

which differ in their tunable frequency ranges. This technique is used in this work for two different purposes. Firstly, the metasurface is designed to operate in full duplex mode for simultaneous receive (Rx: 10.7GHz – 12.75GHz) and transmit (Tx: 13.75GHz – 14.5GHz). To achieve that, an Rx sub-array and a Tx sub-array must be interleaved across the metasurface aperture. Secondly, due to the wide tunable bandwidth required for Rx, the Rx band is further divided into two sub-bands, Rx-Low (RxL) and Rx-High (RxH). This creates the Tripleband Metasurface Antenna (TMA), with one transmit band and two receive bands, in which each sub-array can form and steer its own beam simultaneously and independently from the other two within its band of operation. The Rx band does not necessarily need to be divided into two sub-bands to cover the entire Ku receive band. However, due to a tradeoff between tuning bandwidth and radiation efficiency of each scattering element, an improvement of more than 3dB was achieved by designing two sub-arrays, each covering about 1GHz of the bandwidth instead of one array for the whole 2.05GHz of the receive band.

Figure 2 shows a photograph of the metasurface and highlights a unit cell of this array. The unit cell consists of two sets of RxL, RxH and Tx scattering element (tunable slot radiators). The two sets are placed perpendicular to each other and with a ± 45° rotation with respect propagation vector of the feed wave. By realizing a ± 45° rotation with a high-enough cell density, any polarization can be achieved at the sub-array level (LHCP, RHCP, and linear polarization at any polarization angle) by properly weighting the vector components in modulation.

IV. Flat Panel Display Technology

The discussed metasurface design has been manufactured using flat panel display technology with liquid crystal as a tunable dielectric. This design consists of about 70,000 scattering elements, each equipped with a tunable capacitor and individually controlled through drive electronics and software across a circular aperture of 82cm in diameter. While these requirements are entirely outside the capabilities of standard PCB technology, they pose no challenge to the flat panel display technology, in which more than 3 Megapixels, each individually controlled, are integrated within a similar size display. Like in displays, the metasurface is monolithically integrated between two glass substrates with a liquid crystal mixture in between, optimized for microwave frequencies, and a thin-film transistor matrix drive circuitry to individually address each element in software [4].

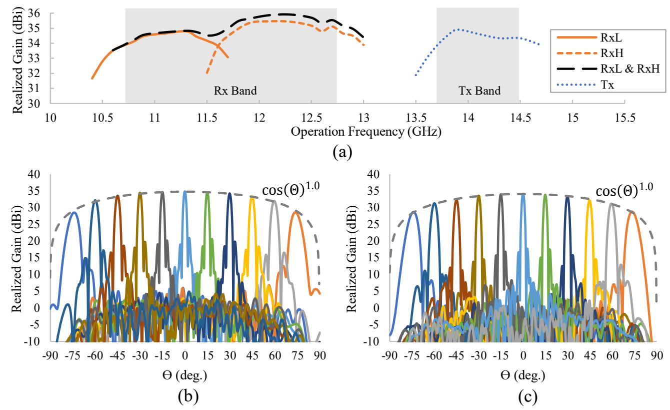

Figure 3. (a) Measured tunable bandwidth, (b) Measured farfield patterns at 11.8GHz (Rx), (c) Measured farfield patterns at 14.2GHz (Tx)

V. Antenna Performance

Figure 3 shows the antenna performance measured in an anechoic chamber. In Figure 3(a), the realized gain over operation frequency is shown, demonstrating the tunable bandwidth of the antenna for each of the three sub-bands at broadside. Although RxL and RxH can operate independently, only one Rx beam is required for the current application of the antenna. It was demonstrated that operating both sub-bands together (RxL & RxH) to form a single Rx beam independent from the operation frequency, the antenna gain is improved and a smoother transition at the border between the sub-bands can be achieved. Figure 3(b) and Figure 3(c) show antenna patterns for pointing angles from -75° to +75° from broadside. The operation frequencies are 11.8GHz for Rx and 14.2GHz for Tx. The two patterns are applied simultaneously, and the polarization is linear with a linear polarization angle of 90° for Rx and 0° for Tx. The scan rolloff for both frequencies is tracking with $\cos(\Theta)^{1.0}$. This excellent scan performance is achieved through a WAIM layer located on top of the TMA and optimized to provide a proper matching to the free space across different scan angles and across the Rx and Tx frequency range.

Conclusion

The Tripleband Metasurface Antenna presented in this paper allows the developed user terminal to cover the entire Ku Rx and Tx bands in a single aperture for full duplex operation, making the user terminal an innovative solution for mobile SATCOM use cases.

References

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