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# Metamaterial Surface Antenna Technology: Commercialization through Diffractive Metamaterials and Liquid Crystal Display Manufacturing

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*Abstract* – **For mobile, broadband satellite communications applications such as the connected car, a high-gain, scanning antenna is required. Kymeta® is commercializing an electronically scanned, metamaterial antenna technology achieved through the use of diffractive metasurfaces and high-birefringence liquid crystals. Kymeta's technology is positioned for mass production by leveraging the manufacturing capabilities of the liquid crystal display industry.**

## I. Introduction

For broadband satellite communications applications where the platform is mobile, where the satellite is non-geostationary, or both, a scanning antenna is required. The satellite communications industry, however, is dominated by dish antennas mounted on motorized gimbals for these applications. These solutions are too large, heavy, and power-consuming to offer solutions for consumer mobile applications such as the connected car or a personal satellite terminal. Another alternative is phased array technology, but this technology is typically available only to government and military customers because of its expense and power consumption.

Kymeta has addressed these obstacles by developing an electronically-scanned antenna technology, based on a diffractive metamaterials concept, called Metamaterial Surface Antenna Technology (MSAT). Electronic scanning is achieved through the use of high-birefringence liquid crystals. The use of liquid crystals (LC) as a tunable dielectric at microwave frequencies permits large-angle (> 60°) beam scanning with power consumption of < 10 Watts and antenna thickness ~ 5.0 cm, with no moving parts. Kymeta's engineering approach, through the use of LC and optimization of the materials and design for compatibility with liquid crystal display (LCD) manufacturing processes, positions the technology for mass production by leveraging the capital infrastructure of the LCD industry.

## II. Metamaterial Surface Antenna Technology

### *A. Metasurfaces*

Conventional three-dimensional metamaterials rely on bulky structures where resonant phenomenon are used to achieve the desired effective medium properties, e.g., negative refractive index [1]. This resonant behavior dramatically limits their bandwidth, efficiency, and ultimate utility for point-to-point communications links. In addition the tolerances required to maintain narrow resonances over physically large structures (such as the aperture sizes required for Ku- and Ka-band satellite communications) prohibits the manufacturing of such materials at consumer electronics scale and cost.

Kymeta is leveraging a metasurface concept, in conjunction with holographic beamforming principles to commercialize MSAT [2]. Metasurfaces have a number of advantages, namely that they take up less physical space and have the potential for less-lossy structures. Metasurfaces are characterized by both the periodicity of scatterers and thickness of the surface being small relative to the wavelength of interest.

### *B. Holographic Diffraction*

In the MSAT approach, the metasurface is treated as a diffractive element, rather than a refractive one [3]. The metasurface is introduced along one of the guiding surfaces of a guided-wave feed structure, as shown in figure 1, such that the scattering elements are weakly coupled to the feed wave. In this particular example, the metasurface is placed across the broad wall of a rectangular waveguide.

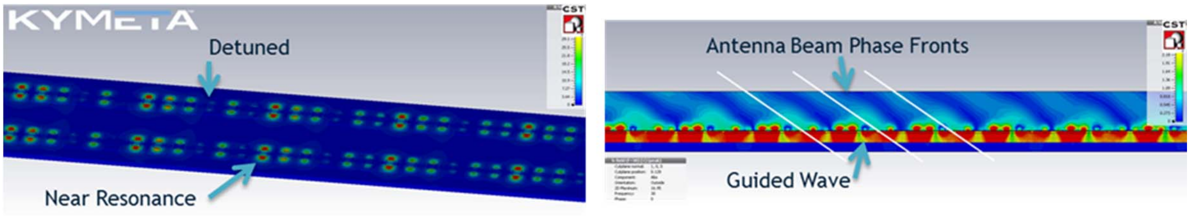



Fig. 1. Top view and cross section showing the metasurface, feed structure, and the antenna beam produced from the holographic diffraction of the guided feed wave against the metasurface.

Figure 1 shows that the scattering elements in the metasurface radiate with a periodicity that corresponds to the scan angle of the beam. The scattering strength is controlled by tuning the resonance frequency of the individual elements. Near their resonant frequency, the scattering elements couple energy from the feed wave and radiate this energy from the surface of the antenna. Detuned elements do not scatter energy from the feed wave at the frequency of interest.

The scattering strength of each element is determined through a holographic calculation where the diffraction pattern between the feed wave, $\Psi_{ref}$ (reference beam), and the outgoing wave, $\Psi_{obj}$ (object beam) is calculated according to the following equations:

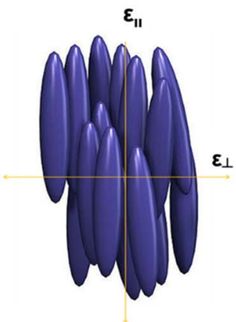
$$\Psi_{ref} \approx \exp(-i\,\boldsymbol{K_s} \cdot \boldsymbol{r}), \quad \Psi_{obj} \approx \exp\left(-i\boldsymbol{K_f}(\theta_o, \varphi_o) \cdot \boldsymbol{r}\right), \quad \Psi_{int} \approx \Psi_{obj}\Psi_{ref}^{*} \tag{1}$$

In equation (1) $\boldsymbol{K_s}$ is the complex propagation constant for the reference feed wave, $\boldsymbol{K_f}(\theta_o, \varphi_o)$ is the desired complex free space propagation vector, which is a function of the desired azimuth and elevation scan angles, $\boldsymbol{r}$ is a coordinate on the metasurface, and * denotes the complex conjugate. When the azimuth and elevation between the antenna and the satellite changes, a diffraction pattern to produce the new object beam at the new look angle is calculated. The scattering from each radiating element on the metasurface is then adjusted to reproduce this diffraction pattern.

A critical factor in the commercialization of MSAT is that with holographic beamforming, the diffraction pattern on the metasurface is produced through the tuning of element resonances, but the antenna beam is not produced *on* a resonance. Thus, the antenna bandwidth is not limited by the resonance of the elements but by the tunability of the elements (change in resonant frequency). MSAT, therefore, can achieve broadband operation as necessary for satellite communications.

## III. Liquid Crystal Display Manufacturing

Kymeta employs high-birefringence, nematic liquid crystals to tune the resonance frequency of the metasurface scattering elements. This material class forms a uniaxial system where the relative permittivity tensor is shown in figure 2, along with the molecular orientation. The physical construction of a metasurface scattering element is shown schematically in figure 2 as well.




$$\begin{pmatrix} D_z \\ D_y \\ D_x \end{pmatrix} = \begin{pmatrix} \varepsilon_{\parallel} & 0 & 0 \\ 0 & \varepsilon_{\perp} & 0 \\ 0 & 0 & \varepsilon_{\perp} \end{pmatrix} \begin{pmatrix} E_z \\ E_y \\ E_x \end{pmatrix} = \begin{pmatrix} \varepsilon_{\parallel} \cdot E_z \\ \varepsilon_{\perp} \cdot E_y \\ \varepsilon_{\perp} \cdot E_x \end{pmatrix}$$

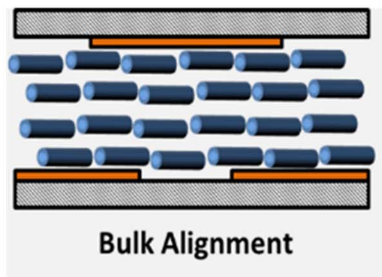



Fig. 2. Illustration of a MSAT scattering element, LC molecular arrangement, and corresponding uniaxial permittivity tensor.

Referring to the schematic cross section in figure 2, a scattering element is comprised of a subwavelength slot coupled to a patch element. This structure results in a magnetic dipole scattering element, but also comprises the electrodes for driving the liquid crystal with a low-frequency AC voltage. When a voltage is applied the LC molecules rotate to follow the applied electric field. Consequently, the RF fields of the scattering element see a change in relative permittivity that changes the capacitance of the scattering element, thus tuning its resonance frequency.

The metasurface construction, with an upper and lower substrate/electrode and LC as the tunable medium, closely resembles the assembly of an LC display. Array elements are individually addressed in an active matrix addressing scheme using printed thin film transistors (TFT), exactly as typical displays are made. The metasurface for Kymeta's Ku-band alpha prototypes is being manufactured in cooperation with Sharp Corporation, where a commercial display line is being used.

## IV. Conclusion

MSAT is a versatile approach that has addressed some of the well-known issues in 3-D metamaterials, namely bandwidth, efficiency, and sensitivity to manufacturing tolerances. With MSAT Kymeta has developed high-gain, electronically scanned arrays in both the Ku and Ka satellite bands. Kymeta's alpha prototypes have demonstrated combined transmit and receive functions from a single aperture, dynamically controllable polarization, ~ 30 dB of cross-polarization discrimination, full 360 degrees of azimuth scanning, and elevation scanning > 60 degrees with negligible impact to return loss. The size, weight, power, performance and manufacturing of MSAT make it well-positioned to address high-volume, low-cost mobile satellite opportunities.

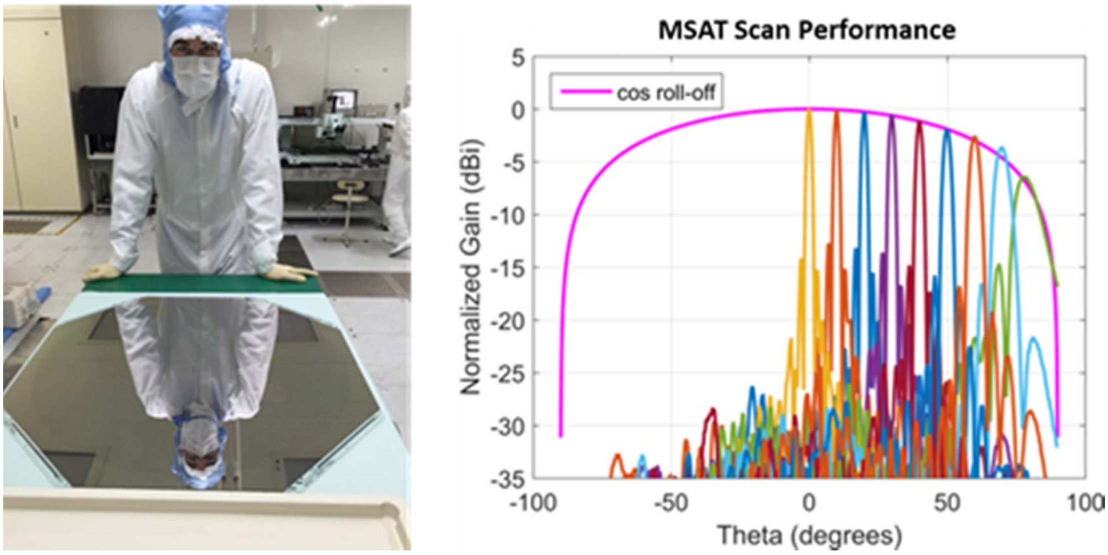



Fig. 3. Kymeta's 70cm Ku-band metasurface on the assembly line (left); 70cm Ku-band MSAT beam patterns vs. scan angle (right).

## References

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