A Dual-Band Leaky Wave Antenna Design for K-Band and W-Band

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***Abstract*—A bi-directional dual-band meta-surface antenna designed to operate at 20 GHz in the longitudinal direction and 80 GHz in the transverse direction is described and simulation results are presented.**

***Index Terms*—Radar, Metasurface antennas, Leaky Wave Antennas**

I. Introduction

Leaky Wave (LW) antennas have a variety of applications across different fields due to their unique ability to continuously radiate electromagnetic waves along the antenna structure, allowing for beam steering and control over the direction of the main beam. This article focuses on radar applications where LW antennas are desirable for their ability to steer the radar beam electronically. This enables scanning over a wide field of view without the need for mechanical movement of the antenna.

Complex avionic systems often require radar for multiple sensing tasks and varying tasks can require designs to have very different nominal operating frequencies for radar. For example, imaging radar systems operate at frequencies where low atmospheric loss and spatial resolution are of interest, e.g., X- and K-bands having frequency ranges (8-12, 12-40) GHz respectively. On the other hand, shorter range high-precision navigation and seeking systems operate in the W- and V-bands having frequency ranges (40-75, 75-110) GHz respectively.

At a system-design level, radar payloads can place demanding requirements due to their size, power, mounting needs, power and need for integration of a radar-transparent radome design on the vehicle envelope. Most radar systems utilize highly directional antennas having typical HPBW of several degrees to less than 1 degree to improve resolution and range at the cost of the aperture of the sensing field. These designs often require slow and expensive mechanical gimbals that point the antenna in the direction of objects of interest.

This article describes simulation outcomes for a prototype dual-band LW antenna design having attributes desirable for serving radar long-range image sensing tasks and shorter-range precision guidance and navigation tasks. We describe the design considerations of the antenna and present results from the EM simulation. Contributions of this work follow:

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1) the design merges a 22 cm LW antenna design for operation in the K-band with a 4.2 cm LW antenna design for operation in the W-band.
2) the design exploits non-radiating portions of the low-frequency LW antenna design as locations where multiple W-band antenna can be overlaid to provide dual band operation.
3) complementary meta-surface (MTS) split-ring resonators implement a Substrate Integrated Waveguide (SIW) design for the K-band antenna without drilling vias simplifying fabrication.

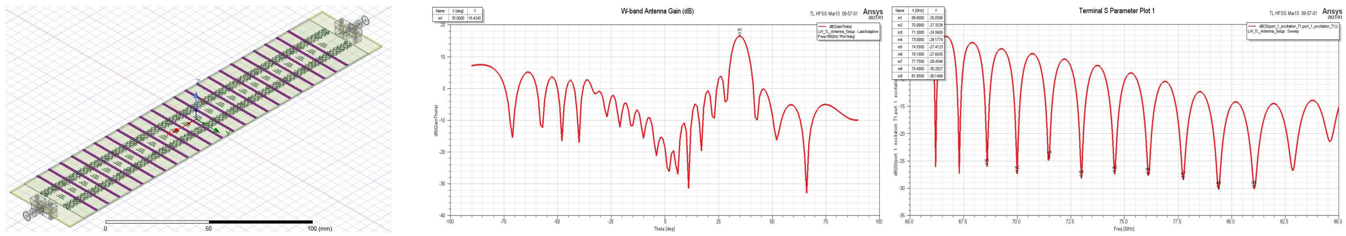
This article describes the two antennas designed and provides simulation results for the integrated dual-band design for both the K- and W-bands.

The dual-band antenna is constructed as a sequence of 5 layers of alternating conductive and dielectric layers (metal, dielectric, metal, dielectric, metal). The first 3-layers implement a K-band (20 GHz) LW antenna fed in the x-direction having (x, y) dimensions of 220×42 mm. The following 2-layers implement a W-band (80 GHz) LW antenna fed in the y-direction having (x, y) dimensions of 42×4 mm. The W-band antenna is placed at non-radiating locations along the extent of the Ku-band antenna and uses the K-band antenna transmission line as the W-band antenna ground plane.

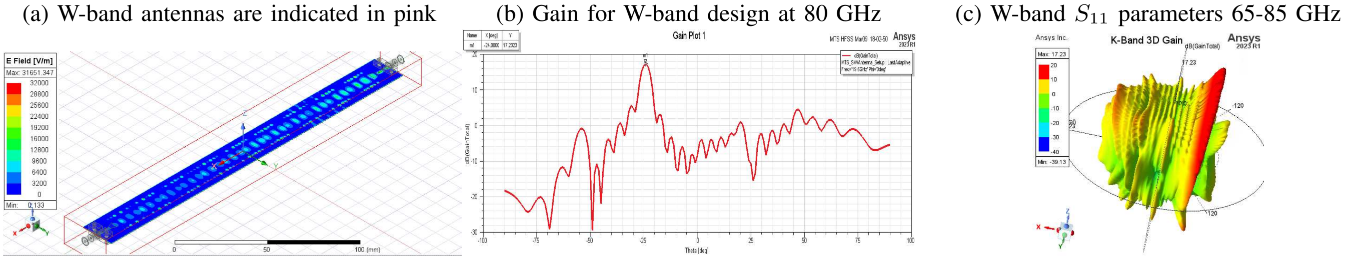
The Ku-band antenna includes 24 slotted patterns where the bulk of the 20 GHz radiation occurs. Radiation slots are separated in the x-direction by 5.6 mm Parallel-Plate Wave Guide (PPWG) regions where the local structure of the Ku-band antenna resembles a PPWG. These regions of the K-band antenna are non-radiating and 23 W-band LW antenna designs are centered on these PPWG regions along the extent of the K-band design. The W-band antennas leak waves in the y-direction and are designed to be fed from local circuitry distinct from the K-band antenna.

II. Results and Discussion

Radiation characteristics for the K and W band antennas were determined through simulation using Ansys HFSS. Figure 1e and 1b show the gain as a function of elevation with $\theta = 0$ denoting broadside radiation. Both antennas exhibit good radiation power with a peak gain of 17.23 dB (K-band) or 16.42 dB (W-band) and approximately 8-degree



(a) W-band antennas are indicated in pink (b) Gain for W-band design at 80 GHz (c) W-band S_{11} parameters 65-85 GHz



(d) SIW $|\mathbf{E}|$ in substrate of K-band antenna (e) Gain for K-band design at 19.6 GHz (f) 3D Gain Pattern for K-band design in dB

Fig. 1: (a-f) illustrate antenna design aspects. (b,e) show gain for both K- and W-band antennas, (c) shows the W-band S_{11} antenna parameters (d) shows the K-band MTS SIW E-field guidance and (f) shows the 3D K-band gain pattern.

mainlobe width. Figure 1f shows the 3D structure of the K-band radiation pattern.

The K-band antenna uses complementary MTS split-ring resonators inscribed on opposite sides of the substrate that serve as a MTS implementation of a SIW [1]. This confines the K-band wave within the appropriate extent of the K-band antenna and allows the y-dimension of the antenna to be extended to allow the W-band antenna to be almost $10\lambda_W$ long improving the radiation efficiency.

K-band and W-band antennas have complementary designs in the sense that the K-band LW antenna uses metal, i.e., copper, as the transmission line which has low loss at K-band frequencies. In contrast, the W-band antenna uses the dielectric slab for transmission and small metal patches perturb propagation constants since conduction loss in metal is significantly higher at mm-Wave frequencies. The K-band design uses 18 μm copper-clad Duroid 5880 with a thickness of 0.787 mm. The W-band design uses 0.13 mm glass with gold patches deposited on top of this substrate to implement the LW antenna.

The radiation pattern for the W-band antenna is governed by equation (1)

$$\theta = \sin^{-1}\left(\frac{\beta}{k_0} - \frac{2\pi}{k_0 d}\right) \tag{1}$$

where β and k_0 are the phase constants in the dielectric guide and free space respectively and d is the periodicity of the conducting patch perturbations on the surface of the waveguide [2], [3].

Analysis operates the two antennas in isolation and concurrent operation has not been characterized in the scope of this article. The W-band design is intended to be compatible with the Texas Instruments AWR1843 chipset for future device level and radar integration experiments. The AWR1843 is an automotive radar sensor chip that provides a high-fidelity RF backend for 3 transmit and 4 receive antennas per chip that use antennas operating in the 76-81 GHz range for short range (< 1 km) applications.

III. Conclusion

This article briefly discusses a 5 layer dual-band leaky wave antenna design. The design consists of a 3-layer 20 GHz antenna structure operating along the x-axis and a sequence of 2-layer 80 GHz antenna structures deposited onto the surface of the 3-layer structure. The 3-layer 20 GHz antenna is a meta-surface leaky wave antenna measuring 220×42 mm in length. Each 2-layer 80 GHz antenna is placed on top of the 20 GHz leaky wave structure at electrically inactive (non-radiating) areas. Each 80 GHz antenna is a leaky wave antenna having a thin glass dielectric layer. The 20 GHz antenna uses complementary split-ring resonator MTS structures that serve as a wave guide without requiring drilling and metallic infill of the dielectric layer with a conductor. Dual band operation allows the antenna to radiate at vastly different frequencies and electrically control the direction of emitted RF by varying the excitation frequencies.

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