Metal 3D Printed D-Band Waveguide to Surface Wave Transition

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***Abstract*— The coupling efficiency between free space waves and surface waves is low, narrowband, or both. Highly efficient broadband (better than 20% fractional bandwidth) coupling from waveguide modes can be achieved through sophisticated transitions whose fabrication can be enabled through additive manufacturing (e.g. selective laser melting). Here, we present alternative metallic transitions designed to couple the fundamental mode of a D-band waveguide to the fundamental transverse-magnetic surface mode supported by a periodic metal corrugated grating. Simulations of the coupling process and initial measurements have been undertaken.**

I. INTRODUCTION

AT Terahertz frequencies, metals behave as perfect electrical conductors, and hence surface plasmons cannot exist. Nevertheless, structures can be designed to support electromagnetic modes whose field distribution resembles that of surfaces plasmons [1]-[3]. Such modes, known for decades in the microwave literature [1],[4]-[6], have been revisited, expanded and renamed as spoof plasmons [2],[3],[7]. These surface waves share both the spatial and dispersive properties of surface plasmons, depending entirely on the geometric parameters of the structure. They provide a compact method of transmitting electromagnetic radiation [7],[8]-[10], while the high field confinement can be utilized for sensing applications [11]-[13]. Each of these applications rely on efficient coupling of waveguide to surface modes [14].

Here, we present a graded grating structure and upper flare, designed for efficient coupling from a continuous wave TeraSense IMPATT diode waveguide port, operating at 0.14 THz, to a metallic grating platform (see figure 1).

II. RESULTS

To support a highly-confined surface mode at 0.14 THz, a grating structure was designed, with periodicity d = 0.5 mm, corrugation height h = 0.4 mm and width w = 0.2 mm (see the unit cell in figure 2(a)) [1],[4]-[6]. To this end, the eigen-mode solver of CST Microwave Studio® was used.

To facilitate the coupling of energy from the waveguide mode to the surface wave, a coupling transition of ~$2.6\lambda_0$ in length (where λ_0 is the free-space wavelength at 0.14 THz) was designed, consisting of a graded grating section and a smooth upper flare. In the graded grating section, the corrugation height was increased exponentially from h = 0 mm to h = 0.4 mm, while two alternative profiles were designed for the upper flare: exponential [14] and linear [4]. Each of these components were optimized in the transient-solver of CST Microwave Studio®. To avoid reflections of the surface wave, an inverse of the graded grating region was replicated at the end of the structure to facilitate the coupling of the surface mode to free space. Hence, the prototype is also working as an end-fire antenna.



Fig. 1. A photograph of the full transition platform, including the UG-387 flange. Fabrication of the Al-alloy structure involved selective laser melting.

Prior to fabrication, simulations of the full Al-alloy (92 weight percent (wt. %) Al, 5 wt. % Cu, and 3 wt. % others) structure were carried out in CST Microwave Studio® in order to determine the coupling efficiency. Figure 2(a) and (b) present the S_{11} along with the *E*-field distribution at 0.138 THz for the exponential and linear flare profiles, respectively. One can observe efficient coupling to the surface wave up to the Brillouin zone band-edge of ~0.142 THz for each design, above which the grating does not support a surface wave. The reduction in S_{11} for the linear flare indicates that there are reflections between the flare and the corrugated structure. The linear flare is shorter and hence induces increased scattering of the fields, as is evident from the *E*-field distribution presented in figure 2(b). Thus, there is a reduction in coupling efficiency for the linear flare. The exponential flare was therefore selected as the optimum design to be fabricated.

The structure was subsequently fabricated through selective laser melting, see figure 1. Currently, the full characterization of the transition in terms of S_{11} and radiation pattern is on-going using a combination of the Keysight N5247B PNA-X with VDI frequency extenders available at University of Birmingham and the ABmm MVNA-8-350 and Keysight N5242A PNA-X with OML frequency extenders available at Universidad Pública de Navarra. Preliminary results of the radiation pattern measured with the Keysight N5242A PNA-X with OML frequency extenders for both E- and H-plane as well as diagonal planes can be found in figure 3. Such radiation patterns are estimated using a standard near-field (measurements done 20 mm from the tip of the prototype) to far-field transformation. In accordance with the simulations, the maximum directivity ~20.5 dB happens at 135 GHz and the E-plane displays a characteristic edge diffraction pattern.

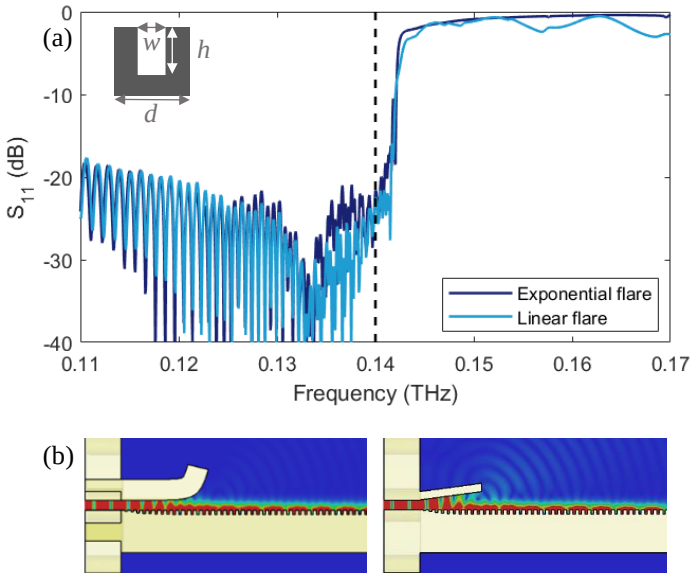


Fig. 2. (a) Simulated – including ohmic losses – S_{11} for the exponential and linear flare designs. Inset: unit cell of the grating designed to support a confined surface mode at 0.14 THz. (b) Tangential *E*-field at 0.138 THz for the exponential (left) and linear (right) flares.

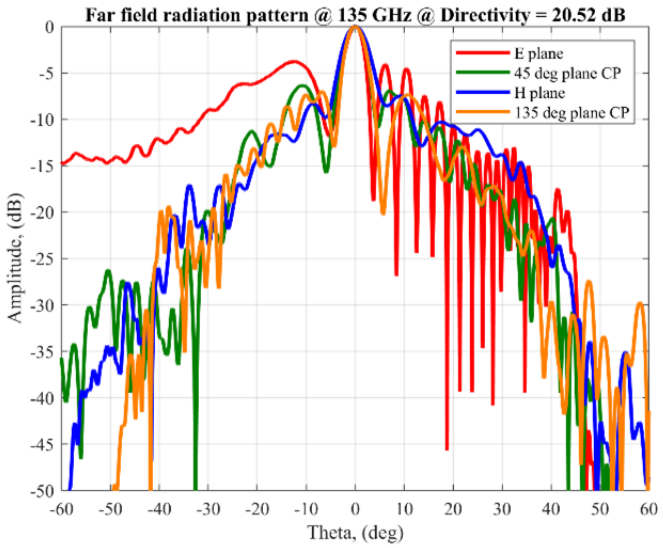


Fig. 3. Measured far-field radiation pattern at 135 GHz.

III. Summary

We have presented initial numerical results and measurements for alternative flares designed for efficient coupling of a waveguide mode to a surface mode through simulations. The exponential flare shows more promising coupling efficiencies over the linear flare, which exhibited large amounts of scattering of fields. Future work aims to complete the characterization of the fabricated exponential flare structure as a waveguide to surface wave transition and end-fire antenna.

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