Low Profile THz Periodic Leaky-Wave Antenna

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***Abstract* — In this work, a 0.566THz flat leaky-wave antenna, consisting of a central $\lambda_0/2$ slot surrounded by straight parallel wedge corrugations, is numerically and experimentally analyzed. Simulations show a moderately high gain and no significant differences when compared with a typical square corrugation profile. Numerical comparison is also made for the designed and manufactured antennas. High transmission enhancement in the corrugated case is obtained, compared to that given by a single central slot with no grooves. This kind of antennas finds several applications in different frequency ranges, including the nowadays high-interest range of the THz.**

Keywords—leaky wave antennas, THz, antennas, millimeter waves, corrugations, resonant slot

I. INTRODUCTION

Leaky wave antennas (LWA) [1], [2] stand out from other antenna designs as they present, despite their low profile, comparable or even higher radiation characteristics compared to larger volume antennas, as horns. Besides, the THz range is nowadays one of the hottest topics in electromagnetics research [3]–[6], as this part of the spectrum has not been fully exploited, giving rise to the proposal of new applications and novel devices. LWAs are thus of high interest for several applications in the THz range, as pulse- and beam-shapers[7], [8]. We can find two kinds of LWAs in the literature, those with a uniform profile, and those which follow a periodic profile. Framed in the latter group, the antenna we deal with here presents corrugations periodically distributed.

Closely associated with this kind of designs is the phenomenon of Extraordinary Optical Transmission (EOT), initially found in the optical range. It was at the beginning of the 21st century, when it was observed that a metallic slab with sublambda perforations presented a high transmittance, in sharp contrast with what could be expected by applying directly the classical diffraction theory through a narrow aperture [9], [10]. This behavior was later observed for a central sublambda aperture surrounded by corrugations [11]. Some examples of the utility of the EOT can be found in [12]–[15]. The plasmonic interpretation firstly given for this phenomenon was not suitable for the microwave and millimeter range later studied [16], being replaced by a leaky wave interpretation. Based in this, several prototypes were designed and experimentally analyzed. All of them presented straight corrugations as a common feature [17], [18], with the exception of the Bull's-Eye antenna [19], whose corrugations were annular and concentric. This modification highly enhanced the antenna gain. The main characteristic of these corrugated leaky wave antennas is the capability of coupling the incident power to a leaky-wave, i.e. a surface-wave which propagates along the surface and is then in-phase reradiated to the free space by means of its corrugations, which for a single beam must excite only the n = -1 space harmonic [20], [21], achieving narrow beams and high directivity with a very low profile. Following this research line, two LWAs operating at 560 GHz (λ_0=536µm) were designed and numerically analyzed with the full-wave 3D EM solver CST Microwave Studio™: one with square grooves and a second one presenting a triangular corrugations profile. For the latter, manufacturing and experimental studies were carried out. The research on their radiation properties, along with the radiation and temporal properties of a THz Bull's-Eye antenna and how radiated pulses are shaped, were published in [22].

Designs are presented in Section I, followed by simulations in Section II and experimental results in Section III. Conclusions in Section IV provide a brief summary of the work.

II. DESIGN

Two prototypes were designed in order to compare their radiation characteristics: an antenna with square corrugations and a triangular grooves antenna. Both antennas consist of a metallic flat slab with a central slot, surrounded by periodically distributed straight grooves, approximately half the operating wavelength wide, $S_x = \lambda_0/2$, and a slot height S_y of about $\lambda_0/9$. It couples, through its transversal resonance, the power given by a feed-waveguide at the input face to the output face. The width of the slot gives this transversal resonance, whereas its height mainly fixes the operation bandwidth. In order to obtain a near broadside radiation, the period between corrugations must be approximately equal to λ_0 and the distance from the slot to the first pair of opposite grooves, namely offset, d_1 and d_2, should be such as that in-phase radiation is achieved. This last parameter was obtained by means of a fine optimization, as well as the grooves' depth and width, g_z and g_y.

Fig.1 shows both square and triangular profile antennas' cross-sectional views and a perspective view of the latter. As it can be concluded from the parameters shown in Table I, the structures only differ, apart from the geometry and dimensions of the grooves, in the distribution of the corrugations along the plate.

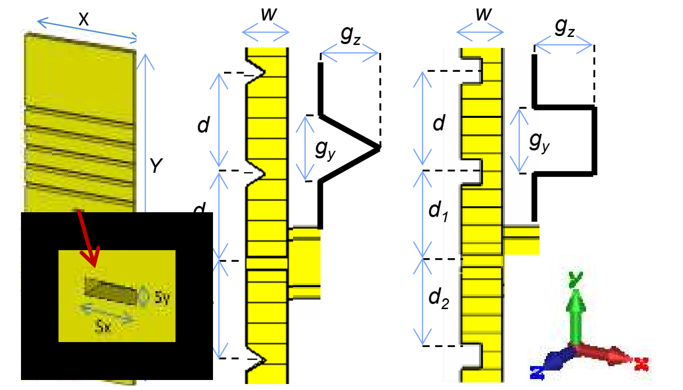

Fig. 1. Triangular and square profile antennas. Inset shows slot in detail.

TABLE I. DESIGN PARAMETERS FOR ANTENNAS

Parameter	Triangle (µm)	Triangle Fabr. (µm)	Square (µm)
Plate Width, X	3000	2986	3000
Plate Height, Y	9000	8938	9000
Plate Thick., w	200	200	200
Slot Width, S_x	268	266	268
Slot Height, S_y	56.6	67.2	56.6
Period, d	519	519	519
Offset1, d_1	463.24	458	449.17
Offset2, d_2	463.24	493	449.17
Gr.width, gy	132.91	133	104.7
Gr. depth, gz	94	95	74

After manufacturing, a new design was also modelled with the measured dimensions (also in Table I) of the fabricated structure. This was done was as, due to fabrication tolerances, some deviations were introduced between designed and manufactured prototypes, being the offset distances and the slot height the most notable of them. As stated previously in this section, the slot height mainly fixes operation bandwidth, thus, only offset distances remained crucial.

In order to reduce computation time, magnetic and electric symmetries were used for the Y-Z and X-Z planes correspondingly, except for the fabricated design, which lacks of electric symmetry. As the fabricated structure is coated with gold, the metallic plate material considered for the simulation was gold, with electric conductivity $4.56{\times}10^7$ S/m.

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III. SIMULATION RESULTS

Spatio-temporal properties of above described structures were analyzed by means of the Transient Solver provided by CST MWS^{TM}. As stated in Section II, the slot width determines the transversal resonance which couples incident wave, polarized in the Y direction, to the output interface in the form of a TM_z mode surface-wave.

It was also verified that a second resonance, corresponding to the longitudinal resonance, given by the slot depth (or slab thickness), appears at around $f \sim 0.8$THz. Fig. 2 shows how both triangular and square corrugations designs barely differ in their behavior, presenting approximately a 16dB gain for f = 0.566THz, i.e. a 10dB enhancement compared to the flat structure.

Regarding the -3dB beamwidth (θ_{-3dB}), the triangular grooves structure radiates a 5.8deg beam for the E-plane, 1deg narrower than the square grooves case. In the H-plane the beam is substantially wider, θ_{-3dB} = 26deg. In addition, triangular corrugations present an 8.6dB side lobe level, whilst the second case has a 9.7dB level. When we study in detail the broadband gain obtained for these structures, Fig. 3, it can be seen that the triangular grooves case has its maximum value at f = 0.566THz, 15.88dB, whereas the square corrugations antenna presents 16.52dB at f = 0.553THz. These minor differences are due to the higher degree of freedom when it comes to design the squared corrugations, as they are not affected by the fabrication constraints that triangular grooves do.

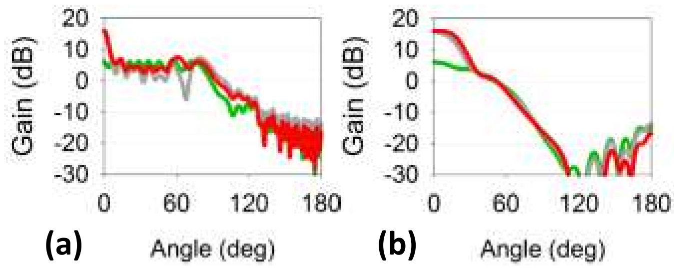

Fig. 2. Radiation diagrams at 0.566THz in (a) E- and (b) H-planes for the triangular (red), square (green) and no grooves (gray) structures.

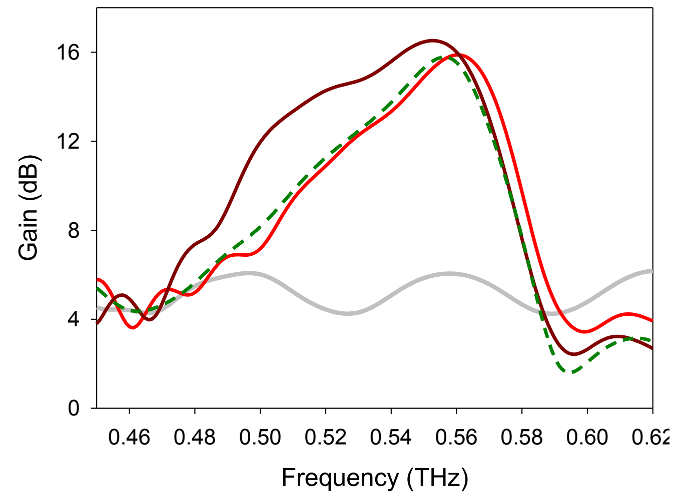

Fig. 3. Simulated broadband gain for triangular (red) and rectangular (brown) grooves structures and fabricated (green dashed) and flat structures (gray).

The fabrication procedure fixes an angle of 70.52deg for the triangular corrugations, restricting the corrugation width. There is also another maximum at around f = 0.8THz, slightly higher than the value given for the flat structure, corresponding to the power coupled by the longitudinal resonance, for which corrugations have little effect at that frequency. Numerical comparison between designed antenna and fabricated one displays that the latter only differs from the ideal case on a slightly reduced directivity for almost all the band and a minor frequency shift of the maximum.

IV. Experimental results

In order to experimentally evaluate the fabricated antenna, Fig. 4, measurements were carried out by means of a TeraView TPS 3000 Modular Terahertz Instrument. This spectrometer excites the antenna with a Gaussian beam instead of a waveguide, thus, the characterization is more similar to a frequency selective surface measurement than to a proper antenna characterization. It was intended to quantify the transmission enhancement obtained when a flat metallic surface was patterned with periodically distributed grooves. Radiation diagrams were not evaluated, as we lacked of the adequate instruments to properly them at such frequencies.

In order to accomplish this, two measures were made. First, the corrugations were covered with copper film, so as to acquire transmission through the slot for the impinging Gaussian beam in the absence of grooves. The second test consisted in obtaining transmission when the incidence was done on the corrugated side.

As it was expected, a high increment was observed for the second case, registering an increase of almost 30dB, inset Fig. 5, when periodic grooves are present. Fig. 5 shows recorded transmission normalized to the maximum of the uncovered case, localized at f = 0.566THz. A minor second peak at $f \sim$ 0.8THz, corresponding to the longitudinal resonance, was also obtained.

V. Conclusions

In this work, we have numerically proved that a 10dB gain enhancement is achievable for a flat slab with a central resonant slot when a periodic grooves pattern is placed surrounding the aperture. Around 16dB directivity with less than 7deg beamwidth and less than 10dB side lobe level is observed for both analyzed triangular and square corrugations structures, barely differing in their behavior. On the other hand, an increase of approximately 30dB is experimentally recorded at 0.566THz when a corrugated and a non-corrugated structure are illuminated with a THz Gaussian beam.

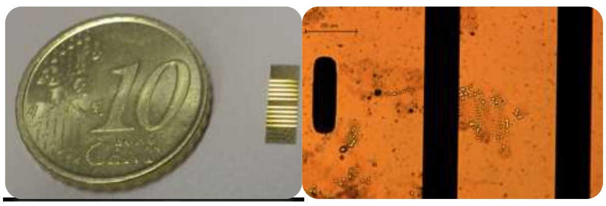

Fig. 4. Fabricated 0.566THz triangular corrugations LWA.

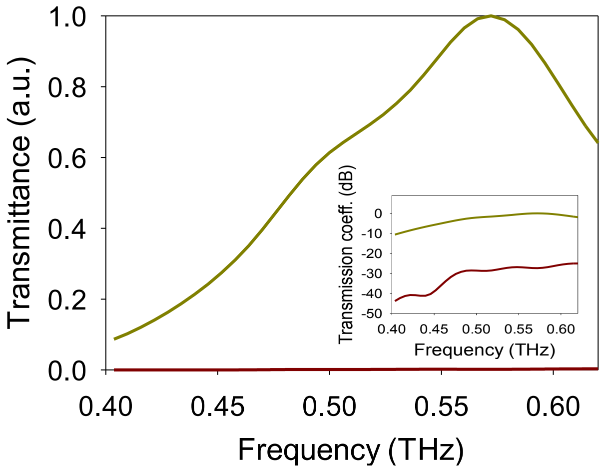

Fig. 5. Normalized transmitance for grooved (green) and covered (brown) structures. Registered transmission coefficient (inset).

It was also be observed a second maximum at approximately $f \sim$ 0.8THz corresponding to the longitudinal resonance of the slot for which corrugations, designed for f = 0.566THz, have little effect. These kind of structures are highly interesting for the THz range, for example, due to their capability of collimating an impinging beam, enhancing thus its gain, which may result useful for quantum cascade lasers and other novel THz devices.

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