New Leaky-Wave Antennas Using Surface-Wave Launchers and Planar Metallic Grating Lenses

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Abstract — **Planar metallic grating lenses for SW divergence and bound, plane-wave generation are utilized in the design of leaky-wave antennas (LWAs) for millimeter-wave frequencies of operation. By using a printed surface-wave launcher (SWL) feed and circular and straight metallic strips, cylindrical leaky-waves (LWs) can be excited on a planar grounded dielectric slab (GDS). Specifically, by the addition of these planar lenses SWs can be refracted, altering the phase velocity and field distribution of the guided wave, realizing a larger effective aperture. Increased gain values can be observed in the far field by such passive beam pattern control. These 2-D LWAs may be desirable for their compatibility with other planar designs, low cost, and directive beam patterns, thus making them attractive for radar systems and satellite communications.**

1 INTRODUCTION

Leaky-wave antennas (LWAs) have sustained much interest and attention within the electromagnetics community. Recent planar configurations have utilized bound surface-waves (SWs) for leaky-wave (LW) excitation at millimeter-wave frequencies [1]-[6]. In these designs the unwanted and typically parasitic effects associated with SWs are negated and utilized to the advantage of the planar antenna designer or research scientist. By the addition of appropriately designed metallic segments or strips, SWs can be generated by a surface-wave launcher (SWL) source and transformed into a radiated LW mode, generating pencil and conical-sector beam patterns in the far field [3]-[6]. These uni-planar designs may be advantageous for surveillance systems and radar applications where low-cost and low-profile antennas are of interest.

1.1 Integrated Feeding Technique for Surface Wave Excitation and Control

Coplanar waveguide transmission lines can feed these completely printed LWA designs allowing for simple integration with other planar devices and monolithic topologies. Efficient SW excitation can be achieved by the appropriate configuration of slots in the antenna ground plane and these SWLs can be thought to act as magnetic dipole sources for the investigated LWAs [3]-[6]. Essentially, the input signal is inductively coupled into the dominant TM_0 SW mode of the grounded dielectric slab (GDS) and wave confinement is realized [7]. In addition, the possibility of SW power combining and dividing has been shown [8], [9] and increased SW control is possible by the inclusion of planar metallic grating lens configurations [10].

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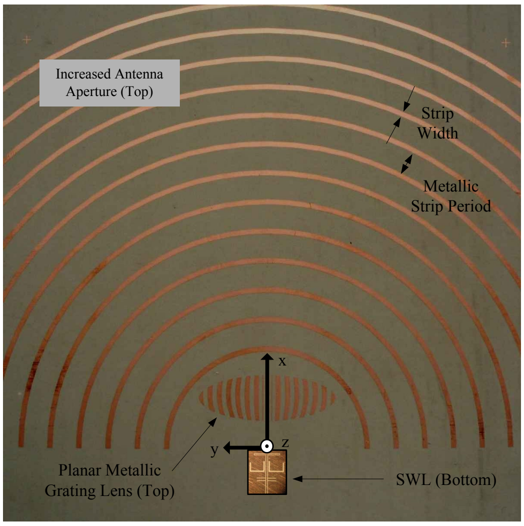

Figure 1: Realized planar LWA considered in this work. Using printed curvilinear strips on a GDS LWs can be excited (from a central SWL source) generating directive beam patterns in the far field. By the addition of a planar metallic grating lens on top of the GDS (for SW divergence) increased gain values can be observed in the far field.

1.2 Proposed Leaky-Wave Antennas using Planar Metallic Grating Lenses

This work incorporates such practical grating lenses in the design of new LWAs for increased gain values and radiation performances. By the implementation of the aforementioned SWL sources [3]-[6] and new grating lenses [10], cylindrical LWs can be excited [11] by the appropriate placement of metallic strips on top of the slab. Proposed designs are shown in Figs. 1-3. Specifically, by using a grating lens for SW divergence, increased gain values can be observed for an antenna aperture composed of circular metallic strips. Improvements can also be observed for a LWA defined by linear strips using a grating lens for bound plane-wave generation. Comparisons are made to analogous circular and straight LWAs with no grating lenses and equivalent strip configurations.

Physically, these planar metallic grating lenses can alter the SW propagation constant along the guiding surface and thus control the excited LW field distribution on the antenna aperture, and hence, the gen-

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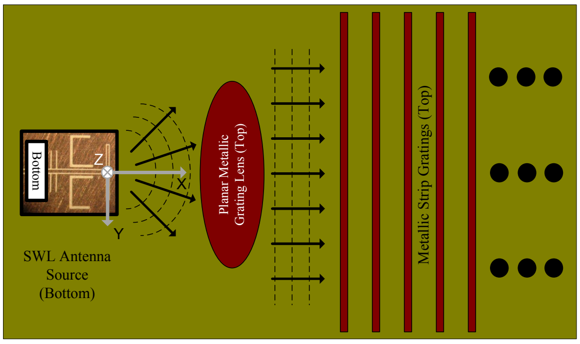

Figure 2: Illustration of the proposed LWA with printed strips. A bound plane-wave can be generated by the lens for in phase diffraction and directive beam patterns in the far field.

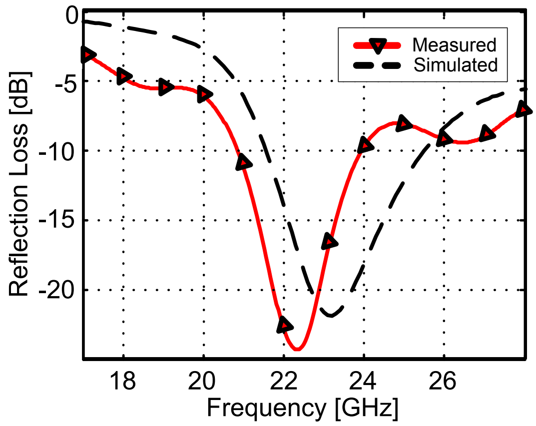

Figure 4: Reflection loss values of the directive SWL source in the antenna ground plane with no grating lenses or strips on top of the GDS.

erated far field beam patterns. Further SW and thus LW control may be possible by the inclusion of tunable elements within the metallic gratings for increased versatility and functionality.

2 PRINTED SLOTS FOR DIRECTIVE SURFACE-WAVE LAUNCHING

The Yagi-Uda like SWLs are defined by half wavelength slots in the antenna ground plane of the utilized GDS ($\epsilon_r = 10.2$, $h = 1.27$ mm, $\tan\delta = 0.0023$). Two coplanar waveguide shorted stubs match the SWLs to the 50 Ω feeding lines for measured reflection loss values below 20 dB at 23 GHz as shown in Fig. 4. Minor deviations can be observed with the simulated values and are likely a result of substrate surface roughness, reflections from the edge of the finite substrate, dielectric thickness variations and difficulty in modeling the SWLs due to microfabrication [6].

Essentially, the slotted configurations couple energy into the dominant TM_0 SW mode of the slab exciting bound, cylindrical-waves which propagate along the guiding surface [3]-[6]. Unidirectional SW propagation is achieved by the addition of secondary folded reflector slots but at the cost of TE_1 SW mode excitation. Fig. 5 (a) illustrates the TM (E_z) and TE (E_ϕ) field distributions generated on the GDS by the directive SWL source placed at the origin (with no strips and grating lens) while Fig. 6 shows the cylindrical TM phase front along the guiding surface.

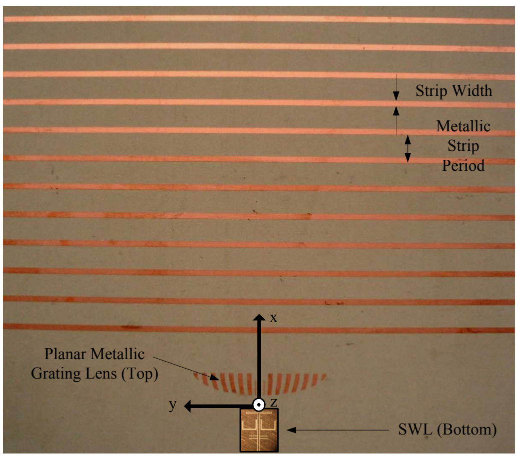

Figure 3: Planar antenna with a printed grating lens (for a linear phase front on the aperture) and straight strips.

3 METALLIC GRATING LENSES FOR PASSIVE SURFACE-WAVE CONTROL

The grating lenses for divergence and plane-wave generation were designed for bound propagation along the GDS and minimal parasitic radiation into the far field [10]. Specifically, by the addition of these planar lenses, the excited TM SW field distribution (from the SWL source) can capacitively couple to the parasitic grating elements, altering the phase velocity of the guided SW. Refraction is realized and the resultant field distributions are shown in Figs. 5 (b) and (c). In addition, the uniform phase distribution generated by the plane-wave lens is shown in Fig. 7.

4 INVESTIGATED PLANAR ANTENNAS

By utilizing the aforementioned SWL sources and planar metallic grating lens configurations, and by the addition of an appropriate metallic strip aperture, TM_z cylindrical LWs can be excited realizing far field beam scanning as a function of frequency [11]. Essentially, these grating lenses can be thought to increase the effective aperture of the proposed LWAs and thus offer increased gain values as shown in Figs. 8-10.

The printed metallic strips define a capacitive partially reflective surface (PRS) and radiation is achieved by diffraction of the guided waves along the aperture. Physically, the bound TM field distribution on the aperture inductively couples to the strips and the current distribution (on the strips) radiates and defines the far-field beam pattern. With large effective strip apertures and uniform current distributions, directive pencil beam patterns can be generated in the far field.

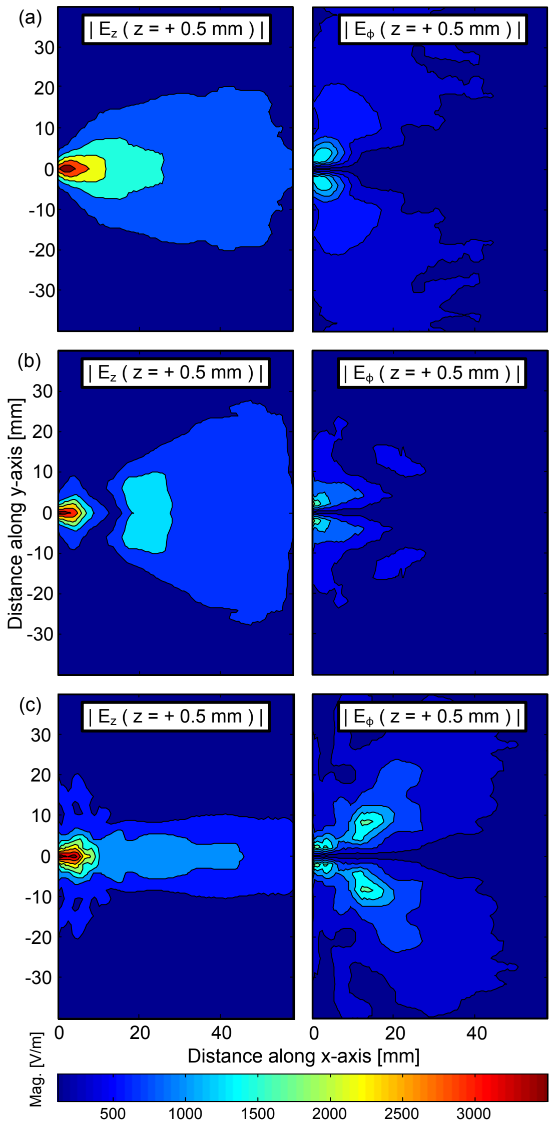

Figure 5: Simulated TM (E_z) and TE (E_ϕ) SW field distributions generated on the guiding surface (with and without the grating lenses and no strips): (a) no lens, (b) diffracting lens and (c) plane-wave lens.

4.1 Circular Strip Leaky-Wave Antennas

Circular strip designs are optimal for single beam patterns with high gain values, since the gratings are well matched to the cylindrical SW phase front [4]. In general, these LWAs exhibit backward and forward beam scanning as a function of frequency with minimal radiation at broadside. Sharp beam patterns can be observed at the edge of such LW stopbands [3]-[6].

In this work a LWA with a diffracting grating lens and 13 strips was compared to an analogous standard design with 15 strips (two strips near the origin were removed for placement of the grating lens). Essentially, the LW attenuation constant, α^{LW}, is reduced generating a larger effective radiating aperture and thus increased gain values.

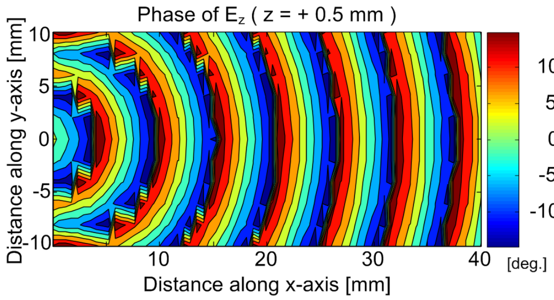

Figure 6: Simulated cylindrical TM field distribution generated on the guiding surface with no the grating lens and strips.

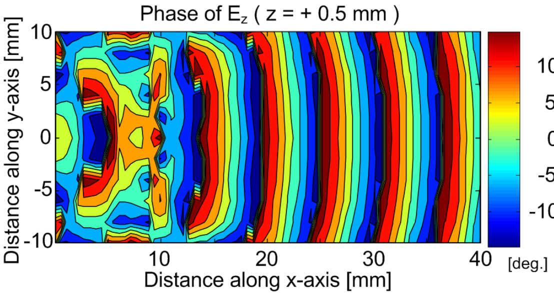

Figure 7: Simulated TM phase distribution generated on the guiding surface by a SWL source placed at the origin with the plane-wave grating lens and no strips. A bound plane-wave distribution is generated for $x \geq 14$ mm and $y \leq |5|$ mm.

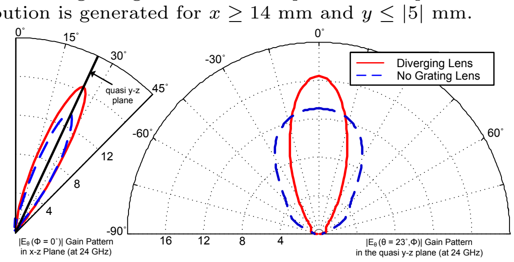

Figure 8: Comparison of far field beam patterns in the $x - z$ and quasi $y - z$ planes at 24 GHz for the circular strip LWAs with and without the planar metallic grating lens for SW divergence.

Both designs had a periodicity of 6.3 mm and a strip width of 1.12 mm. Simulation results are shown in Figs. 8 and 9. Specifically, with the grating lens [standard] LWA design, gain values over 12 dBi from 22.9 to 24.0 [22.9 to 23.4] GHz can be observed over a large [reduced] radiating bandwidth suggesting an increased radiation performance [a reasonable design for comparison].

4.2 Straight Strip Leaky-Wave Antennas

Two LWAs were compared with and without the plane-wave grating lens. With reference to Fig. 3, the grating lens was [strips were] placed 6.15 [15] mm from the origin. Both designs had a total of 12 strips with a periodicity of 6.25 mm and a strip width of 1.25 mm. Increased gain values of approximately 2 dB are shown in the simulation results of Fig. 10 at 23.2 GHz. Typically, such a LWA can generate single or multi-beam patterns in the far field due to periodic current distributions generated on the strips [5]; essentially bound and

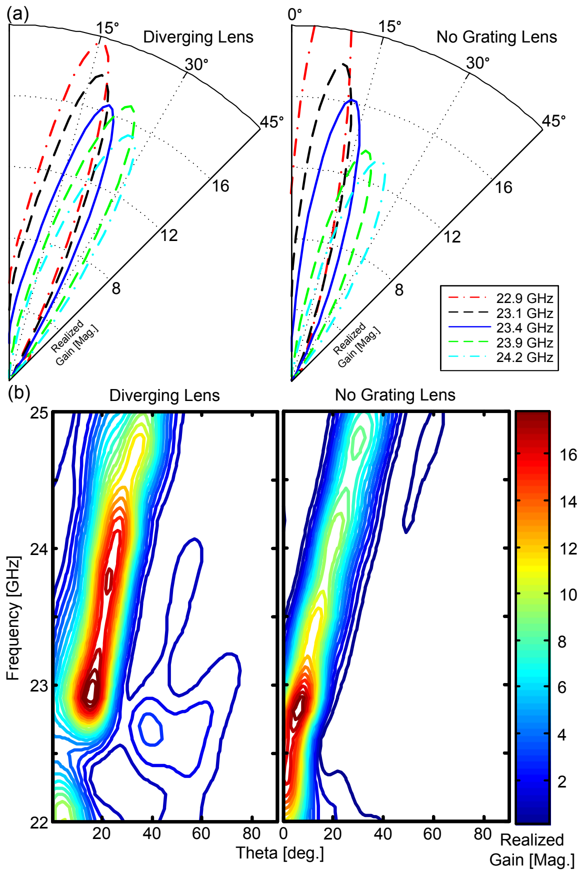

Figure 9: Beam patterns in the $x-z$ plane for the circular strip LWAs: (a) Polar plot of the beam pattern with and without the diverging grating lens. (b) Elevation angle (θ) versus frequency with and without the diverging grating lens. A null is observed at broadside for both designs. Increased gain values are observed over a larger bandwidth for the lens LWA design.

leaky modes are excited as a function of frequency and azimuth on the aperture [12]. With the addition of the plane-wave grating lens, single beam patterns with reduce side lobe levels are observed in the far field at 23.6 GHz (with no variation in tilt angle). Essentially, an in-phase current distribution is generated on the strips by the addition of the plane-wave metallic grating lens.

5 CONCLUSION

New grating lenses are utilized in the design of planar LWAs using SWL sources for millimeter-wave frequencies of operation. Specifically, by using a lens for SW divergence increased gain values can be observed over a large radiating bandwidth (22.9 - 24 GHz). In addition, gain improvements and reduced side lobe levels can also be observed for a LWA defined by linear strips using a plane-wave grating lens. Essentially, these grating lenses generate a uniform current distribution on the circular and straight strips and thus increase the effective aperture for the proposed LWA designs.

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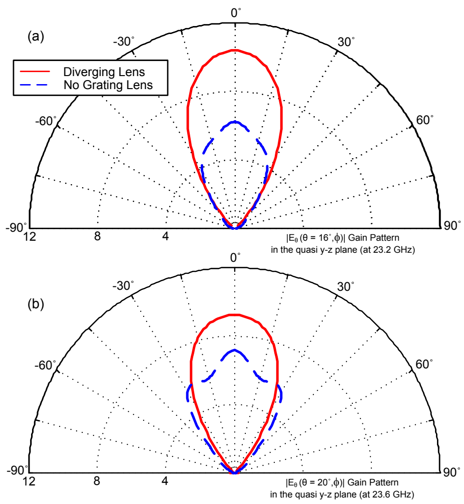

Figure 10: Beam patterns in the quasi $y-z$ planes generated by the linear strips with and without the grating lens for bound plane-wave excitation at (a) 23.2 GHz and (b) 23.6 GHz.