A Planar Leaky-Wave Antenna Offering Beam Steering at Broadside Using Surface-Wave Launchers

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Introduction

High gain leaky-wave antennas (LWAs) have been utilized in the design of many radar and satellite communication systems. In particular, planar 2-D LWAs are advantageous for their compatibility with monolithic devices, low cost and directive beam patterns. These antennas are characterized by a suitable aperture and source configuration; exciting cylindrical leaky-waves (LWs) which leak energy into free space during their radial propagation along the guiding surface. With appropriate design such planar LWAs can achieve highly directive beam patterns at broadside [1]-[4].

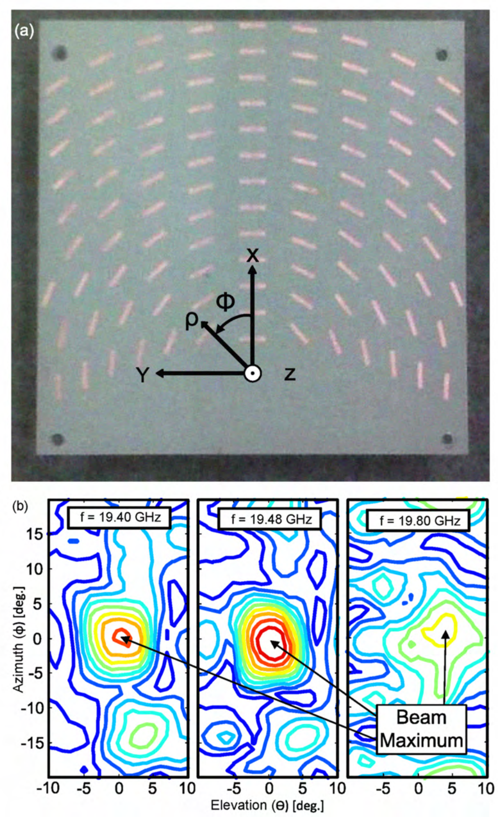

Figure 1: Segmented circular strip grating (a) and measured 2-D gain patterns (b) generated by a single SWL source (measurements shown in linear units and normalized to observed maximum gain at 19.48 GHz) [4].

This paper presents new results of such a broadside radiating LWA [4] using an array of Yagi-Uda like surface-wave launchers (SWLs). Specifically, by utilizing a segmented circular strip grating (as shown in Fig. 1) and cylindrical TM and TE surface-waves (SWs) on a grounded dielectric slab (GDS), conditions can be suitable for controlled cylindrical LW field excitation on the guiding surface, realizing broadside beam patterns that can be steered in the far field with maximum gain.

For instance, the SWL sources can be placed in a two element linear array achieving SW beam scanning on the guiding surface. By modifying the relative phase difference between SWLs or by varying the element weighting distribution, the generated SWs on the GDS can be steered [5]. Such a controlled SW field distribution can dictate the region of LW field excitation on the guiding surface and thus direct broadside beam patterns in the far field. In addition, such planar SWLs [4]-[6] can also be useful for new quasi-optical millimeter-wave circuits and systems [7] and novel printed antenna configurations for beam steering at end-fire in the far field [8].

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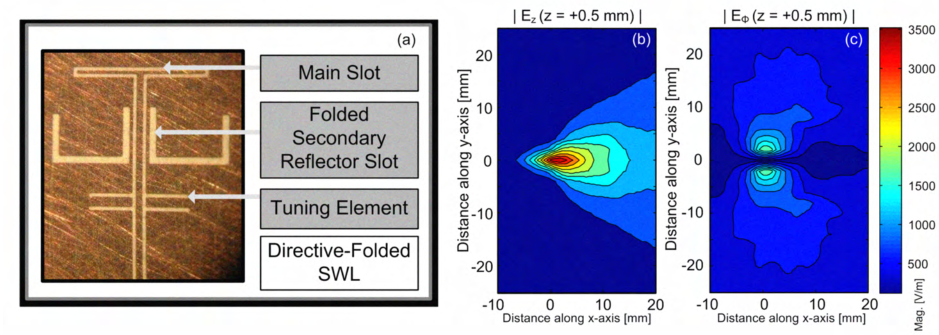

Figure 2: The single directive SWL (a) and simulated $|E_z(x,y)|$ (b) and $|E_\phi(x,y)|$ (c) field distributions (defining TM and TE SWs) generated on the GDS [4]. Plot origin for (b) and (c) defined on the air-dielectric interface above the main slot of the SWL. The majority of the $TM[TE]$ field distribution (0.5 mm above the guiding surface) is directed in the $+\hat{x}$ $[\pm\hat{y}]$ direction[s].

Directive Surface-Wave Excitation using Surface-Wave Launchers

The single planar antenna source is shown in Fig. 2 (a) and is realized by slots in the ground plane of a GDS ($\epsilon_r = 10.2$, $h = 1.27$ mm and $\tan\delta = 0.0023$). These Yagi-Uda like SWLs (placed at the origin, referenced to Fig. 1) are defined by half wavelength slots in the ground plane of the GDS and act as a magnetic dipole sources for the presented 2-D LWA [4]-[6]. Essentially, the slotted configurations can couple energy into the dominant TM_0 SW mode of the slab exciting bound, cylindrical-waves which propagate along the guiding surface. Unidirectional SW propagation is achieved by the addition of secondary folded reflector slots which can also couple energy into the TE_1 SW mode of the slab [4]. Figs. 2 (b) and (c) illustrate the E_z and E_ϕ field distributions excited on the guiding surface (with no strips).

A Segmented Circular Strip Grating for Broadside Radiation

In general, achieving directive radiation at broadside can be challenging with planar LWAs. Physically, the LW fields on the guiding surface can diminish and the main radiating harmonic enters into a LW stopband. By the arrangement of an appropriate circular grid array of strips, directive broadside radiation can be achieved [4] as shown in the 2-D beam patterns of Fig. 1. Essentially, suitable boundary conditions are employed for strip resonance at a specific frequency. The TM SWs propagating along the guiding surface (excited by the SWL) couple to the strips and maximum current excitation can occur at the edges of the strip segments. If strip placement and separation is appropriate, resonance can be in phase.

A pencil beam with maximum gain was observed at broadside at 19.48 GHz, just after the TE_1 SW mode cutoff frequency (19.47 GHz) of the slab, suggesting maximum radiation at the edge of a TE LW stopband (similar to the 1-D case as presented in [1]). Reduced gain levels are also observed below and above 19.48 GHz in the backward ($\theta < 0°$) and forward ($\theta > 0°$) far field regions. In addition, these results also imply that both TM and TE cylindrical LWs were excited on the aperture and that the radiated far-field components combined at broadside ($\theta = 0°, \phi = 0°$) with approximately equal value in both principal E and H planes [2].

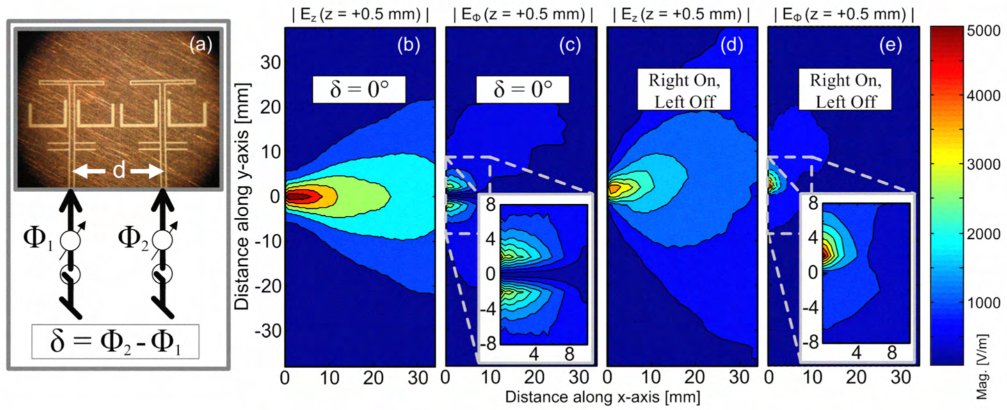

Figure 3: The SWL array (a) and simulated TM and TE SW field distributions (b - e) generated on the GDS. Plot origin defined on the air-dielectric interface centered above the SWLs at $z = 0.5$ mm. A zero phase difference ($\delta = 0°$) between SWLs is shown in (b) and (c) for the $|E_z(x, y)|$ and $|E_\phi(x, y)|$ field distributions (TM and TE), respectfully. The TM (d) and TE (e) SWs can also be controlled by turning on and off the SWL elements (labelled left to right as in a). Additional results for controlled SWs and the corresponding far field beams are shown in Figs. 4 and 5.

If the SWLs are placed in a linear array, SW beam scanning near broadside ($\theta = 0°, \phi \neq 0°$) is possible at a single frequency. The SW field distributions can be steered into different regions on the GDS (as shown in Figs. 3 and 4) dictating the region of LW excitation on the aperture [5]. For instance, broadside beam steering is shown in Figs. 4 and 5 in the far field by varying the relative phase difference between SWLs and by turning on and off the left and right SWLs, respectfully.

Conclusion

New developments of a novel 2-D LWA with maximum gain at broadside have been presented. By the design of an array of SWLs the SW field distribution on the substrate can be controlled and thus broadside beam steering can be observed at a single frequency. Such SWLs can also be used in the design of novel planar circuit structures for guided and radiated applications at millimeter-wave frequencies.

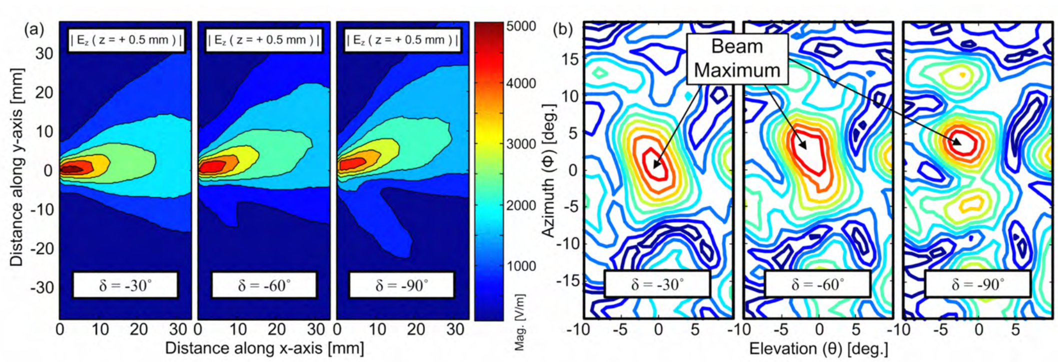

Figure 4: By varying the relative phase difference ($\delta = -30°, -60°$ and $-90°$) the SWs can be controlled on the guiding surface (a). By the addition of the segmented circular strip grating (Fig. 1) broadside beam steering ($\theta = 0°, \phi \in [0.5°, 4°]$) is also observed in the far field at 19.48 GHz (b).

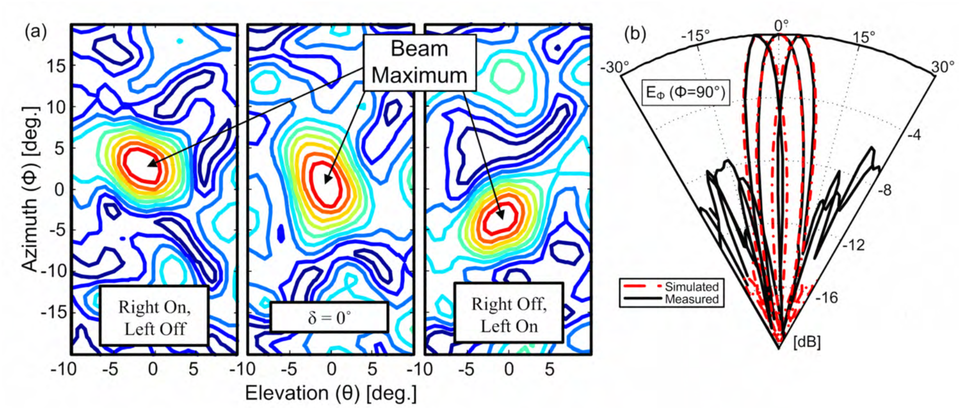

Figure 5: By setting $\delta = 0°$ and by adjusting the effective weighting between SWLs (by turning on/off elements) the main beam can be steered to $\phi = \pm 3°$ at $\theta = 0°$. Measured 2-D beam patterns (a) are shown at 19.48 GHz in the azimuth and elevation (normalized to observed maximum and shown in linear units). In addition, results are shown in dB in the $H(y-z)$ plane (referenced to the main SWL slots) and compared to simulated values (b). Main side lobe levels were difficult to observe since measurements were completed near the noise floor of the anechoic chamber.

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