Planar antenna for directive beam steering at end-fire using an array of surface-wave launchers

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A planar surface-wave antenna (SWA) that achieves radiation at end-fire by surface-wave (SW) excitation is presented for millimetre-wave frequencies of operation. The 2D SWA is fed by a two-element array of printed SW launchers for controlled beam steering in the far-field. Measured results demonstrate a highly directive beam pattern with a 3 dB beamwidth less than 5° at 22.71 GHz. Such a planar low-cost and low-profile SWA design may be advantageous for surveillance systems and radar applications where beam steering at end-fire is of interest.

Introduction: Surface-wave launchers (SWLs) have been shown to be a practical feeding technique for high gain planar leaky-wave antennas (LWAs) at millimetre-wave frequencies. In these designs slotted configurations in the ground plane of a dielectric slab can excite cylindrical TM surface-waves (SWs) which propagate along the guiding surface of a grounded dielectric slab (GDS) [1, 2]. Furthermore, by the addition of appropriately designed gratings or strips, leaky-waves (LWs) can be excited, realising the transformation from a bound mode to a radiated mode [3–5]. In general, these LWAs are desirable for their compatibility with other planar devices, low-profile and low cost. Such LWAs can offer directive beam scanning in the far-field but inherently cannot radiate at end-fire [6, 7].

To achieve end-fire radiation from such a planar structure, a novel surface-wave antenna (SWA) is presented in this Letter for millimetre-wave frequencies. Recent SWA designs have utilised coax feed lines, printed metallic patches and elevated dipole source configurations for operation below 5 GHz [8, 9]. To the authors' knowledge the antenna design presented in this Letter is the first implementation of a uni-planar high gain SWA. Specifically, by reshaping the ground plane of a rectangular GDS, SW radiation at end-fire can be achieved. Using a two-element array of the aforementioned SWLs (embedded in the ground plane) as the SWA feed [5], a new planar radiating structure can be realised as shown in Fig. 1. Measured results at 22.71 GHz display a broad and highly directive pattern in *xz* and *xy* planes, respectively (Fig. 2). Single frequency beam steering at end-fire is also achieved as shown in Fig. 3. Furthermore, the presented low-profile and low cost SWA may be useful for surveillance systems and other radar applications.

Planar SWA configuration: By designing an appropriate guiding structure, SWs can achieve radiation at the end of a guiding surface [6, 7]. In this Letter, a dielectric slab and ground plane configuration provide suitable conditions for such SW edge radiation. The substrate properties ($\epsilon_r = 10.2$, $h = 1.27$ mm, $\tan\delta = 0.0023$) were properly chosen such that approximately 85% of the input power was coupled into the dominant TM_0 SW mode of the slab by the SWLs [2]. The realised 2D planar SWA and the array of printed SWL sources are shown in Fig. 1. The simple recessed ground plane (5 mm from the edge of the GDS at x [y] = 88 [0] mm), characterised by a half-circle (radius, $R = 40$ mm at $x = 48$ mm), provides suitable conditions for SW edge radiation. The top side of the realised 2D SWA is defined by a simple air-dielectric interface. A circular ground plane design is optimal to be conformal to the cylindrical SW phase front generated by the directive SWLs [4]. Other structures were investigated, but the presented ground plane configuration offered the best result in terms of minimal sidelobe levels and main beam directivity. The two SWL antenna sources (defined at the origin) are individually fed by coplanar waveguide transmission lines (as shown in the top inset of Fig. 1). The SWL array is used to excite and steer SWs on the guiding surface [5].

Results and discussion: The large ground plane realises an effectively large aperture in the *xy* plane and thus narrow beamwidths can be observed. Simulation results suggest gain values greater than 8.7 dBi at end-fire. Measured far-field beam patterns at 22.71 GHz are shown in Figs. 2 and 3. Physically, the recessed ground plane at the end of the slab increases the effective aperture of the SWA. The SW field distribution is spread out at the edge of the board and SWs are free to propagate in the upper and lower $\pm z$ regions. Essentially, the abrupt change in boundary conditions perturbs the SW propagation constant of the travelling cylindrical-wave achieving radiation at the end of the board.

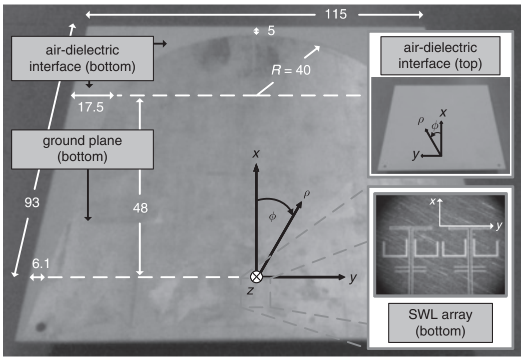

Fig. 1 *Realised 2D planar SWA with dimensions (mm)*
Origin of structure defined at centre of SWLs

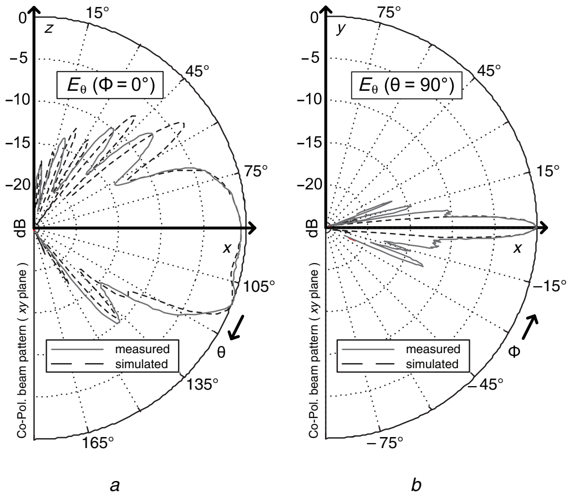

Fig. 2 *End-fire beam pattern (normalised to observed maximum and plotted in dB) for* $\delta = 0°$
a $E_\theta(\phi = 0°)$ in *xz* plane
b $E_\theta(\theta = 90°)$ in *xy* plane
A commercially available full-wave solver tool was used for simulations (Ansoft High Frequency Structural Solver (HFSS))

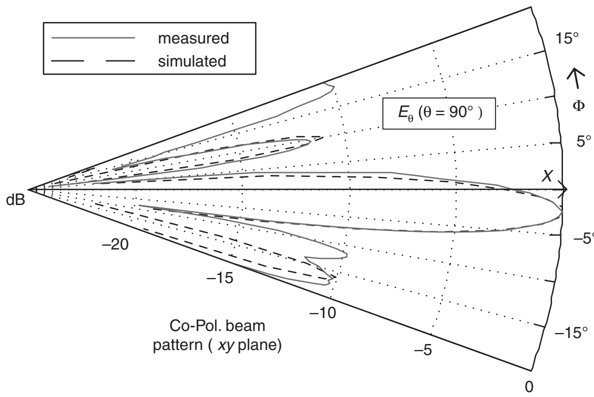

Fig. 3 *Steered beam pattern at end-fire (by turning on and off the left and right SWL elements) using two-element array of SWLs*
Results normalised to observed maximum and plotted in dB. Main beam is steered to $\phi = -2.5°$. For opposite weighting distribution it is expected that main beam can also be steered to $\phi = +2.5°$ since structure is completely symmetric.

By varying the relative phase difference between the SWL feed elements ($\delta = \Phi_2 - \Phi_1$) or by applying an appropriate element weighting, the SW field distribution on the aperture can be adjusted at a single frequency, thus allowing for beam control in the far-field [5]. Fig. 3 illustrates the steered beam at end-fire ($\phi = -2.5°$) by turning on and off the left and right SWL elements, respectively (left and right position defined as in the layout of Fig. 1). Since the design is completely symmetric, it is expected that for the reverse weighting (off and on) the main beam will be steered to $\phi = +2.5°$. In addition, further beam steering is possible by variation in the relative phase difference, δ, between SWL elements.

Conclusion: A planar SWA for radiation at end-fire is presented. Measured results at 22.71 GHz illustrate a highly directive beam pattern in the *xy* plane (3 dB beam width $<5^{\circ}$) using a two-element array of surface-wave launchers (SWLs) for a relative input phase feeding of $\delta = 0^{\circ}$. Good agreement is also observed between the simulated and measured far-field beam patterns. Furthermore, by applying a simple on-off weighting distribution, the end-fire beam pattern can be steered by ± 2.5. It is expected that further beam control can be achieved by additional element weighting distributions and by variation in the relative phase difference between SWL elements.

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