Planar antenna for continuous beam scanning and broadside radiation by selective surface wave suppression

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A printed leaky-wave antenna (LWA) based on a grating of concentric annular microstrip rings fed by a non-directive TM_0 surface-wave launcher (SWL) is presented for two-sided continuous beam scanning and broadside radiation. By appropriate selection of the grating periodicity TE field distributions can be suppressed over a large bandwidth ensuring efficient TM_0 leakage and radiation into the far field. Measured results demonstrate a pencil beam at broadside with a 3 dB beamwidth less than 6° at 17.9 GHz. The presented LWA may be useful for radar and surveillance systems where continuous beam scanning through broadside is desired.

Introduction: Recently, planar leaky-wave antennas (LWAs) have received much interest for their frequency scanning behaviour, high gain, and low fabrication costs [1–4]. Typical implementations include periodic metallic segments or linear strip gratings appropriately arranged on top of a grounded dielectric slab (GDS). In general, broadside radiation and continuous beam scanning in the far field can be challenging with these types of antennas and thus new optimisation techniques and novel design methodologies may be of interest.

To achieve the desired wide-angle beam scanning with broadside radiation an optimal LWA configuration and feeding structure is proposed and examined in this Letter for microwave and millimetre-wave frequencies of operation. The presented design can be characterised by a 2D antenna aperture, defined by a series of annular concentric ('bull's-eye') microstrip rings. This type of antenna can generate two-sided beam patterns in the far field with beam scanning in the upper *x-z* plane from back- and forward-fire towards broadside. With an increase in frequency these two distinct beam patterns can combine together to form a single pencil beam at broadside, followed by beam splitting, and then continued two-sided beam scanning. Concepts are illustrated by inspection of the measured beam patterns as shown in Figs. 1 and 2; continuous beam scanning is observed over the investigated frequency span suggesting sustained antenna leakage. In particular, leaky-wave (LW) radiation of the backward and forward kind in the form of two-sided conical-sector beam patterns is also observed below and above 17.7 and 18.9 GHz, respectively. We also note that measured reflection-loss values are less than 10 dB from 15–23.5 GHz for the realised LWA structure, as shown in Fig. 3.

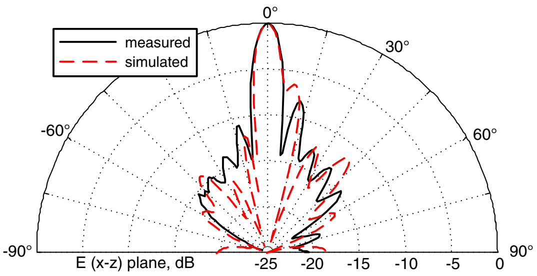

Fig. 1 *Measured $E_\theta(\phi = 0°)$ beam pattern in x-z plane at 17.9 GHz (E plane referenced to main slot of SWL). Results normalised and compared to simulations performed through Ansoft HFSS*

Other 'bull's-eye' designs have recently been investigated in [1, 4] where theoretical dispersion diagrams were examined and far field beam patterns were provided by the assistance of commercial solvers. In this Letter a similar antenna configuration is considered, but with an optimised grating periodicity, to achieve the aforementioned radiation performance. More specifically, a simple design equation is developed relating the 'bull's-eye' spatial periodicity (d) to the substrate thickness (h) and relative dielectric constant (ε_r) of the utilised GDS. To the authors' knowledge this is the first time that such an optimal LWA has been fabricated and tested, offering broadside radiation and continuous two-sided beam scanning. Applications of the proposed antenna include radar systems and satellite communications.

Antenna feed by practical surface wave launching: Antenna feeding techniques for such planar LWAs can be challenging at microwave and millimetre-wave frequencies. A possible strategy is to excite surface waves (SWs) by selecting electrically thick substrates with relatively high dielectric constant values [3, 4]. However, a new planar surface-wave launcher (SWL) [4] is used for the proposed LWA under study, which has shown much promise for efficient SW excitation.

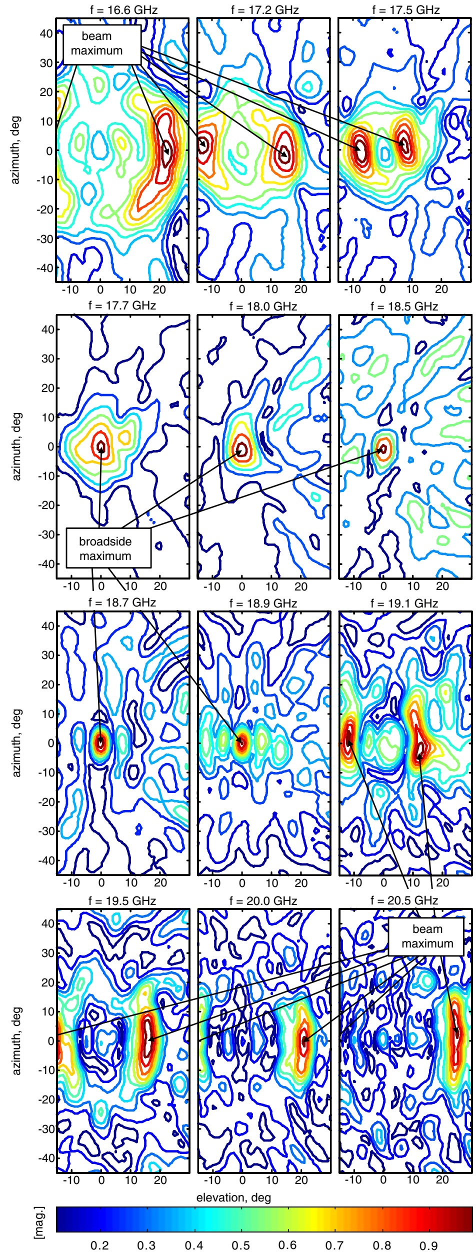

Fig. 2 *Measured gain patterns in azimuth and elevation. Continuous two-sided beam scanning through broadside is observed against frequency from 16.6 to 20.5 GHz. Values normalised to observed maxima and results shown in linear units*

The completely planar SWL, as shown in the inset of Fig. 3, was placed at the centre of the 'bull's-eye' rings and was embedded in the ground plane of the utilised GDS ($\varepsilon_r = 10.2$, $h = 1.27$ mm, tan $\delta = 0.023$). The non-directive SWL was fed by a 50 Ω coplanar-waveguide transmission line from the substrate periphery. In addition, the bi-directional SW source can be characterised by a main slot (≃2 mm) and secondary tuning slots for good reflection-loss values. Physically, the SWL couples energy into the dominant TM_0 SW of the slab and bi-directional field distributions can be generated on the antenna aperture realising the aforementioned two-sided beam patterns in the far field [4]. In addition, excitation of the TM_0 SW is desired owing to its zero cutoff frequency and thus possibility for leakage over a large radiating bandwidth.

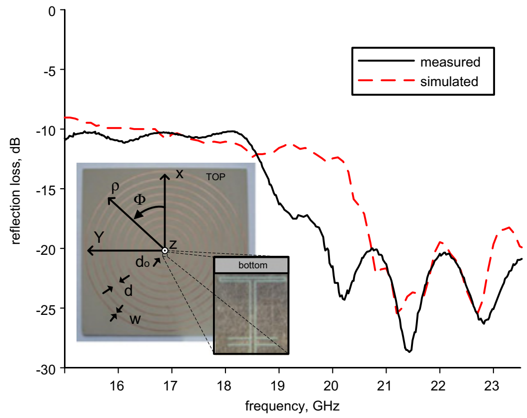

Fig. 3 *Reflection-loss values for realised non-directive SWL feed and LWA structure shown inset (defined by an annular metallic strip 'bull's-eye' grating on 17 by 17 cm GDS)*

Antenna design, results and discussion: By using such a TM_0 planar SWL, and by the addition of the annular metallic grating (strip width, $w = 1$ mm, and spatial period, $d = 8$ mm offset from the origin by $d_0 = 9{:}3$ mm), LW field distributions can be excited on the 2D antenna aperture with radial propagation along the perturbed guiding surface. The measured LWA offers directive broadside radiation (with maximum and minimum gain values of 13.1 and 4.8 dBi, respectively) over a 1.2 GHz radiating bandwidth (17.7–18.9 GHz). Physically, radially directed ($\hat{\rho}$) current distributions can be realised on the 'bull's-eye' rings and wide-angle frequency beam scanning (along with broadside radiation) can be induced by the excitation of the fundamental TM_0 LW mode. Furthermore, the desired and observed beam scanning quality over the large radiating bandwidth (15–22 GHz) can be achieved by TE field suppression [1]. In fact, for efficient operation of the proposed antenna, leakage should occur in a regime without any other LW or SW field distributions. For example, if TE_1 SWs are generated on the antenna aperture azimuthally directed ($\hat{\phi}$) current distributions (along with radially directed, owing to TM_0 LWs) can be observed on the 'bull's-eye' rings and beam scanning quality may deteriorate [4]. It should be noted that this new design strategy is in contrast to previous methodologies for TM_0 SW suppression [3].

To limit TE SW propagation on the proposed antenna aperture and to permit radiation of TM_0 LWs only, the grating periodicity (d) should be properly chosen such that the antenna operates in an LW regime with TE_1 SW suppression. This is ensured by letting the spatial period d be larger than $\lambda_0/2$ at the cutoff frequency $f_c = c/(4h\sqrt{\varepsilon_r - 1})$ of the TE_1 SW mode of the unperturbed GDS (where λ_0 and c are the wavelength and speed of light in free space, respectively); this results in a simple equation that provides a minimum value for the grating periodicity:

$$d > 2h\sqrt{\varepsilon_r - 1} \qquad (1)$$

Therefore, by selecting $d = 8$ mm, the TE_1 SW is driven below cutoff while the TM_0 LW is radiating. It should be noted that a uni-modal dielectric slab could have also been used for operation of the proposed 'bull's-eye' LWA and SWL source; For example, limit antenna operation below the TE_1 SW mode cutoff frequency of the slab [3], but a reduced radiating bandwidth may have ensued. Finally, to avoid grating lobes for any particular broadside radiating frequency (f_b), the structure periodicity should be less than the free space wavelength ($d < \lambda_0|_{f_b}$).

Conclusions: This Letter has presented a planar leaky-wave antenna for two-sided continuous beam scanning through broadside. Measured results at 17.9 GHz illustrate a directive pencil beam pattern in the E (x-z) plane with a pattern beamwidth $< 6°$. Reflection losses are below 10 dB from 15 to 23.5 GHz using a non-directive surface-wave-launcher source as the printed antenna feed. Agreement is also observed between simulations and measurements. Wide-angle beam scanning is achieved by suppression of TE field distributions on the radial antenna aperture giving rise to the large radiating bandwidth.

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One or more of the Figures in this Letter are available in colour online.

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