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


A printed leaky-wave antenna (LWA) based on a grating of concentric annular microstrip rings fed by a non-directive TM₀ 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 TM₀ 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.

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 (εr) 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.

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 (εr = 10.2, h = 1.27 mm, tan δ = 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 TM₀ 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 TM₀ SW is desired owing to its zero cutoff frequency and thus possibility for leakage over a large radiating bandwidth.

Fig. 1 Measured E(θ = 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.

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.
Therefore, by selecting $d = 8 \text{ mm}$, the $\text{TE}_1$ SW is driven below cutoff while the $\text{TM}_0$ 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 $\text{TE}_1$ 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 $< 6^\circ$. 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.

References


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