

Summary

Achieving accurate two-dimensional direction-of-arrival (2-D DoA) estimation with a passive, compact, low-cost, single-port system is challenging. Conventional digital solutions typically rely on multi-element antenna arrays, with dedicated radio-frequency chains and analog-to-digital converters, but at the cost of hardware complexity, power consumption, and data throughput. Analog and hybrid solutions, including phased arrays based on phase shifters and radio-frequency combining networks, reduce the number of receiver chains but still require multiple elements and beam scanning or reconfigurable states. Frequency-scanned leaky-wave antennas (LWAs) provide a passive alternative by mapping the direction of arrival onto the frequency-dependent antenna response. However, most performing implementations are limited to one-dimensional estimation or rely on multiport, cascaded, reconfigurable, or tunable architectures. This thesis presents and experimentally validates an all-metal single-port LWA for unambiguous 2-D DoA estimation at millimeter-wave frequencies.

The antenna is based on a closed sectorial radial waveguide with lower-plate corrugations that engineer the radial-mode dispersion and top-plate concentric slots that enable rapid frequency scanning. Since no general closed-form dispersion relation is available for corrugated sectorial waveguides, the Adjacent-Zeros Method (AZM) is developed to extract the phase constant $\beta(f, \phi)$ from full-wave simulations. It is first validated on a sectorial waveguide, whose fundamental TM_{01}^z mode is known analytically, and then applied to the corrugated structures. Two topologies are considered: concentric corrugations, which follow the cylindrical wavefronts and define the sectorial waveguide with concentric corrugations (SWCC), and straight corrugations, which define the sectorial waveguide with straight corrugations (SWSC). For the SWCC, an analytical corrugated parallel-plate-waveguide model in the soft direction is combined with AZM to select the corrugation parameters, whereas the SWSC is designed directly from the AZM results.

Floquet theory is used to choose the slot period so that only the backward-radiating $n = -1$ harmonic is visible. The resulting leaky-wave antenna with concentric corrugations (LWACC) exhibits an almost azimuth-independent dispersion, whereas the leaky-wave antenna with straight corrugations (LWASC) shows an azimuth-dependent dispersion, whose beam variation with frequency and azimuth provides

the diversity required for 2-D DoA estimation. Normalized autocorrelation measures the similarity between realized-gain responses and reveals distinguishability limits and angular ambiguities. In the LWA-based multiple signal classification (MUSIC) algorithm, frequency samples of the single-port realized-gain response replace the spatial samples of a conventional array, and source directions are identified from the pseudospectrum peaks. Both antennas provide good impedance matching and wide backward beam scanning. Consequently, the LWASC can distinguish sources separated in azimuth and estimate both θ and ϕ , while the LWACC is essentially limited to elevation discrimination.

Both antennas are symmetric with respect to $\phi = 0$, producing identical responses for opposite azimuths and a mirrored DoA ambiguity. This symmetry is broken by using different corrugation heights on the two sides of the LWASC. The resulting asymmetric antenna preserves the main leaky-wave radiation characteristics while distinguishing positive and negative azimuths. Autocorrelation and MUSIC confirm the suppression of mirrored solutions and correct source localization, although the azimuthal discrimination becomes weaker near $\phi = 0$.

A CNC-fabricated prototype confirms the predicted behavior, showing good impedance matching and measured 2-D realized-gain maps that reproduce the designed asymmetry. Autocorrelation confirms the suppression of the mirrored ambiguity, while MUSIC applied to the measured antenna responses correctly identifies the investigated source directions. These results demonstrate that engineering the dispersion and radiation asymmetry of a passive, all-metal single-port LWA enables experimentally validated and unambiguous 2-D DoA estimation with reduced receiver complexity.

The activity documented in this thesis led to 1 journal paper, 5 conference papers, and 1 journal paper *in preparation*.