

# Recent Advances in Metamaterial Leaky-Wave Antennas

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## Abstract

The paper present an overview of recent advances in metamaterial leaky-wave antennas (LWAs), including the resolution of the issue of inefficient broadside radiation (Sec. 2), new technological implementations (Sec. 3), new design procedures (Sec. 4), efficiency and space scanning enhancement techniques (Sec. 5), electronic beam-shaping structures (Sec. 6) and exotic systems (Sec. 7).

**Keywords :** Metamaterials, Leaky Waves, Antennas

## 1. Introduction

A leaky-wave antenna (LWA) is a waveguiding structure which radiates by progressively leaking its energy out to free space from a traveling wave with a phase velocity larger than the speed of light. Their main benefits are their high directivity, their beam steering capability (without a complex feeding network) and their frequency-independent size. Since the invention of the first practical LWA back in 1940 [1], much research and development has been done in this area, and several textbook chapters have been written on the topic [2-5]. However, it is arguably over the past decade that, due to the advent of metamaterials, the most significant innovations have been made in LWA technology. Some of them are reported in [6-8]. This paper puts them into perspective.

## 2. Broadside Radiation Issue

Until recently, LWAs had been plagued by inexistent or inefficient radiation efficiency when scanning through broadside due to the existence of an open stop-band at the corresponding dispersion point. Following some interesting but imperfect solutions [9,10], the problem was fully solved in metamaterial composite right/left-handed (CRLH) LWAs [8,11], and this solution, consisting in suppressing the open stop-band by ensuring simultaneous series and shunt radiation (corresponding to a leakage factor equal to the square root of the product and the series and shunt radiation resistances), was refined and extended also to other LWAs [12-16].

## 3. Technological Implementations

LWAs had been implemented in all kinds of waveguide and planar technologies in the past. Recently, novel substrate integrated implementations were proposed, starting with CRLH LWAs, allowing the realization of some waveguide (e.g. slotted waveguide) LWAs in planar technology [17-20].

## **4. Design Techniques**

While traditional LWA design have been often restricted to iterative analysis procedures based on the extraction of the complex propagation constant from scattering parameters using commercial softwares, important advances have been recently accomplished in this area, including the development of a full-wave electromagnetic modal analysis [21], the treatment of strongly truncated structure [22], the elaboration of novel circuit models [23], and the subsequent derivation of fundamental broadside and off-broadside formulas for the main LWA parameters [24].

## **5. Efficiency and Space Scanning Enhancement**

When size restrictions exist, LWAs often suffer of low efficiency, because a significant amount of their power has not radiated when reached the load and is therefore dissipated in it. A recent proposal to recycle the output power back toward the input via a power regulation system has solved this problem [25,26]. Another progress is the development of phase-reversal or arbitrary unit-cell phased LWAs producing full-space scanning on a desired space harmonic without suffering of spurious beams from other space harmonics [27]. Metamaterials offer particular flexibility in such designs.

## **6. Electronic Beam Shaping**

Many practical beam-scanning systems, require fixed frequency steering capability, as realized by phased array antennas. Based on metamaterial structures, which lend themselves particularly well to the incorporation of tuning elements, such as varactors, along their periodic cell, several efficient electronically scanned or beam shaped CRLH LWAs have been reported since 2004 [28-30]. A challenge in such designs is the maintain high matching over the complete range of scanning angles. However, this problem has been addressed successfully, by using advanced independent series-shunt element tuning. Commercial products following form these innovations are currently under development.

## **7. Exotic LWA Systems**

Traditionally, LWAs have been limited to operate as simple antennas. However, recent metamaterial-related innovations have paved the way for a system era for LWAs. For instance, based on the first uniform CRLH-type LWA, which consists of an open ferrite-loaded waveguide [31], a novel integrated antenna-duplexer/diplexer with extremely high LO-RF isolation and tunable operation frequency by a static magnetic field has been reported in [32]. Another example is that of a real-time spectrum analyzer, imitating an optical fiber grating, to provide the spectrogram of time-variant signals, overcoming the frequency and bandwidth limitations of commercial purely digital solutions [33]. Finally, in [34] the first LWA-based direction of arrival system was presented as a competitive alternative do array solutions, featuring much higher simplicity (no complex feeding network required) and subsequent lower cost.

## **8. Concluding Remarks and Perspectives**

Leaky-waves, as recognized by Nathan Marcuvitz back in 1956 [35], are an extremely rich and powerful concept of electrodynamics. Over the past seventy years, they have led to a wealth of LWAs, exhibiting unit properties and characteristics. Since the advent of metamaterials at the turn

of the 21<sup>st</sup> century, LWAs have known a particularly strong regain of interest, which has led to important advances, including the resolution of the fundamental issue of inefficient broadside radiation, the development of refined full-wave and circuit model solutions, novel implementations, enhanced efficiency, scanning flexibility and beam shaping capability, and the extension to communication and instrumentation systems.

We anticipate that novel emerging radio technologies, such as nano and THz technologies, will lead to the discovery of novel leaky-wave phenomena and subsequent novel LWA devices and systems. As an example, the talk will be concluded by the presentation of unique leaky-wave effects existing in graphene structures, with comments on related challenges and opportunities.

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