

## Review on fixed-frequency beam steering for leaky wave antenna

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### Abstract

*This paper aims to survey the efforts of researchers in response to the novel and effective technology of control radiation pattern at a fixed frequency for leaky wave antenna (LWA), map the research landscape from the literature onto coherent taxonomy and determine the basic properties of this potential field. In addition, this paper investigates the motivation behind using beam steering in LWA and the open challenges that impede the utility of this antenna design. This paper offers valuable recommendations to improve beam steering in LWA. The review revealed the development and improvement of several techniques of beam scanning LWA. However, several areas or aspects require further attention. All the articles, regardless of their research focus, attempt to address the challenges that impede the full utility of beam scanning and offer recommendations to mitigate their drawbacks. This paper contributes to this area of research by providing a detailed review of the available options and problems to allow other researchers and participants to further develop beam scanning. The new directions for this research are also described.*

**Keywords:** beam steering, control beam scanning, control radiation pattern, HWMLWA, leaky wave antenna (LWA)

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### 1. Introduction

The inception of a slotted rectangular waveguide in the 1940s introduced the leaky wave antennas (LWAs) [1]. A stable growth saw recent developments being focused on planar LWAs. The properties of a microstrip transmission line's (MTL) higher-order mode was first published by Ermert in the late 1970s [2, 3]. Unfortunately, the microstrip leaky wave antennas (MLWAs) were deemed incomplete because of its longitudinal propagation constant, which was composed of only a phase constant ( $\beta$ ), without the leakage or attenuation constant ( $\alpha$ ). Concurrently, an article on MTL antenna utilising the first higher-order mode was published by Menzel [4, 5], who assumed a meaningful leakage constant to permit the radiation of the structure. However, he failed to notice that he built an LWA; thus, it was just a short one [6]. The leaky travelling wave antenna with a complex propagation constant developed by Menzel was further clarified by Oliner [7]. For further background details and history, readers are referred to [8, 9]. In the recent decades, the microstrip higher-order modes' radiation characteristics have received intensive studies due to the ease of manufacturing, large bandwidth, narrow beam width, inherent beam steering with frequency abilities, high gain and benefit of being low profile configuration [10, 11]. These properties allow them to have easily integrate with millimeter-wave and microwave circuits. The complexity of most systems that rely on control radiation pattern facilities such as surveillance, point to multi-point wireless communications and automotive radar etc. is reduced by the inherent beam-scanning abilities of LWAs [12-14]. Researches have done and still being carried out on first microstrip LWA. The distinct versions of LWAs that have been built to date include a substrate integrated waveguide-leaky wave antenna (SIW-LWA) with transverse slots, dominant-mode LWA based on metamaterial, a 1D Fabry Perot (FP)-LWA, a half width microstrip LWA (HW-MLWA) with edge loading and a double-periodic CRLH SIW-LWA, a butterfly SIW-LWA, a multilayered composite right/left-handed (CRLH) LWA, a SIW LWA for endfire radiation, a periodic phase reversal LWA, a half mode substrate integrated waveguide (HM-SIW)

circularly polarized LWA, a periodic HW- LWA, a CRLH SIW LWA, a coupled HW-LWA EH1-mode antenna, a HW- LWA with periodic short circuits, a substrate integrated composite right left hand (CRLH) LWA with two elements [15]. Since the electric field is bound strongly between the microstrip line and the ground plane, the uniform microstrip line's fundamental mode lacks radiation. Some of the microstrip's higher-order modes radiate as leaky waves. Electric-field is null at center and phase is reversal in first higher-order mode

This paper aims to analyses the fixed frequency beam steering of MLWAs a topic that has not been systematically reviewed. This paper aims to provide valuable insights for researchers by comprehending the options that are available and unlocking key features that characterize this potential line of research. The following section explains the coherent taxonomy. This particular topic has been discussed in many manuscripts, and a systemic review is necessary to summarize all the latest research findings. The method of this paper is highlighted by discussing the motivations of previous studies. This also aids new researchers in developing their respective studies.

## 2. Beam Steering Techniques

A map of taxonomy categorizing articles following goals and the respective study direction of contribution is provided in Figure 1. Seven main classes are included in this categorization. Research associated to the control of radiation pattern classification is the first class. A beam steering is indicated by the results of articles within this category via metamaterial technique. Seventeen articles are in this set (17%). Fourteen articles representing studies about loading with varactors are in the second class (14%). Eight articles representing the studies on beam steering by applied electric and magnetic field to the liquid crystal are in the third class (8%). Six articles representing studies on beam steering by altering capacitor capacitance, connected at the HM-SIW free edge side, are in the fourth class (6%). Six articles representing studies of beam steering via the utilization of gap capacitor are in the fifth class (6%). Two articles representing studies on beam steering via stub loaded are in the sixth class (2%). Six articles representing studies on other techniques are in the seventh class (6%). The last class includes four articles that represent review and survey articles about LWAs (4%). The next subsection provides a detailed elaboration on the articles linked with each category. the 63 articles produced by the final set. All selected articles were linked to beam scanning for MLWAs at fixed frequency, with 4 articles review and survey.

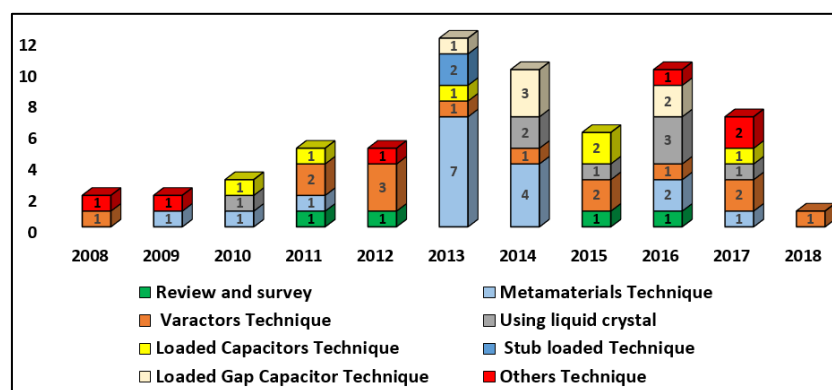


Figure 1. Number of relevant critical articles in different techniques of beam steering by year of publication

### 2.1. Review and Survey Articles

Surveys and reviews of literature related to beam steering make up the last and smallest group of articles (4) in our taxonomy. A review and summary of latest developments for LWAs and the basic physics and operating mechanisms is done by researchers in [16]. Some of the latest developments in the LWA field have been linked to latest developments in the metamaterials area, which has particularly inspired new designs. They have also analyzed

distinct designs that addressed the stopband issue at broadside. The major issues surrounding the utilization of millimeter wave frequencies for 5G communication systems are discussed in [17], which includes attenuation by objects, antenna misalignments and sever path loss. Explanations are also provided on the way beam steering can solve this issue, as recommended in literature. Distinct beam steering techniques sourced from literature are presented and compared in terms of figures of merit (instead of LWA) in this review. The basic practical applications and theoretical principles of electromagnetic leaky waves are reviewed in [18], with few connections linked to microwave, engineering and optical physics. In addition, discussions are made on the way the theory of leaky wave has a significant role in understanding different phenomena, including some of the anomalous optical impacts that are unexplainable by traditional geometrical optics and diffraction theory. Researchers in [19] have looked into the evolution of CRLH-LWAs to produce few new CRLH LWA. The introduction of the concept of CRLH-LWAs led to the discussion of the concave and convex passive CRLH LWAs along with the conformation impacts in each case. To compensate for the conformation impact and thus redirect focus onto the main radiation beam, dispersion engineering system is introduced. Moreover, reviews are made about the planar and conformal varactors based on CRLH-LWAs that are electronically controlled.

## 2.2. Beam Steering by Using Metamaterials

The initial segment of the research is directed the use of metamaterials to regulate radiation pattern. The type of metamaterials and control main beam technique were classified by utilizing articles listed in this group. This class holds 19% of the selected studies under the classification category. A dielectric film fitted with metal strips and fed by the image line composed of high dielectric material constant was utilized by researchers in [20]. A simple structure is achieved by utilizing a 10.8 relative dielectric constant image line, wide and symmetrical beam-steering angle. A particular weakness of this design system is that it is non-reconfigurable, thus large cells are not operable for other configurations following fabrication. As illustrated in Figure 2, the design in [21] is made up of varactor diodes with unit cell in shunt and series configuration, with the waveguide's  $\beta$  being electronically altered through two DC voltages ( $V_S$ ,  $V_{SH}$ ) from left hand to right hand. The future work of this design is can switching between the two input ports the beam can be steered from broadside to negative and positive angles, but the gain for each pattern is low between (3–4) dBi.

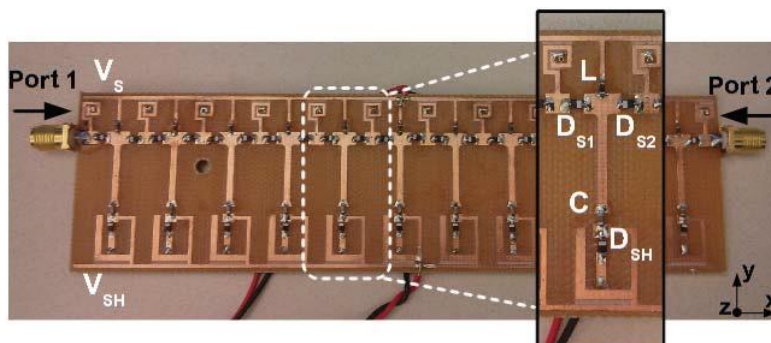


Figure 2. Prototype of CRLH-LWA and details of the unit cell [21]

## 2.3. Loaded Varactor-based Technique

Due to the fact that their capacitance is easily changeable through the bias voltage, provide reconfigurable surface impedance by varactor diodes are integrated into the LWA, thus allowing fixed-frequency beam scanning. Subsequently, the leaky wave's radiation direction can be steered in an electronically way at a fixed frequency. Researchers in [22] are given fixed-frequency beam steering abilities in this communication. A shunt and series capacitive tuning elements load the antenna, thus providing two degrees of freedom which allows manipulation of its dispersion properties. As illustrated in Figure 3, the suggested design of the LWA in this article has shown to have excellent potential for fixed operating frequency applications that need a wide range of beam scanning.



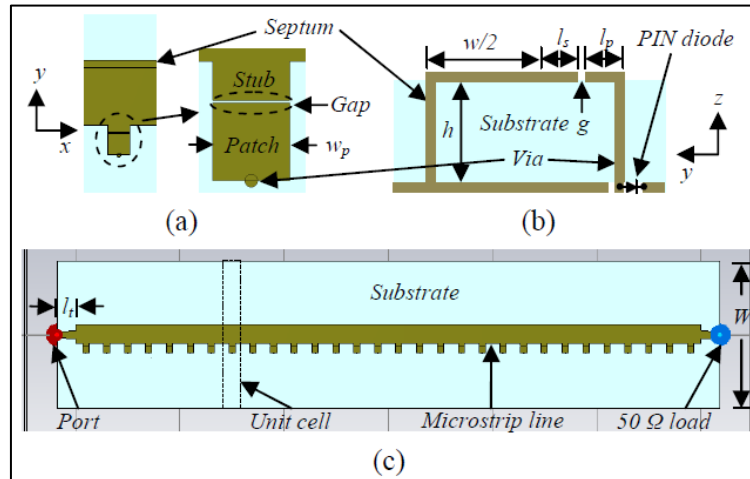


Figure 4. structure of reconfigurable HW-MLWA: (a) top view of unit cell, (b) side view of unit cell, and (c) top view of all structure [27]

### 3. Comparison of Techniques

An overview of each scanning technique found in literature and characteristics following the tables discussed in section 2 is presented in Table 1. Continuous steering based on the active device utilized can be achieved by beam steering by using metamaterials. The antenna's overall size is larger than the metamaterial surface compared with the original antenna. The standard quality of Chemical vapour deposition (CVD) graphene results in low levels of ohmic, as revealed by the first realizations of graphene-based devices [30]. The varactor technique, which is commonly loaded on LWAs, has lower cost of production and can be independently controlled [31]. However, network biasing is commonly complicated, and the varactor can only be utilized at frequencies below 10 GHz [32], thus limiting its application. The MEMS can switch between two distinct states, but it possesses a small and discontinuity tuning range as a tunable mean [33]. MEMS, ferrites and diodes, are mainly utilized in the LWA as tunable means. Ferrites possess light weight, high tuning speed, high permittivity and permeability [34], and can easily achieve wide scan angle and miniaturization without lowering gain [35]. However, they entail a high cost of production and strength magnetic field and have bigger effects on microwave band devices [36]. The lumped element (capacitor) technique may not be suitable for space borne applications because they can result in losses. Owing to its low insertion losses and performance that is not degraded at any point, the gap capacitor beam steering technique may be ideal for beam steering.

Table 1. Comparison between of Beam Scanning Techniques

Type of beam steering technique	Complexity	losses	Size	Cost	Scanning range
Metamaterials based technique	medium	high	medium	high	low
Liquid crystal-based technique	High	high	medium	high	low
Loaded capacitor-based technique	medium	medium	dependent on operating frequency	low	medium
Loaded varactor-based technique	medium	medium	dependent on operating frequency	low	medium
Loaded stub-based technique	medium	low	dependent on operating frequency	low	medium
One gap capacitor-based technique	Low	low	dependent on operating frequency	low	medium

### 4. Recommendations

We provide brief recommendations for beam steering for LWAs at a fixed frequency that is dependent on technique utilized based on literature, as illustrated in Figure 5.

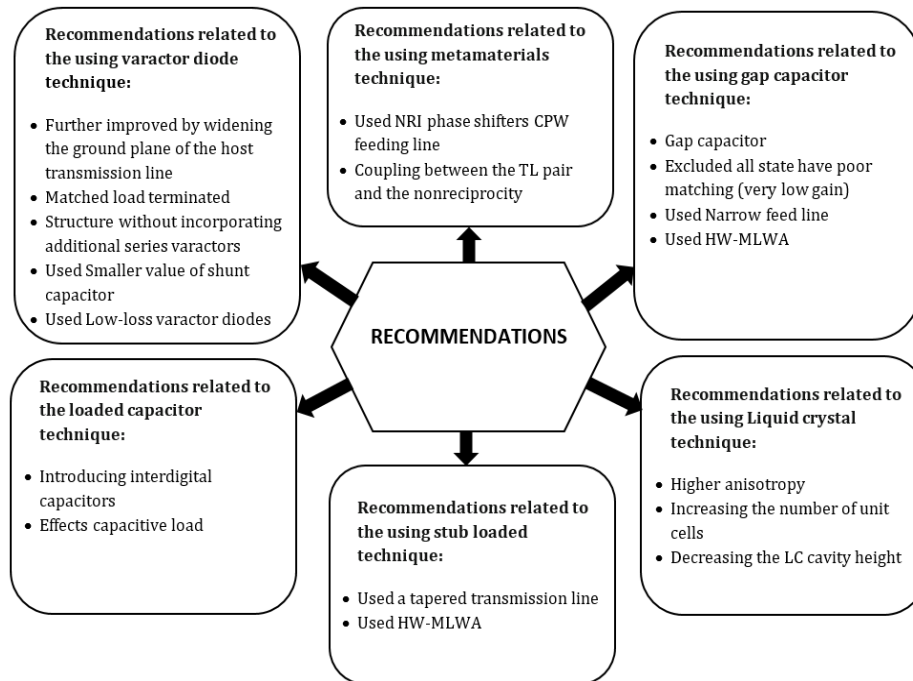


Figure 5. Recommendations categories for control radiation pattern for LWAs at fixed frequency

#### 4.1. Recommendations Related to the using Metamaterials Technique

Researchers in [37] made recommendations on the general performance of this simple antenna structure, citing it as extremely promising for integration into future version of all-graphene reconfigurable THz sensors and transreceivers

#### 4.2. Recommendations Related to the Use of the Varactor Diode Technique

Researchers in [38] recommended further improvements of the pattern by increasing the width of the host transmission line's ground place (this enhancement is limited by technical requirements to the structure's maximum overall width). From the perspective of all antenna parameters, the matched load terminated structure is the best design.

#### 4.3. Recommendations Related to the Use of the Liquid Crystal (LC) Technique

Researchers in [23] suggested that improvements can be made by using LC materials with higher anisotropy to increase the difference between the two tuning states. Improved R&D LC mixtures, which are only available in small quantity now demonstrate almost two times higher tunability than the LC utilised for demonstration.

#### 4.4. Recommendations Related to the Use of the Loaded Capacitor Technique

The introduction of interdigital capacitors allows the control of the reactance profile at the free edge, whereas digital switches allow the control of their connection at the ground plane [26]. Authors in [39] recommended two significant effects of adding a capacitive load.

#### 4.5. Recommendations Related to the Use of the Stub-based Technique

The authors in [27] suggested that a good impedance match is possible by using tapered transmission line at the feed port and the matching port.

#### 4.6. Recommendations Related to Use of the using Gap Capacitor Technique

This approach was suggested to assist in the design and analysis of a reconfigurable periodic structure in a systematic manner by researchers in[40]. The capacitance of the gap between the patch and microstrip edge influences the beam scanning range of the proposed design antenna

## 5. Conclusion

This review covers the key item of this research, that is, MLWAs' beam steering. A systematic review protocol is designed based on articles using three key terms. The Methods section describes the rationale of this selection. The identified exclusion and inclusion criteria underwent three iterations of article screening and reading. Several beam steering methods obtained from the literature are compared and loaded gap capacitor technique beam steering is identified as the ideal form of beam steering because it does not involve insertion losses. This research method is highlighted by discussing the motivation of previous studies. It also assists new researchers in building their respective research works. Analyses assist researchers in developing more research experiments that are within the scope of the research. The gaps highlighted by the distinct analysis type of beam steering techniques can be addressed by these experiments. For instance, they help identify techniques that have not been tested in our applications. The analysis of previous studies' technique configurations also enables this taxonomy to assist researchers in designing their studies. The knowledge of the taxonomy patterns of previous research also enables researchers to identify possible directions for future research.

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