EH_0-Mode Microstrip Leaky-Wave Antennas with Periodical Loading of Shorting Pins

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***Abstract*—A novel microstrip leaky-wave antenna (MLWA) under the operation of the fundamental leaky-wave EH_0 mode in a microstrip line (MSL) is presented. Different from the conventional EH_0-mode (quasi-TEM) structure with $\beta/k_0 > 1$, the proposed EH_0-mode MLWA is implemented by periodically loading inductive shorting pins along the MSL to excite an EH_0-mode fast-wave region with $\beta/k_0 < 1$ for radiation. Herein, both the antenna structure and feeding line are simultaneously excited under the operation of the same EH_0 mode, leading to the mode purity with simplified feeding mechanism. Most importantly, the proposed leaky-wave EH_0 mode is not restricted by transverse resonant condition of higher-order modes, resulting to realize an arbitrary fast-wave region by virtue of varied periodicity of shorting pins.**

Keywords*—Microstrip leaky-wave antenna (MLWA); leaky-wave EH_0 mode; periodical loading of shorting pins; microstrip line

I. Introduction

Since Menzel first demonstrated the microstrip leaky-wave antenna (MLWA) under the first higher-order EH_1-mode operation [1], a large number of researchers have been attracted to develop the MLWAs by employing the higher-order EH_1 or EH_2 mode in a microstrip line (MSL). However, the strip widths of these higher-order modes must be electrically wide enough, thus to meet the requirement of transverse resonant condition, i.e., half an effective wavelength for EH_1 mode [2, 3] and one effective wavelength for EH_2 mode. Besides, the feeding structures must be carefully designed according to their field distributions for better excitation of these modes. And essential mode transformation circuits are necessarily required to convert the quasi-TEM or EH_0 mode at the feeder to the higher-order mode in the core MLWA section.

Recently, our research evidently discovers that a row of shorting pins can be effectively utilized to transform the fundamental EH_0 mode from the original slow-wave status into a fast-wave or leaky-wave status [4]. It only needs to periodically install the inductive shorting pins along the longitudinal direction of the traditional EH_0-mode (Quasi-TEM) MSL, thereby causing inductive effect to reduce the phase constant of the slow-wave MSL below its free-space counterpart, i.e., $\beta < k_0$. Hence, both the feeding line and antenna structure are excited under the same EH_0 mode, without any requirements to design the mode transformation and suppression mechanisms. What's more, the loaded inductive effects of the installed shorting pins are capable to flexibly manipulate the operating mode along the spectrum, which may provide significantly more design flexibilities compared with the conventional transversely-resonant type of higher-order EH_1-/EH_2-mode MLWAs.

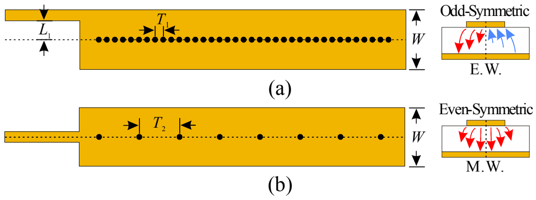

Fig. 1. Pin-loaded MLWAs comparisons. (a) Under the conventional EH_1 mode. (b) Under the proposed leaky-wave EH_0 mode.

II. Working Principle of EH_0-Mode MLWA

A. Comparisons of Pin-Loaded EH_1/EH_0-Mode MLWAs

As is known, conventional EH_1-mode MLWAs are usually loaded with periodic shorting pins, as shown in Fig. 1(a). These closely-aligned shorting pins function as an electric wall (E. W.) along the centerline of the MSL. The transverse fields are in the odd-symmetric distribution, with suppression of the even-symmetric modes including EH_0 mode. Thus, the feeding line must be connected at edge side of the MSL with offset distance L_1 for better excitation of odd-symmetric EH_1 mode.

Contrarily, in Fig. 1(b), the sparsely-installed periodical shorting pins are utilized to generate the inductive-loading effect along the slow-wave fundamental EH_0-mode (quasi-TEM) MSL. The shorting pins successfully accelerate the phase velocity and slow down the fast-wave region with $\beta/k_0 < 1$ [4]. Owing to the same EH_0 mode with even-symmetric field distribution in both the feeding line and antenna structure, no mode transformation from EH_0 to EH_1 or EH_2 mode is required. Therefore, the antenna could be directly connected with the feeding line in a center-to-center way, resulting in simple symmetric configuration with intrinsic suppression of the odd-symmetric modes including EH_1-mode.

B. Characterization of the Proposed Leaky-Wave EH_0 Mode

To further illustrate the propagation characteristics of the proposed EH_0-mode MLWA, the normalized phase and attenuation constant of the proposed structure are extracted by using our developed HFSS-SOL extraction method [5, 6]. As shown in Fig. 2(a), two distinctive operating modes exist in one

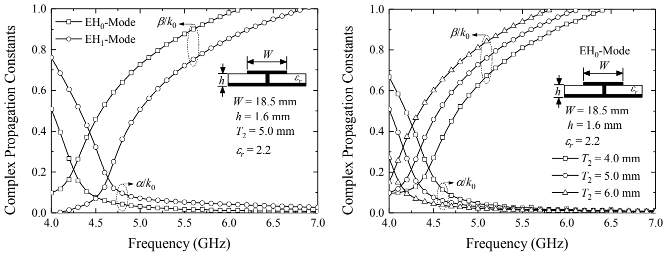

Fig. 2. Extracted normalized propagation constants. (a) Proposed leaky-wave EH_0 mode and conventional EH_1 mode existed in the same pin-loaded structure in Fig. 1(b). (b) Flexibly-selected fast-wave region of the proposed EH_0-mode MLWA controlled by varied periodicities of the shorting pins.

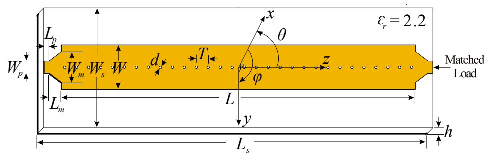

Fig. 3. Geometry of the proposed EH_0-mode MLWA.

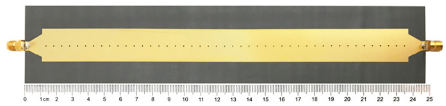

Fig. 4. Photograph of the fabricated antenna prototype.

pin-loaded leaky-wave MSL structure. The EH_0 mode owns a cut-off frequency smaller than the width-dependent higher-order EH_1-mode counterpart. Besides, as shown in Fig. 2(b), the fast-wave region of the proposed EH_0 mode can be easily adjusted by changing the periodicity of the shorting pins. It is unprecedentedly flexible to implement EH_0-mode MLWAs with the desired lower or higher fast-wave regions without any necessities to transversely widen up or narrow down their corresponding strip widths.

III. Antenna Design, Implementation and Measurement

The geometry of the proposed antenna prototype is depicted in Fig. 3. The whole structure is based on a dielectric substrate F4B with relative permittivity of $\varepsilon_r = 2.2$, dielectric loss tangent of $\tan\delta = 0.001$, and height of $h = 1.6$ mm. The antenna is fed by a 50-Ω feeding line via a triangular transition as an impedance transformer. To reduce the back lobes caused by the reflected waves in the terminal port, a matched load is installed at the end of the antenna. Final dimensional parameters of the proposed EH_0-mode MLWA are obtained, as listed in Table I. An antenna prototype is subsequently fabricated, and its photograph is exhibited in Fig. 4. The reflection coefficient is measured with the use of R&S ZNB-20 Vector Network Analyzer, as shown in Fig. 5(a). The simulated and measured reflection coefficients are in good accordance, with -10 dB bandwidth covering the whole fast-wave region. In addition, the radiation pattern is measured with the StarLab SATIMO measurement system, as shown in Fig. 5(b). The measured results verify the frequency-dependent beam scanning capability of the proposed EH_0-mode MLWA.

IV. Conclusion

A new class of MLWA under the fundamental leaky-wave EH_0 mode in a MSL is presented. Compared with existing MLWAs using the higher-order EH_1/EH_2 modes, the proposed EH_0-mode MLWA can be directly fed or excited without any mode transformation mechanism. Moreover, a distinct feature to effectively control the fast-wave region by varying the periodicity of the shorting pins is demonstrated with extracted complex propagation constants. Finally, an antenna prototype is designed, fabricated and measured. The proposed EH_0-mode MLWA owns a few advanced features such as simplified feeding mechanism, controllable leaky-wave operating region, simple structure, easy fabrication, etc., which may be extensively developed into various MLWA applications.

TABLE I. Dimensions of EH_0-Mode MLWA Prototype.

Parameter	***Value (mm)***	***Parameter***	***Value (mm)***	***Parameter***	***Value (mm)***
W	18.5	W_s	50.0	W_m	13.0
T	5.0	L_s	247.0	L_m	8.0
h	1.6	N	45	W_p	5.0
d	0.8	L	225.0	L_p	3.0

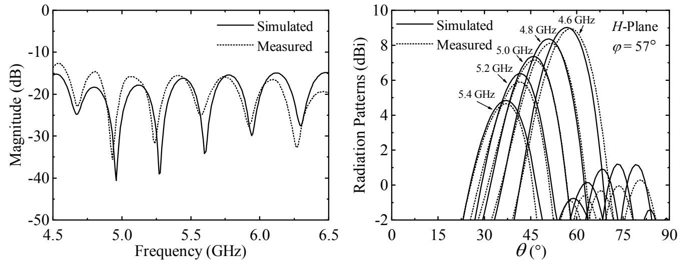

Fig. 5. Simulated and measured results. (a) Reflection coefficients. (b) Radiation patterns.

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