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How to cite this article: Adhikary M, Mukherjee S, Biswas A, Akhtar MJ. Air filled substrate integrated waveguide cavity backed slot antenna. *Microw Opt Technol Lett.* 2018;60:2605–2608. https://doi.org/10.1002/mop.31357

Received: 5 March 2018

DOI: 10.1002/mop.31496

Wide scanning angle LWA based on DIL with H-shaped grooves

Du-Juan Wei | **Jian-Ying Li** | **Jie Liu** | **Rui Xu** | **Guang-Wei Yang**

School of Electronics and Information, Northwestern Polytechnial University (NWPU), Xi'an, China

Correspondence
Du-Juan Wei, Northwestern Polytechnical University, School of Electronics and Information, 1 Dongxiang Road, Chang'an District, Xi'an, Shaanxi, 710129, P. R. China.
Email: weidj@mail.nwpu.edu.cn

Abstract

A dielectric image line (DIL)-based leaky wave antenna (LWA) with H-shaped grooves is proposed in this paper. By periodically carving a set of H-shaped grooves in the ground of the DIL, infinite space harmonics are excited, and the proposed antenna works with $n = -1$ order mode. The H-shaped radiator can effectively eliminate open stopband (OSB). Over the operating band from 11.1 GHz to 15 GHz, the beam of the proposed antenna scans widely from $-72°$ to $31°$ (including the broadside) with the realized gain from 9.7 dBi to 12.9 dBi. A prototype is fabricated and measured, which testifies the design theory and the simulation results.

KEYWORDS

dielectric image line, H-shaped groove, leaky wave antenna, open stopband, wide scanning angle

1 | INTRODUCTION

LWAs are a kind of traveling wave antenna. Waves travel through a guiding structure, while gradually leaking out into the free space. LWAs are well known by outstanding merits, like broad impedance band, simple feeding network, high directivity, and frequency beam-scanning property[1]. Therefore, LWAs have been received much attention in recent years for applications in radar systems, wireless communication systems, and surveillance systems.

LWAs are generally based on two types of wave-guiding structures: the fast-wave structure and the slow-wave structure. By introducing uniform discontinuous radiators in the fast-wave structure, this kind of LWA, namely uniform LWA, is capable of working at fundamental mode[2,3]. However, the radiation beam only covers the forward region above the cutoff (broadside). To get the LWA having beams from the backward to forward scanning, metamaterials (Dirac LWA, composite righ/left-handed LWA)[4–6] or periodical units (periodical LWA)[7,8] are used in the fast-wave structures. The CRLH LWA is able to achieve continuous beams (including broadside) when the CRLH unit cell arrives at the balanced state[5,6]. The slow-wave guiding structure (like microstrip line and DIL) can confine waves inside or the surface of the structure at the fundamental mode, which has good transmission property rather than power leakage. The way of the uniform LWAs based on the slow-wave structure is unavailable. Normally, the second way of using metamaterials and periodical radiators are efficient. For the periodical LWA based on slow-wave structure, some higher space harmonics excited by periodical units will fall in the fast-wave region where the LWA can get scanning beam.

Various designs of DIL-based LWAs are reported[9–13]. DILs as the feeding networks provide the phase difference for the radiation units (microstrip patches)[9,10]. Slots and holes are carved in the ground plane of DIL to realize the DIL-based LWA for millimeters waves[11]. A LWA based on DIL for broadside radiation is proposed by using pairs of circular patches printed on the top of the DIL[12]. A wide beam-angle DIL-based LWA from the backward to forward is proposed, which works at the $n = -1$ order mode realized by a set of periodic holes in the DIL[13].

In this paper, a DIL-based LWA with H-shaped grooves carved in the ground is proposed. The basic wave-guiding structure of the propose antenna is the DIL from the paper[14]. The fundamental mode of the DIL is slow wave. However, by introducing a periodic set of discontinuous units in the ground, the fundamental mode is perturbed by the infinite space harmonics where the $n = -1$ order mode is in the fast region. What is more, the OSB is closed obviously by using the H-shaped groove unit, which improves the impendence matching of the proposed antenna at the broadside frequency. The structure has simple structure and easy to design. The performance of the proposed antenna is good with broad beam scanning region and stable gain.

2 | ANTENNA STRUCTURE

Figure 1 illustrates the configuration of the proposed antenna, which is a DIL-based LWA with H-shaped grooves in the big ground. The fundamental mode of the DIL is in the low-wave region without power leakage. To realize leaky-wave radiation, a set of H-shaped grooves are periodically carved in the big ground of the DIL. The H-shaped groove is composed of a pair of transverse grooves and a longitudinal groove. The width and length of the transverse groove are Ws and Ls, and the distance between them is p1. The period of the unit cells is p. The width and thickness of the dielectric line is W1 and H1, and the relative permittivity ε_r is 10.2. The structure of the feeding network is introduced from the study[14], which is a substrate truncated microstrip line with capacitive gaps and inductive metal strips. a and b are the width and the tapered length of the microstrip line, respectively. The width of the gap and the metal strip are g and s, respectively.

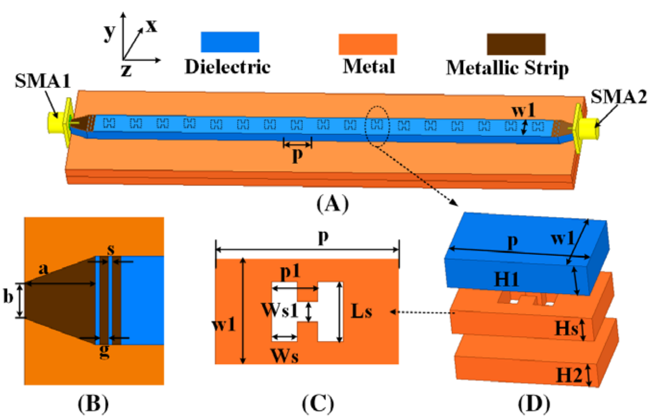

FIGURE 1 Configuration of the proposed antenna. (A) overall structure, (B) feeding network, (C) H-shaped slot, (D) unit cell. H1=2.52mm, w1=6.25mm, p=10.75mm, Hs=2mm, Ws=1.5mm, ls=3.5mm, p1=2.7mm, Ws1=1.2mm,, H2=2mm, g=0.3mm, s=0.6mm, a=5mm, b=2.54mm [Color figure can be viewed at wileyonlinelibrary.com]

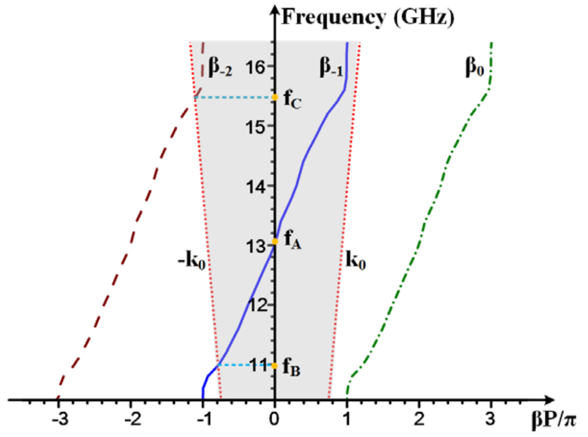

FIGURE 2 Dispersion diagram of the unit cell [Color figure can be viewed at wileyonlinelibrary.com]

3 | OPERATION PRINCIPLE

The dominant mode of DIL is in slow wave region where no wave radiates even though the structure is open. A group of H-shaped grooves carved periodically in the ground along the transmitting direction (z-axial) can generate infinite space harmonics according to Bloch–Floquet theory, where the phase constant of the nth order space harmonics is given by[13].

$$\beta_n = \beta_0 + \frac{2n\pi}{p} \tag{1}$$

where β_0 and β_n are the phase constant for the fundamental and nth order space harmonics, respectively. n is an integer.

As shown in Figure 2 of the dispersion diagram of a unit cell, the first space harmonics ($n = -1$) is in the fast wave region. So the antenna can radiate power. The phase constant of the unit cell is zero at f_A (about 13.1 GHz), which means the beam is on the broadside. Before f_A, the beam scans in the backward radiation till the negative endfire appears at f_B (about 11 GHz). After f_A, the forward radiation takes pace till the next order space harmonics ($n = -2$) appears at f_C (about 15.5).

The beam direction of the LWA can be determined by the phase constant in the guiding structure. The relation is given by

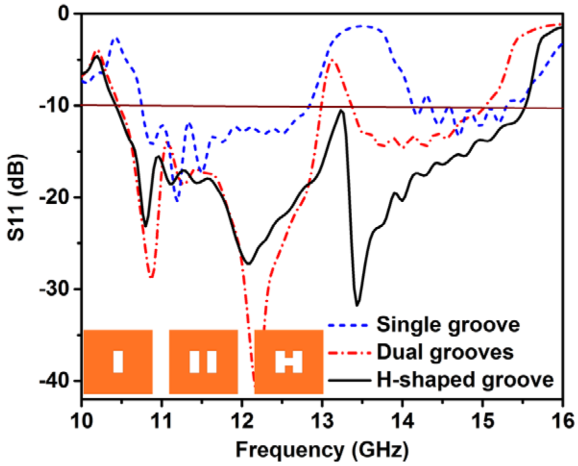

FIGURE 3 S parameters of 17 unit cell antenna with 3 types of grooves [Color figure can be viewed at wileyonlinelibrary.com]

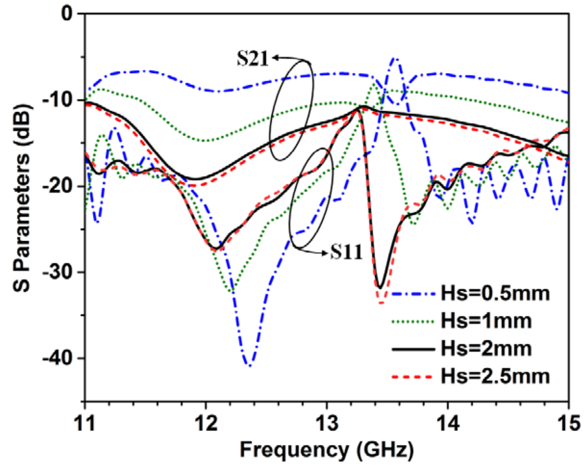

FIGURE 4 S parameters of 17 unit cell antenna against depth of the H-shaped groove [Color figure can be viewed at wileyonlinelibrary.com]

$$\sin\theta = \frac{\beta_n}{k_0} \tag{2}$$

Where k_0 is wavenumber in the free space at frequency of interest, and θ is the beam direction with respect to y-axial.

The $n = -1$ space harmonics is in fast-wave region. Based on (1) and (2), the beam direction is given by

$$\theta = \arcsin\left(\frac{\beta_{n-1}}{k_0}\right) = \arcsin\left(\frac{\beta_0}{k_0} - \frac{2\pi}{pk_0}\right) \tag{3}$$

As expression in (3), the radiation direction is determined by the phase constant β_0 of the fundamental mode and the period p of unit cells. Once the parameters of DIL are fixed, β_0 will be certain. Therefore, the broadside beam at the frequency point of interest will be realized by changing the period p.

4 | UNIT CELL OF H-SHAPED GROOVE

It is well known that the OSB effect at the broadside is an important issue of LWA, which is always due to the inphase reflective superposition of the space harmonics generated by the radiators in the guiding structure. Figure 3 gives the return loss of the antennas with 3 styles of unite cells. The structures (the single groove, the dual grooves, and H-shaped groove) are also inserted in Figure 3. The antenna with the single-groove unit has a wide OSB. An efficient method reported[12] to reduce the OSB is to introduce an extra radiator to the original one about $\lambda_g/4$ (a quarter of guided wavelength at the broadside frequency) away. According to the theory[12], an extra groove is carved to compose the dual-groove unit. The OSB of the dual-groove cell is obviously narrower than the single-groove cell. To ease the manufacture complexity, the dual grooves have the same depths. But the depth of the groove has very important influence on the impendence of the antenna, especially for the reactance[15]. So, the OSB is just attenuated partly by using the dual-groove unit. To further eliminate the OSB effect, the H-shaped groove unit is proposed, which is to add a longitude groove based on the dual grooves. The equivalent circuit of the dual-groove unit is that two impendences are cascaded. The equivalent circuit of the H-shaped groove is T-type, namely introducing an extra shunt impendence between two series impendences, which can further complete the closing of the OSB. As a result, the return loss of the antenna with the H-shaped groove is reduced below −10 dB around the broadside frequency.

The depth of the H-shaped groove carved in the ground is an important parameter of the proposed antenna, so the effect of the depth on the property of the antenna should be studied. Figure 4 and Figure 5 illustrate S parameters and the antenna gain against the depth Hs varying from 0.5 to

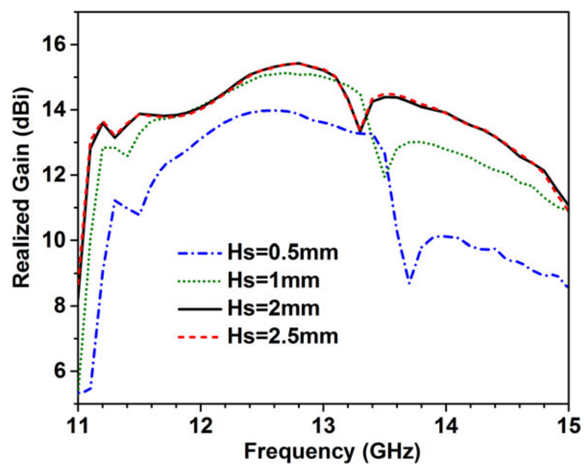

FIGURE 5 Realized gain of 17 unit cell antenna against depth of the H-shaped groove [Color figure can be viewed at wileyonlinelibrary.com]

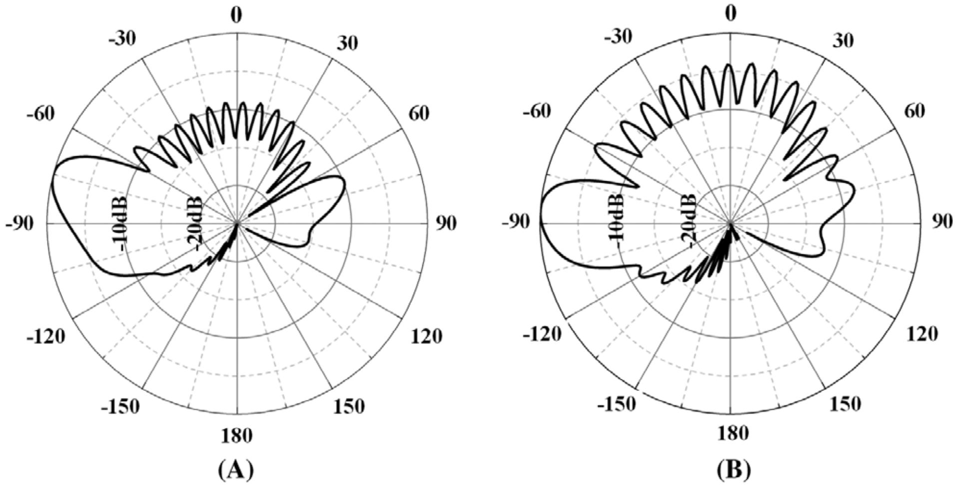

FIGURE 6 Normalized radiation patterns of 17 unit cell antenna. (A) f=11.1 GHz, (B) f=11 GHz

2.5 mm. With the increasing of the depth, less power is absorbed at the end and the radiation power from cells are becoming dominant, which leads to the antenna gain increasing significantly. When the depth is deep enough to 2 mm, S parameters and gain are constant. In this paper, the depth of the groove is designed to 2 mm.

It is noticed that the gain of the proposed antenna with Hs = 2 mm decreases drastically from 12.8 dBi at 11.1GHz to 8.2 dBi at 11 GHz in Figure 5. The normalized radiation patterns at 11.1 GHz and 11 GHz are given in Figure 6, which show that the main beams arrive at −72° with −9.1 dB SLL at 11.1 GHz and point to −86° with −4.5 dB side lobe level (SLL) at 11 GHz. Multiple side lobes with high SLL lead to the low gain of the main beam at 11 GHz, which is unacceptable in the engineering practice. So, the working frequency band should start from 11.1 GHz. A small dip of the gain at around 13.3 GHz in Figure 5 is observed where is a transition region between the backward to the forward propagation.

5 | EXPERIMENT RESULTS AND DISCUSSION

The proposed antenna is simulated with commercial software HFSS, then manufactured and measured. The prototype of the fabricated antenna is given in Figure 7. The proposed antenna is the DIL-based LWA with 10 units of H-shaped grooves periodically carved on the big ground.

FIGURE 7 Photograph of the proposed antenna [Color figure can be viewed at wileyonlinelibrary.com]

The simulated and measured S parameters of the proposed antenna is described in Figure 8. The structure of the propose antenna is totally symmetrical on the Z- axial. So the return loss on two ports are the same. Over the working frequency band from 11.1 to 15 GHz, the return loss is less than −10 dB, and the measured results has good trend with the simulated result. Although the point at the broadside frequency is obviously raised, it is still less than −10 dB. In terms of the transmission coefficient, the simulated and measured S21 is less than −6.6 dB and − 10 dB, so the simulated and measured total efficiency of the proposed antenna are more than 78% and 90%, respectively. The higher efficiency of the experiment than the simulation is mainly led by the dielectric attenuation and the manufacture tolerance.

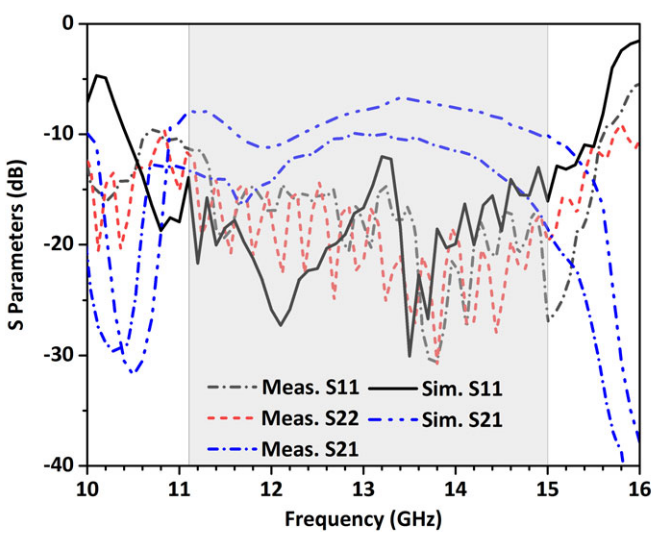

FIGURE 8 Simulated and measured S parameters of the proposed antenna [Color figure can be viewed at wileyonlinelibrary.com]

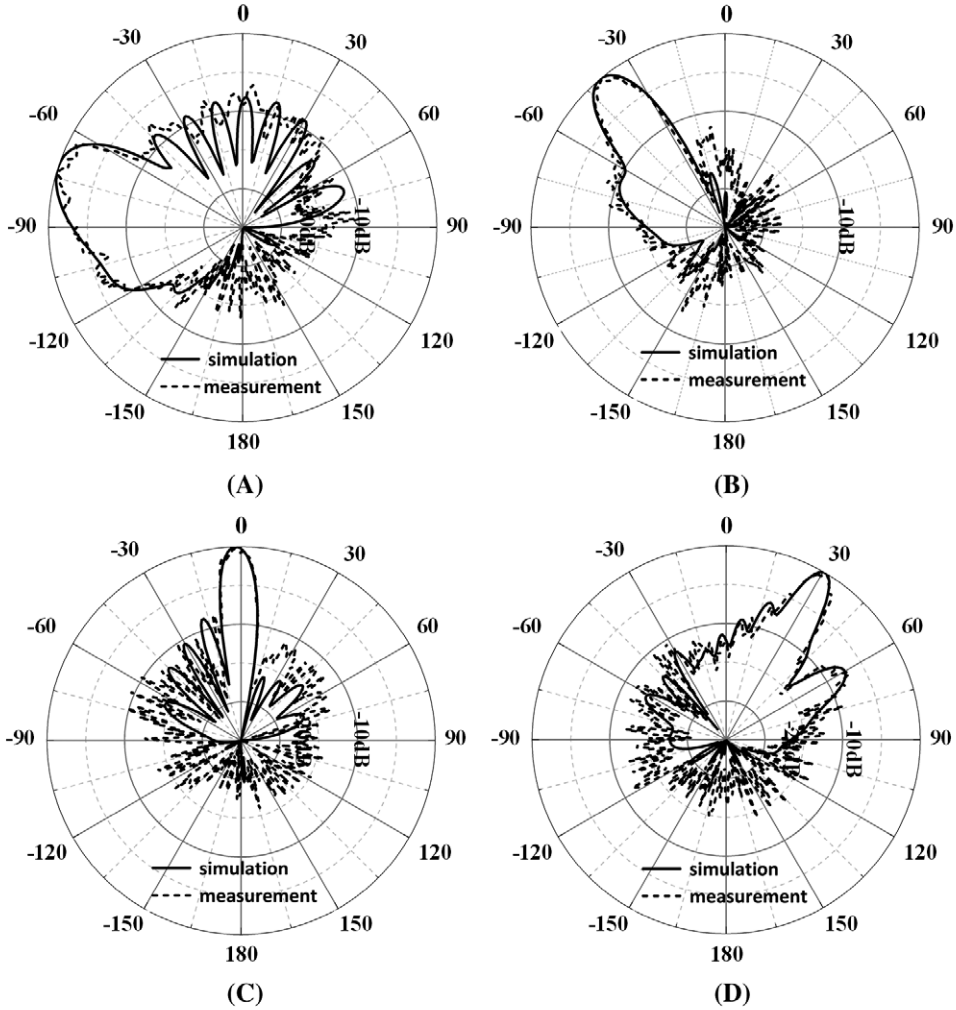

FIGURE 9 Normalized radiation patterns of the proposed antenna. (A) 11.1 GHz, (B) 11.8 GHz, (C) 13.3 GHz, (D) 15 GHz

As shown in Figure 9, the proposed antenna has wide beam scanning angle, which is from the backward with −72° at 11.1 GHz, through −40° at 11.8 GHz, to the forward with 31° at 15 GHz, including the broadside at 13.3 GHz.

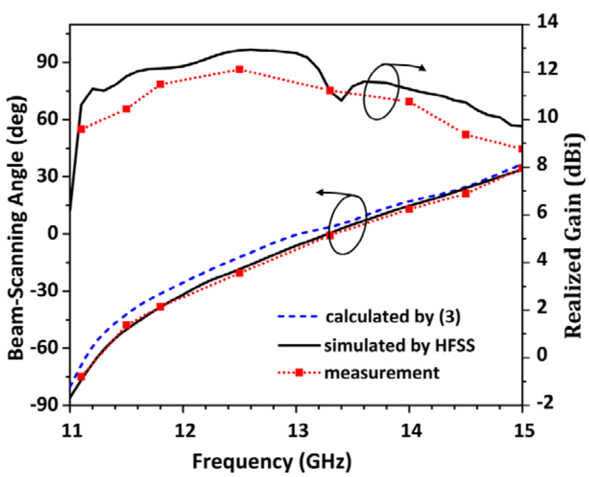

FIGURE 10 Beam-scanning angle and realized gain against frequency [Color figure can be viewed at wileyonlinelibrary.com]

The measured results have good agreement with the simulated results. The beam-scanning angle of the H-shpaped groove DIL-based LWA calculated by (3), simulated by HFSS, and measured in the microwave anechoic chamber are described in Figure 10. The scanning angle by two ways of HFSS and formular (3) are not coicident totoally at some points, which is due to the coupling of unit cells. The measured results have good agreement with the simulation results, which testy the theory annalysis. Meanwhile, the realized gain with frequency variation is also gaven in Figure 10. Over the working frequency band from 11.1 GHz to 15 GHz, the simulated realized gain is from 9.7 dBi to 12.9 dBi. And the measured result is little less than the simulation results beacause of the dielectric attenuation and the manufacture tolerance.

6 | CONCLUSION

In this paper, a wide beam-scanning DIL-based LWA with the H-shaped grooves is proposed. By carving the H-shaped grooves periodically in the ground, the dominate mode of the

DIL is perturbed by infinite space harmonics. The proposed antenna works at $n = -1$ mode in the fast-wave region. The H-shaped radiation element can eliminate the OSB effect at the broadside effectively. When the H-shaped groove is deep enough to 2 mm, the wave broadcasting to the back of the antenna is prohibited, and the antenna has the stable working performance. The beam can scan from $-72°$ at 11.1 GHz to $31°$ at 15 GHz (including the broadside at 13.3 GHz). The realized gain over the working band keeps from 9.7 dBi to 12.9 dBi.

ORCID

Du-Juan Wei http://orcid.org/0000-0002-7739-1594
Guang-Wei Yang http://orcid.org/0000-0002-1763-403X

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How to cite this article: Wei D-J, Li J-Y, Liu J, Xu R, Yang G-W. Wide scanning angle LWA based on DIL with H-shaped grooves. *Microw Opt Technol Lett*. 2018;60:2608–2613. https://doi.org/10.1002/mop.31496

Received: 8 March 2018

DOI: 10.1002/mop.31491

Demonstration of an optical wireless communication link with pre-emphasis circuit for high-speed application

David Silveira | **Wimansha Wijekoon** | **Ghang-Ho Lee**

Department of Electrical and Computer Engineering, California State University, Chico, California

Correspondence
Ghang-Ho Lee, Department of Electrical and Computer Engineering, California State University, Chico, 95929, CA.
Email: ghlee@csuchico.edu

Abstract

In this article, we experimentally demonstrate an optical wireless communication link based on Non-Return to Zero (NRZ) On-Off Keying (OOK) modulation with pre-emphasis circuit for high-speed application. We propose an economical hardware pre-emphasis circuit comprise of one operational amplifier and an RC filter stage with a high-pass frequency response to enhance passband characteristic of optical wireless communication link. The validity of the pre-emphasis circuit has been demonstrated by using existing fiber optic and optical wireless communication link and components in our laboratory operating at 1550 nm. But the same pre-emphasis circuit can be used in other wavelength applications including visual light wavelength range via light-emitting diodes (LED). By using proposed pre-emphasis circuit, 3 dB bandwidth of optical wireless link can be extended from