Study of High Efficiency and Low Sidelobe Level CRLH Leaky-Wave Antenna Based on Short-End and Tapered Cells

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***Abstract*—This paper presents a study that improves the radiation efficiency and the sidelobe level (SLL) of a composite right/left handed (CRLH) substrate integrated waveguide (SIW) leaky-wave antenna (LWA). Because of the constructive electric field interference on each interdigital slot of a SIW from short-end, a CRLH SIW LWA can have higher radiation efficiency. In addition, controlling leakage amount of an interdigital slot, we can make a LWA have lower SLL. For verifying the concept, the tapered CRLH SIW LWA with short-end is designed and fabricated. The measured results verify the study.**

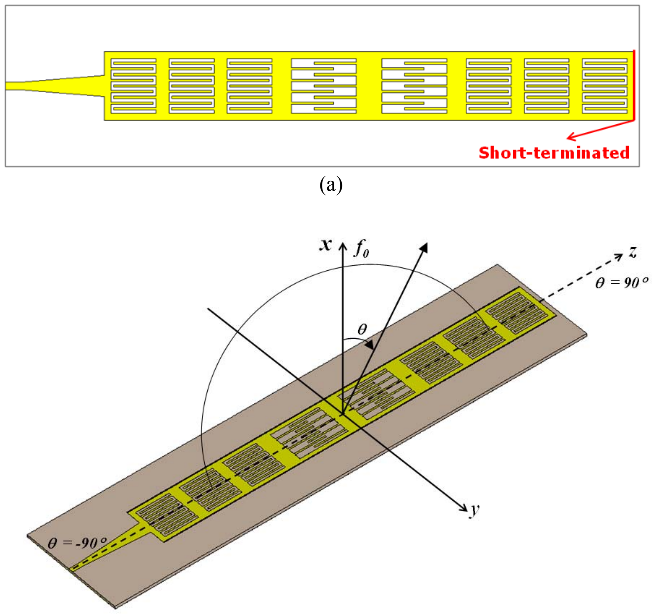
Keywords- Composite right/left handed (CRLH); leaky-wave antenna (LWA); substrate integrated waveguide (SIW) ; sidelobe level (SLL)

I. INTRODUCTION

A leaky-wave antenna (LWA) supports its radiation with leakage of traveling wave in a guided structure [1-3]. Since its leakage factor is generally low, the size of the antenna becomes large for having high radiation efficiency. A LWA based on power-recycling scheme could be one possible candidate for enhancing radiation efficiency with fixed antenna size [4]. However, it may suffer from additional loss of a coupler structure.

In this study, radiation efficiency of a composite right/left handed (CRLH) substrate integrated waveguide (SIW) LWA [5] is improved by terminating output with a short but not a matched load. The non-radiated power at the end of the antenna returns back and it enhances the radiation efficiency. It is found that only short-end makes constructive interference on a radiating element and open- or pure reactive-end does not help to improve the efficiency.

In addition, we present a novel tapered CRLH SIW structure for reducing a sidelobe level (SLL) of a LWA. By investigating an interdigital slot (radiating element of a CRLH SIW LWA), its main parameter affecting leakage amount is determined. The result is applied to design a tapered structure.



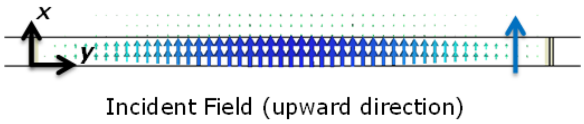
(a)

(b)

Fig. 1. (a) Proposed tapered CRLH SIW LWA with short-end. (b) Axis definition of the antenna.

II. THEORY

Figure 1 shows the tapered CRLH SIW LWA with short-end. The antenna is terminated with conductor wall at the end of the structure for enhancing radiation efficiency while it consists of tapered interdigital slot array for low SLL. In the proposed antenna, only center frequency (920 MHz) where broadside radiation appears is considered (maximum benefit from short-end and tapered slot). For certain applications such as the base station of the RFID, the beam scanning capability of LWA is not needed as long as a wide angle efficient beam is available. All antennas in this paper are realized using FR4 substrate (ε_r = 4.2, h = 2.8 mm, TanD = 0.02) and via holes with the diameter of d = 0.3 mm. Conductive wall is created by



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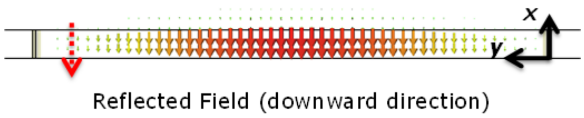

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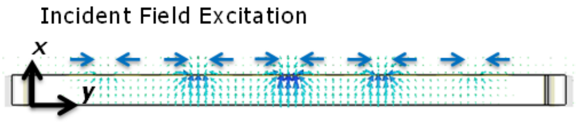

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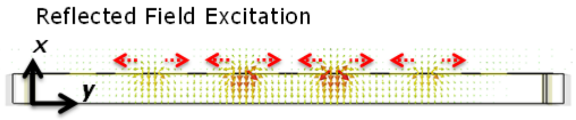

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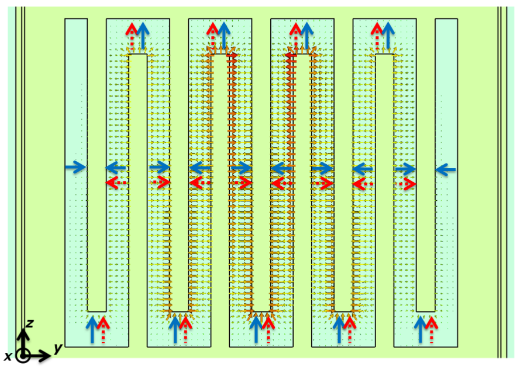
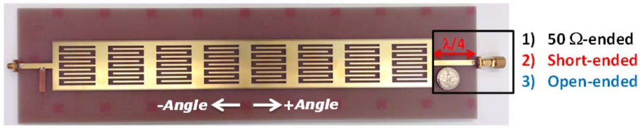


(e)

Fig. 2. Operating concept of short-end. (a) Incident field. (b) Reflected field at the end of the antenna. (c) Electric field distribution on middle of the interdigital slot with incident field. (d) Field distribution on middle of the interdigital slot with reflected field. (e) Field distribution on the slot with both excitations (top view).



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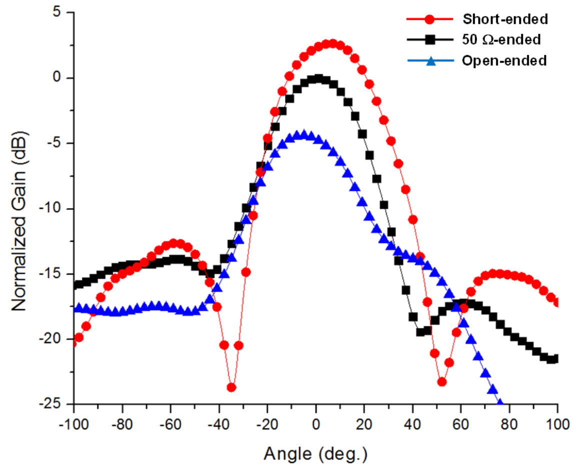
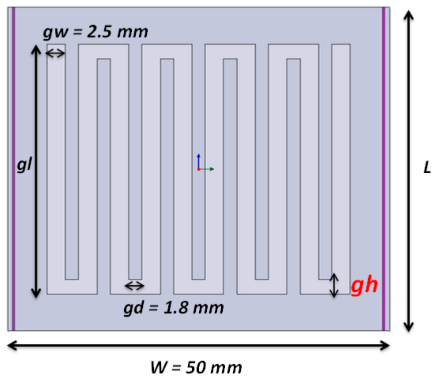


(b)

Fig. 3. (a) Conventional 8-cell LWA with three terminations. (b) Measured normalized far field patterns of conventional 8-cell LWA with short-, 50Ω-, and open-end.



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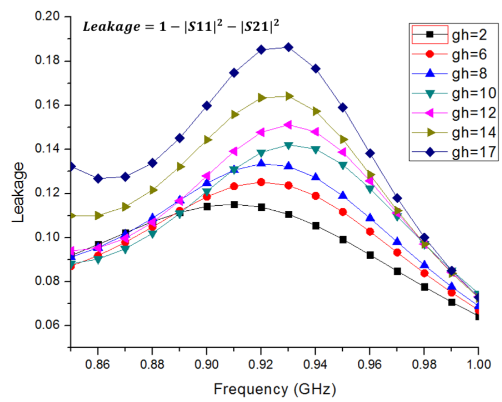

(b)

Fig. 4. (a) Dimensions of a interdigital slot. (b) Leakage amount with various 'gh' parameters

placing the vias with the center-to-center spacing of s = 0.75 mm.

A. Short-End for High Radiation Efficiency

Figure 2 shows operating concept of short-end in the proposed antenna. The incident electric field inside the SIW has x-direction as shown in Fig. 2(a). Because the antenna is short-terminated and operating at the center frequency (broadside radiation), the reflected electric field has –x-direction and it is shown in Fig. 2(b). Fig. 2(c) and (d) show the electric field distribution at middle of the interdigital slot excited by the incident field and the reflect field, respectively. Solid arrows of Fig. 2(c) on the slot surface show the electric field direction induced by the incident field. On the contrary, dotted arrows shown in Fig. 2(d) represent the field direction excited by the reflected field on the slot surface. Comparing

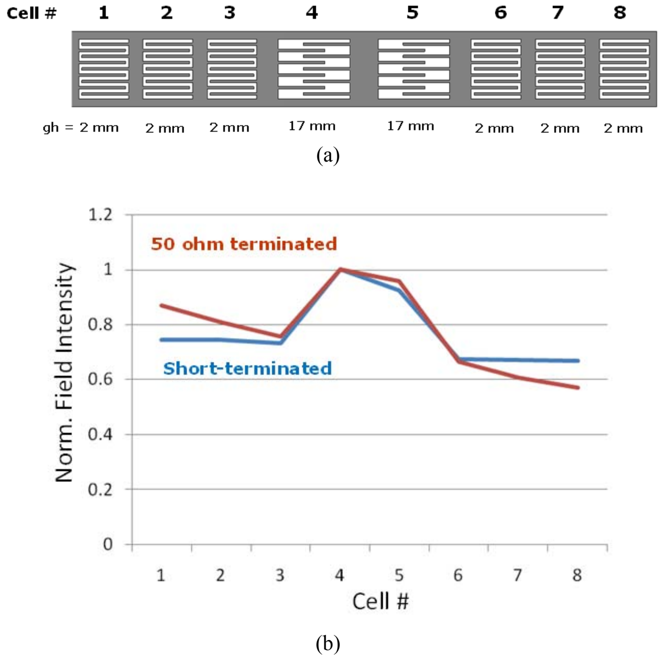

Fig. 5. (a) Configuration of tapered slot array. (b) Normalized electric field intensities on slots.

those, we can observe the field direction induced by the reflected field is same with that excited by the incident field. However, the field shown in Fig. 2(c) and (d) do not directly contribute to the far field pattern, because each field has its counterpart having opposite direction. The z-directed electric field distribution shown in Fig. 2(e) contributes to the radiation, which is induced by the field distribution shown in Fig. 2(c) and (d). In summary, with short-end constructive interference appeared on interdigital slots. Thus the radiation efficiency is improved. If open-end is used, we can observe destructive interference on interdigital slots. It prevents radiation.

To verify this, we use 8 cell LWA shown in Fig. 3(a) with changing terminations. For getting short-end, we use an open termination and it shows similar results with the antenna having a direct short-end. This configuration also supports other termination cases. Fig. 3(b) shows that the antenna with short-end has largest gain as we expected. It is around 3 dB larger than that with 50 Ω-end and 8 dB larger than open-end case.

B. Tapered Interdigital Slot Array

In an array antenna design, an adequate power distribution of radiating elements improves SLL [6]. This approach can be beneficial to design a LWA [7]. In this study, we notice that a leakage amount of an interdigital slot on SIW can be controlled, and using this it is possible to design a CRLH SIW LWA with low SLL [8].

Fig. 4(a) shows dimensions of an interdigital slot. The parameter 'gh' is one of the main factors for adjusting leakage amount, and the leakage amount is increased with larger value of 'gh' at the center frequency. Fig. 4(b) shows that leakage

TABLE I
INTERDIGITAL SLOT PARAMETERS

920 MHz center frequency & Balanced Condition (mm)		
gh	***gl***	***L***
2	34	44
6	38	51
8	40	54
10	42	58
12	44	61
14	46	63.5
17	49	68.5

TABLE II
INTERDIGITAL SLOT PARAMETERS

Cell #	Normalized Field Intensity	
	50 Ω-End	Short-End
1	0.87	0.78
2	0.81	0.78
3	0.76	0.8
4	1	1
5	0.96	0.91
6	0.66	0.67
7	0.61	0.62
8	0.57	0.65

amount of a slot is increased with larger 'gh'. While increasing the value of 'gh', parameters 'gl' and 'L' are also increased for satisfying balanced CRLH condition with 920 MHz center frequency. For accurate array factor approach, the change of a unit cell length should be considered. Table 1 shows several parameters satisfying the condition.

Fig. 5(a) shows 8 cell tapered array consisting of 2 mm 'gh' cells and 17 mm 'gh' cells. The normalized field intensity (contributing radiation) on each slot with two types of termination is shown in Fig. 5(b). The intensities are obtained by the probe function of the CST Microwave Studio and they are also summarized in Table II. In both terminations, the field intensities of the cells having larger 'gh' are higher than that of smaller 'gh'. More symmetric field distribution is observed with short-end case.

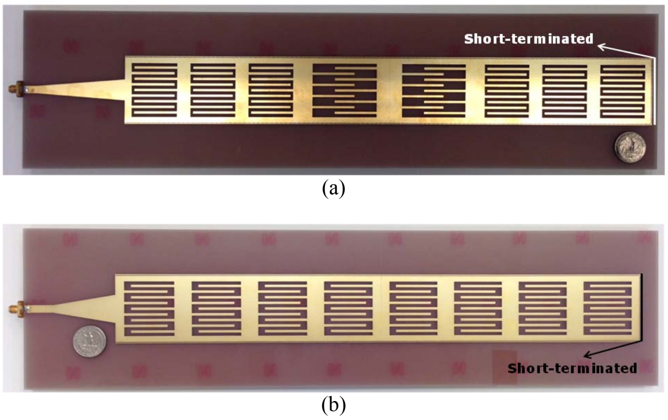

Fig. 6. Photograph of (a) Proposed tapered LWA and (b) Conventional LWA with short-end.

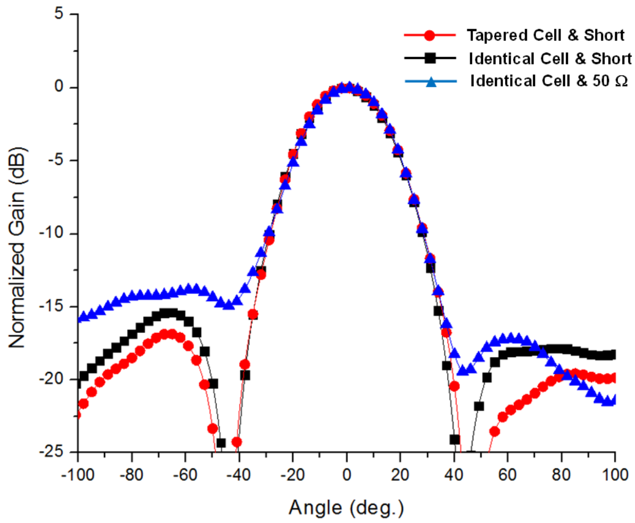

Fig. 7. Measured far field patterns of LWAs shown in Fig. 6(a), (b), and Fig. 3(a) at the center frequency.

III. TAPERED CRLH LWA WITH SHORT-END

To demonstrate the proposed antenna, 8 cell tapered CRLH LWA with short-end is designed and fabricated. Fig. 6(a) shows a photograph of the fabricated antenna. For comparing the far field patterns, conventional 8 cell CRLH LWA with short-end (same size with the tapered antenna) is also fabricated and shown in Fig. 6(b).

The far field patterns of the LWAs are measured in a near field antenna chamber. In Fig. 7, the measured results of the tapered LWA with short-end, the conventional LWA with short-end, and the conventional LWA with 50 Ω-end are compared. The SLLs of the antenna having tapered cells are lower by 1.03 dB (-Angle) and 1.73 dB (+Angle) than that of the conventional antenna with short-end. Comparing with the conventional antenna with 50 Ω-end, the proposed tapered antenna shows 3.02 dB (-Angle) and 2.37 dB (+Angle) lower SLLs. With an optimization process, the SLLs of the antenna with tapered cells would be improved.

IV. CONCLUSION

A study to realize high efficiency and low SLL CRLH SIW leaky-wave antenna (LWA) was carried out. The proposed antenna provides lower SLL using tapered interdigital slots, of which leakage amount can be controlled with 'gh' parameter. In addition, the proposed antenna can have higher efficiency with simple termination method. Hence the proposed antenna may serve as a good candidate for wireless applications requiring high efficiency and low SLL.

REFERENCES

[1] D. R. Jackson, C. Caloz, and T. Itoh, "Leaky-wave antennas," *IEEE Proceedings*, vol. 100, no.7, pp. 2194-2206, July 2012.

[2] D. R. Jackson and A. A. Oliner, "Leaky-wave antennas," in *Modern Antenna Handbook*, C. Balanis, Ed. New York: Wiley, 2008.

[3] A. A. Oliner and D. R. Jackson, "Leaky-wave antennas," in *Antenna Engineering Handbook*, C. J. L. Volakis, Ed. New York: McGraw-Hill, 2007.

[4] H. V. Nguyen, A. Parsa, and C. Caloz, "Power-recycling feedback system for maximization of leaky-wave antennas radiation efficiency," *IEEE Trans. Microwave Theory Tech.*, vol. 58, no. 7, pp. 1641–1650, July 2010.

[5] Y. Dong and T. Itoh, "Composite right/left-handed substrate integrated waveguide and half mode substrate integrated waveguide leaky-wave structures," *IEEE Transactions on Antennas and Propagation*, vol. 59, no. 3, pp. 767-775, Mar. 2011.

[6] R. S. Elliott, *Antenna theory and design,* Prentice-Hall, 1981.

[7] C. Caloz, "Array factor approach of leaky-wave antennas and application to 1-D/2-D composite right/left-handed (CRLH) structures," *IEEE Microwave and Wireless Components Letters*, vol. 14, no. 6, pp. 274–276, June 2004.

[8] C R. Siragusa, E. Perret, P. Lemaître-Auger, H. V. Nguyen, S. Tedjini, and C. Caloz, "A tapered CRLH interdigital/stub leaky-wave antenna with minimized sidelobe levels," *IEEE Antennas Wireless Propag. Lett.*, vol.11,pp.1214–1217,2012.