A Ka Band Planar Slot Array Antenna for 45 Degree Linear Polarization Using Substrate Integrated Waveguide

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***Abstract*— In this paper, a waveguide-fed series slot planar array antenna for 45° linear polarization (LP) operating in the Ka band is proposed. The inductive and capacitive loaded alternating reactance slot pairs are etched on the upper plate of radiating waveguides (WGs) as radiating units. Also all radiating slots are separated by a one-half guided wavelength and are fed by a standing-wave excitation. Grating lobes can be avoided in the direction of the guided wave propagation due to the dielectric materials of substrate and alternating reactance slot pairs. The antenna is designed using substrate integrated waveguides (SIWs) instead of dielectric-filled metallic WGs and verified using electrical performances such as reflection coefficient, gain, aperture efficiency, and radiation patterns using commercially available full-wave simulator, CST MWS.**

I. Introduction

Due to their electrical and physical advantages such as high gain, efficiency, and low-profile, waveguide-fed (WG-fed) slot array antennas are widely used for many millimeter-wave communication systems. In many radar systems, like collision avoidance automotive radar, monopulse tracking radar, and synthesis aperture radar (SAR), these waveguide-fed slot array antennas are promising candidates for accurate beam forming, as well as suppression of side lobe levels. Over the recent decades, the conventional waveguide-fed shunt slot array antennas have been designed with well-established design equations that consider both internal and external coupling effects [1]. The series slot array antennas also have been investigated and analysed, in a similar way to the shunt slot array design procedure, by Orefice and Elliott [2]. Meanwhile, in some specific radar applications, such as a collision avoidance automotive radar system, a 45°-inclined linear polarization (LP) is required to avoid the interference coming from the opposite direction [3, 4]. Also, a dual polarized LP monopulse tracking radar antenna is proposed using twisted cavity polarizer [7]. For that reason, we present the series slot planar array antenna for 45° LP. The proposed antenna is designed using substrate integrated waveguide (SIW) technology to overcome the drawbacks that come from conventional metallic rectangular waveguide.

In Section II, the authors introduce the geometry of a whole planar array antenna structure. Specifically, the alternating reactance slot pairs and series-to-series coupling slots of radiating and feeding waveguides (WGs) are designed for uniform field excitation. Finally, the authors analyse and verify the simulated electrical performances of the proposed antenna in Section III.

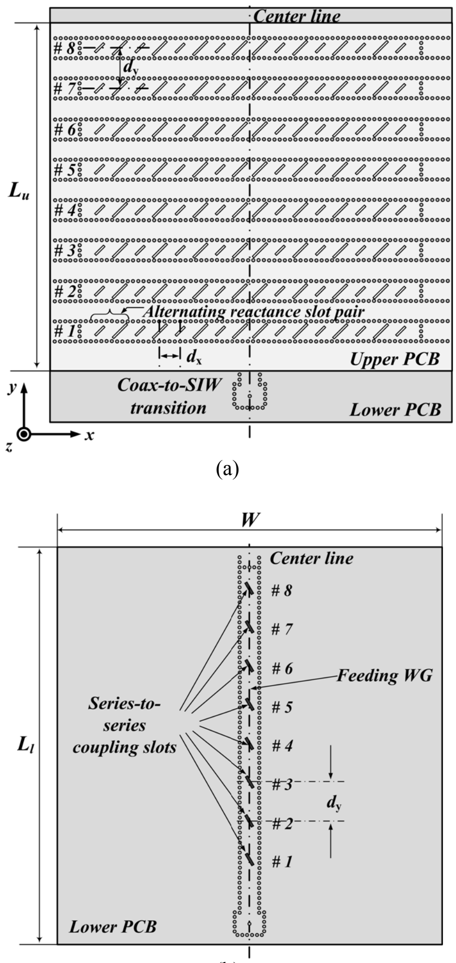

Fig. 1. Proposed SIW planar antenna structure. (a) Series slot arrays located on the radiating WG of upper plate. (b) Series-to-series coupling slots lying on center of main line of lower plate.

II. Proposed Antenna Structure

To avoid the grating lobes in radiation patterns, the spacing of radiating slots located in each radiating WG (d_x in Fig. 1(a)), as well as the distance between each radiating WG (center-to-center, d_y in Fig. 1(a)), are set to be less than one wavelength of free space at 35 GHz in the Ka band (λ_0 = 8.57 mm). Therefore, the width of radiating and feeding WGs (w_r, w_f) and the dielectric constant of the substrate are simultaneously used to determine the slot spacing. The entire antenna structure has been designed by employing RO3035^{TM} (Rogers) substrates as a double layered structure, having a relative permittivity of 3.5, a loss tangent of 0.0018 at 10 GHz, and thicknesses of 0.75 mm (h_l) and 1.52 mm (h_u) for lower and upper printed circuit board (PCB), respectively.

A. Radiating slot design

The proposed planar slot array antenna is composed of eight radiating WGs and connected with a single feeding WG as depicted in Fig. 1. Each radiating WG has sixteen 45°-inclined series slot arrays and a coupling junction connecting a feeding WG through a series-to-series coupling slot.

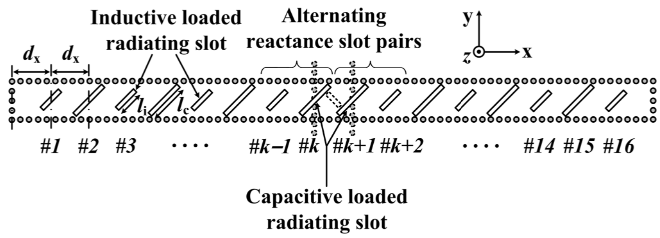

Fig. 2. A linear slot array antenna structure.

As shown in Fig. 2, all radiating series slots are etched at a tilt angle of 45° along the axis line of arrays and separated by one-half guided wavelength. Every radiating WG is terminated by short circuits realized by one-half guided wavelength (d_x in Fig. 2) WG stubs. Notice that the sixteen radiating slot arrays (eight alternating reactance slot pairs) are placed in an alternating arrangement of shorter and longer slots compared to the resonant slot length, which corresponds to the inductive and capacitive series impedances at the design frequency, 35 GHz, respectively. These are essential for uniform electric field distribution and input matching through cancelling the reactance of each slots, simultaneously.

B. SIW transmission line design

In the design of SIW transmission lines, the diameter (d) and spacing (s) of metallic via arrays connecting upper and lower copper sheets of PCB are determined to be 0.4 mm and 0.7 mm, respectively, as described in Fig. 3. By deciding the appropriate parameter values of SIW transmission lines in accordance with [5], the radiation, dielectric, and conduction losses can be ignored. The width of radiating WG (w_r in Fig. 3) is set to be 3.44 mm for a fundamental TE_{10}-mode propagation and the corresponding guided wavelength can be calculated to be 6.55 mm (= $2d_x$) [6]. Also, the spacing of series-to-series coupling slots is 6.88 mm to deliver in-phase fields to every radiating WG. Therefore, the width of feeding WG is set to be 3.38 mm ($w_r = 0.5d_y$ in Fig. 1 and 3).

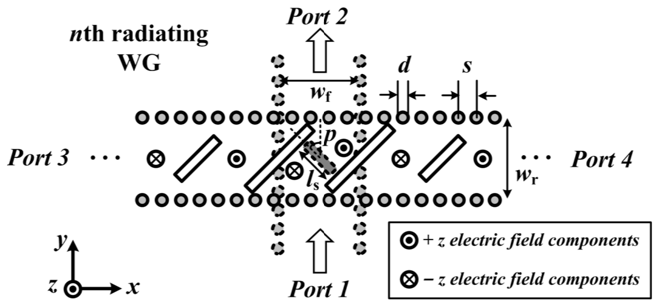

Fig. 3. Coupling junction and electric field distribution (z-component) in a radiating WG.

TABLE I
DESIGN PARAMETERS AND ITS CORRESPONDING VALUES OF PROPOSED ANTENNA

SIW structure	d	s			
Value	0.4	0.7			
Radiating WG	d_x	d_y	l_c	l_i	w_r
Value	3.4	6.88	3.6116	2.3045	3.44
Feeding WG	l_s	p	w_f	h_b	
Value	2.248	8	3.38	0.11	
Antenna dimension	L_l	L_u	W	h_l	h_u
Value	78	51.6	68	0.75	1.52

(Unit: mm, degree only for parameter 'p')

C. Coupling junction design

The input power is transferred by a wideband coaxial-to-SIW transition and series-to-series coupling slots of a SIW feeding WG. The series-to-series coupling slot is a simple four-port network that can be used for equal power division with out-of-phase property for left and right radiating WG branch lines [8]. The partial coupling junction geometry of the proposed antenna feeding network is shown in Fig. 3. There is a radiating WG connected to a feeding WG with the coupling slot parameters, such as the slot length (l_s) and the tilt angle (p). These parameter values can be optimized by the full-wave EM simulation and summarized in Table I. Notice that radiating slots above every series-to-series coupling slot have the same longer slot length (l_c), which is one of the alternating reactance slot pairs used to excite the in-phase aperture field. In a similar way, the shorter length of radiating slots can be substituted as the nearest radiating slots around every coupling slot to facilitate in-phase field distribution.

In addition, an RO4450B^{TM} (Rogers) bonding sheet with a permittivity of 3.5 and a thickness (h_b) of 0.11 mm was used to bond lower and upper PCBs to result in minimum reflection. The total dimension of the proposed antenna, including lower PCB, is 68 (W) × 78 (L_l) mm, while the size of pure rectangular aperture of the upper PCB containing the radiating slot arrays is 68 (W) × 51.6 (L_u) mm.

III. ELECTRICAL PERFORMANCES

The proposed antenna was designed for uniform field excitation and verified using finite-difference time-domain (FDTD) full-wave simulator, CST-Microwave studio [9]. The simulated result of the reflection coefficient is shown in Fig. 4. The impedance bandwidth is 470 MHz ranging from 34.76

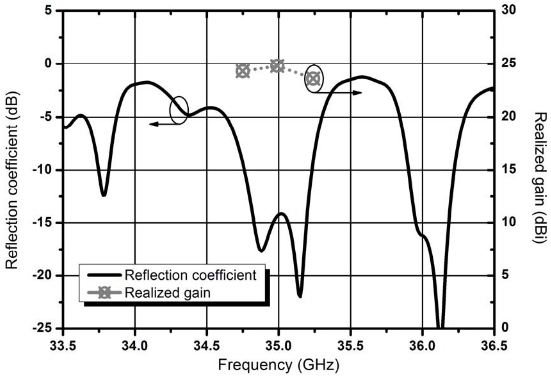

Fig. 4. Reflection coefficient and realized gain.

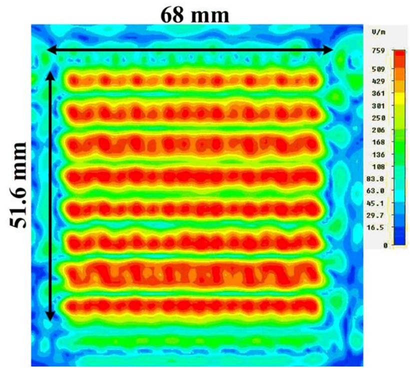

Fig. 5. Electric field distribution above the planar aperture (z = 2 mm) at 35 GHz.

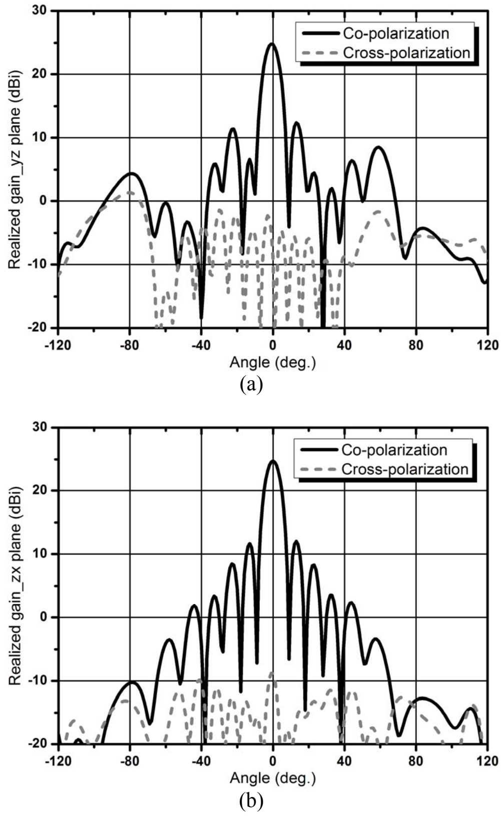

Fig. 6. Radiation patterns at 35 GHz. (a) *yz* plane and (b) *zx* plane.

TABLE II
ELECTRICAL PERFORMANCE OF THE PROPOSED PLANAR SLOT ARRAY ANTENNA

	Bandwidth (< -10 dB)	*At 35 GHz*						
		Gain	SLL		HPBW		XPD*
			yz	*zx*	*yz*	*zx*	
Values	470 MHz (1.34 %)	24.8 dBi	12.4 dB	12.7 dB	8.0°	8.1°	33.56 dB

Cross Polarization Discrimination*

GHz to 35.23 under the criteria of −10 dB. The electric field intensity above the antenna aperture is depicted in Fig. 5. It is found that the difference between maximum and minimum field intensity is less than −4.42 dB among 128 radiating slots. In addition, the realized gain and the side lobe levels for *yz*-, and *zx*-plane are acquired with 24.8 dBi, −12.4 dB, and −12.7 dB, respectively, as shown in Fig. 4 and 6. The aperture efficiency can be calculated to 50.3% from the results of an aperture area and the obtained realized gain.

IV. CONCLUSIONS

The waveguide-fed series slot planar array antenna for 45° LP using substrate integrated waveguide technology is presented for the Ka band. The proposed antenna is designed with a standing-wave type using the combination of alternating reactance slot pairs separated with one-half guide wavelength. The grating lobes have been eliminated in both *yz*- and *zx*-planes spontaneously. Furthermore, the proposed antenna guarantees that alternating reactance slot pairs are useful for 45° LP generating standing-wave type antennas in millimeter-wave applications.

REFERENCES

[1] R. S. Elliott, "An improved design procedure for small arrays of shunt slots, *IEEE Trans. Antennas and Propagation*, vol. AP−31, pp. 48−53, Jan. 1983.

[2] M. Orefice and R. S. Elliott, "Design of waveguide-fed series slot arrays," *IEE Proc.*, vol. 129, pp. 165−169, Aug. 1982, Dt. H.

[3] A. Mizutani, K. Sakakibara, N. Kikuma, and H. Hirayama, "Grating lobe suppression of narrow-wall slotted hollow waveguide millimeter-wave planar antenna for arbitrary linear polarization," *IEEE Trans. Antennas and Propagation*, vol. 55, no. 2, pp. 313−320, Feb. 2007.

[4] J. Hirokawa and M. Ando, "45° linearly polarized post-wall waveguide-fed parallel plate slot arrays," in *Proc. Inst. Elect. Eng.-Microw. Antennas Propag.*, vol. 147, no. 6, pp. 515−519, Dec. 2000.

[5] M. Bozzi, M. Pasian, L. Perregrini, and K. Wu, "On the losses in substrate integrated waveguides," *37th European Microwave Conference 2007*, Munich, Germany, pp. 384−387, Oct. 2007.

[6] F. Xu and K. Wu, "Guided-wave and leakage characteristics of substrate integrated waveguide," *IEEE Trans. Microw. Thoery Tech.*, vol. 53, no. 1, pp. 66−73, Jan. 2005.

[7] M. Guler and S. Kim, "Dual-polarized, millimeter wave slot array," in *Proc. Aerospace Conference 2003*, vol. 2, pp. 1077−1083, 2003.

[8] S. R. Rengarajan, "Analysis of a centered-inclined waveguide slot coupler," *IEEE Trans. Microw. Thoery Tech.*, vol. 37, no. 5, pp. 884−889, May 1989.

[9] CST Microwave Studio (MWS) 2010, CST Corporation. Available: http://www.cst.com