A New Comb Circular Polarizer Suitable for Millimeter-Band Application

Soon Young Eom and Y. B. Korchemkin

ABSTRACT—This letter presents a new polarizer which has a simple comb structure inside a circular waveguide. The electrical performance of the proposed comb polarizer is optimized by a circular waveguide radius and by the physical parameters of the comb plates. This polarizer is suitable for providing good performance in millimeter-band application because of its simple structure and low fabrication cost. In our experiments the dual-band comb polarizer designed in band 1(K) and band 2(Ka) showed good electrical performance without any tuning elements.

Keywords—Circular polarizer, comb structure, dual-band, millimeter-band.

I. Introduction

In satellite communications of the millimeter-band, there has recently been an increasing demand for dual-band circular polarizers which can be simply fabricated without corrugated irises, metallic posts, or a dielectric slab taper [1]-[3]. Conventional circular polarizers in the millimeter-band are not able to provide high performance due to manufacturing inaccuracy, the difficulty of setting up tuning elements, and high-fabrication costs.

To overcome the above disadvantages, grooved circular waveguide polarizers without tuning elements have been presented [4]. It is more complicated and expensive to make rectangular coupling grooves into a circular waveguide. But, the comb polarizer newly proposed in this letter is very simple and inexpensive to fabricate. As shown in Fig. 1, it is composed of two parts of a half circular waveguide and two metallic comb plates. All of the component parts are assembled with screws, and four guide-pins are used so that the two comb plates are put into the positions required by the circular waveguide channel. Another advantage of this polarizer is that electrical performance can be easily improved or modified by changing only the comb plates.

The linearly polarized incident wave that has a + 45° or – 45° offset with respect to the diagonal alignment of the cogs can be divided into two orthogonal modes, that is, perpendicular and parallel. The differential 90° phase shift between them is produced by optimizing the size and number of cogs, and the spacing between the cogs realized in the comb plates.

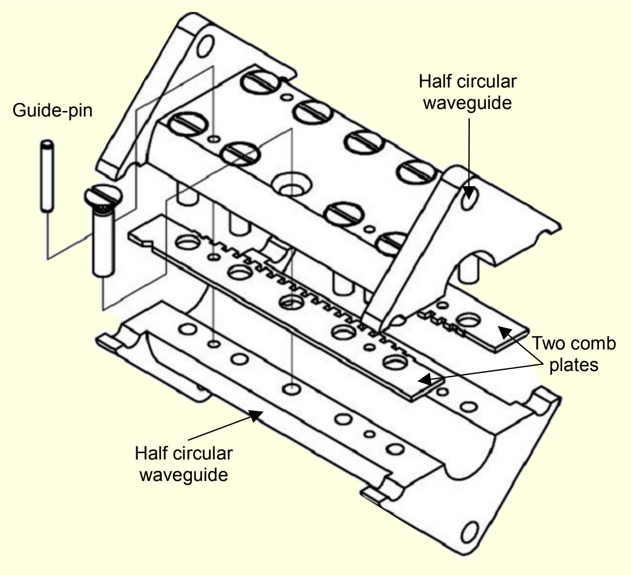


Fig. 1. Proposed comb circular polarizer.

II. Dual-Band Comb Polarizer Design

The design of the dual-band circular polarizer using the

Manuscript received June 12, 2006.

Soon Young Eom (phone: +82 42 860 4853, email: syeom@etri.re.kr) is with Radio & Broadcasting Research Division, ETRI, Daejeon, Korea.

Y. B. Korchemkin (email: jscapex@online.ru) is with Microwave Circuit Department, JSC-Radiophyzika, Russia.

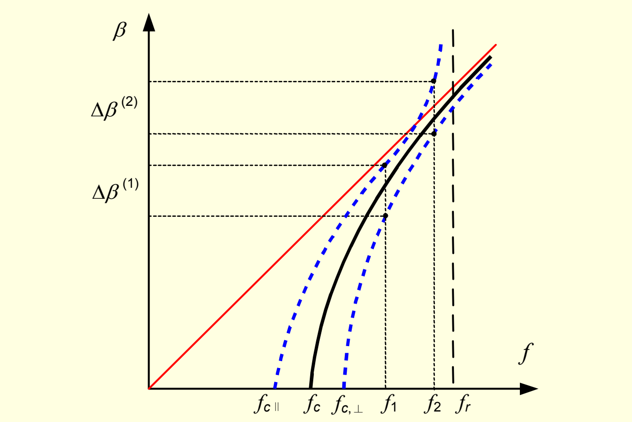


Fig. 2. Conceptual relationship between propagation constant and frequency.

proposed comb structure, and the relationship between the propagation constant and frequency is shown in Fig. 2. For the dual-band circular polarizer, differential propagation constants, $\Delta\beta^{(1)}$ and $\Delta\beta^{(2)}$, of two orthogonal fundamental modes should be simultaneous as shown in Fig. 2, and (1) should be satisfied at dual operating frequencies of f_1 and f_2.

$$\Delta\varphi = \Delta\beta^{(1)} \cdot L = \Delta\beta^{(2)} \cdot L = 90^\circ, \tag{1}$$

where $\Delta\beta^{(i)} = \left(\beta_{\parallel}^{(i)} - \beta_{\perp}^{(i)}\right) \cdot L,\ i = 1, 2.$ $|$ and $\perp$ represent parallel and perpendicular fields, respectively, which are referenced to two metallic comb plates, and, L is the waveguide length to cause the phase perturbation. The cut-off and resonant frequencies of the circular waveguide with comb plates are f_c and f_r, respectively.

The comb polarizer proposed in this letter is designed for K/Ka dual-band purpose in satellite communications. Its operating bands range from 20.355 to 21.155 GHz (band 1) and from 30.085 to 30.885 GHz (band 2).

Because the symmetrical comb structure causes second modes such as TM_{01}, TE_{21}, TE_{01} to disappear, a circular waveguide radius that limits its operating band range should be properly chosen not to propagate only higher modes such as TM_{11}, TE_{31}, TM_{21}, TE_{12} modes. Therefore, its radius can be bounded as presented in the inequality formula (2).

$$\frac{\lambda_{1,\max}}{C_1} < R < \frac{\lambda_{2,\min}}{C_2}, \tag{2}$$

where R is a circular waveguide radius, C_1 and C_2 are coefficients of TE_{11} and TM_{11} modes with $C_1=3.413$, $C_2=1.640$, respectively [5]. If R is chosen as 5.335 mm, the operating frequency range of 16.5 GHz $< f <$ 34.3 GHz is set, and such a range is quite reasonable in the dual-band design discussed in this letter. Therefore, with R=5.335 mm in our studies, the comb polarizer was optimized using CST Microwave Studio™ in order that the phase difference between two orthogonal signals should be equal to 90°± 5° in the dual-band. Optimal design parameters are specified in Fig. 3.

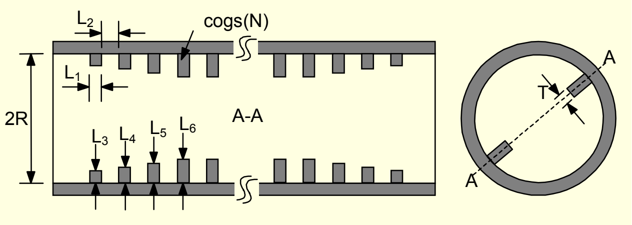
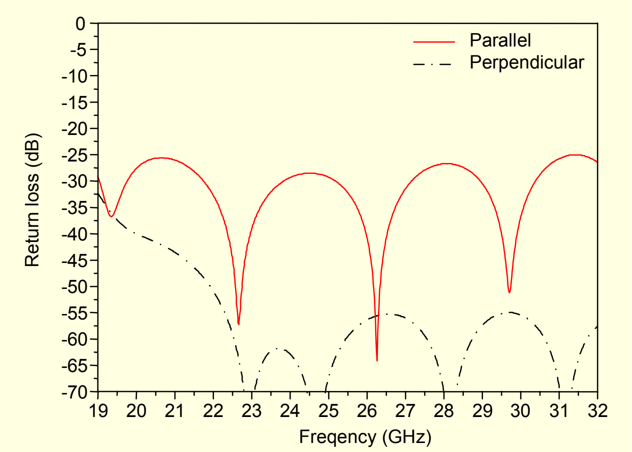
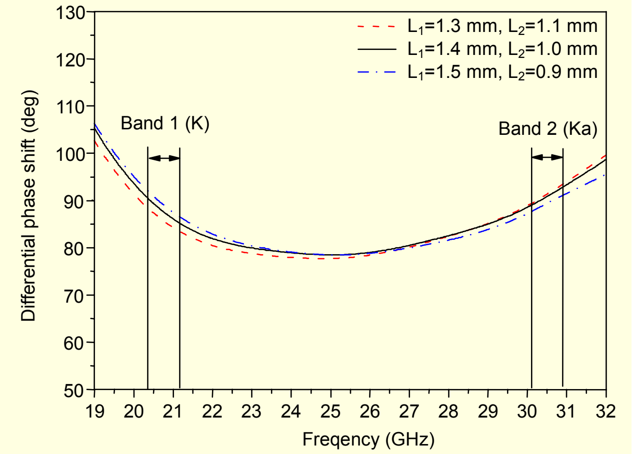


Fig. 3. Design parameters of the proposed comb polarizer. (N=20, T=0.9 mm, L_1=1.4 mm, L_2=1.0 mm, L_3=0.3 mm, L_4=0.6 mm, L_5=0.9 mm, L_6=1.23 mm).



(a) Return loss



(b) Differential phase shift

Fig. 4. Simulation performance of dual-band comb polarizer.

The input and output impedance match of the polarizer is made by three cogs (L_3, L_4, and L_5) with tapered heights of $0.25L_6$, $0.5L_6$, and $0.75L_6$, respectively. Simulation performance of the dual-band comb polarizer is shown in Fig. 4.

From our simulations, the return losses at the two orthogonal polarizations are less than –25 dB in the required dual-band. Figure 4(b) shows that when the spacing between cogs is fixed, the differences in cog size can determine the differential phase curve in order to obtain the required and optimized differential phase shift in two bands. Figure 4(b) also shows that band 2 (Ka) generally used as the Tx-band was optimized more than band 1 (K).

III. Fabrication and Experimental Results

The comb polarizer fabricated using the design parameters of Fig. 3 is shown in Fig. 5. For the comb polarizer without any tuning elements, the fabrication tolerance of the design parameters was considered to be less than ± 0.01 mm.

The return loss of the fabricated comb polarizer was measured using two kinds of rectangular-circular waveguide transition adaptors which were used to connect the polarizer breadboard to the WR-28 and WR-42 flanges of the measurement equipment. The waveguide transition adaptors used for testing showed a return loss of less than –30 dB in each operating band. The measured return loss is shown in Fig. 6.

The measurements were independently made under the incidence of parallel or perpendicular signal. Although the measured return loss shown in Fig. 6 includes many ripples caused by the test accessories over the operating band, it still shows good match performance: less than –18.8 dB in the band 1 (K) and less than –26.4 dB in the band 2 (Ka).

The cross-polarization levels were measured using the "rotating probe" method. In this method, the linear-polarized signal oriented by 45° with respect to the plane of comb plates is supplied to the polarizer input. The output signal levels are measured at different angles using the rotated linear-polarized probe. The maximal difference between measured output signals, ΔA in dB-scale is determined, and such a value means the axial ratio at each test frequency. Also, the cross-polarization level can be calculated by the following formula:

$$L_{cross} = 10 \cdot \log \left(\frac{1 - 10^{-\frac{\Delta A}{20}}}{1 + 10^{-\frac{\Delta A}{20}}} \right)^2 \quad (dB) . \tag{3}$$

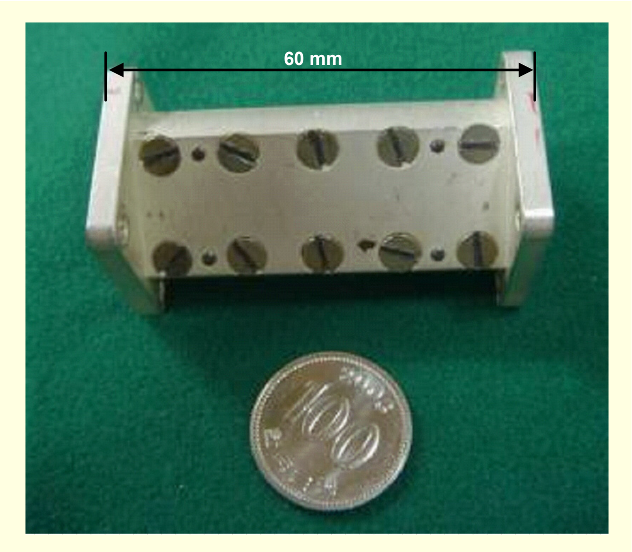


Fig. 5. Photo of fabricated comb polarizer breadboard.

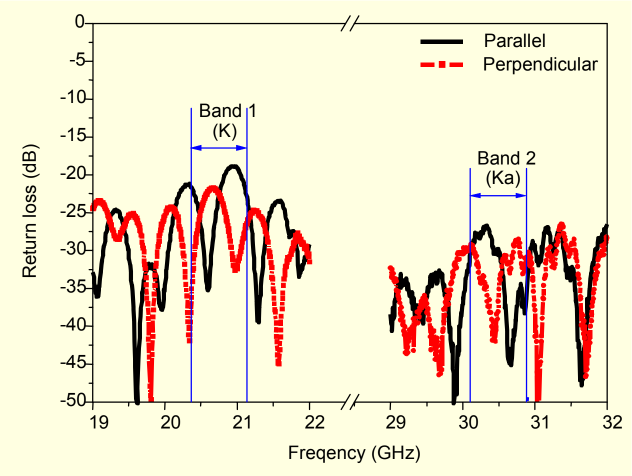


Fig. 6. Measured return loss of dual-band comb polarizer.

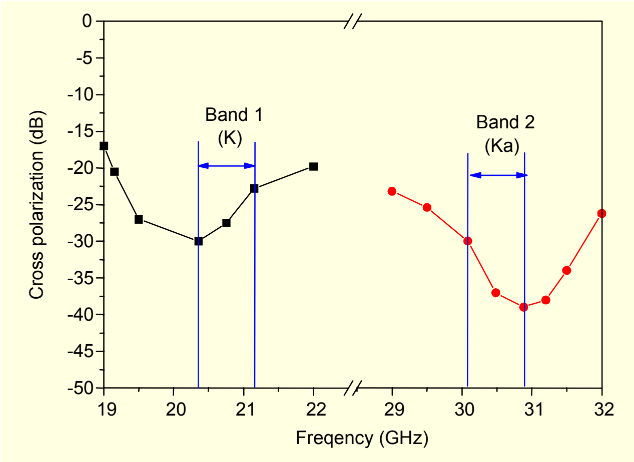


Fig. 7. Measured cross-polarization of dual-band comb polarizer.

The measured cross-polarization characteristic of the dual-band comb polarizer is shown in Fig. 7. The cross-polarization levels measured in the band 1 (K) and band 2 (Ka) were less than –22.9 dB and –30.0 dB, respectively.

IV. Conclusion

In this letter, a new comb circular polarizer was proposed. The simplicity and low cost of fabrication are great advantages for millimeter-band application. This polarizer, without any tuning elements, was composed of two half-housings of a circular waveguide and two comb plates which were inserted between them. In our experiments, the electrical performance of the comb polarizer was optimized by a circular waveguide radius and by the number and physical parameters of the comb cogs. In the dual-band design of the proposed comb polarizer, the breadboard with simple fabrication and assembly showed very good electrical performance which makes it suitable for millimeter-band application.

References

[1] T. Kitsuregawa, *Adavanced Technology in Satellite Communication Antennas: Electrical and Mechanical Design,* Artech House, Norwood, MA, 1990, pp. 81-86.

[2] J. Uher, J. Bornemann, and U. Rosenberg, *Waveguide Components for Antenna Feed System: Theory and CAD,* Norwood, MA: Artech House, 1993, pp. 417-435.

[3] U. Tucholke, F. Arndt, and T. Wriedt, "Field Theory Design of Square Waveguide Iris Polarizers," *IEEE Trans. on Microwave Theory and Tech.*, vol. MTT-34, no. 1, Jan. 1986.

[4] N. Yoneda, M. Miyazaki, H. Matsumura, and M. Yamato, "A Design of Novel Grooved Circular Waveguide Polarizers," *IEEE Trans. on Microwave Theory and Tech.*, vol. 48, no. 12, Dec. 2000.

[5] N. Marcuvitz, *Waveguide Handbook*, McGraw-Hill, New York, 1951, pp. 66-71.