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10 GHz Standing-Wave Coplanar Stripline on LiNbO₃ **Crystal for Radio to Optical-Wave Conversion**

F Darwis¹, Y N Wijayanto¹, A Setiawan¹, D Mahmudin¹, A N Rahman¹ and P **Daud**¹

¹Research Center for Electronic and Telecommunication, LIPI, Kampus LIPI, Jl. Sangkuriang, Bandung 40135, Indonesia

E-mail: fajri.darwis@lipi.go.id

Abstract. Recently, X-band radar systems are used widely for surveillance and navigation applications. Especially in archipelago or maritime country, the surveillance/navigation radar systems are required to monitoring critical areas and managing marine traffic. Accurate detection and fast analysis should be improved furthermore to provide security and safety condition. Therefore, several radar systems should be installed in many places to coverage the critical areas within radar networks. The radar network can be connected using optical fibers since it has extremely low propagation loss with optical-wave to carry-out the radar-wave. One important component in the scenario is a radio to optical-wave conversion component. In this paper, we report a 10 GHz radio to optical-wave conversion component using standing-wave coplanar stripline (CPS) on LiNbO3 optical crystal as the substrate. The standing-wave CPS electrodes with narrow slot are arranged in an array structure. An optical waveguide is located close to the narrow slot. The CPS electrodes were analysed using electromagnetic analysis software for 10 GHz operational frequency. Responses for slot width and electrode length variation are reported. As results, return loss of -14.580 dB and -19.517 dB are obtained for single and array CPS electrodes respectively. Optimization of the designed radio to optical-wave conversion devices was also done.

1. Introduction

Nowadays, radar systems are important to provide security and safety condition using electromagneticwave in radio-bands to identifying objects. The radar systems can be used in many applications such as for military and defend, traffic management, agricultural, medical, and so on. Especially in archipelago country with many islands, radar systems are required to monitoring and surveying remote or borderline areas on land and sea. We have developed radar systems for surveillance and navigation in X-band operational frequency [1]. The developed radar systems were installed in coastal area to surveillance of ship traffics and other objects in a strait. The developed radar systems have detection range of up-to 20 Nautical Mile with radiation power less than 1W. Based on these results, detection range should be improved to cover large areas.

Improvement of the detection area can be solved by adding and installing radar units in many places. It can be realized using a network of radar systems. Optical fiber links are promising to support the radar networks through radio-over-fiber (RoF) technology [2]. Optical fibers have low propagation loss characteristics of 0.2dB/km using lightwave to carry out the radar signals. In RoF technology, an interface to convert wireless radar signal to a lightwave signal is important [3]. The interface can be

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implemented by combining radar antennas and optical modulators [4]. An interface using patch antennas embedded with a gap was reported [5-6].

In this paper, a design of an interface between microwave and lightwave using Coplanar Stripline (CPS) on LiNbO₃ substrate was proposed. The design consists of a substrate with two pieces of conductors arranged to operate in parallel and separated by a narrow gap. The advantage of the CPS is that it can be installed in series or in shunt and CPS is the balanced transmission line [7].

In the following sections, we will discuss the proposed interface structure and analyse its characteristics. Performance of the proposed interface to detect wireless microwave polarization are also reported and discussed.

2. Device Structure

The coplanar strip line (CPS) structure consists of a pair of symmetric electrodes with certain length which is used in a ground–signal configuration [8-9]. The structure of CPS is depicted in Figure 1.





Figure 2. The proposed design of CPS.

L50Ω

In Figure 1, the gap between two conductors is define by variable a and the sum of total width of two conductors and a is defined by b. Variable h is height of substrate. Figure 2 shows the proposed design of CPS with feeding. The CPS uses 50 Ω of feeding. First position of the feeding is placed in center of CPS. The feeding will be connected to connector as input of microwave signals. Lithium Niobate (LiNbO₃) is used as a substrate. The substrate has a good characteristic for light wave [10].

To design the CPS, first we must determine the values of the width of electrode (w = 0.142 mm), gap between two electrodes (a = s = 0.031 mm), height of substrate (h = 0.3 mm), relative permittivity of substrate ($\varepsilon_r = 28$), and working frequency (f = 10 GHz). The characteristic impedance of CPS is calculated using equations (1) till (5).

$$k = \frac{a}{b} \qquad k' = \sqrt{1 - k^2} \tag{1}$$

$$k_1 = \frac{\sinh(\pi a/4h)}{\sinh(\pi b/4h)} \tag{2}$$

$$\varepsilon_{eff} = 1 + \frac{\varepsilon_r - 1}{2} \, \frac{K'(k)}{K(k)} \, \frac{K(k_1)}{K'(k_1)} \tag{3}$$

$$\frac{K'(k)}{K(k)} = \begin{cases} \left[\frac{1}{\pi} ln\left(2\frac{1+\sqrt{k'}}{1-\sqrt{k'}}\right)\right] & \text{for } 0 \le k \le 0.707\\ \left[\frac{1}{\pi} ln\left(2\frac{1+\sqrt{k}}{1-\sqrt{k}}\right)\right]^{-1} & \text{for } 0.707 \le k \le 1 \end{cases}$$
(4)

$$Z_0 = \frac{\eta}{\sqrt{\varepsilon_{eff}}} \frac{K(k)}{K'(k)} \tag{5}$$

From the equations above, the value of characteristic impedance (Z_0) is 42.65 Ω .

After the design of CPS is done, we need to design the feeding of CPS. The feeding of CPS use

microstrip line with characteristic impedance 50 Ω . LineCalc software is used to calculate the length and width of microstrip line. We obtain the length of microstrip line is 1.951 mm and the width of microstrip line is 0.058 mm.

The proposed design will be simulated and optimized using ADS 2011.10 software to find the numerical characteristic. From the software we obtain the S(1,1) characteristic. The graph of S(1,1) characteristic is depicted in Figure 3.



Figure 3. S(1,1) characteristic of single CPS.

In Figure 3, the value of return loss is -14.580 dB. This result is acquired by optimization using ADS 2011.10. The positions of feeding affect the return loss value. The best position of feeding after optimization are $L_1 = 1.7405$ mm and $L_2 = 1.5905$ mm and the length of CPS is 3.392 mm. For the width of feeding is 0.061 mm.

3. Operational Principle

In previous section, we know that the CPS consists of two electrodes. The electrodes are separated with certain gap. One electrode is used as a signal and the other as a ground. In this design, we consider gap value between electrodes. It is to get the good electric field. To make connection between microwave signals to CPS, the feeding is used. The size of feeding is 50 Ω due to the connector impedance we use for this design is 50 Ω . So, matching of connector and feeding line is needed to have the maximum power transfer.

In order to see the influence of gap between frequencies, we make this design with 3 difference values of gap. The response frequency is showed in Figure 4. From Figure 4 we see that the frequency is shifted in gap value 41 μ m and 51 μ m. It occurs because effective the electric constant (ε_{eff}) is reduced as shown in equation (1) till (4). The return loss of proposed design better than the others, but all of them still have good return loss. Plot of the electric field (normalized to the voltage) with gap is depicted in Figure 5. The high electric field is obtained from the smallest gap between electrodes.



Figure 4. Response frequency with several values of gap.



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4. Array Structure

To see the characteristic of CPS with array structure, we use four CPS with feeding that are arranged in horizontal position. The proposed design of array structure is depicted in Figure 6.

In Figure 6, we use wilkinson power divider technique to divide the power from input port [11]. The characteristic impedance in input port is 50 Ω . This design uses three of 2-way power divider to connect four CPS. Two of 2-way power divider is used to connect the two CPS in each power divider. The last power divider is used to connect the two of 2-way power divider. The power divider is designed using microstrip line. The characteristic impedance after 50 Ω of transmission line is $Z_0\sqrt{2}$ equal with 70.71 Ω .

Since the CPS is designed for microwave - light wave conversion, range between CPS must consider the light wave transmission. By using the equation below, the range from starting point first CPS to starting point second CPS (d) can be calculated.

$$F(\theta) = \sum_{h=1}^{N} A \exp\left[-j(h-1)k_m \left(n_0 d \sin \theta - n_g d\right)\right]$$
(6)

Where A: amplitude, N: number of array, k_m : wave number, d: range CPS, n: refractive index and $\sin \theta = 0$. The value of d is 13.94 mm calculated with 1 wavelength.

The characteristic of array CPS is depicted in Figure 7. In the figure, the return loss before optimization is about -5.71 dB. To find the best result of return loss, we do the optimization. The optimization was done by change the impedance Z_0 (width of feeding) in feeding. The best widths of feeding that we have are 0.1 mm in input, 0.02 mm in CPS feeding and 0.03 mm in between input and CPS. The return loss after optimization is -19.517 dB. It shows that the performance of array CPS is good.



Figure 6. The proposed design of array CPS.



Figure 7. S(1,1) characteristic of Array CPS.

5. Discussion

We have been designed the CPS that used for microwave – light wave conversion. The performance of single CPS and array CPS show good return loss at 10 GHz of frequency. From the design, we can see the relationship between CPS and frequency. For the single CPS, to achieve the operational frequency, 10 GHz, the length of CPS is 3.392 mm. We have found the characteristic of length CPS and frequency. The relationship between length CPS and frequency is showed in Figure 8.

From Figure 8, it shows that the length of CPS inversely proportional with frequency. To know the relationship between feeding position with electric field magnitude, we change the position of feeding, L_1 and L_2 , to get the values of electric field. Figure 9 shows the effect of 3 condition of feeding position to electric field.

On position of $L_1 = 1.7405$ mm and $L_2 = 1.5905$ mm shows the maximum of electric field in 10 GHz of frequency. It's mean that the standing wave in that position of feeding better than the others. From the return loss value, we find the VSWR is about 1.46.

The strong microwave electric field can be generated using the proposed CPS structure. Since lighwave propagates into an optical waveguide where it is located close to the slot of CPS structure. The electric fields between microwave and lightwave are interacted each other's. The interaction of them can be calculated by considering transit-time effect. As results, optical modulation can be obtained by considering transit-time and interaction between microwave and lightwave electric fields.

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Figure 8. Length CPS vs Frequency.

Figure 9. Normalized Electric field with feeding position.

6. Conclusion

The radio to optical-wave conversion using standing-wave CPS electrodes on a LiNbO₃ crystal as the substrate was proposed and reported for 10 GHz operational frequency. The standing-wave CPS electrodes can be generated strong radio-wave electric field when radio-wave signal is coupled to the feeding of the CPS electrodes. The strong radio-wave electric field can be used for optical modulation by considering interaction of the radio and optical-wave electric fields. Analysis of the CPS electrodes was reported in 10 GHz operational frequency. Calculation results for return loss, VSWR, and radio-wave electric field in single and array CPS electrodes was reported and discussed. The proposed device is promising for radio to optical-wave conversion in the ROF technology. The ROF technology can be applied for high-speed communication and high-resolution imaging systems.

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