TUPM 2-3

FREQUENCY RESPONSE IMPROVEMENT OF ELECTRIC FIELD SENSOR USING OPTICAL MODULATOR

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Abstract

This paper describes a method of improving the frequency response of an electric field sensor. A modified $LiNbO_3$ substrate shape reduces the sensitivity deviation from 4[dB] to 1[dB] and the maximum operating frequency is raised from 300[MHz] to 1[GHz] by using a resistive loaded element.

1. Introduction

Recent progress in electromagnetic compatibility (EMC) has created a need for a small wide-band electric field sensor for testing EMC measurement facilities and the measuring electromagnetic pulses and environments. The areas for further improvement in these sensors are reducing the influence of the connecting cable, increasing operation band width, and reducing its size.

Sensors using optical modulator has been developed to apply these EMC measurement[1],[2]. These have several advantage: the influence on electromagnetic field is reduced because most of the materials are nonmetallic, its size can be reduced, and the operating frequency bandwidth is very wide. Various sensors, such as an isotropic electric-field meter[1], a high sensitivity electric field sensor using a Mach-Zehnder interferometer[2], and a small wideband antenna with a 9.5[mm] long printed dipole element[3], have been proposed[1]-[4].

One recently proposed sensor can measure an electric field in the frequency range from 1[kHz] to 1[GHz][4]. However, the flatness of its frequency response should be improved. Many factors affect the response. Two key factors are the resonance of the $LiNbO_3$ substrate, on which the optical modulator is formed, and the resonance of the sensor element. This paper describes an electric field sensor that suppresses the resonances of the $LiNbO_3$ substrate and the sensor element.

2. Configuration

The configuration of the electric field sensor is illustrated in Fig. 1. The sensor consists of the sensor element, an optical modulator, an optical source, a photodetector, and optical fibers. A polarization maintaining fiber connects the optical source to the optical modulator and a single-mode fiber connects photodetector to the optical modulator.

The optical source is a laser diode (LD), the photodetector is a PIN photodiode, and optical modulator is Mach-Zehnder interferometer which formed by Ti diffusion on 55mm long, 1mm wide, and 0.5mm thick z-cut $LiNbO_3$ substrate. The half wave

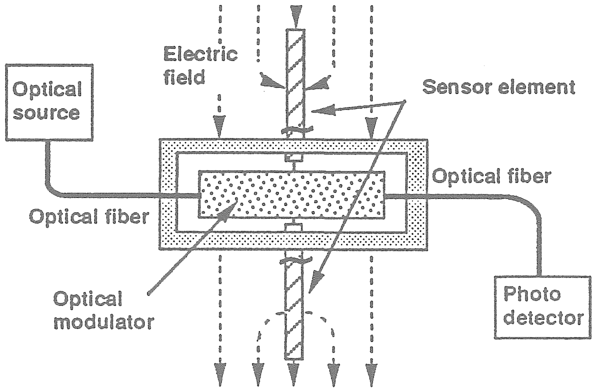

Fig. 1 Configuration of electric field sensor

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voltage of the optical modulator is about 2[V] and its operation bandwidth is from DC to 4[GHz].

When the sensor element is set in an electric field, a voltage appears between the electrodes of the optical modulator. The optical modulator modulates the optical power according to the voltage. The electric field strength is obtained by measuring the modulated signal level with the photodetector.

3. Improvement in sensitivity deviation

When a voltage appears on the electrode of the modulator, an elastic wave appears in the substrate. This wave changes the refractive index of the optical waveguide by the piezoelectric effect of $LiNbO_3$. The change in the refractive index affects the sensor sensitivity. Therefore, the resonance of the $LiNbO_3$ substrate appear to be due to the elastic wave in the substrate.

An example of the frequency response is shown in Fig.2. The resonance appears between 100[kHz] to 100[MHz], and the deviation in the frequency response is more than 4[dB]. This is caused by the resonance of the elastic wave in the substrate. The resonance frequency of the elastic wave is represented by this equation[5].

$$f_r = (v_s/2l)$$
$$= (1/2l)^* \; C_{ij}/\rho \qquad (1)$$

where C_{ij} is the stiffness constant of the $LiNbO_3$, i and j are the propagation directions of the elastic wave, l is the length in the propagation direction, and ρ is the mass density. This equation shows that the resonance frequency depends on the size of the substrate.

The resonance frequency is calculated and compared with the measured value in Fig. 2, when the resonance is caused by sliding vibration[5]. The results are summarized in table 1. The calculated results are almost agree with the measured results. This means that the dominant resonance is due to the sliding vibration.

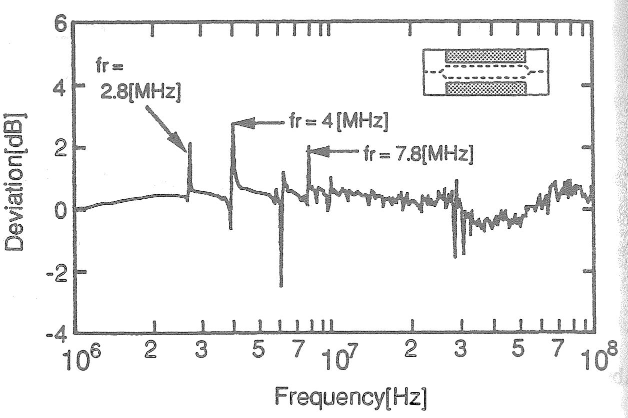
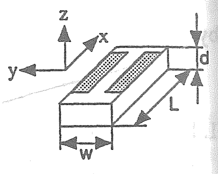


Fig. 2 Frequency response of electric filed sensor

Table 1 Resonance frequency of $LiNbO_3$ substrate

Direction	Resonance frequency	
	Calculated	Measured
y-axis(S)*	2.5 [MHz]	2.8 [MHz]
z-axis(S)	3.6 [MHz]	4.0 [MHz]
z-axis(L)	7.2 [MHz]	7.8 [MHz]



co-ordinate

*S : side wave, L:longitudinal wave

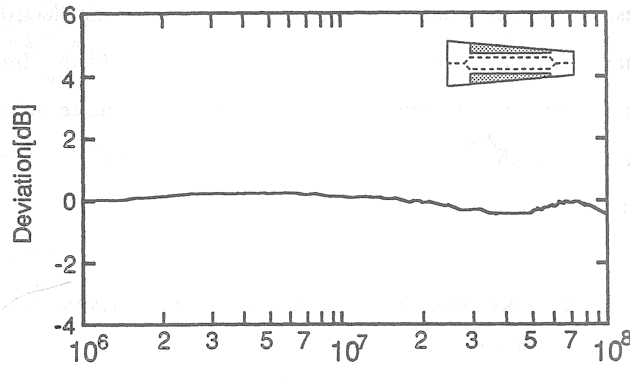


Fig. 3 Frequency response of electric field sensor with modified substrate.

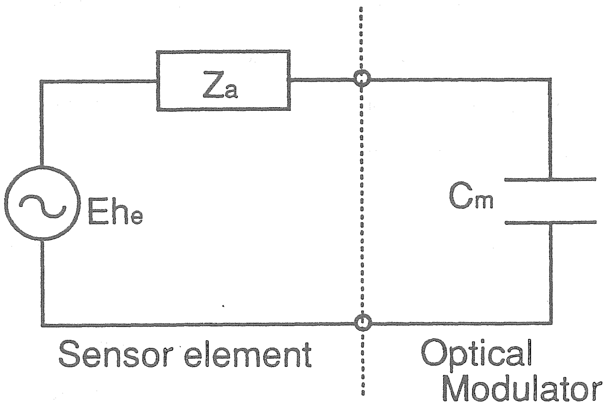


Fig. 4 Equivalent circuit of the electric field sensor

A new substrate shape was developed to suppress the resonance. The substrate width changes with the distance along the z-axis from one end of substrate, and the resonance frequency at a z-axis point is modified to reduce the effect of the resonance. The frequency response using the new substrate is shown in Fig. 3. The sensitivity deviation is reduced from 4[dB] to 1[dB].

4. Improvement in maximum operation frequency

The resonance of the sensor element can be reduced by loading a resistance on the element[6]. A design method for determining the resistance values was developed for an antenna terminating with a constant resistance. However, the input impedance of the electric field sensor is not constant. The equivalent circuit of the electric field sensor is illustrated in Fig. 4. In Fig. 4, E is the electric field strength, h_e is the effective length of the element , Z_a is the driving point impedance of the element, and C_m is input capacitance of the optical modulator. As shown in Fig. 4, the input impedance of the optical modulator is represented by a capacitance because the electrode of the modulator is insulated.

This results means that new calculation method should be developed to determine the optimum loading resistance distribution.

The distribution of the loading resistance, when the antenna terminating impedance is constant, is given by[6]

$$Z(z)=60\Psi(z)/(h/2-z) \qquad (2)$$

here

$$\Psi(z)=4\pi A_z(z)/(\mu_0 I_z(z)) \qquad (3)$$

where Z(z) is the load impedance for unit length, h is the element length, $A_z(z)$ is the vector potential, $I_z(z)$ is the current in the element, and μ_0 is the permeability in free space.

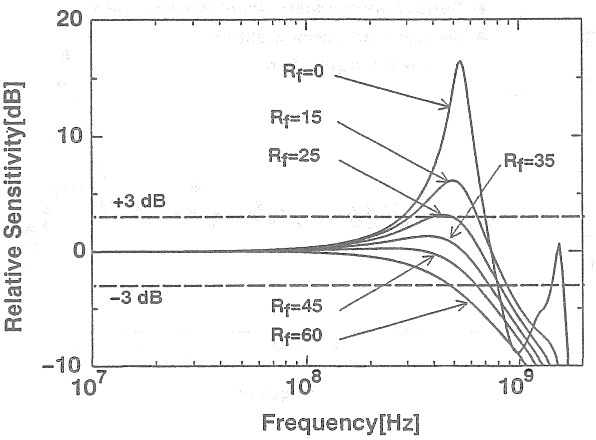


Fig. 5 Calculated frequency response of the electric field sensor with resistive element.

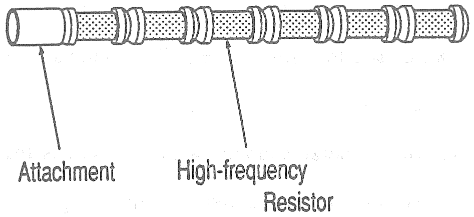


Fig. 6 Configuration of resistive element

Equation (2) is modified to

$$Z(z)=R_f\Psi(z)/(h/2-z) \qquad (4)$$

The frequency response is calculated to change R_f from 0 to 60, where R_f=0 means the sensor element is perfectly conductive. In the calculation, the moment method[6] is used. The results shown in Fig. 5. The maximum frequency bandwidth is obtained when R_f is 25. In this case, the maximum sensor operating frequency, where the sensor sensitivity deviation is within 3[dB], is improved from 300[MHz] to 800[MHz], compared with the response when R_f=25 and R_f=0.

The configuration of resistive sensor element is shown in Fig. 6. The sensor element is constructed with the no-cut and no-lead resistance. The value of the resistance is determined to fit the resistance distribution represented by Eq. (4).

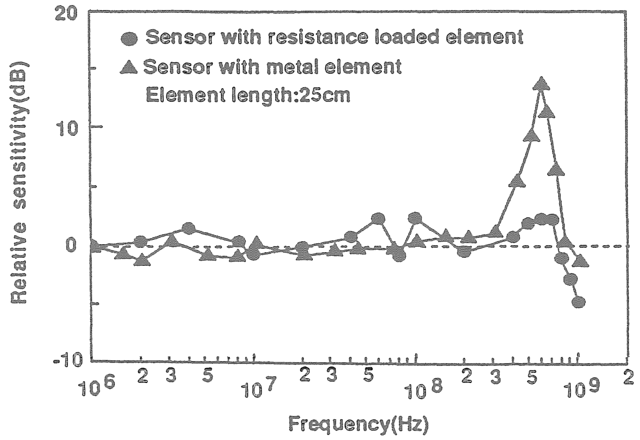


Fig. 7 Measurement frequency response of the electric field sensor

Figure 7 shows an example of the frequency response of the sensor with resistance loaded elements. TEM and GTEM cells[7] were used for measurement. The figure shows the frequency response normalized by the value for 1[MHz]. The frequency response with a metal element whose length is the same as the resistive loading element is also shown in Fig.7. The sensitivity changes within 3[dB] from 1[MHz] to 1[GHz], and the maximum frequency where the sensitivity deviation is within 3dB is improved from 300[MHz] to 1[GHz].

5. Conclusions

Electric field sensors with improved frequency response have been developed for EMC measurements.

The sensitivity deviation due to the elastic wave in the $LiNbO_3$ substrate is improved by modifying the substrate shape. The sensitivity deviation from 1[MHz] to 100[MHz] is reduced from 4[dB] to 1[dB].

A resistive element is used to suppress the resonance due to the sensor element. The optimum resistance distribution is obtained from the calculation using the moment method. The maximum frequency, where the relative sensitivity deviation is within 3[dB] is improved from 300[MHz] to 1[GHz].

Acknowledgments

The authors would like to thank Dr. K. Kitami and T Ideguch for their helpful advice, and Dr. J. Minowa and T. Sugamata for their assistance in producing optical modulator.

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