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Characteristic Evaluation of Impedance-Loaded SAW Sensor Using Finite Element Method and High Frequency Circuit Simulator

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1. Introduction

Aging bridges have become a serious problem in recent years. Therefore, we have proposed a structural health monitoring system (SHM) using surface acoustic wave (SAW) sensors. Impedance-loaded SAW sensors have the advantage of being wireless and powerless when combined with impedance-change sensors. In a previous study[1], damage detection of a beam simulating a bridge was performed. High damage detection accuracy was achieved by using machine learning. However, the impedance-loaded SAW sensor has the disadvantage of requiring an amplifier in the external sensor section due to its low sensitivity, so it cannot be used without a power supply.

In this study, simulations are carried out to improve the sensitivity of the impedance-loaded SAW sensor. Specifically, the finite element method (FEM) was used to analyze the SAW delay line, and a circuit simulator was used to include the influence of the external capacitance characteristics. The capacitance characteristics are a performance index for impedance-loaded SAW sensors. The validity of the simulated results was confirmed by comparing the results with measured results. Then, we discuss how to improve method of the sensitivity.

2. Simulation method

In this study, an impedance-loaded SAW sensor is simulated using the FEM-based numerical analysis software Femtet[2] and the circuit simulator QucsStudio[3]. The SAW delay lines were modeled as shown in **Fig. 1**, and the S-parameters were calculated. The obtained S-parameters were applied to the circuit simulator to calculate the time responses of the impedance-loaded SAW sensors. The capacitance was connected between port 2 and port 3 (**Fig. 2**). The frequency response of S_{11} was simulated. Finally, the time responses of S_{11} were obtained from the inverse Fourier transform. In the time responses, the first echo amplitude was focused. Specifically, the amplitude was calculated as a function of the capacitance in Fig. 2. The simulated and measured[4] amplitudes are shown in **Fig. 3**. There was a difference between the simulated amplitude and measured ones. When an inductance of 1 μH was connected in series with the capacitance, the simulated results agree with the measured results. We concluded that the actual measurement was affected by the inductance of the connected cables between the SAW device and capacitance. Therefore, this simulation method can be used to study how to improve the sensitivity of impedance-loaded SAW sensors.

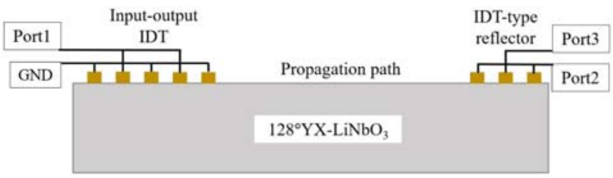

Fig. 1 Modeling of SAW delay line using Femtet.

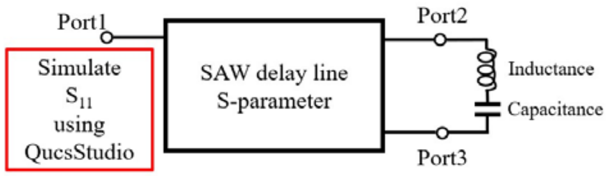

Fig. 2 Simulation model of S_{11} using QucsStudio.

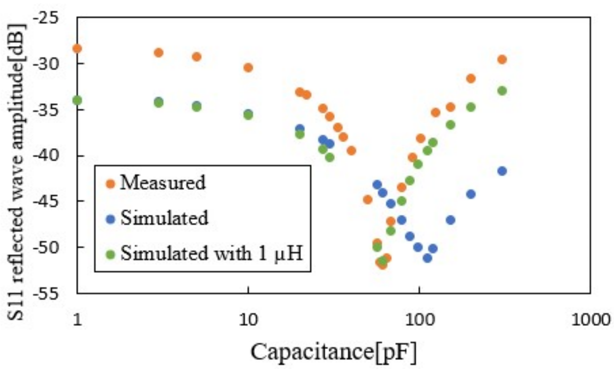

Fig. 3 Comparison of measured[4] and simulated results of the echo amplitude as a function of capacitance.

3. External circuit for improved sensitivity

The simulation method was used to improve the sensitivity of impedance-loaded SAW sensors. Since the relationship between amplitude and

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capacitance in Fig. 3 is not a linear change, it is difficult to define the sensitivity. Therefore, in this study, we focused on the range from 5 to 30 pF based on the performance of the varactor diode used in the previous study[1] to obtain and evaluate the average sensitivity. Therefore, to achieve high sensitivity, the amplitude should be a minimum peak when the capacitance is 30 pF.

The inductance was inserted in series with capacitance for the adjusting peak value at 30 pF. **Fig. 4** shows the amplitude before and after peak adjustment. The figure shows that the slope of the capacitance characteristic has increased due to the peak adjustment. The average sensitivity is -0.220 dB/pF before the peak adjustment, while it is -0.670 dB/pF by adjusting the peak at 30 pF. Therefore, the sensitivity can be improved by inserting inductance in series to correspond to the external sensor characteristics of the impedance-loaded SAW sensors.

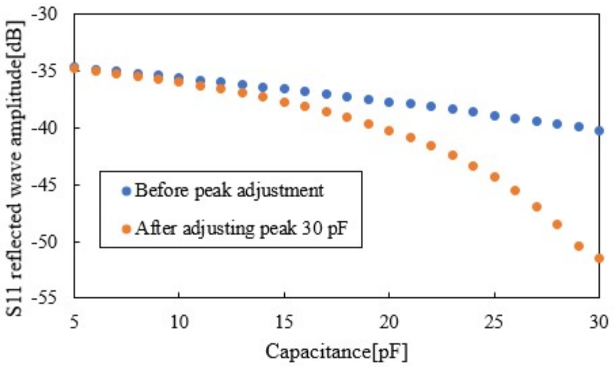

Fig. 4 Capacitance characteristics before and after peak adjustment.

4. New shape delay line for improved sensitivity

It is important to improve the structure of the SAW delay line to further increase sensitivity. The conventional SAW delay line (Fig. 1) only handles SAW reflections in one direction. Therefore, to incorporate bidirectional SAW reflections, an input-output IDT was installed in the center, and reflectors were installed at both ends (**Fig. 5**). Since the left and right propagation distances are equidistant from *L*, the reflected SAWs strengthen each other and the reflected wave is considered to be larger. A comparison of the capacitance characteristics with a delay line of conventional shape is shown in **Fig. 6**. It can be seen that the reflected wave is larger than that of the conventional delay line. The average sensitivity of the new shape is improved to -0.771 dB/pF. Therefore, we consider that the new SAW delay lines are suitable for high-sensitivity impedance-loaded SAW sensors.

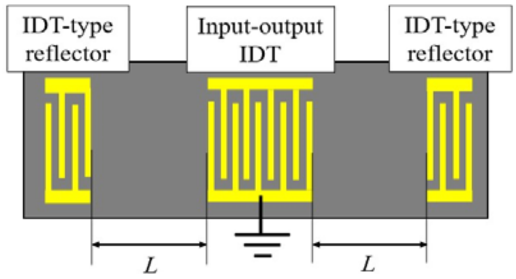

Fig. 5 New shape SAW delay line.

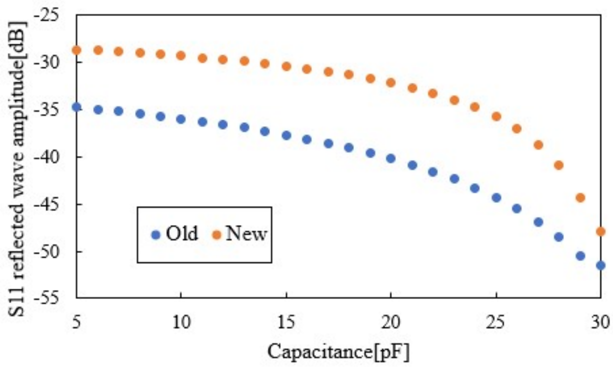

Fig. 6 Capacitance characteristics of the new shape impedance-loaded SAW sensor.

5. Conclusion

In this study, we proposed a simulation method and a new shaped SAW delay line to increase the sensitivity of impedance-loaded SAW sensors. The simulation results reproduced the actual measurements, and it was shown that a high-sensitivity impedance-loaded SAW sensor can be realized by using the new shaped delay lines.

References

1. S. Baba, J. Kondoh: "Damage evaluation of fixed beams at both ends for bridge health monitoring using a combination of a vibration sensor and a surface acoustic wave device," Engineering Structures, Vol. 262, 114323 (2022).
2. Femtet: https://www.muratasoftware.com/.
3. QucsStudio: http://qucsstudio.de/.
4. M. Oishi, H. Hamashima, and J. Kondoh, "Measurement of cantilever vibration using impedance-loaded surface acoustic wave sensor," Jpn. J. Appl. Phys., Vol. 55, 07KD06 (2016).