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Operational Verification in Multiplex Transmission System for Gate Drive Signals of Inverter Circuit using SAW Filters
SAW フィルタを用いたインバータにおけるゲート信号多重化の動作検証

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1. Introduction

Recently, power inverter circuits have been actively developed for high-voltage applications. In these applications, high reliability and high output power quality are required. To provide an inverter with better characteristics, a multilevel inverter system that has a number of power switching devices (10–100 pieces) was reported[1]. This multilevel inverter has many electrical signal wires that control each power switching device separately. However, increased numbers of electrical wires increase both the cost and the system failure rate, and it is thus necessary to reduce the number of electrical wires used.

Wide-gap semiconductors based on SiC and GaN have also been developed[2]. One of the major features of typical wide-gap semiconductors is a wide operating temperature range (over 200°C). High temperature operation can reduce energy losses by shortening the power wires, and wide-gap switching devices can thus be installed in high temperature environments such as the vicinity of a motor or an engine room[3]. However, controller circuits based on wide-gap semiconductors have not been fabricated to date. Because the operating temperatures of Si-based controllers are limited to the range under 125°C, these controllers must be located in the vicinity of the cooler. Therefore, a signal transmission system that is suitable for power inverter systems is also required.

We propose a new signal transmission system for these power inverter systems based on frequency-division multiple access (FDMA) and using surface acoustic wave (SAW) devices. SAW devices have suitable characteristics for use in next-generation wide-gap switching devices, including high temperature operation, good electrical insulation, low cost and high reliability. Our system can reduce the number of electrical signal wires required and thus simplify the transmission system. In this paper, a single phase power inverter system with a direct digital synthesizer (DDS) and SAW filters is demonstrated.

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We show that the proposed system was able to drive the inverter, and that the inverter system delay times were lower than the desired values.

2. Multiplexed Transmission System and Measurement Results

Figure 1 shows a schematic of the proposed system design. The controller multiplexes radio-frequency (RF) signals that are identified with specific power switching devices. The RF signals are transmitted to the receivers through a coaxial line, and the frequency components are divided and directed into various switching devices using SAW band-pass filters. Electrical insulation circuits such as photocouplers are unnecessary because of the structual characteristics of the SAW filters. The signals that drive the MOSFETs are controlled by ON/OFF switching of the RF signal. The target transmission signal delay time is <1 μs.

We used the DDS as a transmitter that can switch the output frequencies via an external control signal. The SAW filters were fabricated on 128°Y-X $LiNbO_3$ wafers. Because the Curie point of $LiNbO_3$ is 1200°C, it has sufficiently thermostable characteristics. A transversal SAW filter was used to ensure the electrical insulation between input and output ports. A single electrode interdigital transducer (IDT) pair was fabricated using a 1000-Å-thick aluminum film. **Table I** shows the specifications of two types of SAW filter.

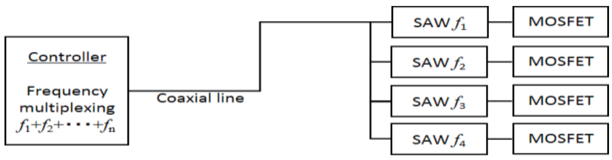

Fig. 1 Schematic of multiplex transmission system design.

Table I SAW filter specifications.

Wavelength λ (μm)	Center frequency f_0 (MHz)	Propagation path L	Number of electrode finger pairs N
6.4	612	100λ (640 μm)	15
8.0	492	50λ (400 μm)	10

These SAW filters have adequate suppression ratios (level differences) of more than 16 dB with respect to each other at the center frequency. The SAW filter delay time was measured by switching of the DDS control signal. The delay time was 63% of the output waveform variation. **Figure 2** shows the output waveforms of the SAW filter. Both the rise and fall times of the SAW filter at the wavelength λ of 6.4 μm were 534 ns. The SAW filter delay time is caused by the propagation path L and the triple transit echo (TTE). When L is long, the SAW filter insulation performance improves. It is thus necessary to determine the appropriate value of L. The TTE is the response of the reflected SAW in the IDT. Significant TTE occurs when the number of pairs of electrode fingers N is large. If N is reduced to minimize the influence of the TTE, the suppression ratio is also reduced. When using multiple switching devices, it is necessary to consider the electrode shape; for example, a unidirectional electrode gives small TTE and insertion loss values.

We then verified the operation of the half-bridge inverter. **Figure 3** shows the inverter's circuit structure. The frequency of the control signal input to the DDS was 10 kHz. The SAW filter output signal was demodulated using the RF signal detector. The gate drive circuit, which amplifies the detector output signal, was set between the detector and the MOSFET.

The total system delay time is the time until the gate driver determines the threshold value, and the final delay times are shown in **Table II**. The total delay time of the two signals must not exceed the 1-μs target value. The delay time at 612 MHz was longer than that at 492 MHz for the rise time. This time difference was caused by the SAW filter delay time. In the fall time results, because the threshold value was strict, a delay time was generated. This delay time can be reduced if the threshold value is adjusted.

Figure 4 shows the output waveform of the inverter at 10 kHz. The inverter power supply voltage was 100 V, and a resistance of 50 Ω and an 860-μH inductor were connected to the output port. The delay time difference of each signal was <0.2 μs. The inverter was thus able to operate without causing an arm short circuit. We confirmed that the inverter could operate appropriately at 10 kHz.

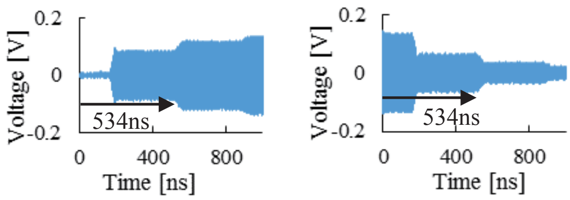

Fig. 2 Output of the SAW filter (λ=6.4 μm).

3. Conclusions

We have demonstrated a frequency multiplexed transmission system for next generation inverters. We accomplished the target delay time of 1 μs, and the validity of the proposed system was verified. The delay time of the SAW filter constituted about 0.5 μs of the total delay time of 1 μs; however, it is possible to further reduce the delay time when the propagation path L is reduced when considering the insulation of the SAW filter. We must also consider a SAW filter pass band to apply the proposed system to multilevel inverters that use multiple power devices. We intend to design an optimal SAW filter to minimize the delay time with due consideration of the insulation properties and using a pass band.

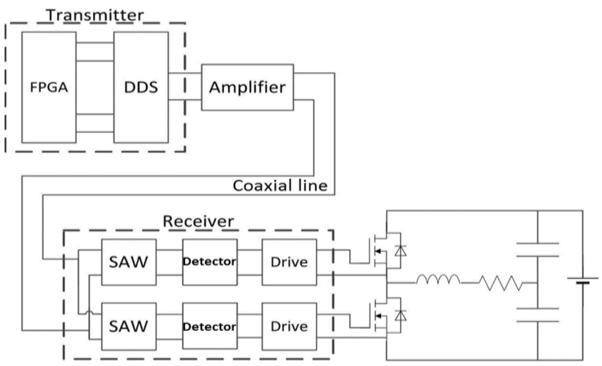

Fig. 3 Circuit structure of half-bridge inverter system.

Table II Final delay times.

Frequency (MHz)	Delay times (μs)	
	Rise	Fall
612	0.53	0.82
492	0.45	1.01

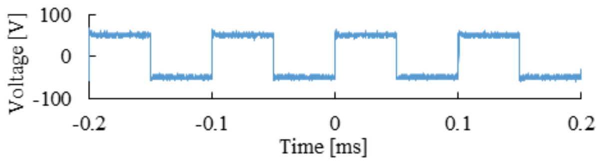

Fig. 4 Output of the inverter at 10 kHz.

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