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Interface Electronics Design for Wireless Generation of Surface Acoustic Wave Utilized in Wearable Drug Delivery Application

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Abstract

In this research, we aim to build a wearable SAW-driven drug delivery system that utilizes surface acoustic waves (SAWs) to control and deliver micro-sized microfluidic medicine to cure certain diseases. In order to make this application portable and wearable, the interface electronics that can wirelessly transfer the power and trigger the generation of SAW is designed and tested in this work. The modeling schematics, simulation results, experimental circuits, and measurement results are included in this report, showing the expected functions have been well-designed and achieved.

1 Introduction

Significant effort has been put into the research area of biomedical engineering since the 'lab-on-chip' concept has aroused in recent years. Control and manipulation of micro-fluids, nanoparticles and biomolecules have been achieved in a variety of mechanisms and methods. Recent research [1] suggests that surface acoustic wave (SAW) is an effective method to control and deliver nanoparticles and biomolecules within micro-fluids on certain lab-on-chip devices. SAW is generated on a piezoelectric material by a high frequency AC voltage applied to the metal interdigital transducers (IDTs), which causes mechanical stress and surface deformation and periodically propagates along the delay line [2, 3]. When the SAW encounters a droplet or liquids in a microfluidic channel on the surface of piezoelectric material, part of its energy will refract into the liquid, generating a leakage acoustic wave and corresponding pressure fluctuations inside the liquid. This will result in acoustic forces on both the fluid and the particles inside [4, 5].

SAW-based microfluidic devices provide the following features: compact, high biocompatibility, fast actuation, large force, and convenient on-chip integration with sensors [4]. However, SAWs in most designs from previously reported study [6, 7] are powered by wired signal generator or electronic circuits, which make them not appropriate to be used as wearable or implantable devices. Therefore, in this work, we aim to design and build an interface electronics that can wirelessly transfer the high frequency signals and generate the SAW on a passive and wearable SAW-driven drug delivery device.

Figure 1 shows the block diagram and working flow of the wearable SAW-driven drug delivery device with a wireless remote controller. This drug delivery system consists of a wearable part (sensors, signal transmitter, power receiver and oscillator, drug delivery) and a remote-control unit (microcontroller, power transmitter). Referring to these parts, the sensors are used to monitor the status of the wound and to send signals to the microcontroller unit (MCU) through signal transmitter. The MCU switches on/off the power transmitter module based on the received signals. The power transmitter module is used to wirelessly transfer power to the receiver module to generate high frequency sinusoidal voltage to drive the IDTs. The activated IDTs then generate SAWs to release and deliver the micro-sized microfluidic medicine.

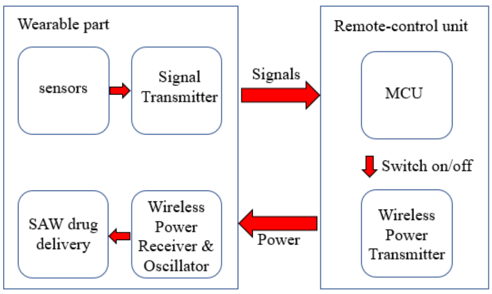

Figure 1. Block diagram of the wireless and wearable SAW-driven drug delivery system.

In this paper, the methods including simulation and experimental setup that used to build the interface electronics for the wireless generation of SAW are demonstrated. The devices used at this stage are presented to prove the concept. Both the simulation results and the experimental measurement results are presented in the following sections, verifying the achieved functions and meet the requirement as expected.

2 Block Diagrams, Schematics and Simulations

As shown in figure 2, the remote control-control unit consists of a Bluetooth signal receiver, Microcontroller, wireless power transmitter module, and the battery to support the whole unit.

The wireless power transfer electronics consist of two parts: the power transmitter module in the remote-control unit and the power receiver module in the wearable device. Detailed description of each module and the overall simulation results are given in this section.

A lithium polymer (Li-Po) battery CU-J794 is used to supply 11.1 volts DC output for not only the transmitter module, but also for the Bluetooth signal receiver and the microcontroller. The Bluetooth signal receiver receives the sensing information from the sensors and sends it to the microcontroller. The microcontroller then switches on/off the voltage boost circuit based on the signals. For a better power transfer efficiency, a sinusoids wave featured a high peak voltage is desired. The wireless power transmitter module transforms the 11.1 V DC into a positive-half sinusoidal wave whose peak voltage is 48 V. For the purpose of building proof of concept device, the power will be transferred by a pair of coils.

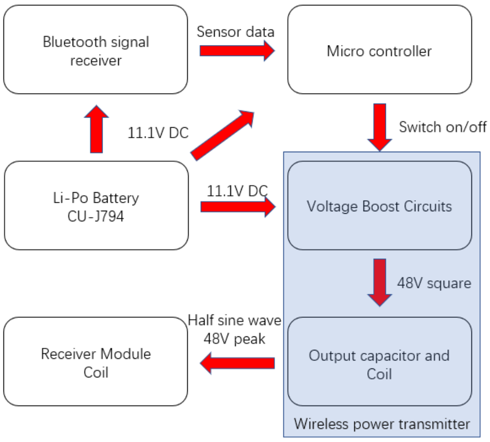

Figure 2. Block diagram of the remote-control unit.

To meet the demand of transform 11.1V DC to the sinusoids wave with 48V peak voltage to drive the SAW device, a DC-DC boost converter combined output capacitor and coil could be used. A typical topology circuit of such type of converter is shown in Figure 3.

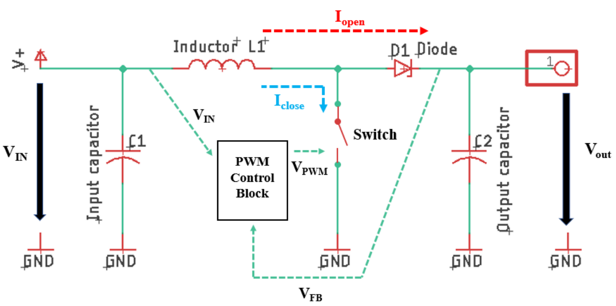

Figure 3. Schematic of typical boost converter topology.

This boost method is achieved mainly by a Pulse width modulation (PWM) controller, an inductor, and two capacitors. The control block generates PWM waves with different duty cycle based on the input voltage VIN and feedback voltage VFB。The switch is controlled by the PWM wave. While the switch is closed, current goes through the blue path and the output capacitor C2 will not be charged. When the switch is open, the current goes through the red path. The energy stored in the inductor L will charge the output capacitor C2 and supply the load with a higher voltage. By switching on/off the switch periodically with the control of the PWM signal, the low DC voltage could be transformed into a square wave with higher voltage. The combination of output capacitor and inductor (coil) will be transform the square wave into a sinusoids wave, which is suitable for wireless transfer.

To realize the boost concept, we built the circuit shown in Figure 4 with different components. This circuit is based on a PWM controller, an amplifier, a transistor switch, and the output coil. While the voltage of the transistor's base terminal is fixed, the open or close of the transistor switch is determined by the voltage of the emitter voltage. The emitter voltage is controlled by the signal from Pin 8 of the PWM controller. Hence, the output voltage of Pin 6 will be high/low periodically. This signal will be amplified by the amplifier and control the voltage of the lower side of the inductor (coil). Because of the effect of the output capacitor, the sine wave with high peak voltage will be generated as illustrated earlier. This sinusoidal wave will be transferred through the transmitter coil.

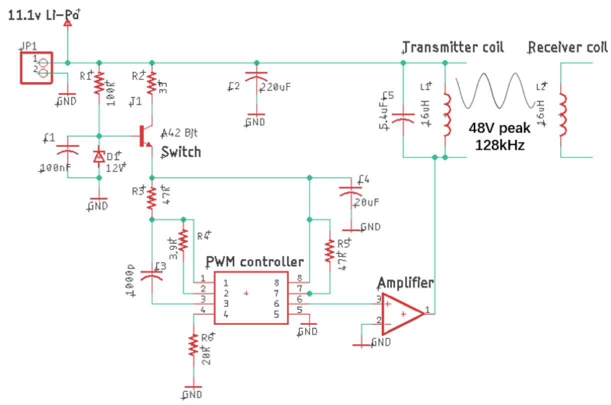

Figure 4. Schematic of the wireless power transmitter module.

The block diagram of the wireless power receiver module is shown in Figure 5. The bridge rectifier, filter capacitor, and voltage regulator are used as an AC-DC converter to transfer the half-sinusoidal signal with 32V peak voltage to a 12V DC voltage to supply the LC oscillator circuit.

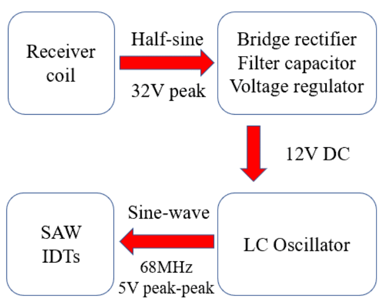

Figure 5. Block diagram of the wireless power receiver module.

The schematic of the power receiver module is shown in Figure 6. The AC-DC converter is on the left side of the blue dashed line. The four diodes play the role of the bridge rectifier to transform the negative voltage into positive. The filter capacitor is used to keep the signal always higher than 12V. The IC1 7812DT is a 12 Volts voltage regulator which could turn the unstable voltage from the filter capacitor into a stable 12V DC. The oscillator circuit is on the right side of the blue dashed line. The frequency of the oscillator is determined by the LC oscillation tank (yellow square) formed by the two capacitors and one inductor. The sinewave generated by the oscillation tank will be sent back to the base terminal of the transistor. The transistor will amplify the sinewave to a higher voltage. The capacitor and resistor on the right side will filter the direct component in the amplified sinewave to make the output could drive the SAW IDTs directly.

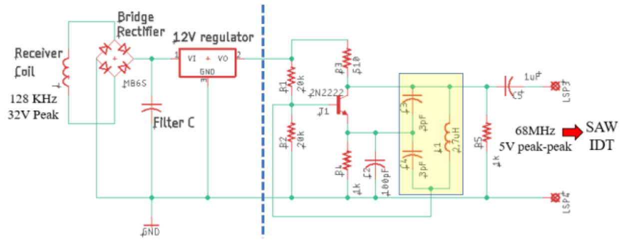

Figure 6. Schematic of the wireless power receiver module

After modeling all above schematics together in the simulation tool and set up the input signals, the simulation result of the entire wireless power transfer interface electronics is obtained and shown in Figure 7. With ignoring the parasitic capacitance induced by the wires and connections, an output featured 79 MHz frequency and 5 volts peak to peak voltage are achieved by the designed wireless power transfer interface electronics.

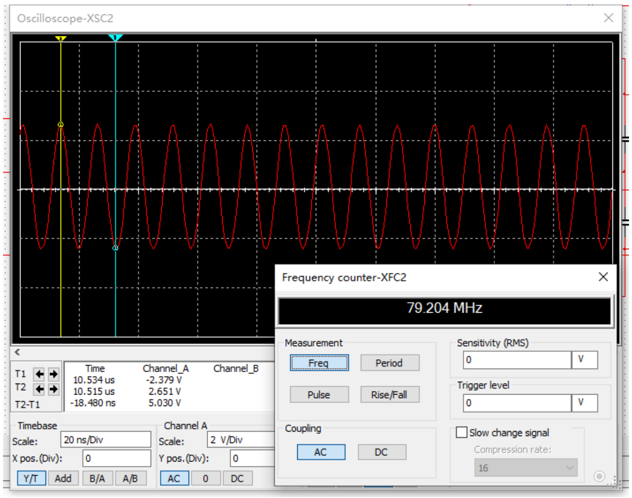

Figure 7. Simulation result of the overall wireless power transfer interface electronics.

3 Experimental Setup and Test

The setup of the wireless power transmitter module and receiver module is shown in Figure 8. The transmitter module and coil are on the left. The AC-DC converter circuit which provides 12V for the oscillator is on the white breadboard. The LC oscillator is built on the green board as indicated in Figure 8. The two coils will be put overlap while working.

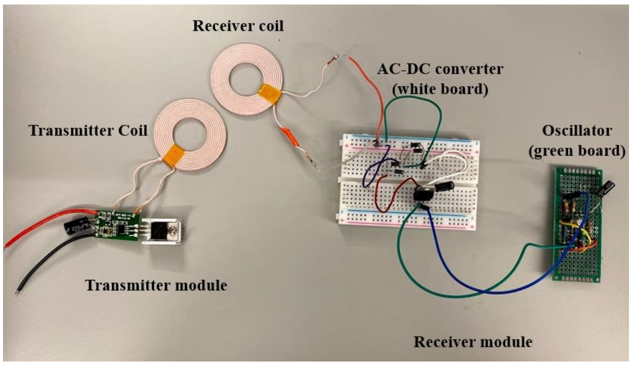

Figure 8. Setup of the wireless power transmitter module (left) and the receiver module (right).

The signals measured from the transmitter coil and the receiver coil are shown in Figure 9 and Figure 10. The peak voltages of the transmitter coil and the receiver coil are 48V and 32V, respectively.

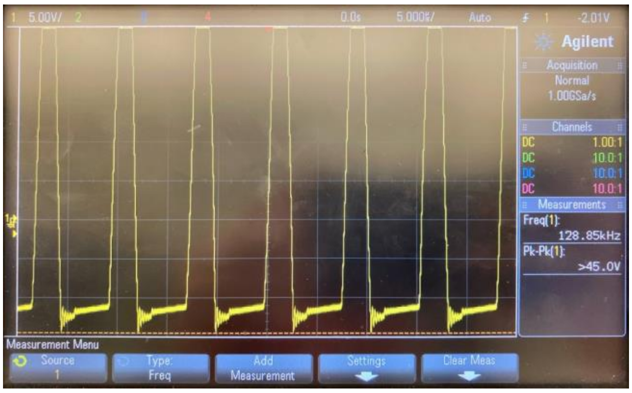

Figure 9. Signal of the transmitter coil.

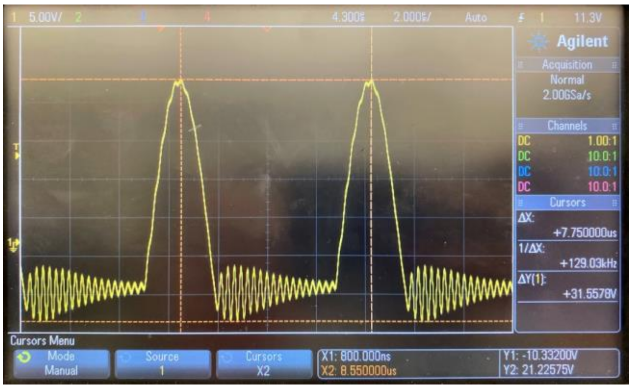

Figure 10. Signal of the receiver coil.

Figure 11 shows the input power of the experimental test, which is also the power consumption of the entire wireless power transfer interface electronics. According to the voltage and current shown in Figure 11, the power consumption is 0.96 Watts. Per calculation, an 1100 mAh cellphone battery with an 11.1 V output is able to supply this system for 12 hours.

Figure 11. Input power of the entire wireless SAW generation interface electronics.

Figure 12 shows the 68MHz, -2.5V~2.5V sinusoidal wave which is obtained from the output of the oscillator. Compared with the one shown in Figure 7, the experimental test result is slightly different from the simulation result. This difference is due to the parasitic capacitance introduced by the wires and connections in the experimental setup. According to the theory, the parasitic capacitance will affect the signal frequency because the frequency of LC oscillator is determined by the oscillation loop which consists of small capacitors and inductors. In future work, by putting together all the components of the receiver module and the oscillator on a same PCB, a higher frequency and higher peak voltage can be achieved.

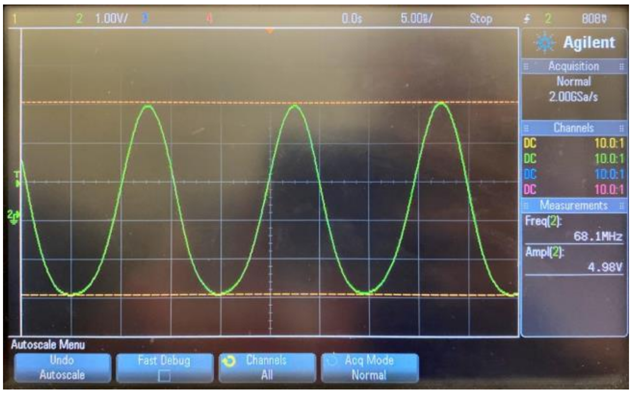

Figure 12. Output signal of the entire wireless SAW generation interface electronics.

4 Conclusions

In this work, we studied and demonstrated the method to design and build an interface electronics that can be used to wirelessly transfer high frequency power and generate the SAW. Both the simulation result and the experimental test result verified the expected outcome has been successfully achieved. This wireless electronic design makes it possible and provides the foundation for building a passive and wearable SAW-driven drug delivery device. In future work, we will focus on several features such as using smaller components and flexible piezoelectric materials, and also using a flexible PCB to hold both the AC-DC converter and the oscillator circuits on one surface. The purpose is to further reduce the size of the device and to make it more suitable to be a wearable or implantable biomedical application.

5 References

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