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New electronic device for driving surface acoustic wave actuators

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Abstract

Surface acoustic wave (SAW) actuators are driven by a high frequency signal. The frequency range for an ideal SAW-generation is usually very narrow banded and may shift depending on various environmental conditions. We present a new electronic device which self-aligns to the optimal excitation frequency within a wide range. Any kind of SAW-actuator can be used. The device continuously scans a certain frequency range and characterizes the SAW-component. The ideal excitation frequency is then determined and used to drive the SAW-device. In case of changes like loading conditions or temperature variations the device automatically readjusts to the optimal frequency and prevents possible damage of the device or actuator in case of an error.

Keywords: Surface acoustic wave; SAW; Actuator; Acoustic streaming; Micromixer;

1. Introduction

Actuators based on surface acoustic waves (SAW) promise to solve problems in microfluidics and lab-on-chip (LOC) applications [3, 6]. Mixing and agitation of small amounts of liquid are of particular interest (Fig. 1, Fig. 7). Further applications are manipulation and separation of small particles or molecules like DNA or nanotubes. Enhancing the convection in small reaction chambers accelerates biosensor procedures like surface plasmon resonance (SPR) or quartz crystal microbalance (QCM).

SAW-actuators are formed by interdigital transducers (IDT) deposited on a piezoelectric material. The excitation frequency is mostly given by the layout of the IDT's and the sound velocity of the substrate. The bandwith of this frequency is generally narrow banded (Fig. 2). Special designed IDT's for emitting a higher power may have an even narrower

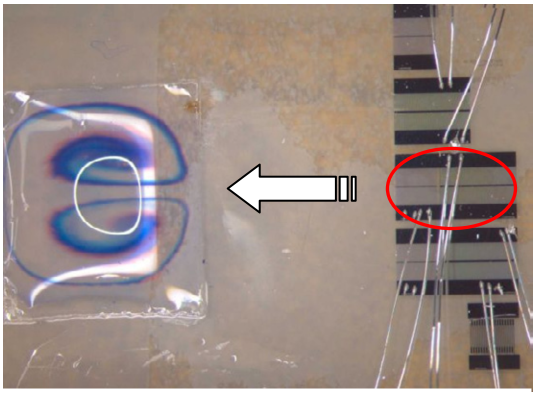

Fig 1: Mixing droplets with surface acoustic waves (SAW).

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bandwidth. Usually a combination of frequency generator and amplifier is used for driving the actuator. Unless stability optimized SAW-filters the optimal excitation frequency of the actuator may shift, due to many possible influences. The most important effects are: manufacturing tolerances, additional coating on the surface (e.g. insulation, scratch resistant layer), loading (fluid, particles), possible contamination in open systems, temperature changes (self heating), aging or even degradation of the IDT's. The properties of the SAW-device can be determined very accuratly in advance. However, the characteristic of the SAW-actuator changes during its usage. We experienced that the SAW-excitation is not ideal or stable if only a generator with a fixed frequency is used. Additionaly in case of a defect (short or open circuit) the amplifier can be damaged by the reflected power.

2. Driving device

We have developed a new electronic device which continuously scans a certain frequency range and measures the $|S_{11}|$-characteristic of the connected SAW-actuator. The ideal excitation frequency of the actuator is usually determined by a minimum of the reflection coefficient. As soon as a minimum of $|S_{11}|$ is detected, the device will switch on the intended power (in continuous mode) to drive the actuator, but continues to scan the $|S_{11}|$-characteristic in short intervals. Additional frequency offsets between the $|S_{11}|$-minimum and the driving frequency can be programmed. Using this algorithm the driving device always self aligns to the optimal frequency of the connected actuator. This combination of network analyzer, frequency generator and power amplifier simplifies handling and research with SAW-actuators very much.

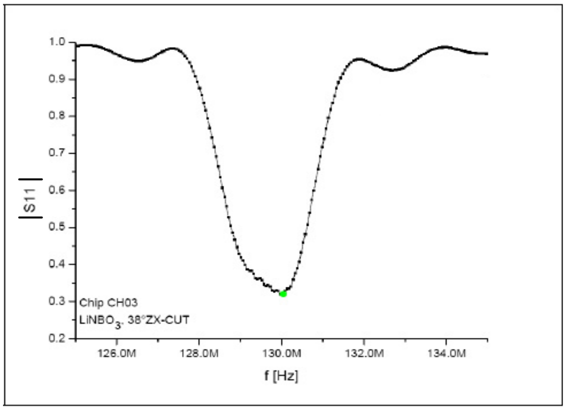

Fig. 2: typical $|S_{11}|$ characteristic of a SAW-actuator. The minimum indicates the ideal excitation frequency.

3. Operating mode

Figure 3 shows the main principle of the device. A voltage controlled oscillator (VCO) is used for scanning and frequency generation. A high-frequency amplifier provides the intended driving power. The measurement module determines the reflection coefficient $|S_{11}|$. A microcontroller controls scanning and driving of the actuator and gives information to the user.

VCO

The voltage controlled oscillator (minicircuits ZOS-150) has a frequency range of 75-150 MHz. This is sufficient for most types of SAW-actuators but the VCO can be easily exchanged for different frequency ranges. The output frequency is controlled by a DC voltage. Together with an 11bit digital-analog converter, which is controlled by the microcontroller, frequency steps of ≈30 kHz are realised for scanning and frequency generating. This gives a high resolution to control the SAW-actuators.

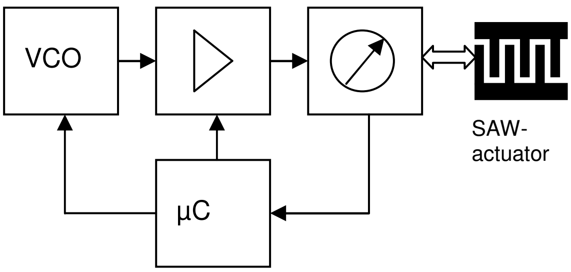

Fig. 3: Principle of the new SAW-actuator driving device. It combines a simplified network analyzer with frequency generator and power amplifier.

Amplifier

High frequency amplifiers usually have a fixed gain. Therefore a variable attenuator is used in combination with the amplifier to control the output power. The VCO gives an output level of +9dBm and the amplifier has a gain of 30dB. The variable attenuator is adjusted for an output power range of 0 to 33 dBm, corresponding to 1mW to 2W. The output power is controlled by the user or a computer program. At any time, the microcontroller can switch to maximum attenuation (0 dBm output power) for frequency scanning or in case of a defect (e.g. open or short circuit).

Measurement module

The measurement module is the most important part of the device. One way to characterize the SAW-actuator is to use the network analyzer principle. In this case it is simplified to determining $|S_{11}|$. A bidirectional coupler decouples parts of the transmitted power waves (both forward and backward) into output ports for measuring. Two logarithmic amplifiers (analog devices AD8310) create a DC signal which is proportional to the logarithm of the amplitude. All parts are kept on the 50 Ohm characteristic impedance. Therefore the signal amplitude is proportional to the power. Finally the signal is measured by the analog-digital converter integrated in the microcontroller. Since the measurement module must be located behind the amplifier both the bidirectional coupler and the logarithmic amplifiers must have a high dynamic range and work with the high transmitted power. Fig. 4 shows the main components of the measurement module. Determining the absolute value of the reflexion coefficient $|S_{11}|$ is adequate for characterizing the connected SAW-actuator. No phase information between transmitted and reflected power is necessary. However, this may cause measurement errors if the connecting cables between the driving device and the SAW-actuator are unusually long (>10m). In such case the programmed measurement time for each frequency step can be changed. In between the intervals of scanning the $|S_{11}|$ characteristic, the SAW-actuator is driven at its determined ideal excitation frequency. During this time the measurement module is used as a power meter. In case of a defect (open, short) or possible unplugging the SAW-actuator the reflexion coefficient rises to 1 and all power is reflected. To prevent any damage to the amplifier the microcontroller immediately minimizes the output power.

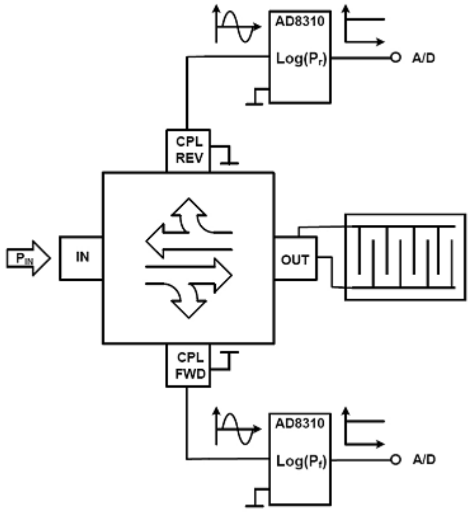

Fig. 4: The measurement module consists of a bidirectional coupler and 2 logarithmic amplifiers to determine $|S_{11}|$.

Microcontroller

An Atmel Atmega168 microcontroller controls scanning and driving of the whole device. With a clock rate of 20MHz, 16 KB of memory, various interfaces and easy to program the AVR-controllers provides a perfect solution for many kinds of controller applications. A display gives relevant information like frequency and driving power to the user. Several interfaces are used to control all connected parts. A first SPI is used for the display, a second one for the digital-analog-converter to control the VCO. Two of the integrated analog-digital-converters are used for the measurement module to determine $|S_{11}|$. An additional USB-RS232-bridge realizes a PC-connection. A basic type of control algorithms is described below. After powering on the device, the microcontroller keeps the output power minimized and starts to scan a certain frequency range. The $|S_{11}|$ characteristic at the output port is the measured. In case that a working SAW-actuator is connected, the microcontroller detects a minimum of $|S_{11}|$. Then the frequency is set according to that minimum and the intended power is switched on to drive the SAW-actuator. After a short period of time (about 1s) the power is switched off and the scanning starts anew. 90-10-cycles of about 0.9 s driving and 0.1 s scanning proved well working. Changes to the SAW device like frequency drifts are recognized and the excitation

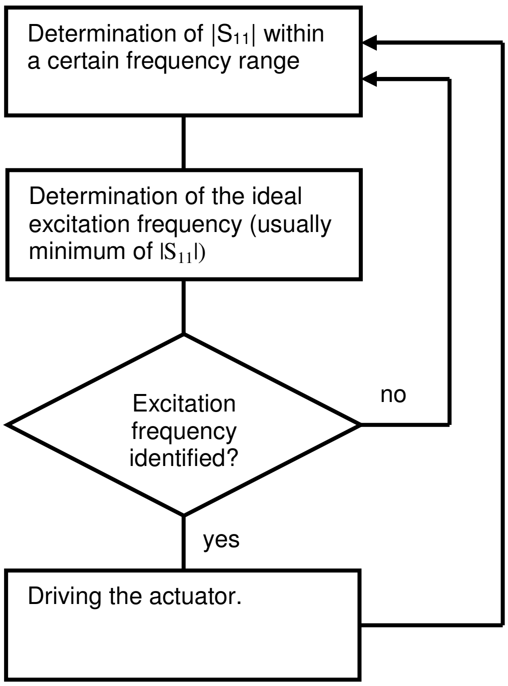

Fig. 5: basic algorithm for the driving device

frequency is continuously re-adjusted so that the SAW-excitation remains at its optimal condition. In case that an open or short condition occurs during driving the actuator, the reflected power rises and the reflexion coefficient gets close to 1. Then the output power is shut down immediately and the microcontroller continues with scanning at low power. This simplifies handling of SAW-actuators very much, because the user can unplug the SAW-device at any time and reconnect new ones. Any type of SAW-actuator can be used as long as their excitation frequency lies in between the frequency range of the VCO. A possible mismatch of the SAW-actuators characteristic impedance to the used 50 Ohm system is tolerated within wide range of up to $|S_{11}| \approx 0.7$. Fig. 5 shows the programmed algorithm.

4. Summary and Outlook

A new device for driving SAW-actuators has been developed and successfully tested. Its new operating mode of continuous scanning and driving the SAW-actuator combines a simplified network analyser, frequency generator, power amplifier and power meter. Handling of SAW-actuators is very much simplified because the device always self adjusts to the ideal excitation frequency. The user can unplug the SAW-actuator at any time or reconnect it. Possible errors are recognized and the output power is then reduced immediately. The output power can be adjusted between 1 mW to 2 W and the possible frequencies lie in between 75 to 150 MHz. This is a large range for most applications.

Fig. 6: Evaluation model of the new controller for SAW-actuators

The new device showed that the principle of scanning and driving the SAW-actuator is working. For future devices some improvements, as results of the current tests and usage, will be made. Especially, higher integrated electrical components would allow more features and more flexible usage. A direct-digital-synthesis (DDS) device will be used for frequency generation. This improves the possible frequency range and allows more operating modes like pulsed operation or different kinds of modulation. Our tests also showed that the output power must not necessarily be raised, but a lower minimum output would be of advantage for very small mixing applications.

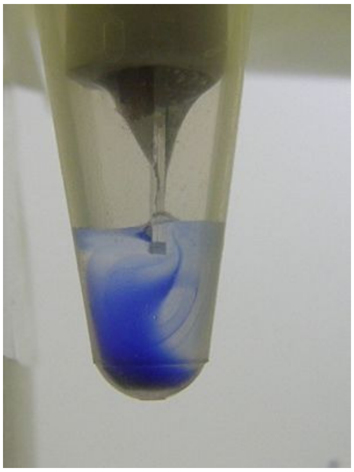
Fig. 7: Mixing of a 100µl sample in a microcentrifuge-tube (Eppendorf). The SAW-actuator is dipped in from atop. The power level is about 50mW.

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