Title: Towards digitally controlled ultrasonic IQ modulator

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Background, Motivation, and Objective:

Fourier transform computation in the Ultrasonic domain can be implemented using a 2D thin film piezoelectric transducer array as the transmit aperture [Liu 2018]. The far-field of the transducer generated field is approximately the Fourier transform of the input. In this paper, a digitally controlled ultrasonic IQ modulator is presented to control amplitude and phase of ultrasonic waves without extra electronics. The implications of this result are that the burden of phase control that is typically relegated to analog CMOS, can be shifted to direct modulation of piezoelectric transducers. This eases the density of CMOS circuitry needed to implement a physical computer for Fast Fourier Transforms. This approach can also be used in general to modulate GHz phases for ultrasound and RF applications.

Statement of Contribution/Methods:

A cross section of the ultrasonic IQ modulator (Fig (1a)) shows that the transducer pixel is divided into 2-pixels, that are fabricated shifted in height by a step of $\lambda/4$ (~1.2um at 1.2GHz in Silicon dioxide). AlN thin films is used as the piezoelectric material with a bulk mode resonance frequency of 1.2GHz. An RF pulse (1.2 GHz carrier, 50 ns wide, 2V) is used to actuate the transducers. Digitally controlled RF switches are used to select one of the four electrodes to apply the RF pulse to. The generated ultrasonic pulse propagates through the silicon substrate, reflect from the silicon backside and is measured at the center receiver. Four quadrature phases were measured at the receive transducer (I^+, I^-, Q^+, Q^-) by properly driving the two pixels. Fig. (1b) shows the SEM cross-section and an optical microphotograph of the device.

Results/Discussion:

Fig. (1c) shows the output signal for the four cases. The Si substrate thickness is 400 μm so the roundtrip delay of the ultrasonic pulse is 105 ns. The returned pulse has a quadrature phase with a slightly different amplitude due to fabrication and wirebonding mismatch. Amplitude of the input RF pulse actuating the I and Q transducers can be controlled to generate different phases and amplitude at the receive transducer. Alternatively, the pixel can be divided to binary weighted IQ transducers each controlled separately to control amplitude and phase of generated ultrasonic wave. Analysis shows that for 8-bit IQ transducers, 256 different amplitude/phase combinations can be achieved Fig. (1d).