REALIZING RADIO FREQUENCY ACOUSTIC DELAYS AND TRANSVERSAL FILTERING WITH SUB-2 DB INSERTION LOSS AND 10% FRACTIONAL BANDWIDTH

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ABSTRACT

This work demonstrates a lithium niobate thin film-based radio frequency (RF) acoustic delay structure with a low insertion loss (IL) of 2 dB and a fractional bandwidth (FBW) of 10%. In both aspects, this work surpasses the state of the art (SOA) delay lines.

INTRODUCTION

Acoustic delay structures are instrumental for a wide range of passive signal processing functions, including transversal filters [1], matched filters [2], and true time delays. These devices consist of a pair of electromechanical transducers as the input and output to access the acoustic domain. A transversal or matched filter convolves the frequency domain transfer functions of the input and output transducers to produce either a passband or correlated pulse response, while a delay line uses the separation between input and output to impose a wave propagation-induced time delay. All of abovementioned devices harness the small wavelengths and low phase velocities of acoustic waves at RF to achieve form factors and delay lengths that are unattainable with their electromagnetic counterparts. Despite these advantages, their applications in recent years are quite limited due to their unfavorable tradeoff between insertion loss (IL) and fractional bandwidth (FBW). Fundamentally, the limit in such a tradeoff arises from the insufficient electromechanical coupling (k^2) of existing electromechanical systems built on various electrostatic and piezoelectric platforms.

DEVICE DESCRIPTION AND MODELLING

In this work, we resort to the fundamental shear horizontal mode (SH0) in suspended lithium niobate (LiNbO₃) thin films, which has recently been demonstrated with high k^2 and low loss simultaneously, to overcome the limits of SOA [3]. As seen in Fig. 1, the device consists of two 100 nm gold interdigital transducers (IDT) on a 700 nm LiNbO₃ thin film. To eliminate the bidirectionality and subsequently minimize the IL, a type of single phase unidirectional transducers (SPUDT), known as electrode width controlled (EWC), is employed [4]. The transducer, as seen in Fig. 1, has a periodicity of λ_0 , which is also the acoustic wavelength at the design frequency and the width of the unit cell. In each unit cell, two types of electrodes are adopted. A pair of transduction electrodes in the middle are configured with a width of $\lambda_0/8$ to be non-reflective. Electrodes of width $\lambda_0/4$ introduce distributed reflection along the IDT. The asymmetric arrangement of the reflectors causes constructive interference for the waves radiated towards acoustic port 2 (FWD), and destructive interference towards acoustic port 1 (BWD), giving rise to the desired directionality towards port 2. Taking advantage of our suspended structure, a higher directionality is obtained compared to traditional delay lines based on SAW, due to the greater reflections introduced by the larger mass loading of reflection electrodes on the thin film. Note this work focuses on low loss constant group delays with large FBW, thus differing from our prior effort in chirp compressors where dispersion engineering and

Table 1: Comparison of the obtained results with previously reported filters based on acoustic delay lines.

Reference	IL	FBW
[6]	3.5 dB	4%
[7]	2.6 dB	5%
This work	2 dB	10%

Figure 1: (a) Schematic of an acoustic delay line formed by two Au IDTs in a thin film of LiNbO₃. (b) Unit cell of an EWC-based SPUDT. The unit cell is depicted as a three-port device, with one electrical and two acoustic ports. The wide electrodes behave as reflectors for the acoustic waves of wavelength λ_0 , with an equivalent reflector center in the middle of the electrode, and a complex reflection coefficient. The distance from a transducer center (T) to its closest reflection center (R) on the left is different from the distance to the closest reflection center on the right. (c) Design parameters of the fabricated delay line.

Figure 2: Sectional equivalent circuit of the transducer based on Mason model. Different acoustic characteristics are prescribed to the metallized and non-metallized sections to account for acoustic reflections.

compression is the focus [5].

The performance of the device is carefully modeled using

Figure 3: (a) S_{21} predicted by Mason model for the SPUDT-embedded delay line shown in Fig. 1(a). The model assumes no propagation loss in the delay line. (b) Zoom-in showing the passband with an IL below 1.5 dB.

Figure 4: (a) FEA model of a SPUDT to test directionality. Power radiated to the FWD and BWD acoustic ports, calculated with Mason model and FEA for SPUDT with (b) 5 and (c) 10 unit cells.

Figure 5: Fabricated devices for testing directionality. The devices have SPUDT on one side and conventional bidirectional IDT on the other side. The directionality of SPUDT is configured toward the bidirectional IDT in FWD, and toward the opposite direction in BWD. The contrast between measured transmissions of these two configurations indicates the measured directionality, which exceeds 20 dB at the center frequency, and agrees with modeled results.

Mason's model (Fig. 2). For the designed device without considering propagation loss, an IL below 2 dB is predicted as seen in Fig. 3. Fig. 4 shows the predicted directionality using Mason's model and FEM simulation.

EXPERIMENTAL RESULTS

The device was fabricated with the process detailed in [5]. Two test devices for measuring the directionality were included. The results, as shown in Fig. 4, show a directionality above 20 dB at the center of the transmission band. The measured S-parameters of the SPUDT-embedded delay line are shown in Fig. 5. The measured performance shows a delay around 60 ns with a

minimum insertion loss of 2 dB. The bandwidth obtained is above 15 MHz at a center frequency of 160 MHz. These results show that

Figure 6: Measured S-parameter results of the fabricated delay line with SPUDTs. (a) S_{21} . (b) zoomed-in view of the passband. (c) S_{11} . (d) Group delay. (e) Top-view optical picture of the device and zoomed-in showing the SPUDTs each with 10 unit cells.

SH0 mode on thin-film LiNbO₃ can enable low IL and high bandwidth delay lines and transversal filters, thanks to the high coupling and high reflectivity of the electrodes.

CONCLUSION

A new type of acoustic delay line has been demonstrated based on shear-horizontal waves on lithium niobate. The high electromechanical coupling and low loss of this platform allows for delays in the range of tens of nanoseconds with a sub 2 dB insertion loss and a fractional bandwidth in excess of 10%.

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