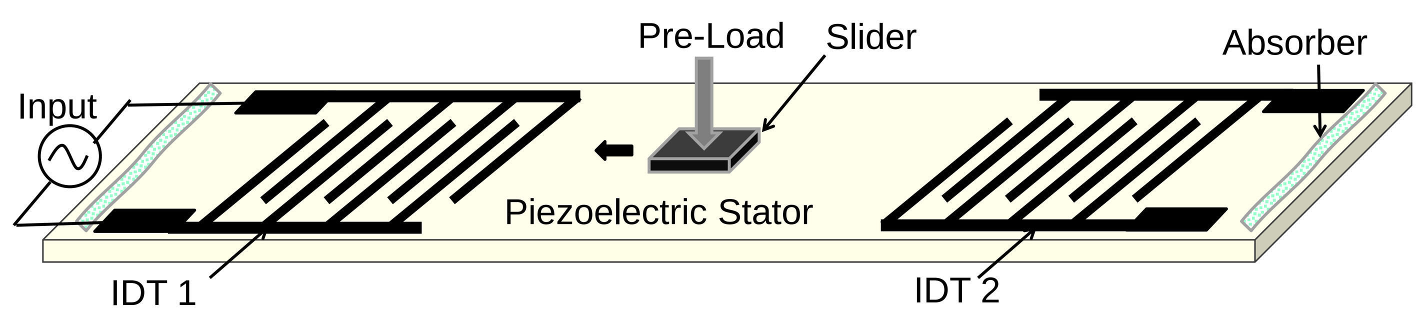
Simulation of Piezoelectric SAW Motor using COMSOL Multiphysics®

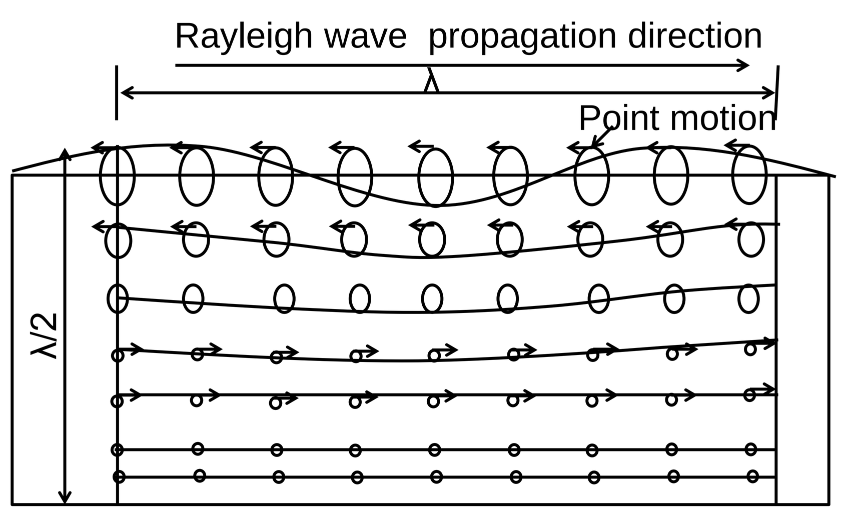
Basudeba Behera, Harshal B. Nemade
Indian Institute of Technology Guwahati, Department of EEE, Guwahati, Assam, Pin 781039.

Introduction:

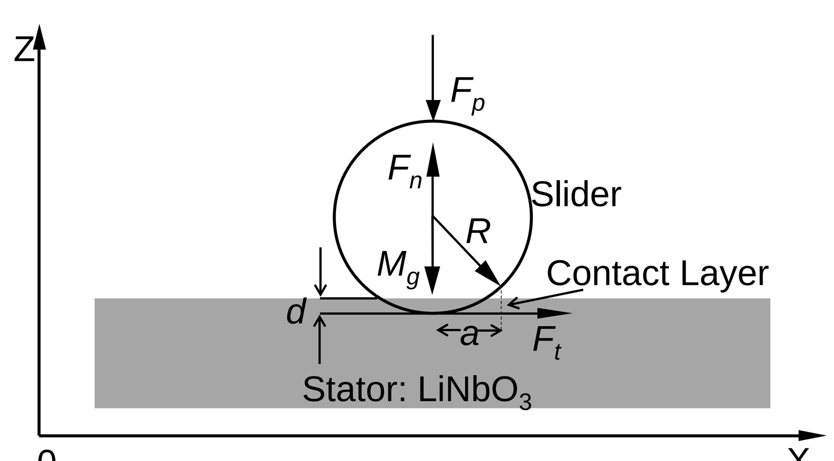
A surface acoustic wave (SAW) linear motor is developed utilizing the friction principle for driving. When a slider is placed on the Rayleigh waves generated on a piezoelectric stator due to application of RF power, the slider moves in reverse direction of the wave propagation due to friction between stator and slider. A $LiNbO_3$ piezoelectric substrate is used as stator where comb-structured Al electrodes are fabricated and called as Inter-digital transducers (IDT).



Piezoelectric SAW motor[3]

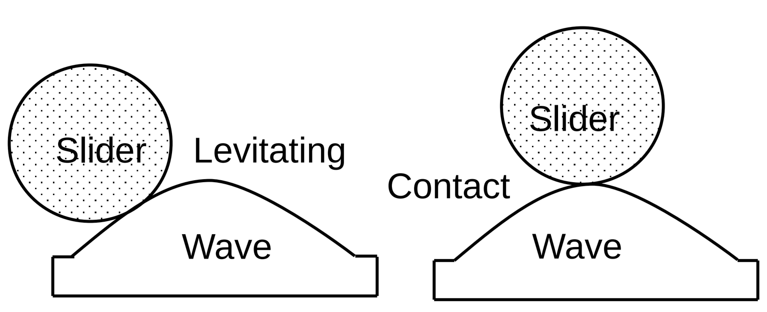


Propagation of Rayleigh wave



Slider placed in contact with stator

Computational Methods[2,4]:



Contact and levitating motion of the slider[1]

The motion of the slider in normal direction can be represented by,

During contact position:

$$\dot{z} = \frac{1}{m}\int (F_n - R_z\dot{z} - F_p)dt$$

$$d = u_z\cos(\omega t) - z$$

During levitating position:

$$\dot{z} = \frac{1}{m}\int (-R_z\dot{z} - F_p)dt$$

$$d = 0$$

The motion of the slider in tangential direction

$$\dot{x} = \frac{1}{m}\int F_t dt$$

The normal friction can be given by[5]

$$F_n = \frac{4E\sqrt{R}d^{1.5}}{3}$$

The tangential friction can be given by

$$F_t = \mu_d F_n sign(\dot{u}_x - \dot{x})$$

x : Position of the slider in tangential direction
z : Position of the slider in normal direction
u_z : Vibration amplitude in vertical direction
u_x : Vibration amplitude in horizontal direction
m : Mass of the slider
f : Applied frequency
F_p : Force applied on the slider
F_n : Force in normal direction
F_t : Force in tangential direction
ω : Angular frequency
k : Wave number
E : Young's modulus
v : Poisson's ratio
d : Space between stator and slider

Modeling in COMSOL Multiphysics®:

Geometry Settings:

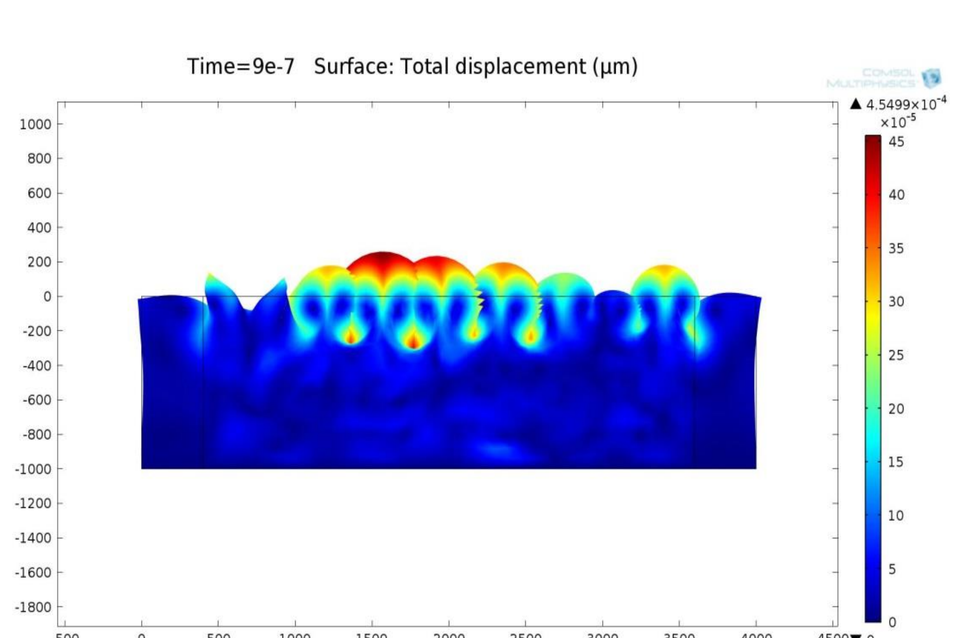
- The 3D plane geometry of a delay line made of piezo-substrate is modeled as shown below.
- The size of the piezo-substrate used is 400 µm (1 λ) × 2000 µm (5 λ).
- The size of the IDT electrodes are 400 µm (1 λ) × 100 µm (1/4 λ) used.
- Slider is of 200 µm × 100 µm × 100 µm having cylindrical projections at bottom of diameter 20 µm and space 20 µm.

Sub-domain Settings:

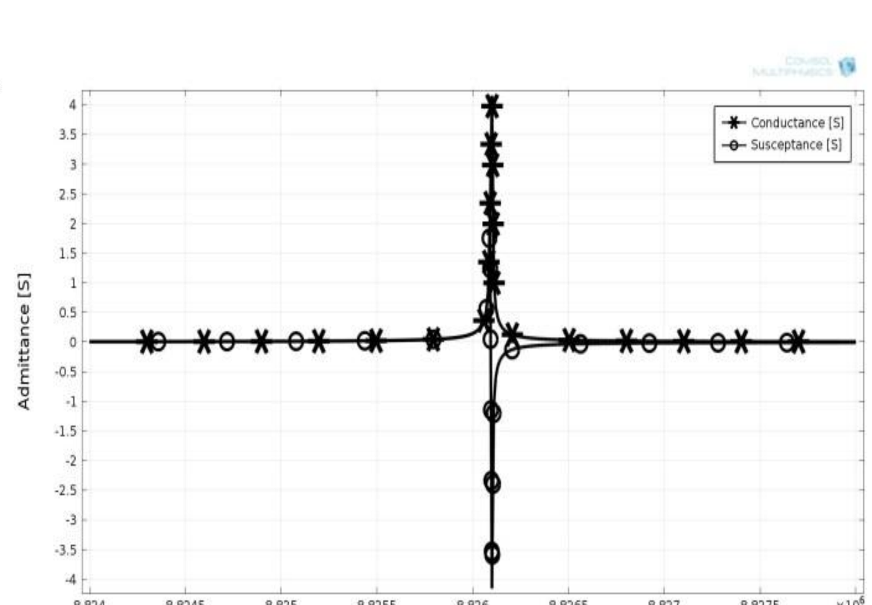
- The substrate used for the simulation is 128º rotated *YX*-cut $LiNbO_3$.
- Slider is made of silicon.

Boundary Settings:

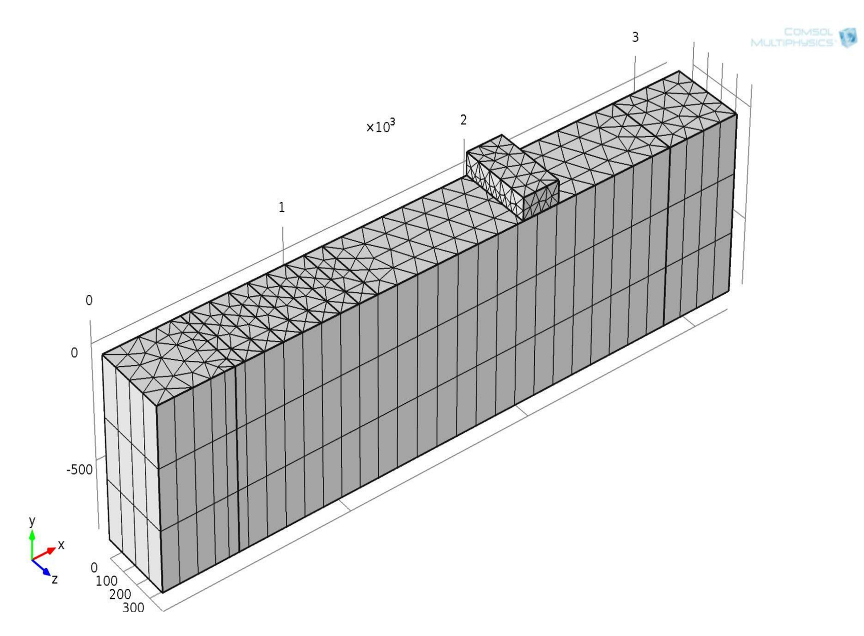
- The slider is in contact pair with the stator.
- The motion of the side boundary is kept free to move in prescribed displacement.
- Swept meshing was done for all the domains.



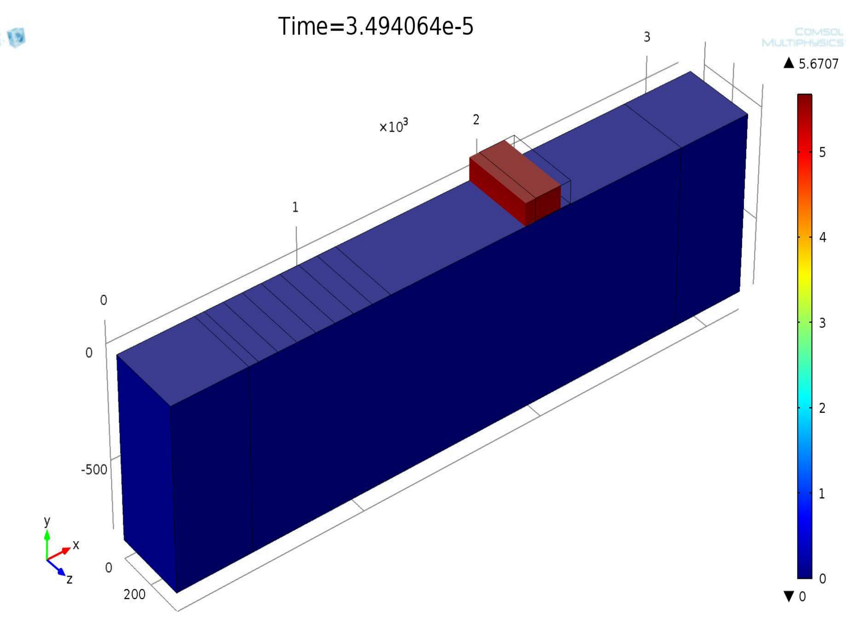
Delay line



Admittance plot



Meshing model of Motor



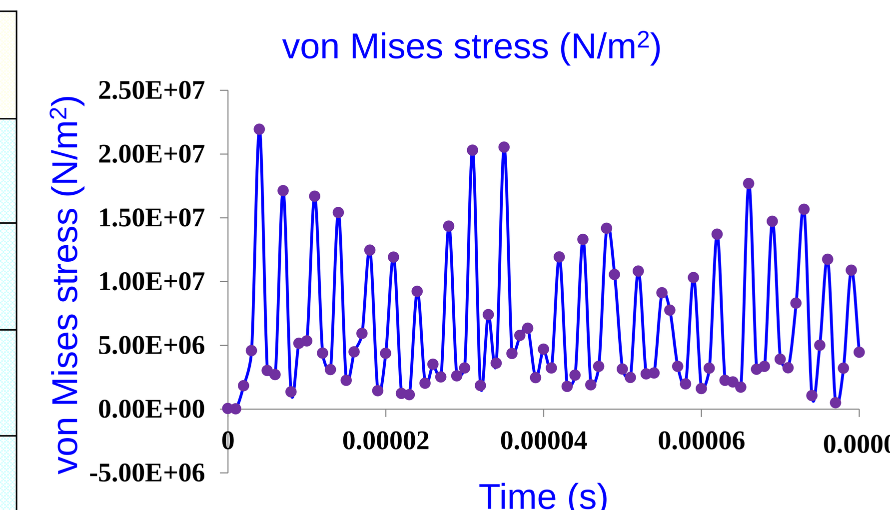
Solved model of motor

Results from Simulation of the Device in COMSOL Multiphysics®:

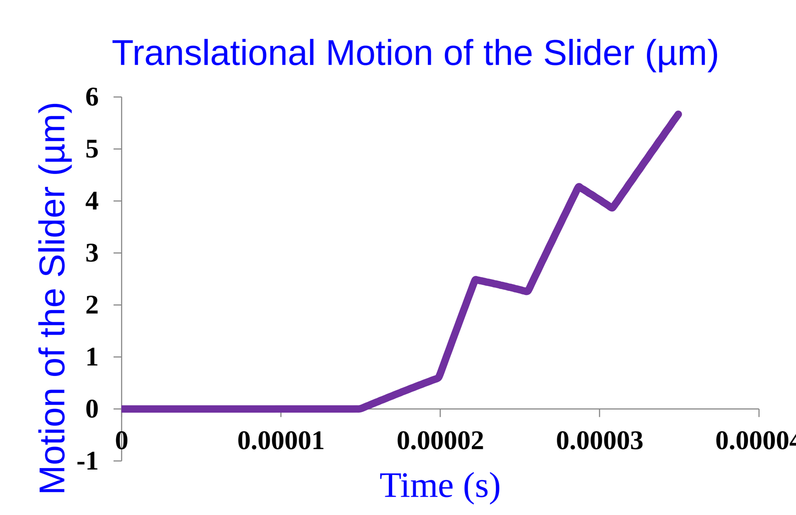
Below the given graphs demonstrate the results obtained from of the Multiphysics simulation of the SAW motor.

Parameters	Value	Units
Young's modulus of Slider	215e9	Pa
Young's modulus of Stator	173e9	Pa
Poisson's ratio of Slider	0.29	-
Poisson's ratio of Slider	0.33	-
Frequency	8.82	MHz

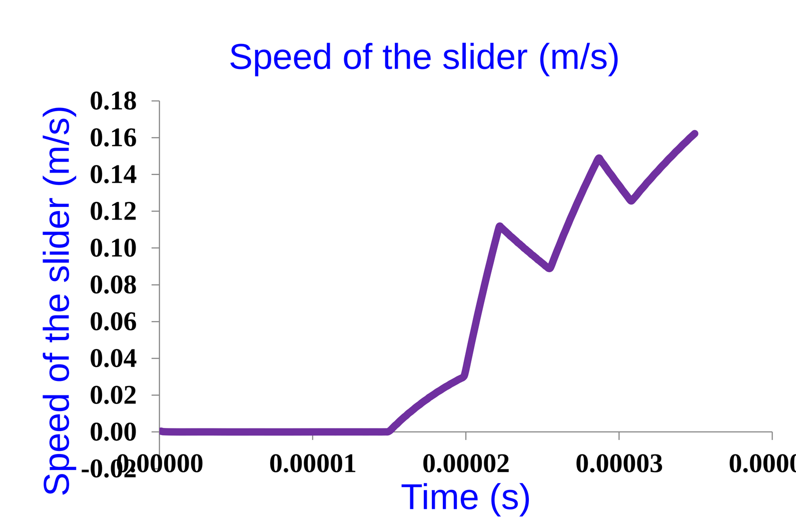
Parameters used for Simulation



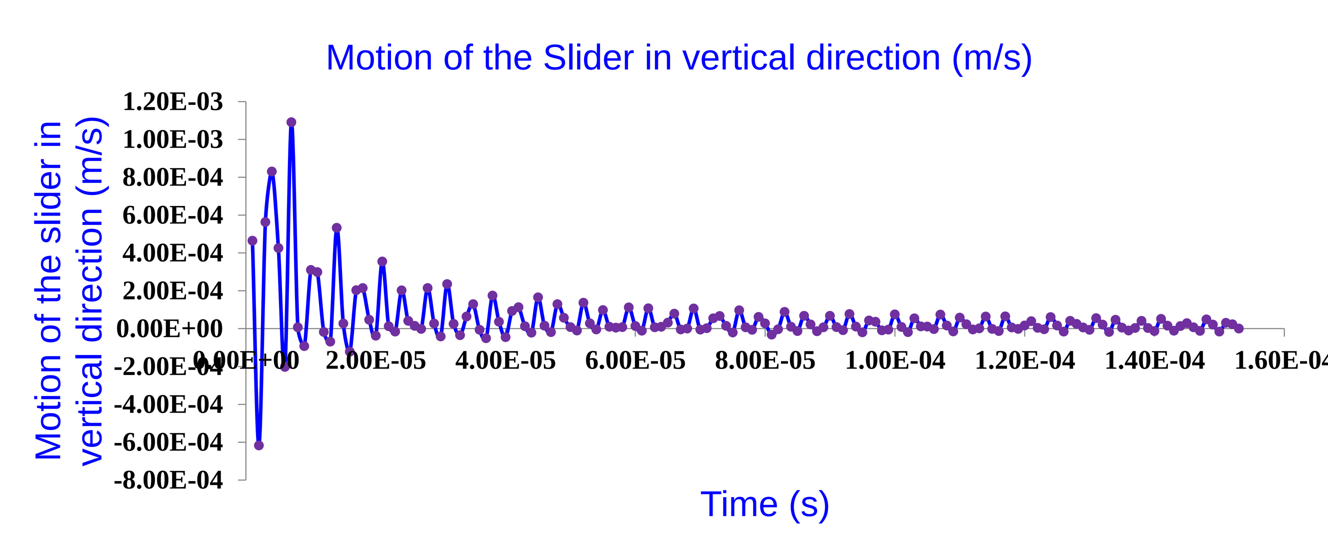
Von Mises stress on the stator due to the slider



Motion of the Slider



Speed of the Slider



Motion of Slider in Vertical direction

- The COMSOL simulation uses the coupling of piezoelectric and solid mechanics physics.
- The frequency applied for the simulation is 8.82 MHz.
- The translational motion of the slider achieved which is shown in the figure above, where the slider moves in a step size motion.
- The motion of the slider in vertical direction get saturated after couple of Rayleigh waves have passed.
- 20 MPa stress is generated on stator due to motion of slider upon it.

Conclusions:

The slider in the SAW motor can make motion in micro step when a burst of signal is provided as per the above figure and attains a speed of 0.3 m/s with the application continuous power signal of high frequency of 8.82 MHz Rayleigh wave. The movement of slider in vertical direction is stabilized with minimum time duration near about 0.16 ms.

References:

1. Kurosawa M. et. al., Numerical analysis of the property of a hybrid transducer type ultrasonic motor, in *Proc. IEEE Ultrasonic. Symposium* pp.1187, 1990.
2. Morita T. et. al., Simulation of surface acoustic wave motor with spherical slider, *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, vol. 46, no. 4, July 1999.
3. Zhao C. , *Ultrasonic Motors Technology and Applications*, 1st ed. Springer, 2010.
4. Feenstra P. J., Modeling and control of surface acoustic wave motors, Thesis, Department of Electrical Engineering at the University of Twente, Netherlands, September 2005.
5. Johnson K. L., *Contact Mechanics*, 1st edition, Cambridge University Press, 1985.

Excerpt from the Proceedings of the 2014 COMSOL Conference in Bangalore