PRACTICAL MEASUREMENTS OF SURFACE ACOUSTIC WAVE VELOCITY USING PHASE TECHNIQUE

**Aly. H. Moustafa, **T. E. Taha, *M. S. Zaghloul, *K.EL-Shennawy, *Senior Member,IEEE*

*Arab Academy for Science and Technology
**Faculty of Electronic Eng. Minufiya University
E-mail:- khamies@aast.edu

Abstract- *This paper presents practical measurements of surface acoustic wave (SAW) velocity using phase technique.* ***The*** *two most important practical properties relating surface wave propagation on piezoelectric substrate are the wave velocity and electromechanical coupling coefficient. The main technique for obtaining precise results of SAW velocity is based on the use of laser probe method, which is expensive and complex. The presented method using phase technique is simple and accurate. The practical measurements are applied across the usable bandwidth of the SAW devices from 30 to 40 MHz, the used SAW filters are chosen due to its operating frequencies, commercial, and have wide bandwidth. This method is applied practically for two available commercial SAW filters F1034, Toshiba product and X101 (E8335) Sanyo product both are used in IF stages in color TV. Moreover, measurements with and without deposited sample of liquid are made for both types of filters. The interpretation of the obtained results indicate that this simple method of measurement along with the preceding programs have the possibility to be used as characterization technique for loading liquid properties, which is best suitable for chemical sensors and biosensors.*

I. INTRODUCTION

Surface waves are piezoelectric microwaves, which can be propagated over the surface of piezoelectric crystals at a velocity of the order of 3500 m/s [1]. Measurements of acoustic wave velocities are of interest in many of SAW applications. The main technique for obtaining precise SAW velocity measurements depend on using laser probe method but it is still complex and expensive [2]. The SAW velocity commonly use single crystal such as quartz or lithium niobate. Electromechanical properties of ceramics can be determined by impedance method. The Coupling Coefficient (K^2) is defined in terms of piezoelectric parameters as $K^2 = e^2/\varepsilon c$. where e is piezoelectric constant, ε is dielectric permittivity, and c is elastic constant. This parameter may also be obtained experimentally, however, with recourse to the relation. $K^2 = -2\Delta V/V$ where $|\Delta V|$ is the magnitude of the SAW velocity change that occurs when the free surface of the piezoelectric is shorted by a thin high conducting metal film, and V is the unperturbed SAW velocity [3]. The impedance method does not show very good accuracy results on SAW velocity measurements.

This study is a general case, which can be applied for any type of SAW transducer (apodized or unapodized). The setup technique is simple which has not the difficulty of IEEE 488 bus interface or complex equipment as network analyzer, also the setup use simple and inexpensive equipment which can be found in any electronic laboratory that helps for using this technique as educational one. The used components are available commercial, is already presoldered and capsolized, and used in T.V, Mobile and other commercial devices, this is optimum due to the fact that the possibility of unavailable processes of fabrication in our country. This technique is trend of sensor with cheap available commercial component. The transmission loss is ignored in our calculation due to its small relative value (3-4 dB). The matching circuits for both input and output transducers are to get red of the effect of the total capacitance (C_t).

II. PRINCIPLE OF MEASURING TECHNIQUE

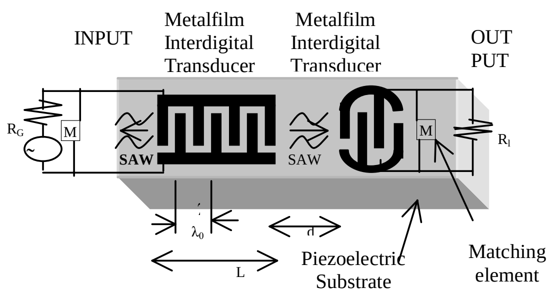

Fig.1 - SAW delay line

Consider the SAW delay line consisting of two Interdigital Transducers (IDT) laid down on a Piezoelectric material as shown in Fig.1 It is assumed that the propagation of acoustic waves is nondispersive and one of the two IDT is apodised and the other is unapodised. The main device response is

$$H_t = R_L \frac{Z_e}{Z_e + R_G} H_{sc} \frac{Z_s}{Z_s + R_L} \qquad (1)$$

given by (output to input voltage) V_L / V_G where R_G is the internal resistance of the generator, R_L is the external resistance of the load, Z_e is the input impedance, Z_s is the output impedance, H_{sc} is the short circuit response [3]. The phase of the transfer function is

$$\varphi(H_t) = \varphi(\frac{Z_e}{Z_e + R_G}) - \frac{\omega}{V_o} L' + \varphi(\frac{Z_s}{Z_s + R_L}) \qquad (2)$$

The three terms in the phase equation represent the phase due to the input transducer, the propagation path between the two transducers and the output transducer respectively, where, $L^/$ is the equivalent length of the SAW delay line[4]. The input and output impedance (Z_e & Z_s) for the IDT can be calculated by Morgan analyses [5].

III. PROCEDURES

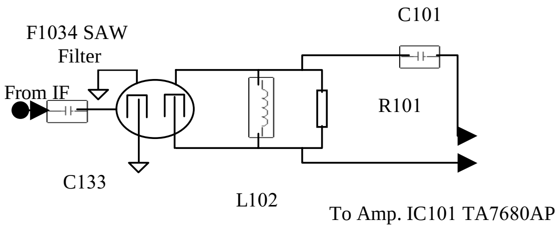

Fig.2 - SAW filter (T)

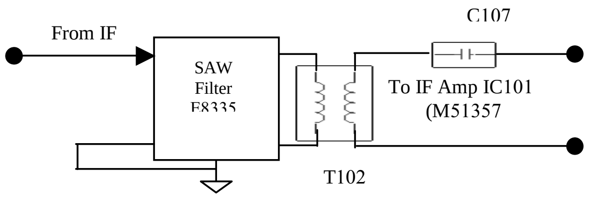

Fig.3 - SAW filter (S)

Measuring the phase of the main response (H_t) using the equipment and procedure mentioned below, determine the input impedance of each transducer, and determine the SAW velocity. The used SAW filters, unit under test (UUT) are of type F1034, Toshiba product, IF band, used in color TV 206Q3EL, 184Q3EL (T filter) and type X101, E8335, Sanyo product, IF band, used in color TV No CT- 201/M-00 (S filter). One of the transducers of these filters is apodised transducer. The circuit diagram for T filter and S filter with their matching networks are shown in Fig.2 and Fig.3 respectively.

IV. Measurement System and Experimental Apparatus

The hard ware of the system is simple to implement and is composed of TTL pulse generator (2002), pule modulator (6145), main power supply (544441), signal generator PSG 1000, digitizing oscilloscope (TDS420A) and unit under test (SAW device). The Pulse Modulator has three inputs 24v dc, train of pulses of amplitude 5v at pulse repetition time 05 micro second, and Radio frequency of amplitude of 1 volt and frequency variation from 30 MHz to 40 MHz (in 0.25 MHz step). These outputs are fed to dc input, the TTL input and RF input respectively, and are fed from the main power supply, pulse generator and signal generator respectively. The output of the pulse modulator is applied to both UUT and to the digitizing oscilloscope channel (A). The output of the UUT is applied to channel (B) of the digitizing oscilloscope, which used to measure amplitude of output signal from UUT, also it is used to measure the phase

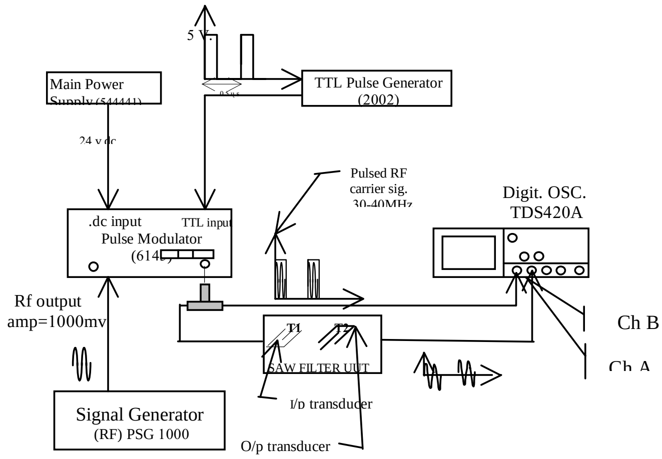

Fig.4 – Equipment setup for measurement system

difference between the input and output signal of UUT. The output from pule modulator to UUT has frequency variation of 30 MHz to 40 MHz in 0.25 MHz step with constant input amplitude of 1000 mv. The theory to calculate the free surface wave velocity (V_0) in appendix (I) and the flowchart for the computer program is shown in appendix (II). The practical measured phases for phase delay of T and S filter without and with load are used to calculate the SAW velocity for the two filters in both cases. The obtained transfer function (module and phase) without loading of the T and S filter is shown in Fig.5 and Fig.6. Also the obtained transfer function (module and phase), with liquid (water) loading of the S and T filter is shown in Fig.7 and Fig.8. The velocity inside the transducer is lower than the velocity on a free surface.

The free surface wave velocity is given by:-

$$V_o = \frac{(d + L)Vmeas.Vm}{V_m L' + V_{meas} \ L} \qquad (3)$$

Where V_m is the metaled surface wave velocity equal to 3457m/s, V_{meas} is the measured velocity, d is distance between input and output transducers, L is length of transducer. Applying equation 3 for filters T and S without load will lead to SAW velocity of 3437,3478 respectively. And for filters T and S with load will lead to SAW velocity of 3849,4240 respectively.

Although the presented method does not show that it is effectively used for characterization insertion loss at each frequency, the least square method can be used in this

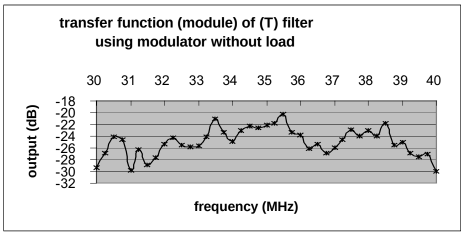

Fig .5 a

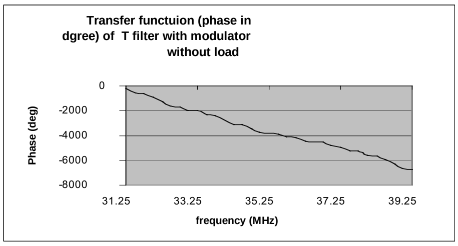

Fig.5 b

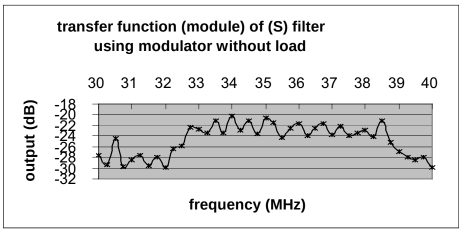

Fig .6 a

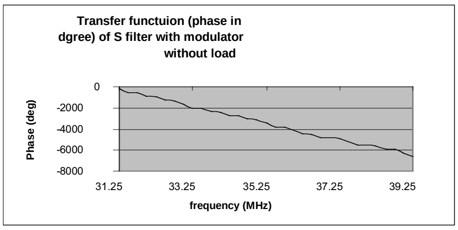

Fig.6 b

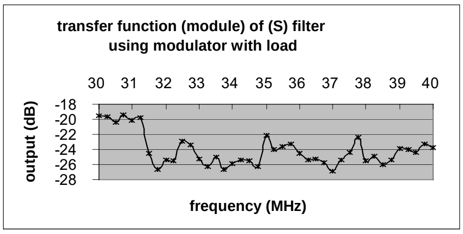

Fig .7 a

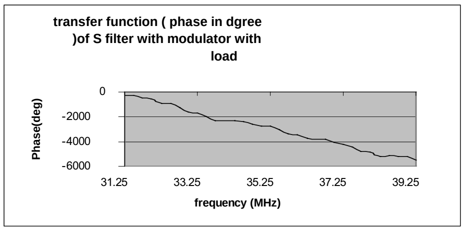

Fig.7 b

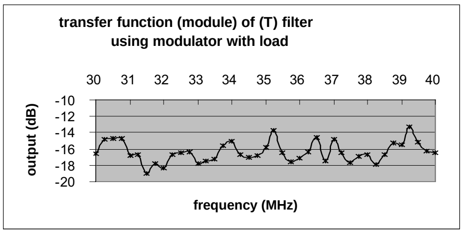

Fig. 8 a

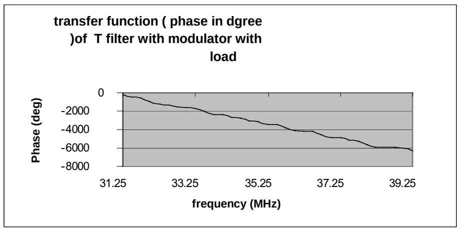

Fig. 8 b

technique, the measurement of the insertion loss (IL) can be expressed by $IL = a_0 f + a_1 f^2 + a_2 f^3 + \dots + a_{n-1} f^n$ where f is the frequency, and a_0, a_1, a_2,… , a_{n-1} are factors, from IL expression we can obtained the value of insertion loss at each frequency. In this practical measurement technique, the curve representing the behavior of the filter at different frequencies, will study the characterization of the filter.

V. CONCLUSION

The presented simple technique is shown to be effective in measuring the velocity of SAW device. The system is practical to implement and easy to apply, and is effective in testing or

characterizing SAW devices. This new method is developed that allow the measurement of SAW velocity, compared to the previous methods, this approach has the major advantages that uses commercial available devices, general approach, and can be used as tutorial technique. It is also shown that this technique is trend of SAW sensor.

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Appendix (I)

Equation derivation to calculate the free surface wave velocity (Vo)

Total time delay (t_{total}) is the sum of time delay due to input (t_m), propagation path (t_0) and output metal transducer (t_m) respectively.

$$t_{total} = t_m\ (i/p) + t_0 + t_m\ (o/p)$$

$$\frac{L`}{V_{meas}} = \frac{(L/2)}{V_m} + \frac{d}{V_o} + \frac{(L/2)}{V_m}$$

where L is length of transducer**,** d is distance between i/p and o/p transducers, V_m is metalized velocity, L` is effective length of transducer, L/2 is half length of transducer due to metalized ratio 50 %, V_{meas} is the measured velocity, V_o is the free surface wave velocity.

$$V_o = \frac{dV_m V_{meas}}{L`V_m - LV_{meas}} \qquad (1)$$

This is the same expression which, was obtained [4], but in the previous approach the non-metal distance between the i/p and o/p transducers were ignored, to consider this

$$\frac{L`}{V_{meas}} = \frac{(L/2)}{V_m} + \frac{(L/2)}{V_0} + \frac{d}{V_0} + \frac{(L/2)}{V_m} + \frac{(L/2)}{V_0}$$

$$V_o = \frac{(d + L)V_{meas} V_m}{V_m L` - V_{meas} L} \qquad (2)$$

there is difference term between the obtained value of free surface velocity and what was published [4]

$$\text{equal} \quad \frac{LV_{meas} V_m}{V_m L` - LV_{meas}}$$

In previous equation d, L`, L, V_m are known, the only unknown V_{meas} which can be calculated from the phase of the transfer function

$\Phi_t (H_t) = \Phi_{i/p\ t\ r} - \Phi_{prop} + \Phi_{o/p\ t\ r}$

$\Phi_{i/p\ t\ r}$, $\Phi_{o/p\ t\ r}$ are phases due to input and output transducer, Φ_{prop} is phase due to propagation, w is the operating frequency.

$$\varphi(H_t) = \varphi\left(\frac{Z_e}{Z_e + R_G}\right) - \frac{w}{V_o} L` + \varphi\left(\frac{Z_S}{Z_S + R_G}\right)$$

input admitance $Y_{i/p} = G_a + j\ w\ C_T + B_a(w)$,

at resonance $\quad Y_{i/p} = Ga + j\ w\ C_{T,}$

$$= \frac{4}{\Pi} k^2 (Wo\ C_s) N^2 + j\ w\ C_T,$$

$$= 8\ k^2\ fo\ C_s\ N^2 + j\ w\ C_T$$

where $C_{T=}\ N\ C_s$

input impedance $Z_{i/p}$

$$Z_{i/p} = \frac{1}{Yi/p} = \frac{1}{8k^2 foCsN^2 + jwC_T}$$

For input transducer $Z_{i/p} = Z_e$,

$$Ze = \frac{1}{Ye} = \frac{1}{8k^2 foCsN^2 + jwC_T}$$

$$\frac{Z_e}{Z_e + R_G} = \frac{1}{8k^2 foC_s N^2 + jwC_T} \Big/ \left(\frac{1}{8k^2 f_0 C_s N^2 + jwC_T} + R_G\right)$$

$$\Phi\left(\frac{Z_e}{Z_e + R_G}\right) = \tan^{-1}\left(\frac{-WC_T R_G}{1 + R_G\, 8k^2 f_0 C_s N^2}\right)$$

Similarly for output transducer

$$\Phi\left(\frac{Z_s}{Z_e + R_L}\right) = \tan^{-1}\left(\frac{-WC_T R_L}{1 + R_L\, 8k^2 f_0 C_0 N^2}\right)$$

$$\Phi_t(H_t) = \tan^{-1}\left(\frac{-WC_t R_G}{1 + R_G\, 8k^2 f_0 C_s N^2}\right) - \frac{W}{Vmeas} L` + \tan^{-1}\left(\frac{-WC_T R_L}{1 + R_L\, 8k^2 f_0 C_s N^2}\right)$$

$\Phi_t(H_t)$ is measured practically, $\Phi_{transducer}$ is calculated for transducer, $\Phi_{prop} = \frac{w}{Vmeas} L`$,

$$\Phi_{prop} = \Phi_t - \Phi_{tran}$$

$, V_{meas} = -w\ L` / (\Phi_t - \Phi_{tran})$,

substitute V_{meas} in equation 1 we get free surface wave velocity V_0, if the two transducers are different and has length L_1, L_2 ,(1) and (2) respectively will be:-

$$v_0 = \frac{d\ v_m v_{meas}}{L'\ V_m - (0.5L_1 + 0.5L_2)v_{meas}}$$

$$v_0 = \frac{[d + (0.5\ L_1 + 0.5\ L_2)]v_m v_{meas}}{L'\ v_m - (0.5\ L_1 + 0.5L_2)v_{meas}}$$

Appendix (II)

Computer program flow chart