Acoustic Scattering Parameters of the Electrically Loaded Interdigital Surface Wave Transducer

Abstract—Acoustic scattering parameters for the interdigital transducer are calculated as a function of electrical loading and frequency using an equivalent circuit model of the interdigital transducer. Measurements of the surface wave scattering parameters at 100 MHz are reported which are in close agreement with theory. Applications of the interdigital array as an efficient reflector of surface waves and as a weak low-reflecting tapping transducer are discussed.

INTRODUCTION

An equivalent circuit model of the interdigital (ID) surface acoustic wave transducer has been described [1]. In that paper, some discrepancy was found between the predicted and the measured acoustic scattering coefficients of an electrically loaded ID transducer (see Figs. 9 and 10 in [1]). The discrepancy is resolved in this letter by extending the predictions of the equivalent circuit model to give scattering coefficients at frequencies slightly away from acoustic synchronism.

The ID transducer is a three-port device with two laterally symmetric acoustic ports and is usually excited by an RF voltage applied directly [2], or through an impedance matching network [3], to a third port, the electrical input terminals. As a result of bilateral symmetry two oppositely directed and equal amplitude surface waves are generated simultaneously with half the input power delivered to each acoustic port. When the surface wave is incident at an acoustic port the distribution of scattered power depends on the electrical loading. In general, the incident wave is partially transmitted and partially reflected while delivering some power to the electrical load resistance. The scattering parameters, presented below, give this distribution of power as a function of electrical loading and frequency for frequencies near the acoustic synchronous frequency of the transducer.

THEORY

The operation of an N-period transducer on Y-cut, Z-propagating lithium niobate is considered, and it is assumed that the device is well represented by the "crossed-field" model given in [1]. The transducer is viewed as a three-port network with one electrical port and two identical acoustic ports. Among the transducer properties described by the model are the power scattering coefficients for the situation of an acoustic wave incident at acoustic port 1. The three power scattering coefficients are:

\[ p_{31} = \text{fraction of incident power reflected at port 1} \]
\[ p_{31} = \text{fraction of incident power transmitted to acoustic port 2} \]
\[ p_{21} = \text{fraction of incident power coupled to the electrical load (port 3).} \]

In [1] simple expressions were given for \( p_{31} \) as a function of the load on the electrical port. It was assumed that the transducer is operated at the synchronous frequency where the acoustic wavelength equals the period of the interdigital array.

Here the results are extended to include frequencies near, but slightly away from, synchronism. \( \delta \) is defined as the fractional deviation of frequency from synchronism, i.e.,

\[ \delta = 2\pi \left( \frac{f - f_0}{f_0} \right). \]  

This quantity also appears in the admittance matrix description given in [11] of [1]. Suppose that the acoustic port 2 is terminated in the characteristic acoustic admittance \( Y_a \). Let the electrical port be terminated in \( Y_e \). These conditions and (11) of [1] then give the desired power scattering coefficients to first order in \( \delta \) [4]:

\[ p_{31} = \frac{\left( \frac{N\delta}{2} \right)}{D(N\delta, \bar{Y})}, \]

\[ p_{21} = \frac{\left( \frac{N\delta}{2} \right)}{D(N\delta, \bar{Y})}, \]

\[ p_{21} = \frac{2\delta}{D(N\delta, \bar{Y})}, \]

where \( \bar{Y} \) and \( \bar{Y} \) denote the real and imaginary parts of the normalized electric port load \( Y \), given by

\[ \bar{Y} = \frac{Y_L + j\omega C_T}{Y_a}. \]

The common denominator is

\[ D(N\delta, \bar{Y}) = 1 + 2 \left( \bar{Y} - Y_a \frac{N\delta}{2} \right) + \left| \bar{Y} \right|^2 \left( 1 + \frac{N\delta}{2} \right). \]

For the case of \( f = f_0 \) (i.e., \( \delta = 0 \)), (2) to (6) reduce to the corresponding equations given in [1] for \( Y_a = 0 \) or \( Y_a = \infty \). Since power ratios are usually measured in decibels, we define

\[ L_{ij} = -10 \log_{10}(p_{ij}) \text{ dB} \]

as the appropriate scattering loss quantities.

EXPERIMENT

As described in [1], the surface wave scattering parameters \( L_{ij} \) were measured at constant frequency as a function of electrical load. The results appear unaltered in this letter, and below they are compared with (1) through (6) for a frequency very near synchronism (\( \delta < 2\pi \)).

The sample used in these measurements is shown schematically in Fig. 1. Three identical ID transducers of \( N = 15 \) periods were photoetched from a 4000 A thick vacuum-deposited aluminum film. The propagating axes of the collinear transducers were oriented to within 20° of the Z-axis of the highly polished Y-cut surface of a lithium niobate crystal. Electrode width and spacing of 8.1 \( \mu \text{m} \) corresponds to the transducer synchronism frequency for measurement of radiation admittance versus frequency in [1] to be 104.5 MHz. The acoustic beamwidth was 0.050 inch corresponding to a measured transducer admittance and capacitance of \( G_a = 2.35 \times 10^{-4} \text{mhos and } C_T = 6.5 \text{pF} \), respectively. As shown in Fig. 1, the end transducers were matched electrically and used for excitation and detection of the surface wave scattered by the center array. The transducers were spaced by 0.600 inch (4.4 \( \mu \text{m} \)), and RF pulses of 3 \( \mu \text{s} \) duration at frequency \( f = 105.5 \text{MHz} \) were used for the measurements. The propagation loss between transducers was measured initially by electrically matching port 3. Neglecting network conduction loss, the insertion loss between ports 1 and 3 and 2 and 3 in Fig. 1 then corresponds to 6 dB bidirectional loss plus acoustic propagation loss, which measured 2.25 dB for both paths. Two experiments were performed. In the first [Fig. 1(a)], a variable inductor or capacitor of high \( Q \) was used to load port 3. The level of the first echo at port 1 and transmitted pulse at port 2 were measured as a function of load susceptance. A Wayne-Kerr 8801 admittance bridge was used, and corrections for the measured electrical characteristics of the network connecting the load to the electrical terminals of the transducer were made. In this manner the measured electrical load admittance was referred to the plane of the electrical terminals of the transducer.

In the second experiment [Fig. 1(b)], the loading network on the center transducer was designed to resonate the transducer electrode capacitance \( C_T \) and present a variable conduction at the electrical terminals of the transducer when the electrical load on port 3 was 50 \( \Omega \). In this manner, \( L_{11}, L_{21}, \) and \( L_{31} \) could be measured simultaneously using 50 \( \Omega \) detectors.

Fig. 2 compares the results of the first..
experiment with the predictions of (2) and (3) for \( \gamma = 0 \) and \( N_2 = 0.9 \), corresponding to \( f = 105.5 \) MHz and \( f_0 = 104.5 \) MHz in (2). For \( B_1 + \omega C_1 = 0 \) the transducer is highly reflecting with a transmission loss of 35 dB and reflection loss of zero dB within the \( \pm 0.25 \) dB measurement accuracy. The transmission loss of 35 dB corresponds to a load conductance of \( \Re Y_L = 10^{-4} \) mhos, or a circuit \( Q \) of 40. This value is consistent with the estimated loaded \( Q \) of the electrically resonant transducer at \( f = 105.5 \) MHz.

Fig. 3 compares the results of the second experiment with the predictions of (2) through (4) for \( \gamma = 0 \) and \( N_2 = 0.9 \). In both cases experiment and theory are in close agreement. Thus, it is clear that the disagreement found in [1] is a result of making the assumption \( \delta = 0 \).

**CONCLUSIONS**

The agreement between theory and experiment in Figs. 2 and 3 adds further support to the validity of the equivalent circuit model presented in [1]. Note that the scattering characteristics provide a sensitive experimental tool for determining the acoustic synchronous frequency. Moreover, the scattering characteristics of the 1D transducer suggest interesting device applications. The highly reflecting transducer provides a novel technique for efficient reflection of surface acoustic waves. It has been used as a parasitic element in the fabrication of a highly directional surface wave transducer [5] and might be employed in the design of surface wave switches, filters, and resonators. Fig. 3 shows that with properly designed electrical loading, a tradeoff of insertion loss versus the level of the reflected signal can be achieved. This may be of importance in the design of multiple tapped delay lines where high echo suppression is necessary and weak taping can be tolerated. It is also worth noting that the total scattered surface wave power measured was equal to the incident power to within an experimental accuracy of 10 percent. This indicates that no appreciable mode conversion to bulk waves or off-axis surface waves occurs at the scattering transducer.

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**REFERENCES**


**Correction to "Exact Solutions of Stepped Impedance Transformers Having Maximally Flat and Chebyshev Characteristics"**

In (15) of the above paper, page 380, the term in the denominator outside the bracket should have read \( 2\sqrt{R} \).

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