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Letter to the Editor

COMPUTATION ANALYSIS OF INTERDIGITAL TRANSDUCER[1])

РАСЧЕТНЫЙ АНАЛИЗ ВСТРЕЧНО-ШТЫРЕВОГО ПРЕОБРАЗОВАТЕЛЯ

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A short survey and comparison of interdigital transducer models is presented and the principles of simple models suitable for a rapid computational analysis are briefly described. It follows from theoretical and experimental results shown for the rather complicated interdigital transducer that the mixed field model should give satisfactory results in many cases.

Today the interdigital transducer (IDT) is almost exclusively used for the generation and the detection of a surface acoustic wave (SAW). From the physical point of view, the IDT is a very complicated three-dimensional electromechanical system, which does not allow the correct determination of all its properties by present computers. Nevertheless the satisfactory description of the IDT from the practical point of view can be obtained from a suitably chosen model.

The general form of the interdigital transducer electrodes on the surface of a piezoelectric medium is in Fig. 1. The SAW is generated and detected by means of an eliptically polarized dynamic field in the medium under the electrodes. The IDT models [1, 2, 3, 4] approximate this field with a different degree of accuracy, see for example Fig. 2. The most important and widely used models arranged with increasing complexity are: the δ-function model [1], the equivalent circuit model [2], the generalized equivalent circuit model [3] and the physical model [4].

The δ-function model approximates the normal component of the static electric field in Fig. 2a by a set of δ-functions that can be placed either into the centre of each finger (Fig. 2b) or at its edges (Fig. 2c), which is a somewhat better approximation. The relative SAW amplitude generated by the unit voltage on the transducer (the frequency characteristic) is given by formula

$$H(\omega)=\sum_{n=1}^{N} A_n \exp\left(j\omega \frac{x_n}{v}\right) \tag{1}$$

where A_n is the relative amplitude of a point source, x_n is its position, v is the SAW velocity, ω is the angular frequency of the unit voltage and N is the number of the sources.

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The relative amplitudes A_n are determined from the geometric form of the transducer electrodes. To obtain the absolute values, the physical properties of the substrate should be considered. The formula for the amplitudes derived from the comparison with the equivalent circuit model has the form

$$A_n^{(a)}=2K\sqrt{2f_0C_f} \tag{2}$$

where K is the electromechanical coupling factor, f_0 is the centre frequency of the transducer and C_f is the static capacity of the finger. The model with the absolute amplitudes is called the modified δ-function one.

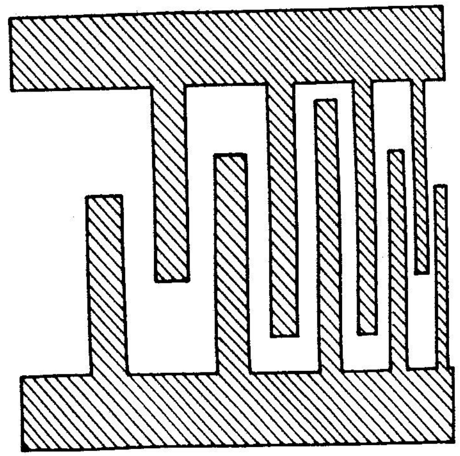

Fig. 1. A general schematic form of the IDT electrodes.

The equivalent circuit model approximates the two-dimensional static electric field under the fingers, sketched in Fig. 2a, by a one-dimensional one. The transducer is divided into sections, the section is usually the region consisting of one finger and the corresponding part of gaps on its sides. The simplest approximation considers the field perpendicular (Fig. 2d) or parallel (Fig. 2e) to the SAW propagation and is called the crossed field or the in-line field model, respectively. A much better approximation, the mixed field model in Fig. 2f, divides the section into three parts: without the electric field with the parallel and with the perpendicular electric field.

The section can be replaced by the equivalent electromechanical circuit [5] shown in Fig. 3 for the general case of the mixed field model. The mechanical circuit quantities are the force F and the acoustic velocity V, the electrical ones are the voltage U and the current I. The right part of this circuit is for the region of the section without the electric field.

The electromechanical circuit consists of the acoustic delay line with the mechanical impedance Z_m, ideal electromechanical transformer with the transform ratio p, the static capacity C_0 and the negative capacity — $C_0/\alpha p^2$. These quantities can be determined easily from geometric and material properties by the known formulae [5]. The coefficients α and β are derived from the experiment and l is the width of the section. The equivalent circuit of the crossed field and the in-line field model can be easily obtained by the choice $\alpha=0$, $\beta=0$ and $\alpha=1$, $\beta=0$, respectively.

In the unpodized IDT with the same finger length each section is replaced by the equivalent circuit and from their proper connection the equivalent circuit of the whole transducer can be made. The apodized transducer, as for example in Fig. 1, can be transformed into the previous case by a suitable choice of the transformer ratio or, more accurately, it can be divided by small strips into a system of small unapodized parallel connected transducers.

The generalized equivalent circuit model [3], which takes into account the actual normal component of the static electric field leads to a more complicated equivalent circuit than that in Fig. 3. The physical model considers the actual dynamic electric field in the transducer.

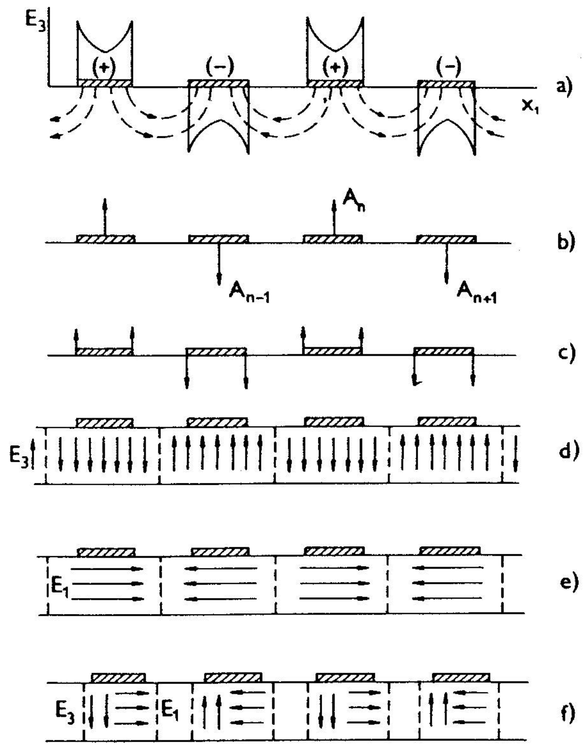

Fig. 2. Simple IDT models: a) a normal component of the electric field and its two-dimensional form, b) the δ-function model with point sources in the centre of fingers, c) the δ-function model with point sources at the edges of fingers, d) the crossed field model, e) the in-line field model, f) the mixed field model.

The comparison of all described models in Table 1 is based on the properties and the second order effects taken into account, namely the frequency characteristic, input impedance of the IDT, reflection of the SAW on the edges of the fingers, properties at higher harmonics, the generation of the volume waves and the SAW diffraction.

We have studied extensively the simple models and prepared some programmes for the application of the modified δ-function and the mixed field models to the general form of the transducer in Fig. 1. The

Table 1

Comparison of the IDT models

Model	Absolute characteristic	Input impedance	Reflection of the SAW	High harmonics	Volume waves	Diffraction
δ-function	—	—	—	—	—	—
modified δ-function	/	/	—	—	—	—
equivalent circuit	/	/	/	—	—	—
generalized equivalent circuit	/	/	/	/	—	—
physical	/.	/	/	/	/	—

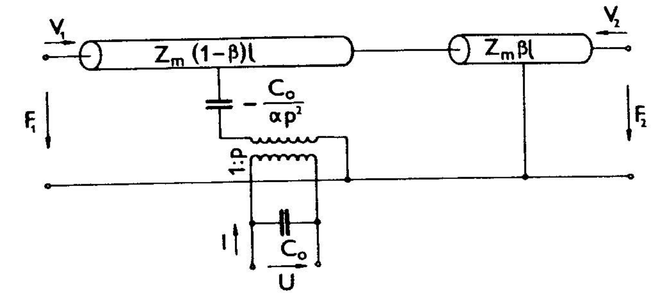

Fig. 3. The electromechanical circuit of the section using the mixed field model.

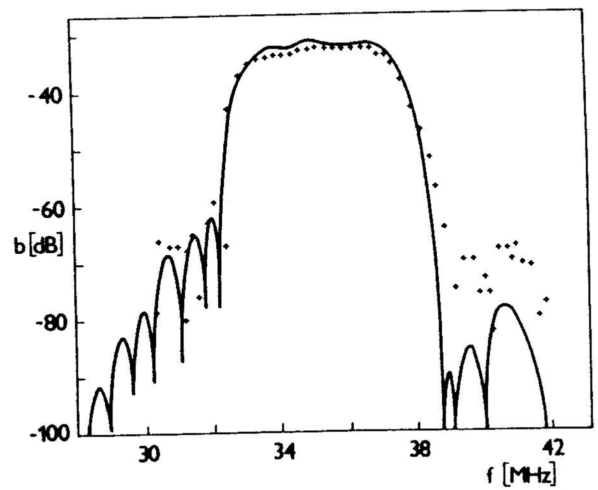

Fig. 4. The frequency characteristic of the intermediate frequency filter and comparison with the experiment.

frequency characteristic of the television intermediate frequency SAW filter [6] obtained by the application of the programme with the mixed field model and the variable transformer ratio is in Fig. 4. The experimental points of a randomly chosen sample are shown too. In the passband and the lower frequency stopband the agreement with the experiment is satisfactory. In the higher frequency stopband this agreement is only qualitative due to the generation of the volume waves which this simple model cannot take into account.

The applications of the IDT models and the programmes based on them are namely in the design and the analysis of the SAW electronic devices. They may be also used for the preliminary analysis and the possible optimization of transducers used in the physical experiments with the SAW and in the analysis of these measurements.

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