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An Analysis of a Mutual Capacitance of SAW Periodic Strips Having Different Metallization Ratio

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The analytical expression for mutual capacitance of periodic strips is presented in this paper. This expression utilizing the spectral theory is obtained. It is studied how the metallization ratio affects a mutual capacitance of periodic strips. The mutual capacitance of periodic strips as a function of metallization ratio, for split electrodes, was shown in the paper. This approach should be applicable to modeling of the surface acoustic waves interdigital transducers.

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1. Introduction

A surface acoustics waves (SAW) dispersive delay line consists transducer having thousand strips [1]. For the development of high-quality SAW devices we need to apply specific theory and simulations. Interdigital transducers (IDT's) practically are modeled as a periodic array of metallic strips placed on piezodielectric surface. The spectral theory, which take into consideration influence of a periodic grating structure on wave propagation, is one of the promising candidates for this purpose. The coupling problem between periodic electrodes structure due to the propagation of a surface wave under a periodic metal grating on a piezoelectric substrate is theoretically studied in many papers [2, 3]. The description of the surface acoustic waves can be based on the surface permittivity, which characterizes the phenomena on the piezoelectric material surface. For the analytical evaluation of SAW excitation and propagation under periodic electrodes the method presented in [2, 3] can be applied. Neglecting SAW, strip mutual capacitance can be obtained.

In this paper the analytical expression for mutual capacitance of periodic strips is obtained utilized the spectral theory. It is studied how the metallization ratio affects a mutual capacitance of periodic strips.

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2. The analysis of mutual capacitance of a periodic strips

The spectral theory of periodic strips [2] yields simply, physically relationship for the current I_n flowing to n-th grounded strip resulting from the applied voltage V_m to the m-th strip (Fig. 1):

$$I_n = \sum_m y_{nm} V_m, \tag{1}$$

where

$$y_{nm} = y^c_{nm} + y^r_{nm}. \tag{2}$$

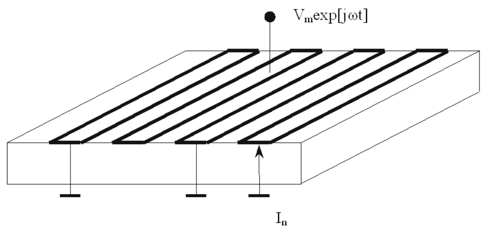

Fig. 1. Metal strips on a surface of a piezodielectric substrate.

Accounting for bulk waves results in complex SAW wave numbers for both the cases of isolated and short-circuited strips, it also affects the element factor characterizing generation and detection efficiency of periodic strips (the second component of Eq. (2)) [3].

The first component of (2) will be analyzed in the paper. We obtain strip mutual capacitance in the following form:

$$C_{pn} = \frac{y^c_{nm}}{\mathrm{j}\omega} = 2\varepsilon_\mathrm{e} \int_0^K \frac{P_{-r/K}(\cos\Delta)}{P_{-r/K}(-\cos\Delta)} \sin\pi\frac{r}{K} \mathrm{e}^{-\mathrm{j}r(n-m)\lambda} \frac{\mathrm{d}r}{K}, \tag{3}$$

where $r \in (0, K)$, and P — the Legendre functions, $\Delta = \pi d$, $d = w/\Lambda$, w — the strip width, ε_e — effective permittivity, $K = 2\pi/\Lambda$, Λ — the strip period (in computation we applied $K = 1$).

Equation (3) can be compared to their values obtained for $\cos\Delta = 0$ and $p = |n - m|$:

$$C_p = \varepsilon_\mathrm{e} \frac{4}{\pi} \frac{1}{1 - 4p^2}. \tag{4}$$

The same result was obtained in [4, 5]. However, the conductance and capacitance of periodic metal strips were related to the charge distribution and electrode currents in a single tap transducer. The shape of Eq. (4) as an "element factor" was written by Hunsinger [6].

It has been studied how the metallization ratio, from extreme low, to extreme high, affects the mutual capacitance of periodic electrodes in the paper. The dependence of C_p on the metallization ratio is strong for small p only. The

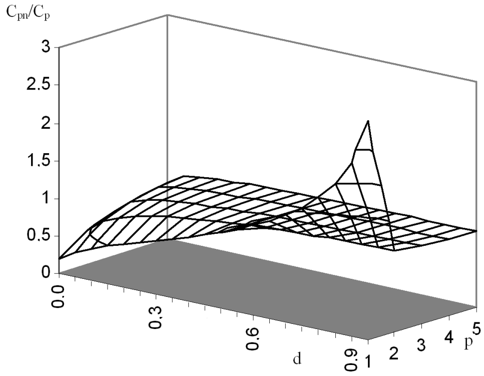

Fig. 2. The normalized interelectrode capacitance as a function of metallization ratio for five neighbors.

mutual capacitance of periodic strips as a function of metallization ratio, for split electrodes, has been shown in the paper.

From expression (4) we can see that the interelectrode capacitance depends on effective permittivity and on neighboring electrodes (p parameter). The main influence to the value of capacitance has a few neighboring electrodes, independently of the metallization ratio (Fig. 2).

It can be approximated by the following expression as a part of (3):

$$\eta = \int_0^K \frac{P_{-r/K}(\cos \Delta)}{P_{-r/K}(-\cos \Delta)} \sin \pi \frac{r}{K} \mathrm{e}^{-\mathrm{j}r(n-m)\lambda} \frac{\mathrm{d}r}{K}. \tag{5}$$

Under assumption that approximation error will be smaller than 0.1%, the following expressions have been obtained:

$$\eta(d) = \begin{cases} -0.02808 - 0.72954d + 1.4192d^2 - 1.31992d^3 & \text{for} \quad p = 1, \\ -1.30406 + \frac{1.25771}{d^{0.005}} & \text{for} \quad p = 2, \\ -0.03307 + \frac{0.01403}{d^{0.1}} & \text{for} \quad p = 3, \\ -0.01341 + \frac{0.003}{d^{0.16}} & \text{for} \quad p = 4, \\ -0.0076 + \frac{0.00104}{d^{0.2}} & \text{for} \quad p = 5. \end{cases} \tag{6}$$

The above analyzed structure of periodic electrodes contains two electrodes per SAW wavelength.

The normalized interelectrode capacitance of transducer having 4 electrodes per SAW wavelength is 1.41 times greater than for 2 electrodes per SAW wavelength, in case of $d = 0.5$ (Fig. 3).

3. Conclusions

A large number of practical transducers are modeled as a periodic array of metallic strips. A numerical analysis of the efficiency of periodic strips at higher overtones has been proposed in [3]. The analytical expression for mutual

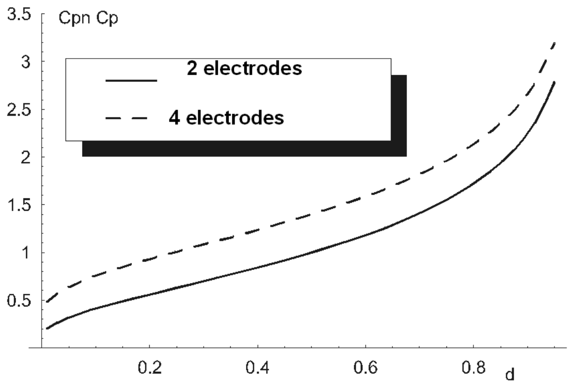

Fig. 3. The normalized interelectrode capacitance as a function of metallization ratio of electrodes.

capacitance of periodic strips was presented. The results obtained with the use of the spectral theory are in agreement with the results presented in previous papers [4, 7]. This expression utilizing the spectral theory is obtained. Efficient method to compute the static capacitance of both single and split finger electrode has been presented. The metallization ratio affects a mutual capacitance of periodic strips. The mutual capacitance of periodic strips as a function of metallization ratio, for split electrodes has been presented in the paper. This approach should be applicable to modeling of the surface acoustic waves interdigital transducers. The knowledge of mutual capacitance is especially useful for the SAW devices and the filters containing interdigital transducer.

An applying of the obtained functions makes it possible a fast calculation of a mutual capacitance of periodic strips having different metallization ratio.

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