SIMULATION OF ELECTROMAGNETIC EFFECTS IN SAW RF FILTERS

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Abstract

The characteristics of surface acoustic wave (SAW) filters are influenced by the electromagnetic properties of the immediate environment of the acoustically active structures.

This paper presents a model for electromagnetic effects caused by the filter environment. Here, the filter environment comprises the set-up surrounding the SAW structures, e.g., pads, bonds, pins, et cetera. The components, which are particularly relevant to the performance of SAW filters, are identified. Measurement and simulation are compared showing good agreement in the characteristics of the filter.

1 Introduction

With the electromagnetic behavior of the acoustical structures' immediate environment being very important for the overall filter performance, modeling of the filter set-up and the printed circuit board becomes a major concern in guaranteeing an accurate simulation. This paper presents a model for electromagnetic effects that are relevant to SAW filters.

The basic idea of the method applied in this paper is to split a SAW device into its physical components. For each of these components the electromagnetic behavior is described individually. Thus, for each component a subnetwork with lumped network elements is obtained. These subnetworks are put together to the network describing the electrical behavior of the whole device. Applying this method the computational effort can be kept reasonably low.

2 Components

To apply the described concept, the physical components, into which the filter is separated, must be selected very carefully. Especially, the interactions within the set of components should be negligible. The following set of components has been a good choice. It has been proved that, from the inner to the outer of the filter, the chip pads, the bonds, the package pins, and finally the printed circuit board influence the filter performance.

2.1 Chip Pads

Chip pads are metal structures on the chip that are not used for acoustical purposes. Examples are bond pads, connection pads, and bus bars. At high operating frequencies chip pads cannot be considered as ideal connections any more. On the contrary, they work as transmission lines which interfere with each other.

Regarding the cross-section view in Fig. 1, chip pads are metal strips over a metal groundplate which are separated by two dielectrics. The two dielectrics, i.e., the chip and the adhesive, are considered as one dielectric with thickness

$$D_{\mathrm{s}} = D_{\mathrm{c}} + D_{\mathrm{a}} \qquad (1)$$

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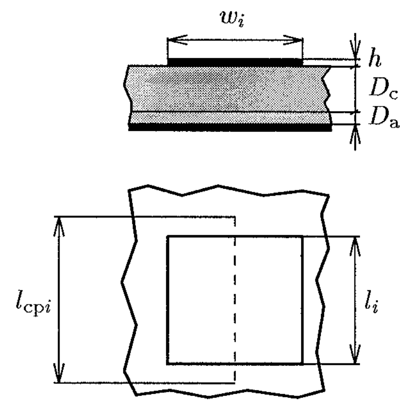

Fig. 1: View of chip pad.

and effective relative permittivity

$$\epsilon_{rs} = \frac{\epsilon_{rc}\,\epsilon_{ra}\,(D_c + D_a)}{\epsilon_{rc}\,D_a + \epsilon_{ra}\,D_c} \quad . \qquad (2)$$

Eq. (2) holds for both dielectric and conductive adhesives, if in the latter case, the thickness of the adhesive D_a is set to zero. With this simplification and the assumption that the heights of the metal strips and the metal ground-plate are identical, the configuration can be analyzed using formulae for microstrip lines.

Since these transmission lines are short compared to the electromagnetic wavelength, they can be represented by a simple network of lumped network elements. The left and right side of Fig. 2 show the equivalent circuit of two (distinct) chip pads i and j ignoring capacitance C_{ij} at this time. A chip pad is modeled by

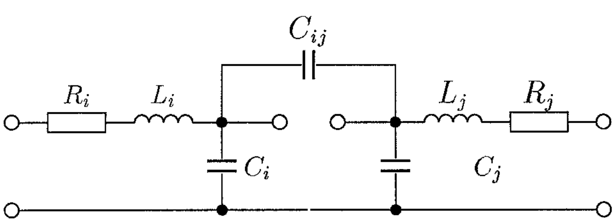

Fig. 2: Equivalent circuit of two chip pads.

an L-section of series resistance R_i and inductance L_i followed by shunt capacitance C_i. The equivalent circuit parameters L_i and C_i are derived from the distributed line parameters L'_i and C'_i of a loss-less microstrip line. The equivalent circuit parameter R_i is computed from the distributed line parameter R'_i using the sheet resistance $R_\square$ of a thin metal layer.

The distributed inductance and capacitance L'_i and C'_i are obtained from the electromagnetic wave velocity in vacuum c_0 and the propagation parameters of a microstrip line Z_{Li} and ϵ_{ri}^{eff}. The formulae for the characteristic impedance Z_{Li} and the relative effective permittivity ϵ_{ri}^{eff} of a microstrip line described in Fig. 1 can be readily found in textbooks [1]. Having calculated the distributed inductance and capacitance L'_i and C'_i, the equivalent circuit parameters L_i and C_i are easily obtained by multiplication with the current path length l_{cpi} and the chip pad length l_i, respectively.

The distributed resistance R'_i is given by $R'_i = R_\square / w_i$ with $R_\square = \rho / h$ where $R_\square$, w_i, ρ, and h are the sheet resistance, the width, the specific resistance, and the metalization height of the metal strip, respectively. Eventually, the distributed resistance R'_i and the current path length l_{cpi} determine the equivalent circuit parameter R_i.

Investigations on interdigitated interdigital transducer (IIDT) filters by Fischerauer et al. [2, 3] showed that there exists an electrostatic coupling between chip pads. Thus, the equivalent circuit in Fig. 2 is completed by a coupling capacitance C_{ij}, $i \neq j$. The capacitance C_{ij} is calculated numerically by analyzing the charge distribution on the complete pad configuration.

2.2 Bonds

Fig. 3 illustrates an individual bond wire connection. The shape of a bond wire is characterized by the three points where the bond wire touches the package pad (point A) and the chip pad (point B) as well as where the bond loop reaches its highest point (point C).

As shown in Fig. 4, the electrical behavior

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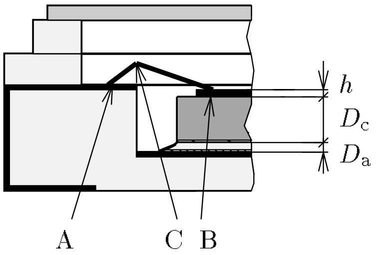

Fig. 3: Cross-section view of bond in SMD-package.

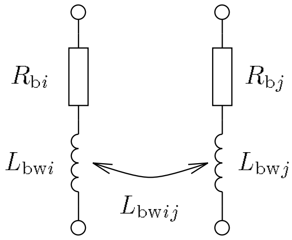

Fig. 4: Equivalent circuit of a pair of bonds.

of a pair of bonds is modeled by two bond resistances and one transformer representing the ohmic losses in the bonds as well as the self-induction and inductive coupling of the bond wires, respectively. The self-induction and the mutual coupling of the bond wires is given by the self-inductances L_{bwi} and L_{bwj} in conjunction with the mutual inductance L_{bwij}, $i \neq j$. These inductances are obtained numerically by discretizing the bond wires according to Fig. 3 in two straight sections. Then, the procedure in [2] yields a coupling matrix containing the desired self-inductances and mutual inductances. Ohmic losses due to the bond connection are considered by the bond resistances R_{bi} and R_{bj}. The latter resistances comprise the bond wire resistances as well as the transition resistances between bond wires/package pads and bond wires/chip pads.

2.3 Package

In order to model the electromagnetic behavior of the filter package, Fischerauer et al. [2, 3] describe certain parts of the package by means of several measurements. For this purpose they use self-made calibration standards which enable them to de-embed the package from the rest of the test fixture. The resulting description is given in Fig. 5.

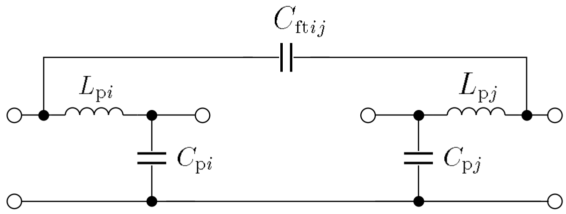

Fig. 5: Equivalent circuit of package pins and package feedthrough.

According to Fischerauer et al. [2, 3] the package pins exhibit a low-pass behavior. Thus, each single pin of an SMD-package is modeled by an L-section of series inductance L_{pi} and shunt capacitance C_{pi}. The circuit element values of such an L-C-low-pass, i.e., the pin inductance L_{pi} and the pin capacitance C_{pi}, have been measured.

Another effect caused by the filter package is a capacitive feedthrough from the filter input to the filter output, which was identified and measured by Fischerauer et al. [2, 3]. The feedthrough is introduced by the capacitance C_{ftij} between pins i and j as done in Fig. 5.

2.4 Printed Circuit Board

Finally, the printed circuit board, onto which the filter is soldered, has to be incorporated into the filter model. The reason is the non-ideal grounding resulting in a ground loop. A well known ground loop model for SAW transversal filters originating from Dufilié and Desbois [4] consists of an inductance L_{gl}. In Fig. 6 this model has been completed by a resistance R_{gl} to increase accuracy. Fig. 6 shows the equivalent circuit of the ground loop as well as its integration into the whole network.

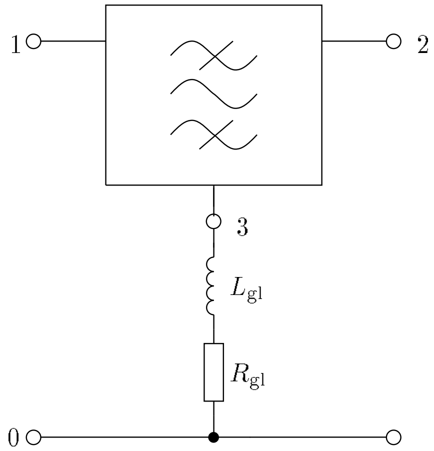

Fig. 6: Equivalent circuit of ground loop.

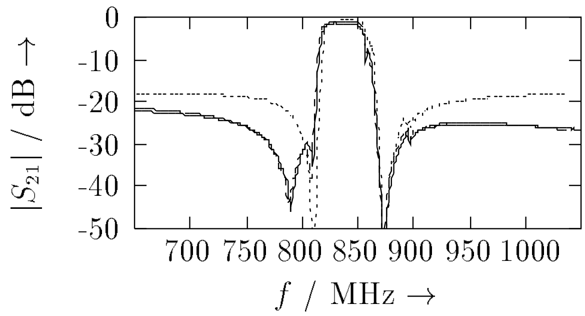

Fig. 7: Transmission function S_{21}

3 Comparison

Having modeled all components which have significant electromagnetic effects on the performance of a SAW reactance filter by subnetworks with lumped elements and having determined the corresponding element values, the network describing the complete filter can be put together. Inserting the SAW simulation results of the one-port resonators, the filter performance comprising acoustics and electromagnetics can be analyzed.

Comparison of measurement and simulation indicates excellent agreement in all filter characteristics. Fig. 7 displays the measured (solid line) and simulated (dashed line) transmission function S_{21} of the filter. Furthermore, a simple simulation (dotted line) without electromagnetics is included in this figure. Since this simulation obviously cannot be used to predict reality, the necessity to model electromagnetics becomes evident.

4 Conclusion

The paper proved the necessity to include electromagnetics of the immediate environment of the acoustically active structures into the filter model. Thus, models consisting of lumped network elements have been presented for the chip pads, the bonds, the package pins, and the printed circuit board. The simulations of filter models considering the electromagnetic effects of the components agreed excellently with the corresponding measurements.

References

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