MEASUREMENT OF THE EQUIVALENT CIRCUIT PARAMETERS OF TRANSVERSELY COUPLED SAW RESONATOR FILTERS

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Abstract - Transversely Coupled SAW resonator Filters (TCF's) are usually described by their transmission characteristics (S21) at a given termination impedance. The element values of their equivalent electrical circuit diagram can not be derived directly from these data. They are, however, important for the applications of TCF's in Voltage Controlled SAW Oscillators (VCSO). Because of the fundamental similarity of two-pole TCF's to bulk wave Monolithic two-pole Crystal Filters (MCF's), the equivalent circuit of a MCF can be used for describing the TCF. The circuit parameters can be determined from the measurement of the complex impedance at the symmetric and the antisymmetric frequency of the SAW device.
This paper describes the theoretical background and the measurement procedure, and presents experimental results showing a good correlation between the observed filter performance and the results computed from the equivalent circuit parameters obtained with this method.

INTRODUCTION

In the last few years Transversely Coupled SAW resonator Filters (TCF's) have found a wide field of application. They were first presented by TIERSTEN and SMYTHE in 1975 [1]. This filter type offers a small bandwidth, very low insertion loss across the passband, steep passband skirts, high stopband rejection and a small size. Therefore they are used for Voltage Controlled SAW Oscillators (VCSO's) [2] and in communication systems [3].
The basic configuration of a TCF is shown in Fig.1. This two-pole filter consists of two (usually identical) SAW resonators, which are in close longitudinal proximity to each other. The fundamental symmetric and the first antisymmetric wave mode are important for the filter performance (see Fig.1). HARTMANN et al. [4] presented a Coupling-Of-Modes theory and an equivalent electrical circuit diagram for TCF. Fig.2 shows this electrical circuit. Y_A and Y_B are two serial resonant circuits.
A TCF unit is usually described by its transmission characteristic (S21) at a defined termination impedance. The element values of the equivalent electrical circuit can not be calculated from these S21-data directly.

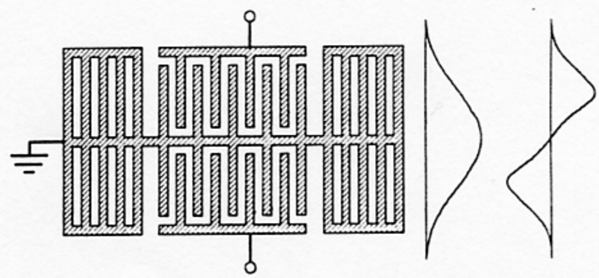

Fig.1: Basic configuration of a Transversely Coupled SAW resonator Filter (TCF)

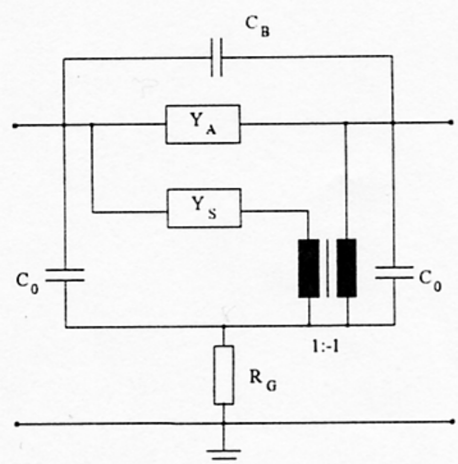

Fig.2: Equivalent electrical circuit diagram of a TCF (HARTMANN et al. [4])

It is possible to use a numerical optimization method to get the element values from the S-parameter data and a good fitting between the measured filter characteristic and the computed characteristic of the equivalent circuit. But in most cases it is only possible to get a very good correlation for one part of the S21-characteristic, either magnitude or phase. The fitting method is complicated, time consuming and has a high risk of ill-conditioned results due to the large number of interdependent variables. Therefore it is a problem to calculate the element values with help of a fitting method.

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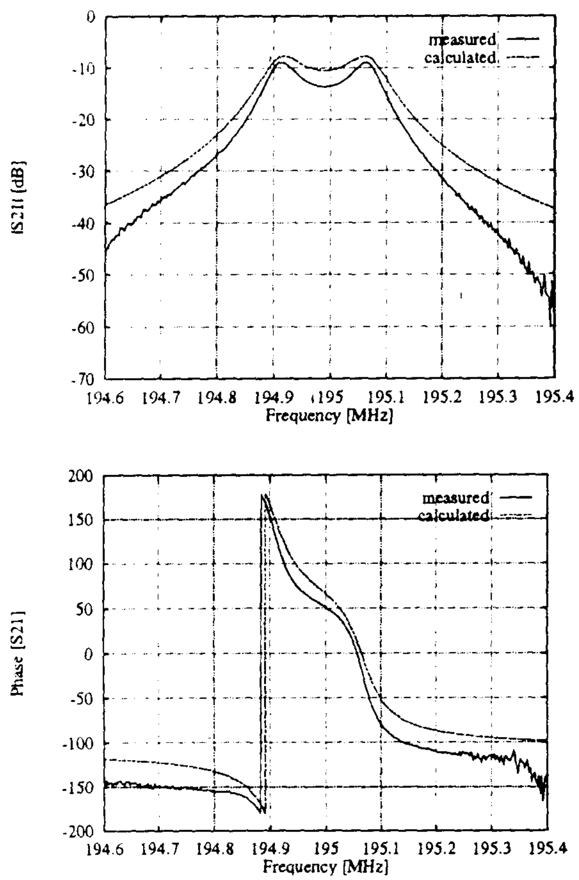

Fig.7: Comparision of the measured and the computed S21-charactertistic

DISCUSSION

A good correlation between both characteristics in magnitude and phase in the range from 194,6 MHz to 195,4 MHz is observed, especially in the passband area. The remaining difference is mainly due to the non-ideal adapter between the Pi-network reference plane (used for calibration) and the SAW device leads.
The correlation observed in the stopband area shows larger differences. One reason therefore is that C_B and R_G were neglected in the MCF-like equivalent electrical circuit. Disturbing modes present in the SAW device are also not considered in the equivalent circuit.

SUMMARY

The presented method allows the fast and simple determination of the values of the equivalent electrical circuit elements of TCF's, which is very useful for circuit simulations, e.g. in oscillator applications (VCSO's) and other applications with main attention in the passband area. The paper describes the theoretical background of the method, the measurement procedure and presents experimental results showing a good correlation in the passband area between the observed filter performance and the results computed from the equivalent circuit parameters obtained with this method.

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THEORETICAL BACKGROUND

There is a fundamental similarity between a two-pole TCF and a MCF.
The idea is to use the well known equivalent circuit of a MCF for characterizing the TCF. Fig.3 shows one possible equivalent circuit diagram for MCF's.

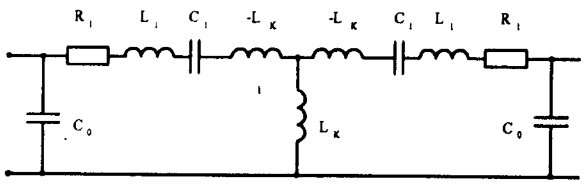

Fig.3: Equivalent electrical circuit of a MCF with inducting coupling network

Usually the equivalent electrical circuit of this passive two-port device has a symmetrical structure. In this case it can be transformed into the equivalent structure of a X-network. This transformation can be done using the bisection theorem of BARTLETT [5]. The basic principle of this theorem is illustrated in Fig.4.

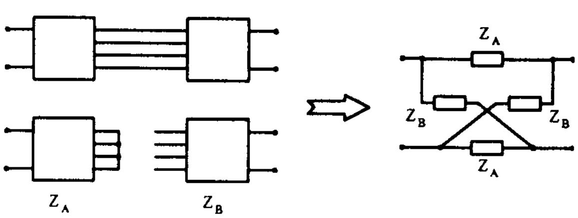

Fig.4: Bisection theorem of BARTLETT [5]

The result of this first step of the transformation is a X-network as shown in Fig.5a, 5b. After two other steps (see Fig.5c, 5d) the transformation provides an electrical circuit which is identical to the circuit of HARTMANN et al. [4] but without R_G and C_B.

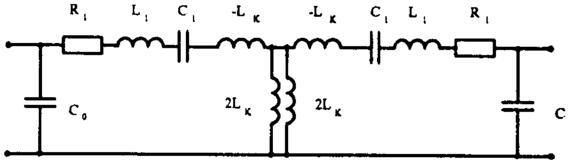

Fig.5a: The MCF-like equivalent circuit as a two-port device with symmetrical structure

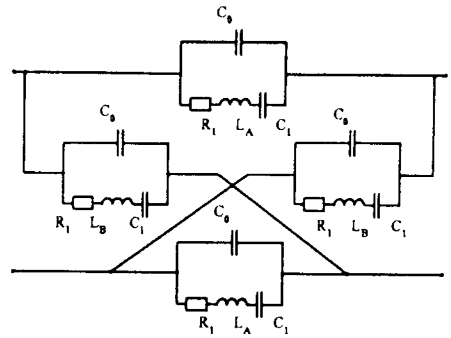

Fig.5b: Transformation into a X-Network, using the BARTLETT-Theorem (with $L_A=L_1-L_K$ and $L_B=L_1+L_K$)

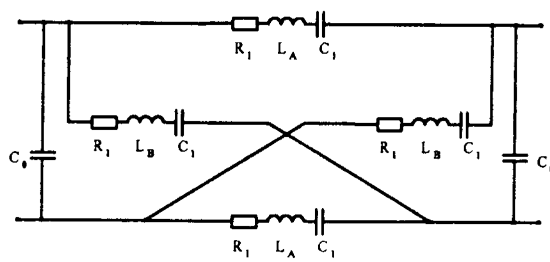

Fig.5c: Next step of the transformation of the equivalent circuit

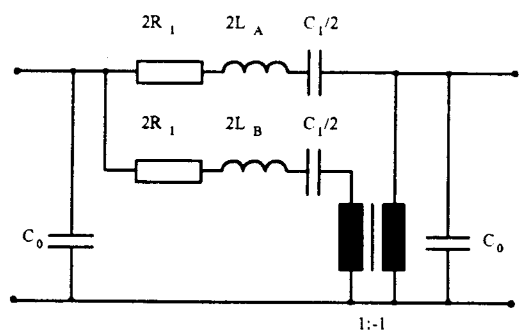

Fig.5d: Structure of the equivalent electrical circuit after finishing the transformation

This illustrates the similarity between the two filter types and the possibility to use a MCF-like equivalent electrical circuit for describing a TCF unit.
For most VCSO applications the neglecting of R_G and C_B can be accepted because the two elements have only influence on the stopband performance of the TCF whereas the VCSO characteristics are mainly determined by the passband parameter.

MEASUREMENT PROCEDURE

Filter units like MCF's or TCF's with two coupled resonators have two characteristic modes at two typical frequencies: the symmetric frequency f_{sym} and the antisymmetric frequency f_{asym}.
These modes can be activated if the two resonators are parallel-connected in the first case and serially-connected in the second case. Fig.6 shows both cases for a MCF unit [6].

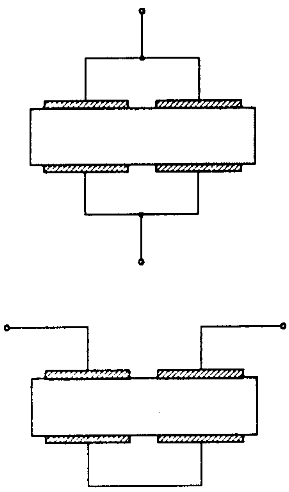

Fig.6: Symmetrical and antisymmetrical measurement mode of a MCF unit

The circuit with the connected resonators works as a one-port device. In both modes this one-port device behaves like a single resonator with a resonance frequency f_{sym} and f_{asym} respectively and different values of the series resonant network.
In the symmetrical mode the frequency and the complex impedance (C*, R*) have to be measured, for the antisymmetrical mode only the frequency f_{asym} has to be determined. This can be done with S11 and /or S21 measurements in a 50 Ohm S-parameter test system. For frequencies below approx. 500 MHz the impedance can be determined alternatively by conventional amplitude and phase measurements in a transmission system using e.g. the Pi-network system with error correction according to IEC 444-5, as it is commonly used for bulk wave crystal measurements [7]. The frequencies f_{sym} and f_{asym} and the element values R*, C*, and the static capacitance C_0 are results of the measurement procedure.

With help of the equations (1)-(6) the element values of the MCF-like equivalent electrical circuit can be calculated :

$$C_1 = C^*/2 \quad (1)$$

$$R_1 = 2R^* \quad (2)$$

$$f_m \approx (f_{sym} + f_{asym})/2 \quad (3)$$

$$L_1 = 1/(4\pi^2 C_1 f_m^2) \quad (4)$$

$$L_{12} = 1/(2\pi^2 C_1 [f_{asym}^2 - f_{sym}^2]) \quad (5)$$

$$L_K = L_1^2/(2L_1 + L_{12}) \quad (6)$$

EXPERIMENTAL RESULTS

The measurements were done using a network analyzer HP8751A in combination with a Pi-network-system with error correction according to IEC standard 444-5, normally used for bulk wave crystal measurements. The TCF unit was connected to the Pi-network through an adapter element. The center frequency of the TCF was 195 MHz. For this device the following values were obtained:

f_{sym} = 194,910819 MHz

f_{asym} = 195,069492 MHz

R* = 34,8 Ohm

C* = 2,4 pF

C_0 = 2,6 pF

Fig.7 shows the S21-characteristic computed from the measured element values (magnitude and phase) of the MCF-like equivalent electrical circuit in comparison to the measured S21 response.