

W-CDMA RF FILTER WITH 60 MHz BANDWIDTH BASED ON PARALLEL CONNECTED BAW STACKED CRYSTAL FILTERS

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Abstract—This paper presents a novel bulk acoustic wave stacked crystal filter (SCF) configuration that improves the inherent narrow bandwidth of this kind of devices and increases their selectivity allocating transmission zeros in the stopbands. A set of parallel connected SCFs with their resonant frequencies split along the passband achieves the bandwidth improvement. The SCF detuning is carried out by the thickness of its middle metallic electrode. The filter response covers the 60 MHz bandwidth of a W-CDMA RF application working at 2.14 GHz. The use of SCFs considerably simplifies the layer stack configuration in contrast to other acoustically coupled structures as coupled resonator filters.

1. INTRODUCTION

Bulk Acoustic Wave (BAW) based filters have been spreading in mobile terminals during the last years due to their small size, high quality factor, Q , and high frequency operation [1]. The basic element of the BAW technology is the resonator. It possesses high Q because of the low losses of acoustic materials. Its miniaturization comes from its acoustic wave speed that is around five orders of magnitude less than in an electromagnetic wave [2]. Advances in IC processes have allowed thinning the BAW resonator plates to the order of μm . In this way high frequency operation can be achieved [3].

BAW technology filters are based on the electrical connection between resonators or on the coupling interaction between resonators in the acoustic or in the electrical domain. Ladder and lattice configurations are examples of electrically connected filters, Stacked

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Crystal Filters (SCFs) and Coupled Resonator Filters (CRFs) are examples of acoustically coupled resonators [4]. New generation wireless systems are requiring miniaturized filters, with wider bandwidths, less insertion loss and higher selectivity. At the same time, easy-fabrication structures are preferred due to their simplicity and less unintended effects.

This work presents a W-CDMA RF filter with the high miniaturization and low insertion loss typical of BAW technology and the layer configuration simplicity of SCFs versus CRFs. The main drawbacks of SCFs, which are poor bandwidths and low selectivity, have been overcome using the novel proposed design topology achieving a bandwidth of 60 MHz to fulfil the W-CDMA specifications and improving the selectivity allocating transmission zeros close to the passband.

2. STACKED CRYSTAL FILTERS

SCFs belong to the acoustically coupled resonators class of microwave BAW devices. They are composed of two basic BAW resonators stacked one on top of the other. Fig. 1(a) shows its plate structure consisting of top, middle and bottom metallic electrodes and piezoelectric plates between electrodes. The middle electrode is usually

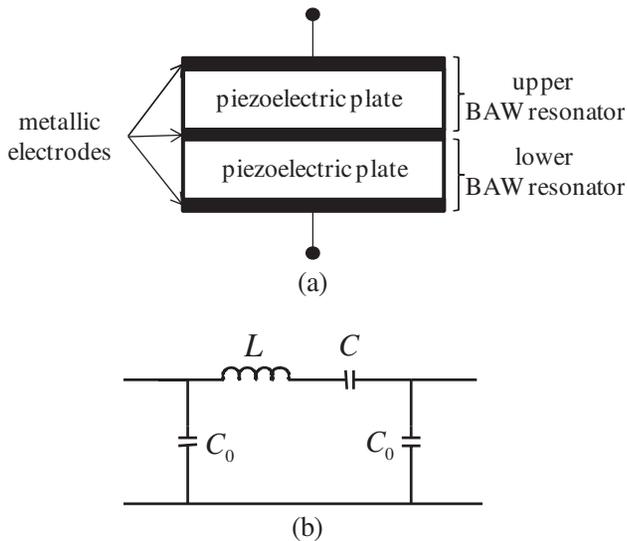


Figure 1. (a) Stacked crystal filter layer diagram and (b) equivalent electrical model.

electrically grounded shielding the electric fields between the input and the output. The input resonator turns the applied electrical signal to a mechanical one by means of its piezoelectric plate. The mechanical wave propagates to the output resonator where the signal is turned to the electric domain again. The two BAW resonators are absolutely not acoustically decoupled and in this way, both of them act as a single resonator as shown in its equivalent electrical circuit in Fig. 1(b) [5]. An acoustic longitudinal standing wave is created through the whole set of plates at the resonance frequency of the structure. The device must have suitable boundary surfaces that act to confine the mechanical wave to the resonance region. The capacitor C_0 models the intrinsic capacitance that is formed between electrodes.

Later, an extension of the SCF approach was presented [6], that new device, known as CRF, introduces a set of coupling layers between the two BAW resonators acoustically decoupling them. The set of passive coupling layers implements an impedance inverter which has to fulfill a desired coupling value [7]. The basic CRF behaves as a filter of order 2 and therefore it has been considered as a device that improves the attainable bandwidths of a SCF. Taking into account this bandwidth improvement, during the last years the efforts related to acoustically coupled resonators have turned to CRFs [8–10]. However, CRFs present a fabrication drawback regarding SCFs, the extra set of coupling layers makes its fabrication quite more difficult than in the SCF case. The number of coupling layers is usually 3 or 5 depending on the desired coupling and only for a single CRF stage. Meanwhile, in the case of a SCF, the total number of layers is not far from a simple BAW resonator making its fabrication easier.

In the next sections, a new topology based on SCFs is proposed to achieve filtering responses with bandwidths as wide as those that can be achieved with CRFs and moreover introducing transmission zeros close the pass-band increasing the slope of the transition to the stop-band. The proposed filter presents an advanced filtering response jointly with the fabrication easiness of SCF devices.

3. PARALLEL CONNECTED SCFS TOPOLOGY

In this section, a W-CDMA filter working at $f_0 = 2.14$ GHz, bandwidth of 60 MHz, order 4 and return losses of 22 dB is presented. One transmission zero is allocated above the pass-band and one below to increase the filter selectivity. The proposed topology is based on the parallel connection of resonators and each resonator is implemented with a single SCF. No resonator is coupled with another one but everyone is coupled with source and load following the nodal diagram

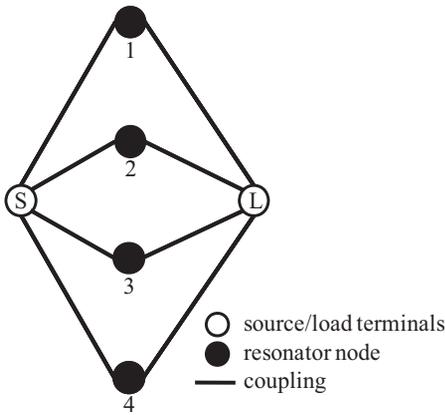


Figure 2. Nodal diagram of the parallel resonators topology.

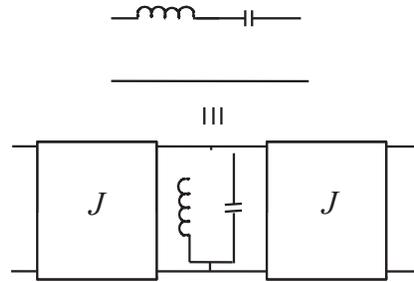


Figure 3. Equivalence between a series LC resonator and a shunt LC resonator.

shown in Fig. 2. The couplings between source or load and a resonator, that is to say the external quality factor (Q_e) of every resonator, and the self-couplings are determined from the filter specifications following a Chebyshev response filter synthesis procedure [11].

The shunt static capacitor, C_{0i} , of every SCF i is removed by means of a shunt inductor with the convenient value to cancel the capacitance effect at f_0 . In this way, the equivalent series resonator can also be expressed as a shunt resonator between admittance inverters as shown in Fig. 3 which can be identified with every branch of the parallel connected topology in Fig. 2.

The four presented SCFs have the same dimensions with the exception of their areas and the thickness of the middle electrodes. The control of the area determines the input and the output Q_e of the resonators and the control of the middle electrode thickness determines their resonance frequencies. During the design process all the layers of the resonators are taken into account to determine design parameters such as Q_e and the resonance frequencies. As shown in [12], it is important to include the electrode effect to the resonator behavior during the design process to obtain accurate results.

In this topology, each resonator presents a different resonance frequency determined from the self-couplings $M_{11} = 1.3696$, $M_{22} = 0.6927$, $M_{33} = -0.6927$ and $M_{44} = -1.3696$. Those asynchronous resonators provide a bandwidth enhancement of the overall filter response splitting the transmission poles along the passband. As the resonators are detuned by means of the middle electrode, all the other

layers remain identical in terms of thickness for all the resonators allowing a simple plate growing during the fabrication process due to these layers can be processed in parallel. The resonance frequencies of the SCFs that fulfil the specifications are $f_1 = 2.0993$ GHz, $f_2 = 2.1193$ GHz, $f_3 = 2.1609$ GHz and $f_4 = 2.1815$ GHz.

In this case, the Q_e between a resonator and the input or the output is the same and $Q_{e1} = Q_{e4} = 207.29$ and $Q_{e2} = Q_{e3} = 87.65$. In the SCF, it is the area that mainly controls the resonator Q_e . The proposed SCF symmetric geometry keeps the input and output Q_e equal as required, that is to say, if the frequency detuning were made by, for example, the upper electrodes, the input and the output Q_e would be different.

The parallel resonator topology demands a change of the phase sign between branches 1–3 and 2–4. In this work, a transmission line of impedance Z_0 and electric length of 180° has been added to the output of branches 1 and 3 to create the phase inversion. An additional effect of those lines is the contribution of an out-of-band transmission zero which does not present an inconvenient due to it contributes with higher selectivity to the overall response.

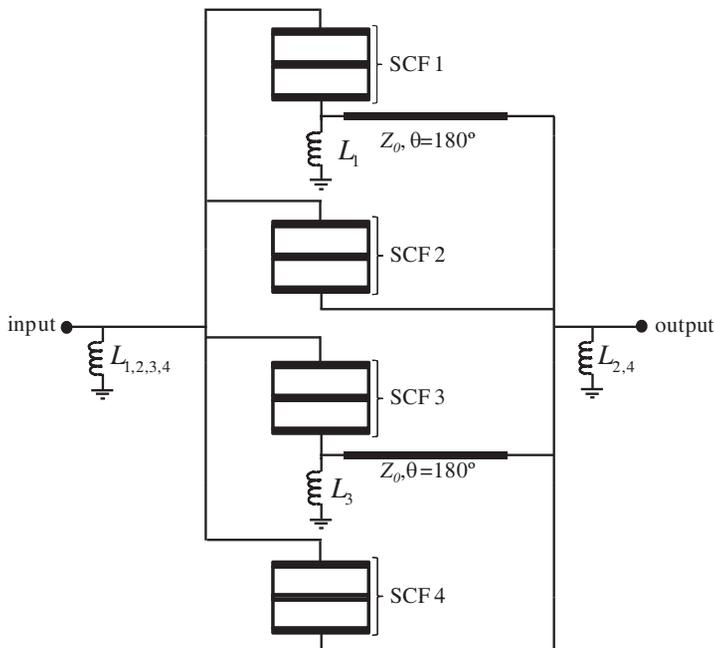


Figure 4. Parallel connected stacked crystal filters configuration.

Figure 4 shows the schematic of the proposed filter consisting of 4 parallel connected SCFs with the cancelling shunt inductors at their inputs and outputs. The shunt inductors that coincide in the same node have been turned to the equivalent one. Branches 1 and 3 present the above mentioned transmission lines.

The SCFs considered are composed of piezoelectric plates of aluminium nitride and electrodes of molybdenum. Table 1 summarizes their dimensions to fulfil the requirements in terms of Q_e and resonance frequencies. The values of the cancelling inductors are $L_1 = 21.05$ nH, $L_3 = 9.28$ nH, $L_{2,4} = 6.4$ nH and $L_{1,2,3,4} = 3.21$ nH.

4. FILTER RESPONSE

Figure 5 shows the individual response in terms of transmission of every SCF, which are tuned to their corresponding resonance frequency. Simulations have been obtained by means of Agilent's ADS software and the Mason model to take into account the acoustic effects. Each SCF also presents a different bandwidth due to the different Q_e to which they were designed. The losses of the electroacoustic device have been taken into account by means of the Mason model, which allows the inclusion of resistors which model the losses [4].

Finally, Fig. 6 shows the filtering response of the proposed structure with the 2 expected transmission zeros: 1 above the passband and 1 below. It is also present in the lower stop-band the above discussed transmission zero originated from the inverting transmission line of 180° . The quality factor of the resonators is about 1000. The insertion losses are better than 3 dB along the passband, a rejection better than 38 dB is achieved up to 2.06 GHz and from 2.22 GHz.

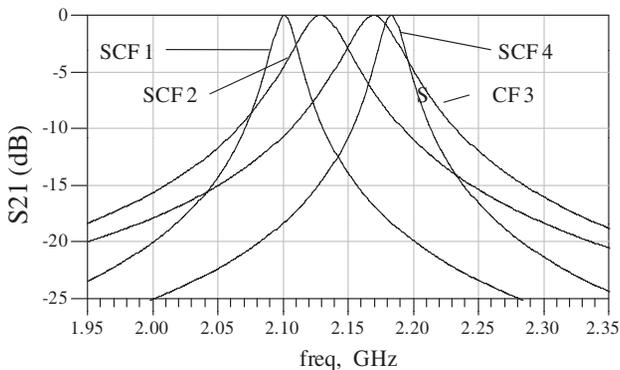


Figure 5. Individual S_{21} response of every stacked crystal filter.

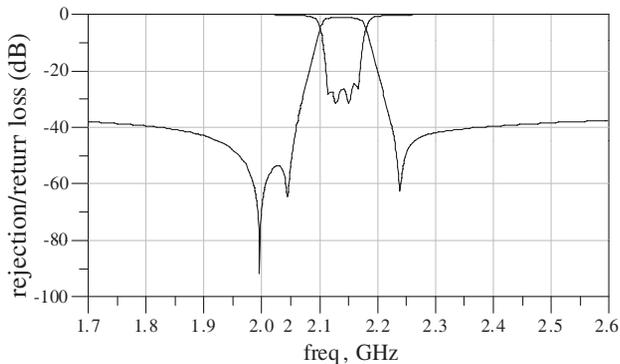


Figure 6. Response of the parallel connected SCFs structure.

Table 1. SCF dimensions

	SCF 1	SCF 2	SCF 3	SCF 4
Top electrode thickness (nm)	100	100	100	100
Upper piezoelectric thickness (nm)	2120	2120	2120	2120
Middle electrode thickness (nm)	133	116	84.4	69.4
Lower piezoelectric thickness (nm)	2120	2120	2120	2120
Bottom electrode thickness (nm)	100	100	100	100
Area (μm^2)	100	100	100	100

5. CONCLUSIONS

High selectivity filters usually involve the use of ladder structures which are limited in bandwidth due to the restrictions on their effective coupling coefficient. The use of ladder filters allows the presence of transmission zeros, which is the principle of the high selectivity of its passband. Acoustically coupled resonators have been used at the moment to provide passband filters with wider bandwidths but with less selectivity than ladder filters, not presenting transmission zeros. This work presents a novel topology composed of acoustically coupled resonators that allocate controlled transmission zeros in the passband and at the same time providing a wide bandwidth.

A miniaturized, high performance W-CDMA RF BAW filter based on Stacked Crystal Filters and on a novel topology applied to this technology has been presented in this paper. The use of parallel connected SCFs has increased their operative bandwidth covering a passband of 60 MHz required for W-CDMA systems working at 2.14 GHz. Moreover, the presented design allocates transmission zeros

close to the passband achieving an out of band rejection better than 38 dB up to 2.06 GHz and from 2.22 GHz.

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