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N-Plexer and N-Band acoustic filters based on transversal configuration

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Abstract— **This work shows the feasibility of using filters with transversal configuration to create N-Plexers and N-Band responses, by directly connecting several BAW filters in a transversal manner. The new multi-filtering solutions might indeed help on the existing and forthcoming challenges for LTE or 5G, such as the efficient management of the limited spectrum allocation or the non-contiguous spectrum, with the aim of increasing the network capacity and higher data rates. The filter arrangement proposed shows as well flexibility on dynamic scenarios like the ones occurring in a Carrier Aggregation (CA) access [1].**

Keywords— BAW Filters, Filter Synthesis, Multiband, Multiplexers, Carrier Aggregation, Transversal Filters.

I. INTRODUCTION

The evolution of the wireless communication technology is leading the new connectivity era where all devices have to be connected (IoT), having access to a large number of services and with a demanding increment of data rates (5G). This implies the coexistence of multiple technologies and operating bands in every single wireless device. In turn, the number of mobile subscribers is steadily increasing [1], which directly translates into an enlargement of mobile data traffic. Such scope demands for a continuous research on finding new solutions that help the mobile operators to efficiently handle the limited network resources and spectrum.

Carrier Aggregation (CA) techniques have been adopted to address the challenges of huge capacity demand. CA consists of combining multiple Long-Term Evolution (LTE) component carriers (CCs) across the available frequency spectrum, in order to support wider bandwidth signals and to increase data rates. Therefore, there is a special need of designing multi-frequency and dynamic RF filtering performances, in order to overcome the problem that the frequency spectrum is limited and non-contiguous.

So far, RF filtering functions have been certainly achieved by the use of electro-acoustic technology, which met the filtering demands, in terms of miniaturization, low insertion losses and selectivity [2], [3]. Increase of complexity on the filtering function, such as multiplexing has been performed along the past years, by applying smart tinkering approaches, whose solution starts by defining standalone filter networks which are later modified to be integrated into a more complex filtering solution. These steps are not trivial and require of large experience on the selection of the initial standalone filter topology, along with connection to other filters through a somehow matching network.

Providing multi-filtering solutions for the new access approaches (CA), might be a major challenge that needs of a more general and systematic solution, which allows to achieve dynamic multiplexing and multiband performance.

This work proposes and demonstrates the use of transversal acoustic filters [4],[5] as suitable network configurations to offer simple connection, without the inclusion of external matching networks between the standalone filters, for creating either multiplexing or multiband filtering responses. Such simple connectivity allows at the same time for a dynamic connection or disconnection of several filters, to accommodate the desired scenario, with barely affecting the responses of the connected filters.

The paper starts, in Section II, by recalling the concept of transversal configuration applied to acoustic resonators [4][5], and give details on the synthesis procedure to obtain the transversal networks. This will give insight on how later those filters can be connected with other transversal networks to provide N-Plexers and N-band filters.

In Section III.A, the synthesized response of a 9-Plexer is presented. In order to prove the feasibility of this approach, the frequency guards between the different bandpass filters are set to be quite close, demonstrating that a single band performance is barely affected by the near band filter. The response of the 9-plexer is evaluated in terms of transmission and reflection coefficients. This section also evaluates the case of deactivating two of the filters forming the 9-Plexer, i.e., resulting therefore in a 7-Plexer. The matching response in the 7-Plexer, still shows very good performance and the seven existing frequency bands do not deviate from the initial response.

To further illustrate the flexibility of the proposed approach Section III.B applies the same concept to create a multiband response with five different passbands. Last example, in Section III.C, gathers the two latter cases together, this is multiplexing and multiband configurations, in order to create a multiplexing configuration where each output (or input) of the device exhibits a multiband response.

II. Background: Transversal filter configuration

The transversal filter configuration consists on arranging all the acoustic resonators forming the filter in a transversal manner [4]. This is all individual resonators are electrically connected from the input to the output. The resulting response is then obtained from the contribution of each individual path, which depends on the impedance of the resonator and the way the resonator is connected to the input or the output. Although several approaches might exist, the most common approach results in a configuration where each signal path (each resonator path) is centered at a given in-band frequency. Note that this is somehow a multiband network where each band is set by an individual resonator. In order to be able to achieve any filter response, the sign of each individual path also matters. This results in a transversal configuration where either the input or the output needs to be performed by a balanced port. This function can be latter be offered by a balun section. The result of the transversal acoustic approach is then an unbalanced configuration electrically connected from input to output with two groups of branches: no shifted or positive branches and 180-shifted or negative branches.

This network configuration might provide any advanced filtering response, such as very wideband filters, and with an arbitrary number and position of the transmission zeros. Note that this is already an important advantage over the widely used ladder configuration. Even more significant is that the filter response does not depend on the electro-acoustic coupling coefficient. So, there exists full flexibility for prescribing the coupling coefficient of each individual resonator from the very beginning of the synthesis. Further circuit transformations into the initial transversal network help to provide further flexibility on the selection of the resonator impedances and their resonant frequencies [5], [7].

Below we outline the synthesis procedure to obtain the transversal network based on acoustic resonators. This will mathematically confirm the statement about arbitrary number of transmission zeros and their positions and the full flexibility on the selection of the coupling coefficient.

A. Synthesis of the Lowpass prototype

The synthesis procedure starts by selecting the characteristic polynomials to meet the filter electrical requirements, which fulfil the prescribed requirements. Those depend on the order of the filter, number and location of transmission zeros and nominal return losses. In this case, the synthesized response is a general Chebyshev type response, which allows all the responses achievable with acoustic wave resonators-based filter. Conventional synthesis approach can be applied to those polynomials to obtain a conventional transversal network [6], based on shunt LC resonators coupled to the input and output by an admittance inverter. Figure 1a illustrates the equivalent circuit corresponding to a single path of a conventional transversal network.

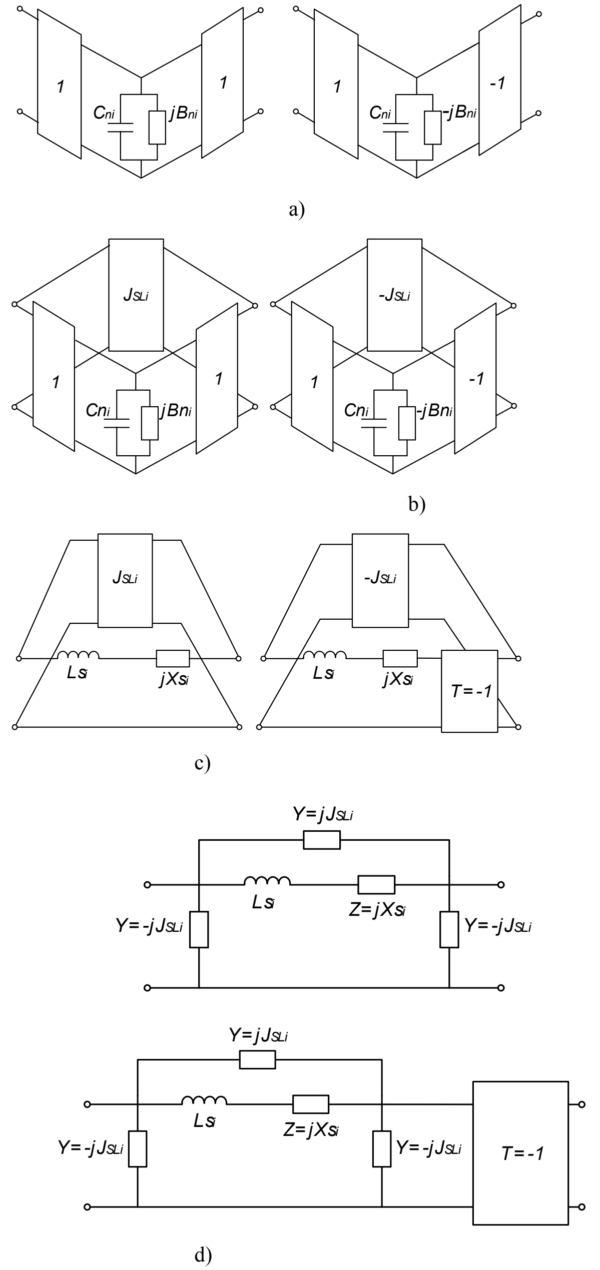

Fig 1. Outlined of the two transversal paths on the low pass prototype.

To continue outlining the synthesis procedure, let's assume a symmetric second order filter. Then, the transversal network would result in two branches as the ones in Fig. 1a. The impedance of the branch is defined by C_{ni}, equal for both resonators, and the mutual coupling (defined by the shunt reactance jB_{ni}), which is equal in magnitude and it has opposite phase and defines the resonant frequency of the resonators in the band-pass domain [6]. Figure 1a also reveals that the coupling to the output differs in 180º between the two branches. This always occurs in Chebyshev responses [6]. The next step is shown in Fig 1.b, where an admittance inverter (J_{SLi}) with opposite sign is added at each branch. It does not affect the frequency response since the branches are connected in parallel, so the effect is cancelled by each other. This latter statement also means that the selected value of the inverter can be selected by the designer. The shunt admittances are transformed into series impedances (Fig 1.c), where L_{Si}=C_{ni} and X_{Si}=B_{ni}. The term T corresponds to a transformer of -1 or a phase shift of 180º. The parallel inverters (J_{SLi}) can be transformed to a π–network circuit model which defines an admittance inverter [7]. The resulting circuit model of the two branches are defined in Fig.1d, where we can clearly identify the low-pass prototype of a Butterworth-Van-Dyke (BVD) circuit. The transversal admittance at Fig 1.d ($Y = jJS_{Li}$) will define the parallel capacitance on the bandpass BVD model, which defines the electro-acoustic coupling coefficient and value of the resonator series inductance (therefore, the impedance of the resonators) [3]. Note that this value was selected by the designer and it does not affect the filter response, which means that the electro-acoustic coupling is not a restriction on the achievable performance [4],[5]. The circuit model of Fig. 1d also reveals the existence of a shunt admittance $Y = -jJS_{Li}$, which results in an input and output shunt inductance in the bandpass model.

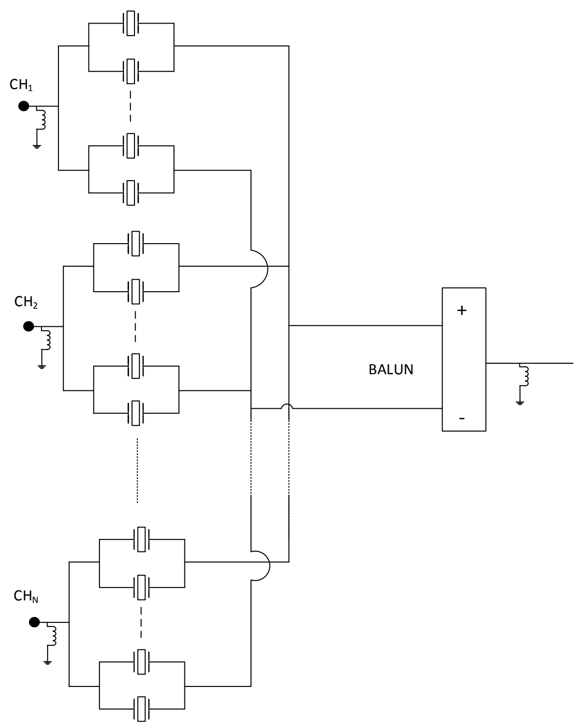

Fig 2. Transversal multiplexer topology.

III. Multi-operable Responses

The acoustic transversal technology allows to create multiplexers and multiband filters without including any additional matching network for interconnecting each filter or band. Moreover, there is no need of a special synthesis to integrate the complex filtering solution at all.

A. Multiplexers

In transversal multiplexers design, each band is defined by a standalone transversal filter and then, they are simply connected in a transversal manner again, as indicated in Fig. 2. Figure 3 shows a 9-Plexer response as an example. The overall bandwidth is almost 1 GHz. All the bands are very close located, and different bandwidths are used to synthesize each filter. For this example, we use the same low-pass prototype for all standalone filters, although there is no restriction in terms of combining bands with different specifications. As observed in Fig. 3, appropriate in band matching is met for all the filters.

As outlined in the introduction, this approach allows to disconnect filters without barely affect the performance of each band, as it shows Fig. 4. In this case, the 2nd and the 7th filters have been directly disconnected from the 9-Plexer. Then, the structure behaves as a 7-Plexer. This in an important aspect because it could be useful for techniques like CA where different bands are combined, or not, depending on how the demand of capacity is.

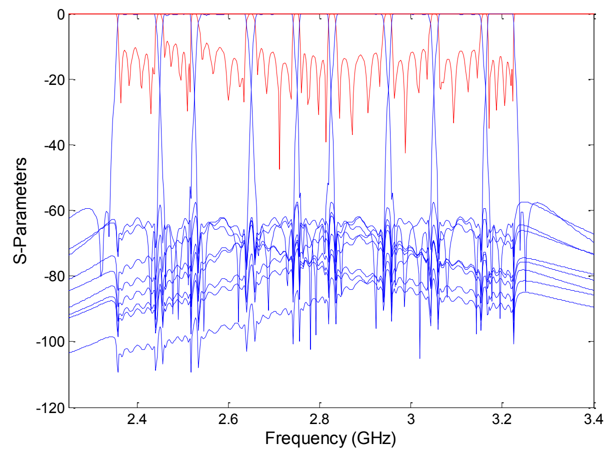

Fig 3. Transversal 9-Plexer response.

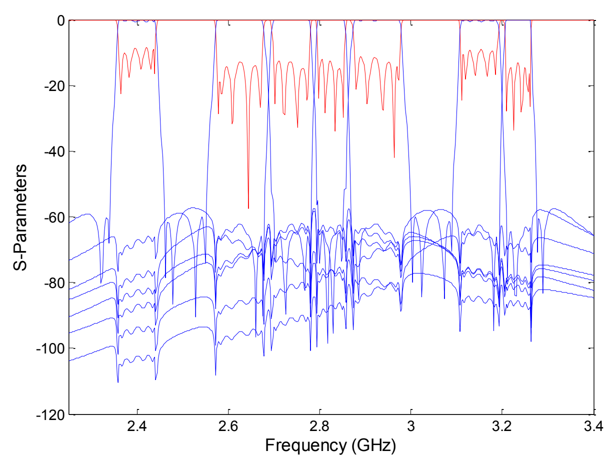

Fig 4. Transversal 9-Plexer response disconnecting 2nd and 7th filters.

B. Multiband filters

Multiband filters take benefit as well of the transversal configuration in the same way as the multiplexers. Figure 5 shows the network of a multiband filter, which has been created by directly connecting the input and output of the standalone transversal filters. In the configuration of Fig. 5, all the inputs are connected together while the outputs are connected to the positive and negative ports of an eventual balun. Since the performance of a standalone single-band filter does not depend if the resonators are connected to the positive or negative node of the balun, as long as they keep the 180º shift, the designer can select where to connect the output branches of the individual filters. This creates many arrangement combinations to produce the multiband response.

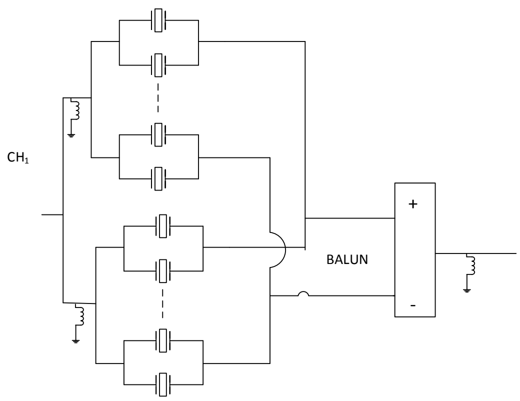

Fig 5. Transversal multiband filter topology.

Figure 6 outlines the transmission and reflection coefficients of two different arrangements of the multiband network. Note that all the responses overlap fairly good in the in-band, for both transmission and reflection, but differ out-of-band, where the rejection is larger for the combination outlined in green. This property indeed offers more flexibility on the design of multiband responses.

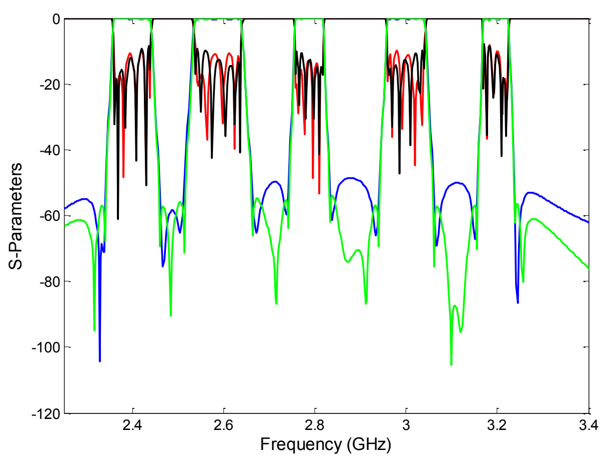

Fig 6. Transversal Multiband filter response.

C. Multiband 2-Plexer

The two previous configurations directly might lead to the creation of multiplexer with multiband responses by arranging the filters as a combination of Fig. 2 and 5. This last subsection shows the frequency response of a duplexer where each branch of the duplexer performs as a multiband filter, one as a 5-band filter, and one as 4-band filter. Results of such response are detailed in Fig.7, where we can clearly identify the performance of each branch. This response uses the same filters than in section III.A for the 9-Plexer. The performance of this structure is similar to the 9-Plexer in Fig. 3.

CONCLUSION

This work demonstrates that the use of the novel transversal topology based on acoustic wave resonators could be extended in order to get complex filtering solutions. Multiplexers and multiband filters covering a wide range of frequencies and with very near bands can be synthesized without the need of applying any additional process to interconnect the different filters composing the whole structure. Current challenges like the limited spectrum allocation or the non-contiguous spectrum could be solved by designing filters following this technology.

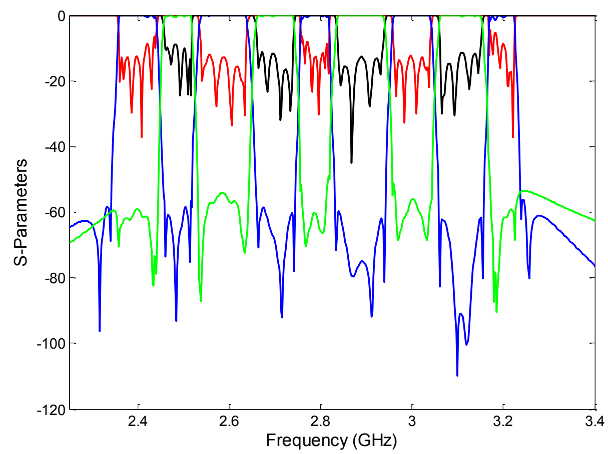

Fig 7. Transversal Multiband 2-Plexer response.

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