# Bandwidth And Central Frequency Control On Tunable Bandpass Filter By Using MEMS Cantilevers

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*Abstract* — **This paper deals with a tunable bandpass filter topology which controls independently and simultaneously both the central frequency and bandwidth. This tunable filter results from the association of MEMS cantilevers, used as variable capacities, with an original passive topology. The latter is based on Dual Behavior Resonators (DBRs), each of them is constituted of low- and high-frequency open-ended stubs. The associated filter electrical response is characterized by tunable frequency transmission zeros. A millimeter bandpass filter with central frequency and relative bandwidth tunability of about 10 and 75%, respectively, is presented.**

## I. Introduction

The growing number of multi-standard and multi-application telecommunication systems has led to the development of new tunable filter topologies. Nevertheless, neither the central frequency nor the bandwidth is independently and simultaneously controlled by the existing tunable filters. These structures are, indeed, based on classical topologies of coupled lines or quarter wavelength stubs filters according to the required bandwidths. In these topologies, the central frequency is perfectly controlled by the line lengths, but the bandwidth can only be modified through coupling or impedance level(s) control [1],[2].

In this paper, we describe a novel tunable filter topology that allows the independent and simultaneous control of both the central frequency and bandwidth of the pass band. This topology, termed Dual Behavior Resonator (DBR), is based on the parallel association of two different open-ended stubs. It creates a pass band between the two transmission zeros associated to each stub [3],[4]. Central frequency- and bandwidth-tuning are both obtained by adding a variable capacity at the end of each open-ended stub to modify the stub electrical length and, thus, the associated transmission zero frequency.

Thanks to very good performances in terms of losses, noise and consumption, variable capacities are realized through MEMS cantilevers. To obtain continuous frequency tunability, MEMS are used in their stable region. Then, as their capacitance variation is low, the filter is designed in the millimetric frequency band.

## II. Passive Topology and Tuning Principle

In this first part, we will discuss about the passive DBR topology to finally introduce the principle used to tune central frequency and bandwidth.

### A. Passive DBR topology

A DBR resonator (Fig. 1) results from the parallel association of two different open-ended stubs. In the particular case of uniform stubs, each of them creates a transmission zero whose frequency is fixed by the stub length. A pass band can then be created by a constructive stub impedance-based recombination (Fig. 2). The use of a specific and original synthesis allows the calculation of all the parameters of an n-order filter for desired specifications both in the pass band and in the attenuated region. According to the numerous freedom degrees, the characteristics of bandwidth and of the lower- and upper-attenuated bands can be independently controlled.

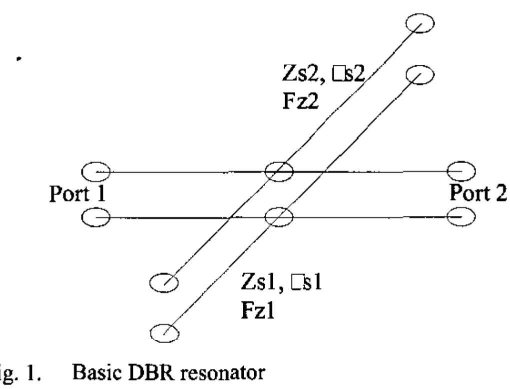


Fig. 1. Basic DBR resonator



 

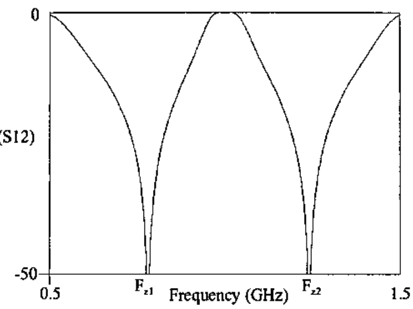


Fig. 2. Frequency response of a basic DBR.

*B. Tuning principle*

By modifying the stub electrical characteristics, jointly or not, the central frequency and bandwidth of the bandpass filter can be varied. In fact, each transmission zero frequency is associated with only one stub, and then the two transmission zeros, $F_{z1}$ and $F_{z2}$, are independent.

To realize an n-order filter, n DBRs are needed. Then, the frequency of only one, or many, transmission zero(s) is modified by changing the electrical length of the corresponding stubs. This can be done by adding a variable capacity at the end of each stub: it thus enables one to modify, jointly or not, both the central frequency and bandwidth. Size optimization allows one to keep a correct matching level in the pass band despite important changes of transmission zero frequencies. Fig. 3 gives an example of a second-order DBR filter with additional variable capacities $C_1$ and $C_2$. Initially, the central frequency of this filter is 30 GHz and its 3-dB relative bandwidth is 10% with $C_1 = C_2 = 125$ fF. To obtain continuous central frequency or bandwidth tunability, the capacities are varied from 100 to 150 fF. These values are equivalent to the MEMS ones; they will be used later in our application.

To obtain continuous central frequency variations with this filter, the capacities, $C_1$ and $C_2$, are tuned jointly and continuously. Nevertheless, keeping the same bandwidth requires to adjust the value of each of them independently of the other. Fig. 4 illustrates variations of the central frequency: it tunes from 28.55 GHz ($C_1 = 150$ fF and $C_2 = 140$ fF) to 31.61 GHz ($C_1 = 100$ fF and $C_2 = 110$ fF). The relative central frequency tuning is then 10.2%. In the same time, the 3-dB relative bandwidth of our filter is kept equal to 10%.

The bandwidth tunability is based on opposite variations of the capacities $C_1$ and $C_2$. One should note on Fig. 5, for a second-order DBR filter, a continuous variation of the bandwidth between 5.9% ($C_1 = 100$ fF and $C_2 = 142$ fF) and 14.8% ($C_1 = 150$ fF and $C_2 = 110$ fF), which is equivalent to a relative bandwidth tuning of 89%.

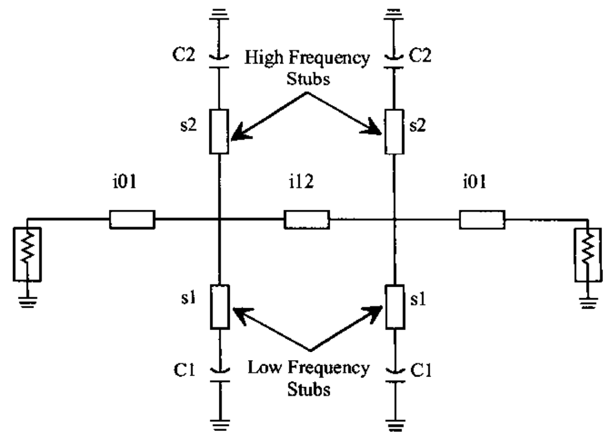


Fig. 3. Ideal second-order DBR filter with variable capacities

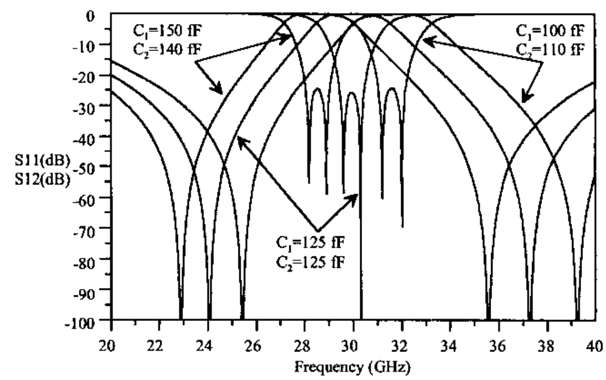


Fig. 4. Central frequency variations of an ideal second-order DBR filter.

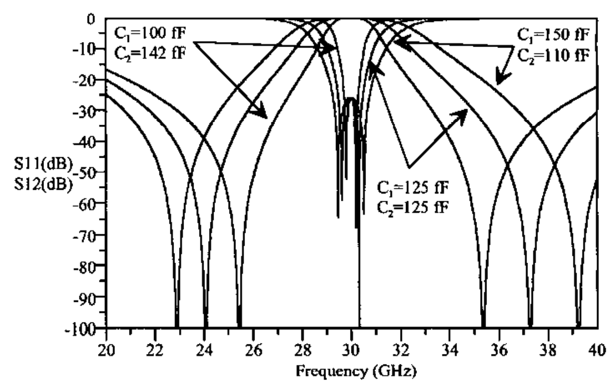


Fig. 5. Bandwidth tuning of an ideal second-order DBR filter

The above examples were simulated in ideal lines; they show the tuning possibilities offered by the DBR filter topology. With such a topology, the central frequency and bandwidth of the filter are both controlled independently and simultaneously through the use of independently controlled variable capacities.

### III. APPLICATION

We used the above tunable filter principle to achieve a second-order DBR filter using MEMS cantilevers as variable capacities.

### *A. MEMS use and fabrication process*

MEMS cantilevers were chosen because this technology offers higher performances than lumped components about near-zero power consumption, high isolation, low insertion losses, low noise,... [5].

In our application, electrostatically actuated MEMS cantilevers are laid at the end of each resonator. A MEMS cantilever is equivalent to a series capacity. Its capacitance is inversely proportional to the distance between its two electrodes. This distance can be changed by applying a DC bias voltage between the electrodes. MEMS are used either as ON/OFF switches by applying a critical voltage, called pull-down voltage, to obtain discrete variations of their capacitance, or in their stable region by applying a bias voltage below the pull-down one to produce continuous variation of the capacitance. Here, we used the second solution to get continuous variations of the central frequency and the bandwidth.

MEMS fabrication starts with the deposition of a 300Å/9000Å Cr/Au evaporated layer on a 1-mm thick fused silica substrate. Cr/Au is patterned, and a 2000-Å thick alumina layer is deposited with a laser ablation deposition system. This layer is then lifted off, and forms an insulating film that prevents direct contact between the first and second metal layers. Then, a 2.8-µm thick sacrificial layer is spun and patterned onto the wafer. A second layer of 50Å/1000Å Ti/Au layer is evaporated, and gold is electroplated up to 3 µm. Once this last metallization has been patterned, the sacrificial layer is removed and the component released using a $CO_2$ critical point drying system.

### *B. Second-order tunable DBR filter*

Fig. 6 presents the photograph of the second-order tunable filter fabricated at the IRCOM laboratory. The filter is composed of low-impedance, low-frequency stubs and high-impedance, high-frequency stubs. For low- and high-frequency stubs, two and one MEMS are used, respectively. Each actuation system is realized by using a decoupling capacitor in order to dissociate the MEMS height variations from one stub to the other.

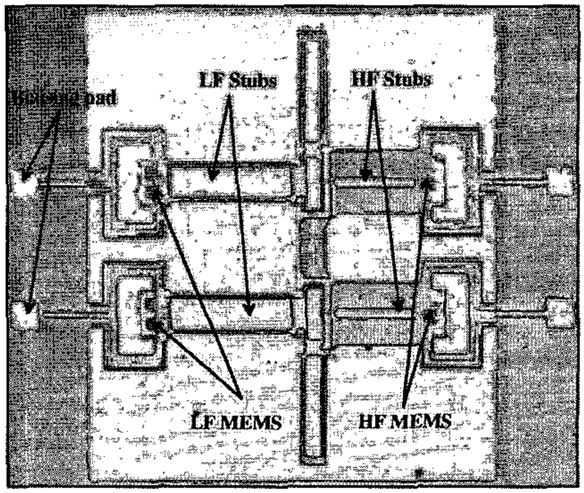

Fig. 6. Photograph of the fabricated second-order tunable filter

According to the MEMS dynamics, our filter is designed in the millimetric frequency range.

Figs. 7 and 8 respectively display the simulated S-parameters for central frequency and bandwidth tuning. Simulations were performed with the electromagnetic simulation software Ansoft HFSS©.

The central frequency tunes continuously from 29.5 GHz, where all MEMS are at the low limit of their stable region (State 1), to 32.4 GHz, where all MEMS are in the up state (State 3); around 31.3 GHz all MEMS are in the middle of their stable region (State 2). The relative central frequency variation is 9.3%. Nevertheless, in these simulations, the 3-dB relative bandwidth is not constant. Tuning is within 8.4 and 9.4%, i.e. State 2 and State 1, respectively. To obtain a constant 3-dB relative bandwidth, the MEMS height should be precisely adjusted.

The 3-dB relative bandwidth tunes continuously from 6.3%, when LF MEMS are in the up state and HF MEMS at the low limit of their stable region (State 1), to 12.7% when LF and HF MEMS are in the reversed positions (State 3); it is around 8.4% when all MEMS are in the middle of their stable region (State 2). So, the relative bandwidth variation is 76.2%. Under these conditions, central frequency is not constant, but control remains possible through a precise adjustment of MEMS height.

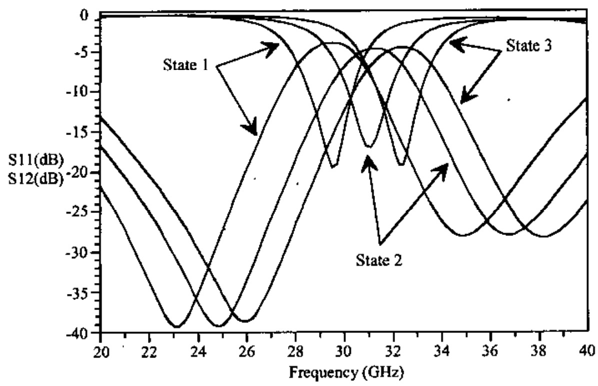


Fig. 7. Simulated S-parameters for central frequency tuning

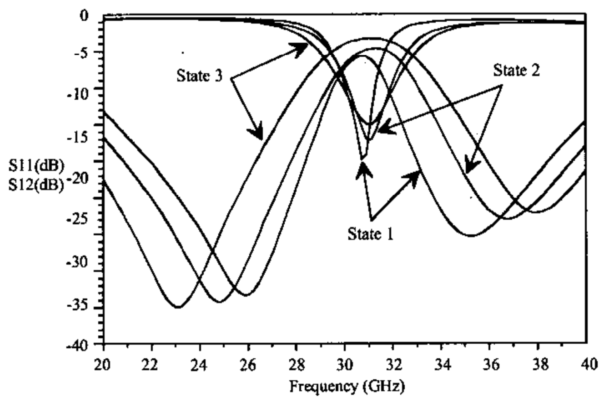


Fig. 8. Simulated S-parameters for bandwidth tuning

At this time, only a first set of measured data, about central frequency tuning, is available. Experimental results concerning bandwidth tunability will be presented during the conference.

Fig. 9 gives the measured S-parameters obtained after these first measurements. Bias voltage tunes from 0 V to 30 V. Central frequency tunes then from 34.74 GHz to 33.11 GHz, respectively. This variation of 1.63 GHz is equivalent to a relative frequency tuning of about 5%. In the same time, bandwidth varies of $\pm$ 0.5 around 8.6 %.

Despite a frequency shift due to technological dispersions, these first experimental results are quite good and show a good agreement with simulated ones. A correct matching level better than 20 dB is obtained. Moreover a constant insertion losses level of about 3.6 dB is obtained all over the tuning frequency range.

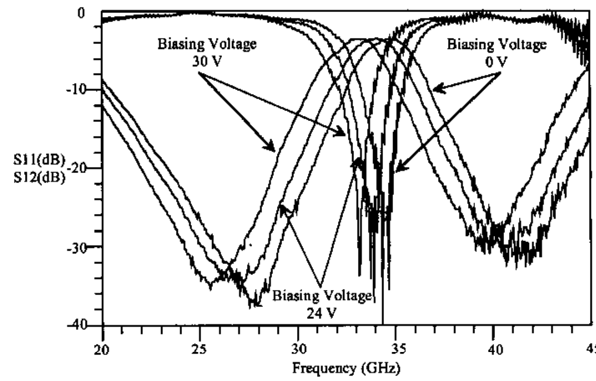


Fig. 9 Measured central frequency variations

## IV. CONCLUSION

We described an original tunable bandpass filter topology. This tunable filter is obtained by associating a DBR bandpass filter and MEMS capacities. Such an association allows to tune simultaneously and independently both central frequency and bandwidth. In order to illustrate this idea, a millimeter second-order DBR filter with MEMS cantilevers is presented. First experimental results are presented and about 5% central frequency tuning is obtained. Constant level of 20 and 3.6 dB are obtained for matching level and insertion losses respectively.

## ACKNOWLEDGEMENT

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