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Micromachined overlapped resonators for wide electromagnetic coupling ranges

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Abstract - In this paper, a compact S type resonator is presented, where the proposed resonator is surface micromachined over transmission lines or other resonators, in order to obtain a wide range of possible electromagnetic couplings. The structure has been applied in two compact, bandstop and bandpass filters with moderate fractional bandwidths (FBW) of 20% and 25% respectively. The bandstop filter presented, was designed by the combination of two design methods in order to obtain the proposed fractional bandwidth, where traditionally, coupled resonator bandstop filters have been used for narrow stopbands. The bandpass filter illustrates the use of the proposed suspended resonator structure to obtain a wide range of electric type coupling coefficients, and external quality factors for the filter. This paper describes the design methodology, concepts and fabrication method proposed for the design of these filters.

1. Introduction

Multilayer filters have been studied [1][2], where generally the designs use multiple dielectrics, or a single one with lines patterned on both sides. In this paper we present a way of obtaining a multilayer structure by using surface micromachining techniques, where overlapping transmission lines are obtained, with the objective of having the possibility of obtaining a wide range of possible electromagnetic couplings. The suspended resonators or transmission lines have been used in two filter topologies, the first one presented is a bandstop configuration, where we have obtained a 20% fractional bandwidth (FBW), this designed FBW, stands between a wide stopband response, which can be obtained using connected stub resonators [3], and a narrow stopband response, that can be obtained using coupled resonator filters [3]. The second filter topology is a 25% FBW, capacitively coupled resonator bandpass filter, where micromachined suspended transmission lines were used to obtain a strong coupling between resonators, and an adequate input and output to the filter.

2. S type suspended resonator

In this section we introduce the S type resonator, which will then be used in the design of the two filters presented in section 3. The proposed compact resonator is a half wavelength long at the frequency of interest, in form of an S. This resonator is then used as a suspended structure over a transmission line or resonator, to form the microwave filters presented in section 3. Figure 1 illustrates the suspended structures. The resonator is suspended by using anchors at the substrate, where also etch holes located along the center of the suspended structures were added, in order to remove the sacrificial layer used for its fabrication.

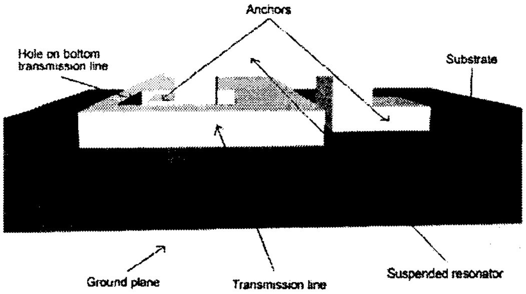


Figure 1. Suspended transmission lines

3. Filter design using the suspended S type resonator

This section is divided in two subsections, the first one describes a 20% FBW, three pole bandstop filter, made by overlapping S resonators over a transmission line. Section two presents a 25% FBW, two pole bandpass filter using electric type coupled, overlapped resonators and feed lines. Both filter topologies presented in this section were designed to have a Chebyshev response with a 0.1 dB passband ripple.

3.1 Bandstop filter design

In order to achieve the 20% FBW, bandstop coupled resonator filter shown in figure 2, we have used the theory given in [4], which presents a procedure adequate for filters with wide and narrow stopbands. The design starts with the calculation using stub resonators connected by a transmission line, where an impedance step in the main transmission line is introduced [4]. After this, the stub resonators are replaced by S coupled resonators, exhibiting the same reactance slope parameter than those of the stub resonators. If we consider the initial connecting stub resonators, suitable for wide stopbands, as the design bandwidth becomes narrower, they will exhibit a reduction in width making them inadequate for narrow stopbands, because of either a reduction in Q, or extremely narrow stub resonators. On the other hand, conventional coupled resonator bandstop filters have been used for narrow stopbands [3][5][6]. Here we demonstrate the use of the micromachined overlapping resonator structure to produce a moderate bandwidth, using coupled resonators. Thus the proposed micromachined structure provides an alternative between the connected stub resonator filters, and the traditional coupled resonator bandstop filters.

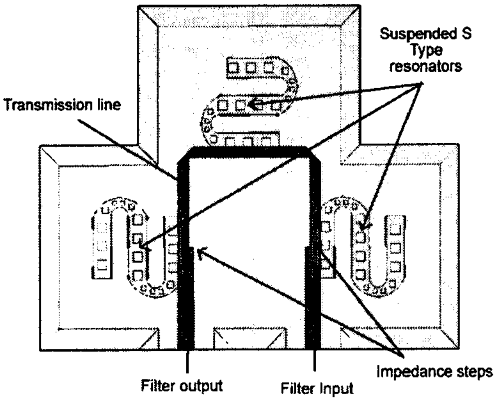


Figure 2. Bandstop filter topology

Figure 3 shows the reactance slope parameter of a resonator coupled to the main transmission line, extracted using the theory provided in [3]. The y axis shows the reactance slope parameter, normalized to the characteristic impedance step on the main transmission line, for different resonator spacings from the main transmission line, denoted as S on the x axis.

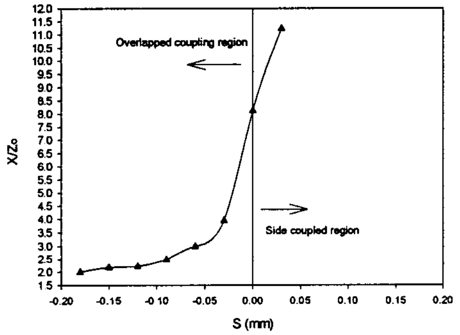


Figure 3. Normalized reactance slope parameter of the suspended S type resonator

The computed response of the proposed bandstop filter using [7] is shown in figure 4, where a moderate 20% FBW has been obtained using the proposed micromachined suspended resonator structure.

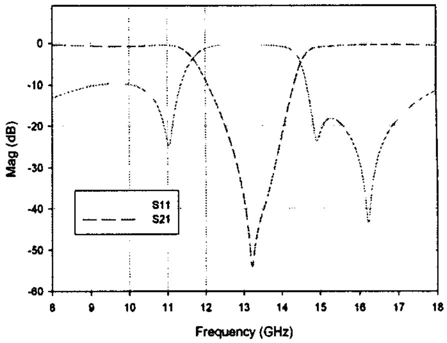


Figure 4. Bandstop filter response

3.2 Bandpass filter design

A two pole, 25% FBW bandpass filter has been designed, in order to demonstrate the wide coupling ranges that can be obtained using the proposed micromachined suspended structures. The filter topology is shown in figure 5, which consists of two overlapped S resonators, fed underneath the fist resonator, and above the second one.

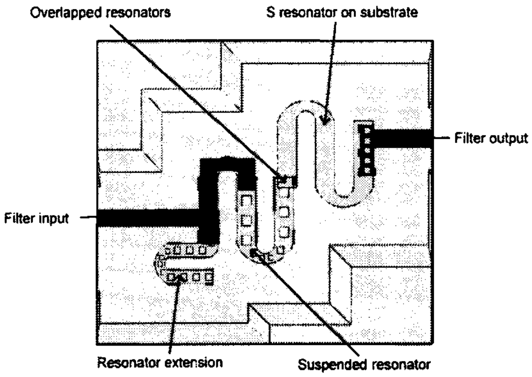


Figure 5. Bandpass filter topology

The design of the filter, follows the general filter theory described in [3], here we focus on the wide range of electric type couplings (Kc), shown in figure 6, obtained using this particular filter topology. Different overlapping distances between resonators, are denoted as x on the graph, where it can be seen that the couplings become much stronger as the overlapping region between resonators increases. Similarly to the coupling coefficient, the extracted external quality factor for this filter is obtained by overlapping the transmission lines shown in figure 7. Here only the feeding transmission line structures are shown, and can be referred to the input and output of the filter indicated in figure 5.

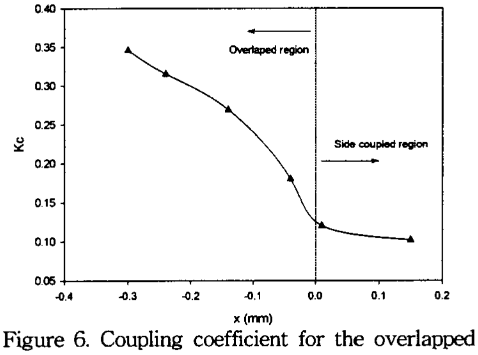
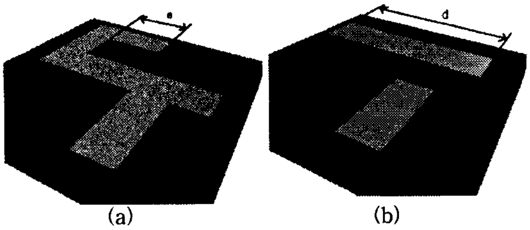


Figure 6. Coupling coefficient for the overlapped S

resonators



(a) (b)

Figure 7. Feeding structures for the bandpass filter
(a) feed underneath the resonator
(b) feed suspended above the resonator

Figure 8 shows the extracted Qe's for different values of e and d, defined in figure 7.

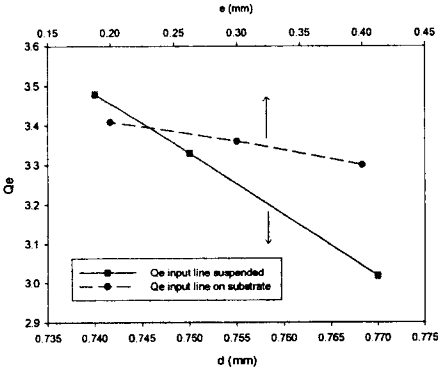


Figure 8. Extracting Qe for the bandpass filter

By setting the adequate design parameters for the filter, a final adjustment is made to the first resonator, to include the resonator extension shown in figure 5. This extension compensates for the frequency shift of the first resonator by introducing the feed line underneath it. The computed response of the final filter using [7] is shown in figure 9.

4. Fabrication process

The proposed filters are fabricated on high resistivity silicon (HRS) with a thickness of 430 μm. The microstrip lines are formed using electroplating technology, where 5-μm thick gold is electroplated at a current density of $4mA/cm^2$. The 10-μm air-gap between the suspended transmission lines and substrate, is formed by using a photoresist sacrificial layer, removed by an O_2 plasma ashing process. After releasing the suspended transmission lines, the filters are encapsulated using a 470 μm tall silicon substrate cavity, excluding a CPW-microstrip transition for on wafer probing. The silicon cavity is etched using a 40 wt% KOH solution, where gold is evaporated on the etched silicon side. Finally, the fabricated filters and cap substrate are eutectic bonded using an EV 501 bonder (EV, Austria) adding pressure and heat. The silicon cap substrate makes electric contact with the microstrip ground plane and the CPW ground plane used for probing.

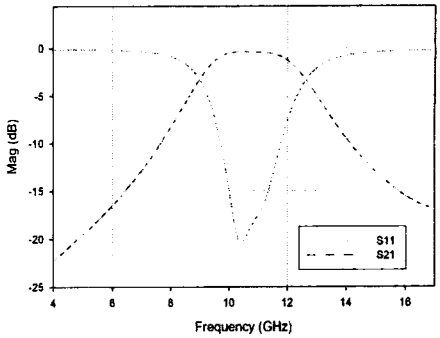


Figure 9. Bandpass filter response

5. Conclusions

In this paper we demonstrated a micromachined suspended resonator structure, that has been used to produce two moderate bandwidth filters. The overlapping structure presents the possibility of obtaining a wide range of possible electromagnetic coupling ranges for filter design.

[참 고 문 헌]

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