Tuning of a MEMS RF Filter

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ABSTRACT

We present an *analytical* model and closed-form expressions describing the response of a tunable MEMS RF filter. It extends our earlier model to general operating conditions by allowing for a combined DC and AC input signal and an independent DC voltage V_{DC2} applied to the output beam. The model is obtained by discretizing the distributed-parameter system using a Galerkin procedure to produce a reduced-order model of the filter. It consists of two nonlinearly coupled ordinary-differential equations of motions. The mismatch in the effective DC voltage applied to the input and output beams modifies the global modes significantly, reflecting localization of the response in either of the two beams. We present results describing variation of the center frequency, bandwidth, and sensitivity with V_{DC2}.

Keywords: MEMS, RF filter, tuning, localization.

1 INTRODUCTION

In modern communication systems, there is a continuous trend towards miniaturization to allow for the integration of transmitters and receivers on the same chip. To ensure that they do not interfere with each other, narrow-band filtering is required. The successful implementation of high-Q micromechanical resonators in many on-chip systems suggests a method for miniaturizing and integrating highly selective filters alongside other IC components. A mechanical filter is composed of two or more mechanically coupled resonators. Bannon et al. [1] first demonstrated filters comprised of two clamped-clamped beams coupled mechanically by a soft spring (a flexural-mode beam) and later presented [2] a step-by-step design procedure for these filters.

A two-resonator filter is made up of two similar resonators and a coupling spring. It has two distinct mode shapes defining the filter bandwidth. In the mode shape associated with the lower end of the bandwidth, the two resonators vibrate in-phase, whereas at the high end of the bandwidth, they vibrate 180° out-of-phase. The bandwidth is determined by the stiffness of the coupling spring, while the center frequency is determined by the frequency of the resonators. Electromechanical filters use an electrode underneath the input resonator to transform the electric signal into an electrostatic force, which is used to vibrate the resonator. The resonator produces measurable motions in the neighborhood of its resonance frequencies only; that is, when the signal frequency is within the bandwidth of the filter. This motion is transmitted to the output resonator via the coupling spring. The output resonator converts the resulting motion into an electrical capacitance sensed by an output electrode.

2 PROBLEM FORMULATION

We consider a filter, Figure 1, composed of two identical clamped-clamped (primary) microbeams of rectangular cross sections connected at their midspans by a weak microbeam. Two electrodes of identical dimensions to the primary beams are patterned underneath them. The input resonator transforms an input signal, $v_1(t) = V_{DC1} + V_{AC}\cos\Omega t$, to an electrostatic force, which actuates the microbeam. A DC voltage V_{DC2} is applied to the output resonator to magnify the RF signal, tune the filter, reduce the insertion loss, and generate an AC current out of the motions of the microbeam. The nondimensional Lagrangian describing the motions of this filter can be written as [3], [4]

$$\begin{aligned}\mathcal{L} = &\sum_{k=1}^{2}\int_0^1 \dot{w}_k^2 dx + T_c^2\int_0^c \dot{w}_c^2 dx - \sum_{k=1}^{2}\int_0^1 (w_k'')^2 dx \\ &-R_c\int_0^c (w_c'')^2 dx - \sum_{k=1}^{2} P_{p,k}\int_0^1 (w_k')^2 dx - P_c\int_0^c (w_c')^2 dx \\ &-\frac{\alpha_1}{2}\sum_{k=1}^{2}\left(\int_0^1 (w_k')^2 dx\right)^2 + 2\alpha_2\sum_{k=1}^{2} v_k^2(t)\int_0^1 \frac{1}{1-w_k} \quad (1)\end{aligned}$$

where x is the position along each beam's axis, $w(x,t)$ is the downward transverse deflection of the beam, ℓ is the length of the primary beams, and c is the ratio of the length of the coupling beam to ℓ. Throughout this paper, $k = 1$ and $k = 2$ refer to quantities related to the input and output beams, respectively. The parameters