Discretely tuned RF-MEMS bandstop filter with wide tuning range and uniform high rejection

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A new bandstop filter is presented providing a two-state discrete wide tuning range from 20 to 30 GHz with the same high rejection level of 36 dB. In the design, metal-insulator-metal capacitors are placed on one end of the resonators and on the other end capacitive micro-electromechanical systems (MEMS) switches are used to discretely tune the centre reject band of the filter.

Introduction: Discretely tuned bandstop filters based on MEMS technology have been reported in the literature [1–5]. The performance of these devices is summarised in Table 1, where f_1 and f_2 are the minimum and maximum centre frequencies that the filters can achieve and the tuning range is computed at mid-band frequency. These filters can tune their centre frequency by using MEMS switches to provide a discrete tuning range. In the work reported in this Letter, a two-state bandstop filter has been designed using strongly-coupled MIM capacitors on one end of the resonators and MEMS capacitive switches on the other end. With this compact topology a discretely tuned, wide centre frequency tuning range (40%) has been obtained with a high (36 dB) and uniform rejection at both centre frequencies, as reported in Table 1.

Table 1: Relevant characteristics of discretely tunable bandstop filters using MEMS switches (extracted from measured data)

Reference	[1]	[2]	[3]	[4]	[5]	This Letter
f_1 (GHz)	8.92	59.2	18.5	10.7	8	20.1
f_2 (GHz)	11.34	62.7	21.05	15.5	15	30
Tuning range (%)	23.8	5.7	12.9	36.6	60	39.5
Tuning range (GHz)	2.42	3.5	2.55	4.8	7	9.9
Size (mm^2)	7.3 × 7.5	–	1.7 × 3.3	2.2 × 1.5	6.1 × 6.2	2.5 × 5.4
Rejection level at f_1 (dB)	27.37	19	13	10	20	36.44
Rejection level at f_2 (dB)	27.57	17.5	20	21	27	34.16

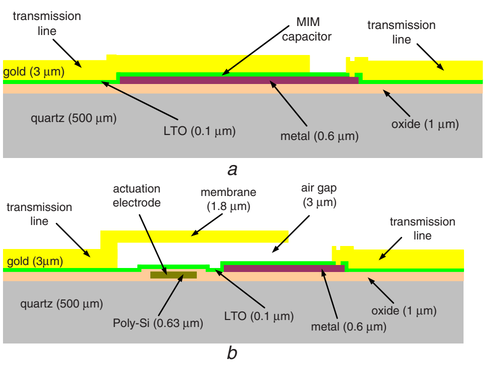

Fig. 1 *Schematic of MIM capacitor and MEMS capacitive switch*
a MIM capacitor
b MEMS capacitive switch

Wide tuning range bandstop filter design: The filter topology is based on a coplanar waveguide (CPW), and consists of a CPW transmission line with two capacitive coupled resonators that produce a bandstop response. Each coupling uses a MIM capacitor formed between the CPW transmission line and a buried metallisation separated by a thin low temperature oxide layer (LTO), as shown in Fig. 1*a*. To obtain a strong coupling between the transmission line and the two decoupling resonators, the MIMS capacitors are designed for a reactance slope parameter [6] $x/Z_0 = 14$ and $x/Z_0 = 45$ at the two centre frequencies $f_1 = 20$ GHz and $f_2 = 30$ GHz, respectively. In this way, a wide tuning range is attained while keeping a strong rejection level at both frequencies. The filter centre frequency tuning is provided by the MEMS capacitive switches shown schematically in Fig. 1*b*, situated on the other end of the resonators. Each switch consists of a cantilever suspended over a metal underpass line covered by an insulating LTO layer and is actuated electrostatically by using a DC bias voltage applied to a buried Poly-Si electrode. The cantilever extends the CPW transmission line providing an up-state (low) capacitance (12 fF), and it can collapse over the LTO to produce a down-state (high) capacitance (151 fF). When both switches are down-state, the centre frequency of the reject band is at 20 GHz while in the up-state position the reject band is centred at 30 GHz.

The technology used for the fabrication of the filter consists of an eight-mask surface micromachining process from FBK [7]. A photograph of the filter is shown in Fig. 2, where the resonators, MIM capacitors and MEMS switches can be located.

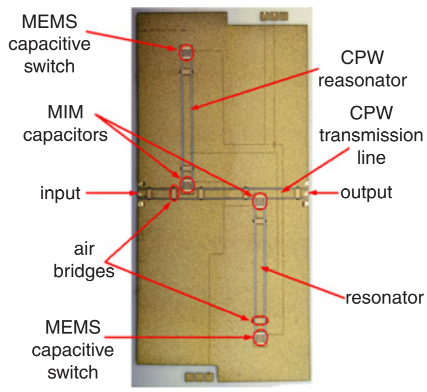

Fig. 2 *Bandstop filter photograph*

Results: The simulated and measured S_{21} response of the filter in both states is shown in Fig. 3. Simulations were performed using Agilent Momentum^{TM}. The measured and simulated maximum rejection level at 20 GHz are 36.44 dB and 36.91 dB, respectively, and 34.16 dB and 38.27 dB, respectively, at 30 GHz. The measured response at 20 GHz shifted 0.1 GHz with respect to the simulated one due to a slight increase of 35 fF in the down-state capacitance of the switch with respect to the simulations. Outside the 20 GHz reject band the measured and simulated losses of the filter are around 2.02 dB and 0.40 dB on the lower side and 0.99 dB and 0.41 dB on the upper side of the reject band, respectively. When the filter operates at 30 GHz the measured and simulated losses are around 1.33 dB and 0.29 dB on the lower side of the reject band and 1.06 dB and 0.50 dB on the upper side of the reject band, respectively. The simulations and measurements are in good agreement for both states.

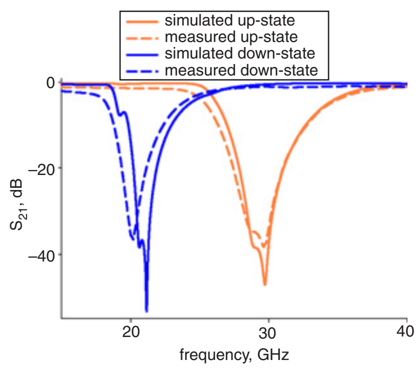

Fig. 3 *Bandstop simulated and measured S_{21} response*

Conclusions: A new CPW millimetre-wave bandstop filter design has been presented featuring a discretely tuned two-state reject band while keeping a uniform high rejection level. MIM capacitors and capacitive MEMS switches are integrated in a compact topology by using a surface-micromachining fabrication technology.

The MIM capacitive coupling between a CPW transmission line and two decoupling resonators provides a high and uniform rejection at both centre frequencies. The MEMS switches are used for bandstop centre frequency tuning. This filter topology can be used to include more than one MEMS switch at the end of the resonators to implement more than two filter states. In agreement with simulations, the measurements demonstrate a wide tuning range of 40 % from 20 to 30 GHz, with a constant reject band of 36 dB at both filter states, thus validating the design approach and the proposed filter topology.

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One or more of the Figures in this Letter are available in colour online.

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