Tunable stop-band filter at Q-band based on RF-MEMS metamaterials

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Presented for the first time is a metamaterial transmission line that combines complementary split ring resonators (CSRRs) and RF microelectromechanical systems (RF-MEMS). The device consists on a coplanar waveguide structure loaded in its central strip with CSRRs embedding RF-MEMS variable capacitors. Owing to the presence of the CSRRs, the structure behaves as a stop-band filter. Through the actuation of the electrostatic RF-MEMS devices, the electromagnetic characteristics of the CSRRs are modified so that their resonance frequency, and as a result the central frequency of the stop-band filter, can be tuned. This is the first time that an RF-MEMS tunable metamaterial-based filter has been designed for operation at Q-band.

Introduction: Metamaterial transmission lines are artificial lines consisting of a host line loaded with reactive elements. There are two main approaches for the synthesis of these lines: (i) the CL-loaded approach [1–3] and (ii) the resonant-type approach [4, 5]. In resonant-type metamaterial transmission lines, either split rings resonators (SRRs) [4] or complementary split rings resonators (CSRRs) [5] are used as loading elements. If these electronically small resonators (SRRs or CSRRs) are the single elements loading the line, the structure exhibits stop-band behaviour. This behaviour can be interpreted, in terms of circuit theory, as due to the presence of a transmission zero or, in terms of continuous media, as due to the extreme values of the effective permeability (for SRR-loaded lines) or permittivity (for CSRR-loaded lines) in the vicinity of the resonance frequency (highly positive and negative) [6]. Alternatively, bandpass structures with left-handed wave propagation in the allowed band can be implemented by combining SRRs with shunt inductive elements (grounded vias or metallic strips), or CSRRs with series capacitances (series gaps or interdigital capacitors). Both SRR and CSRRs have been used to design miniature filters [7, 8] and diplexers [9] based on new concepts derived from metamaterial theory, or to improve the performance of conventional (distributed) implementations (for instance, for spurious passband rejection) [10].

Results: The reported device is a proof-of-concept demonstrator, rather than a tunable notch filter for specific applications. It consists of a 50 Ω CPW structure with rectangular shaped CSRRs etched in the central strip and RF-MEMS bridges on top of them. The dimensions of the CSRRs are (in reference to Fig. 1) $c = d = 10 \, \mu m$, $l = 480 \, \mu m$ and $w = 130 \, \mu m$. CPW dimensions are: strip width $W = 150 \, \mu m$ and slot width $G = 30 \, \mu m$. Finally, the geometry of the MEMS bridges is: $B = 80 \, \mu m$, $b = 100 \, \mu m$, $h = 40 \, \mu m$ and $H = 290 \, \mu m$. The structure is a four-stage periodic device where the distance between adjacent CSRRs is 220 μm. The electromagnetic characteristic of the structure and the photograph of the fabricated device (detail of the former two stages) are both depicted in Fig. 2.

The first tunable notch filter based on metamaterial concepts was proposed by Gil et al. [11] and realised by loading a microstrip line with varactor-loaded split ring resonators (VLSRRs). These particles consist of SRRs with modified topology to accommodate the diode varactors. By varying the DC-bias applied to the varactors, the effective capacitance of the VLSRRs can be modified, and hence the position of the notch frequency. In the present Letter, a similar idea is explored using CSRRs, etched in the signal strip of a coplanar waveguide (CPW) transmission line. The surface-mounted varactors of [11] are replaced by integrated RF-MEMS bridges that provide its tunability to the structure (see Fig. 1). The result is a tunable stop-band filter with 20% tuning range operating at Q-band.

RF-MEMS technology: RF-MEMS technology is widely regarded as a key enabling technology for future telecommunication applications. It offers high-quality passives for RF circuits, e.g. inductors, transmission lines and resonators, combined with a certain degree of tunability, e.g. switches, varicaps, tuners, tunable filters and antennas [12, 13]. Typical electrostatic parallel-plate varactors are constituted of a movable electrode mechanically anchored on the substrate and suspended above a second fixed electrode. Under DC-bias, the device tends to close, adjusting the capacitance defined by the two plates [14]. Owing to the intrinsic instability of this actuation scheme, these devices are often used, as in this work, in switch-mode. Only up- and down-states, i.e. small and large capacitance, are functional. In this work, we used a stripped-down RF-MEMS technology using only three lithographic steps [15] to define the structures of Fig. 1. First, a 1 μm-thick Al layer is sputter-deposited and patterned on a 650 μm-thick AF45 glass substrate ($t = 5.9$) to define mainly the CPW structures. Then, a 3 μm-thick sacrificial photoresist layer is spun and patterned to define the anchoring regions of the MEMS devices before a second Al layer is deposited and patterned in the same way as the first one. So, the MEMS beams are defined. Finally, the sacrificial photoresist is ashed to release the devices.

The actual MEMS device implemented in the CSRRs uses an electrically floating bridge anchored directly on the substrate in holes of the CPW ground planes. Its voltage evolves freely between those applied to the strip and ground planes of the CPW. In down-state, the bridge contacts only the centre of the CPW strip. The device uses the native Al oxide as interposer to prevent DC shorts.

The simulated (by means of the Agilent Momentum by excluding losses) and measured (by means of the HP8510C vector network analyser) S-parameters of the device are depicted in Fig. 3. As expected,
Electro combination of complementary split ring resonators and RF-MEMS

A tunable stop-band filter at Q-band, based on the

Conclusion: Simulations done by considering plate heights of 0.5 and 2 mm for down- and up-state, respectively

Fig. 3 Simulated and measured insertion and return losses for device of Fig. 2

a Simulated
b Measured
Simulations done by considering plate heights of 0.5 and 2 μm for down- and up-state, respectively

Fig. 2

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References


