MAGNETIC-FREE RADIO FREQUENCY CIRCULATOR BASED ON SPATIOTEMPORAL COMMUTATION OF MEMS RESONATORS
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This abstract reports on the first demonstration of a magnetic-free radio frequency (RF) Microelectromechanical Resonant Circulator (MIRC). For the first time, magnetic-free non-reciprocity is achieved by imparting an effective angular momentum bias to a MEMS resonant circuit. The angular momentum is efficiently realized through spatiotemporal modulation of 3 strongly coupled high-Q (>1000) Aluminum Nitride (AlN) Contour Mode MEMS Resonators (CMRs) with signals of the same magnitude and phase difference of 120°. Differently from previous demonstrations based on varactor-based frequency modulation of low-Q LC networks (N. Estep, et al. Nature Physics, 10, 923-927, 2014), in this work the spatiotemporal modulation of the high-Q MEMS resonators is implemented by means of switched capacitors which minimizes the complexity of the modulation network, increases the modulation efficiency and mitigates the fundamental linearity limitations associated with solid-state varactors. Furthermore, due to the high Q of the MEMS resonators employed, strong non-reciprocity is achieved with an ultra-low modulation frequency of ~120 kHz (~0.08% of the RF frequency, orders of magnitude lower than previous demonstrations) which directly enables a total power consumption of only ~38 µW which, to the best of our knowledge, is the lowest ever reported for magnetic-free RF circulators based on temporally modulated circuits.

The MIRC architecture consists of three 146 MHz AlN CMRs (monolithically integrated on the same chip showing k_t^2~1.7%, Q~1000) connected in a loop and frequency commutated by means of series switched capacitors mounted on a PCB and electrically connected to the MEMS chip by wire bonding. The 3 switched capacitors are controlled by 120 kHz square wave signals of equal amplitude and phase difference of 120° to impart an effective angular momentum bias which breaks reciprocity and time reversal symmetry.

The performance of the MIRC prototype was evaluated by measuring its S-parameters using a 4-port vector network analyzer. Strong non-reciprocity (~30 dB isolation between transmit and receive ports) is achieved at ~145 MHz with a modulation frequency of only 120 kHz. It is worth noting that the relatively high insertion loss (IL~8dB) of this first MIRC prototype is due to the relatively low FoM ($k_t^2 \cdot Q$~17) of the CMRs employed. Circuital simulations show that IL as low as 2 dB can be readily achieved by simply employing resonators with same Q and reasonably higher k_t^2~5% which is achievable using AlN Cross-Sectional Lame Mode Resonators (C. Cassella, et al. JMEMS, 25, 2, 275-285, 2016)