MEMS and Si-Micromachined Components for Low-Power, High-Frequency Communications Systems

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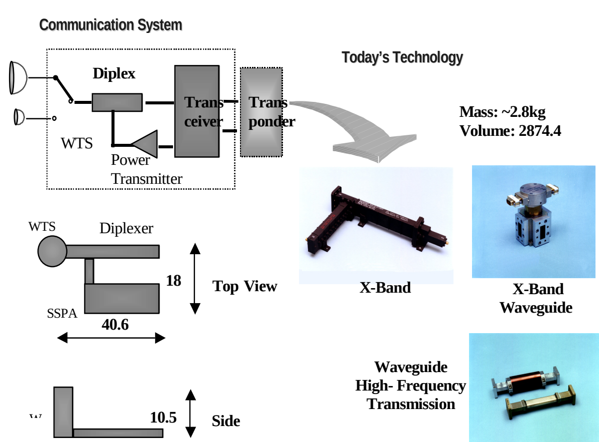
SUMMARY

Future personal and ground communications systems require very low weight, small volume and very low-power. In addition to decreasing size, the functionality of the platforms is increasing necessitating the use of highly integrated RF front ends. Furthermore, in order to transmit/receive the maximum amount of data, communications systems are moving up in frequency to X, K and Ka-bands (10-40 GHz). Electronic packaging can account up to 30% of the overall system mass, thus making advanced high-frequency micro-electronics, high-density integration and packaging a key to reducing mass while improving performance.

The next leap beyond the state of the art in multichip module (MCM) for communications systems is the development of a technology which can integrate high-frequency Si/Ge based active devices, advanced micromechanical (MEMS) devices and micromachined components into one wafer [1], [5]. Figure 1 shows a traditional X-band front-end based on waveguide technology. Circuit optimization methods applied to MCM [3], [4] or waveguide technologies cannot allow simultaneously for minimal volume, excellent performance, very low cost and very low power. Critical advancements based on new concepts at fundamental levels of circuit design are needed in order to replace the main components of a communication system front end such as the transfer switch, diplexer, RF amplifiers, mixers, IF filters, local oscillators and IF amplifiers by very small yet power efficient monolithic versions. This presentation will discuss the development of MEMS/Si micromachined components that can replace the passive components of an existing communication system. The emphasis of this presentation will be on the transfer switch and high-Q RF /IF filters and resonators.

FIGURE 1. X-Band Waveguide Based Communication System



(a) Transfer Switch

Recently, Si micromachining has been used effectively for the development of low-loss RF switches with insertion loss less than 1 dB in frequencies varying from 100 MHz to 30 GHz [2]. These micromechanical structures require very low power, have long lifetimes and survivability. Bulk and surface Si micromachining can be used to provide a switch which can deliver a speed of 10^{-7} to 10^{-6} sec with a dc Voltage of less than 3 Volts. Recent work at the University of Michigan has demonstrated the capability to provide a very low-cost, high yield realization of this switch (see Figure 2). Results of this effort will be presented and discussed during the presentation.

FIGURE 2. MEMS RF Switches

† Switch Parameters

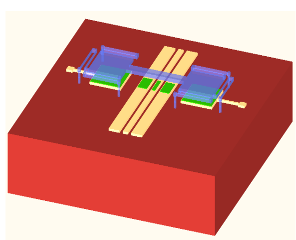
V_{pi} = 3 V

K_z = 0.239 N/m

τ_s = 8.0 ns

f_0 = 2 kHz

Q = 27.87



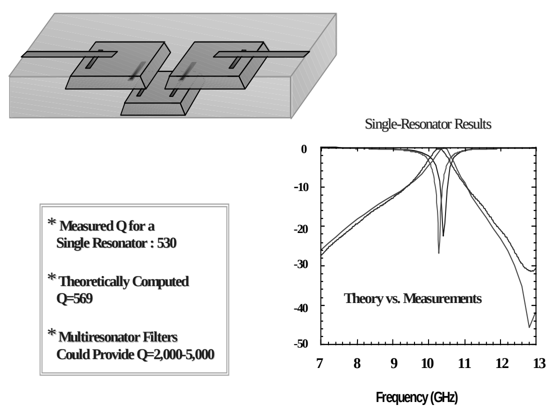
(b) High-Q Micromachined Resonators for RF Filters/Diplexers

The use of micromachining can lead to the development of a micromachined waveguide diplexer which can be excited by conventional or micromachined planar lines for compatibility to the monolithic technology. This diplexer can be designed to provide performance in combination with low insertion loss and small size. Important issues such as high out-of-band attenuation and suppression of multiple bands can be addressed by use of appropriate micromachined structures as high-Q resonators (see Figure 3). Two approaches will be discussed during this presentation: (a) Vertically integrated filters to allow for a vertical interconnection during filtering [10] and (b) Horizontally integrated resonators and filters for a uniplanar circuit integration. Results of recent efforts on the development of these filters will be presented and discussed extensively.

(c) MEMS IF Filters

Vibrating mechanical tank components, such as crystal and SAW resonators, are widely used for frequency selection in communication subsystems because of their high quality factor (Q's in the tens of thousands) and exceptional stability against thermal variations and aging. In particular, the majority of heterodyning communication transceivers rely heavily upon the high Q of SAW and bulk acoustic mechanical resonators to achieve adequate frequency selection in their RF and IF filtering stages and to realize the required low phase noise and stability in their local oscillators.

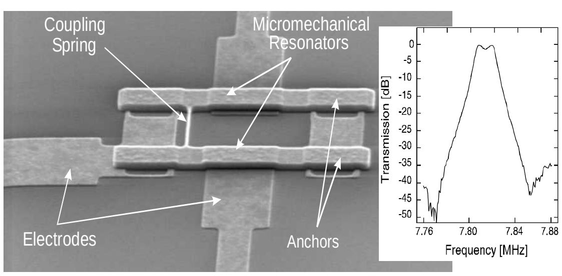
FIGURE 3. Micromachined High-Q Resonators



At present, such mechanical resonator tanks are off-chip components, and so must interface with integrated electronics at the board level, often consuming a sizable portion of the total subsystem area. In this respect, these devices pose an important bottleneck against the ultimate miniaturization and portability of wireless transceivers. For this reason, many research efforts are focused upon strategies for either miniaturizing these components [6-8] or eliminating the need for them altogether [8,9].

Recent demonstrations of micro-scale high-Q oscillators and mechanical bandpass filters with area dimensions on the order of 30 mm x 20 mm now bring the first of the above strategies closer to reality. Such devices utilize high-Q, on-chip, micromechanical (abbreviated "μmechanical") resonators [8,9] constructed in polycrystalline silicon using IC-compatible surface micromachining fabrication techniques, and featuring Q's of over 80,000 [9] under vacuum and center frequency temperature coefficients in the range of -10 ppm/^{o}C (several times less with nulling techniques). To date, two-resonator micromechanical bandpass filters have been demonstrated with frequencies up to 14.5 MHz, percent bandwidths on the order of 0.2%, and insertion losses less than 1 dB (Figure 4). Higher-order three-resonator filters with frequencies near 455 kHz have also been achieved, with equally impressive insertion losses for 0.09% bandwidths, and with more than 64 dB of passband rejection. LF (i.e., 20 kHz), high-Q oscillators, fully-integrated with sustaining CMOS electronics, have also been demonstrated in this technology.

FIGURE 4. MEMS IF Filters



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