Classic Discrete Design Skills Are Making a Comeback

Advanced CMOS-MEMS technology is making passive components digitally programmable.

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Modern CMOS processes that enable integration of both logic and RF functionality are commonly used in the design of transceiver circuits for wireless devices. While logic and radio functions benefit from the integration possibilities, high-Q, high precision passive elements often used for impedance matching and frequency selectivity are usually left outside the chip in the form of discrete elements or filter circuits.

With the introduction of on–chip integration of discrete MEMS components with extremely high quality (Q)–factor in mainstream CMOS process technology, it is now time to brush up on the old-school microwave design techniques that will be required to create entirely new dynamic RF-components with never-before seen functionality. Discrete design with MEMS inductors and capacitors can be used to create exciting dynamic functions in front-end filter networks, matching circuits and antennas where tunability can greatly enhance versatility. In this way, formerly static RF-front end components can be made highly dynamic and serve as the perfect complement to a software defined radio (SDR) baseband section. MEMS in Mobile Phones

It has taken a while, but within the last few years, MEMS-based products are now widely deployed and almost taken for granted in new mobile phone designs. MEMS-based accelerometers have enabled new functions, and they help to make the user interface more intuitive, while MEMS-based microphones have improved the voice quality. Today, there is no question about the usefulness of MEMS technology and its viability in a high-volume, mass market product.

The continual growth of the mobile device market, along with the introduction of numerous new frequency bands and additional radio standards, has created a renewed interest in MEMS technology for creating agile RF components and re-configurable RF front-ends. The obvious benefit is that these programmable RF components can be much more flexible, and they can accommodate multiple frequency bands and operation modes with simple digital re-programming. We are going to take a look at what properties are most important when RF-MEMS are used in the RF-part of a mobile phone design. Q-factor and Repeatability

Every RF designer knows that his best friend is component Q-value. The component Q is a dimensionless ratio that describes how much energy a component or even a whole circuit can store compared to how much is lost per unit time. The higher the Q-value is, the lower the losses are in the component. Circuit Q-value can be increased by minimizing resistive losses in metal layers, dielectric loss and radiation effects. Q is also inversely related to the relative bandwidth in the system with an inverse proportional relationship. This is important when considering matching or tuning circuits since a high Q-value restricts the bandwidth that a tuned circuit can cover.

Low loss components are especially important in tuned circuits such as filters and resonators because they determine the overall sharpness of the resulting frequency response. Using low–Q resonators in a filter design tends to limit pass band flatness and side-skirt roll-off rate.

In classic microwave L-C filter design where the individual resonators are built up using pairs of inductors and capacitors, a high Q-values will enable the kind of sharp and steep responses required by modern communication standards. As Q in the circuit deteriorates, the frequency response becomes more and more rounded off, and it can even become impossible to get to the desired specified response.

In microwave design, high-Q capacitors are necessary in all the positions where there is either a need to define a frequency response such as for a filter resonator or where high reactive currents are flowing &#151 as in the case of amplifier output power matching circuits &#151 which has generally very low impedance.

The low impedance means more current and less voltage and that more reactive current is flowing back and forth in the capacitor without going anywhere, thereby generating higher resistive losses. The above mentioned output stage of a RF-amplifier is an example of where a low impedance output stage needs to be matched by high-Q capacitor elements. Accuracy for Frequency Selection

For a filter structure, the resonant frequency is inversely proportional to the square root of the product of the capacitor and inductor value. Any deviation of the nominal component value will move the actual center frequency of a response away from the target center frequency. This is of special importance to filter structures where this component value variation directly determines the center frequency of each resonator in the filter and the combination of multiple resonator responses makes up to the filter frequency response curve. With this reasoning, it is clear that any tunable structure that is intended to add agility to the RF signal path must have very fine and predictable component value steps as well as a very high Q-value.

Capacitors built on RF-MEMS technology inherently have a very high Q-value and by making such a structure digital (the capacitors are either in full up position for minimum capacitance or in full down position for maximum capacitance), the addressable capacitance value can have very high resolution. Since the size of the smallest element is limited only by lithography and mask rules in the manufacturing process, the smallest capacitance step can be extremely small and hence be able to address capacitance changes down in the femto-Farad range. So with a digital capacitor bank, both high resolution and accuracy can be fulfilled without compromising the low-loss properties of the RF-MEMS technology. Multiple Signal

Paths

With an increasing number of new frequency bands and wireless communication standards being introduced, modern cell phones today commonly contain four or more separate signal paths with each path designed specifically for a particular frequency band and communication standard. Since in most user-scenarios only one signal path is used at any given time, this represents a huge overhead in component cost and circuit board space. Furthermore, because of frequency planning issues, the frequency bands that a particular mobile phone design has to support vary depending on where in the world the phone is sold. Since virtually every manufacturer of mobile devices operate worldwide, this leads to a logistical problem with far too many different versions of the same design &#151 something that could be easily remedied with a software configurable front-end technology.
Integration on Silicon

By integrating high-Q MEMS capacitor elements into a mainstream RF-CMOS process technology, it is possible to bring together the benefits of a high-volume, low cost process with the advantages of high performance RF-MEMS technology. As pictured in Figure 1, individual capacitor elements are integrated as parallel plate capacitors with a variable air gap. The parallel plate capacitor structure is extremely well suited to microwave applications and air is the lowest loss dielectric. The resulting digital capacitor bank is well behaved, free of higher modes and suitable for RF-applications well in to the X-band domain.

In order to make interfacing the circuit easy and to keep the number of external components low, an integrated charge pump circuitry generates the voltage necessary for the MEMS actuation while a serial bus makes control of the device straightforward. To set the capacitor bank to a particular value, a digital word corresponding to the desired value is loaded over the serial port interface. The internal logic and driver circuits then automatically set the capacitor bank to the selected value. This programming can be repeated with high frequency to create dynamic functionality.

Advanced RF-CMOS processes are used to build highly integrated transceivers for virtually all communication standards since it allows integration of both the RF building blocks and the logic functions. By adding dynamic RF functions and network tunability, new opportunities for value-added integration will quickly emerge. Applications such as on-chip real-time tuning, agile filtering and active output-stage matching become new exciting applications that will enhance mobile device performance and associated user experience.

The technology allows for the integration of digital radio functionality and RF building blocks such as low noise amplifiers (LNA), up- and down-converters and modulators together with an agile RF front end filter implemented in CMOS-MEMS. So instead of using multiple parallel RF-paths and switches response around to different frequency bands, the front-end circuit can be re-configured and programmed to select the desired response and operation mode. Since the CMOS-MEMS elements are, in essence, dynamically variable passive components, high-level skills in passive network design, Smith-chart impedance matching techniques and general circuit theory are going to be highly valuable assets as microwave engineers start to explore the new opportunities and applications this family of components will give rise to.

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