Unlocking the Potential of RF MEMS with New Design Approaches

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At the recent Consumer Electronics Show (CES), a major trend in many of the whizzy new gadgets that were on display was the enhanced interactivity and environmental sensing capabilities of products, from smart phones to games to the burgeoning tablet market. Whether it’s rotating a display from portrait to landscape mode; determining location, direction and elevation, or even improving the wireless transmission quality and battery life, there is a common thread connecting this new wave of innovation in devices: MEMS, or Micro-Electro-Mechanical Systems.

MEMS have long been critical components in automobiles for engine control and safety features such as crash detection and stability control. More recently, as cost and power consumption have become ever more critical for mobile devices, product developers have discovered the benefits of incorporating MEMS into their devices. Each successive wave of smartphones and tablets that comes to market sets a new standard in functionality thanks to MEMS-enabled features.

A tear down of a new Samsung Focus Flash smart phone revealed the use of MEMS to dynamically tune the antenna to different baseband frequencies. It has long been believed that RF MEMS, which include switches, varactors (tunable capacitors), and resonators, hold the potential to dramatically reduce the size, cost and power consumption of wireless transmitters and receivers, and many companies have pursued this goal. (See Figure 1). But the MEMS device from WiSpry in the Samsung phone is the first known use of RF MEMS in a volume commercial product, according to IHS iSuppli, and may well prove to be a watershed event.

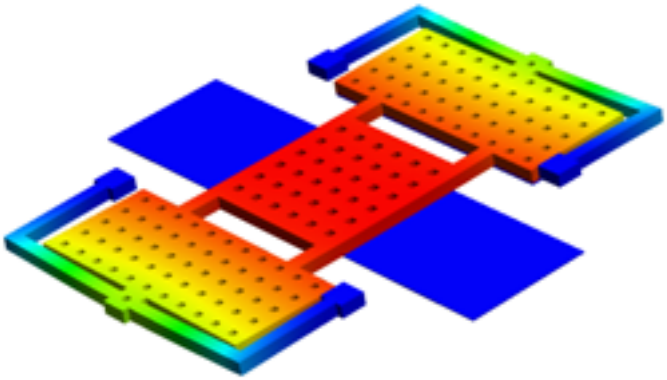

Figure 1

It’s no wonder that MEMS components, currently a $9 billion market, are projected to experience double-digit growth annually through 2015, when sales are forecasted to reach $12.1 billion, according to IHS/iSuppli. Noting the above-mentioned discovery of the RF MEMS in the Samsung phone, the firm said it expects the RF MEMS industry to grow 200-fold through 2015.

New opportunities, new challenges

If RF MEMS are to realize their huge potential in the mobile and consumer electronics markets, the industry must develop and integrate these devices on a faster time scale. On average, according to one analyst report, it takes 4 years of development and $45M in investment to bring a MEMS component to market. The gestation period for RF MEMS has been much longer.

To be sure, existing players and new entrants will benefit from the emergence of a MEMS eco system, similar to the eco system that exists for analog/mixed-signal ICs. The MEMS eco system will include design tools, a reference design flow, standardized fabrication processes, and process design kits. The pieces of this eco system are just starting to come together.

Design tools and methodology for RF MEMS are one part of the MEMS eco system that’s already at hand. Similar to IC designers, RF MEMS designers need to simulate their designs in advance of actual fabrication, or face a long, costly series of build-and-test cycles. But unlike ICs, which consist solely of electrical components, RF MEMS devices involve multiple physical domains including electrical, mechanical, thermal, and fluidic effects that are not easy to simulate (see Figure 2).

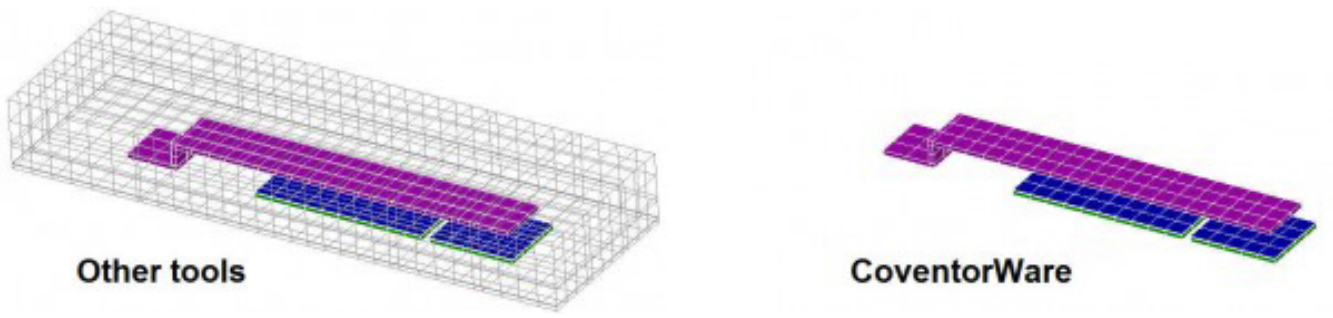

Figure 2

Simulation challenges that are specific to RF MEMS include:

• RF switches and varactors (such as the WiSpry device) depend on nonlinear coupling between electrostatic and mechanical forces for actuation, and have an “air gap” of variable thickness that is challenging to simulate;
• Predicting the reliability of RF switches and varactors, which must actuate for billions of cycles, requires accurate simulations of contact forces as the devices close; and
• RF resonators rely on nonlinear electro-mechanical coupling effects or high-order piezo-electric resonances that must be accurately simulated. These devices also must be designed to minimize energy loss through attachment anchors, thermo-elastic damping and gas damping to achieve high Q factors.

RF MEMS pioneers used a combination of analytic formulas and general purpose finite element tools to simulate the physical behavior of their design, but the analytic formulas required extensive numerical and experimental validation, while the general purpose finite elements tools fall short for addressing these specific simulation challenges. The most advanced developers now rely on specialized tools

to simulate their designs.

The engineers at WiSpry, for instance, use a MEMS design automation platform supplied by Coventor, Inc. The platform includes a system-level modeling tool called MEMS+ that works in conjunction with the widely-used MATLAB environment to replace custom analytic formulas with sophisticated analytical and numerical models. The MEMS+ model library incorporates many years of MEMS simulation know-how and has been validated in collaboration with industry partners, thus providing a significant jump start to designers who are new to MEMS. A suite of field solvers, known as CoventorWare, comprises the other part of Coventor's platform. Most notably, Coventor uses a hybrid finite-element/boundary element approach to simulate coupled electro-mechanics accurately and efficiently. The hybrid approach eliminates the need to generate a volume mesh in the variable "air gaps" and yet accurately captures 3D electrostatic fringing field effects (See Figure 3). CoventorWare also simulates other MEMS-specific physics such as gas damping, thermo-elastic damping and anchor losses.

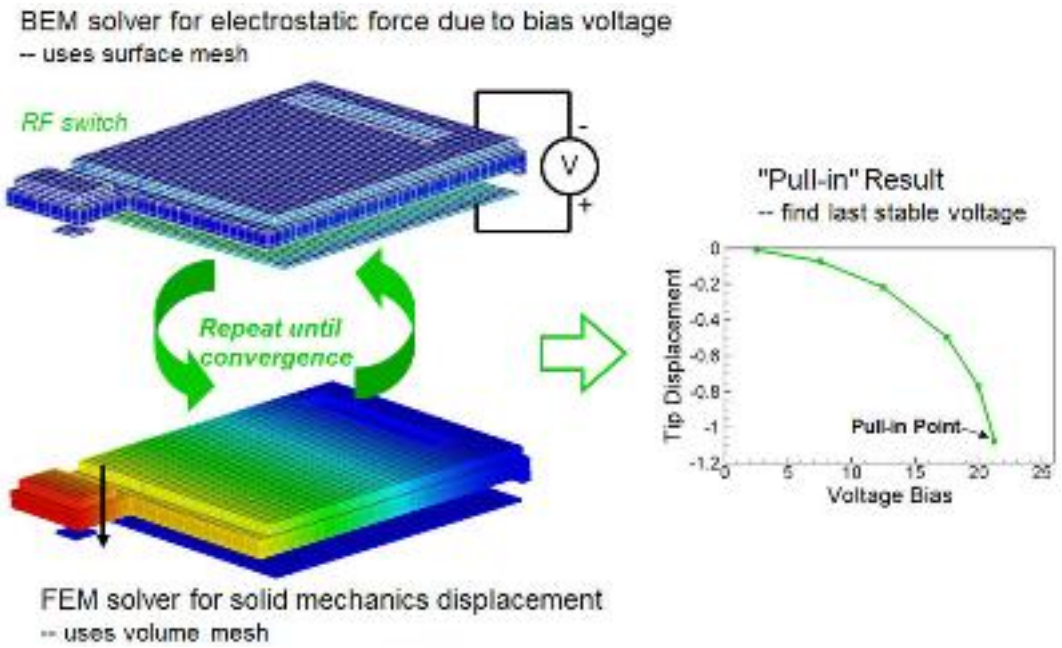

Figure 3

An example of MEMS varactor design and simulation

A varactor, or variable capacitor, can be implemented in MEMS technology with a suspended structure that "pulls in" to the substrate in response to applying a bias voltage between the structure and an electrode deposited on the surface of the substrate. Such a device offers two capacitance values: a low value when the structure stays in its undeformed state, and a high value when it is pulled in by electrostatic forces to contact the substrate. The WiSpry device, for example, contains an array of these structures that can be configured in serial or parallel to achieve a range of capacitance values. Designing these structures to pull in and lift off with a reasonable bias voltage, and to do so reliably for billions of cycles is a tricky business.

A successful design must be flexible enough to actuate with the minimum bias

voltage, yet have enough mechanical stiffness that it will return to its unbiased state when the bias voltage is removed, overcoming residual electrostatic and contact forces. Furthermore, the impact force that occurs when the device pulls in must be minimized to attain reliability goals. Engineers at WiSpry made extensive use of Coventor's simulation tools to verify and optimize their design.

Building out the MEMS eco system

As mentioned above, other parts of the MEMS eco-system are starting to fall into place. Renowned semiconductor research institute IMEC has developed a monolithic MEMS-on-CMOS fabrication process that could serve as a standardized process technology for RF MEMS. IMEC and Coventor have partnered to develop a reference flow and process design kits (PDKs). Specialty foundries such as Silex and X-FAB offer standardized MEMS process flows. And leading pure-play foundries such as TSMC and GlobalFoundries have announced their intention to offer MEMS technology. The future is bright for RF MEMS, offering new opportunities for fabless companies and wireless system developers to apply their capabilities in fast-moving and high growth markets.

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