No More Dropped Calls

Using true multiphysics incorporating fluid, electrostatic and mechanical effects, engineers are simulating the transient dynamic response of an innovative RF-MEMS switch for improving cell phone signal strength.

By Jeroen Bielen and Jiri Stulemeijer, EPCOS NL, Nijmegen
Sander Noijen, Philips Applied Technologies, Eindhoven, The Netherlands

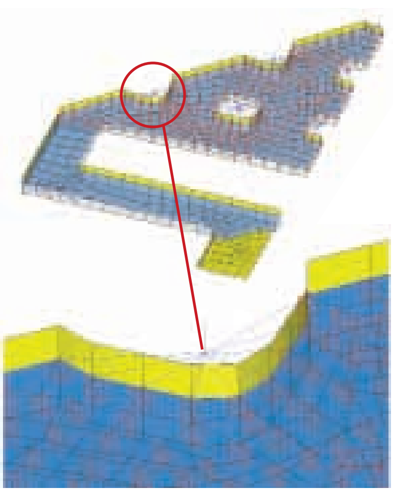
One of the most perplexing problems for mobile phone users is dropped calls — those annoying and unpredictable disconnections when signal strength falls below a given threshold. Typically the problem is a mismatch in impedance (resistance to electromagnetic wave transmission) between the phone's antenna and power amplifier, causing signals to be partially reflected back into the amplifier rather than transmitted into the surrounding open space. Such impedance mismatches usually are caused by the presence of objects adjacent to the antenna — the caller's hand, a car frame or building wall, for example — resulting not only in dropped calls but also shortened talk time as battery power is drained trying to maintain signal strength.

An innovative solution to this problem is an adaptive antenna-matching module that senses the mismatch and automatically changes the phone's impedance by adjusting a capacitor value in a matching network between the power amplifier and antenna. The device is expected to reduce power consumption of mobile handsets by up to 25 percent and significantly reduce the number of dropped calls.

The heart of the module is a set of RF-MEMS (radio frequency-microelectromechanical systems) switches, made with semiconductor manufacturing techniques and materials. The compact size, sensitivity and speed of MEMS devices are being leveraged in an expanding range of applications including automotive manifold pressure sensors, ink-jet printer nozzles, pacemakers and industrial equipment systems.

This particular module is under development at component manufacturer EPCOS NL, which recently announced the acquisition of the RF-MEMS activities from NXP Semiconductors. At specific points in the development, Philips Applied Technologies — a contract research and development supplier — supported the RF-MEMS activities with their specific expertise in finite element modeling.

RF-MEMS switches are well suited for this adaptive antenna-matching application because of their linearity and accuracy, and the large on–off capacitance ratio (1:20) needed to change impedance levels to an optimal value for better signal transmission. One of the major challenges in developing the device is ensuring that the switch actuates in 50 microseconds or less — fast enough to shift impedance before a call is disconnected.



A single directly-coupled multi-field model of the RF-MEMS switch containing elements accounting for three effects: fluid (blue), electrostatic (red) and mechanical (yellow)

With conventional electromechanical switches, such performance is easily verified and refined through a series of test and redesign cycles using hardware prototypes. Semiconductor fabrication setup for MEMS is costly and time-intensive, so engineering simulation is an indispensable tool in optimizing MEMS designs early in development. Simulation is especially helpful in predicting the complex MEMS performance, which typically is influenced by several interdependent variables and often defies intuitive logic. Amazingly, the RF-MEMS switch in this application is small enough to fit on the head of a pin — approximately 250 microns square and five microns thick, with a three-micron travel distance for the capacitive switching plate.

The engineering team used ANSYS Multiphysics software extensively in the development of the RF-MEMS switch. The solution was especially important in determining switching speed, a critical parameter that depends on three interrelated effects:

- Electrostatic force of a transducer that actuates the opening and closing of the switch when an electrical voltage is applied

- Mechanical configuration of components, including the residual gap between electrode plates that determines the capacitance of the closed switch
- Fluid behavior of the inert gas in the hermetically sealed module as it is squeezed from the gap between the electrode plates as the switch closes

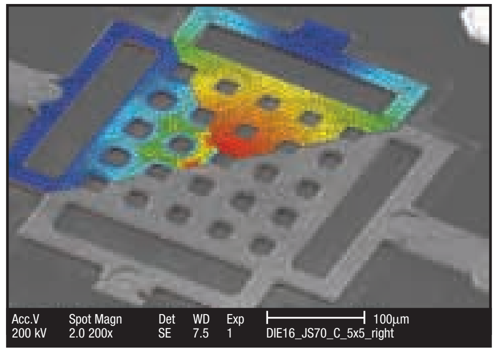
Software from ANSYS accounted for all three of these interrelated effects using the same directly-coupled multiphysics model, thus avoiding the delays and potential inaccuracies of exchanging results between different models.

Parametric capabilities of the software were especially helpful in modifying the configuration of the switch by merely changing a few key parameters rather than rebuilding the model from scratch. In particular, scripting features of the ANSYS Parametric Design Language (APDL) enabled the engineering team to implement an algorithm for readily determining the capacitance–voltage (CV) curve, including nonlinear snap-back instabilities that characterize the quasi-static behavior. APDL was also used to run design optimization and sensitivity studies, most importantly in simulating the potential instability of the switch in its "almost closed" state.

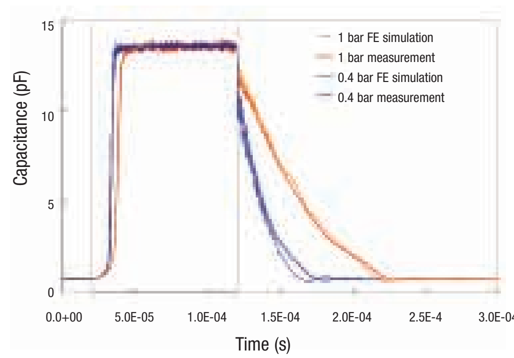
The engineering group used specialized ANSYS elements to accurately represent switch behavior for the various stages of gap closure between the switch's electrode plates, especially in the critical "almost closed" state. Nonlinear gap elements were used to capture the mechanical action of the switch, including contact of the electrode plates at complete closure. Similarly, electrostatic transducer elements provided high-fidelity simulation throughout. A new nonlinear transient squeeze-film formulation capability of the FLUID136 element was used to accurately represent the air gap and fluid damping effects in the switch. EPCOS and Philips Applied Technologies assisted in validation of this element for use in larger pressure regimes.

Taking into account fluid, electrostatic and mechanical effects in a single model, ANSYS Multiphysics technology accurately predicted the switching time for the module and allowed engineers to refine the design for optimal performance. The process enables the team to simulate numerous module configurations quickly, providing fast turnaround for rapidly changing cell phone requirements for a wide range of phone models. Moreover, software from ANSYS is used in studying other aspects of module design, including thermal–mechanical simulation to predict material creep and plasticity for solder joint fatigue life calculation, or structural analysis to determine stress and deformation for various packaging alternatives.

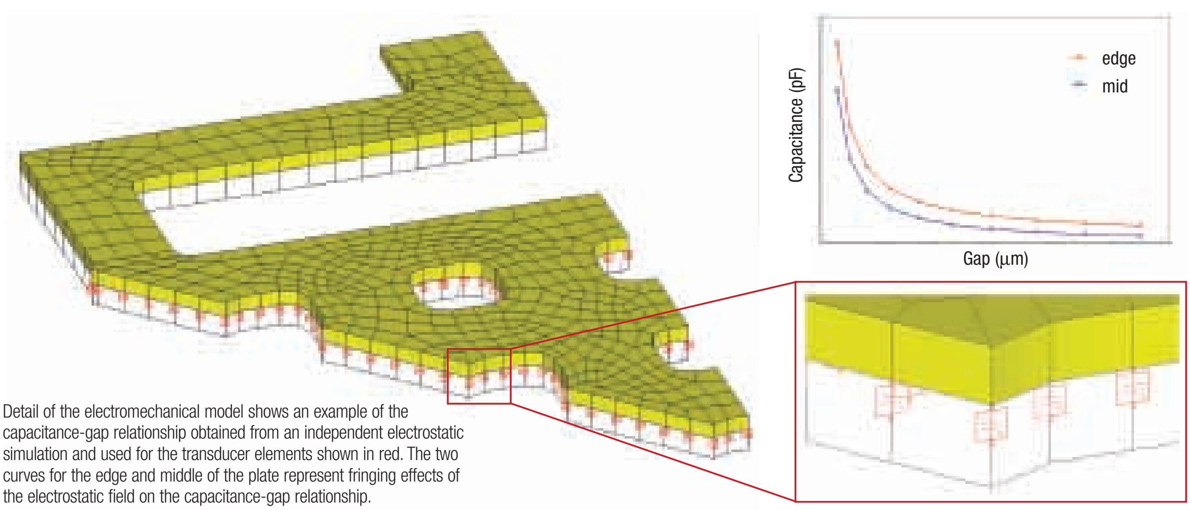
As a result of these capabilities of ANSYS Multiphysics software, an optimal design will be released to production in the 2010 time frame, strengthening EPCOS's position in the competitive telecommunications market with an innovative product that meets a significant consumer demand. ■



Finite element model showing pressure (left quadrant) and displacement (right quadrant) overlaid on scanning electron microscope image of an RF-MEMS switch measuring 250 microns wide



Simulation results of opening and closing transients at two ambient pressures agree closely with test measurements.



Detail of the electromechanical model shows an example of the capacitance-gap relationship obtained from an independent electrostatic simulation and used for the transducer elements shown in red. The two curves for the edge and middle of the plate represent fringing effects of the electrostatic field on the capacitance-gap relationship.