Microwave Journal

ELECTROMAGNETIC SIMULATION OF MOBILE PHONE ANTENNA PERFORMANCE

The telecommunications sector is making great advances aimed at delivering an even stream of high-tech devices, covering the significant consumer demands in this sector. Electromagnetic (EM) simulation is becoming an increasingly important tool in the design flow, not only at the antenna level but also at the phone and environmental levels. This article compares simulated results with measurements for several steps in the phone design chain.

Today's handsets have to meet tough technical requirements. Mobile phones have to deal with an ever-increasing number of services, while at the same time the cost of the systems is being reduced. R&D in the mobile phone industry copes with this situation by continuously improving the mobile phone efficiency in order to accommodate service enhancements in the mobile network. Thus, we are moving towards mobile designs that are not only becoming thinner, smaller and more complex with every generation, but also have to perform with the same or even better performance, and in more frequency bands.

In addition to maximizing the antenna-accepted power of the handsets, the effects on the antenna performance from surrounding objects such as the human body have to be studied and considered. Homogeneous models are used when measuring the effects on antenna performance and represent a conservative estimation of antenna losses and dissipated power. The performance of the antenna and the entire system may be quantified using sets of technical requirements for both passive and active modes.

In passive mode, the antenna performance is often measured by the antenna efficiency, which is subdivided into the radiation efficiency and the return-loss efficiency. In active

OMID SOTOUDEH
Sony Ericsson Mobile Communications
Kista, Sweden
TILMANN WITTIG
CST GmbH
Darmstadt, Germany

Reprinted with permission of **MICROWAVE JOURNAL®** from the January 2008 issue.

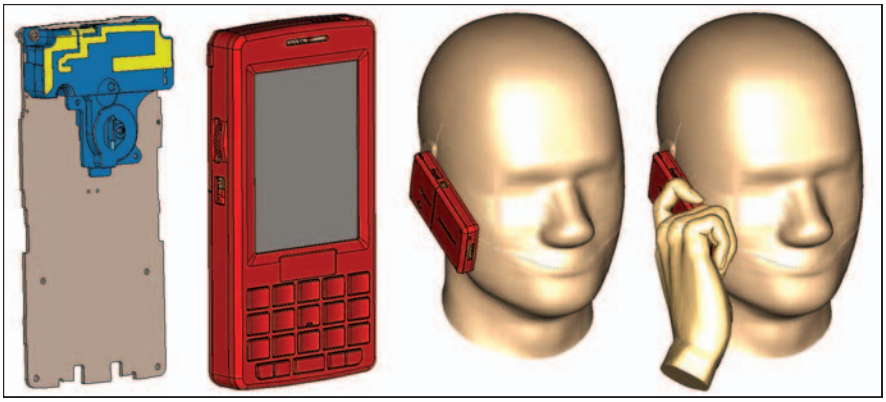


Fig. 1 *Analysis phases of the mobile phone study.*

TABLE I

CONVERGENCE STUDY FOR THE ANTENNA LEVEL CASE IN FIGURE 1

	Run 1	Run 2	Run 3
No. of mesh-cells	221,610	383,160	660,539
Simulation time (s)	450	690	1130
Max. difference	–	0.067	0.014
Radiation efficiency 1 GHz	0.894	0.901	0.906
Radiation efficiency 2 GHz	0.908	0.924	0.923

mode, the entire system efficiency is defined by the total radiated power (TRP) on transmitting (Tx), and the total isotropic sensitivity (TIS) on receiving (Rx). The active performance of the handset is often measured using exact and time-consuming procedures. These have to be conducted several times during the development phase of the device. Furthermore, the product has to be developed to a certain stage before any measurement or reliable prediction of antenna performance is possible.

Numerical simulation of terminal antennas has been actively discussed in literature. There has been considerable development in both hardware and software recently and it is important to continuously update the field with the latest developments. This article considers the accuracy of calculation of mobile phone models by comparing these calculations with measurements. The models used are taken from the recently released Sony Ericsson M600 mobile phone[1] and measurements were conducted at Sony Ericsson's test facilities. The emphasis is on the accuracy of calculations using the present state-of-the-art.

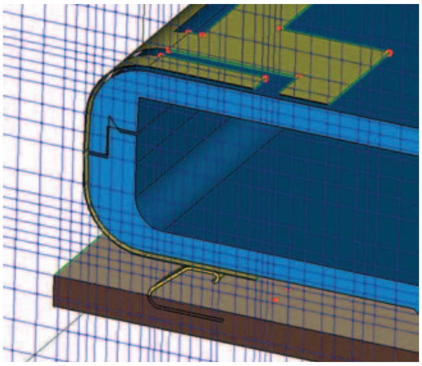


Fig. 2 *The converged mesh for the antenna simulation.*

SIMULATION TECHNOLOGY

For all simulations, the 3D EM tool CST MICROWAVE STUDIO® (CST MWS),[2] based on the finite integration technique (FIT),[3] was used. This method represents a consistent transformation of the analytical Maxwell equations into a set of matrix equations, the Maxwell Grid Equations (MGE). Thereby, essential physical properties of the analytical equations, such as energy conservation and passivity, are maintained in discrete space.[4] The MGEs can be solved by various techniques, from statics to the optical regime, in the time and frequency domains.

In the microwave range, the frequency domain approach is very flexible in the choice of discretization (tetrahedral or Cartesian meshes may be used), but it requires the solution of a large linear system of equations for each frequency step. The time domain solver, in contrast, if used on a Cartesian mesh, only requires matrix vector multiplications and therefore scales linearly with the number of mesh cells, both in terms of memory requirements and in simulation time. This offers an advantage for complex simulation models such as mobile phones; however, traditional time domain methods like FDTD can exhibit poor convergence properties.

Within the frame of FIT, advanced meshing techniques such as the Perfect Boundary Approximation (PBA)® and Thin Sheet Techniques (TST)™ can be implemented. Still based on a Cartesian mesh, the geometry is described conformally, but all the advantages of a time-domain approach, like memory efficiency and broadband results, are maintained. To improve the efficiency of certain simulations even further, a stable multi-level sub-gridding scheme can be implemented.

In order to calculate radiation efficiency correctly, it is important to model the skin depth of lossy metal accurately. FIT can be extended to consider the frequency dependency for permeability, permittivity and conductivity in one broadband simulation. Taking dispersion into account is especially important when modeling tissue-simulating materials.

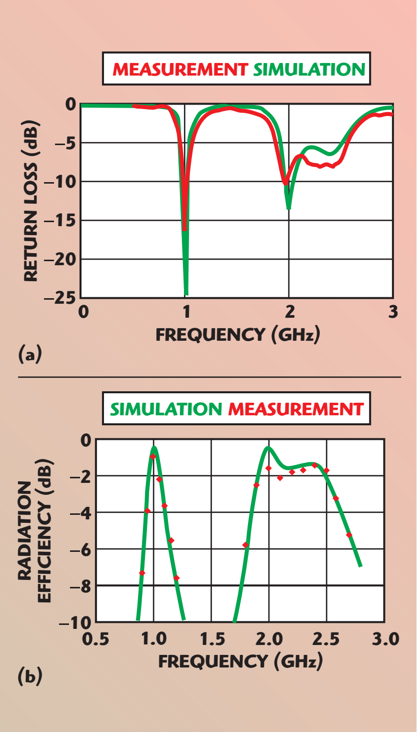


Fig. 3 *Simulation vs. measurement at the antenna level; (a) return loss and (b) antenna efficiency.*

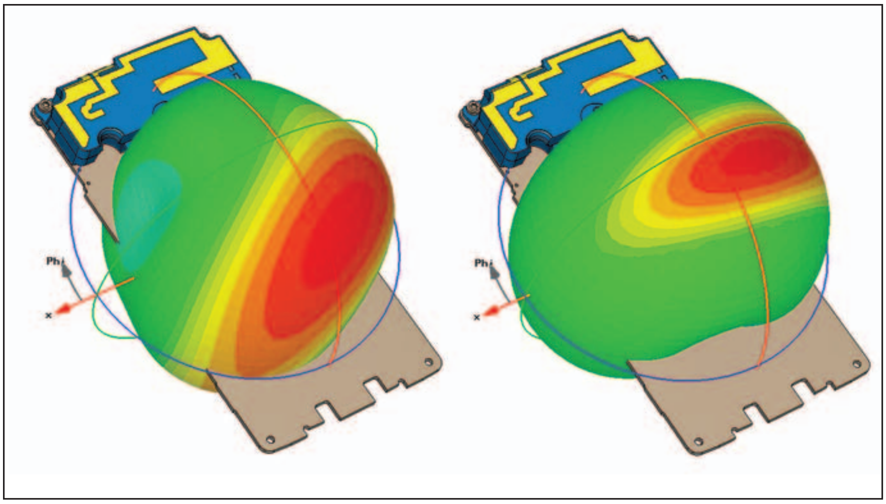


Fig. 4 The radiation pattern of an antenna for two GSM bands.

ANALYZED STRUCTURES

The EM simulations conducted on the M600 mobile phone was done on several system complexity levels. These are shown in ***Figure 1***, from left to right with the least complex structures, such as the simple antenna design and PCB, to the complete phone structure containing several hundred components and finally the entire system using the head of the Standard Anthropomorphic Model (SAM),[5,6] a homogeneous hand model and the full phone.

In real mobile phones, many objects in the vicinity of the antenna element have to be considered because of their effect on the performance of the system. Therefore, great care must be taken when selecting and setting the correct simulation parameters for the relevant objects.

The analysis of antenna performance in the vicinity of bodies often comprises assumptions and simplifications. In general, homogeneous bodies are utilized in order to measure the most conservative behavior of the system. Because of this, homogeneous head and hand models are used for simulations as well. Throughout this work, the antenna effects were quantified by calculating input impedance and antenna efficiency.

SIMULATION AT ANTENNA LEVEL

At the antenna level, the design and optimization of the antenna itself is the prime goal. Results of interest are typically the return loss, radiation efficiency and radiation pattern of the antenna at various frequencies. Even though the transient solver is used for the simulations, frequency quantities like near and far fields can be evaluated easily at numerous frequencies during one transient run due to field monitors based on discrete Fourier transforms (DFT). Realistic loss values were chosen for both the metallic and dielectric objects.

A convergence study indicates that the model converges to an accurate solution. Starting with a relatively coarse mesh of 221,000 mesh cells, and refining it using an energy-based criterion, the final solution is achieved in only three steps. The criterion for stopping the study is that the maximum difference of an S-parameter between two runs is less then 0.02 over the complete band (0 to 3 GHz). Additionally, the convergence of the radiation efficiency at the two bands was evaluated.

The total convergence took 38 minutes. For further simulations and structure optimizations, the third run can be skipped, as the mesh setup in the second run with around 383,000 mesh cells delivers well converged results. This means that all further simulations in the optimization process will have a run time of only 12 minutes. Details including individual simulation times can be taken from ***Table 1***.

The converged mesh is shown in ***Figure 2***. The bent planar parts of the PIFA antenna, the antenna carrier and the PCB can be seen clearly. As the bendings are not aligned with the Cartesian mesh, this would cause

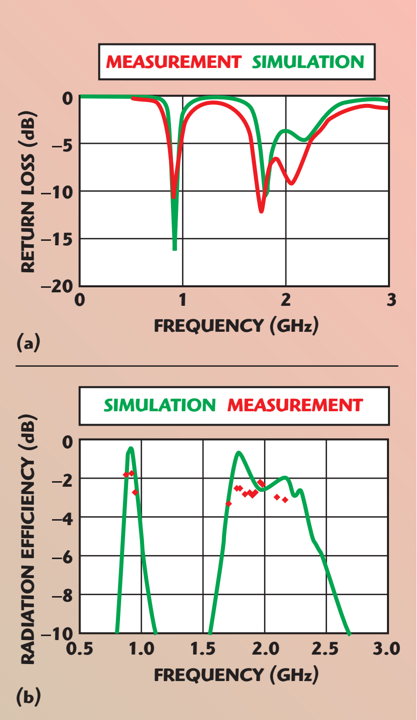


Fig. 6 Comparison of simulation and measurement for the full phone simulation; (a) return loss and (b) antenna efficiency.

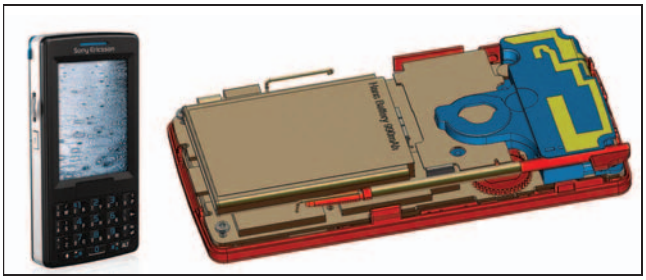


Fig. 5 Full phone model containing phone plastics (red and blue) and metallic parts (copper and gold).

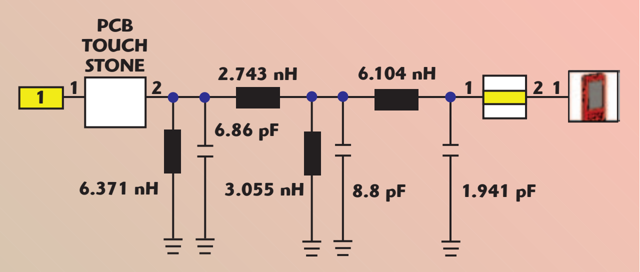


Fig. 7 Network simulation including matching network and the 3D results of the antenna.

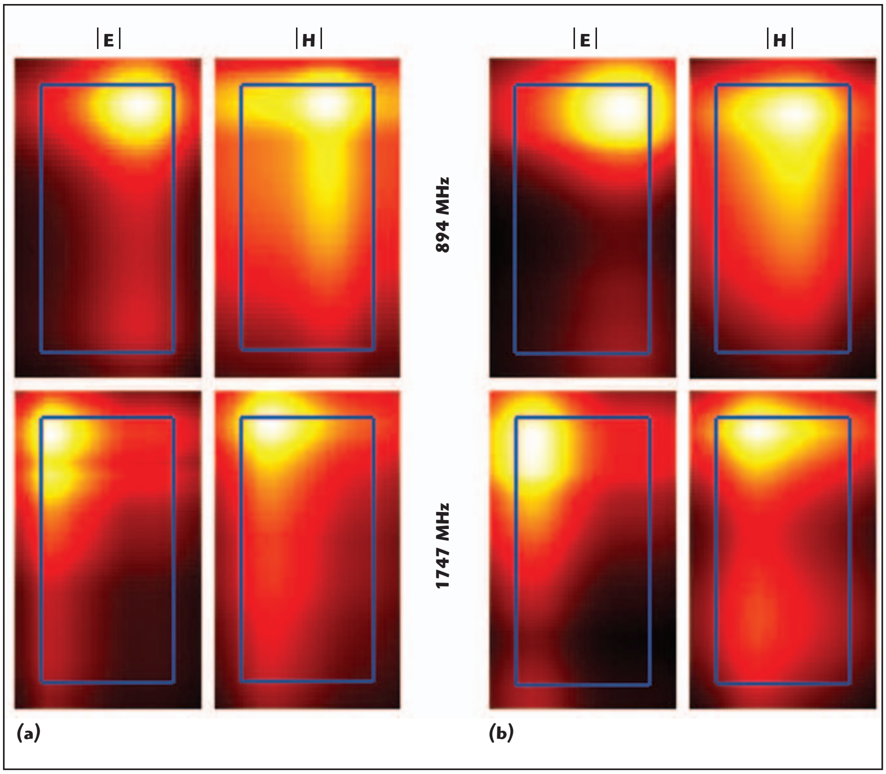
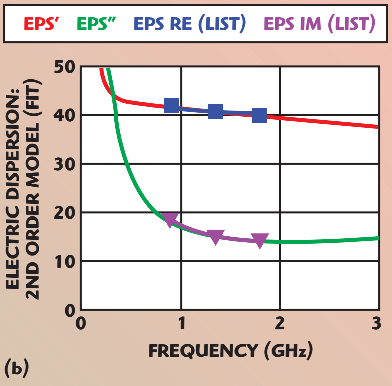


Fig. 8 *Electric and magnetic near fields on the back of the phone; (a) simulation and (b) measurement.*

significant problems in simple staircase methods; however, due to the thin sheet technique, mesh cells can be intersected by metallic sheets. Together with the PBA technique, the shown grid, although it might look relatively coarse, delivers fully converged results.

FREQUENCY (MHz)	ε_r	σ (S/m)
835	41.5	0.90
900	41.5	0.97
1800-2000	40.0	1.40

(a)



(b)

Fig. 9 *Tabulated values for the tissue properties by IEEE 1528 (a) and the broadband material fit used by CST MWS (b).*

The converged simulation results of the antenna compared with measurements are shown in ***Figure 3***. The results are in agreement for both the return loss and the radiation efficiency. Finally, the radiation pattern is shown in ***Figure 4*** for two GSM frequencies. Since the plastic housing is not considered for this study, the resonances are slightly shifted to ~1 and ~2 GHz.

SIMULATION AT PHONE LEVEL

After the antenna design is complete, the next step is to include it in the complete phone. This enables the evaluation of the coupling effects of neighboring objects such as the battery, camera, flash capacitors, etc., as well as the influence of dielectric materials such as the housing and display screen.

The phone is subdivided into roughly 60 components, each consisting of hundreds or even thousands of individual facets(see ***Figure 5***—the back cover and battery lid are hidden for the picture). The components used for the simulation are chosen based on their influence on electromagnetic fields (which is controlled by both dimensions and location), in order to give an accurate simplification of the phone geometry for the investigated frequencies.

The structure was imported into CST MWS using the STEP interface. No additional healing was necessary before conducting the simulations, which is an important pre-requisite for efficient industrial design and workflow. The simulation of the full mobile phone consisted of 594,000 mesh cells (again after a convergence study as described in the previous section). The total simulation for the converged model took 19 minutes.

The simulation of the return loss and radiation efficiency of the full phone is compared with measurements in ***Figure 6***. As the complete phone is now considered, the frequencies are shifted down to the well-known mobile phone bands. The results again agree well with respect to resonance frequencies, bandwidths and radiation efficiency, but some differences occur in the return loss for the upper frequencies.

These can be explained by the uncertainty regarding the antenna's exact feeding point during measurement and measurement de-embedding. Additionally, the properties of the various materials used in the phone model may be inexact.

Alongside radiation efficiency and return loss, global quantities such as the TRP and the TIS are relevant for the simulation of the complete phone. These values require the consideration not only of the antenna characteristics but also the amplifier, the signal transmission inside the printed circuit board and the matching network. ***Figure 7*** shows the simplified setup of such a circuit in CST DESIGN STUDIO™ (CST DS) including an idealized source, touchstone file describing the PCB transmission, matching network and a microstripline to feed the antenna. The simulation delivers system S-parameters, system near and far fields, and from these, the TRP value. The TRP value of this idealized setup gives 23.27 dBm at 1.8 GHz and amplifier power of 0.25 W.

The near field is also of significance for the complete phone, as interaction with other electromagnetic devices such as hearing aids (hearing aid compatibility, HAC) might occur. Near-field information can be predicted accurately by means of simula-

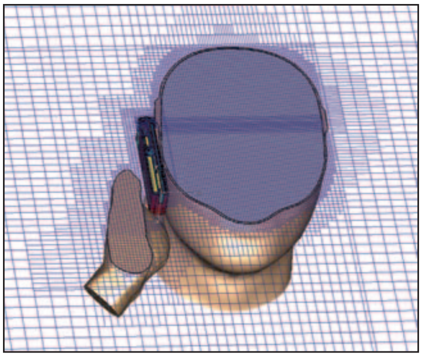


Fig. 10 Sub-grid setup for a mobile phone simulation in the presence of head and hand.

tion. ***Figure 8*** compares the normalized E and H near fields at a distance of 10 mm from the back of the phone in a free space configuration. The blue outline represents the position of the phone. (Measurements were performed by Ericsson Research, Stockholm, Sweden.)

SIMULATION AT BODY LEVEL

A final test for the mobile phone is to evaluate it in the presence of a human body, with particular emphasis on the head and hand. In accordance with IEC and IEEE standards,[5,6] the Standard Anthropomorphic Model is used as the head model. The frequency dependent dielectric properties of the tissue simulating liquid are also defined by this standard and can be modeled as a dispersive material in the simulation tool. ***Figure 9*** shows the required values tabulated and realized in the simulation tool.

The simulation of this phone, with head and hand models, required 4.24 million mesh cells and had a simulation run time of 1.58 hours on a PC (dual core dual CPU, 2 GHz, 8 GB RAM). The number of mesh cells can be reduced using the sub-gridding scheme. When applied, a very fine mesh is created inside the phone, a coarser one in the head and a very basic one in the vacuum (see ***Figure 10***). Using sub-gridding reduces the number of mesh cells to only 922,000 and the simulation time to 44 minutes.

If the simulation is started without sub-gridding on a hardware acceleration card, the simulation time can be reduced even further to only 27 minutes. Excluding the meshing time, the solver speed-up using sub-gridding is 3.6. With the accelerator card, a speed-up factor of 5.8 can be achieved compared to a non-accelerated workstation.

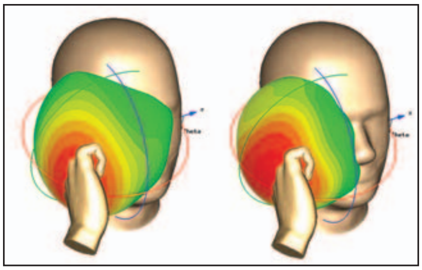


Fig. 11 The modified radiation pattern for the two GSM bands in the presence of head and hand.

Such a simulation can give important insight into how the SAM phantom or the homogeneous body models affect the performance of the mobile phone. The radiation pattern is obviously affected, but the radiation efficiency is also influenced by the head and hand. ***Figure 11*** shows the radiation pattern of the phone; a significant difference is visible in comparison to the plain antenna far fields from Figure 4.

As previously mentioned, the radiation efficiency is influenced by the body models. ***Table 2*** shows the antenna efficiency calculations for only the phone, the phone placed at the right cheek of SAM and the phone held at SAM's right cheek with a hand model present.

Finally, full-SAM simulations are very useful to predict dissipated power. This quantity—as a measured value—is another important design issue and a requirement for certification. However, a simulation allows the designer to control this power at a much earlier design stage.

CONCLUSION

This article has shown what is currently possible in the world of advanced 3D EM simulation. Throughout all steps of a mobile phone's terminal antenna development—from antenna design, through full phone optimization up to investigating the influence of, and impact on a body model—simulation and measurement have been compared and shown to be in very good agreement. In addition to measurable data, numerical simulation grants insight into previously unseen electromagnetic detail.

TABLE II

ANTENNA EFFICIENCY CALCULATIONS

Frequency	897.4 MHz	1747.6 MHz
Phone	100%	100%
Phone head	23% (–6.3 dB)	48% (–3.2 dB)
Phone head hand	6% (–12.2 dB)	7% (–11.5 dB)

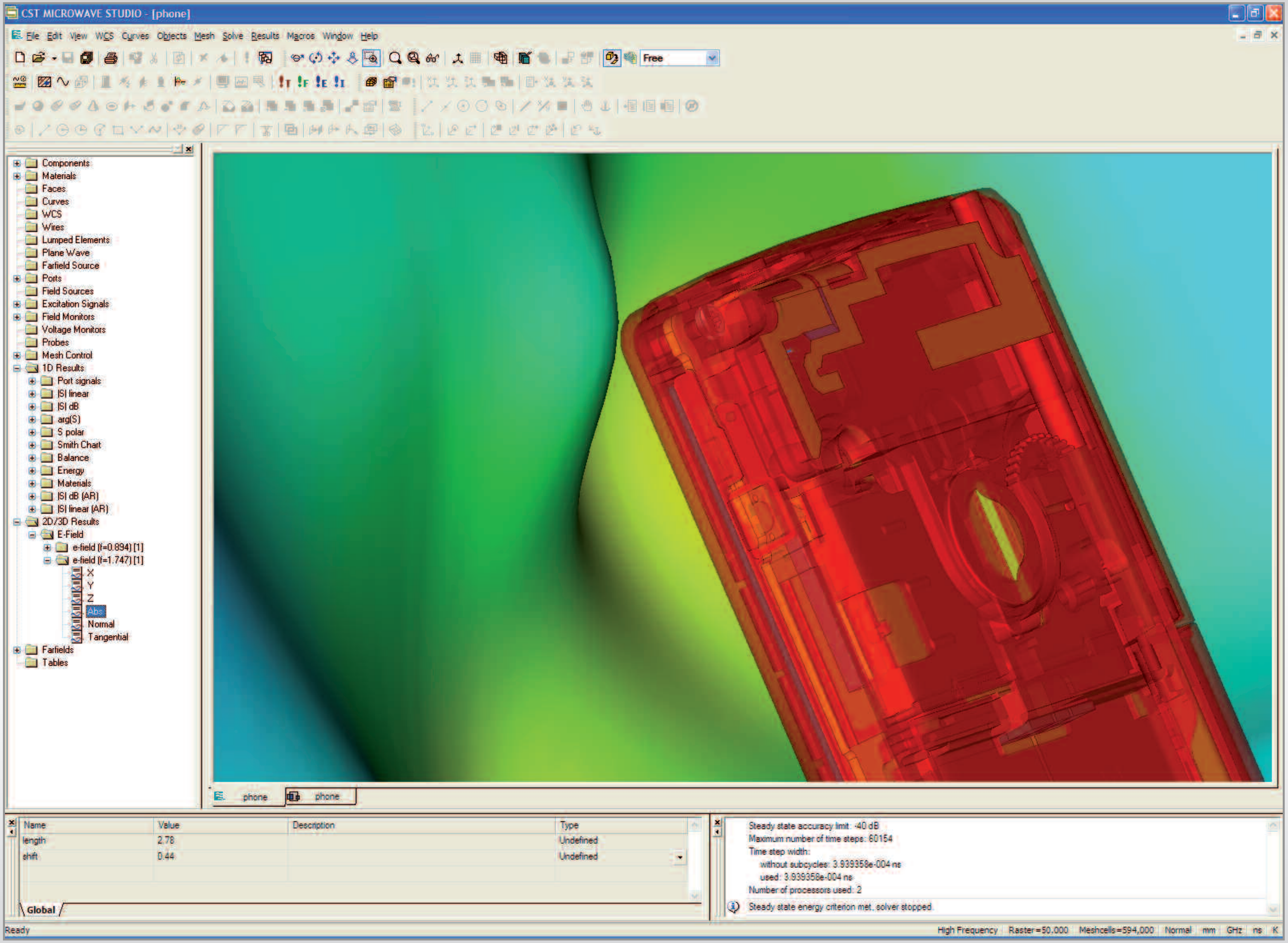
Within one simulation run, all-important quantities such as return loss, radiation efficiency, near and far fields, and loss monitors (all at various frequencies) can be obtained. Advanced mesh technology significantly reduces the simulation time, bringing it down to a few minutes for an antenna simulation. Even complex automatic optimization runs become feasible. The increasing efficiency and reliability of simulation, which reduces design cost risk, is recognized as indispensable in the industry. ■

References

1. www.sonyericsson.com.
2. www.cst.com.
3. T. Weiland, "A Discretization Method for the Solution of Maxwell's Equations for Six-Component Fields," *Electronics and Communication*, (AEÜ), Vol. 31, 1977, p. 116.
4. T. Weiland, "Time Domain Electromagnetic Field Computation with Finite Difference Methods," *Int. J. Num. Modeling*, Vol. 9, 1996, pp. 295–319.
5. IEEE Standard 1528-2003, www.ieee.org.
6. IEC Standard 62209-1, www.iec.ch.

Omid Sotoudeh *was awarded his MSc degree in satellite engineering from the Swedish Institute of Space Physics in 2001 and his PhD degree in electrical engineering from Chalmers University of Technology, Gothenburg, in 2005. He then joined Sony Ericsson Mobile Communications AB in Stockholm, where he has worked on research into antennas and propagation, especially in the field of numerical modeling.*

Tilmann Wittig *received his Dipl-Ing degree in electrical engineering in 1998 and his PhD degree in the field of numerical simulation of electromagnetic fields in 2003, both from the University of Technology, Darmstadt, Germany. He joined CST's technical team in Germany in 2004, where he currently works as a senior application engineer for EM field simulations.*



Name	Value	Description	Type
length	2.78		Undefined
shift	0.44		Undefined

```
Steady state accuracy limit: -40 dB
Maximum number of time steps: 60154
Time step width:
   without subcycles: 3.939358e-004 ns
   used: 3.939358e-004 ns
Number of processors used: 2
Steady state energy criterion met, solver stopped.
```

Sony Ericsson M600 simulated using CST MICROWAVE STUDIO® 2008