Simulating your product’s EM (electromagnetic) radiation will help ensure that you pass FCC (Federal Communications Commission) and CE (Conformité Européenne) tests and will keep your project on schedule. Every product must have EMC (electromagnetic-compatibility) tests. The FCC requires that you test your products to ensure that EM radiation will not cause interference with radios, phones, and TVs. In addition to testing for EM radiation, your product must also exhibit electromagnetic immunity, meaning that a strike from a defined EM pulse will not significantly disturb the product’s performance (Reference 1).

You need sophisticated software tools to perform EM simulations. These simulations must take into account both small and large features over a broad frequency range (Figure 1). You must also select an appropriate simulation method, which can be either a time-domain technique, such as FEM (finite-element method), or a frequency-based one, such as MOM (method of moments). For the largest problems, you need to break the simulations into subdomains or use asymptotic-solutions techniques.

Once you have a powerful computer and the right software, you must place physical and electrical data into the software using database importation or by feeding in mechanical configurations with Gerber and DXF (Drawing Exchange Format) files and manually entering dielectric constants and board-stackup specifications. Finally, you must provide a stimulus to the software, either with Spice or S-parameter data or with a near-field-simulation result from a previous simulation on a subsystem in the product.

**SPICE VERSUS FIELD SOLVER**

You cannot use Spice to simulate EMC because Spice is a matrix-math computational solver for Kirchhoff’s equations that uses lumped-element models of discrete components. At best, you can use Spice to model a lossy transmission line to define what happens to the signal, but it does not reveal which fields radiate into space. For this problem, you need a field-solver simula-
A field solver uses finite elements, meshing, and iteration to solve Maxwell’s equations for your circuit design. EM-simulation software must account for the mechanical configuration and the materials you use in the design (see sidebar “Computer power”).

The highest frequencies you are trying to simulate and the size of the circuit dictate the scope of the field-solver problems you will encounter. Wavelengths are 30cm at 10 MHz, meaning that a 1-cm trace is much smaller than the wavelength (Figure 2). The software would not have to mesh the trace into smaller sections to iterate toward a solution. The 30cm wave acts almost uniformly on the 1-cm trace. Imagine a 10-GHz radar signal with a 2-cm wavelength bouncing off a battleship. The field-solver software must break the battleship into billions of tiny meshes, fitting 10 or even 100 into each square centimeter of the ship’s surface.

The surface of a metal battleship is not purely reflective, so the software must do 3-D meshing and has even more elements to compute because it must also do the interior areas. The workstation that runs the software needs hundreds of gigabytes of memory to store intermediate calculations for the meshes, and it would take months to solve for the fields over this large area. You can solve the memory problem by breaking the problem into domains and solving them iteratively, but that approach would take even longer.

When you test for EMC, small mechanical features result in big changes in performance. A slot in a cover, a misrouted trace, or an aluminum heat sink on an IC package can all cause your product to fail EMC-radiation testing. These mechanical features serve as antennas, so they also receive energy from their surroundings, giving your product poor electromagnetic immunity. The standards require compliance to frequencies of 960 MHz and beyond. For this reason, simulating for EMC is a broadband problem with heavy computational requirements. You must simulate for those frequencies; thus, simulating a large system takes an unacceptably long time. The complexity of the problem is monstrous even for a rather simple product. Also, multiple phenomena, including electrical fields radiating from traces, magnetic fields from inductors, and both types of fields radiating into and from cables, are responsible for EMI (electromagnetic interference).

A typical EM-simulation strategy divides the problem into pieces and depends on both relative and absolute measurements. You need to know how customers will use the product, divide your EMC analysis into manageable pieces, and then evaluate those pieces as they relate to the whole problem. The principle of superposition can be a big help. It states that, for all linear systems, the net response at a given place and time that two or more stimuli cause is the sum of the responses that each stimulus individually would have caused. If three main contributors are affecting your EMI signature, you can individually simulate each one, with different techniques if necessary, and then add the results in an rms (root-mean-square) fashion if they are not related. Sometimes, though, one system affects the other, and they do interact.

Once you have simulated the PCB (printed-circuit board), you represent that simulation as a radiating model that you then plug into a larger assembly. Even if you can use likely signals to simulate the radiation from your PCB, you may also have a few switching power supplies that have not only electric fields, but also magnetic ones. A case surrounds these components, and the cables from the product are antennas that radiate energy to make you fail EMC testing and receive energy to make your circuit fail immunity tests. You may also have to decide how disparate radiation patterns add up to a total emissions level. That decision may bring up the ugly reality of nonlinear

### Table 1 Finite-Element and Time-Domain Techniques

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Electrical length (wavelengths)</th>
<th>FEM</th>
<th>TD</th>
<th>MOM/MLFMM</th>
<th>Asymptotic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 MHz</td>
<td>0.5</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>10 MHz</td>
<td>5</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>100 MHz</td>
<td>50</td>
<td></td>
<td>X</td>
<td>X</td>
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<td>1 GHz</td>
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<td>10 GHz</td>
<td>5000</td>
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<td>X</td>
<td>X</td>
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</tr>
</tbody>
</table>

Source: CST
circuits, such as RF-power amplifiers that you drive into saturation to get good efficiency. Superposition techniques don’t work in nonlinear systems and may cause you to underestimate the radiation from the circuitry.

SELECTING A TECHNIQUE

The mathematicians and software wizards who work at field-solver companies have developed many methods to help you do EM simulations. You can use 2-D simulation programs, such as HyperLynx and SIwave (signal-integrity wave) to evaluate the EMC of a PCB. Fixing the signal- or power-integrity problems on the card often fixes your EMC problem, as well. You can use time-domain simulations for lower frequencies and smaller physical problems. The key benefit of the time-domain techniques is that they use GPU (graphics-processing-unit) cards, which speed up the math.

James Stack, training, applications, and consulting manager at Remcom Technology Solutions, reports that adding one GPU speeds solvers by a factor of 30 and stuffing your computer with four GPU cards can speed things up by a factor of 150. David Johns, vice president of technical support and engineering at CST (Computer Simulation Technology), reports that his company’s time-domain solver runs problems 12 times faster with a GPU.

Unfortunately, at higher frequencies, time-domain techniques are not the best way to solve for EM fields. FEM and time-domain field-solver techniques work best for slower signals, while MOM and asymptotic solvers work for faster speeds and larger problems (Table 1). You are better off using a frequency-based solver in a PC workstation with lots of memory and multiple CPU cores. Companies such as Feko and CST use MLFMM (multilevel-fast-multipole-method) techniques, which solve large problems with less computer power. As the problems become large and must run at frequencies greater than 10 GHz, you must use special solvers that can do asymptotic analysis, which solves for large sets. In some simulations, one physical domain affects another (see sidebar “Multiphysics keeps tabs on your design”).

Some products, such as those from Cadence, Mentor Graphics, and Zuen, have tools to get electrical and physical information into the simulation software. When you do your PCB design in these vendors’ tools, the vendors provide a complete representation of the PCB-layer stackup and material, allowing their signal-integrity and field-solver tools to use this data in their simulations. Also make sure that point tools can accept your PCB data. CST and Sigirity take databases from Cadence, Mentor, Zuen, and Altium, and these tools and many others accept ODB (open-data-base)+ PCB fabrication to define the physical configuration and materials in PCBs. Full-wave-simulation vendors, such as SPEAG and 2Comu, are familiar with 3-D databases and can import STEP (Standard for the Exchange of Product Model Data), IGES (Initial Graphics Exchange Specification), DXF, and other mechanical-solid-modeling outputs (Figure 3). Once in the simulation program, the program meshes the solids with algorithms appropriate to the method.

Defining the mechanical shapes and dielectric constants of the physical design is only part of the EMC-analysis problem. When using a time-domain technique, you can just put the proper

Figure 2 This battleship is meshed for a 10-MHz analysis. A 10-GHz analysis would have a 100-times-finer mesh (courtesy CST).
time-domain waveforms on the ends of the traces. IBIS (I/O-buffer-information specification), a time-domain look-up table of driver-pin waveforms, can describe the rise and fall of a signal on a pin. You also must define the data on the pin; a PBRS (pseudorandom binary sequence) is often adequate for representing the spectral content of the signal on a functional product.

You can use IBIS-AMI (algorithmic-modeling interface) to define the preemphasis circuits and equalizers in the chips you are using, but it does not define the actual waveforms that will appear when your product is running. Typically, you just use a PBRS into the IBIS-AMI blocks. Meanwhile, your design may have hundreds of traces that might interact (Figure 4).

S parameters are the best way to represent the spectral content for the sources of EM noise at high frequencies. An S-parameter representation of a PCB block still does not give you the spectral content that the block will output unless you properly excite the block with signals typical of those that the product will use. Using EM simulations for EMC does give rise to a “chicken-or-egg” problem. Sometimes, the only thing that has the adequate representation of the frequency spectrum being radiated is a working board inside a real case. In that situation, it may make no sense to simulate the problem when you can simply test it, but doing simulations is important. You must know where your simulations deviate from actual results, and doing a correlation between the simulations and real measurements allows you to improve your models, your meshing, or your technique. This approach may not save time for the product you are currently working on, but it can shave months or even years off the development of the next one. Getting results from a Spice simulation that creates a near-field model that you then import to a 3-D solver is a good way to stay in control of your EMC problems.

**TOOLS FOR EM SIMULATION**

No single piece of software can do EMC analysis. You should assemble a suite of software tools to help battle your EMC demons. For example, board-level tools can ensure that the signals go where you intend instead of radiating to space. All enterprise-class PCB companies have good field-solver tools to help with signal integrity (Reference 3). Mentor Graphics may be most well-known for its HyperLynx tool, but Cadence, Ansoft, and Zuken also have powerful tools that work on a PCB with hundreds or thousands of traces. SiSoft makes a signal-integrity tool similar to HyperLynx. Sigri Systems offers its software as a point tool to plug into PCB flows. This tool finds how power-integrity problems and signal-integrity problems relate to each other (see sidebar “SI and power integrity are also important”). Once you have a well-designed PCB, you may then have to approach the problem as if you were an RF-board designer.

RF-design-software companies Agilent ADS, AWR Microwave Office, Ansoft, Sonnet, CST, and dozens of others can help you deal with the vagaries of EMC analysis. Most of these companies also offer plug-in software, such as the EMPro software in Agilent’s ADS, which performs EM modeling. These tools also account for metal boxes and shields around the circuits and can evaluate the relationship between the electrical and mechanical aspects of your design—an inherent requirement of RF design. RF designers know that their circuits’ performance changes after the cover is on. RF-design tools can model the cooling slots in the case and tell you the amount of radiation coming from them for a given frequency excitation.

Excitation constituting random fields pouring from your PCB as it operates is a more intractable problem, but field-solver companies CST and Ansoft demonstrate how you can solve...
MULTIPHYSICS KEEPS TABS ON YOUR DESIGN

With experience and deliberation, you can break up your EMC (electromagnetic-compatibility) analysis and use software at all points in the process to ensure you pass FCC (Federal Communications Commission) and CE (Conformité Européenne) testing. Remember, though, that surprises can always occur. The term “multiphysics,” relating to the interactions of domains in simulation, often comes up in EMC. For example, if the RF energy heats a material that exhibits a Curie point, then the simulation must account not only for the electrical behavior of the space around that material, but also the thermal effects on the material. It must then calculate the change in fields that the changes in the magnetic properties of the material cause.

A more common multiphysics problem occurs when it. You use time-domain simulations with real waveforms on multiple traces to do a simulation. You then capture a near-field representation of the radiation from the PCB. At a short distance from a source, the electric and magnetic fields do not directly relate, as they do in a wave propagating through space. You then plug this near-field result into a full-wave solver that can calculate the effects of your product’s case, cables, and other mechanical features (Figure 5).

SOFTWARE CAN’T THINK

Field-solver EM simulations do not provide an EMC panacea. Furthermore, they are not magical genies that can solve a design disaster. Field-solver vendors stress that computer simulations are parts of the entire design process, not some tucked-on afterthoughts that you do as a penance when your product fails FCC testing. You can’t expect a computer simulation to identify every area in which you may have to make improvements. However, if you use and understand the simulations of various parts of your design as it progresses, you will be in better shape when submitting your product for FCC and CE testing. In many cases, the most valuable thing that a computer simulation will do is teach you the nonintuitive behavior of EM fields in a complex product. Playing with the configurations, materials, and shielding will help you understand what is going on, and you can design the product to comply with regulations.

With signal frequencies in the gigahertz, a finned heat sink on an FPGA acts as a phased-array antenna, radiating energy in your product. The cooling slots on the case are also phased antennas. Even if you do not have the time or budget to do a full simulation of the electrical signals on the board radiating to a point 3m away, you can still use full-wave simulations. A broadband simula-

Figure 5 Use a 2-D solver to calculate the near fields from a PCB. You can then use the near-field data as a source in a 3-D solver to yield EMC-performance data outside an enclosure (courtesy Ansoft).

Figure 6 The flow for an EMC simulation can involve imports from 2-D solvers and PCB software, as well as direct input from the user.
tions of the heat sink tells you at which frequencies the sink resonates and the spatial pattern of the resonance. You can also do a broadband excitation of the slotted case. If the frequencies and locations of the heat-sink resonance align with the resonance of the case, those frequencies will cause trouble. The fix may be as simple as rotating the heat sink 90° or changing the spacing of the fins, the slots on the case, or both.

Field-solver programs have steep learning curves, especially for engineers unfamiliar with 3-D simulations (Figure 6). Once you understand the software, you must learn how to import your physical configurations and electrical stimuli. It may seem like an endless task, but once you get a simulation to accurately predict the EMC performance of your product, you will see the attraction of using simulations (Figure 7). They allow you to evaluate things in hours instead of months. They don’t guarantee that your product will pass radiation and immunity tests, but they give you a big head start over companies that simply use “cut-and-try” methods to get their products through FCC and CE approvals. You do testing at the end of the product cycle, when whether you ship the product determines your company’s fortunes.

Lawrence Williams, director of product-management groups at Ansoft, says that SI, power integrity, and EMC reside under a common “product-integrity” umbrella. You can often use a simpler 2-D solver to help you design a PCB with good signal integrity. EMC is a 3-D, full-wave field-solver problem, but, if you optimize the signal and power integrity on the board, it radiates less.

More than a decade ago, Mentor Graphics’ HyperLynx tool predicted the performance on FCC (Federal Communications Commission) tests of a complex PCB. Since then, Mentor Graphics has acquired—and is adding to HyperLynx—3-D field-solver software from Zeeland. This approach will help solve for vias and connector stubs that carry signals that are faster than 6 GHz. At that speed, even PCBs need 3-D solvers. Just as signal integrity relates to EMC, reducing radiation often also reduces immunity problems.

Field solvers are useful for evaluating the SI (signal integrity) of your circuits. Solvers can also help with the related problem of power integrity on your PCBs (printed-circuit boards). These problems are related to EMC (electromagnetic compatibility) because solving SI and power-integrity problems often solves radiation and susceptibility problems, as well.

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