Welcome to the Darker Side. This column is devoted to “black magic” subjects, but this month I will discuss a topic even more obscure than usual: shielding. Of course I am talking about electromagnetic shields, nothing related to armors or Arduino extensions.

Assume you are suffering from interference between two electronic systems, an offender A and a victim B. If you ask for advice you will usually get an answer such as, “Easy, just add some shielding!” But is it so easy?

IS A SHIELD REQUIRED?

Adding a shield on an electronic device could be a good advice, but I encourage you to double check all other solutions first. Why? Because shielding is always complex and expensive as I will explain in a minute. Moreover, it simply may not solve the problem.

A shield protects against RF radiation. Therefore you must verify that the perturbation is indeed radiated from system A to system B. This may not be the case if there is any wire between the two systems. For example a common power supply (e.g., wire) can conduct the perturbations quite easily and would render a shield useless. Try separating the power supplies, using batteries if possible. Try adding some ferrite clamps on all wires. Try adding filtering capacitors on all interconnecting wires. Is the problem diminished at all? If yes, it will be a good idea to solve these conducted perturbations at least as a first step. You may also try to shield the interconnecting cables before blaming the board, as a cable is a very good antenna. (Refer to my article “Cable Shielding Experiments,” Circuit Cellar 219, 2008.)

If you are sure that the issue is a radiated coupling between the two systems, what do you do next? Before dealing with board shielding I encourage you to try to either reduce the perturbations radiated by the offender or to increase the victim’s immunity. How? Try to reduce the amplitude of the offender’s signals, as it will make them more harmless. You can also increase the impedance of the noisy signals still on the offender’s side. Reciprocally, try to increase the amplitude of the victim’s signals, as it will make them more
resistant. Also try to reduce the impedance of all susceptible signals. Adding a 100-Ω resistor to ground can be magical.

The last common trick is to reduce the edge rates of all digital signals (e.g., by using a slower digital technology), as it will drastically limit their harmonics. Recently one of my colleagues reduced the harmonics radiated by a 13.56-MHz power amplifier by 10 dB by adding a small resistor between a fast logic driver and the power MOSFET’s gate.

Now assume that everything else failed and you will need to add a shield on either the offender A or the victim B. Theoretically, both solutions provide the same result. Shielding the offender is cleaner for the other potential victims, whereas shielding the victim may be a better idea if other source of perturbations can appear in the vicinity. So this choice will be design-dependent. Of course you can also shield both, but it will be twice as expensive.

SHIELD EFFICIENCY

What can you reasonably expect in terms of noise reduction with a shield? Plenty of “shield efficiency calculators” are available online (see Resources). Such tools provide the theoretical attenuation at a given frequency for a given sheet of metal. Theory is great, but real life is always a little trickier.

I will share some experiments I’ve done. The idea was to build a simple test setup to measure some typical shields’ actual efficiency. But how do you define “efficiency?” I stayed as close as possible to real-life situations and assumed that two configurations were representative.

First, the offender and victim could be very close to each other. For example, this appears if the two subcircuits are on the same PCB. In that case, the coupling is usually either purely magnetic or is a close-field electromagnetic coupling.

The second common configuration is when the two systems are a couple of meters away. In that case, the coupling is usually a classic far-field electromagnetic type and the theory is simpler.

Let’s start with the close-field case. How can the actual efficiency of a given shield in such a situation be measured? First I needed to experiment with a “typical” set of offenders and victims. I etched two identical test PCBs. Each circuit included a 5-cm long 50-Ω microstrip track terminated with a 50-Ω resistor to ground. Remember that a microstrip is a track of a precise width on the PCB’s top side and a full ground plane on the bottom side. (Refer to my article, “Microstrip Techniques,” Circuit Cellar 223, 2009.) I used a standard, 1.6-mm thick FR4 substrate to build my PCBs, so the track width for 50-Ω impedance was 3 mm.

Such a microstrip circuit acts as a very wideband antenna, even if it is a low-efficiency antenna. It could be used to either generate perturbations by connecting it to a signal source, or to measure the received
perturbations on the victim side using a spectrum analyzer. I added an SMA connector on the PCB’s bottom side to easily connect to the RF source or analyzer. Then I added some holes to fix a shield, an extra ground plane on the top layer everywhere except inside the shielded area, and plenty of ground vias (see Photo 1). I used Labcenter Electronics’s Proteus tool suite to develop the computer-aided design (CAD) file. (The file is available for download on Circuit Cellar’s FTP site if you would like to rebuild it.)

To have a complete test setup I then positioned both boards face to face, around 20 cm from each other. I connected them to my trusty old Hewlett-Packard HP71200C spectrum analyzer, which is available in my company’s lab. This equipment includes a Hewlett-Packard HP70300A tracking generator module, which transforms it into a scalar network analyzer. The tracking generator provides a test carrier signal aligned with the frequency measured by the analyzer. It may be more difficult, but you could use any RF signal generator and a standard spectrum analyzer to make the same measurements.

The test procedure is simple: Start with the two boards face to face without any shield. Sweep the offender’s signal frequency from 1 MHz or so to the desired upper frequency (e.g., 1 GHz). Measure how much power is received on the victim’s side at each frequency. This is your reference. Then add a shield on one of the boards and do the measurement again in the same conditions. The difference between the two measurements will give the attenuation provided by the shield, which will be frequency-dependent.

Figure 1 shows the overall test setup. I just added some extra amplifiers to increase the measurement sensitivity. Photo 2 shows the actual experiment.

3-D PRINTED SHIELDS

I recently received my first 3-D printer, a MakerBot Replicator 2X. This experimental printer is a dual-head unit that is optimized for acrylonitrile butadiene styrene (ABS) filaments. ABS is a little less common than the usual poly lactic acid (PLA) used on low-cost 3-D printers, but I ordered this configuration assuming it would enable me to build more robust parts.

What about trying to use a 3-D printer to manufacture a shield? The idea may seem silly since ABS—like nearly all plastics—is nonconductive, but I wanted to give it a try. My first idea was use a standard ABS filament to 3-D-print a shield and then use a conductive paint to paint it. This type of paint is indeed often used to “shield” plastic enclosures and I always wondered if it was really effective.
This test was a good way to find out.

Using the 3-D printer to design and manufacture the ABS shield took me less than 1 h. I simply used a common CAD Drawing Exchange Format (DXF) to export the outline of the required shield from my PCB CAD tool. Then I launched Punch!CAD Labs’s ViaCAD 3-D design software. I imported the DXF file, extended it to a 3-D object, and exported the corresponding stereolithography (STL) file. The last steps were to import the STL file from MakerBot’s software, click on “print,” and voila! (The files are available at Circuit Cellar’s FTP site.)

Photo 3a shows the printer working. I used two layers of Kontakt Chemie’s EMI-35 electromagnetic (EMC) paint to paint the inside of the resulting part (see Photo 3b.) The result is pretty nice, but what about its RF performance?

Photo 4 shows the results of the test using the previously explained procedure. I measured an attenuation of about 10-dB in the lowest frequencies, up to 150/180 MHz. This is actually not too bad as a 10-dB attenuation means that 90% of the perturbations are no longer transmitted. However, the attenuation was close to 0 dB for frequencies above this limit and up to 2 GHz at least. Why? This is probably because the EMC paint I used is not efficient for high frequencies. So, EMC paint can solve your problem, if you are just looking for a couple of decibels of improvement, but use this paint with caution.

I wanted to give 3-D printed shields another chance, so I bought a roll of conductive ABS filaments. These are plastic with some very limited conductivity (some kilo-ohms per centimeter) but I thought it could slightly improve the shielding effectiveness. I used these filaments to print another part, added two layers of EMI-35 paint to be safe, and retested it. The resulting performance was not significantly better than with the standard ABS filament (still around 10-dB attenuation up to 200 MHz or so), but close to zero above that limit. I assume this is due to the “conductive” plastic’s high resistance. I suppose this material could be interesting for electrostatic dissipation, but I need to wait for improved conductive filaments before using them for RF.

USING METALLIC SHIELDS

What about trying a standard metallic shield? What efficiency could you expect? I grabbed an off-the-shelf shield and soldered it on the victim’s test board. First, I just soldered the shield through its six pins. The measured attenuation, which was around 15 to 20 dB, was quite deceptive. Then I took the time to properly solder the shield to the ground plan (i.e., I created a continuous solder joint all around it). Photo 5 shows the results. I used the same test configuration to measure the shield effectiveness again (see Photo 6). I measured a 20-dB attenuation in low frequencies, 25 to 30 dB from 400 MHz to 1.5 GHz, and around 20 dB at 2 GHz.

How do you interpret these results? First, using a metallic shield is obviously far better
than using a conductive paint, especially at high frequencies. Then even a metallic shield is not perfect. Achieving a 20-dB attenuation (i.e., 99% of the perturbations are blocked) is easy when the shield is properly soldered, but going higher is not trivial. And shield soldering must always be done on all its sides, not just through its legs. Why was the measured shield efficiency lower in low frequencies? This was probably because the coupling was then more magnetic than EMC, and a non-ferromagnetic metal doesn’t stop magnetic coupling.

FAR-FIELD COUPLING
After performing these experiments in near-field conditions, I wanted to check if these measurements were more or less consistent with far-field conditions. Fortunately, I have access to an anechoic chamber, which is ideal for these kinds of measurements. An anechoic chamber basically emulates an “open-field” situation, as if you were testing an RF device in the middle of nowhere. There are no external perturbations and no signal reflections on the walls, just a clean line of sight path. I installed one of the test PCBs in the chamber, connected it to a RF generator set to a 1-GHz continuous wave, and measured the 1-GHz signal received by a test antenna three meters away (see Photo 7). This gave me a reference level. Then I added a metallic shield on the PCB and measured the signal’s attenuation. I got an attenuation of about 20 dB. This was roughly consistent with the close-field measurements; remember that I got around 25 dB. Next I replaced the metallic shield with the 3-D-printed conductive ABS shield. This time I measured a 10-dB attenuation. How does this fit with near-field measurements? Remember that the conductive ABS shield provided nearly no attenuation at 1 GHz at close distance, but it still reduced the far-field signal by 10 dB. Why? Honestly, I don’t have a clear answer. I guess this is due to the quite complex behavior of near-field coupling. Perhaps this shield still perturbs the wave propagation through its electric component even if it doesn’t change magnetic close-field coupling, and this reduces the corresponding generated far field by 10 dB? That’s my explanation, I will be glad to hear yours!

WRAPPING UP
The experiments I presented in this article don’t pretend to be science, they are just experiments. Therefore they should be used with caution. Anyway these tests show some orders of magnitude. First a well-soldered metallic shield easily provides a 20-to-30-dB attenuation between two circuits, except at very low frequencies and a close distance where magnetic coupling is the main contributor. Getting an attenuation higher than 20 to 30 dB is significantly more difficult as small leaks could happen everywhere. Moreover, it is probably easier to work on the circuits themselves (e.g., reducing the signals speeds, improving the immunity of the victim, etc.).
What about 3-D printers? They are great, and I’m sure I will use my printer often for packaging, fixing parts, and so forth. However, the use of conductive ABS filament alone doesn’t provide an effective shielding against RF fields, at least using the currently available filaments. Using conductive ABS filament and conductive EMC paint enables better—but still limited—results. With this solution you can expect around 10-dB attenuation, but nearly no attenuation at a close distance above some 200 MHz. The same result will be achieved by adding a couple of EMC paint layers in a plastic casing. Don’t get me wrong: 10 dB is still a huge improvement and could solve your problem, but you need to know that your life will be a little more complex if you need 50-dB improvement.

Finally, as usual, I strongly encourage you to experiment. You probably don’t have an anechoic chamber in your cellar, but your neighbor’s field could be as adequate on a sunny day. If you don’t have an RF signal generator you can easily build one. And if you don’t have a spectrum analyzer and don’t have enough spare time to build one, you can still use a radio receiver or borrow one. You have no excuse: you need to play with shields to understand what’s going on. If not, well, you will need to learn it the hard way the day you have no other solution and a manager or customer is crying over your shoulder.