EMI Suppression Handbook

Communiqués from the Trenches

William D. Kimmel, P.E.
and
Daryl D. Gerke, P.E.

Edited by Dr. E. Thomas Chesworth

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Preamble

For the past decade or so Bill Kimmel and Daryl Gerke have been making their own way in the world as independent EMC consultants. Although they teach a few EMC seminars from time to time, they make the bulk of their living at a client's factory up to their elbows in a malfunctioning piece of electronics equipment. As anyone who has tried it knows, making your living this way is just a bit less rigorous than doing it by turning a spit inside a microwave oven.

For nearly as long as they've been consultants, Bill and Daryl have been recording their trials, tribulations, and war stories in *ENR*'s "EMC Notebook." In this book we present a compilation of their communiques from the trenches. The business of retrofitting all sorts of electronic equipment to fix all sorts of EMI has given them a unique perspective on EMC. Their continued success gives us a warm fuzzy feeling that their advice is most likely useful. These stories describe a variety of EMC problems along with the fixes that resolved them. Perhaps more importantly, taken together they give an insight into a process for discovering and resolving EMI difficulties in electronic equipment.

The book concentrates on problems where, like the cavalry, an outside consultant was called in to rescue the project from failure. They are, therefore, in the main the tough ones that stumped the usually competent in-house engineers. You will notice that certain problems recur and from that you can infer their likelihood of occurrence.

The stories are presented in the order in which they were published between 1989 and 1998 and were not rewritten to "bring them up to date." Some of them include references to particular EMC specifications which may be obsolete now, so the reader should be aware that these references may have only historical significance.

Read them in good health. Write if you get work and hang by your thumbs.

Dr. E. Thomas Chesworth, P.E.
Technical Editor, *ENR*

Table of Contents

Four Key Threats to Microcomputers

When we get calls for help with EMI, the problem usually falls neatly into one of four areas: emissions, electrostatic discharge, power line disturbances, and RF susceptibility. Note that the last three are susceptibility issues.

When we first began EMI consulting, emissions were the overwhelming issue. FCC had just taken action, and most companies lacked the expertise to handle the problems. While emissions are still a problem, there has been a dramatic shift in emphasis to the susceptibility issue, and we would like to point out where the problems are occurring.

Emissions: A Changing Game

Sure, emissions are still an issue. Almost everyone in the computer business has been through the FCC or VDE compliance mill at least once, and it shows. Most products now come equipped with a power line filter to control conducted emissions. Most pay attention to radiated emissions, using ferrites, shielded cables, etc.

But the game is changing. A few years ago, the emissions were pretty well attenuated at 100MHz. Today, high-speed clocks and logic are generating significant harmonic energy up to 500MHz and even higher. This means that even short wires and small slots become efficient radiators. Our rule of thumb is that wires and slots of length greater than 0.05λ start to become efficient radiators. Thus at 500MHz, a wire or slot of much more than an inch is a potential problem.

In the same vein, components degrade at higher frequencies. Capacitors become inductors, inductors become capacitors, resistors become reactive elements. Lead lengths become super critical.

To illustrate this point, wire has about 20nH of inductance per inch. Hence, a 1/4-inch length of wire has a reactance of about 15 ohms at 500MHz. Or, to look at it another way, a $0.01\mu F$ capacitor with a 1/4-inch of total lead length will resonate at about 23MHz and become inductive above that frequency. Similarly, inductors typically resonate at a frequency below 100MHz.

So if you are designing with a new high-speed clock on your microprocessor, don't assume that your existing wire harness and packaging will do the job. Others already have learned the hard way. Learn by their mistakes.

Susceptibility: The New Threat

We believe the susceptibility issue will dominate over the emission issue in the immediate future, and we would like to spend some time on it.

Higher-speed electronics, coupled with smaller geometries, have made your electronics much more susceptible to disturbances. At the same time, electronic equipment is being installed in increasingly hostile environments.

At this time, there are no mandatory government standards for susceptibility. If the designer doesn't voluntarily build in immunity, then it doesn't happen. And the buyer, including the system integrator, is often the unwilling victim.

Here are some "war stories" drawn from our files:

An entire floor of a newly built office building has interference problems with its personal computer systems. Directly across the street is an array of microwave dishes and VHF transmitters.

A system integrator has selected several personal computer elements, added some hardware, and placed it in the field. ESD is determined to be a problem. Unfortunately, the system integrator has no control over the hardware design and must settle for external static control fixes.

A microcomputer-based controller has been installed in a factory environment. The combination of SCR controls and heavy starting and stopping power transients is too much for the controller. Unfortunately, the controller is part of the power control loop, so that power conditioners are not a full solution.

What are the problem areas? We see three key areas today: power disturbances, ESD, and nearby radio transmitters.

Power Disturbances

The principal problem with power quality in the computers is the short-term high-voltage spike and the long-term voltage sags. The sags are a particular problem with the preponderance of switching power supplies in a facility. Each power supply draws energy out of the peak of the cycle. When a sag occurs, the power supply simply runs out of energy, even when the nominal voltage is supposedly sufficient to drive the supply.

Electrostatic Discharge

What about ESD? Two failure modes occur here: direct injection and indirect coupling.

Direct injection to exposed metal components such as metal surfaces (especially near seams and indicator apertures), switches (especially key switches) and controls, and cable connectors (not always accessible to the operator). Good grounding of exposed metal is mandatory, here. ESD must be kept off the circuit board ground as well. "Ground shift" can be as upsetting as injection into a circuit.

Indirect coupling via the electromagnetic field is also a problem. This requires shielding.

If you have a plastic enclosure, then indirect ESD will be a problem. Since you have no shielding, the internal design and grounding system will need extra care. Good design techniques exist, but they have to be applied. It is also important to remember that the fast rise-times of ESD are primarily VHF phenomena and thus require VHF design rules.

RF from Transmitters

The last issue is that of RF susceptibility. If you think this is not a problem in your application, think again. Fixed transmitters are easy to spot (surprisingly, they often are ignored), but the mobile and handheld transmitters are less obvious. And the handheld unit carried by your plant engineer may be just on the other side of the wall. We have had several cases like this, and they require persistence to trace them down.

Fortunately, RF susceptibility and ESD can be treated as one problem on many cases.

Conclusions

Some words to the wise: design and test your product for immunity, as well as for emissions. Watch out for power disturbances, ESD, and RF from nearby transmitters.

At this time, there are still no government-mandated susceptibility limits (except for the military), but the FCC regulations do provide some protection. If problems continue, government standards may appear. But in the meantime, your payoff will be a better-quality product with reduced customer complaints.

May/June 1989 Issue

Automotive EMC Discussions

There is a lot of EMC activity in the automotive world. The 1989 IEEE National Symposium on Electromagnetic Compatibility was held in Denver on May 23-25. The Automotive EMC Session, chaired by Bill Sperber of General Motors, was viewed by more than 100 attendees. This session was the best in our opinion.

John Suriano of Delco Products Division/GM presented a paper entitled "Modeling of Electromechanical and Electromagnetic Disturbances in DC Motors." The model considers the magnetic, mechanical, and electrical components of the DC motor. The level detail to which the motor parameters can be specified provides new opportunities in the analysis of novel motor designs.

Kin Moy of Packard Electric Division/GM addressed the "Test Procedure Development for Automotive Conducted Susceptibility and Conducted Emissions." He compared the test procedures used by General Motors with the SAE and ISO standards. A major goal was the correlation of component level tests to the automobile's internal environment. The successful application of components level test is intended to improve the overall system level performance.

Dr. Anthony Lee of GM Research Laboratories talked about conducted transients in the electrical system of a passenger automobile. This presentation was an extensive survey of electrical transients at various locations in the automobile. Essentially the automobile is characterized by a high concentration of electronic components alongside a large number of power components, a lack of a true ground, and a complex wiring harness. This structural makeup translates to high-level transients coupling to nearby sensitive electronics.

Ed Bronaugh of Electro-Metrics wrapped up the session with a survey of SAE J1816-1987, comparing the levels with J55551, ANSI C63,12 and FCC. He observed that 1816 capitalizes on the existing standards and adds only those requirements unique to the land vehicle. This observation was good news since the past proliferation of standards has caused considerable consternation for the designer.

These were excellent papers with practical information which can be put to work. In fact, there was much more information in the proceedings than could be presented in the time allotted. Anyone who missed the show, especially the automotive sessions, will want to review the proceedings.

The susceptibility issue is really "hot" — all the papers addressed this issue in one respect or another. Bill Sperber noted that the automobile community with its extensive test facilities and R&D staffs has a large stake in EMC. Moreover, this community is producing results of interest to others as well. Bill reported favorable feedback on the sessions from several participants from the military establishment. Also, there are marine, aircraft, and industrial applications, as well as applications for the nonautomobile sector of the industry, including custom coaches, heavy equipment, and agricultural machinery.

July/August 1989 Issue

The ESD Threat

In a previous column, we commented on the principle EMI threats. Obviously, one is emission from equipment. Three others involve susceptibility issues — viz. power line disturbances, radio frequency transmissions, and electrostatic discharge. At present, we would like to address electrostatic discharge, or ESD.

Most ESD programs are structured so as to prevent the occurrence of ESD. This action may take place at the factory level where the primary issue is to prevent damage to sensitive components, or preventive action may take place when the equipment has reached the hands of the end user. Here the primary issue is to prevent functional anomalies, although damage is still a concern.

In any event, once ESD occurs, it becomes an EMI problem. The discharge is a fast rise time intense current pulse which produces an intense magnetic field transient; and of course, it is accompanied by a collapsing electric field. Although static voltages can reach 15 to 20kV, the principal problem is the magnetic field pulse. (Incidentally, theorists mention static voltages up to 35kV, but that's almost impossible to reach in practice.)

ESD has been around for a long time, presumably since time began. However, it is only recently that it has become a problem in electronics. The reason is that circuit speeds have increased to the point where logic can now respond to ESD. Thus, the faster edge rates have opened the "window of susceptibility" to ESD. Couple this fact with the smaller geometries and the increasing use of field effect devices, and the result is electronics which are both susceptible to damage by ESD and capable of erroneously interpreting ESD as valid signals.

There is a lot of work under way to determine what constitutes a good model for testing ESD and what is the best way to test. This controversy is not going to be resolved in the near future, and we don't think it will ever be solved. Anyway, this column is for designers.

The key issues involve coping with ESD. To get some insight, it is worthwhile to look at a Fourier analysis of an ESD event.

The typical ESD event breaks down to two primary types: human discharge and furniture discharge. Human discharge is characterized by a fast rise of current (about one nanosecond) to a peak of up to 10 amps, followed by a decay back to zero. The key issue is the rise time, and a Fourier analysis shows that there are significant components out to about 300MHz. Furniture discharge is characterized by a slower rise of current to a peak up to 50 amps, followed by damped oscillations. A Fourier analysis of this type shows significant components out to about 30MHz.

Note that these limits bracket the VHF band nicely. For this reason, we look at ESD as a VHF problem and advise using VHF design techniques to handle it. That advice brings up an interesting corollary — i.e., designing and testing for ESD is a good way to harden equipment for RF susceptibility as well. Poke around for the soft spots with the ESD gun; when the equipment is hardened for ESD susceptibility, it will have fairly good hardening for RF susceptibility, too. Actually, ESD is a more severe test, compared with RF, for digital equipment. The converse holds true for analog devices.

And what are the soft spots? First, consider direct discharge, where arcing occurs directly to metal on the equipment. In order of vulnerability are operator controls, cable entrance points, metal seams, and metal fasteners. The cable entrance points are particularly sensitive to destructive ESD because arcing can occur directly to exposed signal pins during installation or at any time when the pins of unused connectors are exposed. However, operator controls are the most vulnerable because they are always being touched. Then the seams and fasteners provide a path to the internals of the equipment. The only good defense against direct discharge is to insure that exposed metal parts are well-grounded. Exposed pins should be recessed to prevent direct discharge, or they should be protected with surge protection and filters.

Indirect discharge occurs when there is arcing to a nearby metal surface, such as water pipes, electrical conduit, or even a sizable metal object, such as a file cabinet. This discharge is most noticeable with plastic enclosures. Here the intense field penetrates the enclosure and is picked up by wire loops internal to the enclosure. The best defense is to minimize the loop area in the internal wiring whether on a circuit board or in internal wire or cable. For that reason, it is wise to keep the wire or cable close to the ground surface. A partial shield internal to the enclosure may be needed for sensitive areas. Also, it should be noted that exposed metal in plastic enclosures is still subject to direct discharge as described above.

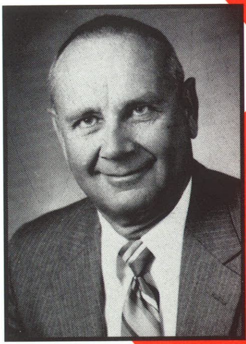
The principal point is that ESD must be kept off the circuit boards at all costs. Once on the board, it is impossible to control. Another key point, when considering possible current paths, is that initial flow (and this is the worst part of the discharge) follows conductive paths. A wire of any length is too inductive to provide much of a path for the initial discharge. This situation means that the green wire on the power cord does not play a significant part in the discharge; capacitive coupling of the enclosure to ground will be the preferred path.

A final comment — last fall, our company started to receive a flood of calls for help in ESD. What was the reason? Along with the heating season in the snow belt come lower humidities and thus even more ESD. The calls ceased when warm weather returned. There is a message in this situation.

Anyone putting the final touches on the preparation of a product to be introduced in the fall would be wise to check out ESD immunity. Otherwise, a nasty shock (figuratively speaking) may occur when temperatures drop. Also, manufacturers in the humid Eastern Sun Belt should be cautious about ESD when shipping products to a drier climate; they face realizing the problem too late when customers start screaming.

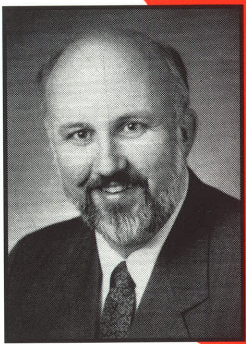
September/October 1989 Issue

TWO CONSULTING ENGINEERS show how to successfully turn electromagnetic interference (EMI) problems into electromagnetic compatibility (EMC) solutions. Here, from the pages of the bimonthly EMC journal, *Electromagnetic News Report*, is a compilation of 51 of Bill Kimmel and Daryl Gerke's "EMC Notebook" articles about EMI in a wide range of industries: computers, medical devices, industrial controls, telecommunications systems, vehicles, and more.



William D. Kimmel, P.E.

Bill received his BSEE with distinction from the University of Minnesota and has worked in the electronics field for more than 30 years. Before becoming an independent consulting engineer he worked for Control Data Corporation and Sperry Defense Systems. His EMC experience includes design, test, and qualification of military systems to MIL-STD-461 and TEMPEST requirements, industrial and commercial systems to FCC and CISPR/IEC, and medical devices to FDA requirements. He is a NARTE-certified EMC and ESD engineer.



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Daryl received his BSEE from the University of Nebraska and has worked for more than 25 years for Collins Radio, Sperry, Tektronix, Intel Corporation, and as a consulting engineer. His EMC experience parallels his partner's with the addition of conducting EMP research. Daryl holds FCC commercial and amateur radio licenses and is a NARTE-certified EMC and ESD engineer.

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