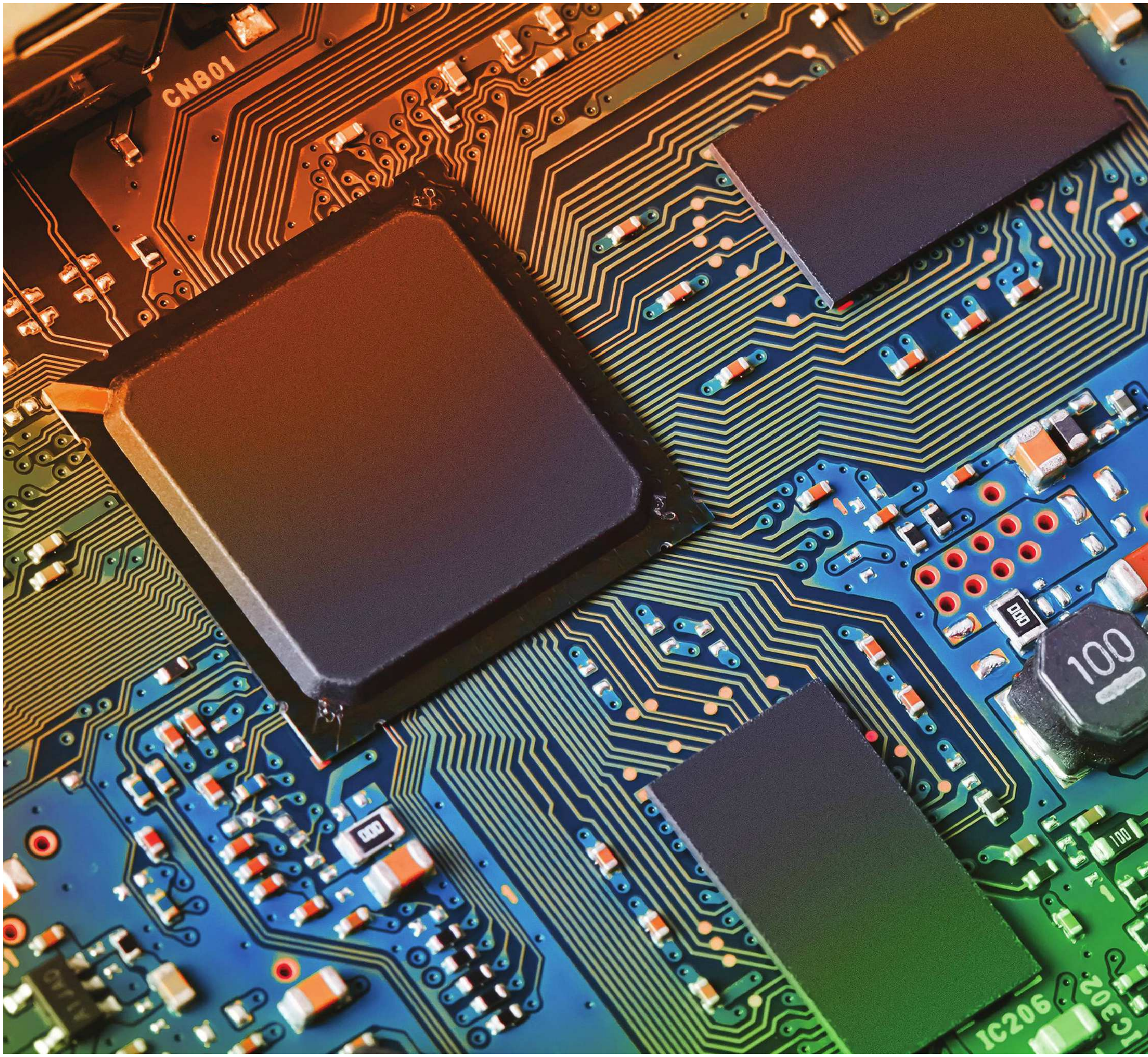
DEALING WITH EMI IN SEMICONDUCTOR DEVICE MANUFACTURING

An Overview of SEMI EMC Standard and Work in Progress



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By Vladimir Kraz

Semiconductor manufacturing puts special demands on the electromagnetic environment at the factory. Among them are:

- *Precision:* It is difficult to achieve adequate yield at emerging small geometries (current goal is 10nm geometry - that's one ten millionth of a millimeter while the diameter of an atom of silicon is not much smaller - 0.23nm) as is - electrical noise in the manufacturing equipment makes achieving required accuracy and yield quite challenging;
- *Process:* Strong interference may alter the "recipe" of a process just enough to scrap expensive wafer and to start over lengthy process;
- *Equipment uptime* (sometimes called "equipment availability"): If a tool is affected by electromagnetic interference to the degree where it can no longer guarantee required yield, that's several millions of $$$ standing idle while the wafers or packaged devices are not being processed;
- *Test:* False positives or false negatives can either halt manufacturing process or cause faulty component to be shipped to a customer. Small geometry, high data speed and low-level signals make test equipment highly susceptible to unwanted electrical noise;
- *Device damage*: Strong electromagnetic interference (EMI), specifically conducted emission with substantial energy, may be able to damage sensitive devices, especially in processes with metal-to-metal contact to the devices.

SEMI (www.semi.org) is a global industry-wide organization serving both semiconductor manufacturers and manufacturers of equipment used in semiconductor processes. SEMI is headquartered in San Jose, California, with offices in Europe and Asia. SEMI has an extensive standards body which focuses on many aspects of the emerging needs of the semiconductor industry.

The particular challenge facing semiconductor manufacturers is that the requirements of commonly-used EMC regulations and standards correspond poorly to the specific environment at the factory and to the key factors that actually affect equipment and process.

Each SEMI standard is debated and issued by a dedicated task force involving expert volunteers from the industry. The EMC Standards Task Force is one of them. It shapes industry-specific EMI and electromagnetic compatibility (EMC) requirements in accordance with the specific needs of semiconductor manufacturing.

The particular challenge facing semiconductor manufacturers is that the requirements of commonly-used EMC regulations and standards correspond poorly to the specific environment at the factory and to the key factors that actually affects equipment and process. In the following sections, we'll consider some of those factors.

QUASI-PEAK VS. PEAK

In most EMC standards, both radiated and conducted emissions are measured using a quasi-peak detector, which is arguably the slowest detector used in EMC field. The problem is that most of electrical noise in manufacturing environment is not continuous but rather transient. Figure 1 shows the typical conducted emission noise in manufacturing environment and the measurement results with both types of detector - peak and RMS (which is as close to quasi-peak the oscilloscope was able to achieve).

In this case the ratio is almost 50, or over 33dB. RMS measurements are more "generous" to the results than quasi-peak - they show higher levels of signal than quasi-peak detector would. No wonder fully-compliant equipment can be an EMI-menace in actual use.

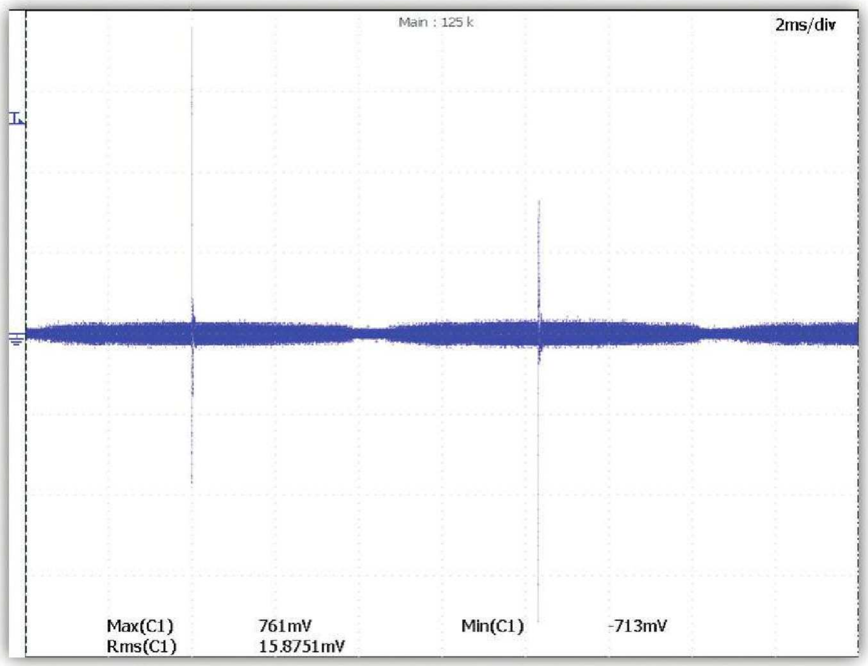

Figure 1: RMS vs. peak measurements

Why is the typical electrical noise transient in nature? The answer lies in the way that equipment operates. Ubiquitous switched-mode power supplies present in virtually all equipment, often in large numbers, convert voltage using pulses, typically between 60 and 200kHz. This rapid switching generates strong narrow spikes with each transition. Quasi-peak measurements would show moderate level of noise at the switching frequency but would greatly underreport much higher-level narrow spikes with the repetition rate (or twice that) of the switching frequency.

Servo motors and variable-frequency drives (VFD) present in automated handling tools also operate using pulses. A typical servo motor or VFD is a three-phase drive using pulses with the frequency of typically 8 to 20 kHz. Each such pulse has rise and fall times as short as 50nS, which leaks throughout the tool and into the ground via capacitive coupling inside the motor and both capacitive and inductive capacitance in wiring. Again, the 8 to 20 kHz signal measured with quasi-peak detector may not amount to much, but the short pulses with that (or double of) repetition frequency may inject current of several amperes into the ground. There are many other sources with similar properties, such as lasers, LED and CFL lights, relays, solenoids and switches.

None of these transient emissions are accurately captured by standardized quasi-peak measurements, but their effect is critical on equipment operations and manufacturing processes.

50 OHMS?

There is a good reason why conducted emission tests use 50 ohms termination. This provides universal consistency and repeatability with minimum signal reflections. However, has anyone seen power line with genuine 50 ohms impedance? What about impedance of the load? Equipment would have to have current consumption of exactly 2.4A at 120VAC across the entire frequency range to present 50 ohms load. In real-world environments, the impedance of a power line is typically less than 1 ohm, and the impedance of the load can vary greatly. How does that affect conducted emission levels? Anywhere from not at all to tens of decibels. Impedance of other than 50 ohms in EMC-focused preventative products can cause amplification of noise rather than its reduction.[1]

INSIDE OR OUTSIDE?

EMC regulations and associated standards are mostly concerned with what happens outside of equipment, i.e., how much noise it sends out. What is also important to semiconductor manufacturers is how much noise is inside the equipment, more specifically in places affecting their processes.

Most semiconductor equipment is a combination of components, in which each individual component manufacturer may provide some means of emission control. But the combination of several parts may be problematic since no one seems to own the EMC profile of the final assembled equipment. Examples include wafer probers and wafer sorters, IC handlers and IC testers, and many others.

In addition, semiconductor equipment manufacturers, like other manufacturers, are under tremendous price pressure. In the spirit of "you always get what you paid for," equipment manufacturers often skip expensive tests (initial cost) and on proper EMC mitigation (on-going cost), since there are no industry requirements to control emissions inside a tool regardless of how it may affect semiconductor manufacturing process.

EMISSION OUTSIDE OF REGULATED LIMITS

Some semiconductor manufacturing operations are susceptible to emissions outside of typical regulated range. As an example, images created by scanning electron microscopes (SEM) are very sensitive to extremely low frequency magnetic fields which makes images appear "wavy." [2,3] This makes inspection of fine geometry nearly impossible.

NEAR VS. FAR FIELDS

Radiated emission tests are conducted in the far field, often 10m away from the "source." Equipment in a semiconductor fabrication facility is often co-located much closer, altering not only the anticipated field strength limits but also the proportion between electric and magnetic fields.[4,5] At close distances, it also matters exactly where stronger emissions are emanating from in the equipment, as it may be too close to the EMI-sensitive section of a neighboring tool.

TEST LAB VS. FACTORY

Overall electromagnetic performance of equipment depends on its installation. Issues include long ground wires vs. short ones, power line distribution issues and UPS, conjoined equipment in production vs. separate pieces in the lab, complex networks of power, ground and data lines vs. "sterile" environment in the test lab. These and other issues can make substantial differences, often altering electromagnetic performance to the degree where its performance in the lab becomes almost irrelevant.

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All these issues need to be addressed in order to help semiconductor manufacturers to cost-effectively produce advanced devices that power today's electronic equipment. SEMI had an old standard SEMI E.33-94 (circa 1994) which addressed specifics of EMC compliance for the semiconductor manufacturing equipment. This document needed to be updated to reflect current EMC regulations and new requirements for semiconductor processes. However, there was no standard or guideline to reflect the needs for managing the EMI environment on the factory level. As a result, a decision was made to first update SEMI E.33 and then to create a new document that would provide guidance for the management of the electromagnetic environment at the factory level.

SEMI E.33-2012: GUIDE FOR ELECTROMAGNETIC COMPLIANCE OF SEMICONDUCTOR EQUIPMENT

SEMI E.33-2102 is structured in the following way:

- Definition of performance criteria, i.e., how do we know when equipment fails
- Definition of what constitutes basic EMC compliance of semiconductor manufacturing equipment
- Definition of EMC non-compliance responsibility between equipment supplier, installer and user
- Recommendations on test methods and documentation

E.33-2012 has two appendices which are a part of the normative document:

- Extremely Low Frequency (ELF) and Very Low Frequency (VLF) Electromagnetic Interference
- EMI Audit

Related information sections that are not a part of the normative document but are provided as a reference and information include:

- Continuous and Transient Electromagnetic Emissions and Their Effect on Operation of Electronic Equipment
- Near-Field Electromagnetic Environment
- Subset List of Guidance Standards, Regulations, and Directives
- Facility Infrastructure

We will discuss some of these items. Basic compliance with E.33-1012 is based on European Union's (EU's) EMC Directive as the most comprehensive compliance document. However, basic compliance is not always sufficient.

Perhaps one of most significant new additions to the E.33 standard is the definition of responsibility boundaries for EMC non-compliance. Should electromagnetic interference plague manufacturing processes or tests, figuring out who is responsible for fixing the problem may be quite contentious. Semiconductor manufacturing equipment is quite complex with its cost easily extending into tens of millions of dollars. In a similar fashion, semiconductor manufacturing processes can be unforgiving when it comes to lost time and yield. Any interruption of the process or any yield issues can result in substantial cost to a company. Clarifying the party responsible for correcting EMI issues in a semiconductor fabrication facility greatly accelerates its resolution while avoiding unnecessary arguments.

Table 1 (taken from E.33-1012) provides assignment of responsibility for correcting EMI-related issues at the factory level.

This greatly simplifies the relationship between different involved parties in case of any EMI-related issues.

To prevent distortion of images in scanning electron microscopes (SEM) caused by magnetic fields of very low frequency (not covered in the EU's EMC

Item	Responsibility
Semiconductor manufacturing equipment itself	Supplier (semiconductor manufacturing equipment manufacturer)
Semiconductor manufacturing equipment in combination with other equipment if supplied (i.e., integrated) by one supplier	Supplier (semiconductor manufacturing equipment integrator)
Semiconductor manufacturing equipment in combination with other equipment if integrated by the user	User
Facility-level electromagnetic environment	User
Semiconductor manufacturing equipment installation-related compliance and EMI-performance	Party responsible for installation
Semiconductor manufacturing equipment collocation	User
Semiconductor manufacturing equipment after repair or maintenance	Party responsible for repair or maintenance
Post-sale additions or modifications made by the supplier that affect EMC compliance	Supplier (semiconductor manufacturing equipment manufacturer or integrator)
Post-sale additions or modifications made by the user that affect EMC compliance	User

Table 1: Recommended EMC-related compliance assignments

Directive or other standards), SEMI E.33-1012 provides several categories of acceptable field strength at or near the locations of ELF/VLF-sensitive equipment, introducing newer low-level categories. Sources of such fields include wafer transports, power transformers and other equipment emanating strong low frequency magnetic fields.

SEMI E.33-1012 also introduces the EMI Audit of facilities as an EMI management tool to prevent and to mitigate EMI-related issues in the manufacturing environment. Among other items, EMI Audit recommends checking for the "usual suspects" such as loose fasteners and connectors, improperly installed equipment covers, excessively long cables and the like. It also addresses EMI mapping of the facility for both continuous and transient signals. Such an EMI Audit needs to be performed periodically, especially before and after equipment installation and/or maintenance.

SEMI E.33-1012 was released in 2012 and can be obtained at www.semi.org.

WORK ON A NEW DOCUMENT "GUIDE TO ELECTROMAGNETIC INTERFERENCE (EMI) IN SEMICONDUCTOR MANUFACTURING ENVIRONMENT"

As discussed above, EMC performance of equipment in the lab often bears little relationship to that of actual EMI environment once equipment is installed and is operational. Users of semiconductor manufacturing equipment are left to deal with EMI issues on their own without any guidance. The SEMI EMC Task Force is currently developing a "Guide to Electromagnetic Interference (EMI) in Semiconductor Manufacturing Environment," which is expected to help address this problem.

Most EMC standards attempt to regulate the relationship between a supplier and a customer, i.e., whether a product for sale would: a) interfere with other equipment; and b) malfunction in what is considered a "typical" electromagnetic environment in normal use. Once equipment is bought and installed, what is a semiconductor manufacturer to do in order to establish EMI environment in the fabrication facility that does not negatively affect yield, reliability and test? It is not just each individual piece of equipment by itself but also many tools, often not

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quite EMI-compatible but co-located close to each other, all connected to common ground and power lines from an EMC point of view.

To date, guidance regarding permissible levels of emission in the environment once that equipment is installed and is operational has not been widely available. Nor is there is guidance on a sufficient and technically-current test methodology. There are however several documents in existence:

- IEEE 473-1985 IEEE Recommended Practice for an Electromagnetic Site Survey (10 kHz to 10 GHz)
- IEEE 475-2000 IEEE Standard Measurement Procedure for Field Disturbance Sensors 300 MHz to 40 GHz
- IEC 61000-4-39 Testing and measurement techniques - radiated fields in close proximity - immunity test
- EPRI TR-102323 Guidelines for Generic Plant Emission Measurements
- IEEE Std 1100-2005 "Emerald Book"

Although each of these documents presents some helpful information, they are either incomplete, only partially relevant or simply obsolete.

Semiconductor manufacturers deserve comprehensive down-to-earth guidance on EMI measurements in their facility, recommended maximum acceptable levels, a methodology of measurements and recommended types of instrumentation, as well as guidelines on mitigating excessive emission at the facility, both radiated and conductive. Dealing with EMI in a manufacturing environment is very different from a test lab. Near-field conditions, the transient nature of most EMI signals, complex power and ground networks, internal to equipment EMI and other issues require an approach other than equipment-based standards alone.

An important aspect of dealing with EMI at the factory level is that, after all, the main focus of semiconductor manufacturing is producing semiconductors, not controlling EMI. Unlike an EMC test lab or a product manufacturing company which regularly designs new products that need to undergo compliance testing, a typical semiconductor manufacturer needs to deal with EMI only periodically. A competent consultant can be of great help, of course, but managing the EMI environment at a factory should be within the ability of technically-competent factory personnel to address, or at least assess. Most important, the document has to be actionable rather than be a theoretical treatise with more complex formulae than practical guidance. Our typical reader is not an EMC expert but a factory engineer or a manager who is tasked with dealing with semiconductor processes, equipment and facilities.

The SEMI EMC Task Force is working on its Guide with the stated purpose of providing "guidance for assessment and mitigation of electromagnetic interference (EMI) in semiconductor manufacturing environment to improve yield, equipment availability, and test time and results." At a minimum, its content is expected to include the following information:

- Basics of EMI in the semiconductor manufacturing environment. This will not and should not replace basic technical education on dealing with EMI issues, but will point readers in a right direction and give them at least a basic summary of what they are up against, especially as it relates to the practical aspects of semiconductor manufacturing. SEMI prides itself in educating semiconductor manufacturers in current and emerging technologies, and our Guide will continue this effort;
- Types of electromagnetic emission in manufacturing environment. This includes radiated and conducted emission, far field and near fields, continuous and transient signals and other relevant properties;
- Sources of EMI in the semiconductor manufacturing environment. Semiconductor process utilizes very specific types of equipment generating certain types of emission;
- Propagation of electrical noise—This section is being constructed to be as relevant to the specifics of semiconductor fabrication and tools, not just an academic exercise in signal propagation;
- Effects of EMI on equipment, devices and communication;
- Measurements of electromagnetic emission - radiated and conducted - in manufacturing environment. This section is a departure from "standards-type" measurements. It involves near-field measurements as well as measurements of peaks and of time-domain properties of the signals. Internal to the equipment EMI measurements will also be included;
- Recommendations on maximum acceptable levels of radiated and conducted emission (all types - peak and continuous) in manufacturing environment - external and internal emission. The recommended levels in the factory will be based not on existing EMC standards but rather on actual needs of the semiconductor process;
- Practical recommendations on mitigation of excessive EMI in the manufacturing environment;
- Guidelines on EMI Audit.

Given the scope of this new document, we invite semiconductor manufacturers to actively participate in our Task Force. Please contact us at vkraz@onfilter.com for information on how you can participate.

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