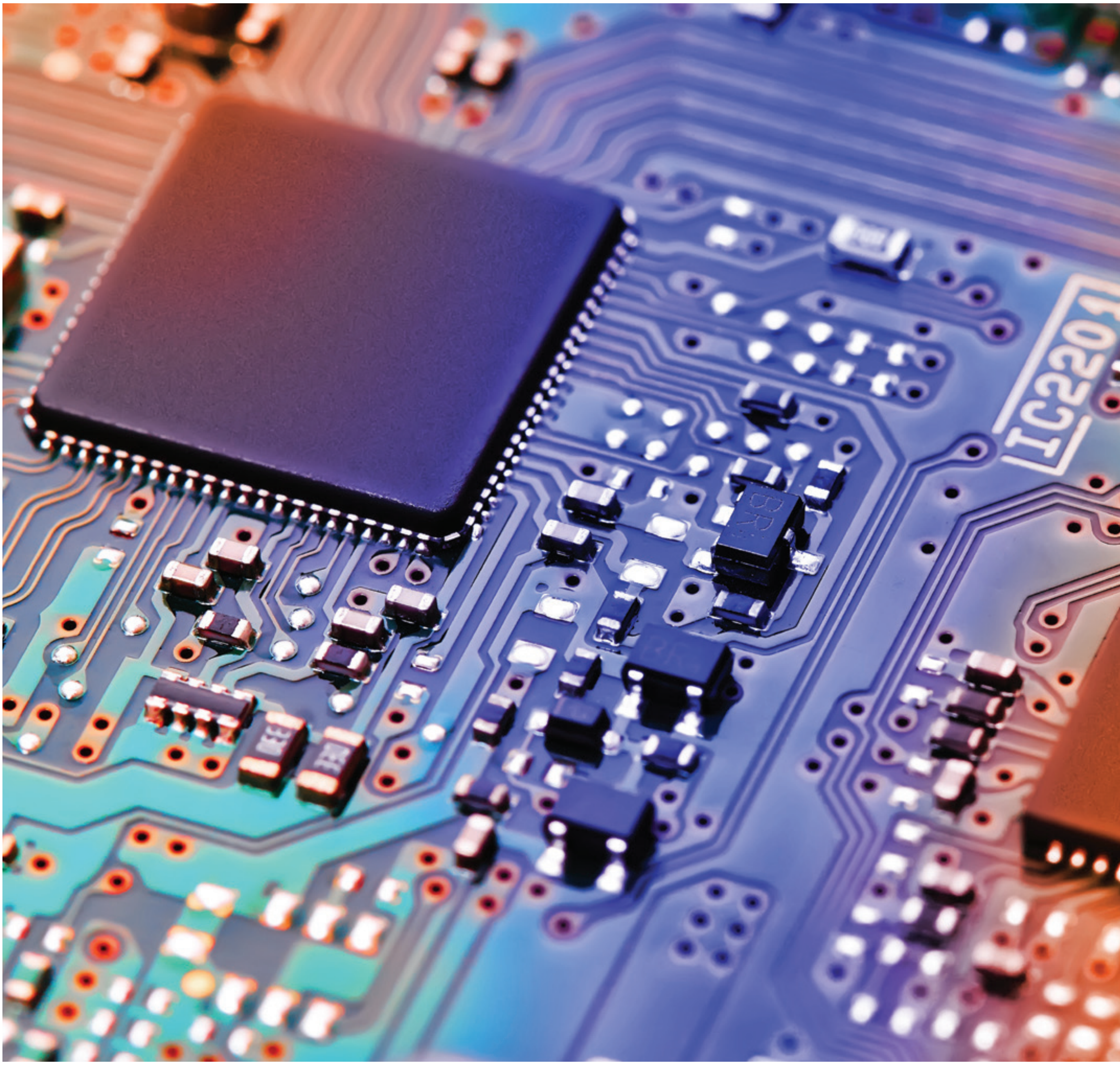
DEALING WITH EMI IN SEMICONDUCTOR MANUFACTURING: PART II

Latest Developments in SEMI EMI Standards: SEMI E176-1017



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By Vladimir Kraz

This is a follow-up to an article[1] that appeared in the June 2016 issue of *In Compliance* Magazine. That article details the specific challenges facing the changing and growing semiconductor manufacturing industry and how the SEMI (www.semi.org) standards organization responds to them. Specifically, that article provided examples of where conventional ways of specifying and measuring electromagnetic emission may not work well for the needs of semiconductor manufacturing and handling, which may be applicable to other industries as well.

The focus of that article was on the SEMI E33-1012 document, which has recently been updated as SEMI E33-0217, "Guide for Semiconductor Manufacturing Equipment Electromagnetic Compatibility (EMC)."[2] A section of the article dealt with the then-ongoing effort on the new document in progress, "Guide to Assess and Minimize Electromagnetic Interference (EMI) in a Semiconductor Manufacturing Environment." The work on this Guide has been concluded and the Guide has now been published as SEMI E176-1017,[3] which is available on the www.semi.org website. This article provides the background and a summary of E176-1017.

WHY SEMI E176 IS NEEDED?

Few if any hard-core EMC specialists would argue with the premise that what ultimately matters is not just the EMC compliance of an individual equipment but, rather, the complete electromagnetic environment in actual installations. With EMC compliance efforts focused only on individual equipment, each 'ingredient' in a big picture may be agreeable, but once all the equipment is installed and operational, the finished EMI 'dish' may not taste well. Often, EMI levels in a factory, especially in an energy-diverse semiconductor fab, reach substantial levels. The new SEMI E176-1017 provides guidance on achieving that 'end result' with the ultimate goal to establish acceptable levels of electromagnetic emission in the end-use environment.

What is the intended audience for this document? It is certainly not just the EMC engineers—their job is pretty much finished once the equipment has met specified requirements on emission and immunity with the tests performed in an EMC lab. Ultimately, those most affected by the undesirable effects of EMI end up being the most interested party—in our case, it would be engineers and technicians in device manufacturing. Excessive emission problems on the manufacturing floor lead to errors in the operation of equipment, data corruption, process variations, and, in extreme cases, damage to sensitive devices.

Most importantly, it is not just applicable to semiconductor manufacturers but also to electronic assembly specialists, because there is not much difference in handling semiconductor devices between an integrated circuit (IC) handler and a surface mount technology (SMT) pick-and-place equipment, for example.

Enter SEMI E176-1017. It places the focus not on limited types of emission from any particular equipment, but on EMI in the overall manufacturing environment and in key locations where it specifically matters.

STRUCTURE OF SEMI E176-1017

SEMI E176-1017 is written to be a concise practical guide for establishing and maintaining acceptable EMI environment in the semiconductor manufacturing and handling process. It is comprised of several sections. It can be loosely divided into several functional chapters:

- Fundamentals
- Measurements

- EMI Audit
- Mitigation
- Recommended EMI limits

With the progressively smaller geometries of semiconductor devices, the requirements for accuracy, precision, consistency of the processes, and susceptibility to electrical overstress are tightening and semiconductor manufacturers are forced to find ways to keep up with these requirements[4]. An aggravating element in this effort is that often the new, more aggressive EMI requirements must be met utilizing already existing equipment and facility infrastructure.

Fundamentals

The E176 is both a guide and an educational document. There is a strong need of a concise 'crash-course' in practical EMI for most of its readers. One only needs to understand that EMI by itself is not an essential element in a process of manufacturing or handling semiconductor devices, which explains the general lack of knowledge of EMI and its mitigation among semiconductor manufacturers. EMI is thought of as a nuisance, a distraction, which it truly is, and therefore little or no training is conducted on the effects of EMI, its nature or its mitigation.

E176 does not attempt to be a textbook, but rather a 'let's not be afraid of EMI' short primer where the initial instinctive fear of EMI is replaced with a concise and very practical explanation of EMI's basic nature, origins, propagation and effects on equipment, processes and devices. E176's opening section, "Basics of EMI in a Semiconductor Manufacturing Environment," does just that. It includes an explanation of radiated and conducted emission and its impact on equipment operation, the manufacturing process, and sensitive devices. It outlines which specific properties of EMI are most harmful, some of which are not properly addressed in current EMC regulations, such as European EMC Directive, but are germane to manufacturing, among them peak amplitudes of signal, pulse width of a pulsed signal, ringing and alike.

There is not much an equipment user in the field can do to reduce excessive emission emanating from expensive equipment that has all the EMC 'insignia' but still generates substantial electrical noise. Equipment is quite complex, it costs a substantial amount of money, and there are inevitable warranty issues preventing users from making any changes to it. But there are ways to reduce the impact of this excessive EMI by controlling its propagation. The section "Propagation of Electrical Noise" focuses on typical ways of propagation of both radiated and conducted emission in a manufacturing environment—blocking of propagation of EMI is one of the most effective ways to reduce the impact of EMI. This section also describes how the propagation path can alter the properties of the signal by presenting complex impedance to the signal. For instance, sharp edges of a pulse having a wide spectrum at the point of origin transforms into much smoother, rounded slopes (often with ringing) with the properties that have little to do with the pulse itself, but a lot to do with the propagation path. Both radiated and conducted emission are addressed with the specifics for each type.

The next section, "Effects of EMI on Equipment, Semiconductor Devices, and Communication Systems," provides specifics on how excessive EMI negatively impacts equipment operation, data communication and, in some cases, sensitive semiconductor devices by causing electrical overstress (EOS). Electrical overstress is "the number one cause of damage to IC components" according to Intel.[5] A detailed explanation is given on the impact of EMI on semiconductor devices, including direct damage from EOS and EMI-caused latch-up. Specific to the semiconductor device manufacturing and handling, for example, it outlines exposure to latch-up conditions of the devices caused by conducted EMI. High-level transients (i.e., high vs. the supply voltages and data signals amplitude) are quite capable of putting ICs into latch up, which causes excessive current through devices, overheating, and eventual catastrophic damage. EMI-caused voltages on the ground as low as 0.3 V are considered harmful to sensitive devices.[6]

The following section, "Sources of EMI in a Semiconductor Manufacturing Environment," lists equipment specific to a manufacturing process that can generate strong EMI with their properties that need to be watched. This is not just a generic list of all equipment that can possibly generate electrical noise, but rather examples of the most typical and most harmful emission sources present in a typical manufacturing environment. Among such sources are servo motors and variable frequency drives (VFD), switched mode power supplies (SMPS), uninterruptable power supplies (UPS) and the like. A listing of each such source is provided with the specifics of their emission properties. As an example, most of such equipment can provide substantial transients into power lines and ground while being fully compliant with the EMC regulation.

The section "Types of Electromagnetic Emission in a Semiconductor Manufacturing Environment" summarizes the types of emission found in manufacturing environment—both radiated and conducted.

Equipped with the information from this chapter, the reader is better suited to understand the summary of the specifics of EMI in semiconductor manufacturing from section 10, "Types of Electromagnetic Emission in a Semiconductor Manufacturing Environment."

Measurements

It is said that "you cannot control what you cannot measure."[7] Without proper measurements there is no way to assess the properties of EMI in any environment, understand its nature, devise a way to reduce it, and attempt to quantify any improvements. Measurements of high-frequency signals on cables, wires and metal parts of equipment are very different from that of commonly-used AC or DC voltage and current measurements to which factory personnel are accustomed. The measurements of high-frequency signals that negatively affect manufacturing are also very different from those made in test laboratories for EMI compliance. Thus, this section is helpful both to novices in EMI as well as for experienced EMC specialists.

An attentive reader of this magazine may remember my article "Electromagnetic Compliance: A View from the Field" published in the September 2017 issue.[8] This article dealt with the discrepancies between what is specified and tested for and the actual effects of EMI on equipment, process and devices. To summarize it, the tests for EMC compliance are performed in the conditions and for the parameters that matter little in the actual equipment use. Plus, the presence of multiple equipment in manufacturing placed close to each other and connected to the same power and ground network renders laboratory measurements done for just one equipment unhelpful.

The first section in this chapter "Time and Frequency-Domain Measurements" provides the basics of measuring both the spectrum of the signal and the signal waveforms of transients and pulsed signals with the recommendations on which measurement types are more appropriate for what type of situation. Frequency-domain measurements that comprise a core of emission regulations are relevant largely only for continuous signals that are by far not the main type of electrical noise in real-life applications, which are the transients. Time-domain measurements are the only correct type of measurement for assessing the properties of such signals. Such measurements are typically done using digital storage oscilloscopes.

The frequency-domain measurements that use a spectrum analyzer are common and the absolute majority of spectrum analyzers can cover the required frequency ranges. However, the requirements for the oscilloscopes for time-domain measurements are not as well-known and the document provides recommendations for both radiated- and conducted-emission measurements, which are quite different. While the spectrum of radiated emission of consequence may reach 3 GHz (covering most of Wi-Fi, Zigbee, Bluetooth and other types of communication protocols), the bulk of the energy of conducted emission is concentrated below 1 - 2 MHz but with some cases extending up to 10 MHz. Therefore, a simple common digital storage oscilloscope with the bandwidth of 200 MHz is quite sufficient.

The section on 'Radiated Emission' advises to make measurements at the distances that matter for operability of equipment, not at an arbitrary 10 m distance used in the EMC regulation tests. There are several good reasons to test emission at a 10 m distance in the lab but, in reality, equipment in manufacturing environment is often co-located at much shorter distances than 10 m. These shorter distances are more importantly in the near-field zone for the lower end of the radiated spectrum[9] and this can affect the operation of nearby equipment.

Conducted-emission measurements are encouraged to be made directly between any conductors, including equipment chassis, robotic arms, etc.

A line impedance stabilization network (LISN)[10] is used exclusively in conducted-emission measurements for EMC compliance. However, it is not very well suited for such measurements due to its physical configuration and because it artificially attenuates and often limits low-frequency signals typical for SMPS, servo motors, VFD and otherwise higher-frequency signals that were modified by long cabling to 'ring' at lower frequencies.

EMI Survey/Audit

An EMI survey/audit is an essential element of EMI control in the factory. The main goals of an EMI survey/audit are several-fold, among them:

- Mapping EMI levels in the facility, specific area, on a specific power or ground line, or inside the equipment;
- Verifying compliance with internal or external EMI limits;
- Identifying the higher sources of emission; and
- Verifying improvements.

This EMI survey/audit is ultimately a responsibility of the factory, not of the equipment manufacturer. After all, there is more than one equipment on the factory floor and all of them are interconnected via the factory's power and ground network.

This chapter outlines specific parameters to measure during such a survey/audit. These parameters are focused on their relevance to the manufacturing process and the devices, not just to abstract requirements of EMC regulations. For example, radiated-emission measurements are recommended to be measured near gaps in metal equipment covers and near cables and wires exiting equipment; while conducted-emission measurements are to be done not only on cables and wires but also on metal structures of the equipment. For example, a difference in high-frequency voltage between a robotic arm and a chassis of equipment can expose sensitive components to an electric overstress. Signal peak measurements are especially encouraged.

Mitigation of Undesirable Electromagnetic Emission

This chapter is the core of the document. Excessive EMI must be contained, and this chapter offers practical guidance on the subject. In its opening, it provides an explanation of why a fully-compliant-with-EMC-regulation equipment could be a significant source of undesirable emission. The reader can find a detailed explanation for this phenomenon in the article "Electromagnetic Compliance: A View from the Field" published in this magazine's September 2017 issue.

One of the issues that needs to be pointed out here is that EMC regulations do not delve into the emission internal to the equipment or to near-field emission in the immediate proximity to the equipment. The specifics of semiconductor manufacturing are that often several equipment, often from different manufacturers, are physically conjoined together to provide the manufacturing flow. For instance, while each individual equipment may pass the radiated emission limits at 10 m, the immediate proximity emission is unarguably higher, which may affect another equipment. Another example is mentioned at the end of the previous paragraph—conducted emission between different internal parts of the same equipment. If a sensitive device is being handled by such equipment—IC handler, wire bonder or SMT pick-and-place equipment—the device may be exposed to electrical overstress.

The mitigation of undesirable EMI can be done at the source of the emission or at the target equipment where the emission may cause undesirable effects. Each such method has its merits and its challenges. Ideally, if the source of the emission is clearly identified, the reduction of the emission at the source may be most effective. The problem is that in a manufacturing environment there are many equipment and most of them are 'noisy.' Plus, it is quite difficult and often inconclusive to match a pattern of emission with the particular equipment due to many factors. This leaves mitigation of the EMI at the target as the most effective way of reducing the EMI. In this case, the tried-and-proven methods of reducing EMI usually produce a desirable effect if applied properly.

For reducing the effect of radiated emission, equipment covers must be put in place and properly fastened. Of course, it sounds trivial, but please do take a walk through your facility and count on your fingers how many equipment have their covers either completely off or just hanging on with one or two screws for the ease of access. Simply tightening connectors on the equipment can seriously reduce near-field radiated EMI at no additional cost.

Further efforts to harden equipment from external radiated emission would involve shortening unnecessarily long wires and cables, including service loops; use of braided cables for grounding both inside the equipment and for connection to the facility ground; use of properly-selected ferrite clamps; routing data cables away from power cables; and similar methods.

For the reduction of the effects of conducted emission, the application of specialty EMI filters proves to be the most effective. For power lines and ground, internal EMI filters employed in most of the equipment for EMC compliance, which may provide attenuation in the laboratory conditions with 50 ohms termination, do not provide adequate attenuation at the lowest end of the spectrum dominated by the most prominent signals in the manufacturing environment. This article[11] shows that a typical power-line EMI filter boosts noise instead of attenuating it as shown in Figure 1. Special filters[12] for the reduction of EMI in real-life installations offer more effective attenuation as shown in Figure 2. Ground EMI filters help to block propagation of EMI throughout the facility and equipment grounding. Motor filters are recommended for the reduction of EMI on drive lines for pulse-width-modulation (PWM) motors such as servo motors and VFD.

Recommended Maximum EMI Levels

The closing chapter is "Recommended EMI Levels for Semiconductor Devices in Process." It should be noted that handling semiconductor devices in PCB assemblies also falls under this category. These limits are coordinated with the IRDS (International Roadmap for Devices and Systems), which is under the IEEE umbrella.[12]

This chapter recommends four categories based on the geometry of the devices. For those not in the business of manufacturing ICs, it is not the size of the IC nor that of a die that is most important. To simplify it, the size and the spacing of the micro traces and the sizes of the structures on the silicon device are the most important. The higher the level of integration, the smaller the geometry of the device. The current 'leading edge' geometry in the semiconductor industry is 10 nm, with some companies having success with 7 nm devices. The smaller the geometry, the easier the device is damaged by electrical overstress. The requirements for manufacturing equipment, including photolithography and metrology equipment, increase dramatically with the shrinking geometry.

All of the above increases the need for less disturbances due to EMI. Recommended levels for different geometries include radiated emission limits (that are measured at the device or at the equipment in question, not in an abstract lab), both in the far field and in the near field, including peak values and continuous signals. Conducted emission is also measured in peak and continuous values. The limits for the ground EMI current (peak values) are also specified. As one example for 10-14.2 nm geometry, the peak radiated emission (transients) is set to no more than 1 V/m in the far field and 0.7 V/m in the near field. The conducted emission is limited to the peak values of 0.1 V and 10 mA ground current.

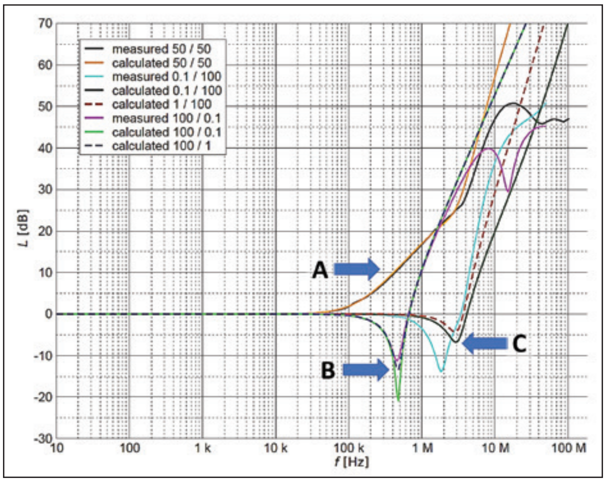

Figure 1: Typical attenuation of a regular EMI filter for EMC compliance. As shown by the curves B and C, noises is amplified, in one case by 20dB.

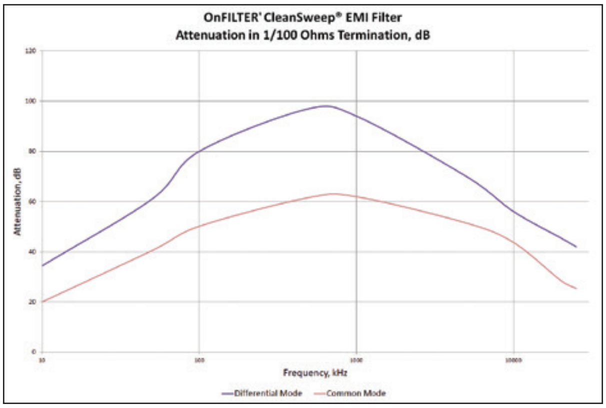

Figure 2: Typical attenuation of a special EMI filter for reduction of EMI in actual installations. As seen, at the same frequencies as in Figure 1 attenuation of noise is 40 to 80 dB

CONCLUSION

SEMI E176-1017 is a much-needed document. EMI has increasingly negative effects on the productivity and on the reliability of the devices, both in the semiconductor and electronics assembly industries. The existing EMC standards provide basic requirements for electromagnetic compatibility only for individual equipment. It is time to address and manage the 'end goal' in EMC compliance—EMI in actual applications. SEMI E176-1017 is the only document in the industry known to the author to provide practical guidance for that.

Anyone in the semiconductor and electronics assembly industries who is interested in contributing to the development and improvement of SEMI Standards is encouraged to contact this author for details. Participation in the SEMI Standards program is free.

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How to Measure Conducted Emission Without Killing Your Oscilloscope

As a side note, connecting an oscilloscope's input directly to high voltage or to an unknown voltage is seldom a good idea. Not only can your oscilloscope be damaged, but the EMI signal will be buried in the high-voltage mains, making triggering and measurements nearly impossible. This is in addition to the creation of a ground loop between the oscilloscope power plug's ground and wherever the ground lead of the scope probe is connected.

For safe and accurate measurements of EMI in the presence of high or uncertain mains' voltage, the 50/60 Hz frequency range must be completely blocked, and the input must be galvanically separated from the output. Special EMI adapters, as shown below, do all that, enabling easy and safe measurements of noise between any two points carrying uncertain voltages by providing a 50 ohms high voltage-limited signal to an oscilloscope or to a spectrum analyzer.

Power line EMI adapter