Practical Aspects of Managing EMI-Caused EOS in IC Handlers and Similar Equipment

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Abstract - Manufacturing and handling of 5G semiconductors require heightened attention to EMI exposure in manufacturing process. This paper outlines detailed methodical steps of bringing a regular IC handler in compliance with EMI recommendations of SEMI E.176 and ESD TR23.0-01-20. Measurements, mitigation, and verification are included. Applicable to any semiconductor process.

I. Introduction

Electrical overstress (EOS) is "…the number one cause of damage to IC components" [1]. More critically, EOS is prone to cause latent damage [2], [3]. Proactive EOS control in manufacturing and handling processes in device manufacturing reduce probability of both yield loss and latent damage in the field. EMI is one of the main causes of EOS in manufacturing process [4]. This paper examines EMI-caused EOS exposure to devices in a common IC handler, compares it with the industry requirements, analyzes possible approaches to mitigation of such exposure, implements the most effective solution for this IC handler, and verifies the improvements made.

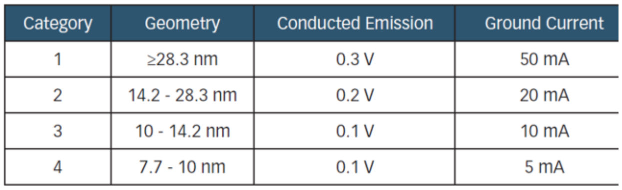
Continuously shrinking geometry of devices and difficulties of implementing effective EOS suppression on silicon make it critical to manage EMI in semiconductor manufacturing and handling on every step. The proposed solution can be used in many tools, both in semiconductor manufacturing and in PCBA.

II. Why Manage EMI in Semiconductor Process

Every new generation of semiconductor devices uses smaller geometry and higher density, making the devices more susceptible to damage, both instant and latent. Since EOS-related failures are of prime concern, all exposure to electrical overstress needs to be examined and, where possible, prevented. Reuse of existing tools in manufacturing processes for the new generations of devices without understanding current levels of EOS-causing EMI and making them conform to the new requirements is planning for future failures. Besides reduction of EOS, a positive side effect of managing EMI in equipment is reduction errors in device test, and reduction of equipment errors.

III. Setting Up Target

An effort of reducing EMI without specific goal cannot be productive unless a specific measurable and achievable goal is set. For ESD there is ANSI/ESD S20.20[???] that sets requirements, among other things, to static voltage levels within certain distance from devices in process. Similarly, there are two documents produced by different peer-based organizations that provide recommendations on managing EMI in semiconductor manufacturing and handling environment. EOS/ESD Association's TR23.0-01-20 [4] provides detailed overview of EMI in manufacturing environment with the EOS angle. It gives specific recommendations on understanding the sources of EMI and mitigating them. TR23, however, does not specify nor recommend any specific acceptable levels of EMI, unlike ANSI/ESD S20.20 that provides a number of specific parameters for ESD.



Category	Geometry	Conducted Emission	Ground Current
1	≥28.3 nm	0.3 V	50 mA
2	14.2 - 28.3 nm	0.2 V	20 mA
3	10 - 14.2 nm	0.1 V	10 mA
4	7.7 - 10 nm	0.1 V	5 mA

Table 1: Maximum EMI Level According to SEMI E.176

Another industry organization – SEMI (www.semi.org), a peer-based global industry association representing the electronics manufacturing – issues relevant to the industry standards. One of such standards, SEMI E.176 [5] – specifically addresses EMI issues in semiconductor device manufacturing and handling, providing industry-recommended acceptable EMI levels.

Table 1 provides an extract of relevant for EOS parameters of EMI. As seen, the smaller the geometry, the smaller levels of EMI are acceptable.

Together, ESDA's TR23 and SEMI E.176 provide solid foundations for analysis, quantification, and mitigation of EMI in a process, and verification of improvements made.

We have made the decision to strive for the highest level with understanding that we may or may not be able to achieve it on the first round.

As a factory, whose first and foremost goal is to be able to ship defect-free devices, we applied industry-wide relevant standards to achieve this goal, quite similarly to use of ANSI/ESD S20.20 to control ESD exposure.

IV. Analysis of EMI in an IC Handler

A common IC handler was selected for this project, although the same approach can be used for other types and makes of tools.

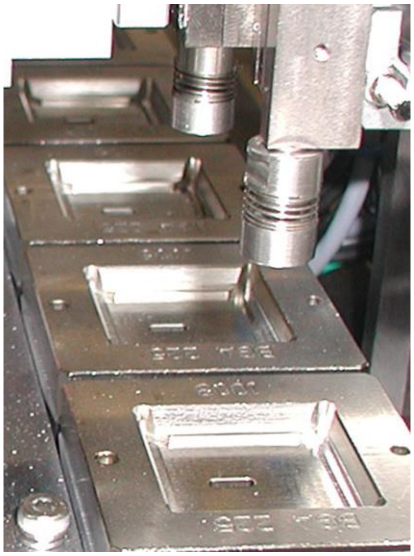


Figure 1: Nozzle and shuttle in an IC handler

1. Where to Apply EMI Control

According to both [4] and [5], the most important locations is where the devices may be exposed to unwanted voltages and currents. In the IC handler it is voltages between the nozzles of the robotic arms and the chassis of the tool (or test socket, or shuttles – see Fig. 1). The device galvanically connects to the latter while being held from the top by the nozzle which is capacitively coupled to the die via thin layer of encapsulation. In case of excessive high-frequency voltage difference this can lead to unacceptable exposure to the devices [7].

2. EMI Environment Inside the Handler

A typical IC handler has three robotic arms, each controlled by either servo or stepper motors (Fig. 2). These motors, along with the switched mode power supplies which are several in a typical handler, are the bigger contributors to EMI in the tool, both radiated and conducted. Both types of motor operate on pulses with typical frequencies between 10kHz and 20kHz (higher for stepper motors). The rise and fall time of these pulses is very short – in order of few nanoseconds – see Fig. 2. The spectrum of such sharp edges extends into signals with such wide spectrum extending into tens, or even hundreds MHz.

Our specific interest is in conducted emission as radiated emission does not have sufficient energy to inflict any measurable EOS in this case. Radiated emission, however, can interfere with measurements, including both IC test and our measurements of conducted EMI. For this we had to employ methodology of cancelling radiated emission data from the total results (see next section).

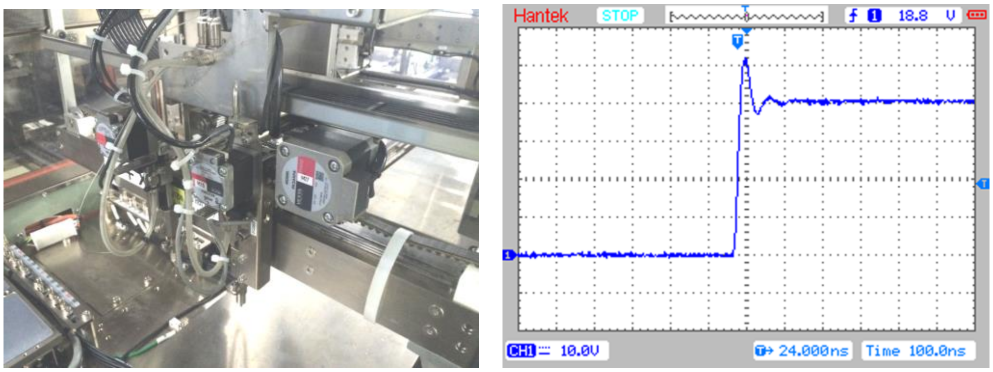


Figure 2: Handler's robotic arm with three motors and typical rise time of drive pulses

3. Methodology of Measurements

Measurements were done using a portable storage oscilloscope and MSN12 EMI Adapter for complete galvanic isolation and for avoiding ground loops. Measurements without an EMI adapter introduce a variety of errors and inaccuracies. During measurements it was discovered that radiated emission induces substantial signals into measurement cables, often to be higher in amplitude than the measured conducted emission. As radiated emission does not have sufficient energy for EOS, we needed to "cancel" it and attend only to conducted EMI. The way we did it was first to first measure high-frequency voltage between the tip of the IC handler and the tool chassis obtaining total EMI levels; then to disconnect one test lead from the chassis and leave it floating in the same physical spot, measuring radiated EMI (Fig. 3a and b). The conducted EMI levels were calculated as a difference from the two above. It is by far not the most precise method, but it was the most relevant, practical, reproducible, and achievable.

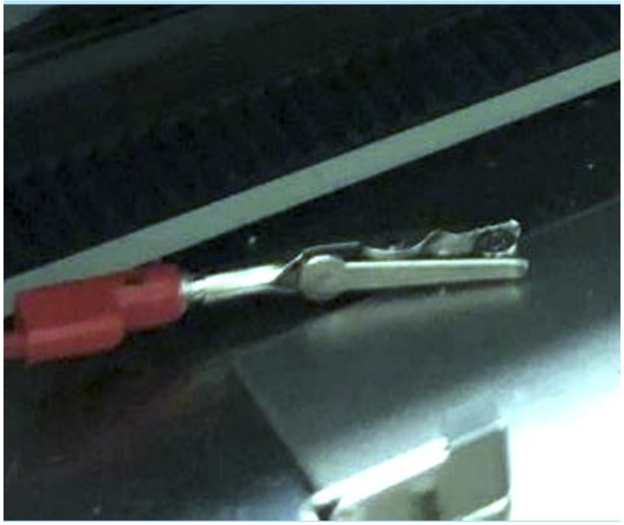


Figure 3a: Test Lead Connected to the Chassis

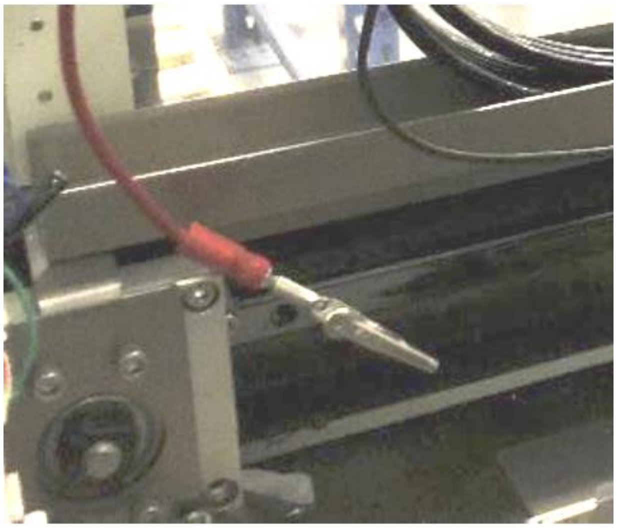


Figure 3b: Test Lead is Floating

4. Baseline Data

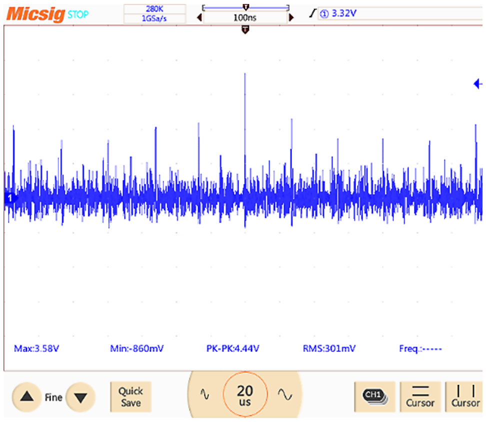


Figure 4: Typical waveform of voltage between the nozzle and the chassis

The results of these measurements are shown in Figure 4. Chassis ground here is essentially the frame of the IC handler and connected to it shuttles and test socket. Machine ground here is the AC power connecting point of the tool.

Figure 4 shows typical waveform of the signal between the nozzle and the chassis. It shows typical spikes from either a servo motor, or, likely, from a stepper motor based on the rate of repetition. Also seen smaller periodic pulses from a multitude of the motors in the tool.

As seen, conducted EMI levels (3.58V peak) are quite high. Maximum EMI levels recommended by SEMI E.176 [5] are shown in Table 1. Measured signals include both radiated and conducted data. To separate one from the other the above methodology was employed.

Figure 5 shows the results of such signal differentiation. As seen, radiated EMI constitutes roughly half of the picked-up signal. Even with the rejection of radiated EMI, results are substantially higher than acceptable limits. EMI on the nozzle needs to be drastically reduced for compliance with even the most relaxed requirements.

V. Mitigation

The major sources of EMI an IC handler, as is true for most automated equipment, are pulse-driven motors[6]. The particular robotic arm has three motors, other arms also have several motors. While it is possible to employ special servo motor filters [6], we focused on using ground filters in the robotic arms themselves – this way no matter where EMI was originated, it would be blocked by the filters. This approach was tested in [7] with good results for attenuation of EMI.

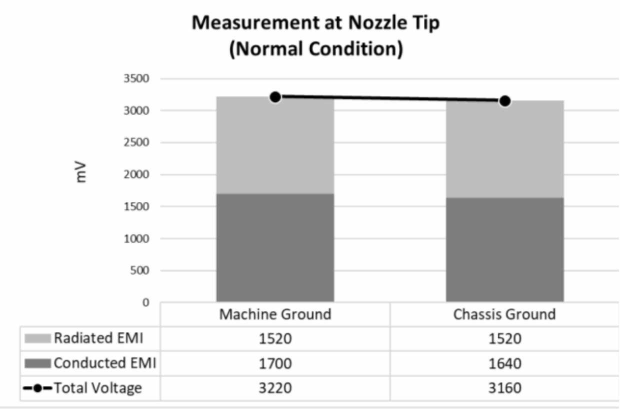


Figure 5: Test Results in Normal Operation of the Handler – Radiated and Conducted Emission Breakdown

The nozzle and the tip of the robotic arm are grounded via two pathways – via mechanical metal connection of the arm itself, and via steel flex cable. The task was to electrically disconnect the tip of the arm from the handler body and provide grounding only via ground filter, thus establishing proper ESD-compliant ground connection but effectively blocking EMI currents. Proper material had to be selected for both electrical and mechanical properties. From mechanical properties the material had to be thin, have high strength and low deformation under pressure; from electrical properties, not only the material had to be insulative, but also have low dielectric constant – the mating metal parts form a capacitor that works as a conductor for high-frequencies, and high dielectric constant would increase capacitance value. A dedicated ground EMI filter GLE04-01[8], [9] was implemented for this purpose – see Fig. 3. The patented design of GLE04-01 provides very low DC resistance (under 0.2 Ohms), but very high suppression level for high-frequency signals (50 to 100 times typ.) and is ETL/CE certified (ground is a safety element).

The difficulty of filtering the EMI signal to the nozzle was in electrical separation of the tip of the robotic arm from the body of the arm itself while preserving mechanical properties of the tool. The “business end” of the robotic arm is fastened with metal hardware to the rest of the robotic arm, providing good electrical connection and shorting any possible filter connected between the two parts.

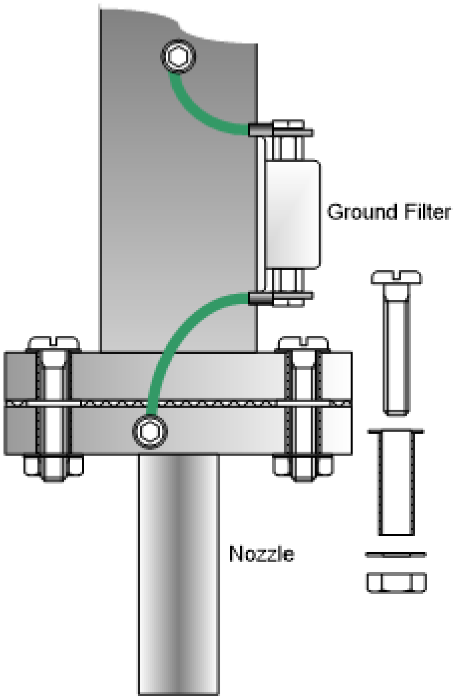


Figure 6: Basic use of ground EMI filter in the robotic arm

Figure 6 shows the approach taken. The drawing is more illustrative than the photo by showing the details. A gasket made of hard insulative material (fiberglass, Bakelite 0.84mm thick, in one of iterations FR4, although it could be other uncompressible insulator with acceptable relevant mechanical properties) is placed between the nozzle part and the rest of the robotic arm. Screws use insulative bushing and washers providing good mechanical connection but complete electrical insulation between the two parts. Ground EMI filter is placed on the upper end of the robotic arm, and the nozzle part is grounded via the filter as shown.

Fig. 7 and 8 show the actual implementation of the above solution. The location of ground filter in Fig. 7 is temporary – it should not be that close to a PWM-driven motor as shown here since can induce EMI into the filter itself, negating its suppression ability.

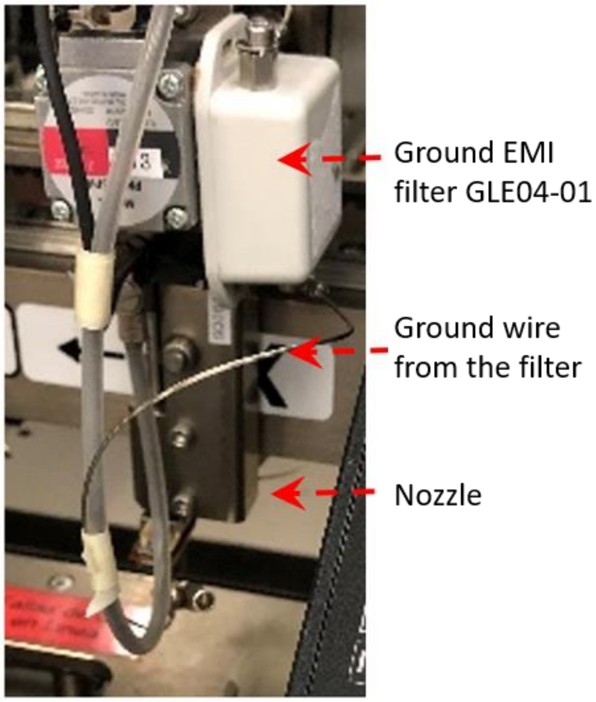


Figure 7: Ground EMI Filter GLE04-01 Installed on Robotic Arm

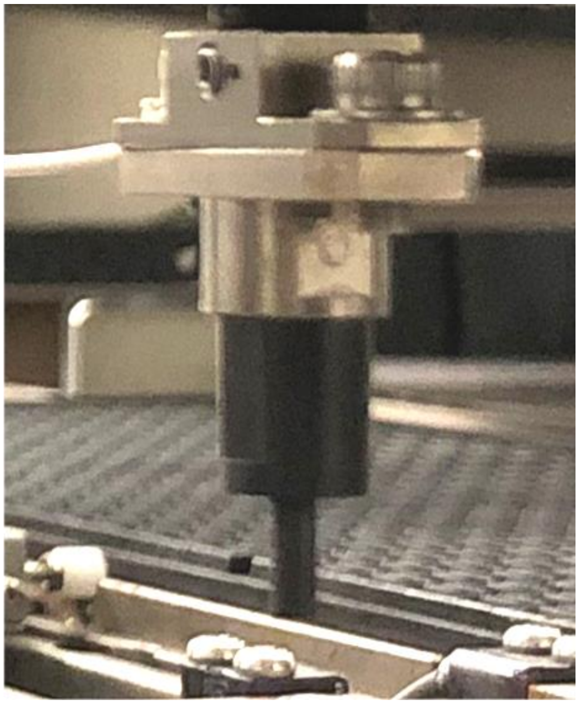


Figure 8: Actual Implementation of EMI Isolation

An intermediate solution consisting of thin Bakelite insulator sheet was tried. While reduction of EMI was substantial, Skyworks team did not stop there - a different approach was tried - different material of the nozzle – Semitron [10] (Figure 8). Semitron has volume resistivity of $10^6 \ldots 10^9$ Ohms/cm While reducing EMI slightly, it did not by itself produce desirable results – see further in the text.

To further reduce EMI, another identical ground filter GLE04-01 was installed between the chassis and the tool’s ground – See Fig. 9.

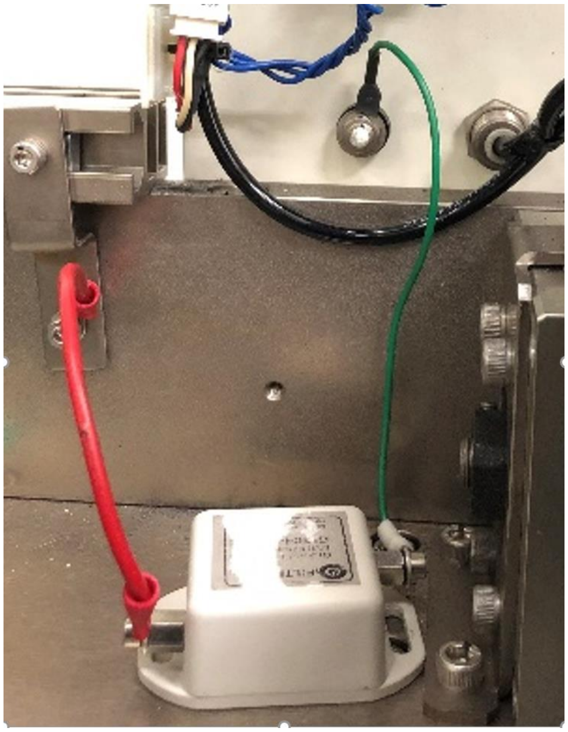


Figure 9: Ground EMI Filters During the Evaluation

VI. Verification of Improvements

Measurements were made after several iterations in the modification of the handler in the same way as before. A typical screenshot is shown in Fig. 10. It comprises both radiated and conducted EMI. As seen, the signal is already below 140mV (~26 times reduction). Radiated emission, which is the result of conducted EMI radiated by antennas of all the wiring, is also reduced accordingly.

As above, radiated emission data were subtracted from total data. Resulting data showed significant reduction of conducted signals - see Fig. 11. As seen, the EMI voltages between tip and ground points have decreased from ~1700 mV to typically below 150mV Radiated EMI levels have dropped as well since fewer wires and parts are radiating EMI.

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VII. Investigation of a Different Nozzle Material

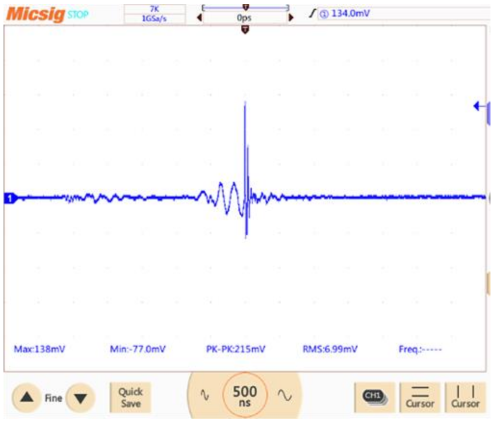

Figure 10: Total EMI (conducted and radiated) between the nozzle and the chassis with the filter

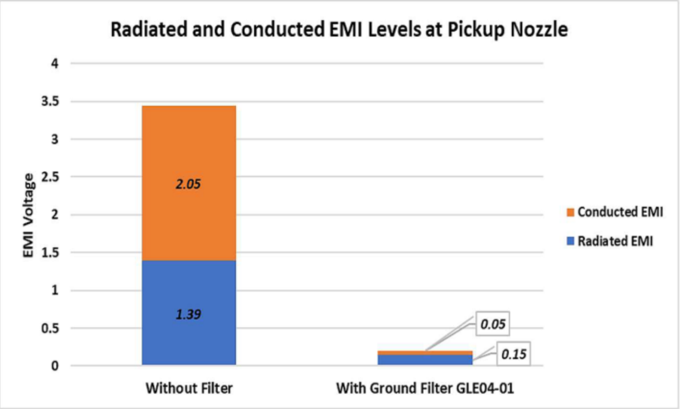

Figure 11: EMI without and with the filter between the nozzle and the chassis

The most optimal configuration was identified - a combination of Semitron nozzle and the filter which proved to be the “winning” combination – see Fig. 12.

VIII. Recommendations on Wiring and Installation

The project involved many iterations, both with the purpose of optimization, but also for verification of the consistency of the improvements made. During the execution of the project the following findings were made:

- Ground filter should be positioned on the robotic arm close to the nozzle. This way the ground wire leading to the nozzle is less affected by radiated emission from other wires and motors.
- EMI filtering of ground between the chassis and main ground substantially helps to reduce EMI on the nozzle
- Avoid close proximity between the motors and motor cables with the ground filters and wires leading to them for the same reason – reduction of influence of radiated emission.
- Shorten ground wires, remove unnecessary and/or redundant ground wiring, Avoid ground loops.
- Tests showed that use of twisted steel cables was more effective in maintaining low levels of EMI than the regular wires. We can speculate on the reasons, but since the purpose of this effort was not research but rather implementation of the best solution, we didn't go into investigation of the cause of this phenomenon.

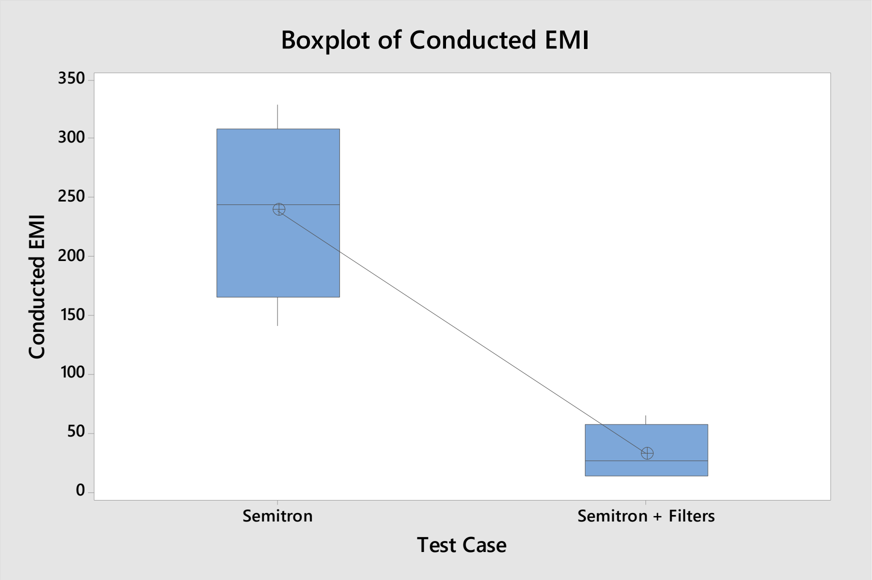

Figure 12: Box plot of reduction of conducted EMI from Semitron nozzle alone and in combination with ground filter

IX. Conclusion

Reduction of EMI-caused EOS provides safer environment for the devices, just like reduction of static voltages below 100V per ANSI/ESD S20.20 helps to establish safe ESD environment. Industry guidance, both ESDA's TR23 and SEMI E.176, provide a good platform for reduction of EMI in semiconductor manufacturing and handling processes. A simple modification of a common IC handler at minimal cost significantly reduces EMI inside the tool and possible EOS exposure to the devices in process. This paper explains in detail how a significant EMI exposure can be substantially reduced. Similar modification of other types of tools can provide similar reduction of EMI making equipment compliant with the requirements of SEMI E.176.

X. References

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