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Reducing EOS Current in Hot Bar Process in Manufacturing of Fiber Optics Components

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Abstract - Excessive ground currents expose sensitive devices to electrical overstress (EOS) in a hot bar soldering process. This paper examines the process, current and voltage exposure to the devices as well as describes mitigation methods to reduce this current, which are applicable to many processes in semiconductor manufacturing and PCB assembly.

I. Introduction

High ground currents were observed in a particular operation process in manufacturing of sensitive fiber optic devices - hot bar soldering. In this process a heated metal bar comes in physical and electrical contact with the device' terminals. The device itself rests on the metal support. The hot bar, itself, is well-grounded and so is the support for the device in the process. Excessive current exposes devices to electrical overstress threatening their operability and long-term reliability due to potential latent damage. The goal of this investigation is to understand actual EOS exposure [1,2] to the devices and explore ways to mitigate it if the exposure is to be found excessive.

It should be noted that the described phenomenon and measurement and mitigation methodology is applicable to any process of manufacturing of semiconductor and similar devices, not only to hot bar soldering process.

II. Quantification of EOS Exposure

How do we know when current through the device is tolerable and when it constitutes EOS exposure? While for each type of device, exposure limits could be different. There are industry documents governing these limits, however imperfectly. In absence of device-specific data, we will use these limits to draw a "line in sand" to determine whether the exposure presents EOS exposure or not. We will consider the following documents:

IPC-A-610F [3]: From section 3.1.1: "...voltages and spikes less than 0.5 volt are acceptable. However, an increasing number of extremely sensitive components require that soldering irons, solder extractors, test instruments and other equipment must never generate spikes greater than 0.3 volts."

IPC-TM-650-2.5.33.3 [4] (Measurement of Electrical Overstress from Soldering Hand Tools - Current Leakage Measurements): "The AC reading shall not exceed 1.0 μA."

ESDA STM13.1 [5]: Voltage: "The recorded values shall be less than 20 mV AC"; current: "The measured current shall be less than 10mA AC."

III. Process Summary: Hot Bar Soldering

Pulsed heat Hot Bar soldering, is a joining technology where two pre-tinned parts are heated to the melting point of the tin. The joining technology results in a permanent electro mechanical joint. The required process energy is supplied by a thermode, also known as a Hot Bar. This thermode is pressed on the upper part to transfer the thermal energy to both parts.

The basic setup of the hot bar process (Figure 1) comprises two metal plates bent into L-shape with a heating element between them. The device is placed in a special fixture (device itself is not shown). The soldering bar is heated by high current from a power supply (see thick gage wire) and then it presses on the device terminals in the fixture. The hot bar process is utilized for several key process steps during the assembly of the high speed fiber optic transceiver module. These process steps involve attaching flexible circuits directly to the sensitive device and also to a PCB. This process step is where the device would be most vulnerable due to the direct contact of the soldering bar to the input pads of the device. The process creates metal-to-metal contact which is capable of conducting excessive currents into device.

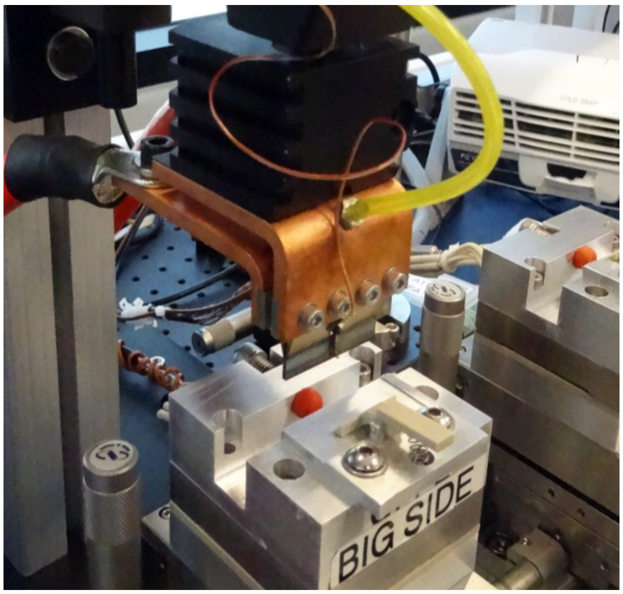
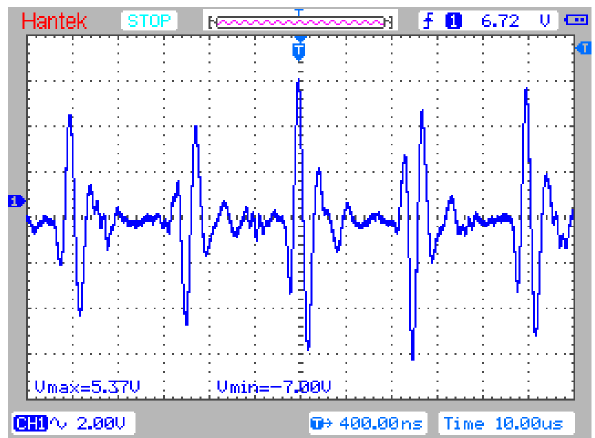


Figure 1: Hot Bar Process

This investigation was triggered by the upcoming new devices which are more sensitive to ESD and EOS than the current ones. The goal of this investigation was to analyze existing EOS currents in the process and to mitigate any problem found for compliance with existing industry levels [3,4,5].

IV. Equipment Setup and Measuring Methodology

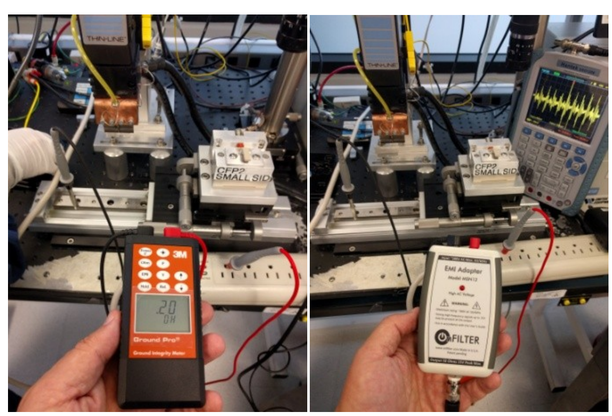
We will be measuring both voltage and current in the tool's ground to assess the current through the device. First, we will measure noise on power lines and ground coming to the tool. While noise can originate within the tool itself, facility noise is always a big factor. For the purpose of this test, the tool was in the "off" state although the power to the tool was active. Figure 2 shows common-mode noise on the power lines. Common-mode signal on the power lines is measured between live and/or neutral and ground; differential signal is measured between the live and neutral wires. In this case, differential noise was quite low and is not shown. As seen, common-mode noise is quite high, indicating presence of noise on ground itself.



Vmax=5.37 V Vmin=-7.00 V t=10 uS/div.

Figure 2: Common-mode noise on power line at the tool

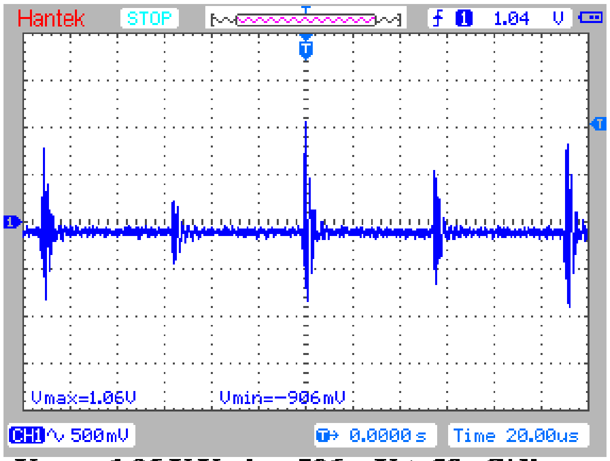
We will continue with analysis of the tool's grounding and possible signals on ground within the tool. Figure 3 shows measurements of noise on the grounded fixture that holds the device during



a) Impedance to ground b) voltage on ground

Figure 3: Grounding of the tool

the process. Measurements are done vs. the tool's ground, which is connected to the facility ground.



Vmax=1.06 V Vmin=-906 mV t=20 uS/div

Figure 4: Voltage between fixture and tool's ground

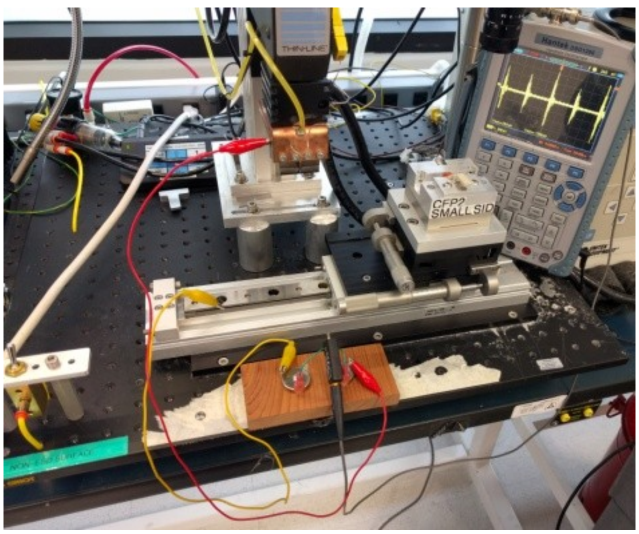
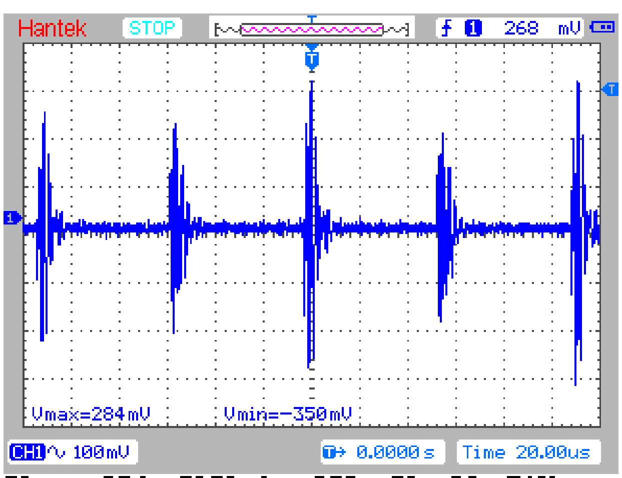


Figure 5a: Current measurements setup. CT1 current probe is used



Vmax=284 mV Vmin=-350 mV t=20 uS/div
Imax=56.8 mA Imin=-70 mA

Figure 5b: Current between hot bar and the fixture.

As seen from Figure 3a, ground impedance between the fixture and facility ground is 0.2 Ω, however the high-frequency noise between the same two points is anything but low [6]. The typical waveform of this noise is shown in Figure 4. By the frequency of repetition of the signal, it appears to be caused by a switched-mode power supply which is one of the main sources of EMI in a manufacturing facility. However high, it is not uncommon to see high-amplitude noise across low-ohm connections. In such cases, it is the evidence that the noise signal has substantial power and can exert significant current. Measurements of actual voltage in a wide band is not addressed in ESD S20.20 nor in ANSI/ESD 6.1 leaving the user erroneously relying on circumstantial and grossly incomplete evidence of an equipotential situation by a secondary parameter, i.e. resistance.

Next, we will examine high-frequency current between the hot bar and the fixture - current is of upmost relevance to potential EOS exposure. Figure 5a shows the setup and Figure 5b shows the results of measurements of current between hot bar and tool's ground. Figure 5a also shows the custom (wooden) fixture made to better utilize current probe CT1. As seen, current peaks were in the range of 70 mA (350 mV/5 mV per CT1 specification). Given the potentially low impedance of the processed device, pulses of 70mA going through it several tens of thousands times per second cannot be considered normally acceptable (by most measures, 10 mA is the maximum allowable current).

V. Mitigation of the Overcurrent

It is clear that any further reduction of the ground impedance will lead nowhere - according to all tenets, 0.2 Ohms impedance should be quite "safe", which it is patently not. Other ways have to be identified and implemented to reduce high-frequency currents. While it may be tempting to identify sources of a particular noise signal(s) and try to suppress the noise from them, in reality, such efforts are largely futile for a number of reasons:

- There are often more than one source of noise
- Some sources of noise may be in other tools making them very difficult to control
- Tracking a particular noise source may be very challenging, given that the shape of the waveform changes with the length of wire - the signal that is measured in one spot may look very different from that very same signal at its source [7].
- The factory is often dynamic - new tools are added, tools move around and the process changes, unpredictably altering the EMI environment.

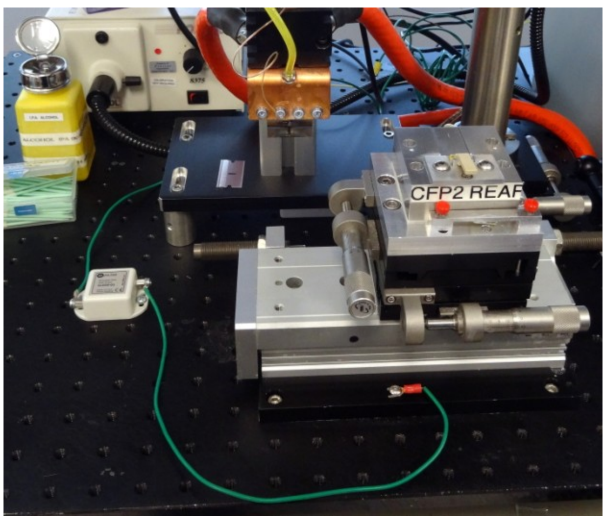
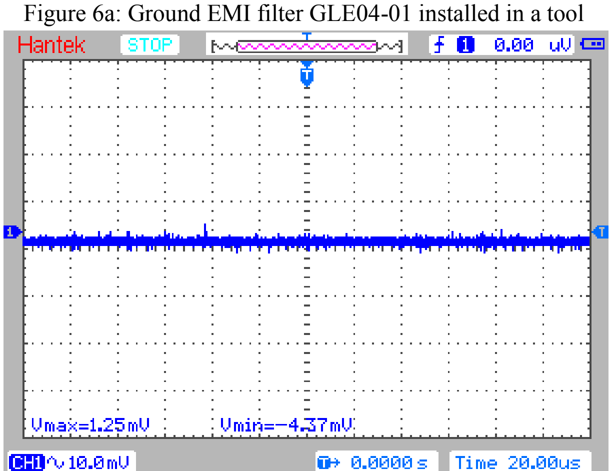


Figure 6a: Ground EMI filter GLE04-01 installed in a tool



Vmax=1.25 mV Vmin=-4.37 mV t=20 uS

Imax=0.25 mA Imin=-0.874 mA

Figure 6b: Current between hot bar and the fixture with ground filter

A much less costly, more focused and overall much more effective solution is to isolate the specific tool or its EMI-sensitive section from the high-frequency noise. This can be easily achieved with proper EMI filtering.

Since the issue at hand is noise on ground, EMI ground filtering would be of first consideration. Selection of a ground filter is not trivial. Ground is a key safety element, and if improperly implemented, can become a safety hazard. There is a variety of safety regulations, both country-wise and industry-wise. Basically, they all summarize that the current capacity of the ground path shall be no less than that of the power feed. Some regulations specify the minimum gage of ground wire based on the current rating. This applies, of course, to the mains-powered equipment and, in some cases, to DC-powered equipment. Getting good performance out of a ground filter, while being fully compliant with all of the safety regulations, is not an easy technical challenge. In this particular case, the bench setup, by itself, is not powered, thus, relaxing some of the requirements.

Figures 6a and 6b show how including ground filter in series with ground reduces current from 70 mA to an essentially immeasurably-low value. Such inclusion is easy to implement, is highly-effective and requires no on-going maintenance or calibration.

Another possibility of filter placement would be in connection to the hot bars themselves, however their grounding is done inside their power supply making access difficult with the possibility of affecting its performance as well as warranty. Since the high frequency current has to be stopped anywhere in its path, grounding of the fixture offers the least invasive and easiest to achieve path.

VI. Providing Complete ESD/EOS Grounding within the Tool

As evident from the above experiment, ESD grounding does not necessarily provide any protection against electrical overstress (EOS).

Inclusion of a proper ground filter in series with existing ESD grounding adds EOS coverage providing complete ESD/EOS protection for sensitive devices. Best practices for inclusion of such protection are described below in this section.

a. Identification of Potential EMI-Caused EOS Locations

First, examine and understand grounding scheme inside the tool. Identify parts of the tool which come or may come in galvanic (metal-to-metal) contact with the devices, or which have appreciable capacitive coupling to the device. Capacitive coupling acts as a conductor at high frequencies which under circumstances can conduct current almost as well as galvanic connection.

Below are examples of such processes and involved parts.

1. Front end semiconductors

- Wafer-level test (capacitive coupling between wafer chuck and the dies)

2. Back end semiconductors

- Wafer saw (close metal contact between the saw and the device's pads)
- Die attach (coupling between the wafer chuck and/or base and the die, as well as between the nozzle and the die)
- Wire bond (galvanic contact between die and bonding wire)
- Singulation (galvanic contact between the blade or cutting die and the pins of device)
- Lead forming (galvanic contact between blade or cutting die and the pins of the device)
- IC handling (multiple metal-to-metal contact between the pins and shuttles and test sockets; capacitive coupling between die and the nozzle)

3. Electronic assembly

- Pick-and-place machine galvanic contact with copper on PCB; capacitive coupling between die of the device and the nozzle)
- Lead forming (galvanic contact between blade or cutting die and the pins of the device)
- Wave soldering (galvanic contact between the devices and solder)
- Lead trimming (galvanic contact between blade and the pins of the device)
- Manual and automated soldering (galvanic contact between the tip of the iron and pins of device). Hot bar process falls into this category
- Test (galvanic contact between tester and pins of device - direct or via connector and PCB traces)

Places without galvanic contact and without capacitive coupling to the device are likely not a concern for EMI-caused EOS, however it is still recommended to assess high-frequency noise elsewhere inside the tool.

b. EMI Measurements

Once problematic locations are identified, measure high-frequency voltage and current between parts of the tool likely to affect the device. It is imperative to perform measurements on a working tool since a lot of noise is generated by equipment inside the tool. Measurements should be done minding safety. For voltage measurements it is advisable to use balanced input instruments since coupling of oscilloscope to ground via power or via parasitic capacitance of scope's ground plane may render results of measurements invalid. The measurements described in this paper were made using OnFILTER's EMI Adapter MSN12 which has true balanced input allowing accurate measurements even when an oscilloscope is plugged into a power line and thus has its own ground connection making measurements doubtful. Current measurements between two presumably grounded points are done with special high-frequency current probe - in our case Tektronix' CT1. It should be noted that CT1 and its "sister" probe CT6 have poor response at lower frequencies - it is safe to assume that a signal with the spectrum less than 100kHz will appear attenuated and the actual signal will be proportionally higher with at lower frequencies. CT2 probe offers better low-frequency response but at five times lower sensitivity. Common AC current clamps are unsuitable for these measurements due to their inadequate bandwidth.

Many of these measurements can be safely skipped, however, because the likelihood of finding unacceptably strong voltages and currents in a typical tool is quite high. It is more practical to proceed directly to the next step - prevention of EMI.

c. Prevention of EMI-Caused EOS

This step ends up being the simplest. Identify grounding wiring scheme that provides grounding for selected parts of the tool described above. Connect ground line filter in line with each such grounding wire, preferably close to the metal part that can come in galvanic contact or in capacitive coupling with the device. Example of such location is shown in Figure 7. Similarly. the corresponding metal part of contact should also be EMI-free - see Figure 8.

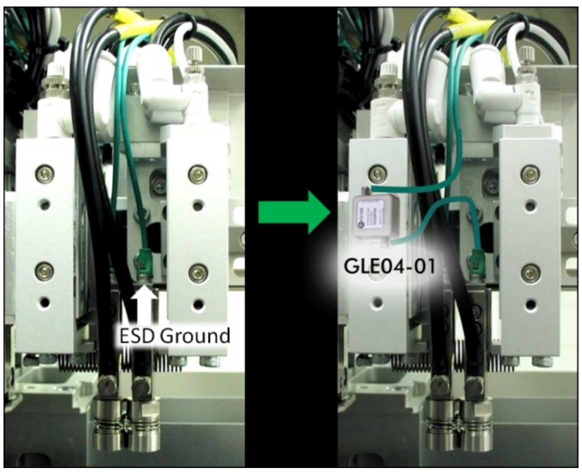


Figure 7: Placement of ground filter on robotic arm

Note whether ESD grounding in the tool is a "star" configuration where all grounding wires come to one central grounding point, or a "daisy chain" configuration where two or more metal parts of the tool are connected in a chain. While from ESD

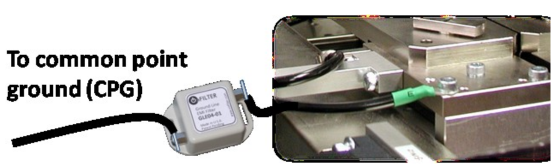


Figure 8: Connection of ground filter in the tool's ESD grounding wiring

point of view there is no measurable difference between these two configurations, daisy chain configuration "accumulates" EMI from many connected sources to a much greater degree than the star configuration. In case of an existing daisy chain configuration separate the part that you want to protect from EMI into a separate branch into which you would install ground filter GLE04-01.

d. Ground Line Filter

The unique ground filter described in this paper is OnFILTER's model GLE04-01. This small filter connects in series with regular ESD grounding throughout the tool as shown in Figure 8. The filter

Figure 9: Ground EMI Filter GLE04-01 used in experiments

itself (Figure 9) offers sub-Ohm resistance (0.2Ohms) for DC currents for static dissipation but effectively blocks high-frequency currents as shown in Figure 10.

Specification of GLE04-01:

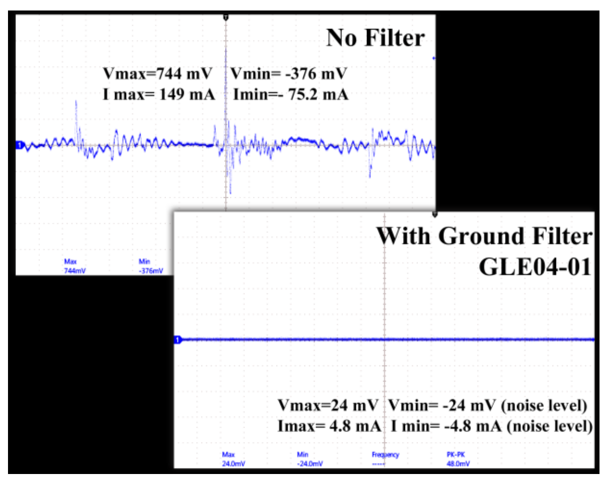


Figure 10. Typical performance of GLE04-01

- DC Resistance: =<0.2 Ω
- Typical high frequency current attenuation: 40dB (100 times)

- Connections: Screw #6 (supplied, with ring terminals),
  Dimensions LxWxD: 2.02" x 1.378" x 0.787"
  51.3mm x 35mm x 20mm

As seen, it is surface mounted and lightweight, and can be placed on moving robotics arms if necessary. It can be attached using screws, Velcro® tape, tie-wraps or other simple methods. It is non-polar and is easy to connect. In hot bar soldering tool it was installed as shown in Figure 6.

e. Verification

While voltage measurements are always more appealing due to their relative simplicity, they are not the most relevant or accurate. Accuracy of voltage measurements suffers from both undetermined impedance of ground circuit and input impedance of instrument. It is ultimately the current that damages the devices - use current probe as was described in previous chapters to quantify improvements of mitigation of EMI.

In our case, reduction of current in hot bar soldering process was at least 80 times bringing high-frequency ground current to essentially immeasurably low levels below instrument's noise floor.

Unlike most of ESD preventive measures, EMI filters do not require maintenance or calibration. Once connected and verified, performance of the filter would remain constant through the life of the tool. This should factor in cost analysis of implementation of EMI filters - their initial cost is the total cost, unlike many of ESD prevention measures where initial cost fades in comparison with the maintenance and replacement requirements.

Conclusion

This study points to several conclusions:

- Many typical manufacturing processes can expose sensitive devices to excessive currents, which is scantily covered in industry standards and test methods.
- Hot bar soldering process common in many operations, including device/flex cable assemblies and alike, can provide high EMI currents into the device causing exposure to EOS
- ESD preventive measures, such as relying on ground connectivity for static dissipation and device safety, are inadequate for preventing EOS exposure.
- Most of EMI-caused EOS exposure can be relatively easy to diagnose.
- Blocking propagation of EMI through ground is highly-effective and inexpensive way of reducing EMI-caused EOS exposure inside tools
- Implementation of EOS preventive EMI filters is easy and is permanent, providing overall low-cost high-performance solution.

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