Freescale Semiconductor
Application Note

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Challenges in Testing for Power Rail Shorts with New Technologies

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This application note addresses a common challenge encountered during circuit board testing with Freescale microprocessors in newer technologies, such as 130 nm and smaller processes. The discussion includes a detailed description of the issue of testing power rails for shorts with devices in these newer technologies, an explanation of why it occurs, and the factors that affect it.

It is common practice for board testing houses to test for shorts on the power rails by measuring the resistance from a power rail to the ground rail. In older technologies, this is a reasonable approach. However, this application note explains why this approach can be problematic when used with devices in newer technologies.

First, however, it is beneficial to understand the goal in performing this type of test. Freescale tests all production devices prior to shipment, including functional tests, opens/shorts tests, and AC and DC specifications. All production devices shipped by Freescale meet reliability requirements and have a guaranteed expected lifetime. By definition, all production devices shipped by Freescale are “good parts.” Therefore, testing for power rail shorts is needed only on the circuit board itself. If bare boards are tested before assembly to verify that there are no issues in the board manufacturing process, testing for shorts after boards are assembled ensures that no shorts were introduced on the board during assembly. If a high degree of confidence in the

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assembly process exists, or if other testing procedures provide similar coverage, this test can be bypassed. Note that devices shipped prior to achieving production status have limited guarantees and are covered separately under Freescale SOP. If further information is needed, contact your sales representative.

1 Interactions Between Ohmmeters and Core Circuits

As stated previously, testing for shorts on a power rail by measuring the resistance from the power plane to the ground plane with the board unpowered does not work well for devices in newer wafer technologies such as 130 nm and smaller processes. It is particularly challenging with respect to the V_{DD} (processor core) power plane due to the number of circuits powered by this plane. This can be understood by examining the core circuits and how the ohmmeter interacts with them. Figure 1 shows a typical core circuit, a 2-input NAND gate. This is a simple circuit, but all core circuits are essentially variations on the theme of totem-pole MOSFETs. The important thing to note is that the circuit consists only of semiconductor transistors. There are no passive components such as resistors. These exist only as parasitic effects of the transistors.

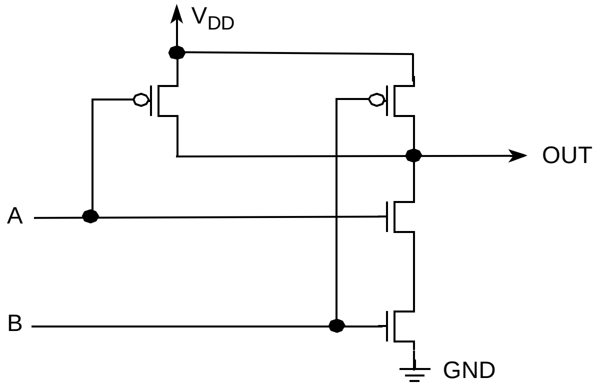


Figure 1. Example Core Circuit: 2-input NAND Gate

Ideally, these transistors are perfect switches and conduct no current in the OFF state. Because the top and bottom FETs are never on at the same time, ideally there is infinite resistance between V_{DD} and GND. In reality, parasitic diode effects cause current to leak through a FET even in the OFF state. The simplest way to think of leakage current is to think of a CMOS FET in the OFF state as a reversed-biased diode, as shown in Figure 2. The diode is a parasitic effect inherent to the p-n junctions in the transistors. These reverse-biased diodes leak current whenever the core circuits are powered.

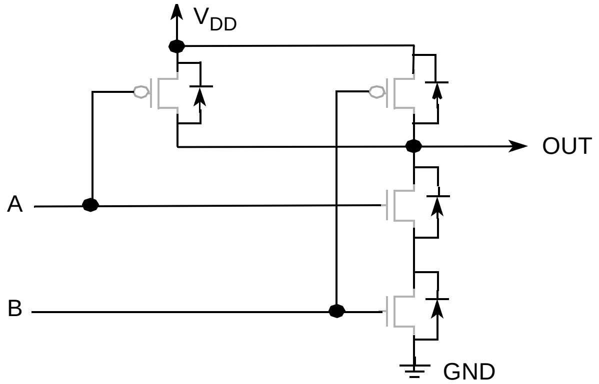


Figure 2. Core Circuit with Parasitic Diodes

The next step is to understand how these core circuits will interact with an ohmmeter when one attempts to measure the resistance from the V_{DD} power plane to the GND plane. To measure resistance, the ohmmeter applies a small voltage (typically in the millivolts) across the probes. The meter then measures the current, converts the reading, and displays ohms, as shown in Figure 3. That is, the meter measures the amount of current flowing from V_{DD} to GND. In this circuit, the meter acts as a power supply to the core and powers the transistors (albeit weakly). However, the only current flowing from V_{DD} to GND is leakage current through the parasitic diodes. Therefore, the meter is not measuring resistance at all—it is measuring leakage current.

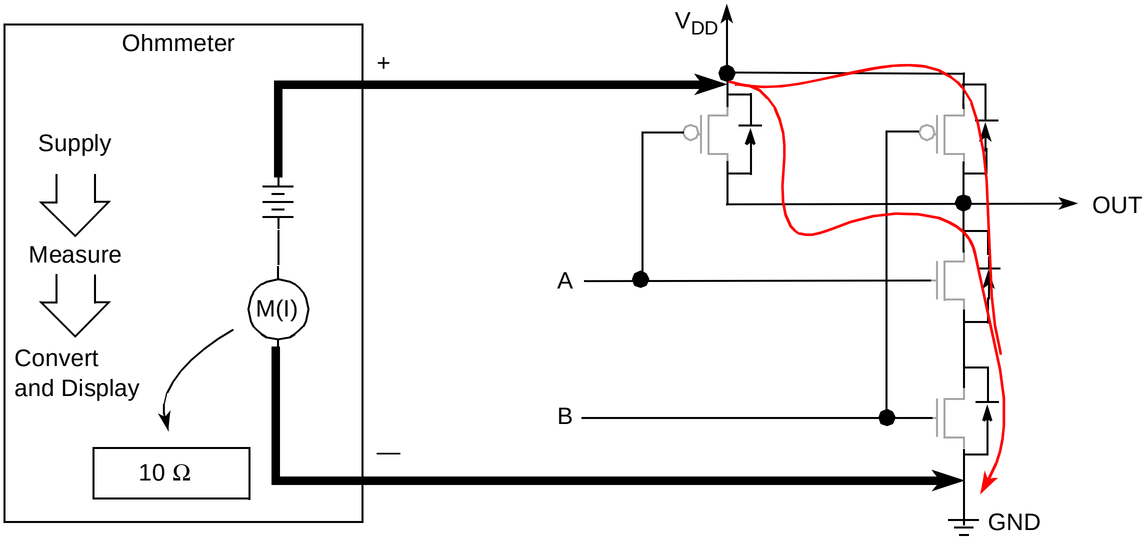


Figure 3. Ohmmeter and Core Circuit, with Leakage Current

2 Leakage Current

One obvious question that arises from the preceding section is whether the test is still valid, regardless of whether the ohmmeter is measuring resistance or leakage current. This section examines the various factors that affect leakage current and why its behavior with respect to these parameters makes this type of test difficult to perform with consistent results on devices in newer technologies.

2.1 Diode Behavior

Because the ohmmeter in the previous example is shown to be measuring leakage current, it is necessary to understand what factors affect it. The transistors in this case behave like reverse-biased diodes, so their behavior is described by the reverse diode equation, as follows:

$$i_{rev} = i_{rev\_sat}\,(e^{qV/kT} - 1)$$

Where:
i_{rev} = reverse (leakage) current (A)
i_{rev_sat} = reverse saturation current (A)
q = charge of an electron (1.6×10^{-19} C)
V = reverse voltage, V_{DD} (V)
k = Boltzman's constant (1.38×10^{-23} J/K)
T = temperature (K)

The reverse saturation current is a function of process parameters (such as doping), device (p-n junction) geometries, and temperature. Similarly, the effect of voltage and temperature also appears in the exponential portion of the equation. Therefore, leakage current is a function of process, geometry, voltage, and temperature, and it is not linear. Figure 4 shows the IV plots for this equation for varying temperatures. For comparison, the IV line for a resistor is also shown. Clearly, semiconductors do not behave like resistors.

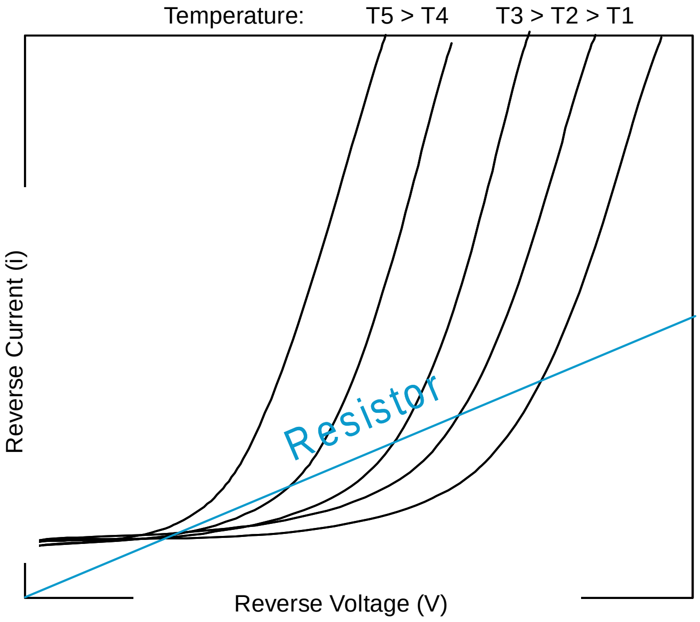


Figure 4. Current & Voltage (IV) Curves for Reverse-Biased Diodes

2.2 Leakage Current and Geometry

An in-depth discussion of process and geometry are beyond the scope of this document. However, we do note that *as geometries shrink, leakage current increases*. This may seem counterintuitive to those who are used to thinking of devices in smaller processes as having lower power consumption. However, it is important to remember that this is overall power. While it is true that overall power is generally reduced in later technologies, this is due to reduced switching currents. Leakage current, the other component of overall power consumption, actually increases because the smaller geometries make it easier for leakage current to flow. For example, Table 1 shows the leakage current for three generations of the e600 family. In all cases, the core voltage (V_{DD}) and temperature are identical. (Core frequency is immaterial to leakage current because leakage current represents the static—that is, DC or zero Hertz—power consumption of the device.)

Table 1. Leakage Currents for e600 Devices in Different Processes

Processor	MPC7445	MPC7447A	MPC7448
Geometry size	180 nm	130 nm	90 nm
Transistor count	33 million	48.6 million	90 million
Deep sleep (leakage) power specification	0.5 W	4.0 W	12.0 W

Note: All specifications are at V_{DD} = 1.3 V and T_j = 105 °C.

All these devices have nearly identical cores. While transistor counts increase due to increases in the L2 cache size, the leakage current increases far more quickly. As shown in Table 1, a modern processor core is composed of tens of millions of transistors. As a result, even a modest increase in the transistor leakage current is magnified millions of times and can cause large increases in total leakage current. Therefore, it is reasonable to expect that devices in different processes have very different leakage currents and behave very differently under the ohmmeter test. For example, an MPC7445 at 1.3 V may have a leakage current of up to 0.5 W/1.3 V = 0.38 A under worst-case temperature conditions while an MPC7448 under identical conditions could have a leakage current as high as 12.0 W/1.3 V = 9 A. If an ohmmeter is used, this means that the measured resistance can be an order of magnitude less for newer generations. Therefore, a test that works well for previous generations of devices may suddenly indicate false failures when applied to newer generations of devices.

2.3 Leakage Current and Process

In addition to the increase in leakage current due to shrinking geometries, all semiconductor devices exhibit natural process variations from device to device, wafer to wafer, lot to lot, and so forth. Devices are sorted primarily based upon their maximum core frequency (fmax) and also upon the established constraints for overall power consumption. Figure 5 illustrates a typical distribution of devices. Each point represents a device. The vertical bars represent speed grades (sometimes called speed bins) into which each device is sorted, where the maximum core frequency of a device must exceed the rated core frequency for a given speed grade. The maximum power consumption creates the vertical ceiling for each speed grade, above which a device does not meet the power specifications for that speed grade and is thus rejected.

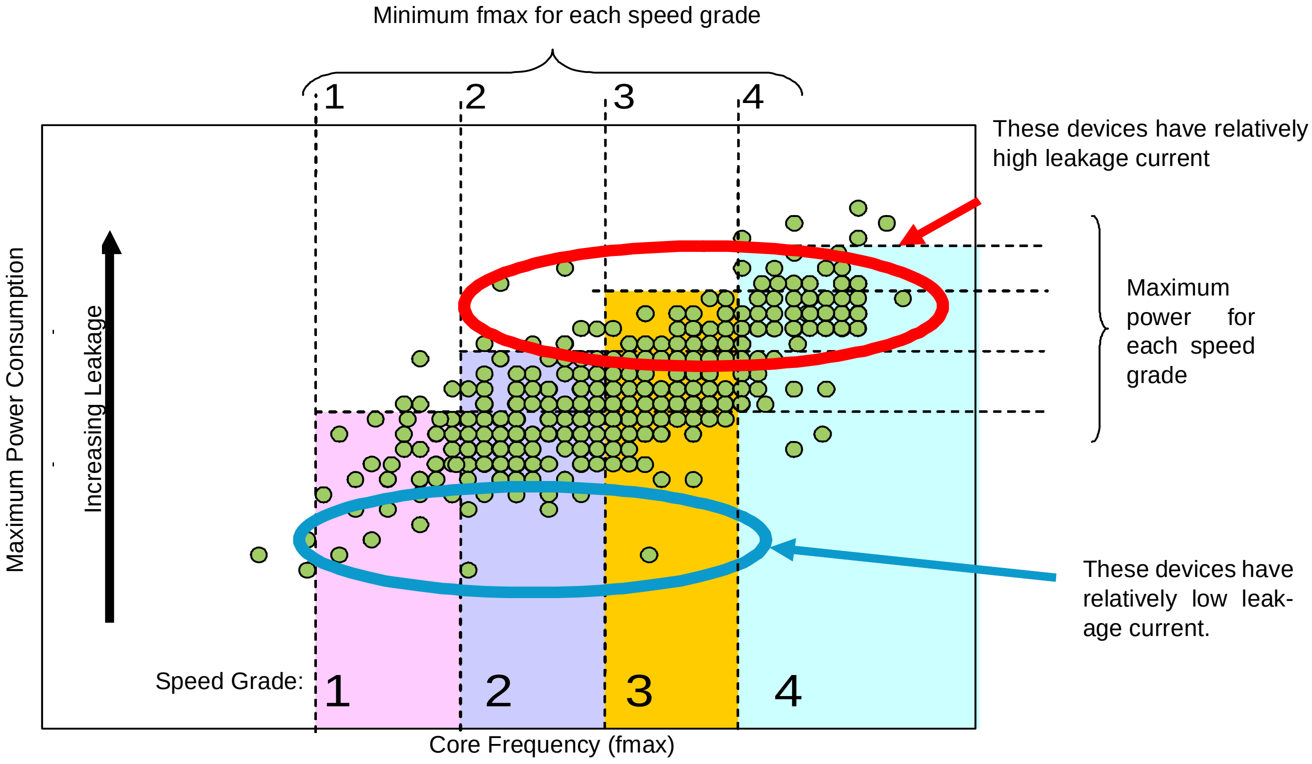
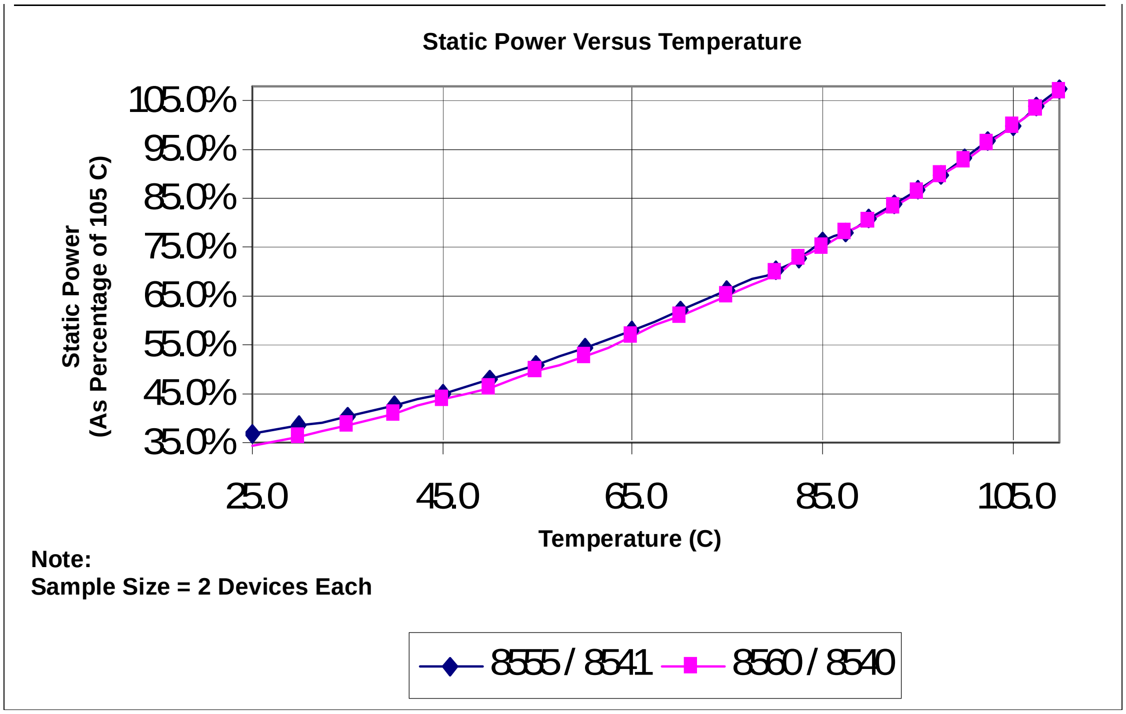


Figure 5. Example Distribution of Devices and Sorting

Devices with higher power consumption generally have higher leakage currents, and these are typically the faster devices. However, some devices may be fast and yet have relatively low power consumption compared to other devices that fall into the same speed grade. As a result of process variations, the leakage current can vary considerably from device to device, even within a given speed grade. Note that Freescale tests and guarantees the maximum power consumption of its devices. Therefore, a device is guaranteed to meet its maximum power consumption specifications, regardless of the leakage current.

2.4 Leakage Current and Temperature

As the reverse diode equation indicates, leakage current is a non-linear function of temperature. Figure 6 shows an example of leakage current measurements taken on two pairs of devices in the 130 nm process. The graph plots the leakage (static) current, expressed as a percentage of the maximum leakage current at 105 °C, versus the temperature. Note that the leakage current nearly doubles between 65 °C and 105 °C. Furthermore, devices with high leakage current tend to be more sensitive to temperature and have even greater slope increase at higher temperature. Therefore, “leaky” devices experience a sharper increase in leakage currents at a high temperature. To summarize, small variations in temperature can have a large impact on the leakage current and thus the resistance that an ohmmeter would measure. Note that these effects are included in the maximum power specifications for all devices, and that all devices are guaranteed to meet those specifications.



Note:
Sample Size = 2 Devices Each

Figure 6. Leakage Current as Function of Temperature

3 Conclusions

The preceding sections illustrate the challenges associated with performing the ohmic test commonly used by many board testing houses to check for shorts on power supplies. The test worked well in the past because the leakage currents of the devices were low enough that they yielded a relatively high effective resistance. For reasons explained in Section 2.2, “Leakage Current and Geometry,” the leakage currents in newer generations of devices are high enough that the resistance measured by an ohmmeter is very low, to the point that it is hard to distinguish from a board-level short. For example, a common limit might be 10 Ω, below which the board would be flagged as having a short-circuit and rejected or sent for further debugging. With devices in 130 nm or 90 nm processes, the measured resistance can be as low as a few ohms or even less than 1 Ω. Measurements in ranges this low are usually difficult to make reliably using a standard ohmmeter, though some manufacturers publish application notes on how to measure very low resistances.

When Freescale tests for shorts, the methodology is similar to the ohmmeter test, except that current is measured directly by a sophisticated tester. Failure limits are usually fairly high because the shorts test is intended only to be a quick test to reject any parts with gross shorts prior to further (expensive) testing. If these were to be converted to an effective resistance, these limits would typically fall into the milliohms range. The exact voltages and currents used for the shorts test vary from device to device (depending on various parameters) and are not specified, nor guaranteed not to change. Therefore, Freescale cannot provide specific guidance on what effective resistance might be measured by an ohmmeter for a given product. This is especially true because leakage current (and hence the effective resistance) is highly dependent on voltage and temperature. Therefore, leakage current can vary greatly depending on the make, model, and tolerances of the ohmmeter in use, as well as the environmental and test conditions. For example, the results vary considerably between a device at room temperature and a device that has been previously powered up and warmed as a result of self-heating, as described in Section 2.4, “Leakage Current and Temperature.”

One approach might be to “characterize” parts by measuring the resistance on a batch of parts, and determining what a typical measurement is for those devices in order to create a lower limit (with some suitable guardband) that can be used for subsequent testing. However, as explained in Section 2.3, “Leakage Current and Process,” the variability between devices is such that one batch may have markedly different results from another, especially if environmental conditions are not tightly controlled. So, it is possible that the batch used for the “characterization” could have relatively low leakage currents and yield a relatively high effective “resistance” limit. If a batch with higher leakage currents (but still meeting overall power consumption limits) were to be procured at some point in the future, the boards with the new devices may fail the ohmmeter test, create false alarm, and needlessly disrupt production.

To conclude, for the reasons mentioned in this application note, board-level testing for shorts is a significant challenge for the board testing industry. In most cases, testing houses already opt to bypass this type of testing with new devices. As processes continue to shrink, this type of test will probably become all but impossible unless the industry produces an advance in board testing technology, or some alternative methods to accomplish the same goal can be devised.

4 Revision History

Table 2 provides a revision history for this application note.

Table 2. Document Revision History

Rev. Number	Date	Substantive Change(s)
0	06/2007	Initial draft.

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