WHITE PAPER

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Push Performance and Power Beyond the Data Sheet

Overview

With IC technology, we can no longer expect performance to naturally increase or power dissipation to decrease as a function of the advances. We need to find new ways to satisfy our continuing demand for more performance and to achieve that performance at a lower power level. By understanding the concepts of dependencies and guard bands, you can uncover hidden performance in your devices.

As long as most of us can remember, IC technology has been the driving force behind innovation. Every couple of years, advances in the state of the art gave us higher performance, lower power dissipation, lower cost and greater density. We even have Moore’s Law to go by. Sadly, those days seem to be coming to a close. We can no longer expect performance to naturally increase as a result of advances in IC technology, nor can we expect power dissipation to decrease as a function of the advances. In fact, one could argue that advances in clock speeds fell off the curve over a decade ago. In the same vein, power dissipation began falling off the pace about five years ago.

The result is that we need to find new ways to satisfy our continuing demand for more performance, and new ways to achieve that performance at a lower power level. One way we can do this is by understanding how performance and power dissipation depend on other variables under our control. It is also important to understand how IC manufacturers use guard bands to guarantee the performance of their products. By understanding these factors, we can uncover hidden performance.

Before we get into the details, let’s look at a few examples of ways TI customers have taken advantage of hidden performance. Many years ago a customer requested a letter guaranteeing that a certain device worked at 200°C. Our initial response was that our devices did not work at 200°C. The customer replied, “Oh yes they do! We are using them at 200°C, but our management wants TI to guarantee them.” We made it clear that we could not guarantee the performance of our devices beyond our specification, and that we had the data to prove it. You’ll be surprised to know that our devices are still being used at 200°C in this application. This customer has characterized the devices and is comfortable that the devices do work at 200°C in their application.

Another customer was buying bare die. We were shipping the devices still in wafer form with a wafer map telling them which die were good and which were bad. One day the customer asked why we sent the wafer map. We explained that it let them know which devices were good. We were startled by their response: “I don’t understand. All of the devices are good, so what do we do with the wafer map?” For their application, all of the die on the wafer were good.

One of our customers, while designing their product, realized that they needed the device to operate 20% faster than the data sheet allowed. By testing many parts in their system, they determined that they could easily over-clock the devices by 20%. As a result, they are shipping their product with the device clock operating 20% out of specification.

These are just three examples of how system designers have pushed devices beyond the data sheet specifications. To understand how these designers were able to “cheat” the specification, we will first discuss the general concept of dependencies and guard bands. Then we will apply these concepts to performance and power dissipation. Finally we will pull it all together and explain how you can use these concepts in your system design.

Conceptual Overview

The performance and power dissipation of a device depend on multiple factors. The dependencies we will focus on are process variation, temperature and voltage. Figure 1 below gives a general view of how performance and power dissipation vary with process, temperature and voltage. Later we will look at the dependencies in detail.

Given these dependencies, IC manufacturers test each device to guarantee that it fully meets the specification. This is not as easy as it sounds. During testing, manufacturers must compensate for various factors, including:

- Calibration variations between pieces of test equipment, both at the vendor and between the vendor and customer.
- Inconsistent test conditions due to differing test fixtures, differing operators, etc.
- Product drift during early life settling.
- Miscellaneous other anomalies.

	Performance	**Power Dissipation**
Process	Linear	Linear
Temperature	1/Logarithmic	Exponential
Voltage	Exponential	Exponential

Figure 1. Overview of key dependencies.

Manufacturers compensate for these variables by testing devices at ranges slightly outside the operating ranges specified in the data sheet. These ranges are known as "guard bands." For example, if a device is specified to operate correctly between 1.1 Volts and 1.2 Volts, the manufacturer might test the device at 1.05 Volts and 1.25 Volts. Similarly, if a device is specified to operate correctly between 10 MHz and 100 MHz, the manufacturer might test it at 9.5 MHz and 105 MHz. If the device is specified to work between 0°C and 70°C, it might be tested at –5°C and 75°C.

Surprisingly, this testing generally does not affect the yield of good devices. If you are wondering how this is possible, the answer is that we have only discussed part of the aspects that are guard banded. Other aspects of the device that have guard bands are:

- The process parameters
- The design parameters

What all of this means at a high level is that there is a significant amount of performance left on the table. It also means that the power dissipation of the device in the specific application will likely be significantly less than the maximum specified. So with that in mind let's look at some details. After we have looked at the details we will talk about what it all means to the system designer.

Performance

ICs can be manufactured in a variety of silicon processes. Processes in use today include 180-nm, 130-nm, and 90-nm processes. The performance of an IC depends on the characteristics of the underlying process. When manufacturers design an IC, they target the nominal process characteristics. However, variations in the process generate devices that are sometimes weaker ("colder") than desired or sometimes stronger ("hotter") than a nominal device. Hot devices can provide higher levels of performance than cold or nominal devices, and vice-versa. A typical relationship is shown in Figure 2 on the following page.

The performance documented in a data sheet takes into account the worse-case process variation. In other words, the maximum operational frequency given in the data sheet is determined by the weakest, cold devices. As illustrated in Figure 2, these weak devices represent only a fraction of the devices shipped. Therefore, the maximum performance of most devices exceeds the data sheet specification.

Similarly, the data sheet provides an operational temperature range, say –40°C–105°C. The documented performance is for the worst performance across the temperature limits. Figure 2 shows how the operational frequency of a device tends to increase with decreasing temperatures. A given device can have a significantly higher performance level if it is run below maximum temperature specification, e.g., at 75°C instead of 105°C.

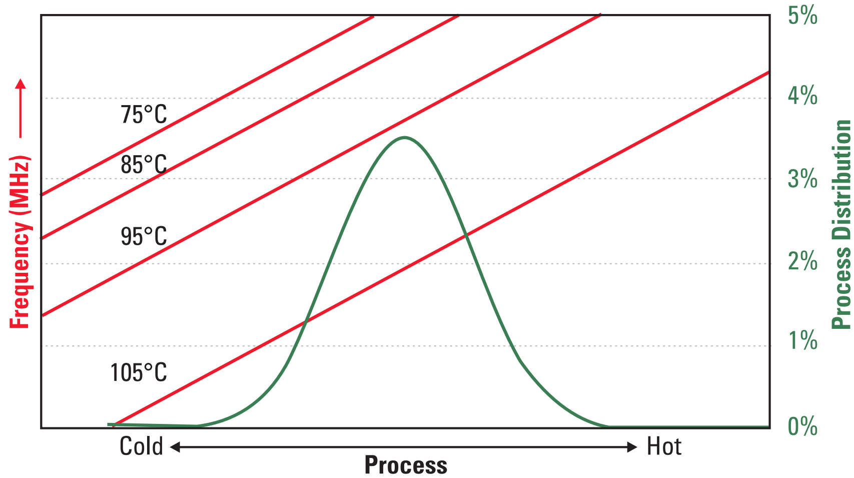

Figure 2. Dependency on process variation and temperature.

There is a similar relationship with respect to voltage. A device provides more performance as the voltage increases. In Figure 3, the minimum voltage Va determines the performance listed in the specification. At higher voltages (Vb, Vc, Vd, respectively), the performance tends to improve.

All of these trends provide the basis for the final specification provided to a customer. In order to provide some margin, each parameter is guard banded to ensure the specification is met under all voltage, frequency, temperature, and process conditions, for a particular number of power-on hours. If a device does not meet the required performance at the limit of the specification plus guard band, the device is discarded.

From a batch of devices that meet the specification, most are likely able to outperform the data sheet performance limits.

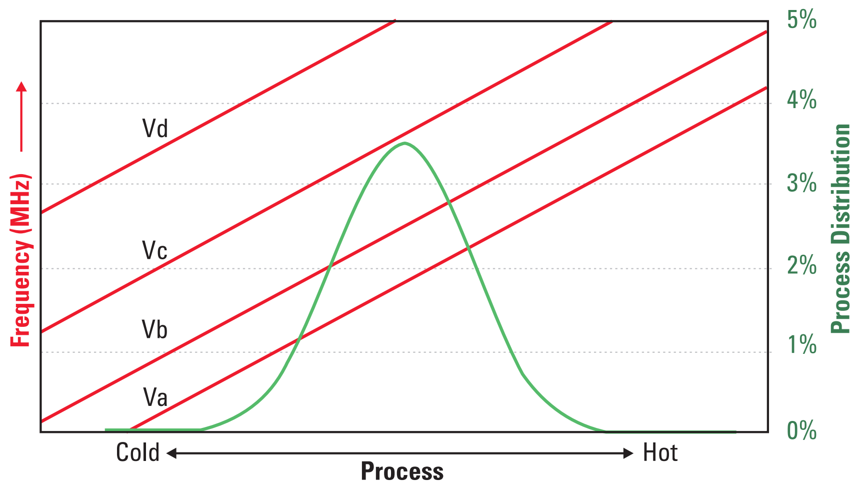

Figure 3. Dependency on voltage.

Power Dissipation

Power dissipation is highly dependent on temperature, process, frequency, activity, and voltage. Power can be broken down into a baseline component and an active component. Both components depend on frequency and voltage. Baseline power is mainly affected by leakage, and leakage is also an increasingly large factor in the total power dissipation. Leakage easily accounts for more than 50% of the power consumed in some high-temperature applications. Figure 4 shows how the power dissipation of a device increases exponentially as a function of temperature and voltage, where Va is less than Vb and Vb is less than Vc. It is also worth noting that leakage is directly linked to the process strength for a given device. A "hot" device yields higher leakage and a "cold" device yields lower leakage.

Power dissipation due to leakage can be controlled by limiting the operating temperature. A small decrease in temperature can have a dramatic effect in power savings for a particular system. Furthermore, a small decrease in voltage may also have an impact in the power dissipation for a device.

Power can be measured in many different ways. It may be measured at either nominal or high temperature, at either nominal or high voltage, and so on. The most conservative way to document power is to base it on the "hot" end of the process at the worst temperature and worst voltage. This provides a guard band against process variations. In other words, leakage should not exceed the specification because it was measured at the hot end of the process. Figure 2 suggests that only a fraction of devices reach the high end of the leakage power dissipation. This means that the vast majority of devices shipped dissipate less leakage power than what is presented in the data sheet.

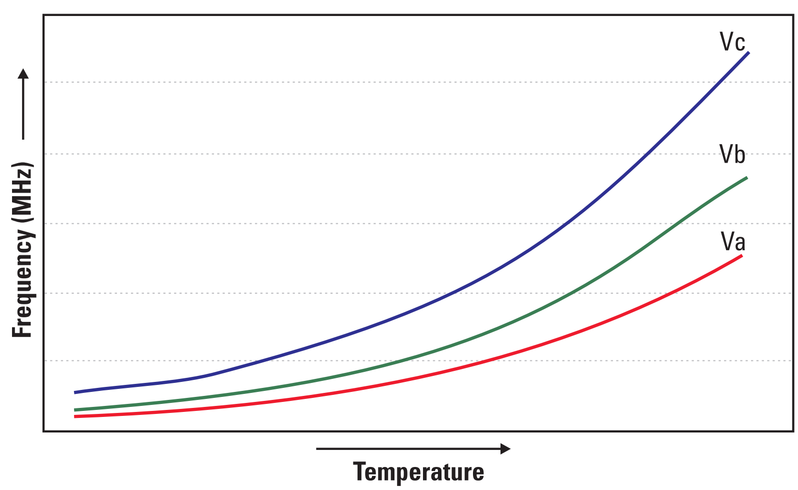

Figure 4. Power dependency on temperature and voltage (Vc>Vb>Va) for a given point in the process.

Putting it in Practice

So, what does all of this mean to the engineer designing the system? It means:

- An application that is performance-centric can find additional performance by lowering the temperature, or by increasing the voltage, or both.
- An application that is power sensitive can lower power by lowering the temperature, lowering the voltage, or both.
- An application that needs both lower power dissipation and higher performance can be optimized for both power and performance if approached correctly.
- Most devices have higher performance and lower power dissipation than the data sheet suggests.

Before you decide to violate all of the data sheet specifications to gain that extra performance or longer battery life, there are a few cautions:

- The vendor cannot and will not guarantee the device's performance if it is being used outside of the data sheet specification.
- There may be an effect on reliability based on the conditions at which the device is being operated.
- Your next shipment of devices may be from a production run that was at the limit of the acceptable process targets.
- You will need to do product testing and life testing to assure yourself that your system can meet you customer's expectations.

By understanding these details behind the data sheet specification, you can create the product you need—even when the data sheet says it is impossible.

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