Analyzing The Power of Mobile SoCs: Pitfalls and Best Practices

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Power is a critical part of the user experience, but assessing the power of a mobile SoC is challenging. We recommend measuring power for the entire chipset rather than the SoC alone, as this method captures system-level optimizations that the vendor has made. A full assessment of the chipset’s power characteristics requires testing across a variety of use cases. A chipset that excels in one area may fare poorly in others, depending on the design choices the chip vendor has made. Many use cases measure power for a fixed task, but some cases require measuring both power and performance for a fair comparison.

Introduction

When choosing an SoC for a smartphone or other mobile device, power usage is a critical criterion. Power not only determines battery life but also affects the size and weight of the device and even its ultimate performance. A power-efficient SoC helps the designer deliver a better mobile device that delights end users.

Accurately comparing the power of mobile SoCs, however, is a difficult task. When an SoC vendor quotes a power rating, many factors may be left unstated. Is the power rating a typical measured value, an estimated maximum value, or a calculated thermal design limit? Does the rating take into account power used by any system components outside of the SoC? Without these and other details spelled out, comparing one vendor’s rated power to another’s is just apples and oranges.

Another important factor in comparing power is the activity of the device during the measurement. Power varies widely depending on the use case. The peak power is typically consumed during web browsing or heavy gaming. But watching a movie, listening to music, making a voice call, or simply leaving the phone turned on in your pocket have differing effects on the device’s power. Furthermore, the power profile of a tablet computer is different from that of a smartphone or an e-reader.

When evaluating power, many people focus on the wrong issues, leading to wrong conclusions. For example, the peak power is often quoted, but most smartphones spend little time at that level during real-world usage. Focusing on SoC power alone may not maximize battery life, because some SoCs integrate functions that must be implemented externally with other SoCs. For example, integrating the Wi-Fi function will increase the SoC’s power, but it will reduce system power because the integrated function is more power efficient. Given the complexities of mobile power, a thorough understanding of the pertinent factors is essential to choosing the right SoC.

Key Concepts

To briefly define some terminology, an SoC is a system-on-a-chip. For a mobile system, the SoC at minimum contains one or more CPU cores (the central processor that runs the
operating system and apps), a GPU (graphics processing unit), and interfaces to external memory, cameras, displays, and other I/O. The mobile SoC is typically sold as a part of a chipset that includes chips for power management, cellular, Wi-Fi, and other connectivity (as required).

The power of the CPU varies widely depending on its clock speed. Power scales linearly with clock frequency. Most mobile SoCs also reduce the CPU voltage at lower frequencies, further improving power efficiency as the CPU slows down. Voltage control provides a greater benefit because power falls with the square of the voltage.

Thus, for light workloads, a good SoC design will shift to a lower speed to improve power efficiency. When maximum performance is needed, however, the SoC shifts to its highest speed. With a multicore SoC, the best efficiency is achieved when the SoC can individually adjust the speed and voltage of each CPU core, since the workload on one core may be low while the workload on another is high.

Many mobile SoCs also adjust their CPU speed on the basis of thermal measurements. These SoCs detect when the system is overheating and automatically back off their CPU power to maintain thermal limits. This process is called clock throttling. Because of throttling, some SoCs can maintain their advertised clock speeds for only seconds at a time before slowing down. The duration of the unthrottled period depends greatly on the thermal capabilities of the system design as well as on the starting temperature of the system.

Frequency and voltage scaling can benefit other elements of the SoC, such as the graphics unit. Good SoC designs alter the clock speed and voltage of the GPU depending on the workload, controlling it separately from the CPUs. Clock throttling can also affect the GPU, and intelligent SoCs will maintain an appropriate ratio of CPU and GPU performance even as the SoC slows down.

The best way to minimize system power is to keep everything turned off as much as possible. Most mobile SoCs contain offload engines that can handle certain tasks more efficiently than the CPU. For example, a small DSP or audio engine can decode MP3 files using a fraction of the power of the main CPU, extending battery life when listening to music. Similarly, a video engine decodes common video formats when the user is watching a movie. Even if an SoC has a low-power CPU, without these specialized engines, it will have poor battery life for these common tasks.

Battery life (hours) is a function of both power (milliwatts) and battery capacity. Batteries are typically rated in milliamp-hours (mAh) or milliwatt-hours (mWh), which is literally the number of hours the battery can supply one milliwatt. Reducing the power by 20%, for example, would extend battery life by 25% for the same battery. Another choice, however, would be to reduce the battery capacity by 20%, thereby maintaining the same battery life. This choice would result in a battery with about 20% less weight and 20% less volume (size). The battery is the heaviest part of most mobile devices and the main factor in the device’s thickness, so a reduction in power can literally result in a thinner and lighter phone or tablet.
Measuring Power

One best practice is to measure power for the chipset rather than the SoC alone. Focusing on the chipset eliminates the difficulty of comparing SoCs that integrate a different set of functions; each SoC must be paired with appropriate external chips to implement a full set of system functions. This approach also encompasses improvements that an SoC makes in reducing its use of external DRAM or in lowering the power of external I/O signals.

The next question is what to include in the chipset. For a smartphone, the primary components are the application processor and cellular baseband (often combined in a single SoC), connectivity (Wi-Fi, Bluetooth, FM, and GPS), RF transceivers for cellular and connectivity, power management (PMU or PMIC), and an audio codec. In the past, designers would often combine components from various vendors, but today’s leading SoC vendors supply most or all of these components, simplifying the comparison. To this bundle, we would add DRAM so as to capture the SoC’s efficiency in using external memory.

Measuring power for a complete chipset is challenging. Measuring the CPU power rail or the entire SoC is straightforward, but instrumenting all the various chipset components is not practical. Therefore, we suggest measuring power at the battery while taking steps to minimize or normalize power from non-chipset components. For example, the display should be turned off whenever possible, and the device should not be transmitting on any wireless interface, as transmission requires much more power than reception. (Most transmit power comes from the power amps, which are not part of the vendor’s offering.)

For some tasks, the system consumes power in a steady state. These tasks include listening to music, watching a video, and making a voice call. In this case, power can be measured at any time during the task, or ideally, measured at several times and averaged (to account for minor variations). The performance (speed) of the system does not affect the duration of the task (the length of the song or video or call).

For other tasks, however, the performance of the system is an important factor. For example, when browsing the web, one system might take two seconds to render a web page while another takes five seconds to render the same web page. Even if the faster system uses twice the power when rendering, the total energy (watt-hours) used is less. The peak power affects the thermal characteristics of the system, whereas the total energy affects battery life. A designer concerned with battery life must accurately measure both the power and the duration of the task.

For these performance-sensitive tasks, clock throttling will affect both power and duration. To properly measure the effects of throttling, power measurements should be performed using a system that closely replicates the thermal characteristics of the end device rather than on an open-air development board. Also, the system should be allowed several minutes between tests to cool.
The same principles can be applied to tablets, e-readers, and other mobile devices, but the details of each type of system differ. First, the chipset components differ: a tablet may lack a cellular subsystem, whereas an e-reader may lack connectivity functions. Instead of taking a different set of measurements, however, a designer can simply focus on the use cases that exercise the relevant components; a tablet designer, for example, can ignore voice-call power.

Second, different systems have different thermal and battery limits. Because of its size, a tablet can tolerate greater levels of heat than a smartphone, allowing the SoC to operate at a higher clock for a longer period of time (less throttling). This ability can change the typical power for web browsing, gaming, and similar performance-focused activities. The higher-resolution tablet display can also affect the power required by the graphics unit. Thus, we recommend replicating these use cases in a tablet environment rather than extrapolating them from tests performed in a smartphone.

**Use Cases**

As we have discussed, no single measurement can capture the power efficiency of a mobile chipset; comparisons must be made across a variety of use cases. This section provides a suggested list of use cases that together demonstrate the primary power-saving features of a mobile chipset.

- **Standby.** The device is powered on but is not performing any tasks, except perhaps monitoring the cellular network for an incoming call. The display is off. This case is important because most mobile devices are in a sleep mode for the vast majority of the day. This case shows the chipset’s ability to turn off all non-essential components while maintaining readiness to wake rapidly when needed.

- **Static display.** The device is powered on and the display is on, but the device is not performing any active tasks. This case is most common for an e-reader, but tablet and smartphone users often look at their screens for several seconds to read a message or a web page. This case tests the chipset’s ability to quickly recognize that the SoC is not needed and power down while waiting for input. Because the chipset power in this case can be very small, minimizing or normalizing display power is critical for generating comparable data. Using an e-paper display, external display, or self-refreshing display can improve the accuracy of the results.

- **Voice call.** The user is conducting a voice call over the cellular network. The display should be off. This case tests the power efficiency of the cellular subsystem, as the main CPU is typically not involved in voice calls. To minimize the power of the transmitter (power amps), the test should be performed with five bars of cellular reception, ideally in the same room as a femtocell or similar signal source. To minimize power to the phone’s speaker, reduce the volume control to zero.

- **Audio playback.** The device is playing an MP3 or other audio file from its internal memory. The display should be off. This case is important because smartphone vendors often advertise battery life during audio playback. This case tests the
efficiency of the audio engine and audio codec. As in the above example, reduce the volume control to zero after checking that audio playback is properly engaged.

- **Audio streaming.** This case is the same as the above, but the device is playing an audio file streaming from the Internet using either cellular data or Wi-Fi. The popularity of Pandora and other types of Internet radio is rising. In addition to the audio subsystem, this case measures the efficiency of the cellular or Wi-Fi subsystem. To avoid variance in Wi-Fi signals, this test should be performed in the same room as the Wi-Fi access point.

- **Video playback.** The device is playing a video file in standard format (e.g. MPEG4) from its internal memory. To minimize display and audio-output power, the video should be routed to an external display (e.g., via HDMI) and the device’s display and speakers should be off. This case tests the efficiency of the video engine as well as the audio engine and display engine. Power will vary depending on the resolution of the video file and the target display; because not all mobile SoCs support 1080p, we recommend using 720p video and display to ensure commonality among the results. Even at 720p, video power is considerably higher than audio power.

- **Video streaming.** This case is the same as the above, but the device is playing a video file streaming from the Internet using either cellular data or Wi-Fi. This case emulates Netflix, YouTube, and other popular video services. In addition to the video and audio subsystems, this case measures the efficiency of the cellular or Wi-Fi subsystem. To avoid variance in Wi-Fi signals, this test should be performed in the same room as the Wi-Fi access point.

- **Web browsing.** The device downloads and displays a web page or series of web pages. This test focuses on the performance of the CPU, which must interpret HTML, Java, and other web encodings to display the page; it also tests the SoCs use of external DRAM. Ideally, the web pages would be preloaded into memory, but to simplify the test, the pages can be downloaded through a cellular or Wi-Fi connection, with the caveats noted previously. Ideally, the display should be off (using external display), or the display power should be normalized and subtracted from the total.

Browsing is the type of fixed-size task for which both the power and the duration are important factors. Users prefer a device that displays web pages more quickly, but the total energy consumed is the factor that affects battery life.

One challenge is choosing the web pages to test. Some pages put a higher load on the SoC than others. The best test is a complex page that pushes the CPU to its maximum rate. Using live pages from the Internet, however, makes it difficult to make repeatable measurements or to compare results across a number of devices. One option is EEMBC’s BrowsingBench test, which incorporates a set of static web pages; this option provides repeatable scores across a range of devices and eliminates the power of the wireless data link.

- **Heavy gaming.** Whereas simple puzzle games put little burden on the CPU and GPU, graphics-intensive games are one of the biggest challenges to a mobile SoC. Stressing
two power-hungry parts of the SoC, as well as the external DRAM, heavy gaming forces the SoC to carefully allocate its power budget. As above, display and speaker use should be minimized or normalized to focus on the SoC power.

Like browsing, gaming results will vary depending on the chosen game and the game-play scenario. Unlike a movie, the frame rate of a game can vary depending on the screen resolution and SoC performance. Thus, when comparing two chipsets, both the frame rate and the power consumption should be considered.

Conclusions

When assessing the power of a mobile SoC, the wrong approach can lead to wrong conclusions. Most mobile-SoC vendors today offer a complete chipset (including baseband, connectivity, and RF). We recommend measuring power for this entire chipset rather than the SoC alone, as this method capture system-level optimizations that the vendor has made. Whenever possible, these measures should exclude the power for the display, speakers, and power amps, which are not part of the SoC chipset and whose power can vary widely.

A full assessment of the chipset’s power characteristics requires testing across a variety of use cases. The use cases discussed in this paper represent common end-user activities, and each exercises a different part of the chipset. A chipset that excels in one area may fare poorly in others, depending on the design choices the chip vendor has made. Many use cases measure power for a fixed task, such as decoding an audio stream, but some cases require measuring both power and performance for a fair comparison.

Platform power is a critical part of the user experience. The thermal limits of a smartphone or tablet can restrict the maximum power of a mobile SoC, thereby limiting the performance for running apps. A lower-power chipset can extend battery life, giving the user more time between charges, or it can allow the system designer to reduce the battery size, improving the size and weight of the device. Accurately assessing the power requirements of a mobile chipset is a key step toward delivering differentiated devices that better serve the end user.

Linley Gwennap is founder and principal analyst of The Linley Group and coauthor of “A Guide to Mobile Processors.” The Linley Group offers the most comprehensive analysis of the mobile-silicon industry. Our in-depth reports covers topics including application processors, cellular-baseband processors, Wi-Fi combos, and other connectivity chips. For more information, see our web site at www.linleygroup.com.

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