Electronic Design

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Enabling 5G Small Cells with Efficient Power Solutions

Millions of 5G small cells are what make a 5G network tick. Companies have started developing 5G small-cell systems to enable this new standard, and those systems will need efficient power supplies.

We've all heard about the upcoming 5G standard and its promise of higher bandwidth and lower-latency mobile coverage. However, 5G operates at much higher frequencies than 4G-LTE. The current LTE systems operate below the 3.6-GHz range. The first-generation 5G systems will operate in the sub-6-GHz range (in the unlicensed spectrum between 3.5 GHz and 6 GHz). Newer 5G networks will support even higher bandwidths and thus will have to operate in the millimeter-wavelength (mmWave) range.

5G networks will help realize data speeds of up to 10 Gb/s, which will not only bring about faster mobile downloads, but also enable smart cities, connected cars, and the Internet of Things (IoT) to operate seamlessly.

The top candidates for future 5G network frequency ranges are 24.25 to 27.5 GHz, 27.5 to 29.5 GHz, 37 GHz, 39 GHz, and 57 to 71 GHz. The advantages of using these higher frequencies are those of free, unlicensed spectrum, and of much higher bandwidths. But coupled with those higher frequencies are significant range and signal-penetration issues.

The 5G waves can carry a lot of data. But they will have a small range (down to 100 m) and will not be able to effectively penetrate obstacles, including some types of building materials. The 4G-LTE cell towers deliver cellular data up to 30 miles away. New 5G mmWave cell towers will cover only a few blocks. Also, these signals are subject to barriers posed by windows, doors, and even rain.

Millions of 5G small cells are needed to make a 5G network work. Some estimates are for one million new 5G small cells to be deployed in the U.S. alone—one every few hundred feet. Small cells will be more prevalent in urban settings due to the population and building density.

Companies such as SureCall have developed a 5G mmWave, FCC-compliant, signal-booster platform that amplifies 28-GHz signals. SK Telecom in Korea devised aits 5GX in-building solution that can double the speed of 5G data transfers inside buildings. "We expect 80% of data traffic to be from inside buildings in the 5G era," said Park Jong-Kwan, who heads 5GX Labs at SK Telecom.[1]

Companies have begun development of 5G small-cell systems to enable this new standard. The 2020 forecast for worldwide 5G small-cell deployment is 742,000 units. And it's expected to be at least 3.4 million units by 2024, a five-year CAGR of 75%.[2] A major portion of the global deployment is expected to be in the Asia Pacific region (56%), primarily driven by demand in China. North America will deploy 19% of the global small cells. The Europe, Middle East, and Africa (EMEA), and Central and Latin America (CALA) regions, will deploy 16% and 9%, respectively, in 2024.

Types of 5G Small Cells

A small cell is basically a small base station that implements the cellular network using smaller systems, such as femtocells, picocells, and microcells. These can be indoor within a residence or covering an apartment building or a small neighborhood. Small cells are typically used in very densely populated urban areas, such as shopping malls, stadiums, railway stations, airports, and office buildings, or any place with a lot of people using data at a given point in time.

Small cells enable the deployment of 5G by increasing data capacity and eliminating expensive rooftop towers. They enablemake it possible for mobile devices to be closer to a base station, which permits operation at lower power for greater battery life. The three small cells available today have distinct features (Table 1).[3]

Femtocells

Femtocells, the smallest of small cells, are primarily used to extend coverage in residential or small business environments. These low-power, low-cost devices extend coverage and capacity in environments where cellular signals can't penetrate. Femtocells are typically self-installed by the end user.

Picocells

Picocells are usually applied in larger spaces such as shopping malls, hospitals, and hotels. They can serve a larger physical area with an increase in transmit power compared to femtocells. Picocells are typically installed and maintained by the telecom or network operator. The location and positioning of the small cells isare also centrally planned by the network operator.

Microcells

Microcells are essentially low-power base stations designed to support up to 2000 active simultaneous users. Their coverage and capacity are generally more substantial than picocells. Microcells will usually be affixed to lamp posts, utility poles, bus shelters, or sides of buildings. They will enable applications such as smart cities.

Challenges of Deploying 5G Small Cells

Small cells must be designed to fit in the available space. This can be the top of a light pole, rooftops of certain buildings, utility poles, or traffic lights, for example. This creates constraints on the system design. Thus, a key design goal is for these systems to be as small as possible.

The heat dissipation of the entire system must also be as low as possible for outdoor deployment, especially considering the small form factor. The components tthat comprise a small-cell system must be smaller and dissipate very low heat. Because battery backup may be required in some cases, it's critical that the system be able to switch to a battery in a power outage. In addition, isolation and protection against voltage and current spikes must be incorporated in the design to ensure these systems are rugged and long-lived.

TABLE 1: TYPES OF SMALL CELLS

Type of small cell	Coverage distance	Indoor or outdoor	Transmit power	Number of users	Backhaul type	Cost
Femtocells	30 to 165 ft 10 to 50 m	Indoor	100 mW 20 dBm	1 to 30	Wired, fiber	Wired, fiber
Picocells	330 to 820 ft 100 to 250m	Indoor Outdoor	250 mW 250 mW	30 to 100	Wired, fiber	Low
Microcells	1600 to 8000 ft 500 to 2500 m	Outdoor	2000 to 5000 mW 33 to 37dBm	100 to 2000	Wired, fiber, microwave	Medium

Heat Dissipation

Small cells typically have no fans or other active cooling built into the design. The components of the system must have very low heat-dissipation properties. Modern microprocessors and FPGAs are optimized for low-power operations (which directly correlates to heat dissipation). However, the regulator that powers various voltage rails within the system can be one of the main heat-dissipation sources.

Small cells can operate from either a 24-V dc power source, a 48-V+ power source if the system is powered over Ethernet (PoE), or from a long-term battery. Either way, the power supply must efficiently generate regulated rails (5 , 3, and 1.8 V) for the system electronics to minimize power losses.

There are two important performance metrics to determine the heat dissipated by the regulated power source: the power-conversion efficiency and thermal resistance (also called θ_{JA}) measured in °C/W. This second metric is sometimes lost in the datasheet and oftenoften isn't considered.

Let's look at a typical regulated dc-dc power converter device. Power-conversion efficiency and thermal resistance are directly related to the operating junction temperature of the device, which is typically limited to +125°C or sometimes 150°C, and that's directly correlated to reliability and failure rates:

Junction temperature rise = θ_{JA} [°C/W] × power loss [W]

Power loss = (1/*Efficiency* – 1) × power output

A typical 60-V, 3-A, dc-dc power converter, such as the MAX17574 from Maxim Integrated, has a thermal resistance (θ_{JA}) of 24 °C/W and efficiency of 90% when converting from 24 V to 5 V at 3 A. By applying the formulas above, the junction temperature rise is 40°C *(Table 2)*. This is about half the junction-temperature rise compared to other high-power dc-dc converters.

The ambient or environmental temperature must be added to the junction rise temperature to determine the operating junction temperature:

Operating junction temperature = ambient temperature + junction temperature rise

Small cells may have to operate in hot outdoor environmental conditions, with no air flow, in ambient temperatures nearing +60°C (or sometimes even 70°C). So, the system must be optimized for lowest heat dissipation. Higher thermal resistance (θ_{JA}), with even a small decrease in efficiency, may cause the device to operate beyond the specified limits, compromising reliability and resulting in failures.

Protecting the System

5G small cells must be ultra-reliable, because system failure means losing access to the 5G network. Also, they must keep working despite system-level events such as voltage spikes, accidental shorts, and transients. It pays to spend a bit more to make the system immune to overcurrent, overvoltage, and short events.

There's a new class of integrated protection devices that provides intelligent protection and customizes the responses to such events. While these devices do incur additional costs, they they're probably the lowest-cost insurance for the system.

For example, consider an event that causes a sudden surge in voltage. Typically, a transient voltage suppressor (TVS) in the system clamps the surge down to a maximum of 53.3 V.

TABLE 2: MAX17574 THERMAL CHARACTERISTICS	
	MAX17574
Junction-to-ambient thermal resistance θJA (in °C/W)	24
Efficiency at 24-V input, 5-V/3-A output	90%
Power loss at 24-V input, 5-V/3-A output	1.67
Rise in junction temperature (in °C)	40

Any electronic component connected to this voltage rail must withstand at least 53.3 V. Though rare, sometimes miswiring can cause a short on the input side or even a reverse-voltage event. This damages the system and must be handled very quickly.

Some systems have a bulk holdup capacitor or supercapacitors that draw high in-rush current during startup. This high-current spike can damage connectors, blow up fuses, and cause voltage ringing on the backplane voltage.

Here's how a modern protection IC safeguards the system. The IC, which operates from +4.5 to +60 V at a 1-A load, can withstand negative input voltage to −65 V *(see figure)*. It includes an integrated PFET and NFET for forward/reverse voltage or current protection, programmable under/overvoltage protection, current-limit thresholds and fault-response modes, and thermal protection with fault-indicator flags. This IC has precision current sensing of ±3%, whereas a discrete solution typically gives ±20% to ±40%. This respresents a significant performance improvement.

The IC also reports the load instantaneous current value on the SETI pin. This feature helps the system to monitor the current consumption of each circuit board. The devices can be programmed to behave in three different ways under the current-limit condition: auto-retry, continuous, or latch-off modes. It's a useful means for the system designer to decide how to manage the load transient to minimize the system downtime and service costs.

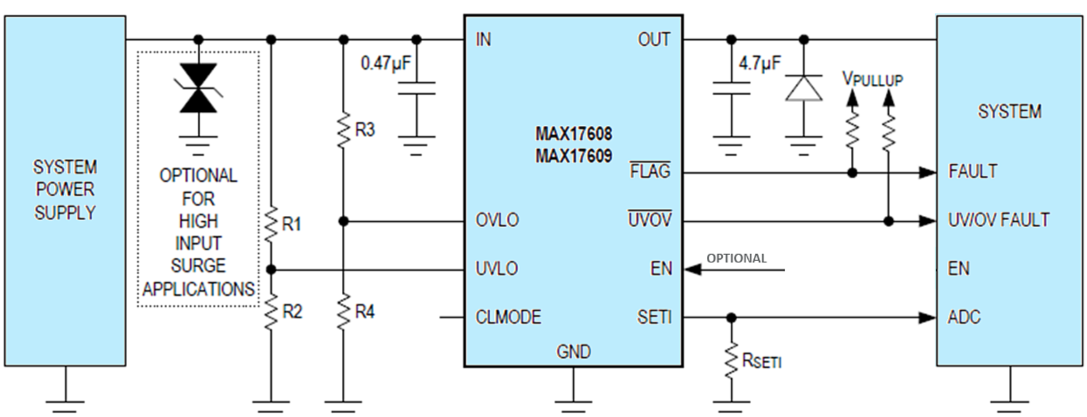
In addition, this device as in-rush current protection. The control FET dissipates a large amount of power during in-rush due to the sizable difference between the input and the output voltages. This power integrated over time is the energy that heats up the FET. These devices have a thermally controlled current-foldback protection feature that always keeps the internal power MOSFET within the safe operating area (SOA).

The device enters the power-limiting mode if its temperature reaches the thermal foldback temperature threshold. It thermally regulates the current through the switch in this mode to protect itself while still delivering as much current as possible to the output regardless of the current-limit type. This steadily charges a large capacitive load during startup. Furthermore, it prevents overheating of the device during startup if the ambient temperature is abnormally high.

The benefit of such an approach is that there's no overheating of FETs, resulting in safer system operation. It also leads to a much simpler design because there's no guesswork in sizing the FET to ensure it's in a SOA. This functionality comes in a 3- x 3-mm, 12-pin, TDFN-EP package.

The other way to protect a 5G small system is to add digital isolation to the I/O pins of the microprocessor or FPGA.

Modern current-limiting ICs (such as the Maxim MAX17608/17609) provide robust protection to next-generation 5G small cells.



Most digital processing devices can withstand a maximum of 5 V at their I/Os. The microprocessor or FPGA can suffer permanent damage if there's a voltage spike or sustained higher voltage. Multichannel digital isolators with two, four, or six channels are available in a small package, with very low power consumption. Independent rating agencies like VDE and TuV rate them equivalent to optocouplers.

Costs are important when taking care of the entire system. A low-cost, low-power, multichannel digital isolator makes sense, given the increase in reliability and lifetime of the system.

Conclusion

5G small cells are the key building blocks of next-generation cellular infrastructure, and will transform the way billions of connected devices interact with each other. They will realize this goal with fast data rates and increased bandwidth capacity.

However, many challenges remain, such as efficiency and power consumption, as small cells require a reduction in size, weight, and power consumption. These challenges call for efficient dc-dc power devices with significantly reduced heat profiles. A reduction in heat allows small cells to operate in harsh outdoor conditions while ensuring reliability.

Also, next-generation 5G small cells will incorporate some of the most advanced components, e.g., FPGAs and millimeter-wave assemblies. These components are relatively expensive and susceptible to system-level voltage spikes and other interferences. Increasingly, integrated protection solutions are needed to protect these sensitive devices to reduce field failures and ultimately drive down total ownership costs.

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1. Modern current-limiting ICs (such as the Maxim MAX17608/17609) provide robust protection to next-generation 5G small cells.

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