Small Cells, Big Impact: Designing Power Solutions for 5G Applications

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We live in an age of global communication made possible by improvements in smartphones, internet speed and accessibility. Today, we are marching into the era of 5G. Internet usage has gone up over 200% in the last decade [1], and is expected to more than double through 2025 as more devices connect to the internet.

5G can help realize the future of Internet of Things (IoT), connected cars and smart cities through higher speeds (up to 10 Gbps), better coverage (capacity expansion by a factor of 1,000) and improved reliability (by leveraging ultra-wide bandwidth and throughput). The traditional wireless infrastructure approach to 5G has certain limitations, however, including penetration ability and signal reach due to a higher spectrum. That's where small cells come in. Small cells increase the amount of traffic that can be handled in an area while also increasing speed. In this white paper, I will discuss what small cells are, how they fit into the 5G ecosystem and the key power requirements in a small-cell design.

What are small cells?

Telecommunications equipment manufacturers have taken traditional macro radio designs and shrunk them down into what's called a small cell. Small cells are smaller and cheaper than a cell tower and can be installed in a variety of areas, bringing more base stations closer to users. A large number of base stations increases the number of people a network can support, while reduced distance to users decreases latency, enabling even faster connectivity.

The trend in 5G radio applications is to use higher frequencies and shorter wavelengths. Increasing the frequency increases the speed of sending/receiving signals and helps shrink the size of the antenna, which in turn shrinks the size of the cell. Shorter wavelengths result in a decrease in signal penetration and radius, reinforcing the need for small cells.

How do small cells fit into the 5G ecosystem?

A cell tower (also called a macrocell) is a huge umbrella used to provide radio signals to thousands of users in large areas with minimal obstructions. To extend the coverage of a macrocell, distributive antenna systems (DASs) are used in conjunction with the cell tower. DASs take a signal from the base station and boost it to increase the area the signal can reach.

While DASs are great for increasing coverage, they do not increase network capacity; the only way to increase network capacity is to add more base stations, which is why small cells are so useful. Unlike macrocells mounted on huge towers that cover thousands of users in the kilometer radius range, small cells serve as a complement, with much smaller radius ranges close to people and houses. Working as a base station itself to send and receive signals, a small cell not only offloads some of the data capacity of a macrocell, it also adds its own data capacity, making the network more robust.

Small cells do not cover the same area or number of users as a macrocell. **Figure 1** shows coverage for each type of small cell. Targeted to support a fewer number of users more efficiently and inexpensively, small cells can serve as an enhanced alternative to multiple macrocells to cover more densely populated areas, complementing macrocell towers and becoming an essential factor for 5G deployment.

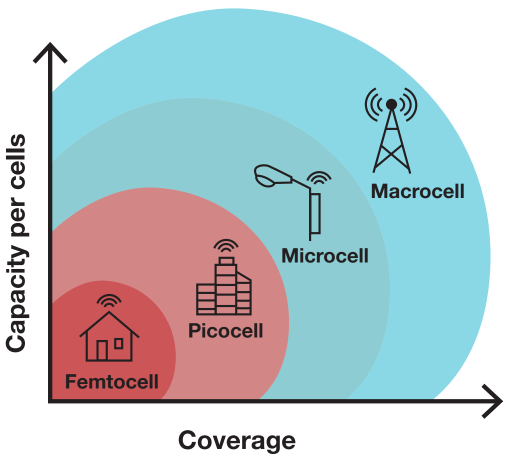


Figure 1. *Small-cell coverage.*

Everyone benefits from the small-cell solution. Service providers can reduce overall network densification costs by avoiding expensive macrocell installations, while consumers benefit from faster connectivity and improved smartphone battery performance. When a mobile device is close to a small-cell base station, the power needed to transmit the signal is much lower compared to the power needed to transmit a signal from a cell tower far away, thus extending smartphone battery life.

Types of small cells

While there isn't a strict industrywide standard to classify small cells, they are generally classified by their coverage range. **Table 1** lists the types of small cells and what they are designed to support. Femtocells, the smallest of the small cells, are meant for individuals to increase their personal connectivity. Femtocell coverage is perfect for homes and small offices. Picocells, the next step up, are used for large office buildings or hotels. Above picocells are microcells, also called metrocells. Microcells are common on light poles or atop buildings in dense urban areas.

Another way to differentiate between the different types of small cells is by their radio frequency (RF) power output, which can dictate the coverage radius and number of users.

Power requirements of small cells

To really understand the power requirements for a system, it is important to talk about what it is powering. In a small cell, the power requirements come from the analog front end (AFE), field-programmable gate array (FPGA) or application-specific integrated circuit (ASIC) that needs power. While every designer does it a little bit differently,

in general, you will need to buck the AC/DC input or power over Ethernet (PoE) voltage down to the 1-2 V needed by the AFE, FPGA or ASIC. The most common method is to use multistage conversion:

Base station type	Number of users	Coverage (km)	Bandwidth (MHz)	RF (W)	Location	Users
Femtocell	1 to 30	0.01 to 0.1	10	0.001 to 0.25	Indoor	Homes or small offices
Picocell	30 to 100	0.1 to 0.2	20	0.25 to 1	Indoor/ outdoor	High-rise buildings, hotels, office buildings or parks
Microcell/ metrocell	100 to 2,000	1 to 2	20 to 40	1 to 10	Indoor/ outdoor	Shopping centers, transportation hubs, city blocks, stadiums, temporary events
Macrocell	>2,000	5 to 32	60 to 75	10 to >50	Outdoor	Suburban, city and rural areas

Table 1. *Base station types.*

first the AC/DC or isolated PoE converter generating the intermediate bus voltage of 12 V or 5 V, and then a point-of-load converter to step down once more to the necessary voltage level. If the PoE architecture includes power-sourcing equipment (PSE), a 48-V power rail has to be stepped down to power the PSE controller. Using a wide V_{IN}, such as LM5164, converter helps to protect against any large spikes with load changes.

Efficiency is just one key challenge when designing a small cell. Cost, power output, thermals and time to market are equally important considerations, intensified by what makes small cells so special – their compact size. As the base station shrinks, so do the components that make up the base station. Every component needs to shrink in size without affecting efficiency or performance.

Power density is a term to correlate the power output of a converter with its size. It is one of the most important elements of designing a small cell, and has been a key vector in the evolution of ICs. Advances in power dense ICs are achieved by innovations with packaging, control topology, integration, the metal-oxide semiconductor field-effect transistor (MOSFET) and in some cases the digital interface. Examples include the TPS543B20 25-A analog buck converter and TPS546D24 40-A Power Management Bus (PMBus) buck converter.

Package innovation

It's easy to overlook package innovations when comparing devices, but there are some significant advantages to different package types that can dramatically benefit a design. A stack-clip quad flat no-lead (QFN) multichip module (MCM) package exemplifies how packaging innovations are game changing for power density. The name itself indicates how the high- and low-side FETs are "stacked" on top of the IC and secured with a "clip."

Figure 2 shows how a 3D architecture drastically reduces the footprint of the converter, now that the high- and low-side FETs are no longer taking up spacing in the x-y plane. Not only does stack-clip QFN shrink the size of the converter, but it also offers reduced parasitics by enabling flexibility in the package layout to incorporate a large ground thermal pad under the package for the best thermal and current capability.

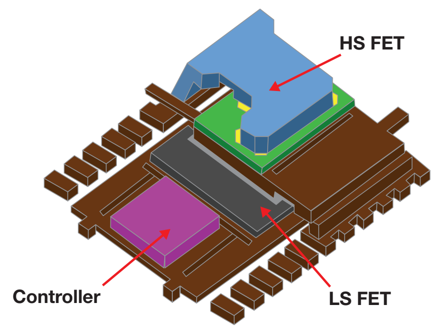


Figure 2. *3D stack-clip QFN package.*

TI's HotRod™ QFN is another variation of packaging that can help increase efficiency. HotRod QFN removes the bond-wire in a regular QFN and connects the die directly to the leadframe, completely eliminating the parasitics from the bond-wire and reducing resistance in the chip overall. The extra room once needed for the bond-wire is eliminated, consequently shrinking the size of the package.

Control topologies

Control topologies such as advanced current mode (ACM) also make a difference in small-cell designs. ACM is a fixed-frequency control mode that integrates the compensation on the silicon, with ultra-fast transient response even at high buck ratios. ACM not only saves external components and printed-circuit-board (PCB) space, but also design time, which means a faster time to market. **Figure 3** compares the components needed for fixed-frequency control with Type III compensation and the components needed for ACM.

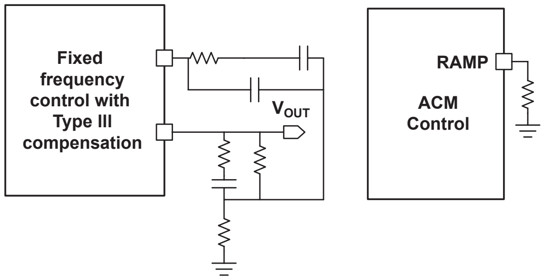


Figure 3. *Extra component comparison.*

Integration

Converters integrate MOSFETs into the package enabling a smaller solution size. Modules take that integration one step further and include the inductor inside the package. Modules are meant to alleviate some of the design burden by being a plug-and-play solution reducing design schedules and extra bill-of-materials (BOM) components.

Figure 4 compares the TPS546C23 converter solution with integrated FETs and the 35-A PMBus TPSM846C23 module solution with integrated FETs and an inductor. You can see how over half of the external components from the converter schematic are no longer needed to complete the power stage in the module schematic, saving design time and BOM cost.

MOSFET innovation

MOSFETs use a low on-state specific resistance to provide better performance. **Figure 5** shows how simply changing out the MOSFETs in a solution can significantly increase converter efficiency. You can double the switching frequency without trading off efficiency, which leads to a smaller solution size. Using a converter that incorporates silicon-based next-generation FETs is another reason to use an integrated solution.

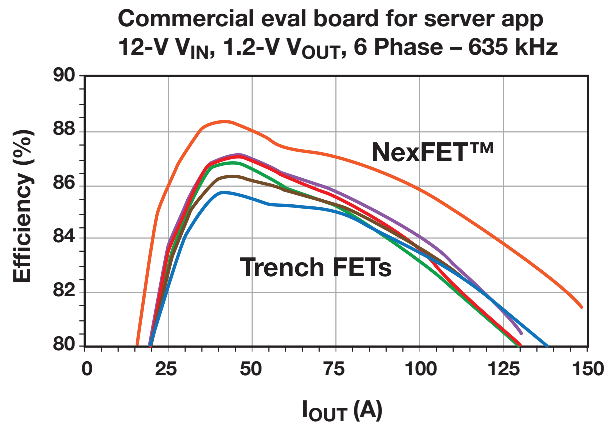
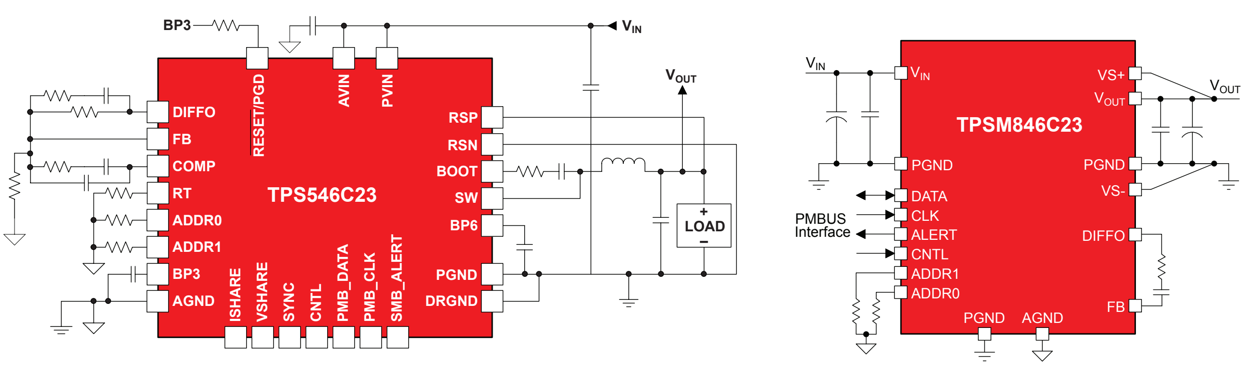


Figure 5. *Improved efficiency provided by NexFET™ technology.*

Digital interface

The demand for intelligent systems in next-generation base stations is leading to the incorporation of digital interfaces into designs. By employing the digital interface of the PMBus and I²C, a system can communicate within itself to increase efficiency and monitor the power consumption of the system. This becomes increasingly important as the system supports more users and the power consumption increases.



(a) *(b)*

Figure 4. *TPS546C23 simplified converter schematic (a); TPSM846C23 simplified module schematic (b).*

Power monitoring, together with adaptive voltage scaling (AVS) by PMBus, can help reduce service provider electric bills. The TPS546D24 is used in small-cell applications for its PMBus programmability along with voltage, current and temperature monitoring.

Other design challenges

Each kind of small cell has specific requirements based on the needs of the niche it supports. Femto- and picocells are more of a consumer product, where consumers more directly assume the cost of the system. Thus, these systems need to be sensitive to cost. These variants operate in temperature-controlled settings such as homes, businesses and shopping malls, and don't need much power because they support fewer users.

Microcells are usually located outside, thus making thermal performance and efficiency top design priorities. In an uncontrolled setting with a wide variety of ambient temperatures, it is very common for devices to withstand PCB temperatures as high as 105°C while still delivering solid performance. This is a challenge for power components, since high-temperature conditions degrade device lifetimes and long-term reliability. To address this consider using high-efficiency devices specifically designed to operate under these strengent conditions to ensure performance over a long lifetime. PMBus is a popular choice, since there is more of a need to monitor, report and adjust system parameters to continuously optimize efficiency and system performance.

Conclusion

The need to increase the number of base stations to provide wider and more dense coverage has led to the creation of small cells. Small cells are a new part of the 5G platform that increase network capacity and speed, while also having a lower deployment cost than macrocells. The compact size of a small cell requires that all components – especially power converters – provide high efficiency, better thermals and eventually the best power density possible. Using new package innovations along with integrating FETs, inductors and compensation are great ways to achieve higher power density to save space and decrease the complexity and cost of materials in a small-cell design, while incorporating PMBus can help you get the most out of power consumed. Understanding the variants of small cells (femto-, pico- and microcells) and the design challenges that come with each will help you find the right solution to fit your needs.

Additional resources

- Explore more TI solutions for small cells, including reference designs.
- To learn more about 5G, read the white papers, "Preparing for a 5G world" and "Analog advancements make waves in 5G wireless communications."

Citations

1. Statistica.com. "Internet usage worldwide – Statistics and Facts."

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