TI TechNotes

Improving RF power amplifier efficiency in 5G radio systems using an adjustable DC/DC buck regulator

Timothy Hegarty

Fifth-generation (5G) wireless communications extend the advances of today's 4G networks by addressing the need for increased capacity and throughput, with improved coverage at a lower system cost. High-speed data transmission, support for a large number of connected devices, low latency, low power consumption and extremely high reliability are essential. The key to a capacity increase lies in the densification of the network topology.

A crucial aspect of the evolution to 5G is solving difficult base-station hardware challenges. Existing towers must provide higher performance in order to carry many more channels at higher data rates. One aspect to successfully meeting expectations is the introduction of multiple-input, multiple-output antenna technology on a massive scale (mMIMO). Another aspect is a large-scale integration of components, along with higher performance and greater power savings.

The imperative here is to operate base stations that can flexibly adjust to traffic demand. Certainly, the transition to and deployment of 5G communications has an inherent requirement for adoption of smart power management in the underlying hardware.

Base Transceiver Station

A base station comprises multiple transceivers (TRX); each TRX comprises a radio-frequency (RF) power amplifier (PA), an RF small-signal section, a baseband (BB) interface including a transmitter (downlink) and receiver (uplink) section, a DC/DC PA power supply, an active cooling system, and an upstream isolation stage to convert from -48 V_{DC} or AC mains voltage. A popular PA circuit known as the Doherty amplifier – using silicon LDMOS or GaN RF transistors in its carrier and peaking cells – provides a linear and highly-efficient RFPA, particularly when operating deep in the output back-off (OBO) region where the efficiency of alternative amplifier solutions drops considerably.

Base Station Efficiency Enhancement

The proliferating frequency bands and modulation schemes of modern cellular networks make it increasingly important that base-station power amplifiers offer the right combination of output power, efficiency and multi-band support – at both peak and average power levels. PAs are the main energy consumers in modern base stations. Moreover, the inefficiency is converted into heat, creating the need for active cooling of the devices and further increasing total power consumption. Consequently, high PA efficiency is essential to reduce operating expenses for mobile network operators, as it can lower power dissipation and the need for cooling.

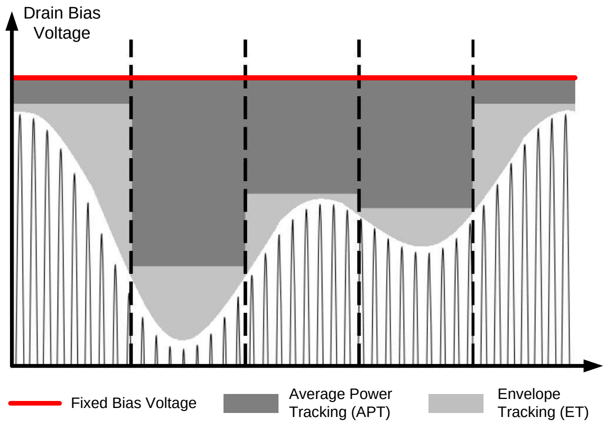

Figure 1. PA drain bias voltage modulation

The signals in modern wireless communication systems have high peak-to-average power ratios (PAPR). Techniques such as average power tracking (APT) and envelope tracking (ET) increase the power efficiency of a PA in a base-station application, as depicted in Figure 1.

For example, APT changes the DC supply voltage to the PA on a timeslot-by-timeslot basis to achieve high efficiency at various loading conditions. The output of the PA can be a function of average power but sufficiently backed off to limit clipping RF signal peaks, which could impact the linearity of the PA.

Meanwhile, ET is faster and more accurate, as it adjusts the supply voltage in real time according to the PA input signal. However, this solution is more complicated than APT because it requires a separate or integrated ET module.

Both APT and ET use hardware and software elements that modulate the voltage supply to the PA in order to reduce total power consumption.

PA Power Supply

A key performance benchmark for the voltage supply to the PA is the ability to adjust the voltage level on the fly according to the specific use case scenario.

A small form-factor power solution balancing efficiency and size is vital. Figure 2 shows a DC/DC buck regulator solution with PWM controller U_1 driving discrete power MOSFETs Q_1 and Q_2. The choice of controller hinges initially on input voltage and switching frequency specifications. Choosing a controller with a wide V_{IN} range and high line transient immunity offers an outsized voltage rating and operating margin to accommodate peak voltage transients.

Selecting a wide V_{IN} range device, such as the LM5145, a voltage-mode synchronous buck controller that operates from 6 V to 75 V, lets designers reduce or eliminate the input bulk capacitor or TVS diode clamp, saving cost and board space. The voltage-mode control architecture with line feedforward enables excellent line- and load-transient dynamics.

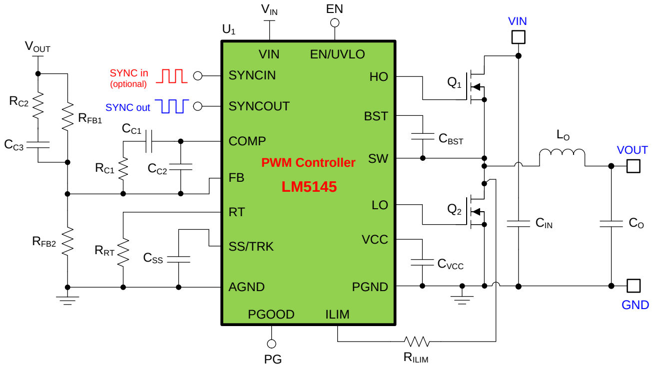

Figure 2. Synchronous buck DC/DC regulator with wide input voltage range

The LM5145 controller drives external high-side and low-side power switches with robust 7.5-V gate drivers suitable for standard-threshold MOSFETs. Adaptively-timed gate drivers minimize body diode conduction during switching transitions, reducing switching losses and improving thermal performance. If an auxiliary rail between 8 V and 13 V is available to supply VCC bias, the input quiescent current of the LM5145 reduces to 325 µA at an input of 50 V, maximizing light-load efficiency and reducing the die temperature of the IC.

Moreover, the LM5145 controller offers a large degree of flexibility in terms of platform design. The adjustable switching frequency – as high as 1 MHz – is synchronizable to an external clock to eliminate beat frequencies in noise-sensitive PA applications. A 180° out-of-phase clock output is a good fit for downstream or multichannel power supplies to reduce input capacitor ripple current and EMI filter size. A minimum off-time of 140 ns enables operation at high duty cycle and low input-to-output voltage differentials.

PA Voltage Adjustment

Typically, an MCU or FPGA provides the APT voltage setpoint command for the PA in digital format, which the power supply should readily interpret. For example, a variable duty cycle PWM output from an MCU could be RC filtered and resistor-coupled to the feedback (FB) pin of the DC/DC regulator. Another option is to apply a DC control voltage at the tracking input of the controller (SS/TRK in Figure 2) for output voltage adjustment.

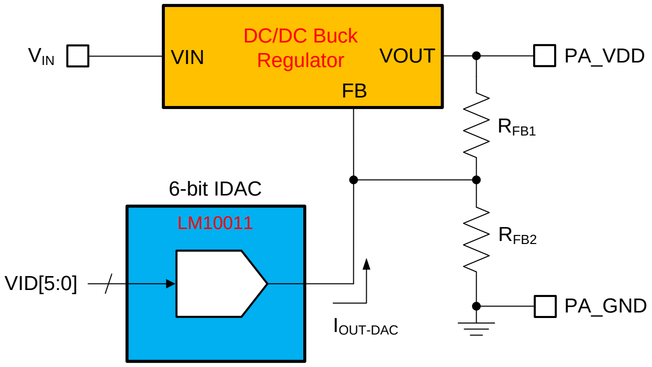

Figure 3. Output voltage adjustment using a digital VID controller

The circuit in Figure 3 exploits VID control using a 6-bit digital interface to a VID programmer that interfaces directly to any analog power stage or controller. The LM10011 captures the VID information presented by the MCU and sets the output of a current DAC connected to the FB pin of the power regulator circuit. In 6-bit mode, 64 current settings with 940-nA resolution and better than 1% accuracy are available.

For example, the MCU arbitrates the supply rail of a GaN transistor PA to a voltage between 36 V and 50.8 V, with a step resolution of 235 mV. Glue logic or level translators are not required, and a programming resistor dictates the PA voltage at startup. The LM10011 can interface to any voltage-mode, current-mode, or ripple-based PWM regulator with a FB input.

Table 1. Alternate controller recommendations

Device	V_{IN} Range	Features	Package
LM25145	6 V to 42 V	Wide duty cycle range	VQFN-20
LM5117	5.5 V to 65 V	Analog current monitor output	HTSSOP-20, WQFN-24
LM5141	3.8 V to 65 V	Low EMI, low I_Q	VQFN-24
LM5143-Q1	3.5 V to 65 V	Multi-phase	VQFN-40
LM5146-Q1	5.5 V to 100 V	150°C operation	VQFN-20

Table 2. Related TI application notes

SNVA803	Improving EMI for free with PCB layout
SNVA806	Powering drones with a wide V_{IN} DC/DC converter

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