Thought Leadership Article

How to Select the Best Power Solution for RF Signal Chain Phase Noise Performance

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Today's radio frequency (RF) systems are becoming more and more complex. This added complexity requires the best performance across all system metrics such as stringent link and noise budgets. Ensuring the proper design of the entire signal chain is critical. An often-overlooked section of this signal chain is DC power. It plays an important role in the system, but it can also introduce unwanted effects. One important measurement for RF systems is phase noise, a metric that can be degraded depending upon the choice of power solution. This article investigates the effect that power designs have on the phase noise of RF amplifiers. From our data collected, we conclude that proper choice of power modules can cause up to a 10 dB improvement in phase noise and is crucial for optimizing RF signal chain performance.

What Is Phase Noise?

Phase noise is the noise that is present in a signal that comes from an unexpected lead or lag when the signal arrives at the receive side of a system. Just as amplitude noise is a shift or deviation from the signal's nominal amplitude, phase noise is a shift or deviation from the signal's nominal phase.

Ideal oscillators output a sine wave as expressed in Equation 1:

$$V_{ideal}(t) = A\ sin(2\pi ft) \quad (1)$$

This sine wave has perfect periodicity, and the Fourier transform of $V_{ideal}(t)$ is represented as a delta function at the frequency of the output waveform. A more realistic representation of an oscillator's output includes random fluctuations in phase (and amplitude), which are represented in Equation 2:

$$V_{real}(t) = [A + E(t)]\ sin(2\pi ft + \phi(t)) \quad (2)$$

This waveform includes some stochastic process, $\phi(t)$, that shifts the phase of the signal by some amount. This shift in phase causes the Fourier transform of the nonideal clock output to look more like Figure 1.

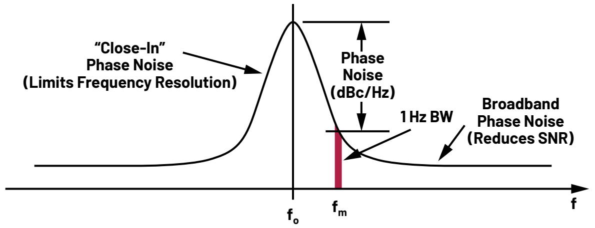

Figure 1. Phase noise of a nonideal sine wave.

Because the phase shifts slightly, there is now more than one frequency component present in the signal. As such, the signal is spread out around the center frequency.

Cause and Contribution of Phase Noise

An important and often-overlooked cause of phase noise is the DC power solution of the signal chain. Any noise or ripple on the power rails that supply the signal chain can couple internally. This can lead to an increase in phase noise, which may hide critical frequency components in the bandwidth transmitted or could induce spurs offset from the carrier. These spurs can be particularly hard to deal with because they are close to the carrier and would pose a challenge to filters due to the stringent transition-band requirements.

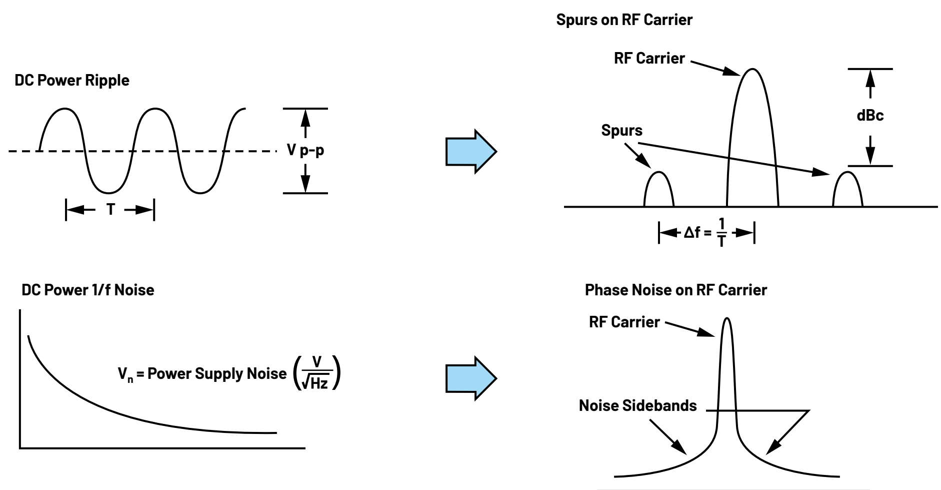

Figure 2. Noise on power rails and its effect on the RF carrier signal.

Many different factors can contribute to phase noise. There are three main sources, known as white floor, shot, and 1/f, or flicker noise. White floor noise is from the random thermal movement of free electrons when current is passing. It is similar to shot noise, which is from the random nature of current flow. Unlike white floor and shot, flicker noise changes over frequency. Arising from defects in the semiconductor lattice structure, it is random in nature as well. Flicker noise does decrease with frequency; therefore, a low 1/f corner frequency is highly desirable. Typical phase noise curves are approximated by regions that have a slope of $1/f^x$, where x = 0 is the white noise floor region (slope = 0 dB/decade), and x = 1 corresponds to the flicker phase noise region (slope = –20 dB/decade). The regions for x = 2, 3, 4 are closer to the carrier frequency.

Power Solutions

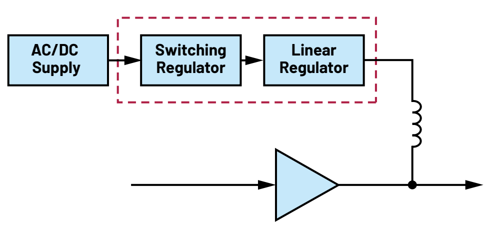

Figure 3. Power supply topology in an RF signal chain.

Ensuring proper biasing and supply of power to amplifiers in an RF signal chain can be a challenge, especially with drain voltages also used as the output port. There are numerous types of power solutions and topologies on the market. Which power solution you may need will depend on your application and system requirements. For this experiment, the data was taken using low dropout (LDO) linear regulators and step-down or buck switching regulators, as shown in Figure 3. Buck switching regulators are a typical solution for large voltage drops with high efficiency and lower operating temperatures. Switching power supplies can step higher voltages, such as 12 V, down to more common chip-level voltages, such as 3.3 V and 1.8 V. However, they can introduce severe switching noise or ripple on the output voltage, leading to a considerable decrease in performance. LDO regulators may be able to step down these voltages as well and with less noise; however, their power dissipation manifests mainly as heat. Using an LDO regulator is a good choice when the difference between input and output voltage is small, but with junction-to-ambient thermal resistance, θ_{JA}, upward of 30°C/W, high current draws from FPGAs and ASICs can quickly degrade the performance of the LDO regulator.

Test Setup

This experiment utilized three different Analog Devices power products: LTM8063, LTM4626, and LT3045. Table 1 summarizes some of the data sheet specifications of the power solutions used.

Table 1. Data Sheet Specifications of Power Solutions Used

	LTM8063	LTM4626	LT3045
Topology	Buck μModule®	Buck μModule	LDO regulator
Input Voltage Range	3.2 V to 40 V	3.1 V to 20 V	1.8 V to 20 V
Output Voltage Range	0.8 V to 15 V	0.6 V to 5.5 V	0 V to 15 V
Output Current	2 A	12 A	500 mA
Noise	~15 mV ripple	~35 mV ripple	1 μV rms
Switching Frequency	200 kHz to 2 MHz	600 kHz to 2 MHz	–

The input signal swept the frequency range of 100 MHz, 200 MHz, 500 MHz, and 1 GHz to 10 GHz. Phase noise was analyzed with a frequency offset of 10 Hz to 30 MHz. The test setup is shown in Figure 4. The input RF signal was generated internally by the Rohde & Schwarz FSWP50 phase noise analyzer. This oscillator exhibits exceptional performance and is used because any additive phase noise or modulated spurs that are induced by the power supply show up clearly.

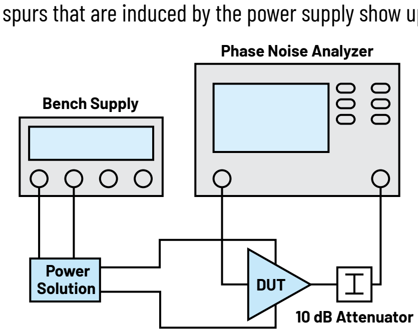

Figure 4. Simplified block diagram of the test setup used in the experiment.

Two Analog Devices amplifier products were used to represent a block in the RF signal chain.

Table 2. Data Sheet Specifications of RF Amplifiers Used

	HMC8411	ADPA9002
Frequency Range	10 MHz to 10 GHz	DC to 10 GHz
V_{DD} (typ.)	5 V	12 V
I_{DD} (typ.)	56 mA	385 mA
Gain	15.5 dB	15 dB
Output P1dB Compression (typ.)	20 dBm	29 dBm

Results

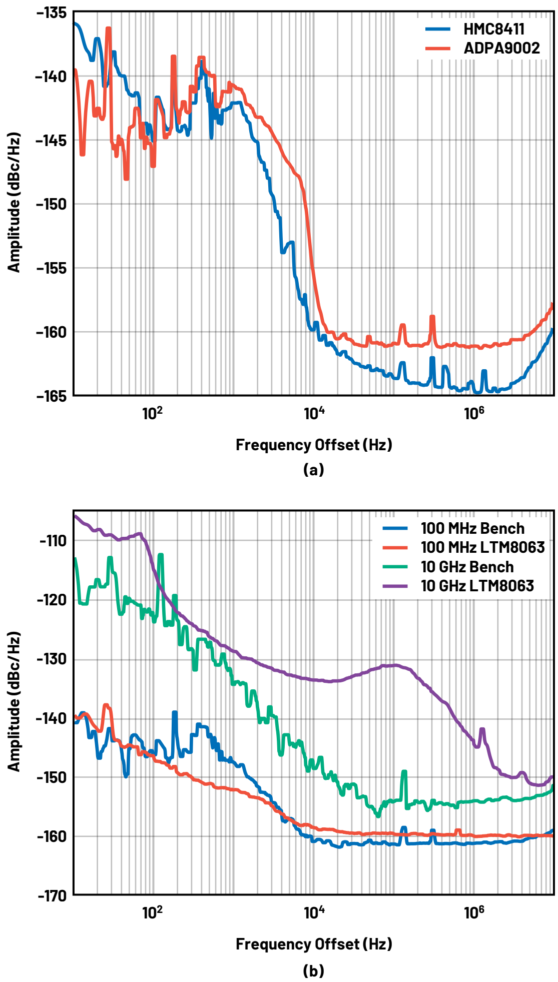

Figure 5. (a) HMC8411 and ADPA9002 performance at 2 GHz, and (b) phase noise response of ADPA9002 powered by the bench and the LTM8063 at two different input frequencies.

Figure 5 compares the phase noise response of the PA when powered with the LTM8063 and the bench supply. The PA is observed to have slightly lower performance past 1/f frequencies. The PA draws substantially more supply current, resulting in roughly a 2 dB to 4 dB increase in observed phase noise.

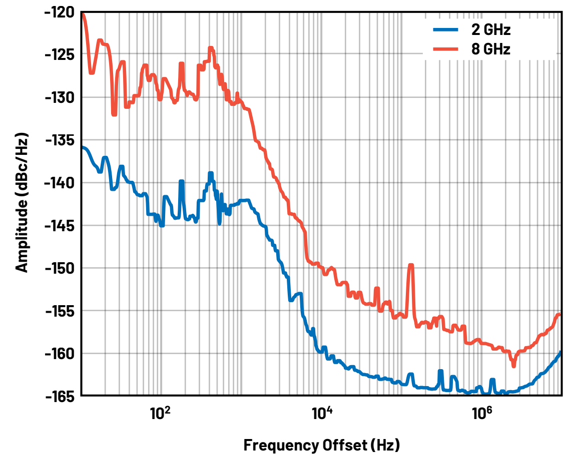

Figure 6. Phase noise response of the HMC8411 with the LTM8063, showing phase noise/frequency relation.

Figure 6 shows the HMC8411 phase noise response with input frequencies of 2 GHz and 8 GHz. The response follows closely with a common phase noise/frequency relation shown in Equation 3:

$$\phi(fc) \propto 20log\left(\frac{fc}{fref}\right) \quad (3)$$

This relationship shows every doubling of the input frequency results in roughly a 6 dB increase in phase noise. This can be seen with a 4× increase in frequency, resulting in approximately a 12 dB increase from 10 Hz to 100 Hz frequency offset.

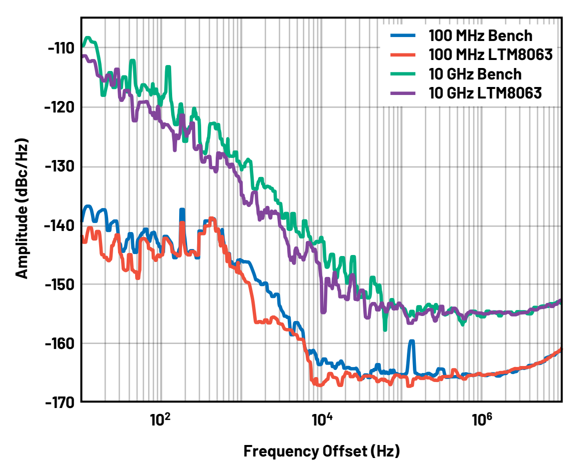

Figure 7. Phase noise response of the HMC8411 powered by the bench and the LTM8063 at two different input frequencies.

Figure 7 shows the phase noise response of the HMC8411 powered by the LTM8063 vs. the bench supply at 100 MHz and 10 GHz. Bench supply phase noise response was used as a baseline to judge the performance of certain power solutions. The LTM8063 has exceptional performance across various frequencies compared to the bench supply, with only an approximate 2 dB increase in the wideband noise floor.

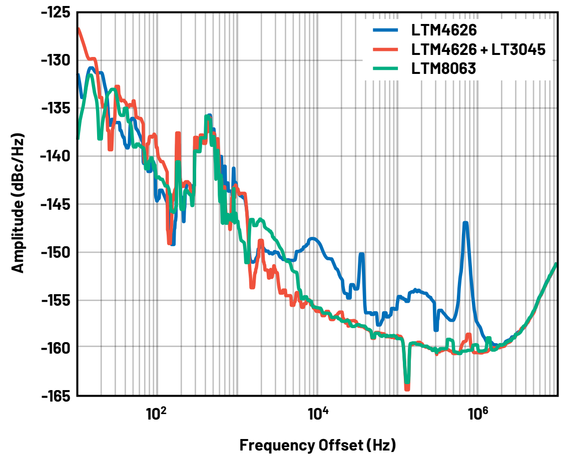

Figure 8. Phase noise response of the HMC8411 with various power solutions. f_c = 5 GHz.

Commonly, a high current module, such as the LTM4626, will be used as the main supply so that the power distribution network can be stepped down according to each circuit block's requirements. In Figure 8, we see the LTM8063 exhibiting similar phase noise performance to the LTM4626 cascaded with the LT3045 ultralow noise LDO regulator. If the voltage and current output supplied by the LTM8063 can satisfy design requirements, this power solution can save considerable cost and board space.

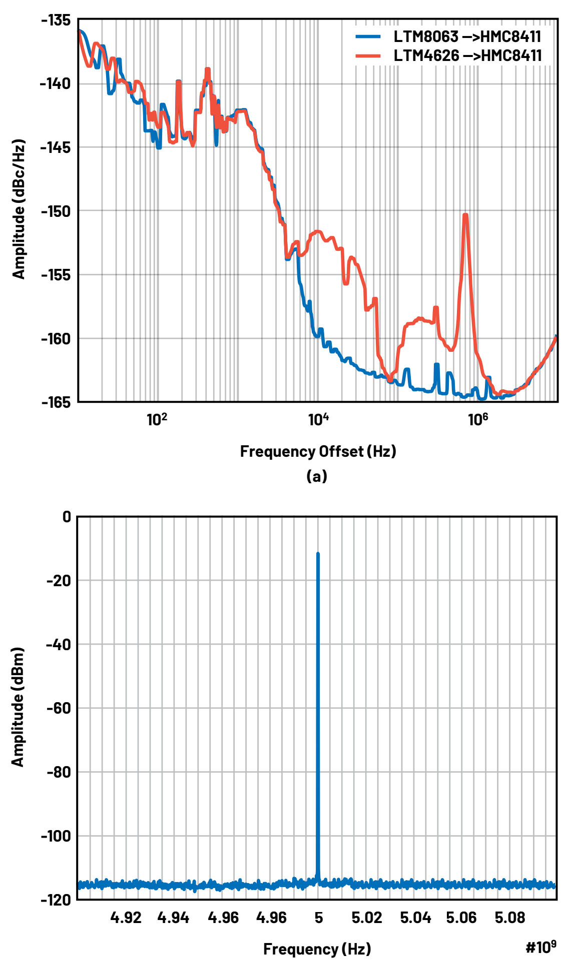

Figure 9. (a) Phase noise response of the HMC8411 at 5 GHz powered by different switching regulators, and (b) spectrum of the HMC8411 powered by the LTM4626 showing no spurs.

Figure 9a shows that switching power supplies can exhibit markedly different behavior in various frequency bands. The LTM8063 and LTM4626 have similarly negligible impact on the power LNA phase noise below 5 kHz but diverge significantly above that. The LTM4626 was designed and optimized to power high end digital products. These devices typically demand high efficiency and fast transient response, so their power supplies may have characteristics such as very low passive impedance, fast switching edge rates, and high control loop gain and bandwidth. These features can create a few millivolts of perturbations in the output voltage. Though inconsequential in a digital system, these perturbations can degrade the performance of a signal chain product. Despite this, the output spectrum using the LTM4626 showed no noticeable spurs with an SFDR of 102.7 dB, as shown in Figure 9b. The LTM8063, however, was designed for low noise—both EMI and output—optimizing its performance in signal chain applications. It exhibits very good low frequency stability, small output perturbations, and much less noise at the switching fundamental and its harmonics.

Conclusion

It is important to consider all sources of noise when performing a signal chain analysis. One commonly overlooked source is the DC power solution, which can couple to and severely degrade the performance of the signal chain. Our results show that proper choice of power modules is paramount and can lead to as much as a 10 dB improvement of phase noise at 10 kHz offset. For this application, the LTM8063 returned the best results. While the LTM4626 cascaded with the LT3045 gave comparable phase noise performance, knowing the correct power solution to choose is very important for optimizing your RF signal chain.

References

Acar, Erkan. "Why a Fully Integrated Translation Loop Device Achieves the Best Phase Noise Performance." Analog Devices, Inc., April 2021.

Bergeron, Jarrah. "Analyzing and Managing the Impact of Supply Noise and Clock Jitter on High Speed DAC Phase Noise." *Analog Dialogue*, Vol. 51, No. 1, March 2017.

Delos, Peter, and Jarrett Liner. "Improved DAC Phase Noise Measurements Enable Ultralow Phase Noise DDS Applications." *Analog Dialogue*, Vol. 51, No. 3, August 2017.

Kester, Walt. "MT-008 Tutorial: Converting Oscillator Phase Noise to Time Jitter." Analog Devices, Inc., 2009.

Liu, Leo. "Comprehensively Understand and Analyze Switching Regulator Noise." Analog Devices, Inc., January 2019.

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