PCS Noise Tamed by Regulator Use

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A PCS telephone handset is a complex two-way radio whose receiver, in the presence of many strong interfering signals, must pick out the desired signal and correctly demodulate it. Given that the difference between the desired signal and interfering noise can exceed 100 dB, the system-wide management of noise is crucial to a successful design. This article identifies a PCS receiver's noise-sensitive sections and shows where to apply low-dropout (LDO) linear regulators to manage the noise.

Noise-Sensitive Areas Within a PCS Handset

The PCS handset incorporates many different noise-sensitive sub-sections working in concert. Because the handset's power supply connects to each of these sub-sections, it provides a conduit for noise transmission throughout the system. Thus the sensitivity of each sub-section to power-supply noise needs to be carefully considered in the following areas:

1) The RF Receiver Front-End (see Figure 1)

The RF front-end noise performance determines the receiver's sensitivity, which is defined as the smallest usable received signal. This front-end noise performance is determined primarily by the RF losses of the duplexer and bandpass filter, and the noise figures of the low-noise amplifier (LNA) and mixer. When the power supply injects noise into the LNA and mixer, their effective noise figures degrade. A low-dropout regulator (LDO 1 in Figure 1) attenuates the low-frequency power-supply noise. To ensure the front-end achieves a low noise figure, high-frequency power-supply noise must also be rejected. The section LDO Limitations below describes how to add this high-frequency filtering to a LDO.

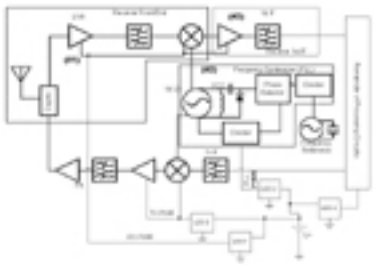

Figure 1. A PCS Phone's RF Front-End and Synthesizer Are Sensitive to Noise

2) The Frequency Synthesizer

A major portion of the PCS radio's noise performance is set by the spectral quality of the Local Oscillator (LO) signal &#151 a signal produced by the frequency synthesizer. An LO spectrum with high levels of phase noise enables interfering signals to significantly degrade the bit error rate (BER) of the demodulated receiver signal. The noise character of the frequency synthesizer is determined by its phase-

locked loop (PLL) bandwidth, the voltage-controlled oscillator (VCO) noise, the noise floor of the frequency reference, and stray noise that modulates the VCO control signal. A low-dropout regulator (LDO 2 in Figure 1) in combination with a high-frequency noise filter tames the stray power-supply noise that could modulate the VCO signal, ensuring that this noise does not corrupt the LO spectrum.

3) The Intermediate Frequency (IF) Section

The IF section contains high-gain circuitry that amplifies signals by 80 dB or more. A low-dropout regulator with additional high-frequency filtering prevents the high-gain IF section from being contaminated by noise from the handset's power amplifier (PA) or its digital processors (LDO1 in Figure 1).

Properly selected and strategically placed within the handset, LDOs offer an economical and power-efficient means to regulate voltages while controlling noise. Design success is ensured, however, by understanding a LDO's operation and its limitations.

LDO Limitations

A typical LDO (see Figure 2) comprises a voltage reference, an error amplifier, a series pass transistor, and a feedback path to sense the output voltage.

A linear regulator forms a closed-loop system with a finite bandwidth. When the frequency of the noise signals appearing at the LDO's input (i.e., at the battery) falls within the LDO's bandwidth, the regulator rejects those signals. For example, the MAX8877 provides greater than 60 dB of noise rejection for frequencies up to 10 kHz. RF noise, whose frequency ranges far above a LDO's loop bandwidth, tends to pass through the regulator and appear on the LDO output. LDOs thus provide noise isolation at low frequencies, but at RF frequencies they do little to attenuate noise. Handset designers add high-frequency filters to power-supply lines to keep the noise from propagating throughout the system. A small inductor and capacitor, both specified at the frequency of interest, effectively filter these noise signals (see Figure 2).

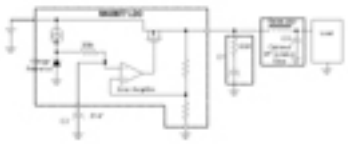

Figure 2. Adding a RF Filter to an LDO Improves Noise Isolation

Output-Capacitor Selection for a LDO with a RF Isolation Filter Added

Adding a RF isolation filter presents a complex impedance to a LDO's output; this impedance can disrupt the regulator's transient response. Despite this complex impedance, using the capacitor specified in the MAX8877 (a single LDO) and MAX1798 (a highly integrated handset power IC with five LDOs) data sheets ensures proper transient response and noise performance. These data sheets suggest a minimum capacitance and a range of allowable ESRs for the output capacitor. When using these LDOs &#151 or any other LDOs &#151 make sure to consider differences among capacitor technologies during the handset's design phase. For example, tantalum capacitors demonstrate a higher ESR than ceramic capacitors of

similar size, voltage, and value.
The MAX1798 requires 2.2&#176F output capacitors whose ESR ranges from 0.01&#176 to 1&#176. A 2.2&#176F ceramic capacitor meets this requirement. Designers must also consider capacitor variation as the temperature changes, since LDO transient response is sensitive to the pole and zero formed by the capacitor's ESR and its capacitance. The capacitance should stay close to 2.2&#176F at both low and high temperatures. Surprisingly, capacitors with certain ceramic dielectrics drop in value by 85% or greater over temperature. Using output capacitors with higher stability dielectrics (e.g., X7R and X5R) eliminates this issue. A 1.0&#176F X7R ceramic capacitor at the output of the MAX8877 linear regulator provides adequate stability and sufficiently low ESR over a wide temperature range. With proper capacitors and the addition of small inductive or ferrite elements, good RF isolation is obtained between the RF front end, the receive IF, and transmit sections of the handset.

The Frequency Synthesizer's Sensitivity to LDO Noise

The frequency synthesizer, which generates the critical first LO in the handset, contains a very high gain VCO. This VCO acts like a very sensitive FM modulator; its gain in a PCS application is approximately 50 MHz/V. Given this extreme sensitivity, small levels of noise present on the VCO control line degrade the clean frequency spectrum and increase the phase-noise content from the synthesizer. Unfortunately, the power circuit supplying the synthesizer provides a path for injecting noise into the PLL. Thus, a good first step to providing clean, quiet power to the synthesizer is to use a separate LDO for power regulation (see LDO 2 in Figure 1).
The LDO, however, produces its own intrinsic noise, which can disrupt the PLL, producing high levels of phase noise. The noise at the output of a LDO originates at its voltage reference; the LDO's error amplifier amplifies this noise. It is tempting to reduce the error amplifier's bandwidth, but doing so slows the regulator's response time, making it far less effective at rejecting noise appearing at its input. To remedy this problem, the reference within both the MAX8877 and the MAX1798 connect to the error amplifier through a high-value resistance. This node is brought out to a pin on the IC, where a noise bypass capacitor (C2 in Figure 2) is connected. In the case of the MAX8877, the resistance is 200 KW. With a 0.01&#176F capacitor, a low-pass filter with an 80 Hz corner frequency is formed. The MAX1798 LDOs, which use the same filtering technique as the MAX8877, demonstrate 45 VRMS of noise from 10 Hz to 100 kHz &#151 the sort of high-quality, low-noise spectrum required when powering a frequency synthesizer (see Figure 3).

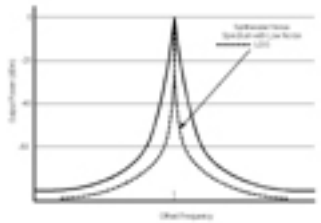

Figure 3. Bypassing a LDO to Reduce Noise Improves the Synthesizer

Spectrum

The RF Front-End, Receiver IF, and Frequency Synthesizer sections of a PCS handset are very sensitive to noise. LDOs used properly and including the correct-value low-ESR output capacitors isolate these sections from low-frequency interference. Additional RF filters improve isolation at high frequencies, allowing the phone to meet system specifications for bit error rate, sensitivity, and transmitted spectral content.

Bypassing a LDO's voltage reference (as illustrated with the MAX8877 and the MAX1798 LDOs) keeps noise intrinsic to the LDO out of the frequency synthesizer.

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