

APPLICATION NOTE 668

Managing Noise in Cell-Phone Handsets

Abstract: Presents cellular telephone handset issues impacting noise performance. Power supply layout improvements are shown to reduce noise problems. Linear regulators are employed to reduce noise at low frequencies. Power amplifier bias modulates noise on to the RF output. Low dropout regulator output noise is explained.

To best handle the problem of cell-phone noise, you should apply an understanding of the phone's noise-coupling mechanisms, noise-sensitive circuit nodes, and noise-generating circuits.

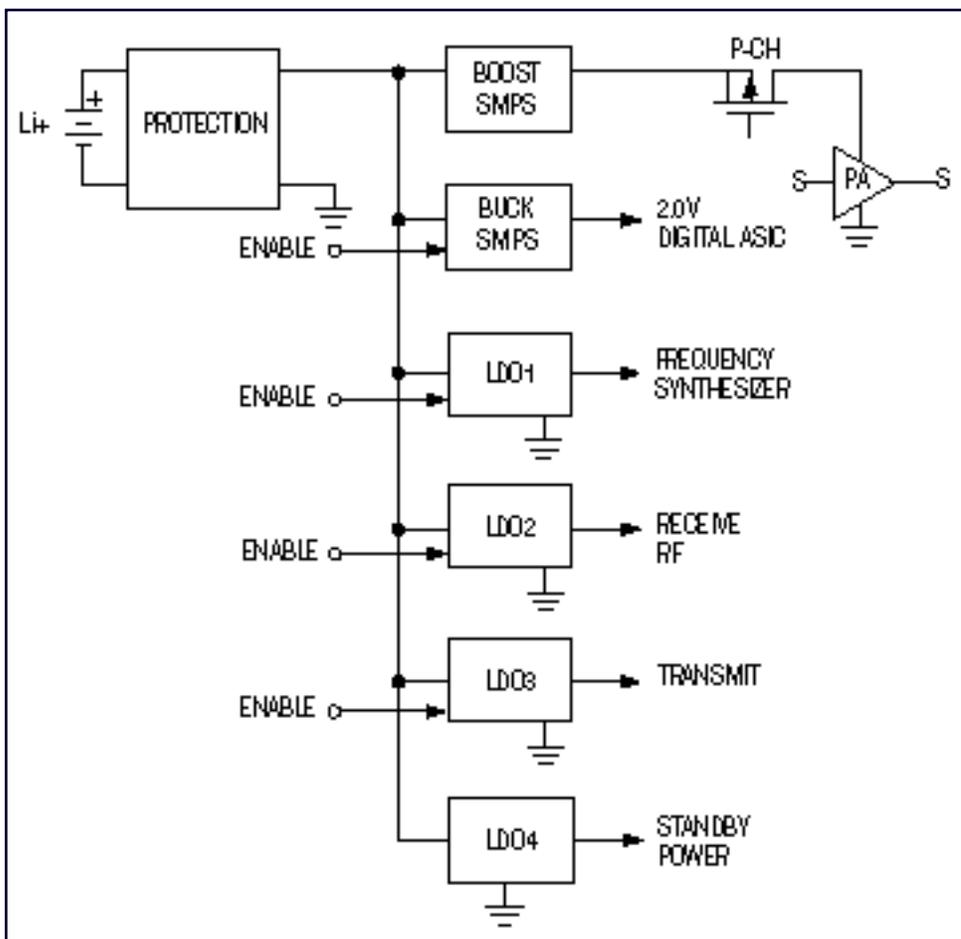


Figure 1. Switch-mode and linear regulators distribute power cleanly and efficiently.

Modern hand-held cellular-radio transceivers have the almost impossible task of selecting and demodulating a desired signal in the midst of many unwanted signals. For a typical cellular radio, the desired signal amplitude may be only 0.35 μV —this is more than 100dB below the amplitude of nearby unwanted signals. To amplify this signal to a level suitable for demodulation, cellular radios often incorporate intermediate frequency (IF) sections with more than 80dB of gain.

To meet the required bit-error rate (BER), the system's electrical noise must be understood and managed. Shielding and filtering are effective, but these measures burden a consumer cell phone with extra weight, size, heat, and cost, while shortening its battery lifetime. As a much better approach, you can design the system from the beginning so that known noise spectra don't interfere with the radio's performance. Managing noise in a

cellular handset requires an understanding of:

- Noise-propagation mechanisms
- Points of greatest noise sensitivity
- Noise-generating circuits

Cellular-Phone Handsets

Comprising RF, digital, and analog circuits, the digital cellular phone is a marvel of packaging, human-interface, and power-conservation considerations. The RF sections consist of filters, low-noise amplifiers, mixers, a power amplifier (PA), and a frequency synthesizer. A mixed-mode ASIC connects to IF signals from the transmit and receive sections.

Working in concert with a digital ASIC containing the digital signal processors (DSPs) and the system-control processor, the mixed-mode ASIC generally contains data converters for modulating and demodulating the IF signals. The system-control processor usually manages the human-interface and intelligent power-management tasks crucial to cell-phone operation.

The power-distribution subsystem manages the battery pack (a single lithium ion [Li+] cell in this case) and distributes operating voltages and currents to the entire handset. Li+ batteries have mandatory protection circuits that prevent catastrophic damage from excessive current or voltage. Cell phones can also include a switch-mode power supply (SMPS) that boosts the cell voltage to a level appropriate for the power amplifier.

New low-voltage ASICs can receive power from a small, step-down SMPS, and the remaining RF and analog circuits can be powered from linear low-dropout regulators. The various regulators turn off and on under processor control, placing the phone in the various operating modes demanded by a particular wireless system (GSM or IS-95, for example). Coupled with an accurate knowledge of cell charge remaining in the battery, this power-management technique enables the longest-possible battery lifetime.

Noise-Propagation Mechanisms

Conduction and radiation are the two methods whereby noise propagates from a noise generator to a noise receiver. The conduction mode channels noise through a wire, a printed-circuit trace or plane, a metal chassis, or an electrical component such as a capacitor. Radiation transfers noise energy through the air or through a dielectric, such as the FR4 circuit-board material. Conducted noise can be filtered with traditional circuit techniques; radiated noise is usually minimized with shielding.

Conducted noise in a system often becomes radiated noise after finding an efficient "antenna." Conducted noise is generally known to be on specific conductors, enabling you to apply filtering only where needed, but radiated noise tends to permeate the system and appear everywhere. Though systems often contain the radiated noise with additional shielding, conductive coatings, and gaskets, these measures are unnecessary if the noise is confined to the conductive mode by proper PC layout and filtering. The best plan, therefore, is to keep noise in the conduction mode and not let it radiate.

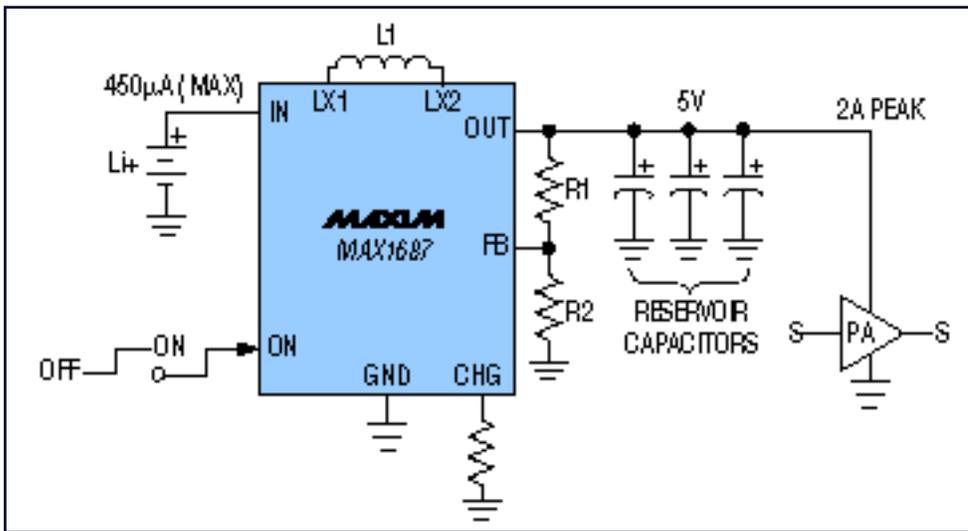


Figure 2. For burst systems such as IS136 and GSM, large transients on the battery are minimized by reservoir capacitors and a boost converter.

The Power Amplifier

The PA generates noise by drawing large currents from the power source. A 3.6V, 50% efficient PA whose signal faces a 3dB loss before reaching the antenna can draw 600mA to 800mA from a single Li+ cell. This large supply current flows through resistance in the Li+ connectors, PCB traces, and ground-return paths, producing increased noise on power-supply lines throughout the cell phone.

The problem is compounded for systems that use a burst-transmission mode as specified by the GSM and IS-136 TDMA standards. By turning on the PA for short intervals only, burst mode imposes severe transients on the power supply and the distribution subsystem.

A popular method for powering the PAs used in burst-mode systems is to boost the supply voltage higher, thereby reducing the peak current, minimizing noise, and enabling the use of PA technology that is more common and thus less expensive. Still, the need to supply a peak current results in a boost converter that is overspecified. A better solution is to store the boosted energy on a large capacitor. Then, the boost converter need only replenish charge on the capacitor between transmitter bursts. Typical transmitter duty cycles are approximately 12%.

The PA-power problem appears solved, but there remains the behavior of a typical DC-DC converter: When it senses a drop in capacitor voltage, it attempts to replenish the charge as quickly as possible, drawing a current surge from the Li+ cell that brings back the noise problem. A unique solution to this problem (powering GSM/TDMA transmitters using a large capacitor) is incorporated in certain chips designed for that purpose.

The MAX1687 and the MAX1688 are boost power converters that recharge the reservoir capacitor either with a peak battery-current limit or with an adaptive current limit algorithm, both set by the user. As a result, the capacitor and the power converter work in concert to maintain efficient power conversion, while minimizing the system disruptions that can follow large surges of current to the PA. To further control noise, these chips allow disabling of their internal SMPS during transmit bursts.

PA Bias

Power amplifiers are also sensitive to bias-voltage variations. The bias voltage on a GaAs-FET PA controls the bias current, which sets the PA's gain and output impedance. As a result, the bias pin is an amplitude-modulation input. Noise appearing on the GaAs PA shows at the RF output as an envelope variation, translating low-frequency noise signals into RF that will pass through the system and be radiated from the antenna along with the desired signal.

GaAs PAs use depletion-mode MOSFETs, which conduct maximum drain currents when a voltage is applied from the source to the drain, without gate bias. To control drain current, the gate potential must be negative (below

1. Power-supply noise, injected in the PLL IC that contains the phase detector.
2. Power-supply noise injected into the VCO.
3. Power-supply noise passed to the output of an active integrator or loop filter (check the op amp's PSRR to estimate this effect).
4. Noise on the crystal oscillator (TCXO/VCTCXO). The oscillator signal in very-high-Q circuits should be clean and noise-free, but excess power-supply noise can raise the oscillator's noise floor. Because the PLL multiplies noise within the loop bandwidth by the PLL division ratio ($\sim 30,000$ for an AMPS handset), the frequency synthesizer is very sensitive to noise from the TCXO.
5. Noise caused by variations in the VCO's output load impedance, which reflects back into the VCO and pulls its operating frequency.

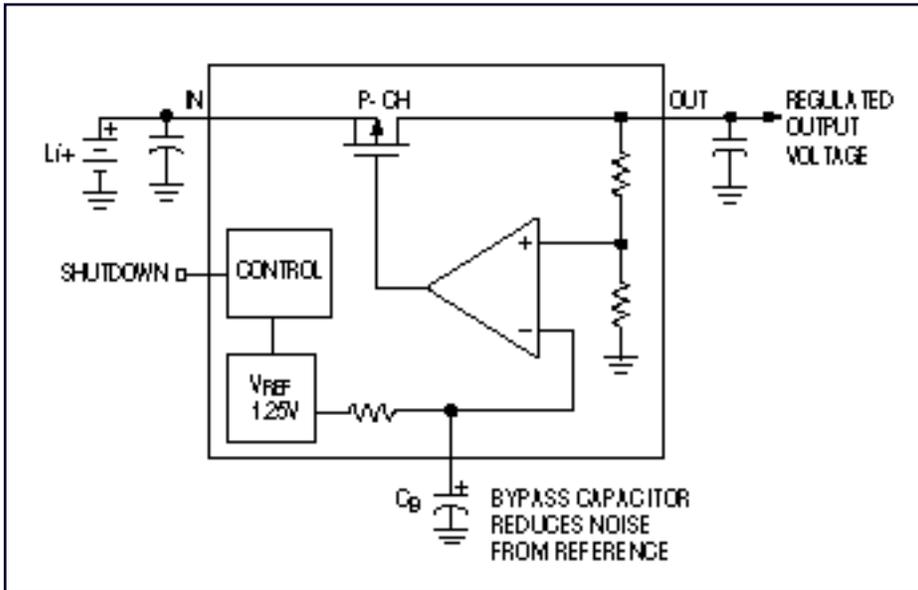


Figure 4. Output noise from an LDO regulator is reduced by adding a bypass capacitor (CB) to the voltage reference.

For systems where loop bandwidth shapes the noise spectrum to fall between DC and 500kHz, items 1 to 4 can be improved with passive filtering. The frequency synthesizer should be powered by a separate, low-dropout (LDO) linear regulator to avoid noise that is conducted in from the power supply. Nevertheless, for modern digital communications systems, the residual phase noise caused by modulation by the power supply is too great. An LDO regulator provides a clean and regulated supply voltage for the frequency synthesizer, but it also produces noise.

Broadband Noise Source

An LDO regulator (a closed-loop system consisting of a voltage reference, an error amplifier, and a series pass transistor) can be a broadband noise source because of the function it performs. The voltage reference can have significant noise content, as can the error amplifier. Compounding this noise with the system gain level (typically 2X to 3X over a 10Hz to 1MHz bandwidth) gives the MAX8863 LDO an output-noise level of $350\mu V_{RMS}$. You can lower this noise lowpass-filter the voltage reference before it amplifies the reference noise.

A low-noise LDO regulator (the MAX8877) brings the reference voltage to a package pin, which lets you bypass the noise to ground by adding a capacitor at that point. A $0.01\mu F$ capacitor, for instance, lowers the output noise to $30\mu V_{RMS}$ over a 10Hz to 100kHz bandwidth. This improvement can lower the PLL noise at 900MHz by 10dB to 20dB.

LDOs also serve to isolate sections of the handset from each other. Within the LDO bandwidth, the MAX8877 suppresses power-supply noise at 10kHz by 60dB. In terms of PCB area, this suppression is a bargain (the IC comes in a SOT23 package). Passive components giving the same filter action at low frequencies would be large and massive. Thus, low-noise LDOs are well suited for use in the modern digital cell phone, whose market constantly demands a smaller size and cost.

Improved Efficiency

Switch-mode power supplies have a place in modern cellular phones, and the latest SMPS ICs offer small size, high efficiency, low dropout voltage, small external components, and noise-control features. The MAX1692, for example, is a step-down (buck) power converter that uses pulse-width modulation (PWM) and synchronous rectification to obtain 90% efficiency and a low, predictable noise spectrum. Operating on a single Li+ cell producing 3V to 4.2V, it generates supply voltages down to 1.25V for use in powering the large ASICs utilized in contemporary cell phones.

To control the interference emanating from high-gain RF sections such as the IF section, the MAX1692 can be synchronized (at frequencies between 500kHz and 1MHz) with an external crystal-controlled clock like that generated by the TCXO. High-frequency operation is crucial for the use of small external components and noise-spectrum planning.

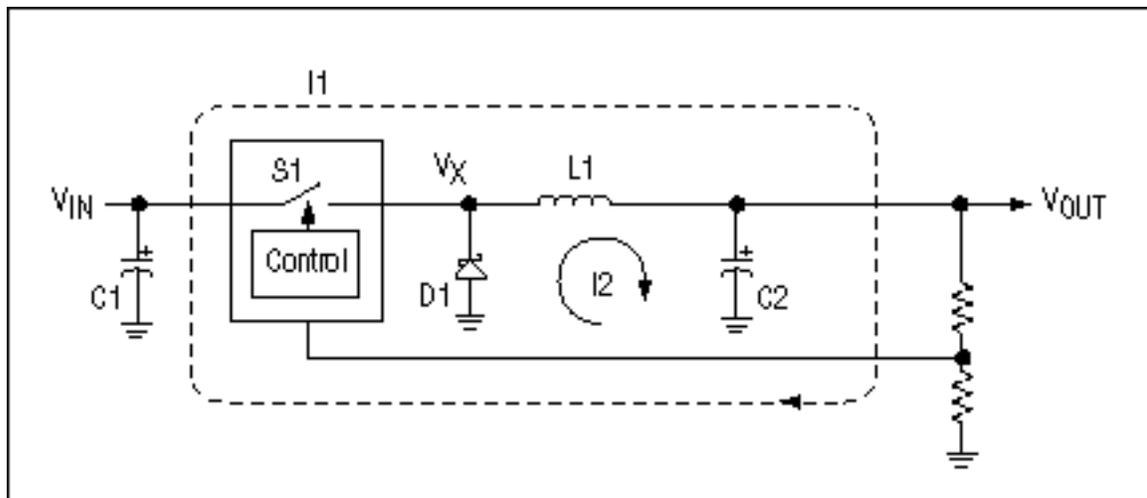


Figure 5. Two current loops produce noise in a buck SMPS.

Switch-mode power supplies produce a noise spectrum in which the lowest frequency is the switch-mode power supplies' fundamental switching frequency. The spacing between harmonics is equal to this fundamental, but other aspects of the spectrum are difficult to predict. Noise power distributed among the harmonics is a function of wave shape (versus time), current level, inductor value, capacitor values, and PCB layout.

Switching noise can be conducted on the input, the output, and the ground lines, or radiated by the PCB traces. You should always minimize the ripple and the noise conducted from a SMPS, even though adding filter networks to reduce conducted noise can actually increase the radiated noise. Such noise radiates from the layout and then propagates efficiently throughout the system, appearing to come from everywhere.

To best handle the problem of cell-phone noise, you should apply an understanding of the phone's noise-coupling mechanisms, noise-sensitive circuit nodes, and noise-generating circuits. A boost power converter and a large capacitor can minimize the conducted noise from PA transients in a GSM/TDMA system. The radiated noise from a SMPS depends heavily on the PC layout, and a novel schematic representation can guide the layout for first-time success. Small linear regulators provide active noise filtering and, with reference bypassing, can yield the very low noise levels required by frequency synthesizers. Finally, placing an IF in the quiet zone between noise harmonics of the power supply can eliminate the signal contamination that spoils bit-error rates in a modern digital cell phone.

Don't Be Misled

The schematic of a typical buck switch-mode power supply provides a good understanding of circuit operation. Unfortunately, it also guides PC-board-layout people to make flawed floor plans for the PC board. Consider the SMPS operation below.

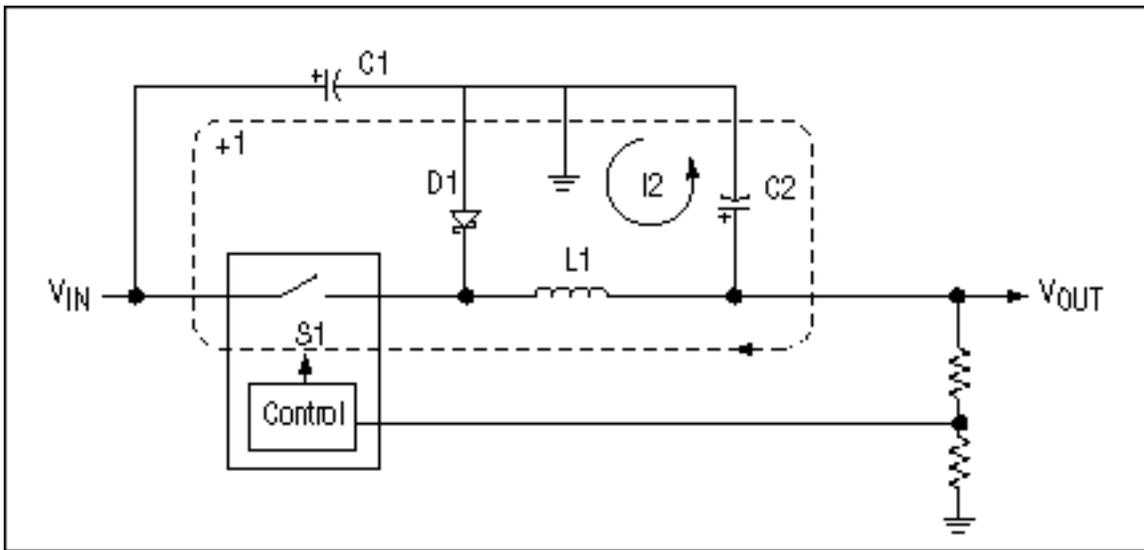


Figure 6. A modified SMPS schematic helps to improve the layout and reduce noise.

When the power-switch element (S1) closes, current flows from C1 through S1 to the inductor (L1) and into C2, returning to the C1(-) terminal through a ground path. When S1 opens, V_x goes low until the diode (D1) conducts. The path for circulating current is now D1 to L1 to C2 and back to D1. Radiated noise power is governed by current flow and the radiating resistance of the loop:

$$P \propto I^2 (A^2 / \lambda^4),$$

where P is radiated noise power, A is the area of the current loop, I is the current, and λ is the wavelength. At any given wavelength (frequency), the radiated noise power is increased by the square of the product of the loop area and the circulating current. Thus, using the standard SMPS schematic generally furnishes a PC-board layout whose loop area produces high levels of conducted and radiated noise. The result is time lost iterating the PC-board layout in trying to tame this noise.

For first-time success, try redrawing the schematic in a way that emphasizes the need for physical proximity in the ground connections for C1, D1, and C2. Such a layout realizes low-noise operation from the start. Assuming you have a clean and optimized PC-board layout, you should examine the operating frequency to determine its relation to the radio receiver's IF and IF bandwidth. If the IF bandwidth is less than the SMPS operating frequency, you should place the IF in a "quiet zone" between SMPS harmonics. Once that is accomplished, SMPS noise can't pollute the high-gain IF section even if noise is present in the system, because the IF passband will be devoid of energy content. To allow proper choice and trade-off, these noise-planning steps should be considered early in the radio's frequency-planning stage.

A similar version of this article appeared in the May 1999 issue of *Computer Design*.

Application Note 668: <http://www.maxim-ic.com/an668>

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