The Amplifier Power of Three: Current, Bandwidth, and Size

Introduction

Remote systems continue to spring up in household, wearable health, and medical circuits. Remote operation enabled by lithium-ion (Li+) batteries brings convenience to these systems (Figure 1). The only caveat is that remote system batteries have tangible limits.

Figure 1. Good Things Come In Threes. These Smartwatches Demand The best in Component Power, Dynamic Bandwidth, and Size

We are seeing a trend where Li+ batteries dominate as a power source in household, wearable health, and medical circuits. These batteries are slowly driving towards higher capacity (ampere-hours) within the same form-factor. On the electronics side, system functionalities are quickly expanding, allowing the number of active elements to increase on shrinking printed circuit boards (PCBs). Even if battery manufacturers improve their technology, on-board electronics need to run with lower power and shrink in size.

In this article, we will examine the requirements and challenges of typical amplifier circuits in nanopower environments. Specifically, we will focus on component power, dynamic frequency range, and size. We will present solutions to address the challenges encountered when designing extremely low power circuits.

nanoPower Amplifier Circuits

The most special feature of a nanoPower amplifier is its extremely low, single-supply current. As an example, the typical supply current of the MAX40007 nanoPower amplifier is only 700nA. This nanoPower amplifier can fit into any standard amplifier circuit configuration, with one stipulation. To complement the nanoampere characteristics, the surrounding components must also use very low operating currents. With this in mind, we will look at three circuits that are appropriate for battery-powered applications and adjust these systems to match ultra-low power requirements:

- Power Monitoring
- 60Hz Notch Filter
- Light Sensing

Monitoring Battery Output Current

One can use nickel-sized, Li+ batteries to power household, wearable health, and medical circuits. A 4.1V Li+ battery typically has a capacity of 600mAh. In other words, a Li+ battery will typically be viable for one hour with a 600mA constant current drain or 600 hours with a 1mA constant current drain. In this stringent environment, battery output current monitoring is critical.

The amount of current drawn over time indicates when there is a need to recharge the battery. A simple battery current sensor circuit can sense the system's current over time with a single amplifier (Figure 2). The low-side current sensor circuit shown senses the battery current through a 10Ω resistor (R_{SENSE}). The gain of the R_{SENSE} voltage through the difference amplifier configuration using the MAX40007 is 2V/V. An analog-to-digital converter (ADC) sends the digital representation of the amplifier's output voltage to the system microcontroller.

The key to designing circuits with ultra-low quiescent currents is to use high-value resistors. This simple and inexpensive, low-side current sensing design is possible due to the 40pA (typ) input bias current of the MAX40007 and its capability of operating 0.1V lower than the circuit ground.

In Figure 2, R1 (100kΩ) in series with R3 (10MΩ) draws a maximum of approximately 300nA. By adding this current to the amplifier's quiescent current, it produces a typical maximum current draw of about 1µA.

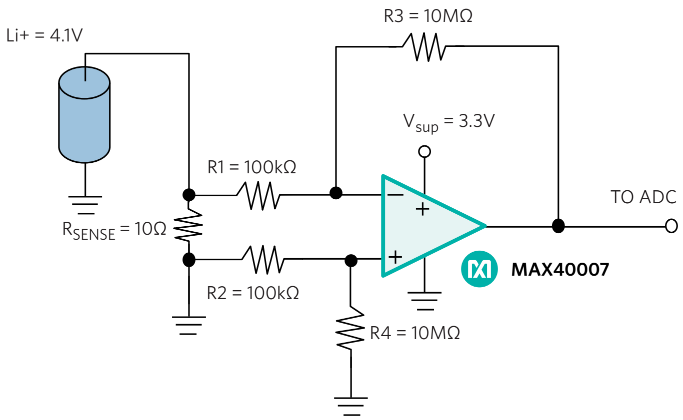

Figure 2. A nanoPower Amplifier is an Integral Part of a Low-Side Current Sensor

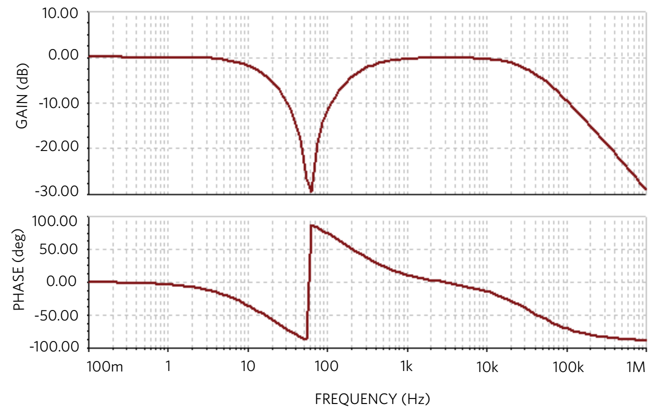

Figure 4. The Gain Response of this Circuit Notches Out 60Hz Signals Down By -30dB

A 60Hz Notch Filter

The transmission from intentional and unintentional electromagnetic interference (EMI) radiators also impacts any circuit. As an example, power-line EMI is usually present around any indoor biopotential measurement system. Imagine trying to get heart diagnosis using a wireless ECG (electrocardiogram) monitor. If the ECG monitor has poor EMI design or if EMI signals are picked up in the room, there could be a false reading. A remote circuit can easily pick up 60Hz EMI signals from the room, which makes a 60Hz notch filter very useful. The implementation of an ultra-low-power 60Hz notch filter requires one amplifier and several resistors and capacitors (Figure 3).

A notch filter is a combination of a lowpass and highpass filter. In Figure 3, R1 (10MΩ), R2 (10MΩ), and C3 (540pF) implement the notch's lowpass filter and C1 (270pF), C2 (270pF), and R3 (5MΩ) implement the notch's highpass filter. The voltage gain in this system is 1V/V.

The MAX40007 Spice simulation in Figure 4 shows a notch occurring at 60Hz. Above -30dB, the gain notches at 60Hz then returns to 0dB at up to 15kHz.

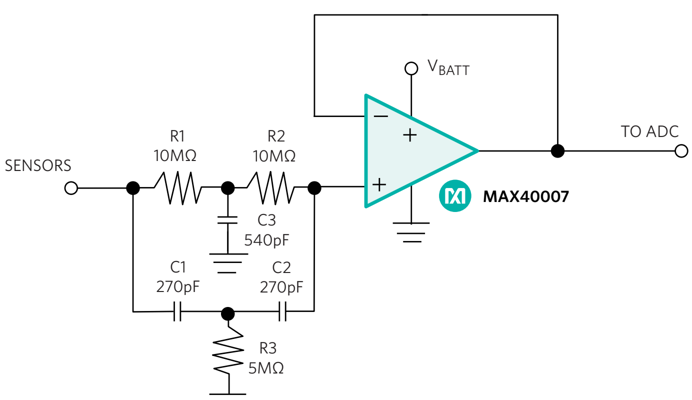

Figure 3. A 60Hz Notch Filter Uses One Amplifier and Several Resistors and Capacitors

Ultra-low-power amplifiers are well known for their limited bandwidth. For quiescent currents that are in the region of hundreds of nanoamperes, one would expect an amplifier bandwidth of less than 10kHz. As shown in Figure 3, this is not always the case. The bandwidth of the MAX40007 amplifier, at 15kHz, makes the circuit's wide bandwidth performance possible.

Light Sensing

Today's battery-powered household, wearable health, and medical equipment frequently include a liquid-crystal display (LCD) as a user interface. To reduce power consumption, an amplifier circuit senses the ambient light magnitude and communicates with the microcontroller. The microcontroller then implements an appropriate increase or reduction in luminance of the display's light source. The classical transimpedance amplifier circuit usually tackles this job (Figure 5).

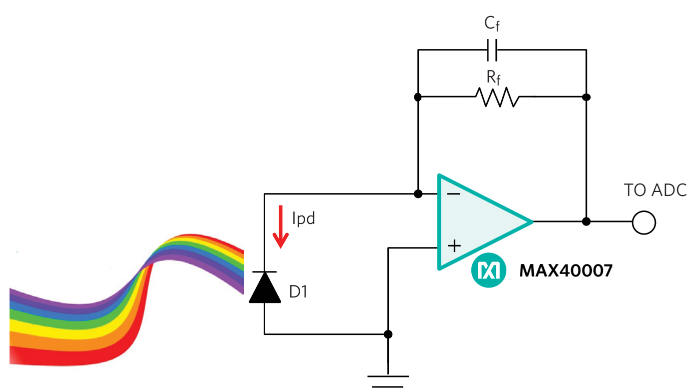

Figure 5. Nanopower Photodetector Circuit Uses Three Components and One Amplifier

In Figure 5, the combination of a CMOS input amplifier, photodetector (D1), and an R/C pair translates the ambient light luminance to voltage. An ADC then converts the amplifier's output voltage to a digital word in preparation for the system's microcontroller. The photodetector's active area is small, with a parasitic capacitance of 1.5pF.

The diode's small active region causes the output current for this detector to be in the sub-milliamperes region. A large feedback resistor, R_f, converts the photodetector's current to voltage. In this circuit, the feedback resistor (R_f) and capacitor (C_f) are 10MΩ and 1.6pF, inclusive. In concert with the system's low-power requirements, the maximum current consumption of the amplifier and photodetector at full luminance is equal to 740nA.

Size Provides the Finishing Touch

Household, wearable health, and medical circuits are all on the path to PCB miniaturization. The MAX40007 in a wafer-level package (WLP) complements this trend with dimensions of 1.1mm × 0.76mm × 0.35mm. Table 1 shows a comparison between the size of a standard surface-mount capacitor (SMT 0603) and the MAX40007 WLP package. The WLP package is only 63% the size of the SMT capacitor and 13% the size of the 5-pin SC70 package.

Device	Package	No. of Pins	Package Dimensions (L x W x H) (mm)	PCB Area (mm²)
MAX40007	WLP	6	1.1 × 0.76 × 0.35	0.84
0.1µF Capacitor	SMT (0603)	2	1.55 × 0.85 × 0.45	1.32

Table 1. Size Comparison Between a WLP Package and a Surface-Mount Capacitor

Figure 6 shows the relative sizes of the WLP amplifier and SMT capacitor mounted on an evaluation board.

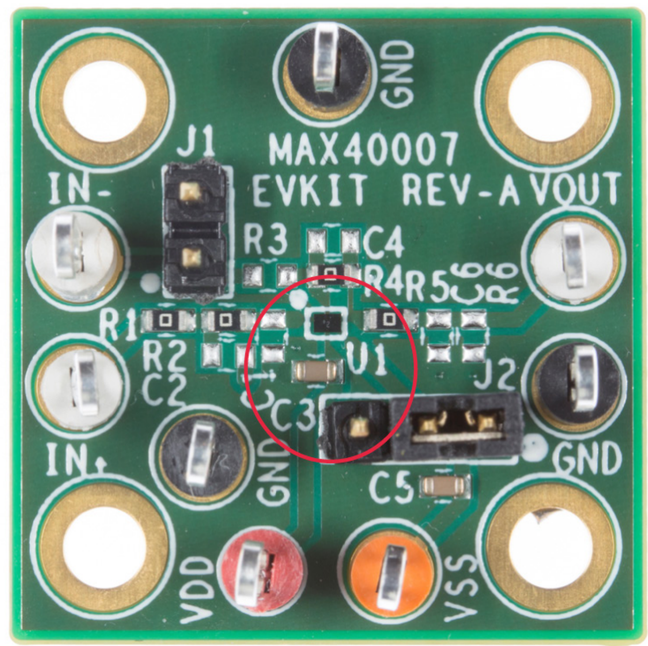

Figure 6. MAX40007EVKIT Board with the MAX40007 Device (U1) in a WLP and the 0.1µF Bypass Capacitor (C3) in an SMT-0603 Package

The Power of Three

As we have seen, battery-powered household, wearable health, and medical circuits require small, ultra-low-power components to fit on shrinking PCBs. Operational amplifiers in these application systems must meet nanopower specifications without compromising key performance specifications.

The nanoPower MAX40007 op amp supports battery-powered and wearable device circuit trends with a three-punch strategy. With uncompromised bandwidth, a nanoPower amplifier circuit provides ultra-low-power operation in an ultra-small package.

Learn more:

MAX40007 nanoPower Op Amp in Ultra-Tiny WLP and SOT23 Packages

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