Digital-to-analog converters are widely used in many different applications and an amplifier often accompanies them to signal-condition the output. The amplifier functions to increase output current drive, to convert differential to single ended output, to isolate the downstream signal path, or to provide a complementary bipolar output voltage. Figure 1 shows a typical section of a single supply signal chain, consisting of a voltage reference, a digital-to-analog converter, and a buffer. To maintain a high dynamic output range and high signal-to-noise ratio, digital-to-analog converters (DACs) are often designed to operate full swing, where the reference voltage (VREF) is set equal to the supply voltage (VDD). This allows maximum usage of the digital codes. With a single supply, the DAC and the output buffer power supply are often connected to the same supply line. In this configuration, a rail-to-rail input and output amplifier is required to buffer the converter.

A classic non rail-to-rail input amplifier uses a p-type (or n-type) differential pair at its input stage. The p-type input amplifiers allow input common-mode voltage to reach and include the lower supply rail. This is especially useful in ground sensing application. On the other hand, the n-type input amplifiers allow input voltage to range from a few Volts above the lower supply rail to the upper supply rail. Such amplifiers suit applications that need to include the upper supply rail, for example, high side current sensing monitors. To enable the input common-mode voltage to extend to both supply rails, rail-to-rail input amplifiers incorporate both n-type and p-type input stages.

The majority of rail-to-rail input amplifiers are designed using two input differential pairs in parallel, an n-type and a complementary p-type. The input common-mode voltage determines which differential pair turns on and is active. The p-type differential pair turns on when the input voltage approaches and reaches the lower supply rail. The n-type differential pair topology. Refer to Figure 2 for an example. For this amplifier running on +5V and ground, the crossover region occurs at 3.4 Volts of input common-mode voltage. Such an amplifier is used in applications where the input voltage range goes rail to rail, but can pose a problem when the input common-mode voltage is at the transition region. As an example, this unique characteristic causes nonlinearity when the amplifier is used as a buffer for a DAC output.

Figure 3 shows the integral nonlinearity (INL) error of a circuit using a 16 bit digital-to-analog converter and a typical rail-to-rail input and output buffer. INL error is the deviation (in LSBs) of the actual converter transfer function from an idealized transfer function. Note that the input of the digital-to-analog converter is swept from code 200 to code 216-200. Approximately 15mV (200 codes) from either end of the range is excluded because a rail-to-rail output amplifier is not truly rail to rail out and requires some output headroom (usually specified in the data sheet). The crossover distortion is detected at an input digital code of about 45000. This corresponds to an input common-mode voltage of 3.4V. Clearly, the amplifier crossover distortion degrades INL, affecting system accuracy. In this particular example, the crossover nonlinearity is as high as 4 to 5 LSBs for a 16-bit system. Many systems perform calibration to remove initial offset voltage, but such nonlinearity cannot be removed by calibration.

Crossover nonlinearity can be resolved by using a zero-crossover-distortion amplifier. This type of amplifier integrates a charge pump input enhancement circuit.
DAC Systems

Zero-crossover-distortion amplifiers improve linearity of DAC Systems

Used in many applications, digital-to-analog converters are often accompanied by an amplifier

By: Vicky Wong, Analog Devices

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Figure 1: Typical section of a single supply signal chain

Input differential pairs commonly exhibit different offset voltages. The hand-off from one pair to the other due to input common-mode voltage change creates a step-like characteristic that is visible in the graph of offset voltage vs. input common-mode voltage. This crossover distortion is inherent to rail-to-rail input amplifiers designed with the dual differential pair topology. Refer to Figure 2 for an example. For this amplifier running on +5V and ground, the crossover region occurs at 3.4 Volts of input common-mode voltage. Such an amplifier is used in applications where the input voltage range goes rail to rail, but can pose a problem when the input common-mode voltage is at the transition region. As an example, this unique characteristic causes nonlinearity when the amplifier is used as a buffer for a DAC output.

Figure 2: Input offset voltage vs. input common-mode voltage of a typical rail-to-rail input amplifier

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Figure 3 shows the integral nonlinearity (INL) error of a circuit using a 16 bit digital-to-analog converter and a typical rail-to-rail input and output buffer. INL error is the deviation (in LSBs) of the actual converter transfer function from an idealized transfer function. Note that the input of the digital-to-analog converter is swept from code 200 to code 216-200. Approximately 15mV (200 codes) from either end of the range is excluded because a rail-to-rail output amplifier is not truly rail to rail out and require some output headroom (usually specified in the data sheet). The crossover distortion is detected at an input digital code of about 45000. This corresponds to an input common-mode voltage of 3.4V. Clearly, the amplifier cross-over distortion degrades INL, affecting system accuracy. In this particular example, the crossover nonlinearity is as high as 4.5 LSBs for a 16-bit system. Many systems perform calibration to remove initial offset voltage, but such nonlinearity cannot be removed by calibration.

Crossover nonlinearity can be resolved by using a zero-crossover-distortion amplifier. This type of amplifier integrates a charge pump input enhancement circuit.
An example of a zero-cross-over-distortion amplifier as Analog Devices’ ADA4500-2. Figure 4 shows the offset voltage vs. input common-mode voltage of the device. Notice that offset voltage is quite constant over the input common-mode voltage range.

Using a zero-cross-over-distortion amplifier eliminates crossover nonlinearity in a digital-to-analog converter system. Figure 5 shows the INL of a circuit using the same 16 bit digital-to-analog converter and the ADA4500-2. The zero-cross-over-distortion feature improves INL to less than +/-1LSB.

As an alternative to using a zero-cross-over-distortion amplifier to avoid crossover nonlinearity, one could also supply the converter with a reference voltage (VREF) that is lower than its supply (VDD). For example, use a 2.5V reference voltage with a 5V supply. This would ensure that the cross-over region of a typical rail-to-rail input amplifier is out of the input digital code range. As a tradeoff, this halves the output range. An external amplifier might also be needed to amplify the output if the signal level is too low. Another option, if the system has multiple supplies, is to provide the amplifier with a higher power supply, allowing the use of a non-rail-to-rail input amplifier. The increase in power supply would provide enough headroom for the input stage. This however would be less power efficient.

All in all, it is important to carefully consider the appropriate amplifier as a DAC output buffer. You can use a lower DAC reference voltage at the expense of a reduced output range, or increase the buffer supplies at the expense of higher power consumption. Better yet, you can use a rail-to-rail input and output amplifier to maximize input and output range, but consider using a zero-cross-over-distortion amplifier to avoid errors that come from crossover nonlinearity.

Figure 4: Offset voltage vs. input common-mode voltage of a zero-cross-over-distortion amplifier on chip to achieve rail-to-rail input swing. The charge pump increases the internal supply by a few Volts to provide the headroom needed for the input stage; the amplifier then achieves rail-to-rail input swing without the need for a complementary input differential pair. Consequently, it does not exhibit crossover distortion.

Figure 5: Integral nonlinearity (INL) of a 16-bit DAC and the ADA4500-2.

Much of the burden of a device’s reliability, run-time, and robustness falls on the power system.

By: Tony Armstrong, Linear Technology

As with many other applications, low power precision components have enabled rapid growth of mobile devices. However, unlike many other applications, portable products targeted at industrial, medical and military applications typically have much higher standards for reliability, run time and robustness. Much of this burden falls on the power system and its components. A common feature of such products is that they must operate properly and switch seamlessly between a variety of power sources. As a result, great lengths must be taken to protect against and tolerate faults, maximize operating time when powered from batteries and ensure that operation is reliable whenever a valid power source is present.

Clearly, the power management integrated circuits (PMICs) required to address these needs must allow an application to receive power from multiple power sources; which could include: a wall adapter, a USB port, a car lighter adapter or even a Li-Ion battery. This can easily be done if the PMIC has integrated PowerPath control. This technique ensures that system power remains uninterrupted and tolerates hot plugging between external power and battery power. In some instances, a battery charger may also be included on the PMIC. If so, this battery charging circuitry needs to ensure that the battery remains charged using excess power not needed by the application. Furthermore, on-chip protection circuitry is sometimes necessary to guard against external overvoltage faults exceeding 30V. Finally, low no-load quiescent current is essential to provide optimal power efficiency over a wide range of load and operating conditions. Features such as these are all critical to the success and utility of any products.

Industry Trends

While product form factors are decreasing, demand for their functionality and features are continuously increasing. Furthermore, the industry trend for sophisticated digital ICs such as microprocessors (μP) and microcontrollers (μC) or field programmable gate arrays (FPGAs) that power mobile products continue to lower their operating voltages while simultaneously increasing their amperage.

Microprocessors are among the most popular of these to design in, and there is a growing list of power efficient types from such suppliers as Freescale, Intel, NVIDIA, Samsung and others. They are designed to provide low power consumption and high performance processing for a wide range of portable, wireless and mobile device applications across multiple market segments.

The original intent of these processors was to enable OEMs to develop smaller and more cost-effective portable handheld devices with long battery life, while simultaneously offering enhanced computing performance to run feature-rich multimedia applications. Nevertheless, demand for this same combination of high power efficiency and processing performance has spread to non- portable applications.