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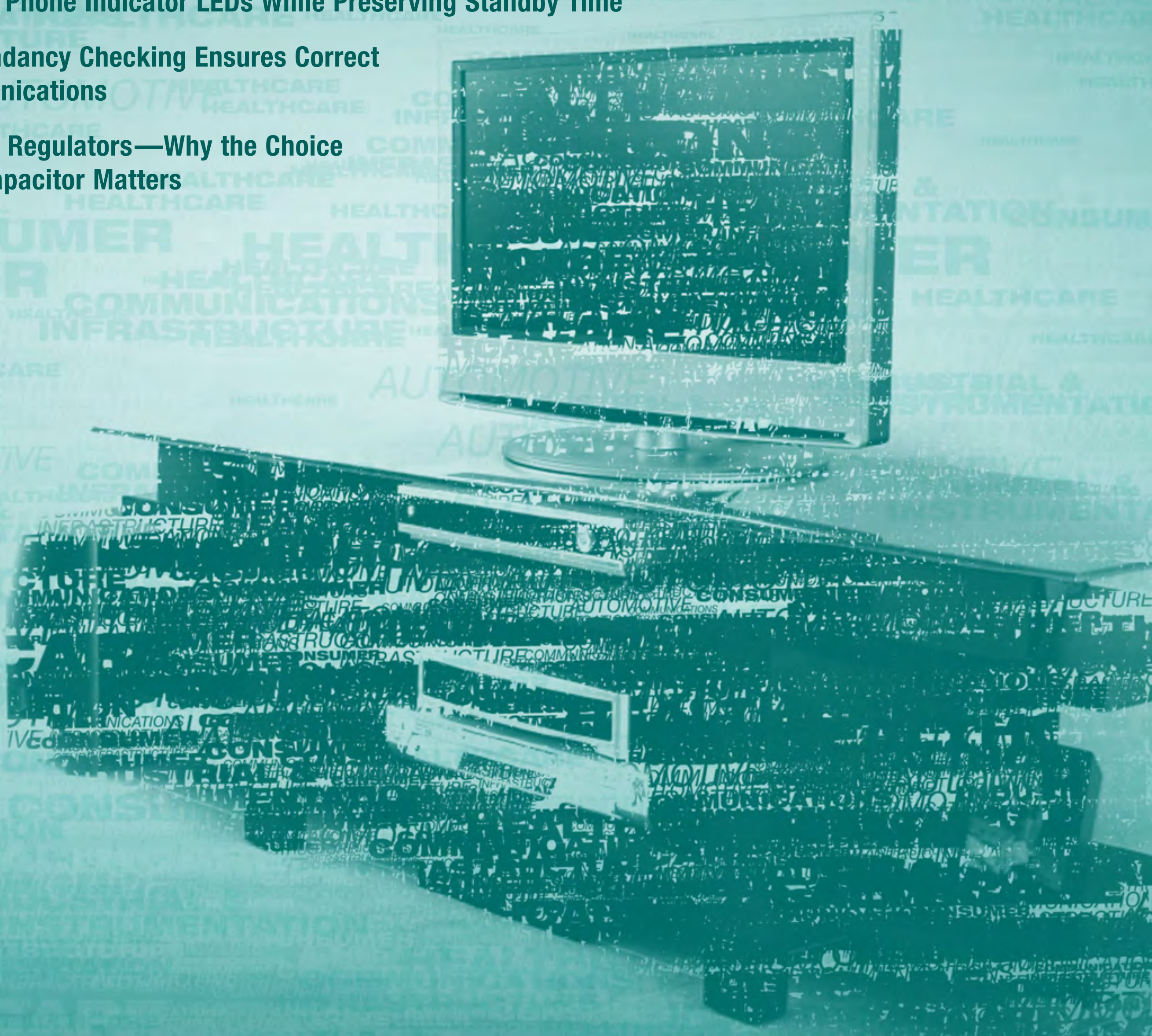
Analog Dialogue

In This Issue



ANALOG DEVICES

Editors' Notes

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Electromagnetic Interference Filtering Reduces Errors in Precision Analog Applications

An often-overlooked problem in equipment using strain gages, transducer interfaces, and current monitors in medical, automotive, and industrial applications is high-frequency interference from external signals. This electromagnetic interference (EMI) can cause large dc offsets in precision analog circuitry through asymmetrical rectification of the RF signal in the input stages of an amplifier. Page 3.

HDMI Transceivers Simplify the Design of Home Theater Systems

As large-screen HDTVs have achieved widespread acceptance, consumers are expanding their home theater systems to include sound bars and AVRs, enhancing the user experience with superb audio to complement the video performance. Home theater systems can now offer all the latest features of the High-Definition Multimedia Interface (HDMI®)—seamlessly integrated within the equipment. Page 5.

Minimizing Noise and Power Consumption in Automotive Audio Systems with SigmaDSP

Digital signal processors bring the benefits of home theater to cars, supplanting radio/CD players with multimedia systems, where DSPs enable excellent audio performance and flexibility—and a powerful multimedia experience for passengers. A new approach to minimizing system noise and power consumption uses the SigmaDSP® processor and the SigmaStudio™ graphical development tool. Page 9.

Activate Cell Phone Indicator LEDs While Preserving Standby Time

Cell phone manufacturers are pressed to provide status LEDs that alert users to messages waiting, impending appointments, and other notifications while the phone is in standby. At the same time, users demand longer battery life. This pair of conflicting issues presents manufacturers with a dilemma: how can they power notification LEDs while keeping standby consumption low? Page 11.

Cyclic Redundancy Checking Ensures Correct Data Communications

Electronic systems must often endure temperature extremes, noise, or other harsh conditions. To ensure correct operation, many DACs implement cyclic redundancy checking (CRC), with 24-bit data augmented with an 8-bit checksum. If the received checksum does not agree with the data, an output pin sends back an error indication. The controller clears the error and resends the data. Page 13.

Low Dropout Regulators—Why the Choice of Bypass Capacitor Matters

Widely seen as a panacea for solving noise issues, capacitors deserve more respect. Designers think that adding capacitors will cure noise problems, but give little thought to parameters other than capacitance and voltage rating. But capacitors are not perfect; they possess parasitic resistance and inductance, their capacitance varies with temperature and voltage, and they are sensitive to mechanical effects. Page 14.

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PRODUCT INTRODUCTIONS: VOLUME 45, NUMBER 1

Data sheets for all ADI products can be found by entering the part number in the search box at www.analog.com.

January

Accelerometer, low-profile, 3-axis, ±3-*g* **ADXL337**
Receiver, HDMI, dual-port, 225-MHz **ADV7612**
Receiver, HDMI, low-power, 165-MHz **ADV7611**
Switches, analog crosspoint, 750-MHz, 8 × 8 .... **ADV3228/ADV3229**
Switches, analog crosspoint, 750-MHz, 16 × 8 .... **ADV3224/ADV3225**

February

Accelerometer, digital, 3-axis, ±1.5-*g*/±3-*g*/±6-*g*/±12-*g* **ADXL312**
Controller, synchronous buck, dual/2-phase **ADP1850**
Processor, Blackfin® **ADSP-BF504**
Sequencer, super, margining control, fault recording **ADM1166**

March

Amplifier, operational, dual, micropower, RRIO **AD8546**
Amplifier, operational, dual, precision, RRIO **AD8657**
Amplifier, operational, ultralow-noise, zero-drift **ADA4528-1**
Converter, analog-to-digital, dual, 8-bit, 250-MSPS, interleaved **AD9286**
Converter, analog-to-digital, dual, 8-bit, 250-MSPS, simultaneous **AD9284**
Converter, analog-to-digital, 8-channel, 12-bit, temperature sensor **AD7291**
Converter, digital-to-analog, 16-bit, 4-mA to 20-mA, loop-power **AD5421**
Converters, synchronous buck, 3-MHz, 800-mA **ADP2138/ADP2139**
Demodulator, quadrature, 750-MHz to 1150-MHz **ADRF6801**
Driver, gate, isolated, 2-channel, 4-A **ADuM3221**
Gyroscope, digital output, high vibration rejection ... **ADXRS450**
Gyroscope, digital output, ultrahigh vibration rejection **ADXRS453**
Microcontroller, precision analog, ARM7TDMI, 12-bit I/O **ADuC7121**
MicroPMU, 800-mA buck converter, two 300-mA LDOs **ADP5042**
Monitor, current shunt, zero-drift, bidirectional **AD8218**
Monitor, current shunt, zero-drift, unidirectional **AD8219**
Prescaler, divide-by-2, 4-GHz to 18-GHz **ADF5000**
Processors, SHARC® **ADSP-2148x**
Receiver, differential, triple, cable equalization **AD8124**
Sensor, inertial, six-degrees-of-freedom, low-profile **ADIS16334**
Transmitter, HDMI, 150-MHz, low-power **ADV7526**

Analog Dialogue

Analog Dialogue, www.analog.com/analogdialogue, the technical magazine of Analog Devices, discusses products, applications, technology, and techniques for analog, digital, and mixed-signal processing. Published continuously for 45 years—starting in 1967—it is available in two versions. Monthly editions offer technical articles; timely information including recent application notes, new-product briefs, pre-release products, webinars and tutorials, and published articles; and *Potpourri*, a universe of links to important and relevant information on the Analog Devices website, www.analog.com. Printable quarterly issues and ebook versions feature collections of monthly articles. For history buffs, the *Analog Dialogue* archive, www.analog.com/library/analogdialogue/archives.html, includes all regular editions, starting with Volume 1, Number 1 (1967), and three special anniversary issues. To subscribe, please go to www.analog.com/library/analogdialogue/subscribe.html. Your comments are always welcome: Facebook: www.facebook.com/analogdialogue; Analog Diablog: analogdiablog.blogspot.com; Email: dialogue.editor@analog.com or *Dan Sheingold*, Editor [dan.sheingold@analog.com], or *Scott Wayne*, Publisher and Managing Editor [scott.wayne@analog.com].

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Electromagnetic Interference (EMI) Filtering Reduces Errors in Precision Analog Applications

By Henri Sino

Equipment design involving strain gages, transducer interfaces, and current monitoring for technologies such as medical equipment, automotive instrumentation, and industrial control often requires a precision analog front-end amplifier that is able to extract and amplify a very small real-world signal, while rejecting unwanted signals such as common-mode voltages and noise. To begin with, the designer will focus on ensuring that accuracy parameters such as component-level noise, offset, gain, and temperature stability are suitable for the application.

Based on these specifications, the designer chooses front-end analog components that will fit the permitted total error budget. However, an often-overlooked problem occurs in such applications, caused by high-frequency interference from external signals. It is typically categorized as *electromagnetic interference* (EMI). Principally affected by the end application, EMI can occur in numerous ways. For example, an instrumentation amplifier might be used in a control board that interfaces with a dc motor. The electrical current loop of the motor, which comprises power leads, brushes, commutator, and wire coil, can often act as an antenna that emits high-frequency signals that can interfere with the small voltages at the inputs of the instrumentation amplifier.

Another example is current sensing in automotive solenoid control. The power to the solenoid is provided by the vehicle battery via long wires that can act as antennas. A series resistive shunt is connected in this wire path, with its voltage measured by a current-sensing amplifier. The inputs of the amplifier are susceptible to external high-frequency common-mode signals that could be present in the wiring. If the analog component is affected by external high-frequency interference, it may lose accuracy, and could perhaps even lose control of the solenoid circuit. This condition would be manifested in the amplifier by its output accuracy exceeding the error budget and data sheet tolerance, or in some cases going into limits, causing shutdown of the control loop.

How can EMI cause large dc deviations? Here's one possible mechanism: Many instrumentation amplifiers are designed and specified to have excellent common-mode rejection at frequencies well up into the tens of kilohertz. The problem comes in exposure of an unshielded amplifier to RF fields in the tens or hundreds of *megahertz*. Asymmetrical rectification can occur in the input stages of the amplifier, producing dc offsets that, further amplified, can be significant and—considering the gain of the amplifier—even drive its output, or some portion of the external circuit, into limits.

Example of How an Analog Component Is Affected by High Frequency Signals

This example will take a closer look at a typical high-side current-sense application. A common configuration for monitoring solenoids or other inductive loads in an automotive environment is shown in Figure 1.

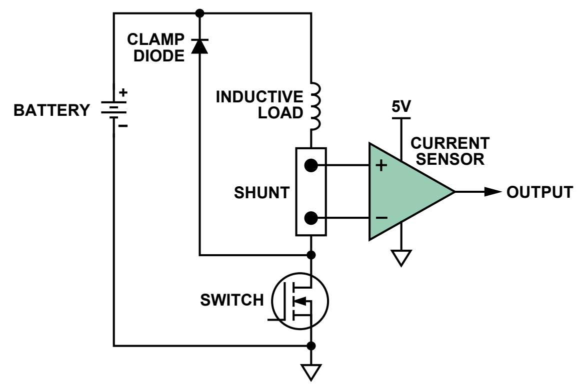

Figure 1. High-side current monitoring.

We investigated the effects of high-frequency interference in such a setup with two current-sense amplifiers of similar design. The functionality and pinout of the two parts were exactly the same; however, one device included internal EMI filter circuitry, while the other did not.

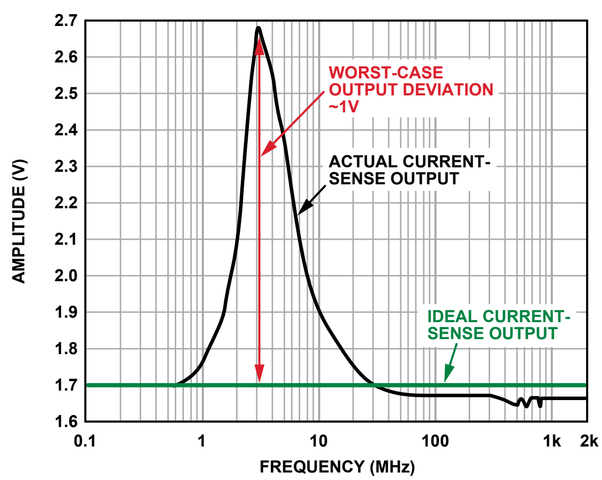

Figure 2. Output of current sensor with no internal EMI filters (forward power = 12 dBm, 100 mV/division, peak dc output at 3 MHz).

Figure 2 shows how the dc output of the current sensor varied from its ideal value as the inputs were subjected to a wide range of frequencies. It can be seen that significant deviations (>0.1 V) occur in the frequency range of 1 MHz to 20 MHz, with a peak dc error of 1 V—a significant portion of the amplifier's 0-V-to-5-V range—at 3 MHz.

Figure 3 shows the results of the same experiment and setup using a pin-compatible current sensor that has the same circuit architecture and similar dc specifications as in the previous case, but it includes internal input EMI filtering. Note that the voltage scale is expanded by 20×.

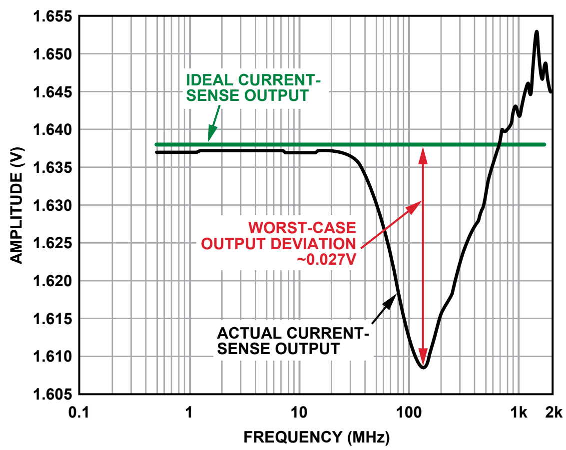

Figure 3. Output of current sensor with internal EMI filters (forward power = 12 dBm, 5 mV/division, peak dc output at >100 MHz).

In this case, the error level is only about 3 mV at 40 MHz, and the peak error, at above 100 MHz, is less than 30 mV, a greater than 35× improvement. This shows quite clearly that internal EMI filtering helped a great deal to shield the current sensor from the high-frequency signals present at its inputs. In a real-world application, where the extent of EMI is unknown, it can be realistically expected that the control loop will remain within its tolerance if the current sensor with internal EMI filtering is used.

The testing was done under the exact same conditions for both parts. The only difference between them is that the AD8208 (see Appendix) includes internal low-pass RF input filters on the input- and power-supply terminals. This might seem like a trivial addition to the silicon, but in this case the current-sense amplifier must withstand continuously switching common-mode voltages up to 45 V, as the applications are typically PWM controlled. Therefore, to maintain accurate high gain and common-mode rejection, the input filters must be closely matched.

Why and How to Design and Test for EMI Compliance

Automotive applications are particularly sensitive to EMI events due to the noisy electrical environment associated with the common battery, bundled wiring, various inductive loads, antennas, and outside interference associated with cars. Because electronics is involved in controlling critical functions, including airbag deployment, cruise control, braking, and suspension, EMI compliance is a must. There can be no false alarms or triggers due to external interference. In earlier times, EMI compliance testing was the last test performed in automotive applications. If something went wrong, designers had to scramble to find a solution—which typically involved changing the board layout, adding additional filters, or even replacing components.

This level of uncertainty is costly and worrisome for engineers, and over time the automotive industry has taken concrete steps to improve EMI compliance. Automotive OEMs, whose equipment must be EMI-compliant, now demand EMI testing at the component level from semiconductor manufacturers, such as Analog Devices, prior to qualifying a part for use. This process is becoming universal, as all IC manufacturers are now instructed to test components for EMI compliance using a standard specification.

Requirements for standard EMI tests for various types of integrated circuits can be purchased from the International Electrotechnical Commission (IEC).[1] Documents such as IEC 62132 and IEC 61967 are very good tools to learn about EMI and EMC; they describe—in great detail—how to test specific integrated circuits using industry-recognized standards. The tests described above were performed using these specified guidelines.

In particular, these tests were done using *direct power injection*, a method that couples an RF signal, via a capacitor, to a particular component pin. Each input of the device is tested, varying the power level and frequency range of the RF signal, depending on the type of IC under test. Figure 4 depicts a simplified schematic of how direct power injection testing is conducted at a particular pin.

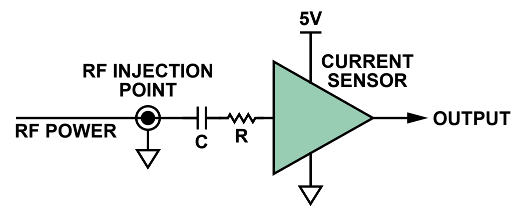

Figure 4. Direct power injection.

The standards include quite a bit of information on the circuit setup, layout methods, and monitoring techniques necessary to understand whether a part passed or failed. A more complete schematic based on the IEC specifications is shown in Figure 5.

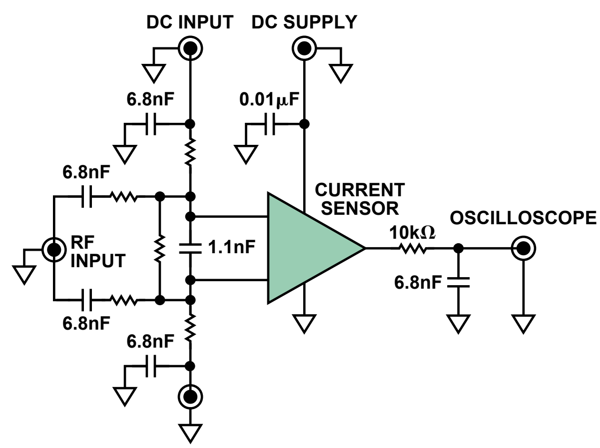

Figure 5. Schematic for EMI susceptibility testing.

Summary

EMI compliance for integrated circuits is critical to successful electronic design. This article shows how two quite similar amplifiers making a dc measurement differed substantially in dc performance in an RF environment, depending only on whether or not they included internal EMI filters. In automotive applications, EMI is a particularly important topic due to safety and reliability concerns. IC manufacturers, such as Analog Devices, now increasingly include EMI susceptibility considerations in designing and testing devices intended for critical applications. The IEC standards provide useful guidelines with significant detail. For the automotive market, current-sense devices, such as the AD8207, AD8208, and AD8209, have undergone EMI testing. Newer devices designed and tested to comply with EMI requirements include the AD8280 lithium-ion battery safety monitor and the AD8556 digitally programmable sensor signal amplifier.

(continued on Page 8)

HDMI Transceivers Simplify the Design of Home Theater Systems

By Ian Beavers, Joe Triggs, and Lie Dou

Introduction

Now that large-screen HDTVs (*high-definition televisions*) have achieved widespread acceptance, many consumers are expanding their electronics collection to include components for a complete home theater system. *Home theater in a box* (HTiB), *sound bars*, and *audio/video receivers* (AVRs) enhance the user experience with superb audio while complementing the HDTV video performance. The ability to extract and process high-fidelity audio signals is a key differentiator among the hardware choices on the market today. Home theater systems can now offer all the latest features of the High-Definition Multimedia Interface (HDMI®)—seamlessly integrated within the equipment.

The effort to improve the home theater experience comes with several implementation challenges for the system designer of HTiBs, sound bars, and AVRs. The latest version of the HDMI standard includes new optional features, such as an *audio return channel* (ARC), 3D display formats, and enhancements to the *consumer electronics control* (CEC) protocol. Consumers, of course, want their new home theater equipment to include all of these new HDMI features—at lower cost and with more user-friendly controls. Designers of home theater equipment must thus adapt to the new standards, while shrinking their *bill-of-material* (BOM) costs, development costs, and time to market. To help designers meet these challenges, Analog Devices has created *HDMI transceiver* products that incorporate these new features.

An example of an HDMI transceiver is the ADV7623, which incorporates a 4:1 HDMI input *multiplexer* (mux), HDMI receiver, *on-screen-display* (OSD) engine, and HDMI transmitter. Individually, these functions would require discrete ICs, each with its own unique firmware, but a transceiver can combine all these functions in a comprehensive solution, reducing board area, firmware complexity, and BOM costs for the home-theater system designer.

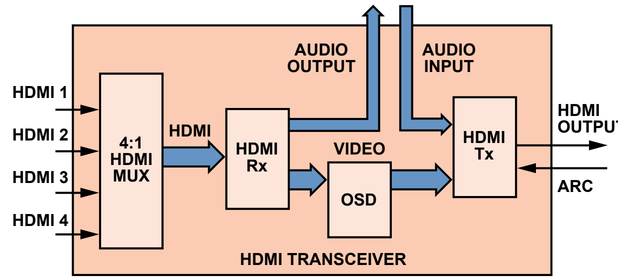

Figure 1. Functional block diagram of an HDMI transceiver.

Home Theater in a Box

HTiBs are complete video playback systems. They generally include a multichannel audio amplifier and a surround-sound speaker system for playback of audio. In addition, they usually include a DVD or Blu-ray™ video player. HTiBs ease installation and power matching between the video player, amplifier, and speakers. HTiBs principally process audio; the video is passed through to the TV over the HDMI interface. Figure 2 depicts a typical HTiB system.

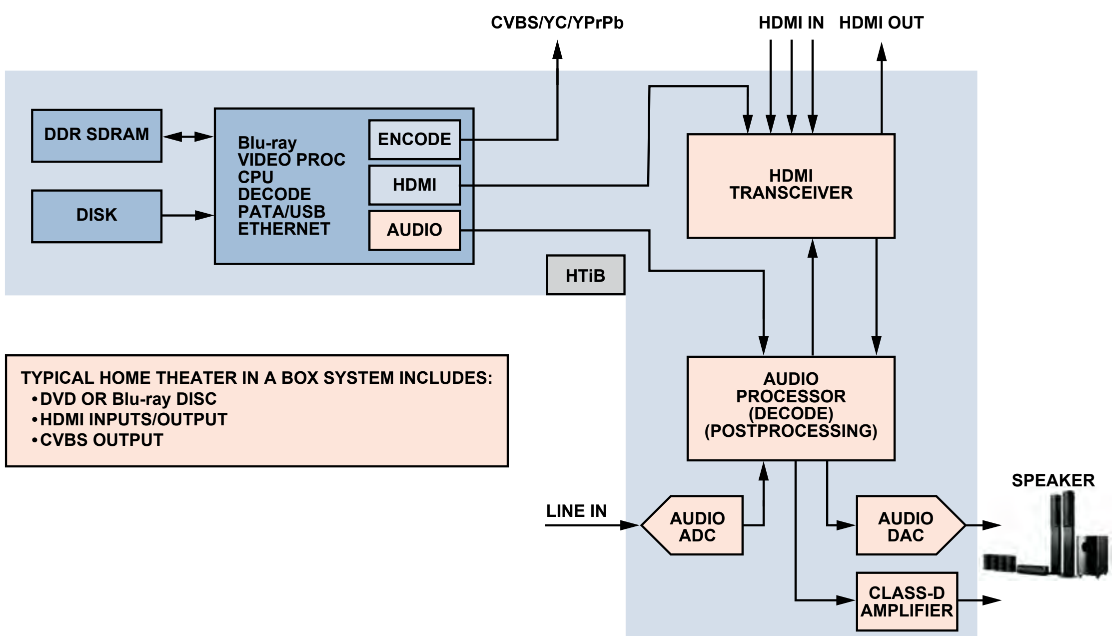

Figure 2. Block diagram of a typical HTiB system.

Sound Bars

With the increased popularity of thin, large screen, flat panel TVs, *sound bars* are emerging as complementary AV systems. These are compact, easy-to-set-up speaker systems that provide much better sound quality than the TV speakers. Since most HTiBs and sound bars are used with large-screen HDTVs, their audio and video connectors mainly utilize HDMI. A typical sound bar will have multiple HDMI inputs to handle various sources, a single HDMI output for the connected TV, built-in audio processing, and speakers. Figure 3 illustrates a typical sound-bar system.

Advanced sound bars comprise multiple speakers and amplifiers with surround-sound decoding capability. Their electronic and acoustic design features can produce a surround-sound effect without separate speakers at the back of a room. Middle- to high-end sound-bar systems often contain DVD or Blu-ray players, resulting in system architecture similar to that of HTiBs.

Audio Return Channel (ARC)

A new feature in the HDMI specification provides for an *audio return channel* (ARC)—to allow the HTiB to process audio from the downstream device. In order to listen to the TV audio without an ARC, an independent cable (optical S/PDIF or coaxial) would be required to send the audio from the TV or tuner back to the HTiB. With the ARC, the HDMI cable can *return* 2-channel S/PDIF or multichannel audio from the TV back to the HTiB, dispensing with the extra audio cable. HDMI transceivers offer an ARC receiver on the HDMI output port.

ARC adds significant value in the case where the TV, set-top box, or other downstream HDMI sink device uses a tuner to receive new media content. Instead of listening to the audio over the less powerful internal TV speakers, the user can easily employ the higher fidelity HTiB system output. The returned audio data passes on the HDMI cable *from the TV to the HTiB*—in the opposite direction to the traditional video data path—without regard to whether or not the video output to the HTiB is active on the cable.

Extended Display Identification Data (EDID) Replication

HDMI transceivers provide an EDID replication feature that reproduces a single location memory across multiple HDMI ports—even when the HTiB is in power-down mode. This enables faster system start-up times, as all of the upstream HDMI source devices can configure their video outputs properly before the HTiB is powered up. The only power required for EDID replication is furnished by the +5 V/55 mA available from the source via the HDMI cable.

3D Video

As a bridge between 3D content-providing sources, such as game consoles, Blu-ray players, and 3D-capable TVs, HTiB manufacturers must stay ahead of the technology curve to enable customers to benefit in the long term from the full range of features offered by their source and sink devices. HDMI transceivers that incorporate the latest versions of HDMI technology support implementation of 3D video as part of the home theater experience. This new feature of the HDMI standard significantly enhances the user experience; such features are critical to energizing TV sales.

The specification defines an infrastructure for communicating 3D video in the home via a list of mandatory and optional video formats. In a practical application, the HTiB must present to the connected sources a list of supported 3D formats—retrieved from the connected TV and parsed against its own list of supported 3D formats. The connected source then indicates to the HTiB—through HDMI protocol commands—when it is sending 3D content. The HTiB can then extract and output advanced audio formats, such as Dolby TrueHD® or DTS-HD Master Audio,® that were sent over the HDMI link, but that the TV may not be equipped to support.

On-Screen Display (OSD)

HTiBs have many user-accessible controls, such as selection between multiple inputs, selection of desired audio and video formats, and configuration of advanced audio processing options. To enable control of these complex features in a user-friendly manner, an *on-screen display* (OSD) is employed. OSD was usually implemented via a dedicated device, but now HDMI transceivers offer integrated OSD engines to blend the desired on-screen display material onto the output video—offering HTiB manufacturers considerable savings over the external solution. Savings of component cost and bill of materials are possible, as well as reduction of design effort to integrate the OSD software into the system firmware.

Consumer Electronics Control (CEC) Expansion

The consumer electronics control (CEC) channel is a single-wire communication interface that facilitates home entertainment system networking. One example is a single remote control button that simultaneously powers all components of an entertainment system on and off. As the HDMI standard has expanded to support new optional features, such as ARC and HDMI Ethernet channel (HEC), the CEC command library within HDMI transceivers has also expanded to support them. For HTiB designers, supporting the latest HDMI features requires that they also support the latest CEC features. HDMI transceivers now handle the discovery, negotiation, initiation, and termination of ARC and HEC sessions over the single-wire network.

Audio Insertion and Extraction

Another use of an HDMI transceiver within an HTiB is to extract the HDMI audio for processing with a *digital signal processing* (DSP) chip. The audio can then be reinserted into the HDMI

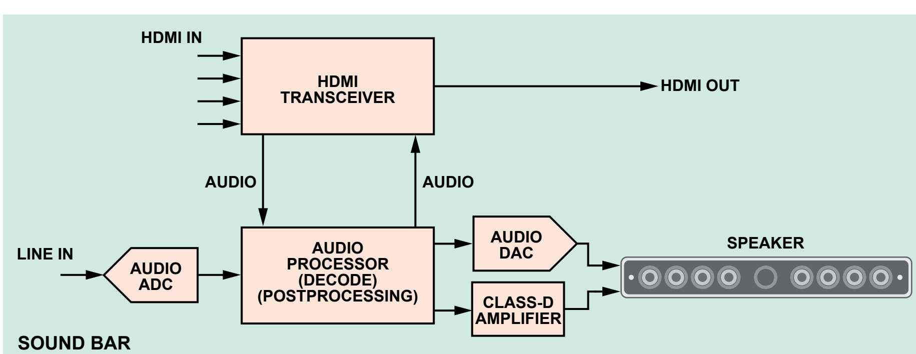

Figure 3. Block diagram of a typical sound bar with HDMI hub.

stream to the TV. Since many TVs cannot handle multichannel audio formats, the DSP chip can downsample the audio to stereo and then reinsert the audio into the HDMI link to the TV.

Alternatively, the incoming audio could be completely replaced with a new stream from another HTiB source and embedded into the HDMI signal to the TV. In this case, only the audio insertion feature would be used. An example of this application could be docking an iPod® to an HTiB and mixing the audio with an independent video stream.

An HTiB system may act as an HDMI repeater when it accepts an HDMI input and also sends it as an output, in a home theater configuration. A Blu-ray player, for example, can be the source as an input to the HTiB system. In order to utilize the superior sound quality of the HTiB as compared to the connected TV, the audio must be extracted from the HDMI signal within the HTiB. In the best case, an audiophile would want a full 8-channel I^2S audio signal output from the HTiB, but 2-channel I^2S or S/PDIF is also available from the HDMI link. The video continues to the TV or display to complete the system path. Only an HDMI/HDCP (*High-bandwidth Digital Content Protection*) repeater or transceiver-type device can handle this audio extraction.

Firmware/Repeater Support

One of the biggest challenges in HTiB and sound-bar design is implementing the HDCP repeater function. The repeater function implemented in an HTiB is a complex mix of content protection, EDID management, and video- and audio muting. HDMI transceivers integrate the entire repeater process into a single device and firmware, reducing system development complexity.

As video and audio processing devices increase in complexity, the availability of qualified hardware-abstracted software libraries and *application programming interfaces* (APIs) becomes a major benefit to the designer—shortening time to market and making it feasible to start from a well-structured HDMI- and HDCP-compliant platform. Further savings can be made by initially adopting the shared code base of a silicon vendor: the rewards of integrating the code for a transceiver in low- to mid-end HTiBs can be reaped in the upgrade possibilities when using discrete receivers and transmitters from the same vendor in mid- to high-end HTiBs.

2-Layer Circuit-Board Design for Cost Savings

New HDMI transceivers offer an efficient board layout and routing scheme by using *quad flat-pack* (QFP) packaging. The *low-profile* LQFP package eases manufacturing cost and complexity—and simplifies inspection following manufacture—compared to more complex *ball grid array* (BGA) packages. The LQFP simplifies layout challenges to such an extent that the package can actually be laid out on a 2-layer board, realizing a lower cost, while still achieving all the required HDMI physical-layer compliance-test impedance measurements.

Design challenges on the 2-layer board include managing power supply routing to the transceiver with sufficient decoupling, providing optimal thermal conduction, and routing the trace impedances required for the *transition minimized differential signaling* (TMDS) differential-pair inputs and outputs. However, successful layouts that do not sacrifice performance are eminently achievable by using surface-mount discrete devices, employing good layout principles, and working closely with *printed-circuit-board* (PCB) and silicon vendors.

Conclusion

HDMI transceivers offer the system designer a lower cost, lower complexity home theater system with the latest HDMI features that consumers desire to support their audio-visual experience. Using these transceivers, HDMI features, such as ARC and 3D video, can now be realized. The integrated on-screen display engine in the HDMI signal path reduces the cost and complexity of HTiB and sound-bar designs. The ability to extract, process, and insert audio within the HDMI stream enhances the home theater experience in consumer system designs. Where HTiB and sound-bar systems may function as HDMI repeaters, new transceiver designs and firmware make the implementation seamless. Routing an HDMI transceiver on a 2-layer board can be achieved to reduce BOM costs.

Figure 4 illustrates a typical HDMI transceiver system using the ADV7623 from Analog Devices. It integrates a four-input HDMI *receiver* (Rx) and an HDMI *transmitter* (Tx) with audio extraction. After the HDMI signal is decoded, the audio content is extracted and processed by a SHARC audio DSP. The processed audio can then be sent to amplifiers and speakers, or can be reinserted into the HDMI signal path.

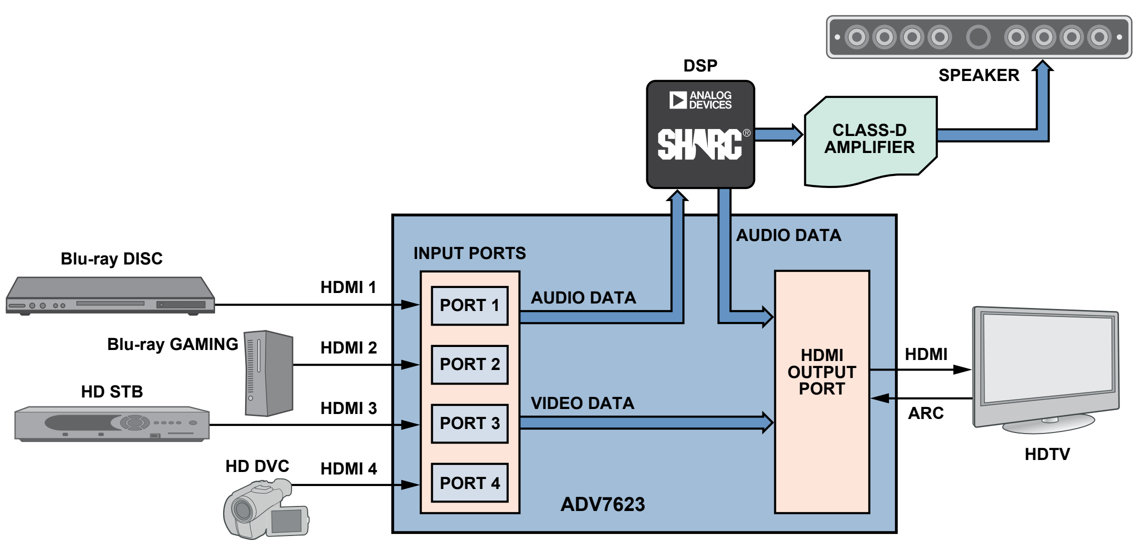

Figure 4. HTiB system using the ADV7623 HDMI transceiver.

This particular transceiver also has integrated OSD, making it practical for sound-bar system design, as it can save the costs of using a discrete OSD engine. The ADV7623 provides EDID replication, HDCP repeater support, and ARC—and supports mandatory 3D video formats. Available now, the ADV7623 comes in a 144-lead LQFP package that facilitates 2-layer PCB design.

HDMI transceivers integrate a multi-input HDMI receiver and HDMI transmitter in a single chip—with flexible audio extraction and insertion. Utilizing HDMI transceivers for HDMI A/V repeater designs—including AVRs, HTiBs, and sound bars—will:

(1) Reduce the system bill-of-materials cost—with fewer components, smaller PCB area, and fewer PCB layers.

(2) Greatly reduce both the hardware and HDMI repeater system software design efforts, thus greatly reducing the time to market.

These advantages make HDMI transceivers an excellent choice for cost-effective high-performance home audio/video system design.

Authors

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Lie Dou [lie.dou@analog.com] is a product marketing manager for the Digital Video Products Group at Analog Devices. He has been with ADI since 2003 and specializes in video and display products. Lie has a BS from Fudan University, China, and a PhD in physics from Wayne State University.

(continued from Page 4)

Appendix

More about the AD8208: The AD8208 (Figure A) is a single-supply difference amplifier ideal for amplifying and low-pass filtering small differential voltages in the presence of a large common-mode voltage. The input common-mode voltage range extends from −2 V to +45 V with a single +5 V supply. The amplifier offers enhanced input overvoltage and ESD protection and includes EMI filtering.

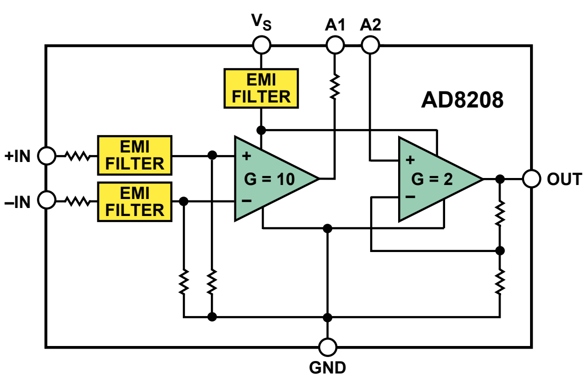

Figure A. AD8208 difference amplifier.

Qualified for automotive applications, which demand robust, precision components for improved system control, the AD8208 provides excellent ac and dc performance. Typical offset and gain drift are less than 5 µV/°C and 10 ppm/°C, respectively. Available in SOIC and MSOP packages, the device delivers a minimum CMR of 80 dB from dc to 10 kHz.

An externally accessible 100-kΩ resistor can be used for low-pass filtering and for establishing gains other than 20.

References

(*Information on all ADI components can be found at www.analog.com.*)

[1]http://webstore.iec.ch.

Author

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Minimizing Noise and Power Consumption in Automotive Audio Systems with SigmaDSP

By Ben Wang

Today, more and more digital signal processors (DSPs) are deployed in automotive electrical systems to process audio signals digitally and provide the benefits of multimedia in vehicles. For example, car radio and CD systems can be supplanted by automotive multimedia systems, where DSPs, such as the ADAU1401 SigmaDSP® processor, are used to achieve outstanding audio performance and flexibility, while providing a more powerful multimedia experience for passengers. These DSPs also provide a useful tool for systems engineers, who are concerned with minimizing power consumption and decreasing the effects of system noise on the listening experience. This article introduces a new approach to minimizing noise and power consumption utilizing the SigmaDSP[1] processor and the SigmaStudio™ graphical development tool.[2]

The ADAU1401 complete single-chip audio system includes a fully programmable 28-/56-bit audio DSP, plus analog-to-digital and digital-to-analog converters, and microcontroller-like control interfaces. Signal processing provides equalization, bass enhancement, multiband dynamics, delay compensation, speaker compensation, and stereo image widening. This processing, comparable to that found in high-end studio equipment, can compensate for real-world limitations of speakers, amplifiers, and listening environments—thus providing dramatic improvements in perceived audio quality.

The easy to use SigmaStudio software allows the user to graphically configure a custom signal processing flow using blocks, such as biquad filters, dynamics processors, level controls, and GPIO interface controls.

Noise Floor

Unlike portable devices, automotive audio systems are equipped with high-power amplifiers; each speaker is capable of delivering up to 40 W or 50 W; each vehicle has at least four speakers. The noise floor can easily be amplified to a level that is perceptible by human ears in a quiet environment. For example, 1 mV rms of noise in a 4-Ω speaker can create a *sound-pressure level* (SPL) of about 24 dB (assuming speaker sensitivity is of the order of 90 dB/W)—a level perceptible by human ears in a quiet environment. There are many possible sources of noise. As shown in Figure 1, among the major noise sources are power-supply noise, (V_G), filter/buffer noise, (V_F), and noise created by improper power ground layout, V_E. V_O is the audio signal from the processor, and V_{IN} is the audio signal input to a speaker's power amplifier.

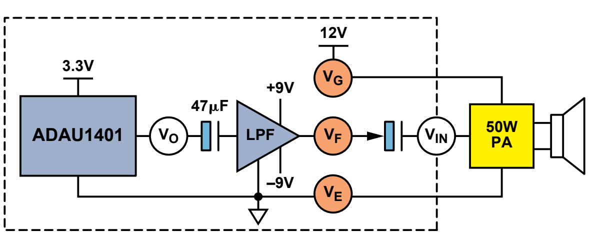

Figure 1. Example of noise sources in an automotive audio system.

Pop Noise During Power On/Off: Automotive audio power amplifiers operate on a single 12-V supply, while DSPs require a lower-voltage supply (for example, 3.3 V), and the filter/buffer operates with a split power supply (for example, ±9 V). Coupling capacitors are required to provide isolation between portions of the circuit operating at these different supply voltages and their differing grounds. During power on/off, capacitors will charge/discharge very quickly, creating a pulse that propagates down the chain, ultimately resulting in pop noise in the speaker. Figure 2 illustrates this process.

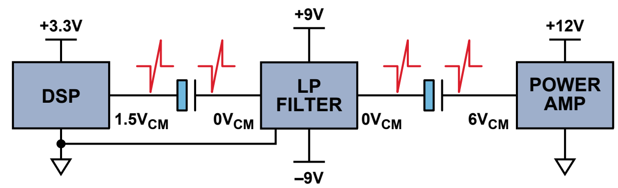

Figure 2. The concept of how pop noise is created in the speaker.

Although the sources of the noise floor and the pop noise are known, and despite efforts to minimize noise at the source through good circuit design and layout techniques—and selection of better devices with lower noise—many uncertainties may appear during design. Designers of automotive multimedia systems must deal with many complex issues, so they must possess a high level of analog/mixed-signal design skill. Even so, the prototype may not perform as originally expected; for example, a noise level of 1 mV rms poses a big challenge. As for pop noise, existing solutions use an MCU to control sequencing of the power amplifier during power on/off, but layout and electromagnetic interference (EMI) are potential problems when the central processor is distant from the power amplifier.

Power Consumption

As more electronics are included in the vehicle, power consumption becomes a bigger challenge. For example, if the audio power amplifier draws quiescent current of up to 200 mA, the power consumption is as much as 2.4 W with a 12-V supply. During times when no sound is required from the speakers, this significant amount of power could be saved if there were a way to detect absence of input signal and shut down the power amplifier without involving a remote processor.

Minimize Noise and Power Consumption of Auto Audio Systems

SigmaDSP technology offers an opportunity to minimize noise, while also saving a significant amount of power, without adding to the hardware cost. Figure 3 is a block diagram of a 4-speaker automotive audio system using an ADAU1401 SigmaDSP processor as the audio post-processor. Besides sampling, converting, digitally processing the audio signal, and generating the additional speaker channels, the SigmaDSP processor has a general-purpose input/output (GPIO) pin that is useful for external control. The microcontroller (MCU) communicates with the SigmaDSP processor via the I^2C interface, and the analog outputs drive a low-pass filter/buffer stage employing the ADA4075-2 precision op amp.

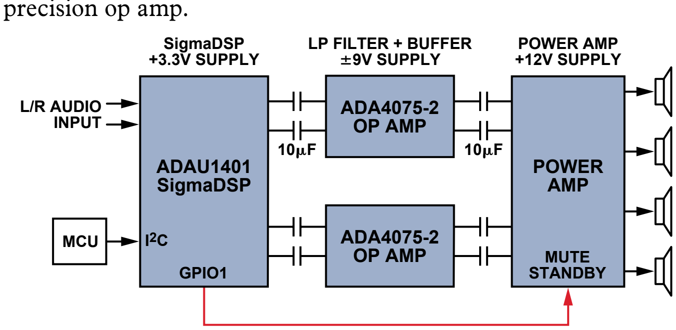

Figure 3. Automotive audio system with four speakers.

The red line between the SigmaDSP processor and the power amplifier controls the mute/standby pin of the power amplifier. In normal default operation, the open-collector GPIO1 pin is set high via a 10-kΩ pull-up resistor. The ADAU1401 has an rms signal detection function, which can be used to determine whether or not there is an input signal. With no input signal, GPIO1 goes low, putting the power amplifier in mute/standby mode, resulting in no amplifier output noise from the speaker, as well as low standby power consumption. When an input signal greater than a predetermined threshold (–45 dB, for example) is detected, GPIO1 goes high, allowing the power amplifier to work normally; the noise floor still exists, but the high signal-to-noise ratio (SNR) masks it, making it imperceptible to human ears.

During power on/off, the SigmaDSP processor, rather than the MCU, has direct control of the *mute/standby* of the power amplifier, but it responds to the MCU. For example, during power on, the I^2C signal from the MCU sets the SigmaDSP processor's GPIO1, keeping it low (mute) until the predetermined capacitor charging process is completed; then the MCU sets the GPIO1 high, thus eliminating pop noise due to start-up transients. On power off, the GPIO is immediately set low, putting the power amplifier in mute/standby, eliminating power off pop noise. By putting the power amplifier under direct control of the SigmaDSP processor, rather than the MCU, layout and EMI control are easier to implement because the SigmaDSP processor is located closer to the power amplifier.

As mentioned earlier, the rms signal level can be determined using a SigmaStudio software algorithm. Using the SigmaStudio graphical development tool, it is easy to set up the rms computation and use it to control the GPIO state, as shown in the example of Figure 4.

RMS detection is achieved by using rms cells and logic cells. The signal threshold includes hysteresis to eliminate chatter of the mute function in response to small changes; for example, the RMS1 threshold is set to –45 dB, and RMS2 is set to –69 dB. When the input signal is greater than –45 dB, GPIO1 is high; when the input signal is less than –69 dB, GPIO1 is low; when the input signal is between the two thresholds, the GPIO1 output signal remains at its previously acquired state (see Figure 5).

Figure 4 also includes compression to further reduce output noise; for example, when the input signal is less than –75 dB, the output signal to the speaker system will be attenuated to –100 dB, thus reducing the noise floor accordingly.

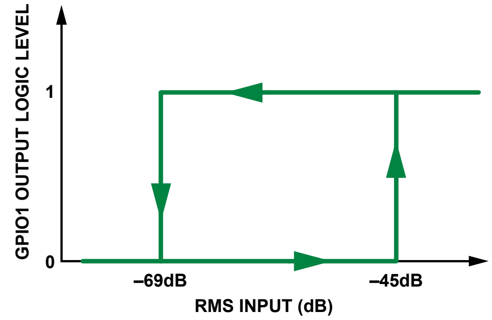

Figure 5. RMS threshold settings and the relationship between input and output.

Summary

Noise and power consumption present great challenges in automotive audio systems. ADI SigmaDSP processors, already widely used in automotive applications for digital audio post-processing, can be easily used to further advantage by employing their rms detection and GPIO control capabilities to minimize noise and reduce power consumption significantly. The SigmaStudio graphical development tool eases the design work by allowing functions to be set up graphically without any need for code writing. Furthermore, since the power amplifier module is physically much closer to the SigmaDSP processor than to the MCU, the use of the SigmaDSP processor to control the mute function makes layout work easier and improves EMI immunity.

References

(*Information on all ADI components can be found at www.analog.com.*)

[1] www.analog.com/en/embedded-processing-dsp/sigmadsp/processors/index.html.

[2] www.analog.com/en/embedded-processing-dsp/sigmadsp/processors/CU_over_SigmaStudio_graphical_dev_tool_overview/fca.html.

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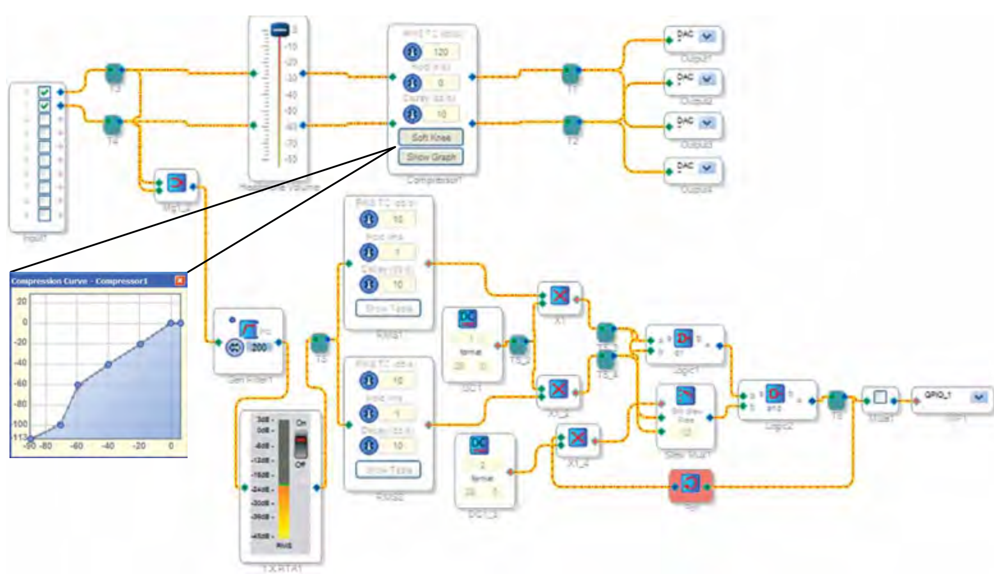

Figure 4. SigmaStudio schematic for rms detection, GPIO control, and compression.

Activate Cell Phone Indicator LEDs While Preserving Standby Time

By Jon Kraft

Cell phone manufacturers are increasingly pressed to provide status LEDs that can alert users to messages waiting, impending calendar appointments, and other notifications while the phone is in standby; indeed, several recent handset releases have received negative reviews for not having a notification LED. At the same time, users are demanding longer standby times from their phones. This pair of seemingly simple issues presents a surprisingly difficult dilemma to manufacturers: how can they power notification LEDs while keeping total standby consumption low?

Indicator LEDs are typically powered from a *power-management IC* (PMIC) or other small processor. This is satisfactory when the phone is awake, but the processor must keep track of the timing to automatically enable and disable each LED, even in sleep mode. Powering the entire PMIC for this function can add several milliamperes to the standby current draw. Table 1 provides an example of data and calculations showing that the average power consumption is dominated by the off-time quiescent current drain.

Table 1. Current Drain and Power Consumption with 7.5-s-*Off*/300-ms-*On* Blink Pattern, 10-mA LED Current, and 3.7-V Input

Power Management	Iq, Off	Iq, On	Iq, Average	Power Consumption
Standard PMIC	5 mA	15 mA	5.39 mA	19.9 mW
ADP8866	300 μA	11 mA	710 μA	2.6 mW
Lossless	0 μA	10 mA	385 μA	1.4 mW

The ADP8866 LED driver, uniquely configured to deal with this challenge, is easily programmed to execute autonomous lighting programs on up to four indicator LEDs, with each LED having an off-time range from 100 ms to 25.2 seconds. When an autonomous lighting program is executing and the LEDs are off, the total IC current consumption is reduced to less than 300 μA. Also, since the ADP8866 controls all of the timing, the LEDs remain perfectly synchronized, even for complex or long-duration patterns. Consider the following two examples:

Example 1: Color Mixing Indicator LEDs

A mobile handset requires seven LEDs for its backlight display and two LEDs for indication. Due to cost and mechanical requirements, the handset manufacturer uses a *red/green* (RG) LED to implement efficient standby notification of three conditions: *message waiting*, *low battery*, and *calendar appointment*. For each of the three conditions a unique color is assigned to the LED: *red*, *green*, and *yellow* (red + green).

The ADP8866 offers an ideal solution to this common scenario, as shown in Figure 1. Seven of its nine LED channels illuminate the display; the red and green signals to the RG LED are controlled by the remaining two channels to generate the blink pattern shown in Figure 2.

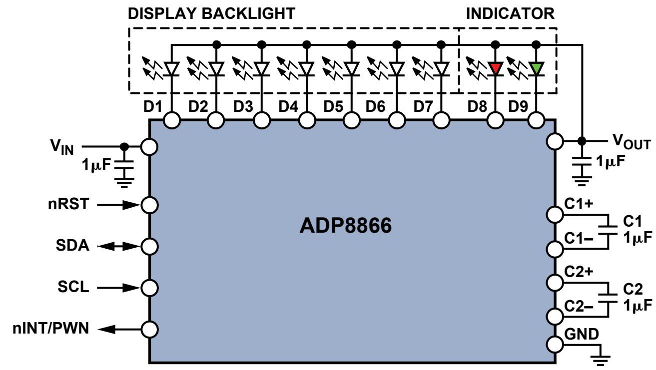

Figure 1. The ADP8866 is set up to control backlight illumination and indicator LEDs.

The evaluation board for the ADP8866 includes a graphical programming utility, shown in Figure 3; its I^2C registers are set to perform the indicator blinking.

The register settings shown in Figure 3 produce a 10-mA red (Sink 8) pulse for 250 ms, followed by a second 250-ms red pulse 500 ms after the first one turns off. The second red pulse draws half as much current (5 mA) to provide even intensity when paired with the green pulse to blink yellow. The green LED (Sink 9) has similar settings, but its first pulse is delayed. When the second green pulse has turned off, the system waits 12 seconds before repeating. When this sequence is enabled, all three colors will flash in repeating succession, as shown in Figure 2. If a red or green indicator is required, then only the first or third pulse is enabled. If only red and yellow notifications are generated, then the red LED is enabled for the first and second pulses, while the green LED is enabled for only the second pulse.

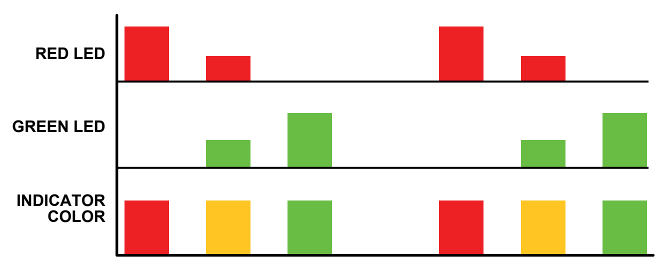

Figure 2. Red and green blinking pulse sequence with resulting colors.

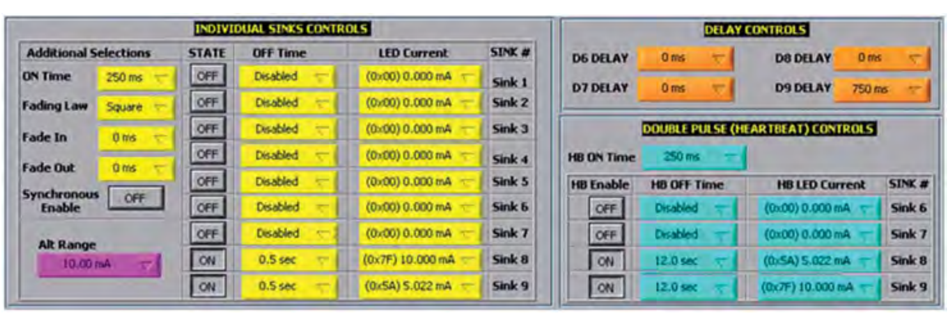

Figure 3. ADP8866 graphical user interface for programming indicator LEDs.

Because the red and green currents are reduced when they overlap, the same intensity is provided by all three indicator colors. Alternatively, the red and green currents can be varied to allow other colors in the RG spectrum to be produced. The width, off time, and magnitude of the pulses are fully customizable, so that a wide variety of effects are possible.

Example 2: High-Visibility Dynamic Indicator Displays

A portable electronic device requires a dynamic, high-visibility notification light that stands out from other background distractions. Once again, the ADP8866 is an ideal solution, as up to four of its LED channels (Sink 6 through Sink 9) can drive complex lighting sequences. The other five LED channels can be used for backlight or keypad lighting. In this example, Sink 6 through Sink 9 are set up to illuminate four LEDs from right to left, then left to right, repeating after a 10-second delay. The pattern is shown in Figure 4.

The fade-in time, fade-out time, and fade profile (square or cubic) are set for both 1st and HB (heartbeat) pulses. The DELAY parameter is adjustable from 0 seconds to 1.270 seconds in 10-ms increments. For this effect, DELAY is set to one-half of the fade-in time, but other delay settings could be used for different effects. The off time between the 1st pulse and the HB pulse is set by the first pulse OFF Time controls. For symmetry, these are set to multiples of the delay. The HB OFF Time sets the delay before the sequence is repeated. In this example, the wait time is 10 seconds, so the Sink 6 HB OFF Time is 10 seconds. The other three HB OFF Times are 10 seconds plus a multiple of the DELAY time. The register states for this sequence are shown in Figure 5.

This same programming method could also be used to generate fun light blinking, phone-ringing notifications, and other patterns. The automated fade-in and fade-out feature enhances the visual appeal of the effect, but the extra fade times cause a slight increase in average power dissipation. In any condition, when all of the LEDs are off, the ADP8866 automatically reverts to its sleep state—waking up in time to start the next LED sequence.

The ADP8866 combines a backlight LED charge-pump driver with automatic blinking functions—enabling independent programming of nine LED drivers at currents up to 25 mA. Current level, fade time, and blink rate can be programmed once and executed autonomously; and separate fade-in and fade-out times can be set for the backlight LEDs. The two-capacitor charge pump provides up to 240 mA from a 2.5-V to 5.5-V supply. The robust design provides integrated soft start, along with short-circuit, overvoltage, and overtemperature protection. Samples are available in 20-lead, 4-mm × 4-mm LFCSP (QFN) packages. Evaluation boards, graphical program, and documentation are also available.

References

(*Information on all ADI components can be found at www.analog.com.*)

Author

Jon Kraft [jon.kraft@analog.com] joined Analog Devices in 2007 and works as an applications engineer at the Power Management Design Center in Longmont, Colorado. He holds a BSEE from Rose-Hulman Institute of Technology and an MSEE from Arizona State University; he has been awarded three patents.

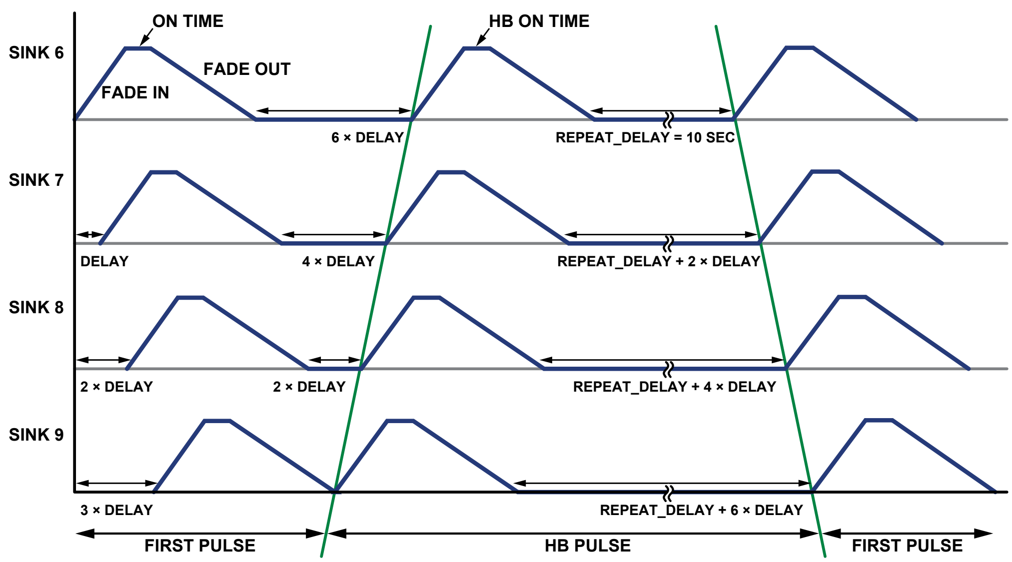

Figure 4. Four-channel dynamic indicator display.

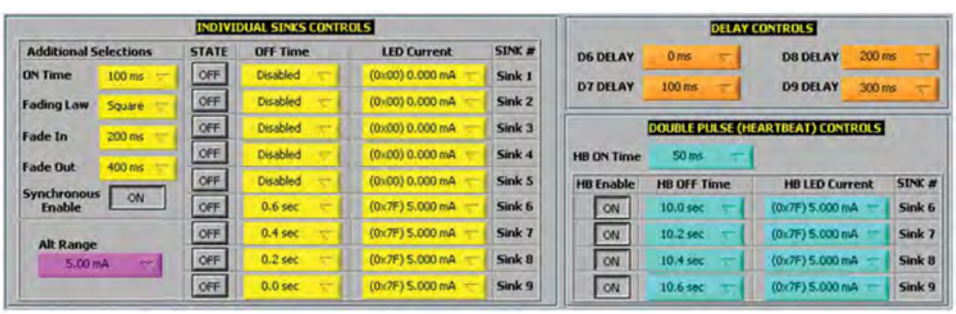

Figure 5. ADP8866 graphical user interface for programming dynamic indicators.

Cyclic Redundancy Checking Ensures Correct Data Communications

By Ken Kavanagh

Electronic systems operating in industrial environments must often endure temperature extremes, electrically noisy environments, or other harsh conditions—nevertheless, it is critical that they work correctly. For example, if the data sent to a DAC controlling the position of a robotic arm were corrupted, the arm could move in an unintended direction. This could not only be dangerous but costly: imagine the arm smashing into the side of a new car on a production line—or, worse yet, into a production worker.

Several methods are available to ensure that the correct data has been received before action is taken. The simplest is for the controller to read back the data that was sent. If the received data doesn't match the sent data, one of them has been corrupted—and new data must be sent and verified. This method is reliable, but it also comes with a large overhead: each piece of data must be verified, doubling the amount of data transferred.

An alternative, *cyclic redundancy checking* (CRC), is to send a checksum with each packet of data. The receiving device will indicate if a problem has occurred, so the controller does not need to verify reception. Checksums are commonly generated by applying a polynomial equation to the data. CRC-8 produces an 8-bit checksum when applied to a 24-bit word. Combining the checksum with the data, transmitting all 32 bits to a device that can analyze the combination, and indicating errors that occur—though not a totally perfect solution—is more efficient than the write-and-read method.

Many Analog Devices DACs implement CRC in the form of a *packet error check* (PEC). 24-bit data is written when the PEC function is not required. To add the PEC function, the 24-bit data is augmented with a corresponding 8-bit checksum. If the received checksum does not agree with the data, an output pin is brought low to indicate the error. The controller clears the error, returns the pin high, and resends the data. Figure 1 shows an example of how the data is applied using an SPI interface. Table 1 lists a sample of Analog Devices parts that can use packet error checking.

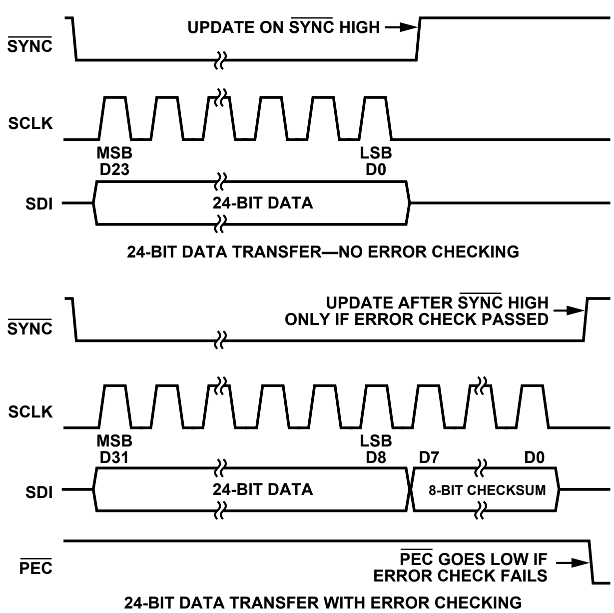

Figure 1. SPI write with and without packet error checking.

Table 1. Examples of Analog Devices Parts That Use Packet Error Checking

Part Number	Description
AD5360/AD5361	16-channel, 16-/14-bit, ±10-V DACs
AD5362/AD5363	8-channel, 16-/14-bit, ±10-V DACs
AD5748	Industrial current/voltage output driver
AD5749	Industrial current output driver
AD5750/ AD5750-1	Industrial current/voltage output drivers with programmable ranges
AD5751	Industrial current/voltage output driver
AD5755/AD5735	4-channel, 16-bit, 4-mA to 20-mA current- and voltage-output DACs
AD5757/AD5737	4-channel, 16-bit, 4-mA to 20-mA current-output DACs
ADT7470	Temperature sensor hub and fan controller

Generating the Packet Error Checksum

The CRC-8 algorithm uses the polynomial $C(x) = x^8 + x^2 + x^1 + 1$. For $x = 2$, this is equivalent to the binary value 100000111. To generate the checksum, the 24-bit data is left-shifted by eight bits to create a 32-bit number ending in eight Logic 0s. The CRC polynomial is aligned so that its MSB is adjacent to the leftmost Logic 1 of the 32-bit data. An exclusive-or (XOR) function is applied to the data to produce a new (shorter) number. (Numbers that match give Logic 0; nonmatches give Logic 1.) The CRC polynomial is again aligned so that its MSB is adjacent to the leftmost Logic 1 of the first result, and the procedure is repeated. Eventually, the original data will be reduced to a value that is less than the CRC polynomial. This is the 8-bit checksum. Figure 2 demonstrates how the checksum is developed.

```
INITIAL VALUE =    01100101010000110010000100000000 = 0x65432100
x^8 + x^2 + x^1 + 1 = 100000111
                    0100100100000011001000010000000
                     100000111
                        1000110001100100001000000000
                        100000111
                            11111110010000100000000
                            100000111
                             1111101111000010000000
                             100000111
                              111100000000100000000
                              100000111
                               11100111000100000000
                               100000111
                                1100100100100000000
                                100000111
                                 100101010100000000
                                 100000111
                                    10110110000000
                                    100000111
                                      1101011000000
                                      100000111
                                       101010110000
                                       100000111
                                         1010001000
                                         100000111
                         CHECKSUM = 10000110 = 0x86
```

Figure 2. Generating a checksum for a 24-bit number (0x654321).

Conclusion

The example shown in Figure 2 uses the (hex) value of 0x654321 as a sample 24-bit data word. Applying the CRC-8 polynomial to the data generates a checksum of 0x86. When the data and checksum are sent to a compatible Analog Devices product, the data will be accepted only if both pieces of data arrive correctly. This method increases the reliability of data transfers and ensures that corrupted data is almost never accepted.

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Low Dropout Regulators—Why the Choice of Bypass Capacitor Matters

By Glenn Morita

Widely seen as a panacea for solving noise-related issues, capacitors deserve more respect. Designers often think that adding a few capacitors will solve most noise problems, but give little thought to parameters other than capacitance and voltage rating. Like all electronic components, however, capacitors are not perfect. Instead, they possess parasitic effective series resistance (ESR) and inductance (ESL); their capacitance varies with temperature and voltage; they are sensitive to mechanical effects.

Designers must consider these factors when selecting bypass capacitors—as well as for use in filters, integrators, timing circuits, and other applications where the actual capacitance value is important. An inappropriate choice can lead to circuit instability, excessive noise and power dissipation, shortened product life, and unpredictable circuit behavior.

Capacitor Technologies

Capacitors are available in a wide variety of form factors, voltage ratings, and other properties to meet the requirements of diverse applications. Commonly used dielectric materials include oil, paper, glass, air, mica, polymer films, and metal oxides. Each dielectric has specific properties that affect its suitability for a particular application.

In voltage regulators, three major classes of capacitors are commonly used as voltage input- and output bypass capacitors: multilayer ceramic, solid-tantalum electrolytic, and aluminum electrolytic. The Appendix provides a comparison.

Multilayer Ceramic

Multilayer ceramic capacitors (MLCC) combine small size, low ESR, low ESL, and wide operating temperature range, making them the first choice for bypass capacitors. They are not without faults, however. Depending on the dielectric material, the capacitance can vary dramatically with temperature, dc bias, and ac signal level. In addition, the piezoelectric nature of the dielectric material can transform vibration or mechanical shock into an ac noise voltage. In most cases, this noise tends to be on the order of microvolts, but in extreme cases, mechanical forces can generate noise in the millivolt range.

Voltage-controlled oscillators (VCOs), phase-locked loops (PLLs), RF power amplifiers (PAs), and other analog circuits are sensitive to noise on their power-supply rails. This noise manifests itself as phase noise in VCOs and PLLs, amplitude modulation in RF PAs, and display artifacts in ultrasound, CT scans, and other applications that process low-level analog signals. Despite these imperfections, virtually every electronic device uses ceramic capacitors due to their small footprint and low cost. For regulators used in noise-sensitive applications, however, designers must carefully evaluate their side effects.

Solid Tantalum Electrolytic

Solid tantalum capacitors are less sensitive to the effects of temperature, bias, and vibration than ceramic capacitors. A recent variation uses a conductive polymer electrolyte instead of the usual manganese dioxide electrolyte, providing improved surge-current capability and eliminating the need for a current-limiting resistor. Lower ESR is an additional benefit of this technology. Solid tantalum capacitors have a stable capacitance with temperature and bias voltage, so the selection criteria need only account for the tolerance, voltage derating at the operating temperature, and maximum ESR.

Conductive polymer tantalum capacitors with low ESR cost more and are somewhat larger than ceramic capacitors, but may be the only choice for applications that cannot tolerate noise due to piezoelectric effects. The leakage current of tantalum capacitors is much larger than for equal-value ceramic capacitors, however, rendering them unsuitable for some low-current applications.

A drawback of the solid polymer electrolyte technology is that this type of tantalum capacitor is more sensitive to the high temperatures encountered in the lead (Pb)-free soldering process, with manufacturers typically specifying that the capacitors not be exposed to more than three soldering cycles. Ignoring this requirement in the assembly process can cause long-term reliability issues.

Aluminum Electrolytic

Conventional aluminum electrolytic capacitors tend to be large and have high ESR and ESL, relatively high leakage current, and limited service lifetimes—measured in thousands of hours. OS-CON capacitors employ an organic semiconductor electrolyte and an aluminum foil cathode to achieve low ESR. Although related to solid polymer tantalum capacitors, they actually preceded tantalum capacitors by 10 years or more. With no liquid electrolyte to dry out, the service lifetime of OS-CON type capacitors is better than that of conventional aluminum electrolytic capacitors. Most are limited to 105°C, but OS-CON type capacitors capable of 125°C operation are now available.

Although the performance of the OS-CON type capacitor is better than that of conventional aluminum electrolytic capacitors, they tend to be larger and have higher ESR than ceramic or solid polymer tantalum capacitors. Like solid polymer tantalum capacitors, they do not suffer from the piezoelectric effect, so they are suitable for use in low-noise applications.

Selecting Capacitors for LDO Circuits

Output Capacitor

Low-dropout regulators[1] (LDOs) from Analog Devices can operate with small, space-saving ceramic capacitors as long as they have low effective series resistance (ESR); the ESR of the output capacitor affects the stability of the LDO control loop. A minimum capacitance of 1 μF with a maximum ESR of 1 Ω is recommended to ensure stability.

The output capacitance also affects the regulator's response to changes in load current. The control loop has finite large-signal bandwidth, so the output capacitor must supply most of the load current for very fast transients. When the load current switches from 1 mA to 200 mA at 500 mA/µs, a 1-µF capacitor, unable to supply enough current, produces a load transient of about 80 mV, as shown in Figure 1. Increasing the capacitance to 10 µF reduces the load transient to about 70 mV, as shown in Figure 2. Increasing the output capacitance further, to 20 µF, allows the regulator control loop to track, actively reducing the load transient as shown in Figure 3. These examples use the ADP151 linear regulator with a 5-V input and a 3.3-V output.

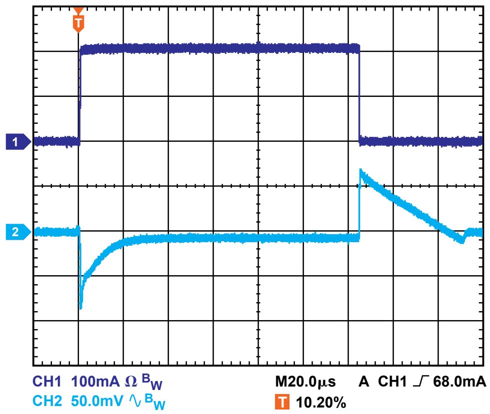

Figure 1. Transient response with C_{OUT} = 1 µF.

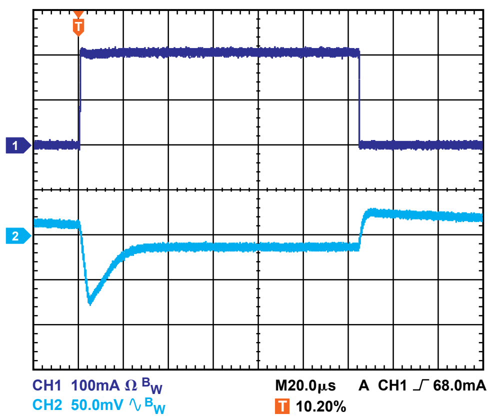

Figure 2. Transient response with C_{OUT} = 10 µF.

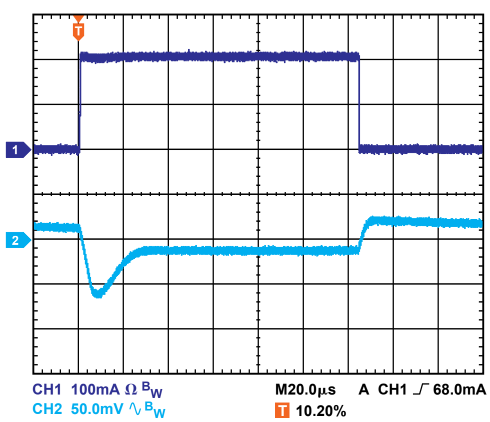

Figure 3. Transient response with C_{OUT} = 20 µF.

Input Bypass Capacitor

Connecting a 1 µF capacitor from V_{IN} to GND reduces the circuit's sensitivity to printed circuit board (PCB) layout, especially when long input traces or high source impedance are encountered. Increase the input capacitance to match the output capacitance when more than 1 µF is required on the output.

Input and Output Capacitor Properties

The input and output capacitors must meet the minimum capacitance requirement at the intended operating temperature and working voltage. Ceramic capacitors are available with a variety of dielectrics, each with different behavior vs. temperature and voltage. X5R or X7R dielectrics with a 6.3-V to 10-V voltage rating are recommended for 5-V applications. Y5V and Z5U dielectrics have poor characteristics vs. temperature and dc bias, so they are not suitable for use with LDOs.

Figure 4 shows the capacitance vs. bias voltage characteristic of a 1-µF, 10-V X5R capacitor in a 0402 package. The capacitor's package size and voltage rating strongly influence its voltage stability. In general, a larger package or higher voltage rating will provide better voltage stability. The temperature variation of the X5R dielectric is ±15% over the −40°C to +85°C temperature range and is not a function of package or voltage rating.

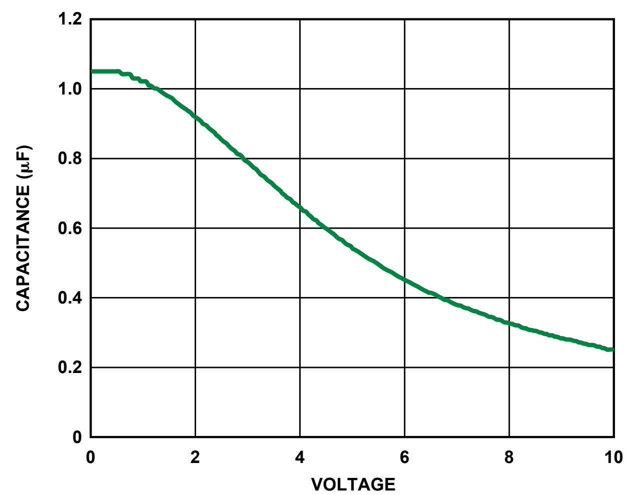

Figure 4. Capacitance vs. voltage characteristic.

To determine the worst-case capacitance over temperature, component tolerance, and voltage, scale the nominal capacitance by the temperature variation and tolerance, as shown in Equation 1:

$$C_{EFF} = C_{BIAS} \times (1 - TVAR) \times (1 - TOL) \qquad (1)$$

Where C_{BIAS} is the nominal capacitance at the operating voltage; *TVAR* is the worst-case capacitance variation over temperature (as a fraction of 1); *TOL* is the worst-case component tolerance (as a fraction of 1).

In this example, *TVAR* is 15% from −40°C to +85°C for an X5R dielectric; *TOL* is 10%; C_{BIAS} is 0.94 µF at 1.8 V, as shown in Figure 4. Using these values in Equation 1 yields:

$$C_{EFF} = 0.94\ \mu F \times (1 - 0.15) \times (1 - 0.1) = 0.719\ \mu F$$

The ADP151 specifies a minimum output bypass capacitance of 0.70 µF over the operating voltage and temperature range, so this capacitor meets this requirement.

Conclusion

To guarantee the performance of an LDO, the effects of dc bias, temperature variation, and tolerance of the bypass capacitor must be understood and evaluated. In applications that require low noise, low drift, or high signal integrity, the capacitor technology must also be considered. All capacitors suffer from the effects of nonideal behavior, so the capacitor technology chosen must match the needs of the application.

Appendix

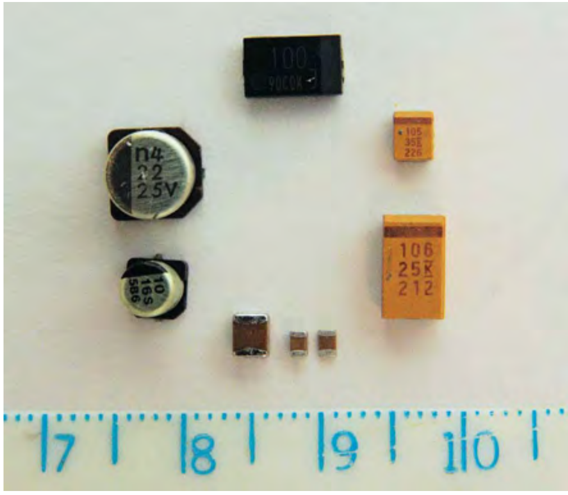

Figure A. Capacitors commonly used for bypassing power supply rails.

Clockwise from top, scale in millimeters:
100-µF/6.3-V polymer solid aluminum capacitor
1-µF/35-V and 10-µF/25-V solid tantalum capacitor
1-µF/25-V, 4.7-µF/16-V, 10-µF/25-V multilayer ceramic capacitor
10-µF/16-V, 22-µF/25-V aluminum electrolytic capacitor

Further Reading

AN-1099 Application Note, *Capacitor Selection Guidelines for Analog Devices, Inc., LDOs*

References

(*Information on all ADI components can be found at www.analog.com.*)

[1] www.analog.com/en/power-management/linear-regulators/products/index.html.

Author

Glenn Morita [glenn.morita@analog.com] graduated from Washington State University with a BSEE in 1976. His first job out of school was at Texas Instruments, where he worked on the infrared spectrometer instrument for the Voyager space probe. Since then, Glenn has worked as a designer in the instrumentation, military and aerospace, and medical industries. In 2007, he joined ADI as an applications engineer with the Power Management Products Team in Bellevue, WA. He has over 25 years of linear and switch-mode power supply design experience at power levels ranging from microwatts to kilowatts. Glenn holds two patents for harvesting energy from body heat to power implantable cardio-defibrillators. In his spare time, he enjoys collecting minerals, faceting gemstones, photography, and visiting the national parks.

Comparison of Critical Parameters of Various Capacitor Technologies

Capacitor Technology	Effective Series Resistance	Effective Series Inductance	Voltage Stability	Temperature Stability	Sensitivity to Vibration	Capacitance/ Unit Volume
Aluminum Electrolytic	Highest	Highest	Good	Lowest	Low	Low
Solid Tantalum	Medium	Medium	Best	Good	Low	High
Polymer Solid Aluminum	Low	Low	Best	Good	Low	High
Multilayer Ceramic	Lowest	Lowest	Poor	Good	High	Medium

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