

# Analog Dialogue

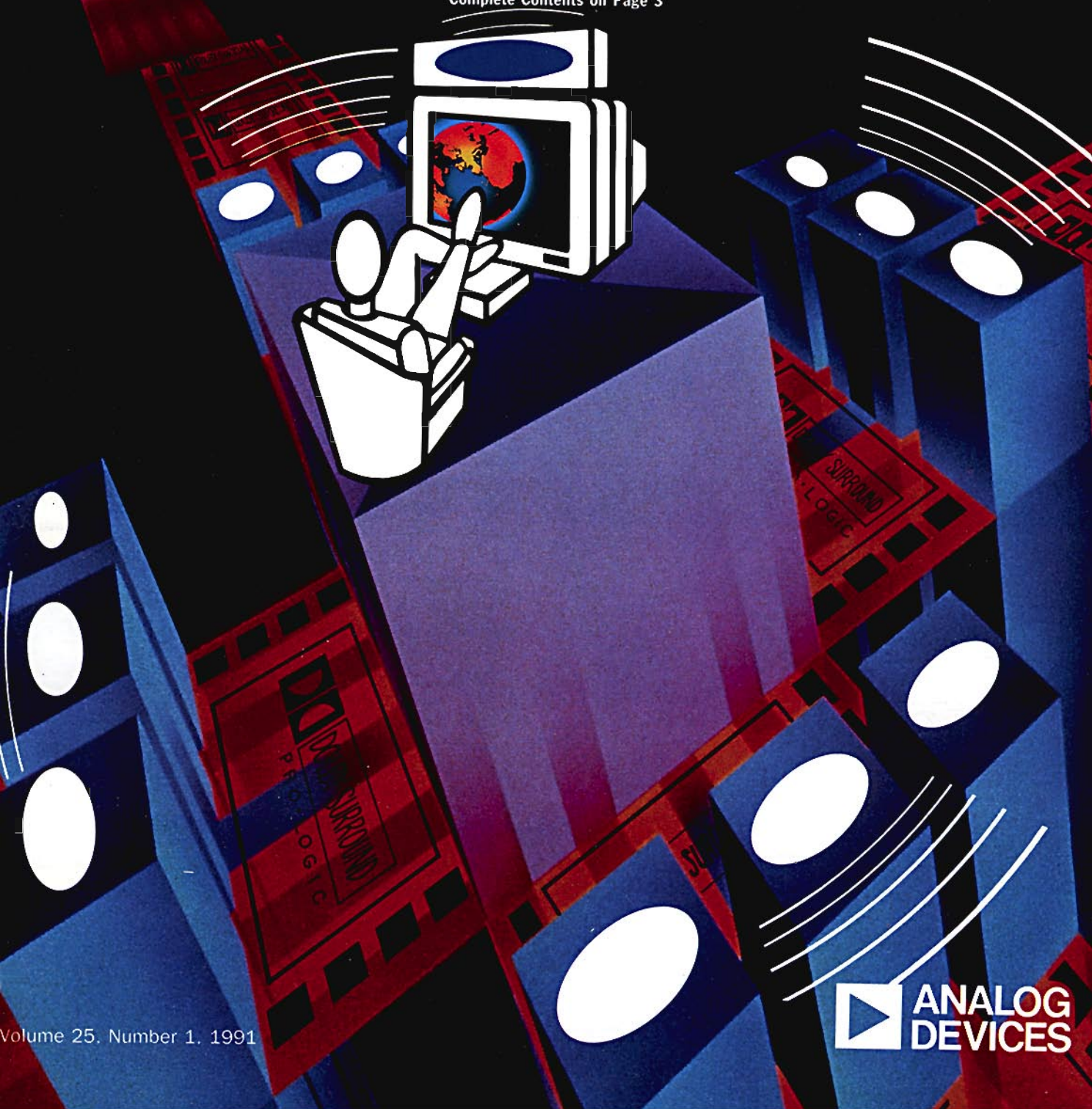
A forum for the exchange of circuits, systems, and software for real-world signal processing

**PRO-LOGIC DECODER: DOLBY SURROUND SOUND FOR THE HOME** (page 3)

Phase accumulator for direct digital synthesis (page 10)

FET-input op amp has lowest  $V$  and  $I$  noise (page 12)

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# Editor's Notes

## 25 YEARS OF ANALOG DIALOGUE

This is the first issue of our 25th year in print. Such round-number anniversaries pose an opportunity for both retrospection and pro-spection. While this issue will be only mildly retrospective (page 17), the next issue will contain a collection of *Analog Dialogue* articles that have retained their usefulness, are still timely, and have been requested by our readers. In a later issue during this year, we hope to summon up the courage to ruminate about our vision of the future of Analog Devices and *Analog Dialogue*—as we look forward to the next quarter-century of this publication.

## PAUL BROKAW: IEEE FELLOW

We are pleased to note that A. Paul Brokaw has been named a Fellow of the Institute of Electrical and Electronics Engineers (IEEE) "for innovations in analog circuit design." According to the IEEE's bylaws, the status is "conferred only by invitation of the Board of Directors upon a person of outstanding and extraordinary qualifications in [the IEEE-designated fields], who has made important individual contributions to one or more of these fields."

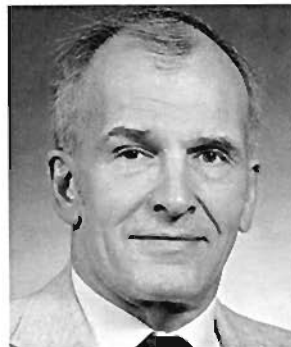
Paul, a Fellow at Analog Devices (one of the highest levels of technical advancement within the Company)<sup>1</sup> is principally an integrated-circuit designer; his work includes the design of monolithic converters, references, and amplifiers. The automotive sensor, discussed on pages 8-9 of this issue, is one of his most-recent designs.

Other significant products he has designed, or participated in the design of, include the AD694 current transmitter (*Analog Dialogue* 24-3, 1990), the AD594 thermocouple signal conditioner (1982), the AD571 complete monolithic a/d converter (1978), the AD521 instrumentation amplifier (1975), and the landmark AD580 2.5-volt bandgap reference (1974). He has also written articles on such practical matters as grounding and bypassing and served as mentor to a generation of designers.

He has more than 50 patents (issued and pending), primarily in circuit design. He has written papers for and served on the program committee of IEEE's International Solid-State Circuits Conference (ISSCC)—and has been an author and guest editor for the *IEEE Journal of Solid-State Circuits*.

Paul has a BS in Physics from Oklahoma State University. His career prior to joining ADI in 1971 includes the design of geophysical instruments at Well Surveys, Inc., the design of instruments for spacecraft at Labko Scientific, Inc., consulting for industrial, scientific, and military clients at Arthur D. Little, Inc., and designing telephone plant and subscriber equipment at Communication Technology, Inc.

Dan Sheingold




## THE AUTHORS

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James Bryant (page 24) is European Applications Manager for ADI, based in Newbury, England. A graduate of the University of Leeds, he earned a B.Sc. in Physics and Philosophy. He has 22 years of applications experience, both at Plessey and ADI. James has numerous publications on a wide range of topics and served as a technical adviser to Parliament on CB radio. His diverse interests include amateur radio (G4CLF), collecting science fiction (>3k volumes), hypnotism, and parapsychology.

Bill Schweber (page 3) is a Senior Technical Marketing Engineer and Contributing Editor to *Analog Dialogue*. Besides having his BSEE and MSEE degrees, he has designed  $\mu$ P-based machine controls, been a product marketing engineer, and written three textbooks. He contributes numerous articles to *Analog Dialogue* and the electronics press—many of which introduce new products to the market.

Ian Bruce (page 8) is a Senior Technical Marketing Engineer in the Marketing Communications Group in Norwood, MA. In over 5 years with Analog Devices, he has worked in design, marketing, and sales in the USA and England (his native country). Ian holds a B.Sc. degree in Electrical Engineering from Coventry College. His interests include reading, travel, and a reluctant MG sports car. 

The cover illustration symbolizes the role of Pro-Logic Surround Sound in heightening cinematic realism in the living room. It was designed and executed by Shelley Cohane, based on a photograph copyrighted by Roy Wiemann, c/o the Image Bank.

## Analog Dialogue

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# Dolby® Pro-Logic Surround Sound Decoder for Audio Realism

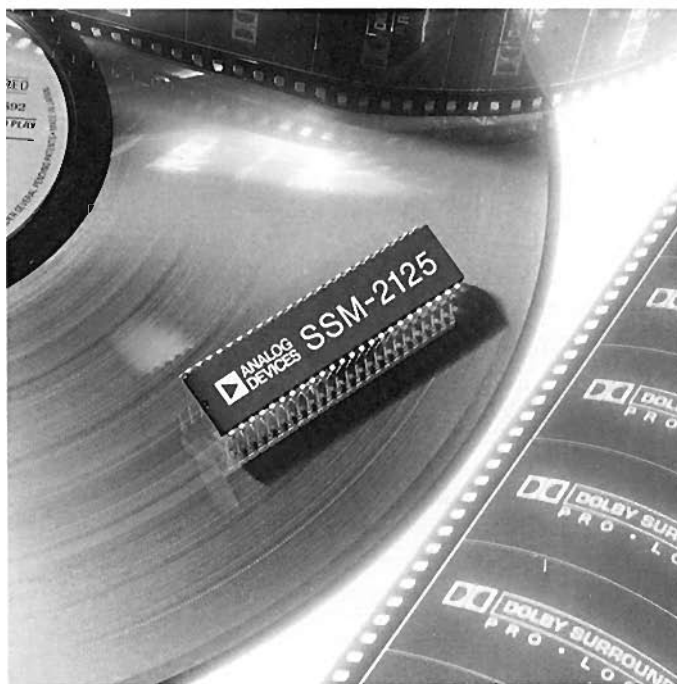
**SSM-2125 IC makes home Surround Sound practical, exciting. Also featured: Analog's wide variety of ICs for audio.**

by Bill Schweber

The SSM-2125 Dolby® Pro-Logic Surround Sound Matrix Decoder,\* a monolithic IC, provides multi-channel audio outputs, decoded from stereo sources which have been encoded using Dolby Surround [see box on Audio Realism and Surround Sound, page 5]. With this device, the benefits of Surround Sound—heretofore limited to movie theaters—are now available to consumer systems in a form for easier application and considerably lower cost than the equivalent commercial circuitry.

The IC—an example of advanced analog signal processing—implements all of the core functions of Pro-Logic, including auto-balance, noise generation, the active decoding matrix, and center-channel mode control.<sup>1</sup> Though designed for three- or four-channel decoding, it has a bypass mode to handle conventional two-channel stereo sound. All modes of operation are controlled by a TTL/CMOS-compatible parallel interface.

To provide all the required Pro-Logic Surround-Sound functions, the IC contains 30 op amps, ten low-noise voltage-controlled amplifiers (VCAs), a new circuit element called an *operational conveyor amplifier*, two dual-output rectifiers, and two log-difference amplifiers, plus comparators, logic circuitry, and a digital noise source. These devices are combined in six major functional blocks: control-logic decoder, noise generator, input switching and autobalance circuit, steering-signal generator, decoder matrix, and output switching circuit. (Figure 1).



The SSM-2125 is fabricated on an advanced BiCMOS process with complementary fully isolated N- and P-channel MOS, plus vertical NPN and PNP bipolar transistors, oxide capacitors; and laser-trimmable thin-film resistors. The 54,000-square-mil (35 mm<sup>2</sup>) chip, housed in a 48-pin plastic DIP, contains about 2,000 active devices and operates from a single +12- to +16-V supply or a dual  $\pm 6$ - to  $\pm 8$ -V supply. Price is \$15 in 100s.

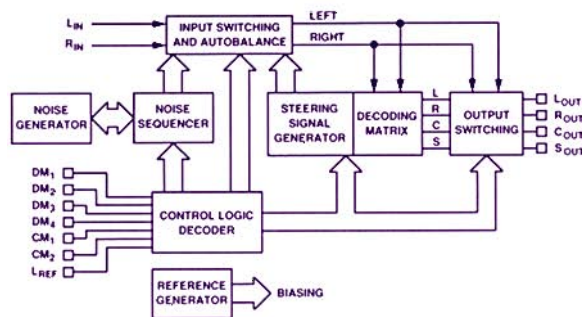


Figure 1. SSM-2125 Block Diagram.

\*Use the reply card for technical data. Circle 1.

Dolby® is a registered trademark of Dolby Laboratories Licensing Corporation. The SSM-2125 is available only to licensees of Dolby Labs; for licensing information, write to Dolby at 100 Potrero Ave., San Francisco, CA 94103—or phone (415) 558-0200.

<sup>1</sup>Henry, P.S. "An Analog LSI Dolby Pro-Logic Decoder IC," Audio Engineering Society, 1990 Convention.

Quain, John R. "Sound in the Round," Video Review, September 1990.

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**Features and Performance** Due to the high level of integration, few external components (plus loudspeakers and power amplifiers) are needed for a complete Pro-Logic system with the SSM-2125. The chip includes a noise generator—a convenience for setup—and autobalance circuits. Autobalance can be switched on or off. Modes of operation include both full 4-channel Pro-Logic and Dolby 3-channel (left, right, and center channels). The center channel can be selected for normal, *off*, wideband, and “phantom” modes. Finally, a direct-path bypass permits operation in the conventional two-channel stereo mode.

Channel separation between any two channels is typically 35dB. The overall dynamic range of the circuitry is 102dB, with total harmonic distortion (THD) of 0.025% (Figures 2 and 3).

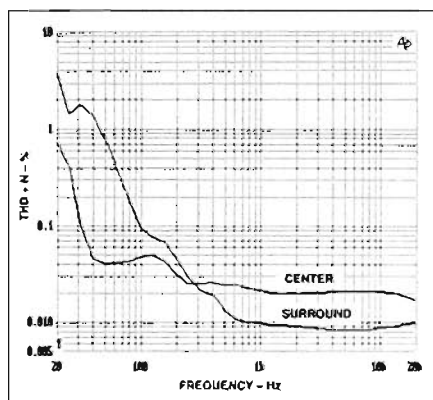


Figure 2. THD+N vs. frequency, Center and Surround channels,  $V_{in} = 500 \text{ mV rms}$ ,  $R_L = 100 \text{ k}\Omega$ .

**Control Logic:** Six digital control lines set the operating modes, including autobalance on/off, Pro-Logic decoding on/off, 3/4-channel logic selection, and noise-source selection. An LREF pin allows the designer to shift the digital input reference between ground and the negative supply, as necessary, for compatibility with single or dual supplies. The digital inputs are level-shifted by CMOS comparators (with threshold at 1.4 V above LREF), then decoded by a dedicated logic array into control signals for the various functions within the IC.

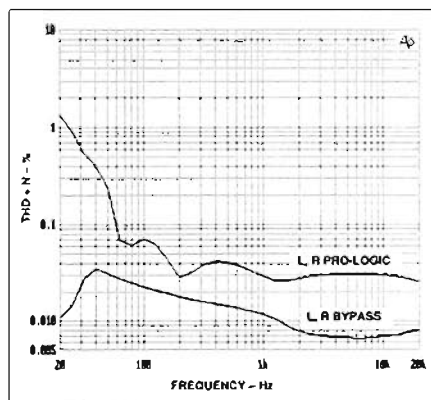


Figure 3. THD+N vs. frequency, L and R Channels in Pro-Logic and Bypass modes.  $V_{in} = 500 \text{ mV rms}$ ,  $R_L = 100 \text{ k}\Omega$ .

**Noise Generator:** Optimal performance of the installed system requires proper balance of the speaker volumes between the different channels. Although inclusion of a noise source seems dissonant with the fundamental goal of a high-fidelity audio system,

noise is very useful as the balance set-up signal, since it would be difficult for a listener to localize the source direction of a single-frequency tone. The SSM-2125 noise source generates a  $(2^{17}-1)$ -step pseudorandom sequence; it consists of a 17-stage shift register (followed by output filter) clocked at 40 kHz. The clock circuitry is contained entirely within the IC, with frequency set by RC oscillators using feedback around logic inverters.

**Steering Signal Generator & Decoding Matrix:** The steering signal generator and the decoding matrix (Figure 4) function as the analog-computer “brains” of the decoder. The left and right signals from the input switching and autobalance block are first bandpass-filtered by the steering signal generator, limiting signals to the 200- to 5,000-Hz range. The circuitry then computes signal amplitudes of the center ( $L + R$ ) and surround-sound ( $L - R$ ) signals. This control-path circuitry uses simple, compact, current-efficient CMOS-input, bipolar-output amplifiers having good output drive and signal headroom (noise is not important here—and low-noise bipolar amplifiers *are* used in the audio signal path).

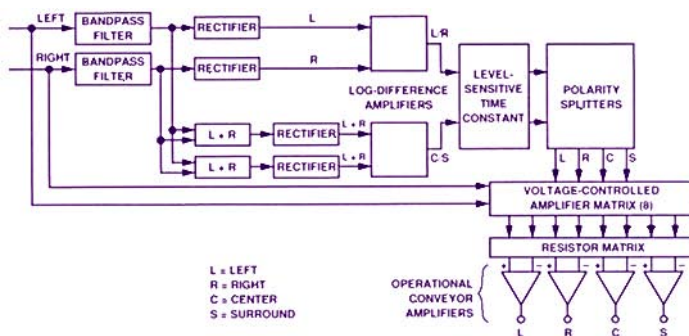


Figure 4. Signal-steering generator and decoder matrix.

Next, the four signals: L, R, ( $L + R$ ), and ( $L - R$ ), are full-wave-rectified and converted to current. The currents representing the L and R amplitudes are fed to the collectors of a differential NPN transistor pair, and the difference in base-emitter voltages is amplified, producing the log-difference (log of the amplitude-ratio) function. The output from this section corresponds to deflection, in dB, along the left-right (L/R) axis. Any offsets at this stage are minimized by laser-trimming.

The ( $L + R$ ) and ( $L - R$ ) signals are processed in the same way to produce a center-surround (C/S) axis signal [log of the ratio of ( $L + R$ ) and ( $L - R$ ) signals]. The C/S and L/R axis deflection signals describe the vector direction of the dominant sound in a set of Cartesian coordinates.

The log-ratio axis signals next pass through a filter circuit with a level-sensitive time-constant; it speeds up the steering response when there is strong directional information present. (The internal resistors for these time constants are laser-trimmed to better than 5% of nominal value (0.4 dB), to allow use of higher-tolerance external capacitors.) The resulting signals are transformed into control voltages for the VCAs in the decoding matrix. If the digital control signals indicate that 3-channel logic has been selected, the surround signal is ignored, leaving the sole information in the L, R, and ( $L + R$ ) channels.

The decoding matrix contains eight VCAs. The input V-to-I resistors of the VCAs are laser-trimmed to establish the necessarily close gain match. The L and R inputs, after buffered processing by the input switching block, become the inputs of the VCAs.

Since the current outputs of the VCAs have limited compliance range—and to avoid the need to buffer the outputs, which would consume die area—the VCA outputs are summed directly as currents and converted to the four output voltages.

Each summing block has two virtual ground inputs (one inverting and one non-inverting), using an *operational conveyor amplifier*—essentially an optimized pushpull current-summing operational amplifier (patent pending) developed expressly for this purpose.<sup>2</sup> The outputs of the conveyor amplifiers, the basic decoded left, right, center, and surround decoded audio signals, go to the output switching network for final processing.

**Input Switching And Autobalance:** The autobalance function automatically compensates for left/right imbalances in the recorded source material. This dramatically improves the center-channel *dialogue separation* (insuring that voices seem to emanate from the screen vicinity of the persons speaking).

In the SSM-2125, the autobalance function is achieved by controlling the left-axis and right-axis signals from the steering-signal generator. Combinations of these signals indicate deflection along a center-surround and left-right axis. When a strong center signal is detected (indicating that much of the sound originates in the center, i.e., on-screen), a servo loop is activated to adjust the left-right balance for zero average deflection.

The corrected left-right axis signal is amplified, passed to a low-noise MOSFET buffer via a filter and hold capacitor, which drives the control ports of complementary VCAs that control the left- and right-input gains. To eliminate audible “wandering”, the response time-constant of the servo loop is about one minute. When no strong center signal is present, the servoloop is cut out and the stored value on the capacitor is used to maintain balance control. Autobalance, available in both Pro-Logic and stereo-bypass modes, will correct up to 4 dB of balance error.

The inputs to the decoding section pass through the autobalance VCAs (or through bypass buffers when autobalance is switched off). When noise input is selected, the external inputs are turned off and noise, encoded to the desired channel, is switched to the inputs of the decoder. All analog signal-path switches are designed to minimize irritating audible clicks, associated with switching, by using relatively long rise and fall times and minimum-geometry (hence low-stored-charge) logic.

**Output Switching:** This block establishes several of the SSM-2125's operating modes. In one, Pro-Logic decoding may be defeated entirely, bypassing the entire decoding matrix and providing minimal audio system noise and distortion. Another is a full *mute* function; it quiets all channels.

The center channel has four modes: normal, wide, phantom, and off. In *normal* mode, the left and right outputs respond to the entire audio band, but in the center channel—whose principal function is to localize speech—the bass is attenuated by a 100-Hz single-pole highpass filter. This permits smaller, more-economical loudspeakers to be used for the center channel, since effective low-frequency audio output usually requires relatively large woofers. *Wide* mode passes the full center channel without any filtering, while *phantom* mode turns the center channel's output off and divides its power equally between the left and right speakers. The

## AUDIO REALISM AND SURROUND SOUND

*Audio* identifies signals and circuits in the range of human hearing, about 20 to 20,000 Hz. Its meaning is usually expanded to include systems for the capture, storage, and reproduction of high-fidelity music and voice—a familiar area to many budding electronic engineers. (Though now involved in other specialities, their first initiation into electronic circuitry, construction, and realities was through experimenting with home audio systems.)

The first audio systems had a single channel of information. These *monophonic* systems could achieve ever-lower distortion and noise, but they could not reproduce the three-dimensional realism of an actual performance. *Stereophonic* systems, first commercially practical in the 1950s, use two independent audio channels and two speakers to more faithfully recreate the sonic wavefront of the original performance in the listening area. In the 1970's, four channels were used in “quadraphonic” home systems in the hope of substantial improvement over stereo—but this multi-channel approach failed for a variety of technical and market reasons.

Multi-channel sound first reached the public in the '30's with Disney's *Fantasia*, using multiple sound tracks and speakers. However, the use of even the now-standard two-track stereo sound systems in movie theaters added extra realism to the action on the screen. A properly installed audio system (with multiple speakers) and appropriate recording gave the viewer the sensation of being totally enveloped by the picture—and the action. For more channels, however, an encoding scheme is needed, since the film has only two optically recorded sound tracks.

In 1975, Dolby Laboratories introduced Dolby Stereo for theaters; it encodes/decodes the two sound tracks into a front left-, front right-, center-, and rear “surround” channel. Dolby Stereo was used for the impressive sound that accompanied the 1977 release of *Star Wars*. The scheme is effective even with quiet scenes, such as realizing a voice and its echoes (e.g., the cave scene in *Dead Poets Society*). Some 2,300 films have been encoded with this format, as is almost every new film.

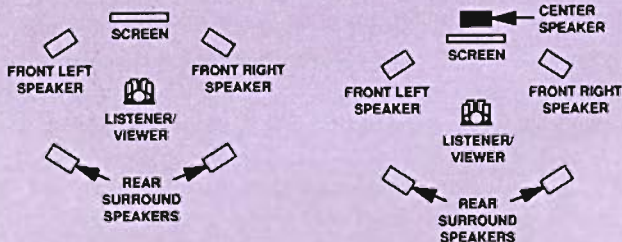
In 1981, a system called Dolby Surround was developed to decode Dolby Stereo from Dolby-encoded film, which has been transferred to videotape or disk, for non-theater (including home) use. The complete system requires a Dolby-encoded audio track, a Dolby decoder, and a stereo VCR or laser-disc player. (Some television broadcasts now have Dolby encoded stereo sound.)

“Surround” sound's characteristics are described in such terms as steering, depth, air, and localization. *Steering* means that surround sound can direct parts of the audio to specific speakers, not just to left side and right side. With *depth*, sounds seem to come from behind the visual point where the dialogue or primary sound originates. When sounds seem to come from all around (the listener is surrounded by the scene and its sound), the phenomenon is known as *air*. Finally, *localization* means that the listener can follow the sound's location in three dimensions, such as when an airplane appears to pass overhead and cross the screen or a sound comes from off-screen. These characteristics have to be managed carefully by the signal-processing circuitry to preserve the acoustic balance and ambience of the entire setting.

Dolby Surround, a passive system, decodes three channels without steering or enhancement. Passive surround (left figure) has front L and R speakers—plus surround speakers in the rear,

<sup>2</sup>Bowers, D.F. & J.E.C. Brown, “The Operational Conveyor Amplifier—A New Circuit Design Block,” *IEEE ISCAS Digest of Technical Papers*, Volume 1, May 1990.

which create an ambience sound (through a signal delay, among other factors). The illusion of a center channel comes from the two front speaker channels, giving the aural effect of a center speaker between them—a phantom channel. Channel separation is 3 dB, and the sound can be optimally localized only at particular spots within the listening (hence viewing) area.



Passive Surround Sound setup.

Pro-Logic Surround Sound setup.

Dolby Pro-Logic Surround, introduced in 1987, enhances the original passive method and is virtually identical to professional cinema systems. It offers additional noise reduction, improved channel separation, increased clarity in steering, plus the addition of a true center channel output for a fifth speaker (right figure). The fifth speaker, located above the screen, helps focus attention on the screen—especially useful for dialogue. Separation increases to at least 25 dB; in addition, the added center channel lets the voices seem to come from the screen regardless of where the listener is seated.

center-off function can be used to adjust balance, by reducing the “leakage” of dialogue into the other channels.

The switches in the audio path are all MOS transmission gates, buffered by bipolar amplifiers, just as in the input switching network. All outputs are capable of driving 600-Ω loads.

**Pro-Logic Encoding:** The Pro-Logic scheme for encoding the audio information onto the two film channels (sound tracks) is:

- *Left* and *Right* are recorded directly onto the L & R channels.
- *Center* is recorded 3-dB down and added in-phase in both left and right channels.
- *Surround* is recorded 3-dB down and phase shifted by  $-90^\circ$  to the left channel and  $+90^\circ$  to the right channel.

### OTHER AUDIO-ICs

The SSM-2125 Decoder is a highly sophisticated component for modern audio systems, just one of the numerous specialized IC components from Analog Devices, each intended to optimize a specific portion of a professional- or consumer audio-signal-processing system. Here’s a brief sampling:<sup>3</sup>

The SSM-2017 Self-Contained Audio Preamplifier<sup>4</sup> in an 8-pin mini-DIP (or 16-pin SOIC) requires only a single external fixed resistor or potentiometer to set any gain in the range of 0 to 60 dB). With a true-differential-input, it is well-suited for use as a microphone preamplifier, bus (line) summing amplifier in audio mix consoles, and even in sonar applications.

<sup>1</sup>Data sheets for 26 SSM- products—and 19 application notes—appear in the SSM Audio Products *Audio Handbook*, available free. Circle 2.

<sup>2</sup>Use the reply card for technical data. Circle 3.

<sup>3</sup>Use the reply card for technical data. Circle 4.

<sup>4</sup>Use the reply card for technical data. Circle 5.

Noise performance in a preamp is critical: the SSM-2017 features a noise figure of 1 dB and spectral density of  $850 \text{ pV}/\sqrt{\text{Hz}}$ . THD is less than 0.01% at gain of 100 over the full audio band. The device is unity-gain stable, with 250-kHz bandwidth at gain of 100; slew rate is 14 V/ $\mu\text{s}$ . The amplifier can develop outputs of up to 10 V rms into 600-Ω loads. Price is \$1.80 in 100s.

The SSM-2018 Voltage-Controlled Amplifier<sup>†</sup> is an audio “gain-block” for use in panning, equalization, remote volume control, and compressor/limiter applications. Within this device, a unique Operational Voltage Controlled Element architecture (OVCE, U.S. patents 4,471,320 and 4,560,947) allows the design of many voltage-controlled functions through simple feedback connections using passive elements only. This amplifier features differential inputs and outputs, and the user can select either current or voltage operation.

With a single external resistor, the user can program the SSM-2018 gain core for Class A, Class AB, or an intermediate class of operation. Traditionally, Class A amplifier operation offers lower distortion than Class B, but signal-to-noise ratio is degraded. In this device, distortion increases but little with class AB, so users can realize both improved noise and low distortion (Figure 5).

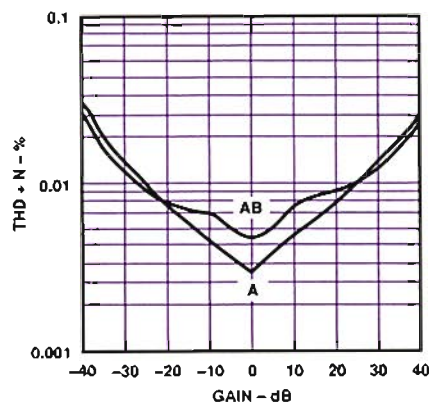


Figure 5. SSM-2018 distortion: Class A vs. Class AB.

Typical dynamic range is 108 dB (Class A) and 118 dB (Class AB). Untrimmed control signal feedthrough is 1 mV (Class AB), reducible by a trim procedure. The SSM-2018 is available in a 16-pin plastic DIP or SOIC. Price is \$3.00 in 100s.

The SSM-2142 Balanced Line Driver<sup>‡</sup> is an integrated analog processor that performs like a transformer-based circuit, converting a single-ended input signal to a precision balanced output with high drive capability. Balanced operation minimizes signal degradation due to power-line hum, ground-voltage drops, and other external noise sources—an especially critical feature when driving long cables. The output of the SSM-2142 can drive 600-Ω cables (single ended or differential) over 500 feet, with signals up to 10 V rms, while maintaining THD of less than 0.01% over the audio frequency range.

No external components are required for operation (except for appropriate bypassing capacitors when desired). The SSM-2142, based on a cross-coupled electronically balanced topology, uses on-chip low-noise thin-film resistors (matched to within 0.005% and tracking with temperature) for excellent balance. Combining this with high-slew-rate amplifiers, distortion is lower than for transformer-based line drivers, less board space is required (it’s housed in an 8-pin DIP or 16-pin SOIC) and common-mode rejection is comparable. It forms, with a complementary IC, the

**SSM-2141 Balanced Line Receiver**, a complete solution for driving and receiving audio signals over long cables and in noisy environments (Figure 6). Price is \$2.95 in 100s.

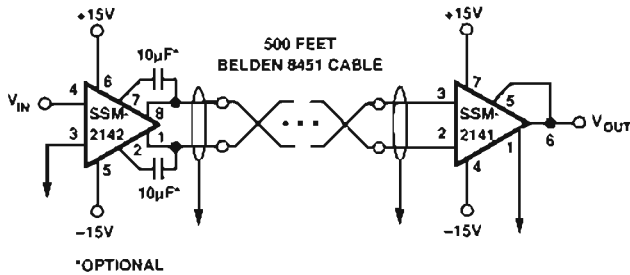


Figure 6. Interconnecting SSM-2141 and SSM-2142.

The **AD713 Quad Precision BiFET Op Amp**§ (and its single and dual versions, AD711 and AD712) offer excellent dc characteristics and superior dynamic characteristics. A multiple device, it offers the inherently close performance matching typical of properly designed monolithic devices.

The AD713 settles to 0.01% in 1 µs for a 10-V step (Figure 7). Slew rate is typically 20 V/µs, and total harmonic distortion is 0.0003% (Figure 8). K grade units have 0.5-mV maximum offset voltage, 20-µV/°C maximum drift, and 200-V/mV open-loop gain. Noise is also low: 2 µV peak-to-peak (typical) from 0.1 to 10 Hz. Price of the AD713 starts at \$3.50 in 100s.

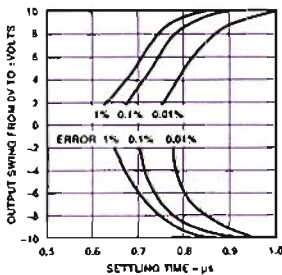


Figure 7. AD713 output swing and error vs. settling time.

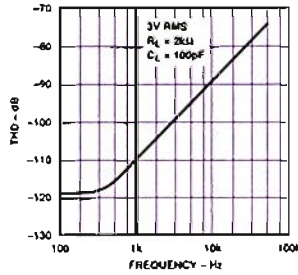


Figure 8. AD713 total harmonic distortion vs. frequency.

**Audio DACs** Until a few years ago, high-fidelity audio had little to do with data conversion, except perhaps for digitally controlled gains using multiplying DACs. But digital audio is now commonplace, driven by the dominance of compact disks as an audio recording medium, along with digital audio tape (DAT), video discs, and digital audio for personal computers.

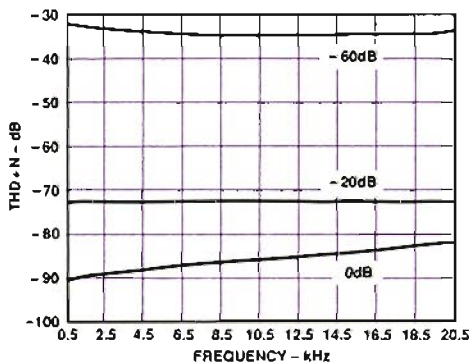


Figure 9. AD1868 THD+N vs. frequency.

The **AD1868 Single-Supply Dual 18-Bit Audio DAC**¶ provides a buffered voltage output on each of its two channels; it needs just a single +5-V supply. Using a partially segmented DAC architecture with laser-trimmed resistors, it achieves typical THD+N of 0.004% (Figure 9) and signal-to-noise (SNR) of 97.5 dB. Channel separation is at least 108 dB.

An internally generated 2.5-V reference obviates the need for "false-ground" networks. Using fast CMOS digital logic, the AD1868 can accept data at an input clock rate of up to 13.5 MHz, for use with 2×, 4×, 8×, and 16× oversampled frequencies on each channel. Available in a 16-pin plastic DIP or SOIC, it dissipates 50 mW. Prices start at \$11.70 in 100s.

The **AD1862 Ultralow Noise 20-bit Audio DAC**\*\* (Figure 10) achieves a further reduction in THD+N, to 0.0016%, and an increase in SNR, to 119 dB (Figure 11). In addition, gain linearity is ±1 dB at -90-dB amplitude. Housed in a 16-pin DIP and operating from ±12-V supplies, it dissipates <288 mW.

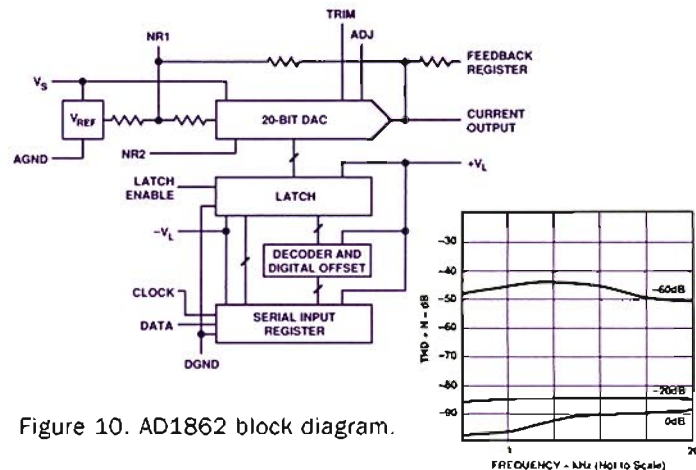


Figure 10. AD1862 block diagram.

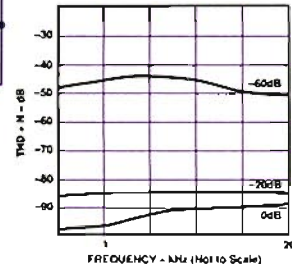


Figure 11. AD1862 THD+N vs. frequency.

20-bit device design requires extra effort to minimize noise and distortion. In the AD1862, the voltage reference for the DAC and its bipolar offset circuitry is a low-noise 9-volt bandgap cell. In addition, provisions are made for connecting noise-reduction capacitors externally. The segmented architecture and R-2R of the DAC core and digital offset combine to produce low distortion at all signal amplitudes. The digital offset technique shifts the mid-scale output voltage (0 V) away from the MSB transition, so that small-amplitude signals are not impacted by MSB changes.

The above list of ICs for audio is representative, but in no way exhaustive. Many appropriate and useful devices are available, and more are coming. For example, at the IEEE ISSCC in February 1991, Ferguson et al<sup>4</sup> described a dual-18-bit analog-digital converter for audio using sigma-delta architecture.

*The SSM-2125 was designed by a team at the Precision Monolithics Division of Analog Devices, Inc., including Messrs. Henry, Bowers, and Brown<sup>1,2</sup>.*

<sup>4</sup>Ferguson, Paul, Jr. et al, "An 18-bit, 20-kHz Dual Σ-Δ A/D Converter," 1991 IEEE International Solid-State Circuits Conference Digest of Technical Papers.

§Use the reply card for technical data. Circle 6.

¶Use the reply card for technical data. Circle 7.

\*\*Use the reply card for technical data. Circle 8.

# Automotive Sensor Detects Lamp and Indicator Failures Automatically

Designed to withstand automotive rigors, the AD22001 monolithic comparator detects failures of lamps and in-line fuses

by Ian Bruce

The AD22001 was designed for a lamp-monitoring application in automobiles. Based on a circuit developed to fill the needs of a major manufacturer, it was the first of a family of automotive products to be announced by Analog Devices.

## AUTOMOTIVE ELECTRONICS

Here are a few of the tests an integrated circuit designed to operate from a +12 V supply must undergo: voltage spikes of +60 V and -40 V for 40 ms; repeated thermal shocks from -55 to +125°C in 7 minute cycles; and vibrations of  $\pm 6$  g. You might assume the device is destined for use in a missile or other military application. Not so. These stringent test are routinely performed on integrated circuits used in automobiles.

The application of electronic technology to automobiles is relatively new. In the past, electrical measurement and control systems in cars have been relatively unsophisticated, often employing simple electromechanical devices. But relatively recent legislative and consumer demands for safer, less polluting, more economical vehicles have caused manufacturers to adopt electronic sensors, signal conditioners and microprocessors specifically designed to withstand and perform in the rigorous automotive environment.

Recognizing that the unique requirements of the automotive industry called for reliable, low-cost, high-performance devices that can work in hostile electrical, mechanical, and thermal environments, Analog Devices formed an Automotive and Sensor Products Group (A/SG) in 1988, chartered to supply electronic sensors and sensor signal-conditioners for vehicles. The group is developing a repertoire of devices that can sense variables as diverse as temperature, magnetic field, voltage, and acceleration for applications such as air-bag deployment, engine-timing and anti-skid braking systems.

## DETECTING BULB FAILURES

Introduced here is the AD22001,\* a monolithic, five-channel comparator for monitoring the functionality of various lamps in a vehicle. The device continuously tests the status of four or five bulbs in both their "on" or "off" states, and also tests the integrity of an in-line fuse in two of the series circuits. Two or more AD22001s can be configured together if additional channels must be monitored. Digital outputs indicate the status of each channel. The AD22001 also provides a voltage-limited power supply output for 15-V CMOS circuits.

\*Use the reply card for technical data. Circle 9.



The AD22001 has five comparators; each monitors the voltage across a sensing shunt resistor, which is part of the lamp circuit. The comparators have a low threshold voltage, nominally 1.75 mV. Because the low threshold calls for low resistance values, copper tracks on the PC board can be used as shunt resistors; this minimizes power dissipation. Although standard copper track has a high temperature coefficient of resistance, the circuit is linearly compensated to correct for it.

The circuit can withstand the EMI (electromagnetic interference) and high transient voltages endemic in automobile applications and it will operate from a single 6-V to 30-V supply over the entire -40 to +125°C temperature range. All control outputs signalling the state of the circuit are NPN collectors with pull-up currents provided by the on-chip power-control section.

## CIRCUIT CONFIGURATIONS

The five basically identical comparators are grouped as one single and two pairs. They are active whenever the power is on. Each comparator accepts a differential input voltage and has an offset of nominally 1.75 mV. Each comparator's output state is low to indicate "no fault" when the positive input is driven low with respect to the negative input. "No fault" is also indicated when the inputs remain at a low common-mode level, even if the positive output has not dropped below the threshold.

A typical application of a comparator is shown in Figure 1. This circuit tests the lamp's integrity at all times, whether off or on. When the lamp is off (switch open), the current source provides a small current (about 60  $\mu$ A) that flows through the lamp's filament, keeping the common-mode voltage low; if the filament is broken, both inputs will be driven high to the current source's

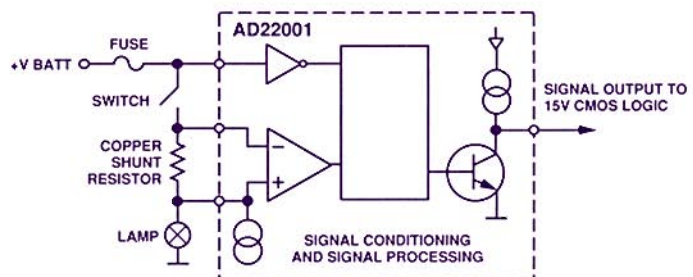


Figure 1. Typical application showing a single-channel lamp monitor.



compliance level, and the comparator's output will go high to indicate a fault. Four of the comparators have current sources of this sort for cold-lamp testing.

When the lamp is on, the common-mode level is high, but the substantial lamp current flowing through the shunt resistor will drive the positive input of the comparator below the threshold, keeping the comparator's output negative. However, if the switch is closed, but no current is drawn because the filament is broken, both inputs will go high and drive the output high, again signaling a fault.

In Figure 2, comparators 3 and 4 are linked to test a pair of lamp circuits, a pair that are switched simultaneously but have independent fuses (examples include low-beam headlights, parking/position lights, and tail-lights). A failure of either or both lamps will be indicated at the common output, OUT 3+4 [logical OR]. A special linkage between the comparators also tests for common mode voltage at both lamps, thus independently testing both in-line fuses. A second output, OUT(3×4)B [logical NAND], tests that both lamps are powered even when they are drawing no current.

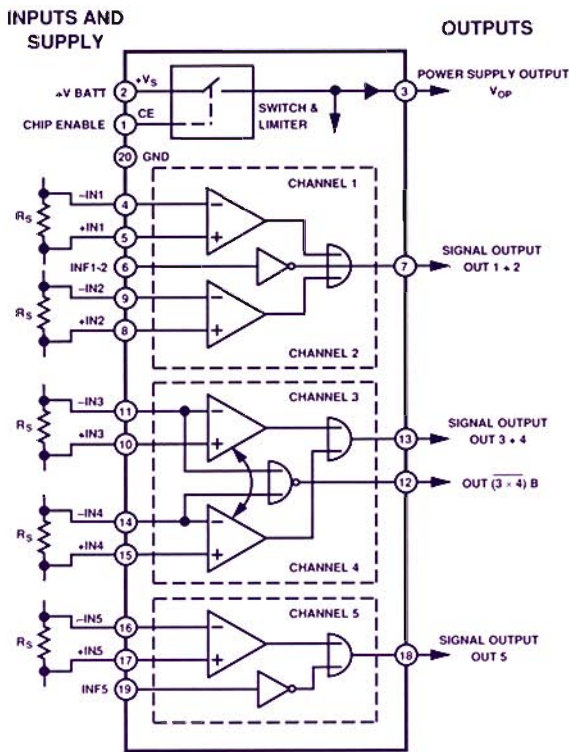


Figure 2. Connection diagram of the AD22001.

Comparators 1 and 2 share a common output and include a cold-lamp-test current. These comparators are intended for two lamps operating from the same in-line fuse. A failure of either or both lamps will be registered at OUT 1+2.

Comparator 5 operates by itself; it includes a fuse test circuit that checks for power at the lamp circuit. It is intended to test brake light systems.

The tables of Figure 3 describe the functions that can be performed by the AD22001 and their applications to automotive electrical circuit testing.

The following functions can be monitored and status can be indicated with the AD22001:

Function	Description
I	Light bulb is functional. This test is performed while the light bulb is switched on.
II	Light bulb is functional. This test is performed while the light bulb is switched off.
III	Electrical fuse is in place and functional.
IV	The two monitored light bulbs are powered simultaneously. This can be used as an implicit fuse test.

To get the maximum performance from the AD22001, channels 1 to 5 are best used for monitoring the following light bulbs:

Channels	Recommended Applications	Functions Performed
1, 2	Fog light front, Fog light rear, Number plate light	I II III
3, 4	Low beam head light, Parking/position, Tail light	I II IV
5	Brake light	I III

Figure 3. Applications of the AD22001.

### DISPENSING WITH SENSE RESISTORS

An important feature of the AD22001 is its ability to discriminate between small differential signals and a large, widely varying common mode signal. The voltage drop produced by a few tenths of an ampere flowing through a short length of copper track on the circuit board is sufficient to allow designers to dispense with the usually mandatory series sense resistor. Even though these copper resistors have a large temperature coefficient, the AD22001's design automatically compensates for the effect by the use of a linear variation of the comparator threshold with temperature.

At a design temperature of 24°C the sheet resistance of 35- $\mu\text{m}$  copper cladding is about 0.5 m $\Omega$  per square, and about 0.25 m $\Omega$ /sq for 70- $\mu\text{m}$ -thick copper. Thus, for example, a resistor made from 35- $\mu\text{m}$  copper with an aspect ratio (length to width) of 1 will have a resistance of 0.5 m $\Omega$ ; and with an aspect ratio of 4, its resistance will be 2  $\Omega$ . When actually calculating the appropriate value and dimension of the copper resistor, care should be taken to compensate for self-heating effects and to take into account the effect of bends in the resistor; a typical example of circuit-board track used as a resistor is shown in Figure 4.

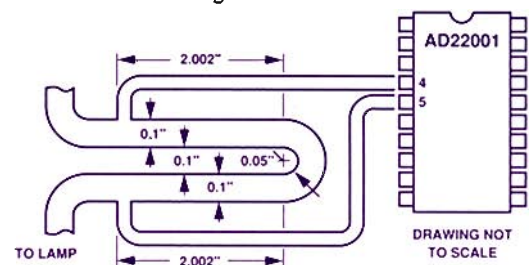


Figure 4. The printed circuit board track as a shunt resistor.

### WHAT'S AVAILABLE?

The AD22001 monolithic five-channel comparator is available in a 20-pin plastic DIP specified over the -40 to +125°C temperature range. Alternative configurations of the device can be engineered for delivery in automotive OEM quantities. The standard unit is priced at \$2.00 in quantity.

The AD22001 was designed by Analog Devices Fellow A. Paul Brokaw for ADI's Automotive/Sensors Group in Wilmington MA.

# Phase Accumulator for Direct Digital Synthesis Resolves to Within 0.7 Hz

**Monolithic 32-bit AD9950 features excellent performance from 30 to 130 MHz. Quad logic minimizes memory needs**

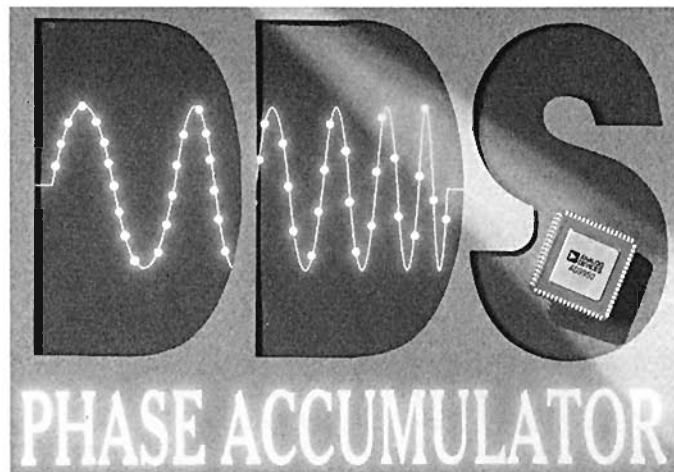
The AD9950\* is a 32-bit phase accumulator designed for direct digital synthesis (DDS) of sine waves at frequencies up to 130 MHz. With an external lookup table and a 10-bit DAC, this monolithic IC forms a system that can synthesize waveforms with 0.7-Hz frequency resolution.

## ABOUT DIRECT DIGITAL SYNTHESIS (DDS)

Since the earliest times, fixed- or variable-frequency reference sine waves (such as those used for test or as carriers in communications systems) have been generated by analog oscillators. Designers of oscillators must deal with such issues as producing the oscillation, limiting its amplitude, frequency stability, frequency control, spectral purity of the waveshape, amplitude stability, response time to changes, and in many cases—especially for synchronized or multiphase oscillators—phase control.

There are many well-established and available purely analog designs for generating reasonably pure sine waves. They fall into several classes: those that rely on high-Q naturally resonant elements, such as crystals or L-C circuits; those in which passive elements—or combinations of active and passive elements—produce 180° phase shifts, while the Q is magnified by gain in a feedback loop; and those that shape triangular waveforms produced by integrating square waves. All rely on components such as capacitors, inductors, resistors, crystals, amplifiers, and non-linear elements to set frequency, amplitude, and phase.

Each approach has its pluses and minuses, depending on the application. Most of them can produce oscillators having clean, stable sine waves at a fixed frequency. But changing frequency by arbitrary amounts requires varying the value of these frequency-setting components, or adjusting a control voltage or current within the oscillator (such as in a voltage-controlled oscillator, VCO). In many cases, the change to a stable new value of frequency (and/or amplitude) can take many cycles—and distortions may occur during the change.



Direct digital synthesis (DDS), an alternative method—analogue to the shaped-triangular-wave approach—stores a digitized function of time—often a sine wave—in memory (e.g., a lookup table) then reads out the digitized values in sequence, usually by counting up and down through the memory locations at a given clock rate (Figure 1). The digital values are converted to analog by a d/a converter (DAC) and low-pass filter to create the desired waveform.

As more bits are used to store the digital equivalent of each value of the sine wave and more samples are used, the difference between a digitized, re-created sine wave and a pure, analog sine wave becomes nearly insignificant. Converter resolutions of 8, 10, and 12 bits are used to represent the analog waveform, providing increasingly low distortion and reduced spurious frequency components in the final reconstructed waveform.

Using a counter to step through memory addresses has some limitations. The frequency of the reconstructed sine wave is determined by the clock rate, which must be adjustable over a wide range and with resolution fine enough to achieve the desired “smoothness” and tuning accuracy.

A better DDS solution is to use a *phase accumulator*, such as the AD9950, to step through the memory addresses. Figure 2 is a simplified accumulator schematic. The phase accumulator, like a special high speed counter, generates phase information about the stored waveform; what makes it special is that the steps, or counts, are programmable rather than fixed. On each (fixed-frequency) clock cycle, the input register's contents are added to the output register. The phase input is thus a digital tuning word that determines the angular (phase) increment corresponding to a clock cycle.

Figure 3 shows a DDS system using a phase accumulator. The output of the phase accumulator is a memory address corresponding to the phase of the sine wave at that instant; the data stored at

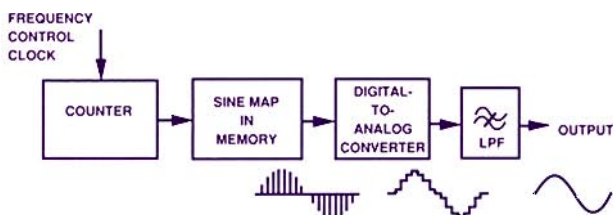


Figure 1. Simple synthesis scheme.

\*Use the reply card for technical data. Circle 10.

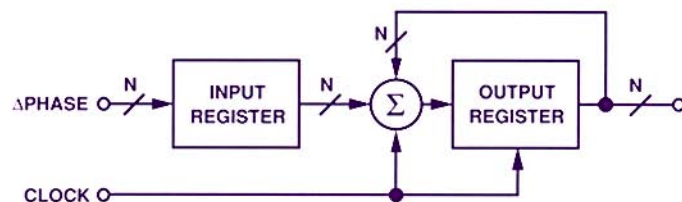


Figure 2. Simplified accumulator block diagram.

that address in the lookup table's memory is the amplitude data point (sine or cosine) corresponding to the phase angle. The frequency of the output sine wave is a fraction of the input clock frequency determined by the ratio of the tuning word ( $m$  per clock cycle) to full scale ( $2^N$ ), where  $N$  is the resolution of the accumulator in bits,  $m \leq 2^N - 1$ .

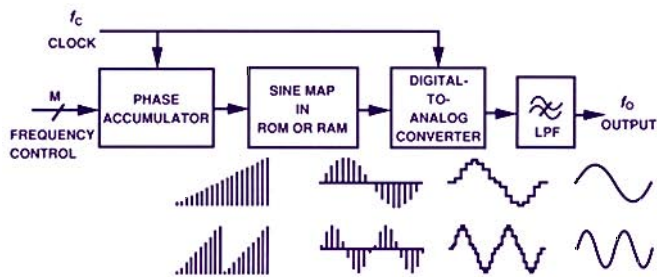


Figure 3. Block diagram of DDS system.

**Benefits of DDS:** Although it generates sine waves as a set of discrete data points that must be filtered, there are distinct advantages to using DDS:

- first, DDS is a *wideband, digitally-controlled, fast switching* sine wave source. Frequency stability is determined by the stability of the clock; frequency value is set by a tuning word that can be controlled by a microprocessor. Amplitude stability depends only on the DAC's scale-factor stability.
- the *span of output frequency* of the DDS, in principle, ranges from dc to Nyquist (one-half the clock frequency). In contrast, a voltage-controlled oscillator or synthesizer based on phase-lock loop can provide only about one octave (2:1) of tuning span.
- the *frequency can be changed to a new discrete value*—or swept through a range of values—quickly and predictably, without concerns about settling or overshoot. Changes in frequency are precise, repeatable, and *phase-coherent*; there is no amplitude discontinuity when the DDS output steps to the new value.
- the *rate at which the frequency can be changed* is determined by the accumulator's architecture. For the AD9950, the frequency can be changed every 17 clock cycles. With a 300-MHz clock, this corresponds to a frequency hop every 57ns, regardless of the amount the frequency is changed. There is no

lag or settling time—as is normally associated with a voltage-controlled oscillator or phase-lock loop error filter.

- *tuning resolution* is determined by the number of bits in the accumulator. An accumulator with more bits divides the 360° of a complete cycle into finer steps, and thus provides finer tuning resolution. When clocked at 300 MHz, the 32-bit AD9950 provides 0.7-Hz resolution. A phase-lock-loop based oscillator also provides discrete frequency steps, but the resolution is limited to the value of the frequency reference of the phase-lock loop (typically >10 kHz).


**The Role of the DAC** The purity of the DDS sine wave output is largely determined by the choice of d/a converter. Note that harmonic content of the DAC output is important in some lower-frequency applications, but in general, spurious frequency content close to the desired frequency output is of greater concern, because it broadens the spectral base of the frequency “spike.”

**APPLICATION—A Complete DDS System:** A complete DDS system based on the AD9950 phase accumulator uses external memory for the lookup table that holds the digital sine values (Figure 4). Because of the inherent symmetries of a sine wave, only 90° of the waveform need be stored in the lookup table. “Quad” logic within the AD9950 counts through the addresses for 0 to 90° of the waveform, then counts backwards for 90° to 180°; for the 180 to 360° phase points, an inverting signal from the AD9950 directs the discrete logic associated with the DAC, causing it to invert its output. Thus, the full 360° of output is available.

The memory of the lookup table typically consists of fast-access (3-ns) ECL RAM ICs. The RAM is loaded from a slower CMOS ROM during a system initialization phase.

At present, DDS is applied primarily for generating sine waves in high-end systems, such as radar, telecommunications, cellular radio, military systems, and frequency synthesizers. But as the costs of implementing DDS decrease, it will be used in a wider range of applications, just as conventional tuning knobs in home TV and radio receivers have been replaced almost entirely by phase-locked-loop synthesizers and push-button tuners.

The AD9950, housed in a 68-pin J-leaded ceramic chip carrier, consumes 1.5 W, using +5- and -5.2-V supplies. Frequency-control signals are TTL-compatible and can be loaded as two 16-bit bytes or a single 32-bit word. Prices begin at \$99.95 (100s).

*The AD9950 was designed by John Studders of ADI's Industrial Electronics Division in Greensboro, North Carolina.* 

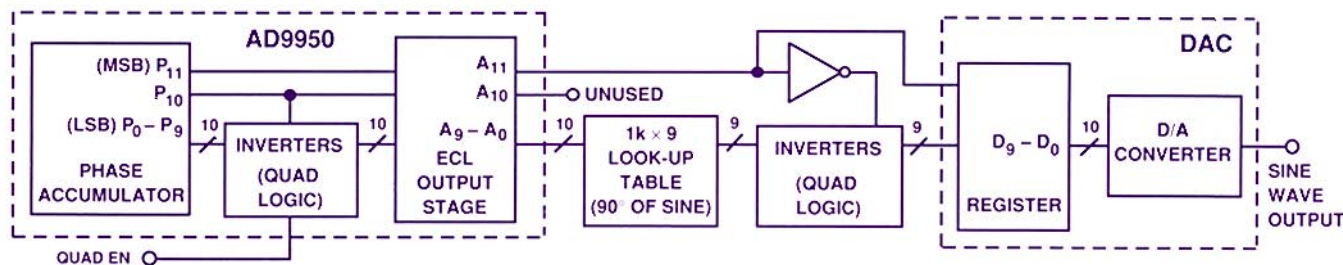


Figure 4. Components of DDS system.

# FET-Input Op Amp Has Lowest Combined V and I Noise

**AD743 has low voltage- and current noise, also low offset and drift, plus excellent ac specs**

The AD743\* monolithic FET-input operational amplifier combines the voltage-noise specifications of a low-noise bipolar-transistor-input amplifier with the very low current noise inherent in a FET-input device. Current noise is typically  $6.9 \text{ fA}/\sqrt{\text{Hz}}$  at 1 kHz, yet voltage noise is only  $2.9 \text{ nV}/\sqrt{\text{Hz}}$  at 10 kHz—the best in its class. A key to its performance can be seen in the metalization diagram (Figure 1), which shows a huge input-transistor pair, occupying about 1/5 of the chip's area. The two halves of each input transistor are diagonally cross-coupled for thermal and electrical balance.

This combination of noise specifications, coupled with total harmonic distortion of  $-110 \text{ dB}$  at 1 kHz, makes the AD743 an excellent choice for applications with low-level, high-impedance sources. The AD743 was specifically designed for preamplifying outputs of capacitive sensors, such as ceramic hydrophones. Other applications call for the same kind of performance, e.g., preamps for accelerometers, oximeters, sonar arrays, and IR spectrometers. Applications also exist in filter circuits with wide dynamic ranges, where high impedance levels can accentuate the effects of current noise. Naturally, the AD743 should be considered for upgrading performance in applications that were originally designed using bipolar-transistor-input amplifiers.

An example of the benefit of the AD743's noise performance can be seen in Figure 2. Here, the noise of an AD743 is compared with that of an OP-27-type amplifier as a function of source resistance in a circuit with balanced input source resistors. Noise voltage spectral density at 1 kHz (referred to the input), is plotted as a function of source resistance. At low  $R_{\text{SOURCE}}$ , both amplifiers have similar noise levels, about  $2.9 \text{ nV}/\sqrt{\text{Hz}}$ . As the resistance value increases beyond about 20 k $\Omega$ , the FET-input AD743

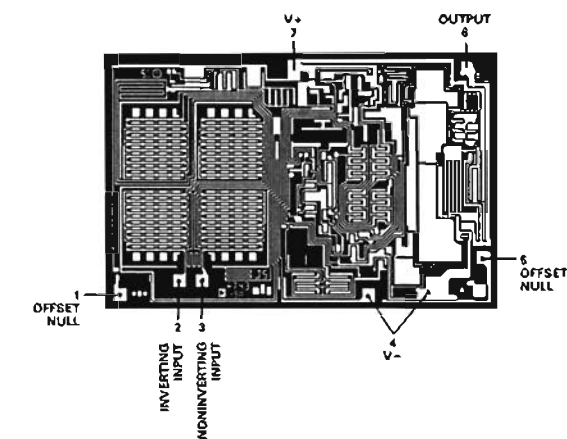
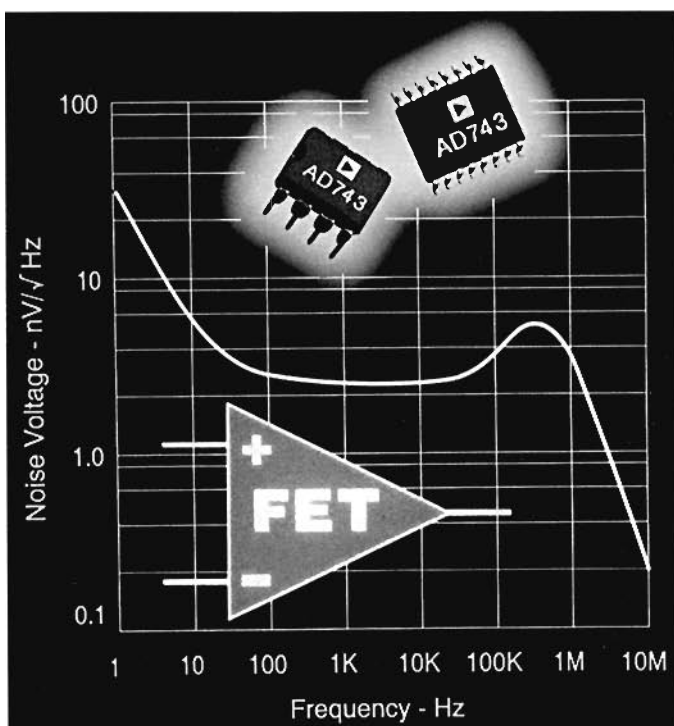


Figure 1. Chip metalization. Input transistors are at left.

\*Use the reply card for technical data. Circle 11.

†Use the reply card for technical data. Circle 12.

circuit's noise simply reflects the noise contribution of the resistor, while the OP-27's current noise generates an additional noise-voltage component that further increases with resistance.

Besides the excellent noise performance, both dc and ac performance are very good. For example, dc gain (K grade) is  $2 \times 10^6 \text{ V/V min}$ , offset is 0.5 mV max, with  $1 \mu\text{V}/^\circ\text{C}$  drift, and bias current is 250 pA max at 25°C. Typical ac specs include 4.5-MHz unity-gain bandwidth, 2.8 V/ $\mu\text{s}$  slew rate, and total harmonic distortion (THD) of 0.0003% ( $-110 \text{ dB}$ ) at 1 kHz. (The AD745† is a variant of the AD743 with a fourfold increase in speed for signal gain magnitudes greater than  $+5$  or  $-4 \text{ V/V}$ .)

The AD743 is available in 8-pin plastic mini-DIPs and cerdips, as well as 16-pin small-outline packages. Available performance grades include J and K for 0 to 70°C, A and B for  $-40$  to  $+85^\circ\text{C}$ , and S grade for  $-55$  to  $+125^\circ\text{C}$  operation (MIL-STD-883 processing is also available). Prices start at \$3.36 in 1,000s.

The AD743 was designed by Scott Wurcer at Analog Devices Semiconductor Division's Amplifier Group, Wilmington, MA.

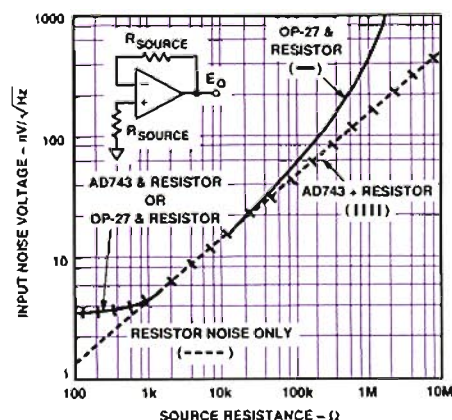


Figure 2. Total 1-kHz noise spectral density as a function of source resistance—comparison of FET-input AD743 and the low-drift OP-27 bipolar amplifier.

# Serial IC Analog I/O Port: 14-Bit Performance in a Small Package

**AD7869's 14-bit DAC and ADC include references, serial bus interfaces. It is interchangeable with the 12-bit AD7868**

The AD7869\* is a complete 14-bit I/O system, comprising a fast, 83-ksp/s sampling analog-to-digital converter, an independent voltage-output d/a converter, temperature-compensated 3-volt references, and serial bus interfaces (Figure 1).

It can pin-compatibly replace the 12-bit AD7868† (*Analog Dialogue* 24-3, p. 23).

Interfacing to both the DAC and the ADC is via serial lines, minimizing pin count. Standard control signals allow serial interfacing to most DSP machines, including the ADSP-2101 family. With either of these ICs, a designer can implement a minimum-cost-and-space analog input/output port in virtually any microprocessor-based system. Optimized for communications applications, it can also be used in digital signal processing, speech recognition and synthesis, high-speed telecom, and DSP-based servo- and motion-control systems.

These I/O ports are designed for low power dissipation ( $\pm 170$  mW max), operating on  $\pm 5$ -V supplies. They are fully specified for both ac and dc performance. Figure 2 shows the output spectrum of the 14-bit AD7869, for a 10-kHz sine wave input sampled at 60 ksp/s. Key device specifications include:

	14-bit AD7869	12-bit AD7868
Throughput	83 ksp/s min	83 ksp/s min
Input SNR	78 dB min	72 dB min
Analog Input/Output Range	$\pm 3$ V	$\pm 3$ V
Output Settling Time	4 $\mu$ s max	3 $\mu$ s max
Output SNR	82 dB min	72 dB
Power Consumption	130 mW typical	130 mW typical
Packaging (both devices)	24-pin, 0.3" DIP and 28-pin SOIC	
Price (100s)	\$32	\$24

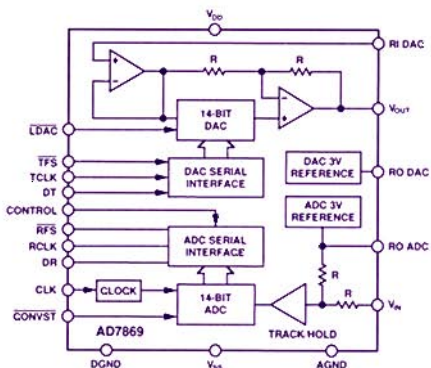


Figure 1. Block diagram of the AD7869.

\*Use the reply card for technical data. Circle 13.

†Use the reply card for technical data. Circle 14.

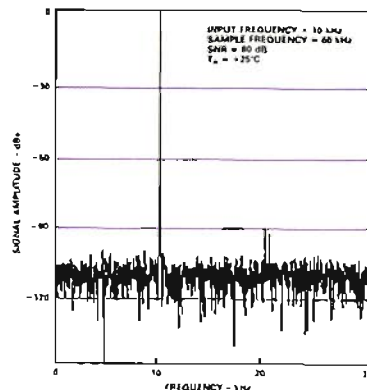
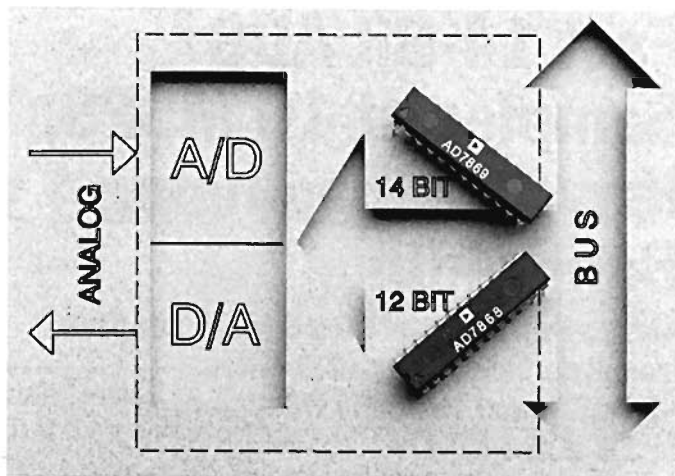


Figure 2. AD7869 a/d converter performance. FFT plot.

Since the 12-bit AD7868 and 14-bit AD7869 use identical packaging and pinout, a designer can wire up a single circuit with a planned upgrade path to higher resolution. Alternatively, the designer has the option of designing just one board layout and trading resolution for lower cost without a rewiring penalty.

**Interfacing to DSPs:** The AD7869 interfaces directly, with no glue logic, to serial ports of the ADSP-2101, DSP56000, and TMS320C25 processors. Figure 3 shows an interface suitable for the ADSP-2101.

*The AD7868 and AD7869 were designed by Ken Deevy, of Analog Devices BV, in Limerick, Ireland.*

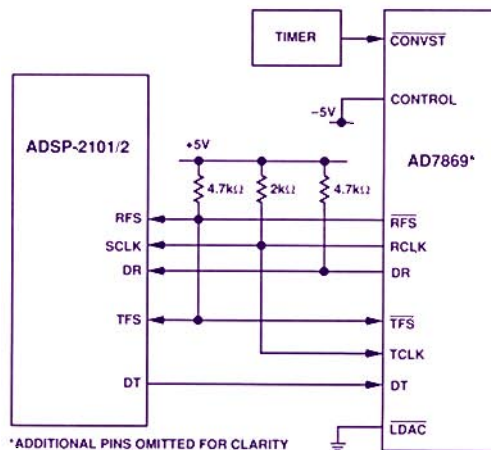


Figure 3. Interfacing the AD7869 to members of the ADSP-2101 family of digital signal processors.

# Fast 14-Bit ADC Samples at 10 MSPS, Has 50-MHz Analog Bandwidth

**AD9014 guarantees 90-dB (min) spurious-free dynamic range to 2.3 MHz, -90-dB (max) two-tone IM distortion to 2.3 & 2.4 MHz**

The AD9014\* is a complete, 14-bit, 10-MSPS ECL analog-to-digital converter comprising two hybrid circuit packages: a track-and-hold and an a/d encoder—on a small 3.25" × 4.22" × 0.5" (107 × 83 × 12.7 mm<sup>3</sup>) multilayer card. It is designed to provide definitive performance in both the time- and frequency domains in challenging applications calling for the combination of high sampling rates and fine resolution.

Guaranteeing 90-dB spurious-free dynamic range (SFDR), the AD9014 is especially suitable for spectrum analysis and imaging applications. Users of this device include designers of systems for digital radio, radar signal analysis, visible and infrared imaging, and FFT operations—with many additional uses in instrumentation, medicine, military, and high-performance laboratory measurements. There being few, if any, competitive devices available, the pioneering AD9014 is intended to provide relief for system designers by supplanting home-brew devices, designed and built from necessity by skillful users at great cost.

A complete subsystem, it is its own "evaluation board." A user need only provide power (+5 V, -5.2 V, and ±15 V), a differential ECL clock source, an analog input signal, and ECL receiver/drivers for the digital output words.

Capable of sampling at 10 MSPS, it has these salient specifications:

- 90-dB (min) SFDR for input frequencies up to 2.5 MHz, holding to 86 dB (min) at 5 MHz
- 75-dB signal-to-noise ratio for analog inputs up to 5 MHz
- -90-dB (min) two-tone intermodulation distortion (Figure 1)
- 0.5-LSB differential nonlinearity and 1.0-LSB integral nonlinearity
- 1.5-ps aperture jitter.

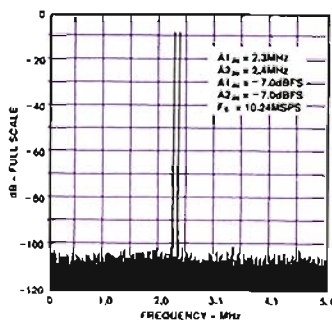
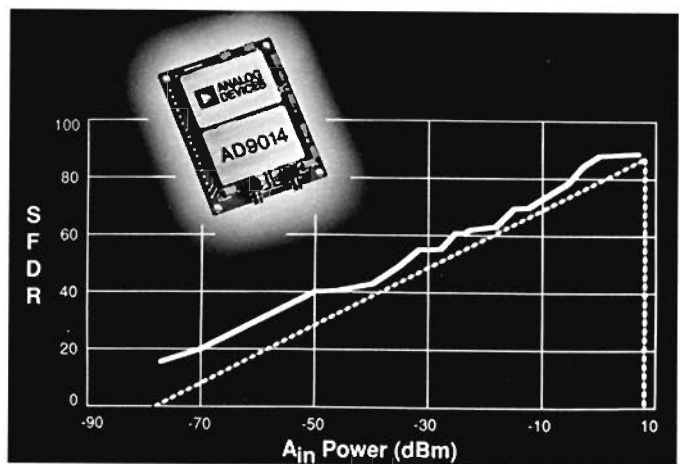


Figure 1. Two-tone intermodulation distortion for -7-dB, 2.3- and 2.4-MHz sine waves sampled at 10.24 MSPS.

\*Use the reply card for technical data. Circle 15.



Its combination of 30-ns transient response to 0.01%, 50-MHz analog full-power bandwidth, and nonlinearity specs make the AD9014 ideal for applications that require fast sampling of relatively low-frequency analog signals, such as CCD and infrared imaging. Nevertheless, the AD9014 can be used to digitize analog input signals at frequencies *exceeding* Nyquist: by arbitrarily defining the full-scale power level to be -6 dBFS, signals in the 5-MHz band between 5 and 10 MHz can be digitized (at 10 MSPS) while maintaining an SFDR of 80 dB. This feature is often useful in communications applications, because it reduces the demands on filters and mixers.

**How it works:** A single-ended analog input signal is converted to a balanced differential signal that is sampled and held by a differential track-and-hold amplifier (Figure 2). The differential track-and-hold achieves first-order cancellation of even-order harmonics while suppressing common-mode noise. The second hybrid is a digitally corrected subranging a/d encoder that uses two 8-bit flash converters and a 16-bit-linear DAC for two bits of overlap correction. Decoupling capacitors have been designed into both hybrids, as well as on the mother board; this on-board decoupling simplifies the task of using the converter successfully. All required references are included on board.

Two versions of the AD9014 are available: The AD9014K is designed for applications that require the highest possible SFDR performance; the AD9014J is intended for applications where spectral-domain information is not as important—for example, in imaging. Prices for the AD9014 start at \$2,750 in 100s.

The AD9014 was designed by Frank Murden, of ADI's Industrial Electronics Division, in Greensboro, North Carolina. ▶

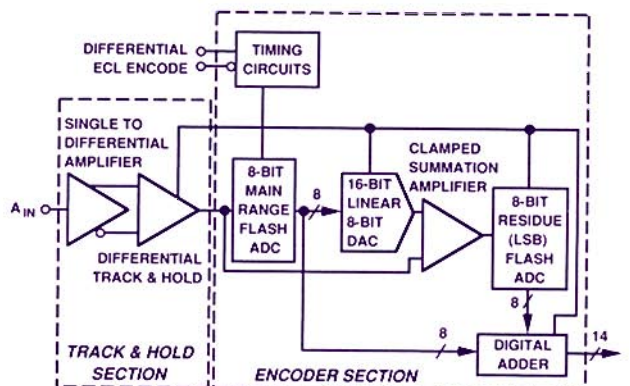


Figure 2. Block Diagram of the AD9014

# Monolithic 16-Bit Voiceband Codec Uses Sigma-Delta Technology

## AD28msp02 has 16-bit ADC and DAC, plus filtering and analog interface circuitry

The AD28msp02\* is a codec (*coder-decoder*) using linear coding and based on sigma-delta technology<sup>1,2</sup>. A mixed-signal peripheral device, with 16-bit sigma-delta *a/d* and *d/a* converters, it provides a complete analog front end for high-performance voiceband digital-signal-processing applications (Figure 1). Like the codec portion of the monolithic ADSP-21msp50<sup>1</sup>, the single monolithic CMOS chip features, in addition to the ADC and DAC

- on-chip antialiasing and anti-imaging filters
- on-chip voltage reference
- 8-kHz sampling frequency
- twos-complement coding
- 65-dB SNR and THD.

Compared to traditional nonlinear  $\mu$ -law and A-law codecs, the AD28msp02's linear-coded ADC and DAC maintain wide dynamic range throughout the transfer function. The sampling rate of 8.0 kHz, plus its 65-dB SNR and THD performance, make the AD28msp02 attractive in many telecommunications applications—such as digital telephones.

Principal applications of the AD28msp02 are in systems with voice input and/or voice output. Examples include voice-mail systems, telephone answering machines, dictation equipment, digital mobile radios, personal computers, bank teller machines, and some FAX machines and modems. It will be used in place of conventional companding codecs to provide superior voice quality in computers and telecom systems, or to provide a more-integrated, lower-cost solution than systems using individual

ADCs and DACs. The AD28msp02 provides a clean, simple interface to industry-standard DSPs at low cost. Prices start at \$10.35 in 1,000s.

The inclusion of on-chip antialiasing and anti-imaging filters, 16-bit ADC, 16-bit DAC, and programmable-gain amplifiers in a 24-pin DIP/SOIC package ensures a highly integrated and compact solution for voiceband analog processing. The device interfaces easily to the ADSP-2101, the low-cost ADSP-2105, the ADSP-2111, MC56001, and TMS320C25 digital signal processors via its serial I/O port (SPORT), which is used to transmit and receive data and/or control information.

**Encoder:** The encoder side of the AD28msp02 consists of two software-selectable analog input amplifiers, an optional 20-dB gain stage, and a sigma-delta analog-to-digital converter. Gain of the input amplifiers can be adjusted with external resistors.

The ADC consists of a sigma-delta modulator, an antialiasing decimation filter, and a (software-bypassable) digital high-pass filter. The modulator noise-shapes the signal and produces one-bit samples at a 1.0-MHz rate. This bit stream, representing the analog input, is fed to the antialiasing decimation filter, which consists of two low-pass filter stages. The first stage reduces the sampling rate to 40 kHz and increases the sample width to 16 bits; the second further reduces the sampling rate to 8 kHz. Each resulting sample is then loaded into the SPORT for transmission.

The decoder consists of a sigma-delta *d/a* converter and a differential output amplifier (gain programmable from +6 to -15 dB). 16-bit samples are read at an 8.0-kHz rate from the SPORT, then low- and high-pass filtered by the anti-imaging and (software-bypassable) high-pass filters. The anti-imaging filter interpolates the sampling rate in two stages, first to 40 kHz, then to 1.0 MHz. The resulting 16-bit samples are processed by the digital sigma-delta modulator, which reduces the sample width to 1 bit. This bit stream is fed to an analog smoothing filter, which converts the data to an analog voltage.

*The AD28msp02 was designed by Jim Wilson, Marc Diamondstein, and Gordon Cheung, of ADI's Signal Processing Division's DSP group in Norwood MA, and Paschal Minogue and Stuart Patterson of Analog Devices BV, Limerick, Ireland.* ▶

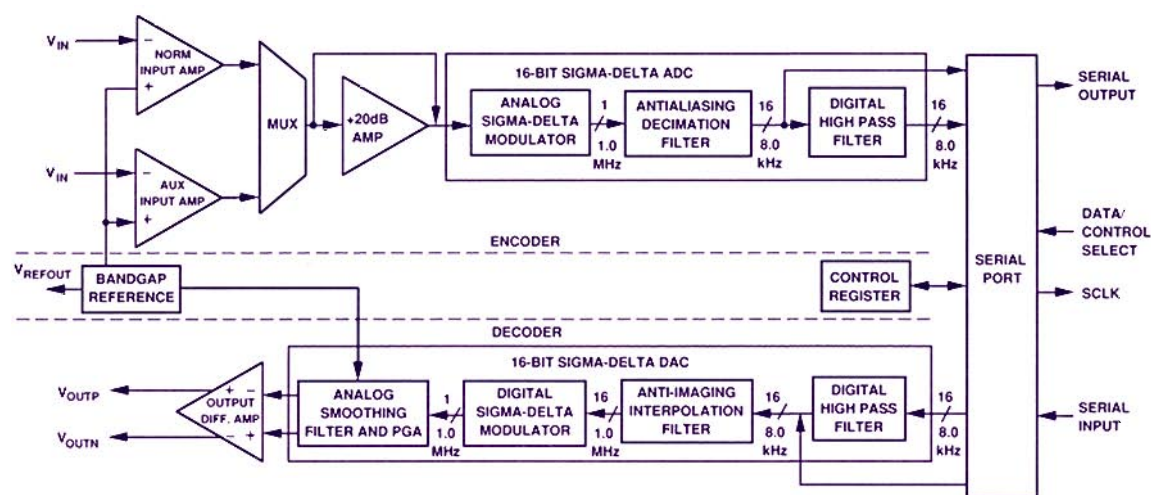


Figure 1. AD28msp02 block diagram.

\*Use the reply card for technical data. Circle 16.

<sup>1</sup>See *Analog Dialogue* 24-2, pages 3-7. For a free copy, use the reply card. Circle 17.

<sup>2</sup>See also the special  $\Sigma$ - $\Delta$  reprint issue of *DSPatch*. Circle 18.





# A Quarter-Century of Analog Dialogue

Many industry "firsts" appeared in these pages through the years. Readers voted on the most significant, and here they are

## THE QUESTIONNAIRE

We included with the North American mailing of *Analog Dialogue* 24-2 a pair of aided-recall questionnaires listing a sampling of products and technical articles that had appeared in these pages through the years. The first allowed readers to tell us which of the innovative product "firsts" published in *Analog Dialogue* were most useful to them (and perhaps helpful to their careers)—and what their significance was; we will show here a sampling of as many of the responses as limited space will permit. The second afforded an opportunity to identify the technical articles whose content was most helpful to users of our products; those articles will be collected in a special jumbo issue of *Analog Dialogue*, to appear this summer.

The questionnaires were rather lengthy, running to five pages of close print. So we weren't surprised that the response was small in numbers, somewhat less than one thousand. But the quality was excellent; most of the respondents had not only gone through the lists with a fine-toothed comb and thoughtfully checked off numerous entries—they had also made many comments, most of which were quite heartening.

We will list here the products that elicited the most responses, with a brief description, and show you a few quotable comments for each.\*

**AD590 temperature sensor** has output current proportional to absolute temperature,  $1 \mu\text{A/K}$ ; response is essentially independent of voltage. It is thus insensitive to voltage noise and interference, as well as lead resistance. It first appeared in *Analog Dialogue* 12-1, 1978, as described by Mike Timko and Goodloe Suttler. Here are just a few of the comments:



- "Made temperature sensing and compensation much easier than other available technology"—Bob Arthur, Arthur Technology
- "Came out at right time to meet compromise between cost/complexity & accuracy needed"—Ray Terry, G. E.
- "Have used in several applications to: monitor temperature of thermocouple reference junctions, temperature of batteries during charging, temperature measurement and strain compensation for semiconductor strain gages—which are otherwise poorly compensated for temperature changes"—Paul Honke, David Taylor Research Center
- "It's the temperature-controlling element in my hot tub"—Arnie Berger, Hewlett-Packard.

\*The comments quoted here are historical statements of experience and should not be considered as endorsements by individuals or companies.

**AD536 rms-to-dc converter** was the first to be manufactured as a monolithic chip. It computed true rms with precision, using Gilbert translinear circuit techniques. It was described in an article by Lew Counts, Barrie Gilbert, and Dave Kress in *Analog Dialogue* 11-2, 1977.

A few of the comments:

- "Cut our parts count tremendously"—C. Hansen, Bendix
- "Allowed true-RMS DPMs to cost same as average-responding"—Dennis Mosbeck, Modutec, Inc.
- "Cost-effective solution to software problem—in small PCB space"—Gregory Cederline, Eldec
- Did rms measurement of ac-excited tungsten filament floating at 10 kV. Space/accuracy critical—Gary W. Johnson, LLNL
- "Allowed us to perform accurate, real-time, in-the-ear measurements for hearing-aid application"—Alan K. Smith, Ensoniq.



**AD520—the first monolithic instrumentation amplifier** had low drift, differential inputs with high input impedance; gain was determined by a pair of external resistors. It was described in an article by Heinrich Krabbe in *Analog Dialogue* 6-1, 1972. Here are some of the comments:

- "Allowed my MSEE project: electronic thermometer and heart rate"—Maurice W. Peterson, Rockwell International
- "Part heavily used in data-acquisition system built for bio-engineering lab as thesis project. Very dependable part. Great price"—Phil King, Hewlett-Packard
- "Helped me in the design of my first medical instrument, and thus my Ph.D. dissertation"—Rick Miles, Ph.D., Micro-medical Technology
- "Our first instrumentation amplifier for a magnetometer"—T. Turner, University of California



The **ADSP-2100 microprocessor** for DSP and high-performance number crunching was the first of a series to combine a multiple bus structure, a powerful instruction set, and independent on-chip computational units (MAC, ALU, and barrel shifter). It first appeared in *Analog Dialogue* 20-2 (1986), in an article authored by Mike Nell and Bob Fine. Comments:



- "First DSP  $\mu\text{P}$ -based satellite communications modem"—Christopher Hanna, Raytheon
- "Used in first DSP IC-based processor for company missile program"—Luis Nunez, Hughes Aircraft
- "Reduced board space, great performance. These devices allowed us to accomplish a lot of processing in a little area"—John F. Schwaller, Harris Corp.
- "Used 2 ADSP-2100A for robust speech recognition, 1 for signal processing and the other for pattern matching. The dual bus architecture allows continuous speech recognition AND unlike other systems, flexible algorithms. We can download linear discriminant transforms to the feature-extraction proces-

sor and have these specific to the user's environment. Very flexible using DSPs rather than ASICs"—David Starks, Canadian Marconi

- "At last, a DSP chip from a large corporation that can FFT like there's no tomorrow. Sonar for US/Canadian navies"—Dr. Rick Hudson, Applied Microsystems
- "Impressed with readable instruction set"—Kevin Cahill, Reflectone, Inc.

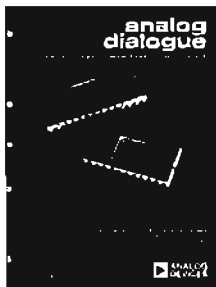
The **AD574 12-bit a/d converter** was the first complete IC of its type. The earliest packages contained a complementary monolithic integrated pair (the AD565—first monolithic 12-bit DAC plus a logic chip), later combined into a single BiMOS chip. First appearing in *Analog Dialogue* 12-3, 1978, it became a widely imitated industry standard (see the new-generation fast sampling version, the AD1674, introduced in page 16 of this issue). Comments on the AD574:

- "Reduced function space from one board to one part"—Bob Gerhardt, Boeing
- "Used in 32-channel autoranging DVM"—Paul Kojola, Syva Co.
- "32-channel medical data acquisition system"—R. A. Villameal, Cadwell Labs, Inc.
- "Peak-to-peak meter (dc to 2 kHz)"—(anonymous)
- "Temperature control system for IC wafer processing"—Harvey Nickerson, NCA Microelectronics
- "Reduced board area in I/O for Avionics Mission Computer"—Amin Bishara, Teledyne Systems Co.
- "An all-time classic: made 12 bits affordable"—Mike Seiler, Atek Corp.
- "Became the standard with multi second sources. Still implementing it in new designs"—George Haddad, Western Atlas

The **AD537 V/f converter**, an easy-to-use, single-supply device, has its own built-in reference, and includes an on-chip thermometer. Unlike many VFCs, its output is a symmetrical square wave, rather than a pulse train. It was introduced in *Analog Dialogue* 10-2, 1976, in an article by Barrie Gilbert and Dave Kress.

Here are some typical comments:

- "Made V/f easy"—Jack F. Barton, Corometric Med. Systems
- "Speedometer for wheelchair"—Charles Chow, Everest & Jennings
- "Used for sending data over fiberoptics from HV power supply for neutral beam injectors (I think ~50 kV ~100A) used for TOKAMAK research"—Jim Pearce, Technology for Energy
- "Extensively used as f/v converter in line-frequency and RPM monitoring"—Dennis Mosbeck, Modutec, Inc.
- "High resolution, high dynamic range front end (VCO)"—Mauro Dresti, Southern California Edison
- "Amp-hour totalizer for battery charge and discharge"—Dean Perkins, Compaq Computer
- "Best IC we've ever used"—Don Sarrell, Sarrell Associates.



The **ECL AD9060 10-bit 75-MSPS flash a/d converter** (and its 60-MSPS TTL companion, the AD9020) is one of the most recent products covered in the survey, yet it drew a large number of responses. It was described in *Analog Dialogue* 24-1, 1990, in an article by Chuck Lane and David Duff. The comments, this early in the game, tended to be prospective, rather than retrospective:


- "Not yet implemented but will be part of a high-speed CCD camera—medical imaging system"—R. Gerson, Scicom
- "High-speed DSP front end"—Paul Beauvilliers, HRB Systems
- "Digital video measurement system with high speed and accuracy"—Todd Moyer, Videotek
- "Useful in our medical imaging investigations"—Paul Lum, Hewlett-Packard
- "AD9020 version meets existing requirements. Reasonably well documented. Evaluation board made 'hands-on' testing very 'painless'"—Anton J. Polcer, ITT AC/O
- "Helped achieve system level NPR specification of 45 dB"—Robert Ponce, ESL

The **AD580 2.5-V bandgap reference**, the first precision IC reference, was introduced briefly in *Analog Dialogue* 8-2 (1974), then followed up with a more comprehensive description in 9-1 (1975), by Paul Brokaw, and a set of interesting applications, by Walt Jung, in 9-2. Reader comments:

- "Allowed us to forget how to calculate Zener-resistor networks and concentrate on real problems"—Tom Messenger, Montedoro-Whitney Corp
- "Power supply designed without trim potentiometers"—Jim Neumiller, Sundstrand
- "Stable buck-out voltage and current-source reference"—Robert Ensmann, Ensmann Instrumentation
- "Super-stable reference for analog computations (ratio,  $\times$ ,  $\div$ )"—Bob Landman, H & L Instruments
- "Need with rms-dc chip for precision reference of pressure spectrum analysis"—R. Gerson, Scicom
- "First good reference available"—Ernie Genaw, System Research

**And much more!** These were just a few of the diverse list of innovative products introduced in these pages during the last 25 years and judged by our readers as tops. Well, the diversity continues. Consider these:

- The AD84X series of precision wideband op amps in CB
- The AD834 500-MHz dc analog multiplier
- The AD640 high-precision wideband log amp

Interestingly, the most mentions were not *products*, but our unique technical-reference-book series: *The Analog-Digital Conversion Handbook*, *Nonlinear Circuits Handbook*, *Transducer Interfacing Handbook*, and *Digital Signal Processing in VLSI*. "These have been my 'Bibles,'" "Stuff they never taught me in school! I still value these books," "Still on my reference shelf. Used during many design projects," "Your literature has been like a mentor to me." 

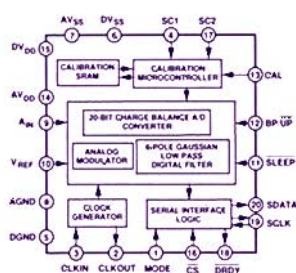


## 20-BIT CMOS SIGNAL ACQUISITION

**AD7703:  $\Sigma$ - $\Delta$  a/d converter: 8-ppm max nonlinearity**  
**Has serial interface, filtering, on-chip self-calibration**

The AD7703\* is a monolithic 20-bit analog-to-digital converter employing sigma-delta conversion technology. With linearity to within 0.0008% max (C version), it is intended for the precision measurement of slowly varying signals. Typical applications are in weigh scales, PLC systems, process-control modules, and temperature- and pressure-measuring instruments. Available in plastic and SOIC for the -40 to +85°C industrial range (as well as in ceramic for the industrial and military ranges), it is also an improved replacement for 5503-type ADCs.

The analog input is continuously sampled by an analog modulator with mean output duty cycle proportional to the input signal. The modulator output is processed by an on-chip 6-pole Gaussian digital filter, which updates the output data register with 20-bit binary words at word rates up to 4 kHz. The sampling rate, filter corner frequency and output word rate are set by a master-

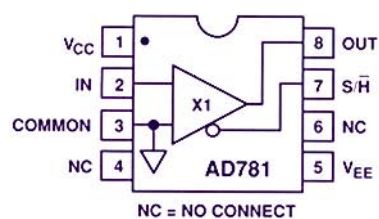


clock input that may be supplied externally or by an on-chip gated oscillator.

The AD7703 is specified for input corner frequencies up to 10 Hz and clock frequencies to 4.096 MHz. It accepts inputs with ranges of 0 to +2.5 V or  $\pm 2.5$  V, using an external 2.5-volt reference. Power consumption is only 40 mW max in normal operation—and 10  $\mu$ W in the "sleep" mode. Its self-calibration of offset and full-scale can be extended to include the external system. It communicates with serial ports of standard microcontrollers and DSPs. Prices start at \$18.50 in 100s. ▶

## FAST S-H AMP

**AD781 is ac-spec'd**  
**and tested**

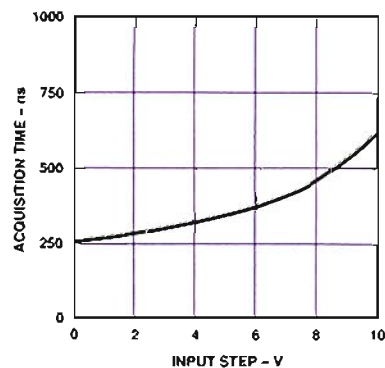


The AD781\* is a complete high-speed, 12-bit-performance low-cost sample-and-hold amplifier housed in an 8-pin mini-DIP (plastic and ceramic). In addition to other specs, its hold-mode signal-to-(noise plus distortion) S/N+D and total harmonic distortion (THD) are specified and tested.

The AD781 was designed to be used with medium-to-high-speed non-sampling 12-bit a/d converters, such as the AD674B (page 16). The AD781 combines dc precision and excellent dynamic performance to serve in sampled-data systems as well as other applications. It requires no external components, is fully specified and easy to use.

Key features include its 700-ns max 0.01% acquisition time, low power (95 mW), on-chip Hold capacitor, tested Hold-mode dynamic specifications, small package, and low cost. Prices (100s) begin at \$6.00.

Representative specifications include 500-ns max Hold settling time, 50-ps aperture jitter, 1  $\mu$ V/ $\mu$ s droop rate, 3-mV hold-mode offset,  $\pm 5$ -volt input range. The AD781's power-supply requirement is  $\pm 12$  volts at 6.5 mA. ▶



\*Use the reply card for technical data. Circle 21.  
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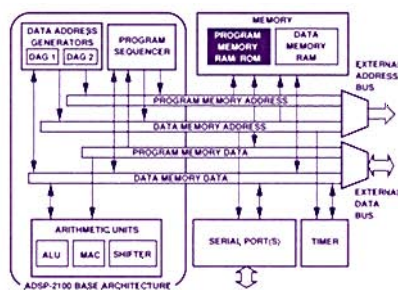
## DSP PROCESSORS WITH ROM

**ADSP-2102 and ADSP-2106: mask-programmable ROM versions of the ADSP-2101 and ADSP-2105**

The ADSP-2102 and ADSP-2106† are DSP microcomputers that allow users to freely define program memory as segments of RAM and mask-programmable ROM; otherwise they are identical to the ADSP-2101§ and ADSP-2105‡ microcomputers.

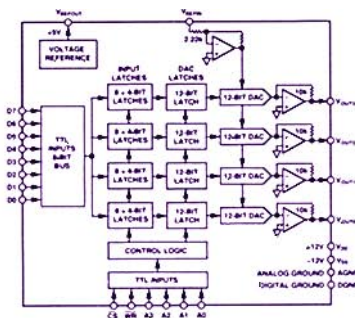
The popular ADSP-2101 (*Analog Dialogue* 23-2, 1989) and its low-cost derivative, the ADSP-2105 (24-2, 1990) have won the hearts and minds—and sockets—of many DSP designers, with their ADSP-2100-based architecture and instruction set, plus serial ports and externally expandable on-chip read-write memory (RAM).

For some designers, it would be helpful to have the programs stored in on-chip mask-programmable ROM, especially where programs were relatively short, production runs were long, and space and parts cost were at a premium. This would permit external memory chips to be eliminated.



The ADSP-2102 and ADSP-2106 are the answer; they allow the large-scale user to custom-specify an arbitrary portion of on-chip program memory as mask-programmed ROM. The remaining read-write program memory is still available for use as data memory. Programs can be written and tested on the RAM versions; and the permanently programmed versions can be bought for production (with ROM protection if desired). Check with your local sales office. ▶

## FAST QUAD DAC 12-bit AD75004 4- $\mu$ s max settling time



The AD75004\* is a monolithic chip comprising four 12-bit voltage-output DACs with independent double-buffered latches; they share an on-chip +5-volt reference, an 8-bit data bus, and control logic. It is fabricated in Analog Devices' BiMOS II process and is housed in a compact 24-pin plastic DIP and a 28-pin PLCC. It is principally characterized by the highest speed among quad DACs, 4- $\mu$ s settling time, and low cost. Price in 100s is \$34.50.

It can replace four single DACs or two duals in applications for multiple DACs, for example, industrial control, instrumentation, robotics, and automatic test equipment.

Laser trimmed on the wafer, the AD75004KN has  $\pm 1/2$ -LSB linearity error at 25°C,  $\pm 3/4$ -LSB over the full operating temperature range, 0 to 70°C. The input latches can respond to strobe pulses as short as 50 ns, and the DAC settling time is 4  $\mu$ s maximum, 2  $\mu$ s typical for a full-scale step change.

The power-supply requirement is  $\pm 30$  mA max at a nominal  $\pm 12$  volts, with total dissipation of 720 mW max, including the reference.

Customizable: The AD75004 is a *linear system macro* (LSM). This means that it has been assembled from cells in the Analog Devices BiMOS II standard-cell library. Other cells from the library may be substituted in or added to the basic architecture to adapt it to a specific set of needs. For example, the multiple DAC might have as many as 6 channels, or a mix of current- and voltage outputs, or separate references. A non-recurring engineering charge (NRE) is involved (check with your local sales office). ▣

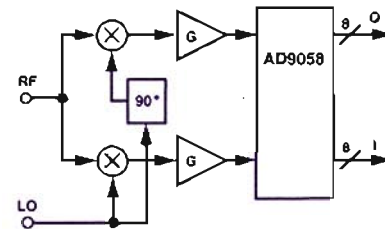
\*Use the reply card for technical data. Circle 26.

## FASTEST IC DUAL 8-BIT ADC Single-chip AD9058 converts two channels simultaneously at speeds up to 50 MSPS

The AD9058† combines two 8-bit ADCs and a +2-volt reference on a single monolithic IC. Saving space, power, and cost in systems where multiple ADCs are required, it is especially useful in applications that require simultaneous sampling of two channels; examples include instrumentation (digital scopes), medical imaging (ultrasound), communications (demodulators in digital radio), and radar.

Signal-to-noise (SNR) is 44 dB min at 10.3 MHz and is typically 48 dB at 2.3 MHz (40 MSPS). Harmonic distortion is typically -58 dBc at 2.3 and 10.3 MHz. The AD9058 is available in J/K grades for 0 to 70°C, T for -55 to +125°C; K guarantees 50-MSPS, J is functionally tested to insure at least 40-MSPS operation. Prices (100s) are \$55/\$85 for J/K.

For a dual device, crosstalk rejection is an important consideration; the AD9058 guarantees 48 dB (58 dB typical) separation be-



tween channels (thus essentially two separate ADCs).

The AD9058 has low input capacitance (10 pF), making it easy to drive; and its dissipation is only 960 mW max, insuring less than 1/2 W per channel, including reference-ladder current. The AD9058 can be configured for unipolar or bipolar inputs. The +2-V reference can drive both ADCs, simplifying unipolar operation. Packages include 44-pin J-lead and 48-pin ceramic DIPs. An evaluation board is available. ▣

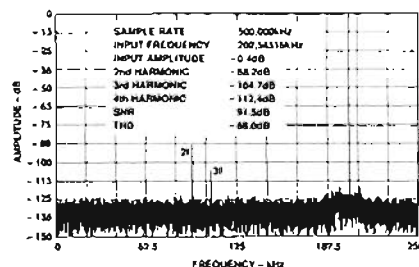
†Use the reply card for technical data. Circle 27.

## 16-BIT, 500-KSPS SAMPLING ADC AD1382 has guaranteed ac specifications Housed in hybrid package, includes T/H

The AD1382‡ is the industry's first wide-band 16-bit sampling analog-to-digital converter, complete with track-and-hold amplifier, housed in a single hybrid package. Its guaranteed ac specifications are the best among hybrids and comparable to those of expensive board-level products.

It is designed to fulfill the *spectral performance* demands of applications such as magnetic-resonance imaging (MRI) equipment and radar; the *speed* requirements of analytical instrumentation—including digital storage oscilloscopes (DSOs) and spectrum analyzers; and the *superior dc precision and functional integration* needed for CAT-scan, precision measurement and test equipment.

AC specs include (for both  $\pm 5$  and  $\pm 10$ -V full-scale, and 500-ksp/s sampling) minimum SNR of 90 dB at 5 kHz and 100 kHz, decreasing to 88 dB at 200 kHz. For  $\pm 10$ -V full-scale, typical specs are 95, 94, and



93 dB. Guaranteed minimum THD and spurious-free dynamic range (SFDR) are 90 dB at 5 kHz, 88 dB at 100 kHz, and 82 dB at 200 kHz.

"DC" specs include  $\pm 0.0006\%$  differential nonlinearity and  $\pm 0.0015\%$  integral nonlinearity (of full-scale range), no missing codes (16 bits). Operating temperature range is 0 to +70°C, required excitation includes power supplies of  $\pm 5$  V and  $\pm 15$  V and a 10-MHz clock; dissipation is 2.8 W. Prices begin at \$595 in 100s. ▣

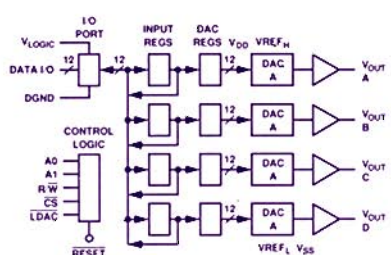
‡Use the reply card for technical data. Circle 28.

## QUAD V-OUT READBACK DACS

**Monolithic 12-bit DAC-8412 works on single +5-V to  $\pm 15$  V, has flexible reference polarity and range**

The DAC-8412 and DAC-8413\* are quad 12-bit, voltage-output DACs with readback capability. They can operate from a wide supply range, including single +5-volt supply (60 mW) up to  $\pm 15$  volts; the reference range is comparably broad. Bus access time is only 70 ns, making this among the highest-speed interfaces available for quad 12-bit DACs. Housed in a variety of 28-pin packages—including LCC—they provide four DAC channels in a very small space—a useful feature for automatic test equipment, servo controls, and missiles.

These voltage-output multiplying DACs accept two external reference voltages ranging from 0 and +2.5 volts to any range within  $\pm 10$  V with  $\pm 15$ -volt supplies. Examples of possible references are: 0 and +10 V for a positive unipolar 10-volt output; -2 and +5 V provides an output range suitable for testing ICs, and -8.192 to +8.192 V provides a  $\pm 8.192$ -V bipolar output with a



4-mV least-significant bit.

Readback and reset functions are also provided. The outputs can be controlled to read the contents of the input registers and when not used can be three-stated. This is useful in confirming the value written to the DAC. The reset function is available as reset to zero scale (DAC-8413) or as a reset to mid-scale (DAC-8412).

The DAC-8412 is available for military and extended industrial temperature ranges—in LCC and ceramic packages (plastic and PLCCS soon). Prices start at \$49 (100s). ▶

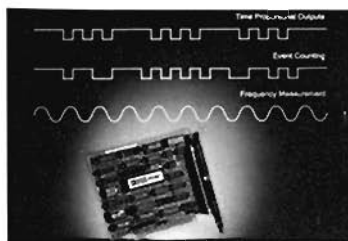
## COUNTER-TIMER I/O FOR PC/XT/AT

**With the RTI-827, a PC can measure frequency, count, and output precision pulse trains**

The RTI-827,† a PC/XT/AT-compatible counter/timer board, has 5 independent 16-bit counter/timers and 7 digital input/output (I/O) channels. To permit direct connection to signal sources in industrial environments, the RTI-827 uses input line receivers and high-current peripheral output drivers.

The counter/timers can be programmed to operate independently or simultaneously in applications requiring frequency- and period measurement, event counting, and pulse generation. The RTI-827 can generate single- or defined numbers of pulses, and can digitally adjust pulse widths. These operations can be synchronized to and/or controlled by outside events through the use of external gating and triggering.

The RTI-827's interface input options allow it to be connected to  $\pm 24$ -volt ac or dc signals; it will measure frequency and count events at rates up to 5 MHz (400 kHz with

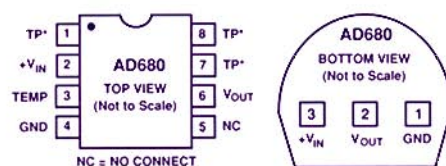


software-programmable debounce). Counter/timer outputs can be configured for TTL or open collector. In the open collector mode, they can sink up to 300 mA, connect directly to +35 Vdc, and drive relay coils, lamps, and other high-current control devices. Interrupts occur when either an internal counter reaches a preset count or an external line goes active.

The RTI-827 is supported by DOS drivers for C, Pascal, and various BASICs. It is shipped with a free Utilities disk with I/O exercise routines and configuration programs. The RTI-827's price is \$325. ▶

## 2.5-V REFERENCE

**AD680: low cost & power 5-mV error, 20 ppm/°C**



\*TP DENOTES FACTORY TEST POINT. NO CONNECTIONS SHOULD BE MADE TO THESE PINS.

The AD680§ is a low-power, low-cost 2.5-volt precision voltage reference. Meeting all specs on a single +5-V supply, it dissipates only 975  $\mu$ W (1.25 mW max). It is available in an 8-pin plastic mini-DIP (AN, JN) and SOIC (JR), and in a plastic 3-pin TO-92 transistor package (JT). Prices (100s) start at \$1.75 in mini-DIP and SOIC, and only \$1.60 in the TO-92.

The AD680AN is laser-trimmed for moderate performance:  $\pm 5$  mV initial error and 20 ppm/°C drift over the extended industrial temperature range, -40 to +85°C; the JN/JR/JT have  $\pm 10$  mV initial error and 25  $\mu$ V/°C drift (30  $\mu$ V/°C for JT), 0 to +70°C. The AD680 is well suited for reference applications with low-supply-voltage  $\Sigma$ - $\Delta$  a/d converters, such as the AD7701 and AD7703.

Quiescent current is low, 250  $\mu$ A max at +25°C and 280  $\mu$ A over temperature; and noise is 10  $\mu$ V max p-p, 0.1 to 10 Hz, and 250 nV/ $\sqrt{\text{Hz}}$  at 100 Hz.

With its low dissipation, the AD680 is ideal for extending battery life in power-sensitive hand-held instrument applications. The 8-pin versions include a PTAT-voltage terminal (proportional to absolute temperature); this allows the AD680 to also serve as a temperature transducer, which can help to compensate for system drifts.

Plastic DIP packaging provides machine insertability, while SOIC packaging provides surface-mount capability. TO-92 packaging offers a cost-effective alternative to two-terminal references, providing a complete solution in the same package in which functionally incomplete two-terminal references are usually found. ▶

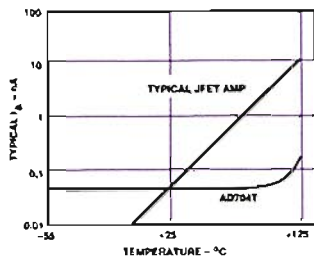
\*Use the reply card for technical data. Circle 29.

†Use the reply card for technical data. Circle 30.

§Use the reply card for technical data. Circle 31.

## QUAD OP AMP

**AD704** has low power, low  $V_{OS}$  and  $I_B$



The AD704\* is a quad operational amplifier that is similar to a pair of AD706 dual op amps (*Analog Dialogue* 24-3, p. 19) or four AD705s (AD 24-1, page 18). All are high-precision types, with low offset voltage and bias current—and they have low current drain, 600  $\mu$ A max per amplifier.

Offset voltage is low: 75  $\mu$ V max at 25°C and 150  $\mu$ V max over temperature, benefiting such applications as weigh scales and strain-gage preamplifiers. The offset voltage is matched to within 130  $\mu$ V max (K grade), a useful feature in constructing circuits requiring balanced inputs.

The AD704's super- $\beta$ -processed bipolar input transistors keep its bias current quite low, 150 pA max, and it holds within 200 pA max over temperature (AD704K, CMV=0 V). This is in striking contrast to most JFET-input op amps; their bias current is very low at low temperature, but it increases exponentially with temperature, as shown in the Figure.

Noise is low, typically 0.5  $\mu$ V p-p (0.1 to 10 Hz). The combination of excellent dc performance and low power drain (600  $\mu$ A per amplifier) is especially helpful in battery-powered applications.

This combination of characteristics makes the AD704 useful wherever groups of op amps combining low offset errors and low bias currents are needed for such applications as instrumentation amplifiers, low-drift active filters, signal conditioning, and medical applications, such as ECG and EEG.

The AD704 is available for the commercial, extended industrial, and military temperature ranges and in plastic, cerdip, and SOIC packages. Prices start at \$4.04 in 1000s.  $\square$

\*Use the reply card for technical data. Circle 32.

## DUAL RESOLVER/DIGITAL CONVERTER

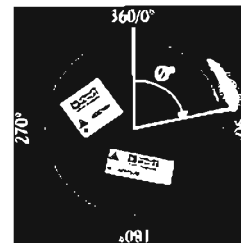
**14-bit, two-channel tracking AD2S34:**  
Built-in power oscillator drives resolvers directly

The AD2S34† is a complete dual-channel conversion system in a single 32-pin hybrid package; it includes two independent resolver-to-digital converters and a built-in power oscillator for resolver drive.

The AD2S34 is especially designed for applications where accuracy, size, and weight are crucial design parameters. It is available in accuracy grades of 2- and 4 arc-minutes, in a 1"  $\times$  1"  $\times$  0.16" (25.4  $\times$  25.4  $\times$  4.6 mm<sup>3</sup>) surface-mount package, and it requires no external circuitry for operation.

Applications include gimbal/gyro control systems, radar and sonar, engine control, coordinate conversion, servo-, fire-control-, avionic- and missile systems, antenna monitoring, and CNC machine tools.

Each channel's independent monolithic tracking converter continually monitors the status of the resolver signals; a shared output latch allows data to be read from either



channel without interrupting the conversion. Both channels also have an analog velocity output with  $\pm$ 1% (typical) non-linearity and  $\pm$ 3% reversion error.

The unique on-board oscillator provides the reference signal necessary to drive both resolvers, with options for 400-Hz, 2.6-kHz, or 4-kHz operation.

The AD2S34 has two accuracy grades, 2.6 and 4.0 arc-minutes, specified over the -55 to +125° military temperature range. Prices begin at \$435 (100s).  $\square$

†Use the reply card for technical data. Circle 33.

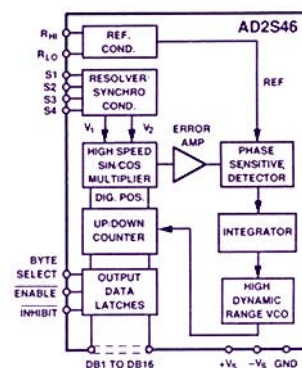
## SYNCHRO, RESOLVER CONVERTER

**16-bit AD2S46 is 1.3 arc-minutes accurate**  
Faster (12-rps), smaller (28-pin DDIP), cheaper

The AD2S46‡ is a single-channel 16-bit resolver- or synchro-to-digital converter with 1.3-arc-minute angular accuracy. Its applications include military stabilized platforms, x/y-coordinate systems, smart munitions, and guidance controls. It is ideally suited for angular measurement and control where cost, size, and accuracy are at a premium. Price is only \$577 in 100s.

The AD2S46 includes a high-accuracy differential input circuit with options for both synchro and resolver transducers. Its 1.3 arc-minute accuracy is maintained over the complete -55 to +125°C temperature range.

Common-mode rejection is better than 74 dB; for 90-volt input signals, the converter has a  $\pm$ 250-volt common-mode range, a 40% improvement on comparable currently available devices. Packaged in an industry-standard 28-pin double-width ceramic DIP package, it is the smallest 1.3-arc-minute device available. (A 2.6-arc-



minute version is also available.)

The use of proprietary IC chips within the device ensures a high level of integration, which tends to minimize possible failure modes. The predicted MTBF (MIL-HDBK-217E) in a naval sheltered environment is 1.75 million hours. Units qualified to /883B specifications will be available in spring, 1991.  $\square$

‡Use the reply card for technical data. Circle 34.

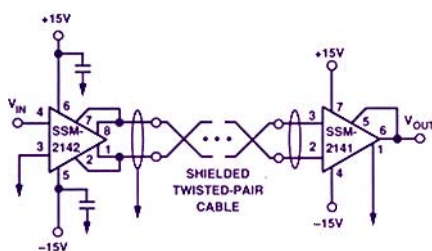
## BALANCED LINE DRIVER FOR AUDIO

**SSM-2142 drives 10 V rms into a 600-Ω load with low distortion and gain error, high slew rate**

The SSM-2142\* is the first low-cost, self-contained differential cable driver for high-quality audio systems. It is an integrated differential-output buffer amplifier that converts a single-ended input signal to a balanced output signal-pair with high output drive.

Oriented primarily toward professional audio, the SSM-2142's ability to transmit analog signals in difficult environments accurately without suffering signal losses will also help designers of instrumentation, telecommunications equipment, and industrial process-control systems.

In addition to being easy to use, it is capable of handling extremely long cables and large capacitive loads; it provides a complete high-performance driver/receiver system when used in conjunction with the SSM-2141 differential receiver. All the user has to do is connect the power, present high-quality audio input to the device, and



connect the differential outputs to the twisted-pair cable that will carry the signal.

The SSM-2142 features >40-dB of common-mode-output-noise rejection. In a typical SSM-2142/SSM-2141 system, total harmonic distortion (THD) is less than 0.006%; and gain error is 0.7% typical, 2% max (i.e., less than 0.2 dB)

Specified for the -40 to +85°C temperature range, the SSM-2142 is available in an 8-pin plastic mini-DIP, cerdip, and 16-lead SO. Prices start at \$2.95 (100s).

\*Use the reply card for technical data. Circle 35.

## 4-QUADRANT ANALOG MULTIPLIER

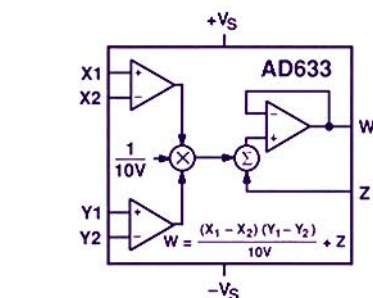
**AD633 is functionally complete in 8-pin package Total error <2% of full scale, price: \$3.38 (1000s)**

The AD633J† is a low-cost, functionally complete four-quadrant analog multiplier, available in 8-pin plastic DIP and SOIC packages. It is complete—no external components required—and laser-trimmed for accuracy and stability.

It can be used to multiply, divide, and square, as well as for phase detection, modulation/demodulation, voltage-controlled amplifiers, attenuators, filters, and oscillators.

As a multiplier, its total error is <2% (0.172 dB) of full-scale, with less than 1% max X-nonlinearity and feedthrough, 0.1% typical Y nonlinearity and feedthrough, and only ±50 mV max output offset voltage. It has a small-signal bandwidth of 1 MHz, 20 V/μs slew rate, and 2-μs settling time to 1% of final value. Wideband noise (10 Hz to 5 MHz) is typically 1 mV. Its high (10-MΩ) input impedance makes signal source loading negligible.

Applications for analog multipliers abound:



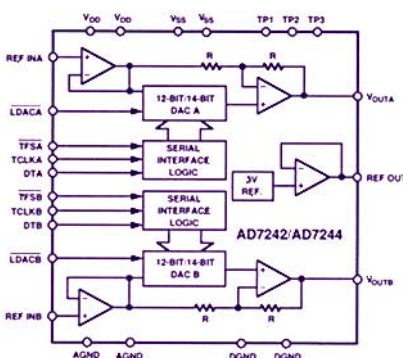
a few examples include power and power-factor meters, sine-cosine transformations, gamma correction in projection TV systems, automatic-gain-control amplifiers, as well as the applications mentioned above.

The AD633J is specified for 0 to +70°C operation. It will operate on power supplies from ±8 V to ±18 V, with excellent power-supply rejection (0.01% full-scale error for ±14 V to ±16 V). It is priced at \$3.75 in 100s, \$3.38 in 1000s.

†Use the reply card for technical data. Circle 36.

## DUAL V-OUT DACs

**12/14-bit AD7242/44 Serial input, low power**



The 12-bit AD7242 and 14-bit AD7244§ are fast, complete, serial-input, voltage-output DACs comprising two independent channels of d/a conversion, with output amplifiers, an on-chip 3-volt reference, and high-speed serial-interface logic.

These devices provide a high-speed, easy-to-use serial interface with two separate ports, to allow direct interfacing to DSP processors and microcontrollers. Serial interfacing minimizes pin count and permits a small package size (a skinny 24-pin plastic DIP or cerdip—or a 28-terminal SOIC).

The DACs dissipate 130 mW, operate from ±5-volt supplies, contain an on-chip precision ±3-volt buried Zener reference, and have ±3-V analog output range. Their analog outputs settle fast, 3 μs to ±1/2 LSB for the AD7242, and 4 μs to ±1/2 LSB for the AD7244. In addition, their linearity over temperature is excellent: ±1/2-LSB max integral nonlinearity for the AD7242K/B, ±2-LSB max for the AD7244J/A/S; and ±1-LSB differential nonlinearity (guaranteed monotonic) for all versions of both types.

Typical applications for these dual devices exist in process control, high-speed modems, high-end hard-disk drives, adaptive noise cancellation, and digital servos.

The devices are fabricated in linear-compatible CMOS (LC<sup>2</sup>MOS), an advanced mixed-technology process that combines precision bipolar circuits with low-power CMOS logic. They are available in identical pinouts to allow easy upgrade from 12- to 14-bit performance. Prices (100s) start at \$14.00/\$17.95 for the AD7242/AD7244.

§Use the reply card for technical data. Circle 37.

# Ask the Applications Engineer—9

## SEMINARS AND SUPPORT

by Chris Hyde

*Q. Are performance, quality, reliability, price, and availability the only important considerations in selecting products for use in the critical portions of my designs?*

A. There is one more—*support*. A manufacturer's support can be an important factor in shortening the design cycle and approaching optimal part selection—but only if you take advantage of it. Using it can make the difference between getting your product to market on time or losing the edge and market window to your competitors.

*Q. What do you mean by support?*

A. At Analog Devices, it basically means *help* for the designer. Its constituents include:

- (mostly) free *literature* and *software* [for example, accurate and comprehensive data sheets, data books, selection guides, tutorial and technical reference books, application notes and guides, SPICE models and other useful disk-based material, and serial publications such as *Analog Dialogue*, *Productlog*, and *DSPatch*]
- *advice* and *information* from our applications engineers, on the phone and in the field, to discuss the technical pros, cons, advantages and pitfalls in using our products to solve your design problems and selecting the right product from among the many choices available
- *samples* and *evaluation boards* from our sales and applications engineers, to try out new products—especially those at the edges of the technology—and
- *seminars*, practical tutorials in various aspects of analog-, digital-, and mixed-signal processing.

*Q. That sounds like a rather full plate. What's in it for you?*

A. We're really quite pragmatic. The products that we manufacture are—more often than not—state of the art and often pace the knowledge of the engineers who will benefit by applying them. It is in Analog Devices' best interest to assist these engineers in learning how and why to apply these products.

Today, designers are at a crossroads and in need of new forms of guidance. Analog Devices' unique combination of abilities in component design, processes, and functional integration, our long-cultivated capability of combining analog and digital functions on a single chip, our 25 years of experience in helping designers deal with the unique problems of transitioning between the analog and digital worlds—and now our unique contributions in digital signal processing—combine to put us in the forefront of a revolution in system design.

The integration of these capabilities shows up in both the products and the ability to provide support for customers using them to deal with the signal-conditioning chain in its entirety. The chain starts and ends with the analog signal—to condition it, convert it, process it in the digital domain, and convert the result back to analog. The physical and electrical environment is often hostile to signals, and there are many (often quite subtle) things for the designer to consider. We are in a unique position to help engineers from both analog and

digital worlds learn about the common ground [no pun intended] of “mixed” signal-processing technology.

*Q. I'd love to go to a real nuts-and-bolts seminar on this topic. Are you planning one?*


A. You read our mind. Between March and June of 1991, Analog Devices is sponsoring a full-day technical course entitled, “Mixed-Signal Design Seminar.” Presented by Analog Devices applications engineers, it is designed to assist both analog and digital designers with many of the trickier aspects of both analog and digital signal processing. The seminar combines fundamental concepts, advanced theory, and practical application. Readers who have attended other Analog Devices seminars—such as last year's high-speed seminar—know that this seminar will not be a “product pitch” (but naturally our discussions of practical application will unabashedly take into account the characteristics of the devices we know best).

*Q. When? Where? How much?*

A. In the above time frame, the widely advertised seminars are given in a variety of locations throughout the United States. Seminars will later be given elsewhere in the World, and thereafter they will be given to groups as the opportunity arises. The minimal cost, \$20, includes lunch and all materials—including a nearly 500-page book of Notes (attendees at last year's High-Speed Design Seminar will recall the excellent book that accompanied it—and is now available for sale\*). To register or obtain more information, call Analog Devices at 1-800-ANALOGD or (617)-937-1430. It's an excellent opportunity to get a taste of Analog Devices support.

*Q. What topics will be included in the Mixed-Signal Design Seminar.*

A. I thought you'd never ask. Here are the *main* headings:

- Signal conditioning and analog signal processing
- Fundamentals of sampled-data systems
- Digital signal-processing techniques
- ADCs in DSP applications
- DACs in DSP applications
- Sigma-delta ADCs and DACs
- DSP hardware fundamentals
- Interfacing ADCs and DACs to DSP chips
- MSP system design examples:  
High-performance modems, digital mobile radio, digital audio
- Techniques 

## VARIOUS TOPICS

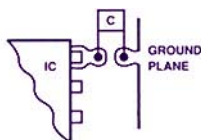
by James Bryant

*Q. Tell me something about supply decoupling.*

A. All precision analog integrated circuits, even low-frequency ones, contain transistors having cutoff frequencies of hundreds of MHz; their supplies must therefore be decoupled to the ground return at high frequency—as close to the IC as feasible to prevent possible instability at very high frequencies. The capacitors used for such decoupling must have low self-inductance, and their leads should be as short as possible (surface-mounted chip ceramic capacitors of 10- to 100 nF are ideal, but leaded chip ceramics are generally quite effective if the lead length is kept to less than 2 mm).

\*To buy a copy of the High-Speed Design Seminar, use the book purchase card bound into this issue or call (617) 461-3392. The Mixed-Signal Design Seminar book will be available for purchase in September, 1991, at \$22.

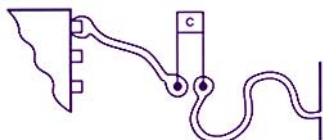




IDEAL HF DECOUPLING HAS

1. LOW INDUCTANCE CAPACITOR (MONOLITHIC CERAMIC)
2. MOUNTED VERY CLOSE TO THE IC
3. WITH SHORT LEADS
4. AND SHORT, WIDE PCB TRACKS

IT MAY BE SHUNTED WITH A TANTALUM BEAD ELECTROLYTIC TO PROVIDE GOOD LF DECOUPLING AS WELL.



THIS SORT OF THING IS USELESS!

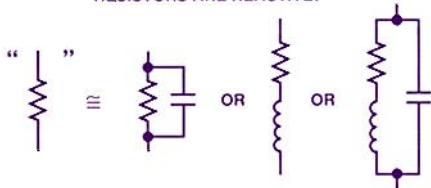
Low-frequency decoupling is also important, since the PSR (power-supply rejection) is normally specified at dc and will deteriorate appreciably with increasing power-supply ripple frequencies. In some high-gain applications, feedback through the common power-supply impedance can lead to low-frequency instability (“motorboating”). However, low-frequency decoupling at each IC is not often necessary.

Supply decoupling does more than prevent instability. An op-amp is a *four-terminal* device (at least), since there must be a return path for both input signals and the output circuit. It is customary to consider the common terminal of both op-amp supplies (for op-amps using  $\pm$  supplies) as the output signal-return path, but in fact, one of the supplies will be the de facto return path at higher frequencies, and the decoupling of the amplifier’s supply terminal for this supply must take into consideration both the necessity of normal high-frequency decoupling and the routing of the output ground.†

Q. In “Ask the Application Engineer,” you’re always describing non-ideal behavior of integrated circuits. It must be a relief to use a simple component like a resistor and know that you have a near-ideal component.

A. I only wish that a resistor was an ideal component, and that that little cylinder with wire ends behaved just like a pure resistance. Real resistors also contain imaginary resistance components—in other words they’re reactive. Most resistors have a small capacitance, typically 1-3 pF, in parallel with their resistance, although some types of film resistors, which have a spiral groove cut in their resistive film, may be inductive, with inductances of a few tens or hundreds of nH.

RESISTORS ARE REACTIVE:



Of course, wirewound resistors are generally inductive rather than capacitive (at least, at the lower frequencies). After all, they consist of a coil of wire. It is commonplace for wirewound resistors to have inductances of several microhenrys or tens of microhenrys, and even so-called “non-inductive” wirewound resistors, which consist of  $N/2$  turns wound clockwise and  $N/2$

turns wound anticlockwise, so that the inductances of the two half windings cancel out, have a residual inductance of a microhenry or even more. (For higher-resistance-value types, above 10 k $\Omega$  or so, the residual reactance may be capacitive rather than inductive, and the capacitance will be higher—by up to 10 pF—than a standard film or composition resistor.) These reactances must be considered carefully when designing high frequency circuits which contain resistors.

Q. But many of the circuits you describe are for making precision measurements at DC or very low frequencies. Stray inductance and capacitance don’t matter in such applications, do they?

A. They actually do. Since transistors (either discrete or within ICs) have very wide bandwidths, if such circuits are terminated with reactive loads, they may sometimes oscillate at frequencies of hundreds or thousands of MHz; bias shifts and rectification associated with the oscillations can have devastating effects on low-frequency precision and stability.

Even worse, this oscillation may not appear on an oscilloscope, either because the oscilloscope bandwidth is too low for such a high frequency to be displayed, or because the scope probe’s capacitance is sufficient to stop the oscillation. It is always wise to use a wideband (LF to 1.5 GHz or more) spectrum analyzer to verify the absence of parasitic oscillations in a system. Such checks should be made while the input is varied throughout its whole dynamic range, since parasitic oscillations may sometimes occur over a narrow range of inputs.

Q. Are there any problems with the resistance of resistors?

A. The resistance of a resistor is not fixed but varies with temperature. The temperature coefficient (TC) varies from a few parts per million per degree Celsius (ppm/ $^{\circ}$ C) to thousands of ppm/ $^{\circ}$ C. The resistors with the best stability are wirewound or metal film types, and the worst are carbon composition.

Large temperature coefficients are sometimes useful (an earlier “Ask the Applications Engineer”\* mentioned how a +3,500-ppm/ $^{\circ}$ C resistor can be used to compensate for the  $kT/q$  term in the equation for the behavior of a junction diode). But in general, the variation of resistance with temperature is likely to be a source of error in precision circuits.

If the accuracy of a circuit depends on the matching of two resistors having different TCs, then, no matter how well-matched at one temperature, they will not match at another; and even if the TCs of two resistors match, there is no guarantee that they will remain at the same temperature. Self-heating by internal dissipation, or external heating from a warm part of the system, will result in a mismatch of temperature, hence resistance. Even with high quality wirewound or metal-film resistors these effects can result in matching errors of several hundred (or even thousand) ppm. The obvious solution is to use resistors which are fabricated in close proximity on the same substrate whenever good matching is necessary for system accuracy. The substrate may be the silicon of a precision analog IC or a glass or metal thin-film substrate. In either case, the resistors will be well-matched during manufacture, will have well-matched TCs, and will be at nearly the same temperature because of their proximity.

(This discussion will be continued in a future issue.)



†This issue is developed in detail in the free application note, “An IC amplifier user’s guide to decoupling, grounding, and making things go right for a change,” by Paul Brokaw. Use the reply card. Circle 38.

\*Analog Dialog 22-2, 1988. p.29. Circle 39 for a copy.

# Worth Reading

## CATALOGS AND BROCHURES

**Supplement to the 1990 Data Acquisition & Control Catalog**, 64 pp., includes 4 new products:  $\mu$ MAC-1060 Single-Board Controller, RTI-827 PC/XT/AT-Compatible Counter/Timer Board [see p. 21], SW-800 Series of RTI-800 Series DOS Drivers, and SPECIFIX Low-Cost Process-Control Software; plus a Selection and Configuration Guide, and a Product Reference and Index. Circle 40

**Mastering The Mix In Signal Processing**, Brochure, 12 pp.—an introduction to the ADSP-21msp50 mixed-signal processor, with an overview of both analog and digital functions. Circle 41

**Analog Devices automotive smart sensors can help you move with the times**, Brochure, 28 pp. Describes several automotive sensor products, including the AD22001 [see page 8]. Circle 42

## SERIAL PUBLICATIONS

**DSPatch—The DSP Applications Newsletter:**

**Number 18**, Winter, 1991, 20 pp. Features: Second-generation ADSP-2100A Simulator and Emulator; ADSP-2102/2106 offer mask-programmable ROM; Generic Adaptable Signal Processor by General Dynamics; DSP Technology in India; EZ-LAB/EZ-ICE for the ADSP-2111; Brown University designs digital audio interface with ADSP-2100; DCT image compression. Plus the usual features: How to talk analog—Proper grounding for mixed-signal circuits; Q&A items; a listing of third-party development tools for DSP processors, and miscellany—updates, paper calls, etc. Circle 43

**Special reprint issue:** Combines the four-part series on sigma-delta conversion into a single reprint. Circle 44

## REPRINTS AVAILABLE

**Isolation barrier precisely passes transducer signals**, by Jeffrey A. Greenwald, *EDN*, June 21, 1990. Describes applications of the AD208 isolator [AD 24-1]. Circle 45

**Automobiles that make sense**, by Kristin Dinsmore et al, *Automotive Engineering*, September 1990. Circle 46

## APPLICATION NOTES

**AD671 12-bit, 2-MHz ADC digitizes CCD outputs for imaging applications**, by Elwyn Davies, 8 pp. Includes an informative overview of charge-coupled devices (CCDs) and image-scanning systems using CCDs. Circle 47

**AD9617/AD9618 Current-Feedback-Amplifier macromodels**, by William E. Tolley, 4 pp. describes the macromodels for these devices, which are included on a diskette with many others, as described at right. Circle 48

**Evaluation board for the AD7701/AD7703 sigma-delta A/D Converters**, by Mike Curtin, 8 pp. Good clean advice on how best to evaluate the AD7701/AD7703 sigma-delta converters. Circle 49

**Replacing the AD1145 with the AD7846**, by Mike Curtin, 6 pp. Compares these somewhat similar 16-bit DACs (an older hybrid and a new monolithic), and offers useful information on revising AD1145 designs to accommodate the AD7846. Circle 50

**$R_{ON}$  modulation in CMOS switches and multiplexers; what it is and how to predict its effects on signal distortion**, by John Wynne, 2 pp. The result of  $R_{ON}$  modulation is distortion; this Application Note gives a simple nomograph to determine THD. Circle 51

**Precision surface measurement using the AD2S58**, by Matthew Finnie, 6 pp. Why the AD2S58 LVDT-to-digital converter is ideal for surface measurements ranging from 2 mm down to 35 nm, types of transducers available, how it compares with alternative techniques, and electrical implementation of measurements with either LVDTs or half-bridge gauges using the AD2S58. Circle 52

## NEW SPICE MODEL LIBRARY

SPICE\* models of Analog Devices IC amplifiers are now available on a free 5 1/4" floppy disk.† Models of 176 unique devices—including various grades of generic types—are included in the largest library currently available from any amplifier vendor. It has several novel features: for the first time, *instrumentation amplifiers* (AMP-01 and AMP-02) are represented by models. Also, many of the models include both voltage- and current noise sources—to permit designers to predict system noise performance using SPICE; this simplifies the task of noise analysis. Finally, the Analog Devices macromodels do not limit the number of poles and zeros available to properly imitate the device's frequency response; the result is that the models mimic device behavior more accurately.‡



The diskette contains the models' *netlist* (SPICE-formatted ASCII files that describe the device model) for each device listed. The models are the input to the SPICE program and will work with most of the popular SPICE simulation software available on the market (examples include Berkeley 2G6 SPICE, PSPICE, HSPICE). Note: the diskette does *not* contain the simulation software to run the models, just the data.

In addition to providing this free disk for engineers doing CAD using PCs, in order to make these models further available to the designer, Analog Devices has entered into agreements with leading vendors of computer-aided-design (CAD) computer systems to include SPICE models of our components in conjunction with their CAD workstations and libraries. These vendors—who supply workstations and software used by designers of electronic circuits and systems—include Cadence Design Systems, Inc., Mentor Graphics Corporation, Meta-Software, Inc., MicroSim Corp., and Valid Logic Systems, Inc.

We are planning to update this library about twice a year and to continually add new products as well as other popular products not yet on the list. Your inputs to our sales and application engineers will help us decide which products to include in the future and provide guidance for improvements. □

\*SPICE stands for simulation program with integrated-circuit emphasis; it is the most widely used computer simulation language for analog circuit analysis.

†To obtain a free copy, use the reply card. Circle 53.

‡See "New SPICE-compatible op-amp model boosts ac simulation accuracy," by Mark Alexander and Derek F. Bowers, *EDN*, February 15, 1990, p.143.

An Eclectic Collection of Miscellaneous Items of Timely and Topical Interest. Further Information on Products Mentioned Here May be Obtained Via the Reply Card.

## IN THE LAST ISSUE

Volume 24, Number 3, 1990, 28 Pages

Editor's Notes, Authors

RAM-DAC upgrade dramatically enhances VGA graphics (CEG/DAC)  
 First monolithic triple 10-bit video DACs provide true color (ADV7121/2)  
 Complete monolithic current transmitter (AD694)  
 DSP enhancements: IC processors, development tools (ADSP-2105/11)  
 Mixed-signal ASICs offer designers an alternative solution  
 Electronic adjustment made easy with the TrimDAC™ (DAC-8800/40/41)  
 New-Product Briefs:

Two precision dual op amp families (AD706, OP-297)  
 Low-noise, low- $I_H$  FET-input op amp (AD645)  
 Video op amp with 2 nV/√Hz, 120-MHz bandwidth (AD829)  
 10-volt dual reference with tracking outputs, ±2-mV error (AD688)  
 Low-distortion, 10-MHz analog multiplier with 94-dB SNR (AD734)  
 Monolithic unity-gain voltage buffer: 600-MHz bandwidth (AD9620)  
 Four-channel 12-bit A/D converter, simultaneous sampling (AD7874)  
 IC multiple 4- and 8-channel track-and-sample-holds (SMP-04-08)  
 Quad 8-bit DAC: complete with 10-V bandgap reference (DAC-8426)  
 16-bit  $\Sigma-\Delta$  ADC has 0.0015% nonlinearity, self-calibration (AD7701)  
 100-ksp/s 14-bit sampling ADCs with ac & dc specs (AD679, AD779)  
 Single-+5-volt-supply 12-bit ADC has Idle mode (AD7880)  
 Serial I/O port has 12-bit DAC & ADC, 83-ksp/s sampling (AD7868)  
 High-speed 12-bit M-DAC has 1/4-LSB linearity error (AD668)  
 20-bit audio DAC: 119-dB SNR, -98-dB THD-N (AD1862)

Ask the Applications Engineer—8: *Op-amp noise continued*

Worth Reading

Potpourri (Last Issue, Errata, Product Notes, Updates, Patents)  
 Advertisement

**STOP PRESS . . .** We note with regret the passing of silicon valley's colorful 53-year-old Bob Widlar, a pioneer of linear-integrated-circuit design and a household name in the industry. Although his labor was in other vineyards, his early work underlay many of the designs you've read about in these pages.

**NEWLY ANNOUNCED PRODUCTS:** . . . AD9005A Improved 12-bit 10-MSPS Sampling ADC (Circle 60 on reply card) with 0.75-LSB max differential nonlinearity; new highest-performance grade, AD9005ALM, has improved SNR, harmonic distortion specs . . . AD9100 Fast Track/Hold (Circle 61) acquires to 0.01% in 16 ns . . . AD75019 Monolithic 16 x 16 Crosspoint Analog Switch Array (Circle 62) handles 26-V signals, has serial control input, is complete with latches . . . AD7774 Complete Analog I/O Port (Circle 63) has 3 DACs (1 @ 11-bits, 2 @ 8-bits) plus a 4-channel 8-bit ADC with two track/holds . . . AD1876 16-Bit, 100-KSPS Sampling ADC (Circle 64) has 1-MHz full-power bandwidth, serial output, 16-pin skinny DIP.

**ERRATA:** . . . ADDS-2100A-ICE data sheet (in-circuit emulator for the ADSP-2100A): figures showing probe dimensions are incorrect. An errata sheet is available, CWYLSO\* . . . ADSP-2111 data sheet, March, 1990: PQFP pinout diagram on page 62 should be labeled "Bottom View" (not "Top View") . . . AD9014 data sheet, block diagram: Analog Ground pin labeled pin 29 [1 of 6] should read Pin 36 . . . AD9020 & AD9060 data sheets, page 11, truth tables: codes labeled 513, 512, 511 should read 512, 511, 510 . . . AD7871/7872 data sheet, package dimensions for the 16-pin SOIC (R-16) should show 0.3" width, not 0.15 [but R-16 dimensions in 1989/90 Data Conversion Data Book are correct] . . . AD1382 data sheet: A 7-item errata sheet is available, CWYLSO\*. In addition, Fig. 22 (Evaluation Board), pins 4 and 5 of U14 should be connected to pin 19 of U9; also U9 Pin 40 (jumper from gain-adjust) should be labeled JMP5 . . . AD394/395/396 max commercial-grade current drain specs are reversed in 1989/90 Data Conversion Products Databook. Correct specs: 28 mA at +15 V, 22 mA @ -15 V.

**PRODUCT NOTES:** . . . AD846 Op Amp's differential input voltage spec, as indicated in 1990/91 Linear Products Databook, should be ±1 V, changed from ±6 V. Back-to-back Schottky protection diodes, when placed across the input terminals, may help avoid problems . . . AD9300 Video Multiplexer is now available in PLCC; also some specs have been changed. For a new data sheet, circle 65 . . . AD9712 & AD9713 DAC PSRR spec is now 350  $\mu$ A/V. PSRR can be reduced to as low as 40  $\mu$ A/V with external circuitry. CWYLSO\* . . . SSM-2142 is now available in plastic for -40 to +85°C. CWYLSO\* . . . ADDS-2101-ICE and ADDS-2100A-ICE full-featured Emulators for the ADSP-2101 and ADSP-2100A, can now be rented—from Technicase Corporation, 43 Fulton St., Newark, NJ 07102, Telephone: (201) 621-RENT, FAX: (201) 643-4409 . . . AD584 pin-programmable voltage reference is now available in 8-pin plastic mini-DIP packages. CWYLSO\* . . . AD588J/K are now available in cerdip for the commercial temperature range at a saving over the industrial-grade A/B parts . . . ADDS-21XX Development Software Release 3.0 supports the entire fixed-point processor family, i.e., ADSP-2100, -2100A, -2101, -2105, -2111, and -21msp50. It replaces all prior software releases. CWYLSO\* . . . An updating addendum is available for the ADSP-2101 data sheet. CWYLSO\* . . . Since ADI has IC, hybrid, and multi-chip module (MCM) capabilities, our custom DSP subsystems can put today's chips to work for you in space-saving dense surface-mount packages. CWYLSO\* . . . AD515A and AD545A—since 1987—are monolithic versions of the AD515 and AD545 electrometer op amps. If you're still standardized on the older versions, you may want to consider the lower cost of these proven monolithic equivalents. CWYLSO\* . . . AD790 comparator has different pin numbers in SOIC and mini-DIP, but in the same order. CWYLSO\* . . . AD1868 is now available in DIP as well as SOIC . . .  $\mu$ MAC-6000 and  $\mu$ MAC-1060 now speak the same language: MComM3, using MACC-Net. For these and other enhancements, CWYLSO\* . . . 6B Series now has simultaneous sampling capability. Also, LABTECH CONTROL 3.0 (now with ICONview) and LABTECH NOTEBOOK 6.1 now support the 6B21 current-output module. CWYLSO\* . . . AD2S80A, the new and improved embodiment of the monolithic AD2S80 R/D converter, is now available—same specs, new grades, Class II ESD. CWYLSO\* . . . Cerdip (Q) instead of side-brazed (D) for AD7240, AD7520/21/22/25, AD7534/35/36 families; also AD7506/07/46/74/81 families . . . The following product families are now guaranteed for -40 to +85°C operation in plastic: AD7524/28/33/37/42/43/47, also AD7821, ADG2XX switches, and ADG5XX multiplexers . . . ADV101 (Circle 66) is available as a second source to BT101, with 1/3 less power and better linearity specs, also in an 80-MHz grade . . . Need software drivers when using CEG™ DACs? Try Gräbert Systems, Inc., 4330 N. Civic Center Plaza, Scottsdale AZ 85251; (800) 521-0240, FAX (602) 949-9937.

**MILITARY ROLL CALL:** . . . Class S listings: Full-MIL-M-38510 QPL certified to level S: OP-07, OP-27, PM-108, PM-155, PM-156, PM-1741, PM-139, DAC-08. For equivalent slash numbers, CWYLSO\* Meeting all requirements: AD534, AD558, AD565, AD571, AD573, AD574, AD584, AD590, AD650, AD9002, AD9012, AD9048, AD9060, AD9300, AD9617, AD9696, AD96685, AD96687. For availability, CWYLSO\* . . . Devices newly available to DESC drawings: AD637, AD630, AD539; ADG201HS, AD2S80, and AD640 are in process. For drawing numbers, CWYLSO\* . . . Newly 883B-qualified: AD827SQ, AD829SQ, AD9300TQ, AD9901TQ and TE, AD386, AD1332TD, AD1334TD. CWYLSO\*

**WORKSHOPS & SHOWS:** . . . DSP: 3-day workshop at your plant; now available for 6 to 12 attendees, "System programming and development with the ADSP-2100 family." CWYLSO\* Ask about ADDS-2190 . . . Upcoming shows in '91. If you're planning to attend, plan to visit us: ICASSP '91, May 14-17, Toronto . . . SIGGRAPH '91, Jul 30-Aug 2, Las Vegas . . . DISKCON '91, Sept. 25-26, San Jose, CA . . . SENSORS EXPO '91, Oct. 1-3, Rosemont, IL . . . AES '91, Oct. 4-7, New York . . . Comdex Fall '91, Oct. 21-25, Las Vegas NV . . . ISA '91, Oct. 27-Nov. 2, Anaheim CA . . . GOMAC '91, Nov. 5-7, Orlando FL.

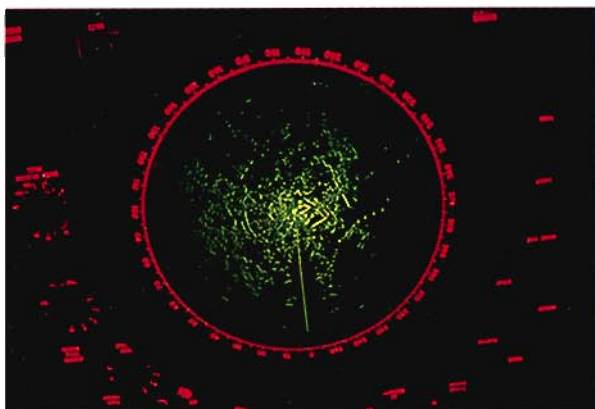
**PATENTS RECEIVED:** . . . 4,969,823 by Jerome F. Lapham and Brad W. Scharf for Integrated circuit with complementary junction-isolated bipolar transistors and method of making same . . . 4,970,470 by Royal A. Gosser for D-C coupled transimpedance amplifier . . . 4,973,978 by E. Perry Jordan for Voltage coupling circuit for digital-to-time converter . . . 4,978,871 by E. Perry Jordan for Level shift circuit for converting a signal referenced to a positive voltage to a signal referenced to a lower voltage . . . 4,980,634 by Andrew M. Mallinson for Electric power measuring system . . . 4,983,929 by Peter Real and David H. Robertson for Cascode current mirror . . . 4,985,739 by Jerome F. Lapham and Adrian P. Brokaw for Low-leakage JFET . . . 4,990,797 by Peter Real, David H. Robertson, Theodore Tewksbury, and Christopher W. Mangelsdorf for Reference voltage distribution system . . . 4,990,803 by Barrie Gilbert for Logarithmic amplifier . . . 4,990,916 by John M. Wynne and Michael Byrne for Single-supply digital-to-analog converter for control function generation.

\*CWYLSO: Check with your local Analog Devices sales office.

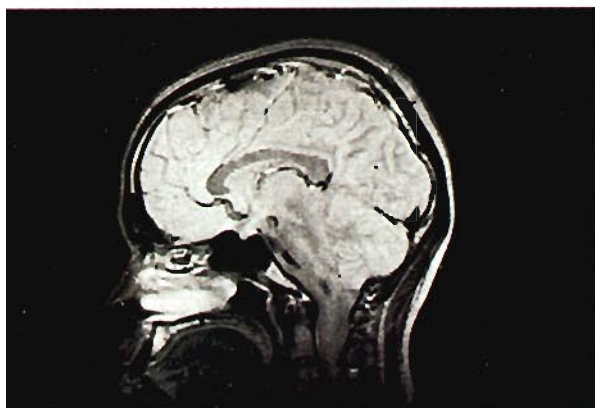
# The only 16-bit, 500 kSPS SADC with guaranteed dynamic performance.

## For the competition, that's not a pretty picture.

If you're working in spectral imaging applications, our new AD1382 presents a very pretty picture indeed. Because it's the first 16-bit, 500 kSPS single-package sampling A/D converter to offer guaranteed ac performance.



*The use of the AD1382 is soaring in radar applications, thanks to its higher level of integration and guaranteed dynamic performance.*



*With its wide dynamic range and low noise, the AD1382 has a great image with people working in magnetic resonance imaging applications.*

board space than more expensive modular or multipackage solutions.

For a better picture of what the AD1382 can do for you, contact Analog Devices at 1-800-262-5643. Or write to Analog Devices, P.O. Box 9106, Norwood, MA 02062-9106.

The AD1382 delivers guaranteed 100% production tested SNR, THD and peak distortion performance at three input frequencies and over two input ranges – testing that gives you the confidence to design for the best possible noise performance in your system.

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And since it's a single package, it's easier to design in and uses less



**AD1382**  
A 16-bit 500 kSPS SADC, the AD1382 provides excellent dynamic and static performance in a dual in-line ceramic package.

Guaranteed (@25°C, ± 5 V input range):

**SNR**

- 5 kHz 90 dB min
- 100 kHz 90 dB min
- 200 kHz 88 dB min

**THD & Peak Distortion**

- 5 kHz – 90 dB min
- 100 kHz – 88 dB min
- 200 kHz – 82 dB min

**DC specifications include:**

0.0015% FSR INL, 0.0006% FSR DNL and NMC guaranteed to 16-bits

**Other features include:**

Zero offset autocalibration  
± 5 V, ± 10 V Bipolar input range

An evaluation board for the AD1382 is available.

