# analog dialogue

A forum for the exchange of circuit technology: Analog and Digital, Monolithic and Discrete

**SERDEX – THE NEAR-IDEAL SYSTEM INTERFACE (P. 3)**


Also in this Issue:
Internally-Trimmed Monolithic Multiplier
CMOS Switches and Multiplexers

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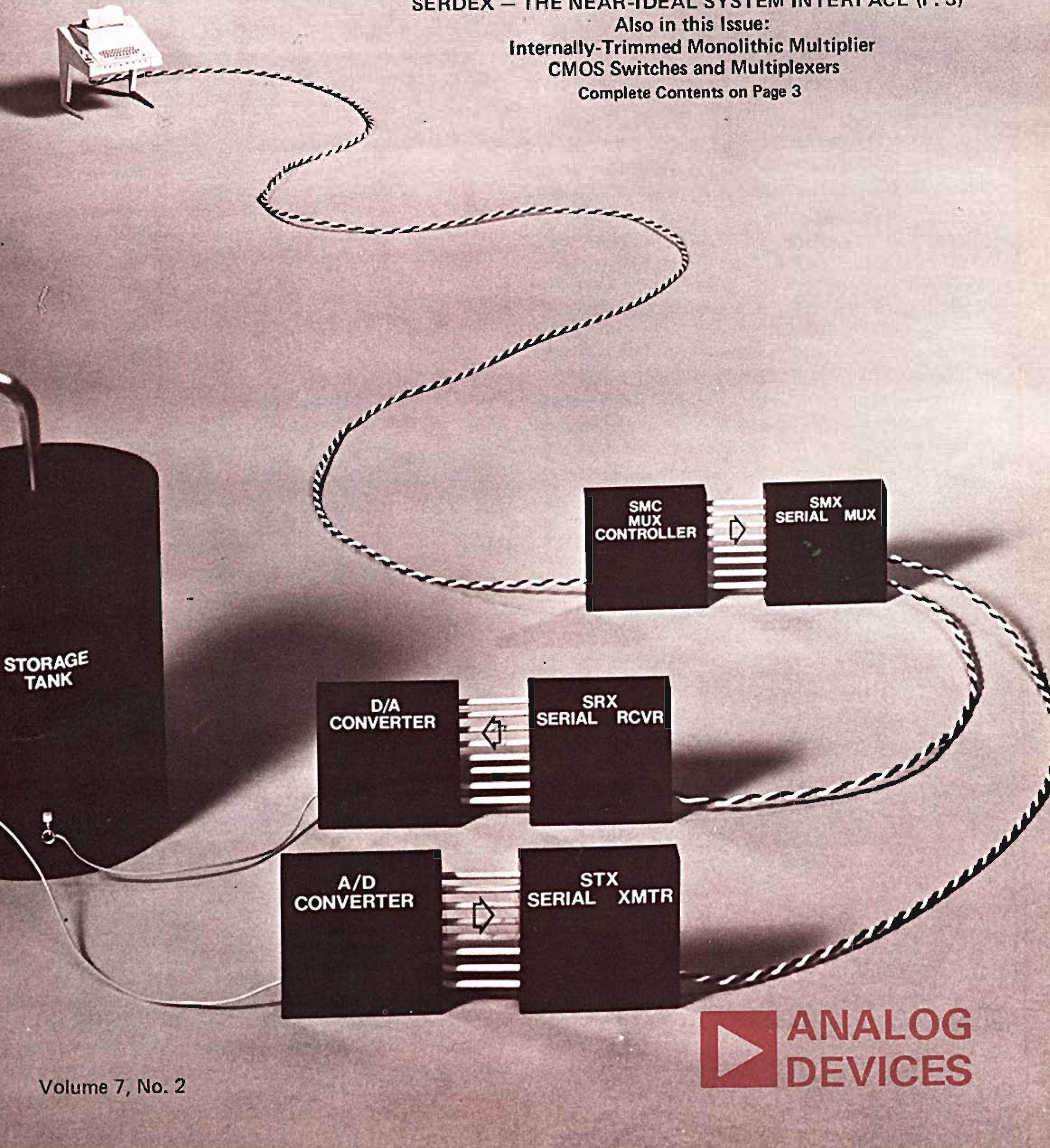


Volume 7, No. 2

ANALOG DEVICES

# Editor's Notes

In this issue of *Analog Dialogue*, we report on substantial accomplishments in three new technological or marketing areas. All are likely to prove important, not only to Analog Devices, but to the industry of which we are a member, and to the markets we serve.

It may be useful to review here the background and implications of these new products, since the underlying thinking may be of benefit to our readers, even if one or more of the specific products currently introduced is not of immediate interest.

## CONTROLLED INTERFACING (SERDEX)

Implementing even a modest data-communication-and-control system calls for a multitude of talents, not all of which are likely to be found in the person who perceives the need for such a system. In many cases, it calls for a lot of unfamiliar hardware, something called "software," and a good deal of money. It involves many engineers and technicians and much time. Though a successful system is often worthwhile at virtually any cost (because it introduces the element of *control*, which is operationally cost-effective), proof of its worth may come long after it has had to be explained, justified, authorized, specified, bid, designed, built, installed, debugged, and operated.

The beauty of the SERDEX idea is that the system's advocate can get started on a pilot basis with a minimum of argument and paperwork, because first-cost is so low. The engineering talent needed is essentially that required to get a transducer signal preamplified and digitized. And, beyond the SERDEX modules, the only further digital interface needed is a standard teletypewriter. The SERDEX modules respond to keyboard commands, and the printer responds to SERDEX-translated data. The only connection to the teletypewriter is a single twisted-pair cable.

And it works! Then, once the concept is proved in a microcosm, it can be extended to the servicing of a more-complex remote station, then to several remote stations. Once the system is proven manually (with teletypewriter or CRT terminal), it may be hooked up to a computer, via its teletype port, and may be controlled by programs written in a high-level language, such as BASIC.

The performance and the growth of the system (and its cost) are always under full control of its champion. And his management will applaud the possibility of planning a large installation, but making it prove itself as it grows, without ever losing control. And without ever having to wait for some large, expensive piece of special-purpose equipment to be delivered, installed, and debugged, while expensive processes suffer down-time.

In other words, it facilitates control, not only over a physical process, but over the entire task of getting communication and control established.

## LINEAR (ANALOG) CMOS

The first fruits of our West-Coast CMOS venture ("Better Circuits Coming," Vol. 6, No. 1) have ripened, in the form of multiplexers and quad switches. Besides low dissipation (and ours have substantially less than most), Complementary Metal-Oxide Semiconductor devices have extremely-high isolation resistance, desirable characteristics for low-current measurement and voltage switching. Future products that will help us achieve our goal of becoming a major supplier of linear CMOS include new generations of switches, complete low-power converters and other interface circuits, and all-analog circuits using CMOS.

## DYNAMICALLY-TRIMMED MONOLITHIC IC's

We were in the field early with laser-trimmed IC's (Vol. 4, No. 4), and with monolithic IC's that benefited by the stability of thin-film resistors deposited on the silicon substrate (Vol. 5, No. 1). Now, both processes mastered, they are combined in the manufacture of monolithic devices needing no external trimming. The AD532 multiplier is a highly-rewarding "opener," eliminating 4 external trim pots for optimum stability and reliability. More gratifying yet is the prospect of such future delights as "zero-offset" op amps, high-linearity monolithic converters, etc.

*Dan Sheingold* ▸▸▸

## THE AUTHORS

*"SERDEX" SERIAL DATA-EXCHANGE MODULES*

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**analog dialogue**

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# "SERDEX" SERIAL DATA EXCHANGE MODULES

## For "No Software" Interfacing in Data Communication and Control Systems

by Ivar Wold, Maurice Klapfish and Michael Lindheimer

### SERDEX* – FOR SYSTEMS YOU CAN DESIGN

Design of digital data-communications and control systems has, until now, called for great expenditures of time, talent, and money. Common sense calls for remote digitizing to avoid analog problems; low-cost converters now make it feasible. But *how to interface the data simply and reliably* has long been a source of perplexity to users and designers alike.

Now, you no longer have to be analog expert, digital expert, software expert, and systems genius (and, incidentally, master of your own field of endeavor) to design complex systems that are neither costly nor beyond your grasp. SERDEX is the solution.

Let us first look at the evolution of some techniques now in use and review their deficiencies. Then the SERDEX idea will be introduced and explained, in the context of simple communication systems. Finally, it will be shown how the same simple techniques are adapted to computer-controlled systems that can monitor and control several (or dozens) of system variables, at distances of up to 3 kilometers (or more, using modems).

### WHERE COMMUNICATION/CONTROL SYSTEMS ARE USED

Communication and control systems are employed when there is a need to acquire from a system data, such as temperature, weight, or liquid level. Or wherever there is a need to transmit digital data to an analog system, to adjust a flow rate or a mechanical position. Or whenever there is a need to issue system control commands that might turn on a heater, open a valve, or dump a hopper. In most cases, the common basic objective is *centralization of control*, whether the system components are in the same room or across the city.

Representative examples of the uses of data-communication and control systems are abundant. One is the remote measurement and control of inventories of stored material, such as petroleum products, milk, sand-and-gravel, wine, grain, cement, flour, etc. Another is monitoring and control of remote pipeline pumping stations. Others include data-logging and control of laboratory experiments, general factory control, control of heating and air-conditioning systems, and programming and control of processing furnaces.

### COMMON APPROACHES

The design and assembly of such communication and control systems have been approached in various ways. Originally, data communication and processing was entirely analog. But electrical analog systems are highly susceptible to noise, and may require expensive shielded cable, as well as careful signal conditioning and isolation, to avoid excessive loss of accuracy and dynamic range as distance increase. More serious, in


Figure 1. SERDEX Modules

today's increasingly computer-oriented world, they cannot interface directly with digital computers.

By the use of analog-to-digital (A/D) and digital-to-analog (D/A) converters, often with analog multiplexing and sample-hold amplifiers, the analog-digital portion of the computer interface could be achieved. But the analog circuit problems still existed, perhaps even more compellingly, because the digital computer is easily capable of dealing with signals having the accuracy and dynamic range of the originally-measured signal (which was always of better quality than the *received* signal). Furthermore, the expensive A/D and D/A converters required analog multiplexing for time-sharing them among many data channels, to reduce the cost/channel.

The analog-multiplexed system is indeed complex! Besides the analog signal-transmission problems, there are also *digital* interface and hardware problems, plus software problems. The computer programs present no mean task to write and debug; cus-

*(continued on p. 4)*

*For complete information on SERDEX™, use the reply card. Request K1.

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tom computer-interface hardware is required; separate cable runs are needed for incoming data, for outgoing analog signals, and for each control channel (increasing the weight —and cost— of wire). Furthermore, faster converters are necessary to maintain sampling rates comparable to those available in a non-multiplexed system. As a consequence of all these considerations, a high level of expertise (and money) is required to design, install, debug, and maintain the multi-channel analog-multiplexed, computer-controlled system.

The recent availability of low-cost (under $100) A/D converters (and D/A's and sample-holds of comparably low cost) have permitted some of the analog transmission problems to be avoided. If one converter is installed at the "remote" end of *each* data channel, analog data-transmission problems are eliminated, since data transmission can be all-digital. However, with this approach (and parallel data), you probably need a dozen or more wires per data channel and one wire for each control channel. Noise immunity is improved, but is only moderate, and often an even-more-complicated computer program and hardware interface is needed than was required in the case of the analog-multiplexed system. Whether this is an improvement over analog communication may well be open to question.

## THE SERDEX SYSTEM

Because it eliminates many of the analog circuit problems, the single-converter-per-channel became the basis of the SERDEX system, which has been designed to simplify the remaining problems.

Suppose a module existed that could transform the parallel (e.g., 12-bit) digital data at the remote A/D converter into standard ASCII* teletypewriter code that could be transmitted over an unshielded twisted pair of wires, in response to a command sent out over the same pair of wires. In addition, suppose another kind of module could exist at a remote location to transform serial ASCII code to parallel digital data, used to program a D/A converter or a digitally-operated output transducer. And suppose a remote digital multiplexer, operated by an ASCII code, allowed a number of remote devices to share the same pair of wires. Then you'd have a revolutionary system — SERDEX.

The advantages of such a system, based on serial ASCII data transmission, are extensive:

- No analog signal transmission; only digital
- Only a single twisted pair required for each remote location
- Several functions per channel: can send data, receive data, and transmit control commands
- Requires no hardware interface to teletypewriters (or to computers and CRT terminals with a teletypewriter port)
- For computer control, all programming may be done in a high-level language, such as BASIC
- Independence of ground-level differentials and high noise immunity result from using optically-isolated standard 20mA current loops. Up to 10,000 ft. (3km) without boosting or modems.
- Only digital multiplexing is required for an unlimited number of channels to share a single twisted pair of wires.
- Initial testing and debugging of computer-controlled systems can be done manually from a teletypewriter.

In short, SERDEX, which makes such a system possible, is the *better way*.

*ASCII: American National Standards Institute Code for Information Interchange, X3.4-1968 (International Organization for Standardization R646). See table on page 7 for partial listing.

SERDEX (SERial Data EXchange) is a family of 5 modules: The STX1003 Serial Transmitter; the SRX1005 Serial Receiver; two modules, the SMC1007 and SMX1004, that together perform the multiplexing function; and the SCL1006 Clock module, which is required in conjunction with each of the other modules.

## THE SERIAL TRANSMITTER

The STX1003 Serial Transmitter's primary function is to convert the parallel binary-coded digital (BCD) output of a remote A/D converter to serial ASCII teletype code and transmit the information over a twisted pair of wires to the central control station. In addition, the STX1003 can receive, over the same twisted pair, commands used to control the STX1003 and several additional system functions. Figure 2 illustrates manual control of liquid level from a teletypewriter.

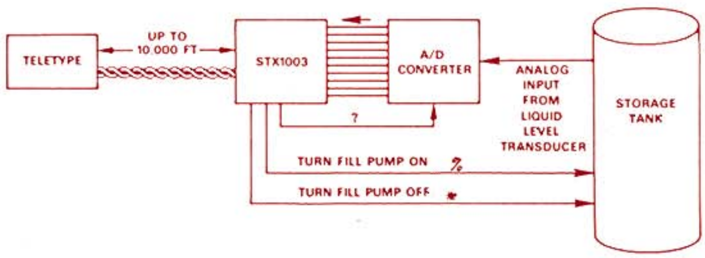



Figure 2. Application of the STX1003 Serial Transmitter

To determine the level in the tank, the operator might type

```
WHAT IS THE LEVEL IN THE TANK?
```

Because the STX1003 can recognize only eight "control commands," the alphabetic characters are ignored. However, when the STX1003 receives the question mark (?), it initiates an A/D conversion and subsequently transmits the data back to the teletypewriter. In a similar manner, the STX1003 can recognize and respond independently to 6 other control characters (%, *, $, !, ', and =) that may be useful for controlling system components, e.g., activating a pump, then turning it off later.

Returning to our check-and-fill example, the dialogue might proceed as follows:

```
WHAT IS THE LEVEL IN THE TANK?287
TURN THE FILL PUMP ON%
WHAT IS THE LEVEL IN THE TANK?496
?575
?681
?760
TURN THE FILL PUMP OFF*
```

In this manual system, the operator decides when the tank is sufficiently full and types the turn-off command. Clearly, no significant difficulty is encountered in replacing the teletypewriter with a computer having a TTY port and a high-level language capability, such as BASIC.

## THE SERIAL RECEIVER

The SRX1005 Serial Receiver, illustrated in Figure 3, performs the reverse function. Data and control commands originating at the central control station are sent over a twisted pair to the Serial Receiver, where they are converted to parallel digital outputs (including 6 independent control lines). These outputs can be used to program a D/A converter and system actuators, such as pumps and valves.

The dialogue in a manual system might look like this:

```
SET FLOW RATE = 137$
TURN ON VALVE*
```

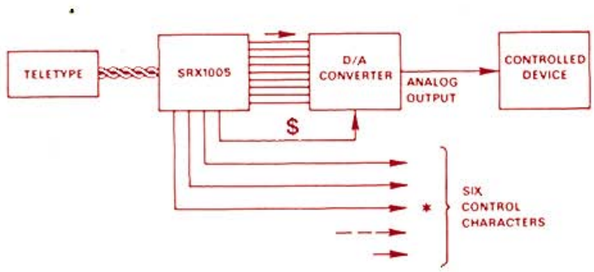



Figure 3. Application of the SRX1005 Serial Receiver

As before, the alphabetic text is ignored. The equal sign (=) designates that data will follow; 137 is the BCD number that programs the (BCD-coded) D/A converter; and the dollar sign ($), indicating end-of-data, strobes the data into the D/A input register. When the asterisk (*) is typed, the SRX1005 issues a pulse that is used to open a valve. Like the STX1003, the SRX1005 is readily computer-controllable.

## THE MULTIPLEXER

By employing the SMC1007/SMX1004 8-channel multiplexer combination, one can create more-elaborate systems (Figure 4). Since the multiplexer will transmit information in either direction, the central controller need only concern itself with addressing the appropriate channel. Once a channel has been addressed, further commands and data transmission or reception proceed exactly as they would via a direct connection, until a new channel is addressed. The controlling teletypewriter or computer selects the desired channel by transmitting the number symbol (#), followed by the channel number.

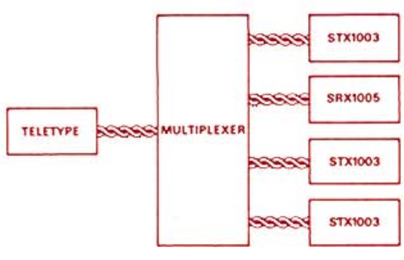



Figure 4. The Multiplexer in a SERDEX System

## THE CLOCK MODULE

The SCL1006 Clock module is an essential accessory module that supplies clock pulses (for clocking the serial data) and -15V power to the STX1003, SRX1005, and SMC1007. (In addition, all devices require power at +5V for TTL logic). An SCL1006 is required wherever one of the other modules is located, but it will serve from three to four modules in its immediate vicinity.

## A MODEST SYSTEM

An inherent virtue of the SERDEX system is that complex, multi-channel systems can be implemented as easily as 1-channel configurations. Figure 5 shows a 3-channel system in which channel 1 monitors a liquid-level transducer, channel 2 controls a valve aperture, and channel 3 verifies the output of channel 2 by an analog measurement, and also issues control commands (* and !) to turn the flow on and off. Typical teletypewriter dialogue might be

```
WHAT IS THE LEVEL IN TANK #1?285
SET FLOW RATE #2 =137$
TURN ON VALVE #3*
WHAT IS FLOW RATE?137
TURN OFF VALVE!
```

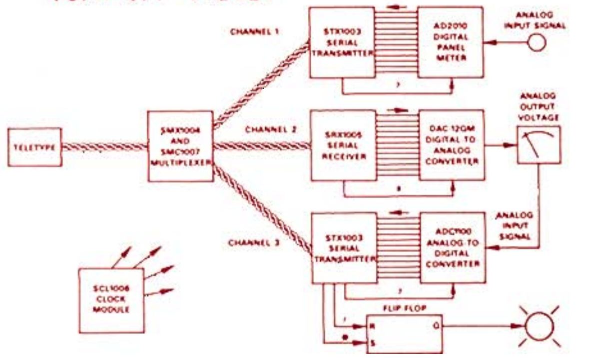



Figure 5. System Application of SERDEX Modules

## OPERATING SEQUENCE FROM A COMPUTER

If the teletypewriter is replaced by a computer that has a standard-teletypewriter port, the SERDEX system may be automated. Only a high-level programming language, such as BASIC or FOCAL, is required. Simple input/output statements eliminate the need for complicated machine-language programming.

The following example illustrates a single-channel program to control an inventory replenishment system: if, when measured, the level of monitored variable A has dropped below 250, it is caused to increase until it reaches 750.

```
100 PRINT "?"
110 INPUT A
120 IF A <250 THEN 150
130 IF A >750 THEN 170
140 GO TO 100
150 PRINT "*"
160 GO TO 100
170 PRINT "!"
180 STOP
190 END
```

When statement 110 is encountered, program execution ceases until all the digits of variable A have been entered. (When programmed in BASIC, the "INPUT" instruction causes a question mark (?) to be printed. Hence, statement 100 is not needed.)

## SUMMARY

We have seen that currently-used data communication and control techniques can call for extremely complex systems. System complexity usually grows geometrically or exponentially as the number of sample points increases. In contrast, complexity of SERDEX systems can be perceived as more nearly a linear function of the number of data channels.

Now let us take a closer look at the modules.

*(continued on p. 6)*

(continued from p. 5)

# HOW THE MODULES WORK

## STX1003 SERIAL TRANSMITTER MODULE (Figure 6)

When one of the control characters is received (%, *, $, =, !, or '), a pulse is issued at the appropriate terminal. If a question mark (?) is received, an A/D conversion is initiated. When the converter's *status* level changes, indicating that conversion is complete, it causes the resulting digital data to be transmitted serially back to the control center. As Figure 6 shows, up to 8 BCD digits can be sent, or up to 24 binary bits (if they are arranged in groups of 3 for transmission as octal digits). By the use of external shift registers, the STX1003's word output can be expanded to transmit a string of characters of any desired length, including outputs of additional A/D converters or such ASCII characters as plus and minus signs, decimal point, space, carriage return, and alphabetic characters.

The serial output of the STX1003's parallel-loaded shift register (and any external extensions) is fed to the parallel-to-ASCII converter, where it is transmitted one-character-at-a-time to the teletypewriter or computer.

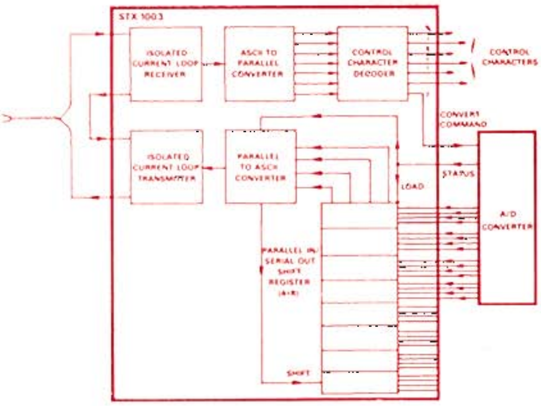



Figure 6. Block Diagram of the STX1003 Serial Transmitter

## SRX1005 SERIAL RECEIVER MODULE (Figure 7)

Upon receiving one of the control characters (%, ?, !, ', /, *), the Serial Receiver emits a pulse on the appropriate pin. The equal sign (=) clears the internal register and the *ready* flip-flop. The data characters that follow can enter the shift register, until a terminating dollar sign ($) is received. The $ sets the *ready* flip-flop, strobes the data into the converter, and inhibits acceptance of additional data until the next = arrives.

The SRX1005 can receive up to 8 BCD digits, or up to 24 binary bits, if the bits are grouped in 3's and transmitted as octal digits. If external shift registers are added, the SRX1005 can be expanded to receive other ASCII characters, such as alphabetics, or to accept a string of characters of any desired length.

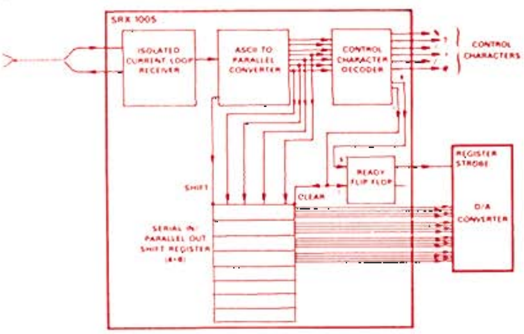



Figure 7. Block Diagram of the SRX1005 Serial Receiver

## SMX1004/SMC1007 SERIAL MULTIPLEXER MODULES (Figure 8)

The SMX1004 and SMC1007 together form an 8-channel bidirectional multiplexer. For up to 16 channels, 1 additional SMX1004 is used. The first eight channels (0 - 7) are addressed from the teletypewriter or computer by transmitting the number symbol (#), followed by a digit from zero (channel 0) through 7 (channel 7); for the second set of eight channels, # is followed by a letter from P through W (i.e., 8 through 15).

Multiple ranking of the SMX1004/SMC1007 combination permits communication with an unlimited number of channels. For example, in a dual-rank configuration (e.g., 8 x 8 = 64 channels), channel 3 of the first rank and channel 6 at the second rank would be addressed if the multiplexers received the characters #36.

Serial data received from the teletypewriter or computer is converted to parallel form, decoded to extract the number symbol and channel address, then converted back to serial data for transmission to the selected channel. Data returning from the remote channel is merely relayed back to the central control station.

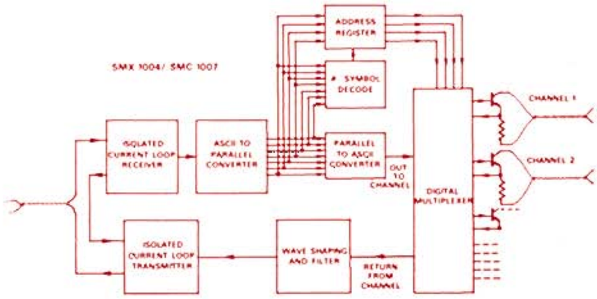



Figure 8. Block Diagram of a SMX1004/SMC1007 Multiplexer

## SCL1006 CLOCK MODULE

By programming the oscillator for either high or low frequency and selecting one of the 8 divider outputs, one can choose among 16 clock frequencies, ranging from 110 Baud (i.e., bits/second) up to 19.2 kilobaud. The SCL1006 also converts +5VDC to -15VDC and furnishes it to the associated modules.

## TRANSMITTING DATA OVER 20mA CURRENT LOOPS (Figure 9)

Data is transmitted to all parts of the loop by opening (0) and closing (1) switches at any point in the loop. Switches and receiver amplifiers can be easily isolated by optical couplers. The 20mA level differential provides high noise immunity using only unshielded twisted-pair wire. Loop defects are easy to detect, since current normally flows in the quiescent condition. ▶▶▶

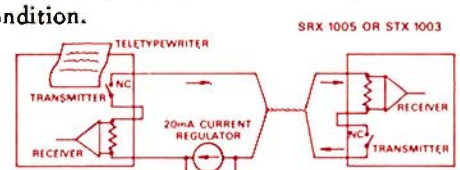



Figure 9. Teletypewriter Current-Loop Principle

# TYPICAL APPLICATIONS

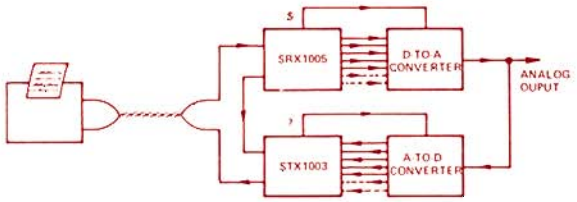



Figure 10. Verification of Programmed Analog Output. An SRX1005 and an STX1003, Operating on the Same Current Loop, Form a Highly-Reliable System. When a ? is Typed, the D/A Converter Output is Converted to Digital and Transmitted Back to the Teletypewriter.

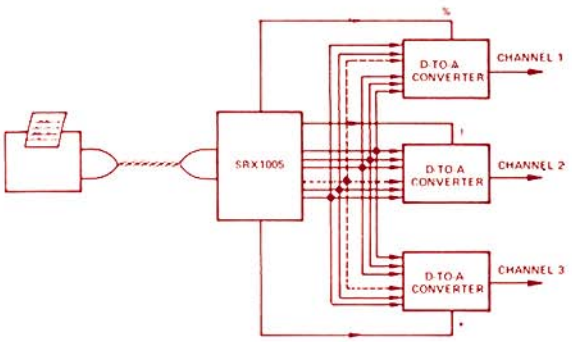



Figure 11. Self-Multiplexed Analog Output. Several D/A Converters are Connected in Parallel to One SRX1005. The %, !, or * Strobes the Input Register of the Desired D/A Converter.

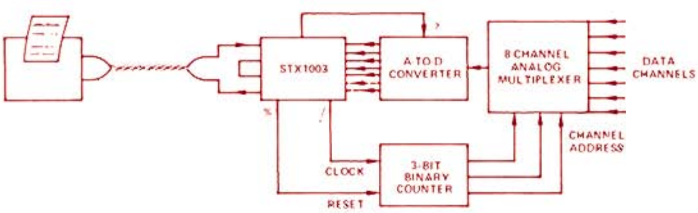



Figure 12. Teletypewriter or Computer-Controlled n-Channel Remote Analog Sequential Channel Addressing, Using Binary Counter. ! Advances the Counter, % Resets to First Channel, and ? Initiates Data Transmission Back to the Teletypewriter.

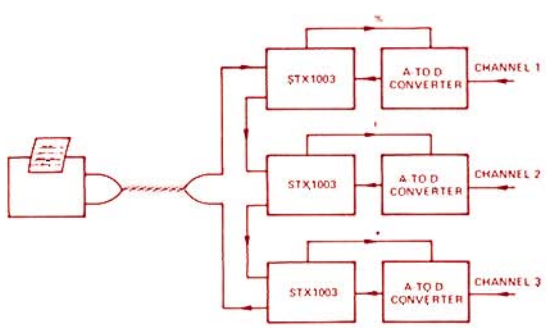



Figure 13. Many Transmitters Self-Multiplexed on One Series Current Loop. %, !, or * Interrogates the Respective Channels and Transmits the Data to the Teletypewriter.

# PERFORMANCE CHARACTERISTICS

## BRIEF SPECIFICATIONS OF SERDEX MODULES

Typical @ +25°C and specified supply unless noted otherwise.

| SYSTEM PERFORMANCE | |
|---|---|
| Clock Rate | 16x bit rate |
| Bit Rate (Baud, max) | |
| Isolated | 4800 Baud, min |
| Direct TTL | 20k Baud, min |
| Inputs and Outputs | TTL-compatible |
| Sampling Rate (@ 4800 Baud, through multiplexer, assuming 4 BCD digits/sample) | ~50 data points/s |
| Operating Temperature | 0 to +70°C |

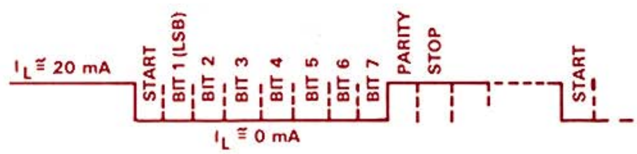
| INDIVIDUAL MODULES | STX1003 | SRX1005 | SMC1007 | SMX1004 | SCL1006 |
|---|---|---|---|---|---|
| Current (mA) | | | | | |
| @ +5V | 350 | 300 | 300 | 150 | (Note 1) |
| +15V (required) | 20 | 20 | 20 | .. | .. |
| -15V (supplied) | .. | .. | .. | .. | 80 |
| Loop supply current from +12V to +20V voltage source (unregulated), mA | 20 (Note 2) | 20 (Note 2) | 20 (Note 2) | 160 | .. |
| Dimensions (inches) | 4.25" x 3.3" x 0.625" | | | 2.1" x 2.1" x 0.6" | |
| (cm) | 10.8 x 8.4 x 1.6 | | | 5.35 x 5.35 x 1.55 | |
| Prices (1-9), $U.S. | $179 | $179 | $139 | $75 | $65 |

Note 1: 200mA plus 75mA per module serviced.

Note 2: Not required if loop current is supplied by the data terminal or the SMX1004.

## ASCII – FORMAT AND CODE NORMALLY USED BY SERDEX

The teletype character format consists of 1 *start* bit, 8 ASCII data bits (LSB first), and two *stop* bits. Prior to the start of a word, representing an ASCII character, current is flowing (1). A *start* signal is given by turning the current off (0). When a *start* signal is received, the incoming bit stream is sampled at the center of each bit interval, until the character is completed.




The eighth bit may be used as a parity bit. The *stop* bits turn the current on, and it remains on until the next character arrives.

## EXAMPLES OF ASCII CHARACTER CODES:

| CHARACTER | BIT 8 | BIT 7 | BIT 6 | BIT 5 | BIT 4 | BIT 3 | BIT 2 | BIT 1 (LSB) |
|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 2 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 |
| 3 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 4 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 5 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 |
| 6 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 |
| 7 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 |
| 8 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 |
| 9 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 |
| ! | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| $ | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| % | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 |
| ' | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 |
| / | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 |
| = | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 |
| ? | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| * | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 |
| # | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 |

# CMOS QUAD SWITCHES AND MULTIPLEXERS

## New Low-Leakage, Low-Dissipation IC's For Analog Circuits

by Roger Van Aken†

Complementary Metal-Oxide Semiconductor (CMOS) monolithic IC technology has been with us for several years and is now widely applied in digital circuitry, ranging from wristwatches to computer mainframes. Its promise is low dissipation, low drive power (allowing greater fanout), and wide voltage swings (hence greater noise immunity). Its uses in analog circuitry, though more limited, are growing; the promise here is near-negligible drive power, low leakage and dissipation, characteristics that happen to be quite interesting for analog switch design.

It has become apparent to Analog Devices that there is a need for high-performance monolithic analog circuitry that takes advantage of the benefits of CMOS. Following a substantial period of development, the products described here represent the first fruits of this technology: the AD7510 quad analog switches, the AD7501 8-channel analog multiplexers, and the AD7502 4-channel dual analog multiplexers.* Additional switches, multiplexers, and other analog-digital interface devices, as well as the possibility of related custom designs, are on the way.

### WHAT IS CMOS?

CMOS is the combination and interconnection of p-channel and n-channel MOS field-effect transistors on a single chip to form monolithic integrated circuits. Examples of such circuits are to be seen in Figures 3 and 4, to be discussed shortly.

The structure of a p-channel MOS transistor is shown in cross-section in Figure 1. Starting with an n-substrate, two $p^+$ areas are diffused in. The portion of the substrate between them will become the channel. Note that two series-opposing P-N junctions are formed, constituting essentially an open circuit. An insulator, a silicon-oxide/nitride sandwich is laid down above the channel, and a metallic contact, the *gate*, is deposited on the insulator, directly above the channel, thus forming a capacitor. When negative voltage is applied to the gate, the channel region becomes positively charged at the interface between the oxide and the silicon substrate, and conduction can take place between the source and drain. The voltage from gate-to-channel at which substantial conduction starts to take place is called the *threshold voltage*.

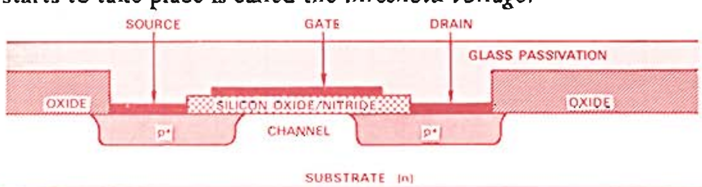



Figure 1. P-Channel MOS FET Construction

The complementary device, an n-channel MOS transistor, is built in essentially the same way, but with a p-substrate and n-diffusions for source and drain. Its channel region conducts when *positive* voltage is applied at the gate.

Both kinds of device are near-ideal voltage-controlled switches. Since conduction is the result of an applied field, gate current is seen to be virtually non-existent, so drive power is quite low. When non-conducting, the channel is like two diodes back-to-back, so breakdown voltage across the channel can be substantial, and leakage is negligible for most purposes. When conducting, the resistance is a function of applied voltage. (It will be seen that in CMOS switches (Figure 4) resistance is nearly constant, because as one parallel path decreases in conductance, the other increases, and the resistance change is only about 20% over a ±10V range.)

Figure 2 shows a substrate with two complementary devices. Starting with the n-substrate, a p-well is diffused into it; this p-well becomes the substrate for the n-channel transistor. The next step consists of diffusing heavily doped $n^+$ source and drain regions for the n-channel device, and $p^+$ source and drain regions for the p-channel device. Then the oxide layers are grown to insulate the gate electrodes.

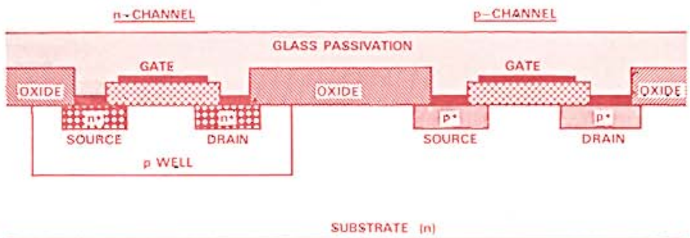



Figure 2. Complementary MOS FET Construction

Figure 3 shows a basic inverter, a complementary pair of p- and n-channel MOS transistors connected in "push-pull" across the supply voltage, with a common gate connection and drain (output) connection. When positive voltage is applied to the gates, the n-channel device conducts and the p-device turns off; the output sinks to a voltage near the negative rail. Only one device conducts at a time, and in the quiescent condition (no load) only leakage current flows (10nW dissipation at ±15V).

Summarizing the advantages of CMOS:

- very low dissipation and leakage current
- extremely high input impedance
- wide power-supply voltage range

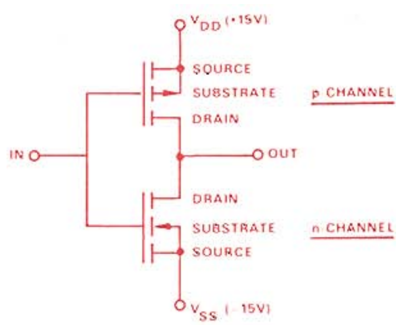



Figure 3. CMOS Inverter

†Roger Van Aken is Marketing Manager of ADI-California, our CMOS and monolithic-dual transistor facility.

*For complete information on these products, use the reply card. Request K2.

## CMOS ANALOG SWITCHES

CMOS devices can be used to form analog voltage-switches having very high resistance in the "open" condition, and less than 100Ω when closed. Figure 4 shows the basic switch configuration.

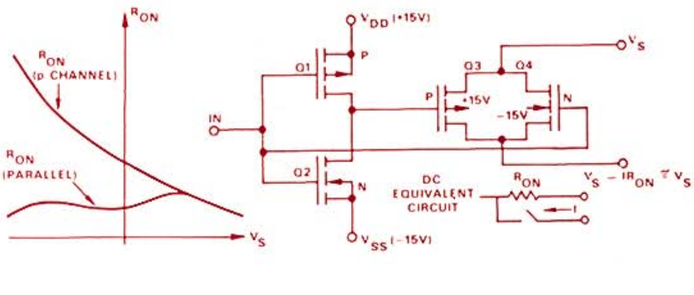



Figure 4. Basic CMOS Switch

Two complementary channels are connected in parallel, with their gates driven in opposite directions by the input and output of an inverter. When the input is *high*, Q1 is off, Q2 is on, and their common drain connection is *low*. The p-channel MOSFET Q3's gate is driven low, so it conducts, and the n-channel Q4 is driven high, so it too conducts, creating a parallel path between points A and B (as long as both terminals are between the extremes of the power supplies and of the input gate drive.

When the input is low, the gates switch polarity, and both Q3 and Q4 are non-conducting.

The curves in Figure 4 show the variation of channel resistance with applied voltage. Although the resistance of the n-channel device increases with positive voltage, and the resistance of the p-channel device increases with negative voltage, their parallel combination changes but little over the whole range, ensuring excellent linearity when loaded by resistance.

## THE AD7510 QUAD-SWITCH FAMILY

The AD7510 comprises four independent switches (Figure 5), housed in a hermetically-sealed 16-pin ceramic dual in-line package (TO-116). *On* resistance at +25°C is less than 100Ω (max), with about 20% variation over the ±10V analog signal range. Leakage current of the individual switches is less than 3nA at +25°C (AD7510S) and the total quiescent power requirement (all four switches *off*) is less than 1μA for both (±15V) supplies.

The switches are *on* for high (i.e., positive true) digital input and *off* for low input. The digital control inputs are compatible with DTL/TTL logic, as well as CMOS, with all necessary level-shift circuitry contained on the chip (requiring no additional drive power, except for the "J" version, which requires a 1-2kΩ "pullup" resistor for DTL/TTL compatibility).

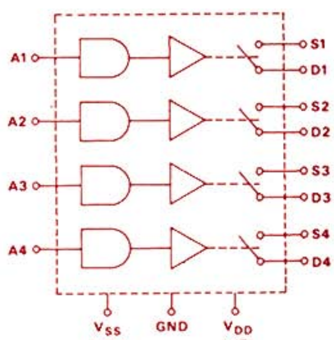



Figure 5. Functional Diagram of AD7510 Quad Switches

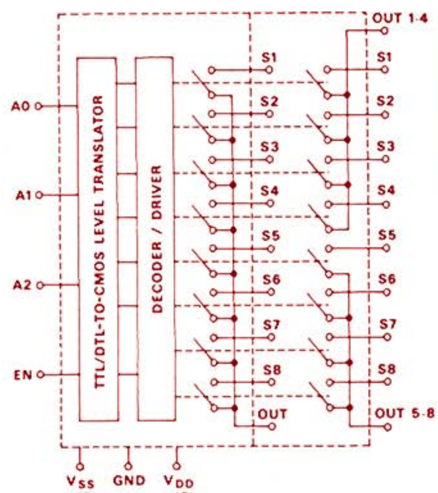
The complete independence of the switches makes possible a wide range of applications, including analog integrators, sample-hold amplifiers, variable-gain amplifiers, D/A and A/D converters, remote-control devices, etc.

The AD7510 is available in three versions: AD7510K, specified for operation from 0 to +75°C, has *off* leakage current less than 5nA at +25°C and 500nA over the temperature range with full-scale analog voltage, and minimum *high* logic level of 2.4V at +25°C; AD7510J has similar temperature range and leakage specifications, but 4.2V minimum *high* logic level; AD7510S is specified for operation from -55°C to +125°C, with 200nA maximum channel leakage, and *high* logic level similar to that of AD7510K. Prices for the J, K, and S versions (1-49) are: $13, $15, and $24.

## THE AD7501 AND AD7502 MULTIPLEXER FAMILIES (FIGURE 6)

The AD7501 is an 8-channel multiplexer, housed in a 16-pin ceramic dual in-line package (TO-116), with 3-bit binary addressing and an *enable* line. The AD7502, structurally similar, is a dual 4-channel multiplexer with 2-bit binary addressing and *enable*; it is useful for routing *differential* analog signals. Applications of these devices include multiplexing, digitally-controlled filters, and signal distribution. The *on* resistance for both types is guaranteed to be less than 300Ω at +25°C, with typical variation of 20% over the entire ±10V analog range. The leakage per switch at +25°C is less than ½nA, (S version) and power-supply current is less than 1μA with all digital inputs *low*. The output (i.e., switch common) current leakage is less than 5nA for the AD7501S and 3nA for the AD7502S.

Both the AD7501 and AD7502 are available in a choice of three options, J, K, and S. J and K are for the "commercial" (0 to +75°C) temperature range, and S is for the extended "military" range (-55°C to +125°C). As is the case with the AD7510, the J differs from the K only in requiring an external "pullup" resistor for DTL/TTL compatibility. Prices of both the AD7501J, K, and S, and the AD7502J, K, and S are: (1-49) $28 (J), $30 (K), $44 (S). ▶▶▶




AD7501

| $A_2$ | $A_1$ | $A_0$ | EN | ON |
|---|---|---|---|---|
| L | L | L | H | 1 |
| L | L | H | H | 2 |
| L | H | L | H | 3 |
| L | H | H | H | 4 |
| H | L | L | H | 5 |
| H | L | H | H | 6 |
| H | H | L | H | 7 |
| H | H | H | H | 8 |
| X | X | X | L | NONE |

AD7502

| $A_1$ | $A_0$ | EN | ON |
|---|---|---|---|
| L | L | H | 1&5 |
| L | H | H | 2&6 |
| H | L | H | 3&7 |
| H | H | H | 4&8 |
| X | X | L | NONE |

Figure 6. Functional Diagram and Truth Tables for AD7501 and AD7502 Multiplexers

# INTERNALLY-TRIMMED MONOLITHIC MULTIPLIER

## No External Components Required For <1% Max. Error

*The AD532* Multiplier, available in both the TO-100 can and the ceramic 14-pin dual-in-line packages, is internally trimmed to within ±1% error. Like the AD530, it has 1MHz bandwidth, and can be connected as a multiplier, divider, squarer, square-rooter. In addition, the internal trim makes available both sets of differential inputs, allowing four-quadrant operation, with choice of polarity, and elimination of external op amps when multiplying by voltage differences.*

Because of the fast-moving technology that characterizes the evolution of analog components, it is a rare occurrence when one can look at a product and say, "That's it. That's the end of the development line. There's virtually nothing that can be done to improve the usability of this product." As we said . . . rare. So, when such a device comes along, it bears careful scrutiny.

Five years ago, the user of analog multipliers could purchase a modular device† for $165. With three or four external trims, and slightly-optimistic specifications analysis, it provided a typical error of ±1%.

Within a few years, this device had evolved into a product, still in modular form, priced in the vicinity of $100, and requiring no external trims for <1% error. Shortly thereafter, a major IC manufacturer introduced an IC "multiplier" at an order-of-magnitude lower price. Unfortunately, because it required many external components (12 to 18), was cumbersome to connect, adjust, and implement the complete multiplication function (the overall accuracy of which had to be guaranteed by the *user*), a large portion of user requirements continued to be satisfied by modular products, which were by then priced in the $40 range, and delivering guaranteed ±1% maximum error with no external trims.

*For complete information on the AD532, use the reply card. Request K5.

†The AD420, first of the commercially-available transconductance multipliers.


The AD530§, introduced in late 1970 (*Dialogue*, Vol. 5, No. 1), was the first IC multiplier to make significant inroads into what had been, until then, modular territory. The AD530 provided less than 1% error, sold for $25, and required only 4 external trims (and no other external components) to achieve its rated accuracy. Despite its obvious and immediate attractiveness to many multiplier users, however, the need to trim the AD530 externally prevented its total acceptance by users for all general-purpose applications.

Now, with the introduction of the AD532, the end of the line in low-cost, medium-accuracy multipliers has been reached. The AD532 is the first totally self-contained, internally-trimmed monolithic multiplier. It has a maximum multiplying error of less than 1%, and ±10V output and input swings without the need for any external trim resistors, op amps, or what have you, and sells at a low price ($24 in 100's, AD532K).

Because it needs no external components to meet the specifications, the AD532 provides design engineers who need to multiply, divide, square, or root, with the best in-board combination of low cost, small size, and simplicity of use. It can be inserted directly into the circuit board (like an internally compensated op amp), saving the user the time and expense of providing external trimming resistors and of performing a somewhat sophisticated adjustment procedure.

§For complete information on the AD530, use the reply card. Request K6.

The AD532 can be used in the same socket as the AD530; just omit the external trim connections and ground the offset-adjustment points. However, its applications go beyond those of the AD530, because its inputs are differential:

$$E_o = \frac{(V_{X_1} - V_{X_2})(V_{Y_1} - V_{Y_2})}{10}$$

Common-mode rejection is 75dB. A terminal is available for adjusting the output offset precisely to zero, for applications that require it.

The AD532J and AD532K have maximum multiplication errors of 2% and 1% at +25°C, and they are rated for operation from 0 to +70°C. The AD532S has maximum multiplication error of 1% at +25°C and is rated for operation from -55°C to +125°C. Maximum error over the extended temperature range is <±4% of full scale, guaranteed by 100% testing at the temperature extremes.

### PRODUCTION TECHNOLOGY BREAKTHROUGH

To eliminate the need for external trim adjustment, the AD532 utilizes a unique method of laser-trimming thin-film resistors that are deposited directly on the AD532's monolithic chip. This is the first time such a technique has been used in the successful volume production of an integrated circuit. Its development and successful implementation provide our IC device-design engineers with a powerful new tool that can be applied to other new high-performance circuits. Circuit mismatches that contribute errors that cannot be avoided by artful design techniques can now be eliminated on the chip nevertheless.

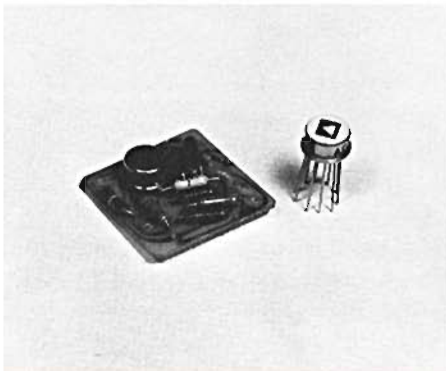
It is manifest that a laser-trimming operation on a silicon chip containing a large number of IC elements and interconnections is both delicate and critical. The thin-film resistor must be carefully chosen as to material, design, and location; tight control and proper direction of the laser beam is essential; closely-controlled slice-fabrication techniques are required; and finally, specially-designed testing and handling equipment are needed to achieve production volume at reasonable cost.

But it's worth striving for. The trimming-on-the-chip technique provides a number of significant advantages over conventional in-package trimming using off-the-chip resistors mounted or deposited on a substrate.

First is cost. Trimming on the chip eliminates the need for a substrate, with its deposited or chip resistors, and the bonding wires that provide the interconnection between the resistors and the chip. (The additional bonds naturally affect the predicted mechanical reliability of the hybrid device.)

Next is power dissipation. On-chip trimming permits the designer to adjust values of resistances in low current-level portions of the circuit without affecting the power dissipated within the package. Because hybrid techniques are often no more than in-the-package variations of the standard external trim, they use additional resistors that require relatively high currents. This necessarily increases in-the-package power dissipation. For example, the power supply current of the internally-trimmed AD532 is typically 4.5mA, the same as that of the AD530. But the AD530, with the recommended external trims, requires 9mA, an increase of 100%.

Third, the power-supply rejection ratio of the AD532 is considerably improved over

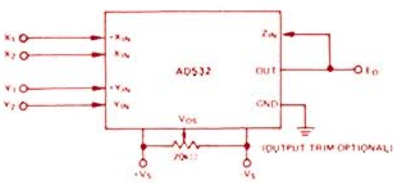


that using conventional trimming resistors, which are usually connected directly to the supply voltage. The power-supply sensitivity of the AD532K (a measure of scale-factor and offset stability) is typically an order-of-magnitude better than that of the AD530 (and similar multipliers), $0.05\%/\%\Delta V_S$ vs. $0.5\%/\%\Delta V_S$.

Finally, since the location of the trim on the chip, both electrically and physically, is largely up to the designer, on-chip trimming frees portions of the circuit and several bonding pads on the die for other uses. This makes possible the differential inputs of the AD532, since the -X and -Y inputs, and their associated bonding pads, are no longer involved in the trim process.

Availability of all versions on the "H" package (TO-100) is from stock; at present, the "D" package requires 2-3 weeks after receipt of the order. Initial deliveries of /883 units require about 6 weeks. In quantities of 1-24, prices of the AD532J/K/S are \$26, \$36, \$49, and the AD532S/883, \$60.

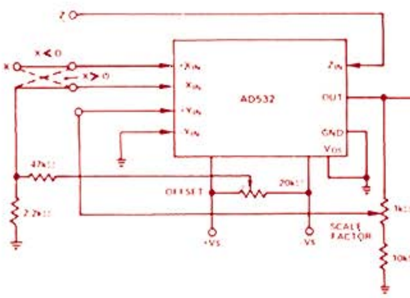
## AD532 Applications



TO REVERSE OUTPUT POLARITY, REVERSE ONE PAIR OF INPUTS

$$E_O = \frac{(X_1 - X_2)(Y_1 - Y_2)}{10}$$

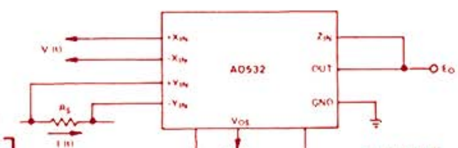
MULTIPLIER CONNECTION



$$E_O = 10\frac{Z}{X} \quad (X < 0)$$

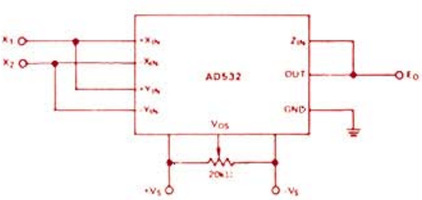
$$E_O = 10\left[\frac{Z}{-X}\right] \quad (X > 0)$$

DIVIDER CONNECTION



$$E_O = \frac{V(t)\,I(t)\,R_S}{10}$$

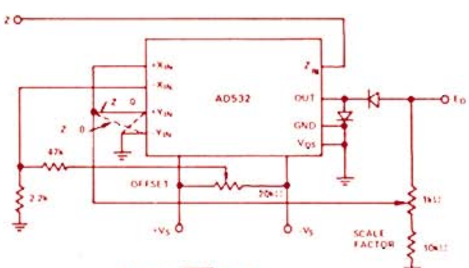
INSTANTANEOUS WATTMETER



TO REVERSE OUTPUT POLARITY, REVERSE ONE PAIR OF INPUTS

$$E_O = \frac{(X_1 - X_2)^2}{10}$$

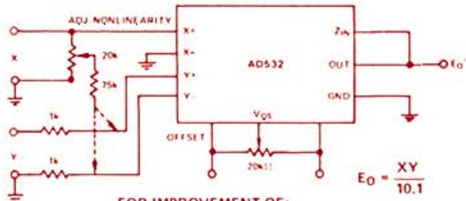
SQUARER CONNECTION



$E_O = -\sqrt{10Z},\ Z > 0$

$E_O = \sqrt{-10Z},\ Z < 0$

SQUARE-ROOT CONNECTION



$$E_O = \frac{XY}{10.1}$$

FOR IMPROVEMENT OF:
5 : 1 FEEDTHROUGH
2 : 1 LINEARITY
CONNECT 75k to Y+ or Y-,
DEPENDING ON DIRECTION OF CURVATURE

IMPROVING MULTIPLIER LINEARITY*

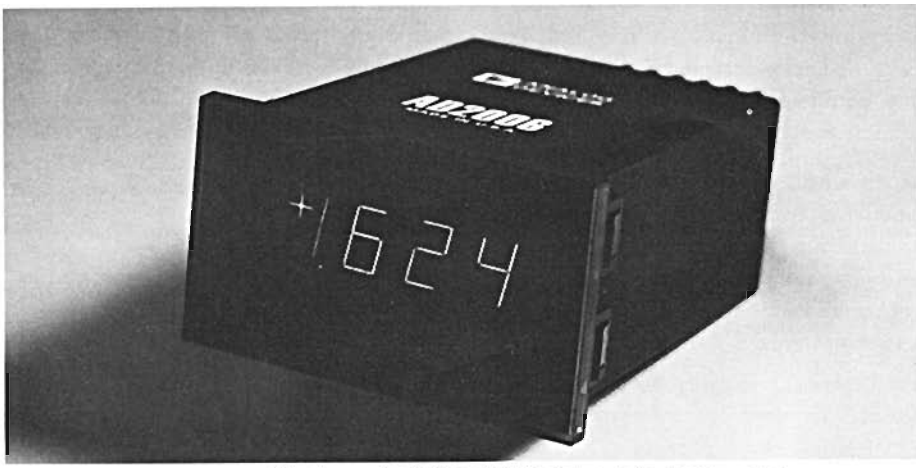
*This technique can also be applied to the AD530, AD531, and similar multipliers. For an application note describing it in greater detail, request K12.

# LINE-OPERATED 3½-DIGIT DPM : AD2006

Analog Devices, Inc., pioneered the concept of powering a small, low-cost digital panel meter from the +5VDC supply in common use for most of today's digital instrumentation. This quickly became a popular product line for us (and was widely imitated by our competitors). But some instruments and remote equipment, especially those requiring readouts only, don't have +5VDC available. They must either use AC-line-powered DPM's or resort to the inconvenience of a separate 5V power supply.

To meet the specific needs of such applications, we have designed the AD2006*, a 3½-digit DPM with the popular bright and easily-readable Sperry gas-discharge display.

The AD2006 provides highly-accurate measurements of bipolar differential input signals over a full-scale range of ±1.999V. The maximum error is ±0.05% (±1 digit), and the temperature coefficient is better than 50ppm/°C. The differential input of the AD2006 provides more than 70dB of common-mode rejection at voltages up to ±5V (>100dB @ ±300V common-mode voltage without digital connections). An optional input filter provides 40dB of normal-mode rejection. While the internally-programmed conversion rate is 5 per second, rates up to 90/s are available with external triggering. Parallel BCD data outputs and full control-signal interface capability are provided.



*Photographed in ambient light and unretouched.*

## DESIGNED FOR VERSATILITY

Ratiometric operation is an inherent feature. Readings may be normalized to an external reference voltage, instead of the internal reference. Since the reading is the ratio of the input voltage to the reference, variations in supply voltage of transducers, such as bridge or potentiometric types, may be automatically compensated-for, by using the transducer supply as the reference.

The AD2006 makes available enough "spare" power to operate such external devices as op amps and digital IC's. This makes it possible to use the AD2006 itself as the transducer supply, relying on the DPM's stable reference voltage, buffered by an op amp that is powered by the AD2006. Such applications versatility can make the AD2006 the "heart" of a measurement system.

## LARGE CLEAR DISPLAY

The AD2006 display uses 0.55"H (1.4cm) Sperry seven-segment planar gas-discharge characters, which appear as continuously-drawn digits. The display's excellent brightness and contrast make the AD2006 readable in any ambient light condition, including direct sunlight. Since all segments are in a single plane, they are readable over a 130° viewing angle without distortion. The display is filtered to provide bright red digits.

Decimal points are externally programmable by a physical connection. They are available optionally with TTL-compatibility. The polarity signal may be blanked for display of unipolar data in engineering units, where polarity indication is not needed. During overload conditions, the display shows all unblinking dashes, while maintaining correct polarity indication (a helpful feature if the input signal is being adjusted back toward the useful range).

## SEPARATE AC TERMINALS FOR SAFETY

On most AC-line-powered DPM's, the AC inputs share the circuit card and edge connector with the other analog/digital interconnections and circuitry. While this is an inexpensive approach to interconnection, it is inherently neither the safest nor the quietest. If an accidental short develops between the AC input and other terminals on the card (not unlikely during system testing and debugging, especially by personnel who have grown careless because of the widespread use of low voltage), extensive and expensive damage may occur to the DPM and any interconnected equipment (as well as to operating personnel).

The AD2006, on the other hand, has a separate covered terminal strip for the AC power connections. No primary voltage is routed on printed-circuit boards, and the aluminum case is fully grounded. Not only does this make for a safer DPM, but it can also have much less noise pickup than devices having analog and power connections on the same connector and/or board.

## STANDARD PACKAGE

The AD2006 uses the same basic extruded aluminum case design as other Analog Devices DPM's and will snap into the same panel cutout as the AD2002, AD2003, AD2004, and AD2010†. The only difference is the depth: the AD2006 case is about 4" deep to accommodate the internal power supply; a mounting strap is provided to insure secure mounting. The AD2006 will be available in the summer of 1973. Price: $169 (1-9), $114 (100's).

▶▶▶

*For complete information on Model AD2006, use the reply card. Request K7.

†For information on these DPM's, use the reply card. Request K8.

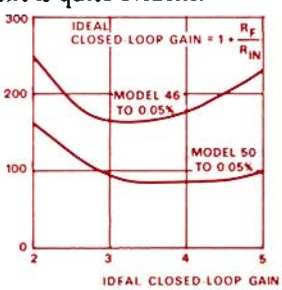
# TWO NEW FET-INPUT OP AMPS

## Model 50: Wideband, Fast-Settling

Model 50* combines gain-bandwidth of 100MHz, output current of ±100mA, and settling-time-to-0.1% (FS) of less than 100ns.

Its high speed makes it ideal as an output current-to-voltage transducer for fast current-output D/A converters; its substantial output power makes it an excellent candidate for application to line-driving, booster, and deflection-amplifier circuitry.

An unusual design feature allows greater-than-usual slew rate (and faster settling time) with small summing-point error, an especially useful feature when the input is a current source having high source impedance but low compliance voltage. The illustration shows a comparison of Model 50's settling time with that of the high-speed Model 46*, as a function of resistive closed-loop gain. The factor-of-2 improvement is quite evident.




The slew-rate economy at low values of error signal is excellent. Despite a top slew rate of 500V/µs, its slew rate at 1V error is 300V/µs. This compares well with Model 46, with a top slew rate of 100V/µs at 5V error, but only 200V/µs at 1V error. If $R_f/R_i = 2$, and the input voltage is 1.5V, only 1V is available to drive the amplifier at its maximum rate.

Other characteristics of Model 50 include open-loop gain of 25,000, CMR of 60dB at ±10V, 1nA bias current, and choice of 50µV/°C (50J) or 15µV/°C (50K) maximum drift. Price (1-9) is $75 (J) and $92 (K).

*For complete information on Model 50, use the reply card. Request **K9**. For information on Model 46, request **K10**.

## High-Voltage Op Amp: Model 171 Supplies to ±150V; CMR, PSR 100dB

Model 171* is a high-performance FET-input op amp designed for operation over a wide range of supply voltages. The line-to-line voltage from the positive supply terminal to the negative supply terminal can range from 300V to below 30V, with *p. s. common* anywhere between. Output and common-mode voltage range are 20V less than the line-to-line supply voltage.

When supplied at ±125V, gain is $10^6$, maximum output is greater than ±115V at ±10mA, and common-mode rejection is 114dB for CMV of ±115V.

DC offset is less than ±1mV, and maximum drift of either ±50 or ±15µV/°C is available, in the J or K versions. Bias current is less than 50pA (171J) or 20pA (171K), doubling per +10°C increase of temperature. Power-supply sensitivity is ±1µV/%$\Delta V_S$ (7µV/V).

Small-signal bandwidth is 3MHz for unity gain, full-power bandwidth is 15kHz, and slew rate is 10V/µs.

### APPLICATIONS

There are many applications for which modern FET-input op amps, capable of operating at moderate-to-high supply voltages, are useful. Typical classes of application include:

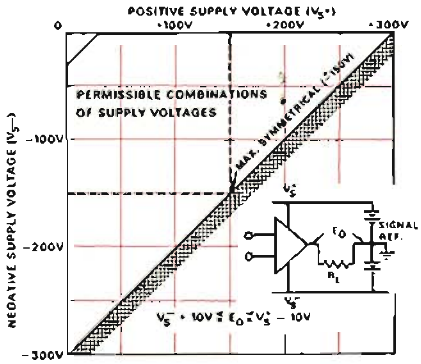
1. Retrofit and auxiliary applications in existing analog computing systems utilizing a standard ±100V signal-voltage range.
2. Use as low-noise buffers and input amplifiers in differential or non-inverting applications with signals derived from high-voltage sources.
3. Applications for which high output voltage is needed, e.g., wide-range precision reference sources, piezoelectric crystal drivers, etc.
4. Applications with moderate signal levels in systems subject to wide variation of supply voltage.

*For complete information on Model 171, request **K11**.


Model 171's excellent performance characteristics, including high supply rejection, high input impedance, low noise, tolerance of capacitive load, and protection against output short circuits, make it ideal for all these classes of application.

In addition, there is one more class that is a bit unusual. For an amplifier to be safe against short-circuits, it must not only be self-protected; it must also protect the supply that feeds it. The 171 is programmed to draw a maximum short-circuit current slightly greater than the 10mA maximum load current plus its quiescent current. For systems where a "keep-alive" current load that is essentially independent of supply voltage is needed, one might consider the 171.

Model 171 is housed in a compact epoxy module, 1.8" x 2.4" x 0.6" (4.6 cm x 6.1 cm x 1.55 cm). Price in small quantity (1-9) is $69 (171J), $79 (171K).



# LOG-RATIO MODULES, MODEL 756

## Low Cost, Small Package, Log-Conformity Within 0.5%

Model 756* can be used to compute the ratio of two currents, two voltages, or a combination of current and voltage, in logarithmic form. For two continuously-variable input currents, $I_{SIG}$ and $I_{REF}$, the output voltage is

$$E_o = -K \log_{10} (I_{SIG}/I_{REF})$$

where K is a built-in (but externally modifiable) constant, nominally equal to 1V. Thus, the output changes by 1V for each factor-of-ten change in the ratio.

There are many uses for log-ratio amplifiers. A few of them are

- Direct calculation of absorbance
- Linearization of exponential measurements (e.g., photometric)
- Normalization of signals having wide dynamic range
- Displaying gain measurements in logarithmic form (e.g., "dB")
- Signal compression
- Generation of powers and roots

Log-ratio amplification is not new. In fact, many of our readers have perhaps assembled log-ratio amplifiers using logarithmic amplifiers, such as Model 755; or using temperature-compensated logarithmic transconductors, such as Model 752 (with an appropriate choice of op amp); or using op amps and matched transistor pairs, with internal temperature-compensated resistors (Model 751) — or external (AD812).†

Now, Model 756 puts log-ratio operations within reach of the busy engineer, in the form of a small (1.5" x 1.5" x 0.4"), complete device at low cost ($75, 1-9; $42, 100+).

Characteristics include operation over 4 decades of $I_{SIG}$ (10nA to 100$\mu$A) and 3 decades of $I_{REF}$ (100nA to 100$\mu$A) with conformance to log behavior within ±1%, and 2 decades of $I_{SIG}$ at constant $I_{REF}$


with log conformity error within ±0.5%. The nominal initial value of the scale-factor K, is 1V ±1%, with a temperature coefficient of ±0.04%/°C. The bias current at $I_{SIG}$ is -10pA *max* at room temperature, doubling per +10°C increase, and the bias current of $I_{REF}$ is 10nA *max*, decreasing with temperature at 1%/°C.

Figure 1 shows measured values of log conformance error vs. $I_{SIG}$ at various values of $I_{REF}$ for a typical unit. The reader should note that 1% log conformance is an error referred to the input. With K = 1, it corresponds to 4.3mV at the output, or 0.43% of a decade.

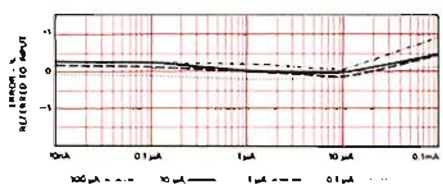


Figure 1. Typical % Error (R.T.I.) vs. $I_{SIG}$ Over 7 Decades of $\frac{I_{SIG}}{I_{REF}}$

### APPLICATIONS

In order to understand how the 756 is applied, it is helpful to refer to Figure 2, which is a simplified schematic of the unit.

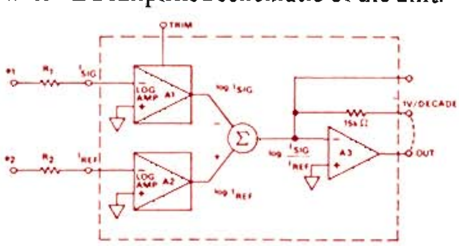


Figure 2. Functional Block Diagram

The input terminals are summing-points of operational amplifiers, and they present a zero-impedance (i.e., an ideal) load to current sources, such as photodiodes, photomultipliers, ion chambers, etc. For operations with voltage, the user connects in series a value of resistance that is appropriate to convert the voltage range to a suitable portion of the specified input-current range ($I_{SIG} = E_{SIG}/R_1$).

Model 756 is available in two basic versions, depending on the signal polarity. If the signal source is a positive voltage or current (flowing toward the 756), the 756*N* (positive K) should be used. If the signal source is *negative*, the 756*P* (negative K) should be used. (Yes, Positive-N, Negative-P, in keeping with apparently-contrary but long-established conventions observed in the industry.)

A built-in 15kΩ resistor provides 1V/decade scale factor, but the feedback connection is made externally, by the user. If a larger K is desired, either an appropriate value of resistance K x 15kΩ may be connected to the summing point of the output amplifier (also available), or resistance may be added in series with the 15kΩ. For smaller values of K, the feedback resistor may be either shunted or bypassed.

Figure 3 shows the simple connections for photometric absorbance measurement. The photodiodes are connected directly to the amplifier summing points (thus providing most-linear response), and the unit computes Absorbance, according to the given equation, with readout directly in volts per decade. ▶▶▶

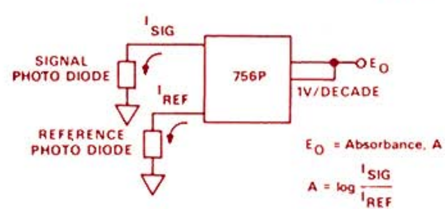



Figure 3. Photometry Application of Model 756

*For complete information on Model 756, use the reply card. Request K13.

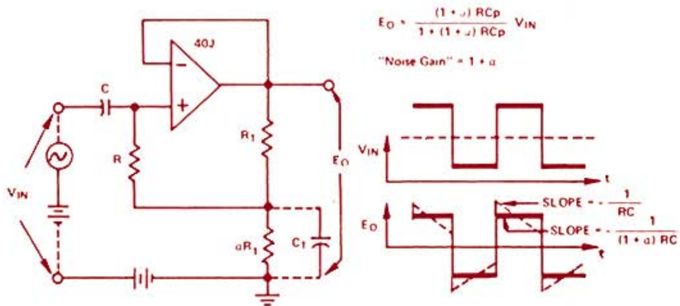
†For information on all these devices, request K14.

# Application Quickie

## Bootstrapped AC Coupling

In this circuit, the coupling time constant is increased by $(1 + a)$. If $R = 10M\Omega$, $C = 1\mu F$, $a = 99$, $R1 = 100\Omega$, the RC of 10 seconds is increased to 1000s. The magnification, $1 + a$, can be adjusted by a low-resistance pot. If the input is caused to "block" by a large transient, the recovery time to the linear range is governed by the shorter RC.

Disadvantages are higher "noise gain" (amplifying $V_{OS}$ and $I_bR$) and reduced bandwidth (often unimportant). C1 helps stability and reduces high-frequency noise gain. $(a' = a/[1 + aR_1C_1p])$ ▶▶▶



# Improved Products

MODEL 42 FET-INPUT ELECTROMETER: The popular Model 42 family† now has greatly-improved specifications. For example, the key parameters – voltage drift and bias current – for Model 42L are 25μV/°C and *75fA* (viz., 75 x $10^{-15}$A). Undoubtedly among the best values for OEM designs, Model 42 has 110dB open-loop gain (3 x $10^5$), 1MHz gain-bandwidth, and CMR of 66dB at ±1V common-mode. Input specifications have also been improved for the 42J & K.

Members of the 42 family may be used in either single-ended or differential applications for performing measurements of low currents or of low voltage at high impedance. Examples include photo- or ion-current transducers, pH cells, and systems where high speed and low input capacitance are essential for accurate measurement at high-impedance levels (such as are found in automated testing). Prices (1-9) are: 42J, $25; 42K, $32; 42L, $37.

MODEL 605 INSTRUMENTATION AMPLIFIER: Model 605§ has always provided good value, with its excellent linearity and low drift referred to the input (the important spec for drift at high gain). Now, the specification of "r.t.o. drift" (the important drift at low gain) has been reduced from 150μV/°C to 100μV/°C (605J), 75μV/°C (605K), 50μV/°C (605L). Other specs include CMR of 70dB with 1kΩ source unbalance, nonlinearity of 0.005%, and r.t.i. drift as low as 0.5μV/°C. For the relationship of "r.t.i." and "r.t.o." drift and gain, see *Dialogue*, Vol. 6, No. 2, page 14. Price is unchanged: for 605J, K, & L, $59, $65, $80 (1-9). ▶▶▶

†For a new data sheet on the 42 family, request **K16**.
§For a new data sheet on the 605 family, request **K17**.

# Worth Reading

## LAST ISSUE OF *ANALOG DIALOGUE* Vol. 7 (1973), No. 1

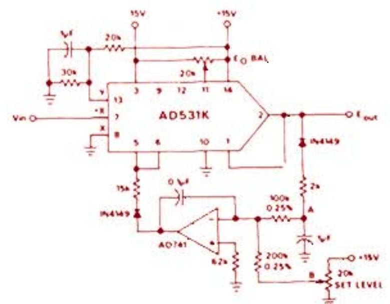
If you haven't seen the last issue of *Dialogue**, here's what you've missed

- *Design of a Slim, Low-Cost 3½ DPM (AD2010)*
- Synchro-Digital Conversion Devices
  - 14-Bit, 10-Bit, and 2-Speed Synchro/Digital Converters
  - 5-Digit Synchro-Angle Display Meter
- Fast, High-Resolution A/D Converters (ADC1103)
- Low-Cost A/D Converter with 3½ BCD Output (ADC1100)
- Four New IC Operational Amplifiers
  - AD509: Fast Op Amp (2μs Settling Time to <0.01%)
  - AD504M: Lowest Noise and Drift
  - AD506L: Economical Low-Drift FET-Input Op Amp
  - AD507S: Wide-Temperature-Range General-Purpose Op Amp
- *Not by Drift Alone... (Chapter 2. The 741 Op Amp Family)*
- *The AD520: Not an Op Amp But an Instrumentation Amplifier*
- Application Briefs:
  - *True-RMS Measurement with the AD531*
  - *30dB Automatic Gain Control* (see also *Erratum* below)
  - *Vector Difference* $\sqrt{V_a^2 - V_b^2}$ *with a Single AD531*
  - *Low-Noise, Low-Drift FET-Input Amplifier Design*
- Book Review: *Operational Amplifiers*, by G. B. Clayton
- Errata: *Analog-Digital Conversion Handbook*
- Editorial Comments: *The Two-Converter Fallacy*

If you missed the last issue, you were also a bit fortunate to have missed one of our more-devastating errors: the power-supply connections of the AGC circuit (page 13) were reversed. The correct circuit is shown below. If you have that issue, please scrawl the following changes on the figure *now:*

1. Exchange the polarities of +15V and -15V to pins 14 and 3
2. Reconnect the fixed 20k resistor to +15V

▶▶▶





*For a copy of Vol. 7, No. 1, use the reply card. Request **K18**.

# And here's another of our low-cost solutions to your conversion problems.


This 5-volt A/D converter gives you dual-slope noise immunity and BCD-plus-sign output for only $67/100's. The ADC1100.

If you're converting for a remote display, or if you've got a special display requirement, this converter was made for you.

Maybe you're timesharing a display with several data sources. Or rescaling the converter output to display pounds, gallons, rpm, or other engineering units. Or using a special display you designed yourself.

Then meet the ADC1100. A dual-slope converter with a 3½-digit BCD-plus-sign output and automatic zero correction. It'll give you normal mode rejection of 40dB (up to 120dB with a phase lock loop circuit). Plus 5VDC operation and guaranteed monotonicity. And the ADC1100 is equally well suited for feeding a computer.

That's an awful lot for only $67 in 100's. ($99 in singles.)

But after all, we're the people who wrote the book on converters. So you expect a lot from us.

And here's what else you can expect.

Two high-resolution, high-accuracy, A/D converters that can save you time and money. Both with parallel and serial outputs, both with user-selected input ranges. The ADC10Z has 10 bit resolution and accuracy 20 μsec (max) conversion time, for $67 in 100's. The ADC12QZ converts in 40 μsec (max), gives you 12-bit resolution and accuracy – $92 in 100's.

Two low-cost general-purpose D/A converters. The DAC10Z provides 10-bit resolution and accuracy, built-in IC output amplifier, unipolar or bipolar outputs – only $27 in 100's. The DAC12QZ gives you 12-bit resolution and accuracy and five user-selected output ranges for only $47 in 100's.

A low-cost sample and hold amplifier. For $32 in 100's, the SHA 5 will hold your attention, too. The perfect companion to our low-cost converters.


For more information on what you can expect from us, give us a call. We can send you samples, comprehensive data sheets, and, for only $3.95, a 400-page handbook on A-D conversion.

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# First we souped-up super beta transistors. Then we closed the gate on FET leakage.

And as if that's not enough, we've come up with the lowest noise, lowest drift dual FET around, too.

These three are just part of the broad line of high performance dual monolithic FETs and transistors we've designed to solve more of your linear circuit problems.

**2000β@20V**
**AD815 NPN**

Our AD815 super beta dual monolithic NPN transistor features 2000 beta at a breakdown voltage of 20V. It can reduce your input noise current by a factor of ten. Plus, you get a 0.5mV offset. Price: $5.50 in 100's.

Our AD830 dual monolithic FET gives you an extremely low leakage current — less than 0.1pA. That's as low as they come. Price: $11.10 in 100's.

**0.1pA@**
**AD830 FET**

And when it comes to super-low noise and drift, our AD840 dual monolithic FET has the lowest noise of any dual FET you can get anywhere: 9nV/√Hz. It delivers an adjusted drift of 1μV/°C, too. Price: $7.80 in 100's.

These designs are just right for upgrading existing circuits in low-current measurement instruments, preamplifiers, and applications involving high impedance sources. Or build them into brand new circuits; they'll make your design a lot better than anybody else's.

**9nV/√Hz**
**1μV/°C**
**AD840 FET**

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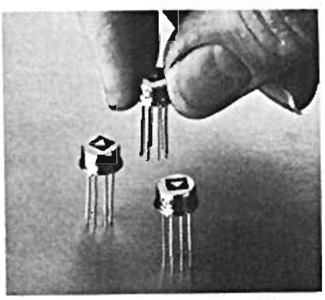
. . . or use the reply card. Request K22.

# Here are three fast, wideband IC op amps.

# And you don't have to be a circuit virtuoso to use them.



Let's face it. Most of the fast, wideband IC op amps on the market require excessive external compensation for stability, sacrifice DC performance to increase speed, and just plain cost too much.

We've done something about that.

With three op amps specifically designed for unconditional stability with minimal use of external components, outstanding DC characteristics, and low cost.

**AD509. For fast settling time to high accuracy.** Settles to 0.01% accuracy in 2.5 μsec (max), and to 0.1% accuracy in 500 nsec (max). We test every single one of them to make sure. Can be unity-gain compensated with a single capacitor and is internally compensated for closed loop gains above 3. Particularly well-suited for use as an output amplifier of D/A converters. AD509J, $8.50 in 100's.

**AD518. Low-cost, high-speed, easy-to-use.** With internal unity-gain compensation, a 70V/μsec slew rate, and a bandwidth of 12MHz. Feed it forward to get over 100V/μsec slew rate and twice the bandwidth. Or compensate it with a single capacitor for under 1.0μsec settling time to 0.1% accuracy, 60° phase margin, for clean response, minimal ringing, and no oscillation — even with a 300pF load. High speed you won't find anywhere else at this price. AD518J. Only $1.95 in 100's.

**AD507. Excellent low-cost combination of AC and DC performance.** Slew rate is 25V/μsec. Unity-gain small-signal bandwidth is 35MHz. Along with that, you get a bias current of 15nA. An offset voltage of 3.0mV (max). And $V_{os}$ drift of 15μV/°C (max). AD507J, $6.95 in 100's.

We can help you with your application, too. Our data sheets tell all: complete specs, suggestions for external compensation, if necessary, even detailed connection information and suggestions. (If you use high-speed op amps, you know they don't just plug in.)

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# If you thought our first I.C. multiplier solved a lot of your problems, take a look at this one.

## AD531. The first programmable XY/Z Multiplier/Divider. From $20 in 100's.

If you have anything to do with I.C. multipliers, you know our two-year-old AD530 line of monolithic multiplier/dividers has become the industry standard.

That kind of reputation we like. And we know our new AD531 will keep it going nicely.

The AD531 has our proven high performance design of a differential transconductance multiplying element, stable reference, and output amplifier combined on a single chip. And we've added a variable scale factor which allows you to set any fixed value of a Z by an external resistor, or to dynamically vary the value of Z by an externally controlled simple reference circuit.

Plus a differential $V_x$ input with 75dB of common mode rejection. All this makes a lot of complex applications very simple. Like automatic gain control.

True RMS-to-DC conversion. Absolute value.

Vector summation.

You can use the instrumentation amplifier input to reject common mode noise. Or to subtract two input signals prior to further processing.

Or you can use the AD531 just to multiply, divide, square, or square root.

The AD531 will help you do all of this and more with an error guaranteed to be less than 0.5%.

The package is the TO-116 14-pin ceramic DIL for high reliability and handling ease. You can choose from three accuracy versions (J,K,L) for operation over the 0°C to +70°C temperature range, and one for −55°C to +125°C operation (S).

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