

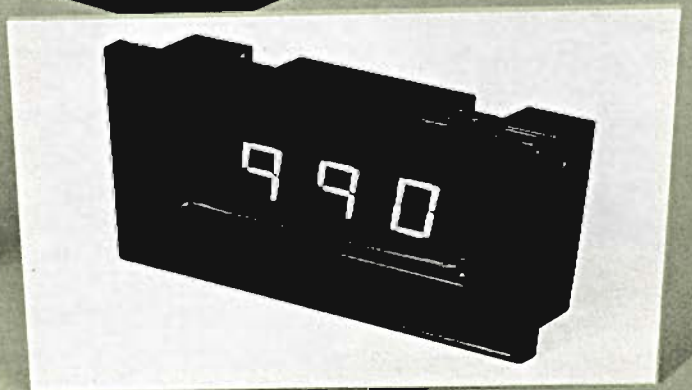
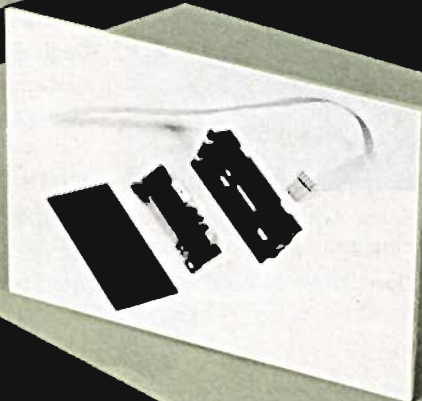
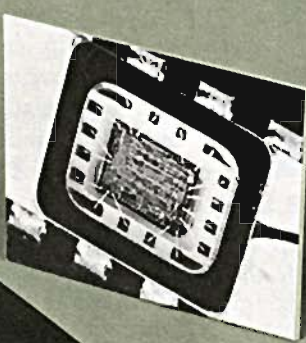
analog dialogue

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

LOW-COST DPM CHALLENGES ANALOG PANEL METERS

Monolithic V/f Converter is Easy to Use

Full Contents on Page 3



Editor's Notes

WHAT'S NEW?

Novelty for its own sake is somewhat of a luxury. Novelty with a purpose is most satisfying to encounter. Before penning these words, we flipped through the pages of this issue, and suddenly realized that — accustomed as these eyes were to encountering



novelty in *Analog Dialogue* — the present pages are fraught with purposeful novelty. There's something new or unusual about almost every page — and none of it trivial.

Some of the new things are new to the world; their like simply never existed before — for example, the panel meter introduced on the next page. Or Barrie Gilbert's AD537 V/f converter — an unusually innovative and flexible IC device that can, among other things, perform a direct ambient-temperature-to-frequency conversion.

Some are first-time applications by Analog Devices of advanced technologies: the dielectrically-isolated CMOS switches (latchproof and overvoltage-proof) and the hybrid instrumentation amplifier with module-like performance — the first product of our new microelectronic facility in Wakefield, Mass.

Yet others were pioneered in the past (here or elsewhere) but were newly adopted by ADI in the belief that we could provide better value to users, now and in the future (you asked us for them!) Examples of such new product lines are the functional DPMs (both committed and uncommitted), the low-power CMOS 12-bit converters, the modular data-acquisition systems, the dc-to-dc converters, and improved medical amplifiers with auxiliary floating power output.

Finally, there are one or two new things about this Journal itself: the expanded "Potpourri" section, on page 19, with its diversity of notes on products, literature, and other phenomena, and the return (for the moment, at least) of "Across the Editor's Desk."

OUR ANNUAL SERMON

Incidentally, that latter department disappeared because of atrophy. Somehow, we just don't get many stimulating letters. One never knows whether that silence is ominous or whether it represents some sort of *nirvana* brought about by utter satisfaction. In any event, we do call this publication a *Dialogue*, and we'd love to have it be that *in fact* to a greater extent than it is now.

Fortunately, there does seem to be a small but fairly continuous supply of readers who have applications that are of interest, and who are interested in both the small honorarium and the *recognition* that come with publication. One such reader (this is true!) found his circle of acquaintance greatly broadened in his Company, especially in the upward direction; it was reported to us in these terms: "it was as good as a salary review."

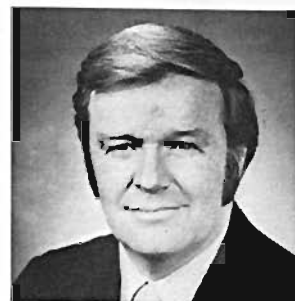
So get it off your chest! Let's hear about your applications, your ideas, your gripes, puzzles, questions. That could be the next thing that's new.

Dan Sheingold



THE AUTHORS

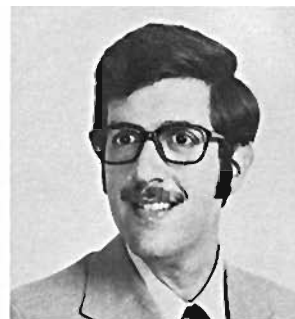
Bob Boole (page 3) is Director of Modular Instruments in ADI's Modular Instrumentation & Systems Group. He came to us in 1973 from Gen-Rad, where he had managed Marketing and Marketing Research. He has written numerous articles on acoustics and signal analysis for various industrial publications. He holds a B.S. from M.I.T. and an M.B.A. from Boston University.



Lew Smith (page 3), Executive Engineer at Analog Devices, and Chairman of the General Technical Committee, has been with ADI since the earliest days. Besides the AD2026, he has designed low-level measurements, parametric and isolation amplifiers, and other significant products. A member of TBII, HKN,

and ΣZ , he has an MSEE from M.I.T.

Jeff Riskin, (page 9), Staff Engineer at ADI's Microelectronics Division, was responsible for development of the AD522. Before the formation of the Hybrid Group, he was Manager of converter-module engineering. Before joining ADI, he designed high-speed converters at Raytheon and E.G. & G. He has both B.S.E.E. and M.S.E.E. degrees from Tufts University.



Al Pollens (page 10) is Marketing Manager, Modular Instruments. He has a B.S.E.E. from Northeastern University and is a member of I.E.E.E. He joined Analog Devices from Weston Associates. Earlier, he had been Marketing Manager for Adage, Inc., and National Sales Manager for Intertel.

Barrie Gilbert (page 6) is the designer of the AD537. A brief biography and his photo appeared in *Dialogue* 9-1.

Dave Kress is Product Marketing Specialist at Analog Devices Semiconductor. A brief biography and photo appeared in 10-1.

(more Authors on page 18)

analog dialogue

Route 1 Industrial Park, P.O. Box 280, Norwood, Mass. 02062

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REVOLUTIONARY PANEL METER USES I²L CHIP

3 Digits, 3/4 Watt @ 5 Volts, Only 14 Components At \$39 in 100's, AD2026 Challenges Analog Panel Meters

by R. Boole and L. Smith

The AD2026* is a 3-digit panel meter (DPM), powered by a single +5V supply, with 0.5" (13mm) LED display, and overall dimensions of 87 X 52 X 22mm (3.43" X 2.04" X 0.85"). Intended to supplant measurement-grade analog panel meters in new instrument designs, it provides high reliability at low cost. Achievement of these usually-conflicting objectives is the culmination of a project that required innovations[†] in design, manufacturing, and test. Key elements include a proprietary I²L[‡] chip that reduces total electrical parts count to 14, a single-board design that is batch-assembled and -tested, and a proprietary case that requires no tools or hardware for assembly and mounting.



Figure 1. The AD2026 Panel Meter

ORIGINS

The design of the AD2026 really started with you, the user. And it started more than five years ago, when we first considered the needs of DPM users. At that time (*Dialogue* 5-5, 1971), our studies established that there was a need for a (then) low-cost, small, +5V-powered 3½-digit meter. The first of its kind, the AD2001, the result of the study, inspired a veritable deluge of imitators and successors.

Always looming on the horizon was the challenge of the analog panel meter (APM). When (if ever) would digital panel meters become capable of competing? And what would be required to make the first serious thrust successful? What were the real needs of laboratory-instrument manufacturers for panel display of measurement results in their low-priced products? Analysis of the responses of about 1000 instrument manufacturers to a survey of their needs and desires led to the following major conclusions about the nature of a digital replacement for many of their current analog-meter applications:

Price: Measurement-grade APM's range in price from \$10 to \$30 and more. A \$39 DPM with the proper features would convert a large volume of those requirements.

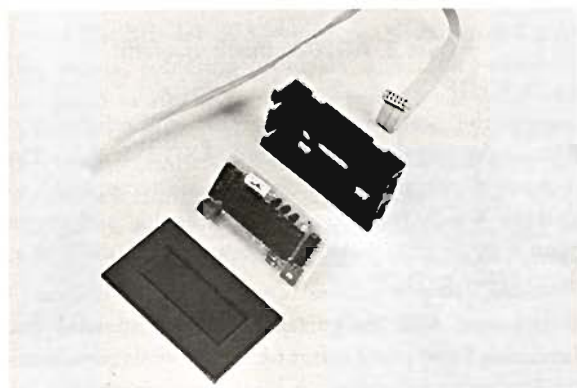


Figure 2. AD2026 Assembly

*Use the reply card for data on the AD2026.
†Patents applied for.
‡Integrated Injection Logic — see page 5.

Display: The majority of measurement-grade APM's purchased have 2½", 3½", or 4½" scale lengths, are linearly calibrated, and read out directly in the engineering units of measurement. Equal or better resolution can be achieved with a 3-digit (999) DPM scaled with a simple resistive divider to provide direct readout in engineering units.

Polarity and Zero: Most applications call for single-polarity indication with zero at the left. The AD2026 has been designed to display 0 to 999 for positive inputs, but a negative range of 10% of full scale (0 to -99) has been provided for ease of adjusting zero for either the meter or the system (Table 1).

(continued on the next page)

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Table 1. AD2026 output vs. input
(3 decimal points selectable at connector)

INPUT	READING
>999mV	E E E
999mV	9 9 9
998mV	9 9 8
•	•
•	•
zero	0 0 0
-1mV	- 0 1
•	•
•	•
-99mV	- 9 9
<-99mV	- - -

Accuracy and Repeatability: The 2% accuracy- and 0.5% repeatability-specs of APM's are their most serious drawback, since they usually limit total accuracy of the instrument. The AD2026 offers order-of-magnitude improvement.

Reliability: The APM, unless physically abused, is a most-reliable component, reflecting decades of refinement. A major concern in replacing it with a DPM is the potential for failures due to internal heating and large numbers of components. The AD2026 runs cool ($\frac{1}{4}W$ max dissipation, $<11^{\circ}C$ internal temperature rise) and has only 14 components (half of which are passive), for a calculated mean-time-between-failures (MTBF) of $>250,000$ hours at $+25^{\circ}C$. The many thousands of unit-hours of life-test data accumulated to-date support our expectation that the theoretical value is realistic.

Size: Both front-panel space and space behind-the-panel are at a premium in most instruments. The AD2026 occupies less space, both on and behind the panel, than $3\frac{1}{2}''$ APM's, while providing readout resolution and repeatability superior to that of $4\frac{1}{2}''$ meters.

Table 2. Salient Characteristics of the AD2026

(typical @ $+25^{\circ}C$ and nominal supply voltage unless noted otherwise)

DISPLAY	
Resolution:	3 Digits (999)
Type:	0.5" (1.3mm) LED
INPUT	
Type:	Limited Bipolar; Balanced Differential
Full-Scale Range	-99mV to +999mV
Impedance:	100M Ω
Common-Mode Rejection:	50dB @ $\pm 0.2V$
Overvoltage Protection:	$\pm 15VDC$, Sustained
Bias Current:	110nA
PERFORMANCE	
Accuracy (max error)	0.1% of reading, ± 1 Digit
Operating Temperature Range:	0 $^{\circ}$ to $+60^{\circ}C$
Temperature Coefficients	
Gain:	50ppm/ $^{\circ}C$
Zero:	10 $\mu V/^{\circ}C$
CASE SIZE (overall to rear of connector):	87 x 52 x 22mm (3.43" x 2.04" x 0.85")
WEIGHT:	53g (1.8 oz)
POWER CONSUMPTION:	0.75 Watts max
CONVERSION RATE:	4/s, Hold (& read) on command
PRICE:	\$62 (1-9), \$39 (100+)

DESIGN

The AD2026 uses the classical dual-slope integrating A/D conversion technique. The input signal is integrated for a fixed interval of time, then a reference of opposite polarity is integrated for the time required for the integrator output to "ramp" back to its starting level. That time interval, measured by counting a train of clock pulses, is proportional to the input (and insensitive to such parameters as integrator time constant and accuracy of the clock rate).¹

In the AD2026, the input is offset, to permit the specified 10% negative capability. The offset is interpreted digitally by relatively simple logic circuitry, which complements the BCD data for negative inputs and provides the minus sign in place of the "hundreds" digit. The offset input eliminates the need for two reference polarities, resulting in greatly improved linearity near zero and a saving of chip area.

Conversion is initiated by pulses at a 4Hz rate, obtained from a divider chain fed by an on-chip clock. The pulse enables a voltage-to-current converter, which feeds a current proportional to the input into the integrating capacitor. After the preset number of counts, the input stage is turned off, and a reference current (derived from an on-chip band-gap reference) is applied, ramping the capacitor back to the original starting value. The ramp time is measured by a second counter (on-chip), multiplexed onto a 4-bit-wide bus, and fed to the display circuit. The signal integration time is 1ms, and complete conversion requires only 2ms.

There are several advantages to short conversion times: No data latches are required, since the displays are blanked during conversion and unchanged at other times. In addition, LSI area is saved by using an essentially passive integrator. Also, the short conversion time reduces the size of integrating capacitor to manageable proportions. Finally, the display blanking during conversion means that interaction between the display and the converter is eliminated, which makes for outstanding differential linearity.

Figure 3 is a block diagram of the AD2026 circuit. Only 13 electrical components are *not* on the proprietary LSI chip: 3 LED's, 3 digit-select transistors, 3 decimal-point current-limiting resistors, 1 LED segment driver, 2 potentiometers, and the integrating capacitor.

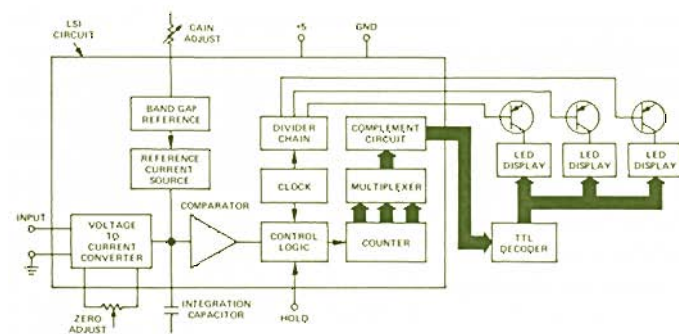


Figure 3. AD2026 block diagram.

THE I²L CHIP

The key to the performance, low cost, and reliability of the AD2026 is the large-scale-integrated (LSI) I²L chip. The current intense developmental activity towards applying I²L to applications which require combining analog and digital circuitry on a single chip testifies to its appropriateness as a technology to apply to DPM's.

Some time ago, ADI recognized I²L's potential for dramatically reducing DPM parts count and cost, while simultaneously further improving reliability. A brief discussion of I²L appears on the next page, and an extended discussion can be found in *Electronics*, "The Bipolar LSI Breakthrough", September 4 and October 2, 1975.

¹ *Designer's Guide to Digital Panel Meters*; for a copy, use reply card.

The only process that approaches I²L in overall economy is CMOS. Table 3 summarizes some significant differences. I²L has much higher logic density and lacks the noise and drift that CMOS tends to have in active analog circuits (though it makes for excellent switches). Inevitably, there are functions which cannot be integrated into a CMOS chip and must be provided by external components. Because I²L is free from the surface effects found in lightly-doped CMOS, the AD2026 performance is exceptionally stable and reliable. As a manufacturer of both IC's and DPM's, Analog Devices is well-qualified to synthesize DPM performance requirements with the capabilities of the I²L process into a uniquely cost-effective chip design. The AD2026 is, in fact, the first commercial application of I²L to DPM design.

Table 3. Comparison of I²L and CMOS

ISSUE	I ² L	CMOS
Yield Factors		
A) Experience	Considerable applicable analog experience.	Considerable digital experience.
B) Major cause of limited yields	Collector to emitter shorts.	Surface contamination.
C) Density	Approximately 10mils ² per gate.	Approximately 30mils ² per gate.
Analog Functions		
A) Versatility	Excellent. Possible circuits include band gap references and power.	Poor. However, good analog switches are inherent.
B) Precision	Good.	Fair.
C) Complexity	Excellent.	Fair. Present state of the art is two or three op amps.
Digital Functions		
A) Power x delay	Less than 1pJ.	Approximately 3pJ.
B) Interface	Good. Will easily sink 10 TTL loads.	Fair. TTL compatibility is possible at the expense of chip area.

MANUFACTURE

As important as circuit-design efficiency is a manufacturing process that minimizes costs of inspection, assembly, test, and quality control. The AD2026 benefits greatly from economies of scale.

Because the low parts count of the AD2026 permits construction on a single board, a further advantage is that the boards themselves can be produced in multiple units. The cover photographs show the assembly sequence. A 12" x 12" pallet board has 15 identical printed circuits; the board has been routed to permit later removal of individual cards. Components for all 15 DPM's are inserted as the pallet moves down the high-speed assembly line.

After assembly and wave-soldering, the board is automatically tested on a Faultfinder 303, which can discover and pinpoint assembly errors, soldering problems, and faulty components, and also perform all the functional tests to the specifications. The units are then burned in under full power for 168 hours, and another functional test is performed. Only then are the DPM's removed from the pallet and inserted in the case (without the use of screws or mechanical fasteners). The lens is snapped on, and the unit is placed in its shipping container, ready for delivery. Even then, the long arm of Quality Assurance spot-checks finished units on an AQL basis, to ensure that the customer does not lose the fruits of all this carefully-planned endeavor.

CONCLUSION

The result is a significant advance in the application of solid-state technology to an industrial product. The AD2026 is a low-cost, simple, reliable, easy-to-read panel meter that

achieves its cost-effectiveness through fundamental investments in technology, circuit design, and mass production. It will replace analog meters in a large number of new-instrument designs. ▶▶▶

WHAT IS I²L?

MOS and bipolar are the two basic LSI semiconductor processes. MOS produces very dense — therefore low-cost — logic circuits but is capable only of crude analog devices. Before I²L, bipolar could offer stable high-quality devices suitable for precision analog circuits, but logic consumed much expensive chip area.

Integrated Injection Logic (I²L) now allows the design of single-chip devices containing both analog and digital functions, without calling for the compromises required in the past. I²L has a logic density that equals or exceeds that of MOS, while employing a bipolar process suitable for precision analog circuitry.

I²L eliminates the complexity of conventional bipolar logic by using inverted transistors (collectors and emitters are interchanged). Figure 4 shows a conventional transistor, with its wraparound P+ isolation region, which is needed to separate the collectors of adjacent transistors. When the transistors are inverted, the collectors are automatically isolated, and the emitters are fortuitously grounded, at the same time.

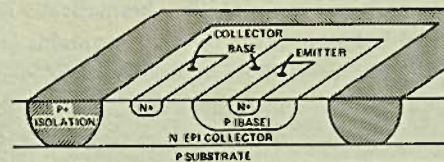


Figure 4. 3-dimensional section of conventional NPN transistor.

Since I²L logic gates can easily have multiple outputs, it is possible to use simple "wired-or logic", a means of implementing the logical or operation using only one conductor (wire). Figure 5a shows an example of two I²L gates wired to implement the nor function.

A major contributor to I²L's compactness is replacement of conventional "pullup" resistors or transistors by an injector bar. In Figure 5b, the P injector acts as a combined power-supply rail and current source for the I²L gates. Holes are injected into the chip and collected by nearby base regions so as to pull-up each gate.

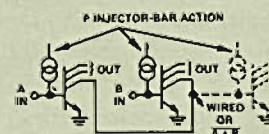


Figure 5a. I²L gates wired to implement NOR function.

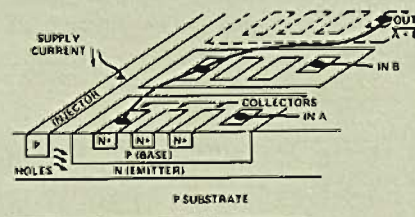


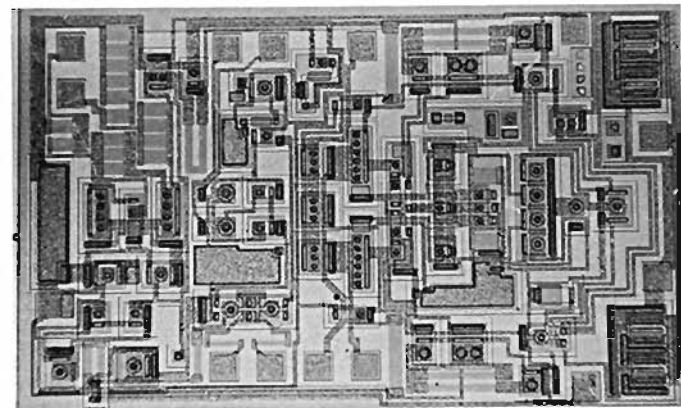
Figure 5b. Sectional view of I²L circuit.

Analog circuitry may be placed on the same chip by using conventional transistors like that of Figure 4. Thus, I²L can be seen to combine the possibility of high-density logic functions with precision analog circuitry. ▶▶▶

VERSATILE MONOLITHIC V/f OR I/f CONVERTER

AD537 is Easy to Use, Works from Single Supply Outputs to Beyond 100kHz; T/f Conversion Inherent

by Dave Kress and Barrie Gilbert



The AD537* is a self-contained monolithic voltage-to-frequency converter fabricated on a single 74 x 118 mil (1.9 x 3mm) silicon chip and mounted in a hermetically-sealed 14-pin ceramic dual in-line package (DIP). It contains (Figure 1) an input amplifier, a precision oscillator system, a reference generator, and a high-current output stage. Only a single external resistor and capacitor are needed to determine the scale factor. Its three versions are AD537J/K (0° to +70°C) and AD537S (-55° to +125°C).

The great strength of the AD537's design lies in the ease of application to a wide variety of instrumentation, communication, and systems uses (eight applications appear on pages 7 & 8). Both positive and negative input voltages, with full-scale values from 100mV to >10V – and current inputs – are easily accommodated. A single external capacitor programs square waves, at full-scale frequencies from <100Hz to >100kHz (+50% overrange).

Square waves are generally more useful than the variable-duty-cycle output pulse-train from most V/f converters. A square wave requires less equivalent bandwidth for transmission and avoids bias-distortion effects in ac-coupled transmission- or recording-media. Since chip dissipation is independent of frequency, thermally-induced nonlinearities under load are avoided.

A unique feature of the AD537 is its pair of reference outputs – a low-drift 1.00V reference, which can be used to drive resistive sensors or provide a precise level for additive input con-

stants; and a 1mV/°K reference voltage that is directly proportional to absolute temperature (at +25°C, its output is 298mV), allowing the AD537 to be used as a direct temperature-to-frequency (hence -digital) transducer. The independent reference outputs, though "soft", can be used for other circuit functions during normal VFC use.

The AD537 operates well with most standard power-supply configurations – for example, a single +4.5 to +36V supply – permitting applications in an all-digital system without requiring a separate analog supply. It functions equally well with standard split supplies (±5V to ±18V). Considerably lower-powered than other VFC's, it needs only 1.2mA of quiescent current, a useful feature for remote-sensing or battery-powered applications.

The SYNC terminal (pin 2) permits external control; the AD537 can be synchronized to a system frequency or inhibited at will. This feature and the open-collector output stage permit multiplexing of several AD537's on a single line-pair in a wired-or configuration.

Many new applications areas, previously closed to IC V/f converters, will be opened by the AD537's flexibility, its convenient 14-pin DIP, and its "IC-type" pricing (\$9.50 in 100's (J)).

HOW IT WORKS (Figure 1)

The versatile input amplifier, used as an op amp, scales the input signal and converts it to the appropriate drive-current level for the oscillator. The input specs are excellent: ±1mV offset, 5μV/°C drift, 100nA bias current, and 250MΩ non-inverting-input impedance. A PNP input stage allows the input signal level to go all the way down to the -V_S single-supply (ground) level and up to (+V_S - 4) volts.

The key element of the design is a precision astable multivibrator. The timing current, supplied by the input, is split precisely among the 3 matched NPN transistors, 2 of which sink the drive current through the timing capacitor. The 3rd transistor drives the bias network for the oscillator – thus all sections of this stage are adaptively biased to match the timing current, reducing nonlinearities due to β and r_E to <0.02%. The switching system and bias transistors force a current of precisely 1/3 in alternating directions through the timing capacitor, which integrates the current. The primary switching transistors compare the capacitor voltage to a level determined by the band-gap reference generator; regenerative switching occurs when the capacitor voltage reaches that level. The reference level has a temperature variation that compensates for the tempo of the switching transistors. Brought to pin 2 (SYNC), this level can be perturbed at multiples of system frequency for synchronization or switched to the supply to inhibit oscillation.

The design of the reference-generator is similar to that of the AD580 2.5V Reference*. Besides the temperature-compensat-
*For data on AD580, use the reply card. See also DIALOGUES 8-2, 9-1, 9-2.

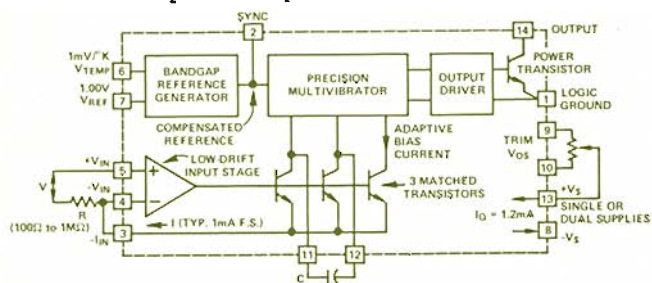


Figure 1. Block diagram of the AD537.

*To request data on the AD537, use the reply card.

ing level for the oscillator, it also supplies externally a low-tempco 1.00V reference and a thermometric voltage, which can be used in direct temperature-to-frequency conversion (page 8), as an ambient temperature reference in systems applications, and for compensating temperature coefficients in the timing circuitry.

The driver converts the oscillator's differential output to a floating switched current, which drives the uncommitted output power-transistor. This configuration offers great flexibility. The output can be taken from either the collector or the emitter of the output transistor; usually, the emitter is grounded and the output is taken from the collector (with a pullup resistor to $+V_S$). Logic common (pin 1) need not be held at either analog input common, or at power-supply common; it can be floated anywhere between $-V_S$ and $(+V_S - 4V)$, with a return to $-V_S$. This means that a direct connection can be made to virtually any type of logic with any supply combination. The digital supply can be up to 36V above $-V_S$, regardless of $+V_S$.

STANDARD APPLICATIONS

Figures 2 and 3 show the most-common basic configurations. For normal positive inputs, pins 3 & 4 are connected together, then via a scaling resistor ($R = V_{IN} F.S./1mA$) to ground. 100% overrange to 2mA is allowed, with somewhat degraded linearity. Only a positive supply is required, even for negative-input applications (but a negative supply can be used for increased input range).

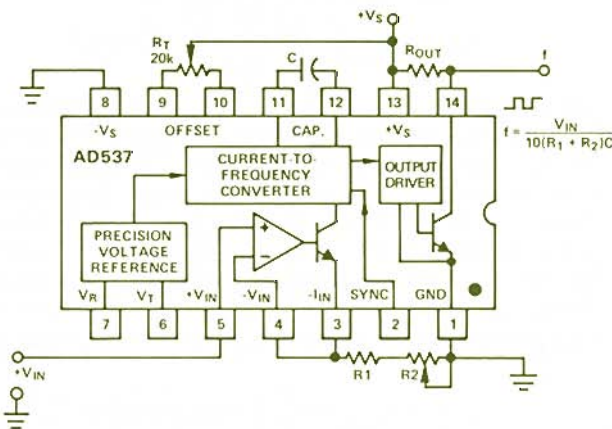


Figure 2. Standard connection for V/f conversion of positive input voltage.

The optional 20kΩ pot is used when trimming the input-amplifier offset. The timing capacitor must be a high-quality polystyrene or NPO ceramic type to minimize nonlinearity due to dielectric absorption. Temperature performance of the circuit is sensitive to the capacitor's tempco. Collector pullup resistance is chosen for sufficient pullup current but minimal power consumption.

For negative inputs (V or I), the positive input is grounded, and the signal source provides the oscillator drive current (Figure 3). The 1kΩ resistor and the diode are required to prevent latching under transient conditions. To accommodate very large negative input levels (even below $-V_S$), select the scaling resistors to give 1mA drive current at full-scale input voltage. The scaling resistors are not used with current inputs;

calibration for a current source can be provided by a 27kΩ resistor in series with a 200kΩ trimmer from pin 7 to ground.

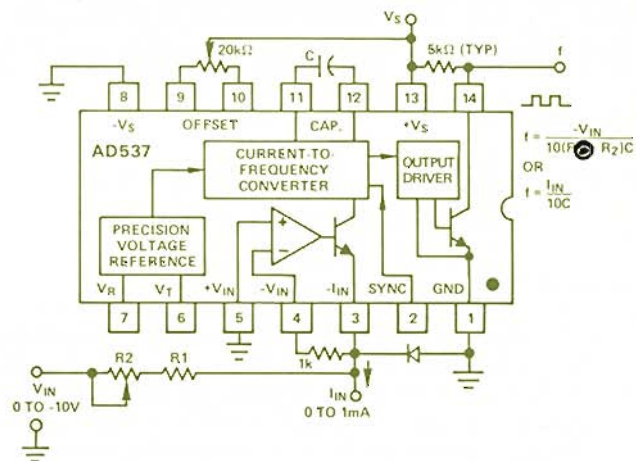


Figure 3. Connection for V/f conversion of negative input voltage or current.

A few salient examples of the wide range of potential applications for the AD537 are shown on the next page.



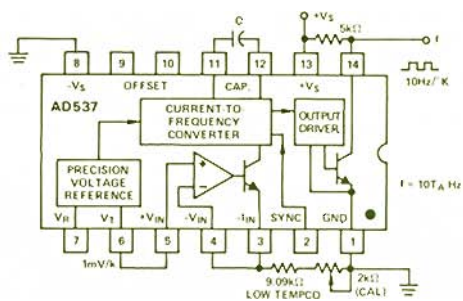
PERFORMANCE CHARACTERISTICS OF THE AD537

(Typical at $+V_S = +5$ to $+15V$, $-V_S = 0V$, $T_A = +25^\circ C$, unless otherwise indicated)

	J	K*	S
ANALOG INPUT AMPLIFIER (voltage-to-current converter)			
Voltage Input Range:		0 to $(V_S + 4)$	
Input Bias Current:		100nA	
Input Resistance (Non-Inverting):		250MΩ	
Input Offset Voltage, vs. Supply:	5mV max	2mV max	2mV max
vs. Temperature:		100μV/V	5μV/°C
CURRENT-TO-FREQUENCY CONVERTER			
Frequency Range:		0 to 150kHz	
Nonlinearity:			
Positive Voltage Input:	0.15% max	0.1% max	0.1% max
Negative Voltage or Current Input, 10kHz full scale:	0.1% max	0.05% max	0.05% max
100kHz full scale:	0.2% max	0.1% max	0.1% max
Full-Scale Calibration Error ($C_T = 1.000nF$, $I_{IN} = 1.000mA$, $f = 10kHz$ nominal)			
Maximum Error (adjustable to 0):	7%	5%	5%
Temperature Coefficient:	150ppm/°C	50ppm/°C	100ppm/°C
Supply Rejection:		0.01%/V	
OUTPUT INTERFACE			
Circuit:		Open-Collector Output	
Waveform:		Symmetrical Square Wave	
Output Sink Current - Output Low			
$V_{OUT} = 0.4V$ max, T_{MIN} to T_{MAX}	20mA min	20mA min	10mA min
Output Leakage Current - Output High			
T_{MIN} to T_{MAX}	200nA max	200nA max	2μA max
Logic Common Level Range:		$-V_S$ to $(+V_S - 4)$ volts	
Rise or Fall Time, $C_T = 0.01μF$			
$I_{IN} = 1mA$:		0.2μs	
$I_{IN} = 1μA$:		1μs	
POWER SUPPLY			
Voltage, Rated Performance			
Single Supply:		4.5V to 36V	
Dual Supply:		±5V to ±18V	
Quiescent Current:		1.2mA	
TEMPERATURE RANGE, OPERATING			
	0° to +70°C	-55° to +125°C	-55° to +125°C
PRICE:			
1 - 24:	\$13.00	\$19.75	\$29.00
100+:	\$9.50	\$13.75	\$19.50

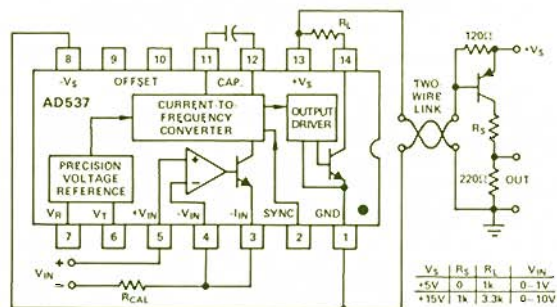
*Specs listed only in this column are common to all three grades.

TEMPERATURE-TO-FREQUENCY CONVERTER



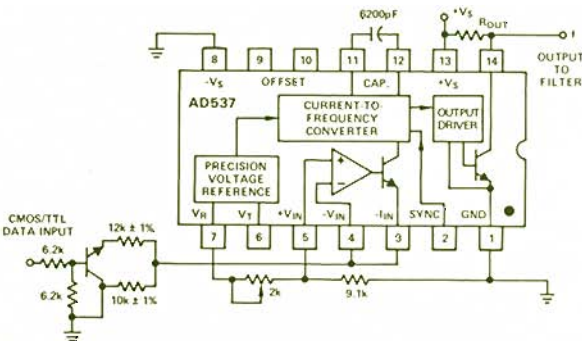
This simple connection results in a direct conversion of temperature to frequency. The $1\text{mV}/^\circ\text{K}$ temperature output serves as the input to the buffer amplifier, and the oscillator drive current is scaled to be $298\mu\text{A}$ at 298°K ($+25^\circ\text{C}$). Use of a 100pF capacitor results in a corresponding frequency of 2.98kHz . A single-point trim for calibration is normally sufficient to give errors less than $\pm 2^\circ\text{C}$ from -55° to $+125^\circ\text{C}$. An NPO capacitor is preferred to minimize nonlinearity due to capacitance drift.

TRUE TWO-WIRE OPERATION



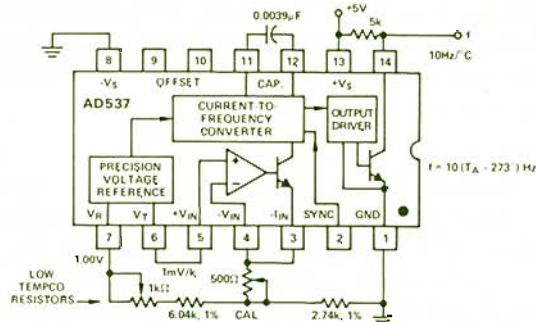
The AD537 can be used for true two-wire operation, as shown here. The frequency information is transmitted as a current signal on the supply line to the device. The signal is converted to a DTL/TTL or CMOS-compatible signal by the single-transistor-termination circuit shown. The excellent supply rejection, high output-drive capability and square-wave output from the AD537 are all advantageous in this application.

BELL SYSTEM 202 DATA ENCODER



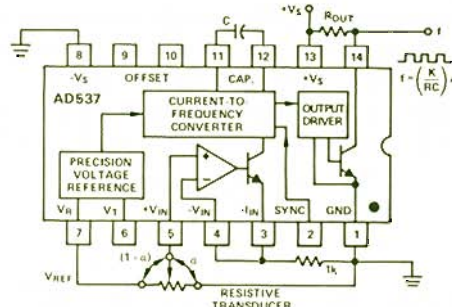
The AD537 is well-suited for frequency-shift modulator and demodulator applications. Requiring little power, it is especially suited to using phone-line power. The Bell-System-202-type data encoder shown here delivers the *mark* frequency of 1.2kHz with the data input *low*. When the input goes *high*, the timing current increases to $165\mu\text{A}$ and generates the *space* frequency of 2.2kHz . The trim shown provides a $\pm 10\%$ range of frequency adjustment. The output goes to the required band-pass filter before transmission over a public telephone line. A complementary demodulator is easy to implement.

FREQUENCY-TO-VOLTAGE CONVERTER



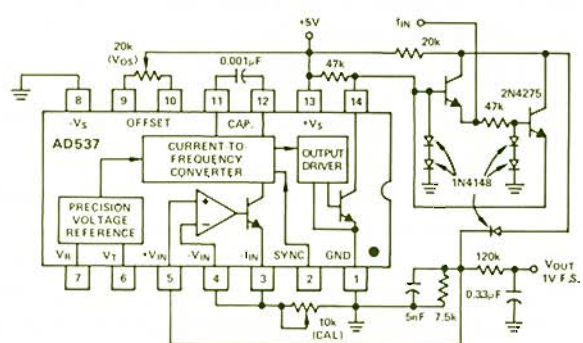
The 1.00V reference output may be combined with the $1\text{mV}/^\circ\text{K}$ output to realize various temperature scales. For the Celsius scale, the lower end of the timing resistor must be offset by 273mV . This is easily accomplished, as shown above, and results in an output from 0 to 1kHz for temperatures from 0°C to $+100^\circ\text{C}$. Other offsets and scale factors are equally easy to implement.

INTERFACING RESISTIVE TRANSDUCERS



All types of resistive-element transducers, such as servo-pots, level indicators, thermistors, photosensors, strain gages, and so on, can be directly connected to the AD537. Resistance values from $3\text{k}\Omega$ to $100\text{k}\Omega$ are easily accommodated. Input-buffer bias-current errors will be noticeable above $100\text{k}\Omega$; values below $3\text{k}\Omega$ will load the reference beyond its output capability. The scale correction factor, K , is a function of resistance, varying from 0.65 to 0.98 for values from $3\text{k}\Omega$ to $100\text{k}\Omega$.

FREQUENCY-TO-VOLTAGE CONVERTER



The AD537 can also be used as a highly-linear voltage-controlled oscillator in a phase-locked loop to perform *frequency-to-voltage* conversion. The transistor pair shown here operates as an exclusive-or gate to perform the phase comparison. It locks onto the input frequency within two cycles. This configuration requires only 3mA for frequencies up to 10kHz . In most situations, an output buffer will be required to unload the filter. Use 0 -to- 5V pulses or square waves with $40\mu\text{s}$ minimum pulsewidth.

DIFFERENTIAL INSTRUMENTATION AMPLIFIER

At \$19.50(1-9), AD522A Has Module Performance at IC Prices

A Laser-Trimmed Thin-Film Hybrid in Hermetic DIL

by Jeff Riskin

The AD522 differential instrumentation amplifier*, designed for applications requiring high precision under less-than-ideal operating conditions, multiplies the difference between two input voltages by a fixed gain, from 1 to 1000, determined by a single external resistance. Built on a precision thin-film substrate in a hermetic DIL package, it combines module-like performance with IC-like small size, low cost, and pinout similar to that of the popular monolithic AD521* (*Dialogue* 9-1).

WHAT IT DOES

Instrumentation amplifiers amplify and translate low-level "floating" transducer outputs to system-ground level. The operating environment is frequently industrial; co-existence with noise-inducing machinery, widely-varying temperatures, and calibration-inhibiting remote locations is the rule. Therefore, high input impedance, high common-mode rejection, low noise, excellent linearity for a wide range of gain settings, and stability with time and temperature changes are all essential.

Modular instrumentation amplifiers fill the bill but tend to be large and costly. Small, low-cost monolithic IC's have relatively poorer performance. The AD522 resolves the dilemma:

Table I. Instrumentation-amplifier comparison.

SPECIFICATION	TYPICAL MODULE	TYPICAL MONOLITHIC IC	AD522C
Nonlinearity (Gain < 100), max	0.01%	0.05%	0.005%
Common-Mode Rejection (dc, G = 1, 1k Ω source unbal.)	80dB	75dB	90dB
G = 1000	120dB	110dB	120dB
Offset Voltage Tempco (r.t.i.), max			
G = 1	50 μ V/ $^{\circ}$ C	150 μ V/ $^{\circ}$ C	10 μ V/ $^{\circ}$ C
G = 1000	0.5 μ V/ $^{\circ}$ C	5 μ V/ $^{\circ}$ C	0.5 μ V/ $^{\circ}$ C
Package	38 x 38 x 10mm (1.5" x 1.5" x 0.4")	14-pin DIP	14-pin DIP
Price (1-9)	\$60 to \$100	\$15 to \$25	\$30

The "C" version is suitable for operation in many 12-bit applications; in Figure 1, a transducer with 0-1V output and 1k Ω source unbalance operates in a noisy environment that induces 1V of CMV (dc to 60Hz) in the ground return. Amplification to a 0-10V range for 12-bit A/D conversion is required ($\frac{1}{2}$ LSB = 125 μ V r.t.i.); operating temperature range is -25 $^{\circ}$ C to +85 $^{\circ}$ C).

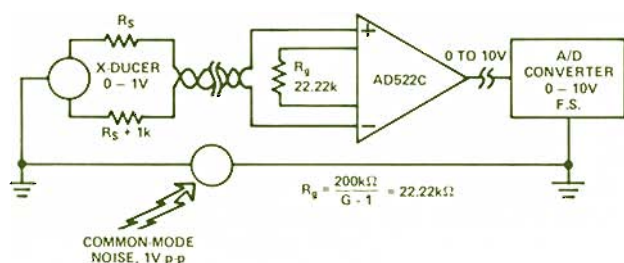


Figure 1. Typical AD522C application.

*For information on products mentioned here, use the reply card.

AD522C errors in this application are detailed in Table II.

Table II. AD522C Errors.

ERROR SOURCE	AD522C MIN/MAX SPEC	EFFECT ON ABSOLUTE ACCURACY	EFFECT ON RESOLUTION
Gain Nonlinearity (G = 10)	$\pm 0.002\%$	20ppm	20ppm
Voltage Drift, r.t.i.	$\pm 1.5\mu$ V/ $^{\circ}$ C	68ppm F.S.	—
Common-Mode Rejection	90dB	30ppm	30ppm
Noise, r.t.i. (0 - 10Hz)	10 μ V (p-p)	5ppm F.S.	5ppm F.S.
Offset-Current Drift	± 50 pA/ $^{\circ}$ C	2ppm F.S.	—
Gain Instability (add 5ppm/ $^{\circ}$ C for external R _g)	± 50 ppm/ $^{\circ}$ C	2475ppm	—
Total Errors		2600ppm	55ppm

The worst errors — offset and gain — add up to $\sim 0.26\%$. In microprocessor-controlled data-acquisition systems, periodic automatic calibration can nullify the effects of gain and offset drifts for better absolute accuracy. Performance is ultimately limited by the specs affecting resolution, adding up to 55ppm (0.005%), adequate even for 13-bit A/D conversion without missing codes (if the rest of the system, including the transducer, is error-free). Dynamic range exceeds 85dB (14 bits).

HOW IT'S DONE

The unusual performance of the AD522 is the fruit of concerted application of ADI's technologies, skills, and experience to a proven conventional design. The keys to its performance are the AD510 low-drift op amps* (*Dialogue* 9-3), and thin-film networks† and substrates from our Microelectronics Division. In addition, critical specs are optimized by active laser-trimming, an Analog Devices forte since 1970 (*Dialogues* 4-2, 9-3).

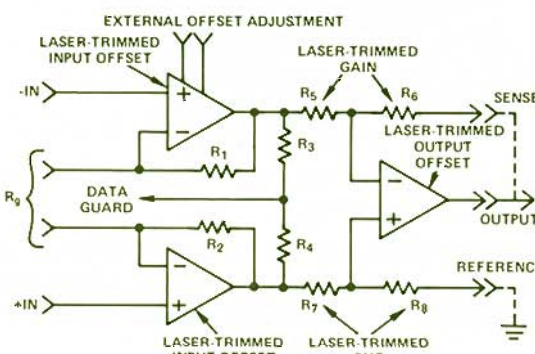


Figure 2. Block diagram of the AD522.

For example, with a large common-mode signal applied, the bridge formed by resistors R5-R8 (Figure 2) can be adjusted for minimum amplifier output, to maximize CMR. Trimming to 1ppm is feasible; after burn-in and final test, 10ppm ratio-match and 2ppm/ $^{\circ}$ C tracking are routinely maintained.



†Thin-film networks have better tempco's and long-term stability than thick films.

MORE THAN A DPM

AD2022's Powered Function-Card Capability Makes Custom Meter Design Easy

by Al Pollens

The AD2022* is a low-cost 3½-digit ac-line-powered functional DPM with a 13mm (½in) LED display. It accommodates a large 95 x 102mm printed-circuit board with more than 7700mm² of usable real estate for extra signal-conditioning or logic circuitry, with service voltages provided. An example of its use for special functions is the AD2033* RMS/dB meter.

The quantity you want to measure seldom matches directly the input and readout of a low-cost general-purpose meter. What do you do, then, when your application calls for a little extra signal-conditioning on the front end of the DPM? Or maybe the problem is housing and powering special logic-circuitry for a more-intelligent DPM. Where to put it? How to power it?

The alternatives frequently leave a great deal to be desired. Even after much bother and cost, the solution may still seem wanting. It's enough to make you wish you could stuff all that extra circuitry inside the nice little DPM box. And that's precisely what the Analog Devices AD2022 (Figure 1) is all about.

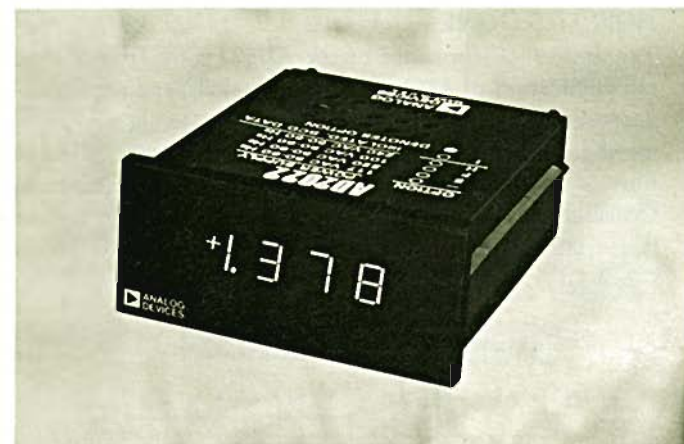


Figure 1. The AD2022 looks like and takes no more space than an ordinary AC line-powered DPM.

In addition to embracing the proven circuitry of a widely-used "second-generation" DPM (the AD2016* - *Dialogue* 9-3) in a U.S. "industry-standard" case, the AD2022 also provides space and power for a special function board. Two sizes of boards are available to the user; the larger is 95 x 102mm (3¾" x 4"), has more than 7700mm² (12in²) of usable circuit space, and accepts components and modules up to 16.5mm (0.65") in seated height.

For powering the added circuitry, up to 20mA at ±12V are available for analog signal conditioning and CMOS, and up to 100mA at +5V for TTL logic (30mA if the isolated parallel BCD data-output option is specified).

*For information on any of these products, use the reply card.

SPACE AND POWER TO DO A LOT

There's plenty of space on the board, and ample power to go with it. You can use the AD2022's function-board capability to make a digital temperature meter, a digital scale, a digital pH meter, or . . . what do you need? Here are some of the possibilities:

PHYSICAL MEASUREMENTS

- Temperature Meters (TC, RTD, Thermistor)
- pH Meters
- Pressure Meters
- Digital Weighing Scales
- Humidity Meters
- Flow Meters
- Digital Micrometers
- Gauss Meters
- Etc.

ELECTRICAL MEASUREMENTS

- Voltmeters (AC/DC, rms, peak, average)
- Ammeters
- Power and VAR Meters
- Analog Computer Monitoring
- Ratiometers
- Capacitance Meters
- Inductance Meters
- Conductance/Resistance Meters
- Etc.

"SECOND-GENERATION" DESIGN

O.K. The possibilities are extensive, if not limitless, but the functional options would be of questionable value if the basic DPM itself were not a reliable, low-cost, high-performance "second-generation" design. That the design has already been proven in the form of the AD2016 is so much the better.

Readers of this Journal (9-3) may recall that "second generation" means replacement of the mixed bag of displays, small-scale logic IC's, and discrete analog circuitry of the earlier units by a shift to MOS/LSI (metal-oxide semiconductor, large-scale integration) IC's and improved light-emitting diodes (LED's) with larger digit size, greater intensity, and significantly lower cost.

To the DPM user, "second generation" adds up to almost 50% fewer parts, larger (easier-to-read) displays, 15% to 35% lower prices, and a big gain in reliability (when properly used). The gain in reliability is primarily the result of the reduced parts count and decreased internal temperature rise.

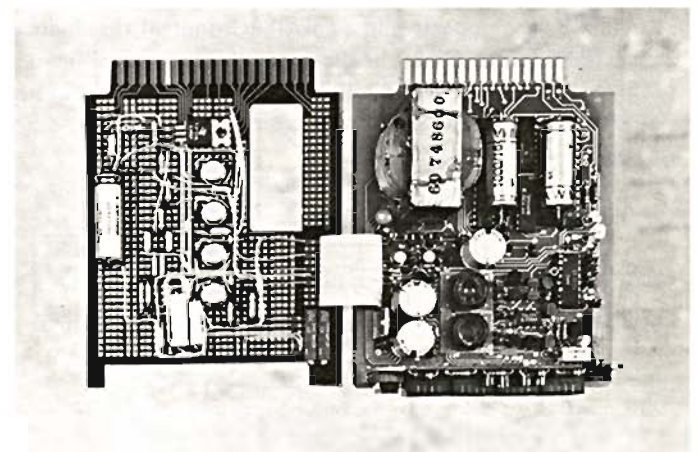


Figure 2. The hand wired custom function board on the left has the special circuitry that turns the AD2022 into a dedicated instrument.

The basic DPM is ac-line powered; its "universal" transformer, with simple strapping changes, can accommodate to any standard voltage and frequency available throughout the world. Other design features include full-scale range of 0 to $\pm 1.999V$ dc, auto-zero correction, limited differential input (fully-floating isolation as an option), character-serial data output (isolated parallel BCD as an option), optional ratiometric operation, and a case that is an industry standard in the U.S.

HOW TO USE THE FUNCTIONAL CAPABILITY

Figure 2 shows an AD2022 with its circuit boards removed from the case. The standard AD2022 DPM converter board is the one on the right. To its left, and connected to it by a length of ribbon cable, is the custom-function board. The one shown is hand-wired from the circuit of Figure 3, for application as the complete circuit of a digital weighing scale, except for the bridge transducer. Note that bridge excitation is supplied from the card, and that ratiometric conversion makes the readout independent of the actual excitation value.

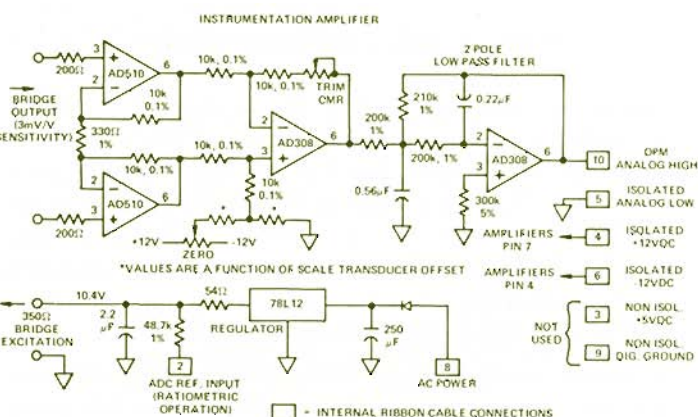


Figure 3. Schematic of the special circuitry on the custom function board of Figure 2.

The approach used in Figures 2 & 3 is one of the three ways in which the AD2022 can be used to build a custom meter. In this case, the special circuitry has been hand-wired on a standard AC2615 "blank" board (Figure 4). The circuit side has solder pads to facilitate interconnection of the component leads and the wiring to the 18-pin input/output connector and

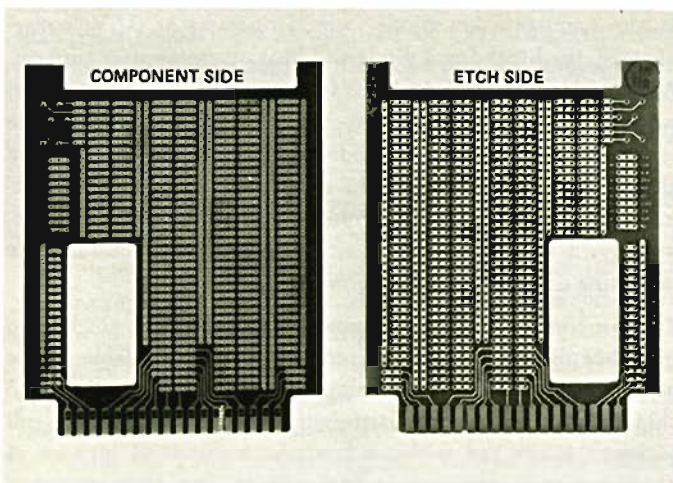


Figure 4. Standard ADI function boards for building small quantity specials and prototypes.

the ribbon cable. The reverse (component) side of the board is silk-screened to show the location of the solder pads on the circuit side.

The hand-wired approach is the obvious way to get started, especially for prototypes and small-quantity production. The "blank" boards can be purchased from Analog Devices in any quantity. For more-finished circuitry in large-volume instruments, the user may well want to lay out a custom board for fabrication by preferred local suppliers. Analog Devices will furnish board outline dimensions and mounting instructions.

For applications involving just a small amount of functional circuitry, the user can avoid the large board and ribbon cable by soldering a function card no larger than 36 x 28mm (1.4" x 1.1") to the converter board in place of the ribbon cable.

AD2022 BECOMES THE AD2033 RMS/dB METER

The new AD2033* RMS/dB meter is an example of what can be done with the AD2022, using a manufactured function board that provides all of the specialized circuitry to transform it into a high-performance RMS/dB meter with guaranteeable specs. Superficially, except for model and function identification, it is identical to the AD2022. Figure 5 shows the physical difference.

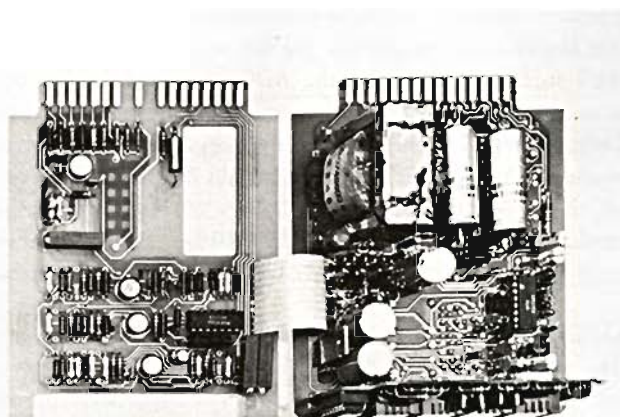


Figure 5. The quantity-produced function board on the left is the key to the new AD2033 RMS/dB Meter.

And electrically? Its large LED's will display 3½-digit true-rms readings of ac or combined ac-and-dc input voltages with full-scale ranges of 600V, 200V, 20V, 2V, or 200mV rms. The AD2033 can also provide readings of these voltages in dB (log-ratio) form. For fixed internal or external reference, AD2033 is capable of readings in dB or dBm (1mW in 600 Ω) over a 60dB range. With variable reference over the full range, 5mV to 5V, readout can range from -60dB to +60dB.

Input impedance is 100k Ω on the 200mV range and 1M Ω on all others.

TRY IT YOUR WAY

The AD2022 is a flexible DPM in a standard package. Whether you use 1 or 5,000, you can have your own custom instrument that you tailor to your own needs. We provide the standard converter, readout, power supply, and house. The "value added" is yours. Price of the basic AD2022 is \$142 (1-9), \$104 in 100's.



REALLY-GOOD LOW-POWER MODULAR CONVERTERS

Call for More Than Just a Few Off-the-Shelf I.C.'s

(Insights Into the Design of Low-Power 12-Bit ADC's & DAC's)

by Jack Memishian and Wayne Marshall

In the design of modular converters, size, cost, and manufacturability are key considerations. Thus, all other things being equal, our engineers would prefer to use a few complex integrated circuits rather than a large number of discrete components as the building blocks of their devices. And, in fact, many recently-introduced A/D and D/A converters in modular and hybrid form consist mainly of IC DAC-elements and successive approximation registers, plus standard IC op amps, comparators, and latches.¹

But when we launched into the design of a pair of very low-power 12-bit converters (the ADC1121* and the DAC1122*), we knew that off-the-shelf IC's would simply not give the required performance.

For example, our own AD7521* 12-bit monolithic CMOS DAC is an excellent and economical choice for many applications, but its $\pm 0.05\%$ maximum nonlinearity error ruled it out as a component of these particular designs. IC comparators with sufficient speed for the ADC's targeted $5\mu\text{s}/\text{bit}$ conversion rate would, by themselves, consume more power than had been allotted for the entire converter; and the commercially-available "low-power" op amps would do the same when used at the speed desired of the DAC's output amplifier ($10\mu\text{s}$ settling time to accuracy within 0.01% F.S.). It was evident that we had to design our new units from the ground up.

DESIGNING THE ADC1121

The architecture settled-upon for our A/D converter was fairly straightforward, as Figure 1 shows. The successive-approximations register, CMOS single-pole double-throw switches, and R-2R resistance-ladder network were readily available, but the reference and the comparator posed problems.

To avoid the high current-drain of "off-the-shelf" comparators, we settled on a discrete design using the classical FM limiter-amplifier scheme, employing many low-gain fast stages

in cascade (Figure 2). This contrasts with the typical IC-comparator scheme of taking all the gain in 1 or 2 stages.

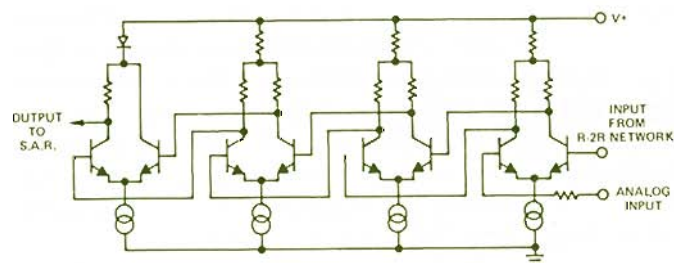


Figure 2. Comparator block diagram.

Suppose one takes a gain of 10^4 in one stage. With a single-pole rolloff, if that gain becomes unity at 1MHz, it is 10^4 at frequencies below 100Hz. But if each of the four stages has a gain of 10, rolling off to unity at 1MHz, then the gain of the four cascaded stages is asymptotic to 10^4 at 100kHz. The second scheme produces a comparator which is 1000 times faster but only consumes a fraction as much current ($300\mu\text{A}$ vs. 6mA) as a one-stage comparator of equivalent speed.

The analog circuits of the ADC1121 are powered-up only during conversion, to save power between conversions. This places a double burden on the reference circuit. Not only must it draw as little power as possible when on; it must also turn on quickly, settling to within 0.01% of the final value in about $5\mu\text{s}$, in order that the converter be ready at all times.

Almost all of the available reference diodes on the market are large-geometry devices, which incorporate a silicon diode for temperature compensation. Temperature-tracking of the Zener and the forward-biased diodes inside the package relies on both being at the same temperature. However, the breakdown diode, with a 5.8V drop, dissipates nine times as much power as the compensation diode, which operates at 0.6V; consequently, the breakdown diode will heat up faster after turn-on. At some later time (1 to 10ms for low-power Zeners), the forward diode will be heated to the same temperature as the reverse-biased breakdown diode, by conduction through the glass body of the package. The result is an unacceptable thermal "tail" in the reference-voltage settling curve, and consequently, a long delay between the *convert* command and the beginning of accurate conversion.

The problem can be solved neatly by the use of single-chip reference diodes, which have recently become available. These parts have the Zener and compensating diodes on the same chip, so that temperature differentials are minimized and full accuracy is reached within a few microseconds of turn-on. A discrete-circuit micropower buffer with fast turn-on and a very low output impedance completes the reference circuit.

A FET switch turns the reference on when the *status* output

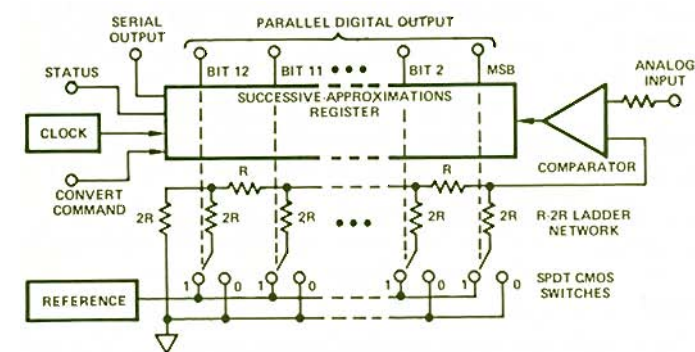


Figure 1. ADC1121 basic circuit.

¹ Some now-standard typical designs can be found in the *Analog-Digital Conversion Handbook*, available from AD1 at \$3.95.

*Use the reply card to request technical data on these products.

goes to logic "1" at the beginning of conversion; it turns it off when the *status* returns to "0" at the end of conversion. The reference source draws a low 1.5mA during the 70 μ s of conversion and virtually nothing (<0.01 μ A) when the unit is not converting.

DESIGNING THE DAC1122

The DAC1122 was also designed with an R-2R resistor network and SPDT switches, as shown in Figure 3. The pin breakout was chosen to give the user maximum flexibility, i.e., the opportunity to implement a wide variety of digital-to-analog functions without the need for additional (power-consuming) signal-conditioning circuits. The ability to apply the converter in a power-saving manner is just as important a characteristic as the power consumption of the unit itself. For example, the DAC1122 can be used as either a fixed-reference or a multiplying DAC; in either configuration, it can be used as either a voltage- or a current-output device. The internal reference circuitry can be disconnected completely (eliminating the power it normally dissipates), and the unit can be driven by an external reference source to save power, if the application warrants.

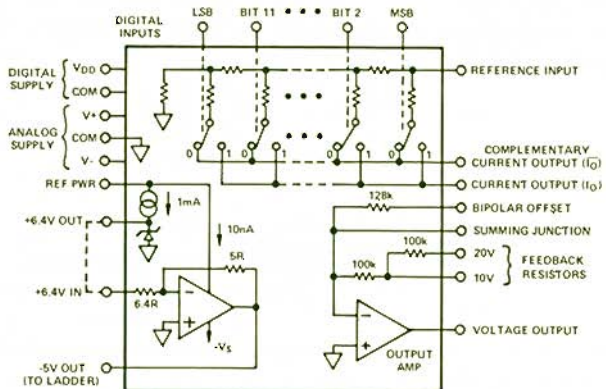


Figure 3. DAC1122 basic circuit. Note the flexibility of inter-connection, including the complete or partial disabling of the reference circuit.

As with the ADC, the analog circuit elements presented the biggest design challenges. The output amplifier had to be reasonably fast, provide good output-current drive capability, yet have low power consumption. A discrete FET-input inverting op amp was designed, which, with a settling time of less than 12 μ s to 0.01%, a slewing rate of 6V/ μ s, a current drive capability of \pm 5mA, and an unloaded power consumption of less than 8.5mW, met all the desired specifications and far exceeded the performance of any known low-power IC op amp.

Because a D/A converter normally operates continuously, a standard low-power Zener could be used to provide the 6.4V reference. However, a single-chip type was employed so that the reference could be quickly strobed from its (separate) power-supply pin if desired. Another discrete-circuit micro-power op amp (drawing less than 10 μ A) was used to scale the +6.4V to the -5.0V needed by the DAC for fixed-reference, positive-true-output operation. In this design, an external resistor can be placed in series with the reference-supply input to disable the Zener and save up to 15mW of power when an external 6.4V source is available. If an external -5.0V reference source is available, even more power can be saved by disabling the reference-inverting amplifier.

THE FRUITS OF OUR LABOR

After combining the low-power sub-circuit designs with the CMOS switches, resistor networks, SAR's, etc., we had two converters with which a user could be happy. They set new standards for high performance and low power drain in D/A and A/D converters, as the following data shows.

ADC1121. The ADC1121 performs 12-bit conversions with less than 0.01% error in less than 70 μ s, with an energy consumption of less than 6 μ J per conversion. The total power consumption at the fastest conversion rate and with worst-case value of supply voltages is less than 100mW (5mW standby). At supply voltages typical of low-power systems ($V_{DD} = 5V$, $V_{AA} = 15V$), the total power consumption is 50mW at full speed and 50 μ W when not converting (Figure 4).

The ADC1121 can be powered by a single +12V to +15V supply or by separate 12–15V analog and 5–15V digital supplies for matching the appropriate logic levels. If batteries are used as the power source (a likely occurrence in the remote and portable applications for which the device is designed), a voltage droop from 15V to 12V will cause only 1/2LSB of gain and zero shift, as a result of the device's excellent power-supply rejection. Data outputs are binary, offset-binary, or 2's complement codes, available in both parallel and NRZ serial form. The operating temperature range is 0 $^{\circ}$ to +70 $^{\circ}$ C, size is 51 x 102 x 10mm (2" x 4" x 0.4") and price is only \$229 (1–9).

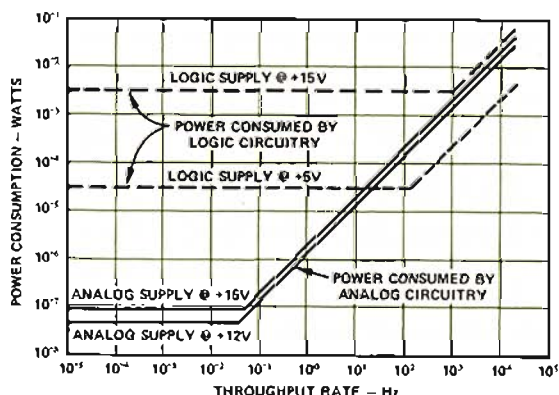


Figure 4. ADC1121 power consumption vs. throughput rate and supply voltages.

DAC1122. The versatile DAC1122 has 12 bits of resolution, \pm 0.01% linearity error (max), and 11 μ s settling time to within 0.01% F.S. (DAC1122K). Good temperature performance is evidenced by its 15ppm/ $^{\circ}$ C gain TC and monotonic behavior from 0 $^{\circ}$ to +70 $^{\circ}$ C. Power consumption of an unloaded DAC1122 with internal reference is less than 30mW; even with the 12 digital inputs toggled simultaneously from "0" to "1", power consumption typically increases by only 250 μ W/kHz of switching rate.

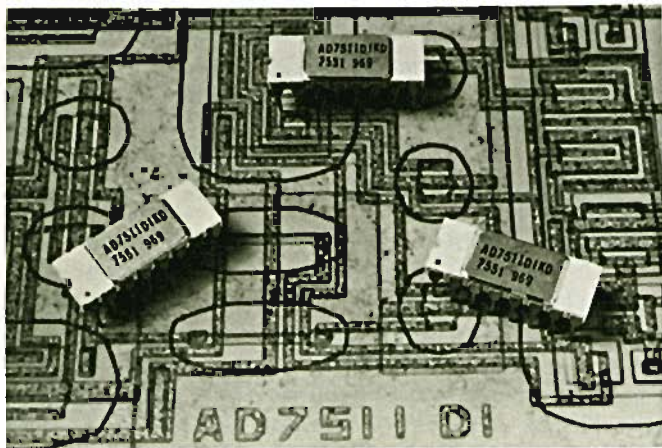
With an external 6.4V reference, power consumption drops to 10mW; as a multiplying DAC, power consumption is an extremely economical 8.5mW. When operated as a 2-quadrant multiplying DAC, ac performance is excellent. Full-power bandwidth is 100kHz for the 10V output range, and feed-through is less than 1/2LSB for frequencies up to 25kHz, and still less than 1LSB for frequencies up to 50kHz. Package size is a compact 51 x 76 x 10mm (2" x 3" x 0.4"); price (1–9) is \$189 for DAC1122K and \$139 for DAC1122J.



PROTECTED ANALOG SWITCHES

Dielectrically-Isolated AD7510DI Family Are Latchproof and Overvoltage-Proof (to $\pm 25V \pm V_{DD}$ or V_{SS})

by Will Ritmanich



The AD7510DI is a member of a family* of dielectrically-isolated CMOS switches in plastic or hermetically-sealed ceramic dual-in-line packages. They are protected against overvoltage to $\pm 25V$ beyond the supplies, with latchproof operation, yet retain low R_{ON} (75Ω) and low leakage current ($400pA$). They are designed for very low power dissipation ($3mW$), yet they can be directly interfaced with TTL or CMOS logic; they will switch up to $50mA$ continuously or $150mA$ surges. They are designed as direct physical replacements (and improved electrical replacements) for earlier (obsolete) namesakes without the "DI" suffix. Prices in 100's range from \$5.80 to \$18 (\$8 to \$24, 1-49).

CMOS switches offer many benefits to the designer, including low power consumption, no dc offset, and low leakage, while accepting signals at levels up to the supply "rails". CMOS switches are causally bilateral, which permits them to be used for either multiplexing or signal distribution.

Until recently, however, the designer had to waste valuable time and resources to make sure that these devices were fully protected against destruction in unusual ways by not-unusual overvoltage levels. For example, when subjected to power-supply transients or input-voltage spikes, they could latch up and burn out. The explanation proved simple but discouraging: With junction-isolated devices, certain inherently-parasitic junctions that were reverse-biased under normal conditions could become latched in the forward-biased condition

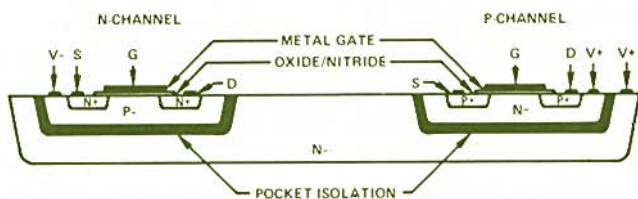


Figure 1. Dielectrically-isolated CMOS.

*For complete information on the AD7510DI, AD7511DI, and AD7512DI, use the reply card.

† See "Keys to Longer Life for CMOS", *Analog Dialogue* 8-2 (1974).

when overvoltage, causing high internal currents and possible destruction.¹ Techniques that eliminate this fault condition typically exchange protection for poorer performance — e.g., higher R_{ON} or leakage current. The AD7510DI, however, combines dielectric isolation and clever circuitry to avoid such tradeoffs. A cross-section of a dielectrically-isolated device is shown in Figure 1.

Figure 2 shows the equivalent circuit of the output switch in the off condition, and R_{ON} as a function of applied voltage and operating temperature. Figure 3 shows the output circuitry of a typical switch. The closed-circuit switching path consists of devices #4 and #5 in parallel (each circled device occupies a separate DI pocket). When they conduct, #1 and #2 are off and #3 is on; the back gates are tied together and float, which fosters the flat resistance characteristic shown in Figure 2.

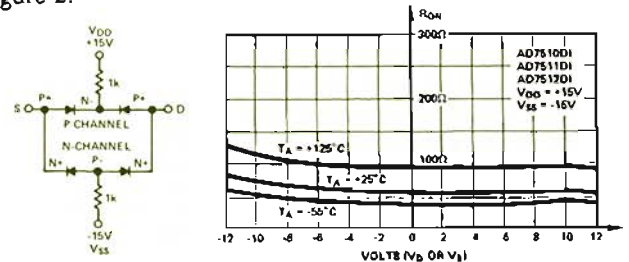


Figure 2. Typical AD7510 switch — equivalent circuit in off condition, series resistance in on condition.

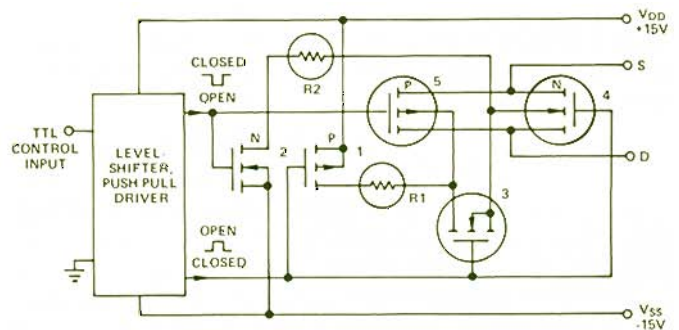


Figure 3. Switching circuitry of the AD7510. Circled devices reside in isolated pockets.

In the open condition, #1 and #2 are on, #3 is off; the back gates of #4 and #5 are tied to the supplies via #2 and #1 in series with $1k\Omega$ resistors. Excessive back voltage applied to the S or D terminal forward-biases the S- or D-to-backgate diode, but current is limited by the series resistance. The overvoltage protection extends to $25V$ beyond V_{SS} and V_{DD} , and operation is latchproof. In addition, capacitance across the output switch is reduced, decreasing switching time, charge injection, and transient power consumption.

Available at present in this series are: AD7510DI (4 SPST switches — positive true), AD7511DI (4SPST switches — negative true), and AD7512DI (2 SPDT switches).

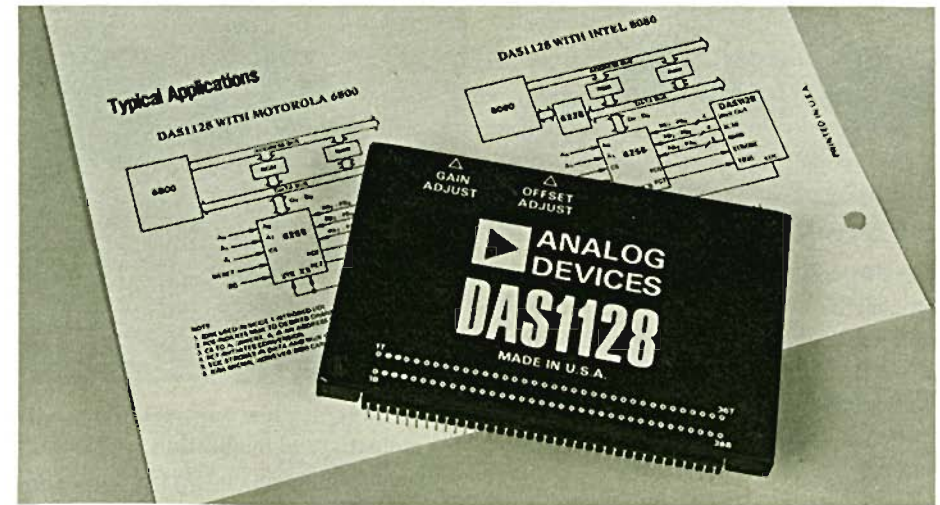


DATA-ACQUISITION SYSTEM DAS1128 Has 12-Bit Output, 16-Channel [8 Differential] Inputs Self-Contained, Up to 50 kHz Throughput Rate, Low Price

The DAS1128* is a complete self-contained miniature high-speed data-acquisition system in a compact 76 x 117 x 9.5mm (3" x 4.6" x 0.375") module. It contains an analog input-signal multiplexer, a sample-hold amplifier, a 12-bit A/D converter, and all of the programming, timing, and control circuitry needed to perform the complete data-acquisition function.

A high-performance device, it can digitize an analog signal accurately to within $\pm 1/2$ LSB of 12 bits, relative to full scale, with a gain-temperature coefficient of ± 8 ppm/ $^{\circ}$ C. The maximum throughput rate can be varied from 35,000 conversions/second for a 12-bit conversion ($\pm 1/2$ LSB) from different input channels to 200,000 conversions per second for successive 4-bit conversions at a single channel.

The DAS1128 finds application in mini-computer and microprocessor interfacing, A/D conversion between remote sensors and modems or telemetry transmitters, data-logging systems, spectrum-analysis systems, satellite telephony, and a host of



other areas. It is a compatible alternative to several popular competitive models, at a rather attractive price (\$295, 1-9).

VERSATILE PERFORMANCE

Limited space does not permit a complete description here*, but there are a number of features that make the DAS1128 exceptionally convenient to apply.

The multiplexer and differential amplifier can accept 16 single-ended inputs (or

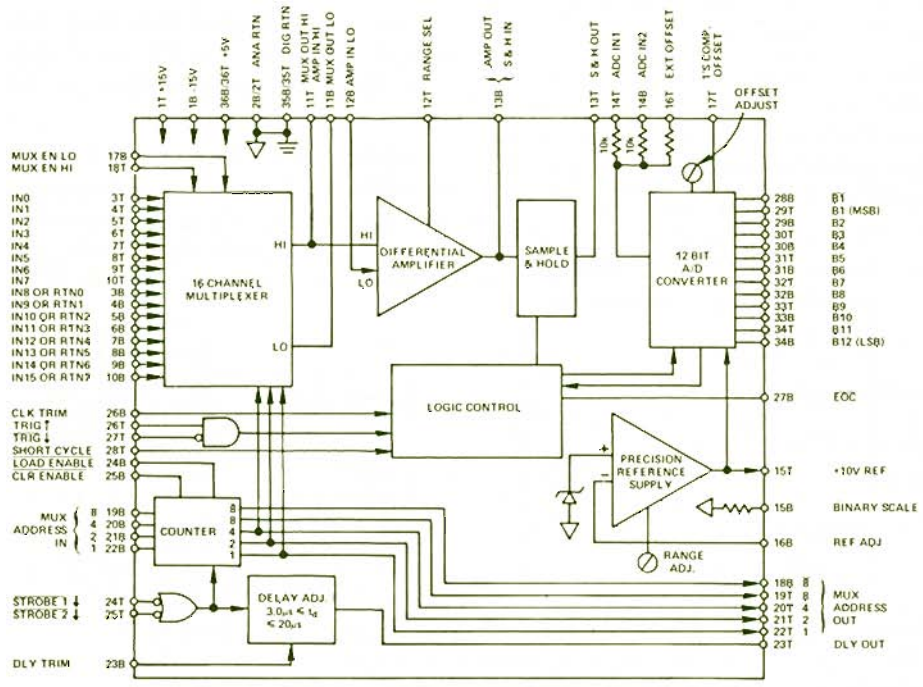
differential inputs with a common "low") or 8 fully differential inputs. The amplifier gain is externally jumper-programmable; and a choice among 8 full-scale ranges is available without external components.

External terminals are provided for the MUX address counter, permitting configuration for the following modes: continuous sequential scanning (free running), sequential scanning with external step command, abbreviated continuous scan, and random channel selection.

To trade faster conversion for fewer bits, the DAS1128 can be *short cycled*, i.e., conversion can be stopped after *n* bits by connecting an external jumper between the short cycle terminal and one of the output terminals.

For applications where it is necessary to optimize the throughput rate under differing conditions, the internal clock is externally adjustable, and the MUX can be operated in an *overlap mode*, selecting the next channel to be sampled while the previously acquired sample is held by the sample-hold for conversion.

Power required is 40mA at +15V, 70mA @ -15V, and 250mA @ 5V; operating temperature range is 0 $^{\circ}$ to +70 $^{\circ}$ C.



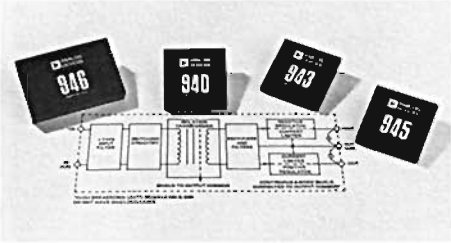
Functional block diagram.

*Use the reply card for complete data on the DAS1128.

New Products

DC-DC CONVERTERS

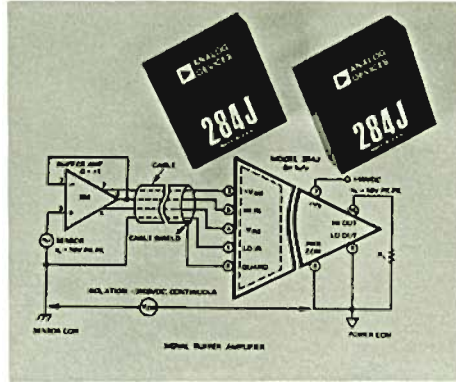
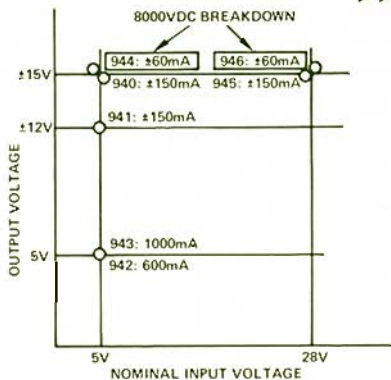
$\pm 15V$, $\pm 12V$, $+5V$ from $5V$, $28V$
Efficient and Economical



The 940 series* provides a full line of compact dc-to-dc converters to satisfy a wide variety of floating power requirements in analog and digital applications. The variety of input and output voltage and current ranges is shown in the graph below.

They are *efficient* (typically $>60\%$ at full load), *cool* (junctions run at least $+25^\circ C$ below rating under full load at $+71^\circ C T_A$), *quiet* (most units have 6-sided shielding for EMI/RFI protection, all have π -type input filters to keep noise off the line, and the $>20kHz$ switching frequency is inaudible), *reliable* (all have 100-hour burn-in at full load, require no derating or heat sinks over the entire temperature range, and can sustain short circuits for at least 8 hours at $+71^\circ C$), and *low-cost* (prices, 1-9, are: \$62 - 944 & 946, \$79 - 943, and \$67 for the rest).

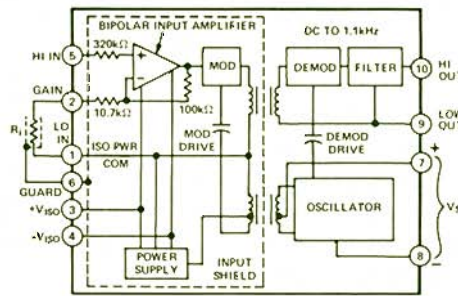
Applications include: Analog power from digital supplies to avoid grounding problems; subsystem/central-system power separation to avoid propagating subsystem faults; floating transducer power; isolated power from wide-range inputs; protection against 500-8000VDC CMV's.



Model 284J* is a low-cost versatile isolator for industrial and medication applications, with adjustable gain (1-10); CMR of 110dB *min* @ 60Hz, 5k Ω unbalance; *max* safe CMV of 5000V (10ms); noise of 8 μV p-p (0.05 to 100Hz), referred to the input; and price of \$59 (1-9), \$41 in 100's.

Despite its small size - 38 x 38 x 15.8mm (1.5" x 1.5" x 0.62"), it is completely self-contained. An internal isolated power supply provides front-end excitation and floating power of up to $\pm 5mA$ at $\pm 8.5V$. The input circuit is isolated from both the output and the power source, and these last are isolated from one another. The block diagram shows the basic isolation scheme employed.

The 284J requires only a single two-terminal power supply, from which it draws only 85mW at 12V; it will operate at voltages as low as 8V. It is therefore quite useful for battery-powered applications, in remote, portable, and mobile (ambulance), as well as bedside environments.



Availability of adjustable gain helps to minimize drift and noise, referred to the input, and to permit greater latitude in

LOW-COST ISOLATION AMPLIFIER

Small, Furnishes Floating Power
Meets UL544 Isolation Ratings

the design of the succeeding amplifier stage. The common-mode rejection and noise specifications are compatible with low-level signal interfacing requirements in hostile environments.

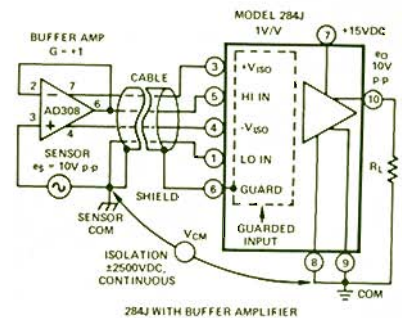
The configuration of the model 284 permits great versatility in industrial and medical applications. The data sheet* shows a single unit used in a multilead ECG with right-leg drive and calibration.

The floating power supply is useful with front-end buffers and remote transducers. The diagram below shows how easily model 284J can be combined with a remote buffer amplifier at some distance.

For components used in medical equipment, safety and reliability are paramount. The 284 meets such standards as US544 dielectric withstand (paragraph 31.11) and leakage current for Type A and Type B patient-connected equipment (paragraph 27.5).

Besides these qualifications, readers of these pages for the last 5 years¹ will recognize the value of ADI's experience in manufacturing reliable transformer-type isolators, and the qualification of certain types (273 and 276) by governmental bodies, such as the Los Angeles City Testing Laboratory (*Dialogue* 9-2, 1975).

The 284, now the lowest-priced isolator in our line, delivers performance comparable to that of the 276 in only 12% of the space.



284J WITH BUFFER AMPLIFIER

*Use the reply card for data on these supplies.

*Use the reply card for data on model 284.

¹ See *Analog Dialogue* 5-2, 1971, p.10.

CONSTANT CUTTING SPEED In Numerically-Controlled Lathe Obtained with Analog Divider

by W. R. Hungerford

In lathe operations, the optimum speed of the work past the tool depends on the material and the required depth of cut per pass. If the spindle to which the work is attached rotates at constant angular speed, f_S (Figure 1), the speed of the work past the tool (cutting speed - V_T) will decrease as the tool moves inward. For a substantial range of radii (R), a chosen optimum speed of cut cannot be maintained.

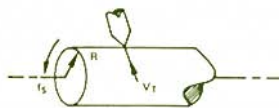


Figure 1. Relationship between cutting speed (V_T), radius (R), and spindle speed (f_S).

The relationship between cutting speed, radius, and spindle speed is a simple one.

$$V_T = 2\pi R f_S \quad (1)$$

In numerically-controlled lathes, where the cutting radius and spindle speeds are programmable, there is an opportunity to maintain a constant cutting speed by performing the simple computation required to determine the necessary spindle speed as a function of the radius. Equation (1) can be restated:

$$f_S = \frac{V_T}{2\pi R} \quad (2)$$

Thus, the required value of spindle speed is proportional to the ratio of cutting speed to radius.

One way of accomplishing this is shown in Figure 2, for a system in which the spindle speed is controlled by an analog voltage. Two modes of operation are available - programmed f_S and variable f_S . In the latter case, voltages derived from the digital control signals by two D/A converters are divided (Equation 2) by means of a wide-range multiplier-divider (model 433*), with a digitally-programmed scale factor. As the cutting radius changes during machining, the spindle slows down or speeds up to hold the cutting speed constant. ▶▶▶

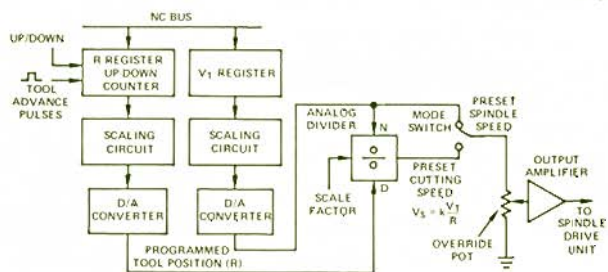


Figure 2. Block diagram of the spindle-speed control circuit. Output amplifier provides gain changing and polarity switching.

*Use the reply card to request information on the 433 and 434 wide-range multiplier-dividers.

HIGH-RESOLUTION SCALE Measures up to 250 lb ± 0.01 lb Detects a Single Bite of Food

by James Williams

At the M.I.T. Nutrition & Food Science Instrumentation Laboratory, a scheme that is straightforward in concept but exacting in execution has resulted in the development of a scale that is both accurate (needing no calibration long-term) and able to measure small increments of weight gain or loss (such as intake of food or loss of water through perspiration).

A carefully-designed nonlinear filter permits large changes of weight to be stably registered within 5 seconds, small changes within one second, and fast disturbances, such as body motions or the pulsation of blood with each heartbeat, to be rejected. (Interestingly, the raw measurement voltage can be filtered by a different scheme to provide a "ballistocardiographic" measure of pulse rate without any electrical connections to the subject*.)

As Figure 1 shows¹, the system consists of a high-linearity temperature-compensated bridge - excited by a floating 10.000V reference supply, a noninverting chopper-preamplifier, a level-controlled filter, and an AD2025† 4½-digit panel meter that permits weight to be read directly up to the system maximum of 250.00 lb, with a resolution of 0.01 lb (4.5g).

The weighing platform is supported by four symmetrically-disposed bonded strain gages, in a bridge configuration. The linearized low-level output is 15mV full-scale; 600nV (600 x 10⁻⁹ V) corresponds to 0.01 lb. To eliminate calibrations after installation the excitation voltage is based on a selected 1N829A that has been aged for 2500 hours, running at a precisely maintained constant current, and buffered from the ~100Ω load by a boosted AD504† low-drift op amp.

The bridge output, amplified by a 261† non-inverting chopper amplifier, is applied to a nonlinear filter that combines rapid slewing for weights greater than 4 lb. with a 1s-time-constant filter applied to small noise signals.

Because of the low levels, attention to grounding, shielding, and careful component selection are essential in order to obtain the specified performance of absolute accuracy to within 0.02% (0.05 lb.), repeatability and sensitivity of 40 ppm (0.01 lb.), operating temperature range 20° - 30°C, and no field adjustments. ▶▶▶

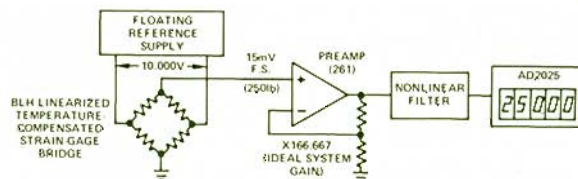


Figure 1. Block diagram of the weighing system.

¹The system is described in greater detail in an article appearing in EDN magazine (October 5, 1976, Vol. 21, No. 18).

*Patent applied for.

†For information on ADI products, use the reply card.

Across the Editor's Desk

LAST ISSUE OF *ANALOG DIALOGUE*
Volume 10 (1976), Number 1

Editor's Notes, Authors

- 13-Bit Monolithic CMOS A/D Converter (AD7550)
- Monolithic Sample-Hold Amplifiers (AD582, 583)
- Inductosyn-to-Digital Converters
- 10-Volt ($\pm 1mV$) Reference (AD2700, 2701, 2702)
- FET-Input IC Electrometers (AD515)

New Products:

- Low-Cost Chopper (235J/K/L)
- 6-Decade Log Ratio (757)
- 100kHz V/f Converters (452J/K/L)
- Three More "2nd-Generation" DPM's (AD2016, 2025, 2028)

Application Briefs:

- Simple Rules for Choosing Resistor Values in Adder-Subtractor Circuits
- D/A Conversion with Single-Supply Circuit
- Differential High-Impedance rms-to-dc Conversion
- Audio Applications Ideas for CMOS DAC's

Potpourri: More Authors, HP-25 Resistance-Computation Program for Adder-Subtractor Circuits, etc.

Worth Reading: Book Review (Operational Amplifiers - Roberge), Last Issue of *Dialogue*, Erratum

ERRATUM: Page 4, Figure 4. A set of parallel connections from the MN74C928's a, b, c, d, e, f, g terminals to the display via resistors has been omitted. ▶▶▶

MORE AUTHORS

(continued from page 2)

Jack Memishian (page 12) is Senior Project Engineer at ADI's Modular Instrumentation and Systems Group, designing interfaces between analog and digital worlds. Before joining Analog, he spent a number of years at Raytheon, designing fast analog computers. He has a B.S. from M.I.T., holds one patent, another in progress.



Wayne Marshall (page 12) is no longer at Analog Devices. His photo can be found in *Dialogue* 5-3.

Will Ritmanich (page 14), Applications Engineer at Analog Devices Microsystems, appeared in *Dialogue* 10-1.

James Williams (page 17) has been involved in biomedical research and teaching at M.I.T. since 1971. He also is co-owner of Consultek, a Wellesley, Mass., consulting firm and is active in several companies. The sensitive scale is one of a number of unusual high-resolution projects he has worked on. He studied psychology at Wayne State University.



EVERY LITTLE BIT COUNTS

There is a misprint in the article "13-Bit Monolithic CMOS A/D Converter" (*Dialogue* 10-1, page 5) regarding 2's-complement code. As implemented in the AD7550, the negative range includes one more code of LSB weight than the positive range, so that the largest negative number is 1 0000 0000 0000, not 1 0000 0000 0001. For example, with a reference of 4.250V, the full-scale analog input range is from $2(1 - 1/4096)$ to -2.000V, represented by the 8192-code binary range from 0 1111 1111 1111 through 0 (all zero's) to 1 0000 0000 0000. Input voltage exceeding these limits by $1/2$ LSB will produce a full-scale code and set the overrange bit. (See Figure 6, page II-19 of the *Analog-Digital Conversion Handbook*.)¹

Dennis Langley
Senior Project Engineer
Analog Devices Microsystems

The rule for forming 2's complement arithmetically is "complement every bit and add 1LSB".^{1,2} If we complement the largest positive number, 0 1111 1111 1111, and add 1, we obtain 1 0000 0000 0001. Since there is no larger positive number, there is no way, arithmetically, within the 13-bit constraint, of generating 1 0000 0000 0000 as an unambiguous 2's-complement number (note that the 2's complement of 1 0000 0000 0000 is itself). Nevertheless, as you accurately indicated, it is a point on the conversion continuum and is available at the AD7550's output for full-scale negative signals. Page II-21 of the *Analog-Digital Conversion Handbook* notes (with allowances for the differences between offset binary and 2's complement): "The . . . negative full-scale code (1000 . . .), though not used in computing, . . . is nevertheless useful as a converter-checking and -adjustment code."

-Ed

. . . [True! But,] regarding the utility of the negative full-scale code, it seems to me that the above discussion applies to computing systems limited to 13 bits, a rather rare situation. A 16-bit system (double-precision in an 8-bit microprocessor) would propagate the sign bit left to bit 7 of the high byte. Thus, for negative full-scale, the code, in two bytes, would be 1111 00000000 0000. If we take the 2's complement, the result is 0001 00000000 0000, so that negative full-scale is indeed a unique and computationally-useful number.

Dennis Langley

Touche!

-Ed ▶▶▶

Bill Hungerford (page 17) is working on the design and application of Numerical Control Systems at Bendix Industrial Controls Division. After receiving an MSEE degree from Wayne State University, in Detroit, he joined Bendix as a Product Engineer. His job includes the design of control features for machine tools, such as the one described.



¹ *Analog-Digital Conversion Handbook*, D. H. Sheingold, ed., Analog Devices, 1972, page II-22.
² *Minicomputers for Engineers and Scientists*, G. A. Korn, McGraw-Hill, 1973, page 11.

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

NEW PRODUCTS , , , Model 277 Isolated Operational Amplifier: It features $1\mu\text{V}/^\circ\text{C}$ max drift, 160dB min CMR, $\pm 3500\text{V rms CMV}$, and floating power output of $\pm 15\text{mA}$ @ $\pm 15\text{V}$. Use it for current-shunt measurements, isolated excitation and conditioning for bridge measurements, etc. . . . Two new F/V Converters (451 -- 10kHz, 453 -- 100kHz), now in stock, convert a wide range of input waveforms into a voltage output (+10V F.S.) that is proportional to frequency. Pin-compatible with popular competitive modules, at an attractive price (\$35, \$36, in 100's). . . 442J/K/L Wideband High-Accuracy True-rms-to-dc Converters are now available from stock. Max error untrimmed is $\pm 2\text{mV} \pm 0.15\%$ of reading (all versions), can be trimmed to $\pm 1\text{mV} \pm 0.05\%$ of reading. Bandwidth (-3dB) is 8MHz, accuracy to within 0.5% for crest factors up to 10 . . . The AD7531 Low-Cost Monolithic 12-Bit CMOS D/A Converter is available with 8, 9, or 10-bit linearity, gain tempco of $10\text{ppm}/^\circ\text{C}$, settling time 500ns for all-1's-to-all-0's, and analog feedthrough less than $\frac{1}{2}$ LSB at 50kHz. It's a low-cost version of the AD7521. . . Two new Synchro-to-Digital Conversion products: The low-cost SDC1786 is a 10-bit tracking s/d converter, similar to the SDC1603 but with improved specs (and only \$199, 1-49) . . . The SCM1677 Sine/Cosine Module is a digital-angle to digital-sine/cosine converter.

NEW LITERATURE , , , The 20-page Designer's Guide to Digital Panel Meters, mentioned in a footnote in the last issue, is still available, free A short-form catalog, IC's for Precision Measurement and Control, is available upon request A 42-page booklet, Applications of Synchro-to-Digital Conversion, is available free as long as the supply lasts.

PRODUCT NOTES , , , The 942/943 dc-to-dc Converters, mentioned in this issue (page 16), can be used as either positive or negative logic supplies, just depends on your choice of output terminal to ground. No ill effects, since they're isolated. . . . A number of 2V DPM's are available with built-in 10:1 attenuators, for a 20V full-scale input range, a "V" option; for information on available types, request the DPM Short-Form Guide. . . . A new version of the AD2008 Digital Panel Meter is the /S option, with a full-scale range of 199.99mV and resolution of $10\mu\text{V}$ If you have the AD2008 data sheet, this may interest you: An "Addenda" sheet to accompany the AD2008 data sheets contains errata and significant information of interest (including the /S option). . . . There are some new tempco specs for the DAC1132, which will appear on a revised data sheet: Gain— $\pm 8\text{ ppm}/^\circ\text{C}$ ($\pm 15\text{ ppm}/^\circ\text{C}$ max), Unipolar offset— $\pm 5\text{ ppm}/^\circ\text{C}$ ($\pm 20\text{ ppm}/^\circ\text{C}$ max), Bipolar Offset— $\pm 8\text{ ppm}/^\circ\text{C}$ ($\pm 25\text{ ppm}/^\circ\text{C}$ max) An "Errata and Addenda" sheet for the AD7550 13-Bit Monolithic CMOS A/D Converter is now available upon request. It contains some important items of information, including revised ratings, e.g., V_{DD} range (+10V to +14V), V_{SS} range (-5V to -14V).

OTHER NOTES , , , All GSA Contracts held by Analog Devices have been renewed (see Dialogue 9-3, page 23). For an attachment to update your Analog Devices catalog or product file with contract numbers, renewal periods, applicable discounts, and other pertinent information, write on letterhead, if your group is authorized to purchase on GSA contracts. . . . A number of our monolithic IC's are available in chip form (in quantity) for commercial or military applications. Consult your local ADI Sales office.

IN THE NEXT ISSUE , , , Converter-microprocessor circuits . . . Versatile Multiplier/Divider . . . Integrated-circuit A/D and D/A converters . . . monolithic RMS.

A lot of people's V/F-F/V Converters are pin compatible.

COMPETITIVE ANALYSIS SUMMARY

For Field Sales Personnel
J. P. Maxwell - 5/3/76

		V/F - F/V CONVERTERS				Comments
Competition	ADI Model	Price (\$1-9) ADI/Brand X	Linearity (ppm) ADI/Brand X	Gain Drift (ppm/°C) ADI/Brand X	Offset Drift (µV/°C) ADI/Brand X	
			300/1000	120/150	100/100	ADI clear winner! Price and performance.
Brand A	456J 10kHz, V/F	29/39, 50				Brand A has degraded linearity for low level signals.
Brand A	456K 10kHz, V/F	34/53, 50	200/500	80/100	100/100	Brand B has non-standard pin-out. ADI clear winner.
Brand B	450J 10kHz, V/F	37/55	100/500	50/100	50/100	Brand C in large 2" x 2" package vs. ADI 1.5" x 1.5" with superior linearity.
Brand C	450K 10kHz, V/F	45/53	50/100	25/20	20/20	Save 38% with ADI, and get 40% better linearity.
Brand A	452K 100kHz, V/F	49/70	150/250	100/100	30/30	Save 46% with ADI.
Brand B	452J 100kHz, V/F	39/75	150/150	150/150	30/100	Brand D in large 2" x 2" box and costs more.
Brand B	452K 100kHz, V/F	49/69	150/500	100/100	30/30	Brand A price is 37% higher. Upgrade to ADI "K" version for twice the performance at only \$45.
Brand A	451J 10kHz, F/V	39/53, 50	300/300	100/100	30/50	Brand C has better gain drift but needs 10% more real estate.
Brand C	451L 10kHz, F/V	55/51	80/100	50/30	30/30	Brand A has better gain drift. Otherwise ADI is superior and costs 48% less.
Brand A	453K 100kHz, F/V	45/79	150/200	50/44	30/50	Brand C has edge on drift. ADI leads in linearity, price, size.
Brand C	453L 100kHz, F/V	55/81	80/100	50/30	30/20	Unbelievable... Brand D has no signal conditioning capability so users must convert signals to pulse... and still pay 77% more.
Brand D	453J 100kHz, F/V	39/69	300/500	100/100	30/30	

How about their price and performance?



All V/F-F/V Converters are not created equal. You shouldn't have to sacrifice performance for price. Or vice versa.

That's why Analog Devices created a family of V/F-F/V Converters that are completely pin compatible with greater performance, higher reliability and lower price than any on the market.

They are more versatile, less susceptible to noise and offer low non-linearity and excellent stability over the temperature range. They're available in three convenient full scale frequency ranges of 10kHz, 20kHz and 100kHz to perform accurate analog measurements while directly interfacing with digital circuits.

For all general purpose applications the Model 450 V/F can achieve 0.01% (13-bit) accuracy over the 1mV to +15V signal range. Model 454 V/F accepts 0 to +20V or 0 to .67 mA inputs and can be operated with bipolar signals up to ±10V. Model 456 V/F

offers the lowest cost for applications requiring 0.1% (10-bit) accuracy. Model 452 V/F is a low cost 100kHz converter that offers resolution of better than 16 bits and low non-linearity error of 0.025% max. over 120 dB signal range.

For low cost interfacing to a wide variety of frequency transducer signals — such as pulse type tachometers, magnetic pick up coils, flow meter outputs — our family of 10kHz F/V converters, Models 451J/K/L, and 100kHz F/V converters, Model 453J/K/L, offer excellent application versatility. Best of all, our V/F-F/V are available at the lowest prices around, starting at just \$25 in 100's.

Find out how the Analog Devices family of V/F-F/V Converters can give you the best of everything. The best performance. The best price. The best answers to your application problems. Write Analog Devices, the real company in precision measurement and control.



The real V/F Converter company.

Analog Devices, Inc., Norwood, Massachusetts 02062
 East Coast: (617) 329-4700, Midwest: (312) 894-3300, West Coast: (213) 595-1783, Texas: (214) 231-5094, Belgium: 03 38 27 07, Denmark: 97 95 99, England: 01/94 10 46 6, France: 686-77 60, Germany: 089/53 03 19, Japan: 03/26 36 82 6, Netherlands: 076-122555 and representatives around the world.