Increase your design options with analog-MUX ICs

Useful for more than commutating analog signals in data-acquisition systems, multiplexer ICs can also provide alternative and often superior solutions to many design problems. Applications range from servo positioning to waveform synthesis.

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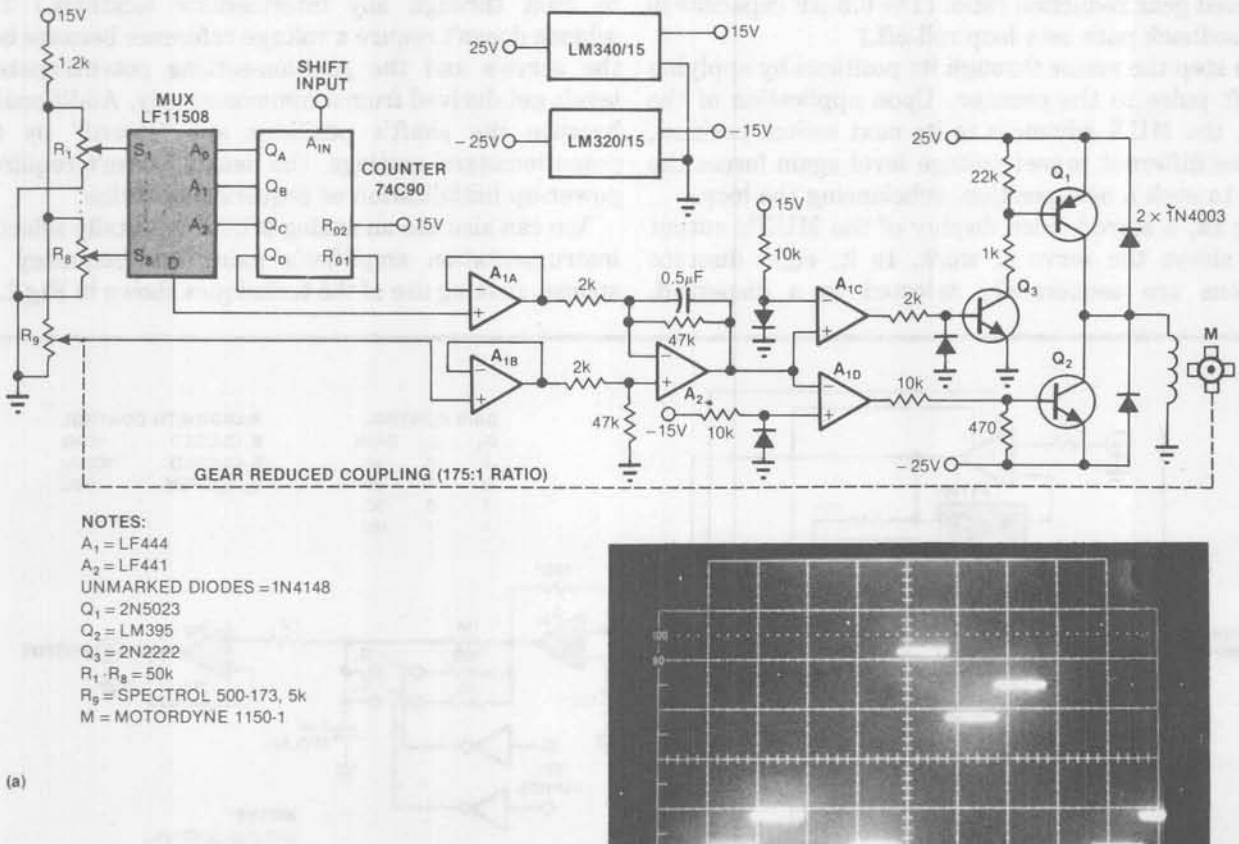
An analog data-multiplexer (MUX) IC's capabilities provide you with an additional tool for solving a range of diverse design problems. These features—fast multipole switching, high input-to-output isolation and direct digital interfacing—allow you to achieve some interesting and useful circuit realizations.

The design shown in **Fig 1**, for example, uses an 8-pole MUX in an arrangement that permits setting a servomotor in any of eight predetermined positions. You can preset these positions—via potentiometers R_1



NOTES:
A_1 = LF444
A_2 = LF441
UNMARKED DIODES = 1N4148
Q_1 = 2N5023
Q_2 = LM395
Q_3 = 2N2222
R_1-R_8 = 50k
R_9 = SPECTROL 500-173, 5k
M = MOTORDYNE 1150-1

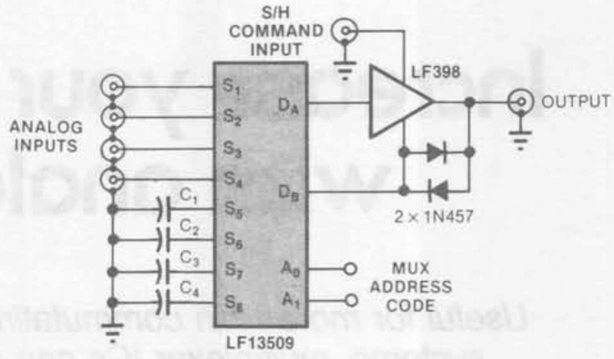
(a)

(b)

VERTICAL 2V/DIV
HORIZONTAL 200 mSEC/DIV

Fig 1—A servomotor's shaft position *settles into one of eight MUX-selected locations when a motor-driven potentiometer (R_9) balances out the addressed potentiometers' (R_{1-8}) preset level* ***(a).*** *Driven by a Shift pulse* ***(b),*** *the counter sequentially selects—via the MUX—each reference voltage.*

Analog-multiplexer ICs steer servomotors to random positions



CAPACITOR	ACQUISITION TIME TO 0.01%	DROOP RATE (V/SEC)
C_1 1000 pF	10 µSEC	30 mV
C_2 0.01 µF	25 µSEC	3 mV
C_3 0.1 µF	300 µSEC	300 µV
C_4 1 µF	3 mSEC	30 µV

Fig 3—A multiplexer selects this sample/hold amplifier's 1-of-4 inputs *and its acquisition time. Requiring only a 2-bit address, the 4-channel MUX can apply any hold capacitor to any input signal.*

through R_8—and then sequentially home the motor in. And because the drive circuits are complementary, the motor can run bidirectionally.

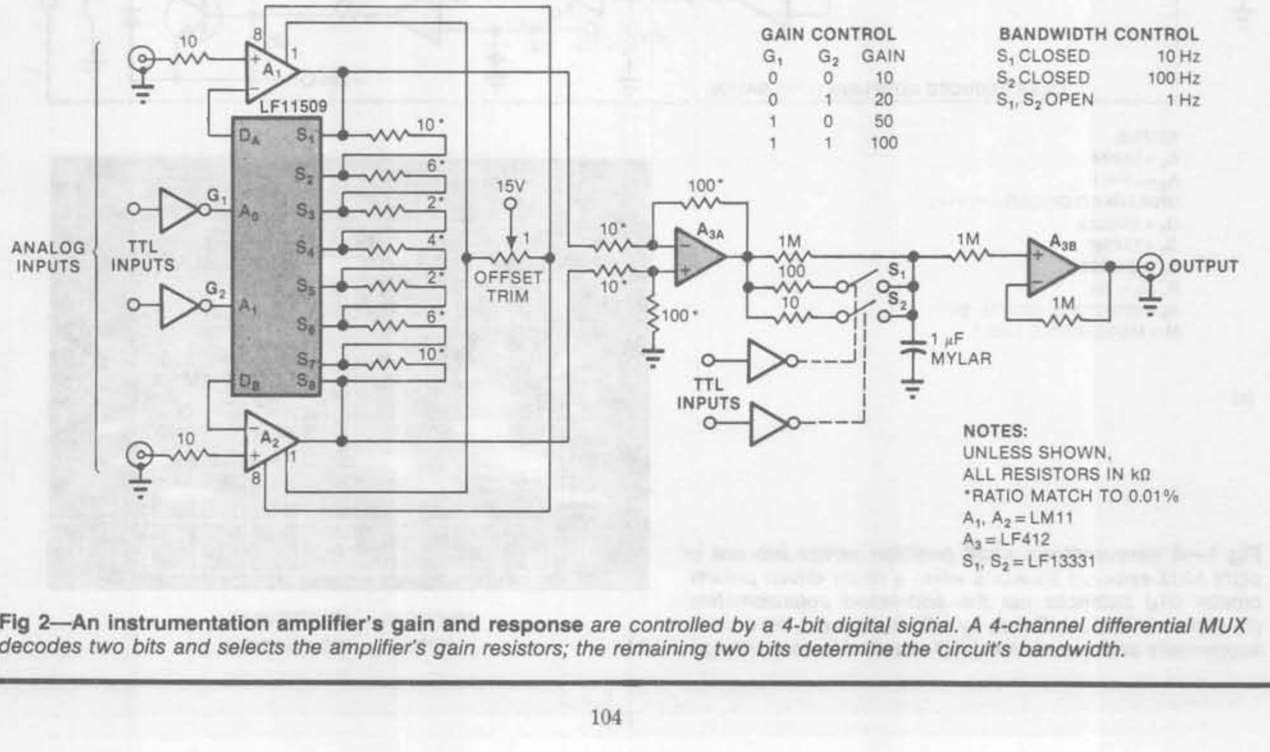
Assume power has just been applied and the counter's output is 0000. This all-ZERO input to the MUX closes its first switch (S_1) and feeds R_1's wiper voltage into the feedback loop. The potential difference between R_1's output and the servo potentiometer's (R_9) gets amplified by A_{1A} and A_{1B} and fed to A_2. This stage algebraically sums the signals and drives A_{1C} and A_{1D}, amplifiers configured as a dual limit comparator with deadband. Depending on A_2's output polarity, the appropriate comparator outputs a high-level voltage and turns its associated driver on. This action in turn drives the motor in the direction necessary to force a null at A_2's output. When that output falls within the diode-generated 0.6V deadband, both comparators' outputs drop LOW, and the motor stops.

A_2 operates at a gain of 30 and thus provides adequate sensitivity for precise positioning. Good loop dynamics result from using ±25V supplies and the indicated gear reduction ratio. (The 0.5-µF capacitor in A_2's feedback path sets loop roll-off.)

You step the motor through its positions by applying a Shift pulse to the counter. Upon application of the pulse, the MUX advances to its next switch position, and the different preset voltage level again forces the servo to seek a new position, rebalancing the loop.

Fig 1b, a stored-trace display of the MUX's output port, shows the servo at work. In it, eight discrete positions are sequentially selected in a dispersed, nonmonotone fashion. (Note how you can attain any desired positioning sequence without requiring the loop to hunt through any intermediate locations.) This scheme doesn't requre a voltage reference because both the servo's and the position-setting potentiometers' levels get derived from a common supply. Additionally, because the shaft's positions are "stored" by the potentiometers' settings, the design doesn't require a power-up initialization or sequencing routine.

You can also use an analog MUX to digitally select an instrumentation amplifier's gain and frequency response, making use of the techniques shown in **Fig 2.** In



GAIN CONTROL

G_1	G_2	GAIN
0	0	10
0	1	20
1	0	50
1	1	100

BANDWIDTH CONTROL

S_1 CLOSED	10 Hz
S_2 CLOSED	100 Hz
S_1, S_2 OPEN	1 Hz

NOTES:
UNLESS SHOWN,
ALL RESISTORS IN kΩ
*RATIO MATCH TO 0.01%
A_1, A_2 = LM11
A_3 = LF412
S_1, S_2 = LF13331

Fig 2—An instrumentation amplifier's gain and response *are controlled by a 4-bit digital signal. A 4-channel differential MUX decodes two bits and selects the amplifier's gain resistors; the remaining two bits determine the circuit's bandwidth.*

this approach, a 4-channel differentially switched MUX selects the feedback resistors for the design's input stages, A_1 and A_2. These stages' differential outputs get summed and amplified at a gain of 10 by A_{3A}. The resultant single-ended signal feeds an RC low-pass network consisting of 1-of-3 switch-selected resistors and a 1-μF capacitor. The final stage (A_{3B}) functions as an output buffer.

Thus, with a 4-bit digital signal, you can determine the amplifier's gain and response; two bits set the gain and the remaining two set the response as shown in **Fig 2**'s tables. You can realize true instrumentation-amplifier performance by using LM11s for A_1 and A_2; circuit drift then remains within 2 μV/°C, and you can achieve a CMRR of 100 dB with 0.01% resistor matching.

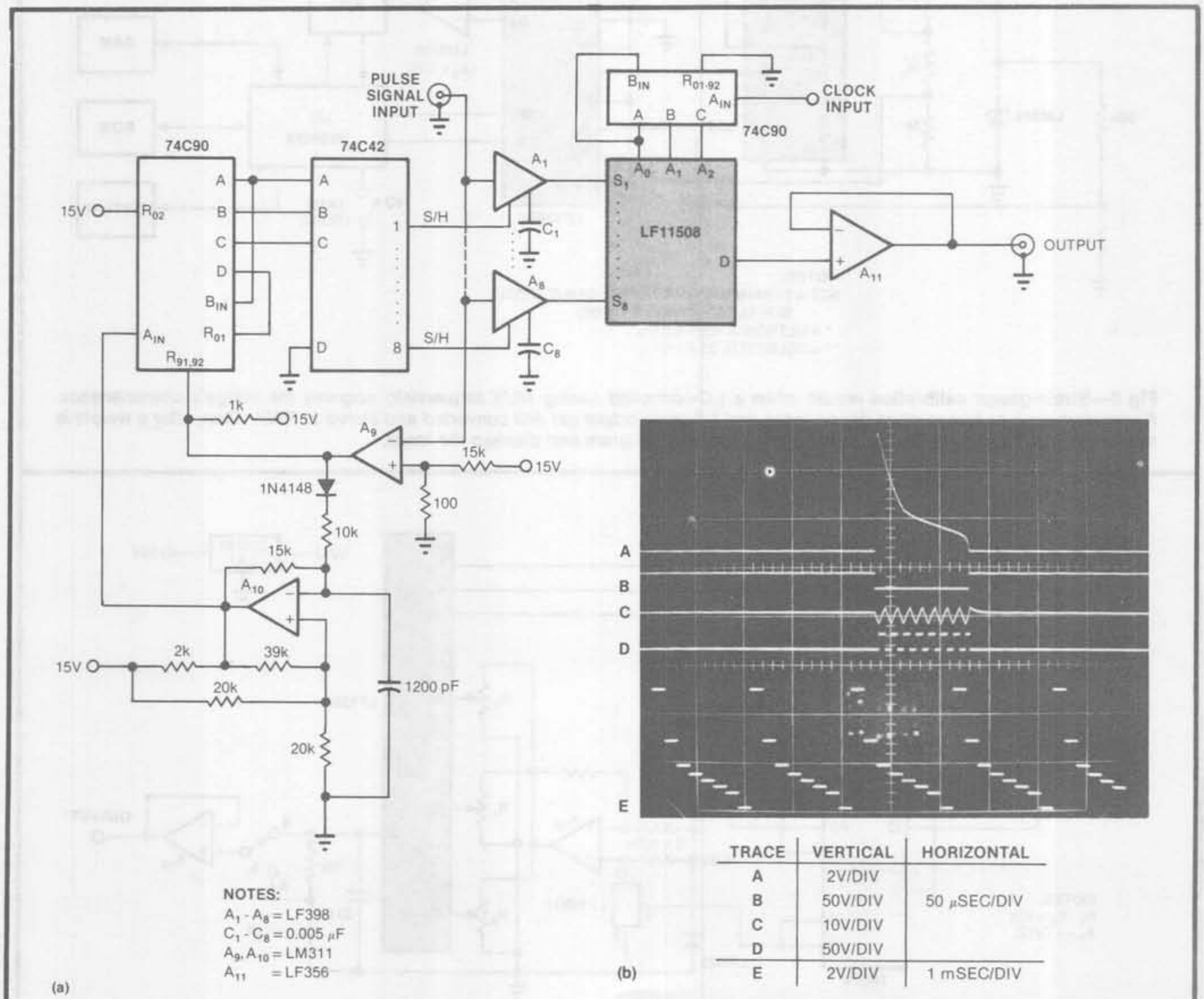
MUX a S/H amplifier for variable performance

Another analog-MUX application occurs when you're using sample-and-hold (S/H) amplifiers, which are usually constrained to processing a single input signal over a limited range of acquisition times and droop rates. The MUX-based design shown in **Fig 3** not only accepts any of four inputs, it also provides a wide range of acquisition and droop options.

This approach employs a 4-channel differential MUX to sort out the input and hold-capacitor options; half of the MUX selects the desired input, and the other half determines the in-circuit hold capacitor's value. Because any address code simultaneously selects the corresponding switches in both halves of the MUX, you can use any desired hold capacitance for any input.

A flash sampler captures single events

Fig 4a illustrates a technique for using analog MUXs for capturing single-shot or low-repetition-rate waveforms and then repetitively displaying the signal on an oscilloscope. It doesn't require a pretrigger signal because the input signal itself initiates the sampler



NOTES:
A_1 - A_8 = LF398
C_1 - C_8 = 0.005 μF
A_9, A_{10} = LM311
A_{11} = LF356

TRACE	VERTICAL	HORIZONTAL
A	2V/DIV	
B	50V/DIV	50 μSEC/DIV
C	10V/DIV	
D	50V/DIV	
E	2V/DIV	1 mSEC/DIV

Fig 4—This flash-sampler design (a) *captures single-event signals and provides an instant and repetitive scope display. An incoming signal (***(b), trace A)** *triggers* **A_9 (B)**, *resets the counter and starts the oscillator* **A_{10} (C)**. *A_{10}'s output* **(D)** *drives the counter that sequentially addresses the sampling amplifiers, A_1 through A_8. A clocked counter then steps through the MUX's switches and reconstructs the sampled input* **(E)**.

An analog flash converter can provide an instant signal replay

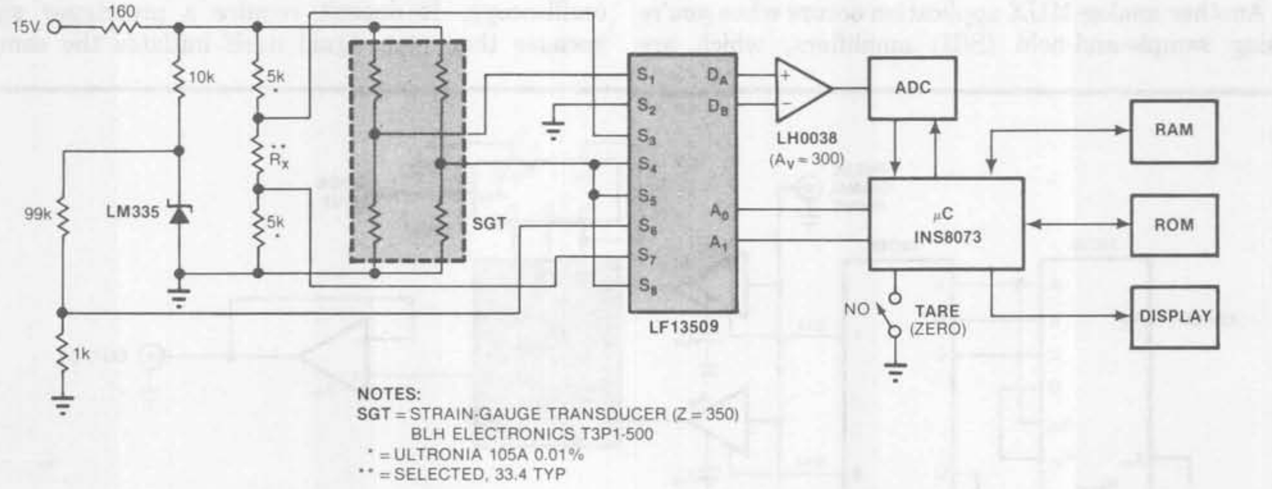
string. And because the circuit's output is independently clocked, you can vary the scope's display rate to suit your requirements.

An incoming signal (**Fig 4b,** trace **A**) triggers comparator A_9 LOW, as shown by trace **B.** This action allows A_{10}'s 15-kΩ/1200-pF combination to start charging (**C**); as a result, A_{10} outputs a pulse train (**D**). Advanced in count by these pulses, the counter's BCD-encoded output gets decoded by the 74C42 and is used to sequentially drive the eight paralleled sample/hold amps (A_1 through A_8). In this manner, each S/H stage acquires a fraction of the input signal.

When the input signal ceases, A_9's output again goes HIGH, A_{10} no longer generates pulses and the sampling procedure stops. To display the stored waveform, enable the clock input to the MUX-controlling counter. The counter's outputs sequentially address the MUX's switches, and stored signal segments go to the output buffer (A_{11}). Trace **E** demonstrates how you can repetitively display the reconstructed waveform at a rate governed by the clock's frequency.

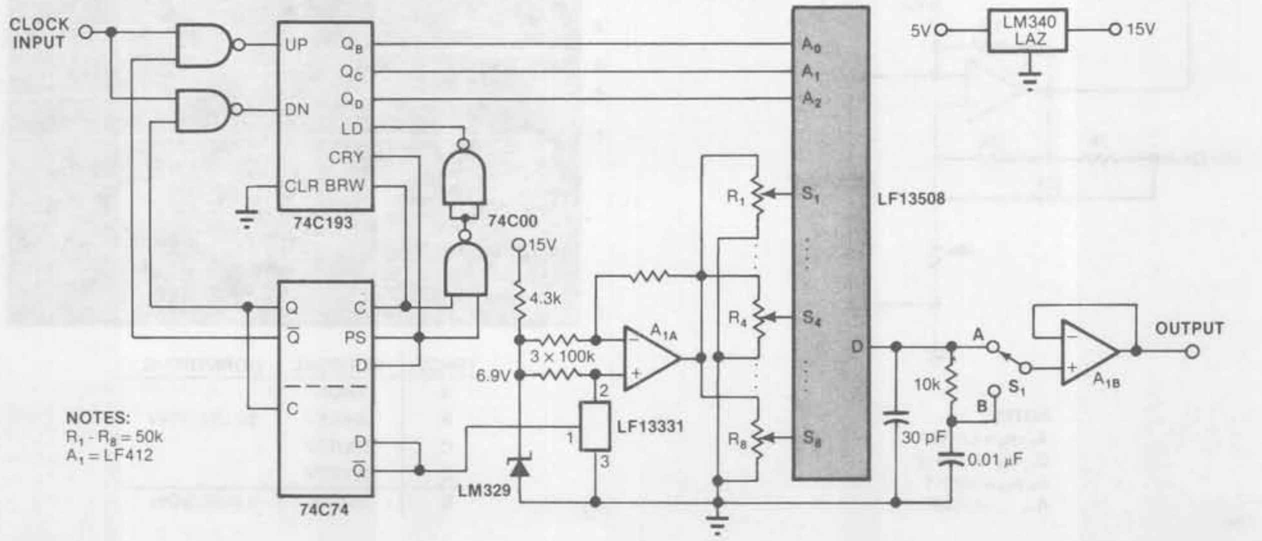
A μC-driven MUX calibrates strain gauges

Fig 5's design shows how you can use a MUX to realize an autocalibration arrangement that eliminates



NOTES:
SGT = STRAIN-GAUGE TRANSDUCER (Z = 350)
BLH ELECTRONICS T3P1-500
* = ULTRONIA 105A 0.01%
** = SELECTED, 33.4 TYP

Fig 5—Strain-gauge calibration *results when a μC-controlled analog MUX sequentially acquires the bridge's characteristics. Parameters such as temperature dependence and full-scale output get A/D converted and stored in RAM. Then, after a weight is measured and converted, the μC runs a correction-factor program and displays the result.*



NOTES:
R_1 - R_8 = 50k
A_1 = LF412

Fig 6—A programmable waveform *is created when a counter-driven 8-channel MUX samples preset potentiometers. When clocked, the counter counts up and then down and in the process switches the amplifier's input between 6.9V and ground. This action permits the amplifier to synthesize both the positive- and negative-going portions of the waveform, as shown in* **Fig 7.**

almost all of the errors inherent in strain-gauge load-cell transducer measurements. Errors arising from drift over time and temperature are cancelled, and you can interchange transducers without having to rezero or recalibrate the circuit's gain. This design performs four separate operations to determine the factors necessary for correcting transducer output.

The measurement cycle commences when the μC switches the MUX into position 1. This action connects the strain gauge's output to the instrumentation amplifier. After amplification, the analog signal gets converted to a digital equivalent and stored in the RAM. When advanced to position 2, the MUX acquires the output of the load-cell-mounted LM335 temperature sensor. This value is also amplified, converted and stored in memory. (Note that the LM335's high output must be divided to prevent saturating the amplifier.)

The load cell's precise full-scale output voltage gets acquired when the MUX is in position 3 and connected to R_X, the cell-mounted resistor. By making this data inherently available with each cell, the system can ascertain (and correct for) the cell's gain slope. This capability eliminates the need for recalibration whenever you change cells. Position 4 provides the system with an electrical zero by connecting both of the amplifier's inputs to the bridge's common-mode point.

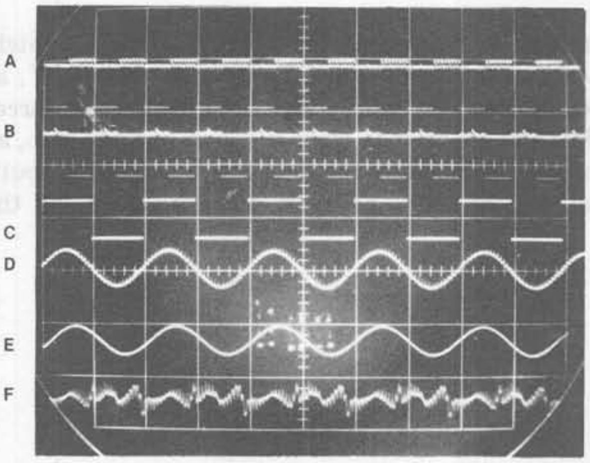
Physical-zero information (ie, tare (container) weight) is fed to the μC when you operate the pushbutton with no load on the cell. (You must perform this operation only when the system is turned on or after a different cell has been connected.) The system's memory then holds values for zero, the loaded bridge's output, its full-scale output and its temperature. Additionally, a tare-weight value has been determined. Using this data, the μC's program can calculate the strain gauge's precise loading regardless of drifts or the cells' individual gain-slope characteristics.

The temperature information provides a first-order correction factor for the relatively small effect that ambient temperature has on gain slope and zero. The bridge's voltage needn't be stabilized because it's common to the gain-calibration string and therefore ratiometrically cancels. In fact, the system's stability is governed solely by the stability of the gain-calibration string's resistors. MUX-controlled systems of this type achieve repeatability of one part in 20,000 in industrial environments.

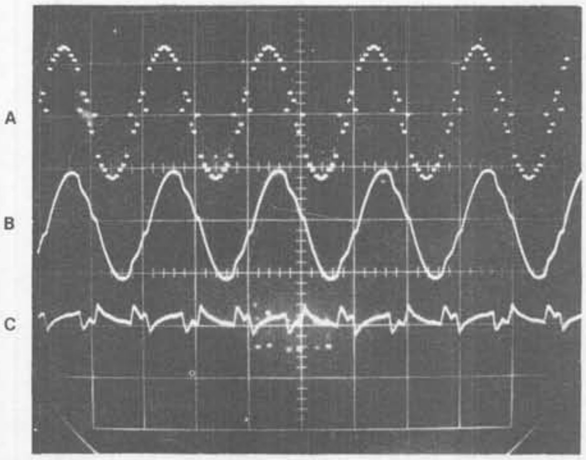
Switched resistors generate waveforms

Fig 6 diagrams how you can use an 8-channel MUX to generate a 32-piece approximation of any desired waveform—a sine wave demonstrates the approach. When clocked, the logic circuits combine to force the MUX to count up to eight. (The counter's Up/Down control inputs appear as traces **A** and **B** in **Fig 7**'s top photo.) When this operation is completed, the MUX counts down to zero and resamples the potentiometers' settings in the process. These two cycles create the positive half of the output's waveform.

The logic next inverts the potentiometers' voltage by



TRACE	VERTICAL	HORIZONTAL
A	5V/DIV	
B	5V/DIV	
C	20V/DIV	500 μSEC/DIV
D	20V/DIV	
E	20V/DIV	
F	0.5V/DIV	



TRACE	VERTICAL	HORIZONTAL
A	5V/DIV	
B	5V/DIV	500 μSEC/DIV
C	0.5V/DIV	

Fig 7—Waveform synthesis *proceeds when* **Fig 6**'s *counter cycles through its first up/down sequence (top, traces* **A** *and* **B***). After this sequence, the D flip flop's Q output drives the amplifier's input (and therefore its output) LOW* **(C)***. The counter/MUX combination recycles through the up/down sequence and creates the negative half of the waveform. The unfiltered* **(D)** *and filtered* **(E)** *outputs indicate how well a sine wave can be synthesized. This 32-step approximation results in a distortion level of less than 0.5%* **(F)***. The bottom photo depicts how you can intentionally distort a waveform: The unfiltered* **(A)** *and filtered* **(B)** *outputs indicate that trace* **C**'s *7% distortion is easily achieved.*

MUXing a strain-gauge bridge relieves recalibration pains

grounding A_{1A}'s + input via an LF1331 FET switch. This action forces the amplifier's output to −6.9V, as shown by trace **C**. Concurrently, the logic again forces the MUX to count up to eight and back down to zero, an action that synthesizes the negative half of the output's waveform. At the conclusion of these 32 counts, the logic resets, A_{1A}'s output switches to a 6.9V level and the entire cycle repeats.

When appropriately set, the potentiometers can provide the correct levels for synthesizing a sine wave, as shown by trace **D**. When filtered, this signal **(E)** contains less than 0.5% distortion **(F)**. As the bottom photo in **Fig 7** shows, you can intentionally distort the output by resetting the potentiometers. Trace **A** displays the 32-piece approximation of the distorted signal, and **B** shows the filtered version. A distortion analyzer's output signal **(C)** indicates a 7% distortion level. **EDN**