Exploit D/A converters in unusual controller designs

More than just a data manipulator, a multiplying DAC simplifies designs such as scanner positioners, temperature regulators and electronic locks.

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Employing multiplying digital-to-analog-converter (MDAC) ICs in other-than-standard data-handling tasks allows you to control many diverse—and difficult-to-interface—analog functions. MDACs such as the 12-bit DAC1218 and the 10-bit DAC1020 provide features that bring digital accuracy to familiar control chores involving temperature, voltage and vibration.

Digitally position mechanical scanners

Consider, for example, the use of these devices in the scanning-electrophoresis technique that biochemists employ to separate unidentified cells or molecular structures from each other. In one form of this process, a motor-driven scanner examines a sample suspended in a suitable liquid and contained within a glass or quartz tube approximately 1 ft long. A high voltage applied along the tube's length separates the cells according to their charge gradient, resulting in a series of bands within the tube where like cells collect. Photometrically scanning the tube's length, noting the bands' distances from a reference point and matching these locations against the potential's gradient, accomplishes cell identification.

The key to this technique lies in the scanning process:

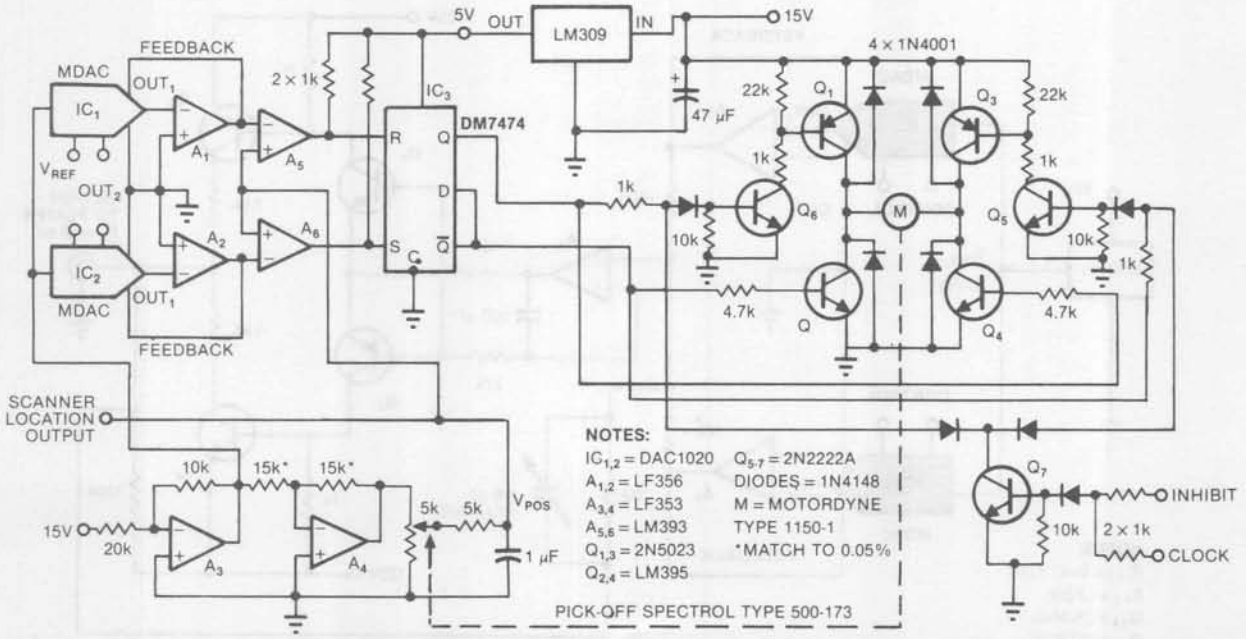


Fig 1—Digital words *determine a motor-driven scanner's excursion limits via a dual-MDAC-controlled transistor-bridge drive scheme. Two comparators (A_5, A_6) match a motor-position analog voltage (V_{POS}) with the MDAC's outputs and set or reset flip flop IC_3 accordingly. When the flip flop is set, for example, its Q output goes HIGH and turns transistors Q_1 and Q_4 on until V_{POS} is nulled.*

Digital-to-analog converters provide biochemical controls

Ideally, both the scanner's speed and the minimum and maximum scan length should be programmable. In Fig 1's approach, MDACs establish the scanner's travel limits via two sets of digital input codes. The scanner's motor drives a pick-off potentiometer, providing an analog voltage proportional to the scanner's position. This signal in turn feeds limit comparators A_5 and A_6, driving one of these device's outputs HIGH when either the high (A_5 and IC_1)- or low-position limit (A_6 and IC_2)

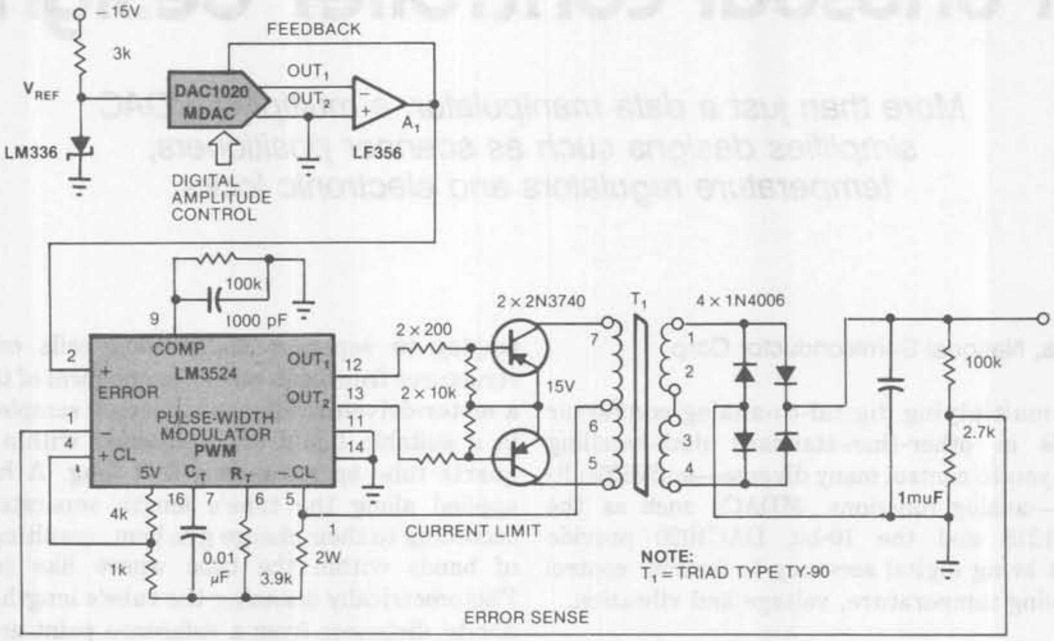


Fig 2—A settable output voltage *results when an MDAC controls a pulse-width modulator's input reference voltage. Overcurrent protection occurs when the voltage to the PWM's −CL input exceeds its +CL reference.*

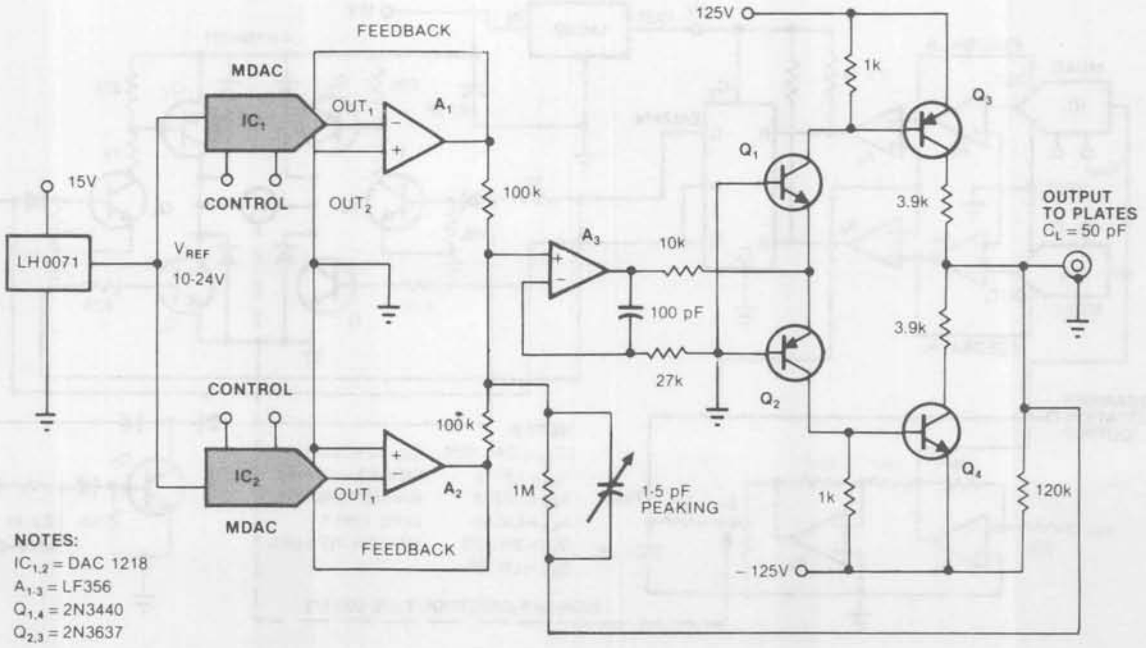
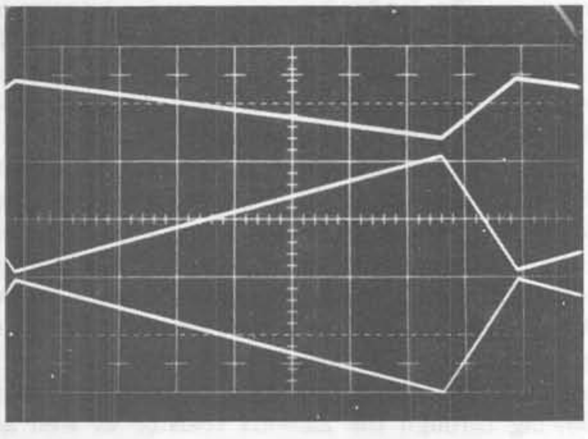


Fig 3—Dual MDACs *provide both dc and ac output voltages when driving a complementary transistor pair. A fixed digital code controls one MDAC to set the dc level; the other MDAC generates the ac component when its digital inputs are varied.*

is exceeded. (A_1 and A_2 serve as current-to-voltage converters, while A_3 and A_4 establish the feedback loop's reference voltages.)

When the scanner reaches a limit condition, these limit comparators set (S) or reset (R) flip flop IC_3; the resulting HIGH Q or $\bar{Q}$ output switches a transistor bridge on in a direction that reverses the motor's rotation. Thus, the scanner's motor bidirectionally runs the photometer head between the encoded scan limits.



TRACE	VERTICAL	HORIZONTAL
TOP	10V/DIV	
MIDDLE	100V/DIV	50 μSEC/DIV
BOTTOM	100V/DIV	

Fig 4—An ac-driven MDAC *generates these CRT deflection voltages using the scheme shown in* ***Fig 3.*** *Buffer amplifier A_1's output (top) can be converted to a high-voltage complementary (middle) or in-phase equivalent (bottom) waveform.*

Q_7 and its associated diodes control the motor's speed. When both Inhibit and Clock inputs are LOW, Q_7 is OFF and the flip flop's Q and $\bar{Q}$ signals can drive Q_5 and Q_6. However, if either Inhibit or Clock is HIGH, Q_7 turns on and shunts the drive signals to ground. You can employ a μC to generate all the scanner's control functions. For example, using a software-generated pulse-width-modulated signal as the clock allows you to dynamically alter the scanner's speed to run rapidly across distances where there aren't cell bands and slowly where there are. Similarly, you can use software to set the scan limits to home in on a cell-populated portion of the tube.

5V logic sets high-voltage levels

MDACs can control high-voltage sources as well as scanner positioners. Consider, for example, **Fig 2**'s circuit, which serves as a digitally controlled 15 to 100V supply suited to automatic-testing applications. This circuit couples a pulse-width-modulator (PWM)-driven push/pull voltage-converter stage with an MDAC in a feedback loop. The MDAC, in conjunction with A_1, establishes the PWM's setpoint voltage. The PWM in turn drives the transistors and—via the step-up transformer—converts the 15V to as much as 100V.

The transformer's square-wave output gets rectified, filtered and divided down by the resistor string. The resulting voltage level feeds back to the PWM's error amplifier, completing the control loop. You set the loop's gain and frequency characteristics with the 1000-pF/100-kΩ pair. Short-circuit protection results

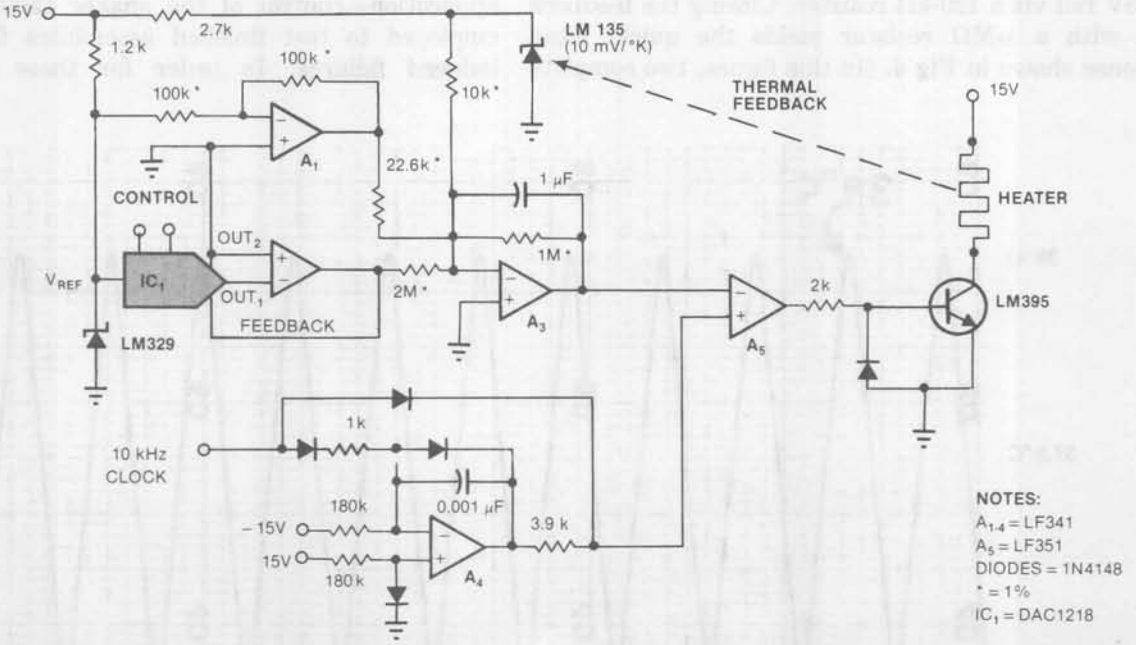


Fig 5—Precise temperature excursions *result when A_3 sums an MDAC-generated triangular waveform with A_1's fixed reference and the LM135's temperature-dependent signal. A_4 pulse-width-modulates the resulting error voltage and controls the heater's ON time.*

when the IR drop across the 1Ω resistor exceeds the 1V reference at the PWM's +CL input. (For a complete discussion of the PWM's functions, see EDN, September 2, pg 202.)

Although you can rapidly update the MDAC's output, the transformer's 20-kHz capability and the loop's time constants limit the design's bandwidth. In practice, though, you can modulate the MDAC's input at 250 Hz and still deliver a 100V sine wave into a 1-kΩ load.

Digitally modulate your CRT's plates

Another high-voltage requirement centers on modulating a CRT's deflection plates in electron-optics applications. In contrast to the previous high-voltage circuit, this design operates at greater bandwidths but has a low current-delivering capability. (Actually, this low-current limitation is not significant because the CRT's plates act like a very large resistor shunted by 50 pF.)

Fig 3's scheme uses two MDAC/op-amp pairs to generate the CRT's signals: One MDAC establishes the static (dc) bias; the second provides the dynamic (ac) drive signal (typically a ramp). A_3 sums these signals and feeds the result to the high-voltage stage, consisting of Q_1 through Q_4. This stage acts as an inverting, complementary, common-base-driven common-emitter amplifier with gain. And because the output-current requirements are low, you can avoid the usual crossover-distortion problems without complex compensation circuitry; merely tie the stage's output to the −125V rail via a 120-kΩ resistor. Closing the feedback loop with a 1-MΩ resistor yields the quick, clean response shown in **Fig 4.** (In this figure, two complete MDAC-driven amplifiers were used to produce the traces.) The top trace shows the ac signal created by digitally modulating IC_1's inputs; the middle and bottom traces depict the resulting high-voltage outputs.

MDACs regulate temperatures

MDACs also serve in temperature-regulating applications—such as those involving critical biochemical reactions occurring only within or at the edges of very specific (and often very narrow) temperature limits. **Fig 5**'s circuit, for example, employs an MDAC to regulate a heater and overcome the inability of standard temperature-control methods to provide both fine-grain resolution and long-term stability.

The basic temperature-control loop comprises an MDAC-controlled PWM (A_1 through A_5). Thermal feedback to the LM135 closes the loop; it varies the PWM's duty cycle to establish the controller's setpoint. Note that the PWM action results from A_5's comparing A_3's setpoint-equivalent output with the ramp output generated by the clock-driven integrator, A_4. A_3's output is in turn a function of the setpoint current flowing through the 22.6-kΩ resistor as well as the LM135's signal. (Amplifier A_3's 10-MΩ/1-μF feedback values limit the loop's response to 0.1 Hz.)

You control the temperature's excursions around the setpoint by modulating the MDAC's digital inputs with a slowly varying digitally encoded triangular waveform; the number of bits changed controls the temperature's span. **Fig 6**'s strip-chart recording demonstrates this design's advantages: Temperature can vary by ±1.5°C around a 37.5°C setpoint for many hours.

MDACs develop high-power audio signals

Now consider an MDAC's use in an audio-frequency application—control of the shaker tables frequently employed to test finished assemblies for vibration-induced failures. In order for these tests to be

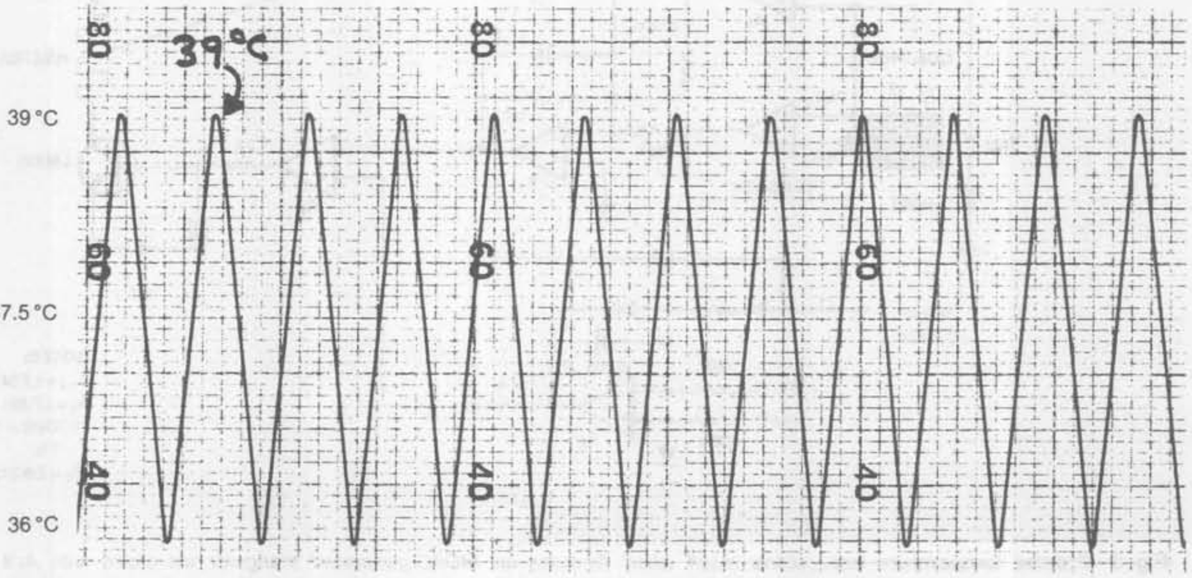


Fig 6—Long-term temperature control *is the result when* **Fig 5***'s design modulates the 37.5°C baseline setting via a triangular-wave-driven MDAC. The MDAC's digital input code controls the peak-to-peak oscillation amplitude.*

meaningful, the vibration patterns must be tightly controlled in terms of duration, frequency and amplitude. **Fig 7**'s dual-MDAC scheme can meet these requirements.

Frequency control results when MDAC IC$_1$ drives the integrator formed by A_1. This stage's output ramps until its 10-kΩ derived current just balances the feedback current at comparator A_2's + input. At this point, A_2's output changes state and forces the zener-diode network to furnish an equal-magnitude but opposite-polarity reference voltage. Because this now-inverted reference feeds both the MDAC and the comparator, the integrator generates a triangular waveform symmetrically centered on ground. Using this circuit technique, you can use 12 bits to encode the MDAC and synthesize a 1-Hz to 30-kHz output signal.

A sine wave results when the synthesized triangular signal feeds the dual npn/pnp stage; the logarithmic relationship between the LM394's collector current and its V_{BE} performs the smoothing function. You adjust the offset and wave-shape pots for low distortion.

The digital amplitude-control feature occurs in the

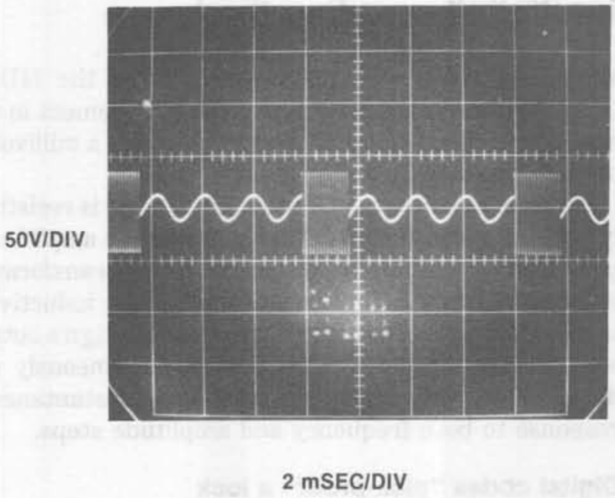


Fig 8—A signal's frequency or amplitude *is quickly changed by* ***Fig 7****'s MDAC controllers. Using this technique, you can vary output frequency from 1 Hz to 30 kHz.*

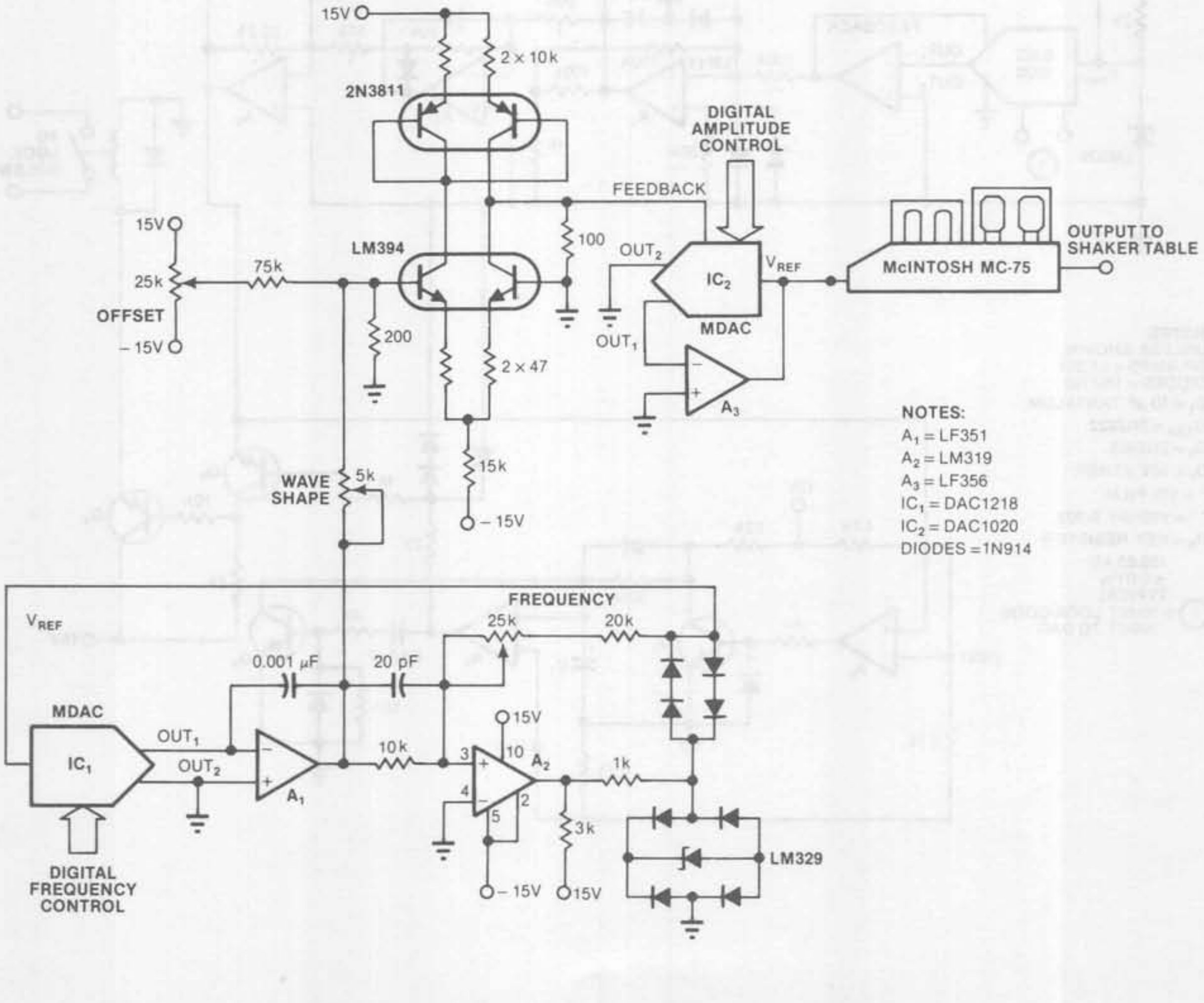


Fig 7—Digitally variable frequency and amplitude signals *arise when the triangular wave generated by IC$_1$ through A_2 is converted to a sine wave by the pnp/npn stage and modulated by MDAC IC$_2$. Both the frequency and amplitude functions can be fixed (via switches) or swept.*

associated MDAC/op-amp network. Here the MDAC (IC_2) operates as the programmable gain element in the op amp's feedback loop. This trick provides a millivolts-to-volts range at A_3's output pin.

Because a shaker table's input impedance is resistively low and inductively high, a vacuum-tube amplifier is your best choice for the power stage; its transformer-isolated output is immune to the table's inductively induced flyback spikes. **Fig 8** shows this design's output waveform when both MDACs are simultaneously updated. Note its clean and essentially instantaneous response to both frequency and amplitude steps.

Digital codes "pick-proof" a lock

Fig 9's circuit serves an unusual MDAC application: the programming of an electronically keyed combination lock. Because the inserted key is an 0.01% resistor, security is assured against all but the most determined and sophisticated thieves. If the key you insert isn't the correct one, the circuit knows it within 250 msec and ignores any further lock-opening attempts for 5 min. Decade-box- or potentiometer-equipped thieves thus don't have a chance.

When "key resistor" R_K has the correct value, the MDAC's output current precisely balances R_K's current at A_1's input and drives A_1's output to zero. The absolute-value stages (A_2 and A_3) sense this condition, and A_3's output, Q_1's emitter and A_4's + input also go to zero. And when A_4's input reaches zero, its output goes negative, Q_3 cuts off and C_1 starts charging toward the 15V supply level via the 22-kΩ/diode network. During this 250-msec charging time, A_5's HIGH output level turns the Q_1/Q_2 stage on and therefore opens the door's lock. When C_1 charges past 5V, A_5's output goes LOW and disables the lock again.

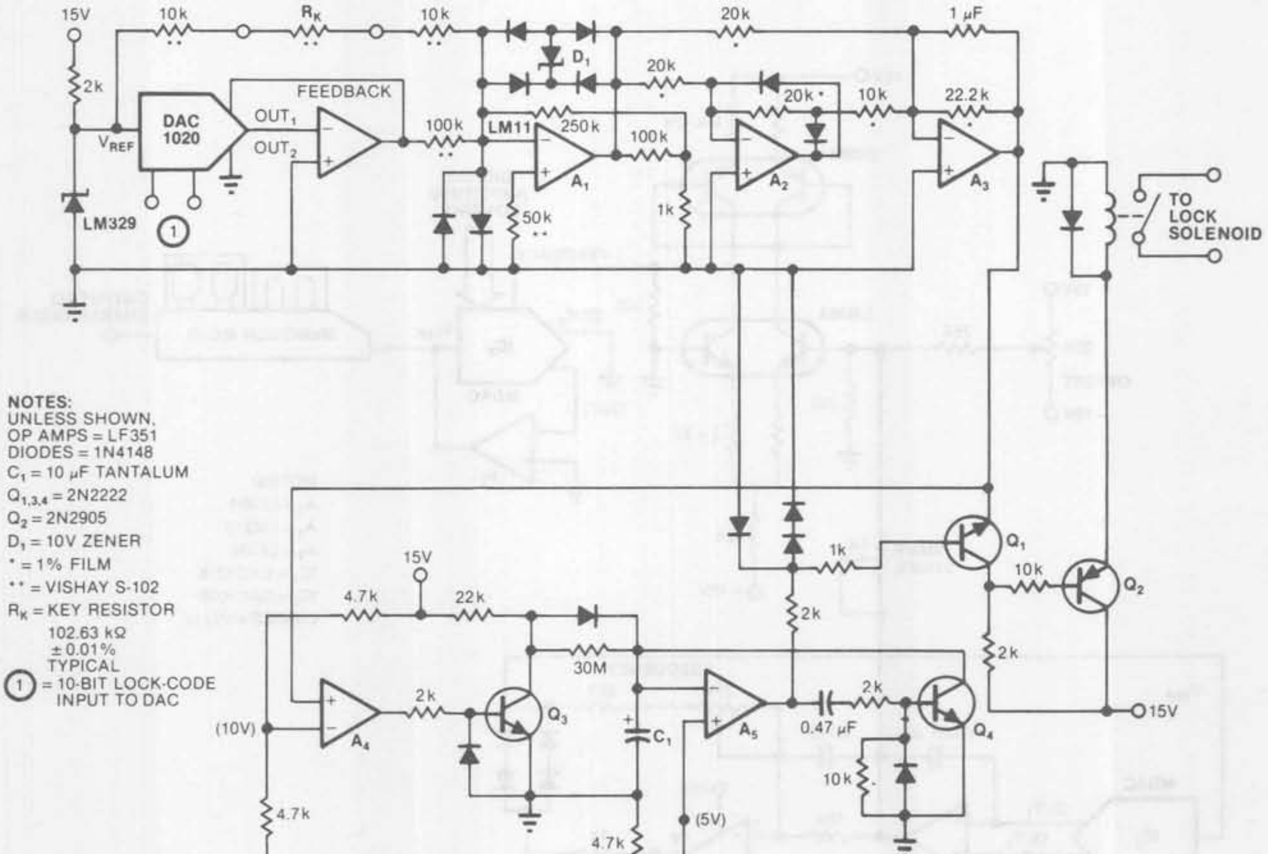


Fig 9—A virtually pick-proof electronic lock *employs an MDAC in a digital-code-to-resistor-value comparison loop. Resistor R_K serves as a key. When the inserted resistor's value isn't correct and accepted within 250 msec, the circuit inhibits another lock-opening attempt for 5 min.*

Pick-proof lock frustrates sophisticated thieves

If you try opening the lock with an illegal R_K, the absolute-value stages (A_2, A_3) don't settle to zero and Q_1 remains OFF. Under these conditions, it takes 5 min before C_1 discharges back down to 5V—via the 30-MΩ resistor—and is reset to 0V by Q_4.

This design discourages even the most sophisticated and/or frustrated thieves: Amplifier A_1's zener-diode bridge and input clamps prevent anyone from monitoring the summing junction's requirements or intentionally destroying the unit. And the 12-bit MDAC provides security via 4096 possible combinations. **EDN**