Improve Function Generators with Matched D/A Converters

by Paul Toomey

*With a pair of precisely matched 8-bit CMOS DACs in one IC,
you can create inexpensive circuits that digitally control
high-precision analog waveforms.*

Using the AD7528, a low-cost IC containing two 8-bit CMOS multiplying DACs, you can design a variety of signal-generation circuits for audio, computer-graphics and process-control applications. These designs, which require a pair of closely matched, tightly tracking D/A converters, have heretofore proved impractical to produce because the selection and testing necessary to match the DACs has made them quite expensive.

Three useful circuits—a programmable sine-wave oscillator, a function-fitting sine-wave synthesizer and a triangle/rectangle-wave generator—clearly demonstrate the 7528's design potential. Each circuit is digitally controlled; therefore, before considering the specific designs, you should examine interfaces for widely used microprocessors.

To that end, note that the AD7528's two on-chip 8-bit latches and control inputs ($\overline{CS}$, $\overline{WR}$ and DAC Select) are logic-level and speed compatible with most µPs. Data-hold time, often a problem in applications using members of the 6800 family, equals zero. Fig 1a shows an interface to a 6800-based system, while Fig 1b details the connections for an 8085-based system.

Use dual DACs as ganged potentiometers

With this background information, turn to the dual DAC's applications. You can control the frequency of many oscillator circuits by using two ganged potentiometers, provided that the pots track precisely over their full resistance range. Fig 2's high-performance sine-wave oscillator is a state-variable filter design in which an AD7528 acts as a pair of digitally controlled matched resistors to replace the ganged potentiometer. The equivalent resistance of each DAC, as seen by op amps A_2 and A_3, varies from infinity at input code 00_H to a minimum of 10 kΩ (the DAC ladder resistance) at FF_H.

Because the same code is loaded into each DAC, the expression for the output frequency (in hertz) becomes $f = N/256(2\pi RC)$, where N is the DAC code (base 10), R

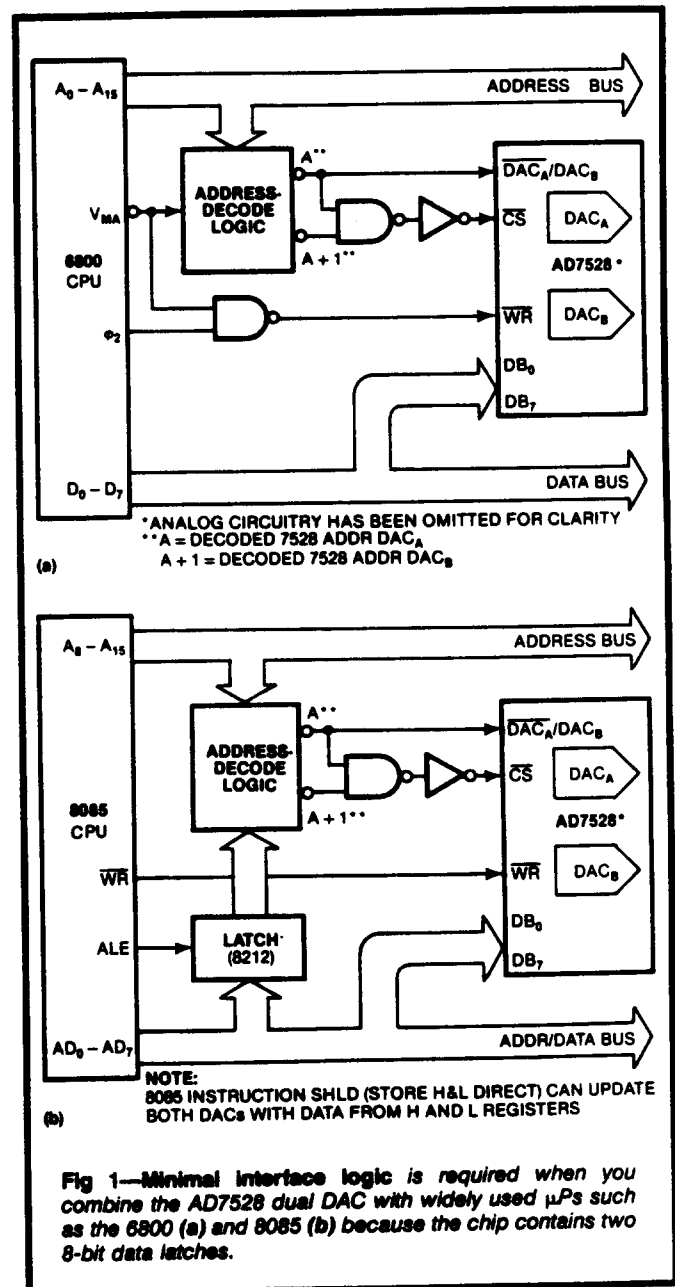*ANALOG CIRCUITRY HAS BEEN OMITTED FOR CLARITY
**A = DECODED 7528 ADDR DAC$_A$
A + 1 = DECODED 7528 ADDR DAC$_B$

(a)

NOTE:
8085 INSTRUCTION SHLD (STORE H&L DIRECT) CAN UPDATE BOTH DACs WITH DATA FROM H AND L REGISTERS

(b)

Fig 1—Minimal interface logic *is required when you combine the AD7528 dual DAC with widely used µPs such as the 6800 (a) and 8085 (b) because the chip contains two 8-bit data latches.*

Summing resistors are critical
to function fitter's performance

ʰ the DAC ladder resistance and C is the feedback pacitance for A_2 and A_3. For the circuit values shown ın Fig 2, output frequency varies from 0 to 15 kHz in steps of approximately 60 Hz, with an amplitude of about 20V p-p. Total harmonic distortion measures −53 dB at 1 kHz and −43 dB at 14 kHz.

Combine multiplication and function fitting

Function fitting translates a mathematical or empirical relationship from one medium (such as a mathematical formula) to another (usually a physically realizable device or system). By taking advantage of the multiplying capabilities of the AD7528's two CMOS DACs, you can use this technique to synthesize extremely low-frequency, highly stable sine waves. For example, in Fig 3a's design, the IC implements a 1-quadrant sin X approximation in the form of the quadratic polynomial $Y = 1.828N - 0.828N^2$, where $0 \leq N \leq 1$ and $N = (2/\pi)X$. (See Appendix for the derivation of this equation.) By ramping N up and down and strategically switching the


Identical twins

The AD7528 contains two 8-bit CMOS multiplying current-output D/A converters, each with its own 8-bit latch. Because both DACs are fabricated at the same time on the same chip, they have virtually the same R/2R-ladder characteristics, and these characteristics track extremely closely as the supply voltage varies and the ambient temperature changes.
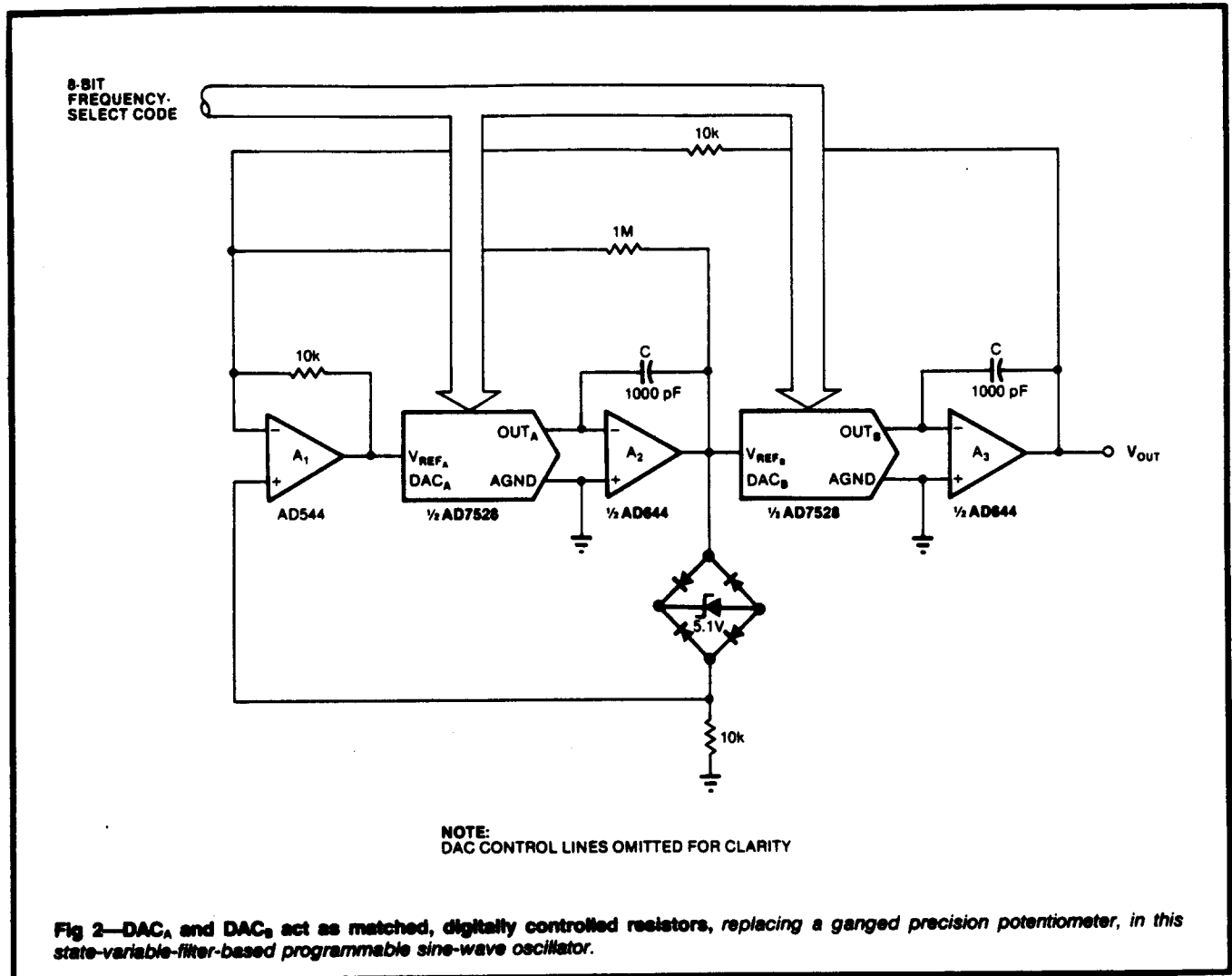
Data inputs to the AD7528's on-chip latches share a common input data bus; you control the data flow with the $\overline{DAC_A}/DAC_B$ latch-select input. Each section of the IC provides its own analog reference and feedback inputs, so you can operate the DACs independently. Channel-to-channel isolation typically measures −77 dB at 100 kHz.

Settling time varies with supply voltage. After a digital input change, the analog output settles to within 90% of its final value in 80 nsec with a 15V supply; with a 5V supply, settling occurs in 270 nsec. Regardless of the supply voltage, though, the AD7528 typically draws just 1 mA.

For more information on the AD7528, Circle No 750.
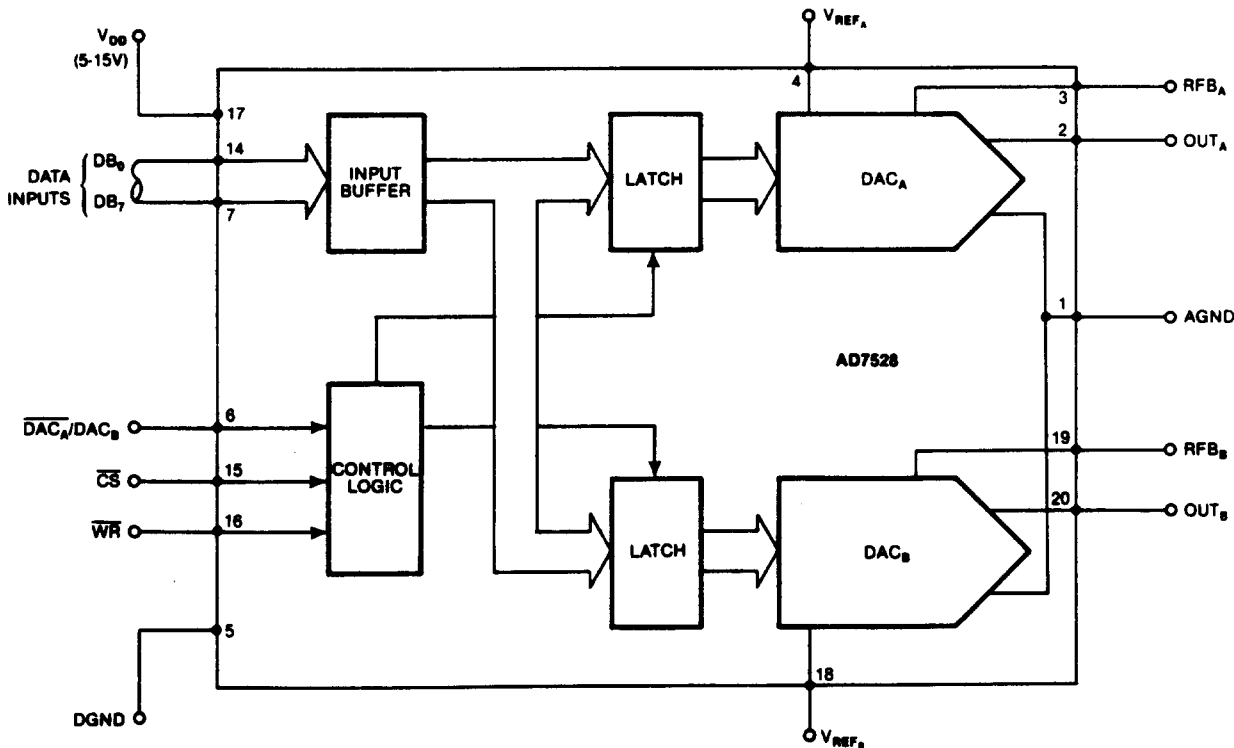
Simultaneous fabrication of the AD7528's two CMOS multiplying DACs yields virtually identical R/2R-ladder characteristics.

8-BIT
FREQUENCY-
SELECT CODE

Fig 2—DAC_A and DAC_B act as matched, digitally controlled resistors, *replacing a ganged precision potentiometer, in this state-variable-filter-based programmable sine-wave oscillator.*

NOTE:
DAC CONTROL LINES OMITTED FOR CLARITY

output polarity, the circuit generates sin X in four stages (Fig 3b).

Specifically, an input square-wave clock drives a counter that counts up and down continuously, providing a Borrow output pulse every time it reaches the all-ZEROs count. In turn, DAC_A produces a triangle wave consisting of two ramps of opposite slope, each generated in 256 steps of op amp A_1's output. This is the analog N variable.

To produce the analog N^2 variable, DAC_B multiplies N's digital version by its analog version. Op amp A_2 inverts the product signal, producing $-N^2$. Then amplifier A_3 sums the two variables in the correct 1.828 and 0.828 weighting, as determined by R_A and R_B, to produce the Y signal. A smooth sine wave results when op amp A_4 switches the circuit's output polarity to generate properly timed positive and negative signals.

Distortion in the output sine wave is a function of the quadratic-approximation fit to the sine curve. Therefore, the values of R_A and R_B are critical to proper circuit operation. Measured distortion for **Fig 3**'s circuit
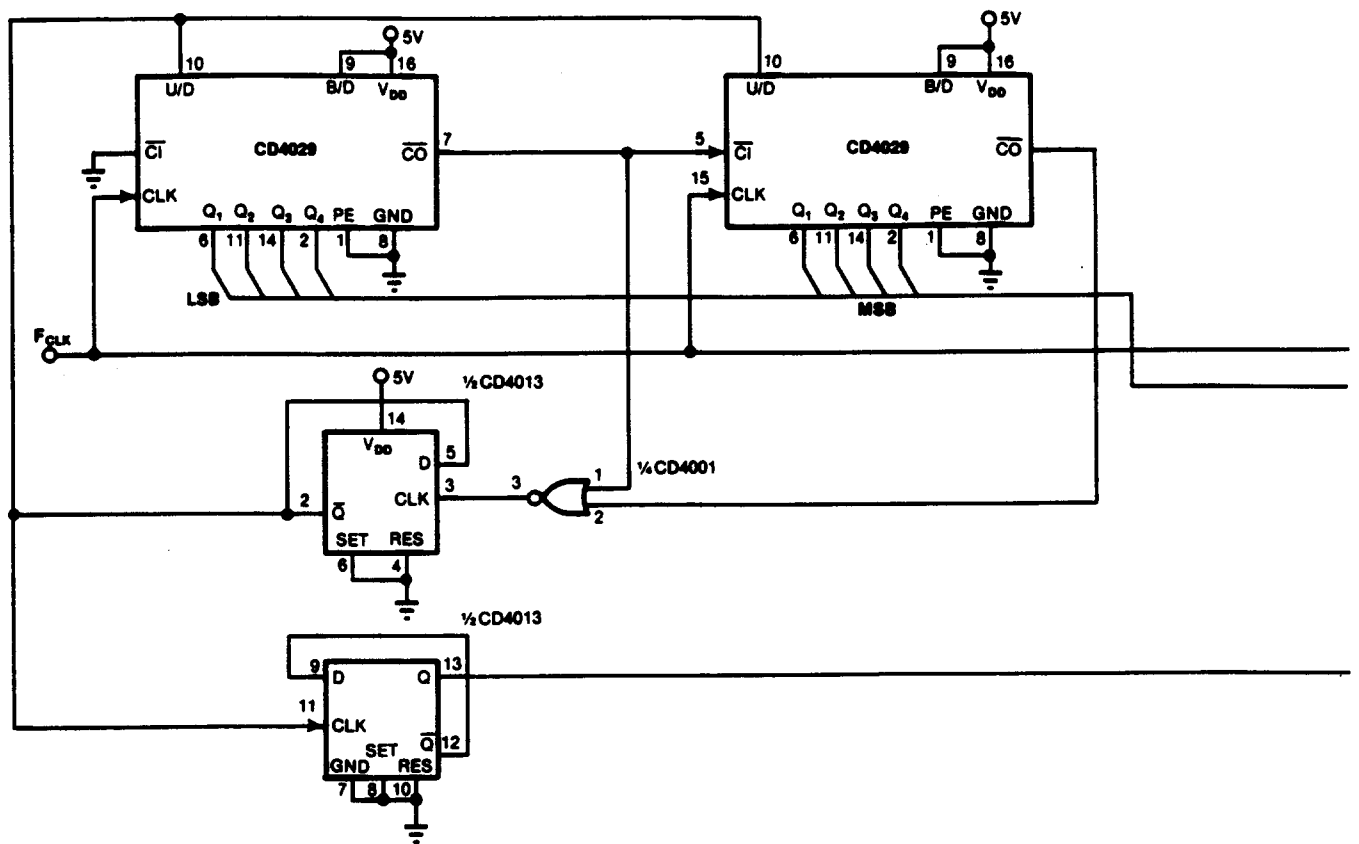
values is -35 dB; it remains constant over the 0 to 2500-Hz range, as does the output amplitude.

If you want to sweep the circuit's output frequency, you can do so rapidly by varying the input clock rate. The counter's Borrow output provides a valuable zero-crossing pulse in such use. Additionally, by applying an ac signal to DAC_A's reference input, you can amplitude-modulate the output sine wave.

Generating triangles and rectangular pulses

Certain applications require triangular or rectangular waveforms in which you can program the period of each half cycle. For example, the former serve as sweep signals in vector-scan CRT displays to generate variable-length vectors. The design depicted in **Fig 4** serves such requirements extremely well.

In operation, DAC_A defines the ramp rate for the triangle's positive slope; DAC_B, the rate for the negative slope. Comparators A_4 and A_5 sense the integrator's output, driving gates G_1 and G_2 when the level reaches $+10$ or -10V. These gates act as an RS

(a)

A₁ OUTPUT = x VARIABLE

A₂ OUTPUT = x²

A₃ OUTPUT = FULL-WAVE-RECTIFIED SINE
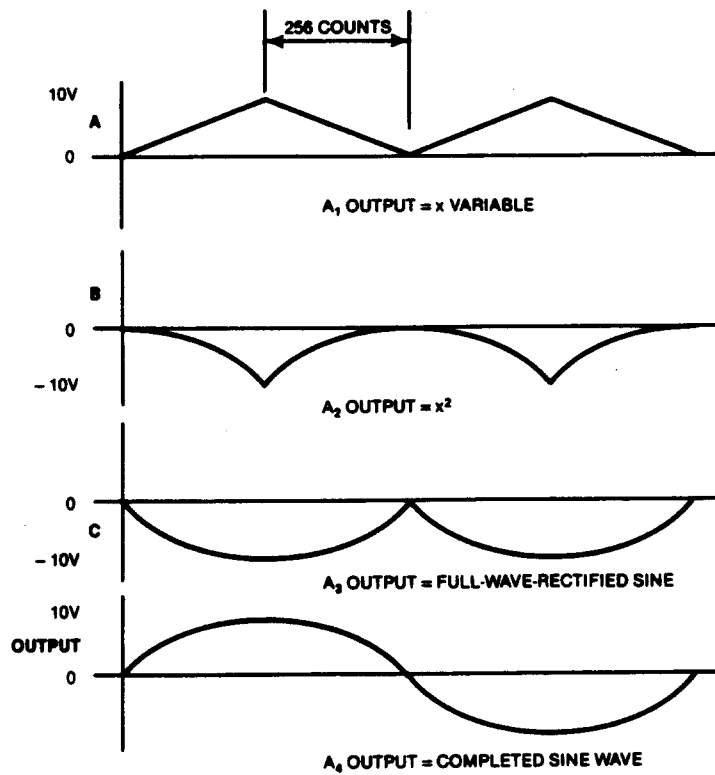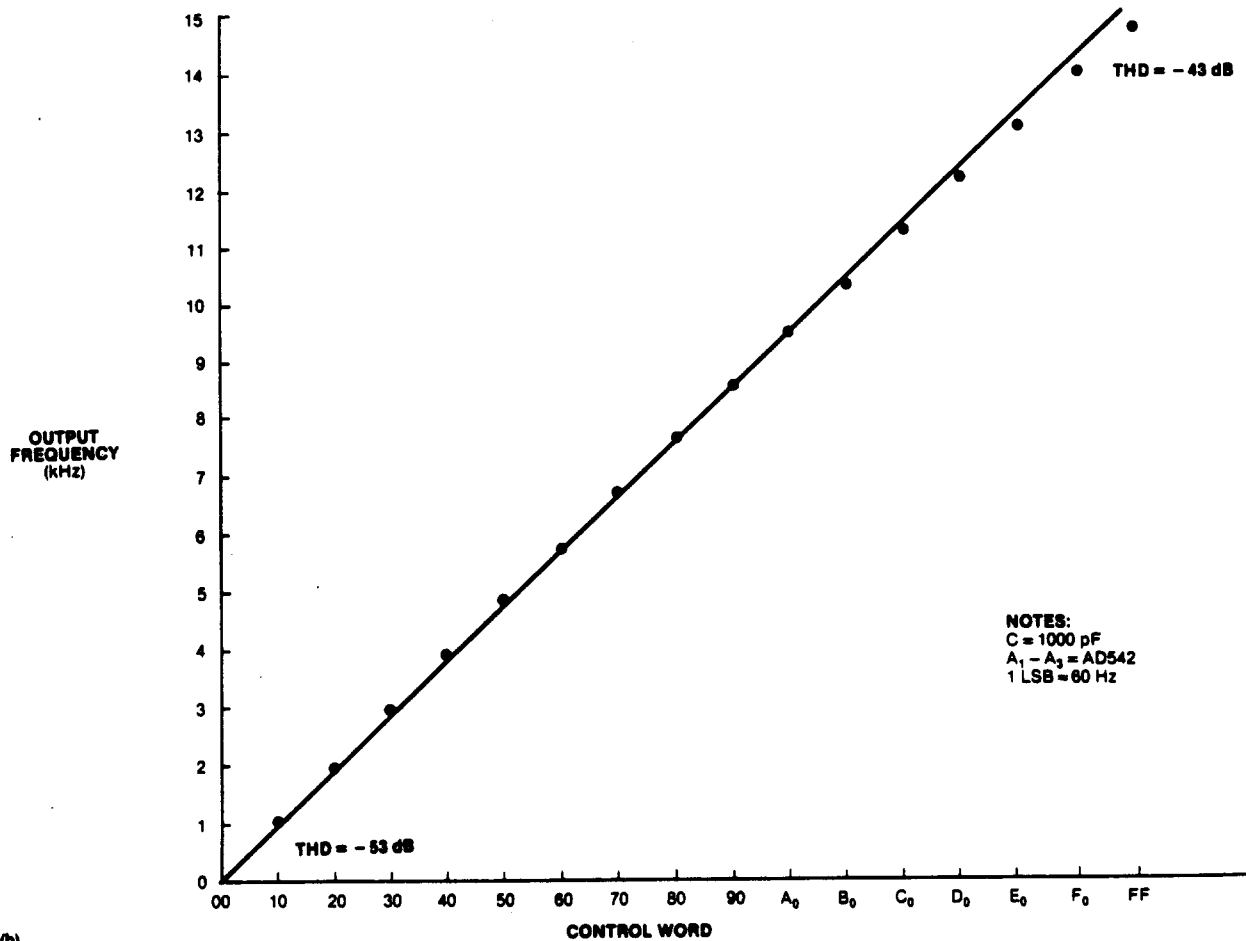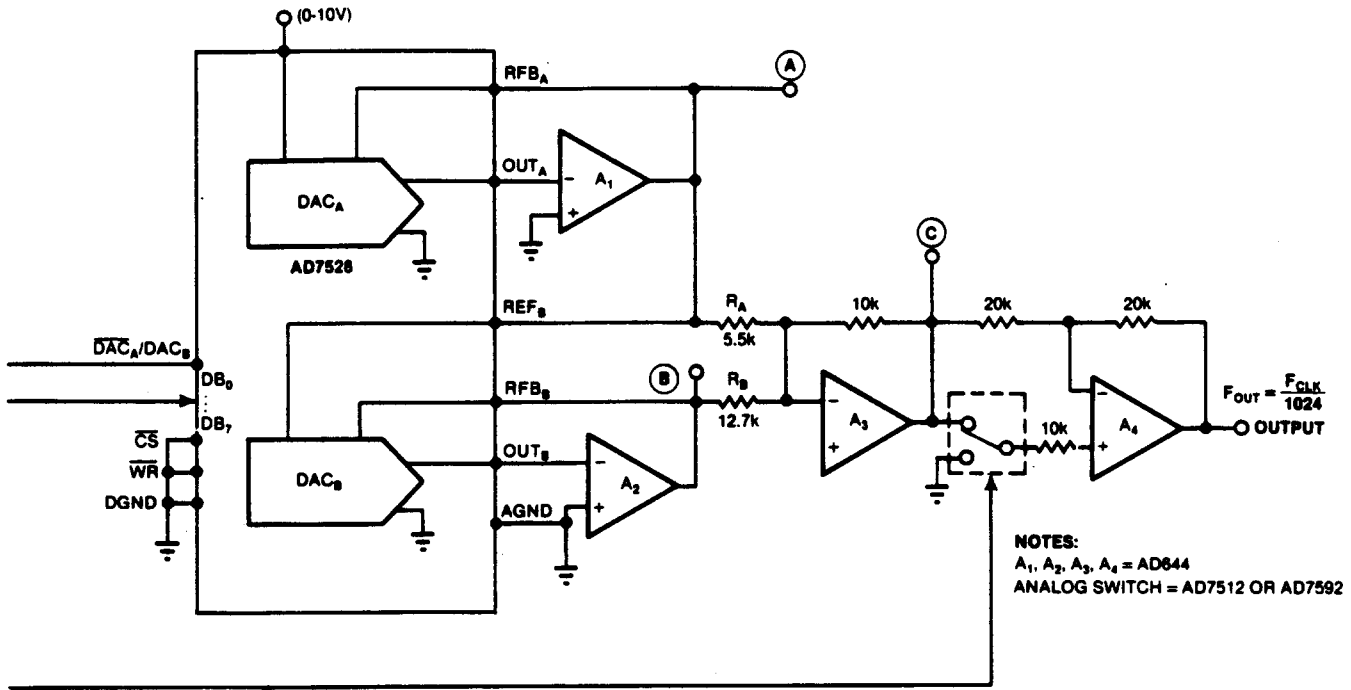
A₄ OUTPUT = COMPLETED SINE WAVE

Fig 3—The multiplying capability of the AD7528 gets used to advantage in this function-fitting sine-wave generator (a). The digital representation of N is DAC_B's input word, while the analog representation of N drives the DAC's analog reference input. As a result, DAC_B outputs an analog signal equal to N². Resistors R_A and R_B relate to the quadratic polynomial that approximates the 1-quadrant sin X function; they must be stable and accurate to achieve minimum distortion (b).

(0-10V)

RFB$_A$

Ⓐ

OUT$_A$

A$_1$

DAC$_A$

AD7528

REF$_B$

R$_A$
5.5k

10k

Ⓒ

20k

20k

$\overline{DAC_A}$/DAC$_B$

DB$_0$

RFB$_B$

Ⓑ

R$_B$
12.7k

A$_3$

DB$_7$

$\overline{CS}$

$\overline{WR}$

DGND

DAC$_B$

OUT$_B$

A$_2$

AGND

10k

A$_4$

$F_{OUT} = \dfrac{F_{CLK}}{1024}$

OUTPUT

NOTES:
A$_1$, A$_2$, A$_3$, A$_4$ = AD644
ANALOG SWITCH = AD7512 OR AD7592

8

THD = −43 dB

OUTPUT
FREQUENCY
(kHz)

NOTES:
C = 1000 pF
A$_1$ − A$_3$ = AD542
1 LSB = 60 Hz

THD = −53 dB

(b)

CONTROL WORD

00 10 20 30 40 50 60 70 80 90 A$_0$ B$_0$ C$_0$ D$_0$ E$_0$ F$_0$ FF

`p flop to select the output of the appropriate DAC via
_nalog switches SW₁ and SW₂.

The arrangement shown lets you use high-speed switches, such as types CD4016 or AD7592, without introducing significant glitches at the DAC changeover. Furthermore, you can update one DAC from the data bus and allow it to settle while using the second DAC to generate the ramp signal. The flip-flop output automatically connects the "unused" DAC to the data bus for further data updating if necessary. You can also use the output to drive the interrupts of a μP.

Calculate the period of the waveforms generated by this circuit from the expression

$$T = 512RC((1/N_A) + (1/N_B)),$$

where N_A and N_B are the DAC_A and DAC_B codes (1 to 256), respectively.

If the latches for both DACs contain the same code, the expression for T is simplified:

$$T = 1024RC/N$$

$$\text{or } f = N/1024RC \text{ (in hertz)}.$$

The mark-to-space ratio of the rectangular wave equals N_B/N_A.

Note one caution regarding **Fig 4's** circuit. If the code in either DAC becomes all ZEROs, the integrator input voltage becomes zero, and the circuit stops oscillating. `*f this condition can occur in your application, connect a `-MΩ resistor from each DAC's V_{REF} terminal to its output terminal. This provision produces sufficient bias current to keep the circuit oscillating, yet it doesn't significantly affect frequency calculations, adding only ¼-LSB error into each DAC output.

Appendix

The expression to approximate sin X (0≤X≤π/2) has the form
$$Y = AX + BX^2,$$
where A and B are constants. You can evaluate these constants as follows:

Replace X (0≤X≤π/2) with N (0≤N≤1), where N=(digital code)/256. Next, substitute values for Y and N at two points along the sine curve:
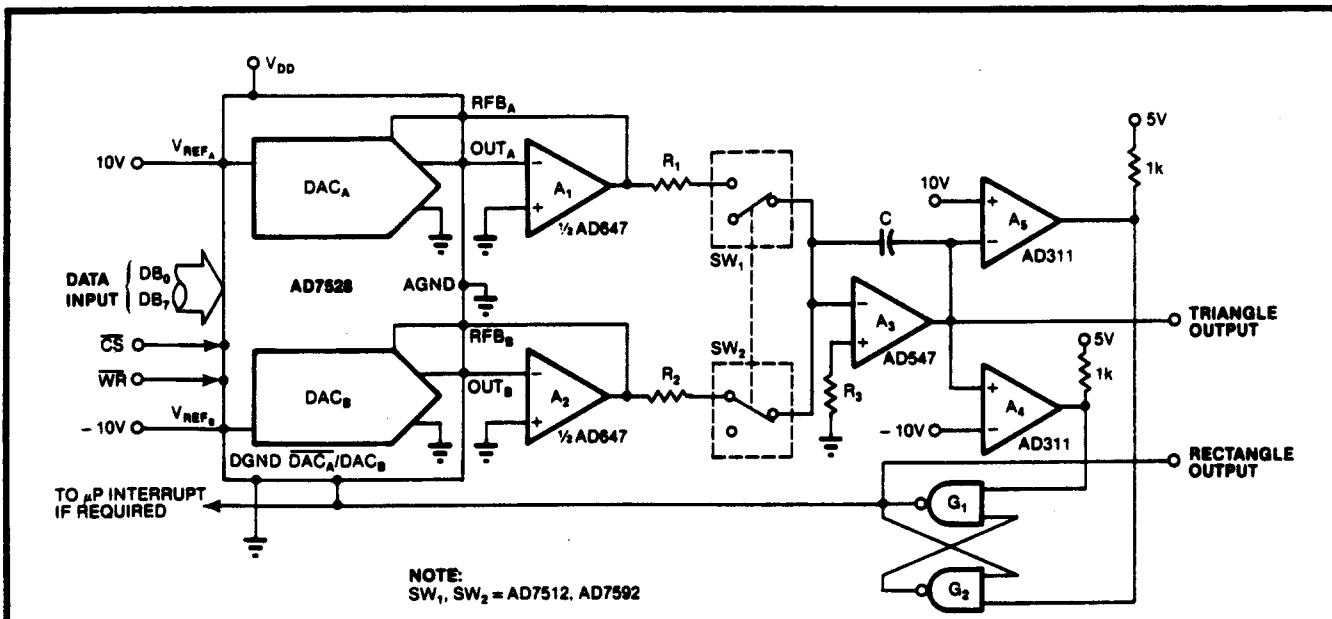
(a) X=π/2, ie, N=1: sin(π/2)=1
(b) X=π/4, ie, N=0.5: sin(π/4)=0.7071.

This substitution produces two equations:
$$1 = A(1) + B(1)^2$$
$$0.7071 = A(½) + B(½)^2.$$

Solving these equations simultaneously for A and B yields A=1.828 and B=0.828.

Thus, the corresponding values for R_A and R_B in **Fig 3a** are R_A=5.5 kΩ and R_B=12.7 kΩ for unity gain.

Fig 4—You can update one DAC and allow it to settle while using the second DAC to generate a ramp in this programmable waveform generator. Oscillation stops if either DAC has an all-ZEROs input code, however. If this is a problem in your application, connect a 10-MΩ resistor between each DAC's V_{REF} and output terminals.