Some "Timeless" Ideas For Design

For this special analog issue, we're trying out a new column concept. Based on some favorable comments received on the January, 1998 "Anniversary" column, this one takes a look back at some older Ideas for Design (IFDs). The general theme here is "Timelessness," that is, ideas which are still as viable today as when they originally appeared. For this initial case, the IFD candidates are limited to my own, which happens to make things expedient. But, we do hope that enough folks out there like revisiting IFD classics, so that in time, the idea can be expanded in scope and frequency. Do let us know your feelings on this!

In choosing from my *Electronic Design* IFDs, I tried to pick those worthwhile, which have also retained (or appreciated) value since their original appearance. Those below date from the 1970's, but I think you'll agree they are just as useful today as back then. More so, if they're modernized by using today's parts.

WALT JUNG

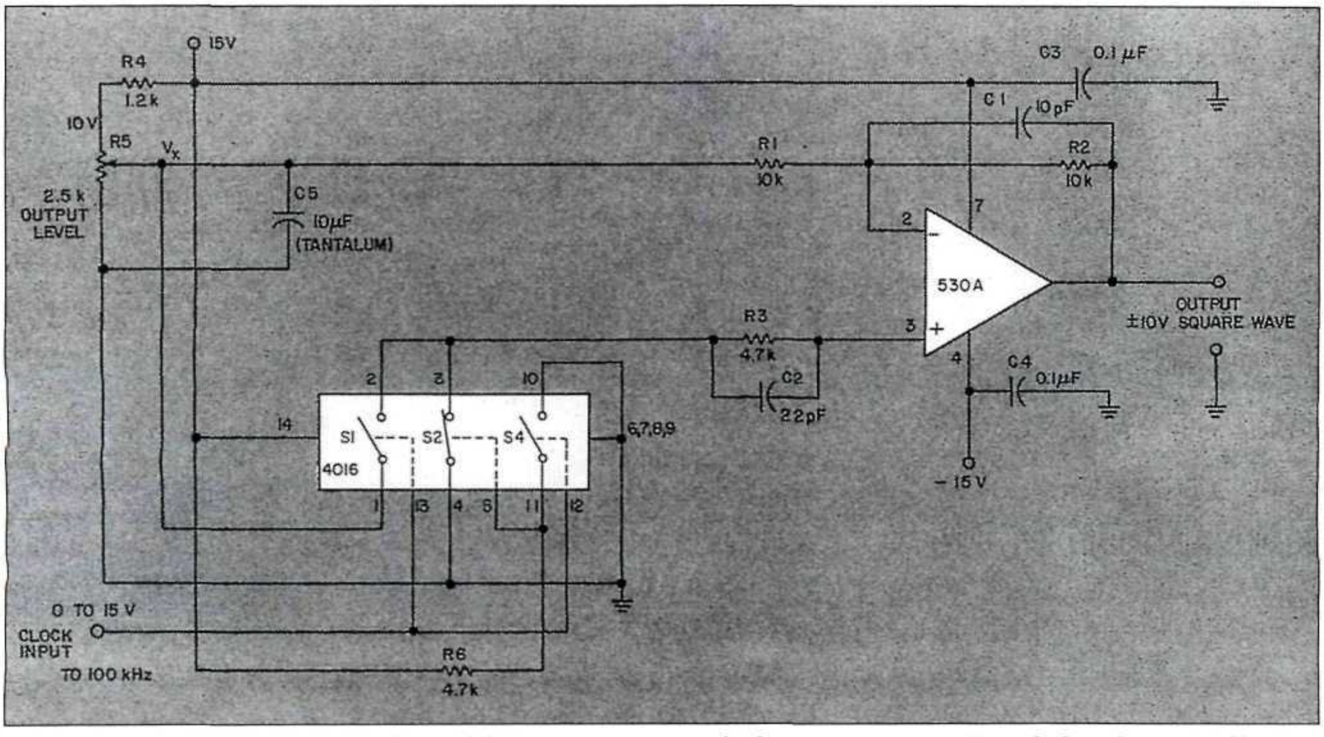
Converting Fast Logic Inputs to Bipolar Analog Signal Levels: A useful analog signal source for the lab is a variable-output, bipolar-level, square- (or rectangular-) wave generator. With just a few parts, standard logic signals can be used to program an analog switch, which drives a fast op amp to ±10-V outputs. As it happens, this is a standard op-amp signal-processing function, known also as a *sign changer*. This name comes from the circuit's ability to multiply an input signal by a precise factor of either +1 or −1.

CMOS switches like 4016s are easily interfaced with standard unipolar CMOS logic levels. But, quite interestingly, they can also be married with a fast, dc-accurate, op-amp sign-changer circuit. An IFD which does this was described in 1977, and the general technique is even more valid using present-day, high-speed op amps and SPDT CMOS switches.[1]

The circuit shown in Figure 1 uses an op amp as a unipolar-to-bipolar, analog-level shifter controlled by 0- to 10- V logic signals. The op amp sees only positive signals at its input, but because it is logic programmed between equal gain states of positive and negative, the output signal is bipolar. With a stable dc level as an input V_X, the op amp is logic programmed between precise gains of ±1. The output amplitude levels are then as stable as the voltage V_X.

The analog switch (originally shown as a CD4016) is driven by the clock input, which also drives a logic inverter stage (another 4016 section—but note that this function would be unnecessary using modern SPDT switches). The complementary logic drive signals program the first two switch sections into a SPDT function, with the switch output arm driving the op amp positive input.

Dependent upon the logic drive state, the positive input is connected to either potentiometer R5's output, V_X, or to ground. Simultaneously, R5 also



1 A sign-changer circuit, built with a CMOS analog switch driving an op amp, generates bipolar-output square waves. V_X can also be made programmable in amplitude, as from a unipolar digital-to-analog converter.

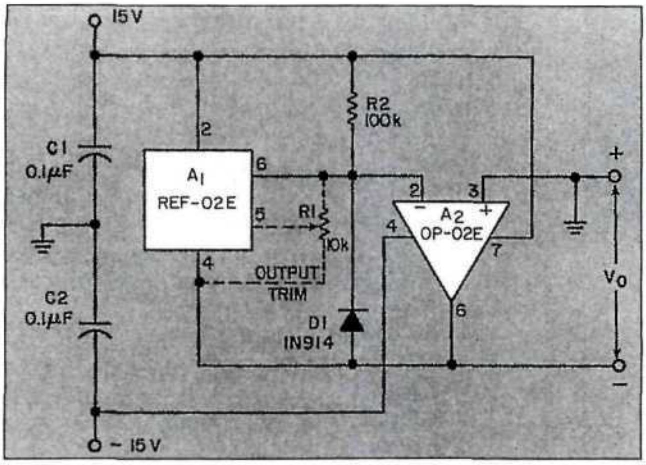
presents the same V_X signal to the op amp's negative input, via R1. Note that the op-amp circuit has a precise gain of –R2/R1 (or –1) for V_X, when the positive input goes to ground, or alternately, a precise gain +1, when the positive input goes to V_X. Thus the name, sign changer!

The op-amp negative-gain accuracy is dependent upon R1-R2 resistor matching, while positive gain is inherently unity (within the allowance of the op-amp common-mode error—usually very small). Although the V_X signal is always a positive dc voltage set by R5, the op amp level shifts and translates this signal, multiplying it by the logic signal. This produces bipolar and symmetrical amplitude output waves of $\pm V_X$.

While signal amplitude symmetry and control of the negative output peak amplitude is primarily governed by the match between R1 and R2, there is also a loading effect. The op amp alternately loads V_X with a value of 10 kΩ, or an open circuit. So, a nonzero source impedance for V_X can produce some time-dependent errors, even though V_X is bypassed by C5. Resistor R3 provides offset-current compensation for the op amp, and the feedback capacitor across R2 reduces the settling time of the circuit (and should be trimmed for the op amp used).

Originally the op amp used was an NE530A, which is no longer available. However, many more-recent op amps offer greater speed (preferably 100 V/µs or more, combined with fast settling). One candidate would be an AD825, which has JFET inputs, and can also handle the large differential input swings without problems (bipolar-input op amps may have problems due to input overload).

The circuit can also be improved by the use of two amplifiers. One can be used for the basic amplifier shown, and the second as a unity-gain buffer for V_X. This buffer (not part of the original circuit) should be placed between the arm of R5-C5, and the load represented by R1 and the input to the switch. This will remove time-dependent errors due to the dynamic loading of R1.



2 A negative reference built with a positive reference IC (A1), uses op amp A2 to invert A1's positive output voltage to an exact mirror-image negative at A2's output terminal.

Note that when a stable, 5-V (or 10-V) reference source is used for V_X, the output amplitude will be tightly controlled. Or, a DAC can also allow amplitude programmability via software.

Generating Negative Voltage References with Low Errors: Voltage reference ICs proliferate, but they are predominantly in positive-output, three-terminal formats. So, when you do need a negative reference, you can also find it a challenge. To implement a negative reference based on a positive output type, one straightforward approach is to follow a positive-output IC with a standard op-amp inverter, to create a –5-V output from, say, a 5-V positive input.

While this approach *functionally* achieves the requirement, it also adds some serious drawbacks. For example, the ratio temperature coefficient (TC) of the inverter's gain-set resistors can easily be far worse than the TC of a good reference (which is 10 ppm/°C or less). And, if the resistors are specified well enough, their net price can be more than the basic reference IC itself!

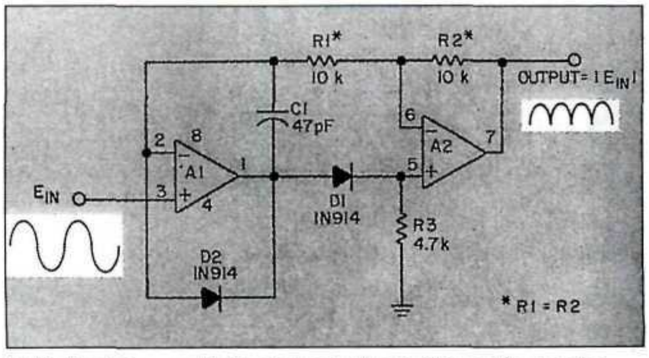
But, you *can* still have your cake and eat it too, as a mirror-imaging scheme allows a positive reference to be "polarity-flipped," to produce a negative output of the same magnitude and stability of the reference IC used. This scheme, described in an IFD in 1978, circumvents the added errors and expense of the inversion scheme.^{2}

In the basic, negative-reference circuit of Figure 2, precision op amp A2 allows A1's positive reference voltage to flip over to its exact negative at the output, pin 6 of A2. A1 was originally shown as a REF02E, a standard reference IC. In this case, the output from A2 is –5 V. While the REF02 is still readily available, in principle, just about any three-terminal reference IC can be used in this manner, allowing optimization for the required accuracy, drift, standby power, etc.

In operation, A1 has its positive output connected in A2's feedback loop. With A2's positive input grounded as shown, the normal output pin of A1 is also "virtually grounded," by the feedback hookup. This essentially places the stable reference voltage of A1 between A2's output and the negative input. Using a 5-V REF02, this creates a –5-V output, as accurate as the basic REF02 specs allow. R2 and D1 can aid in circuit startup, but may not be necessary in all applications.

The circuit's output-current rating is dependent upon the op amp used for A2. This will be 10 to 20 mA (or less) for most standard devices, such as an OP07 or OP177 (a preferred choice for the circuit today). The amplifier can be optimized for higher output current if necessary, either by buffering or using a higher-current part.

Using REF02-type parts, output voltage can optionally be trimmed by R1, but this isn't essential for basic operation. Also note that the A1 reference IC itself operates



3 Needing just one matched-resistor pair, this precision rectifier provides accurate absolute-value outputs of ac inputs over a wide frequency range.

with no loading other than R1 (if used), enhancing stability. Other A1 options could include low-quiescent-current operation, by use of a low-current-level reference device for A1.

Overall temperature stability can be enhanced by choosing a precision op amp for A2, such as an OP07E. The maximum drift of this op amp will only contribute about 0.25 ppm/°C of drift beyond that of a 5-V level reference IC for A1, which is negligible. Consequently, the net circuit drift is essentially dominated by A1's drift. Output calibration will also be essentially the tolerance limits of A1, for A2 V_{OS} levels of 0.1 mV or less.

In picking a modern op amp for this circuit, be sure to choose one that is fully compatible with all power supply and accuracy issues. While the OP07 series works fine for older ±15-V supplies, a modern system may need to develop, say, –2.5 V with ±5-V supplies. An OP97EP is a good choice for such a system, along with a AD780BN 2.5-V reference.[3]

Flexibility is another hallmark of this hookup. In fact, it can even accommodate two-terminal (diode-like) reference ICs. For example, with A1 completely removed, and using an AD1580 reference diode for D1, the circuit develops a buffered, –1.225-V output. The op amp allows variable currents from the circuit, unlike the conventional two-terminal device operation.

A Buffered Precision Rectifier: The precision rectifier (also called an absolute-value circuit) is another op-amp staple application. And, toward its optimization, the rectifier is often configured for reduction of precision resistors, amplifiers, etc. One such rectifier was described in a 1978 IFD.[4]

Figure 3 gets down to a bare minimum of matched precision resistors—one pair, R1-R2—without performance reduction. And, with modern, dual IC devices, two op amps aren't necessarily a disadvantage, as many models can be chosen to fit the bill.

In the circuit, A1 serves as an input buffer and/or switch, and A2 as an inverting buffer or follower. Due to the arrangement, the circuit is self-buffered for input/output. It won't load the source, and drives standard loads with good performance.

For positive-going inputs, A1's output is positive, which biases D1 to drive A2's noninverting input. Thus, for this phase of input, the circuit acts as a voltage-follower, and resistors R1-R3 have little influence on accuracy. For negative inputs, D1 is off and D2 is on, closing a loop around A1 as a follower. With R2 = R1, A2 is driven through R1 as a unity-gain inverter.

The circuit's output is a unity-gain, full-wave rectified version of the input—positive for diode polarities shown (reverse for negative output). Interestingly, the only precision components are R1-R2. For the best ac performance, capacitor C1 lowers the effective gain-bandwidth of A1, and helps stability.

In the circuit, FET-input op amps minimize source loading and bias-current errors. However, there is a caveat here—avoid using FET-input parts prone to phase reversal. Wide common-mode range units such as the AD823 are useful in this context. But for good dc and low-frequency accuracy, high common-mode rejection is typically better in bipolar types, and even general-purpose types such as LM358s work OK. More-precise parts do, of course, work better for overall accuracy. Most dual op amps match the standard pinout shown.

We hope that you have enjoyed this trip back in time revisiting a few "timeless" analog designs. If you'd like to see more of this with other *ELECTRONIC DESIGN* IFD classics, drop us a note.

References:
1. Jung, W., "Convert Unipolar CMOS Signals Into Analog Bipolar Outputs," *ELECTRONIC DESIGN*, October 25, 1977, p. 88.
2. Jung, W., "Positive Reference-Voltage IC is Flipped Negative by Adding a Single Component," *ELECTRONIC DESIGN*, February 15, 1978, p. 98.
3. Jung, W., "Getting the Most from IC Voltage References," *Analog Dialogue*, vol. 28-1, 1994.
4. Jung, W., "Get Accurate Absolute-Value Outputs with Only One Matched-Resistor Pair," *ELECTRONIC DESIGN*, December 20, 1978, p. 102.

Walt Jung is a corporate staff applications engineer for Analog Devices, Norwood, Mass. A longtime contributor to ELECTRONIC DESIGN, he can be reached via e-mail at: Walt_Jung@CSI.com.