

Use CMOS in chopper designs.

Analog switches, now available at low cost, considerably simplify the design of multiplexers and choppers.

Need an inexpensive chopper amplifier for conditioning low-level signals, such as those encountered with thermocouples? Combine a 709 and a 714 op amp with a CMOS analog switch, such as the CD4016-AE. You'll end up with a low-cost amplifier that has linearity of better than 0.1% and typical dc drift of only $0.3 \mu\text{V}/^\circ\text{C}$, ideal for your low-level application.

The basic design of the chopper amplifier is depicted in Fig. 1. It consists of ac amplifier A_1 , chopping and demodulating switches SW_A and SW_B and integrating amplifier A_2 . Negative feedback is provided through voltage divider R_1R_2 . The attenuated output voltage, V_f , is thus compared with the input voltage, V_{in} , and the difference is chopped—that is, converted to a pulsating voltage—by switch SW_A and amplified by A_1 . Switch SW_B , which is driven in parallel to SW_A , synchronously rectifies the amplified ac signal, thus retaining the polarity of the amplified error. The demodulated signal is then fed to the integrating amplifier, A_2 , which produces the filtered output, V_o .

The over-all open-loop gain of the amplifier can be approximated by

$$A_{OL} = \frac{1}{2} \cdot \frac{R_{f1}}{R_{in}} \cdot \frac{R_{f2}}{R_1}, \quad (1)$$

where the factor $1/2$ accounts for the fact that the duty cycle is 50%.

The negative feedback factor of the amplifier is

$$\beta = \frac{R_2}{R_1 + R_2}. \quad (2)$$

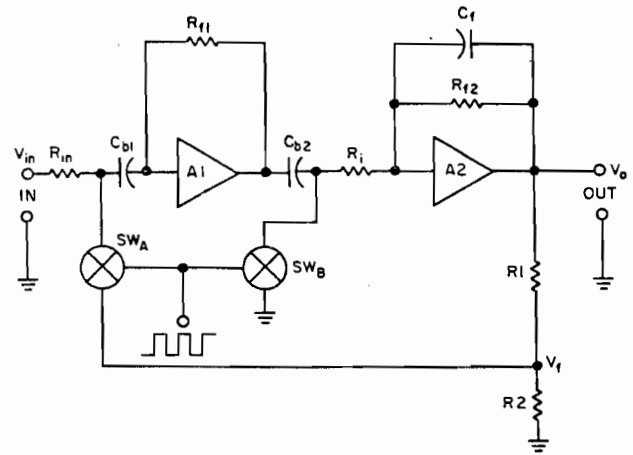
Hence the closed-loop gain is

$$A_{CL} = \frac{\frac{R_{f1} \cdot R_{f2}}{R_{in} \cdot R_1} \cdot \frac{1}{2}}{1 + \frac{R_2 \cdot R_{f1} \cdot R_{f2}}{2(R_1 + R_2) \cdot R_{in} \cdot R_1}}. \quad (3)$$

If $\frac{R_2 \cdot R_{f1} \cdot R_{f2}}{2(R_1 + R_2) \cdot R_{in} \cdot R_1} > 1$,

the closed-loop gain can be approximated by

$$A_{CL} \approx \frac{R_1 + R_2}{R_2}. \quad (5)$$



1. The chopper amplifier consists of ac amplifier A_1 , chopping and demodulating switches SW_A and SW_B , and integrating amplifier A_2 .

If ideal switches are assumed, the only contribution, to dc drift will be the input dc error, caused by the voltage offset and input bias current of amplifier A_2 . Analysis of the output dc offset due to this error can proceed as follows:

The open-loop gain for dc error at the input of A_2 is

$$A_{OL\epsilon} = \frac{R_1 + R_{f2}}{R_2}, \quad (6)$$

whereas the negative feedback factor is

$$B_\epsilon = \frac{1}{2} \cdot \frac{R_2}{R_1 + R_2} \cdot \frac{R_{f1}}{R_{in}}, \quad (7)$$

and the closed-loop gain

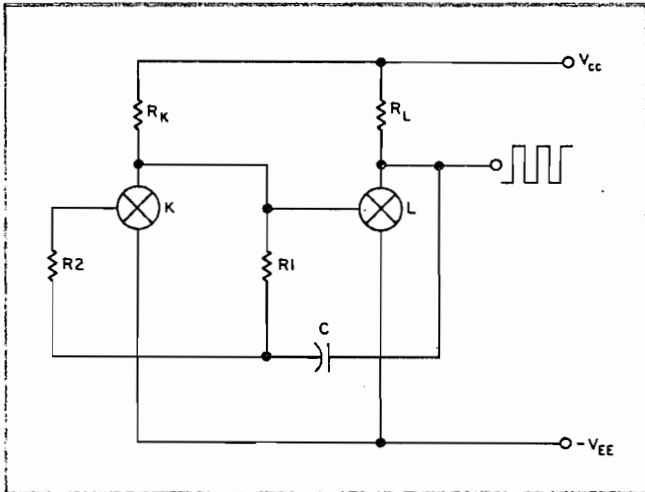
$$A_{CL\epsilon} = \frac{\frac{R_1 + R_{f2}}{R_2}}{1 + \frac{R_2 \cdot R_{f1} \cdot (R_1 + R_{f2})}{2 \cdot R_2 (R_1 + R_2) R_{in}}}, \quad (8)$$

or approximately

$$A_{CL\epsilon} \approx \frac{R_1 + R_2}{R_2} \cdot \frac{R_{in}}{R_{f1}}. \quad (9)$$

If the gain of A_1 , R_{f1}/R_{in} , is adjusted to be at the same order of magnitude of $R_1 + R_2/R_1$ (the closed-loop gain) $A_{CL\epsilon}$ can be made small—say, one. Hence for a properly designed amplifier, the dc error at the output will be in the same order of magnitude as the error at the input of A_2 .

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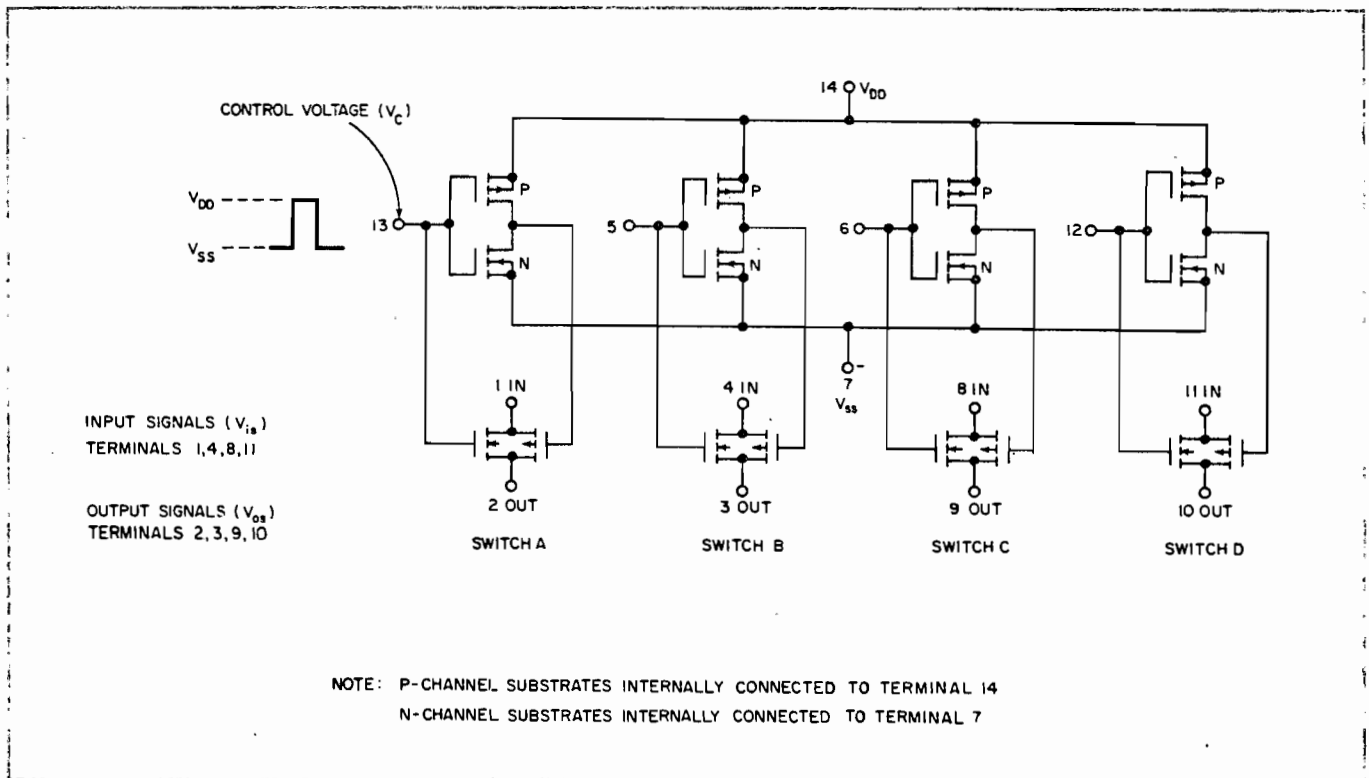
2. A standard CMOS bilateral switch, CD4016AE, includes four switches. Two of these switch sections are used as a square-wave oscillator.

Referred to the input of the chopper amplifier, these errors can be made very small, since the over-all closed-loop gain (Eq. 5) will generally be high.

Another source of dc error at the output is caused by current leakage at the input. Leakage between the two terminals of the chopping switch to ground, or finite switch resistance, are rather unimportant because of the high open-loop gain. However, parasitic current leakage to the supply voltage must be minimized.

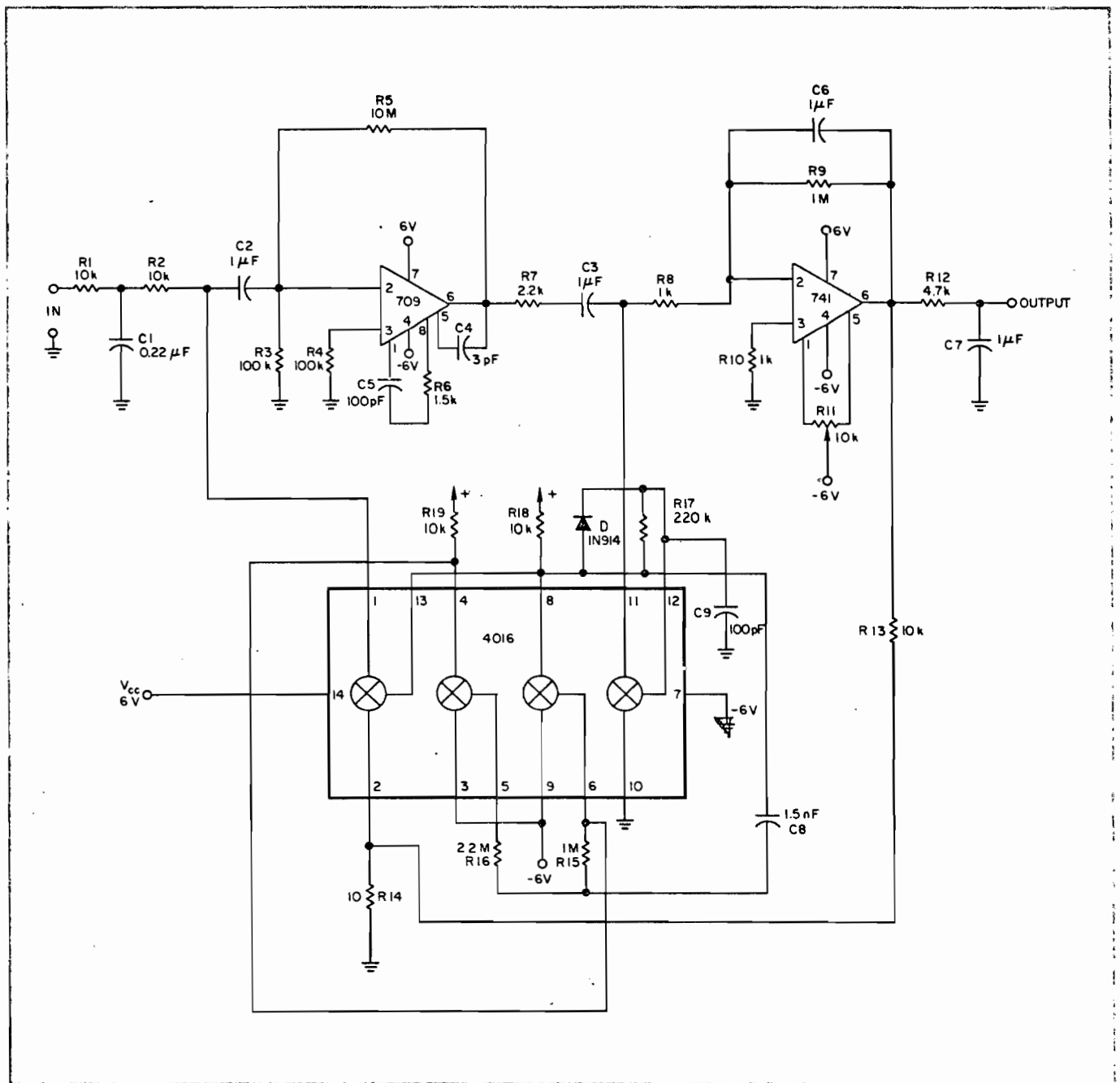
Using surplus sections of CMOS

Since a standard CMOS bilateral switch, such as CD401, includes four switches, the two surplus switches can be used as the square-wave oscillator for driving the switches. This can be accom-



3. The CD4016A quad bilateral switch consists of four independent bilateral switches on a single monolithic

chip. Each of the switches can be controlled by a single logic signal.



4. The final chopper amplifier design includes a 709 op amp for the ac amplifier, a CD4016AE CMOS switch, and

a 741 op amp as the integrating amplifier. Two switches act as choppers, the others form an oscillator.

plished if you convert each of the extra switches to an inverter (Fig. 2) and then connect these to form a conventional oscillator.

The CD4016A (Fig. 3) contains four independent bilateral signal switches, each consisting of an n-channel and a p-channel device. The source of the p-channel device is connected to the drain of the n-channel device and vice versa. Only one control signal is required for each switch and it is applied to the n-channel unit. The p channel is controlled by the control signal, which is reversed in polarity by an inverter (included on the CD4016A chip).

The final chopper amplifier design is shown in

Fig. 4. The ac amplifier uses a 709 type op amp, which provides sufficient bandwidth at the nominal closed-loop gain of approximately 500. The integrating amplifier is built around a 741 and has a dc gain of 1000. The feedback network, R₁₃ and R₁₄, fixes the over-all closed-loop gain of the amplifier at about 1000. The analog switches are driven by the square-wave oscillator at a frequency of about 600 Hz. The network R₁₇, C₉ and D, provides a slight delay to the demodulating switch so it remains closed longer than the chopping switch. This prevents some of the switching transients from being transmitted to the integrating amplifier, A₂. ■■

