Application Brief

BEHIND THE SWITCH SYMBOL

Use CMOS Analog Switches More Effectively When You Consider Them as Circuits

by Jerry Whitmore

CMOS analog switches are widely used to make or break circuits in such applications as multiplexing and function switching. Ideally, they have zero resistance when closed, infinite resistance when open, no leakage, instantaneous glitch-free response, and no parasitic capacitance. While these assumptions are reasonably valid for low-frequency applications at moderate impedance levels, the good designer will always challenge them, to establish what errors may be introduced and even to determine whether the circuit configuration is viable.

SWITCH CIRCUITS

Figure 1 is a reasonable approximation of the circuitry in a single-pole dielectrically isolated CMOS switch (e.g., AD7510DI or AD7590DI series*). The dielectric isolation makes possible protection against latchup and overvoltage to ±25V beyond the supplies. Note that, for one polarity, conduction is via an N-channel FET; for the other polarity, it is via a P-channel FET. The two types are not perfectly symmetrical.

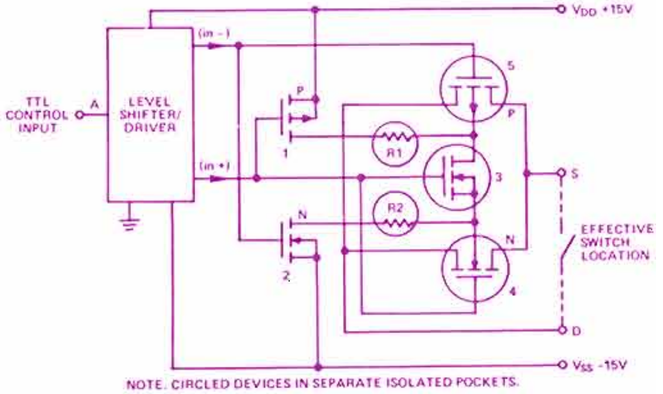

Figure 1. Typical output switch circuitry of the AD7590DI Series.

Figure 2 is an equivalent circuit of a pair of adjacent switches. The parameters are defined in Table 1. There are three principal categories of error one should be concerned about: low-frequency errors due to resistances and current leakage (switch open or closed), high-frequency and signal-transient errors due to stray capacitances (switch open or closed) and dynamic errors due to switching transients while the state of the switch is changing. Because of the present limitations of space, we shall for now consider just the first category, since it answers the most urgent question, "How well does the switch actually work for low-frequency signals?"

Although the leakage currents of the P- and N-channel transistors (devices 4 and 5 in Figure 1) might appear to tend to cancel, they don't, since the P channel is three times larger than the N channel.

Table 1. Nomenclature

C_{DS}:	Open-switch capacitance
C_S,C_D	Source, drain capacitance
R_{ON}	Series on resistance
S,D	Source, drain; electrically interchangeable
C_{SS},C_{DD}	Capacitance between any two corresponding switch terminals
I_{LKG}	Leakage current of back-gate diode

Because of the size mismatch of the reverse-biased source-or-drain-to-back-gate diodes, plus the differing lot-to-lot variations in breakdown voltage of the diodes, it is difficult to predict leakage or its tempco. However, maximum values at 25°C and over temperature are specified and 100% tested.

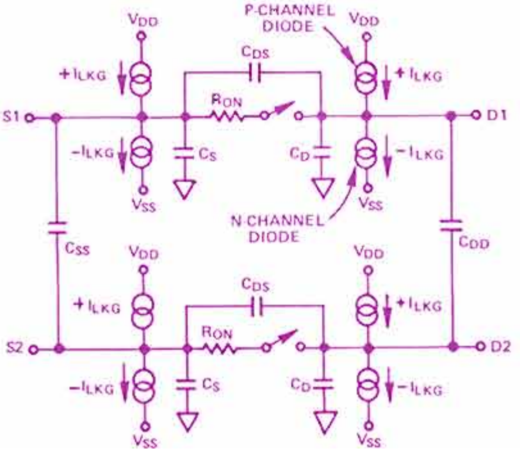

Figure 2. Equivalent circuit of a pair of adjacent switches.

Figure 3 shows the factors affecting dc performance for the *on* switch condition and how the various parameters affect the output voltage. Figure 4 shows typical curves of R_{ON}, as they appear on the product data sheet. They indicate how R_{ON}, is affected, as a function of input voltage, by supply voltages and by temperature, R_{IN} is lower and less signal-dependent at the higher supply voltages and lower temperatures.

How to minimize the influence of variable R_{ON} on circuit accuracy: Figure 5 shows a problem circuit–an inverting amplifier with four switched inputs. R_{ON}, in series with the 10-kilohm input resistor, affects the circuit gain. Even if it is compensated for at one level of suply voltage and analog input voltage, the input's variations will cause the gain to change and degrade the gain accuracy.

The most obvious solution–if the amplifier doesn't have to invert or act as a precision attenuator–is to use the amplifier in a nonin-

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*For technical data, use the reply card.

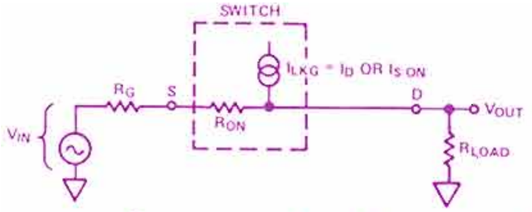
verting mode, as shown in Figure 6. Since there are no resistors in series, there is no effect on gain.

Another solution (Figure 7) is to connect the quad switch at the amplifier's summing point. Then the switch sees only millivolts—rather than volts—of signal variation, minimizing the variation of R_{ON} with signal. This solution can impair bandwidth, since capacitance C_S may require a capacitor in parallel with the feedback resistor for compensation. Also, I_{LKG}, flowing through the feedback resistor, may cause significant error, depending on the accuracy requirements. ($\Delta V_{OUT} = I_{LKG} \times R_F$).

Another possible solution is to use larger values of input and feedback resistance (Figure 8). Then the ΔR_{ON} variations will be small compared to the 1-megohm load. However, bandwidth will be affected by the larger R-C time constants.

Figures 7 and 8 do not compensate for the effects of variation of R_{ON} with temperature. A circuit that provides good compensation (Figure 9) uses one of the switches, wired *on*, in series with the feedback resistor. Its R_{ON} will tend to track that of the other switches on the same substrate with temperature; thus the feedback and input resistances will tend to track quite well, keeping the gain constant.

The principal dc effect in the switch *off* condition is that of I_{LKG} ($I_{D\ OFF}$ or $I_{S\ OFF}$), which will bias the output of a circuit by $I_{LKG} \times R_L$. Polarity of the error is determined by the dominant leakage polarity of a given switch.

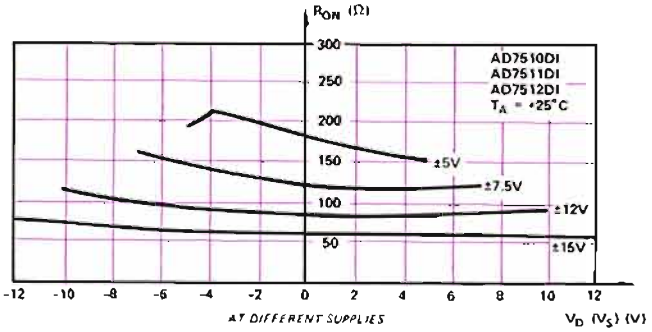


$$V_{OUT} = V_{IN}\left[\frac{R_{LOAD}}{R_G + R_{ON} + R_{LOAD}}\right] + I_{LKG}\left[\frac{R_{LOAD}\,(R_{ON} + R_G)}{R_G + R_{ON} + R_{LOAD}}\right]$$

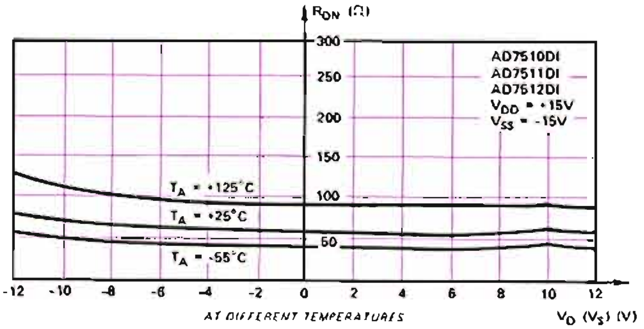
If $R_G \to 0$,

$$V_{OUT} = V_{IN}\left[\frac{R_{LOAD}}{R_{LOAD} + R_{ON}}\right] + I_{LKG}\left[\frac{R_{LOAD}\,R_{ON}}{R_{LOAD} + R_{ON}}\right]$$

Figure 3. Effective circuit of switch in the ON condition.



a. R_{ON} vs. V_D (V_S), as a function of $+V_{DD}$, ($-V_{SS}$.)



b. R_{ON} vs. V_D (V_S), as a function of temperature.

Figure 4. R_{ON} vs. input voltage as a function of supply voltage and temperature.

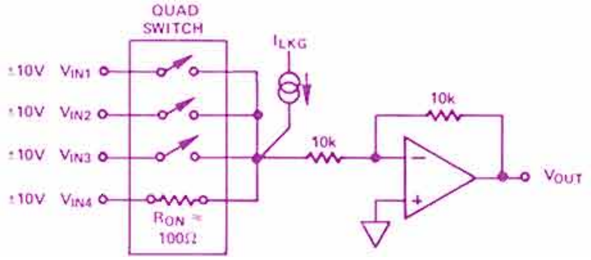


Figure 5. Unity-gain inverter with switched input.

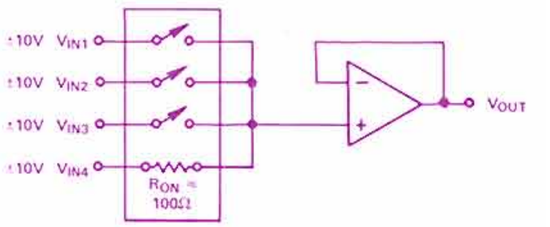


Figure 6. Noninverting solution.

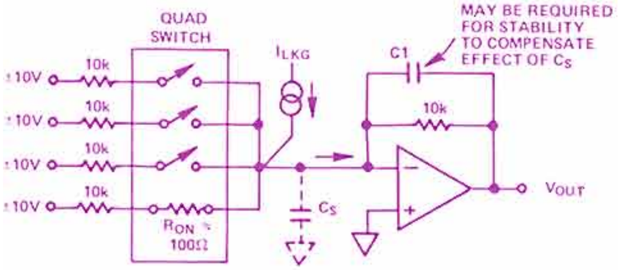


Figure 7. Connecting switch at the summing point.

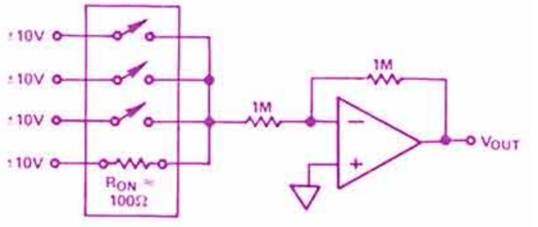


Figure 8. Using larger values of resistance.

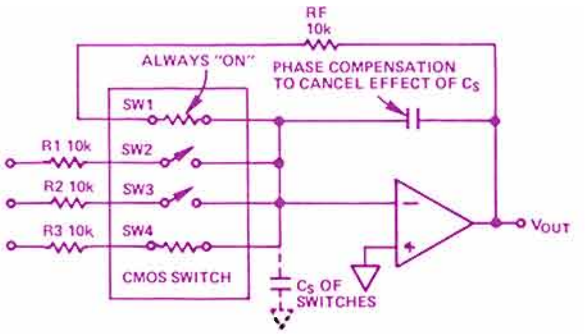


Figure 9. Switch in series with feedback resistor to compensate gain.