# Use Excel To Calculate A-D Level-Shifter Resistor Values

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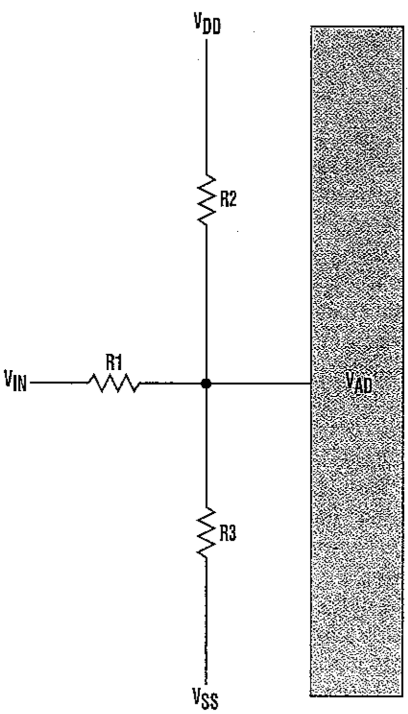
**Many times, the need arises to** interface single-supply analog-to-digital converters (ADCs) and comparators to real-world signals like ±5 V. Of course, it's possible to condition the signal using operational and/or instrumentation amplifiers. But few engineers realize that it's often possible to achieve the level shifting using a resistor network *(Fig. 1)*.

Critics of this technique point out that the resistor network can load the source voltage and cause distortion. We can build this limitation into Microsoft Excel to ensure the resistor values don't overload the input. Another possible concern is that some ADCs won't run properly with a high source impedance, so you would probably have to buffer with a suitable operational amplifier.




**1. This is the basic resistor level shifter circuit used for the ADC. It's used to derive the equations employed in the Excel spreadsheet.**

To calculate resistor values, we need to use Kirchhoff's Law: The sum of currents into a node is zero. Considering the node at the junction of the three resistors, we can write:

$$(V_{IN} - V_{AD})/R1 + (V_{DD} - V_{AD})/R2 + (V_{SS} - V_{AD})/R3 = 0 \qquad (1)$$

As an example, let us assume $V_{DD} = 5$ V, $V_{SS} = 0$ V, $V_{IN} = \pm 5$ V, and the ADC input must go from 0 to 2.5 V. For $V_{IN} = -5$ V, we want $V_{AD} = 0$ V. So we can substitute the values in Equation 1:

$$(-5/R1) + (5/R2) = 0 \qquad (2)$$

For $V_{IN} = +5$ V, we want the input to be 2.5 V, so substituting in Equation 1:

$$(2.5/R1) + (2.5/R2) - (2.5/R3) = 0 \qquad (3)$$

We have two equations with three unknowns, leaving one degree of freedom. Now we can go ahead and solve this. If we reduce the generalization so that $V_{SS}$ is always 0, we can rearrange Equation 1 as follows:

$$V_{AD} = [(-R2 \times R3 \times V_{IN}) - (R1 \times R3 \times V_{DD})]/[(-R1 \times R2) - (R2 \times R3) - (R1 \times R3)] \qquad (4)$$

Each time we do this though, it's a tedious process. But Excel has a feature aptly called "Solver," which will trivialize the whole exercise once it's set up. To use Solver, you must enable it as follows:

In Windows, go to Control Panel and select the Add/Remove Software option. Select the Microsoft Office entry, and then opt for changing or updating the installation. Find Excel in the list and for the Solver Add-in, select "Run from my computer." Follow the prompts to complete the installation. Now start Excel. Click on Tools, followed by Add-Ins, and enable the Solver Add-In. Follow whatever installation prompts occur (if any).

| | A | B | C |
|---|---|---|---|
| 1 | Level Shifter For A/D Converter | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | Supply Voltage, Vdd | 5.00 | |
| 6 | VinMax | 10.00 | |
| 7 | VinMin | -5.00 | |
| 8 | VadMin | 1.00 | |
| 9 | VadMax | 2.50 | |
| 10 | R1 | 116666 | |
| 11 | R2 | 38758 | |
| 12 | R3 | 19434 | |
| 13 | | | |
| 14 | Kirchoff's Law: Minimum Condition | 0.00 | |
| 15 | Kirchoff's Law: Maximum Condition | 0.00 | |
| 16 | | | |
| 17 | Vin | 10.00 | |
| 18 | Vad | 2.50 | |
| 19 | | | |
| 20 | IinMax (mA) | 0.06 | |
| 21 | IinMin (mA) | -0.05 | |

**2. Once loaded into Excel, the worksheet appears as shown here.**

After loading the worksheet, ADinput.xls, which can be found at *www.electronicdesign.com*, open it to reveal Figure 2. The input parameters are in cells B5 through B9. Cell B14 contains Equation 1 suitably modified for the minimum condition as follows:

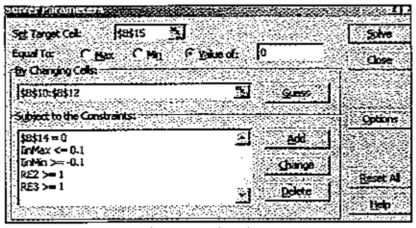
=((VinMin-VadMin)/RE1)+((Vdd-VadMin)/RE2)-(VadMin/RE3)

Similarly cell B15 is modified for the maximum condition:

=((VinMax-VadMax)/RE1)+((Vdd-VadMax)/RE2)-(VadMax/RE3)

Cells B20 and B21 contain the formula for the input current. Notice that it sources when the maximum input voltage is applied and sinks for the minimum.

To invoke Solver, click on Tools | Solver and then make sure the entry parameters are as in Figure 3. Solver will modify cells B10 through B12, trying to keep cells B14 and B15 at zero and cells




**3. Parameters for the Solver Add-in to Excel are entered via this window.**

B20 and B21 below and above predetermined project parameters. In this case, the current is limited to ±0.1 mA. You can modify this by selecting the constraint and clicking on the Change button. Note that you can work with two or more target cells by constructing all but one of the targets as constraints.

Cell B18 is used to prove that the resistor values do, in fact, generate the correct voltage range. By changing the value in cell B17, you can see how the value of Vad changes. Cell B17 contains Equation 4. It's possible to use Excel to generate the standard resistor values as well, but this isn't described here.

**Recommended Reading:**

1. Kagan, Aubrey, *Excel by Example: A Microsoft Excel Cookbook for Electronics Engineers*, Newnes 2004, ISBN 0750677562
2. National Semiconductor, Datasheet ADC0801, DS005671, Nov. 1999

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**ED ONLINE 12123**



# Tiny Circuit Saves Big On Relay Power

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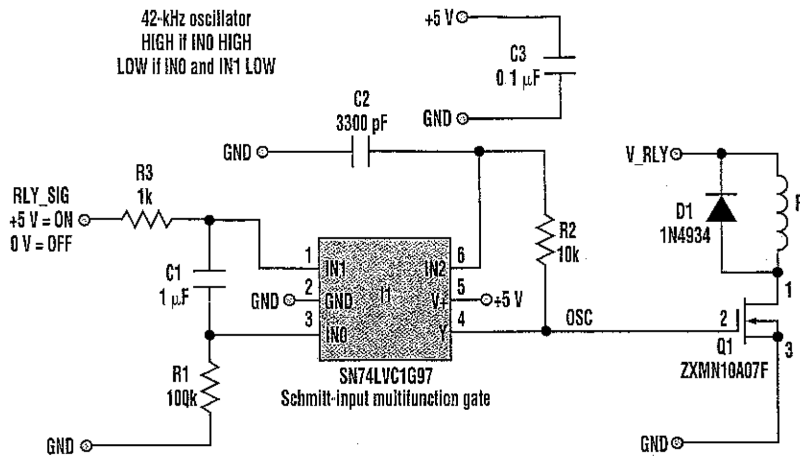


**Based on an SN74LVC1G97 Schmitt-input multifunction gate, this circuit energizes the relay at full power. It then holds the relay latched with the coil current reduced by 50%.**

**Designers frequently use special** circuits to reduce the power required to hold a relay in the latched position. Analog circuits such as the "brute force" resistor-capacitor solution or the time-variable current sink tend to be very bulky or waste energy in the pass-transistor.

The simple and small digital circuit shown in the figure energizes a relay coil at full power for the time required for reliable latch. It then automatically reduces the coil current by 50% to maintain the latched state at reduced power.

At the heart of the circuit lies a Texas Instruments SN74LVC1G97 Schmitt-input multifunction gate (I1) configured as a dual-gated oscillator. When the relay control signal (RLY_SIG) is low, the oscillator output (OSC) is low and the relay coil is off. When RLY_SIG goes high, C1 drives IN0 high.

This forces the output high for approximately 100 ms, which is plenty of time for most relays or solenoids to latch fully. If a longer latch time is required, increase the value of R1.

After the latch time, I1 functions as a 50% duty-cycle oscillator as long as RLY_SIG remains high. R2 and C2 set the oscillator frequency. With the values shown, the oscillator runs at about 42 kHz.

A dc relay coil will stay latched at this frequency because the induced current flowing through the coil and D1 holds up the magnetic field during the off time. Current draw on the +5-V supply is about 10 mA when oscillating and 5 µA when stopped

Using the designated parts, coil voltages of up to 60 V (V_RLY) and coil currents of 500 mA can be accommodated with a wide safety margin. If greater coil current or voltage is required, select a transistor with a higher drain current and/or voltage rating.

Watch out for the ratings of the freewheeling diode (D1), because it's essential in this pulse-width-modulated circuit. The reverse voltage rating of D1 must be greater than the relay supply voltage, and its current rating should equal the steady-state coil current

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