

Do's and Don'ts of Applying A/D Converters

**Introduction**

In many applications, the limitation in the performance of a system lies in how the individual components are used. The Analog-to-Digital Converter (A/D) can also be considered as a component and, therefore, proper design procedures are necessary to obtain the optimum accuracy. Intersil A/D converters are inherently extremely accurate devices. To obtain the optimum performance from them, care should be taken in the hookup and choice of external components used. Test equipment used in system evaluation should be substantially more accurate and stable than the system needs to be. The following sections illustrate do's and don'ts to obtain the best results from any system.

**Don't Introduce Ground Loop Errors**

Plan your grounding carefully. Probably the most common source of error in any Analog-Digital system is improper grounding. Let's look at Figure 1. All the grounds are tied together, so everything should be OK, right? Wrong! Almost everything is wrong with this connection.

The power supply currents for the analog and digital sections, together with the output or display currents, all flow through a lead common to the input. Let us analyze some of the errors we have introduced. The average currents flowing

in the resistance of the common lead will generate a DC offset voltage. Even the auto-zero circuit of an integrating A/D converter cannot remove this error. But in addition, this current will have several varying components. The clock oscillator, and the various digital circuits driven from it, will show supply current variations at the clock frequency, and usually at submultiples also. For a successive approximation converter, these will cause an additional effective offset. For an integrating converter, at least the high-frequency components should average out. In some converters, the analog supply currents will also vary with the clock (or a submultiple) frequency. If the display is multiplexed, that current will vary with the multiplex frequency, usually some fraction of the clock frequency. For an integrating converter, both digital and analog section currents will change as the converter goes from one phase of conversion to another. (Currents of this type injected into an auto-zero loop are particularly obstinate.) Another serious source of variation is the change in digital and display section currents with the result value. This frequently shows up as an oscillating result, and/or missing results; one value being displayed displaces the effective input to a new value, which is converted and displayed, leading to a different displacement, a new value and so on. This sequence usually closes after two or three values, which are displayed in sequence.

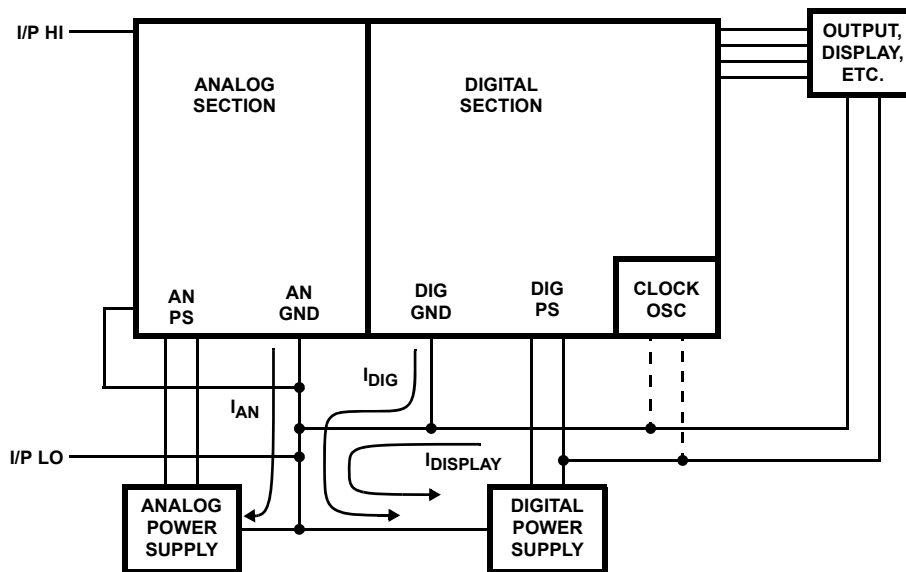


FIGURE 1. DON'T HOOK IT UP LIKE THIS!

A more subtle source of errors in this circuit comes from the clock oscillator frequency. For an integrating converter, variations in clock frequency during a single conversion cycle due to varying digital supply voltage or supply currents, or ground loops to a timing capacitor, will lead to incorrect results.

Figure 2 shows a much better arrangement. The digital and analog grounds are connected by a line carrying only the interface currents between sections, and the input section is also tied back by a low current line. The display current loop will not affect the analog section and the clock section is isolated by a decoupling capacitor. Note that external reference return currents and any other analog system currents must also be returned carefully to analog ground.

### Don't Couple Digital Signals Into Analog Lines

Although Intersil's A/D converter circuits have been designed to minimize the internal coupling of digital signals into analog lines, the external capacitive coupling is controlled by the user. For best results, it is advisable to keep analog and digital sections separated on PC boards. A few examples of the results of capacitive coupling follow.

On dual slope converters, the "busy" line swings from one state to the other at the end and beginning of the autozero cycle. Capacitive coupling from this line to the autozero or integrating capacitors will induce an effective input offset voltage. A similar effect occurs with the "Measure/Zero" line on charge-balancing converters and for a successive approximation converter with coupling between "end of conversion" and a sample-and-hold capacitor. For a multiplexed display device, coupling between the multiplexed or "digit" lines and these capacitors can lead to nonlinearity of the converter. And coupling from any digital line

into a high impedance input line can lead to errors in any system.

### Do Use Adequate Quality Components

For successive approximation converters, the resistors used must have excellent time and temperature stability to maintain accuracy. Any adjustment potentiometers, etc., must be of compatible quality (note that in some trimpots, the slider position moves with temperature!).

For dual slope converters, the component selection is less critical. Long term drifts in the integrating resistor and the capacitors are not important. However, any resistive divider used on the reference, especially if it is adjustable, must be of sufficient stability not to degrade system accuracy. Dielectric absorption in the integrating capacitor is important and the integrating resistor must have a negligible voltage coefficient to ensure linearity [1-7]. Noisy components will lead to noisy performance, whether in the integrator, autozero or clock circuits.

### Do Use a Good Reference

Good references are like good wines; nobody is quite sure how to make them but generally the older the technology used, the better the result, and the proof lies in the tasting (or testing). Thus, it is hard to beat the old temperature compensated zener with the current flow adjusted to the optimum for each diode. If you aren't into Zinfandel Superior Premier Cru (1972), the Intersil ICL8052 has a fairly good reference built in. In either case, the division down to the desired reference voltage requires care also (see above). And it is a fundamental fact that no converter can be better than its reference voltage.

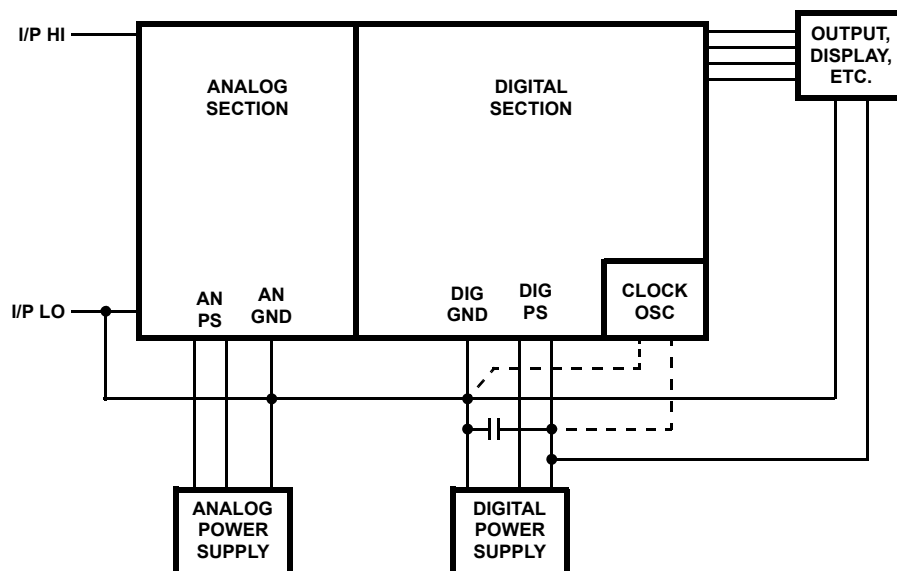


FIGURE 2. DO HOOK IT UP LIKE THIS!

### Do Watch Out for Thermal Effects

All integrated circuits have thermal time constants of a few milliseconds to dissipation changes in the die. These can cause changes in such parameters as offset voltages and  $V_{BE}$  matching. For example, the power dissipation in an 8018 quad current switch depends on the digital value. Although the die is carefully designed to minimize the effects of this, the resultant temperature changes will affect the matching between current switch values to a small degree. Inappropriate choice of supply voltages and current levels can enhance these differences, leading to errors. Similarly, the power dissipated in a dual-slope converter circuit depends on the comparator polarity and hence varies during the conversion cycle. Offset voltage variations due to this cannot be autozeroed out, and so can lead to errors. Again a poor choice of comparator loading or swing will enhance this (normally) minor effect. The power dissipation in an output display could be coupled into the sensitive analog sections of a converter, leading to similar problems. And thermal gradients between IC packages and PC boards can lead to thermoelectric voltage errors in very sensitive systems.

### Do Use the Maximum Input Scale

To minimize all other sources of error, it is advisable to use the highest possible full scale input voltage. This is particularly important with successive approximation converters, where offset voltage errors can quickly get above 1 LSB, but even for integrating-type converters, noise and the various other errors discussed above, will increase in importance for lower-than-maximum full scale ranges. Preconverter gain is usually preferable for small original signals. All Intersil's integrating converters have a digital output line that can be used to extend autozero to preconditioning circuits (being careful not to couple the digital signal into the analog system, of course).

### Do Check These Areas

Tie digital inputs down (or up) if you are not using them. This will prevent stray input spikes from affecting operation. Bypass all supplies with a large and a small capacitor close to the package. Limit input currents into any IC pin to values within the maximum rating of the device (or a few mA if not specified) to avoid damaging the device. Ensure that power supplies do not reverse polarity or spike to high values when turned on or off. Remember that many digital gates take higher-than-normal supply currents for inputs between defined logic levels. Remember also that gates can look like amplifiers under these circumstances. An example is shown in Figure 3, where stray and internal input-to-output capacitance is multiplied by the gain of the gate just at the threshold causing a large effective load capacitance on the ICL8052 comparator. A non-inverting gate here could lead to oscillations.

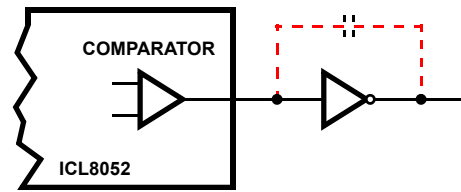


FIGURE 3.

### External Adjustment Procedure

Most of the A/D converters now offered by Intersil do not require an offset adjustment. They have internal autozero circuits which typically give less than  $10\mu\text{V}$  offset. Therefore, the only optional adjustment required to obtain optimum accuracy in a given application is the full scale or gain reading.

With the A/D converter in a continuous mode of conversion, the following procedure is recommended: The full scale adjustment is made by setting the input voltage to precisely  $1/2$  LSB less than full scale or  $1/2$  LSB down from nominal full scale. (Note that the nominal full scale is actually never reached but is always one LSB short.) Adjust the full scale control until the converter output just barely switches from full output to one count less than full output.

### References

For Intersil documents available on the internet, see web site <http://www.intersil.com/>  
Intersil AnswerFAX (321) 724-7800.

- [1] *AN016 Application Note*, Intersil Corporation, "Selecting A/D Converters", AnswerFAX Doc. No. 9016.
- [2] *AN017 Application Note*, Intersil Corporation, "The Integrating A/D Converter", AnswerFAX Doc. No. 9017.
- [3] *AN023 Application Note*, Intersil Corporation, "Low Cost Digital Panel Meter Designs and Complete Instructions for LCD and LED Kits", AnswerFAX Doc. No. 9023.
- [4] *AN028 Application Note*, Intersil Corporation, "Building On Autoranging DMM with the ICL7103A/8052A A/D Converter Pair", AnswerFAX Doc. No. 9028.
- [5] *AN030 Application Note*, Intersil Corporation, "ICL7104, A Binary Output A/D Converter for  $\mu$ Processors", AnswerFAX Doc. No. 9030.
- [6] *AN047 Application Note*, Intersil Corporation, "Games People Play with Intersil's A/D Converters", AnswerFAX Doc. No. 9047.
- [7] *AN052 Application Note*, Intersil Corporation, "Tips for Using Single Chip 3-1/2 Digit A/D Converters", AnswerFAX Doc. No. 9052.

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