PART V

GUIDE FOR THE TROUBLED

Chapter Twenty-Two

Guide For The Troubled

One of the hoped-for byproducts of this book is a more interesting life for data-acquisition manufacturers' Applications Engineers, because the technical inquiries they receive from our readers should become more challenging. This should be in addition to a saving of time and telephone expense for both users and manufacturers.

It is accomplished by making broadly available as much as possible of the information and advice that most commonly passes during seminars and conversations between manufacturers and users; this we have sought to do in the preceding pages.

To be useful, such information must also be accessible. There is, of course, an Index. In addition, this Chapter is intended to provide access by relating material in the book to the typical inquiries that are received, and by listing specific, recurring matters. Telephone conversations typically involve one or more of the following:

- Requests for information
- Requests for advice
- Requests for assistance when things don't seem to work right
- Urgent pleas for rescue

In order to minimize calls in all of these categories, but especially those in the latter two, listed here are a few of the most-frequently occurring topics of conversation, with comments and sources of information likely to resolve the problem. The general headings are: Frequently Asked Questions, Frequently Encountered Problems, Frequently Given Advice, and "If All Else Fails . . ."

22.1 FREQUENTLY ASKED QUESTIONS

Q. What is ESD? Should I worry about it? Why? What can I do about it?

A. ELECTROSTATIC DISCHARGE. Yes. It can kill ICs. Handle ICs, especially CMOS, carefully. Read the 36-page pamphlet, "ESD Prevention Manual," generally available at no charge from Analog Devices, Inc.

Q. How serious are "Absolute Maximum" ratings?

A. They mean what they say. Ignore them, forget them, or accidentally violate them at your peril.

Q. Is it really necessary to read the inside pages of the data sheets?*

A. Only if you want to save time and money, get your design right the first time, and have that delicious feeling of being competent and in command of your project. A great deal of effort goes into data sheets from conscientious manufacturers, in the attempt to ensure best use of the product, anticipate the needs of the user, and answer questions that might be asked. Competently produced data sheets have product descriptions, specifications, descriptions of operation, practical suggestions for the user, and application ideas—and accuracy is a passion with the people who write them.

Q. Is anything else that's "meaty" available to prepare me to use conversion products?

A. There are Application Notes, Application Guides, books like this one, and serial publications, such as ANALOG DIALOGUE. In addition, manufacturers have staffs of trained sales and applications engineers, who provide seminars for users, from time to time, write articles on useful topics for the trade press, and give talks at conferences. They are naturally enthusiastic about their products, but that is generally the total extent of "hype."

Q. What do the codes mean? What is complementary BCD? How does offset-binary relate to twos complement?

A. See Chapter 7.

Q. How do converters work?

A. See Chapter 7.

Q. How do I choose the right converter?

A. See Chapter 11—also Chapters 13, 14, 15, 16, 17.

Q. What are the differences between voltage- and current-switching DAC's?

A. See Chapter 7.

Q. What's a "glitch?" How is it caused? How can I eliminate it?

A. See Chapters 3, 7, 11, 13, 17, 18.

Q. How does input noise affect A/D conversion? How can I combat it?

A. See Chapters 2, 10, 11, 12, 13, 18.

*People really ask questions like this!

Q. Where can I find out about sampled-data systems?

A. See Chapters 2, 6, 7, 12, 13, 18, 21, and Bibliography.

Q. How can a converter have a throughput rate that exceeds 1/(conversion time)?

A. It can if it's "pipelined." For example, if it has three 50-nanosecond stages, several samples can be working internally at the same time, with a new sample accepted—and a new output delivered—every 50 nanoseconds, at a 20-MHz throughput rate. A complete conversion of one sample point nevertheless requires 150 nanoseconds.

Q. What limits the analog bandwidth in a/d conversion?

A. The sampling theorem limits the analog bandwidth to one-half the sampling rate, using equally timed samples. However, the actual bandwidth that can be handled with a given degree of resolution and accuracy may be considerably less, depending on the aperture uncertainty (See Section 2.4). A track-hold can bring about considerable improvement, even with "flash" converters (See Section 13.2.2).[1]

Q. How will my system know when a conversion is complete if my flash converter doesn't have a Data-Ready signal?

A. Set up a time delay—equal to the maximum conversion time expected—between the encode command and the time the external latch is enabled.

Q. I understand that ECL is the predominant form of logic used in flash-type video conversion. How can I convert the ECL to TTL for compatiblity with my system.

A. Probably the simplest way is to use standard ECL-to-TTL converter chips, such as the Motorola 10124 and 10125.

Q. What does a track-hold or sample-hold really do for me?

A. At a definite instant of time, it converts a rapidly changing signal into a single value that the converter perceives as dc (which is much easier to process accurately).

Q. What are the contributions of various components to errors?

A. See Chapters 11, 12, individual product data.

Q. What are the timing constraints on converters?

A. See individual data sheets.

Q. What factors affect timing of systems with sample-holds and multiplexers?

A. See Chapters 2, 3, 11, 12, 13, 18, 19.

Q. What are the requirements on power supplies?

A. See Chapters 11 and 12, individual data sheets, power-supply catalogs.

[1]See also "Flash Converters Work Better with Track-Holds," by Jerry Neal and Jim Surber, *Analog Dialogue* 18-2 (1984): 10-14).

Q. How do I use DACs and ADCs with microprocessors?

A. See Chapters 2, 3, 4, 6, 8, 21, individual product data sheets.

Q. How do I connect a 10-volt device for a 10.24V full-scale range?

A. Scale-factor adjustment will usually have insufficient range, especially in high-resolution devices. Add series feedback resistance with DAC's, with due regard for resistance tempco (the loop is usually closed externally), or use attenuation ahead of the ADC input buffer (sometimes series input resistance can be used with current-summing comparators). Information on 10.24V full-scale range will be found in Chapter 7: see Table 7.3.

Q. How is the bipolar offset circuitry connected and adjusted? How does it affect the specifications?

A. See Chapters 7, 11, 12, 20, individual data sheets.

Q. What are the suggested grounding techniques?

A. See Chapters 2, 3, 10, 12, 13, 17, 20, individual data sheets.

Q. What are the issues in low-level multiplexing vs. instrumentation-amplifier-per-channel? How do instrumentation and isolation amplifiers differ?

A. See Chapters 2, 11, 12, manufacturers' Databooks.

Q. What happens if my 10-V ADC input is overranged at full scale? at zero?

A. With most ADCs, anything less than 0 reads 0, and anything greater than FS – LSB reads all-ones. Some types provide carries to flag F.S. overrange. If indication is required, accurate comparators can be used to provide flags.

Q. What is "Differential Nonlinearity?"

A. See Chapters 7, 11.

Q. Can I use the analog power supply as a source of constant voltage?

A. Yes—if it is sufficiently quiet and well-regulated to provide the desired degree of stability and accuracy. However, precision regulators and substitutes for Zener diodes are available in such numbers and variety—as well as at low cost—to suggest that the designer take advantage of their convenience and supply-independence. See Chapter 20.

22.2 FREQUENTLY ENCOUNTERED PROBLEMS

22.2.1 GROSS MALFUNCTIONS

Power supply not connected to circuitry; power supply not turned on; *a-c line cord not plugged in.**

Wrong digital code ("Positive true" vs. complementary).

Wrong analog polarity relationship.

Using TTL levels for non-TTL-compatible CMOS devices.

*Believe it or not, we do get calls where this is the problem!

Grounds not connected (or interconnected).

Power supply not really connected, wrongly connected, or zapped.

Missing or improper connections (Study the connection diagram).

Wipeouts due to applying power to devices in the wrong order (In general, power downstream units first; avoid, buffer, or protect multiplexers that short in the power-off condition).

ICs destroyed or degraded, and thus rendered useless, after zapping by electrostatic discharges (ESD)—a result of careless handling of susceptible ICs, especially CMOS.

ICs destroyed by excessive current in latchup modes—a result of inadequate protection of susceptible devices (by such techniques as voltage and current limiting, and use of protective diodes—Schottky and otherwise) against excessive or atypical voltages applied to device terminals, or separation of grounds by more than one diode-drop. CMOS logic must not be left "hanging"; all unused inputs should be tied High or Low.

Control-logic improper (polarity, duration, timing, levels). Check logic and timing diagrams on data sheets. Data lines connected in reverse order.

Bad software.

Uncontrolled overflow in counter configurations.

Wrong diode polarity.

Bent pin that didn't go into the socket (or perhaps even broke off).

Damaged high-speed (high-power) circuit due to shorted output.

Damage due to excessive temperature rise resulting from insufficient airflow.

22.2.2 POOR FUNCTIONING

Common-mode problems in "single-ended" system (use proper grounding or difference amplifier).

Grounding problems: no ground connection, fortuitous ground connection, wrong ground connection (common analog and logic return), shields returned to wrong ground or grounded at both ends.

Pickup due to proximity of digital ground plane to analog circuits, or proximity of analog and digital wiring, in general, or poor lead dress: Keep stray capacitance low; keep analog, digital, and power leads apart; if they must cross, analog and digital leads should cross at right angles.

Intermittent behavior due to poor soldering.

Excessive load capacitance on outputs of voltage DAC's or other analog devices can in some cases cause slow response, poor settling, ringing, or oscillation ("noise").

Improper connection of built-in references (unused bipolar offset references may require grounding in unipolar applications; external use of internal Zener voltage reference generally requires buffering).

Op amp voltage offset adjustment used for zeroing anything but op amp *voltage* offsets, e.g., system offsets, can result in increased thermal drift.

Logic overloading (logic outputs may also be used for internal purposes; check actual specified loading on data sheet).

Too much attenuation because "current-output" DAC's output impedance neglected.

Nonlinearity because current-output DAC's specified maximum output voltage range exceeded.

Poor behavior over temperature because tempco of external resistance does not match tempco of on-chip resistors, when they should track.

Noisy A/D conversion, increased differential nonlinearity, and missing codes caused by widening of quantization band due to noise on input signal, or picked up in wiring.

Unanticipated "glitches" due to lack of filtering, inappropriate converter choice, marginal logic timing, limited logic slewing rates due to excessive capacitive load, stray capacitive coupling to analog circuitry.

Last one or two bits of an ADC keep flopping around even though input is "constant." (Is it *really* constant? Look at it on a scope. Check for noise pick-up, either in the environment or via the power supply.)

Digital and analog "glitches" (or worse), due to insufficient power supply (and wiring) capacity to handle transient switching currents in CMOS circuitry; CMOS requires low current and dissipates little power in steady state, but may require large currents when switching between states—especially apparent when systems are clocked. Easily fixed by using power supplies and wiring with adequate capacity and regulation to handle worst-case switching situations.

Gain and offset adjustments performed in wrong order in DACs and ADCs (See Chapter 12).

Excessive thermal drifts due to: improper converter adjustment procedure; bias current flowing through resistances (MUX R_{on}, for example); use of op amp voltage offset adjustment to counteract bias-current or system offsets.

Loss of monotonicity over small or large temperature ranges: possible if a converter is specified at ±1 LSB differential nonlinearity at room temperature— or "monotonic" at room temperature. A conservative specification of ½ LSB or "monotonic over temperature" allows variation of an additional ½ LSB with temperature.

RFI or fast pulses causing rectification that produces offsets in low-level circuits.

"Long-tailed" responses due to thermal transients (some op amp or comparator circuits), or inappropriate capacitor choice (precision capacitors should always have low dielectric absorption—polystyrene, teflon, polycarbonate are among recommended materials). Precision components should be kept at a safe distance from circuits or components that have high, or rapid changes in, dissipation.

Offsets or noise caused by leakage currents (dc) or noise currents (ac) in high-impedance circuitry due to proximity of sensitive low-level leads to power supply leads or high-level digital signals; use shielding and guarding.

In long-running projects in large organizations, problems that arise due to cost-cutting changes made to a good design (e.g., glitches, noise, and missing codes due to replacing an expensive regulated linear supply by a low-cost switcher) at a later stage by a different engineer without taking into account the thinking behind the original design. If you inherit a design that works, don't make changes unless you understand all the consequences of what you're doing.

Oscillation of voltage-output DAC, used to drive loads through long coaxial cable runs (would you drive them with a 741 op amp?) Use inside-the-loop buffer amplifier, with force-sense lead configuration, or place DAC at remote location, using serial communication.

Excessive drift in low-level circuitry due to differential "thermocouple" effects in input leads (e.g., copper-to-Kovar at IC inputs). Differential-input leads should always be close together and their junctions should be as-nearly as-possible isothermal.

When all other possibilities have been eliminated, one should not discount the possibility that the device is malfunctioning or out of specification, either innately, as a result of some recent trauma, or as a result of some "early failure" mechanism. Many manufacturers subject certain of their products to "burn-in" to eliminate innate and "early failure" problems.

By no means are all problems chargeable to the user. Manufacturers of devices and components (including Analog Devices) have been known to have made available—inadvertently, and despite considerable effort—

Data sheets with errors or insufficient data
Devices that failed, for no apparent reason, when first plugged in.

Though rare, these possibilities should not be discounted. The user of conversion devices—especially in quantity—should be prepared to perform at least simple tests on devices to verify their performance; Chapter 10 may be found useful in this respect. A user who finds information on a data sheet that raises questions will find most manufacturers quite willing to discuss them and clarify the point in question, especially as it pertains to the application.

22.3 FREQUENTLY GIVEN ADVICE

22.3.1 PREVENTIVE

First—Read the data sheet—thoroughly—especially the inside pages!

Nothing beats good initial analysis of the basic problem and conservative initial design, with double-checking to make sure that the best-available data has been used, the tolerances on resolution, accuracy, and timing are adequate, and the connection scheme is proper, and follows the manufacturer's suggestions—where appropriate. Breadboarding should be used if any aspect of the circuit or subsystem is unfamiliar or is pushing the state of your art.* The final design is not likely to succeed if the breadboard's performance is just barely in spec—and then only with tweaking and handholding. The design should include features that facilitate testing and trouble-shooting.

Be sure that common-mode, normal-mode, and induced noise problems have been considered and dealt with adequately. (Differential amplifiers, filtering, lead locations and directions.)

Be sure that grounding is proper: no ground "loops" (i.e., ground current is allowed only one path); digital and analog grounds separated; high-power and low-level signal grounds separated; One main "Mecca" point where all grounds meet, if feasible; heavy ground conductors, to avoid voltage drops in signal return leads.

Take care handling and using IC parts. Read up on and beware of electrostatic discharge (ESD). Use sockets whenever feasible, but avoid bending or breaking pins when plugging in or removing ICs. Make sure ratings are not exceeded. Use protective circuitry if necessary.

Be sure that interconnections of devices do not produce surprises as a result of (e.g.) currents and impedance levels, transient overloads during MUX switching, etc.

Despite everything we've said about the noise-rejection characteristics of digital, don't forget that digital circuits and signals are analog in nature (ohms, volts, amperes, farads, henrys). The very fast edges associated with high-frequency clocks (e.g., 10 MHz) can couple through power supplies, long leads, etc., to cause glitches and "mysterious" problems in digital circuits.

If you're using switching-type power supplies anywhere in the equipment, make sure that they are not affecting performance elsewhere, (a) via output leads, (b) reflected back through ac line, or (c) induced, coupled, or broadcast within the equipment. Don't use them for analog supplies.

*Overheard—one side of an all-too-frequent telephone conversation:
"You say you're having trouble with the data-acquisition circuit on your pc board . . .
"Well, how did your breadboard work? . . .
"Oh, you didn't build and test a breadboard? . . ."
"CLICK!"

To minimize noise from ac power supplies, power transformers should have metallic cases to eliminate radiated noise, and there should be electrostatic shielding between primary and secondary windings to minimize coupling of power-line spikes. Such transformers cost more and are often the misguided target of cost-cutting measures; if you expect noise to affect the performance of your system adversely, don't be "penny wise and pound foolish."

If the power transformer is not of adequate size to handle the worst-case load, its core is likely to saturate at the crests of sine waves; the incremental permeability vanishes, and there is no more inductance. Without this permeability in the core, the magnetic field lines can spread about as though there were no iron to channel them. In addition, the discontinuity produced by saturation can cause high-frequency transients to be radiated.

In high-speed circuitry, beware of transmission-line effects (e.g., attenuation and reflections) and antenna-like behavior of wire-wrap terminals.

After assembly, the system should be thoroughly inspected and "buzzed-out", to be sure that all connections have been made, the right elements have been plugged into the right spots, and there are no bent or broken pins.

Check the system out in small pieces and functional groupings before putting it all together. "Going for broke" often results in just that.

Remember that you can't tie two 8-bit DACs together for accurate open-loop resolution of 16 bits *unless one of the DACs has 16-bit accuracy.*

22.3.2 MEASURING DEVICES

For monitoring performance and troubleshooting, the devices that perform dc measurements should have at least twice the resolution and accuracy of the devices they are checking; the devices that perform high-speed measurements should have faster response than the devices they are checking. An oscilloscope should always be used to avoid "flying blind." A simple multimeter may be a trap (it can't see dynamic signals or oscillations; its dc resolution may be inadequate for useful measurements on the kind of high-resolution devices usually found in data systems; and its load impedance may affect the accuracy— if not the actual character— of measurements). Digital voltmeters often present a varying (and active) load to circuits being measured.

23.3.3 MEASURING AND TROUBLE-SHOOTING

First, check supply and ground voltages at terminals of pluggable devices, with the devices removed.

A useful procedure is to then perform dc, manual, and low-speed checks before performing measurements at speed. This ensures that the system is at least working properly under *some* conditions.

Try to isolate the problem.

If more than one unit of a given type is in use, an apparent failure at its location can be checked by substituting another unit. If similar units of the same kind exhibit the same problem, it is likely a design or system problem. (WARNING: If the problem is serious, involving a fault condition, the original unit and its substitute may no longer be in fit condition for further use.)

Check grounding with a simple continuity test. Use an orderly procedure. Have you localized the problem? Is it static or dynamic? Gross or subtle? Catastrophic or slightly "off?" Reproducible or intermittent? Affected by mechanical manipulation (kicking the cabinet)?

22.4 IF ALL ELSE FAILS . . . !

Reputable manufacturers want to help you solve the problem, whether it involves simple advice or the return of a unit. Although different manufacturers back their products up in differing ways, because of the sales channels they use, these guiding principles should be helpful:

If the problem seems to be related to a conversion component (either suspected or proven),

1. Prepare a summary of the problem, and outline it to the manufacturer's applications engineering staff, either at the factory or at a local sales office (or representative or distributor), over the telephone (see (4)). They may suggest some useful diagnostic procedures or put you in touch with Customer Service about having units returned for evaluation.

2. Follow the suggestions and/or instructions they give you. Ask for complete information on returns and warranty service and follow the suggested procedures. Do not return any material without receiving authorization; this procedure will enable the manufacturer or the service organization to identify the material when it arrives and process it expeditiously.

3. Be sure to include with any returned units
   A. The name(s) and telephone number(s) of the person(s) with whom the technical (and business) aspects of the problem can be discussed.
   B. Complete information on the (suspected) malfunction, and the application in which it occurred.
   C. If the unit is believed to be in warranty, the purchase date and entity from whom purchased.

4. If you are using Analog Devices products and are in a critical "bind," phone Components Group Applications, (617)-935-5565, or the Corporate Customer Service staff, (617)-329-4700, for information and action. Their U.S. addresses are:

Components Group Applications
Analog Devices Semiconductor
804 Woburn Street
Wilmington, MA 01887

Customer Service
Analog Devices, Inc.
2 Technology Way
Norwood, MA 02062

Blank space has been provided at the end of this Chapter for readers to note any useful points not covered in the text of this chapter, new discoveries, errors found in the book's text or illustrations, etc., as well as other useful information about manufacturers—Analog Devices and others: local sales-office telephone numbers, names of helpful people, Telex and cable addresses, etc. Even if, as you read these words, you are not in urgent need of help, it may nevertheless prove useful to take a few minutes *right now* to obtain and write down some of that information.

NOTES*

*If, after using this page, you consider the technical content of what you have written to be significant, the authors and editor will welcome copies of it for the benefit of future editions and readers. Send them to Editor, *Analog-Digital Conversion Handbook*, P.O. Box 280, Norwood MA 02062 USA.

*If, after using this page, you consider the technical content of what you have written to be significant, the authors and editor will welcome copies of it for the benefit of future editions and readers. Send them to Editor, *Analog-Digital Conversion Handbook*, P.O. Box 280, Norwood MA 02062 USA.

*If, after using this page, you consider the technical content of what you have written to be significant, the authors and editor will welcome copies of it for the benefit of future editions and readers. Send them to Editor, *Analog-Digital Conversion Handbook*, P.O. Box 280, Norwood MA 02062 USA.