Data Acquisition System for Rocket Test Stand

This problem involves data acquisition at a system level, a problem common to *users* of computer data-acquisition and control (DAQ/C) boards who use them in system-level designs. This DAQ/C user is an astronautical (not astrionic) engineer building a rocket test stand, and he needs to acquire engine data such as chamber pressure and temperature, tank flow rate and pressure and, of course, engine thrust.

"Dear Dennis:

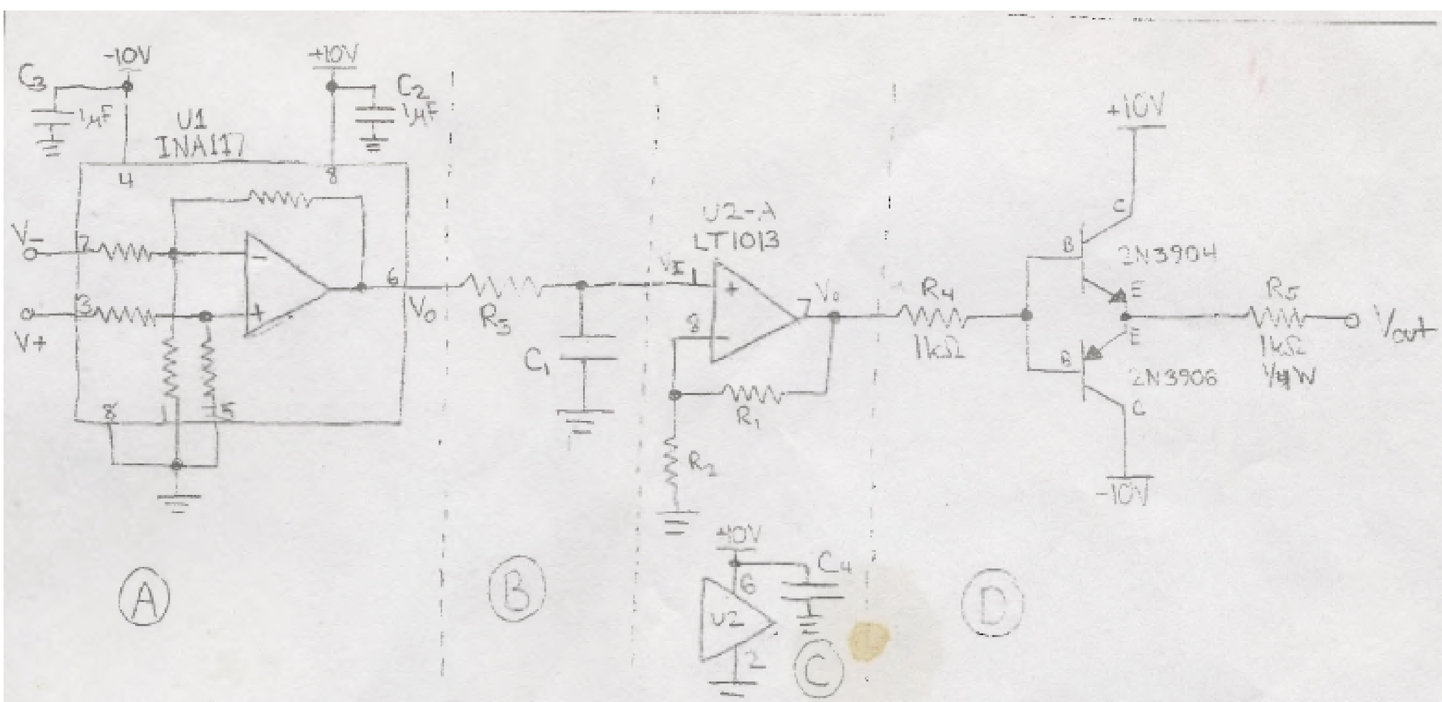
We are building up a data acquisition system for our test stand. Attached is a circuit design for a single channel of signal conditioning. The guy who designed it did signal conditioning design previously and has gone off to grad school and I'm looking for advice on how to build up a few circuits to test out with our A/D boards.

Our test stand will evaluate our ability to throttle a hybrid engine. We have a ball valve with a 15° slot cut into it. The flow control is very linear. We found a radio-control servo used for giant R/C models. The torque is over 400 oz-in and costs $120. We plan to start testing with a manual lever and progress to a throttle control system driven by the servo. The throttle is connected to an R/C receiver and we control it with a standard R/C control transmitter. The signal conditioning will measure load cells and pressure transducers.

Dennis Responds:

Some feedback on the data acquisition amplifier design:

> The design has some design documentation (not included here) to go with it. That's commendable. It gives me insight into what the designer was thinking. The schematic from the designer is below.



The design can be simplified and reduced in cost and parts count as follows:

1. The instrumentation amplifier is somewhat of an expensive IC with no access to the interior nodes. I recommend making the LT1013 into an instrumentation amplifier, using precision resistors, *and* adding Cs to make RC integrators of both inverting and non-inverting paths. Also, the input-stage amplifier should amplify the voltage (>>1) to minimize noise
2. If the final bipolar emitter-follower stage is needed for driving long output lines, then put it inside the loop of the op-amp! Otherwise, it is open-loop and will be horribly distorting. Expect maybe 3 bits or less of accuracy from this circuit. The final driver stage is inherently highly nonlinear around zero volts because it is not biased to remove the deadband. Putting it in the op-amp loop will largely solve this problem
3. It would be best to use standard (computer) supply voltages: +12 V instead of +10 V
4. Unless the DAS card has its own input-limiting circuitry there should be some at the amplifier output
5. The LT1013 is a good amplifier, and costly. Its really low input offset voltage is not necessary if the system is autocalibrated. (see my *Fundamentals of Rocketry* http://www.innovatia.com/FundRoc_ad.htm for a detailed design explanation of autocalibration.) All that is needed is low input-offset-voltage temperature drift, and cheaper op amps have that, such as the LF353 or LF347. Better yet, use an op amp, like the low-distortion (high linearity) Analog Devices OP176, that has some current-drive capability, and eliminate the final driver stage altogether

Anyone who would make this basic of a mistake in analog circuit design will probably overlook a number of other more refined aspects, which I'll not go into here, involving PSRR, common-mode range, gain accuracy, etc. A promising student, but... not there yet.

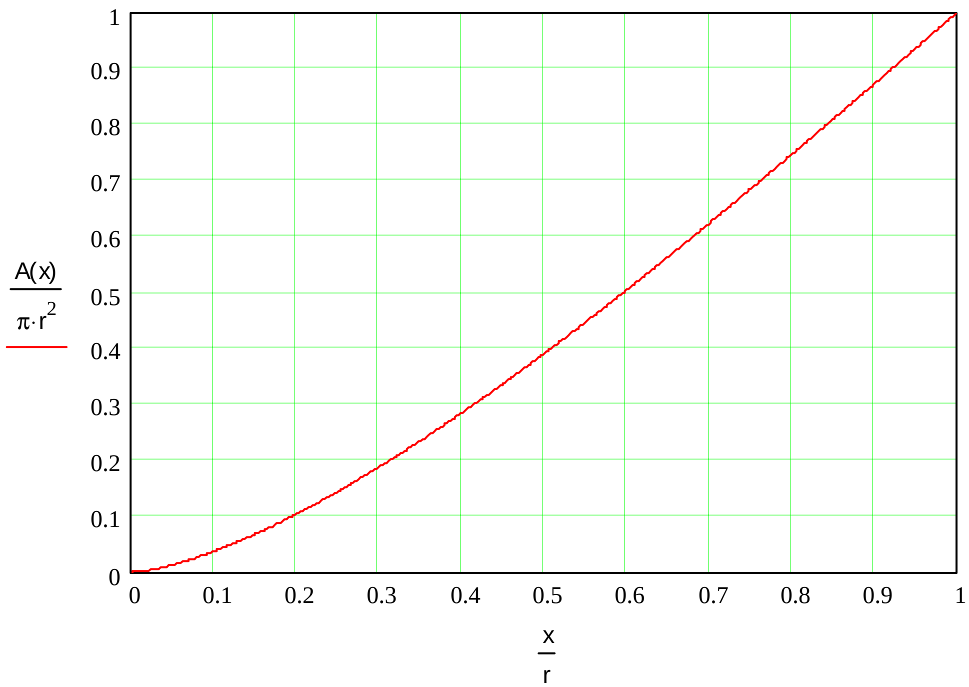
This approach of using one amplifier design for all sensors, ranging from load cells to thermocouples, is not optimal. For instance, the thermocouples must have some additional junction compensation circuitry, and load cells for measuring thrust (force) are usually designed to be in a bridge configuration.

"Our test stand will evaluate our ability to throttle a hybrid engine."

Great! This is exactly the kind of rocket development project that I have been looking forward to because it is necessary for affordable differential thrust-vectored control (DTVC). The Russians do a variation on this instead of gimbaling their engines and it works very well.

"I have a ball valve with a 15° slot cut into it. The flow control is very linear."

I did a study of the flow versus ball angle for the usual circular-channel quarter-turn ball valve a while back. The detailed derivations show that even for a typical ball valve the function is nonlinear but only mildly, as shown below. (The geometry is complicated.)



This is a plot of cross-sectional flow area normalized to the fully-open flow area, plotted against the circumferential distance the ball is rotated in the opening direction, scaled to the ball radius.

The biggest problem in either case is the nonlinearity associated with rotational stiction (coulomb or static friction) causing hysteresis, but that can be taken out by putting the valve in a feedback loop. This problem is very similar to the problem of removing nonlinearity from an output-stage driver like the one in the submitted sensor-amplifier design.

"We found a radio control servo used for giant R/C models. The torque is over 400 oz-in and costs $120. We plan to start testing with a manual lever and progress to a throttle control system driving the servo. The throttle is connected to an R/C receiver and we control it with a standard RC control transmitter. The signal conditioning will measure load cells and pressure transducers."

This should be a viable solution. The Innovatia approach was to drive the valve directly with a gear-motor-based ball-valve controller http://www.innovatia.com/VC1.htm that can be servoed by a digital input from a processor in the feedback loop. This eliminates the potential faults and compliance of the additional mechanical linkages. Two lines are needed to interface to the valve controller: one control line determines valve direction (open-close) while the second line controls on-off. It can be PWM'd to reduce the nonlinear effects of stiction.

"Any suggestions how to build a few up. Can this be bread boarded? If so, how is it done?"

Some senior-level engineer (in capability) needs to do the overall control system design for throttling the engine. I suggest that only one unit be prototyped and refined until the system works. There is no point in repeating hardware errors. This might take a few static test firings, so I recommend starting small-scale to keep it cheap and simple. The control aspects should scale up without difficulty if the engine dynamic response is first-order scale-invariant. That is, if the full-scale engine behaves about the same as the prototype-scale engine, the design scale-up of the control should be straightforward -- mainly parametric tuning.

A throttled hybrid engine is a great choice of a project. I have had it in mind for some time. Accomplishing it will be a major achievement, for then the next step, of DTVC, can be pursued using four of them. (That part is in my book, end of Chapter 5 on *Astrionics*.) Once that is also accomplished, you're essentially there: a safe, reliable guided rocket. Then it will be time to put a space tourist inside as payload.

"Later, a sensor interface problem arose:

> I guess my problem boils down to this. I have two load cells and two pressure transducers and a computer with an A/D board. I need something to go between the two that allows the computer software to tell me what the thrust and pressure are in near real time. I am currently using Labview.

"If I send you the load cells and pressure transducers, could you build something that will do the job? I cannot easily afford a commercial alternative at the moment. As always, any help would be appreciated."

Your student might be able to do it with some guidance. Have him carefully read through the relevant portions of the above comments. The FundRoc chapter on electronics will show how to use autocalibration in the software. He will learn a lot about instrumentation electronics in doing so. It will take work on his/her part, yet far less in money, to follow this route.

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