PURDUE UNIVERSITY DEPARTMENT OF PHYSICS

Physics 53600
Electronics Techniques for Research

Now in PowerPoint!

Spring 2020 Semester

Prof. Matthew Jones

The usual ANNOUNCEMENT

- Obvious changes to the course:
  - No in-person lectures: you'll have to read the lecture notes yourself
  - No more labs: don't worry about it – your grade will be based on work done so far
  - Remaining assignments will try to cover topics that would have been explored in the lab
  - Second mid-term: simplest to cancel it
  - Final exam: I think it will be a 24 hour exam with written responses that can be easily sent by e-mail.
- Changes to grading scheme:
  - Old scheme: Assignments (30%) exams (40%) lab (30%)
  - New scheme: Assignments (50%) exams (25%) lab (25%)

The usual ANNOUNCEMENT

- Because there won't be any in-person lectures, you will have to read the lecture notes yourself.
- To demonstrate that you have read them, you will be required to answer *one or two simple questions* before the next lecture is posted.
- The question will probably be at the beginning and you just have to e-mail me the answer

  mjones@physics.purdue.edu
- To make this easy, please make your subject look like this:

  "PHYS53600 Lecture xx questions Your Name"
- These will be the remaining part of your assignment grade.

More ANNOUNCEMENTS

- Feel free to send me questions about the lecture material if there is anything you don't understand.
- Send me e-mail if you think it would be useful to arrange a time as a class to have a time where you can ask questions by video.
  - So far a couple of people have said it would be
  - Maybe something like Thursday, April 30th at 10:30 am EDT?

LECTURE 27 QUESTIONS

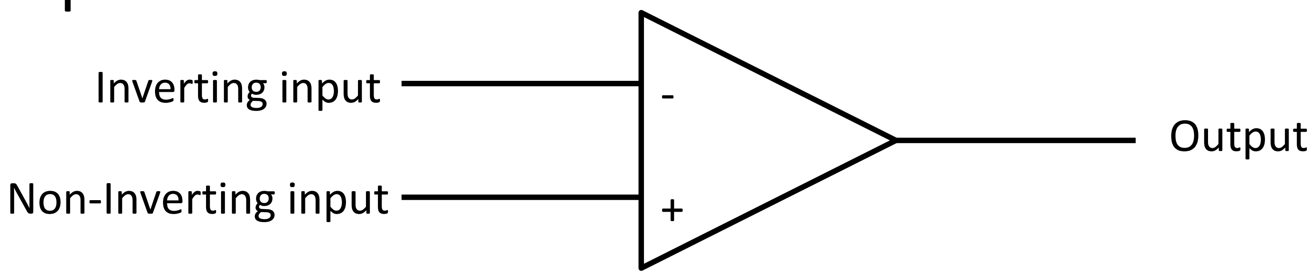
1. *Describe a lab experience you have had (e.g. in research or an undergraduate lab) that would have benefited from using a data acquisition system*
2. *List some of the potential improvements*
   - *Precision of measurements?*
   - *Speed of data acquisition?*
   - *Volume of data recorded?*
   - *Direct recording of digital information?*

Data Acquisition Systems

- Common applications for electronics instrumentation in research is data acquisition and process control systems
- Data acquisition:
  - Converting physical quantities to digital data
  - Usually a combination of a transducer and an analog-to-digital converter
- Process control:
  - Manipulate a system to achieve a desired state

Analog-to-Digital Converters

- Perhaps the simplest analog-to-digital converter is a comparator:



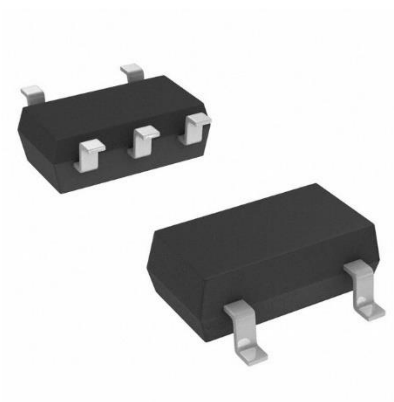
- This looks like an operational amplifier, but the behavior is very different
- The output is a digital logic level
  - Not usually incorporated into a feedback loop
- The output will be ‘1’ when $v_+ > v_-$ and ‘0’ otherwise.

Analog-to-Digital Converter

ANALOG DEVICES

Rail-to-Rail, Very Fast, 2.5 V to 5.5 V, Single-Supply TTL/CMOS Comparators

ADCMP600/ADCMP601/ADCMP602



FUNCTIONAL BLOCK DIAGRAM

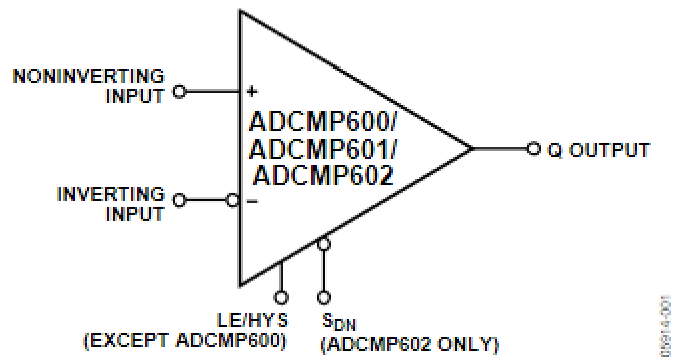


Figure 1.

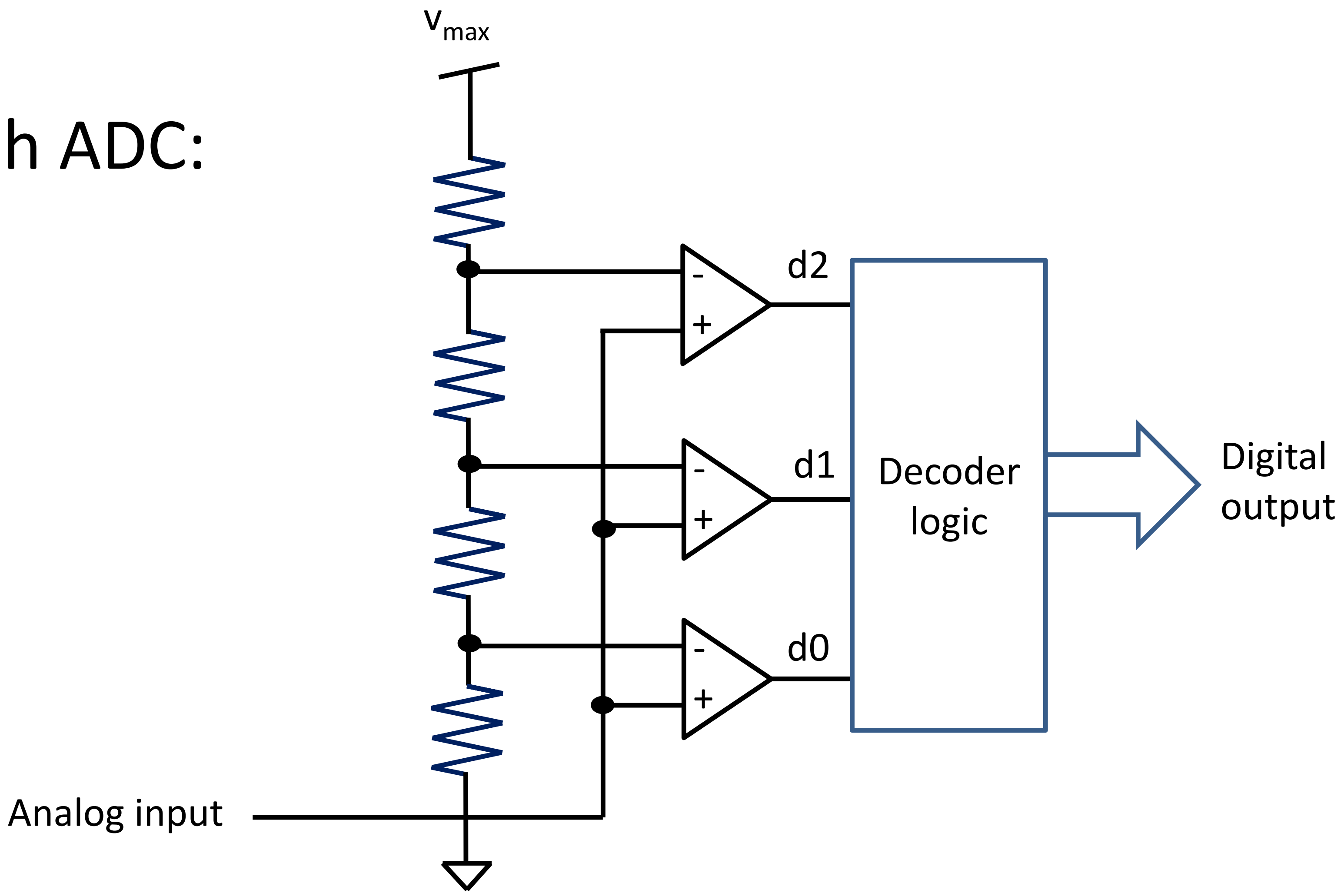
- High impedance inputs (>250 kΩ)
- When the inverting input is driven by a voltage source, the output will be 0 or 1, depending on the voltage at the non-inverting input.

Analog-to-Digital Converter

- Input voltage, v_{in} where $v_{min} < v_{in} < v_{max}$
- n-bit digital output:
  - Output should be a linear function of input voltage
  - Output is 0 when $v_{in} = v_{min}$
  - Output is 2^n-1 when $v_{in} = v_{max}$
- There are several architectures that can achieve this…
  - For example: Analog Devices technical note

ADC Architectures

- Flash ADC:



ADC Architectures

- Other ADC architectures are often more efficient:
  - The Successive-approximations architecture dynamically adjusts the digital output such that an internally generated voltage will match the input
  - Resolution of n bits is achieved after n comparison cycles.

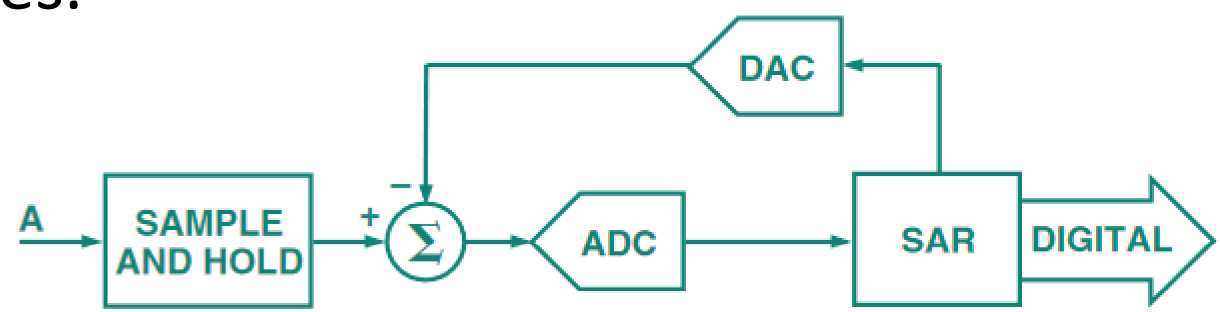


Figure 4. Successive-approximations architecture.

ADC Architectures

- Other ADC architectures are often more efficient:
  - The Sigma-Delta architecture matches the integral of the input and an internally generated digital waveform.

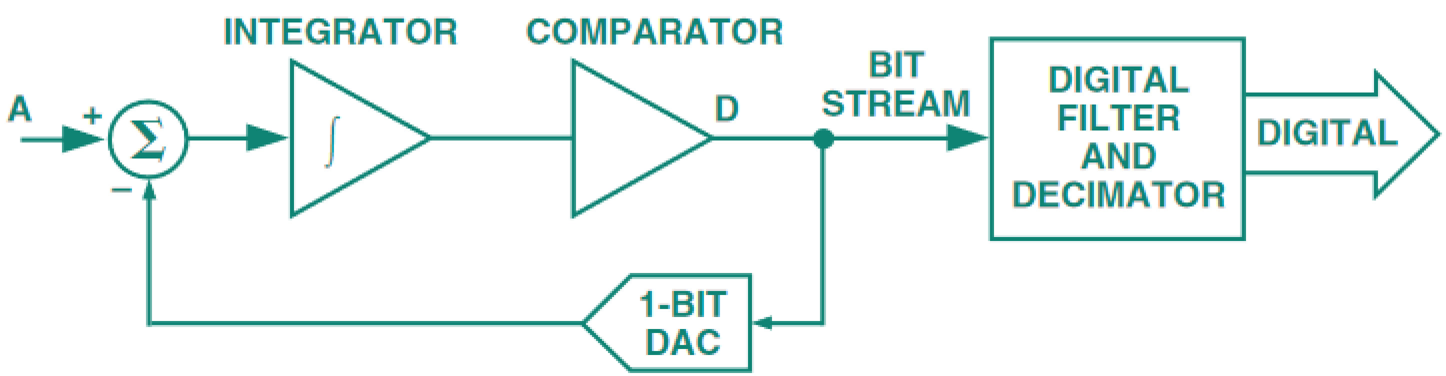
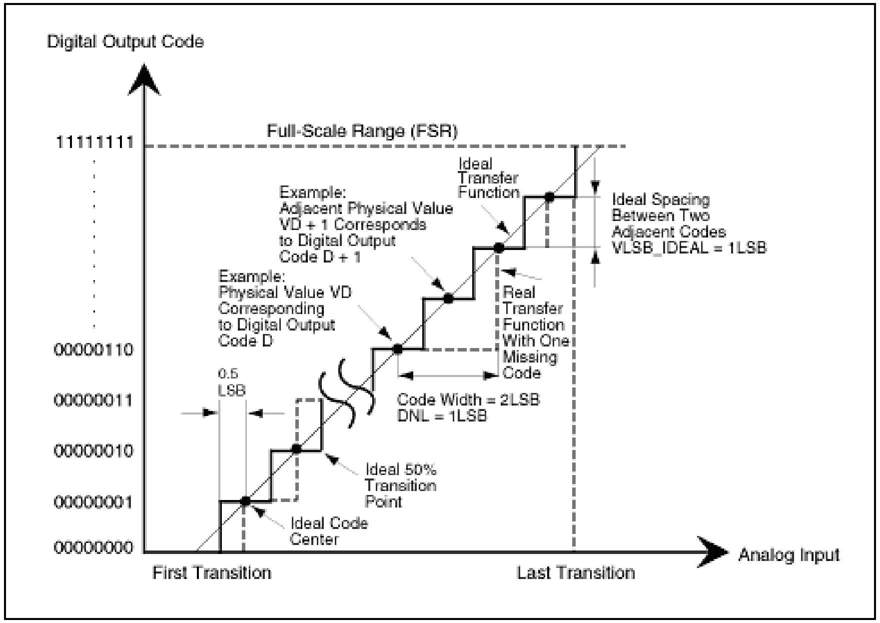
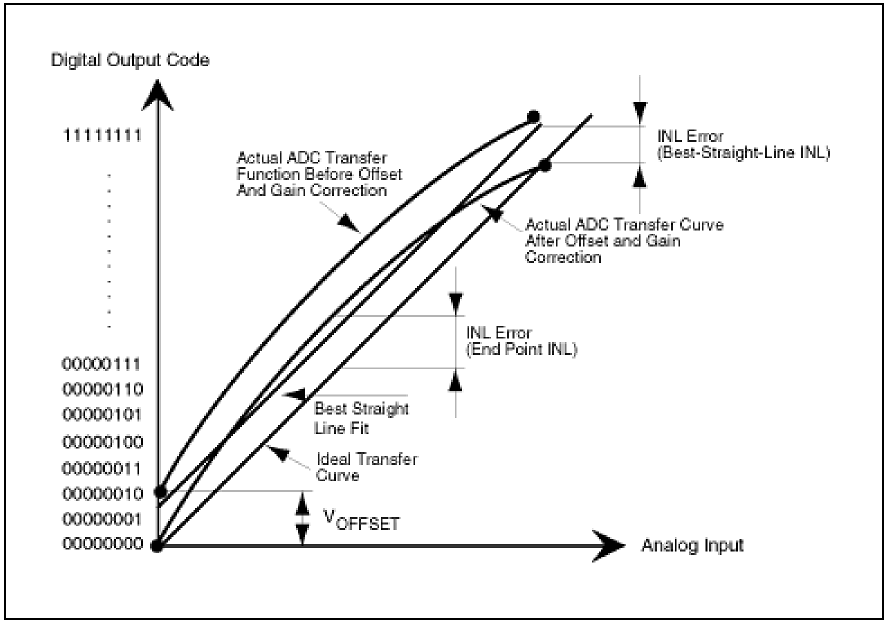


Figure 5. Sigma-delta ADC architecture.

ADC Architectures

- Quantifying ADC performance:





- Sometimes there are tradeoffs between precision, resolution, and speed

ADC Architectures

- Examples from Analog Devices:
  - High-speed ADC's (>20 MSPS)
  - Precision ADC's
- Main characteristics:
  - Sample rate (eg, samples per second)
  - Resolution (number of bits)
  - Intrinsic signal-to-noise
  - Number of channels
  - Cost

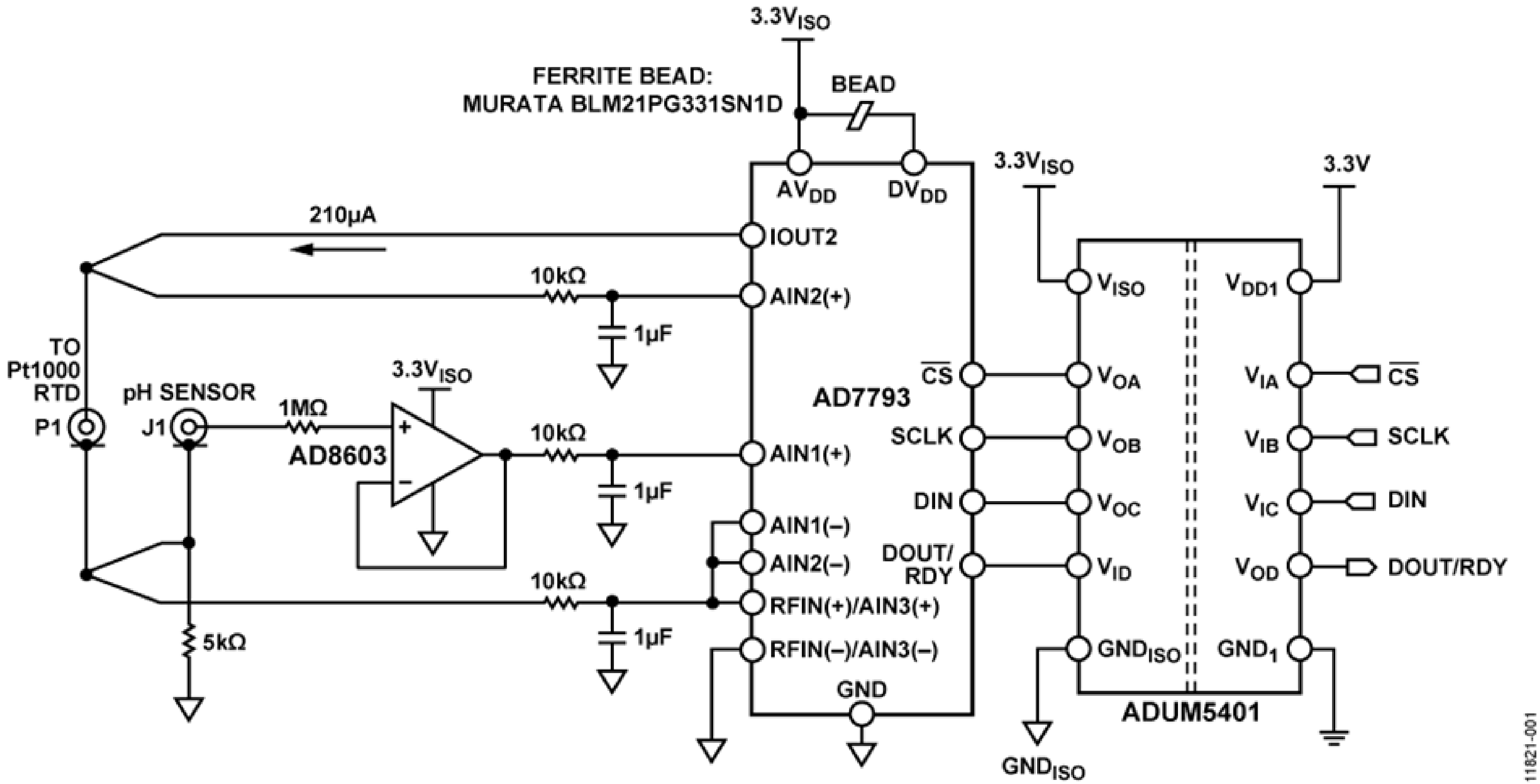
Transducers

- Many physical effects produce an electrical potential difference that changes in response to external conditions
- Examples for measuring temperature:
  - The PN junction voltage depends on temperature (band-gap temperature reference)
  - Thermocouples (voltage difference across junction of dissimilar metals)
  - Resistors (some can have very predictable/repeatable R vs T relationships)
- Mechanical transducers:
  - Piezoelectric devices (voltage output in response to pressure or strain on a crystal)
  - Variable resistors (mechanically adjustable resistance)
- Optical transducers:
  - Photo-multiplier tubes, avalanche photodiodes, various semiconductor materials

Signal Conditioning

- In most cases, transducers act like very non-ideal voltage or current sources
  - For example, they often have very high output impedance
  - Often, the voltage changes can be quite small
- The input to an ADC might have a much lower input impedance
- An analog circuit may be required to amplify a small signal and produce a proportional output voltage with a much lower impedance
  - This output can then be sampled using an ADC

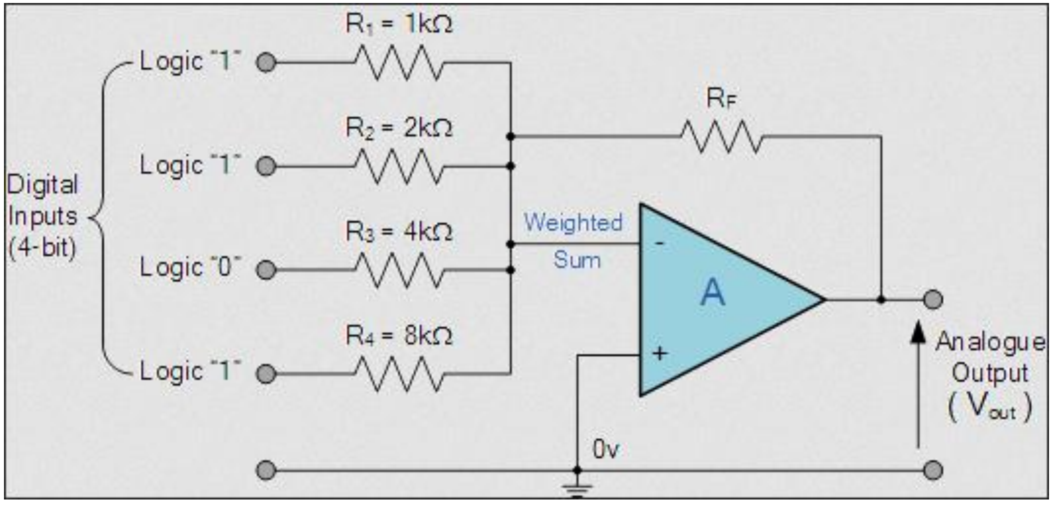
Example: pH Meter



There are some well-established formulas that relate the output voltage from the pH sensor to the actual pH of a solution and to its temperature. Thus, the pH of a solution can be calculated (ie, using a computer), once the temperature and the sensor voltage are measured.

Digital-to-Analog Converters

- Digital outputs can drive an op-amp circuit to produce an analog output:



- Notice that the ratio of adjacent input resistors must be 2 for an output voltage to be proportional to the digital input.

Digital-to-Analog Converters

- Examples from Analog Devices:
  - High speed DAC's
  - Precision DAC's
- Example applications:
  - Precision control of DC output voltage (low speed)
  - Direct digital synthesis of radio signals (high speed)

Data Acquisition Systems

- Data acquisition systems typically require:
  - Generating output voltages to set desired operating conditions
  - Measuring physical quantities of interest
- Instruments need to be controlled using a computer
- Several systems have been developed over the years to achieve this

GPIB (IEEE-488) Interfaces

- Originally developed by Hewlett-Packard in the 1960's
- Short-distance, multi-master, 8-bit parallel bus
- A suitable interface card is needed to connect to a computer

Connector on equipment

Connectors on cable

Interface card

GPIB (IEEE-488) Interfaces

- Lots of legacy equipment have GPIB interfaces
- Newer equipment might provide similar functionality using other interfaces, such as Ethernet
- Adapters between GPIB and Ethernet or USB can be quite useful for interfacing with older equipment

Examples of GPIB Equipment

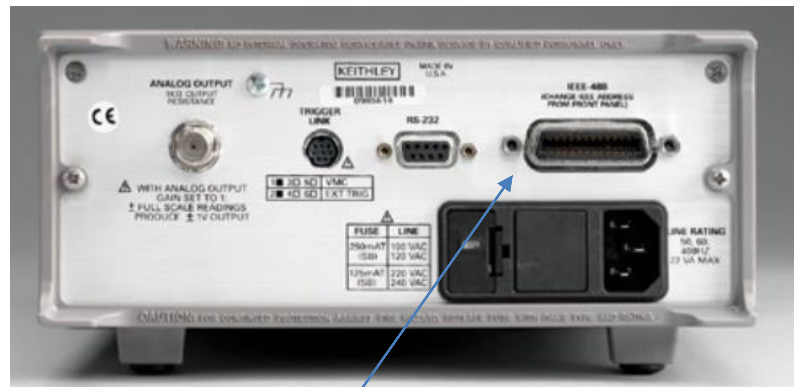
- Power supplies:

GPIB interface

Somewhere, deep inside the box, you would expect to find a DAC circuit…

Examples of GPIB Equipment

- Digital meters:



GPIB interface

Somewhere, deep inside the box, you would expect to find an ADC circuit…

Software Interfaces

- Most vendors provide sufficient documentation for remote operation via GPIB or Ethernet
- National Instruments caters to small-to-medium sized lab-based data acquisition systems:
- Academic software licensing (eg, LabVIEW)