Data Acquisition – Advanced Topics

Details of Data Acquisition Circuitry

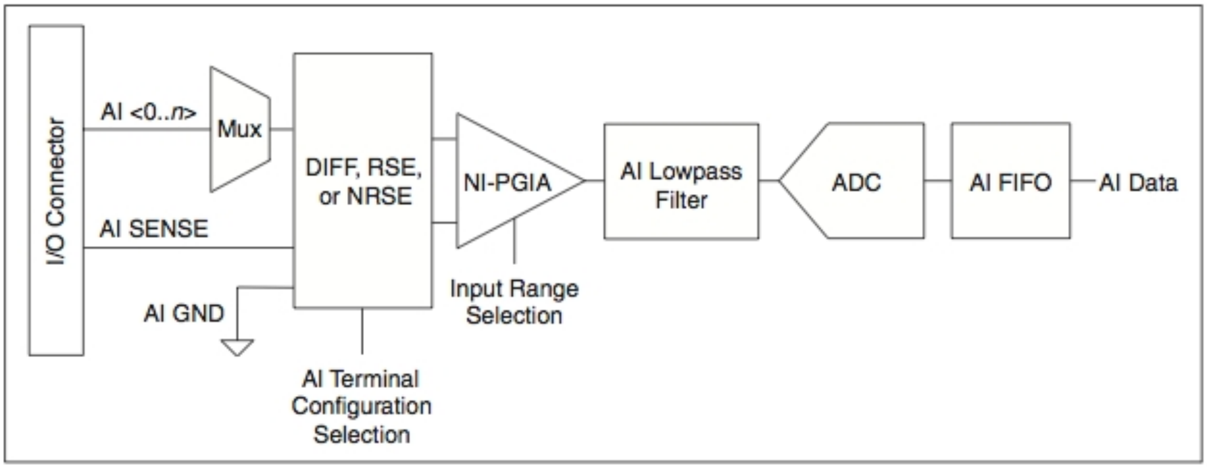

Figure 1: Typical circuitry in a data acquisition system (National Instruments M-series card)

Multiplexing

Most systems have a single A/D converter and circuitry to route each of the multiple input channels through that converter, alternating one sample on each channel. Some more advanced cards have dedicated A/D converters for each channel and do not require multiplexing.

Terminal configuration

Each input terminal can typically be configured to measure either a single signal or the difference between two signals. This configuration takes place in software, but many times hardware connector blocks also have switches that affect the grounding of input signals, so hardware and software settings must be in the appropriate combination for a given signal source. See Connections & Grounding below.

Range selection

Many acquisition systems pass the input signal through an amplifier with a selectable gain. The input range can be selected in software, in reality, this selects how much the signal is amplified or attenuated before going to the A/D converter (which converts a fixed range of voltages to digital numbers). As discussed earlier this semester, some software appears to allow you to select any input range you want but in reality the system will use whichever of the available ranges encompasses the requested range.

Analog lowpass filter

Most systems include an analog lowpass filter prior to A-to-D conversion (digitization). In many cases this filter has a fixed cutoff frequency above the maximum sampling rate of the card. Some more advanced cards have a programmable filter whose cutoff can be adjusted.

Highpass filter – AC vs. DC coupling

Some data acquisition systems allow a choice of the input to be AC or DC coupled. If AC coupled, any DC component is removed (and very low frequency components are attenuated) by a high pass filter with a low frequency cutoff. This allows the fluctuating portion of a signal to be recorded with high fidelity even if it is small compared to the constant portion.

Analog-to-Digital Conversion

This process was discussed earlier in the semester: an analog signal is represented by a digital number with a certain number (N) of bits, giving 2^N possible values.

Data Buffer

Many cards have some amount of memory where data can be stored temporarily before being sent to the computer along a data bus. A FIFO (first-in-first-out) buffer stores data in such a way that no data is lost unless the entire buffer becomes full (the earliest recorded data is sent out on the bus first, freeing up card memory for new data).

Multiplexing Considerations

Simultaneously sampling multi-channel cards have dedicated circuitry for each channel. Since most cards share a A/D for all channels and multiplex between them, there are a number of considerations to ensure best possible signals:

Ghosting

Use signal sources with low output impedance (relative to the input impedance of the data acquistion system). Multiplexers contain switches, typically made of switched capacitors. When one of the channels, for example channel 0, is selected in a multiplexer, those capacitors accumulate charge. When the next channel, for example channel 1, is selected, the accumulated capacitor charge leaks backward through channel 1. If the output impedance of the source connected to channel 1 is high enough, the resulting reading of channel 1 can be partially affected by the voltage on channel 0.

Crosstalk

If the cables carrying signals for different channels run along next to each other, there can be cross-contamination of signals, especially if the cables are particularly long and/or not shielded well.

Scanning Order

Avoid switching from large signals to small signals on adjacent channels whenever possible. After each switch in channels, the circuitry takes a finite amount of time to settle to their new value (from the old). If the new value is very small compared to the old, this settling time is longer. Another strategy is to record a grounded channel in between to real channels, to make sure the signal from the first real channel is completely gone before recording the next real channel.

Scan Speed
The sampling rate must be high enough to record all desired signal components (above the Nyquist frequency, ideally by a decent amount). However, it should not be way higher than necessary, since faster sampling gives less time for things to settle each time the channel is switched by the multiplexer.

Single-Ended vs. Differential Connections, Grounding

Data acquisition systems offer either single-ended or differential input connections. Often, the data acquisition device can be configured to offer either type using software, and usually this setting can be different for each channel.

Single-ended connections use one signal line that is measured relative to ground.

Differential input connections measure the difference between two different input lines.

Thus, a given card might have 8 differential inputs OR 16 single ended inputs.

Differential inputs
Reduce noise pickup and have good common-mode noise rejection (any noise that is added to both conductors in a wire will not show up if the measured signal is the difference between the two wires). Thus, it is appropriate:

- when signal voltage levels are low
- when cables travel through noisy environments (so noise level is high)
- when using very long cables (>10ft) (which also causes high noise levels)

However, two input channels are used per recorded signal, so the total number of channels available is reduced.

Single-ended inputs
More sensitive to noise, so should only be used

- when signal voltage levels are strong
- when cables are short and/or pass through non-noisy environments (low noise level)

Only one input channel is used per recorded signal, increasing the total number available

<table>
<tr>
<th rowspan="2">AI Ground-Reference Setting*</th>
<th>Floating Signal Sources (Not Connected to Building Ground)</th>
<th>Ground-Referenced Signal Sources†</th>
</tr>
<tr>
<td>Examples:
• Ungrounded thermocouples
• Signal conditioning with isolated outputs
• Battery devices</td>
<td>Example:
• Plug-in instruments with non-isolated outputs</td>
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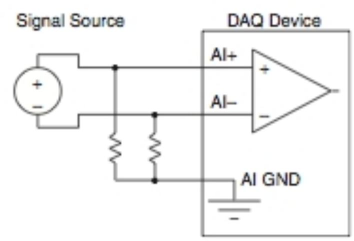
<td>
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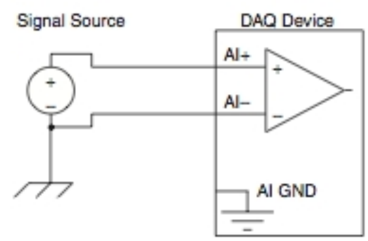
<td>
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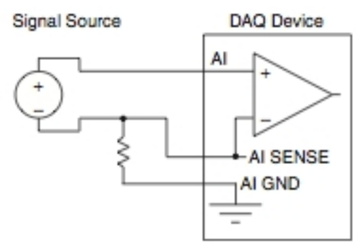
<tr>
<td>Non-Referenced Single-Ended (NRSE)</td>
<td>
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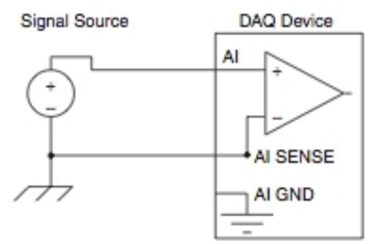
<td>
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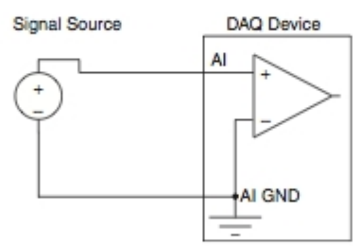
<td>
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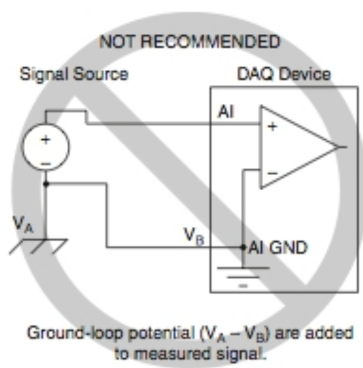
<td>
</td>
</tr>
<tr>
<td colspan="3">* Refer to the Analog Input Ground-Reference Settings section for descriptions of the RSE, NRSE, and DIFF modes and software considerations.
† Refer to the Connecting Ground-Referenced Signal Sources section for more information.</td>
</tr>
</table>

Figure 2: Analog Input Configuration (from National Instruments M-Series User's Manual)

Some connector blocks (such as the BNC-2120 blocks in B16) have fixed connections to the card input channels. For example, the BNC 2120 has 8 Analog Input BNC connectors. The central conductor of each is connected to the first 8 channels on the card, and the outer connector of each is connected to the next 8 channels. That is, the connector labeled AI0 is connected to both channels 0 and 8, the connector labeled AI1 is connected to channels 1 and 9, etc. The card should always be configured for *Differential* mode with such connector blocks.

Other connector blocks have connections that can be switched to accommodate the card operating in either Differential or Single-Ended modes. For example, the BNC 2090A rack-mounted connector block has a DIFF/SE switch for each channel. If the DIFF position, the central conductor is connected to one channel and the outer conductor is connector to another channel (so only half the BNC connectors are in use). In the SE position, the inner conductor is connector to one input channel but the outer conductor is connector to the AISENSE or AIGND channel, and a separate BNC connector is used for each channel (so they can all be in use).

If a data acquisition device is operating in Differential mode, neither input channel in each pair is connected to ground inside the card.

- If the input signal is already grounded (i.e., of the two input channels, one of them is an external ground), there is no problem.
- If the input signal is floating (i.e., the two inputs channels are both nonzero voltages) then one or both channels must be connected to an external ground through a large resistor (so that the voltage is not pulled to ground but a path to ground exists for amplifier bias current).
    - Some connector blocks, such as the BNC-2120, offer a hardware switch that provides the circuitry to do this. The 'FS' switch position is for 'Floating Source,' and will connect the outer conductor to the card's AIGND channel through a 5kΩ resistor. The 'GS' switch position is for 'Grounded Source' and is used when an external ground is supplied by the instrument providing the input signal: the outer conductor will not be connected to the card's ground.

If a data acquisition device is operating in Single-Ended mode, one of the inputs may or may not be connected to ground internally.

- If the input signal is floating, then one of the conductors must be connected to a ground inside the card. Unlike in differential mode, this is not done through a large resistor: the outer conductor is connected to AIGND directly so that the voltage on that conductor is held at zero, with the assumption being that the signal is on the other conductor.
- If the input signal is already grounded, then it should not be grounded again at the card. Some cards offer a Non-Referenced Signal Ended mode, in which the connection is single-ended but the other conductor is not held to ground. An AISENSE channel is provided which can fluctuate if needed to avoid a ground loop.

If a grounded signal source is connected in such a way that an additional ground connection is made to the card, a *ground loop* will result which can cause errors in the measured signal. This will occur:

- If the card is in Differential mode and a grounded signal is also tied to the card's ground through a large resistor (such as with the 'FS' switch on a BNC-2120 connector block)
- If the card is in Referenced Single Ended Mode a grounded signal will also be tied to the card's ground, and the two ground levels may not be precisely the same.

Hardware Timing

Timing of events occurring on a data acquisition cards can typically be controlled by either

- an onboard oscillator running at a fixed speed (perhaps 80 MHz or higher)
- an external signal provided by the computer or another device (typically this is done to synchronize multiple devices)

The card circuitry often has several timebases that run at integer fraction speeds of the onboard oscillator. For example, the PCI-6221 cards used in the lab have an 80 MHz onboard oscillator but control the analog input and output channels with a 20 MHz clock (and have a 100 kHz clock that is also used for some functions).

Every event that happens on the card is triggered by a tick of one of these timebase clocks. This imposes certain limits on the selections that can be made for various timing parameters, such as sampling rate.

For example, the PCI-6221 cards time the analog input sampling based on a 20 MHz clock. The highest possible sampling rate available on these cards (if only one channel is being used) is 250 kS/s (i.e., sampling rate of 250 kHz). If this maximum rate is used, it entails one sample being taken every 80 clock cycles. Any slower rate of sampling can be selected via software, but the actual sampling rates possible must always entail one sample taken every integer number of clock cycles. Thus, the following rates are possible:

Sample Rate	Number of clock cycles per sample	Time between samples
250.00000 kHz	80	4 microseconds
246.91358 kHz	81	4050 nanoseconds
243.90244 kHz	82	4100 nanoseconds
240.96386 kHz	83	4150 nanoseconds
etc.	etc.	must be a multiple of 50 ns

Triggering

Many data acquisition cards can be programmed to trigger acquisition when a particular condition occurs on a digital input. Some can also be programmed to receive a trigger on an analog input channel.

Digital triggers can occur either on the rising edge or falling edge of a digital pulse

Analog triggers can be programmed to occur

- when the analog signal first passes above or below any specified trigger level.
- when the signal first falls below one level and then above another, or vice versa (the difference between the two levels is refered to as a hysteresis value)
- when the signal enters or exits a specified range of values (window)

Bus Structures and Communication

A bus is a system on electrical pathways for transferring data and power, either internally between different components of a devices such as a computer, or externally between different devices (such as between a data acquisition device and a computer). There are a variety of data bus structures that can be classified as *serial* or *parallel* methods. Serial methods transmit data bit-by-bit, while parallel methods send multiple bits simultaneously using multiple wires. Network connections such as Ethernet or WiFi are not generally regarded as buses but serve the same purpose of transferring data (although they do not typically transfer power). Some newer technologies (such as InfiniBand and HyperTransport) further blur the distinction between networks and buses. A wide variety of communications buses have been and/or are currently used for connecting peripherals to computers. Some of those more commonly seen in the context of laboratory measurements and data acquisition are:

External Buses

Devices using the buses connect to ports on the outside of a computer or other device

- RS-232 (original 'Serial Port')
- RS-422 (a similar, higher speed serial bus)
- USB ('Universal Serial Bus')
- IEEE-1394 ('Firewire' 'i-Link' or 'Lynx')
- Centronics (originial 'Parallel Port'), which became IEEE1284
- IEEE-488 (GPIB or HPIB: 'General Purpose Interface Bus' or 'Hewlett-Packard Interface Bus')
- SCSI ('Small Computer System Interface') – parallel bus
- SAS ('Serial-attached SCSI') – a newer, serial version of SCSI
- Ethernet/LAN
- LXI ('LAN eXtensions for Instrumentation') – adds triggering and syncronization features

Internal Buses

Some devices are instead connected to cards mounted in slots internal to a computer.

- PCI ('Peripheral Component Interconnect') and PCI-X ('PCI eXtended') – parallel bus
- PCIe ('PCI Express' introduced in 2004 to supercede PCI) – serial bus
  - "Thunderbolt" is an external connector that combines PCIe with DisplayPort into one serial signal

Dedicated Instrumentation Bus Devices

- PXI ('PCI eXtensions for Instrumentation')
- PXIe ('PXI Express' newer version introduced in 2005)

These latter two (PXI and PXIe) are typically implemented as internal buses in an external chassis (a 'PXI box') that communicates with a computer via a PCI card in the computer itself (since few computers have built-in PXI buses).

Bus Characteristics

- **Bandwidth** is a measure of the rate (typically in bytes/sec, KB/sec, MB/sec, etc.) at which data is transferred
- **Latency** is a measure of the delay in data transmission across the bus
- **Performance over distance –** low-latency communication must typical occur over short distances; error-checking/correction and message padding can allow accurate communication along longer cables but at the expense of greater latency

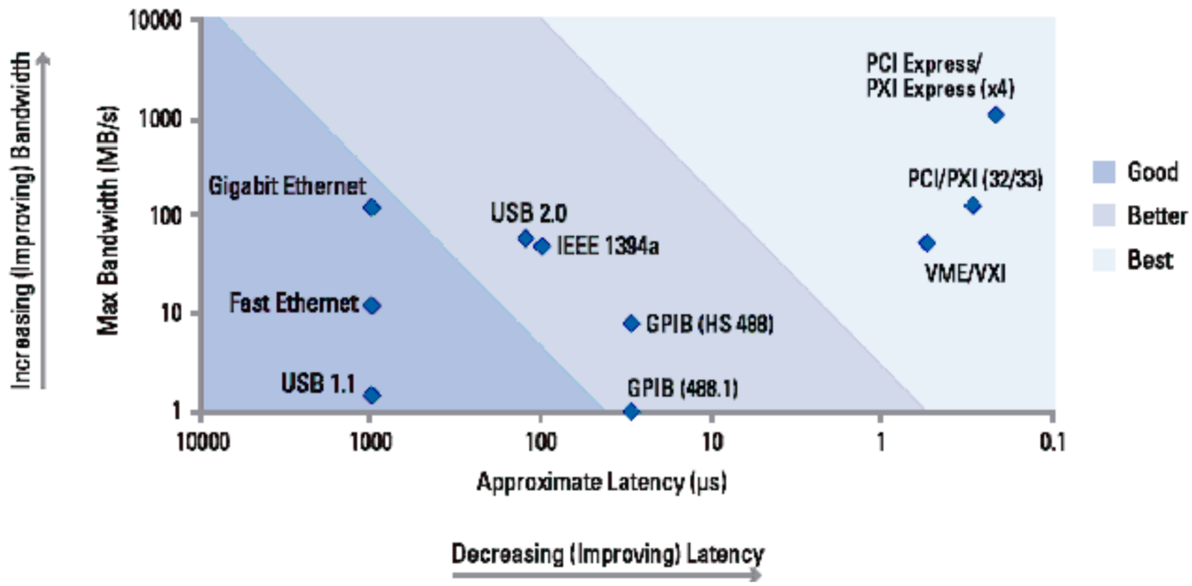


Figure 3: Bandwidth vs. latency for instrumentation buses (from National Instruments white paper 3509, "Instrument Bus Performance – Making Sense of Competing Bus Technologies for Instrument Control" Octobe 2012).

Design of Experiments

1. Formulate a question
   - Is phenomenon *A* affected by phenomenon *B*? (Cause/effect investigation)
   - Does actual behavior *A* match predicted behavior A_{theory} ? (Model validation)
   - Does system behave as desired? (Prototype validation)
   - What is the maximum, minimum, or optimum value of parameter(s) for desired effect? (Optimization study or Limiting-case study)
   - What are physical properties of a particular system? (System identification, Health monitoring)
2. Determine a test that will address the question
   a. What quantities must be measured?
      - Determine acceptable level of uncertainty in results

   b. Design input signals for system being studied (excitation type and characteristics) and automation/control system for experimental apparatus
      - Sufficient power or control authority to produce desired response

   c. What parameters will be help fixed, varied in a controlled way, or may be subject to uncontrolled variation?

   d. Other considerations:
      - Transient vs. steady-state behavior
      - Full-scale vs. model-scale tests
      - Laboratory vs. field testing
3. Select sensor(s) to measure the necessary variable(s), appropriate signal conditioning, and data acquisition equipment
   a. Sensor considerations include sensitivity and range, temporal and spatial sampling rate, frequency response/bandwidth, size, tolerance for environment (temperature, water exposure, electromagnetic interference, impact/shock/high-g loads, etc.), signal path (cables, wireless sensors, etc.), cost, etc.
      - Properly calibrated sensors are essential, consider specific characteristics of individual sensors used (do not rely on nominal characteristics)

   b. Signal conditioning considerations include evaluating various possible sources of noise, which may necessitate amplifiers, analog filters (including antialiasing filters), amplitude modulation/demodulation, as well as impedance of various components, power supply needs for sensors, etc.

   c. Data acquisition considerations include number of channels, sample rate, ability to display data in real-time, bus type for data transfer between components, file format for data storage
      - Raw data is typically preferred so that analysis/processing is a separate step (reprocessing does not require repeating the experiment). Save calibration and offset information independently.
4. Develop a test matrix (vary parameters)
   a. Pre-test measurement of equilibrium conditions, sensor offsets, etc.

   b. Each additional parameter to be varied will potentially *multiply* the number of tests that must be conducted.

    - Tradeoff between throrough parameter study and effort/time (both test and analysis)
    - Intelligent choice of parameter combinations allows use of a sparser matrix (may not need to test every combination).
   c. Evaluate stability and repeatability of data and choose number of repeat tests (and duration of tests) accordingly (statistically significant number of data points)
    - Average results over time, location, or multiple repeated experiments to improve signal-to-noise ratio
    - Acquire statistics on variation over time, location, between multiple tests, multiple test specimens, etc.
   d. Plan order of tests to minimize downtime, configuration or instrumentation changes, risk of damage, etc.
   e. Budget time/effort for Murphy's Law ("anything that can go wrong, will")
5. Setup and run tests
   a. "Shake-down" measurement ("in-place calibration") to verify that all sensors, actuators are functioning as intended *in situ*.
   b. Document all settings, parameters, etc. for each test iteration
    - Automated documentation is ideal (save settings, parameters, date and time along with data rather than relying on experimentalists to write everything down)
    - Automated documentation is usually not sufficient (need to record notes, observations, comments for each test)
    - Distinguish between intended test parameters and actual "as-tested" values
    - Assume things will go wrong and endeavor to make mistakes traceable (record time and date of each test, experimentalists involved, location and filenames of all data, etc.)
6. Preliminary analysis immediately after measurement whenever possible
   a. "Sanity check" to see if collected data was satisfactory, experiment was performed as intended, all components were operational, etc.
    - You should have an expectation for the results of each test, and investigate why if results are unexpected
    - Data acquisition settings may need adjustment (e.g., adjust digitizer range or amplifier gain based on signal strength, adjust duration or number of averages based on signal-to-noise ratio, etc.)
    - Respect possible need for consistency (avoid changing settings or configuration resulting in "apples-to-oranges" comparisons, retake previously recorded data if necessary).
   b. May modify test matrix based on results
    - Add additional tests for new parameter values (intermediate or beyond originally planned range)
    - Remove tests if results are insensitive to some parameters, or due to time considerations, damage, etc.

Communication of Results

Experimental results are primarily communicated by

- Technical paper, report, article, etc. (text supplemented with static graphics)
- Oral presentation (spoken word supplemented with text, static graphics, video, audio, etc)
- Posters, other static displays (mixed text and static graphics, possibly supplemented by spoken word)

Technical Writing

There are two primary purposes of technical writing: to communicate technical information and to provide a permanent record of information for future use. Typically, a report contains interpretation and evaluation of the information as well as bare facts.

Audience

Consider the audience (engineers, management, general public, etc., various expected levels of education and familiarity with the topic) and write at the appropriate level. Provide any relevant background or theory to the experiment but avoid describing in detail background or theoretical information that is (1) already well-known to the anticipated audience, or (2) readily available to the audience elsewhere (use references to refer a reader to existing sources).

Distribution Limitations

Government agencies or private companies may restrict distribution of certain experimental results and analysis (classified work, trade secrets, etc.). Adhere to your employer's practices for ensuring that details of your experimental work are only distributed to the appropriate audience.

Plagiarism

Using the <u>words</u> of others without attribution is plagiarism, a serious breach of ethics. Direct quotes should always be indicated as such. The original author or speaker should be made clear, and if the quotation is from a written work, it must be cited as a reference. Presenting <u>data</u> obtained by others as your own work is also a form of plagiarism. You may sometimes need to include information from other sources, and in such cases should properly cite those sources and distinguish between your own data and others' data. The use of <u>images</u> generated by others without attribution is likewise a form of plagiarism. Charts, graphs, schematics, photographs, and other media must have their sources properly cited if they are not your own creation, and in some cases permission should be obtained before reproducing others' images.

Passive and Active Voice, First person pronouns

Different people have different (often strongly held) opinions about whether it is OK to use the active voice in technical writing ("We conducted measurements…") or whether only passive voice is acceptable ("Measurements were conducted…"). A strongly overlapping issue is the use of first-person pronouns ("I" or "we"), which is frowned upon by some but accepted readily by others. The real issue is that technical writing must always be descriptive, not narrative: the focus should be kept on the experiment and experimental results, not on the experimentalist(s). Avoiding the active voice and first person pronouns is, in essence, a "trick" to force oneself to avoid telling one's own story (text that is about the experimentalist rather than the experiment would sound quite strange if it did not use first person, active voice). However, insistence upon the passive voice can result in awkward sentence structure. **The best writing style is always that which most clearly communicates all relevant information, and avoids extraneous and irrelevant additions.**

Precision of language

Use the simplest language you can that conveys precise meaning. Simple language should not be confused with casual language. A number of specific things to avoid:

1. **Unsupported assertions:** Do not present something as a fact unless it is commonly accepted by your audience – justify any statement that a reasonable reader might be able to challenge. You can use a reference if you have a citation that explains or justifies the point or makes the case for you, otherwise you need to justify it.
2. **Vague assertions:** The reader must be able to retrace your steps. You don't have to spell out every detail of a calculation or derivation but it must be possible for a reader to follow or reconstruct the important steps of your work..
3. **Vague qualifiers:** Examples of vague qualifiers are: "a *little* noise", "a *very large* force", "a *good* signal." You should only use this type of qualifier if you previously establish a quantified criterion for the qualifier. For example "A good signal is established when the probe voltage is greater than 2.0 volts," allows the reader to know exactly what you mean by "good," so the qualifier is no longer vague.

Use of tables and figures in technical writing

a) Include Figure number or Table number (number figures and tables separately).
b) Give a title or caption (but not *both*). The convention is that table captions appear above tables and figure captions appear below figures. For figures with multiple parts (subfigure), clearly indicate in the caption the meaning of each part of the figure.
c) Label any axes and provide proper units for figure axes and tabular data. For nondimensional data, indicate the ratio of quantities or the variables used to rescale data.
d) In a figure with more than one curve or set of points, provide a legend identifying them. Consider the fact that some readers may be colorblind or that some copies of the document may be printed in grayscale.
e) Theoretical or statistical curves should be smooth (no data points) while discrete experimental measurements are typically presented as individual data points whenever the number of points is sufficiently low for individual values to be resolved ("connecting the dots" may imply knowledge of intermediate conditions that were not actually measured).
f) Use logarithmic axes when appropriate to show values of multiple orders of magnitude.
g) Use error bars to indicate uncertainty in measured data or a specified distribution of stastical data (for example, mean +/- one standard deviation).

Use of symbols and abbreviations

All symbols and abbreviations should be defined in the test, typically the first time they are used. If there are a large number of symbols, especially multiple similar symbols (such as the same letter with different sub- or superscripts), consider including a nomenclature section (list of symbols) at the beginning or end of the document. Likewise, a large number of abbreviations may suggest inclusion of a list of abbreviations (this is typically distinct from a list of symbols).

Organization and Content of a Technical Paper

Abstract

An abstract is a concise but complete summary of a written document. It should be able to stand on its own: there are many cases in which a busy reader may only have time to read the abstract of a report or technical paper, or that the abstract may be separated from the body of the report and distributed to a wider audience. Thus, the abstract should still make sense and be useful without the rest of the report. The abstract allows a reader to identify the basic content of the report so that they can decide whether or not to read the entire document. It should include a *quantitative* summary of the work performed, the results obtained, and the conclusions drawn, and should consequently be written *last*, after the sections describing the results and conclusions have been completed. The abstract should enable the reader to obtain the essence of the document in the most compact form possible.

Introduction

An introduction should clearly present the objectives of the experiment (the problem being addressed) and summarize the basic approach taken to solving the problem. It is also typical to include some discussion of the importance of the problem, including background information and previous work on the problem, but this discussion should be concise and should mainly serve to motivate the approach used in the experiment. The introduction must give the reader a clear picture of the reasons for conducting the experiment, the method of approach, and the intended results.

Approach (Experimental Apparatus and Procedure)

Any technical report of an experimental study should include enough detail that a reader can understand what was done sufficiently to be able to duplicate the results. Document the equipment used, how it was connected and configured, what techniques were employed, and what measurements were taken. Specific information about hardware or software should be included only to the extent that it is relevant. In some cases, listing specific attributes of a piece of hardware or software may be appropriate, in other cases, it may be more succinct to simply report the brand name and model/version number, but in either case, this information should only be included to the extent that the results obtained depend on the specific attributes of the component. For example, one shaker may have a different amount of force output than another, or a different usable frequency bandwidth, so it may be important for a reader to know exactly what type of shaker you used to excite some mechanical system. On the other hand, the make and model of the computer used to store and process the data should not affect the results, so it is superfluous to include such information. When in doubt, consider the perspective of someone attempting to reproduce your results, who may choose to use different equipment but will need to properly account for any differences.

If the experiment is related to a theoretical or numerical model, this should be described in sufficient detail as well. Include a conceptualization of the problem indicating all important physical processes, and show any governing equation(s). Provide derivations for equations only if they are not readily available elsewhere. Provide solutions to the relevant equations (if applicable), however, any lengthy calculations should be placed in an Appendix.

Results and Discussions

Results should be presented as text, tables, and graphics as appropriate to the experiment. Graphics must be correctly labeled and scaled appropriately. Every figure or table should be referred to and discussed in the text, which should make clear the purpose of each figure or table and serve to unify and supplement the results presented there. If there is no takeaway point from a given graph, it is likely not worth including in the document. You should describe any techniques (such as statistical analyses) used to convert raw data into the form you present.

All discussion should be quantitative and precise (avoid vague statements and generalizations). This section gives you the opportunity to interpret your results for the reader and point out anything significant that enhances the value of your results. The discussion should leave the reader satisfied that the objective(s) stated for the experiment in the introduction have been achieved.

Conclusions/Recommendations

Close by summarizing your interpretation of the results. Do not merely repeat interpretations given in the results section, rather, inform the reader what is most important about your results, their significance, and what actions you recommend be taken in light of your results. This may include the types of situations or problems to which your results are applicable, what previous ideas, information, or methods have been confirmed or called into question by your new results, etc. Your recommendations can also include suggestions for improving the experimental apparatus and/or procedure, or for future work that builds on the results of the present experiment.

References/Bibliography

Cite all sources used, including books and articles, online documents, and any personal communication/correspondence with outside experts. There are a number of different citation formats in common use: use the style appropriate for your employer or for the venue of publication of the document. References should be complete enough that the reader could locate the material if desired. Avoid citing internet URLs whenever possible since websites change and the information may no longer be available if the reader goes looking for it.

Appendices

The appendices may include raw data, sample calculations, lengthy derivations of equations, or other relevant material too long or detailed to be included in the main body of text.

Technical Presentations

Many of the same considerations for technical writing apply to technical presentations, such as consideration of the intended audience, considerations of distribution limitations, precision of language, general organization (introduction and background, approach, results and discussion, conclusions), and the use of symbols, tables, and figures.

Duration and Pacing

Consider the amount of time allotted to a presentation, and plan the amount of material to be presented accordingly. Practice the delivery while timing yourself to have a proper sense of how long it takes to deliver various material. With experience, note whether your delivery before an audience is typically faster or slower than your deliver during practice, and adjust accordingly (some people speak faster if they are nervous in front of an audience, while other people extemporize extra detail, anecdotes, etc., which slows delivery).

For any specific text or graphics that will be displayed, make sure the level of detail is appropriate to the amount of time the content will be onscreen. Avoid too much text or too much graphical detail onscreen at any given time, such that the audience is unable to take everything in before you move on; conversely, allow an appropriate amount of time for the audience to digest complicated or detail images (and remember that the audience is much less familiar with the content than the presenter and thus needs more time to understand it).

Legibility

Size text and images appropriately so that they are clearly legible to *all* audience members (the limiting case is typically those furthest from the front of the room). Avoid small font sizes, thin lines in graphs, and images with too much fine detail.

Animations, Video, Audio

Presentations are a natural place for video and audio files that may be less easy to include with a written document, and these serve to make the presentation more interesting for the audience. Animation of data also provides an additional dimension (for example, a two-dimensional plot showing the relationship between two quantities x and y may be animated to show their relationship for varying values of a third quantity z).

Whenever including animations, video, or audio, consider whether "handouts" from the presentation will need to be made available to the audience, and how the non-static information will be conveyed in the handout.

Questions and Answers

When writing a technical manuscript, the author must endevor to anticipate all potential reader questions and address them appropriately in the text, but for an oral presentation, the presenter is typically able to field questions from the audience directly. The presentation itself may thus present fewer details than a manuscript would, as long as the presenter is prepared to provide additonal details in response to questions. Many presenters include additional "backup" content that is not part of the planned presentation but that can be available for display in response to such questions.

Posters (and other static displays)

Experimental results (or other technical content) may sometimes be summarized on temporary or permanent displays. The same issues are relevant as for technical writing, with additional consideration of the location (poster session, hallway exhibit, etc.), typical viewing distance (and thus appropriate font and image size), and availability of the author to answer questions (i.e., a display without the author present is more like a technical manuscript, in that it should stand on its own, while in other cases the author may be present to answer questions and provide details not given on the poster).