

Using a Computer to Make Measurements or Control an Experiment

- This week in lab
 - Computer data acquisition
 - Homework due for this week is posted online
- Next class 3/19
 - Spectral analysis
 - Read the *Spectral Analysis* section of the course manual

Why ?

- It's fast.
- Its accurate.
- It can be automated.
- It makes possible experiments that would otherwise be impossible.
- It brings the processing power of the computer into your experiment.

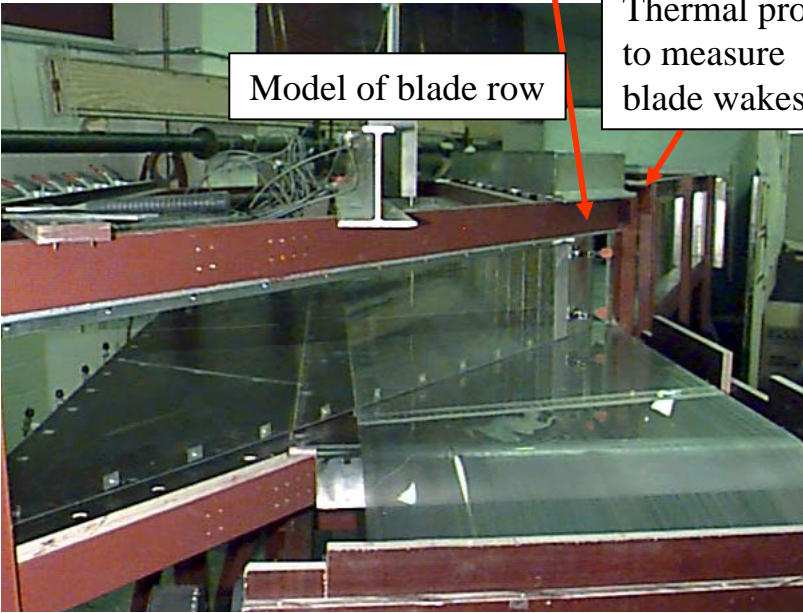
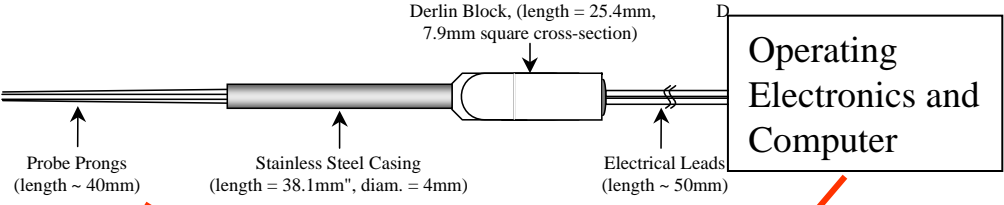
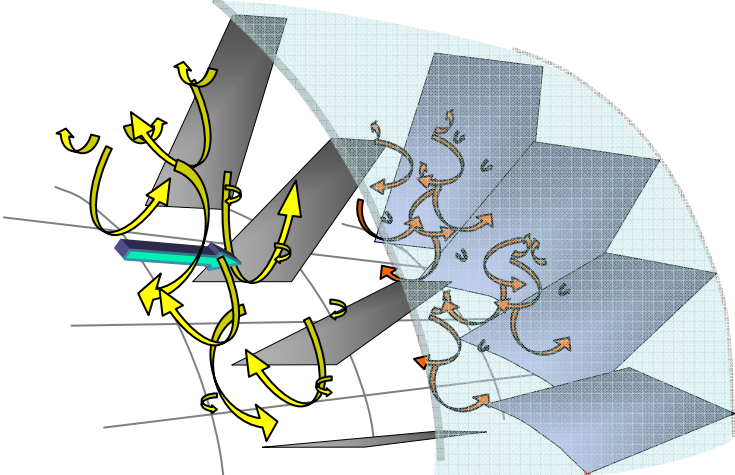
Shock Tube U-12

Korolev, Russia



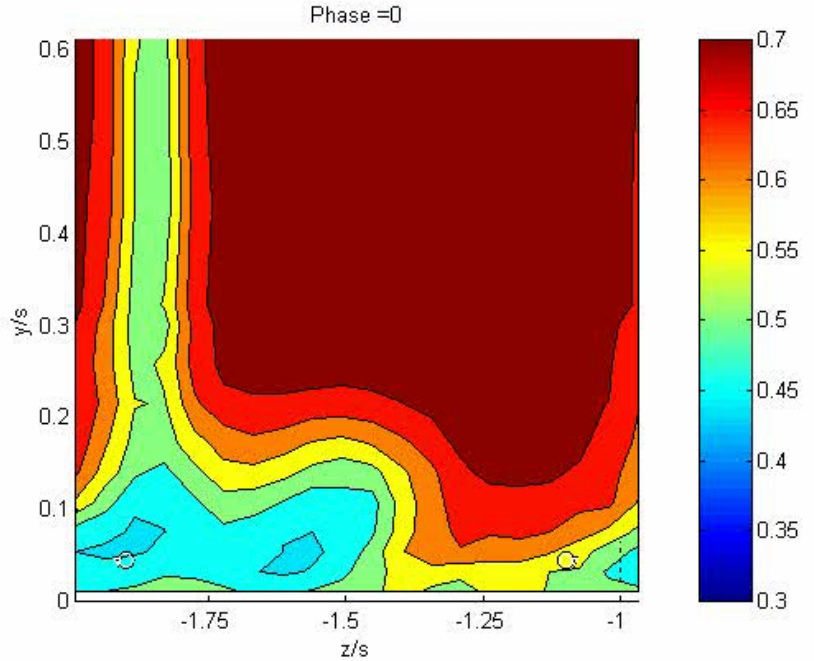
Flow Mach Number:	0.5 - 10
Shock Wave Speed:	350 - 9,000 m/sec
Reynolds Number:	$(0.1 - 2) \times 10^7 \text{ m}^{-1}$
Rarefaction:	$< 1.3 \text{ Pa}$
Pressure:	1.3 Pa - 0.7 MPa
Total Pressure:	$< 5 \text{ MPa}$
High-Pressure Chamber	
Working Pressure:	$< 200 \text{ atm}$
Low-Pressure Chamber	
Initial Pressure:	0.01 mm Hg - 1 atm
Nominal Temperature:	65 - 300 K
Working Fluid (at P < 15 MPa):	O ₂ , Xe, Gaseous Mixtures
Explosive Mixtures Flow	0.025 - 0.1 sec
Duration:	
Cylindrical Drive Tube	0.5 m
Dimensions:	
Inner Diameter	

Propulsor Wake Measurement

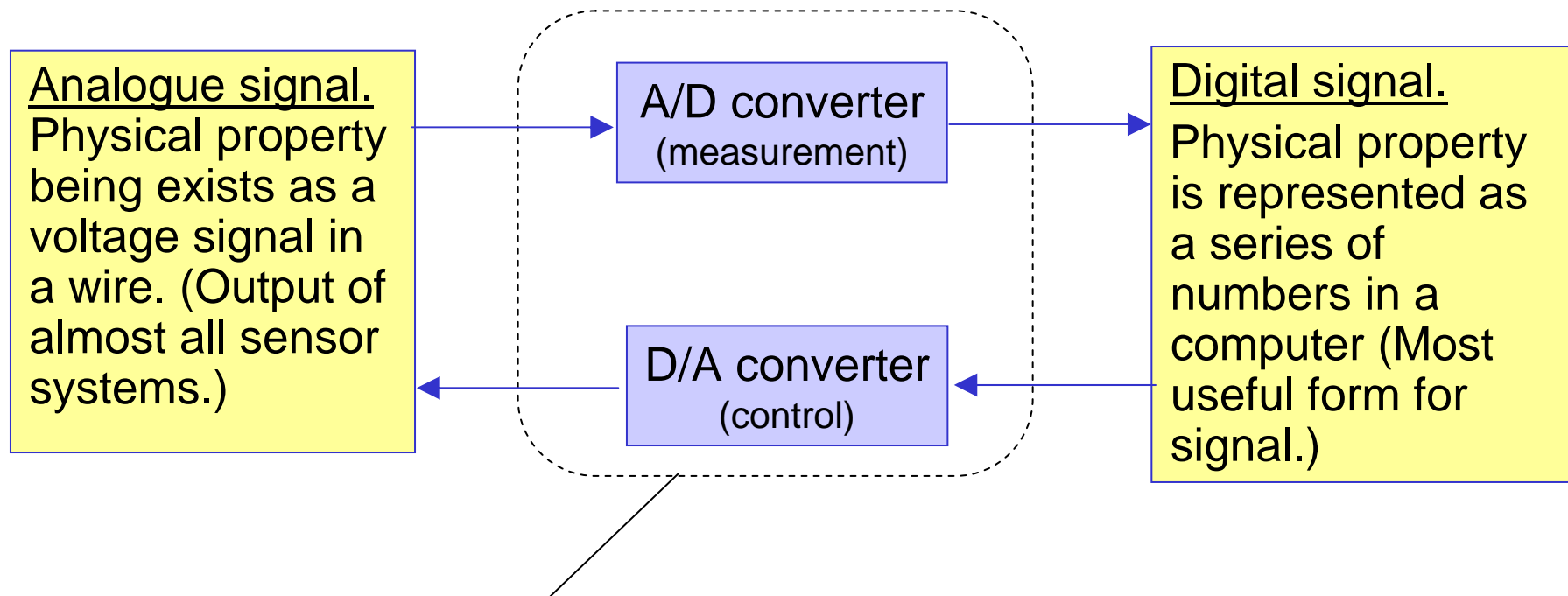


Model of blade row

Thermal probe to measure blade wakes

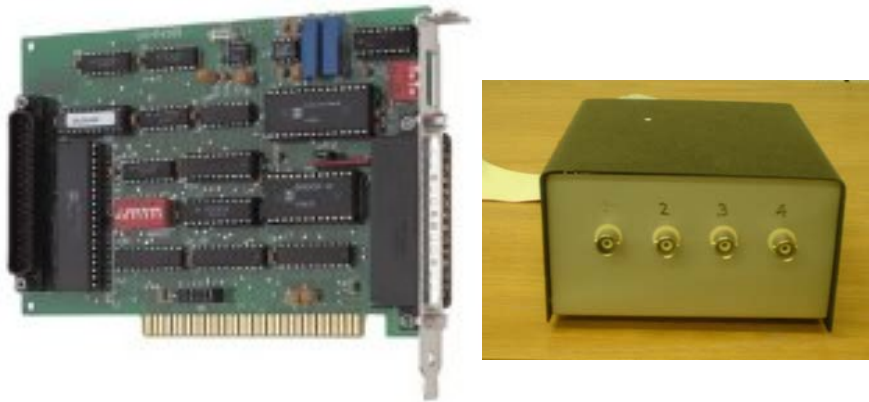


Analogue and Digital



These two devices are often packaged together and are usually referred to as DAQ cards, or DAQ devices, or Data Acquisition Systems, or Digitizers, or A/D converters

Recognizing DAQ Devices



PC Bus Cards



Stand alone systems (VXI/PCI)



USB based devices

(National Instruments USB 6211)

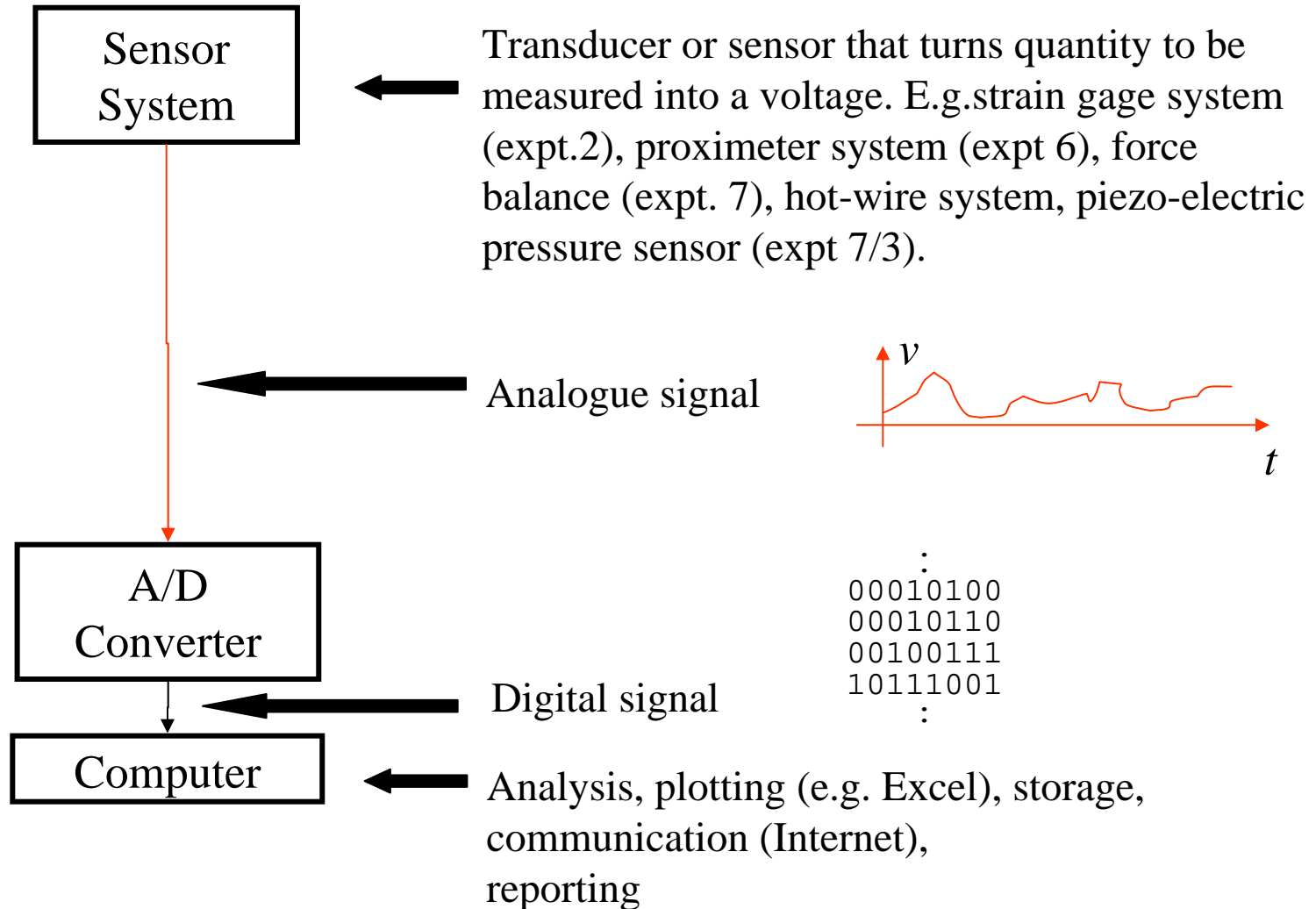
Measuring with *your* computer

Today's Class

- A/D Converters
- D/A Converters

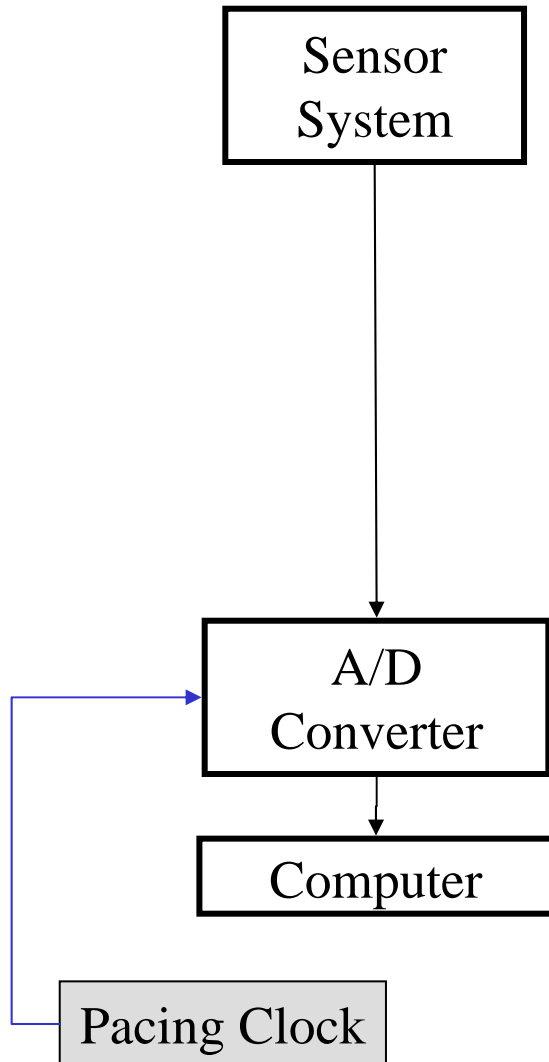
- What they do
- Capabilities/Limitations

The A/D Converter



Capabilities/Limitations

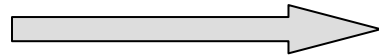
1. Sampling



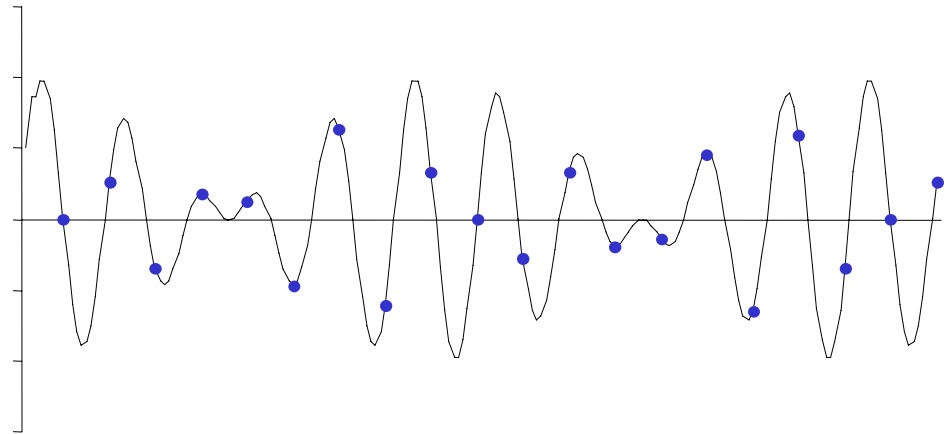
- A/D converters are designed to measure (sample) a voltage signal and convert it to a number at *regular intervals*
- Sampling rate = No. of samples per sec.
- Most A/D converters have variable sampling rates that can be set from the computer software
- Maximum sampling rates are fixed by the hardware. USB 6211 takes up to 250,000 s/sec, Gigasamples per second are possible.
- To ensure that samples are measured at regular intervals, independent of the computer speed, A/D's include a 'Pacing Clock' that drives the acquisition
- This is also a limitation...

Sampling

The inevitable limitation on sampling rate can introduce error when measuring high-frequency signals.



Obviously the sampled data is a poor representation of the original signal. This type of error is called 'aliasing'.



To avoid aliasing it is necessary for

Sampling rate $> 2 \times$ *Highest frequency in signal*

...or...

Highest permissible frequency in signal = *(sampling rate)/2*

...termed the Nyquist frequency.

Capabilities/Limitations

2. Accuracy

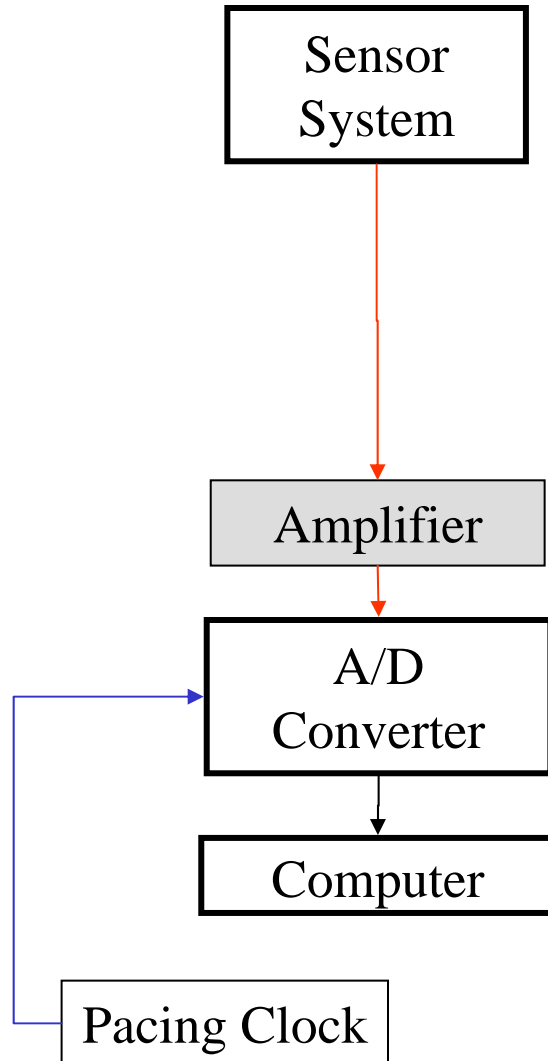
- The A/D converter produces a binary number with a fixed number of digits or ‘bits’. The fixed number of bits limits both the range and resolution of the measurement.

- E.g. consider the possible outputs of an 8-bit converter:

Smallest number	00000000	0	
Largest number	11111111	255	(2^8-1)
Smallest increment	00000001	1	

- Since these numbers are used to indicate the voltage, this means that the A/D converter can only represent a limited range of voltages with a limited resolution.
- Many A/D converters are constructed to have an input voltage range of -10V to +10V. An 8 bit A/D converter with this range will thus have a resolution of $20/2^8 = 0.078V$ and thus only be accurate to 0.039V at best. The USB 6211 is a 16 bit converter with -10 to +10V range, and thus has a resolution of $20/2^{16} = 20/65536 = 0.0003V = 0.3mV$.
- The bit resolution of an A/D converter is a function of how much you paid for it (increases number of bits) and how fast it is (reduces number of bits). 12/14 bit is standard. 16 bit devices are common for applications requiring high accuracy.

Accuracy



- The limited resolution of an A/D can be a serious problem if you want to measure a weak signal (e.g. 10mV amplitude).
- To solve this problem all you need to do is amplify the signal so it fills the full -10 to +10V range.
- A/D converters generally have variable-gain amplifiers built in for this purpose. The gain is usually selectable from the computer software. (USB 6211 has 7 programmable gains of 1, 2, 10 and 50, giving effective input ranges of ± 10 , 5, 1, and 0.2V.)

A/D Converter Capabilities

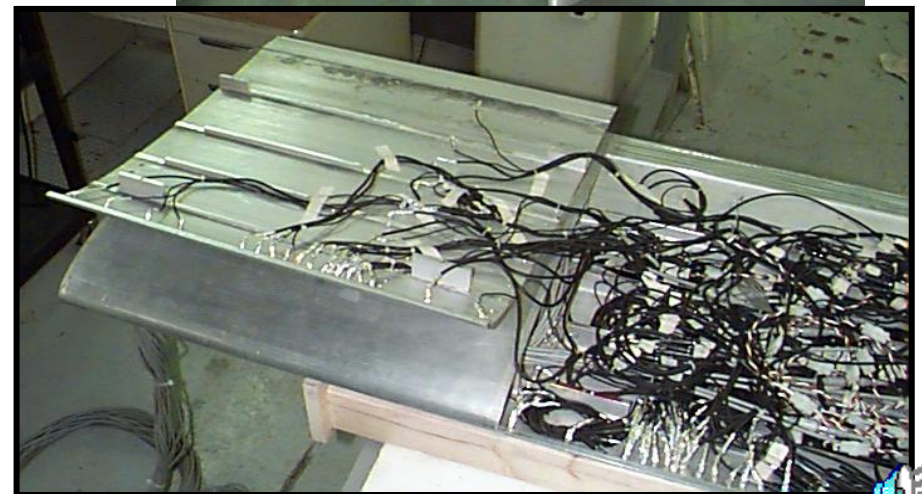
3. Multiple signals



Boeing AH-64A Apache

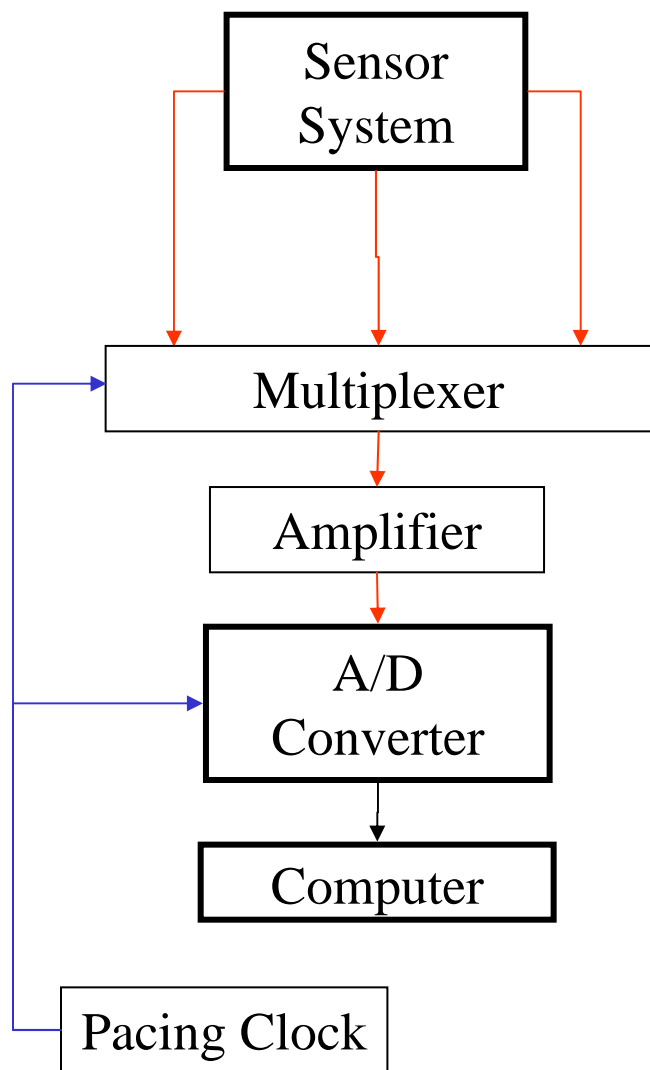
Example Instrumented Blade

- NACA 0012, 2' chord, 6' span
- 96 Sennheiser KE 4-211-2 microphones
- Signal conditioning for each microphone (operating circuitry, signal amplifiers) inside blade to minimize interference. 64-channel, 16-bit data acquisition at 56kHz
- Chordwise resolution - 1%c near leading edge
- Spanwise spacing - 1%c to 96%c

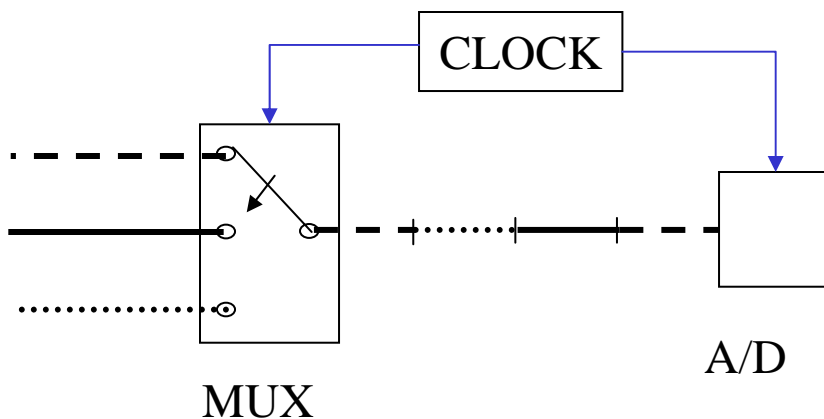


A/D Converter Limitations

3. Only sample one channel



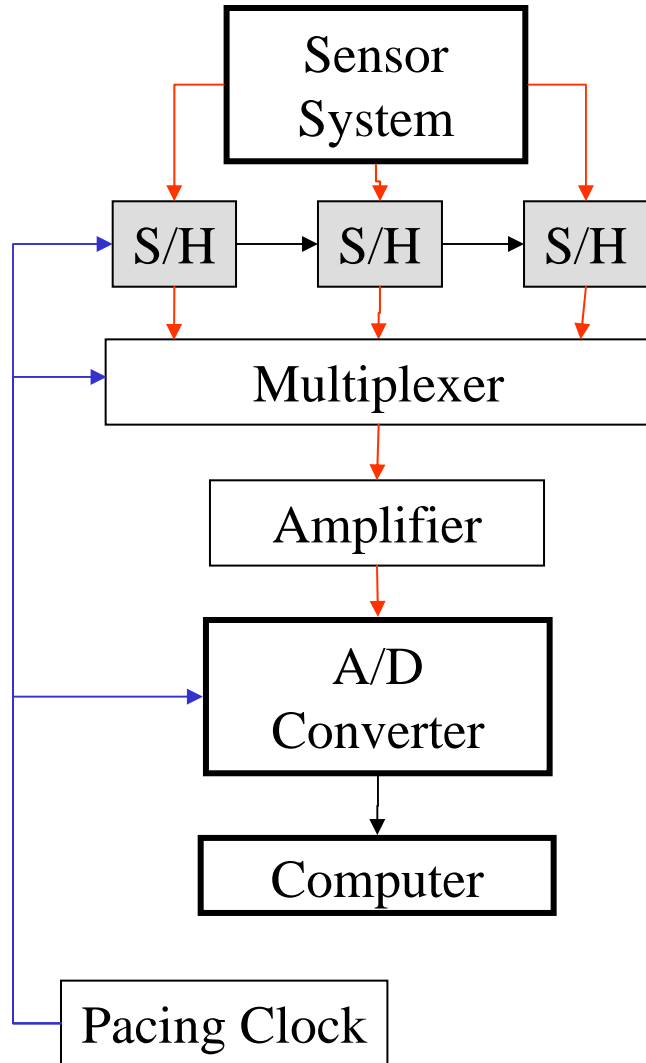
- It is common to want to make measurements of several sensor outputs at the same time.
- To do this, without using multiple A/D converters (an expensive and unnecessary solution), requires a device known as a multiplexer (or MUX). The MUX is essentially an analogue switch that creates a composite signal containing short bursts of each of the signal channels to be measured.



- The MUX is synchronized with the A/D converter using the pacing clock

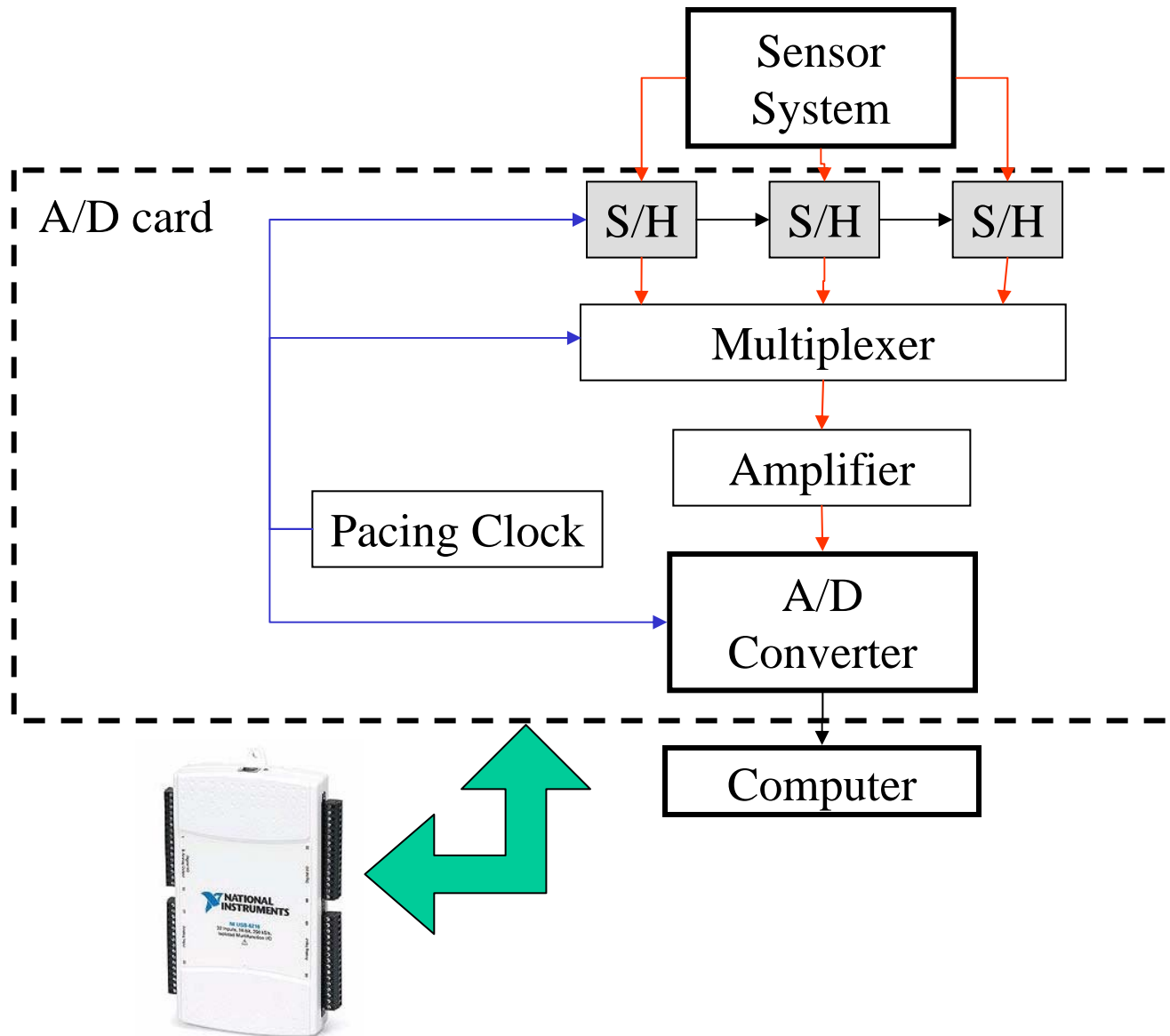
A/D Converter Limitations

3. Only sample one channel

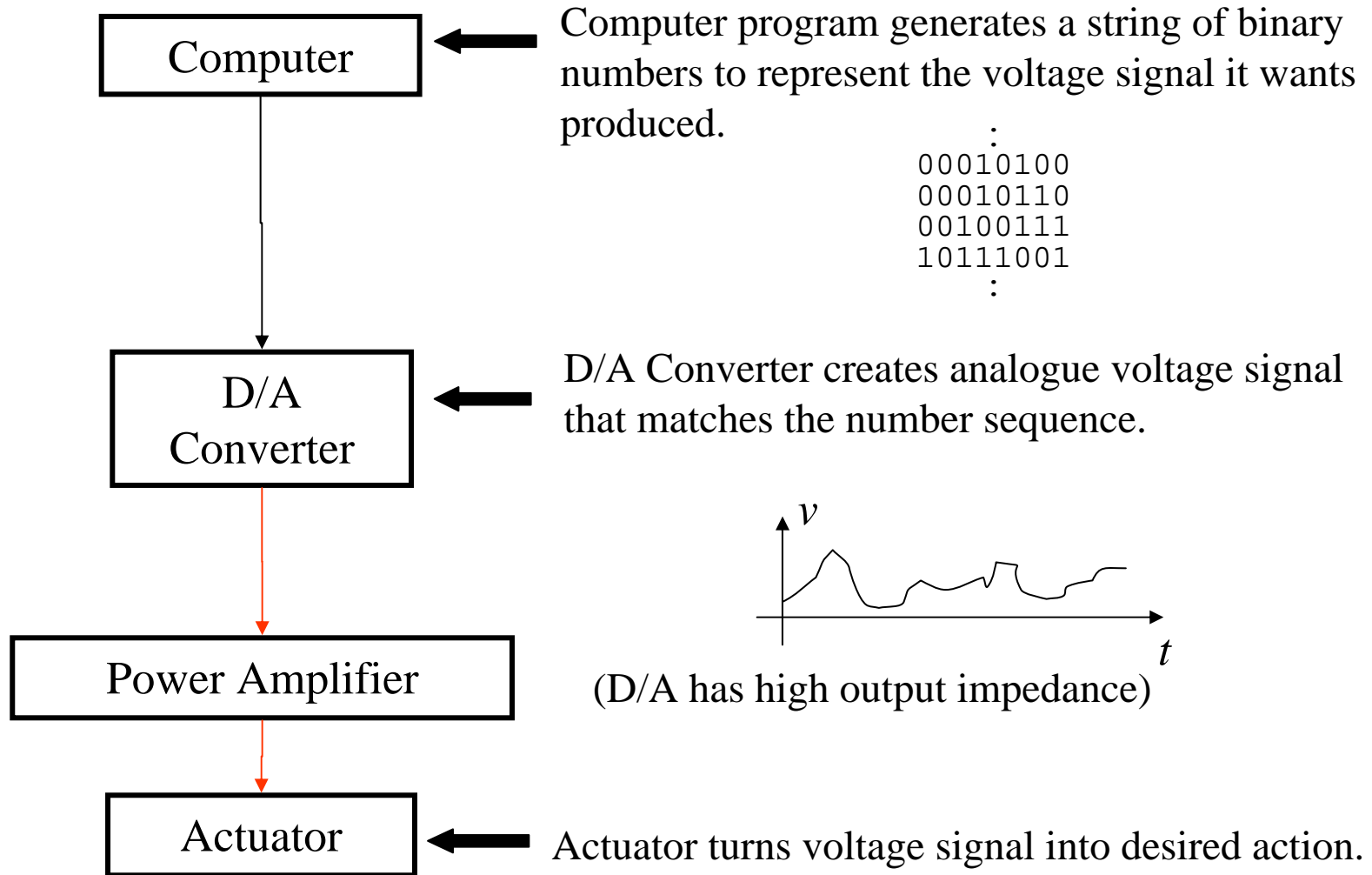


- The sampling rate for each channel is now the sampling rate of the A/D converter divided by the number of channels (i.e. we pay a price in speed).
- MUXs usually give you a choice of input types:
Single ended - A/D measures difference between signal and ground. Same ground is used for all channels.
Differential - A/D measures difference between two signals (reduces noise, but halves number of channels).
- The channels are not actually sampled simultaneously, but sequentially.
- Sometimes true simultaneous sampling is critical (in measuring short transients, or correlations in high-frequency systems). Some A/D converters (not the USB 6211) include sample and hold circuits to provide this capability. These sit in front of the MUX and, on command from the the pacing clock, freeze at their outputs, the voltage sensed at their inputs. The result is truly simultaneous measurements of multiple channels.

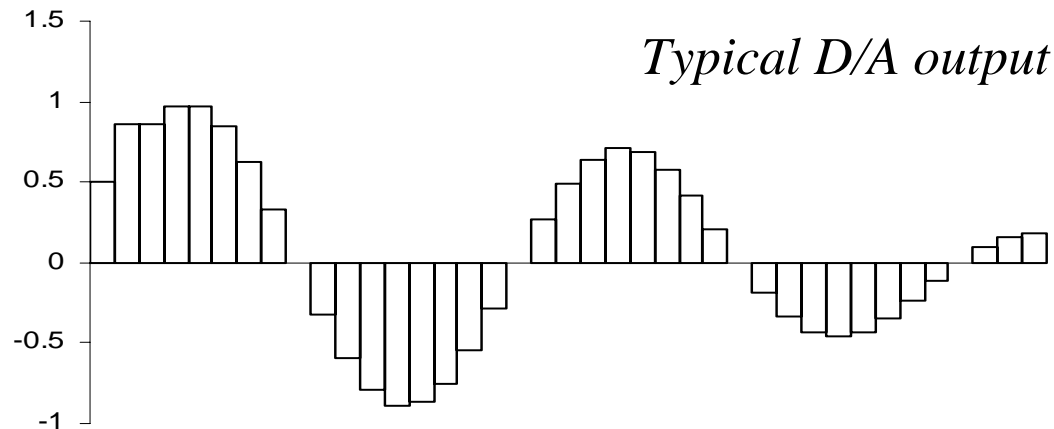
Integration



D/A Converters



D/A Converter Capabilities



1. Rapid conversion

But it has a limited conversion rate. There is thus a limit to the highest frequency that can be produced by a D/A converter. It is half the conversion rate. The max conversion rate for the USB 6211 is 250kHz

2. Accurate (but not without limit)

Since the voltage is specified through a binary integer with a fixed number of bits D/A's have a limited range and resolution. USB 6211 has 16 bit D/A converters with an output range of $\pm 10V$, implying a resolution of $20/2^{16} = 0.0003V$

3. Produces one channel of voltage signal

To produce multiple channels you need multiple D/As (USB 6211 has 2)