

DATA ACQUISITION

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Fall 2003-2004

What is Data Acquisition?

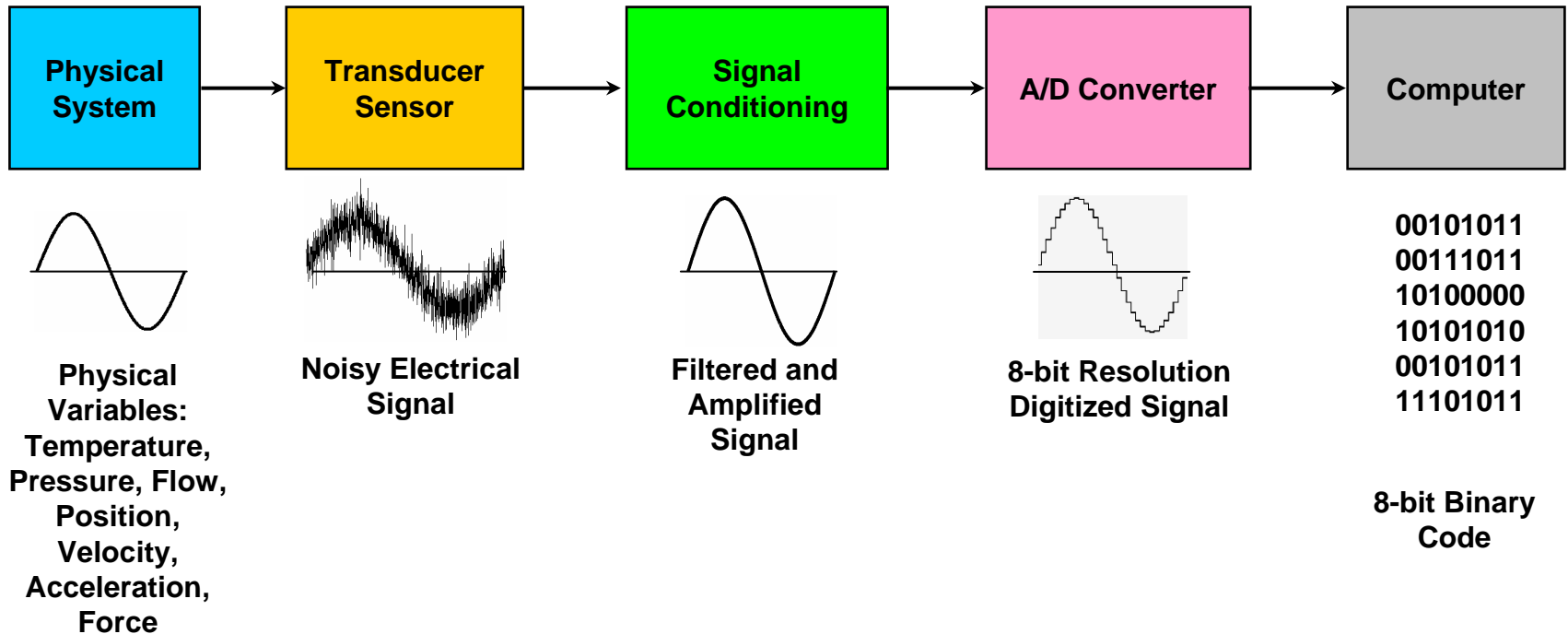
Data acquisition systems are used by most engineers and scientists for laboratory research, industrial control, test and measurement to input and output data to and from a computer.

A ***data acquisition*** and control system typically consist of the followings:

- ***Sensors*** which measure physical variables such as temperature, strain, pressure, flow, force and motion (displacement, velocity, and acceleration)

- ***Signal conditioning***, to convert the sensor outputs into signals readable by the analog input board (A/D) in the PC.
- An ***analog input (A/D) board***, to convert these signals into digital format usable by the PC.

- A **computer** with the appropriate application software to process, analyze and log the data to disk. Such software may also provide a graphical display of the data.
- An **output interface**, to provide an appropriate process control response.



In order to sense and measure physical variables such as pressure, flow and motion, it is necessary to use **transducers (sensors)**, which convert physical variables into electrical signals and transmit these signals either to a *signal conditioning device* or directly to the *data acquisition board*.

The ***signal conditioning*** device performs the following main functions:

- Supplies power to the transducer, when required,
- Amplifies, filters or digitizes the sensor signal,
- Provides appropriate output signal which is easy to capture with an analog input board.

Signal conditioners frequently perform additional functions such as

- bridge balancing,
- integration,
- output calibration,
- overload detection,
- signal level monitoring.

- Signal conditioners must perform these functions over the amplitude and frequency range of the expected input signal.
- Signal conditioners have a large effect on measurement system performance characteristics.

After signal conditioning, the sensor signal is passed to the ***analog input (A/D) board***.

The A/D board converts the conditioned analog voltage or current signal into a digital format which is readable by the PC.

An **analog signal** is continuous-time function with a physical parameter defined for every instance of time. The signal must be converted into a discrete-time signal so that it can be used by the computer to depict the original signal.

A/D conversion is a ratio operation, where the input signal is compared to a reference and converted into a fraction which is then represented as a coded digital number.

To optimize measurement accuracy, there is a minimum and maximum number of data points that need to be acquired.

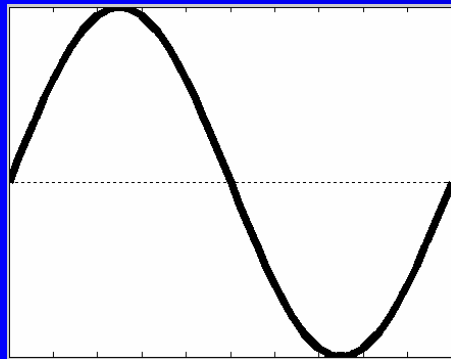
A/D boards often incorporate some of the capabilities below:

- High-speed data transfer to the PC
- Noise and anti-aliasing filtering
- Programmable gain amplifier
- Circuitry for hardware and software triggering

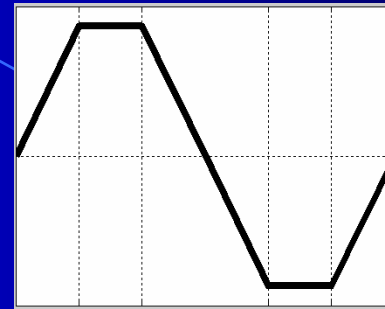
Sampling Rate

One of the most critical factors when selecting an A/D board is **sampling rate** (speed).

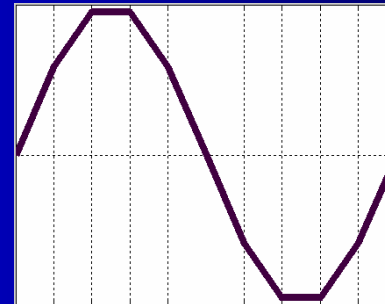
The sampling rate is a measure of how rapidly the A/D board can scan the input channel and identify the discrete value of the signal present with respect to a reference signal.



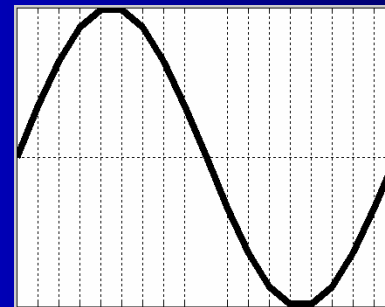
Analog Waveform



4 Samples
per Cycle



8 Samples
per Cycle



16 Samples
per Cycle

If the sampling rate is too slow, then a completely different waveform of a lower frequency is constructed from the data acquired. This effect is called *aliasing*.

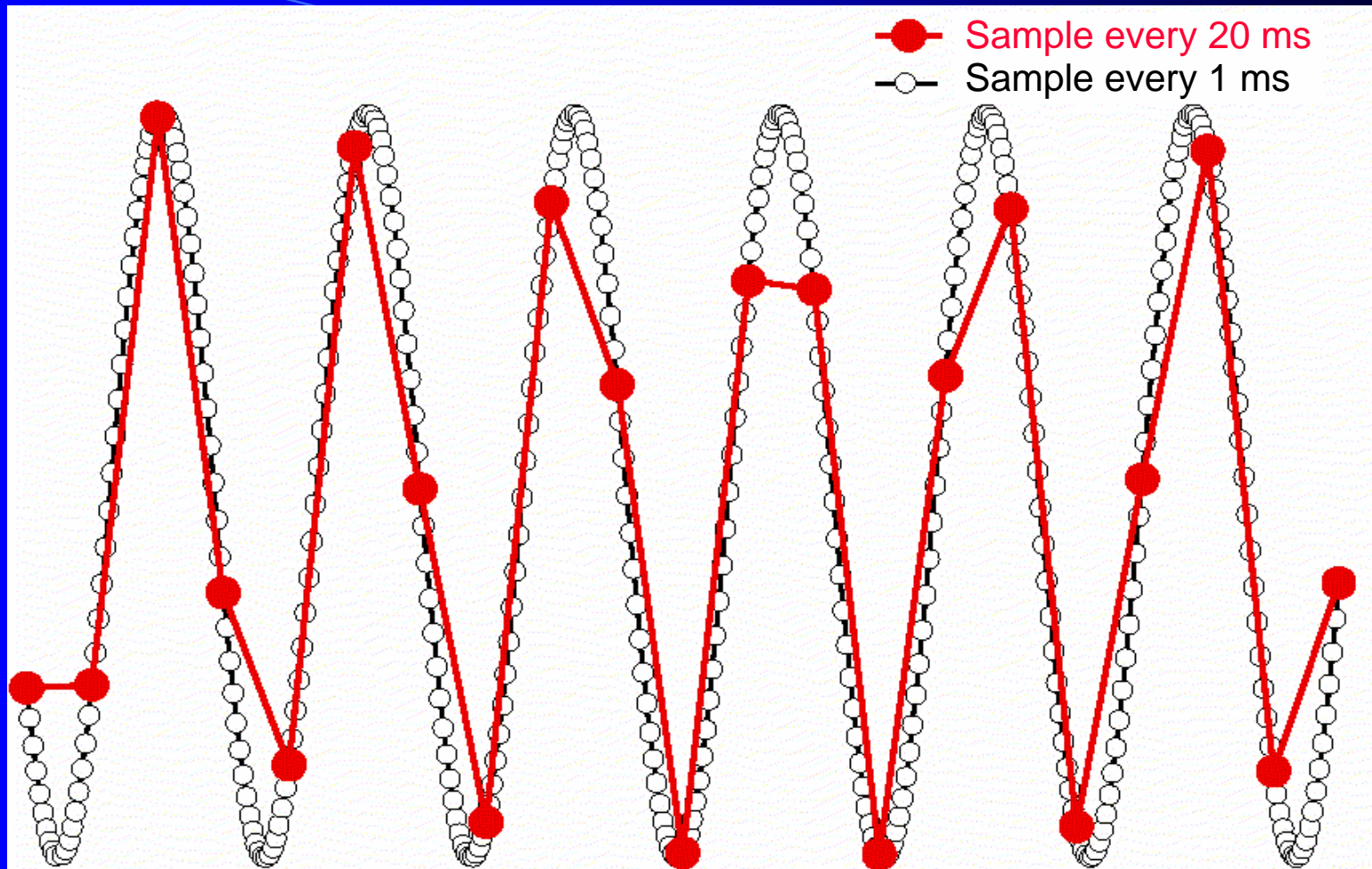
Aliasing

It has the effect of increasing the variance in the recorded signal, i.e. it adds noise to the signal, basically by missing the peaks and troughs of the rapidly changing signal.

So, even if the signal has the same peak all the time, the board will catch the rising and falling phase but miss the peak giving the appearance that the peak (i.e. the maximum value recorded in each cycle) is changing.

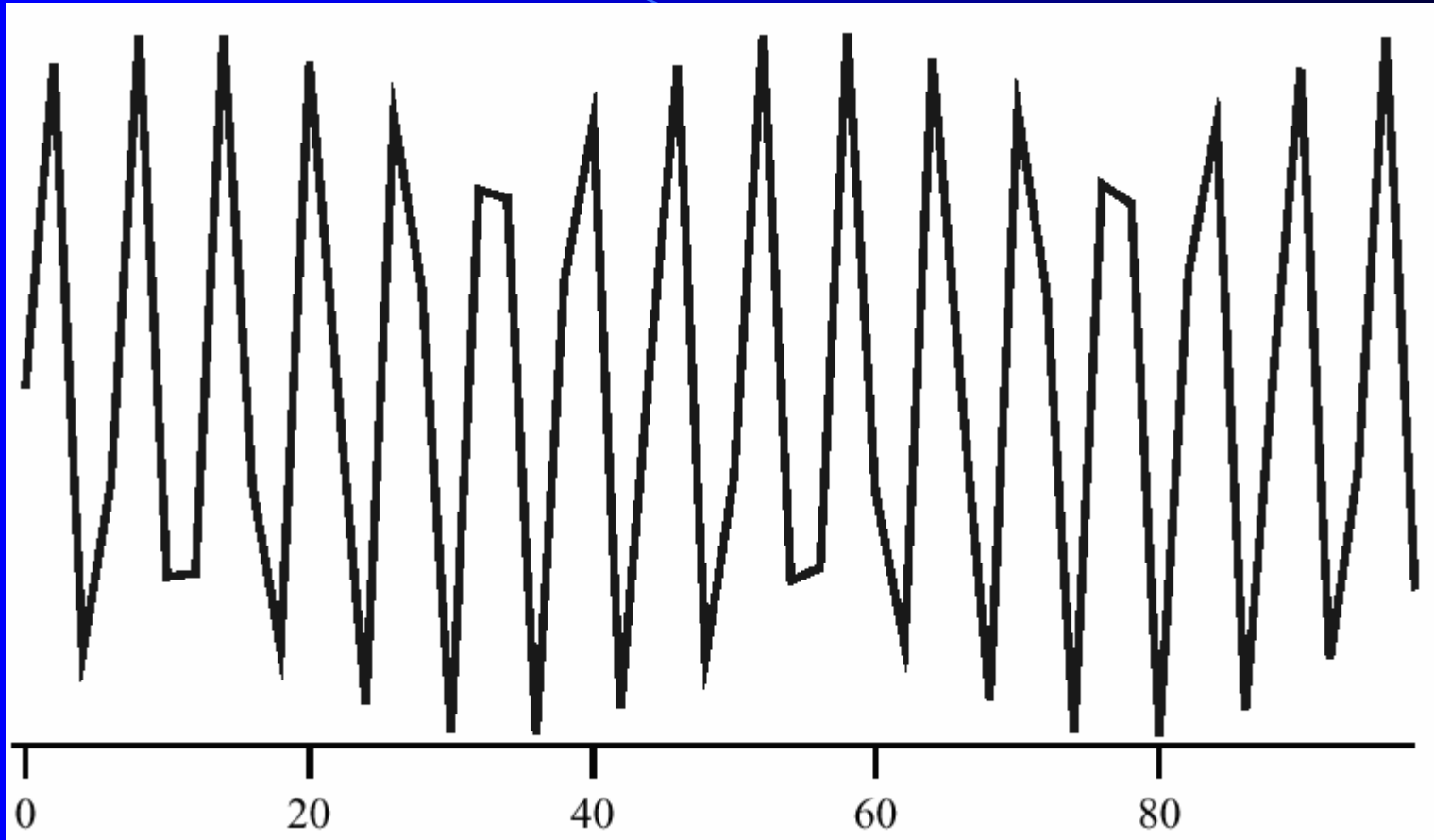
- If you aren't measuring a regularly repeating signal then you won't see such a dramatic aliasing phenomenon.
- Instead you'll just see that if you measure more than once the response will vary in size a lot.

To avoid aliasing, it is necessary that the sample rate be at least *twice* the highest expected frequency input.



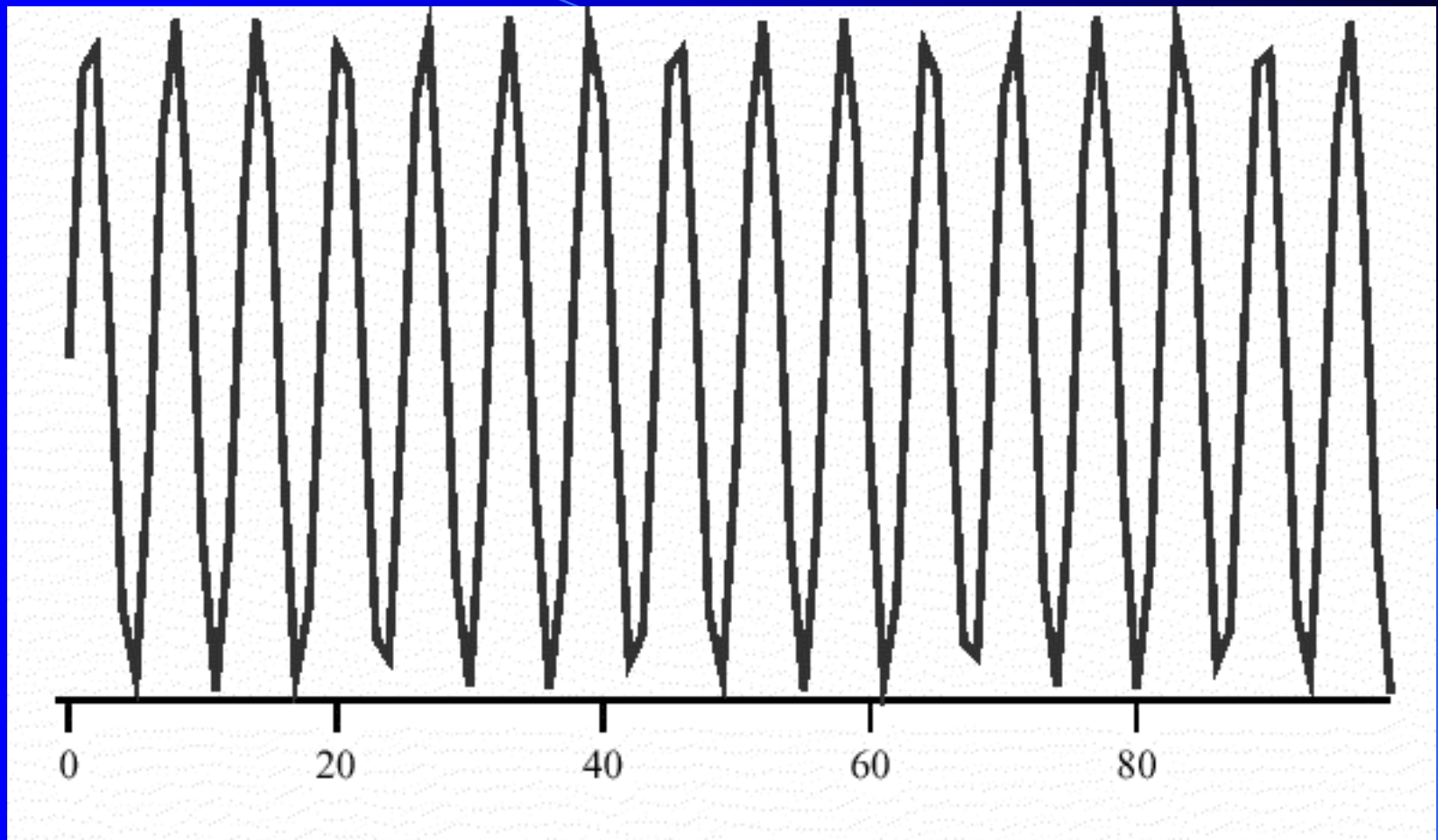
Sampling at a rate that is slow relative to the rate of change of the signal (**red**) results in **undersampling**. You must attempt to match sampling rate to the signal you are interested in.

Sine wave of 160 Hz (6.25 ms between peaks)

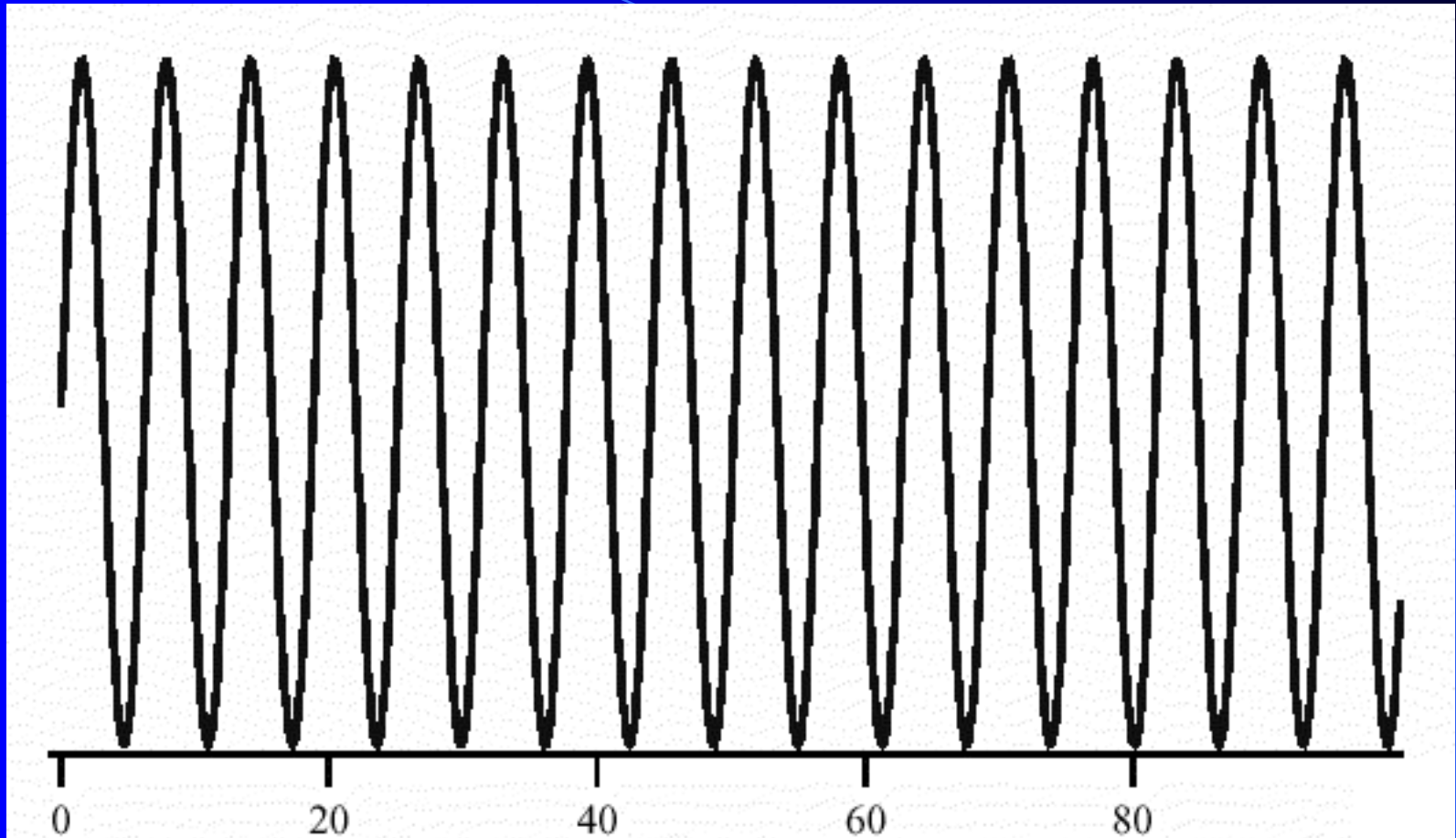


2 ms

The wiggling of the trace up and down is the **ALIASING**.



1 ms



0.1 ms

Oversampling will provide a true picture of the time course of the event being studied but too much oversampling will result in very large data files.

E.g. at 10 kHz sampling rate, one second of 12 bit data is 20 Kbytes.
If you have 2 data channels then that is 40 KB/s or 2.4 MB/min.

Resolution

Resolution defines the number of divisions into which a full-scale input range can be divided to approximate an analog input.

Example

Recording the ambient temperature during the day manually at intervals of 30 minutes.

<u>Time</u>	<u>Temperature(°C)</u>	<u>Time</u>	<u>Temperature (°C)</u>
06:00	10	10:30	15
06:30	11	11:00	15
07:00	11	12:00	17
07:30	12	12:30	18
08:00	13	13:00	19
08:30	13	13:30	19
09:00	14	14:00	19
09:30	14	14:30	18
10:00	15	15:00	16
		15:30	15

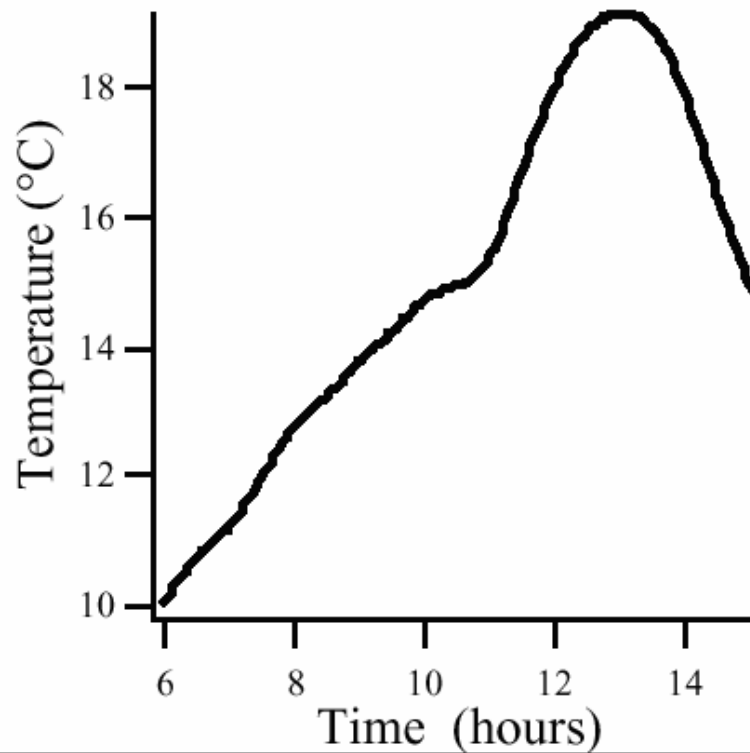
Rather than having to make the measurements manually and then transfer them to the computer by the keyboard it is easier to use a transducer and *data acquisition board* in the computer to directly record the temperature every 30 minutes.

A **platinum resistance thermometer** can be used as the transducer which is a temperature-dependent resistor, and by using an appropriate circuit, a continuous measurement of actual the temperature in the form of a proportional voltage can be obtained.

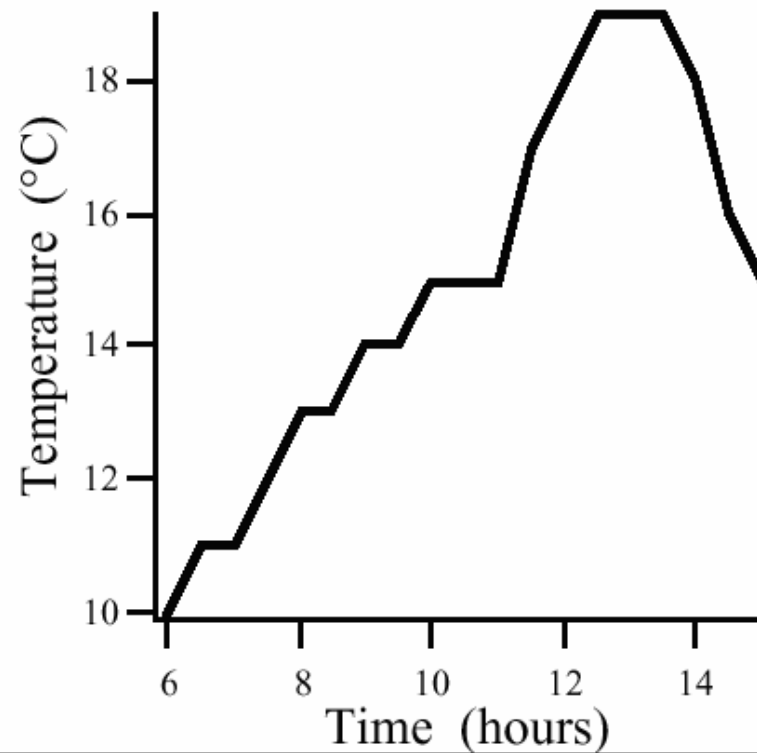
The data acquisition software converts the analog voltage corresponding to the temperature into **binary** numbers (digital format) in every 30 minutes. Since A/D board has finite resolution, a small range of analog values will all produce the same binary number after conversion.

Assume that the A/D board rounds off all numbers within its operating range to the nearest 1°C . That is although the ambient temperature changes continuously, the A/D board only indicates a change in it when a difference greater than 1°C is observed. The data thus changes in 1°C steps.

Continuous, analog measurements of temperature



Discrete digital measurements of temperature



In a real A/D board the total measurement range is divided into a fixed number of possible values. The number of values is a power of two, often referred to as the number of **bits**. Commonly used values are:

8 bits = 2^8 256 values

12 bits = 2^{12} 4,096 values

16 bits = 2^{16} 65,536 values

If it is desired to measure a 0-10V (or $\pm 5V$) signal, and the A/D board has 8-bit resolution, the input signal can be measured in steps of $10/2^8=10/256=0.039V=39\text{ mV}$.

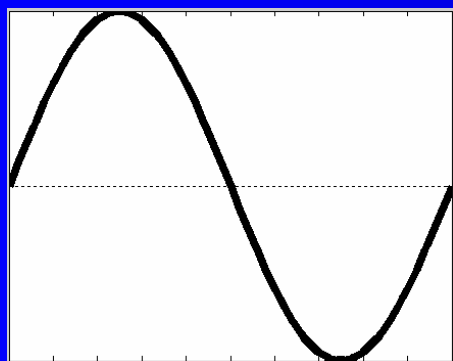
A 10V analog input is equal to the digital number 255, and a 0V analog input equals 0.

This A/D board is capable of detecting only input changes greater than 0.039V.

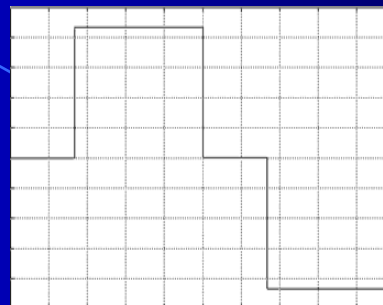
Each 0.039V change in the input is indicated by adding or subtracting 1 from the previous number i.e. 9.961V is digitally represented by 254.

An 12 bit board would be more sensitive to changes in the input voltage since its minimum resolution would be

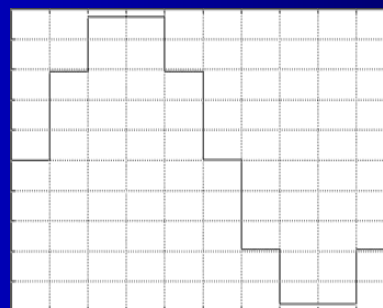
$$10\text{V}/4096 = 2.44\text{mV}$$



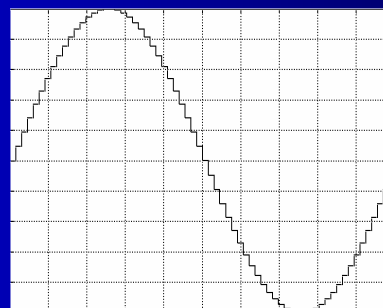
Analog Waveform



2 Bit
conversion



3 Bit
conversion



5 Bit
conversion

The input signal should not exceed 10V or the data acquisition board will **saturate** and it will not be able to report changes in the voltage as a function of time.

This effect will be seen as a perfectly flat line on the computer screen at $255 = 10V$

Even with a 12 bit A/D, it is necessary to use amplifiers prior to the input to the board in order to boost the signal so as to make use of a reasonable portion of the A/D range.

For example, the output of a thermometer might only change $1\text{mV}/^{\circ}\text{C}$, which would mean that the temperature would have to change by 2.5°C before the 12-bit board would indicate a change in digitized value.

By amplifying the signal output of the thermometer by $\times 1000$, each bit on the board is equivalent to a change in output of the thermometer of 0.001 mV which is equal to $0.0025 \text{ }^{\circ}\text{C}$.

Amplifiers are generally used to adjust the magnitude of the output of the transducers to match the input range of the A/D board.

Sometimes it is also necessary to adjust the baseline voltage after amplifying.

If temperature changes around room temperature are measured with x1000 amplification, then room temperature of 22°C is measured as 22V, which is much greater than the input range of the board. Therefore, it is necessary to adjust the output of the amplifier with an **offset**.

A preset offset may be applied.

The output of the amplifier is adjusted so that 22V would be offset by -22V, and the output at room temperature would be 0V.

Thus, the fluctuations of $\pm 5^{\circ}\text{C}$ around 22°C could be recorded by the computer without saturating the board.

Input Configuration

- There are two basic options when connecting the input signals:
 - Single-ended (SE)
 - Differential (Diff)
- SE inputs offer the lower cost per input. However, differential inputs offer greater noise immunity for more accurate readings. A typical A/D board offers 16 SE or 8 differential input channels.

Signal Source Type

Input

Floating Signal Source (Not Connected to Building Ground)

Examples

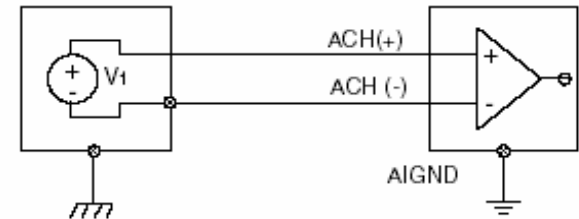
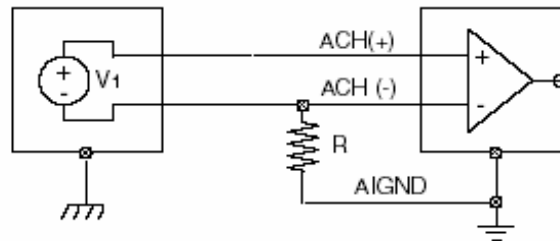
- Ungrounded Thermocouples
- Signal conditioning with isolated outputs
- Battery devices

Grounded Signal Source

Examples

- Plug-in instruments with nonisolated outputs

Differential (DIFF)



Signal Source Type

Input

Floating Signal Source (Not Connected to Building Ground)

Examples

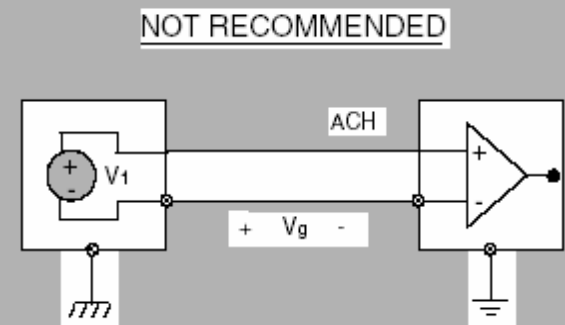
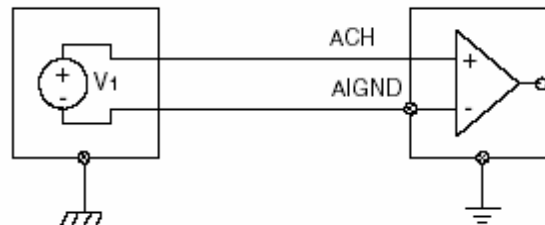
- Ungrounded Thermocouples
- Signal conditioning with isolated outputs
- Battery devices

Grounded Signal Source

Examples

- Plug-in instruments with nonisolated outputs

Single-Ended Ground Referenced (RSE)



Ground-loop losses, V_g , are added to measured signal

Signal Source Type

Input

Floating Signal Source (Not Connected to Building Ground)

Examples

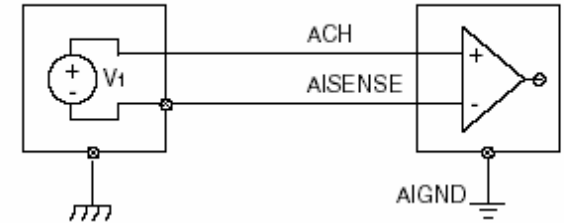
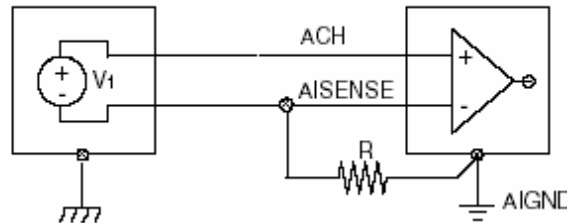
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Grounded Signal Source

Examples

- Plug-in instruments with nonisolated outputs

Single-Ended Non Referenced (NRSE)



Single-Ended vs. Differential Inputs

SE inputs should be utilized whenever analog measurements are to be made with respect to a common external ground and there is no practical way to bring both a remote ground and the analog ground back to the Data Acquisition System's front end.

Differential input configuration should be used when:

- Measuring signals with large common mode voltages, like many strain gauges.
- The input sensor is physically distant from the Data Acquisition System.

- Several sensors with no common ground are to be measured. Connecting the LOW side of each sensor together at a common point can create unwanted ground currents, resulting in offset and noise errors.

The Common Mode Rejection of a true differential input offers noise immunity from cable or transmission line pickup.

Analog Outputs (D/A)

Analog outputs are generated using a procedure which is exact reciprocal of that used to read analog inputs.

The user writes a binary word, which represents a percentage of the full-scale range, to the output register.

The D/A converter generates the analog level until the register is updated.

The **output rate** is a function of the settling time and is critical in determining the maximum frequency of the output waveform.

An analog output is typically required for any application involving a variable control device such as a servo motor or servo valve.

The outputs may be configured as voltages (0-10V, 0-5V, $\pm 10\text{V}$, $\pm 5\text{V}$) or as a 4-20mA current sources.

Digital Inputs and Outputs (DIO)

Most analog input/output boards also incorporate general-purpose digital input/output channels which are useful for many system functions.

Digital I/O lines are commonly used when:

- To sense and control high-power AC/DC voltages through solid-state relays.
- For low-current TTL signals like limit-switch inputs and other digital lines.

- Digital I/O lines can also be used for parallel communication between plug-in expansion cards and to generate strobe, pulse, clock, and other timing signals.
- Special-purpose digital I/O boards which use interrupt-driven control can operate in the background while the computer is running another application.

Data Acquisition by Using Simulink/MATLAB®

- Easy to use
- Toolboxes for different applications
- Real-time simulation
- Control Applications
- Software drivers for common boards

Mahtworks Web Site :



www.mathworks.com

Alternative Software:

LabVIEW®



by National Instruments



Web Site:

www.ni.com

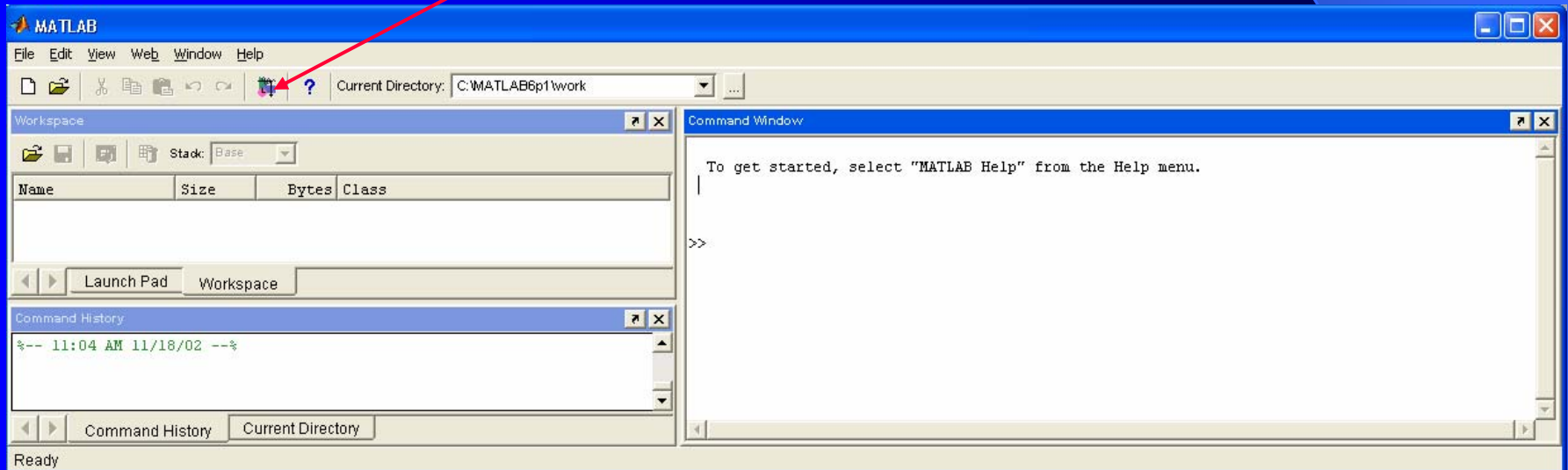
Simulink®

Run MATLAB® (Latest version 6.5 Rev13)

Welcome screen of Matlab®

Select Simulink

Simulink Library Browser



Don't forget to setup Real-Time Windows Target.

On the ***Command Window*** type
`rtwintgt -setup`

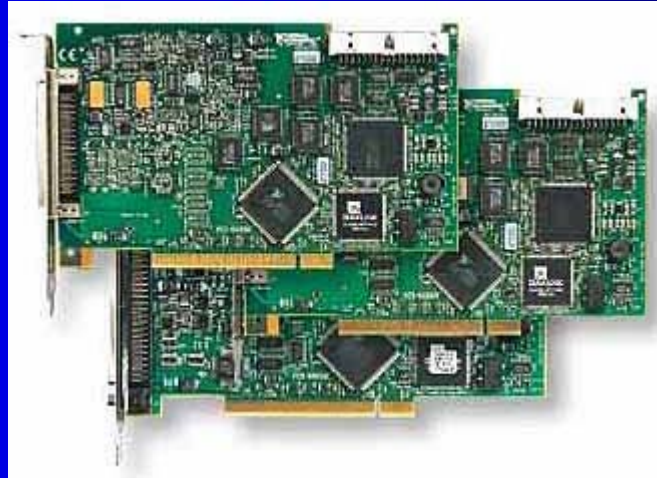
You are going to install the Real-Time Windows Target kernel.

Do you want to proceed? [y] : y

The Real-Time Windows Target kernel has been successfully installed.

You should have a data acquisition card installed in the computer.

In the following example, a **NI PCI6025E** card is used.

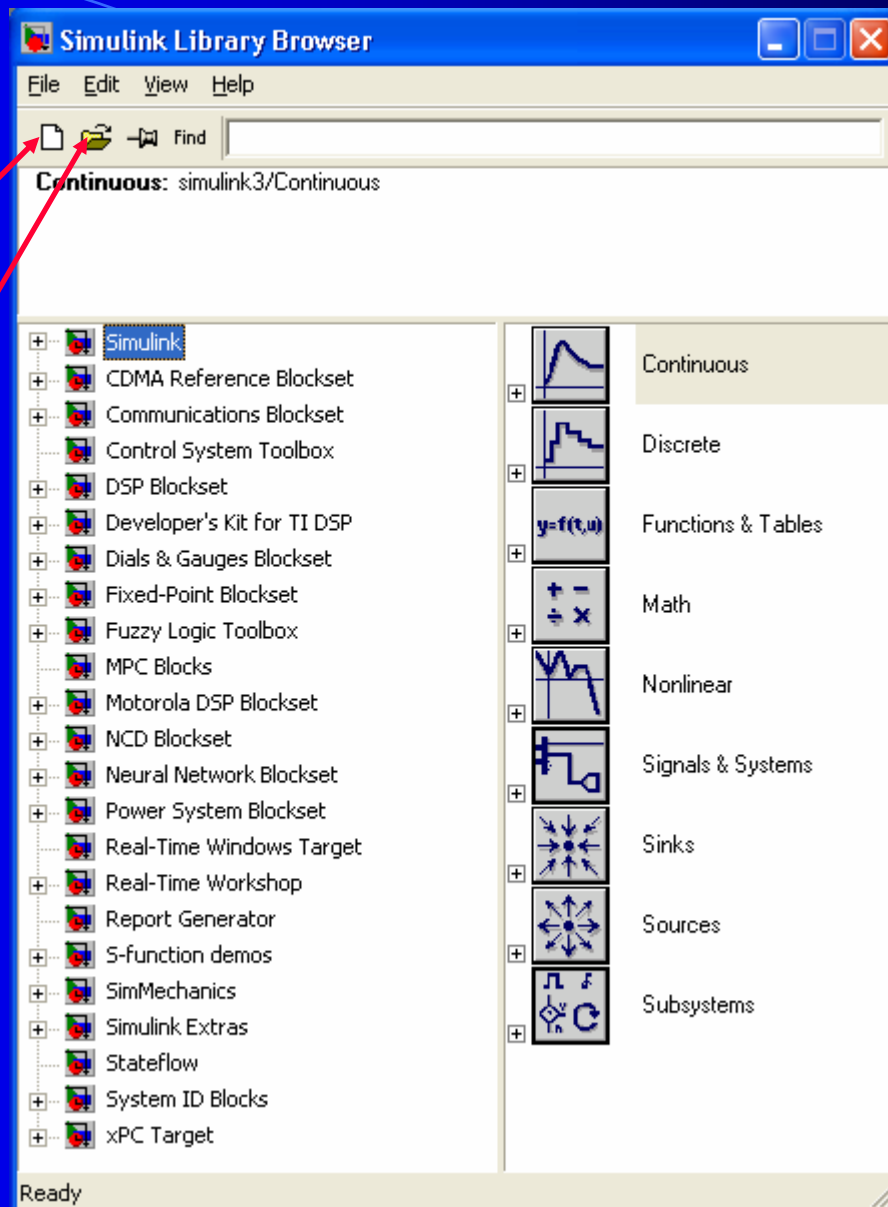


You should have one of the following C-compilers installed in your computer.

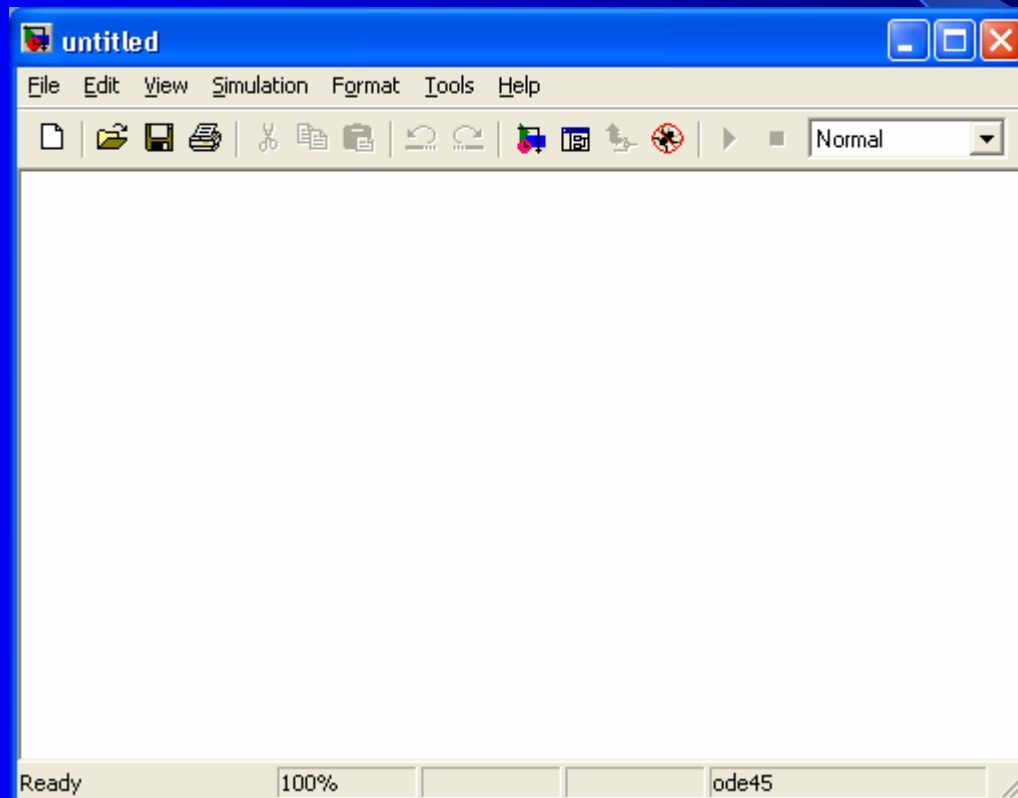
Watcom C/C++ (Version 10.6 or higher)

Microsoft Visual C/C++ (Version 5.0 or higher)

Select
NEW
or
OPEN
(a previous
model file)



An **Untitled** model is opened and using Simulink Library you can create your model.



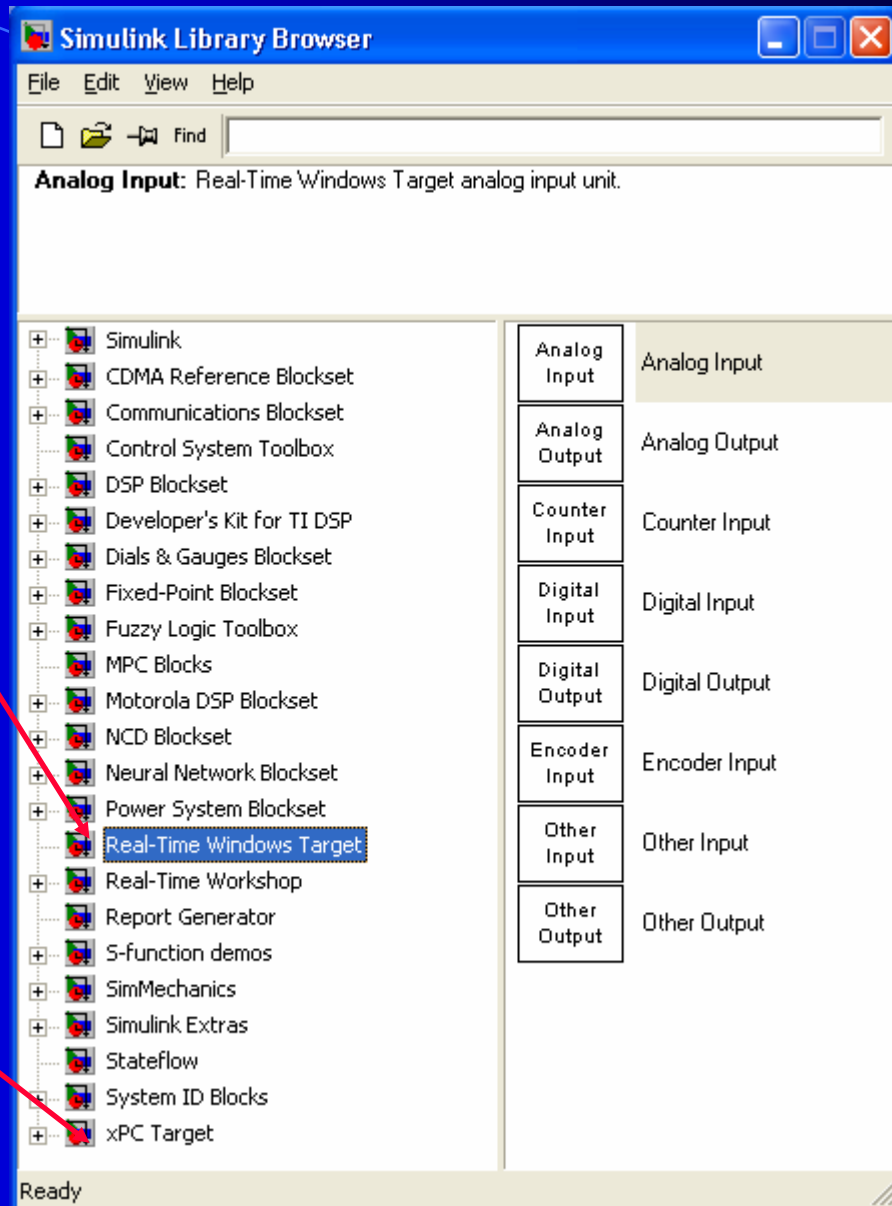
SIMPLE EXAMPLES

Simple PID-control System using a Data Acquisition Card with Analog Output

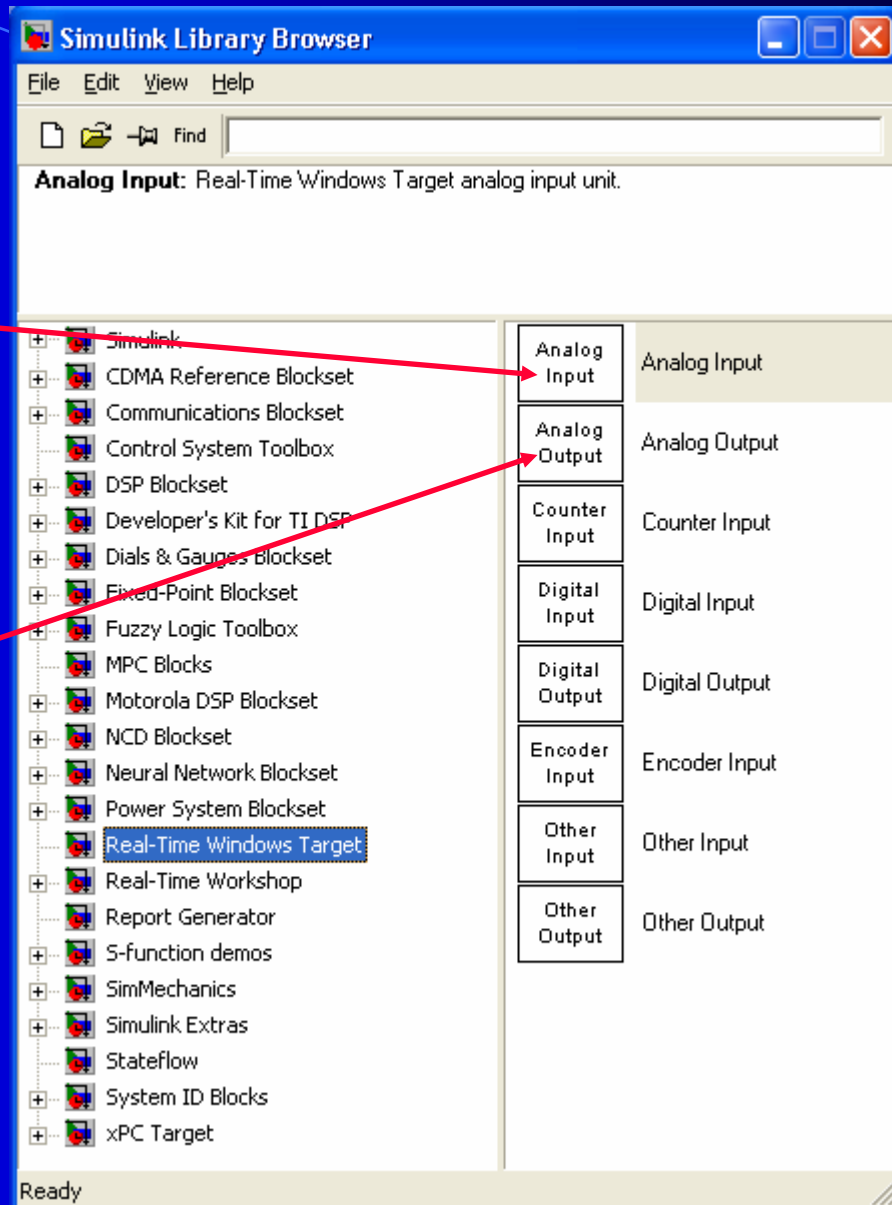
Problem: Find the unit step response of the system and display it on the scope with the input.

Click on
**Real-Time
Windows
Target**

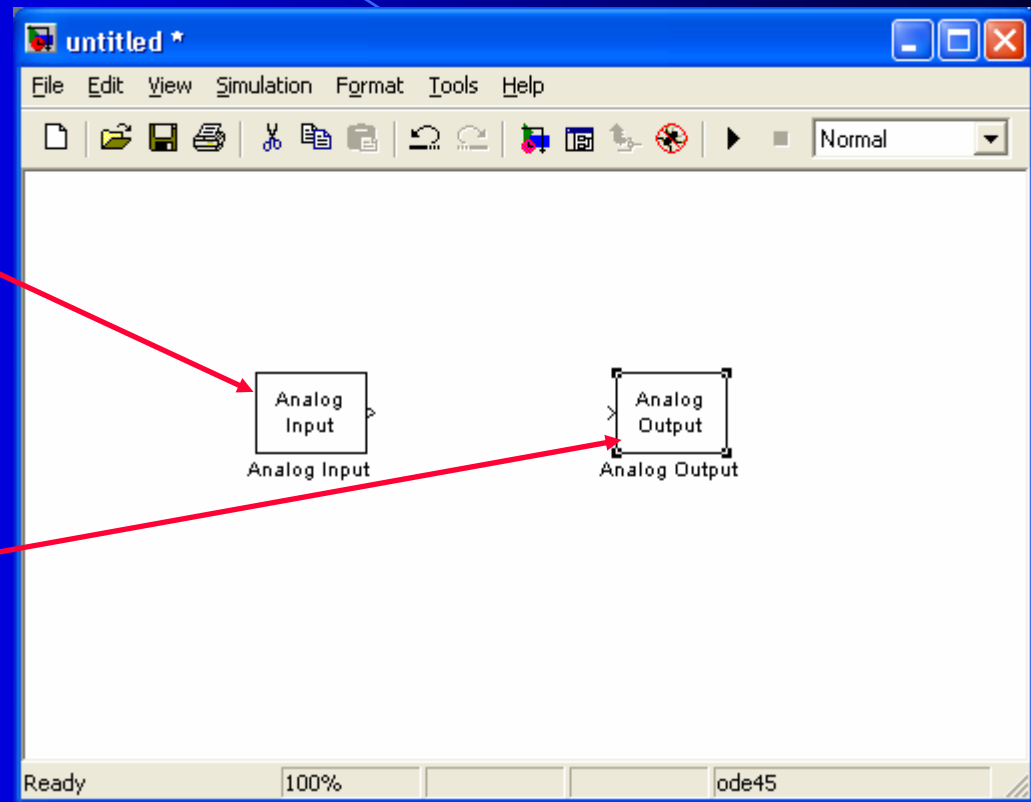
**x-PC
Target** is
now more
popular.



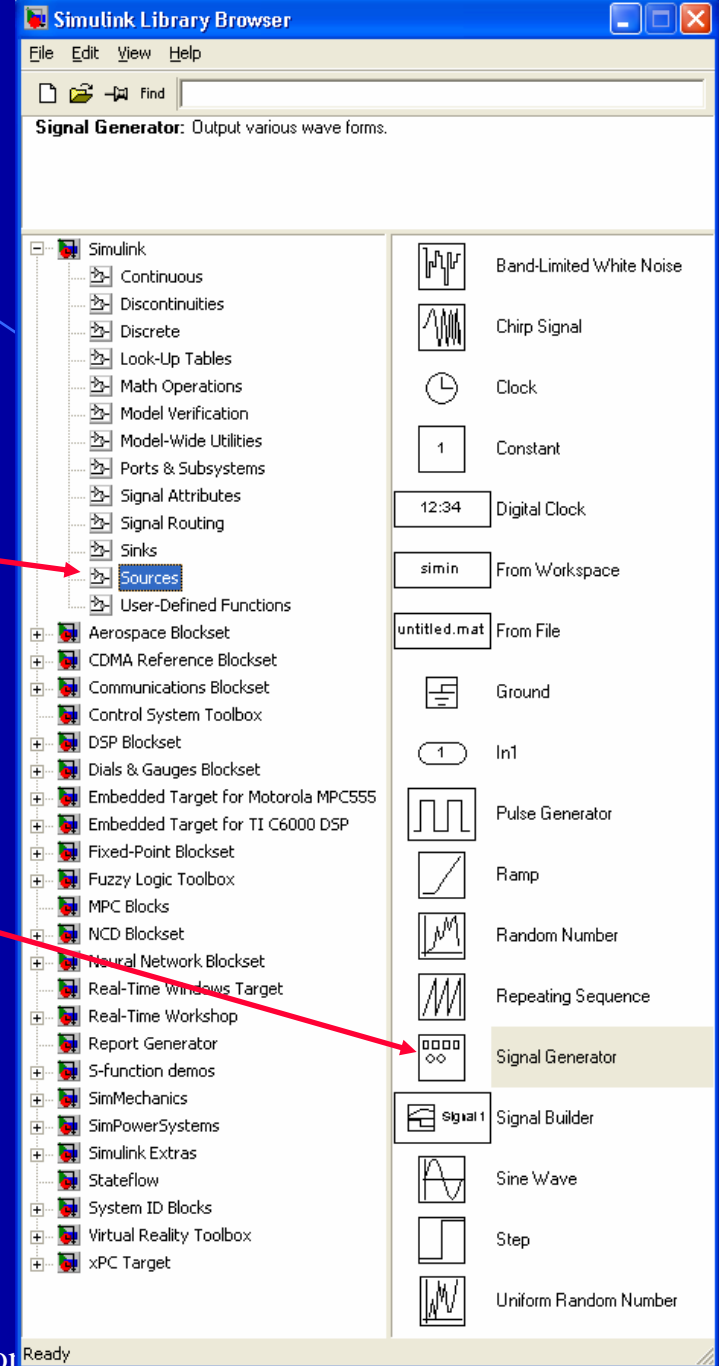
Drag
**Analog
Input
and
Analog
Output**
icons
to model



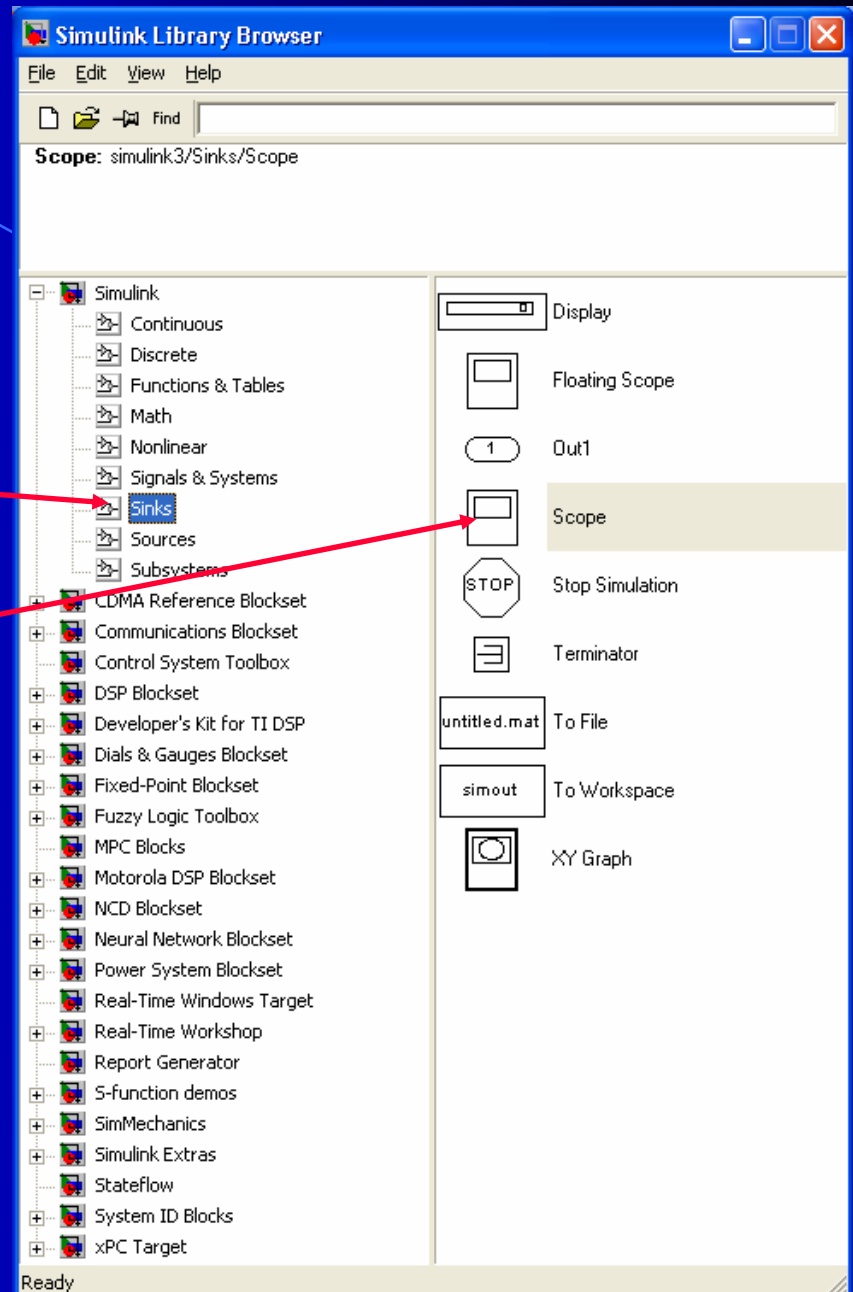
Double
Click on
**Analog
Input**
and
**Analog
Output**
icons
for setting



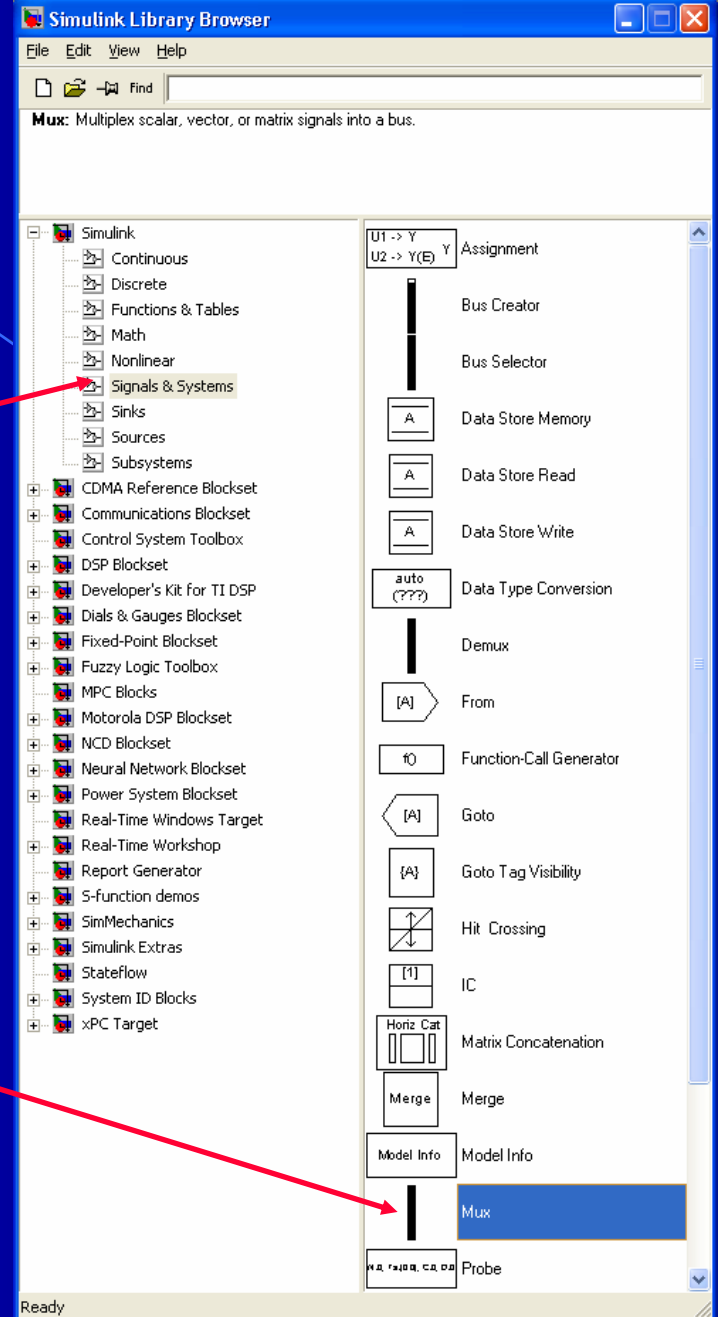
Under
Sources
Select
Signal
Generator
and drag
into model



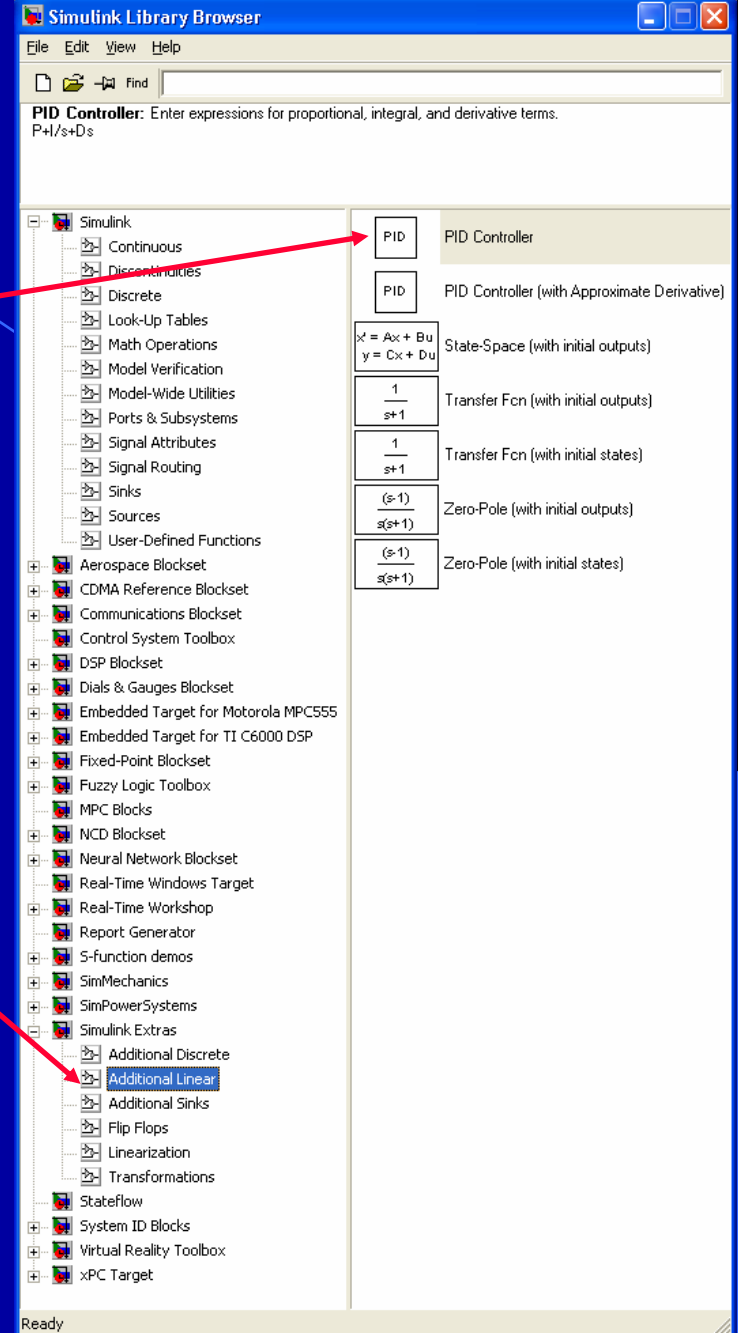
Under
Sinks
Select
Scope
and drag
into
model



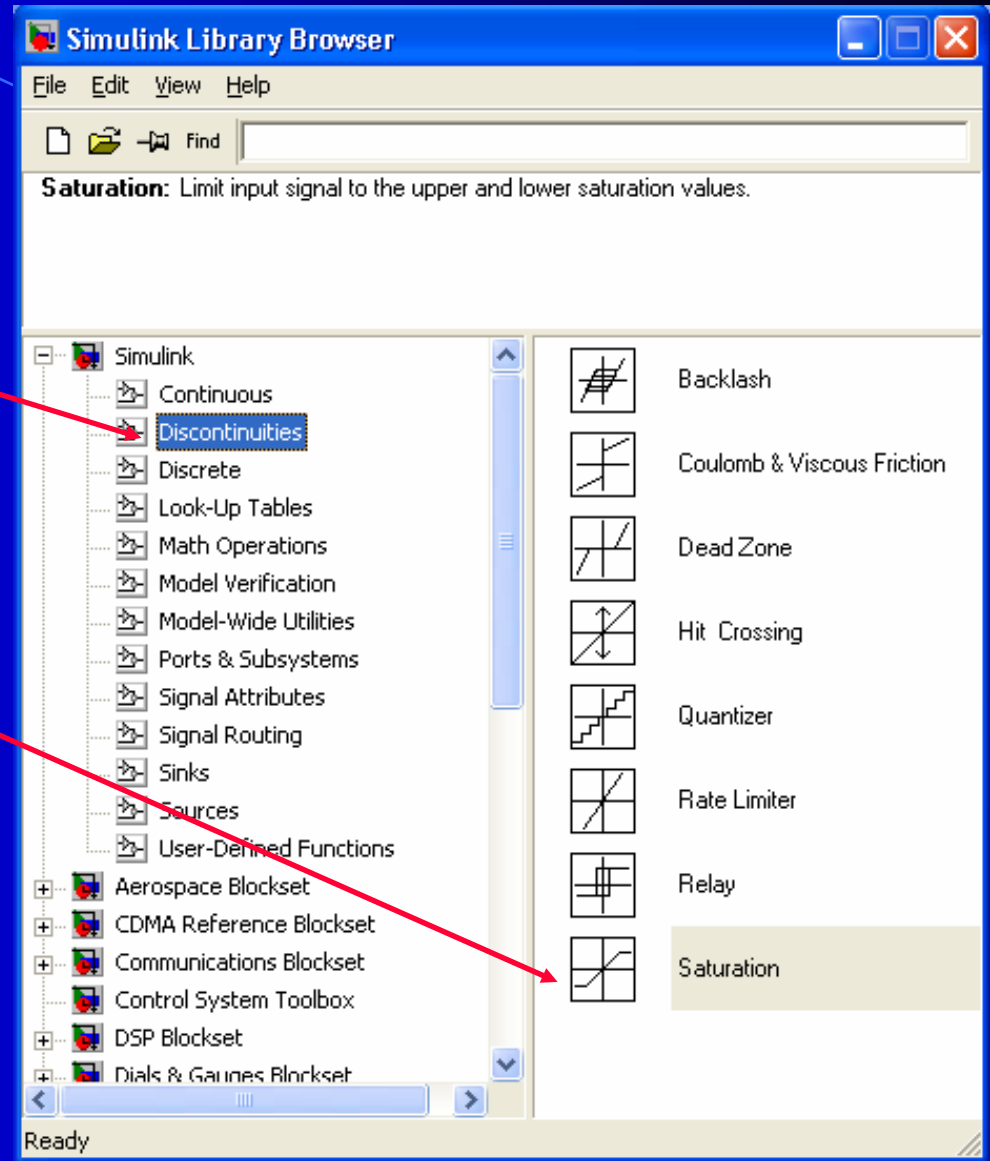
Under
**Signals and
Systems**
Select
Mux
and drag into
model



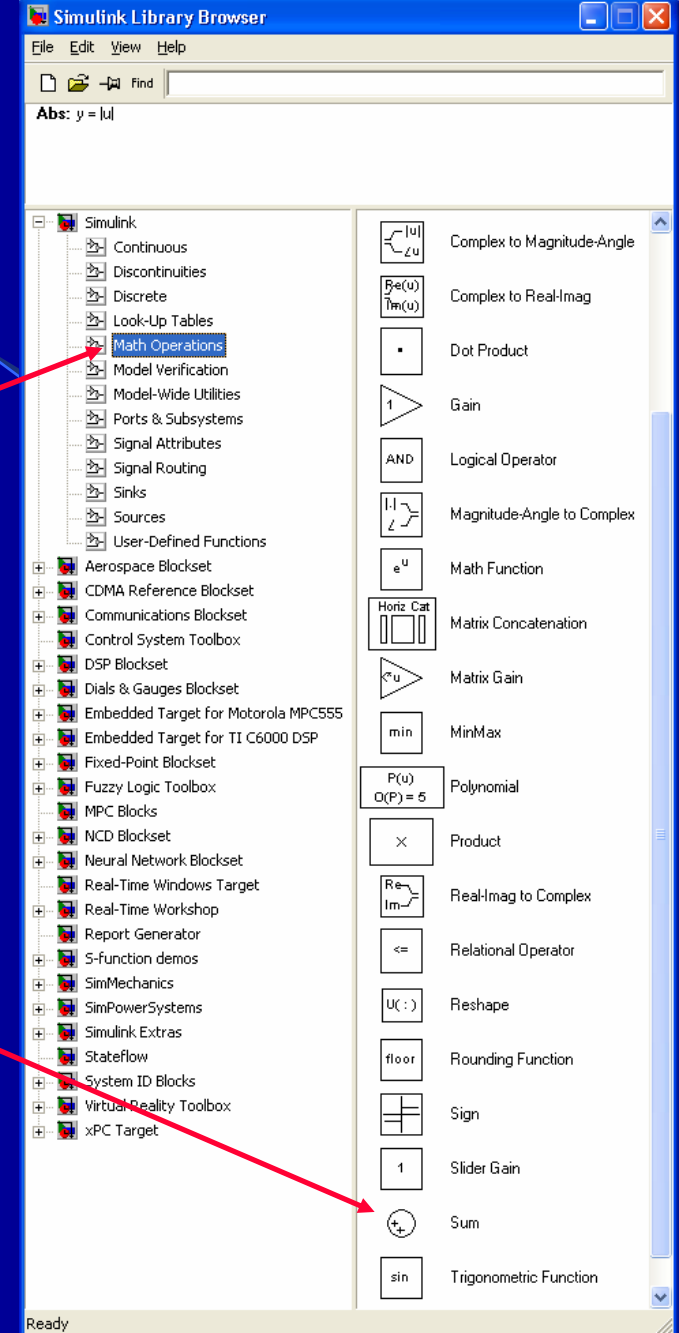
Select
PID Controller
Under
Simulink
Extras
Additional
Linear
and drag into
model



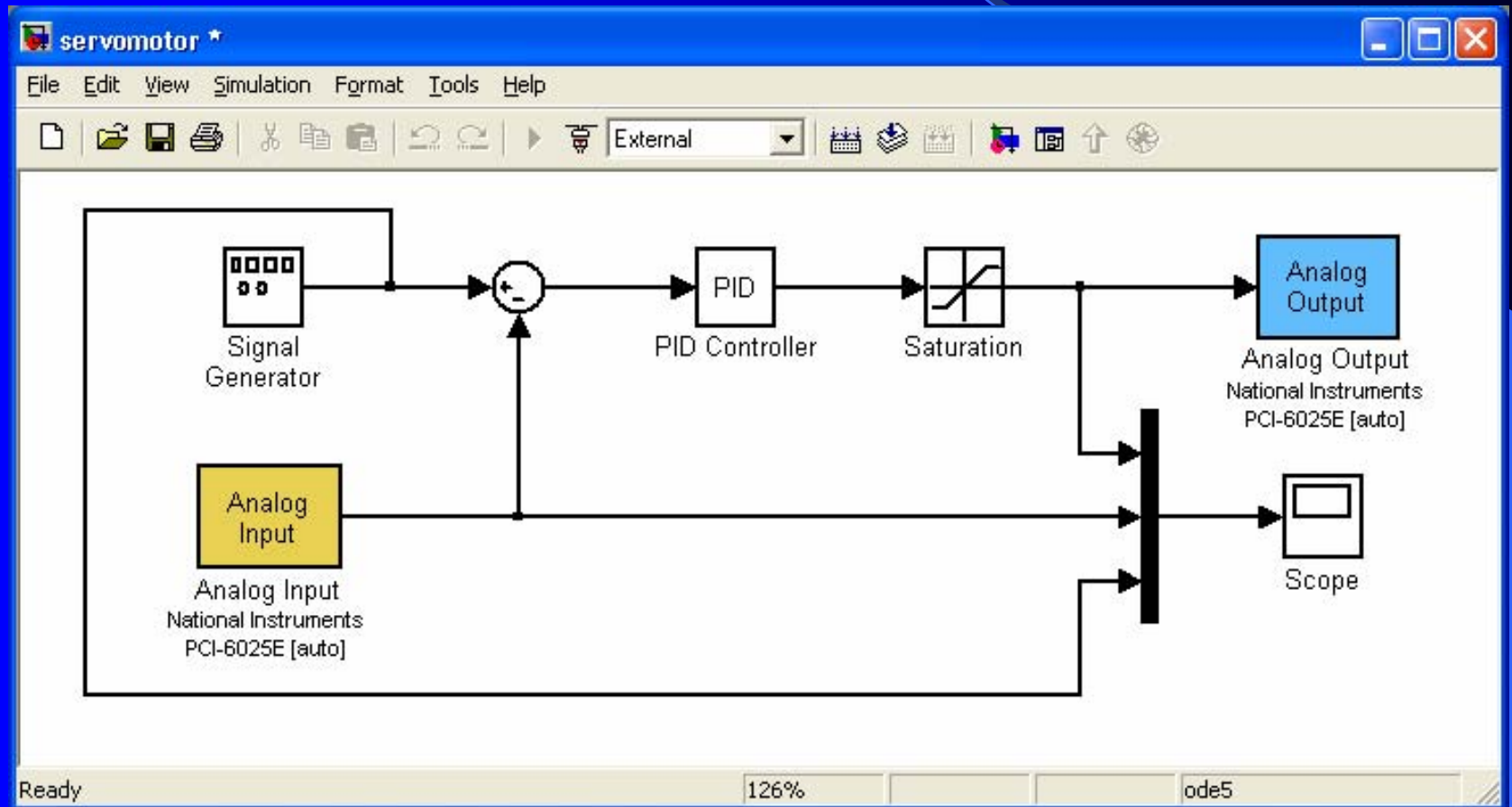
Under
Discontinuities
Select
Saturation
and drag into
model



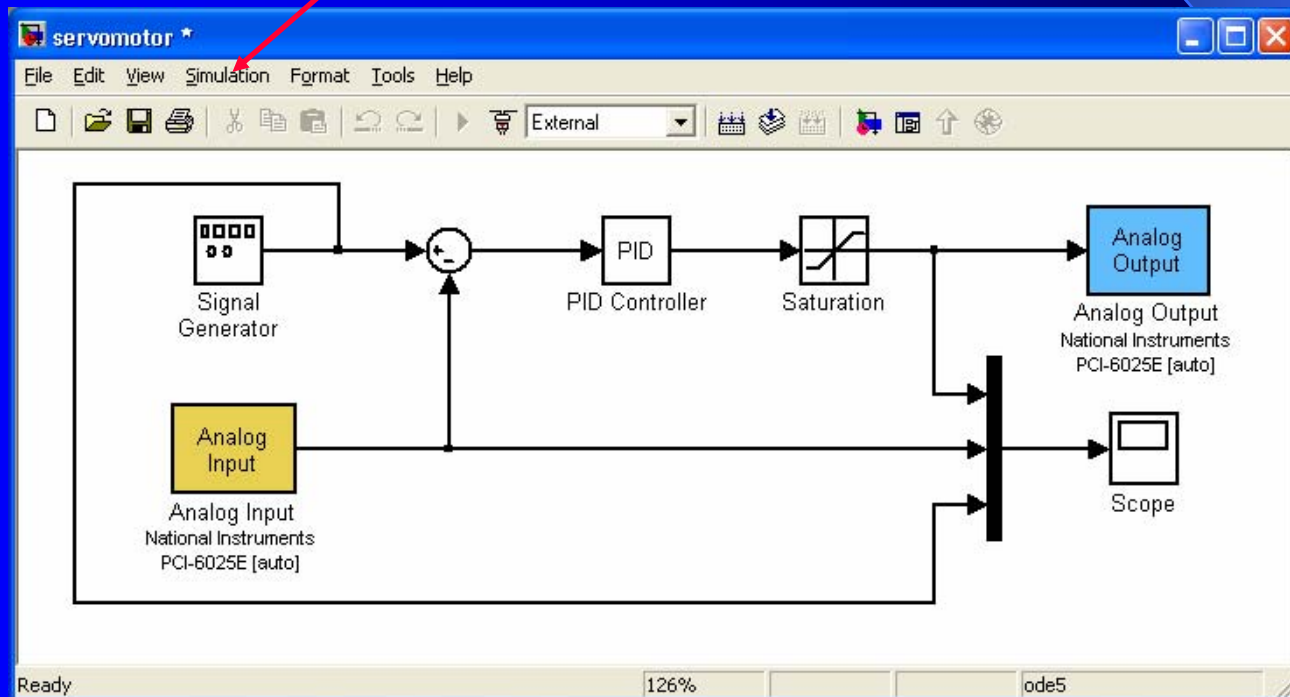
Under
Math Operations
Select
Sum
and drag into
model



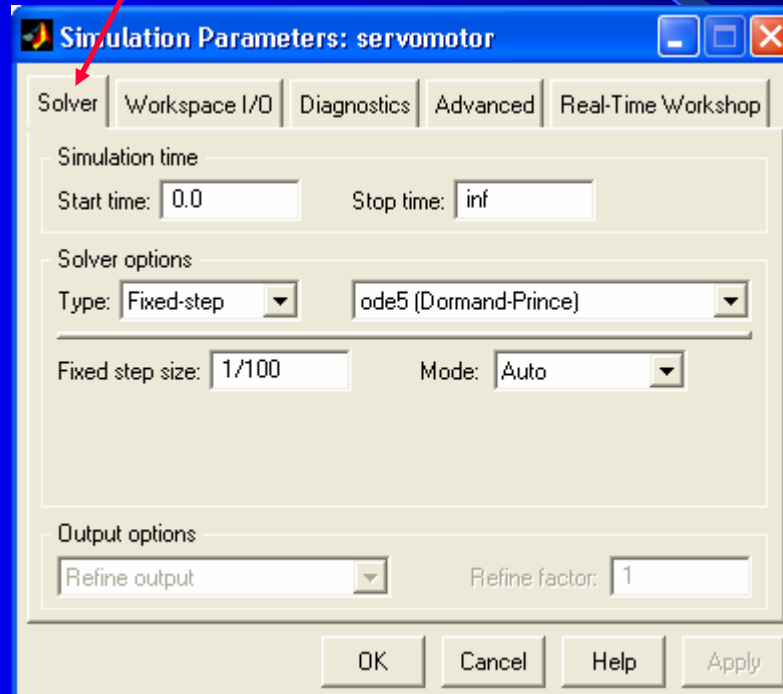
Complete Model



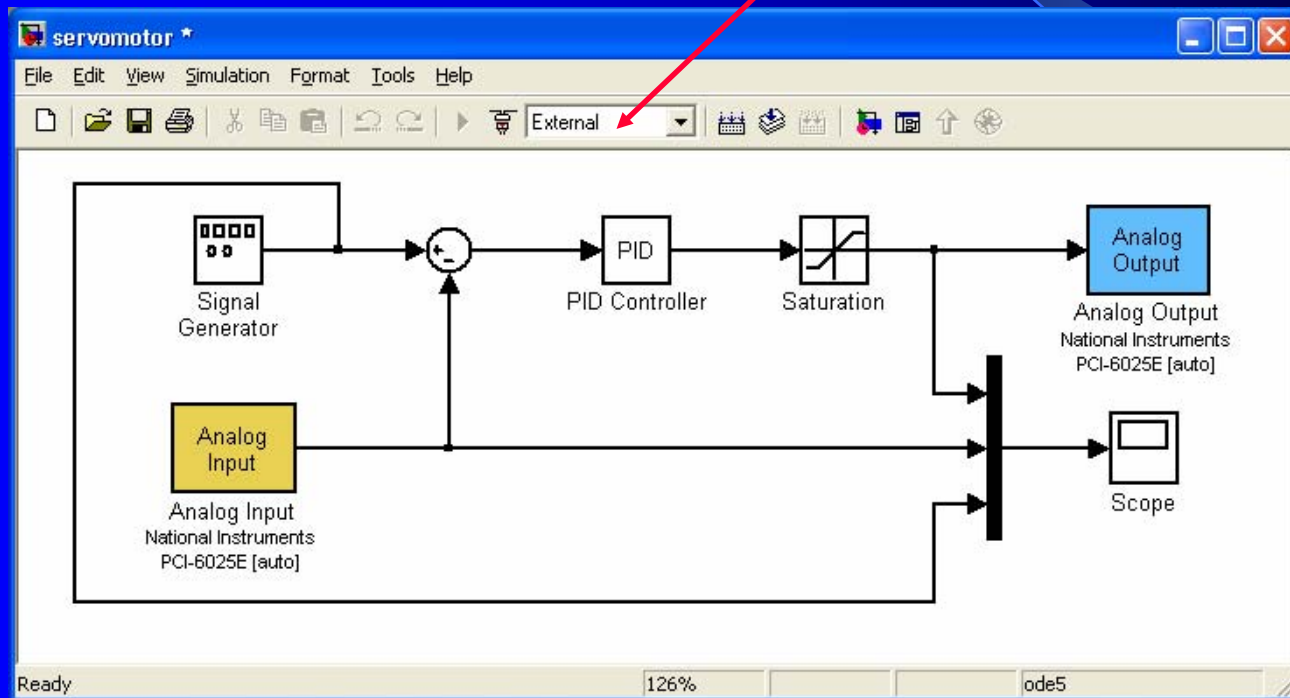
Select Simulation Parameters under **Simulation** Menu



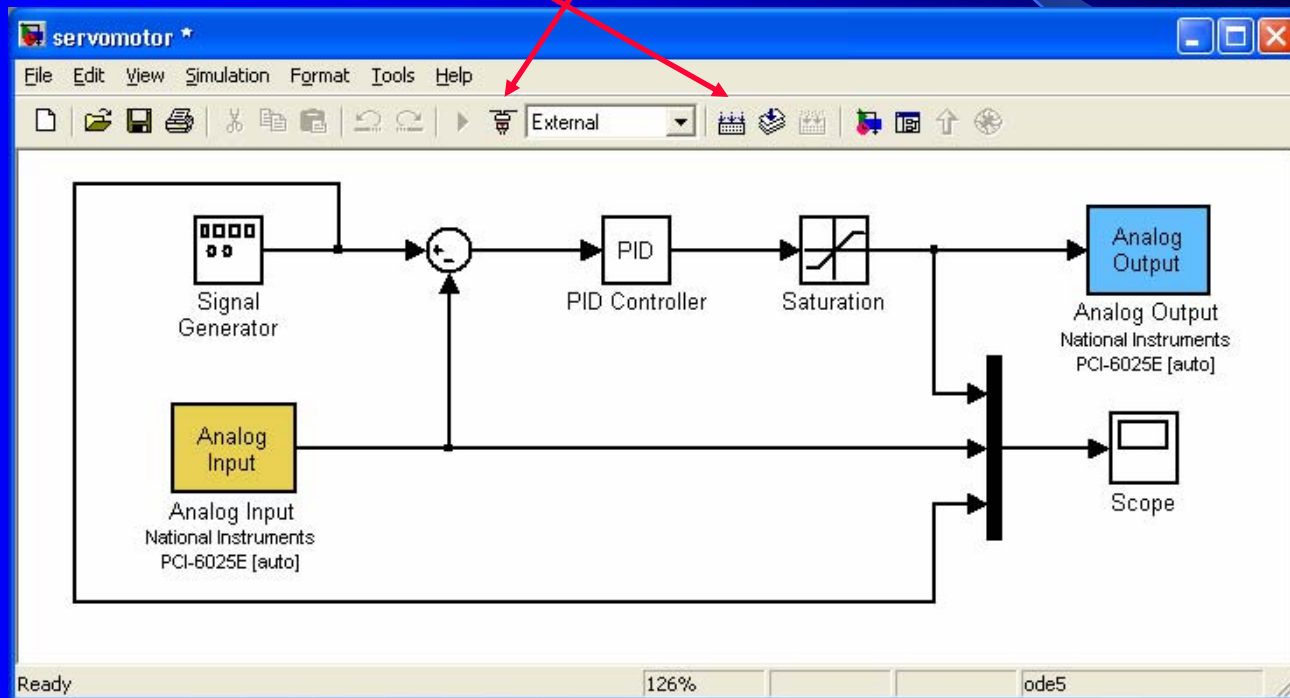
Set Solver Parameters



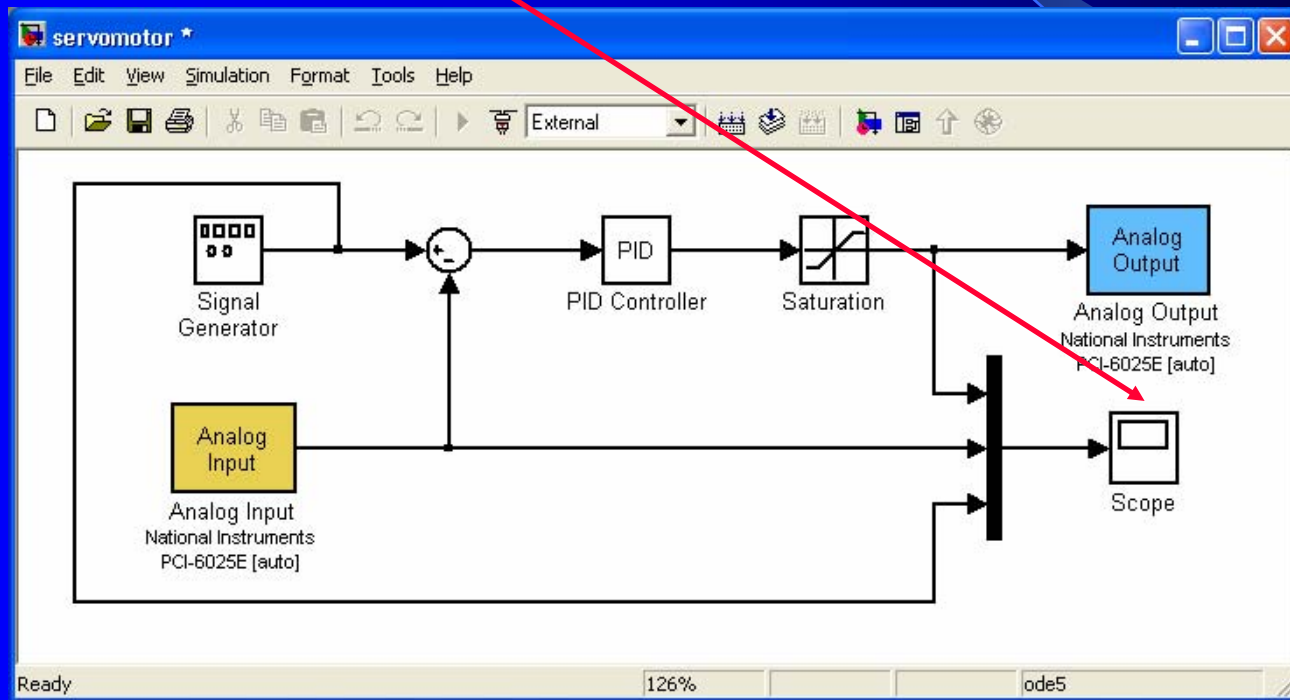
Set mode to External



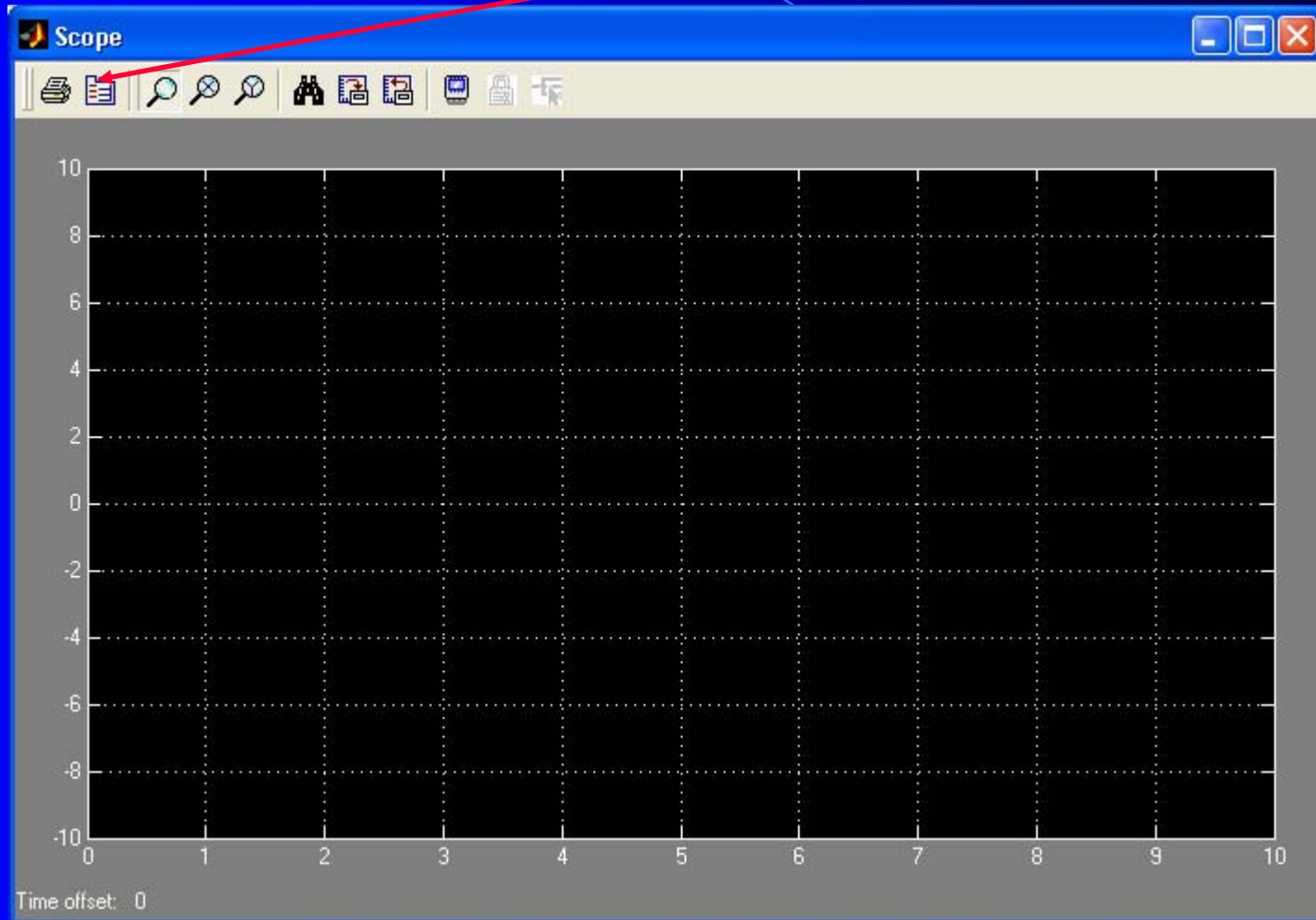
Build and Run the model



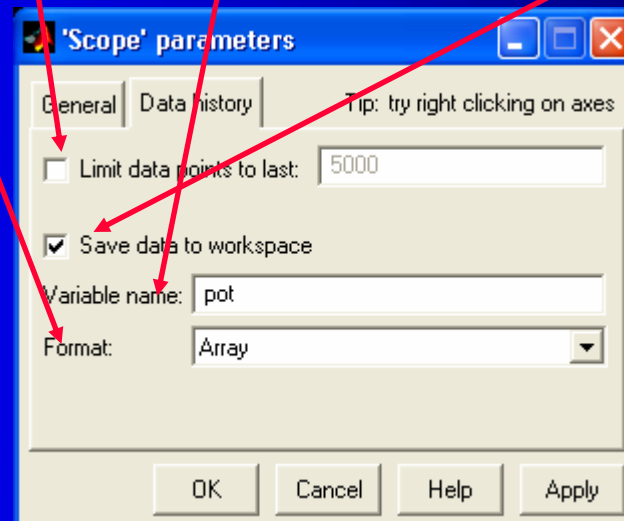
Open **Scope** by double clicking on it



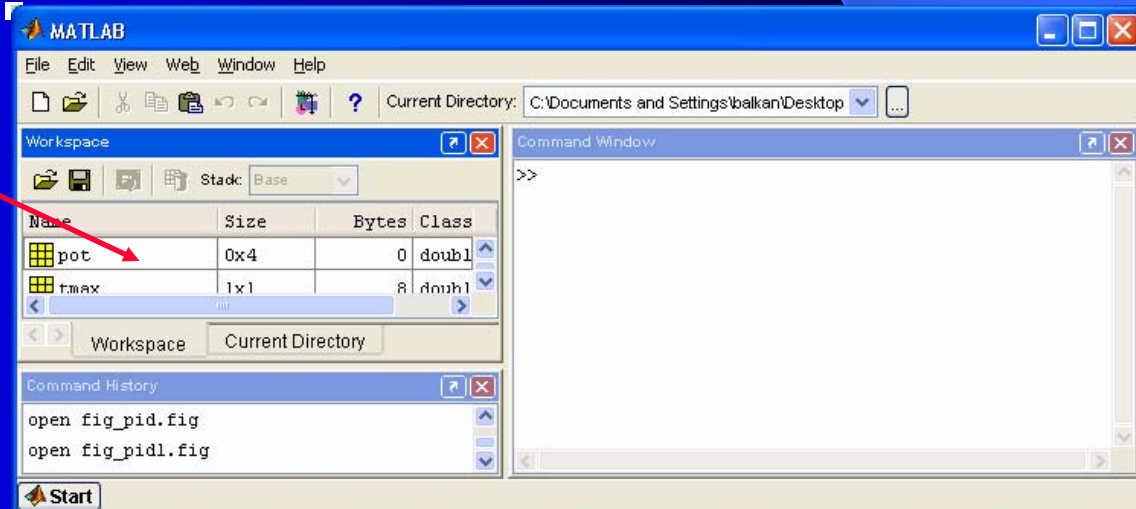
Set Scope Parameters



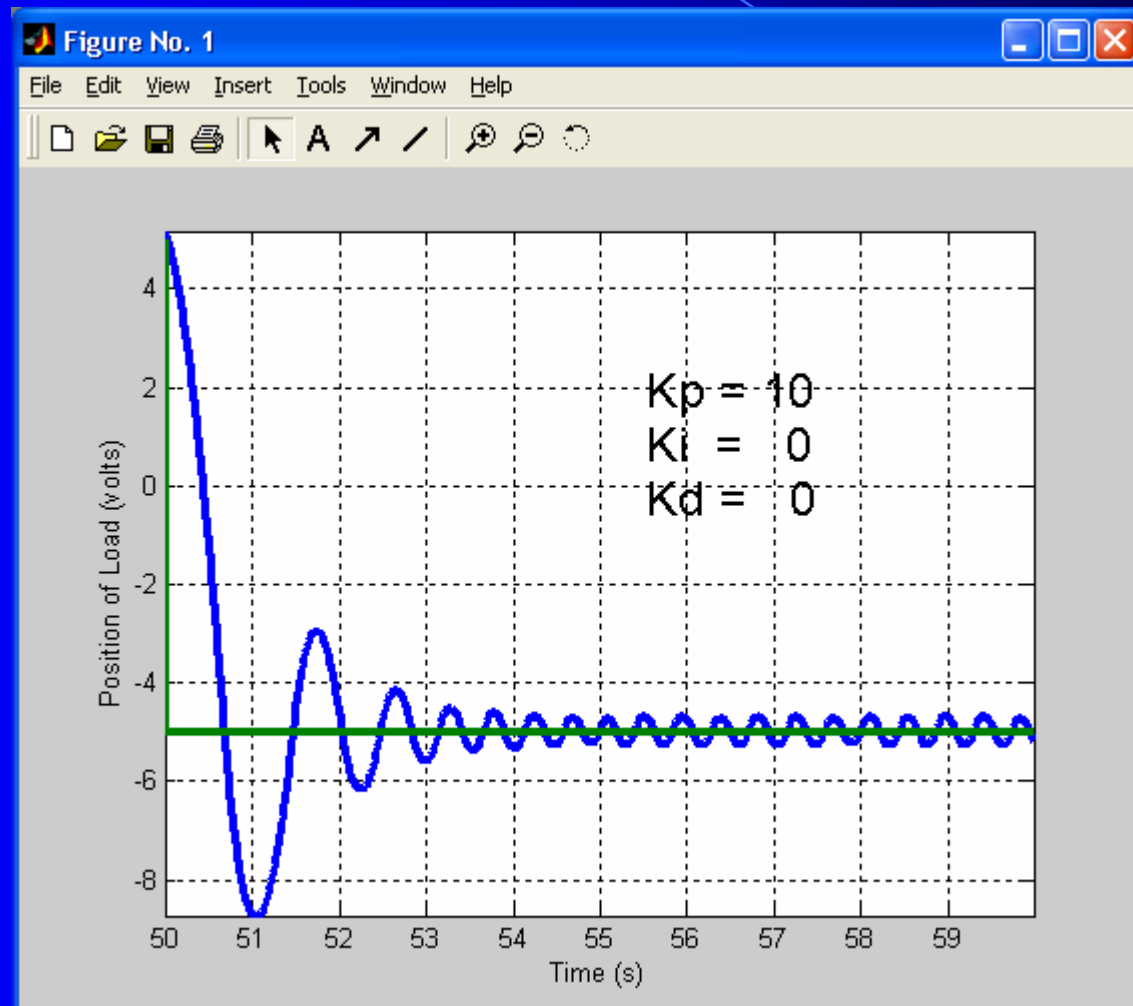
Set **Format** to **Array**, remove the tick on **Limit data points to last**, tick **Save data to workspace**, and give a **variable name**.



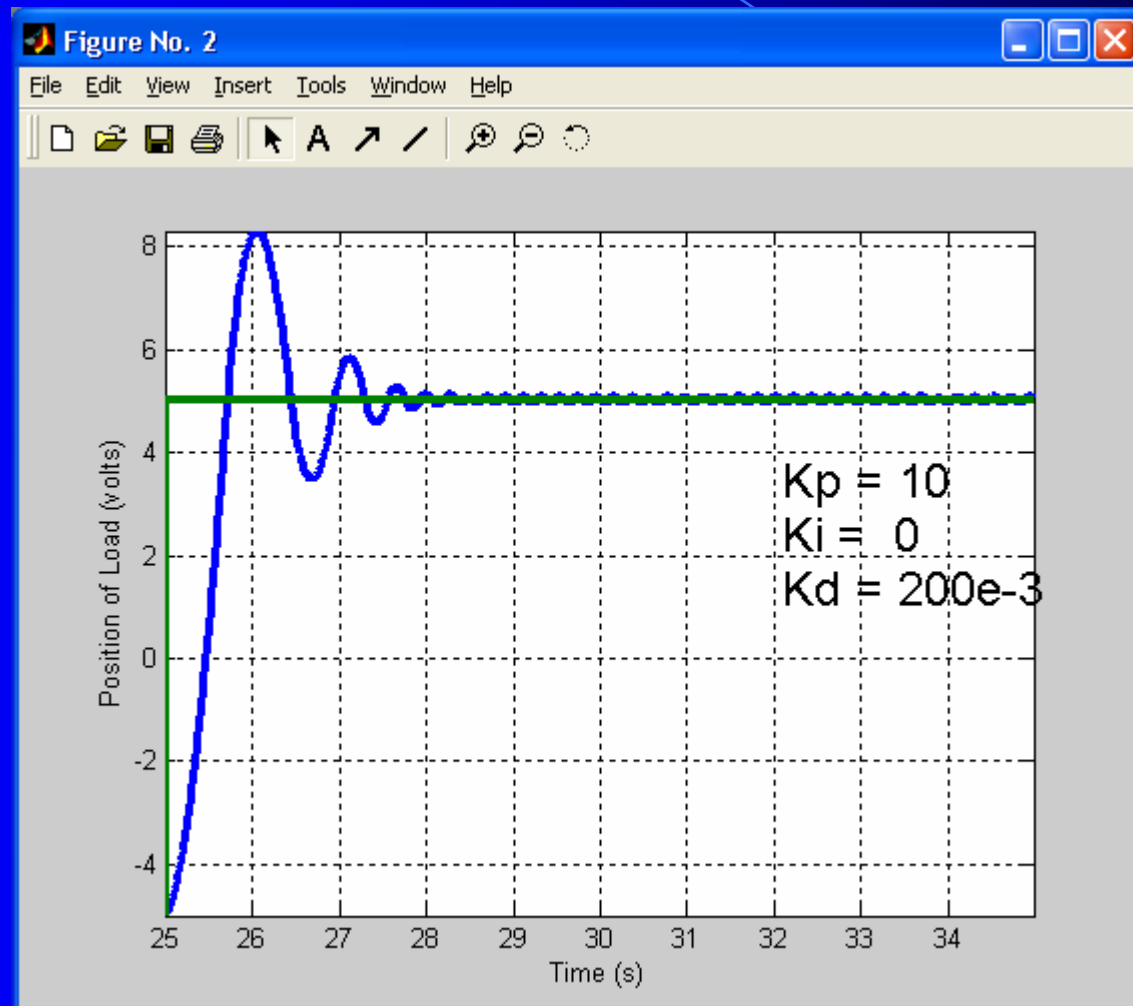
You may plot the response by using **plot** command on the command window by using the data saved in the **workspace**.



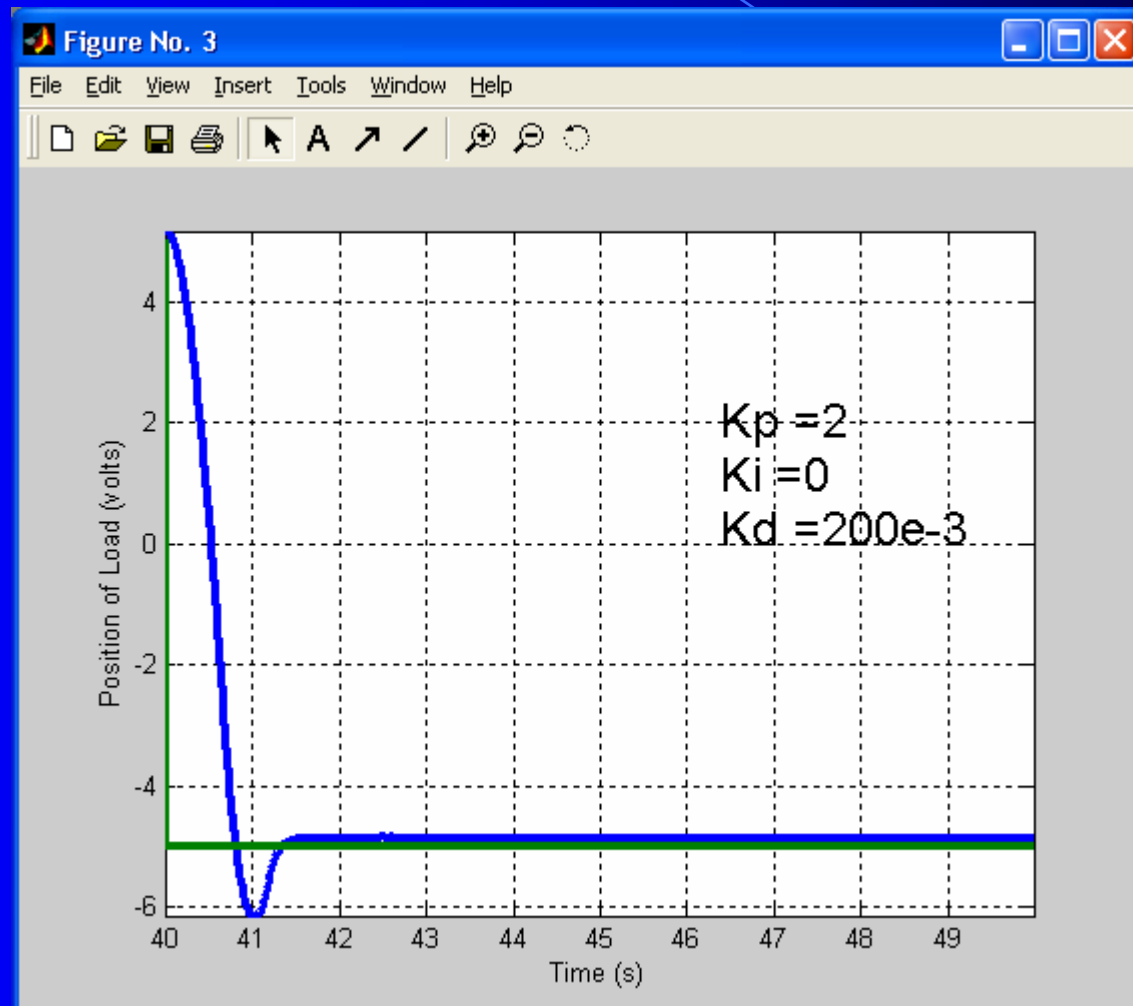
Examples from System Responses (P-control)



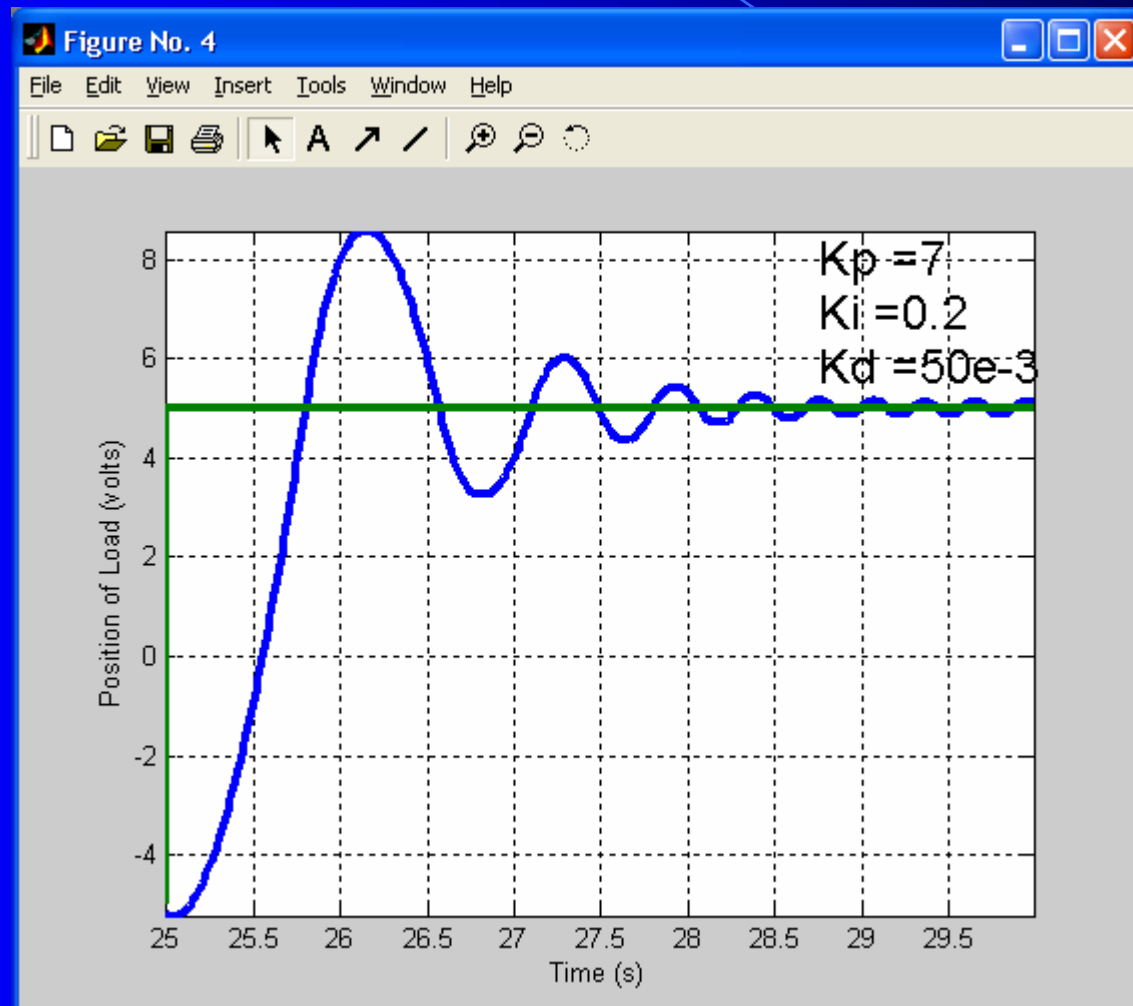
Examples from System Responses (PD-control)



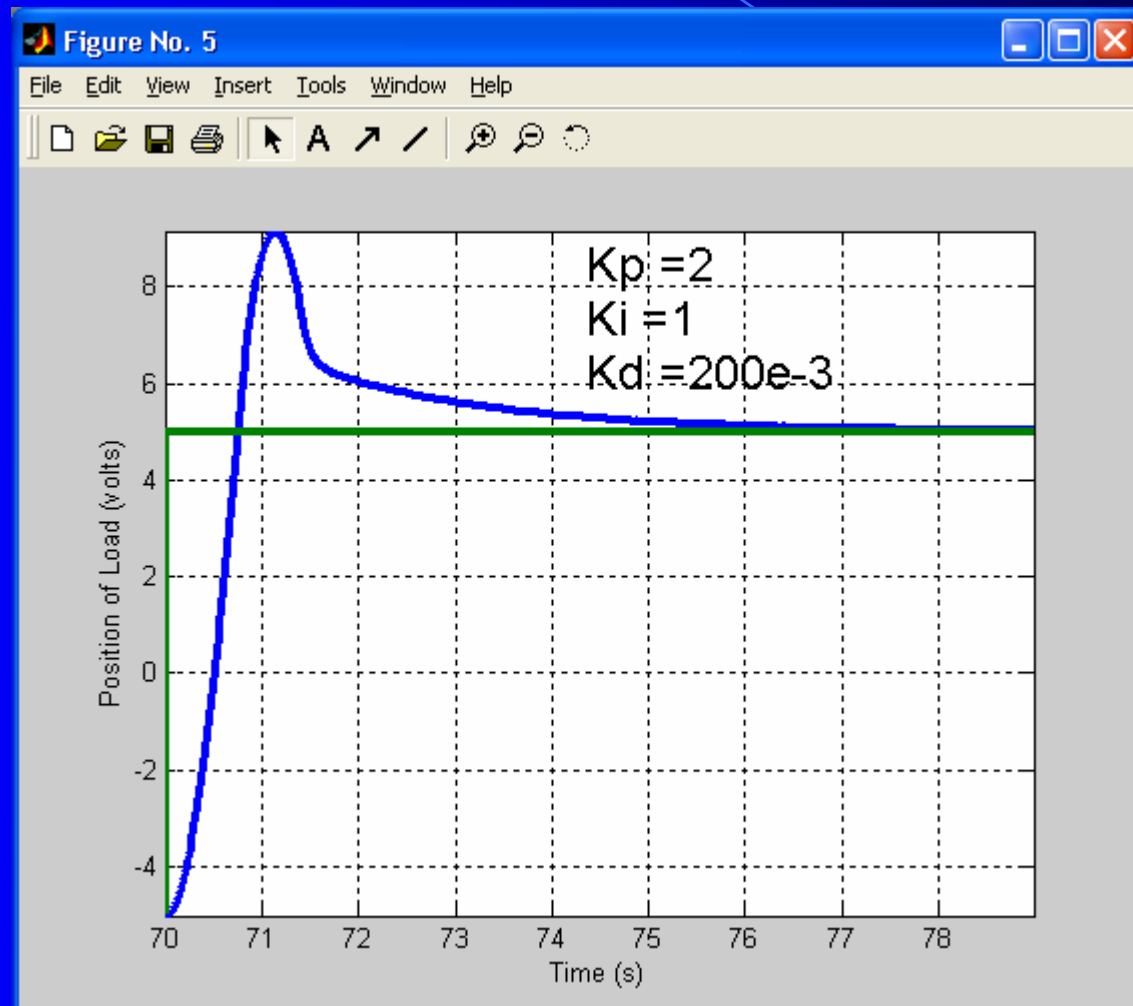
Examples from System Responses (PD-control)



Examples from System Responses (PID-control)

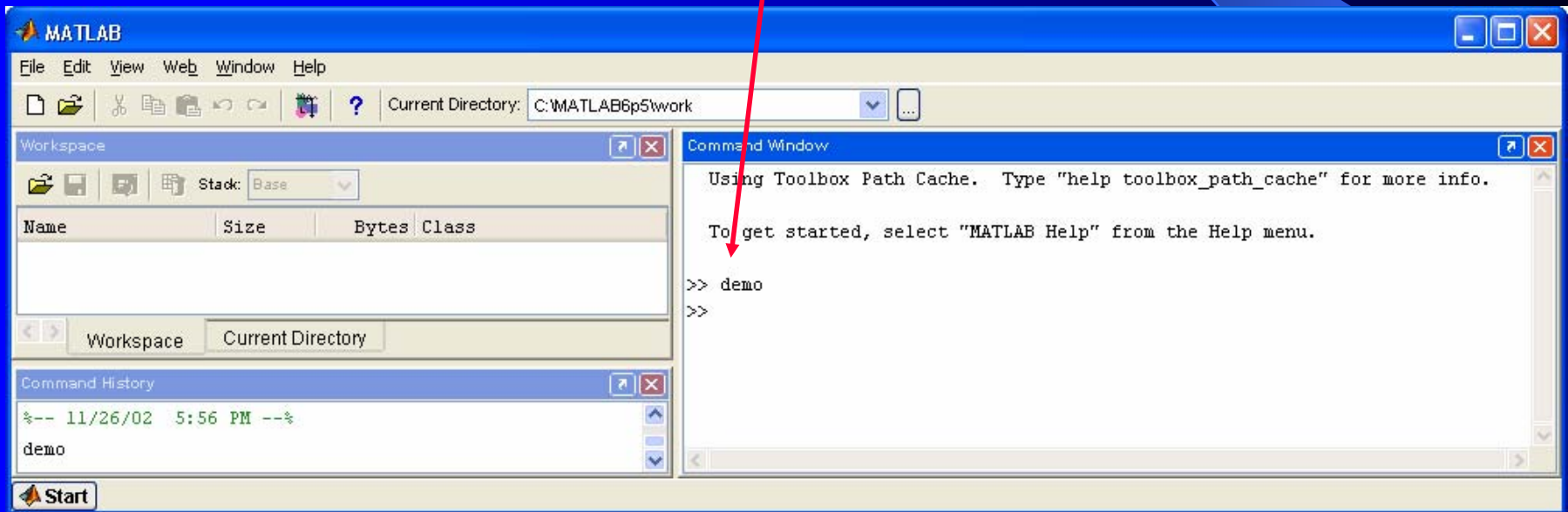


Examples from System Responses (PID-control)

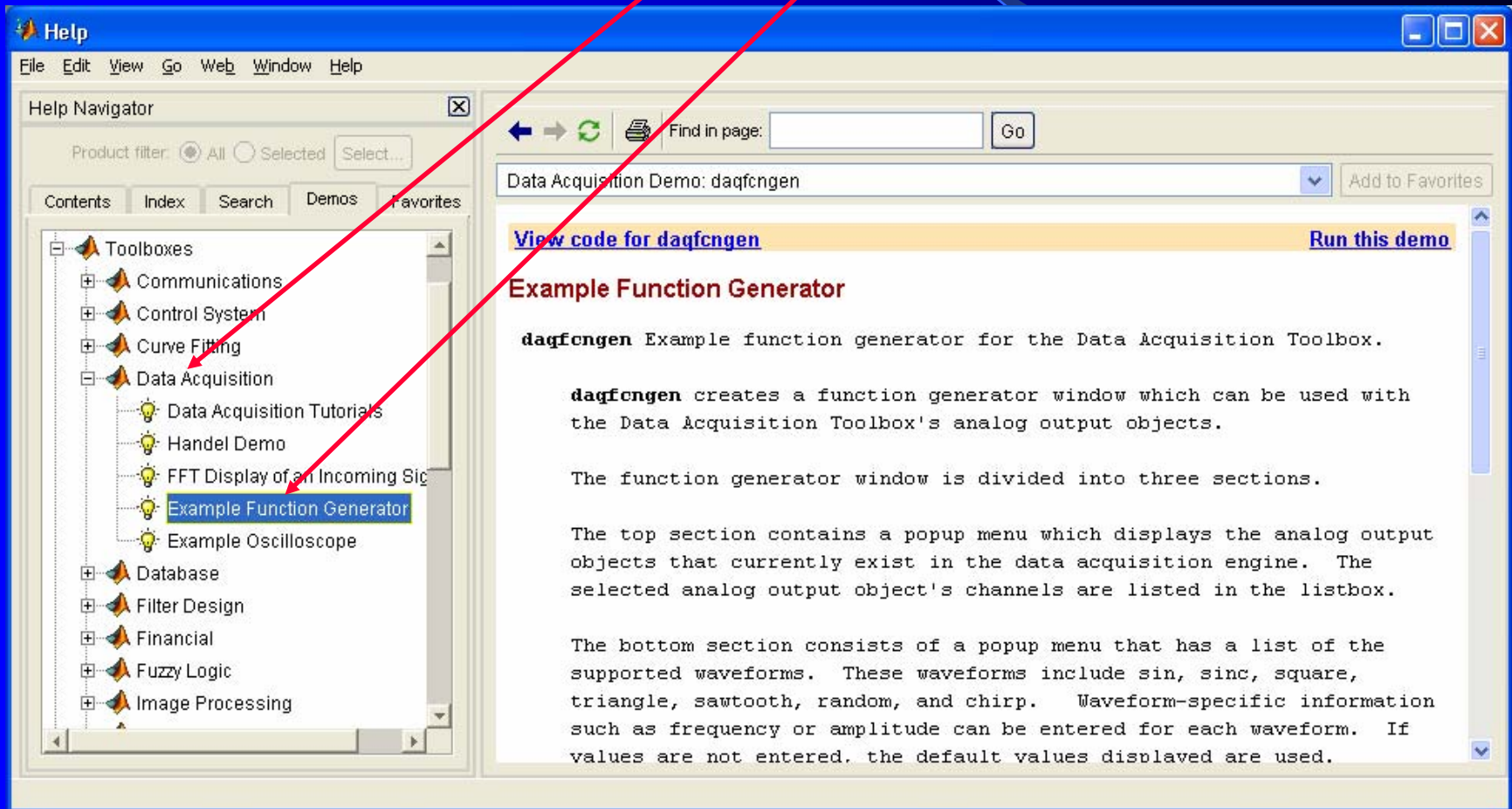


Data Acquisition using Data Acquisition Toolbox and your sound card's microphone input and speaker outputs

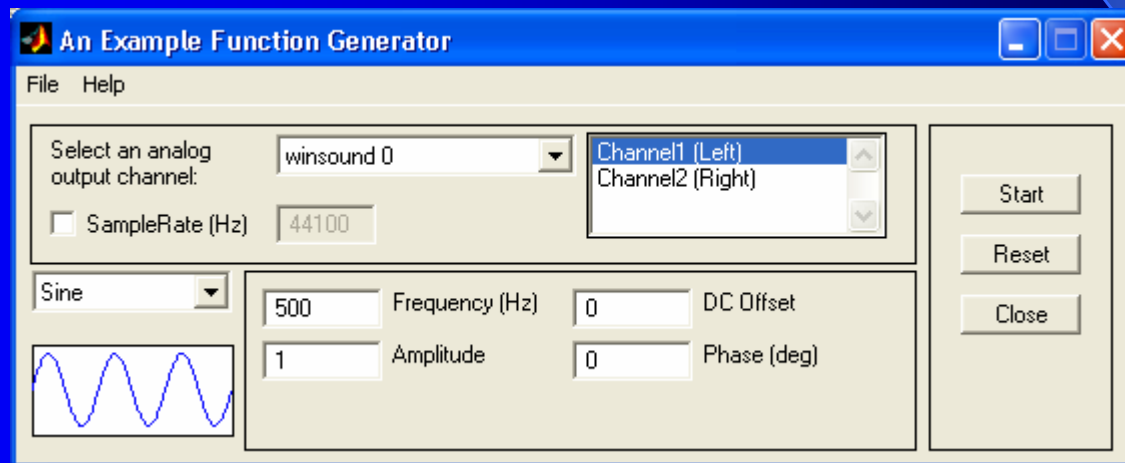
Open DEMO window by typing **demo** on the command window.



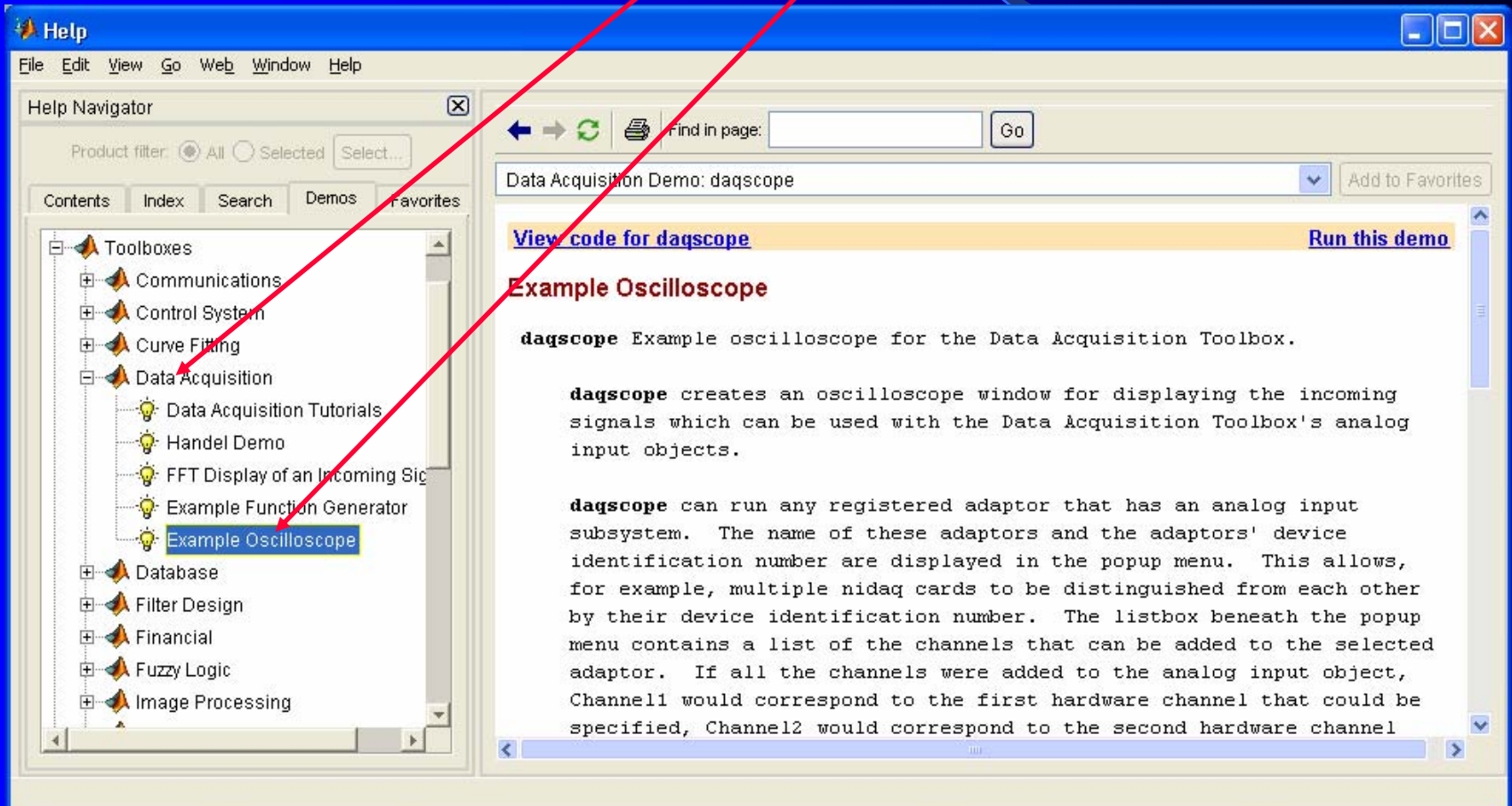
Select Data Acquisition Example Function Generator.



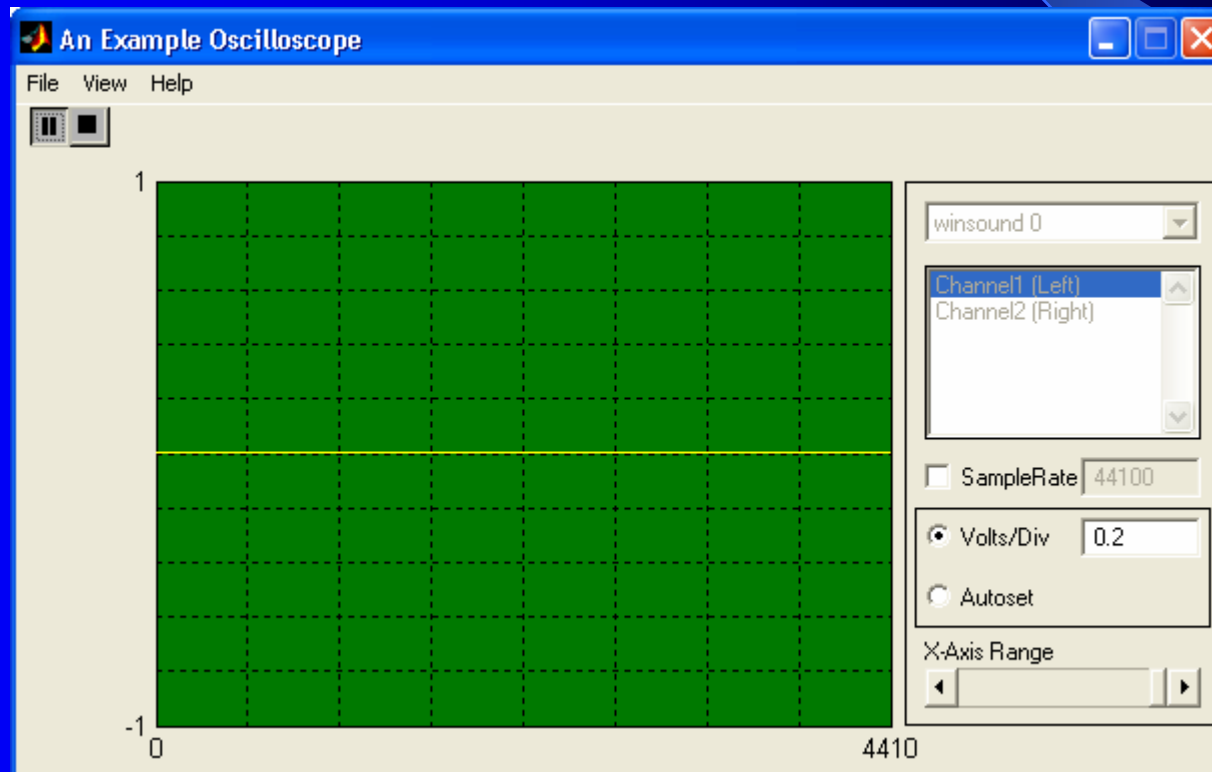
Start demo for analog output.
You will hear sound with
frequency 500 Hz.



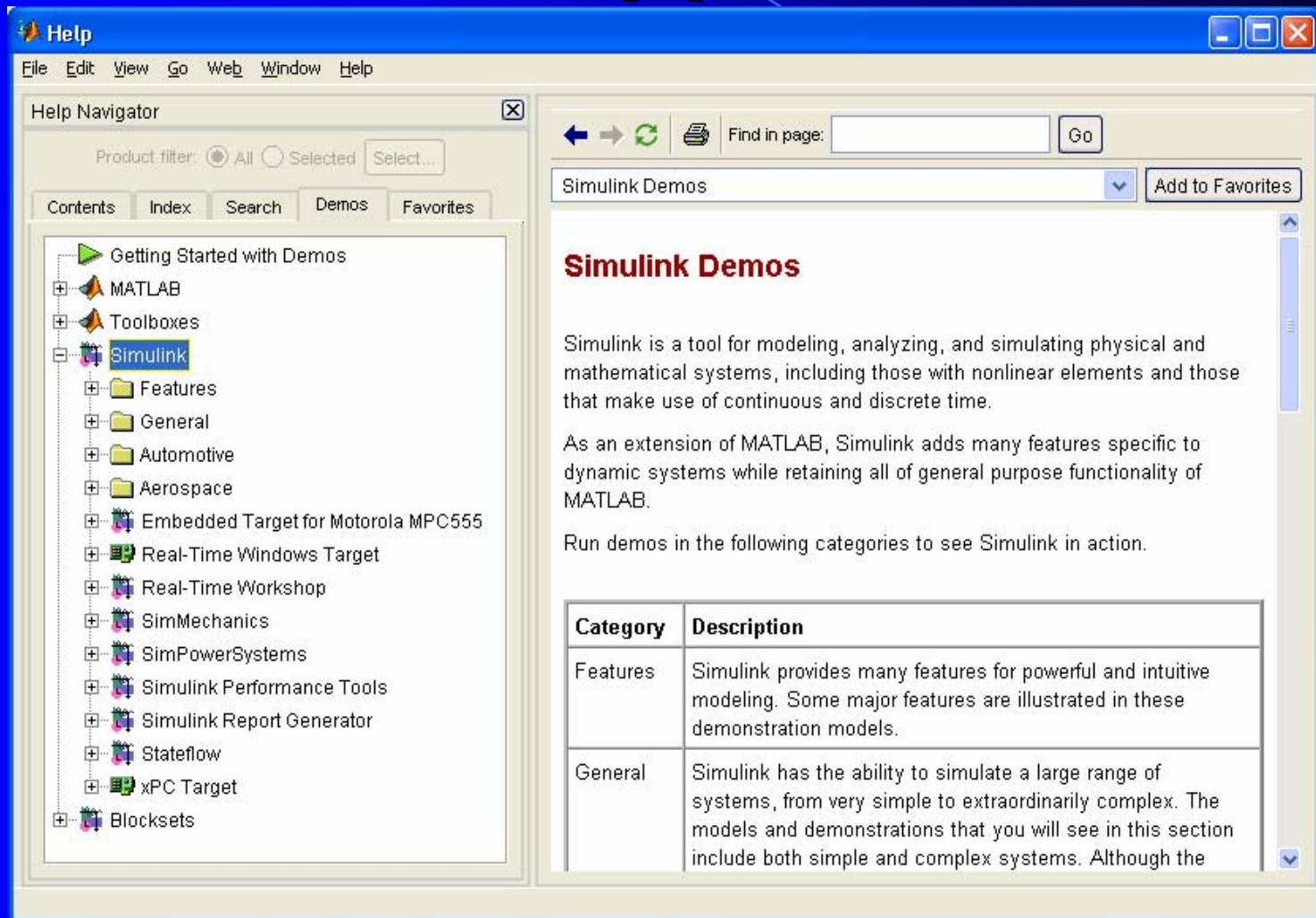
Select Data Acquisition Example Function Generator.



Start demo for **analog input** from microphone. You will see sound waves on the scope.



Look at the other demos for different applications.



DATA ACQUISITION

Next Lecture
Real Time Position
Control of a Motor and
Load (in class)