2.996/6.971 Biomedical Devices Design Laboratory

Lecture 9: Analog Signal Processing

<u>Important Dates</u>

In-class presentations: Dec. 5 and 10

Journal articles due: Dec. 12

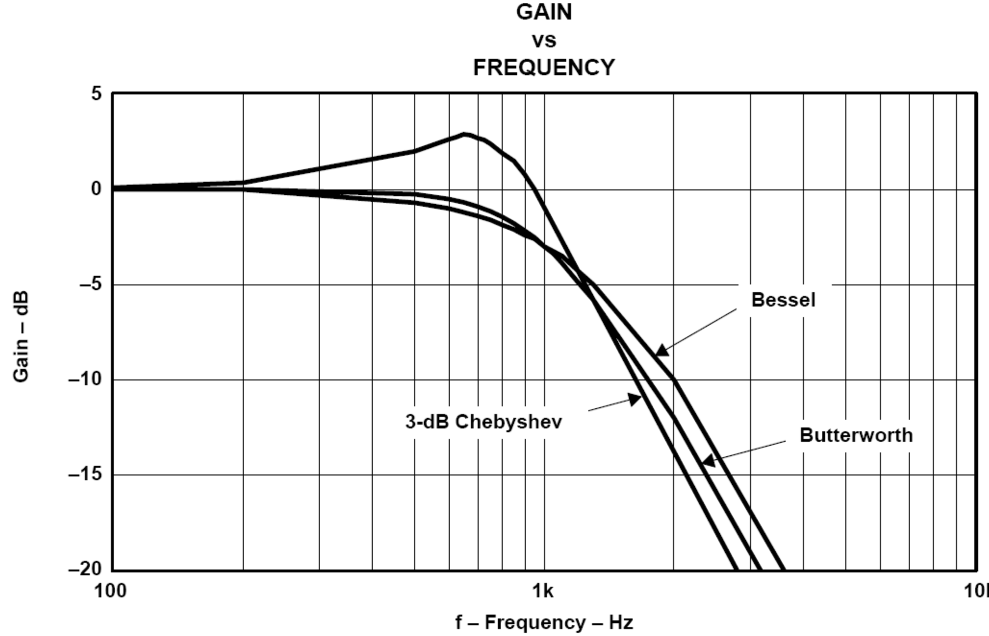
Presentations at MGH: March 4 and 11 (4-6pm)

Active Filters

- Common Filter Tasks
  - LPF – Reduce high frequency noise
  - LPF – Smooth out an envelop
  - HPF – Block DC signal
  - BPF – Remove out-of-band noise
  - Notch filter – Remove interference signal
- Ideal filter characteristics
  - Flat passband gain
  - Infinite stop band attenuation
- 1^{st} order filter → 20 dB per decade attenuation
- What if we want more?

Filter Roll-off Characteristics

- Butterworth
  - Maximum passband flatness
- Bessel
  - Constant phase dispersion
  - Some pass-band attenuation
  - Slow roll-off
- Tschebyscheff
  - Maximum roll-off steepness
  - Passband ripples
  - Tables available for 1, 2, and 3dB passband ripple



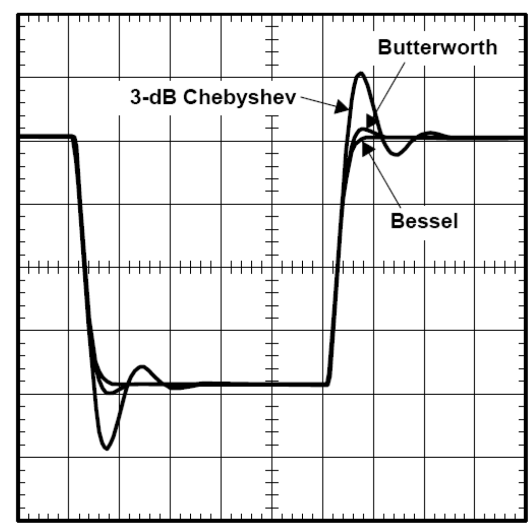
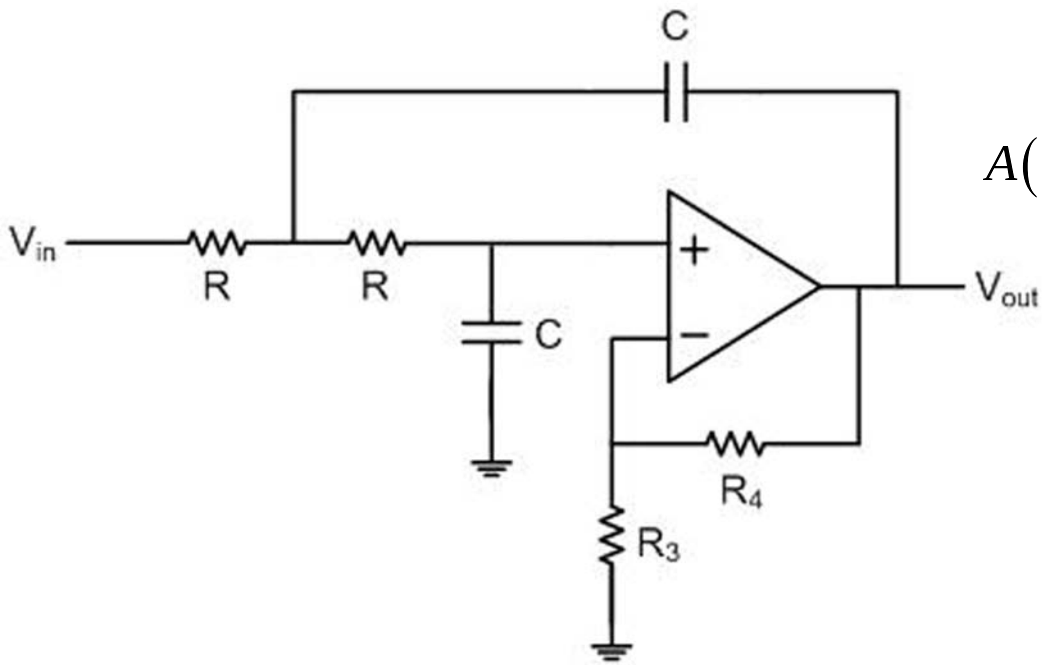


Figure 11. Transient Response of the Three Filters

The Sallen-Key LPF
(Equal component value form)



$$A(s)=\frac{A_0}{1+\omega_C RC\left(3-A_0\right)s+\left(\omega_C RC\right)^2 s^2}$$

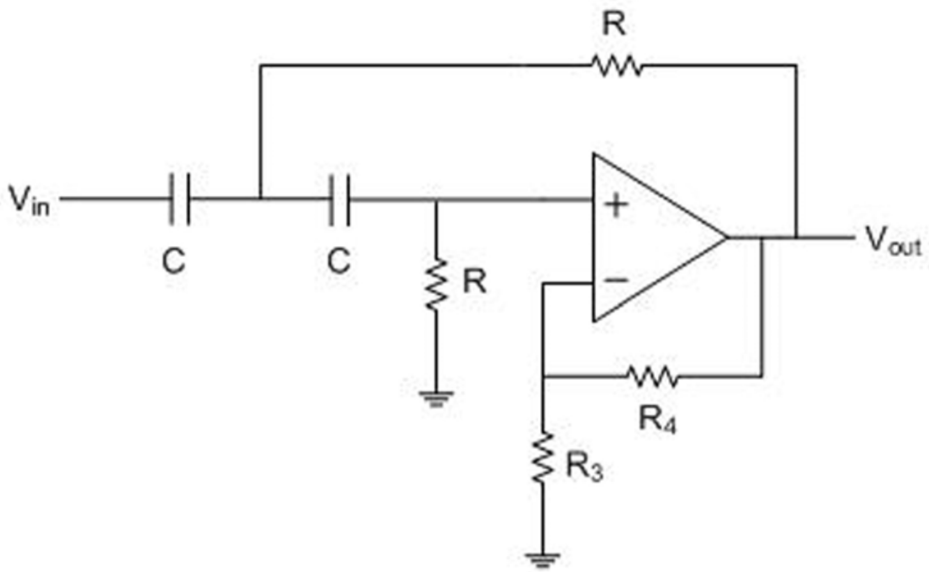
$$A_0=1+\frac{R_4}{R_3}$$

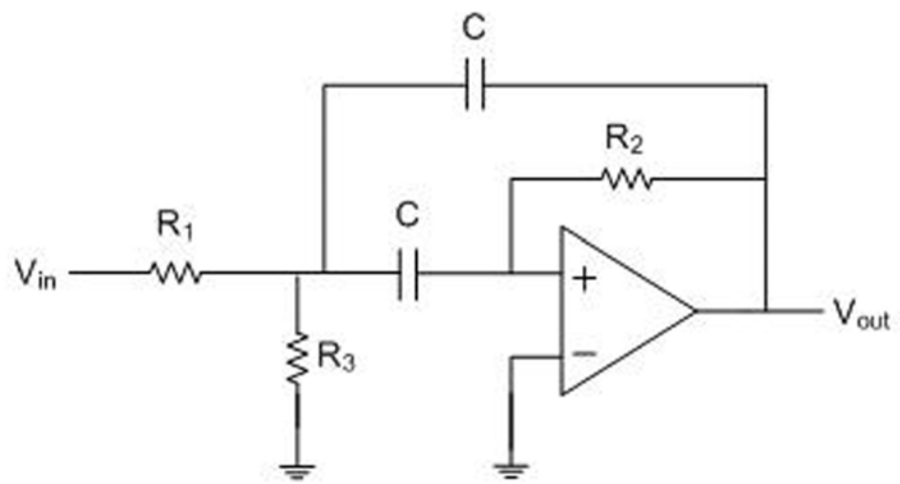
$$\omega_C=\frac{1}{RC}$$

2nd Order filter coefficients (Ref: Op Amps for Everyone, R. Mancini, pp 277)

	Bessel	Butterworth	Tschebyscheff (3dB)
R4/R3	0.268	0.568	0.234
Q	0.58	0.71	1.3

2nd Order HPF and BPF





- Sallen-Key HPF
- Multiple Feedback BPF

LTC1563-x Series Pre-packaged LPF

- Two internal opamps
- Integrated capacitors → better accuracy
- ~$2 in quantity

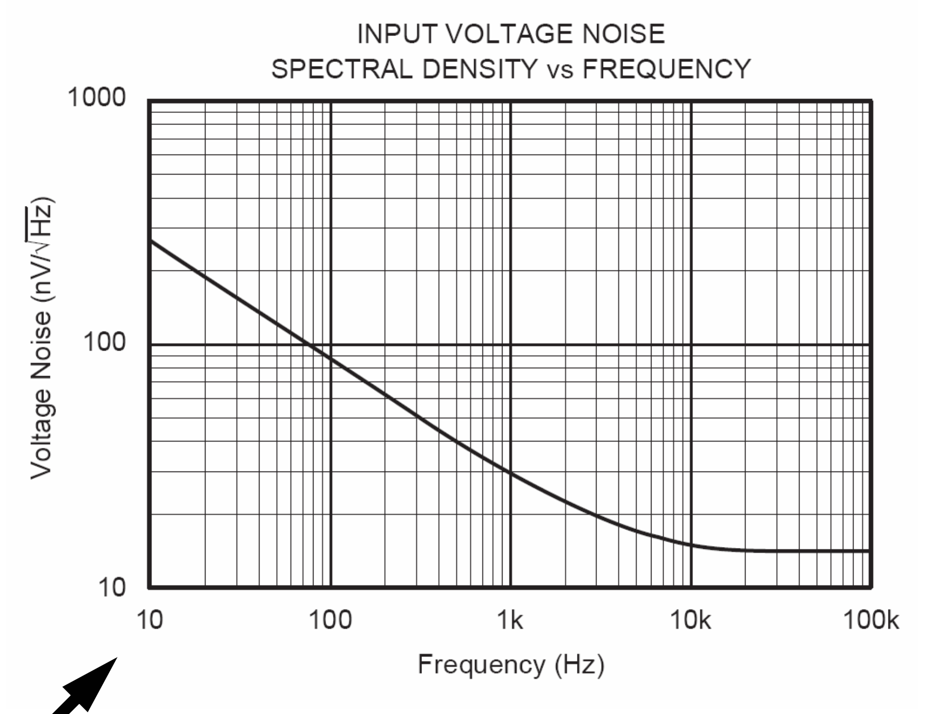
LTC1062 – DC Accurate 5th order LPF

- Switched cap filter; ~$3 each in quantity

Images removed due to copyright restrictions.

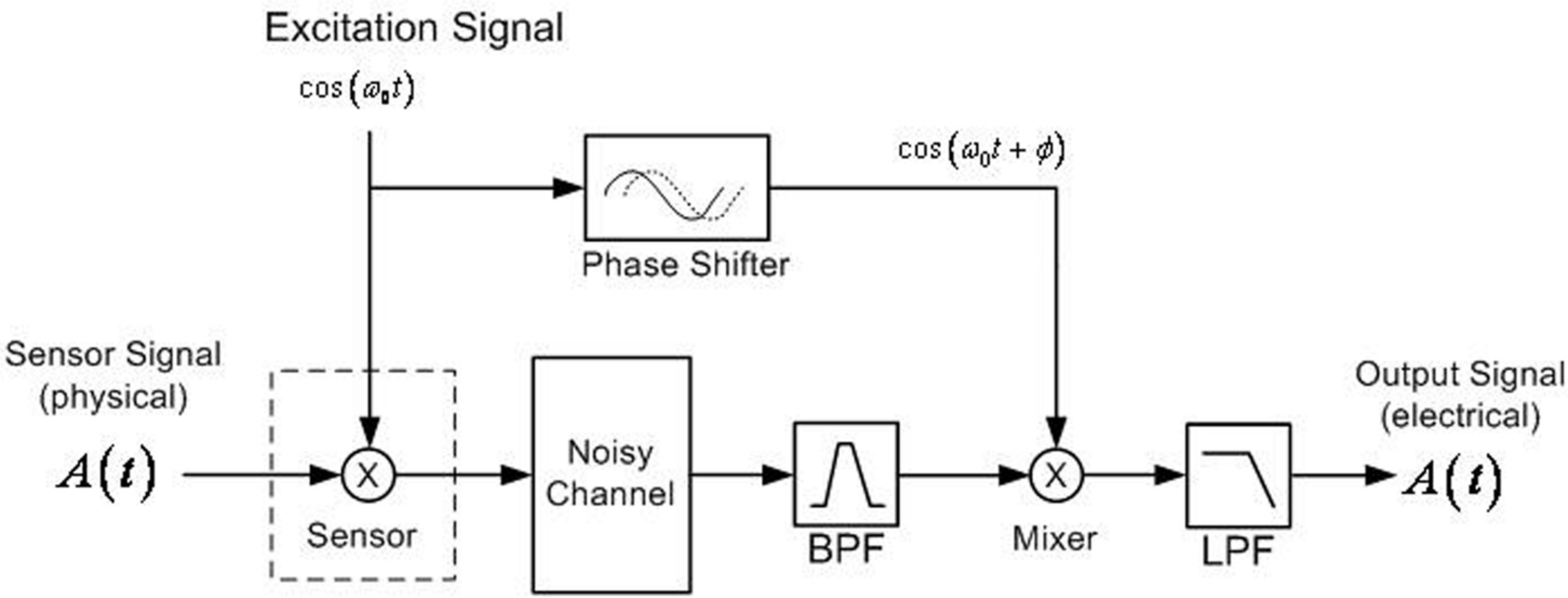
Synchronous Detection

- What is it for?
  - Measuring small signals in a noisy environment
- How does it work?
  - Modulate the excitation signal
  - Demodulate the sensor output
  - Isolate signal from noise using the frequency and phase
- When to use it?
  - Avoiding interference
  - Sensor noise at DC (1/f noise)
  - AC excitation



- Remember: DC-coupled sensors are susceptible to drift errors

Synchronous Detection



- Phase shift attenuates the signal by a cosine factor!

Analog Multipliers

ANALOG DEVICES

Low Cost Analog Multiplier

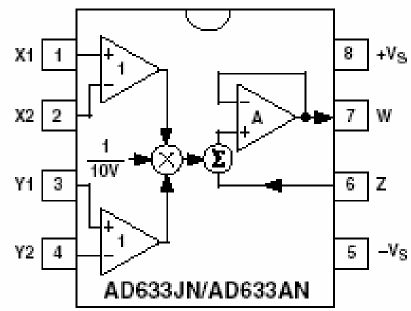
AD633

FEATURES
- 4-Quadrant Multiplication
- Low Cost 8-Lead Package
- Complete – No External Components Required
- Laser-Trimmed Accuracy and Stability
- Total Error within 2% of FS
- Differential High Impedance X and Y Inputs
- High Impedance Unity-Gain Summing Input
- Laser-Trimmed 10 V Scaling Reference

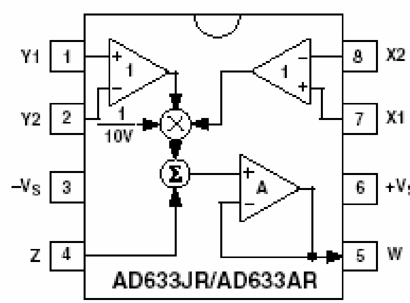
APPLICATIONS
- Multiplication, Division, Squaring
- Modulation/Demodulation, Phase Detection
- Voltage Controlled Amplifiers/Attenuators/Filters

CONNECTION DIAGRAMS

8-Lead Plastic DIP (N) Package



8-Lead Plastic SOIC (RN-8) Package



$$W = \frac{(X_1 - X_2)(Y_1 - Y_2)}{10V} + Z$$

PRODUCT DESCRIPTION

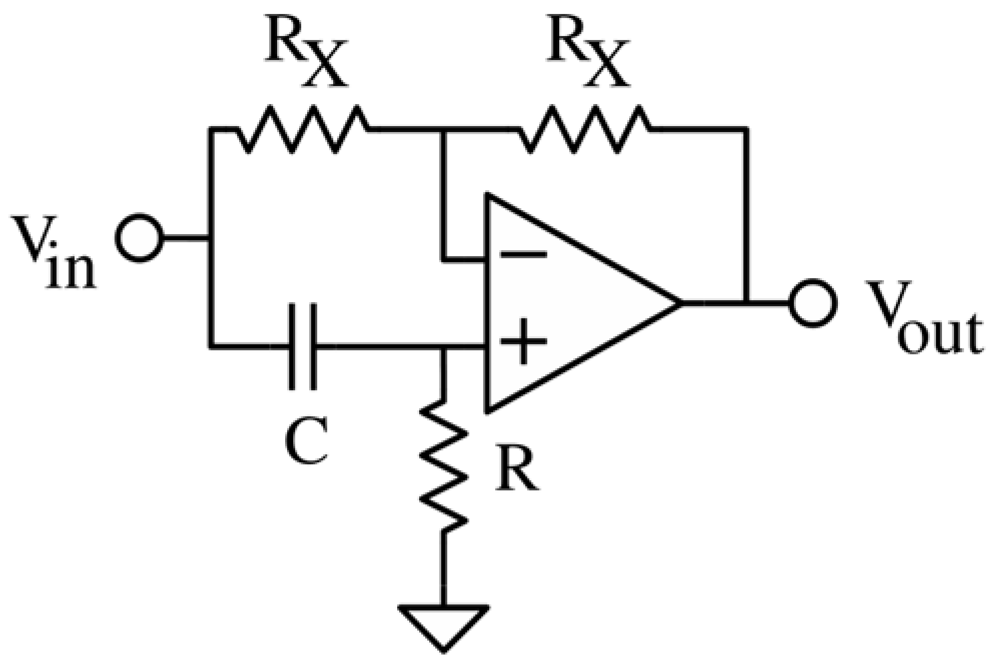
The AD633 is a functionally complete, four-quadrant, analog multiplier. It includes high impedance, differential X and Y inputs and a high impedance summing input (Z). The low impedance output voltage is a nominal 10 V full scale provided by a buried Zener. The AD633 is the first product to offer these features in modestly priced 8-lead plastic DIP and SOIC packages.

The AD633 is laser calibrated to a guaranteed total accuracy of 2% of full scale. Nonlinearity for the Y input is typically less than 0.1% and noise referred to the output is typically less than

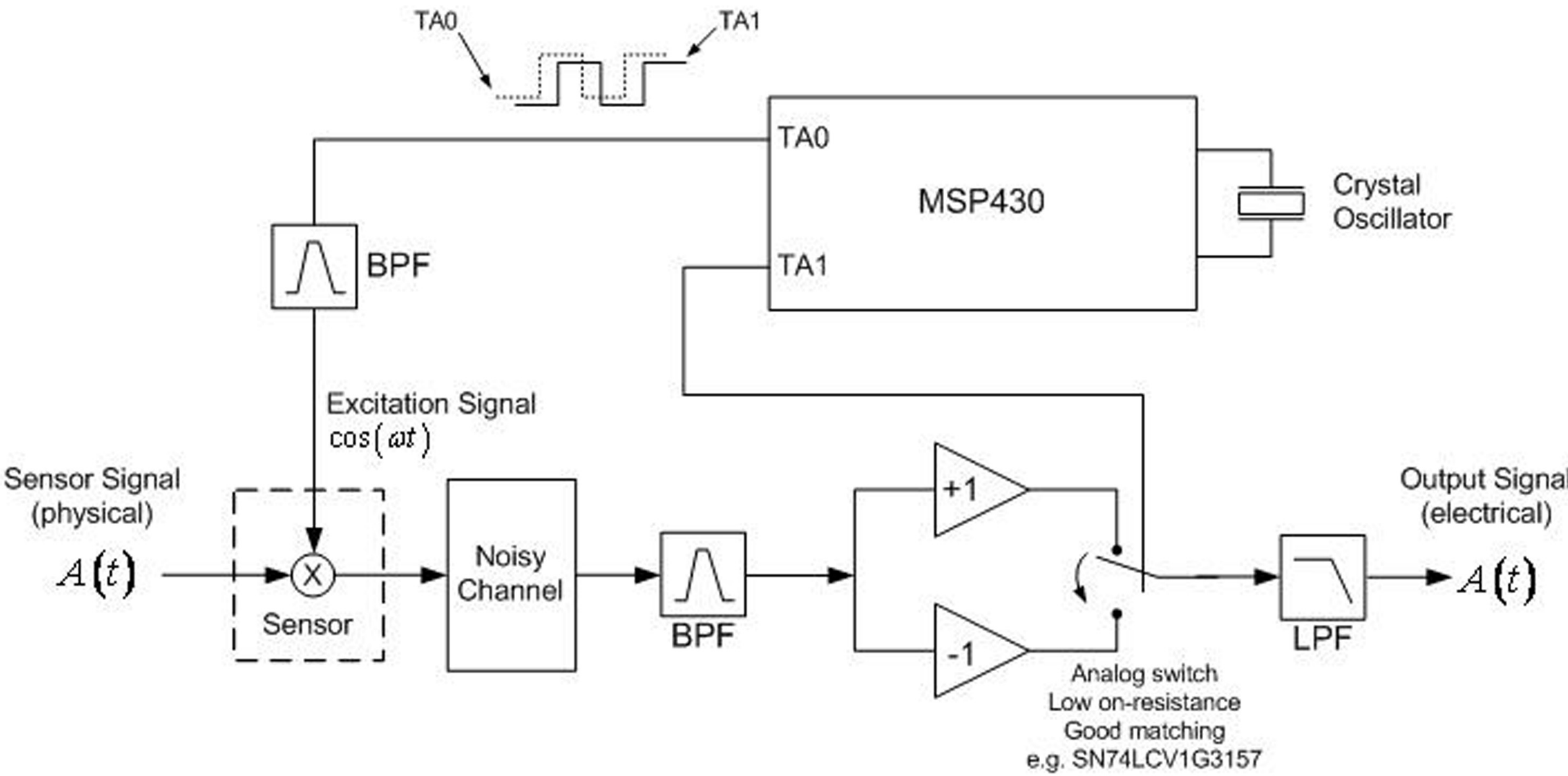
- ~$5 each
- ±15V Supply
- More expensive versions with better BW and accuracy

All Pass Filter

- Unity gain for all frequencies
- Phase shift = 180° for $\omega \to 0$
- Phase shift = 90° for $\omega \to \infty$
- Phase shift = 135° at $\omega = 1/RC$
- Switch R and C to get 0-90° phase shift



Microprocessor-based Sync. Det.



- +1/-1 buffers must have low settling time!

Analog-to-Digital Converters (ADC)

- Fundamental tradeoff between resolution and speed (samples per second)

Analog-to-Digital Converters

- Comparators
  - Differences between a comparator and an Op Amp
  - Hysteresis
- Architectures
  - Flash
  - SAR
  - Sigma-Delta
  - Pipelined
- How to use SAR ADC
  - Flywheel capacitor
- How to use a sigma-delta ADC

Comparators

- A high gain amplifier without feedback
- Hysteresis

ADC Topologies

SAR ADCs

- Free-wheel capacitor

Sigma-Delta ADCs