EE445M/EE360L.6
Embedded and Real-Time Systems/
Real-Time Operating Systems

Lecture 6:

Analog Input, Analog Filters,
Analog-to-Digital Conversion

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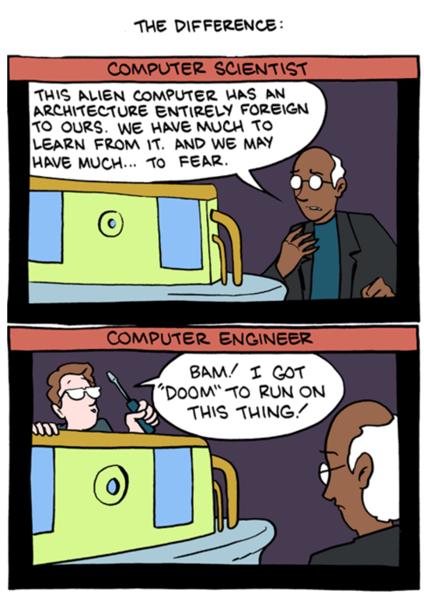
EE445M vs. CS372



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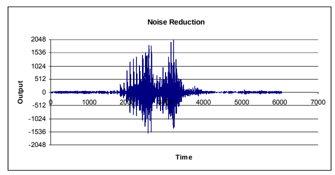
Class Agenda

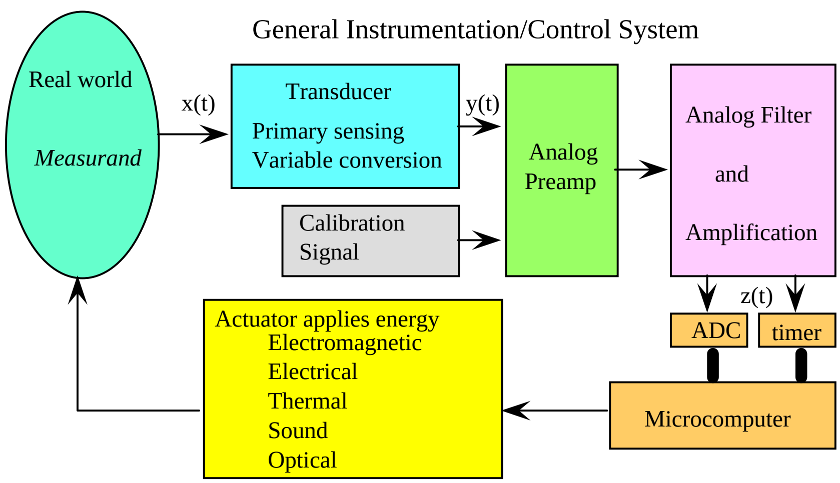
- Recap: RTOS Kernel
  - Multi-tasking, context switch, scheduling
  - Synchronization, communication, semaphores
- Outlook: Applications of RTOS
  - Lab 4: Digital scope & spectrum analyzer
    - Analog input and filters
    - Digital filter, FFT
    - Display amplitude vs. time/frequency on LCD



Reference book, Chapter 5

Instrumentation & Control

General Instrumentation/Control System



Data Acquisition System (DAS)

- Quantitative (thermometer in EE445L)
  - Range (r_x)
  - Resolution (Δx)
  - Precision (n_x in alternatives)
  - Frequencies of interest (f_{min} to f_{max})
- Qualitative (sound recording in EE445M)
  - "sounds good"
  - "looks pretty"
  - "feels right"

Data Acquisition System (DAS)

- Other qualitative DAS
  - Detection of events (baby apnea monitor)
    - true positive (TP): stop breathing & monitor alarm
    - false positive (TP): breathing OK, but monitor alarm
    - false negative (FN): stop breathing & no alarm
  - Prevalence = (TP + FN) / (TP + TN + FP + FN)
  - Sensitivity = TP / (TP + FN)
  - Specificity = TN / (TN + FP)
  - PPV = TP / (TP + FP)
  - NPV = TN / (TN + FN)

Analog Signal Processing

- Analog circuit design with single supply
  - MAX494CPD/TLC2274ACN rail to rail op amp
- Instrumentation amps (EE445L)
  - INA122
- Noise measurements and reduction
- Analog sensors
  - Electret microphones (sound)
  - IR distance sensor
- Analog filters

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Convert to Single Supply

- Vcc = 3.3V, start with design using +Vs -Vs
- Assume ADC range is 0 to Vmax (0 to 3V)
- Add an analog reference, Vref = ½ Vmax
- **Map**
  - **-Vs (-12) to digital ground**
  - **Analog ground to Vref reference**
  - **+Vs (+12) to Vcc supply**

Reference EE345L book, Chapter 5

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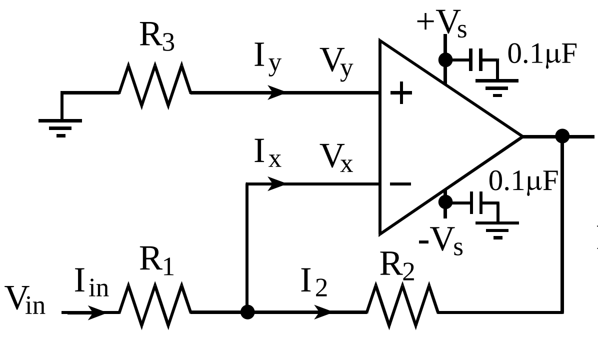
Inverting Amp



$$V_{out} = -\frac{R_2}{R_1} V_{in}$$

$$R_3 = \frac{R_1 * R_2}{R_1 + R_2}$$

Use a rail-to-rail op-amp and map

-Vs	to	digital ground
Analog ground	to	Vref reference
+Vs	to	Vcc supply

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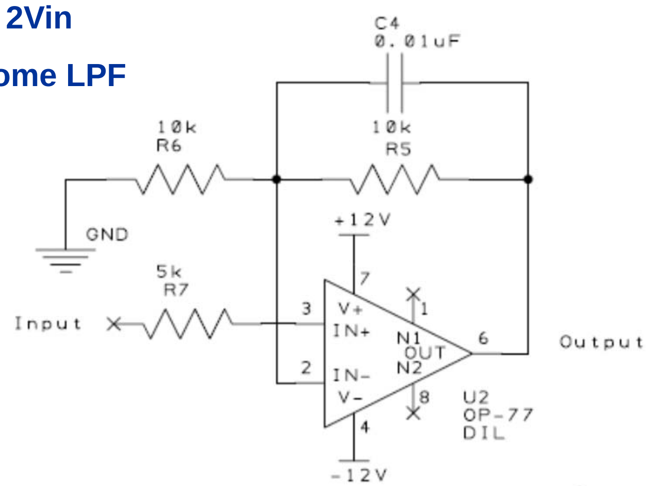
Original Design

Vout = 2Vin

with some LPF



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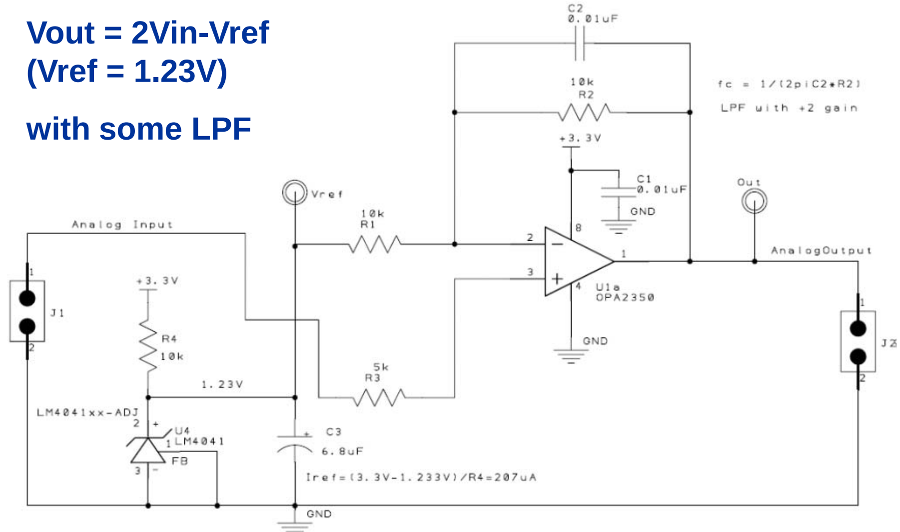
New Design

Vout = 2Vin-Vref
(Vref = 1.23V)

with some LPF



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Instrumentation Amp

- Necessary conditions (must be true)
  - Differential input (as in any op-amp)
- Motivation (at least one must be true)
  - Large gain
  - Large input impedance
  - Large common mode rejection ratio (CMMR)
  - Low noise
  - Small package

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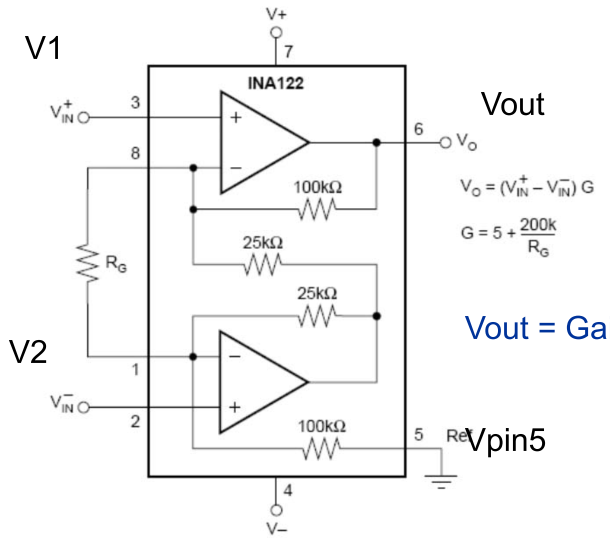
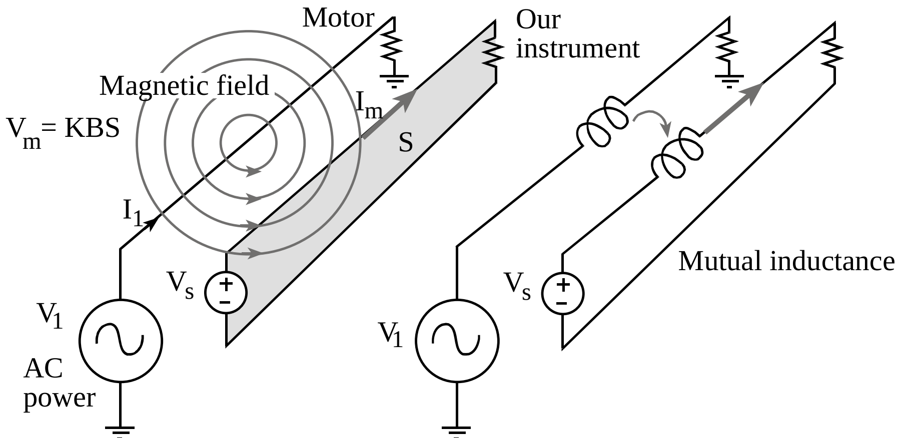
Burr-Brown INA122



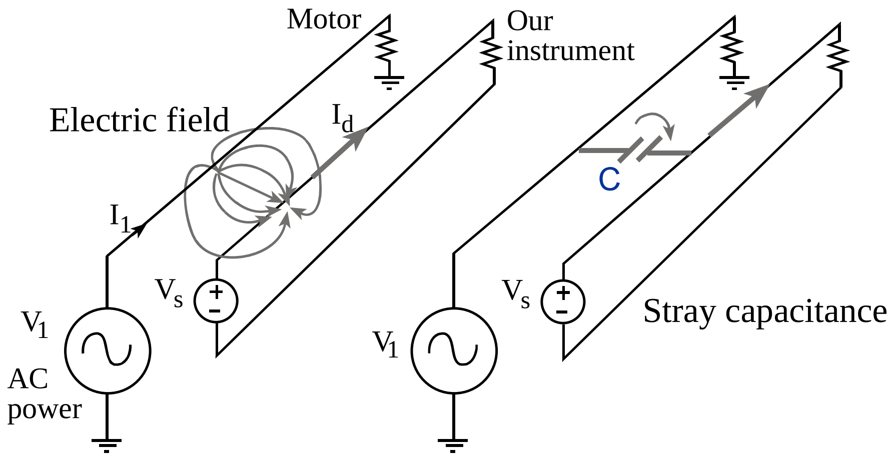
Vout = Gain*(V1-V2) + Vpin5

Magnetic Field Noise



How do you reduce S?

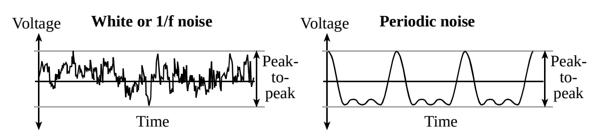
Electric Field Noise



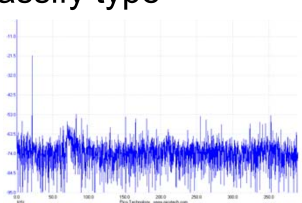
How do you reduce C?

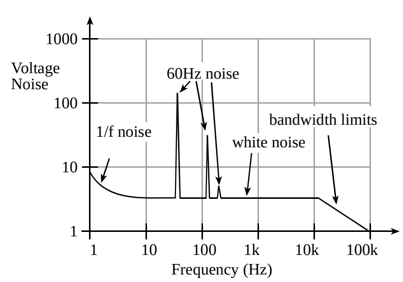
Noise Measurement

- Digital volt meter (AC mode)
  - Most accurate quantitative noise measure
- Oscilloscope (line trigger)
  - Shape



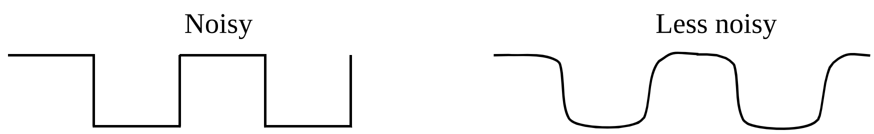
- Spectrum Analyzer
  - Classify type





Noise Reduction (1)

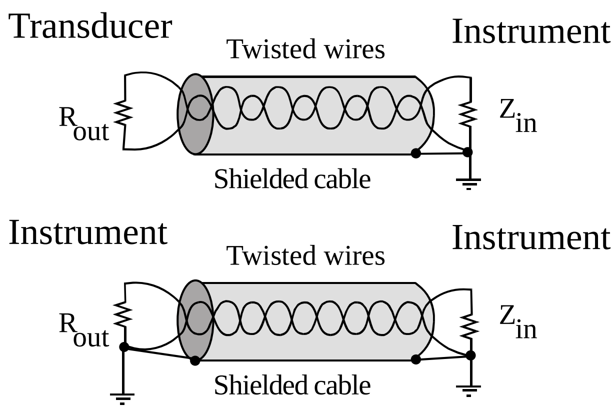
1. Reducing noise from the source
   – Shielding
      • Enclose noisy sources in a grounded metal box
   – Filter noisy signals
   – Limit the rise/fall times of noisy signals.
   – Limiting the dI/dt in the coil.



Noise Reduction (2)

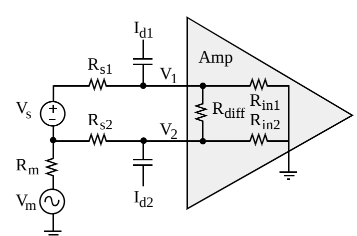
2. Limiting the coupling between the noise source and instrument
   – Maximize the distance from source to instrument
   – Cables with noisy signals should be twisted together
   – Cables should also be shielded.
   – For high frequency signals, use coaxial
   – Reduce the length of a cable
   – Place the delicate electronics in a grounded case
   – Optical or transformer isolation circuits

Limiting the Coupling



Noise Reduction (3)

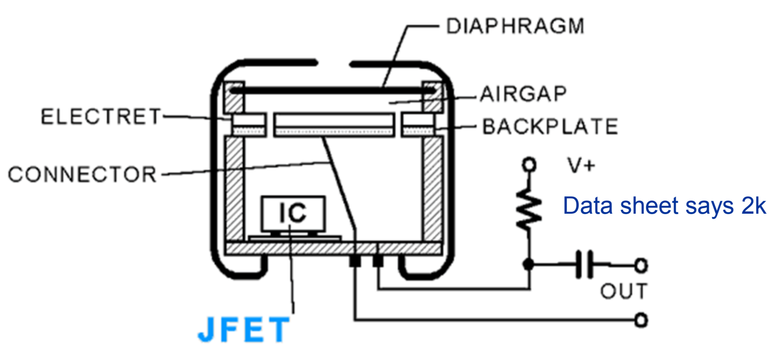
3. Reduce the noise at the receiver
   - Bandwidth should be as small as possible.
   - Add frequency-reject digital filters
   - Use power supply decoupling capacitors on each
   - Twisted wires then Id1 should equal Id2
     - V1-V2 = Rs1 Id1 - Rs2 Id2



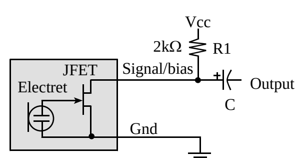
Henry Ott, Noise Reduction Techniques in Electronic Systems, Wiley, 1988.
Ralph Morrison, Grounding and Shielding Techniques, Wiley, 1998.

Electret Condenser Microphone

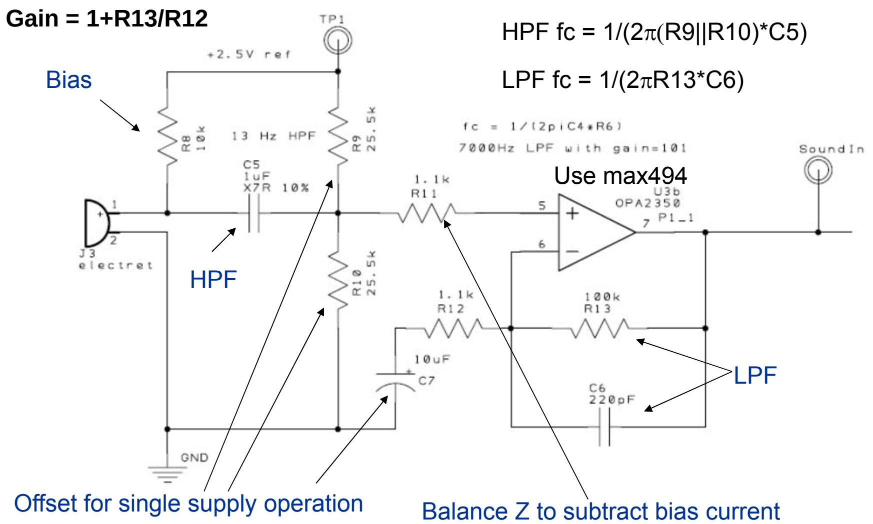
Cross-Section of Typical ECM



- JFET Buffer
- Phantom Biasing



ECM Interface



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Sharp GP2Y0A21YK

- Infrared distance sensor
  - You will need 5V to power IR sensor
  - Needs analog LPF
    - Reduces noise
  - Analog input protection
  - Needs digital median filter
  - Needs 10 mF or larger +5V to Gnd cap for each sensor

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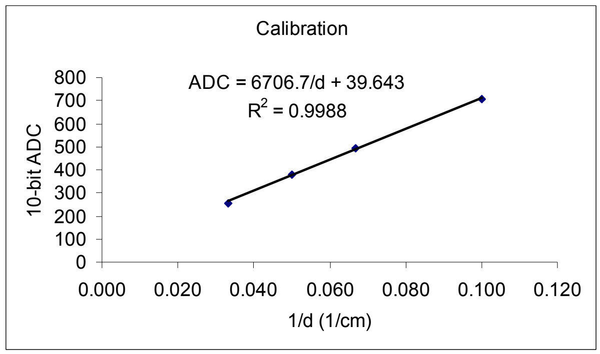
IR Sensor Calibration

d (cm)	1/d	ADC
10	0.100	703
15	0.067	484
20	0.050	380
30	0.033	260



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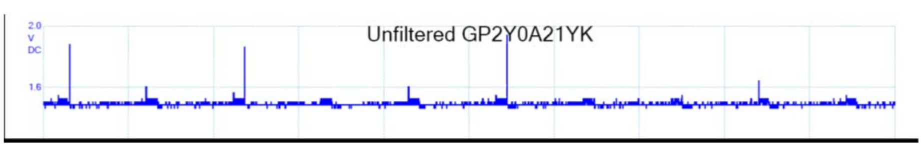
Sharp GP2Y0A21YK

- Accuracy => Calibration
- Resolution => Noise

ADC = 6707/d+40
d = 6707/(ADC-40)
d (0.01cm) = 6706700/(ADC-40)



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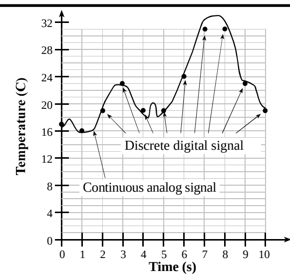
Sampling



- Time & value quantizing
  - Precision $n_z = 2^n$
- Nyquist theory
  - If sampled at $\mathbf{f_s}$, digital samples only contain frequency components from 0 to ½$\mathbf{f_s}$
  - If analog signal contains frequency components larger than ½$\mathbf{f_s}$, **aliasing** error
- System design
  - Choice of sampling rate: $\mathbf{f_s > 2\ f_{max}}$
  - Low pass analog filter to remove frequency components above 0.5$\mathbf{f_s}$
    - A digital filter can not be used to remove aliasing

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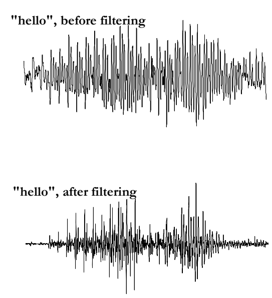
Filter Types



- Analog
  - Low pass filter (LPF)
  - High pass filter (HPF)
  - Band pass filter (BPF)
- Digital
  - Extremely flexible
  - But only available after sampling

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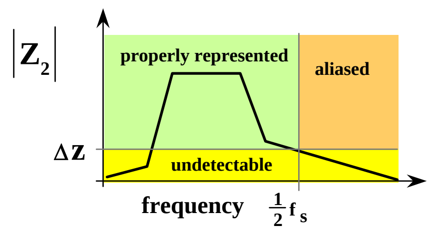
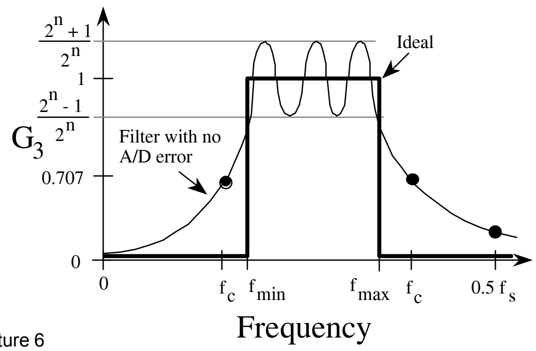
Analog Filters

- Prevent aliasing
  - No signal > $0.5f_s$
- Band-pass filter





Gain G3 = | H3(s) |
Pass $f_{min} \le f \le f_{max}$
Min. error seen by ADC

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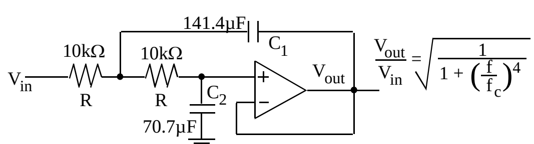
Butterworth Filters



$$\frac{V_{out}}{V_{in}} = \sqrt{\frac{1}{1 + \left(\frac{f}{f_c}\right)^4}}$$

- 2-pole Butterworth filter
  1. Select the cutoff frequency, f_c
  2. Divide the two capacitors by $2\pi f_c$
     - $C_{1A} = 141.4\mu F/2\pi f_c$
     - $C_{2A} = 70.7\mu F/2\pi f_c$
  3. Locate two standard value capacitors (with 2/1 ratio) in the same order of magnitude as the desired values
     - $C_{1B} = C_{1A}/x$
     - $C_{2B} = C_{2A}/x$
  4. Adjust the resistors to maintain the cutoff frequency
     - R = 10kΩ•x

lpf.xls
TI FilterPro

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