## Recap from last time

- RTOS
- Debugging/verification

## Lab 4 Application of RTOS

- Input sound
- Calculate FFT
- Display amplitude versus frequency on the oLED

## Objectives

- Designing analog circuits to run on single supply
- Analog circuit design using op amps
- Instrumentation amps
- Noise measurements and reduction
- Electret microphones

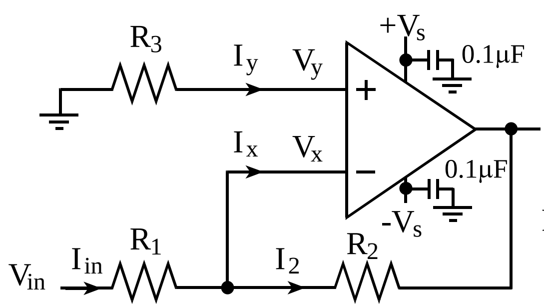
## Convert to single supply, $V_{pow} = 3.3V$

1) Design with $+V_s$ $-V_s$
2) Assume ADC range is 0 to $V_{max}$
3) Add an analog reference, $V_{ref} = ½ V_{max}$
4) Map

| | | |
|---|---|---|
| $-V_s$ | to | digital ground (ADC $V_{min}$) |
| Analog ground | to | $V_{ref}$ reference voltage |
| $+V_s$ | to | $V_{pow}$ supply |

From an analog signal perspective, it behaves like a $\pm V_{ref}$ supply
From the digital signal perspective, everything is 0 to $V_{pow}$

## Example 1



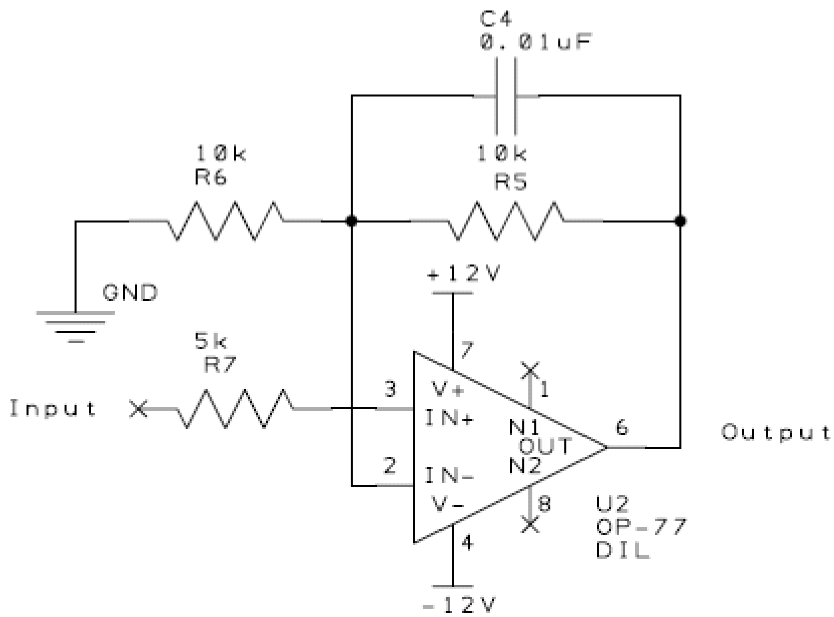

$$V_{out} = -\frac{R_2}{R_1} V_{in}$$

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

Regular design Vout = -5Vin
R1 = 10k
R2 = 50k
R3 = 8.3k

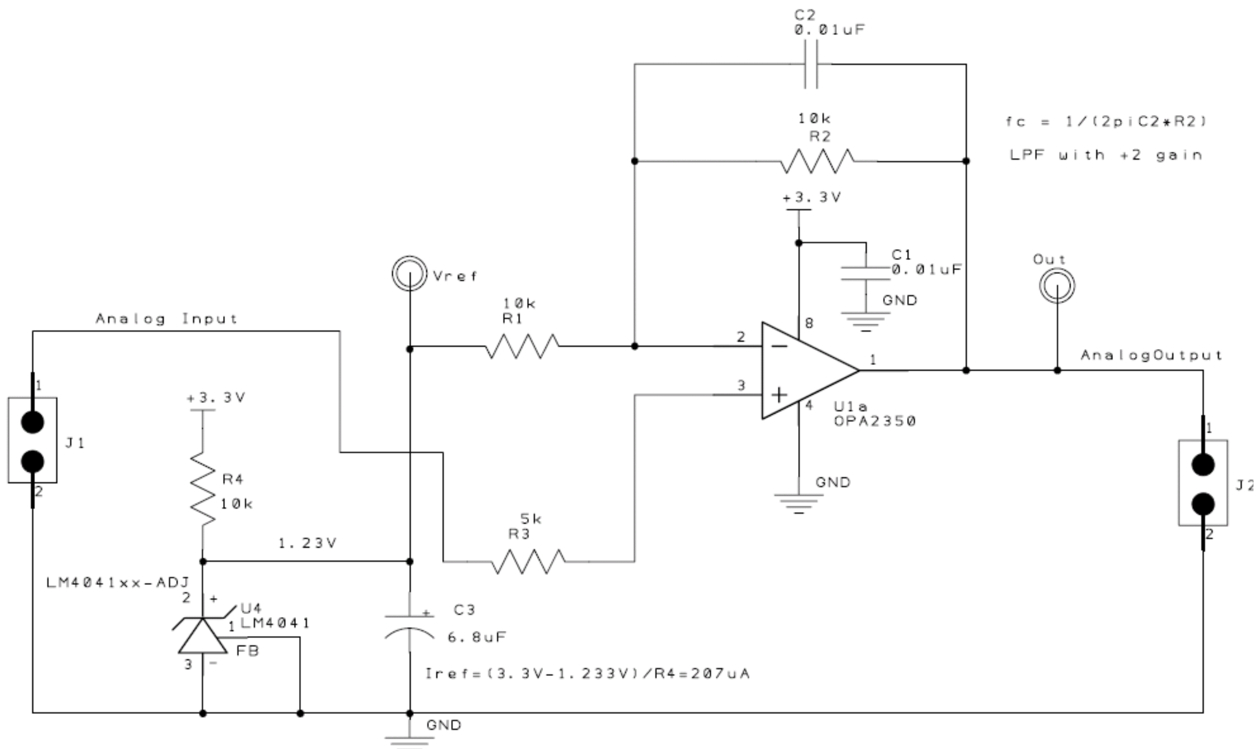
## Example 2

Regular design Vout =2Vin




## Example 3

Vout =2Vin-1.23V




*Noninverting amplifier with an effective -0.62 V to +2.1 V analog signal range.*

Note: LM4041CILPR shunt reference can be adjusted for various offsets

The voltage at pin3 is Vin

Due to feedback, the voltage at pin 2 is Vin

Current across R1 is (Vref-Vin)/R1

Current across R2 is (Vin-Vout)/R2

These two currents are equal (Vref -Vin)/R1=(Vin-Vout)/R2

Solve

$(1.23-Vin)*R2/R1 = (Vin-Vout)$

$Vout = Vin - (Vref - Vin)*R2/R1$

$Vout = (1+R2/R1)Vin - Vref *R2/R1$

$Vout = 2Vin - 1.23$

# Example 4

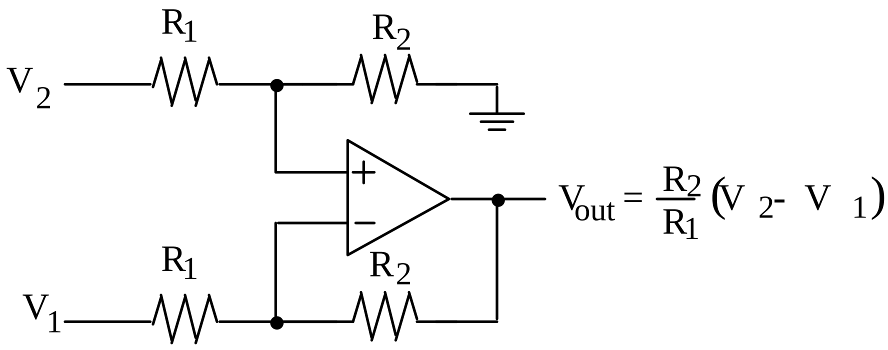
Single supply design Vout = 5(Vin-1.23)

Use rail to rail op amp

R1 = 10k

R2 = 50k

V2 = Vin, V1=1.23

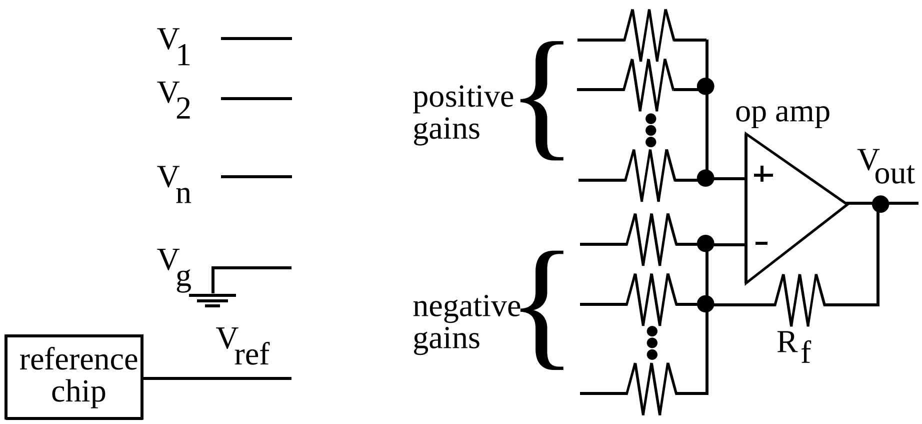



### 11.2.7. Linear Mode Op Amp Circuits (EE445L review)

This design example works with any analog circuit in the form

$$V_{out} = A_1V_1 + A_2V_2 + \ldots + A_nV_n + B$$

designed with one op amp as shown in the following figure.




*Boiler plate circuit model for linear circuit design.*

The **first step** is to choose a reference voltage

***Common Error:*** *If you use resistor divider from the +12V or +5V supply to create a voltage constant, then the power supply ripple will be added directly to your analog signal.*

The **second step** is to rewrite the design equation in terms of the reference voltage, $V_{ref}$.

$$V_{out} = A_1V_1 + A_2V_2 + \ldots + A_nV_n + A_{ref}V_{ref}$$

The **third step** is to add a ground input to the equation. Ground is zero volts ($V_g$=0), but it is necessary to add this ground so that the sum of all the gains is equal to one.

$$V_{out} = A_1V_1 + A_2V_2 +\ldots+A_nV_n + A_{ref}V_{ref} + A_gV_g$$

Choose $A_g$ such that

$$A_1 + A_2 +\ldots+A_n + A_{ref} + A_g = 1$$

In other words, let

$$A_g = 1 - ( A_1 + A_2 +\ldots+A_n + A_{ref} )$$

The **fourth step** is to choose a feedback resistor, $R_f$, in the range of 10 kΩ to 1MΩ. The larger the gains, the larger the value of $R_f$ must be. Then calculate input resistors to create the desired gains. In particular,

$|A_1| = R_f/R_1$ so $R_1 = R_f/|A_1|$
$|A_2| = R_f/R_2$ so $R_2 = R_f/|A_2|$
$|A_n| = R_f/R_n$ so $R_n = R_f/|A_n|$
$|A_{ref}| = R_f/R_{ref}$ so $R_{ref} = R_f/|A_{ref}|$
$|A_g| = R_f/R_g$ so $R_g = R_f/|A_g|$

The **last step** is to build the circuit. If the gain is positive, then the input resistor is connected to the positive terminal of the op amp. Conversely, if the gain is negative, then the input resistor is connected to the negative terminal of the op amp.

For example, we will design the following analog circuit

$$V_{out} = 5V_1 - 3V_2 + 2V_3 - 10$$

The **first step** is to choose a reference voltage. The REF02 +5.00V voltage reference will be used.

The **second step** is to rewrite the design equation in terms of the reference voltage.

$$V_{out} = 5V_1 - 3V_2 + 2V_3 - 2V_{ref}$$

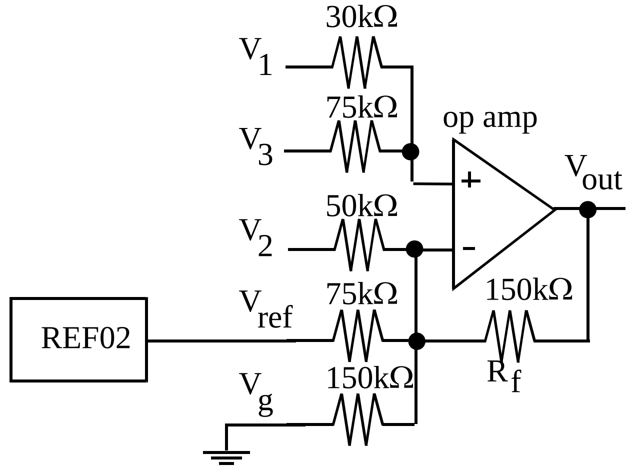
The **third step** is to add a ground input to the equation so that the sum of all the gains is equal to one.

$$V_{out} = 5V_1 - 3V_2 + 2V_3 - 2V_{ref} - V_g$$

The **fourth step** is to choose a feedback resistor, $R_f$ =150 kΩ. The value is a multiple of the least common multiple of the gains: 5,3,2,1. Then calculate input resistors to create the desired gains.

$R_1 = R_f/|A_1| = 150$ kΩ/5 = 30 kΩ
$R_2 = R_f/|A_2| = 150$ kΩ/3 = 50 kΩ
$R_3 = R_f/|A_3| = 150$ kΩ/2 = 75 kΩ
$R_{ref} = R_f/|A_{ref}| = 150$ kΩ/2 = 75 kΩ
$R_g = R_f/|A_g| = 150$ kΩ/1 = 150 kΩ

The **last step** is to build the circuit.

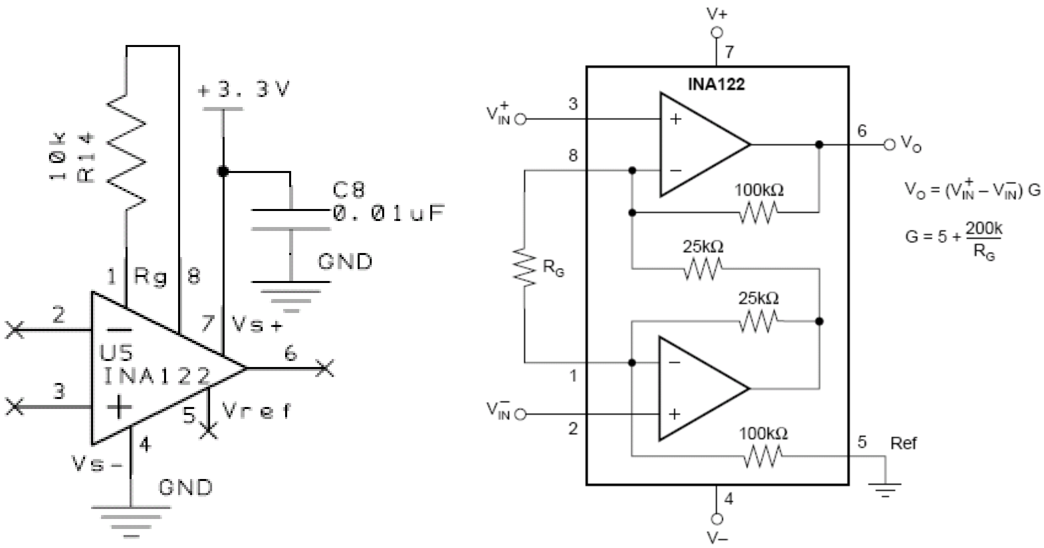



*A linear op amp circuit.*

Instrumentation Amp

**necessary condition** (this must be true)
amplify a differential voltage, shown below as $V_1$-$V_2$

**sufficient condition** (one or more of this made be true)
large gain (above 100),
a high input impedance, and
a good common mode rejection ratio.




*Integrated instrumentation amplifier.*

AD627/INA122 are low-power single supply rail-to-rail instrumentation amps,

**$V_{out} = Gain*(V_1 - V_2) + V_{pin5}$**

**$Gain = 5 + (200k\Omega / R_G)$**

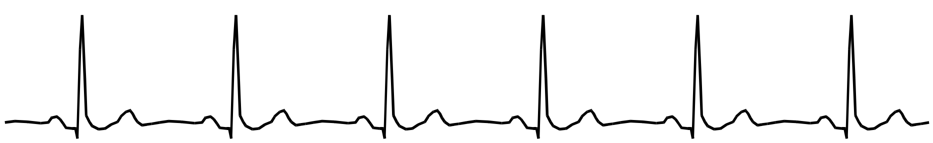
**$V_{out} = V_{pin5}$ when $V_1$ equals $V_2$**

*In EE445L Lab 7, we grounded pin 5,* $V_{pin5} = 0$

**$V_{out} = Gain *( V_1 - V_2)$**

*With an EKG, we connect pin 5,* $V_{ref} = V_{pin5}$

## EKG data acquisition system.



*Normal II-lead electrocardiogram.*

graphical display of EKG is a qualitative data acquisition system.
measurement of heart rate is quantitative

**parameters of an EKG amplifier include:**

- high input impedance (larger than 1 MΩ),
- high gain, 2500, ±1 mV to ±2.5 V
- 0.05 to 100 Hz band-pass filter and
- good common mode rejection ratio.

## Instrumentation amp as preamp stage

- good CMRR,
- high input impedance,
- gain of 10.

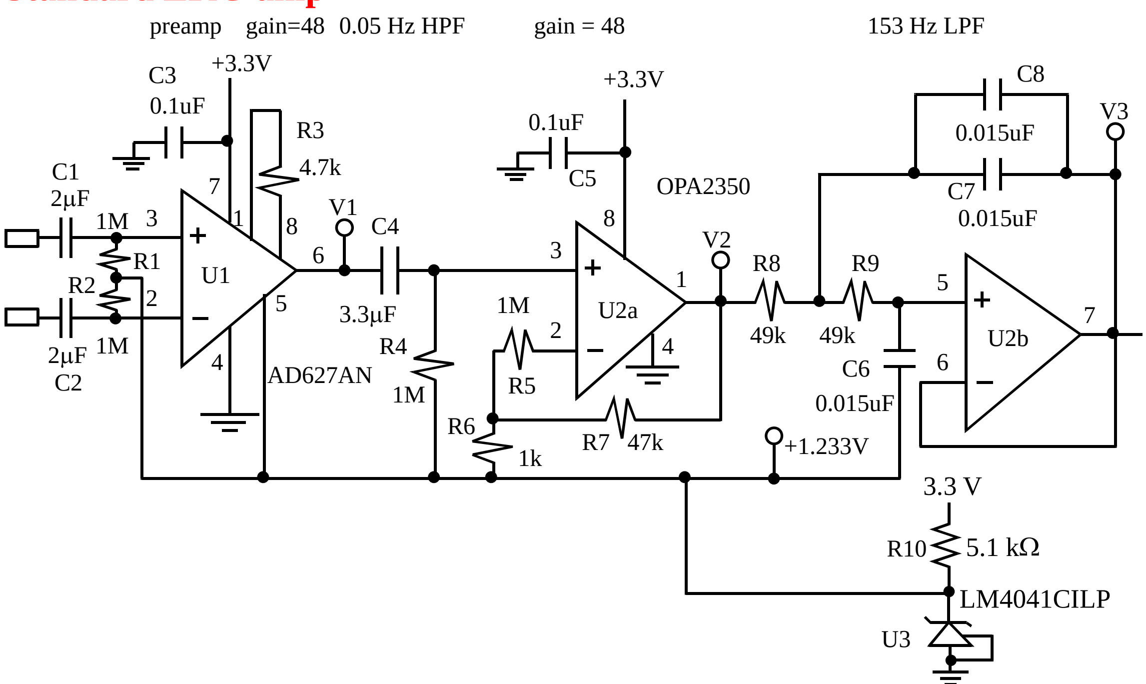
## A 0.05 Hz passive high pass filter

- created by R2 and C2.
- low-leakage capacitor for C2 is critical
- polypropylene or polystyrene would be best,
- low-leakage ceramic is acceptable.

## 2-pole Butterworth LPF.

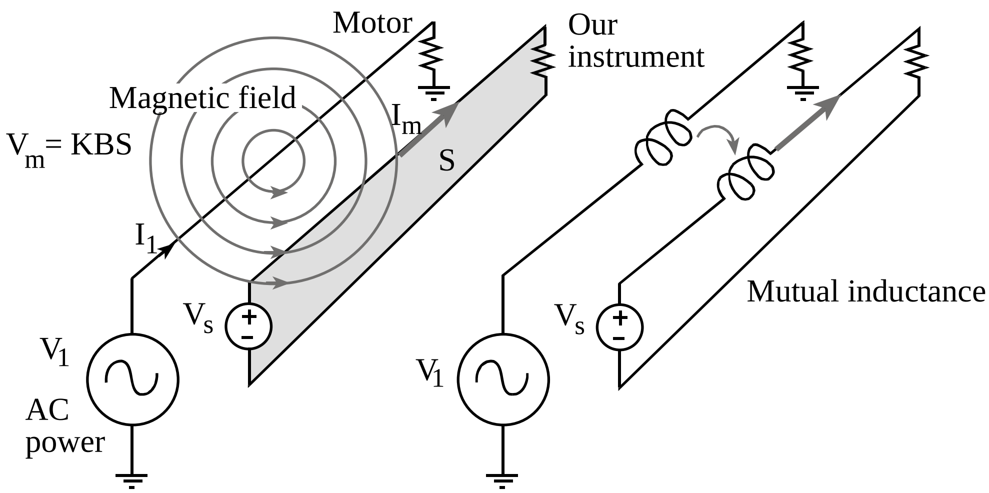
- 153 Hz cutoff is greater than 100Hz
- implemented with standard components

## Standard EKG amp

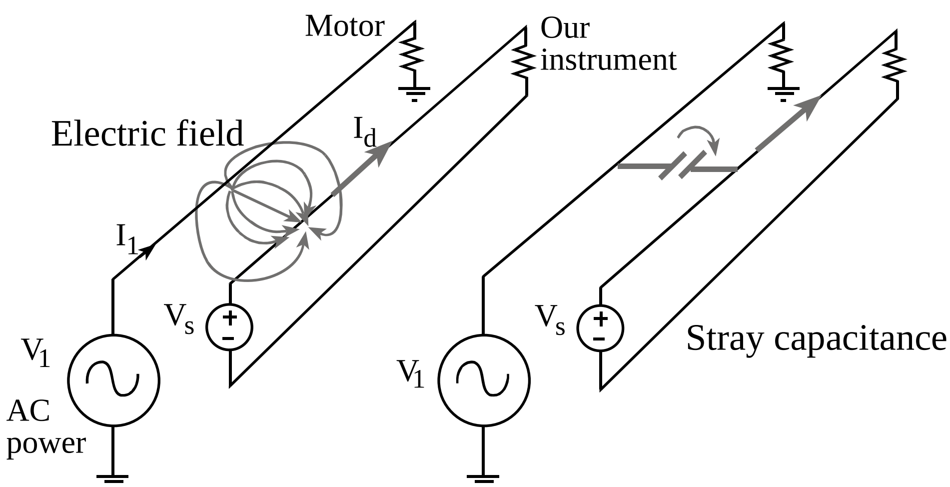



## Single supply rail-to-rail parts

### Electromagnetic field induction




*Magnetic field noise pickup can be modeled as a transformer.*




*Electric field noise pickup can be modeled as a stray capacitance.*

***Observation**: Sometimes the source of EM fields originate from inside the instrument box, such as high frequency digital clocks and switching power supplies.*

**Techniques to measure noise.**

classify the type of noise

broadband (i.e., all frequencies, like white noise)

certain specific frequencies (e.g., 60 Hz EM field)

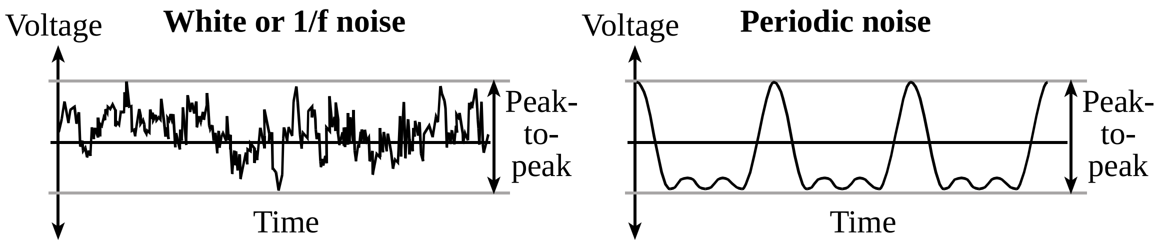
quantify the magnitude of the noise.

## Digital voltmeter (DVM) in AC mode.

calibrated voltmeter is most accurate quantitative method to measure noise.

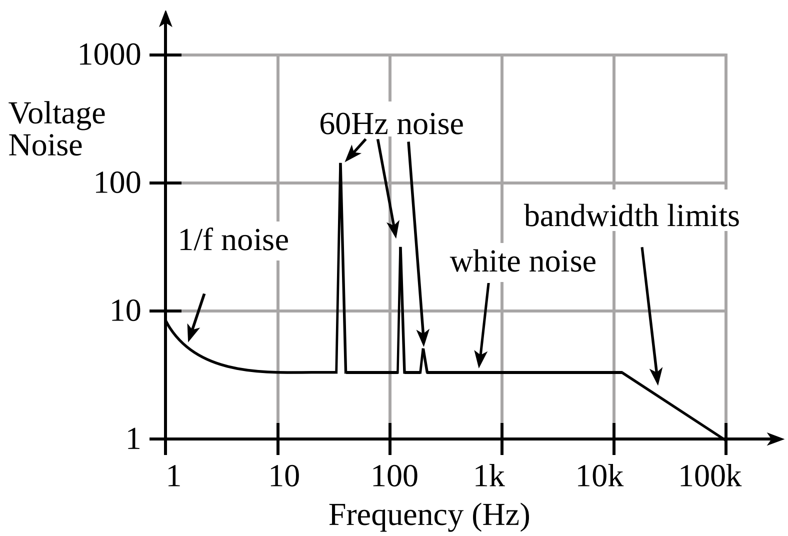
## Analog oscilloscope.

approximate the RMS noise amplitude by dividing the peak-to-peak noise by 8.
**line-trigger** to see if the noise is 60 Hz




*Quantifying noise my measuring peak-to-peak amplitude.*

## Spectrum analyzer.

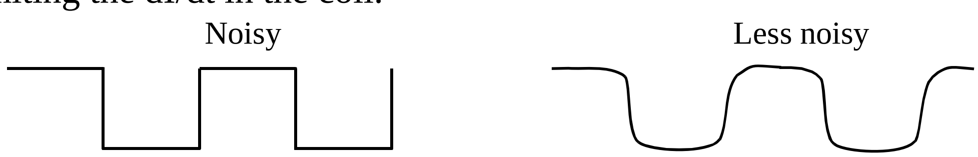



*Classifying noise my measuring the amplitude versus frequency with a spectrum analyzer.*

### Techniques to reduce noise.

1) reducing noise from the source

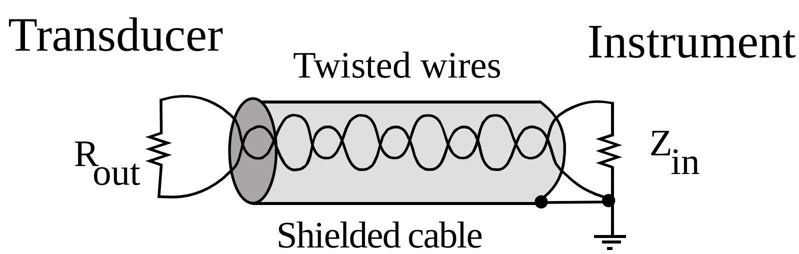
enclose noisy sources in a grounded metal box
filter noisy signals
limit the rise/fall times of noisy signals.
limiting the dI/dt in the coil.

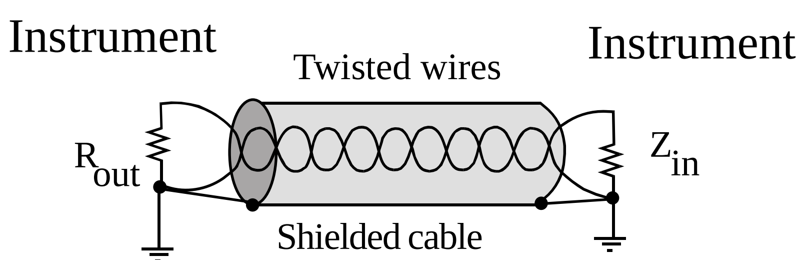


*Limiting rise/fall times can reduce radiated noise.*

2) limiting the coupling between the noise source and your 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



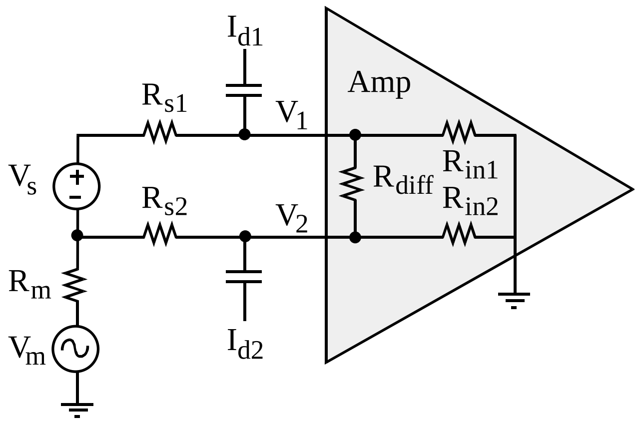




*Proper cabling can reduce noise when connecting a remote transducer or when connecting two instruments.*

3) reduce 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 $I_{d1}$ should equal $I_{d2}$.

$$V_1 - V_2 = R_{s1} I_{d1} - R_{s2} I_{d2}.$$




*FCapacitively coupled displacement currents.*

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

**Integrated Circuits for High Performance Electret Microphones**
*By Arie Van Rhijn* http://www.national.com/nationaledge/dec02/article.html

**Section 5.2 Microphones**

**Current Electret Condenser Microphones**

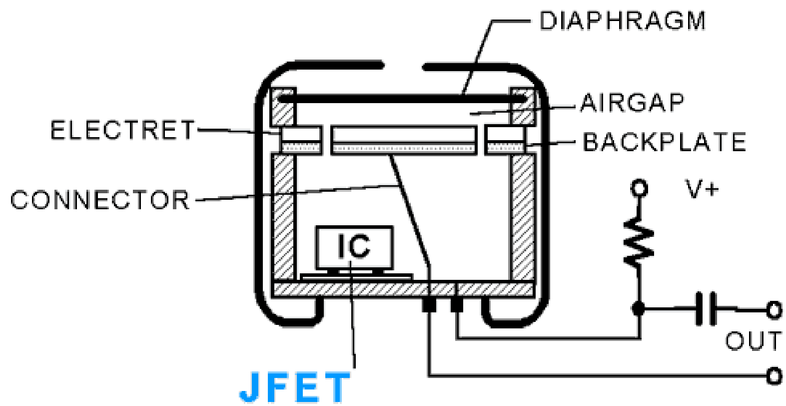



**Fig 1. Typical cross section of an ECM with JFET buffer and Phantom Biasing**

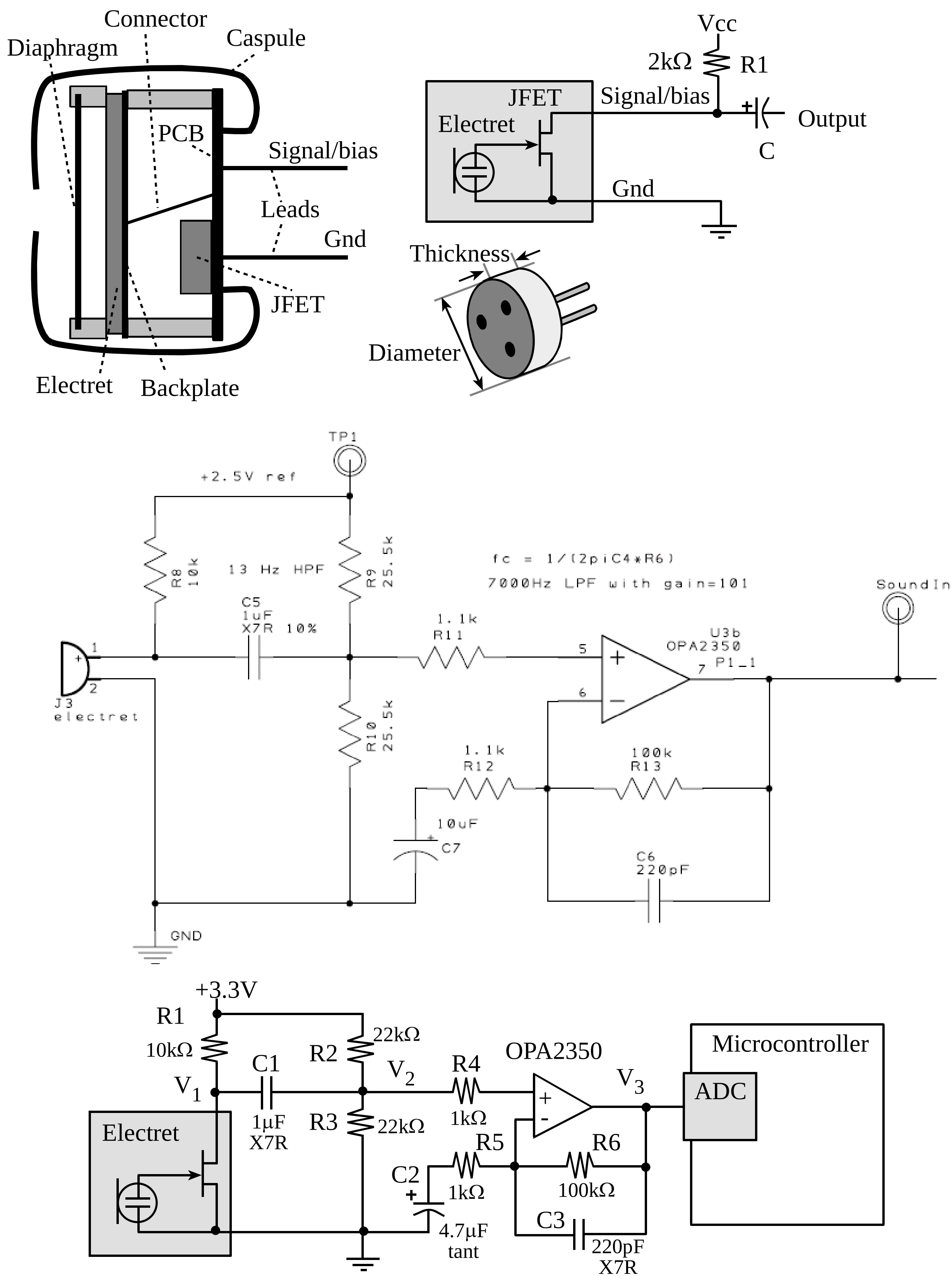



*Figure 5.6. An electret microphone can be used to record sound.*