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, $V_{ref} = \frac{1}{2} V_{max}$
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

\[
V_{out} = -\frac{R_2}{R_1} V_{in}
\]

\[
R_3 = \frac{R_1 \times R_2}{R_1 + R_2}
\]

by Jonathan W. Valvano
Regular design $V_{out} = -5V_{in}$
$R_1 = 10k$
$R_2 = 50k$
$R_3 = 8.3k$

**Example 2**
Regular design $V_{out} = 2V_{in}$

**Example 3**
$V_{out} = 2V_{in} - 1.23V$
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 pin 3 is $V_{in}$

Due to feedback, the voltage at pin 2 is $V_{in}$

Current across $R_1$ is $(V_{ref} - V_{in})/R_1$

Current across $R_2$ is $(V_{in} - V_{out})/R_2$

These two currents are equal $(V_{ref} - V_{in})/R_1 = (V_{in} - V_{out})/R_2$

Solve

$$(1.23 - V_{in})R_2/R_1 = (V_{in} - V_{out})$$


$$V_{out} = V_{in} - (V_{ref} - V_{in})R_2/R_1$$

$$V_{out} = (1 + R_2/R_1)V_{in} - V_{ref}R_2/R_1$$

$$V_{out} = 2V_{in} - 1.23$$

**Example 4**

Single supply design $V_{out} = 5(V_{in} - 1.23)$

Use rail to rail op amp

R1 = 10k

R2 = 50k

V2 = $V_{in}$, V1 = 1.23
11.2.7. Linear Mode Op Amp Circuits (EE445L review)

This design example works with any analog circuit in the form

\[ V_{\text{out}} = A_1 V_1 + A_2 V_2 + \ldots + A_n V_n + B \]

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, \( V_{\text{ref}} \).

\[ V_{\text{out}} = A_1 V_1 + A_2 V_2 + \ldots + A_n V_n + A_{\text{ref}} V_{\text{ref}} \]

by Jonathan W. Valvano
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.

$$V_{out} = A_1 V_1 + A_2 V_2 + \ldots + A_n V_n + A_{ref} V_{ref} + A_g V_g$$

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,

$$|A_1| = \frac{R_f}{R_1} \quad \text{so} \quad R_1 = \frac{R_f}{|A_1|}$$
$$|A_2| = \frac{R_f}{R_2} \quad \text{so} \quad R_2 = \frac{R_f}{|A_2|}$$
$$|A_n| = \frac{R_f}{R_n} \quad \text{so} \quad R_n = \frac{R_f}{|A_n|}$$
$$|A_{ref}| = \frac{R_f}{R_{ref}} \quad \text{so} \quad R_{ref} = \frac{R_f}{|A_{ref}|}$$
$$|A_g| = \frac{R_f}{R_g} \quad \text{so} \quad R_g = \frac{R_f}{|A_g|}$$

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.

by Jonathan W. Valvano
\[ V_{\text{out}} = 5V_1 - 3V_2 + 2V_3 - 2V_{\text{ref}} - V_g \]

The **fourth step** is to choose a feedback resistor, \( R_f = 150 \, \text{kΩ} \). 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.

\[
\begin{align*}
R_1 &= R_f/|A_1| = 150 \, \text{kΩ}/5 = 30 \, \text{kΩ} \\
R_2 &= R_f/|A_2| = 150 \, \text{kΩ}/3 = 50 \, \text{kΩ} \\
R_3 &= R_f/|A_3| = 150 \, \text{kΩ}/2 = 75 \, \text{kΩ} \\
R_{\text{ref}} &= R_f/|A_{\text{ref}}| = 150 \, \text{kΩ}/2 = 75 \, \text{kΩ} \\
R_g &= R_f/|A_g| = 150 \, \text{kΩ}/1 = 150 \, \text{kΩ}
\end{align*}
\]

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,
\[ V_{out} = \text{Gain} \times (V_1 - V_2) + V_{pin5} \]
\[ \text{Gain} = 5 + \left( \frac{200k\Omega}{R_G} \right) \]
\[ V_{out} = V_{pin5} \text{ when } V_1 \text{ equals } V_2 \]
In EE445L Lab 7, we grounded pin 5, \( V_{pin5} = 0 \)
\[ V_{out} = \text{Gain} \times (V_1 - V_2) \]
With an EKG, we connect pin 5, \( V_{ref} = V_{pin5} \)

**EKG data acquisition system.**

![Normal II-lead electrocardiogram.](image)

The 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 M\( \Omega \))
- high gain, 2500, \( \pm 1 \text{ mV to } \pm 2.5 \text{ V} \)
- 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**

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**Single supply rail-to-rail parts**

**Electromagnetic field induction**

by Jonathan W. Valvano
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.

by Jonathan W. Valvano
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 $I_{d2}$.
   $V_1 - V_2 = R_{s1} I_{d1} - R_{s2} I_{d2}$. 

by Jonathan W. Valvano
**Integrated Circuits for High Performance Electret Microphones**

*By Arie Van Rhijn*  [http://www.national.com/nationaledge/dec02/article.html](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.

by Jonathan W. Valvano