

Lecture 15 objectives

- Lab 6 design process
- Instrumentation Amp, Chapter 11

Quantitative DAS (review)

- range (r_x)
- resolution (Δx)
- precision (n_x in alternatives)
- frequencies of interest (f_{min} to f_{max})
- repeatability (σ of repeated measurements, same conditions)
- reproducibility (σ of repeated measurements, different conditions)

Temperature Data Acquisition System (design steps)

The resistance, R_t in ohms, is nonlinearly related to temperature

1) Constraints

- Free stuff from Maxim, TI, or Analog Devices
- Parts from 2nd floor (5% resistors, LCD, TLC2274)
- Murata NTSA0WF104F thermistor, 100 k Ω at 25 $^{\circ}$ C
- 10-bit ADC of the 9S12
- +5 V single power supply

2) Specifications (you can choose these as you wish)

- choose range T , e.g., 10 to 40 $^{\circ}$ C
- frequencies of interest, e.g., 0 to 10 Hz
- resolution, ΔT , of at least 0.1 $^{\circ}$ C

3) Data flow graph

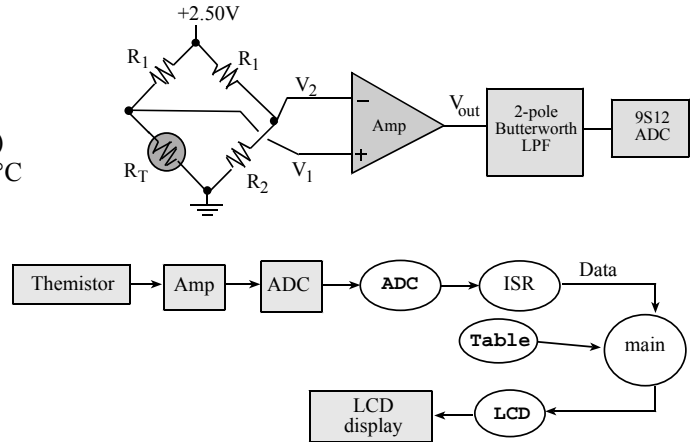
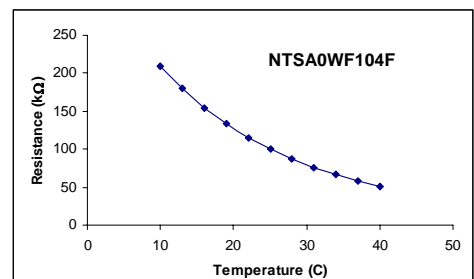


Figure 7.1. Data-flow graph of the data acquisition system (lab).

4) Transducer design/specification

- Operates in the specified range
- Fast enough to pass the frequencies of interest
- Good sensitivity (dR/dT)
- Good selectivity ($dR/dT > dR/dx$, x is another input)
- Good stability (R vs T is constant over time)
- Interchangeability (R vs T is the same for all transducers)
- Linear (if it is **monotonic**, then the inverse function exists)
- Robust (pressure, vibrations, temperature, humidity)



Two approaches to a nonlinear transducer

- Use an ADC with more bits and linearize it in software
- Linearize it with compensating nonlinear analog circuit

5) Amplifier design

- Secondary conversion element (bridge), resistance to voltage
- Operates in the specified range, range match, 0 to +5V ADC
- Fast enough to pass the frequencies of interest
- Impedance loading (Z_{in} in this stage $> 2^n * Z_{out}$ previous stage)

LPF at $\frac{1}{2}f_s$ to eliminate aliasing
 Electrical noise referred to ADC < ADC resolution
 Protect the ADC (limit range from 0 to +5V)

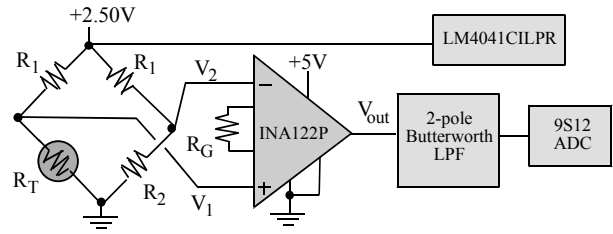


Figure 7.4. Possible thermistor interface (INA122).

- Step 1. Choose a low-noise, accurate input to the bridge (+2.50V)
- Step 2. Perform a two point calibration, room temperature, axilla
 Fit data to $R_T = R_0 e^{+\beta/T}$ (where T is temperature in degrees Kelvin)
- Step 3. Determine the range of thermistor resistances, R_T
- Step 4. Choose R_1 to limit self-heating of thermistor (2.5 mW/°C)
- Step 5. Choose $R_2 =$ minimum R_T (specifies the maximum T)
- Step 6. Choose R_G to range match (specifies the minimum T)
- Step 7. Add a analog low pass filter at $\frac{1}{2}f_s$ to prevent aliasing

*****Show Therm10.XLS*****

Design the circuit

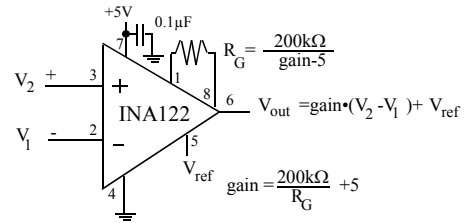
Instrumentation Amp

necessary condition (this must be true)

amplify a differential voltage, shown below as $V_2 - V_1$

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. Or low noise



INA122 is low-power single supply rail-to-rail instrumentation amp,

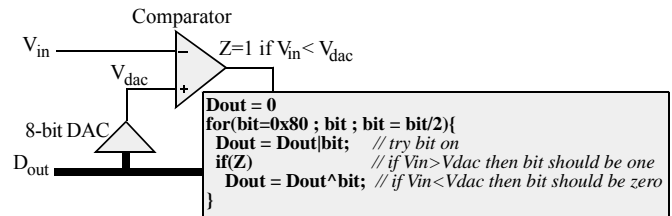
$V_{out} = \text{Gain} * (V_1 - V_2) + V_{ref}$
 (AD627 or INA122) $\text{Gain} = 5 + (200\text{k}\Omega / R_G)$
 $V_{out} = V_{ref}$ when V_1 equals V_2

In Lab 7, we will ground pin 5 ($V_{ref} = 0$)

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

Successive Approximation ADC Converter

I pick a number from 0 to 255, and you try to guess it



11.3.2. Butterworth Filters

2 pole Butterworth analog filter

- 1) select the cutoff frequency, f_c
- 2) divide the two capacitors by $2\pi f_c$ (let C_{1A} , C_{2A} be the new capacitor values)

$C_{1A} = 141.4\mu\text{F} / 2\pi f_c$
 $C_{2A} = 70.7\mu\text{F} / 2\pi f_c$

- 3) locate two standard value capacitors (with the 2/1 ratio) with the same order of magnitude as the desired values

let C_{1B} , C_{2B} be these standard value capacitors, let x be this factor
 $C_{1B} = C_{1A} / x$
 $C_{2B} = C_{2A} / x$

- 4) adjust the resistors to maintain the cutoff frequency

$R = 10\text{k}\Omega \cdot x$

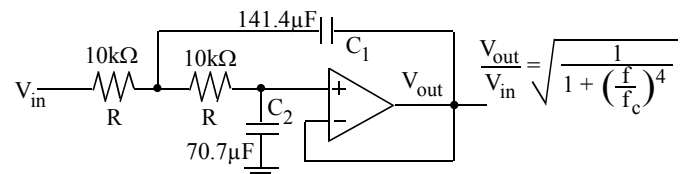


Figure 11.55. Two pole Butterworth low pass analog filter.

The analog filters in this section all require low leakage, high accuracy and low temperature coefficient capacitors like Teflon, polystyrene or polypropylene. Lower quality (lower cost) ceramic COG capacitors could be used if filter accuracy is less important.

Performance Tip: *If you choose standard value resistors near the desired values, you will save money and the circuit will still be a Butterworth filter. The only difference is that the cutoff frequency will be slightly off from the original specification.*

*****Show LPF.XLS*****

*****ADC Project*****

ATDOCTL2 set bit 7 to enable ADC
ATDOCTL3 bits 6,5,4,3 define the sequence length
ATDOCTL4 clear bit 7 for 10-bit ADC, bits 6-0 define sample time
ATDOCTL5 write channel number to start ADC

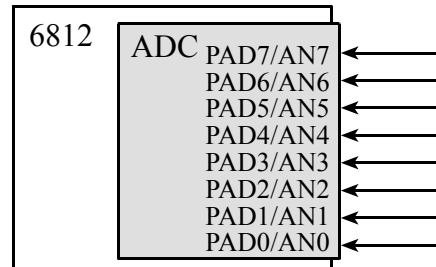
- Bit 7, **DJM** is 1 for right justify
- Bit 6, **DSGN** is 0 for unsigned format
- Bit 5, **SCAN** is 0 for convert once and stop
- Bit 4, **MULT** is 0 for convert same channel
- Bits 2-0 specify the channel number 0 to 7

ATDOSTAT SCF

- cleared by write to **ATDOCTL5**
- **SCF** set when entire conversion sequence is complete

CCF0

- cleared by write to **ATDOCTL5**
- cleared by read **ATDOSTAT1** with CCF0 set, read **ATDODR0**
- **CCF0** set when first ADC conversion is complete



9S12DP512. **ATDODR0** 10-bit ADC result

- precision 10-bit, 1024 alternatives
- range 0 to +5V
- resolution $(5-0)/1024 = 5 \text{ mV}$

9S12DP512. Digital Output = $1023 * V_{in} / 5$

Analog Input (V)	left justified	right justified
0.000	0000	0
0.005	0040	1
0.010	0080	2
0.015	00C0	3
1.250	4000	100
2.500	8000	200
5.000	FFC0	3FF

9S12. **Unsigned binary** format .

show ADC_DP512 project