Potentiometric-based Smart Transducer for Roll Angle Estimation

ELEN4006 Project Presentation

M. van Rooyen J. Ping

School of Electrical and Information Engineering,
University of the Witwatersrand

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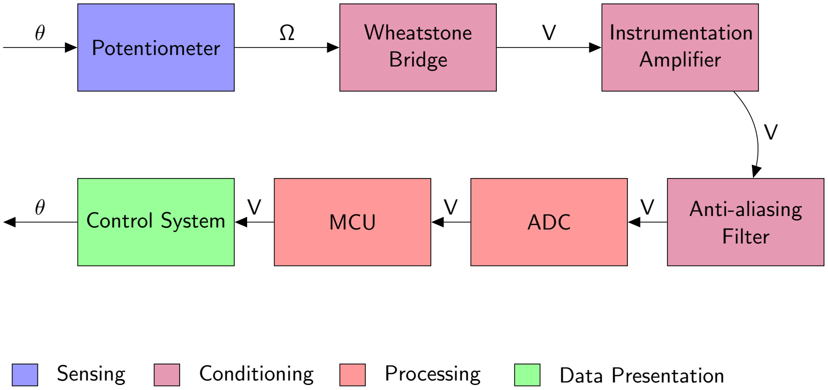
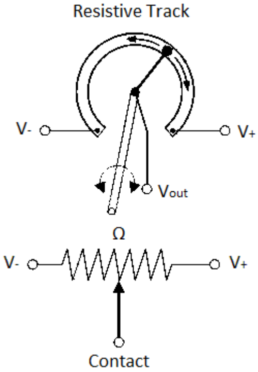
Problem Statement

- Active safety control system prevents unwanted driver conditions
- Angular displacement measured at the wheel base
- Control system must have accurate readings of the roll angle.
- A number of environmental conditions affect this:
    - Road vibrations
    - Tyre pressure
    - Motor vibrations.

Block Diagram



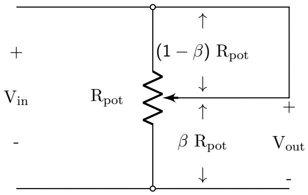
Angular Potentiometer
Diagram



Element	**Material**
Resistor	Conductive Plastic Paste
Terminals	Thick film conductor
Contact	Multiple-fingered equidistant wiper
Actuator	Rotary Shaft

Angular Potentiometer
Circuit Diagram

Roll Angle (°)	R_{pot} (kΩ)	V_{out} (V)
-15	1	0
15	12	5

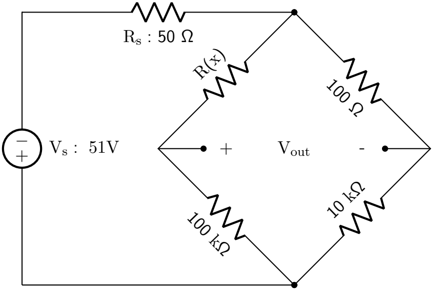


Resistive Element

- Carbon black inert filler
- Strong with long lifespan
- Very high resolution
- Positive Temperature Coefficient ± 100 ppm/°C
- non-linearity of $\sim$ 0.4 %

Wheatstone Bridge

Signal Conditioning Element



- i_{max} at $V_{out} = 1.3$ mA
- $P_{max} = 16.9$ mW
- Resistor tolerances = 0.5 %
- Bandwidth $\approxeq 1$ GHz
- Power Supply (PSU): Output Voltage 51 V ± 1 %, output resistance of 50 Ω

Instrumentation Amplifier

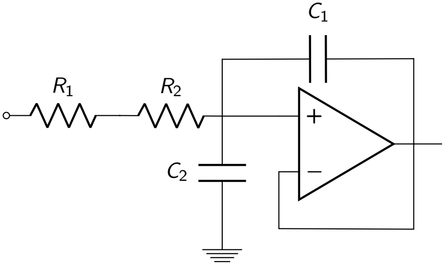
Signal Conditioning Element

Texas Instruments INA188

- 3 Op-amp IC
- G $= 1$
- BW $=$ 600 kHz
- $\mathrm{E_G}$ $= \pm$0.025 % (worst case)
- Input Bias Current: 2.5 pA
- Input Offset Current: 2.5 pA
- Input Impedance: 100 $\mathrm{G\Omega}$
- Operating Temperature Range: $-$55 $^\circ\mathrm{C}$ - 150 $^\circ\mathrm{C}$
- Supply Voltage Range: 4 V - 36 V

Anti-aliasing Filter
Signal Conditioning Element

2nd Order Butterworth LPF

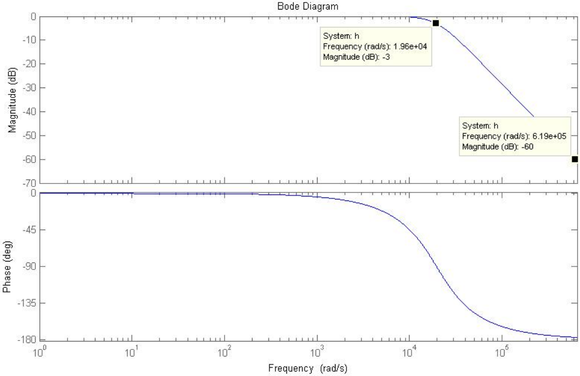


Element	Value
R_1	10kΩ
R_2	10kΩ
C_1	3.60nF
C_2	7.21nF

$$Q = \frac{\sqrt{R_1 R_2 C_1 C_2}}{C_2(R_1 + R_2)} \approx 0.707$$

$$f_c = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} = 3.12\ kHz$$

Anti-aliasing Filter
Signal Conditioning Element



$$f_c \sim 19.6\,\mathrm{kRad.s}^{-1} = 3.12\,\mathrm{kHz}, \quad f_{0.1\%} \sim 619\,\mathrm{kRad.s}^{-1} = 98.5\,\mathrm{kHz}$$

Anti-aliasing Filter

Signal Conditioning Element

Texas Instruments - LMC6022 Operational Amplifier

- Input Bias Current: 200 pA
- Input Offset Current: 100 pA
- Input Impedance: 1 $\mathrm{T\Omega}$
- Operating Temperature Range: $-40^\circ\mathrm{C}$ - $85^\circ\mathrm{C}$
- Supply Voltage Range: 4.5 V - 15.5 V
- Resistor tolerances: 0.5 %
- Capacitor tolerances: 0.5 %

$$H(s) = \frac{1}{1 + 14.4 \times 10^{-6} s + 25.96 \times 10^{-12} s^2}$$

Analog to Digital Converter

Signal Processing Element

- $f_{0.1\%} = 98.5\ \mathrm{kHz}$
- $\therefore$ sample at minimum $\mathrm{f_s} = 200\ \mathrm{kHz}$ to satisfy Nyquist sampling theorem
- $\therefore$ 0.1% aliasing error
- 10 bit resolution
- $\therefore \frac{1}{2^{10}} \times 100\% = \frac{1}{1024} \times 100\% = 0.098\%$ quantization error

Microprocessor
Signal Processing Element

Microchip - dsPIC30F2010

- 7.37 MHz internal oscillator
- 6 $\times$ 10 bit, 1000 ksps ADC
- 20 I/O pins
- Operating Temperature Range: $-40°\mathrm{C}$ - $125°\mathrm{C}$
- Operating Voltage Range: 2.5 V - 5.5 V

Error Analysis

Source	**Value %**
Conductive plastic non-linearity	0.4 %
Potentiometer contact resistance variation (CRV)	0.075 %
Wheatstone bridge non-linearity	2.33 %
Instrumentation amplifier gain error	0.025%
Aliasing error	0.1 %
Resistor tolerance	0.5 %
Capacitor tolerance	0.5 %
Quantization error	0.098 %
Total error	**4.028 %**

Bentley's Model

$$O = KI + a + N(I) + K_M I_M I + K_I I_I \quad (1)$$
$$O = 0.1I + 2.1 + 33.6 \times 10^{-3} + 0.1 \cdot 0.26I + 0.2 \times 10^{-6} I_I$$

- O = Steady-state output $0\text{V to }5\text{V}$
- K = sensitivity $(\text{V}/^\circ)$
- I = Input: -15° to 15°
- a = Zero bias (V)
- $N(I)_{\max} = 33.6\text{mV}$
- K_M = Change in sensitivity for modifying input
- $I_M = \pm1\%$ error in PSU output
- K_I = Sensitivity change due to I_I $(\text{V}/^\circ\text{C})$
- I_I = Difference between operating temperature and 25°C

Smart Transducer Requirements

Core functionality:

- Transduction
- Signal Conditioning
- Signal Processing
- Communication
- Memory

Added functionality:

- Averaging of multiple devices
- Self calibration - differential between each wheel base
- Self diagnosing

Further Work

- Digital Filtering
- Costing
- Finalise all components
- Power Supply

Conclusion

Any questions?