# Strain-Gage Low Noise Signal Conditioning

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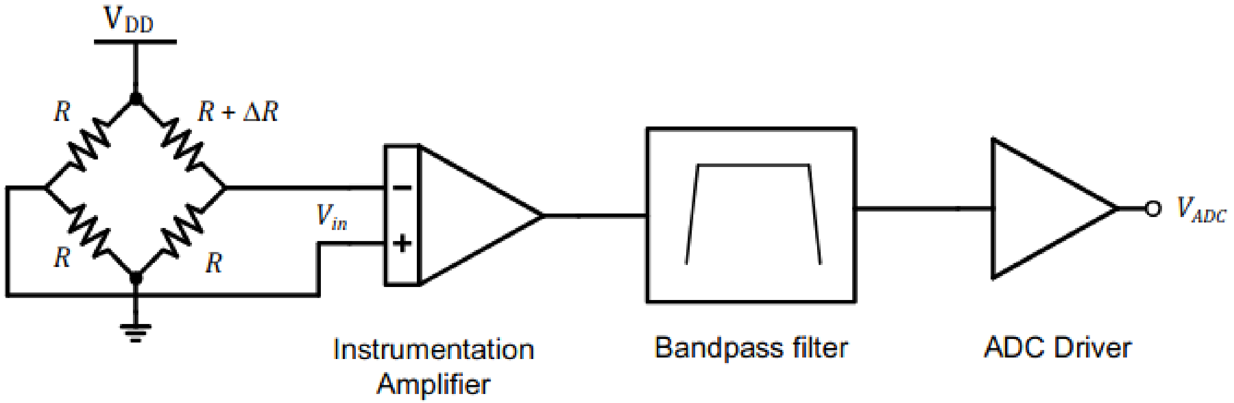
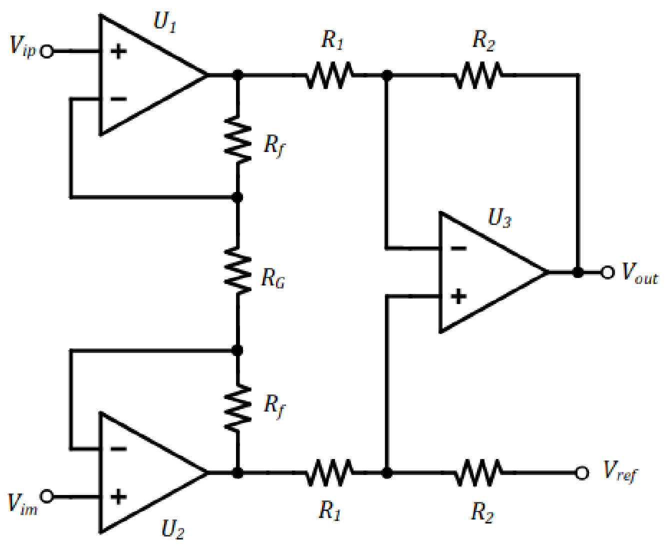
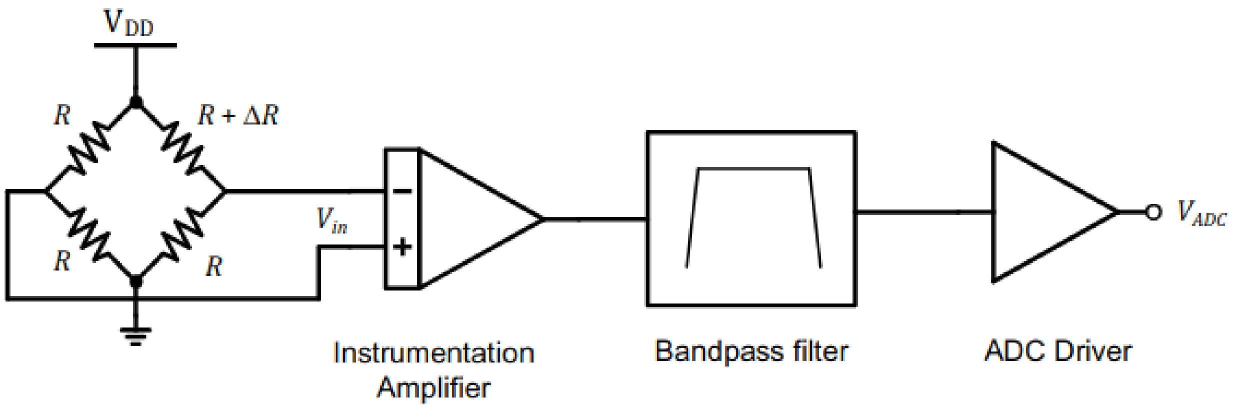


# Instrumentation Amplifier Specs

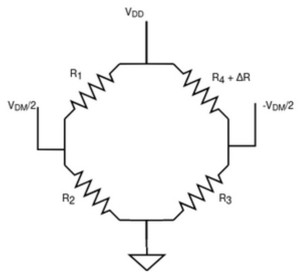
| Parameter | Specification | Unit |
|---|---|---|
| Supply voltage ($V_{DD}$) | 5 | V |
| Peak-to-peak input signal amplitude (max) | 20 | mV |
| Nominal strain gage resistance (R) | 1 | kΩ |
| Peak-to-peak output amplitude (max) | 2 | V |
| Signal-to-noise ratio ($V_{id,rms}$ = 10mV/√2) | ≥ 77 | dB |
| Signal bandwidth | 1 – 5k | Hz |
| CMRR | 90 | dB |
| Power dissipation ($I_{DD} \times V_{DD}$) | Optimize | mW |
| Cost | Optimize | $ |

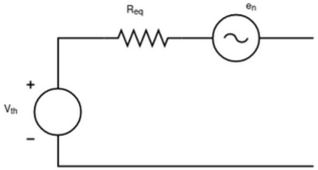


# Strain-Gage Thevenin Eq. + Instrumentation Amp.

## Strain-Gauge



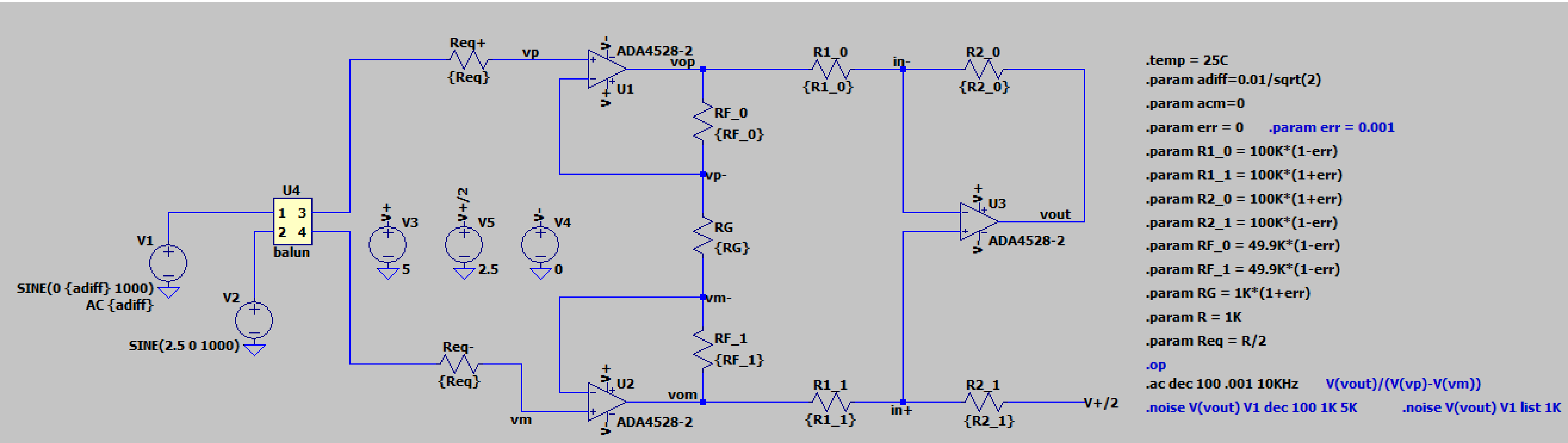

| | | |
|---|---|---|
| $Req$ | 500 | Ω |
| $R_G$ | 10K | Ω |
| $R_F$ | 49.9K | Ω |
| $R_1$ | 100K | Ω |
| $R_2$ | 100K | Ω |

## Ideal Sources

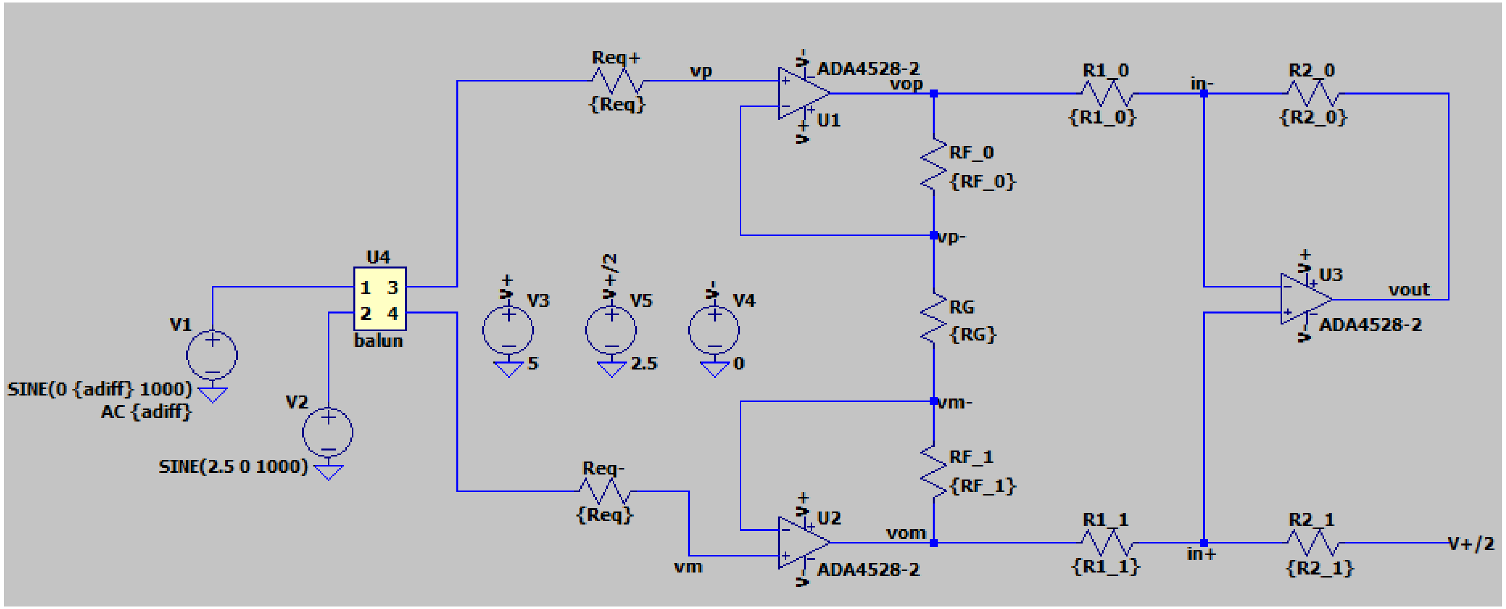
5.0 V Single-ended power supply
2.5 V Single-ended power supply

## Precision Amplifiers

ADA4528: $e_n$ = 5.6nV, $i_n$ = 0.7pA



# DC Operation: 192 Resistor Series (0.1% tolerance)



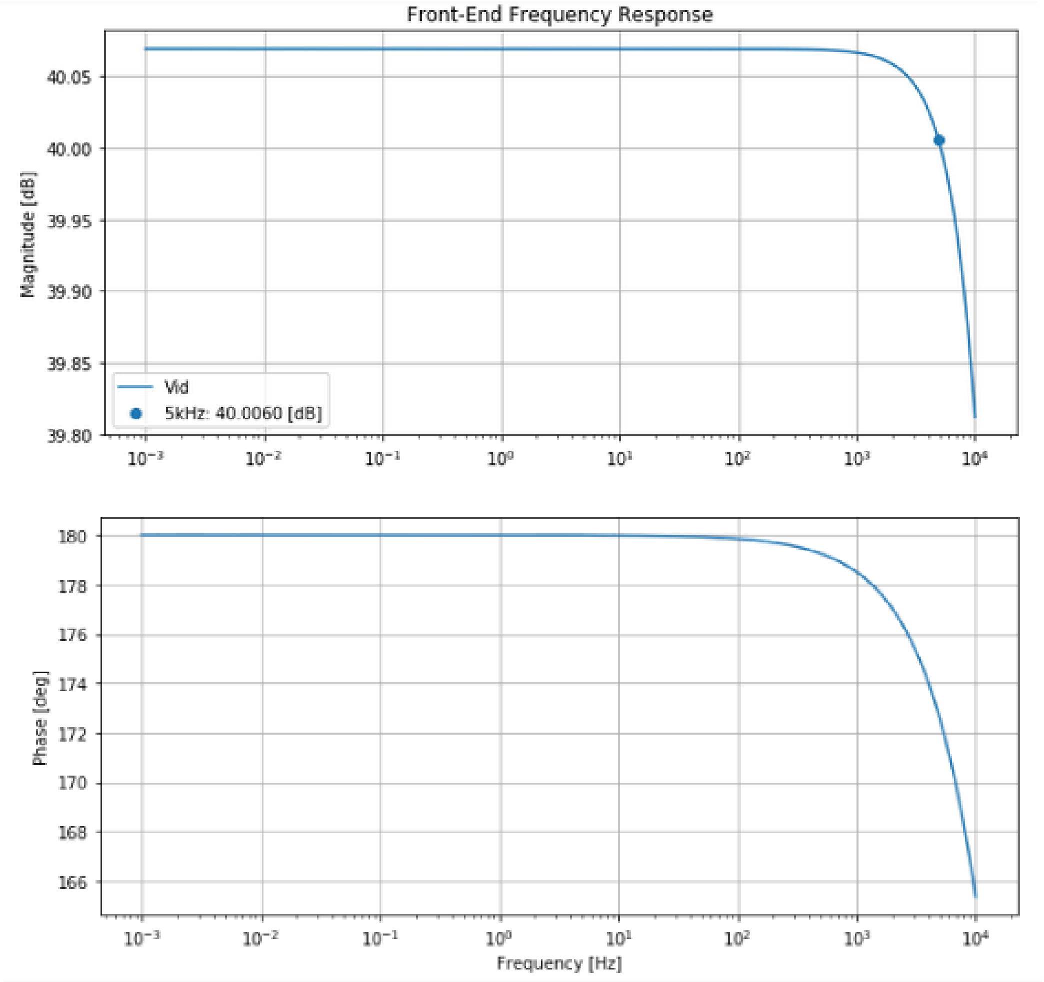

| | | |
|---|---|---|
| $V(vp-)$ | 2.5 | V |
| $V(vm-)$ | 2.5 | V |
| $V(vop)$ | 2.5 | V |
| $V(vom)$ | 2.5 | V |
| $V(in-)$ | 2.49999 | V |
| $V(in+)$ | 2.49999 | V |
| $V(vout)$ | 2.49998 | V |
| $I(Rf_0)$ | -8.51778e-011 | A |
| $I(Rf_1)$ | -8.51778e-011 | A |
| $I(Rg)$ | 1.06581e-017 | A |
| $I(R1_0)$ | -1.87986e-011 | A |
| $I(R1_1)$ | 2.34496e-011 | A |
| $I(R2_0)$ | -1.03976e-010 | A |
| $I(R2_1)$ | 6.17282e-011 | A |

| | | |
|---|---|---|
| $Req$ | 500 | Ω |

| | | |
|---|---|---|
| $R_G$ | 10K | Ω |
| $R_F$ | 49.9K | Ω |

| | | |
|---|---|---|
| $R_1$ | 100K | Ω |
| $R_2$ | 100K | Ω |

# Front-End Frequency Response




## Target

$$\frac{2V_{p-p}}{20mV_{p-p}} = 100\frac{V}{V} = 40\text{dB of gain.}$$

## Actual

$$\frac{V_{out_1}}{V_{in}}\frac{V_{out_2}}{V_{out_1}} = (1 + 2\frac{R_F}{R_G}) \cdot (\frac{R_2}{R_1})$$

$$= (100.8) \cdot (1)$$

$$= 40.07 \text{ dB}$$

## CMMR

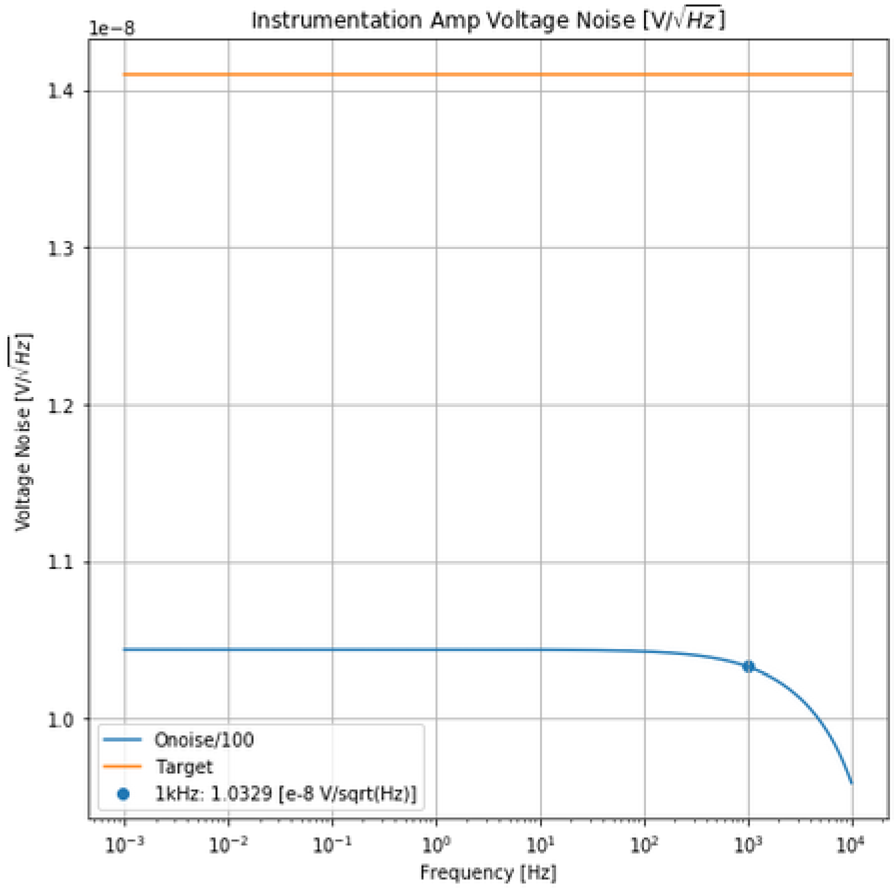
$$\text{CMMR}_1 = 1 + \frac{R_{fp} + R_{fm}}{R_G} = 40.07 \text{ dB}$$

$$\text{CMMR}_2 = \frac{A_{vd2} + 1}{4\epsilon} = \frac{2}{4(0.001)} = 53.98 \text{ dB}$$

$$\text{CMMR}_1 + \text{CMMR}_2 = 94.05 \text{ dB}$$

# Input-Referred Noise Target

ADA4528: $e_n$ = 5.6nV, $i_n$ = 0.7pA



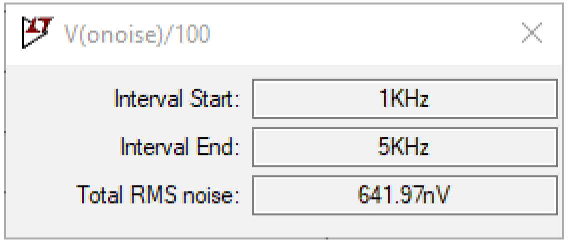

$$\mathrm{SNR} = 20\log\frac{v_{s(rms)}}{v_{n(rms)}} \rightarrow 20\log\frac{7.07\mathrm{mV}}{v_{n(rms)}} \geq 77\mathrm{dB}$$

$$v_{n,in(rms)} \leq 1\mu V$$

$$v_{n,in(\mathrm{rms})} = \sqrt{v_{n,in}^2 \cdot 5\mathrm{KHz}} \leq 1\mu V$$

$$v_{n,in} \leq \frac{1\mu V}{\sqrt{5\mathrm{KHz}}} \approx 1.41 \cdot 10^{-8}\frac{V}{\sqrt{\mathrm{Hz}}}$$

Integrated noise from 1Hz to 5kHz is 641.97 nV.



# Noise Sources

ADA4528: $e_n$ = 5.6nV, $i_n$ = 0.7pA

## Strain-Gage Noise: 1.67 * $10^{-17}$ $V^2$/Hz

$$R_{eq} = \frac{R}{2} = 500\Omega$$

$$e_{n_R}^2 = 4kTR_{eq}\Big|_{T=25C}$$

$$e_{n,gage}^2 = (i_{nn}R_{eq})^2 + e_{n_R}^2 + (i_{np}R_{eq})^2 + e_{n_R}^2$$

$$e_{n,gage}^2 = 2(i_nR_{eq})^2 + 2e_{n_R}^2 \frac{V^2}{\mathrm{Hz}}$$

## Gain Stage: 3.69 * $10^{-15}$ $V^2$/Hz

$$e_{n,out}^2 = 2[(\frac{R_f}{R_G})^2 4kTR_G + 4kTR_f]$$

$$e_{n,out}^2 = 2[(49.9)^2 4kTR_G + 4kTR_f]$$

## Difference Amp Inverting: 8.32 * $10^{-15}$ $V^2$/Hz

$$e_{n,out}^2 = (\frac{R_2}{R_1})^2 4kTR_1 + 4kTR_2 + (1 + \frac{R_2}{R_1})^2 e_n^2 + (i_nR_2)^2$$

$$e_{n,out}^2 = 4kTR_1 + 4kTR_2 + 4e_n^2 + (i_nR_2)^2$$

## Difference Amp Non-Inverting: 8.23 * $10^{-15}$ $V^2$/Hz

$$e_{n,out}^2 = (1 + \frac{R_2}{R_1})^2 4kTR_2 + (1 + \frac{R_2}{R_1})^2 (\frac{R_2}{R_1 + R_2})^2 4kTR_1$$

$$e_{n,out}^2 = (4)4kTR_2 + 4kTR_1$$