Noise 4

Exercises

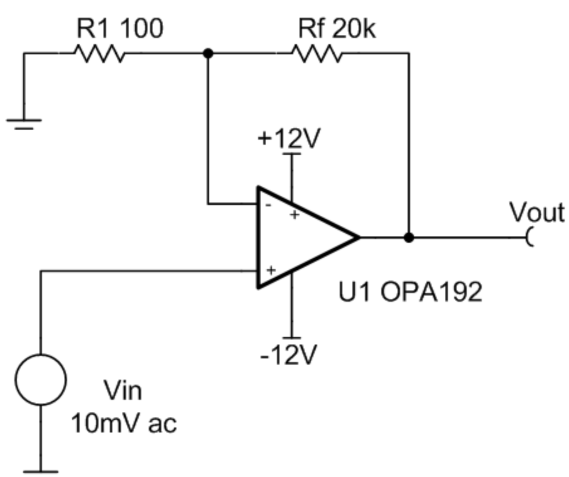
TI Precision Labs – Op Amps

1. **Is current noise or voltage noise dominant for the circuit below?**
2. **Is 1/f or broadband dominant?**
3. **Is resistor or op amp voltage noise dominant?**
4. **Calculate the total noise using appropriate simplifications.**

ELECTRICAL CHARACTERISTICS: V_S= ±2.25 V to ±4 V (V_S= +4.5 V to +8 V)

At T_A = +25°C, V_{CM} = V_{OUT} = V_S / 2, and R_{LOAD} = 10 kΩ connected to V_S / 2, unless otherwise noted.

PARAMETER		TEST CONDITIONS		OPA192 MIN	TYP	MAX	UNIT
NOISE							
E_n	Input voltage noise	(V–) – 0.1 V < V_{CM} < (V+) – 3 V, f = 0.1 Hz to 10 Hz			1.30		μV_{PP}
		(V+) – 1.5 V < V_{CM} < (V+) + 0.1 V, f = 0.1 Hz to 10 Hz			4		μV_{PP}
e_n	Input voltage noise density	(V–) – 0.1 V < V_{CM} < (V+) – 3 V	f = 100 Hz		10.5		nV/√Hz
			f = 1 kHz		5.5		nV/√Hz
		(V+) – 1.5 V < V_{CM} < (V+) + 0.1 V	f = 100 Hz		32		nV/√Hz
			f = 1 kHz		12.5		nV/√Hz
i_n	Input current noise density		f = 1kHz		1.5		fA/√Hz
FREQUENCY RESPONSE							
GBW	Unity gain bandwidth				10		MHz



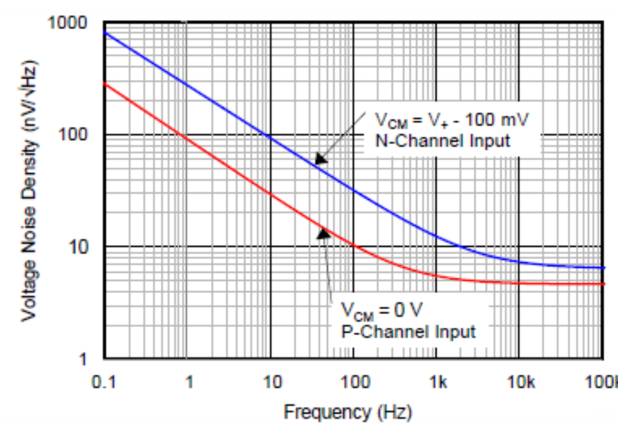


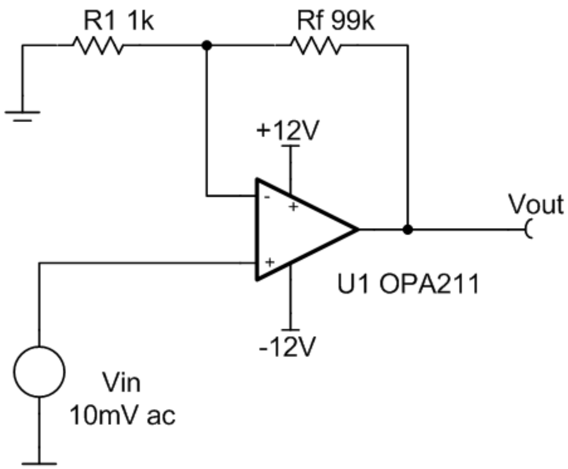
Figure 17. INPUT VOLTAGE NOISE SPECTRAL DENSITY vs FREQUENCY

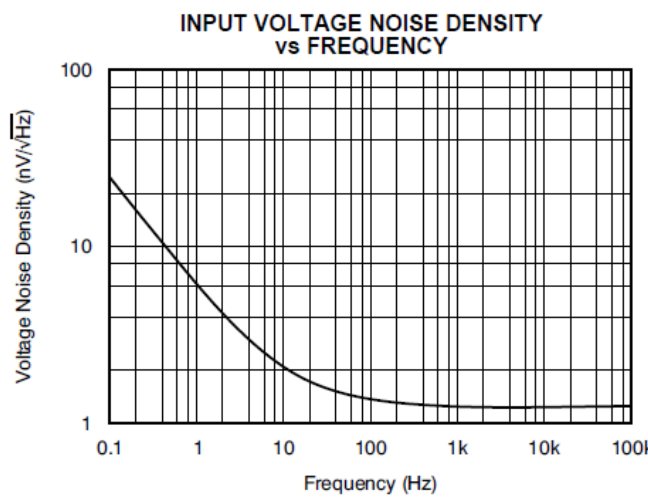
5. Is current noise or voltage noise dominant for the circuit below?
6. Is 1/f or broadband dominant?
7. Is resistor or op amp voltage noise dominant?
8. Calculate the total rms noise at the output.

ELECTRICAL CHARACTERISTICS: V_S = ±2.25V to ±18V

BOLDFACE limits apply over the specified temperature range, T_A = –40°C to +125°C.
At T_A = +25°C, R_L = 10kΩ connected to midsupply, V_{CM} = V_{OUT} = midsupply, unless otherwise noted.

PARAMETER		CONDITIONS	Standard Grade OPA211AI, OPA2211AI			High Grade OPA211I(1)			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
NOISE									
Input Voltage Noise	e_n	f = 0.1Hz to 10Hz		80			80		nV_{PP}
Input Voltage Noise Density		f = 10Hz		2			2		$nV/\sqrt{Hz}$
		f = 100Hz		1.4			1.4		$nV/\sqrt{Hz}$
		f = 1kHz		1.1			1.1		$nV/\sqrt{Hz}$
Input Current Noise Density	I_n	f = 10Hz		3.2			3.2		$pA/\sqrt{Hz}$
		f = 1kHz		1.7			1.7		$pA/\sqrt{Hz}$
FREQUENCY RESPONSE									
Gain-Bandwidth Product	GBW	G = 100		80			80		MHz
		G = 1		45			45		MHz



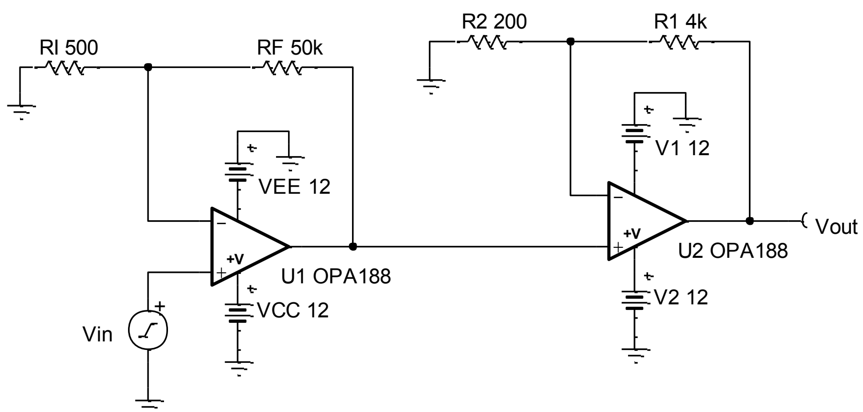


9. Is the input or output stage dominant?
10. Is current noise or voltage noise dominant for the circuit below?
11. Is 1/f or broadband dominant?
12. Is resistor or op amp voltage noise dominant?
13. Calculate the total noise using appropriate simplifications.

ELECTRICAL CHARACTERISTICS:
High-Voltage Operation, V_S = ±4 V to ±18 V (V_S = +8 V to +36 V)

At T_A = +25°C, R_L = 10 kΩ connected to V_S / 2[(1)], and V_{CM} = V_{OUT} = V_S / 2[(1)], unless otherwise noted.

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
NOISE						
e_n	Input voltage noise	f = 0.1 Hz to 10 Hz		250		nV_{PP}
		f = 0.1 Hz to 10 Hz		40		nVrms
	Input voltage noise density	f = 1 kHz		8.8		nV/√Hz
i_n	Input current noise density	f = 1 kHz		7		fA/√Hz
FREQUENCY RESPONSE						
GBW	Gain-bandwidth product			2		MHz



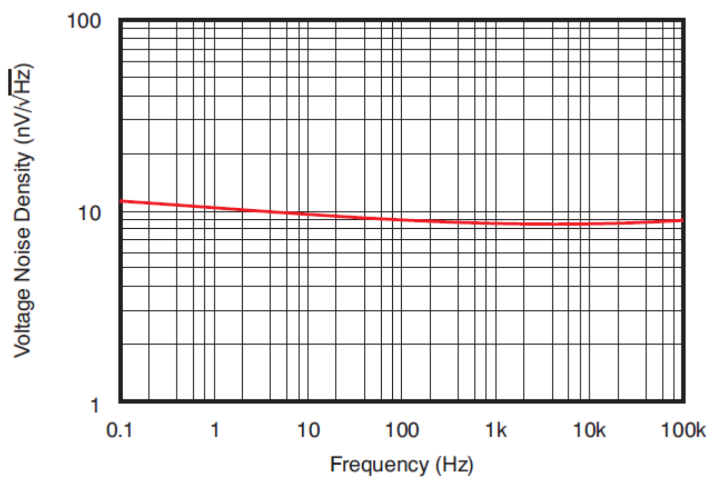


Figure 18. INPUT VOLTAGE NOISE SPECTRAL DENSITY vs FREQUENCY

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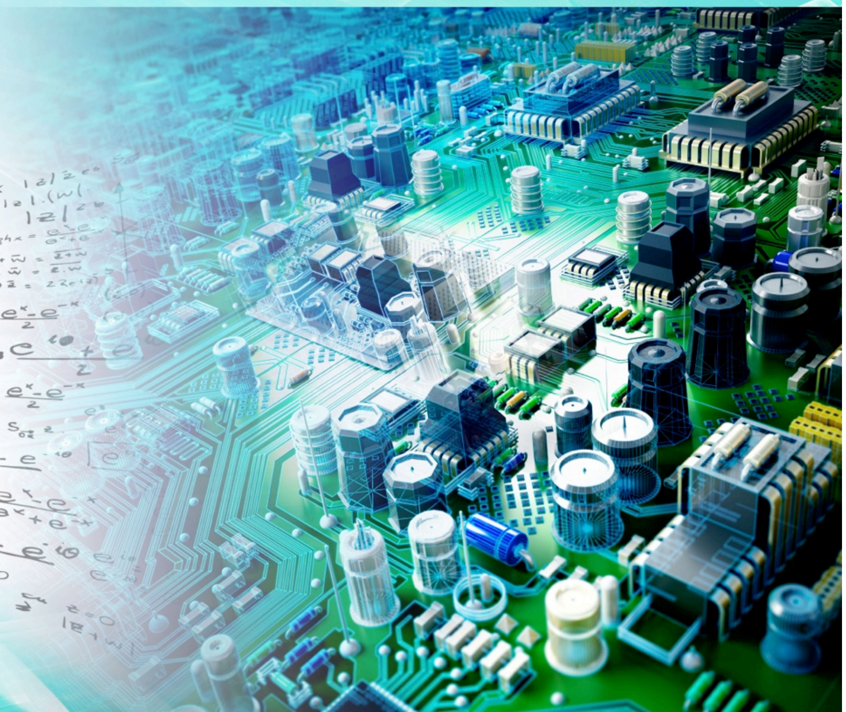
Solutions

TI Precision Labs – Op Amps



1. Is current noise or voltage noise dominant for the circuit below?

$$R_{eq} = Rf\,||R_1 \approx 100\Omega$$
$$e_{ni} = R_{eq} \cdot i_n = (100\Omega)\left(1.5\,\mathrm{fA}/\sqrt{\mathrm{Hz}}\right) = 300\,\mathrm{fV}/\sqrt{\mathrm{Hz}} \text{ or } 0.00015\,\mathrm{nV}/\sqrt{\mathrm{Hz}}$$
$$5.5\,\mathrm{nV}/\sqrt{\mathrm{Hz}} \gg 0.00015\,\mathrm{nV}/\sqrt{\mathrm{Hz}} \quad \Rightarrow \quad e_{nv} \gg e_{ni}$$

Thus voltage noise is dominant

2. Is 1/f or broadband dominant?

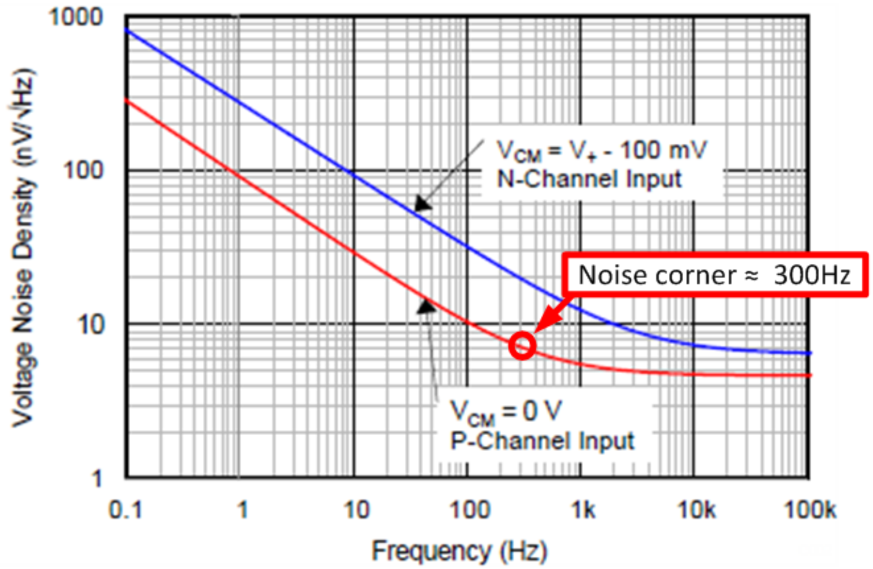


Figure 17. INPUT VOLTAGE NOISE SPECTRAL DENSITY vs FREQUENCY

$$G_n = \frac{R_f}{R_1} + 1 = \frac{20\mathrm{k}\Omega}{100\Omega} + 1 = 201$$
$$f_c = \frac{GBW}{G_n} = \frac{10\mathrm{MHz}}{201} = 49.8\mathrm{kHz}$$
$$BW_n = K_n \cdot f_c = (1.57)(49.8\mathrm{kHz}) = 78.2\mathrm{kHz}$$
$$78.2\mathrm{kHz} \gg 300\mathrm{Hz} \quad \Rightarrow \quad BW_n \gg f_f$$

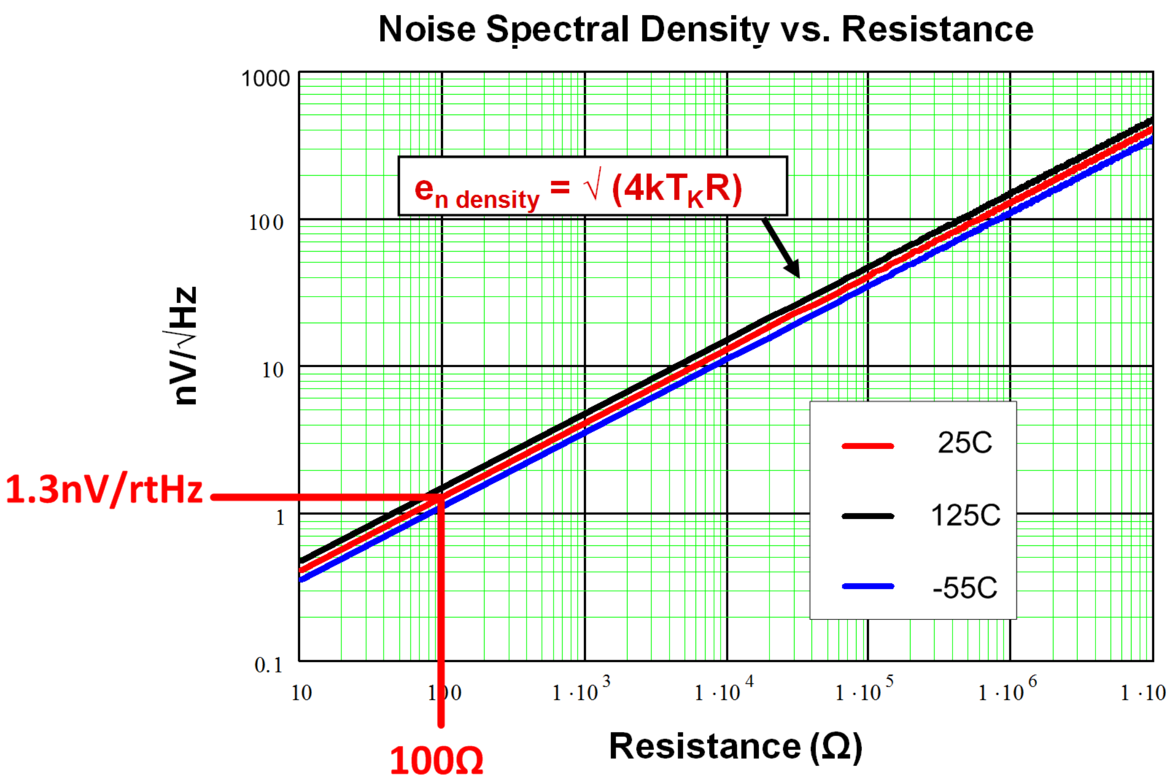
Thus broadband noise is dominant

3. Is resistor or op amp voltage noise dominant?

Refer to the data sheet table. Notice that the op amp voltage noise is dependent on common mode voltage. Vcm = 0V in this example, so noise is 5.5nV/rtHz. The equivalent feedback resistance is approximately 100Ω, so using the chart below the resistor noise is 2nV/rtHz.

1.3nV/rtHz x 3 = 3.9nV/rtHz (apply Rule 1)

5.5nV/rtHz >> 1.3nV/rtHz (op amp voltage noise is dominant)



4. Calculate the total noise using appropriate simplifications.

$$G_n = \frac{R_f}{R_1} + 1 = \frac{20k\Omega}{100\Omega} + 1 = 201$$

$$f_c = \frac{GBW}{G_n} = \frac{10MHz}{201} = 49.8kHz$$

$$BW_n = K_n \cdot f_c = (1.57)(49.8kHz) = 78.2kHz$$

$$E_n = (G_n)(e_n)\sqrt{BW_n} = (201)\left(5.5\ nV/\sqrt{Hz}\right)\sqrt{(78.2kHz)} = 309\mu V\ rms$$

$$E_{npp} = 6E_n = 6(309\mu V\ rms) = 1.85mVpp$$

5. Is current noise or voltage noise dominant for the circuit below?

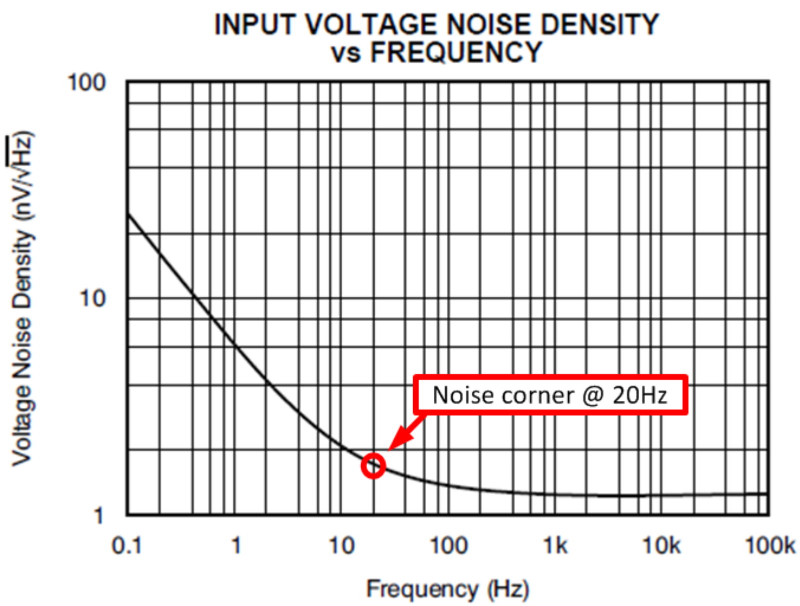
$$R_{eq} = Rf\,||R_1 \approx 1k\Omega$$

$$e_{ni} = R_{eq} \cdot i_n = (1k\Omega)\left(1.7\,pA/\sqrt{Hz}\right) = 1.7\,nV/\sqrt{Hz}$$

$$e_{nv} = 1.1\,nV/\sqrt{Hz} \text{ and } e_{ni} = 1.7\,nV/\sqrt{Hz} \Rightarrow e_{nv} \ngtr e_{ni}$$

$e_{nv} \approx e_{ni}$ ⇨ Thus both voltage noise and current noise need to be considered

6. Is 1/f or broadband dominant?



$$G_n = \frac{R_f}{R_1} + 1 = \frac{99k\Omega}{1k\Omega} + 1 = 101$$

$$f_c = \frac{GBW}{G_n} = \frac{80MHz}{101} = 792kHz$$

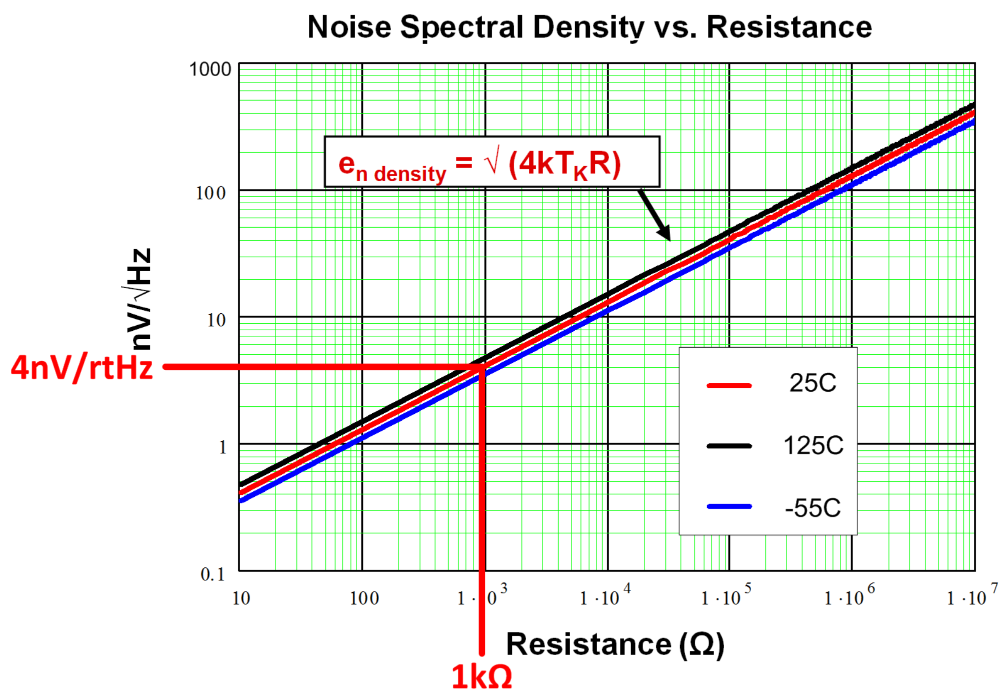
$$BW_n = K_n \cdot f_c = (1.57)(792kHz\,*) = 1.24MHz$$

$1.24MHz \gg 20Hz$ ⇨ $BW_n \gg f_f$

Thus broadband noise is dominant

7. Is resistor or op amp voltage noise dominant?

e_n = 1.1nV/rtHz (op amp noise)
e_{nr} = 4nV/rtHz (resistor noise)
4nV/rtHz x 3 = 12nV/rtHz (apply Rule 1)
The op amp noise needs to be greater than 12nV/rtHz to be dominant.
In this case, resistor noise dominates $e_{nr} >> e_n$
Normally, it is recommended to reduce the feedback impedance to ensure that the op amp noise dominates. The only concern is that lower feedback impedances translate to larger output current requirements.



8. Calculate the total rms noise at the output.

$$e_{ni} = 1.7\,\text{nV}/\sqrt{\text{Hz}}$$
$$e_{nr} = 4\,\text{nV}/\sqrt{\text{Hz}}$$
$$e_{nv} = 1.1\,\text{nV}/\sqrt{\text{Hz}}$$
$$e_{n\_tot} = \sqrt{{e_{ni}}^2 + {e_{nr}}^2 + {e_{nv}}^2} = \sqrt{(1.7)^2 + (4)^2 + (1.1)^2} = 4.5\text{nV}/\sqrt{\text{Hz}}$$
$$E_{n\_tot} = (G_n)(e_{n\_tot})\sqrt{BW_n} = (100)\left(\frac{4.5\text{nV}}{\sqrt{\text{Hz}}}\right)\sqrt{1.24\text{MHz}} = 501\mu\text{V rms}$$

9. Is the input or output stage dominant?

The input stage and the output stage both use the same amplifier. This makes the comparison easy. If a higher noise amplifier were used in the output stage more calculations may be required. In this case, just look at the first stage gain. If it is greater than 3 than the input stage will be dominant (Rule 1). In this case the noise gain of the input stage is 101, so the input stage is dominant. In subsequent calculation we will only consider the input stage. The gain of the output stage only need be considered to calculation the output noise. The noise sources in the second stage are ignored.

Note: In some cases the noise from the second stage may play a role if the bandwidth of the second stage is significantly wider than the first stage. In this case a Cf filter may be advisable.

10. Is current noise or voltage noise dominant for the circuit below?

$$R_{eq} = Rf\,||R_1 \approx 500\Omega$$

$$e_{ni} = R_{eq} \cdot i_n = (500\Omega)\left(7\,fA/\sqrt{Hz}\right) = 0.0035\,nV/\sqrt{Hz}$$

$$e_{nv} = 8.8\,nV/\sqrt{Hz} \text{ and } e_{ni} = 0.0035\,nV/\sqrt{Hz} \Rightarrow e_{nv} \gg e_{ni}$$

Op amp voltage noise is dominant

11. Is 1/f or broadband dominant?

This is a trick question. The OPA188 is a zero drift amplifier and does not have 1/f noise. Notice that the spectral density curve is relatively flat down to 0.1Hz. So in this case broadband is definitely dominant because there is no 1/f noise.

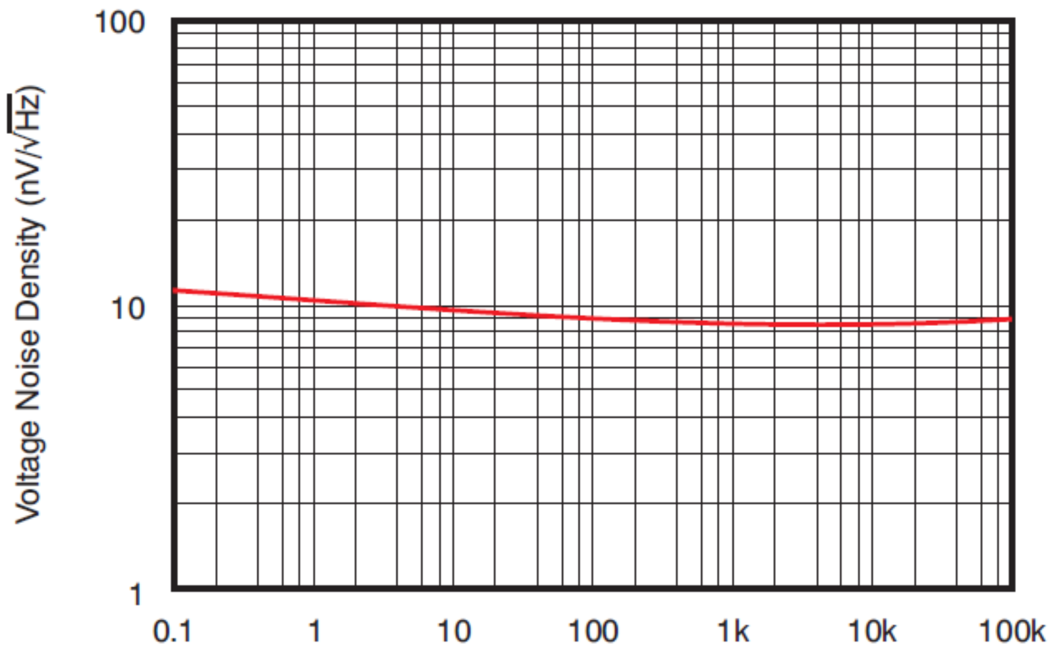
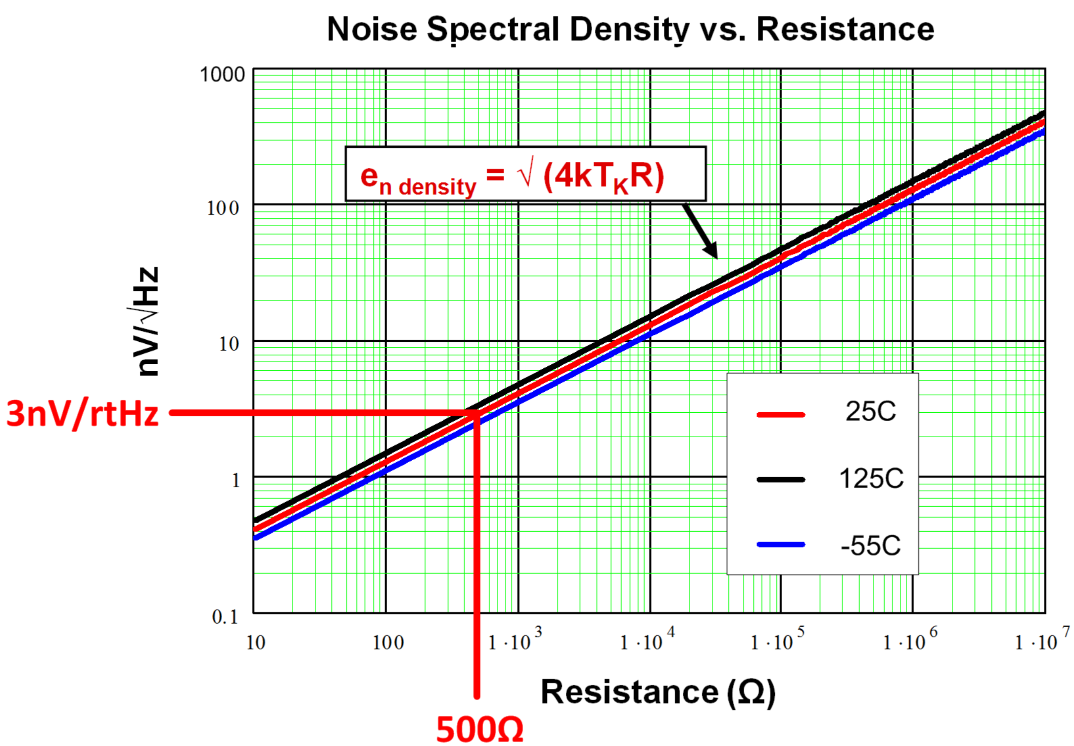


Figure 18. INPUT VOLTAGE NOISE SPECTRAL DENSITY vs FREQUENCY

12. Is resistor or op amp voltage noise dominant?

Op amp noise is 8.8nV/rtHz. The equivalent feedback resistance is approximately 500Ω, so using the chart below the resistor noise is 3nV/rtHz.
3nV/rtHz x 3 = 9nV/rtHz (apply Rule 1)
8.8nV/rtHz >> 3nV/rtHz (Op amp noise almost dominant)
Technically the op amp noise is not quite 3x the resistor noise. However, it's close so let's assume that it's dominant. In a real world design you might further reduce the feedback. However, you don't need to reduce much.



13. Calculate the total noise using appropriate simplifications.

$$G_{n1} = \frac{R_f}{R_1} + 1 = \frac{50k\Omega}{500\Omega} + 1 = 101$$

$$G_{n2} = \frac{R_f}{R_1} + 1 = \frac{4k\Omega}{200\Omega} + 1 = 21$$

$$f_{c1} = \frac{GBW}{G_n} = \frac{2MHz}{101} = 19.8kHz$$

$$BW_n = K_n \cdot f_c = (1.57)(19.8kHz) = 31.1kHz$$

$$E_n = (G_{n1})(G_{n2})(e_n)\sqrt{BW_n} = (101)(21)\left(8.8\,nV/\sqrt{Hz}\right)\sqrt{(15.6kHz)} = 3.30mV\ rms$$

$$E_{npp} = 6E_n = 6(4.64m * V\ rms) = 27.8mVpp$$