Instrumentation Amplifiers: characteristics

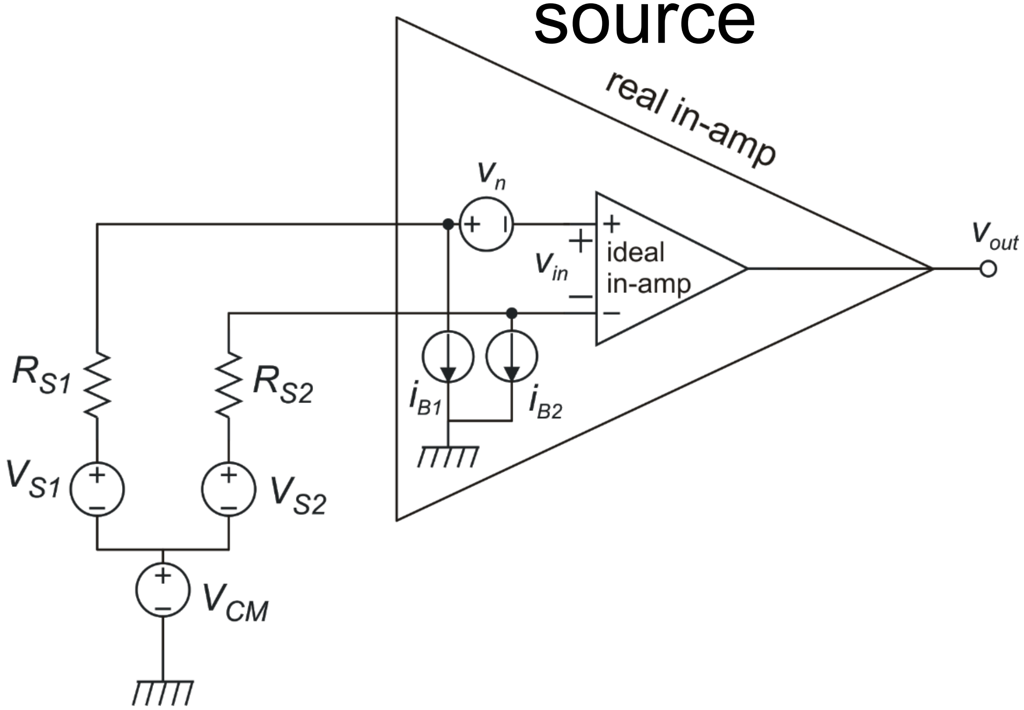
By definition:

- Precise gain
- High input resistance
- Differential input

Other important features

- Low input referred offset voltage
- Low bias currents
- Low input referred voltage and current noise
- High CMRR
- Large bandwidth

Instrumentation Amplifiers: connection to the source



$$v_{in} = V_{S1} - i_{B1}R_{S1} - v_n - \left(V_{S2} - i_{B2}R_{S2}\right) = V_{S1} - V_{S2} - v_{nt}$$

$$v_{nt} = v_n + i_{B1}R_{S1} - i_{B2}R_{S2}$$

$$v_{nt} = v_n + R_S\left(i_{B1} - i_{B2}\right)$$

Balanced case
($R_{S1}=R_{S2}=R_S$)

Offset: $v_n = v_{io}$, $i_{B1} - i_{B2} = I_{B1} - I_{B2} = I_{io}$

$$v_{iot} = v_{io} + R_S\left(I_{B1} - I_{B2}\right) = v_{io} + R_S I_{io}$$

Noise: v_n and i_{n1}, i_{n2} are represented by their PSD (power spectral density)

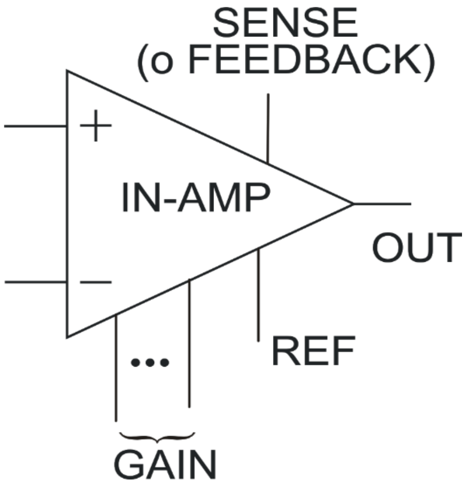
cross-spectrum

$$S_{vnt} = S_{vn} + R_S^2\left(S_{I1} + S_{I2} - 2S_{I1I2}\right)$$

If i_{b1} and i_{b2} are uncorrelated and their PSD is S_I:

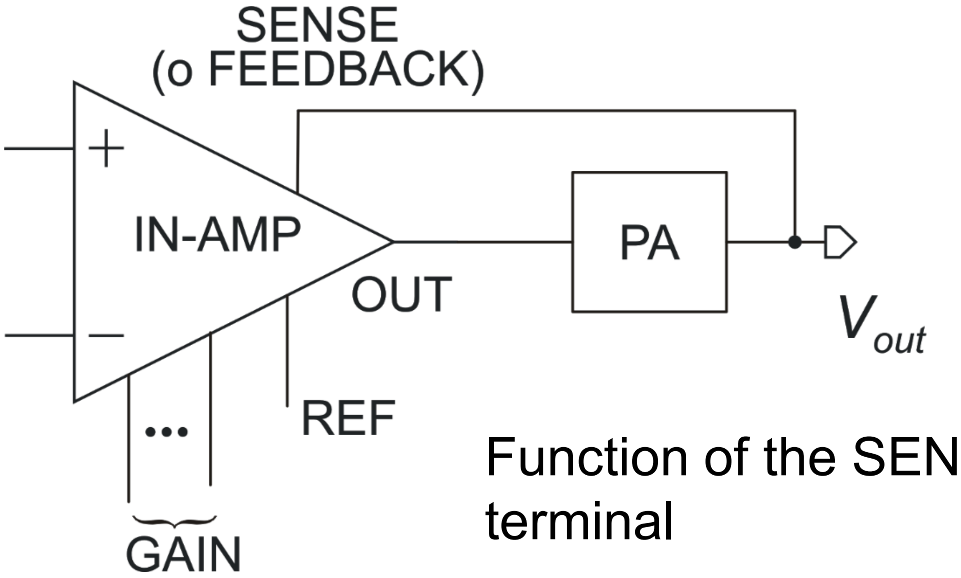
$$S_{vnt} = S_{vn} + 2R_S^2 S_I$$

Monolithic In-Amps



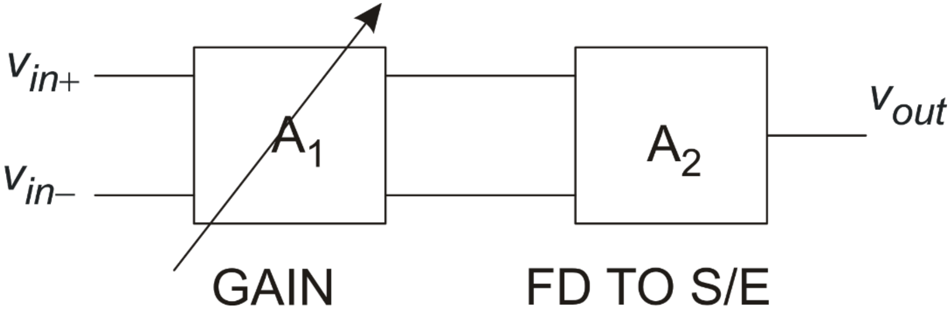
Typical pin configuration

$$V_{out} = G\left(V_{IN+} - V_{IN-}\right) + V_{REF}$$



Function of the SENSE terminal

Input and output offset / noise

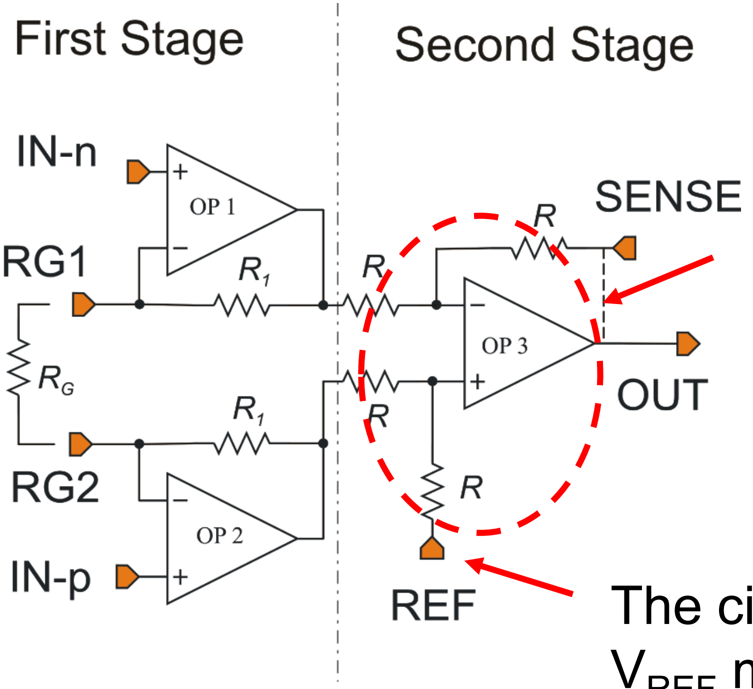


Typical two-stage architecture of In-amps

Generally, $A_2 = 1$, thus:

$$v_{nRTI} = v_{n1} + \frac{v_{n2}}{A_1} = v_{n1} + \frac{v_{n2}}{G}$$

Three-opamp instrumentation amplifier



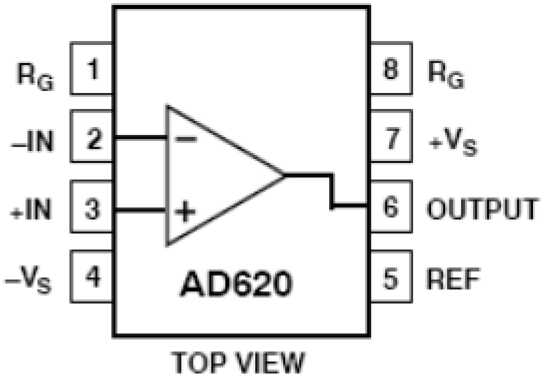
Mismatch of these resistors degrades the CMRR of the second stage. Resistor trimming is necessary for CMRRs > 60 dB

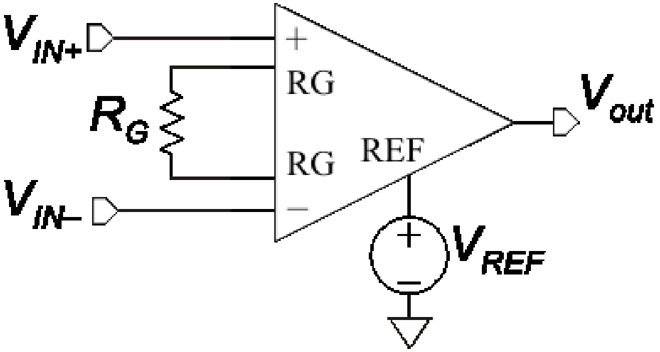
The circuit that provides V_{REF} must have a very low output resistance (<<R)

$$G = 1 + \frac{2R_1}{R_G}$$

Instrumentation Amplifiers

AD 620





$$V_{out} = G\left(V_{IN+} - V_{IN-}\right) + V_{REF}$$

$$G = 1 + 49.4k\Omega / R_G$$

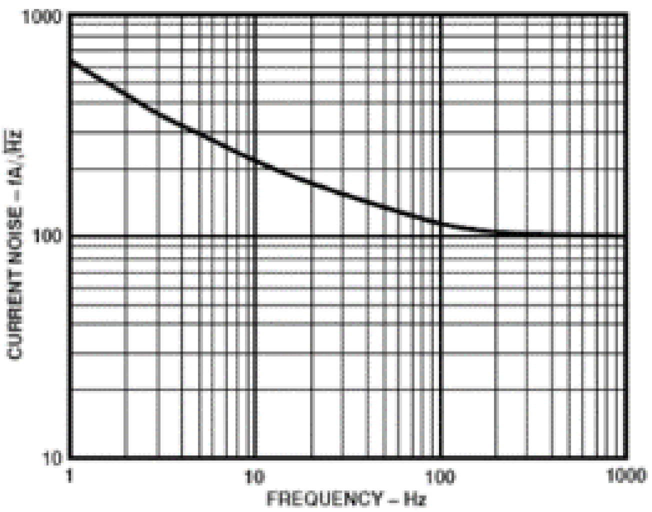
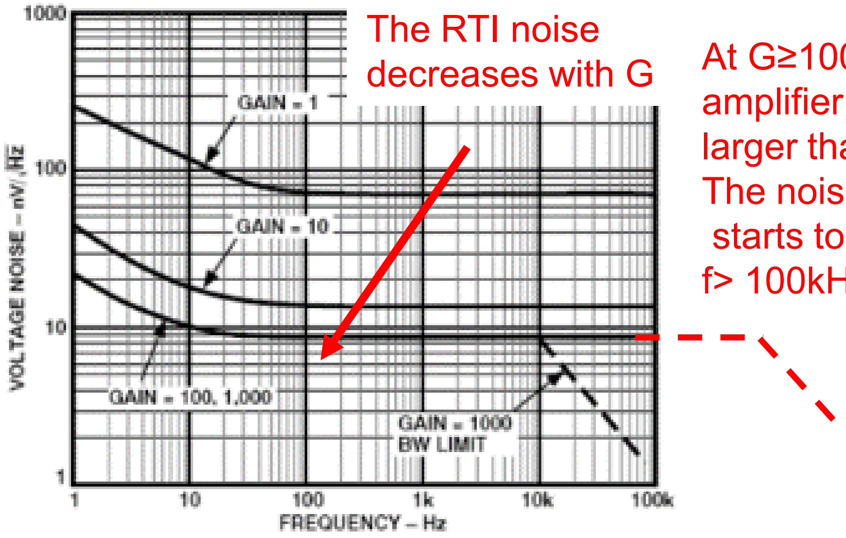


Figure 9. Current Noise Spectral Density vs. Frequenc



The RTI noise decreases with G

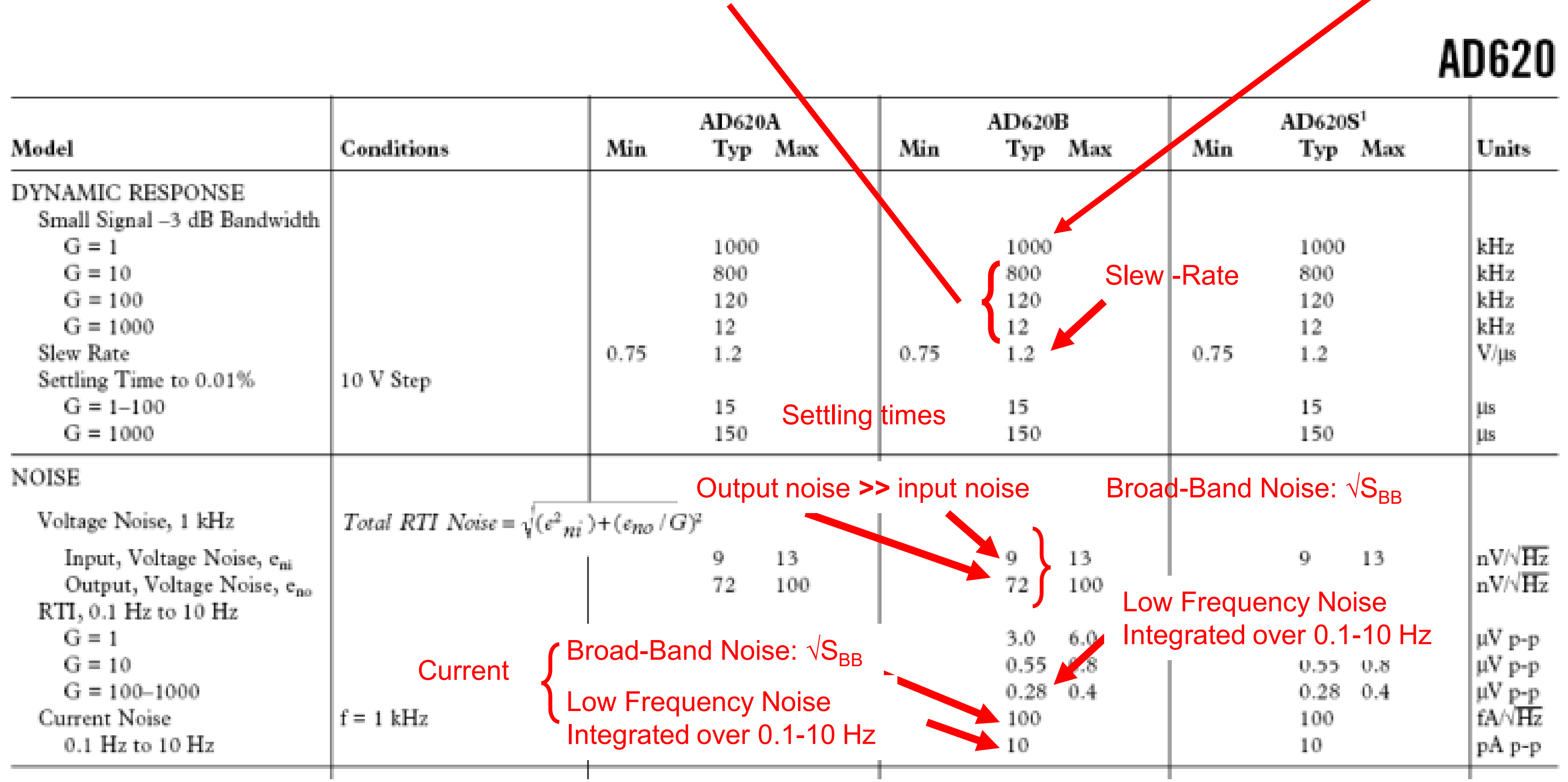
At G≥100 the amplifier BW is larger than 100kHz. The noise density starts to fall for f> 100kHz

Figure 8. Voltage Noise Spectral Density vs. Frequency, (G = 1–1000)

AD 620

GBW does not increase much beyond the G=10 case: BW affected by second stage

Nearly constant GBW product: BW determined by first stage



AD620

Model	Conditions	AD620A Min	AD620A Typ	AD620A Max	AD620B Min	AD620B Typ	AD620B Max	AD620S[1] Min	AD620S[1] Typ	AD620S[1] Max	Units
DYNAMIC RESPONSE											
Small Signal –3 dB Bandwidth											
G = 1			1000			1000			1000		kHz
G = 10			800			800			800		kHz
G = 100			120			120			120		kHz
G = 1000			12			12			12		kHz
Slew Rate		0.75	1.2		0.75	1.2		0.75	1.2		V/μs
Settling Time to 0.01%	10 V Step										
G = 1–100			15			15			15		μs
G = 1000			150			150			150		μs
NOISE											
Voltage Noise, 1 kHz	*Total RTI Noise* $=\sqrt{(e^2_{ni})+(e_{no}/G)^2}$										
Input, Voltage Noise, e_{ni}			9	13		9	13		9	13	nV/√Hz
Output, Voltage Noise, e_{no}			72	100		72	100				nV/√Hz
RTI, 0.1 Hz to 10 Hz											
G = 1						3.0	6.0				μV p-p
G = 10						0.55	0.8		0.55	0.8	μV p-p
G = 100–1000						0.28	0.4		0.28	0.4	μV p-p
Current Noise	f = 1 kHz					100			100		fA/√Hz
0.1 Hz to 10 Hz						10			10		pA p-p

Slew -Rate

Settling times

Output noise >> input noise

Broad-Band Noise: $\sqrt{S_{BB}}$

Low Frequency Noise Integrated over 0.1-10 Hz

Current

Broad-Band Noise: $\sqrt{S_{BB}}$

Low Frequency Noise Integrated over 0.1-10 Hz

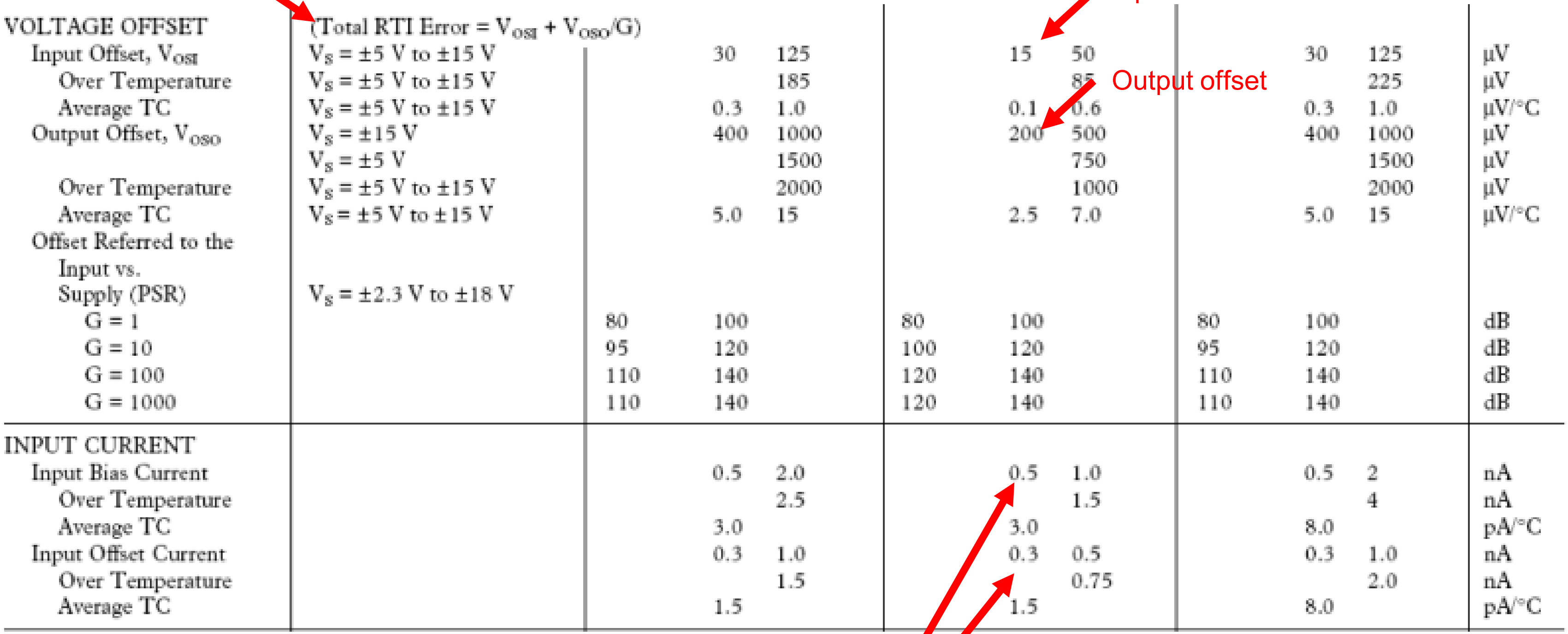
AD 620

The effective input referred offset (RTI) is a combination of the input and output offset

Such a small offset voltage and offset drift is the result of a laser-trimmed resistor-load BJT input pair

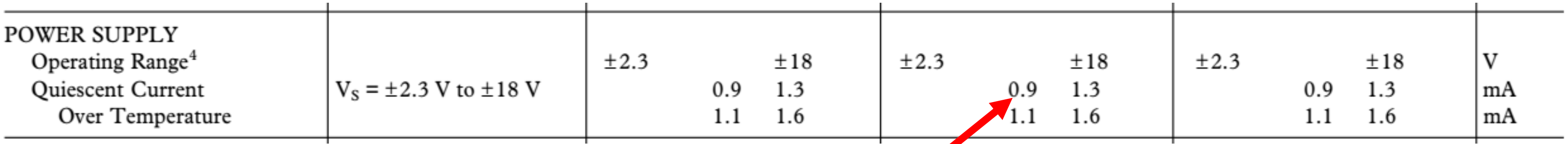
Input offset

Output offset



VOLTAGE OFFSET	(Total RTI Error = $V_{OSI} + V_{OSO}/G$)										
Input Offset, V_{OSI}	$V_S = \pm 5$ V to ± 15 V		30	125		15	50		30	125	μV
Over Temperature	$V_S = \pm 5$ V to ± 15 V			185			85			225	μV
Average TC	$V_S = \pm 5$ V to ± 15 V		0.3	1.0		0.1	0.6		0.3	1.0	μV/°C
Output Offset, V_{OSO}	$V_S = \pm 15$ V		400	1000		200	500		400	1000	μV
	$V_S = \pm 5$ V			1500			750			1500	μV
Over Temperature	$V_S = \pm 5$ V to ± 15 V			2000			1000			2000	μV
Average TC	$V_S = \pm 5$ V to ± 15 V		5.0	15		2.5	7.0		5.0	15	μV/°C
Offset Referred to the Input vs. Supply (PSR)	$V_S = \pm 2.3$ V to ± 18 V										
G = 1		80	100		80	100		80	100		dB
G = 10		95	120		100	120		95	120		dB
G = 100		110	140		120	140		110	140		dB
G = 1000		110	140		120	140		110	140		dB
INPUT CURRENT											
Input Bias Current			0.5	2.0		0.5	1.0		0.5	2	nA
Over Temperature				2.5			1.5			4	nA
Average TC			3.0			3.0			8.0		pA/°C
Input Offset Current			0.3	1.0		0.3	0.5		0.3	1.0	nA
Over Temperature				1.5			0.75			2.0	nA
Average TC			1.5			1.5			8.0		pA/°C

The input bias current and input offset current are similar, since such a small bias current is the result of internal bias current cancellation



POWER SUPPLY											
Operating Range[4]		±2.3		±18	±2.3		±18	±2.3		±18	V
Quiescent Current	$V_S = \pm 2.3$ V to ± 18 V		0.9	1.3		0.9	1.3		0.9	1.3	mA
Over Temperature			1.1	1.6		1.1	1.6		1.1	1.6	mA

The AD 620 in-amp represent a good trade-off between input noise voltage, input bias currents and supply current (quiescent current)

AD 8429

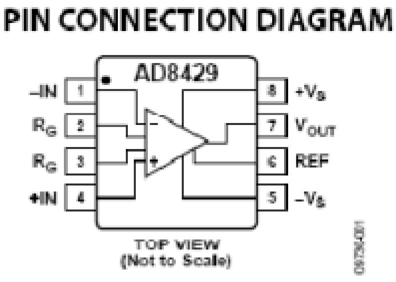


Figure 1.

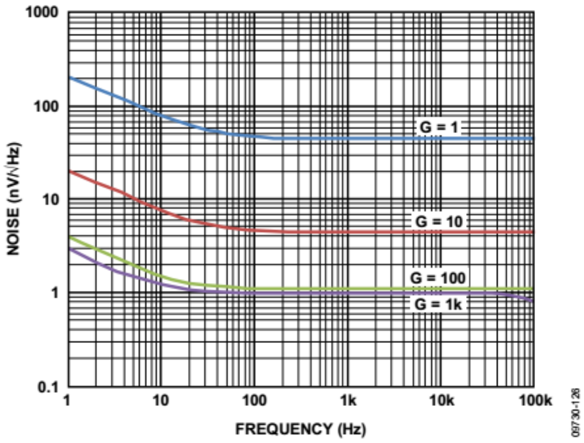


Figure 26. RTI Voltage Noise Spectral Density vs. Frequency

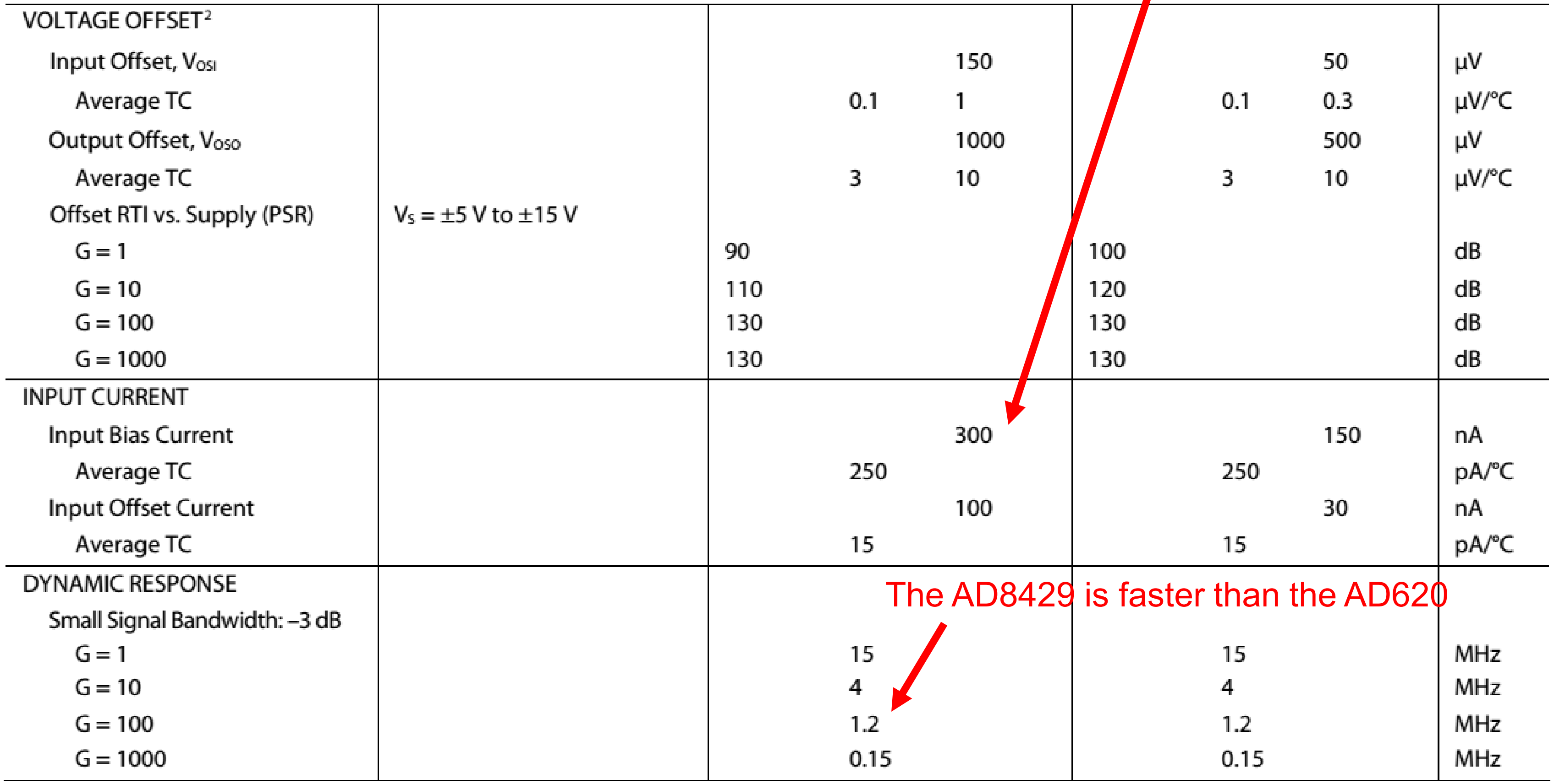
The AD8429 has a much smaller input referred noise than the AD620 (BB-noise) ……..

VOLTAGE NOISE, RTI	$V_{IN}+$, $V_{IN}-$ = 0 V			
Spectral Density[1]: 1 kHz				
Input Voltage Noise, e_{ni}		1.0	1.0	nV/√Hz
Output Voltage Noise, e_{no}		45	45	nV/√Hz
Peak to Peak: 0.1 Hz to 10 Hz				
G = 1		2	2	µV p-p
G = 1000		100	100	nV p-p
CURRENT NOISE				
Spectral Density: 1 kHz		1.5	1.5	pA/√Hz
Peak to Peak: 0.1 Hz to 10 Hz		100	100	pA p-p

….. but its input current noise is much larger..

AD 8429

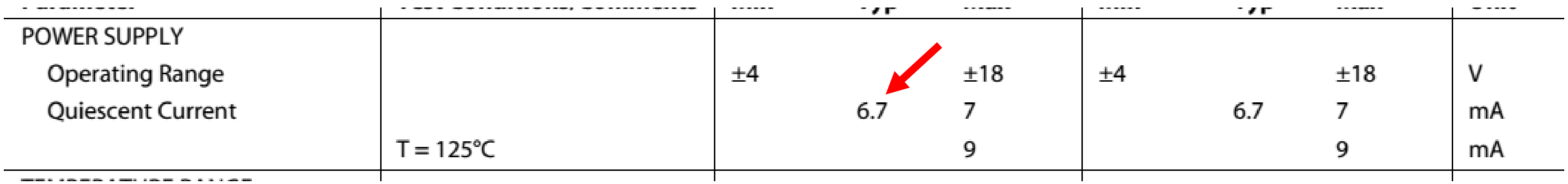
The bias current (dc value) is also much larger than AD620 one



VOLTAGE OFFSET[2]								
Input Offset, V_{OSI}				150			50	μV
Average TC			0.1	1		0.1	0.3	μV/°C
Output Offset, V_{OSO}				1000			500	μV
Average TC			3	10		3	10	μV/°C
Offset RTI vs. Supply (PSR)	V_S = ±5 V to ±15 V							
G = 1		90			100			dB
G = 10		110			120			dB
G = 100		130			130			dB
G = 1000		130			130			dB
INPUT CURRENT								
Input Bias Current				300			150	nA
Average TC			250			250		pA/°C
Input Offset Current				100			30	nA
Average TC			15			15		pA/°C
DYNAMIC RESPONSE								
Small Signal Bandwidth: –3 dB								
G = 1			15			15		MHz
G = 10			4			4		MHz
G = 100			1.2			1.2		MHz
G = 1000			0.15			0.15		MHz

The AD8429 is faster than the AD620

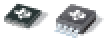
…. but it requires much more quiescent current



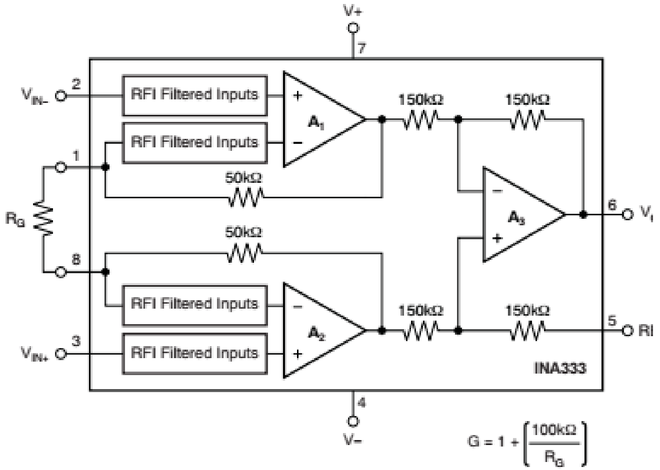
POWER SUPPLY								
Operating Range		±4		±18	±4		±18	V
Quiescent Current			6.7	7		6.7	7	mA
	T = 125°C			9			9	mA

Instrumentation Amplifiers

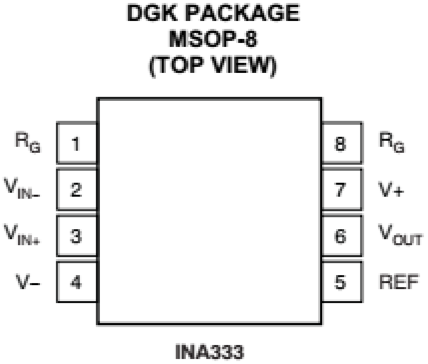
TEXAS INSTRUMENTS



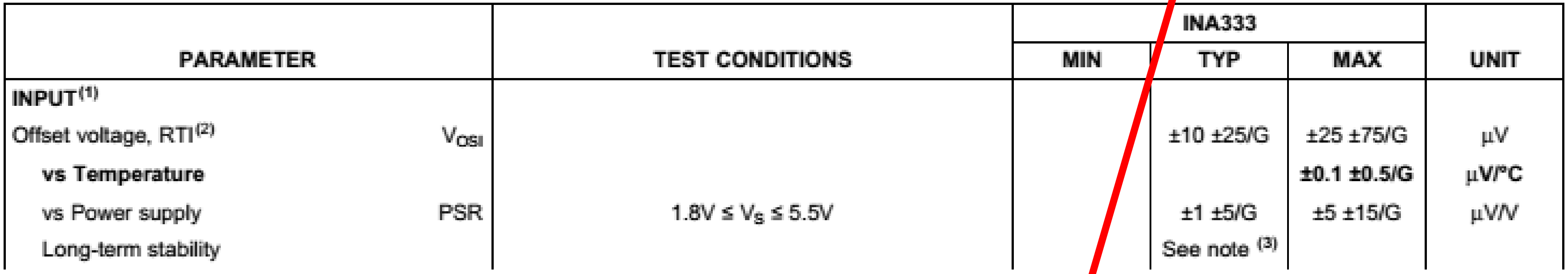
INA333



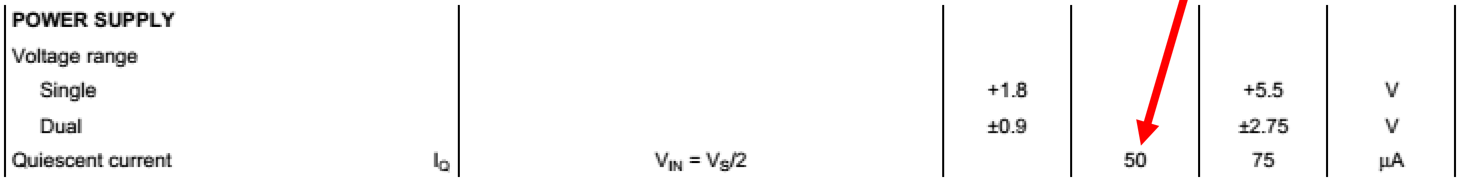
$$G = 1 + \left(\frac{100k\Omega}{R_G}\right)$$



- The INA333 is a very low-power instrumentation amplifier (I_{supply}: 50 µA)
  As a result, its input referred voltage noise is larger and its bandwidth smaller.

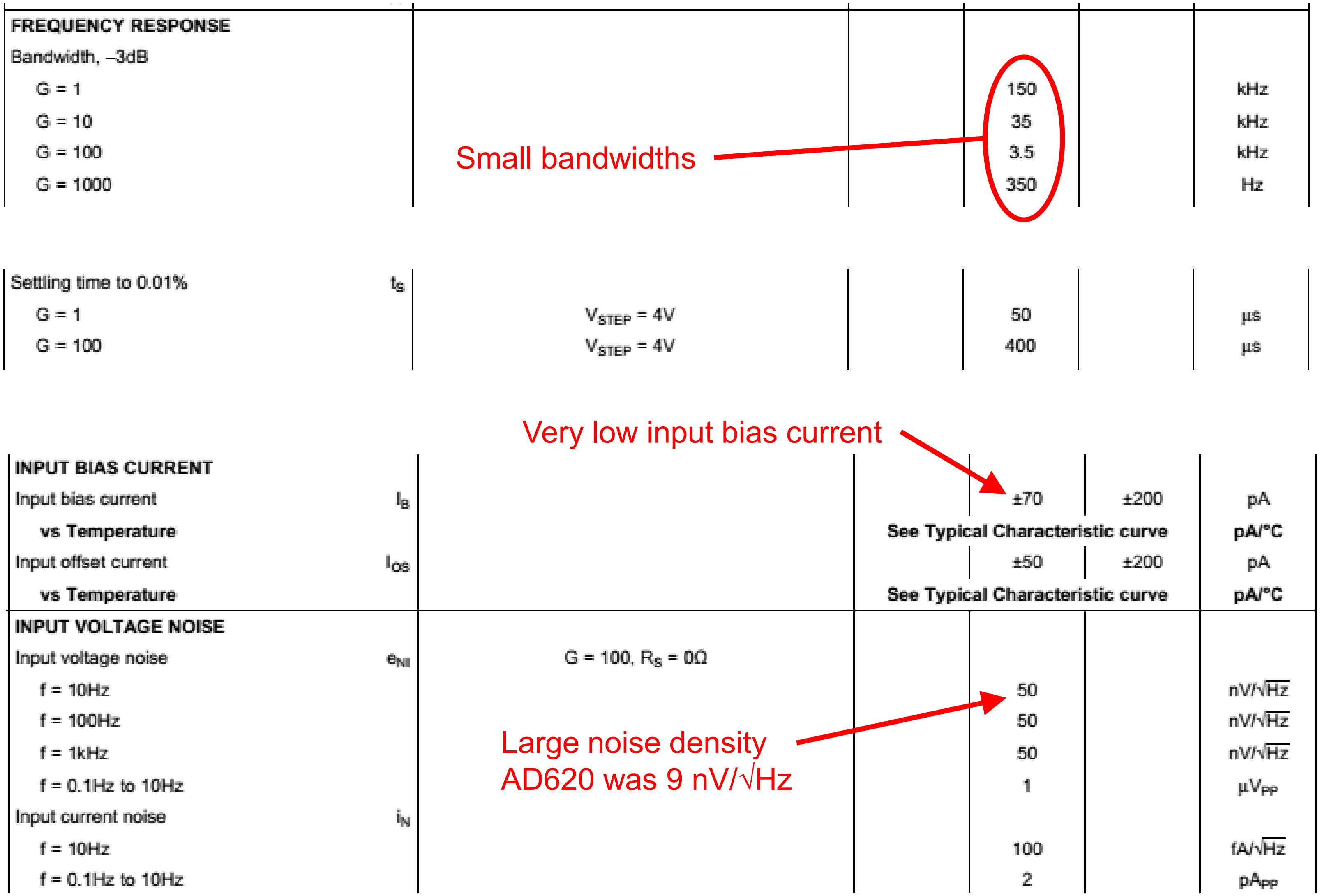


PARAMETER		TEST CONDITIONS	INA333			UNIT
			MIN	TYP	MAX	
INPUT[1]						
Offset voltage, RTI[2]	V_{OSI}			±10 ±25/G	±25 ±75/G	µV
vs Temperature					**±0.1 ±0.5/G**	**µV/°C**
vs Power supply	PSR	1.8V ≤ V_S ≤ 5.5V		±1 ±5/G	±5 ±15/G	µV/V
Long-term stability				See note (3)		



POWER SUPPLY						
Voltage range						
Single			+1.8		+5.5	V
Dual			±0.9		±2.75	V
Quiescent current	I_Q	$V_{IN} = V_S/2$		50	75	µA

INA 333



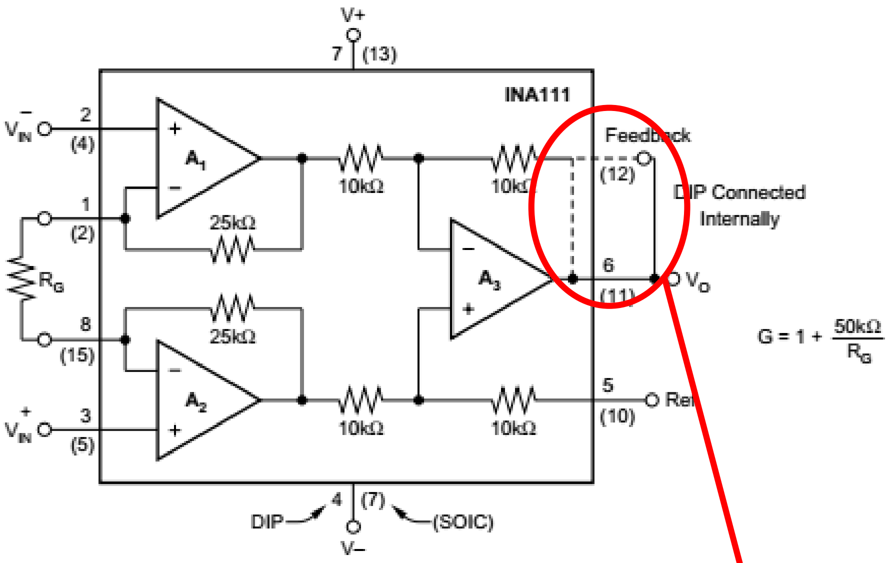
FREQUENCY RESPONSE						
Bandwidth, –3dB						
G = 1				150		kHz
G = 10				35		kHz
G = 100				3.5		kHz
G = 1000				350		Hz
Settling time to 0.01%	t_S					
G = 1		$V_{STEP} = 4V$		50		µs
G = 100		$V_{STEP} = 4V$		400		µs
INPUT BIAS CURRENT						
Input bias current	I_B			±70	±200	pA
vs Temperature			**See Typical Characteristic curve**			**pA/°C**
Input offset current	I_{OS}			±50	±200	pA
vs Temperature			**See Typical Characteristic curve**			**pA/°C**
INPUT VOLTAGE NOISE						
Input voltage noise	e_{NI}	$G = 100, R_S = 0\Omega$				
f = 10Hz				50		nV/√Hz
f = 100Hz				50		nV/√Hz
f = 1kHz				50		nV/√Hz
f = 0.1Hz to 10Hz				1		μV_{PP}
Input current noise	i_N					
f = 10Hz				100		fA/√Hz
f = 0.1Hz to 10Hz				2		pA_{PP}

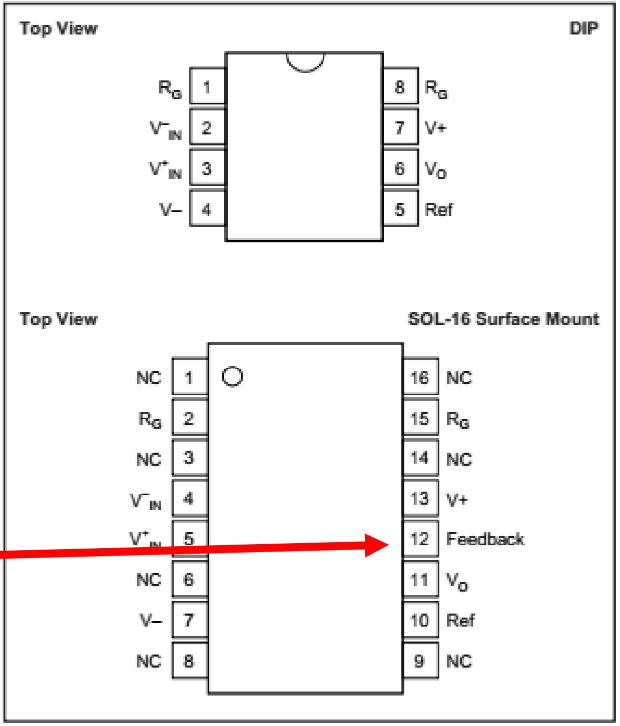
Small bandwidths

Very low input bias current

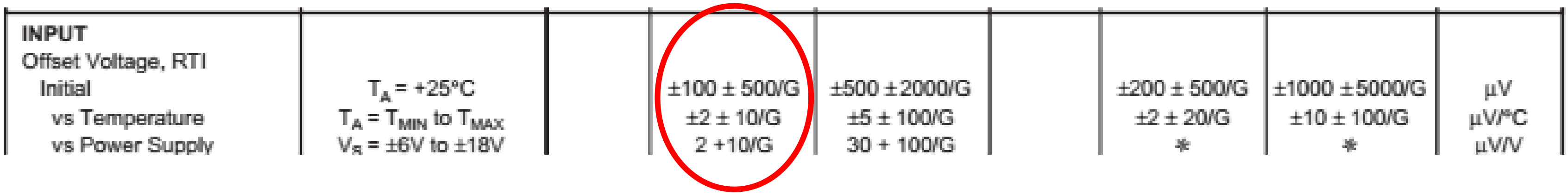
Large noise density
AD620 was 9 nV/√Hz

INA 111: J-Fet input





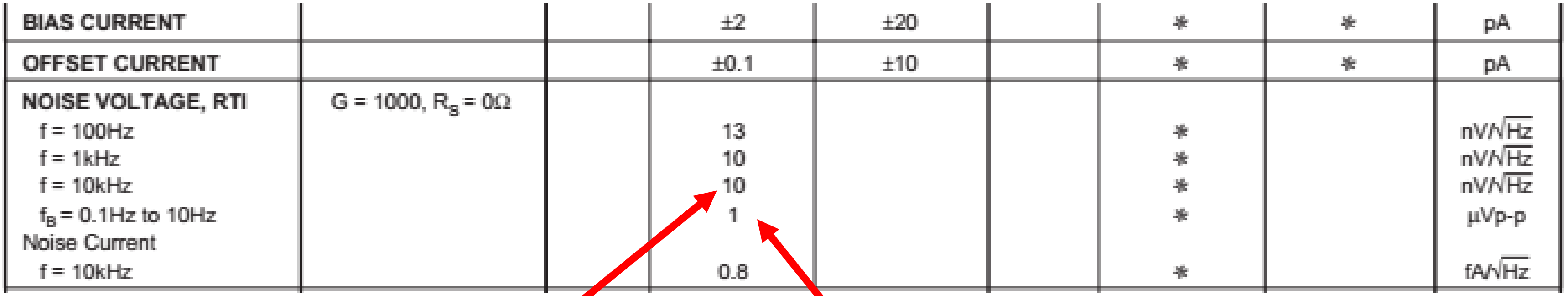
Note the presence of a sense (Feedback) terminal in the 16 pin case



INPUT								
Offset Voltage, RTI								
Initial	$T_A = +25°C$		±100 ± 500/G	±500 ±2000/G		±200 ± 500/G	±1000 ±5000/G	μV
vs Temperature	$T_A = T_{MIN}$ to T_{MAX}		±2 ± 10/G	±5 ± 100/G		±2 ± 20/G	±10 ± 100/G	μV/°C
vs Power Supply	V_S = ±6V to ±18V		2 +10/G	30 + 100/G		*	*	μV/V

Offeset is considerably worse than AD620 and INA 333, which have a BJT input stage

INA 111



BIAS CURRENT			±2	±20		*	*	pA
OFFSET CURRENT			±0.1	±10		*	*	pA
NOISE VOLTAGE, RTI	G = 1000, $R_S = 0\Omega$							
f = 100Hz			13			*		$nV/\sqrt{Hz}$
f = 1kHz			10			*		$nV/\sqrt{Hz}$
f = 10kHz			10			*		$nV/\sqrt{Hz}$
f_B = 0.1Hz to 10Hz			1			*		µVp-p
Noise Current								
f = 10kHz			0.8			*		$fA/\sqrt{Hz}$

The broad-band input referred noise density is similar to AD 620 …..

…. but the (integrated) low-frequency voltage noise is much worse (was 0.28 µV) in the AD 620

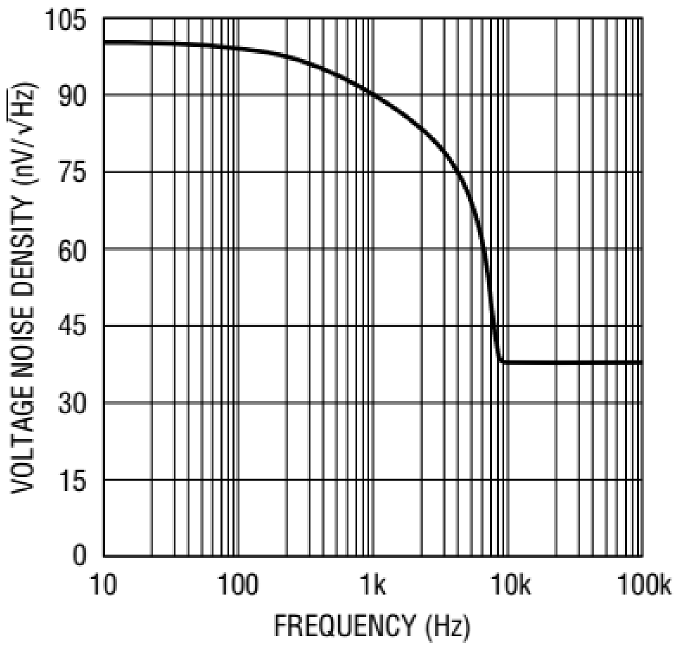
The strong advantage of a JFET input is the negligible noise current density

LINEAR TECHNOLOGY

LTC1100

Precision, Zero-Drift Instrumentation Amplifier

Voltage Noise vs Frequency



The LTC 1100 uses an Autozero technique to cancel the input offset and flicker noise.

The side-effect is foldover, resulting in an increased low-frequency noise density.

Input Offset Voltage	(Note 2)		±1	±10	±1	±10	µV
Input Offset Voltage Drift	(Note 2)	●	±5	±100	±5	±100	nV/°C