Instrumentation Amplifiers: characteristics

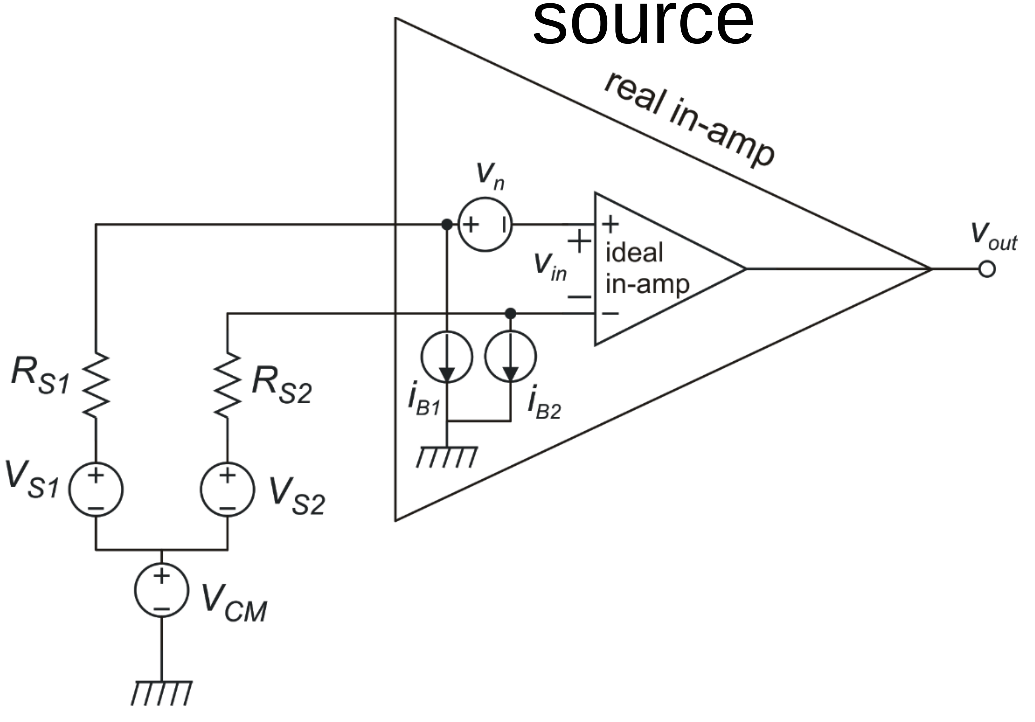
By definition:

- 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)

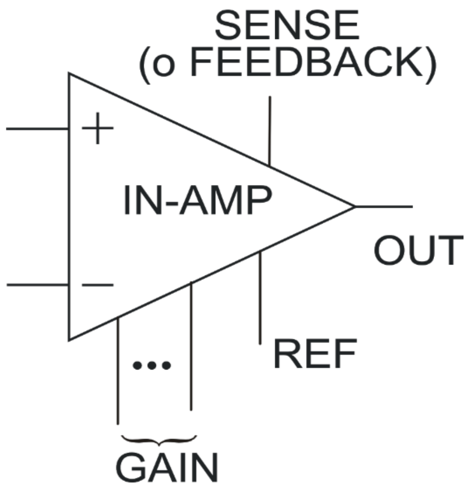
$$S_{vnt} = S_{vn} + R_S^2 \left(S_{I1} + S_{I2} - 2 S_{I1I2} \right)$$

cross-spectrum

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

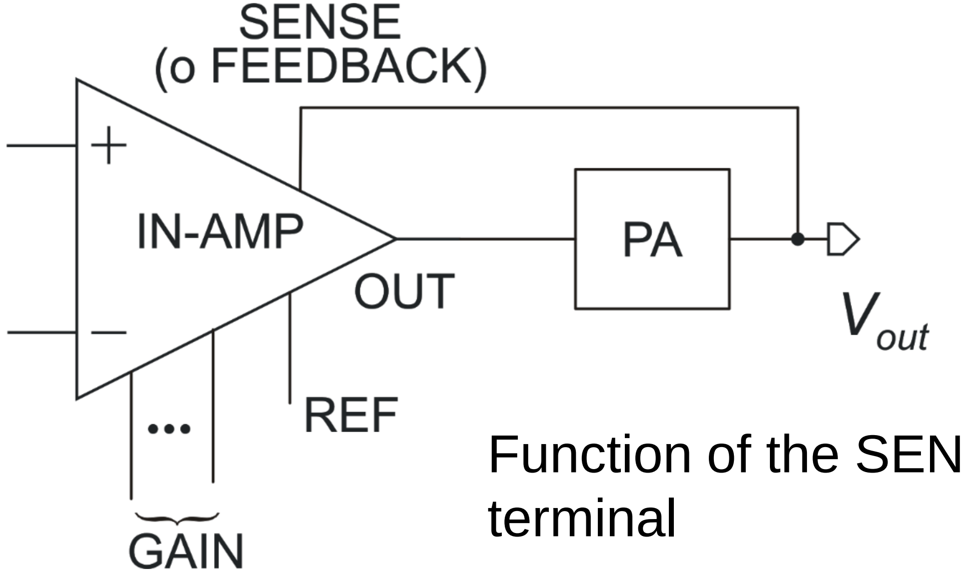
$$S_{vnt} = S_{vn} + 2 R_S^2 S_I$$

Monolithic In-Amps



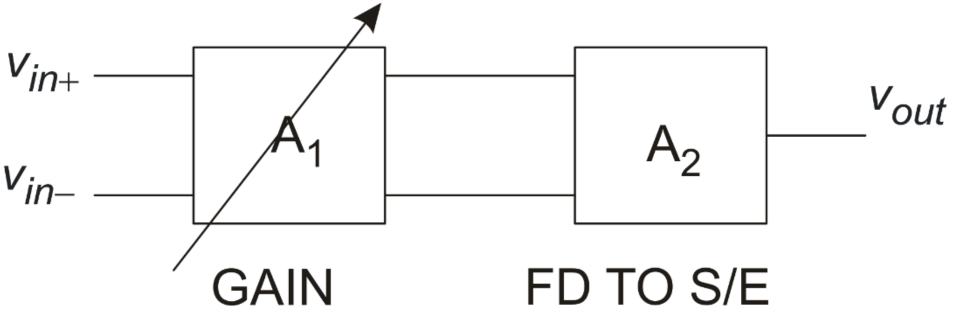
$$V_{out} = G\left(V_{IN+} - V_{IN-}\right) + V_{REF}$$

Typical pin configuration



Function of the SENSE terminal

Input and output offset / noise

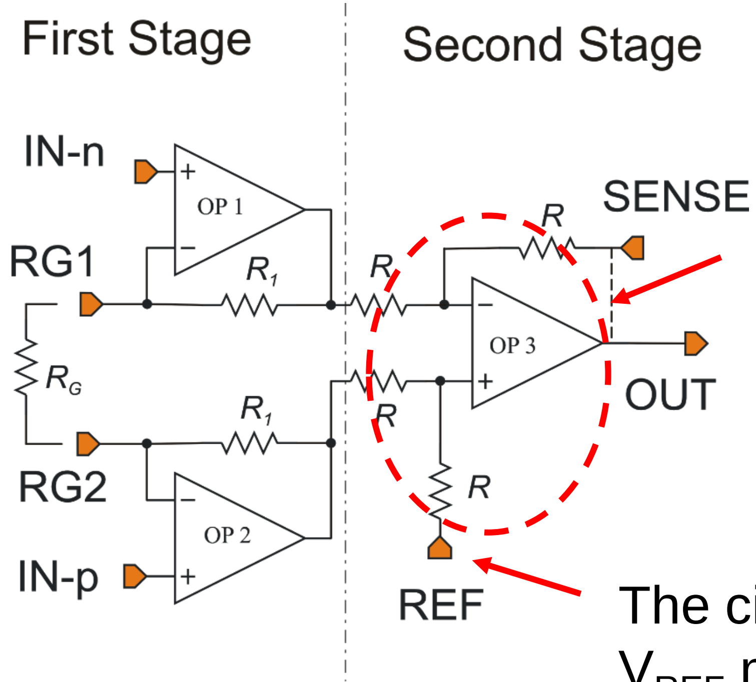


Typical two-stage architecture of In-amps

Generally, $A_2 = 1$, thus:

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

Three-opamp instrumentation amplifier



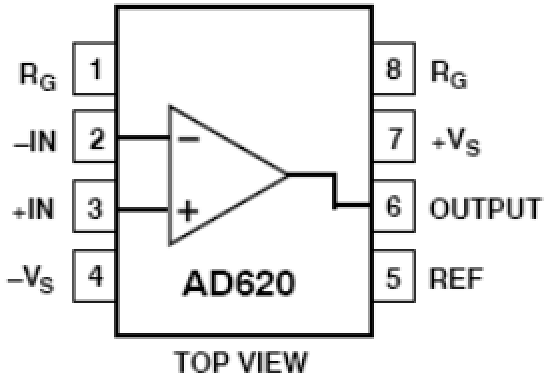
Mismatch of these resistors degrades the CMRR of the second stage. Resistor trimming is necessary for CMRRs > 60 dB

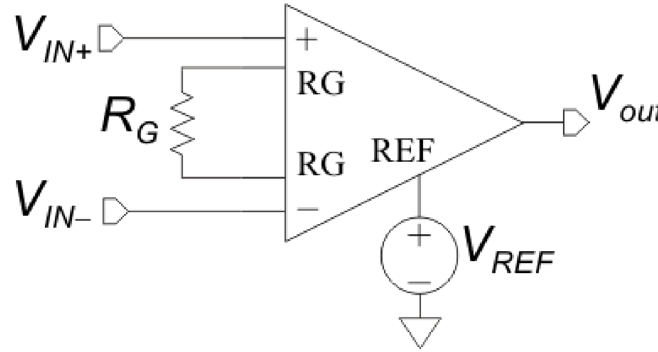
The circuit that provides V_{REF} must have a very low output resistance (<<R)

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

Instrumentation Amplifiers

AD 620





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

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

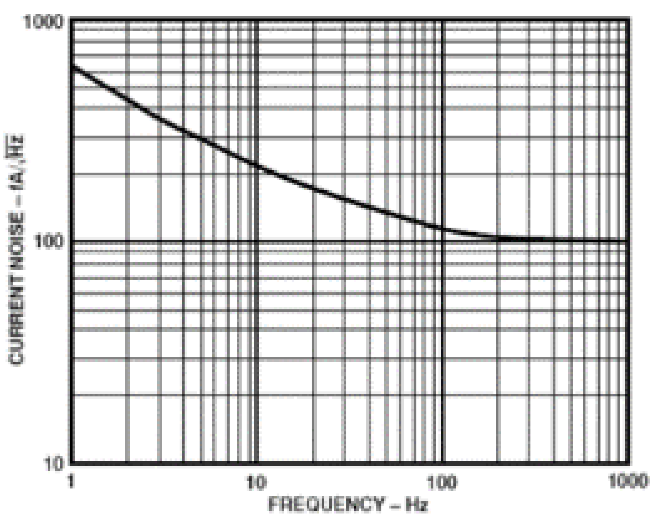
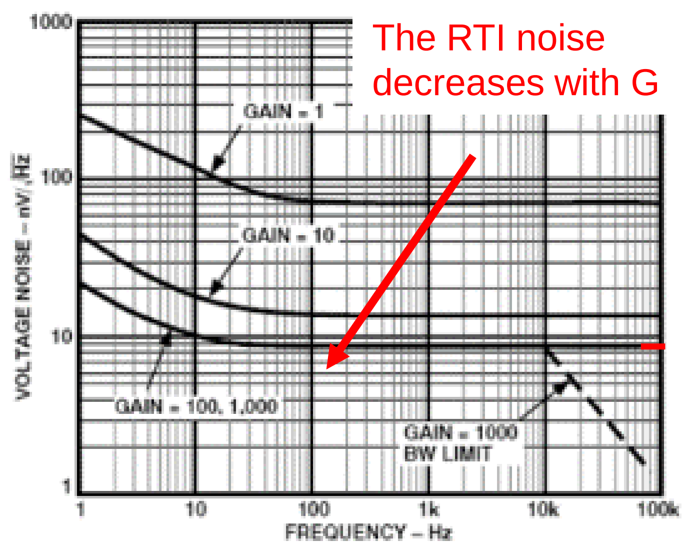


Figure 9. Current Noise Spectral Density vs. Frequenc



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

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

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

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

PIN CONNECTION DIAGRAM

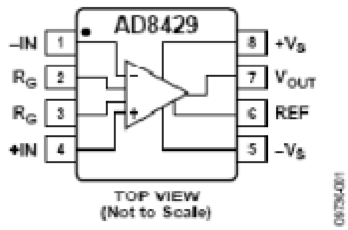


Figure 1.

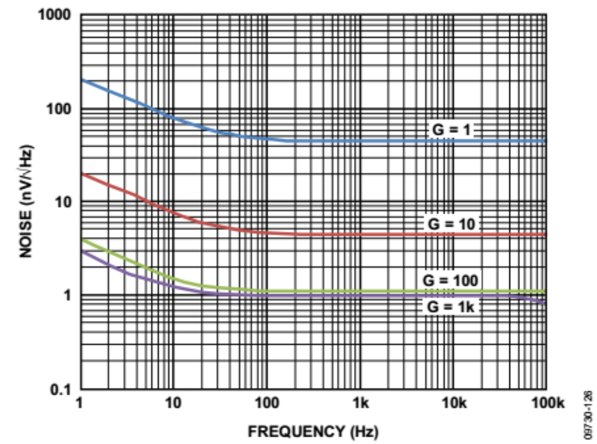


Figure 26. RTI Voltage Noise Spectral Density vs. Frequency

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

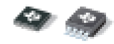
The AD8429 is faster than the AD620

…. but it requires much more quiescent current

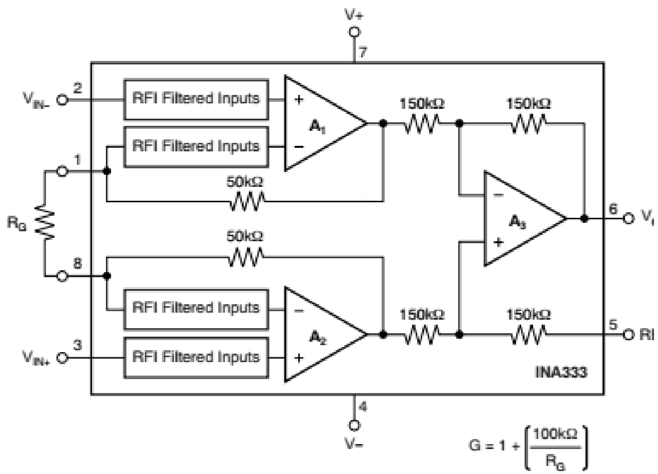
POWER SUPPLY								
Operating Range		±4		±18	±4		±18	V
Quiescent Current			6.7	7		6.7	7	mA
	T = 125°C			9			9	mA

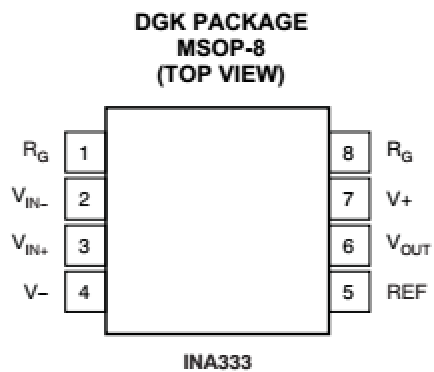
Instrumentation Amplifiers

TEXAS INSTRUMENTS



INA333





- 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 MIN	INA333 TYP	INA333 MAX	UNIT
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	$1.8V \leq V_S \leq 5.5V$		±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

Small bandwidths

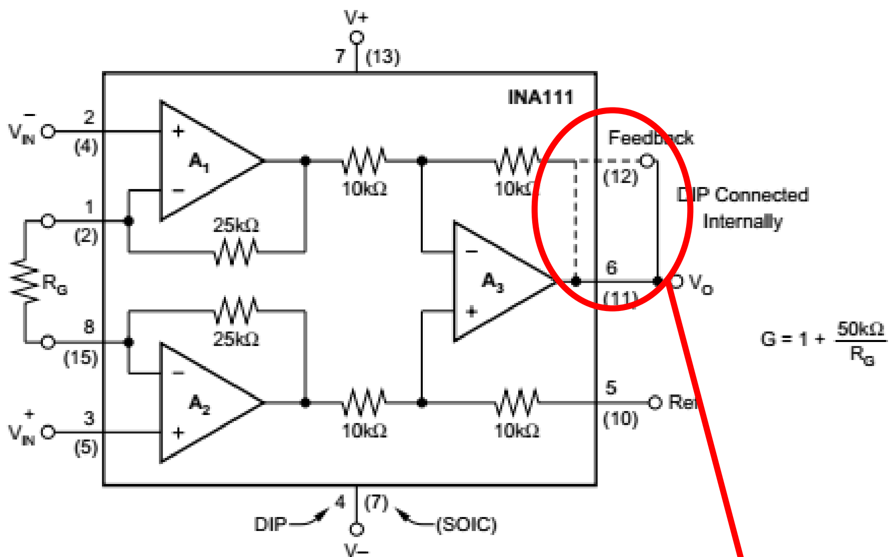
Settling time to 0.01%	t_S					
G = 1		V_{STEP} = 4V		50		µs
G = 100		V_{STEP} = 4V		400		µs

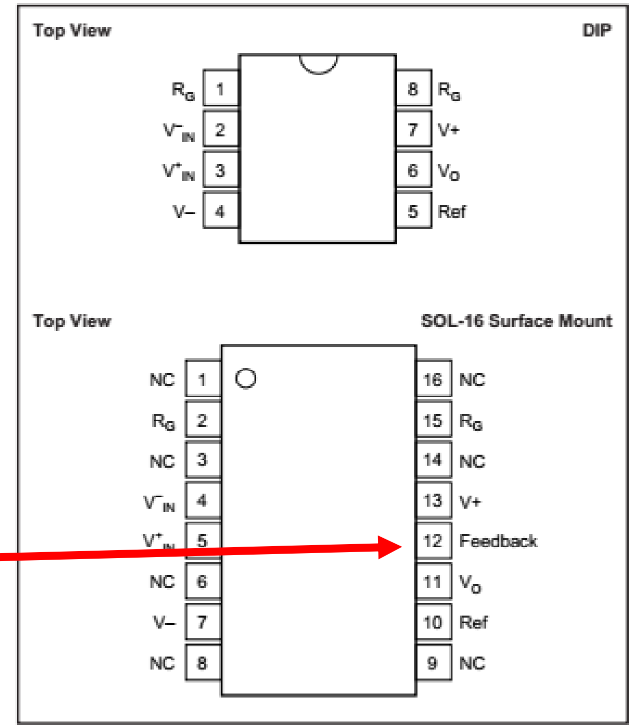
Very low input bias current

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 = 0Ω				
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}

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

Offset is considerably worse than AD620 which has 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			*		$fA/\sqrt{Hz}$

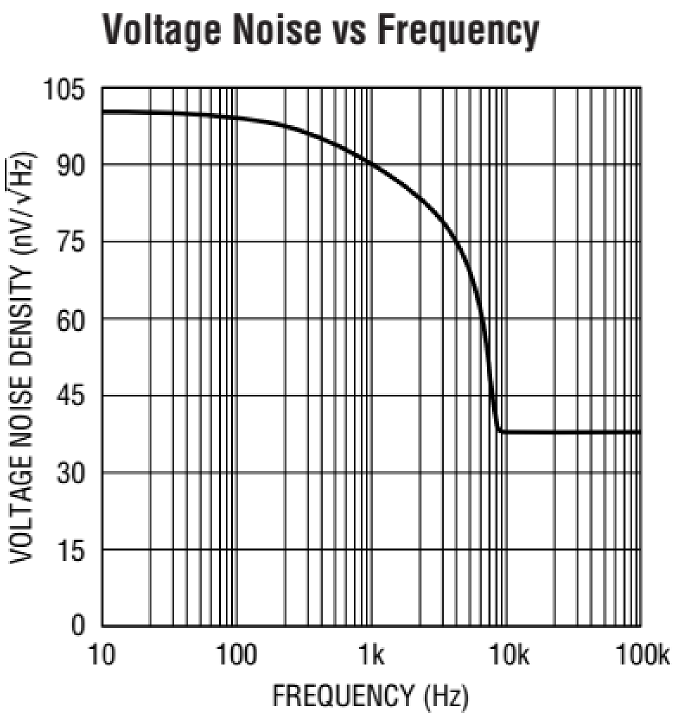
The broad-band input referred noise density is similar to AD 620 …..

…. 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

LTC1100

Precision, Zero-Drift Instrumentation Amplifier



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