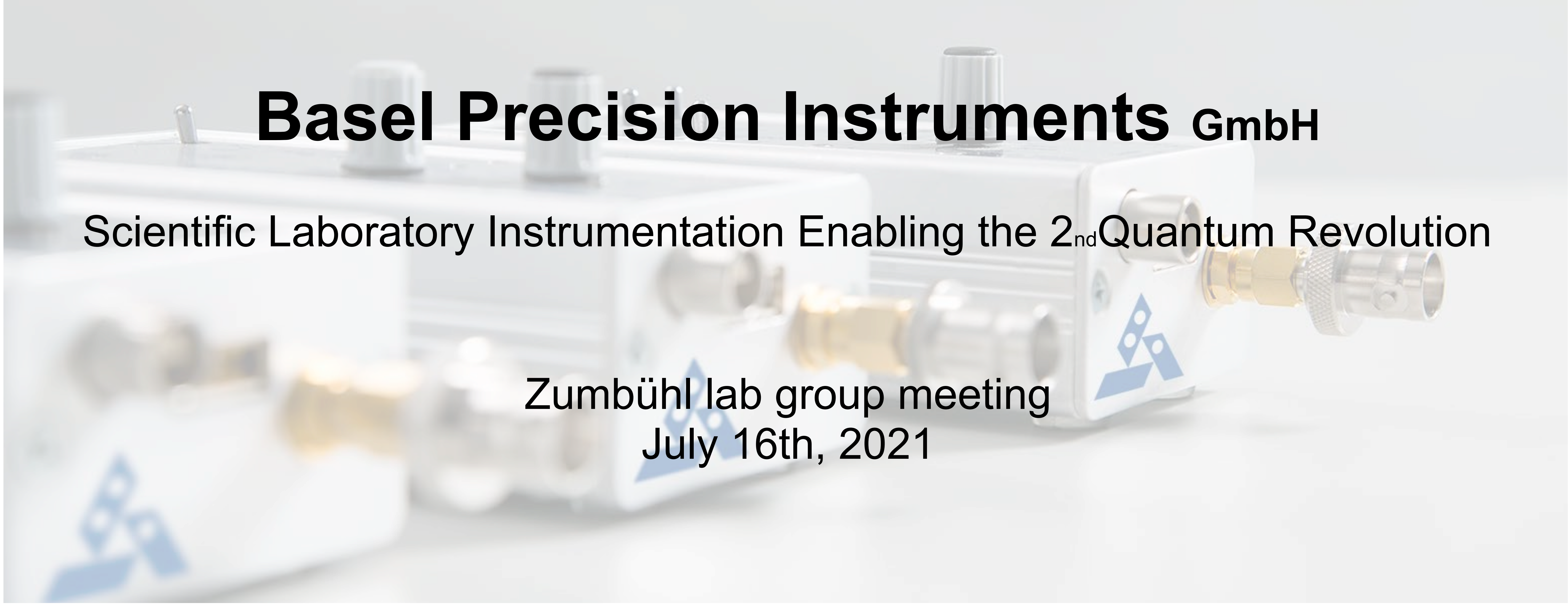
Basel Precision Instruments



Basel Precision Instruments GmbH

Scientific Laboratory Instrumentation Enabling the 2nd Quantum Revolution

Zumbühl lab group meeting
July 16th, 2021

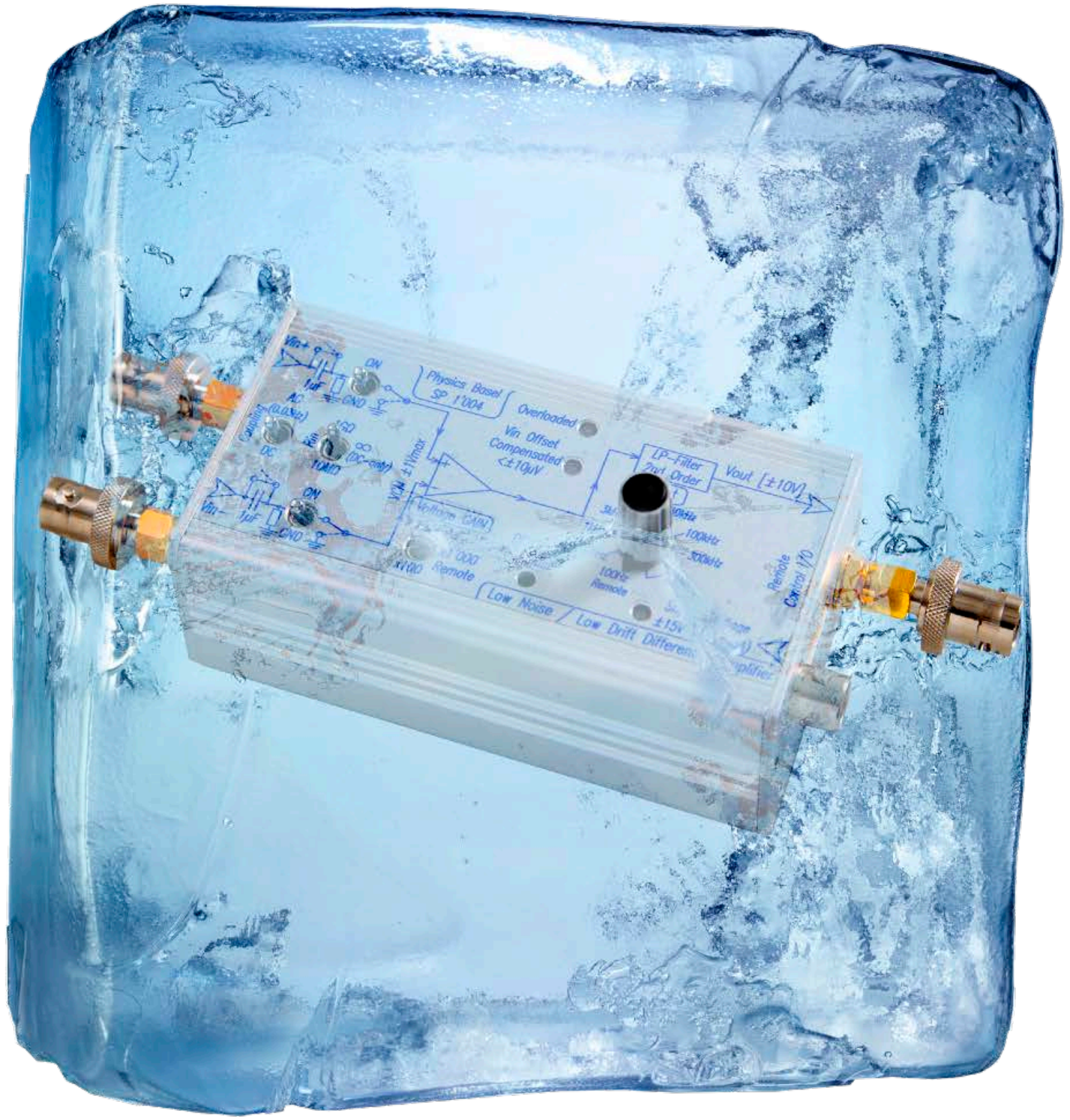
Giving Researchers a Better Lens into the Quantum World

Founded in 2018, BASPI is commercializing the lab instruments behind the **world's coldest chip at < 0.25 mK** at the Zumbühl group at Uni Basel (Samani *et.al.,* APS MM S59.06)

BASPI's premium electronics and cryogenic filters make sensitive measurements possible by:

- minimizing electronic noise
- enhancing stability / minimizing electronic drift and back-action
- lowering sample/electron temperatures

Our instruments make detecting smaller signals & more fragile quantum phenomena possible; hence providing a better lens into the quantum world



World-wide and Expanding Customer Base In the Quantum Market

Sold over 100 instruments in 2020 to low temperature research and government laboratories and companies world-wide

Scaling up goal:
4-fold increase in customer base in the next 2-3 years

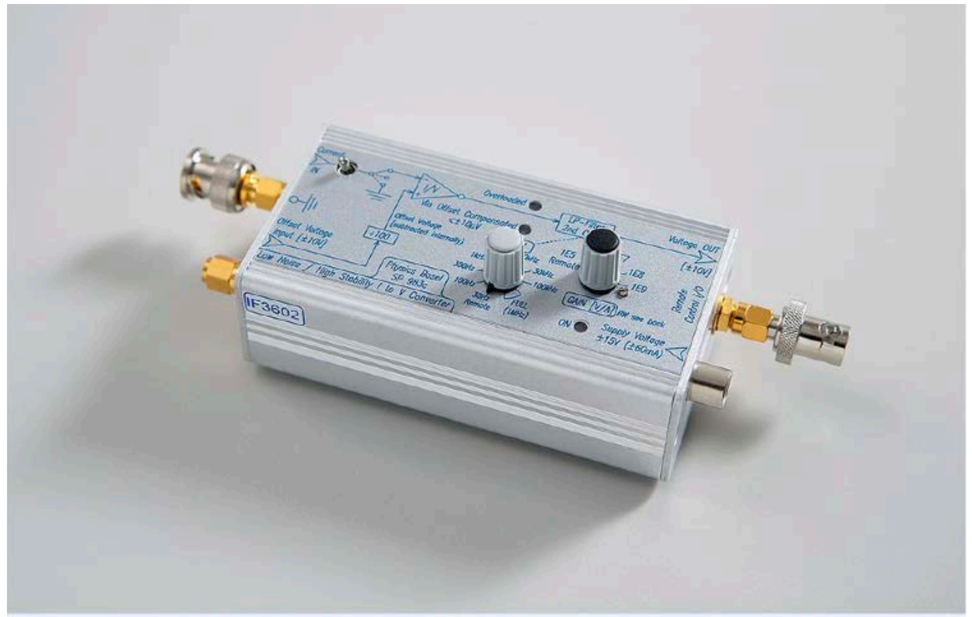
Based in Europe - heart of low temperature research and technology

Most of our competitors: also small European SMEs

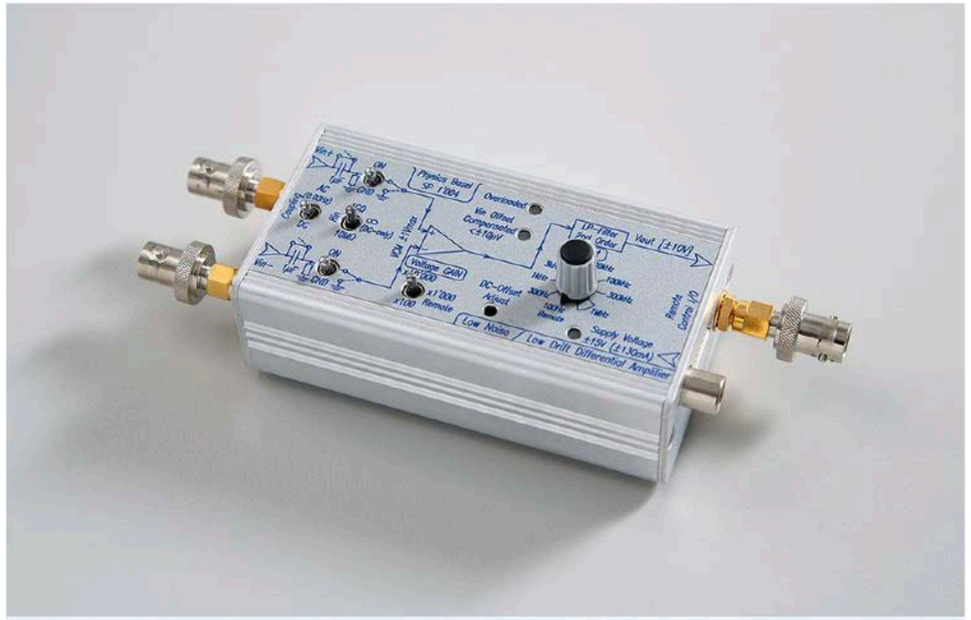
A thorough market research is underway

Current Products

Low Noise | High Resolution DAC



Low Noise | High Stability I to V Converter



Low Noise | Low Drift Differential Amplifier

Microwave Filter | Thermalizer

Upcoming Products

Low Noise I High Resolution DAC II

Microwave Filter Thermalizer Tower

BASPI’s Compact Ultra-Low Noise Preamplifiers

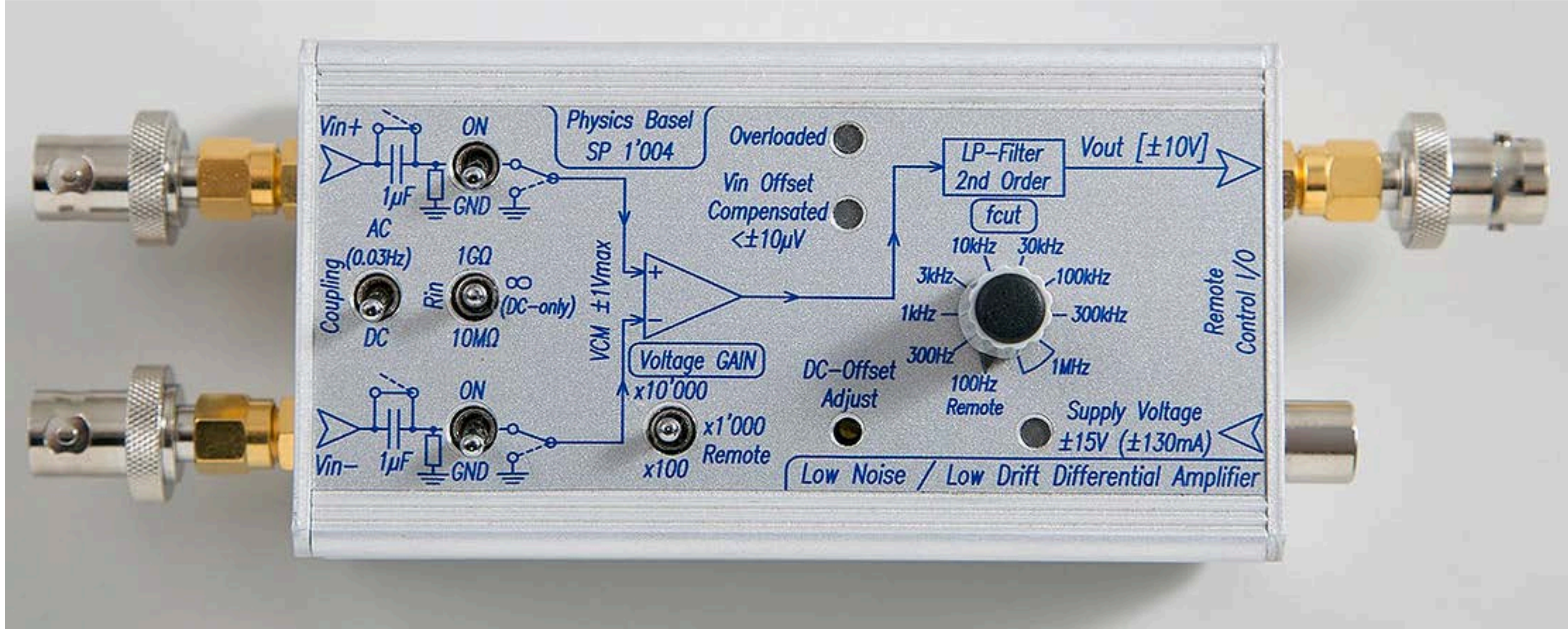
benefits

- ultra-low noise preampfification at the first access point
- no additional noise pick up when mounted directly on the breakout box
- minimized back-action on the experiment
- optimized noise performance for specific load
- solves ground loop issues
- possible to apply bias and measure current on the same lead (IV converter)

key features

- compact and low weight
- floating
- ultra-low input voltage and current noise
- several decades of gain
- integrated low-pass-filter
- actively stabilized back action
- input voltage (external) biasing up to 2V (IV converter)

Low-Noise low-drift differential voltage amplifier



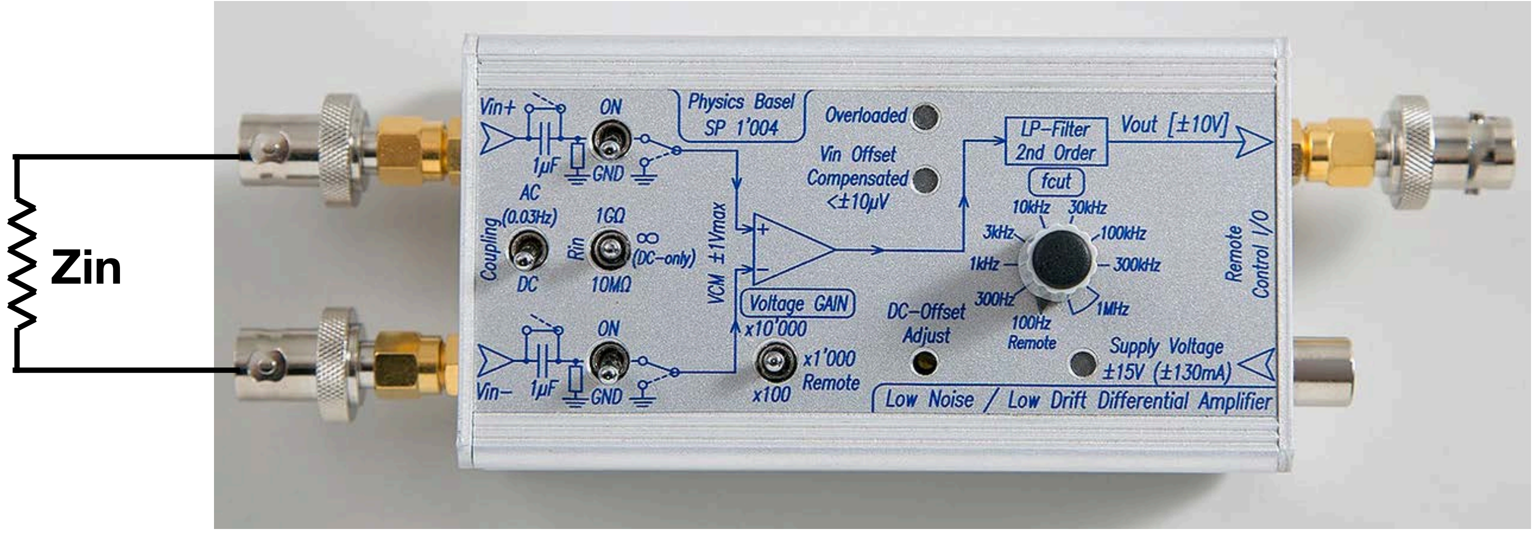
Voltage Preamplifier Noise Sources

Input offset voltage (V_offset)

Input voltage noise (Un)

Input offset or leakage current (I_offset)

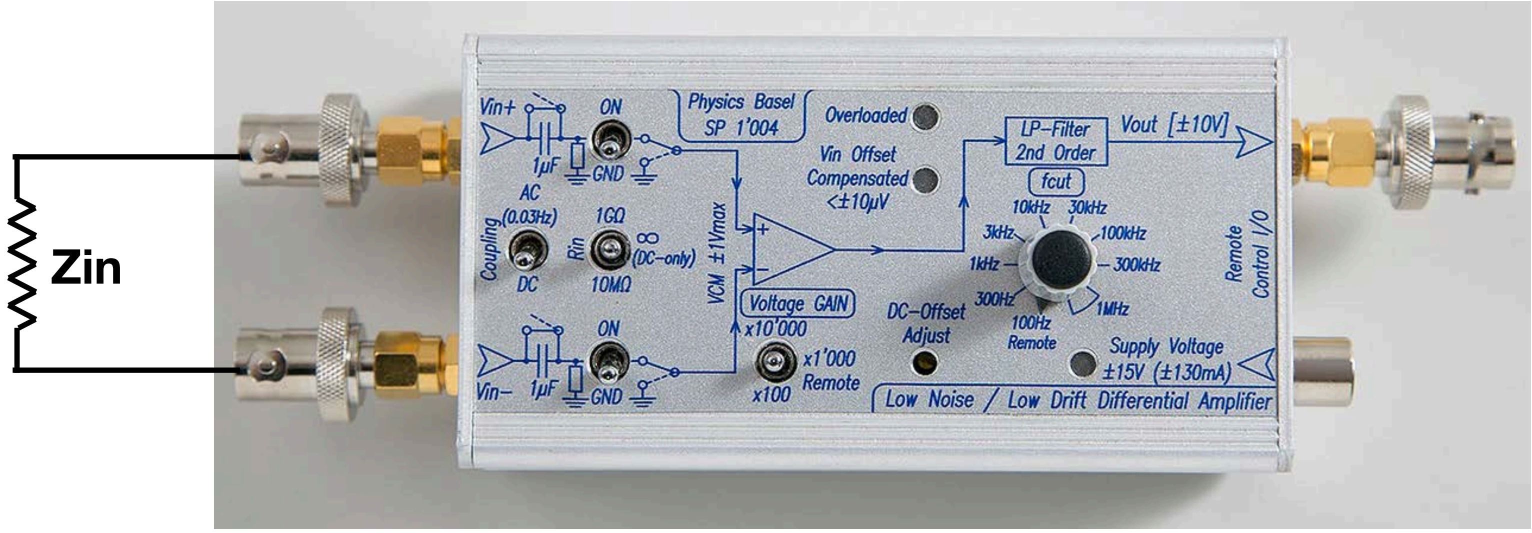
Input current noise (In)



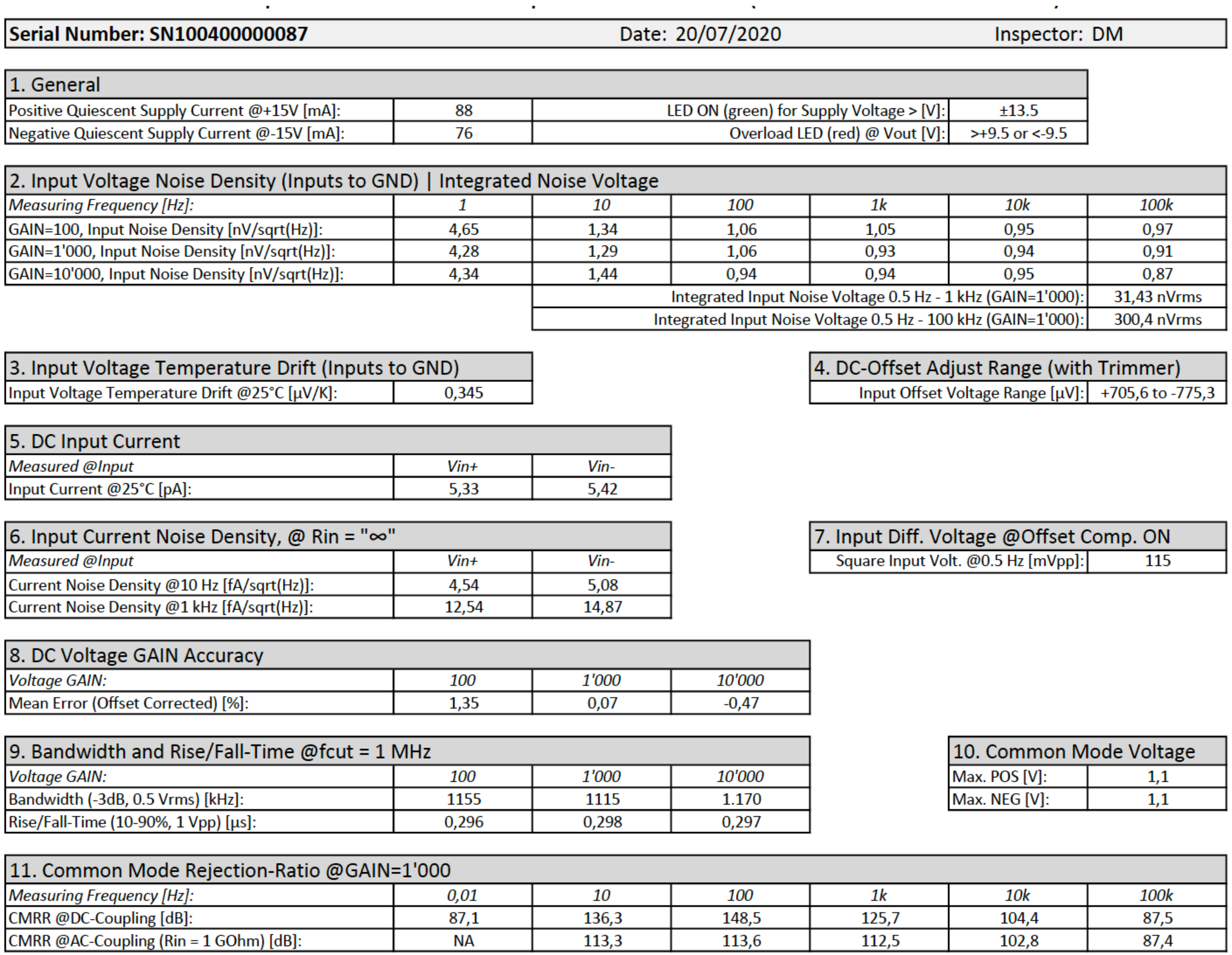
$$\text{V\_output} = \boxed{\text{G V\_offset}} + \boxed{\text{G Un}} + \boxed{\text{G I\_offset Zin}} + \boxed{\text{G In Zin}}$$

Input Offset Voltage (V_offset)

- Actively compensated and stabilized in BASPi’s SP1004 (two decade improvement)
- Can be adjusted manually
- Applied to the sample; relevant for low resistive samples or sensitive bias measurements
- Specs:
  - stabilized voltage within ±10 µV
  - stabilized drift < 0.3 µV/K
  - can be manually adjusted by ±700 µV



Test Report



Serial Number: SN100400000087	Date: 20/07/2020	Inspector: DM

1. General

Positive Quiescent Supply Current @+15V [mA]:	88	LED ON (green) for Supply Voltage > [V]:	±13.5
Negative Quiescent Supply Current @-15V [mA]:	76	Overload LED (red) @ Vout [V]:	>+9.5 or <-9.5

2. Input Voltage Noise Density (Inputs to GND) | Integrated Noise Voltage

Measuring Frequency [Hz]:	*1*	*10*	*100*	*1k*	*10k*	*100k*
GAIN=100, Input Noise Density [nV/sqrt(Hz)]:	4,65	1,34	1,06	1,05	0,95	0,97
GAIN=1'000, Input Noise Density [nV/sqrt(Hz)]:	4,28	1,29	1,06	0,93	0,94	0,91
GAIN=10'000, Input Noise Density [nV/sqrt(Hz)]:	4,34	1,44	0,94	0,94	0,95	0,87

Integrated Input Noise Voltage 0.5 Hz - 1 kHz (GAIN=1'000):	31,43 nVrms
Integrated Input Noise Voltage 0.5 Hz - 100 kHz (GAIN=1'000):	300,4 nVrms

3. Input Voltage Temperature Drift (Inputs to GND)

Input Voltage Temperature Drift @25°C [µV/K]:	0,345

4. DC-Offset Adjust Range (with Trimmer)

Input Offset Voltage Range [µV]:	+705,6 to -775,3

5. DC Input Current

Measured @Input	*Vin+*	*Vin-*
Input Current @25°C [pA]:	5,33	5,42

6. Input Current Noise Density, @ Rin = "∞"

Measured @Input	*Vin+*	*Vin-*
Current Noise Density @10 Hz [fA/sqrt(Hz)]:	4,54	5,08
Current Noise Density @1 kHz [fA/sqrt(Hz)]:	12,54	14,87

7. Input Diff. Voltage @Offset Comp. ON

Square Input Volt. @0.5 Hz [mVpp]:	115

8. DC Voltage GAIN Accuracy

Voltage GAIN:	*100*	*1'000*	*10'000*
Mean Error (Offset Corrected) [%]:	1,35	0,07	-0,47

9. Bandwidth and Rise/Fall-Time @fcut = 1 MHz

Voltage GAIN:	*100*	*1'000*	*10'000*
Bandwidth (-3dB, 0.5 Vrms) [kHz]:	1155	1115	1.170
Rise/Fall-Time (10-90%, 1 Vpp) [µs]:	0,296	0,298	0,297

10. Common Mode Voltage

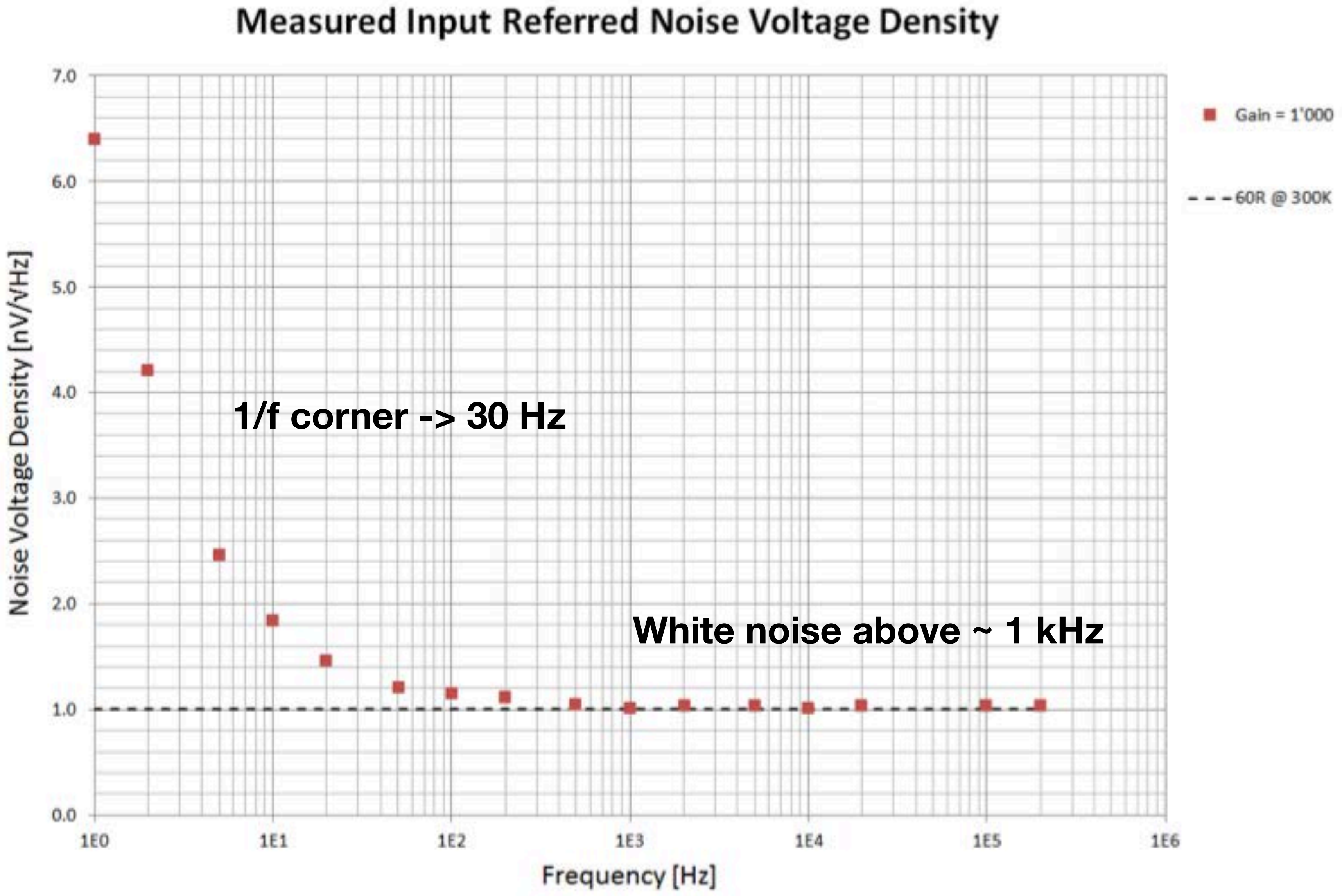
Max. POS [V]:	1,1
Max. NEG [V]:	1,1

11. Common Mode Rejection-Ratio @GAIN=1'000

Measuring Frequency [Hz]:	*0,01*	*10*	*100*	*1k*	*10k*	*100k*
CMRR @DC-Coupling [dB]:	87,1	136,3	148,5	125,7	104,4	87,5
CMRR @AC-Coupling (Rin = 1 GOhm) [dB]:	NA	113,3	113,6	112,5	102,8	87,4

Input Voltage Noise (Un)

- It is amplified by the gain and contributes to the measurement noise
- Applied to the sample, relevant for low resistive loads
- White noise density of 1 nV/√Hz above 1 kHz



1/f corner -> 30 Hz

White noise above ~ 1 kHz

Input Voltage Noise (Un)

- It is amplified by the gain and contributes to the measurement noise
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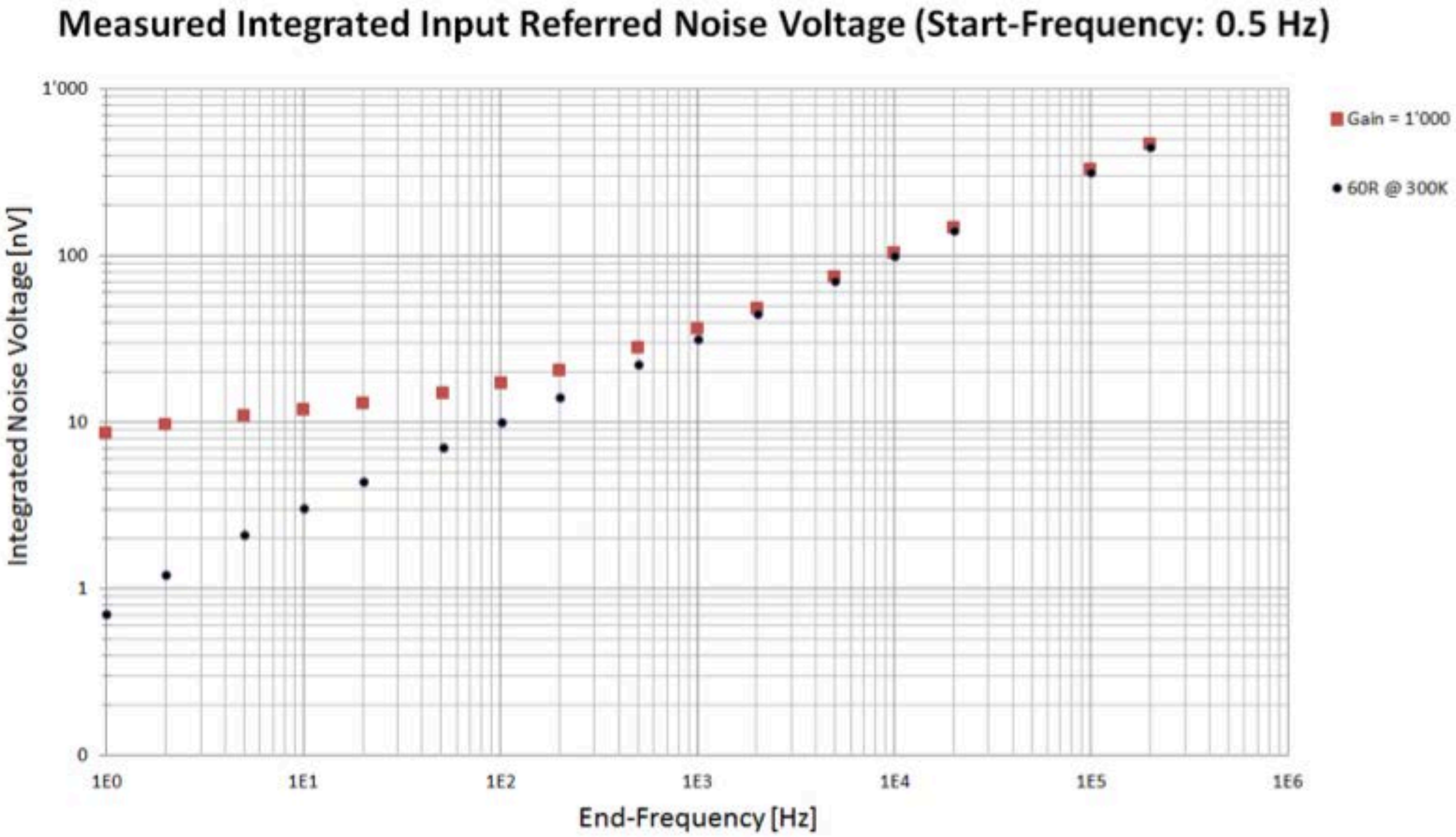
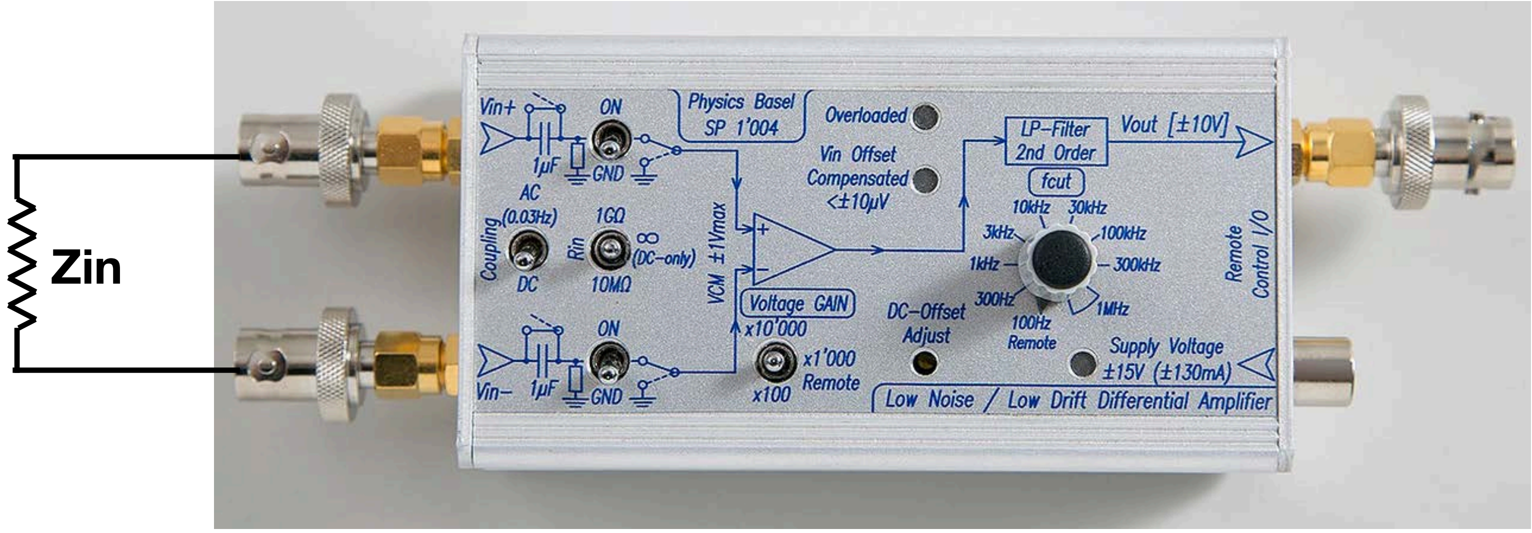
- White noise density of 1 nV/√Hz above 1 kHz



Input Offset or Leakage current (I_offset)

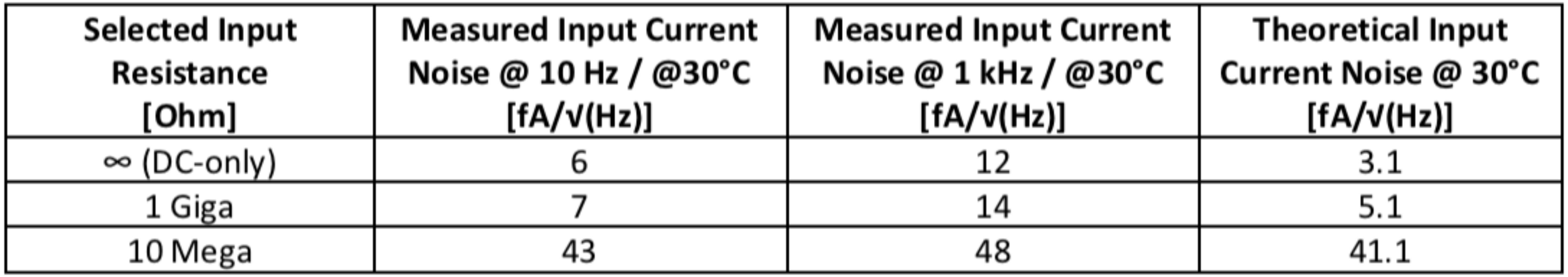
- Originates from the gate leakage of the input J-FET and depends on temperature
- Applied to the sample; creates large voltages across the high resistive loads
- Typical amplitude 15pA; doubles with every 10K temperature increase



Input Current Noise (In)

- Has two components: shot noise of the leakage current and thermal noise of input resistor
- Can be reduced by selecting low leakage current and by using DC coupling/high input resistor
- Is applied to the sample; relevant for high-resistive samples

$$I_{shot} = \sqrt{2e_0 I_{leak}} \qquad I_{noise} = \sqrt{\frac{4kT}{R}}$$



Selected Input Resistance [Ohm]	Measured Input Current Noise @ 10 Hz / @30°C [fA/√(Hz)]	Measured Input Current Noise @ 1 kHz / @30°C [fA/√(Hz)]	Theoretical Input Current Noise @ 30°C [fA/√(Hz)]
∞ (DC-only)	6	12	3.1
1 Giga	7	14	5.1
10 Mega	43	48	41.1

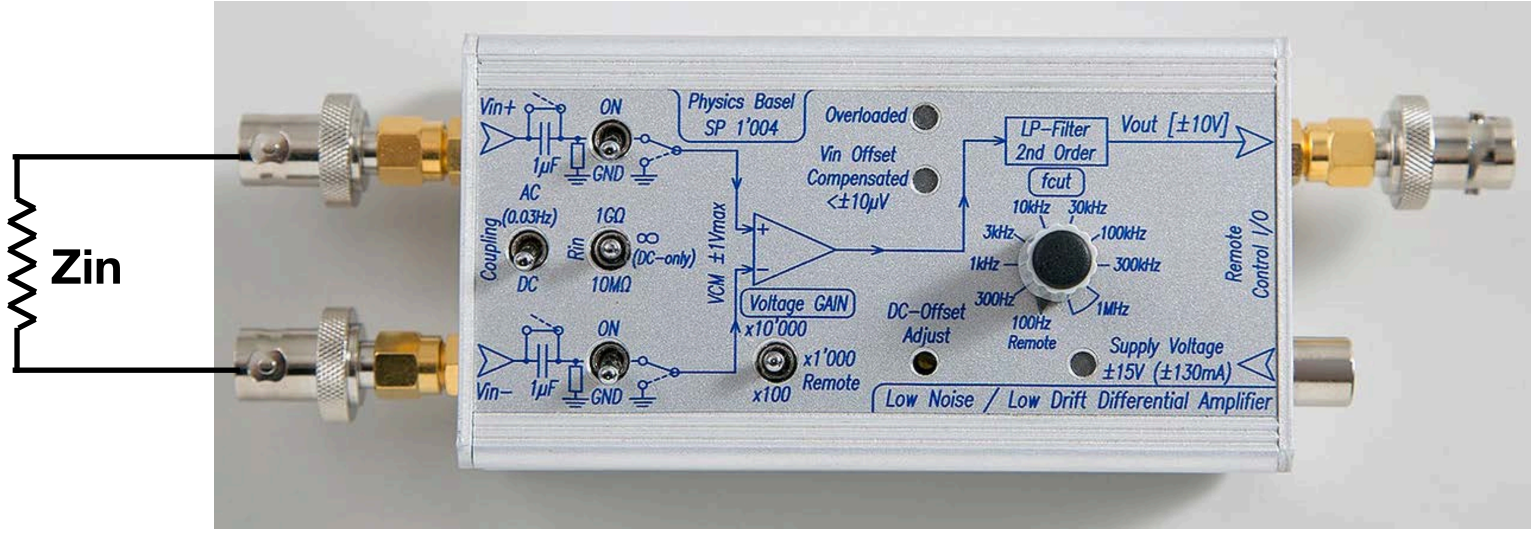
Voltage Preamplifier Noise Sources

Input offset voltage (V_offset)

Input voltage noise (Vn)

Input offset or leakage current (I_offset)

Input current noise (In)



$$\mathbf{V\_output} = \overset{10\ \mu V}{\boxed{\mathbf{G\ V\_offset}}} + \underset{\substack{10\ nV\\ 10\ Hz\ BW}}{\boxed{\mathbf{G\ Un}}} + \overset{15\ pA}{\boxed{\mathbf{G\ I\_offset\ Zin}}} + \underset{\substack{20\ fA\\ 10\ Hz\ BW}}{\boxed{\mathbf{G\ In\ Zin}}}$$

for Z0 < 1MΩ Voltage noise and drift dominates

for Z0 > 1MΩ Current noise and drift dominates

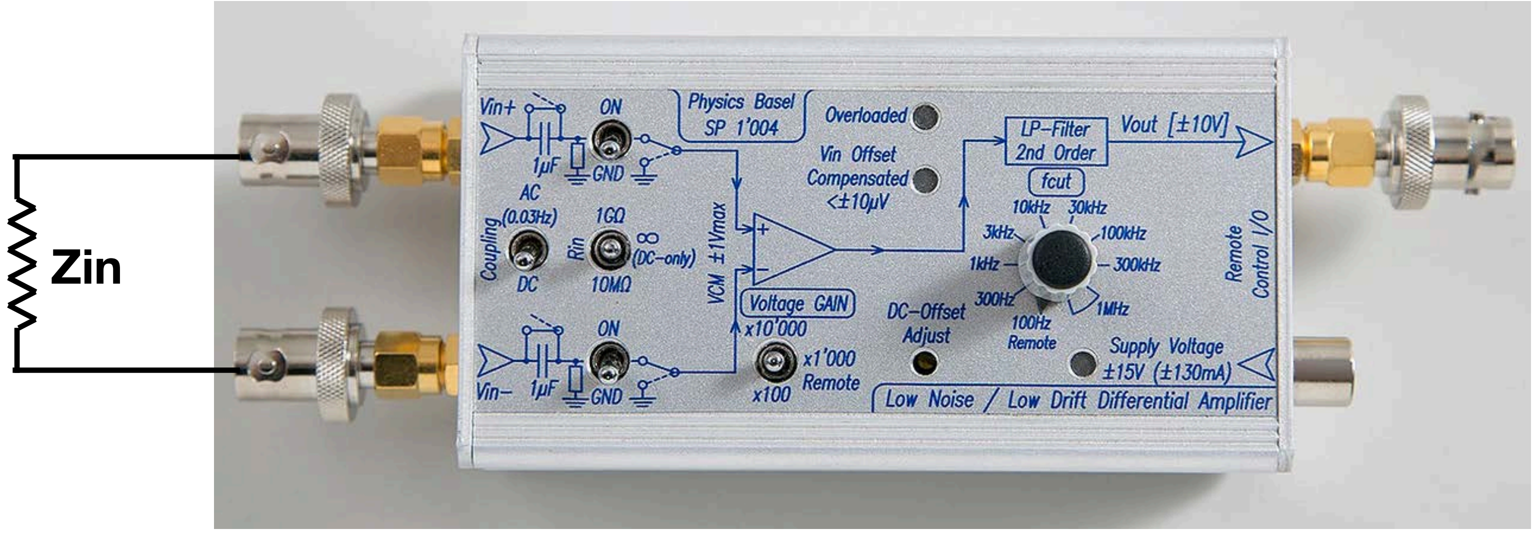
Example:

Measuring the thermal noise of a 1 kΩ resistor at room temperature

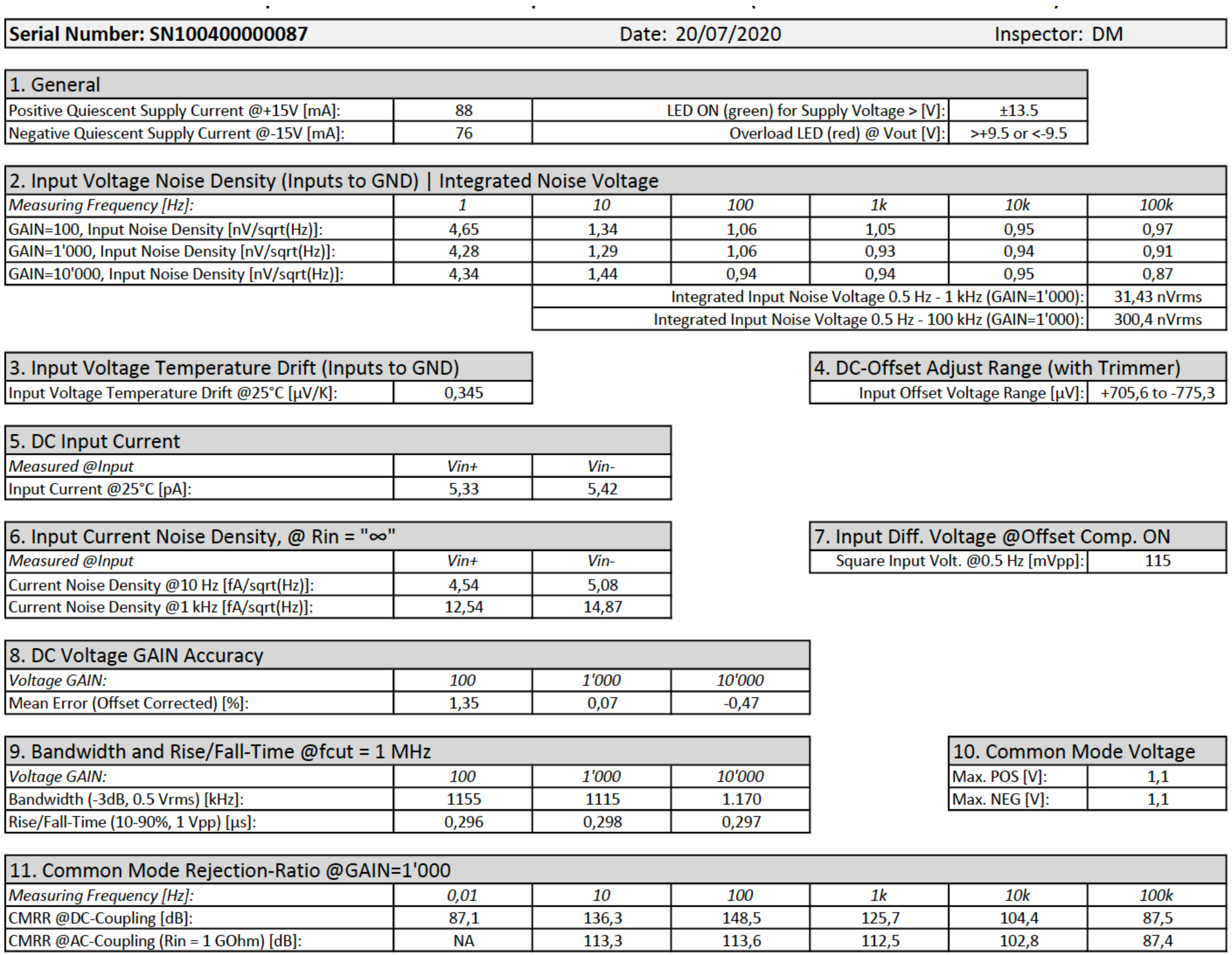
- Johnson noise = 4 nV/√Hz
- Preamp vol. noise = 1 nV/√Hz > 1 kHz
- Select the preamp with lowest voltage noise

Measuring *μ*V signals across a sample with 1 GΩ resistance

- Signal = μV . G
- Current noise = 20 fA . 1E9 . G = 20 μV . G
- Current offset = 15 pA .1E9 . G = 15 mV . G
- Select preamp with lowest current noise, offset and drift



Test Report



Serial Number: SN100400000087 Date: 20/07/2020 Inspector: DM

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6. Input Current Noise Density, @ Rin = "∞"

Measured @Input	*Vin+*	*Vin-*
Current Noise Density @10 Hz [fA/sqrt(Hz)]:	4,54	5,08
Current Noise Density @1 kHz [fA/sqrt(Hz)]:	12,54	14,87

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8. DC Voltage GAIN Accuracy

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Voltage GAIN:	*100*	*1'000*	*10'000*
Bandwidth (-3dB, 0.5 Vrms) [kHz]:	1155	1115	1.170
Rise/Fall-Time (10-90%, 1 Vpp) [µs]:	0,296	0,298	0,297

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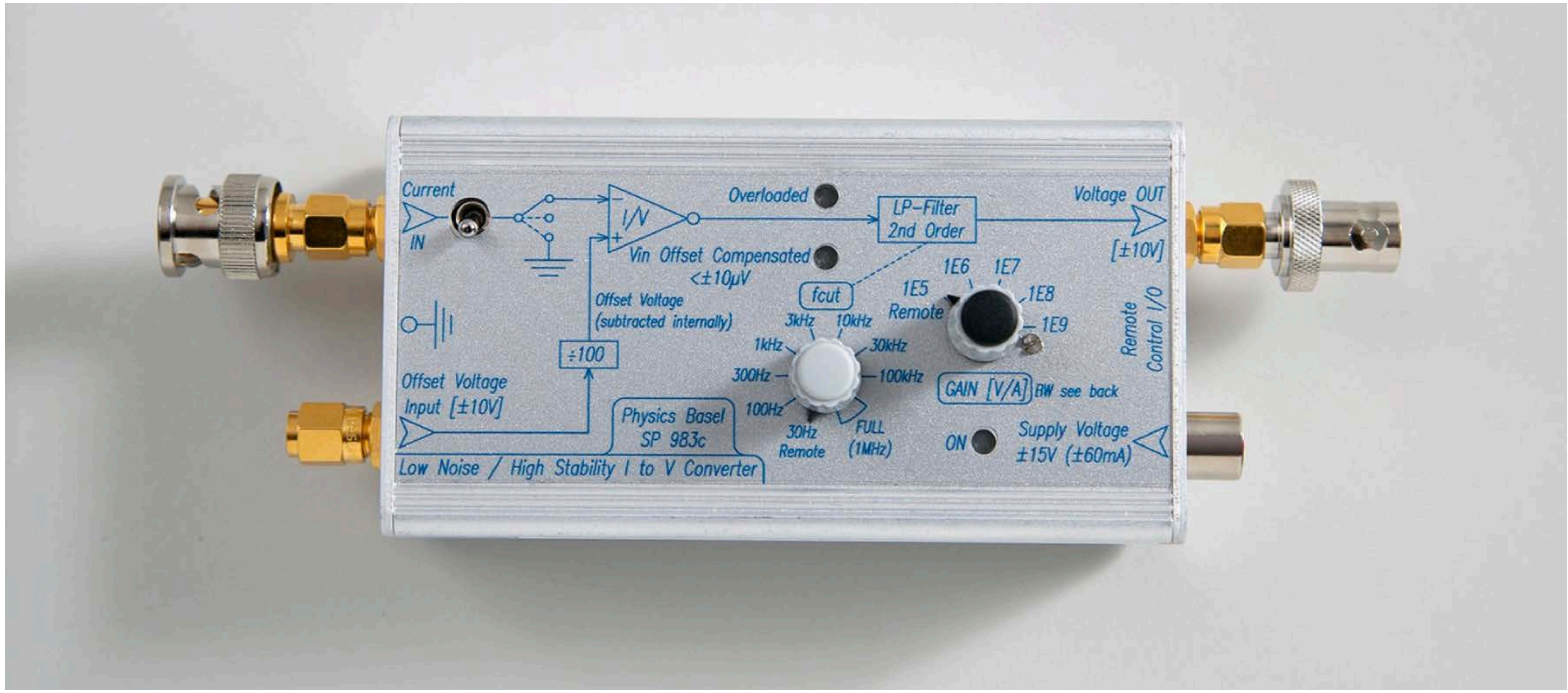
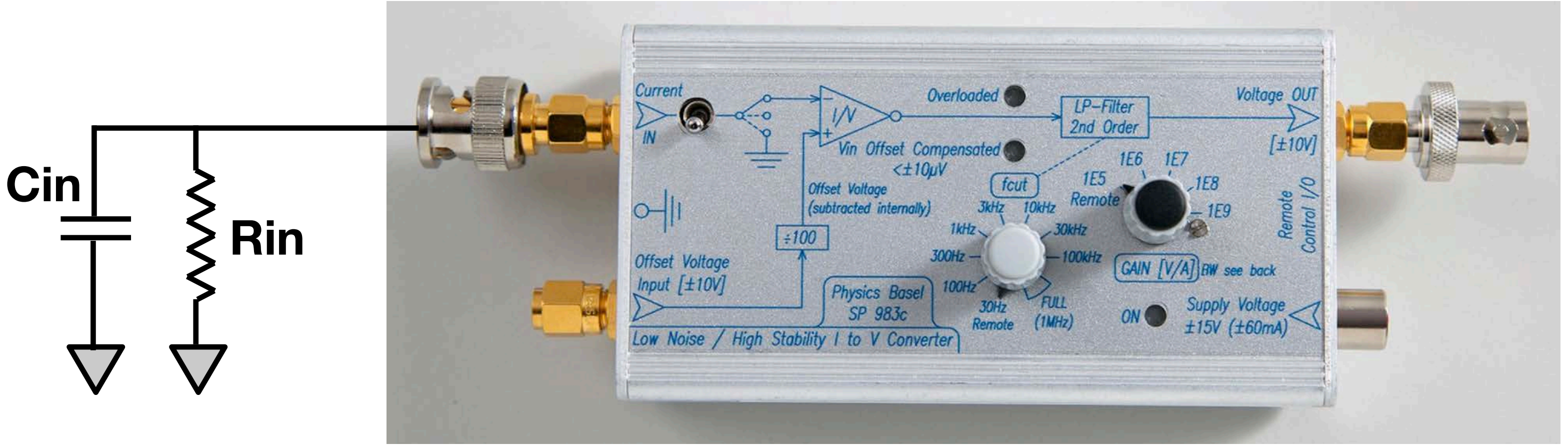
CMRR @DC-Coupling [dB]:	87,1	136,3	148,5	125,7	104,4	87,5
CMRR @AC-Coupling (Rin = 1 GOhm) [dB]:	NA	113,3	113,6	112,5	102,8	87,4

Low-Noise high-stability I to V converter



Current Preamplifier Noise Sources

- Input offset voltage (V_offset)
- Input voltage noise (Un)
- Input offset current (I_offset)
- Input current noise (In)



$$1/Z_{in} = 1/R_{in} + j\,2\pi f\,C_{in}$$

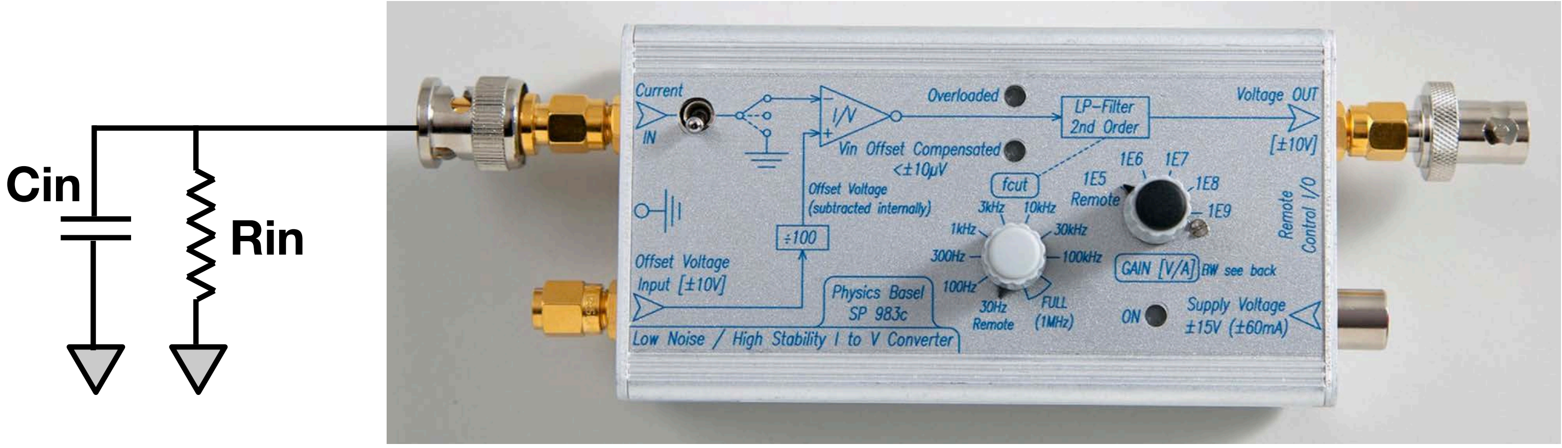
$$V\_output = \boxed{\text{Noise-Gain } V\_offset} + \boxed{\text{Noise-Gain } Un} + \boxed{G\ I\_offset} + \boxed{G\ In}$$

Gain (current gain) = Rf

Noise Gain (voltage gain) = $1+R_f/Z_{in} = 1 + R_f/R_{in} + j\,2\pi f\,R_f\,C_{in}$

Input Offset Voltage (V_offset)

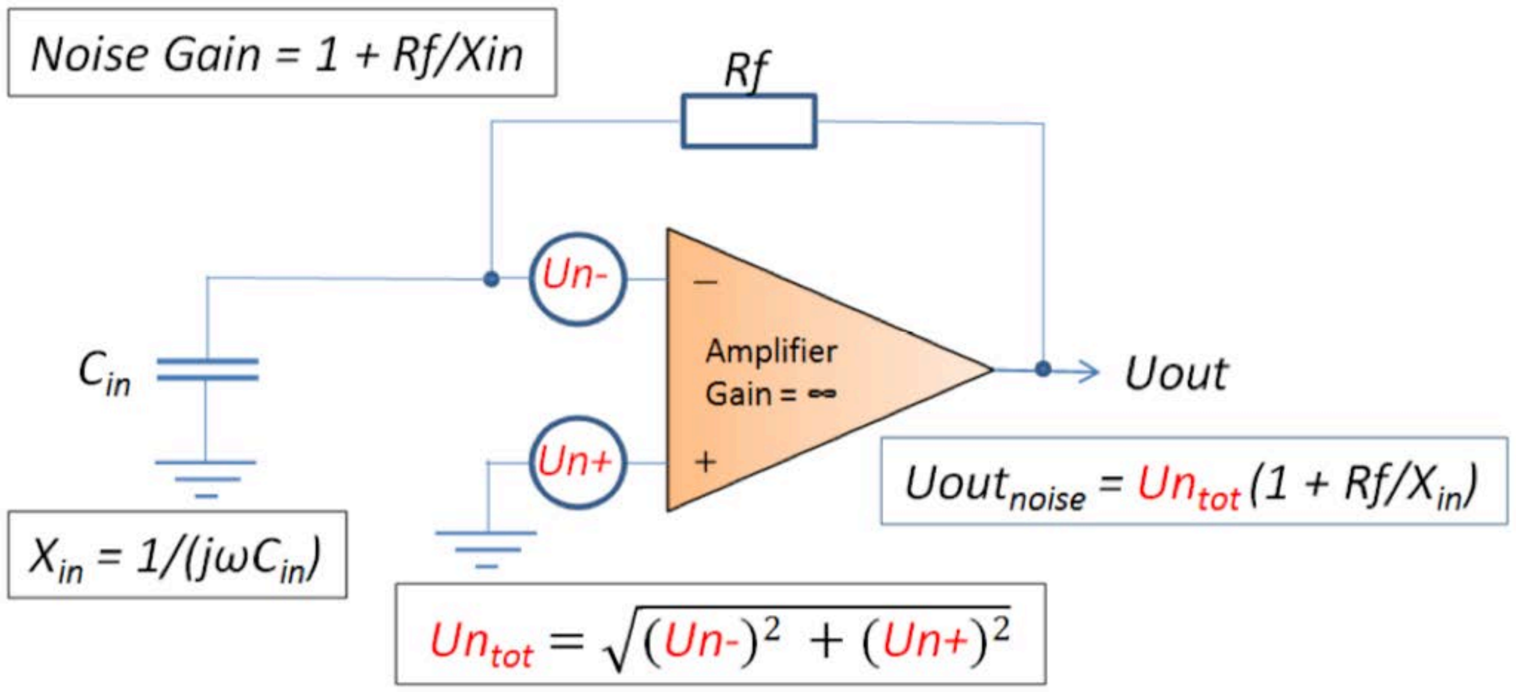
- Actively compensated and stabilized in BASPI's SP983c preamps
- Can be zeroed or shifted using an external bias voltage source
- Is applied to the sample
- Can be used to bias the sample together with an external supply voltage
- Specs:
  - device-specific fixed offset within ±30 µV
  - stabilized drift < 0.15 µV/K @ 25˚C
  - stabilized voltage within ±10 µV with respect to fixed or user defined offset
  - Internally subtracted (external bias)



Input Voltage Noise (Vn)

- It is applied to the sample; causes power dissipation, relevant for low-temperature experiments
- Each J-FET has it's own voltage noise source (Un±) which gets amplified by the noise gain:

Noise Gain = 1+Rf/Zin = 1 + Rf/Rin + j 2π f Rf.Cin



- Relevant for small load impedance
- Increases linearly with frequency for capacitive loads (also noise peaking)

@ f = 10 Hz	@ f = 30 Hz	@ f = 100 Hz	@ f = 1 kHz
2 nV/sqrt(Hz)	1.6 nV/sqrt(Hz)	1.5 nV/sqrt(Hz)	1.2 nV/sqrt(Hz)

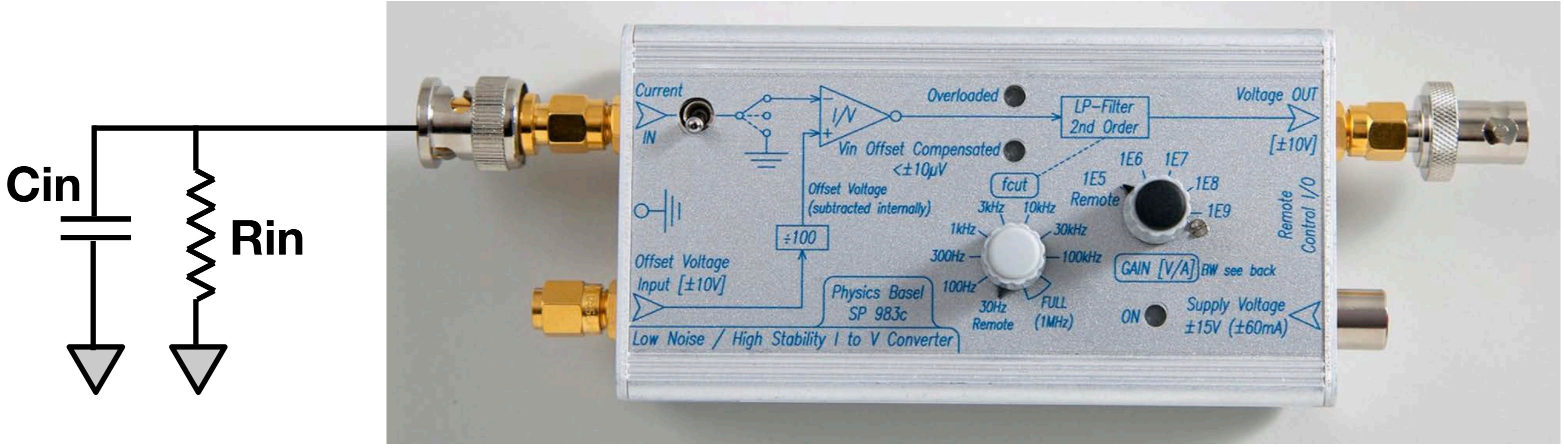
Input Current Noise

- Originates from the thermal noise of the feedback (Gain) resistor with a 1/√Rf dependence
- The signal to noise ratio therefore increases with √Rf; hence use the highest gain possible

GAIN [V/A]	Current Noise @ 10 Hz [fA/sqrt(Hz)]	Current Noise @ 1 kHz [fA/sqrt(Hz)]	Theoretical Limit [fA/sqrt(Hz)]
10^9	6	9	4.1
10^8	14	16	13
10^7	42	43	41
10^6	135	140	130
10^5	576	582	410

Input Offset Current

- Originates from the J-FETs
- Does not go through the sample
- Typical value 35 pA



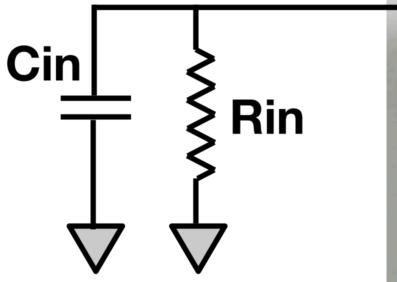
Current Preamplifier Noise Sources

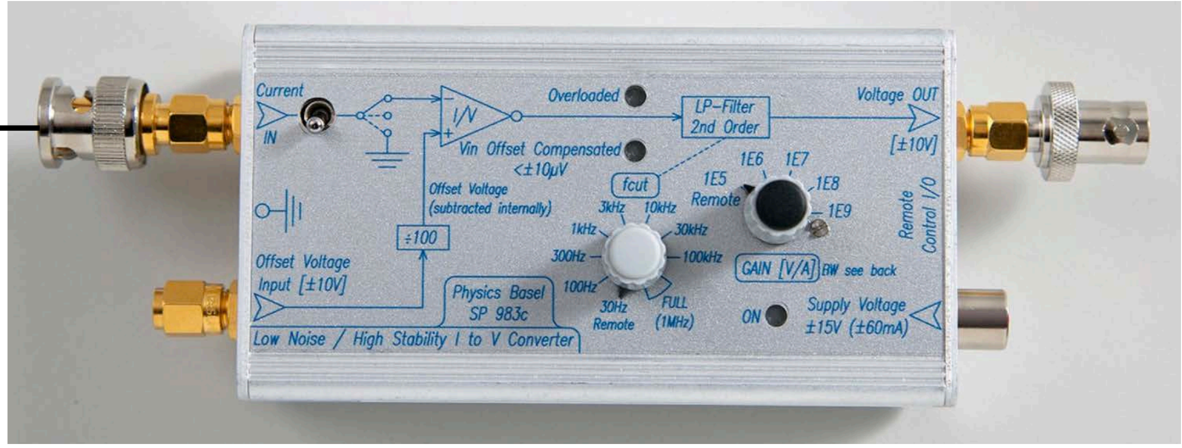
Input offset voltage (V_offset)

Input voltage noise (Un)

Input offset current (I_offset)

Input current noise (In)





6 fA/√Hz @10 Hz and G=10ˆ9
Leads to 6 µV/√Hz output

$$V\_output = \boxed{\text{Noise-Gain } V\_offset} + \boxed{\text{Noise-Gain } Un} + \boxed{G\ I\_offset} + \boxed{G\ In}$$

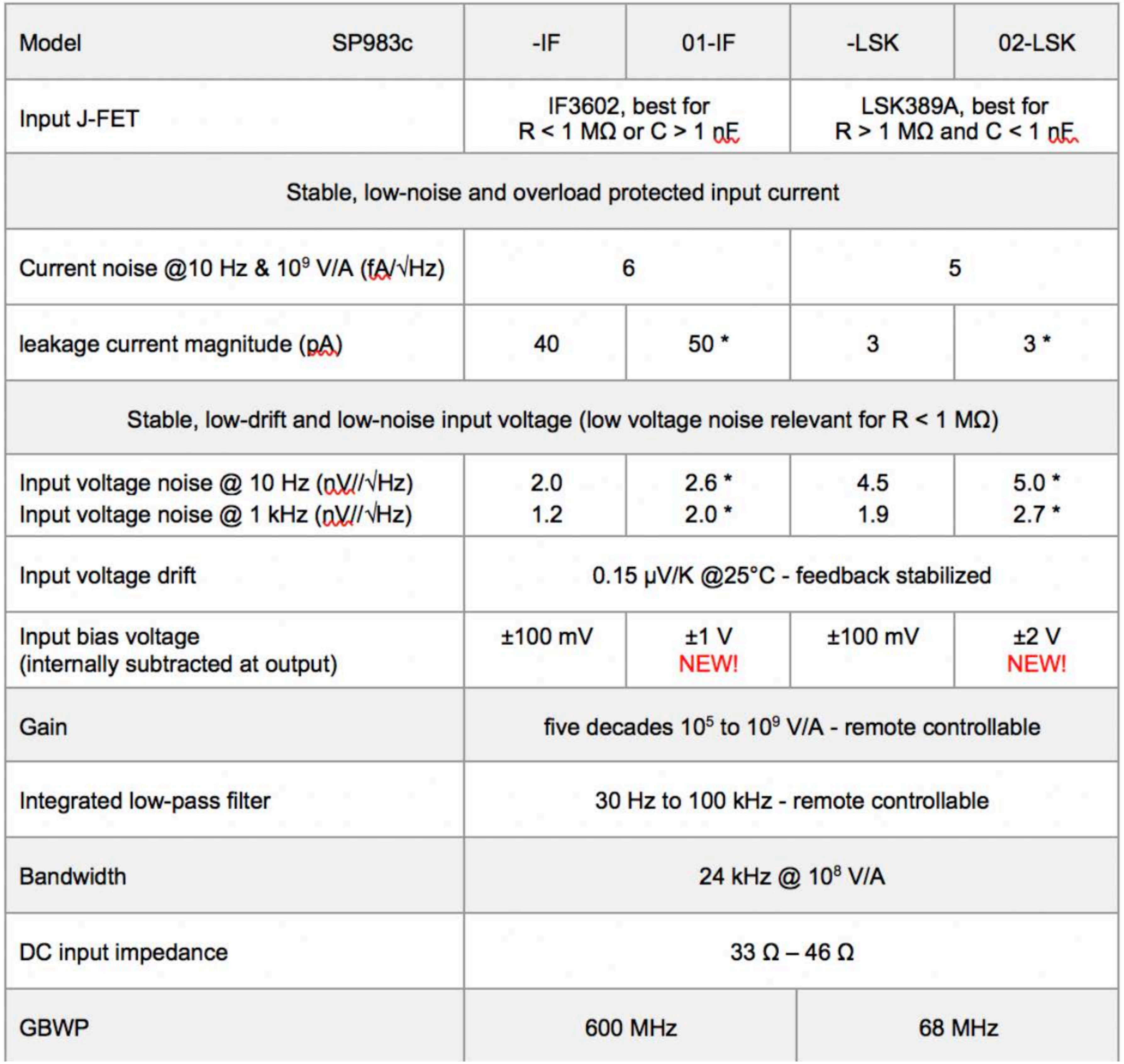
2 nV/√Hz @10 Hz

Current noise dominates for Noise-Gain < 1000

Gain (current gain) = Rf
Noise Gain (voltage gain) = 1+Rf/Zin = 1 + Rf/Rin + j 2π f Rf Cin

Voltage noise dominates for Rin < 1 MΩ or Cin f > 1 nF kHz

Data Sheet



Model SP983c	-IF	01-IF	-LSK	02-LSK
Input J-FET	IF3602, best for R < 1 MΩ or C > 1 nF		LSK389A, best for R > 1 MΩ and C < 1 nF	
Stable, low-noise and overload protected input current				
Current noise @10 Hz & 10^9 V/A (fA/√Hz)	6		5	
leakage current magnitude (pA)	40	50 *	3	3 *
Stable, low-drift and low-noise input voltage (low voltage noise relevant for R < 1 MΩ)				
Input voltage noise @ 10 Hz (nV//√Hz) Input voltage noise @ 1 kHz (nV//√Hz)	2.0 1.2	2.6 * 2.0 *	4.5 1.9	5.0 * 2.7 *
Input voltage drift	0.15 µV/K @25°C - feedback stabilized			
Input bias voltage (internally subtracted at output)	±100 mV	±1 V NEW!	±100 mV	±2 V NEW!
Gain	five decades 10^5 to 10^9 V/A - remote controllable			
Integrated low-pass filter	30 Hz to 100 kHz - remote controllable			
Bandwidth	24 kHz @ 10^8 V/A			
DC input impedance	33 Ω – 46 Ω			
GBWP	600 MHz		68 MHz	

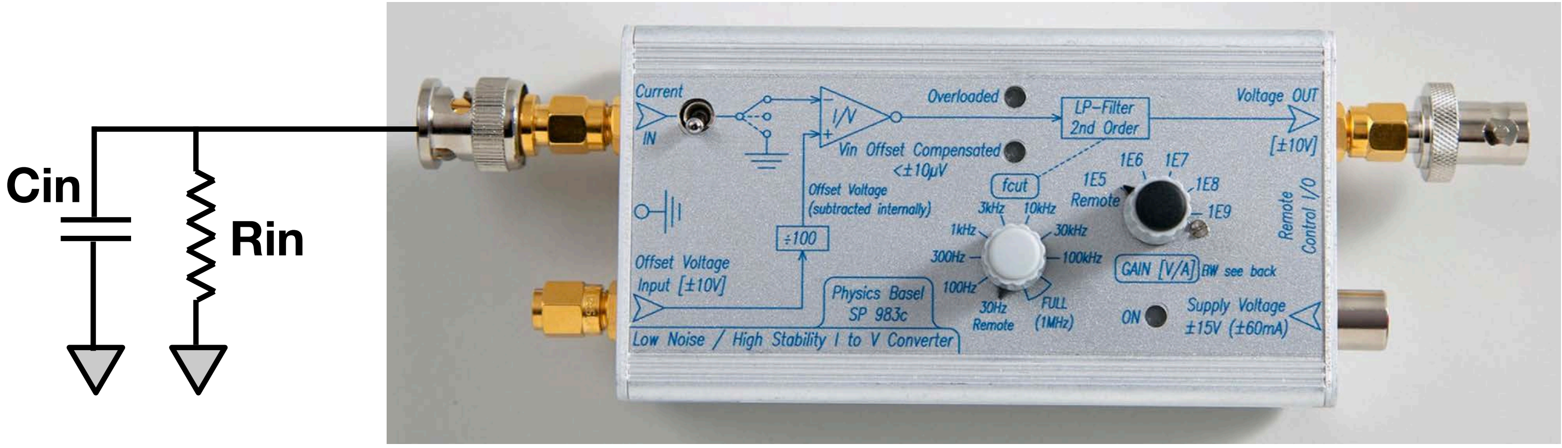
Example:

Measuring pA signal from a highly resistive sample; using Christian's filters on the lines

- Cin = 5 nF, Rin >> Rf
- f=10 Hz -> noise-gain = ~300
  - Use an LSK with low current noise
- f=1kHz -> noise-gain = ~30,000
  - Use IF with low voltage noise

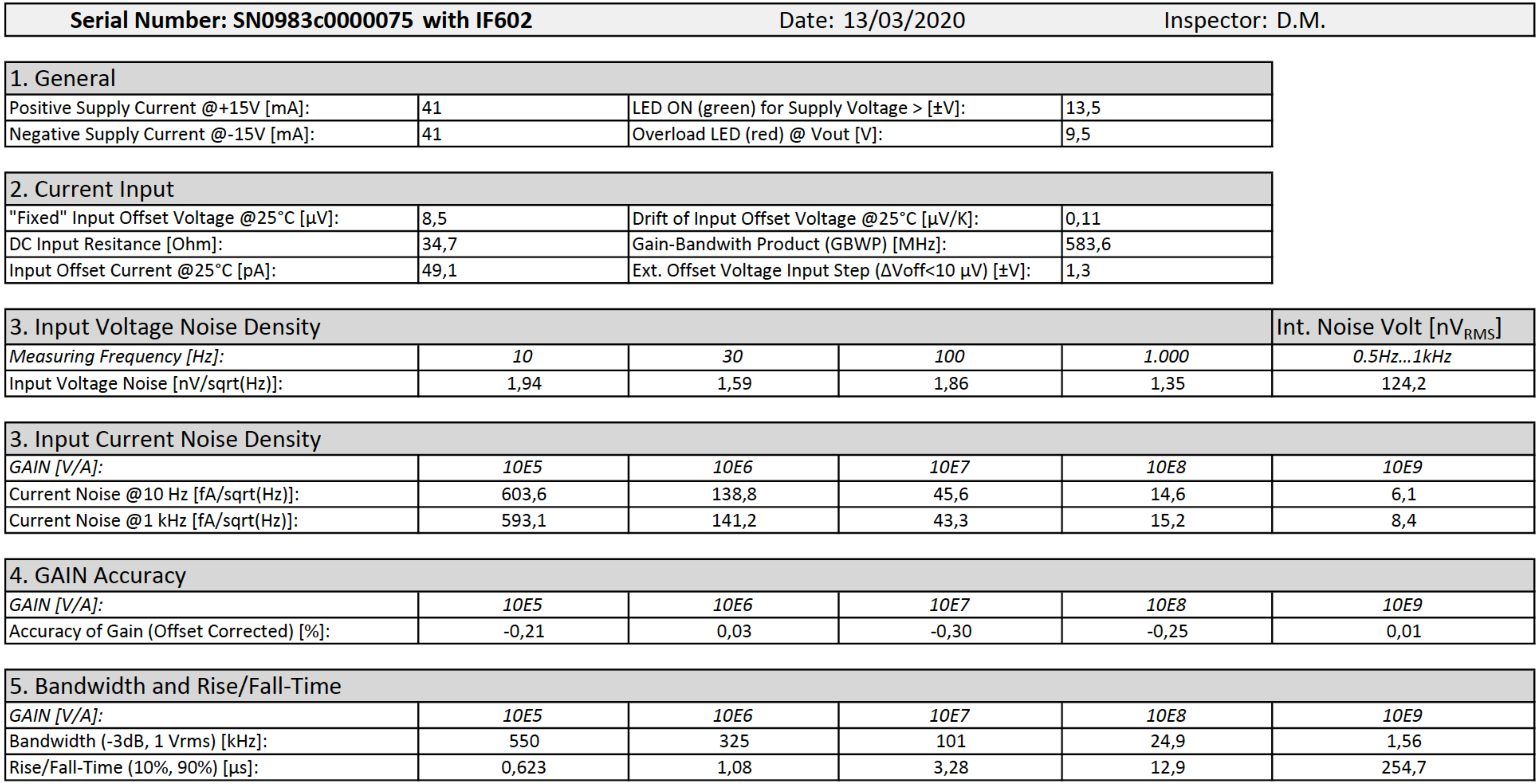
Symmetric Biasing

- How do you select your preamplifiers?



Noise Gain (voltage gain) = 1+Rf/Zin = 1 + Rf/Rin + j 2π f Rf Cin

Test Report



Serial Number: SN0983c0000075 with IF602 Date: 13/03/2020 Inspector: D.M.

1. General			
Positive Supply Current @+15V [mA]:	41	LED ON (green) for Supply Voltage > [±V]:	13,5
Negative Supply Current @-15V [mA]:	41	Overload LED (red) @ Vout [V]:	9,5

2. Current Input			
"Fixed" Input Offset Voltage @25°C [µV]:	8,5	Drift of Input Offset Voltage @25°C [µV/K]:	0,11
DC Input Resitance [Ohm]:	34,7	Gain-Bandwith Product (GBWP) [MHz]:	583,6
Input Offset Current @25°C [pA]:	49,1	Ext. Offset Voltage Input Step (ΔVoff<10 µV) [±V]:	1,3

3. Input Voltage Noise Density					Int. Noise Volt [nV_{RMS}]
Measuring Frequency [Hz]:	*10*	*30*	*100*	*1.000*	*0.5Hz...1kHz*
Input Voltage Noise [nV/sqrt(Hz)]:	1,94	1,59	1,86	1,35	124,2

3. Input Current Noise Density					
GAIN [V/A]:	*10E5*	*10E6*	*10E7*	*10E8*	*10E9*
Current Noise @10 Hz [fA/sqrt(Hz)]:	603,6	138,8	45,6	14,6	6,1
Current Noise @1 kHz [fA/sqrt(Hz)]:	593,1	141,2	43,3	15,2	8,4

4. GAIN Accuracy					
GAIN [V/A]:	*10E5*	*10E6*	*10E7*	*10E8*	*10E9*
Accuracy of Gain (Offset Corrected) [%]:	-0,21	0,03	-0,30	-0,25	0,01

5. Bandwidth and Rise/Fall-Time					
GAIN [V/A]:	*10E5*	*10E6*	*10E7*	*10E8*	*10E9*
Bandwidth (-3dB, 1 Vrms) [kHz]:	550	325	101	24,9	1,56
Rise/Fall-Time (10%, 90%) [µs]:	0,623	1,08	3,28	12,9	254,7

Competitive Analysis for LNHS I-to-V Converter

Product name	IVC	PCG-380F	DLPCA-200	Ithaco 1211	SR 570
Manufacturer	BASPI (CH)	Pluto Inst. (KR)	Femto (DE)	DL Instr. (US)	SRS (US)
Variable gain	Up to 10E9 V/A				
Max Bandwidth at 1E9 gain	1.7 kHz	5 kHz	1.1 kHz	4 kHz	15 Hz
Voltage noise density (nV/sqrt Hz) at 1 kHz	1.2	2	4	10	Not specified
Current noise density (fA/sqrt Hz) at 1E9 gain in	5 @10 Hz	4 @10 Hz	4.3 @100 Hz	5 up to 4kHz rms	6 @10 Hz
Input voltage active stabilization	Yes	No	No	No	No
Input voltage drift at room temperature(/degC)	0.15 µV	1.8 µV	Not specified	Not specified	Not specified
Possibility to apply bias voltage	Up to 2V	None	Up to 10V	Up to 5V	Up to 5V
Amplifier ground floating	Yes	No	No	No	Yes
Form factor and weight	Compact 165 gr	Semi-compact 350 gr	Compact 320 gr	Bulky 3.7Kg	Bulky 6.7 Kg