Op-Amp Noise Test Results

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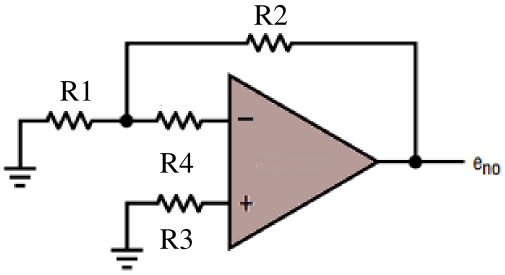
1 Noise Test Circuit Calibration Details

1.1 Voltage Noise Circuit

This is a standard circuit used throughout the tests

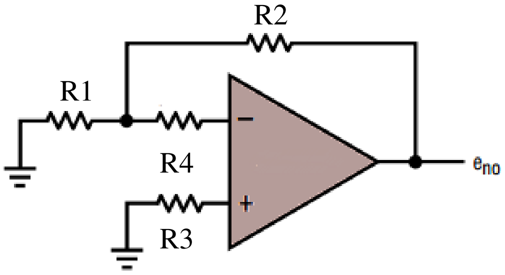


R1=10R
R2=100KR
R3=R4=0R

Input referred voltage noise = vn/10001_______Equation 1
Vn = noise measured at output

1.2 Current Noise Circuit

This is a standard circuit used throughout the tests. This circuit will not work for currents ~0.3pA as the sense resistor noise begins to dominate. Therefore not all results sets contain current noise data.

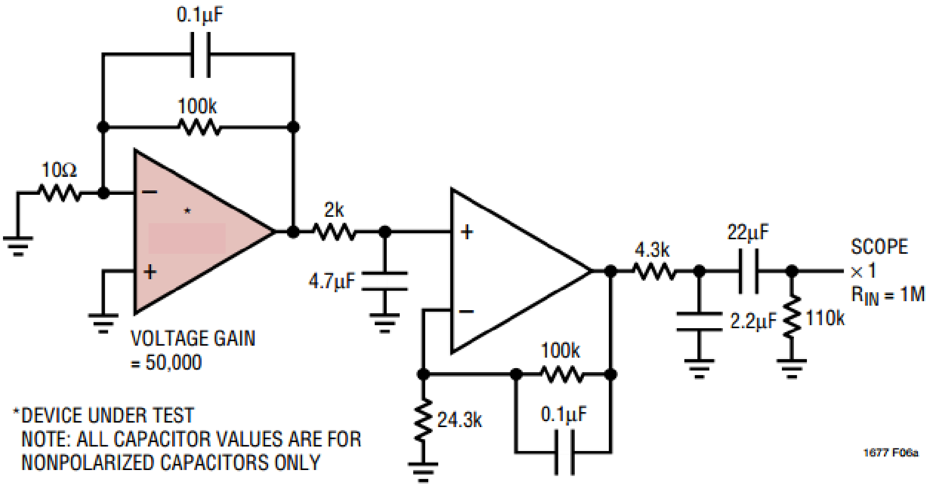


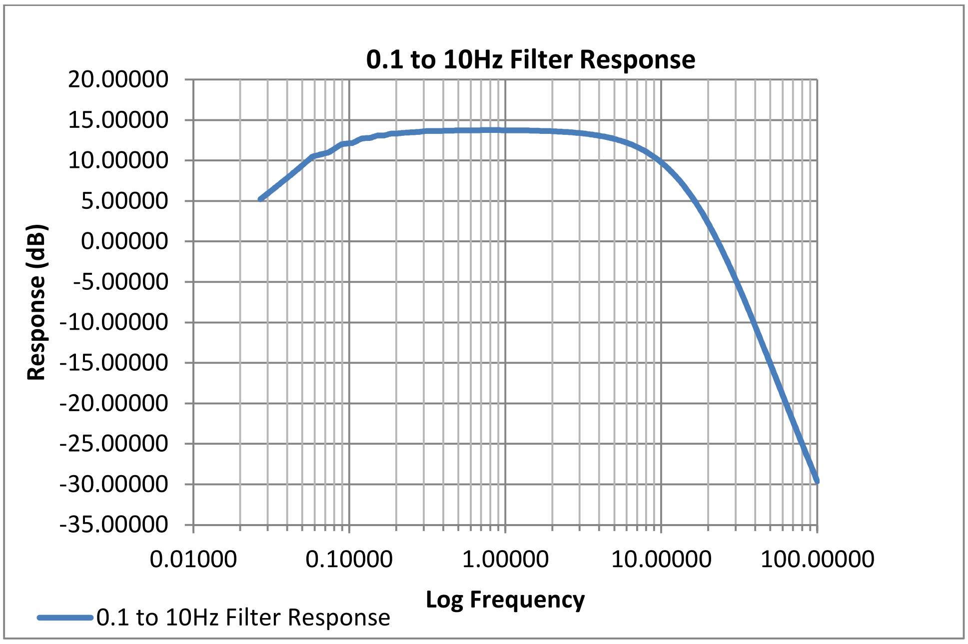
R1=100R
R2=100KR
R3=R4=500KR

Input referred current noise = vn/(1001*($2^{0.5}$)*500K) =vn/707.8*10^6 _______Equation 2
Vn = noise measured at output
(assuming the current noise contribution dominates the total noise, and that the current noise at each input has approx. equal magnitudes, and is uncorrelated).

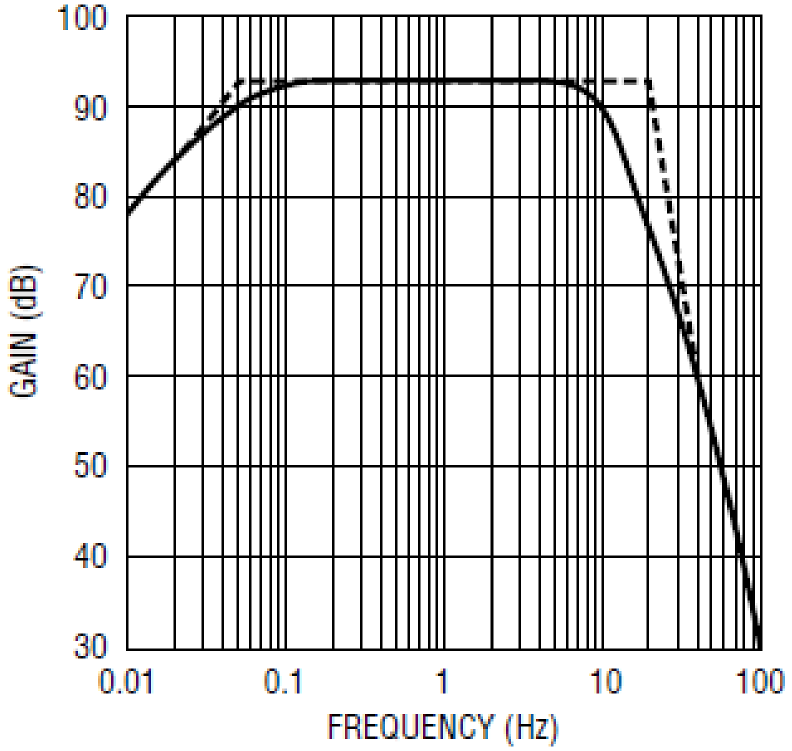
1.3 0.1 to 10Hz Circuit

This is a standard circuit (Source: Linear Technology) which allows comparison of opamp noise time series data (in the range 0.1 to 10Hz) with that given in the device data. Frequency response is given below. Centre in band gain is 4.85.





The Linear technology specified response is shown below for comparison (Nb the gain on this plot includes amplification (80dB=20log(100K/10)) from the previous stage (ie the DUT) and can be adjusted accordingly for comparison.)



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1.4 Dynamic Signal Analyser Configuration for noise spectrum measurement

(Agilent 35670A)

The following setup is valid for collection of data down from 10mHz to 400Hz in 2 ranges. Two instrument setup files have been created N0TO2.STA (range 10mHz to 1.5Hz) and N1TO400.STA (1Hz to 400Hz) for use with the instrument. The key settings are listed below (menu buttons are underlined, with settings in that menu listed below):

Measurement Data
Source: Ch1
Power Spectrum Ch 1
Trace Coordinates
Log Magnitude
X Units: Hz
Y Units: Vrms/√Hz
X axis: Log
Scale
Auto-scale: on
Top reference
Active Trace
Active Trace: A
Display Format
Single Display
Instrument Mode
FFT Analysis on Ch1
Frequency
Start and Stop Frequency: 0 to 1.5Hz or 1 to 400Hz as required (for Low frequency range use ‘zero start’ button to set 0Hz start frequency)

Record Length: 512s or 2s (respectively depending on frequency range)
Resolution: 800 lines

Input
(for Ch 1)
Range: Typically set at ~25mV peak for voltage noise measurement, (adjust range to get occasional ‘half range’ led flash, but no overloads (if possible)).
Input Float
DC Couple
Anti-alias filter: on
A wt filter: off

Trigger
Ch1
Free-run

Average
Averaging: on
Number: 30
Type: RMS
Fast Avg: Off
Overlap: 50%
Ovld Reject: 0n

Acquired data is stored to disk as an SDF file, and translated to text for import to Excel using the sdftoasc.exe utility with the following command and switches.

```
sdftoasc filename_in.dat filename_out.txt /X /T:M /Y:LDR
```

1.5 Oscilloscope Configuration for 0.1 to 10Hz noise measurement

Sample length: 2^{20} samples at 200Ksps (5.24s of data).
Input attenuator: 5mV or 10mV/div.
(Note: Scope internal noise << measured noise)

A Stanford Research Preamplifier SR560 could be used if required, but noise data gathered for these results was at least 5 times greater than the oscilloscope noise floor, so a preamplifier was not used.

2 Results for OPA188#1

2.1 OPA188 #1 Voltage Noise 0.1 to 10Hz

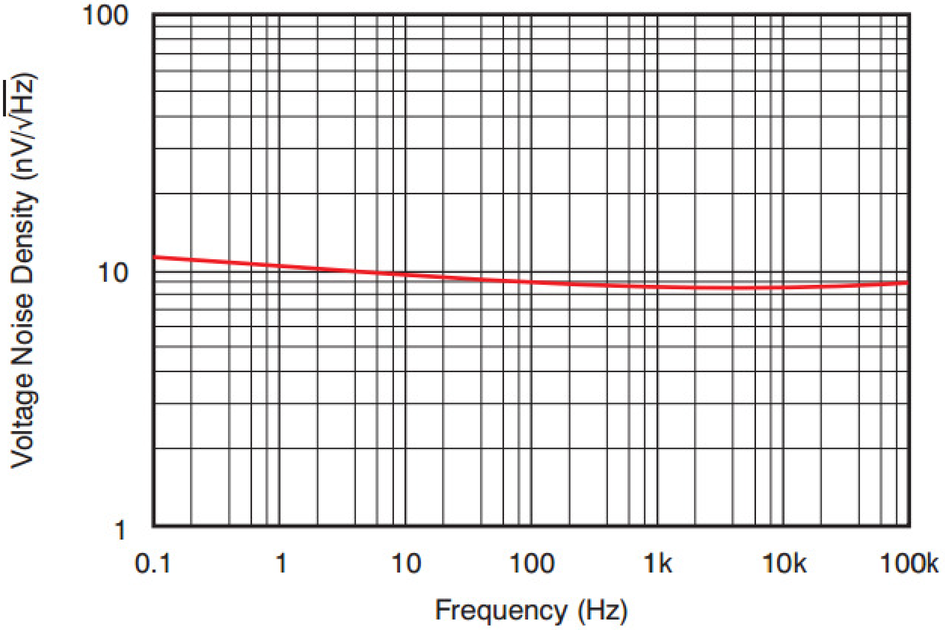
Test conditions:
Vs: ±9v
Temperature: 23.5C.

The noise of the device tested is as follows:
Voltage noise rms: 25.8nV
(cf to data sheet typical:40nV rms)

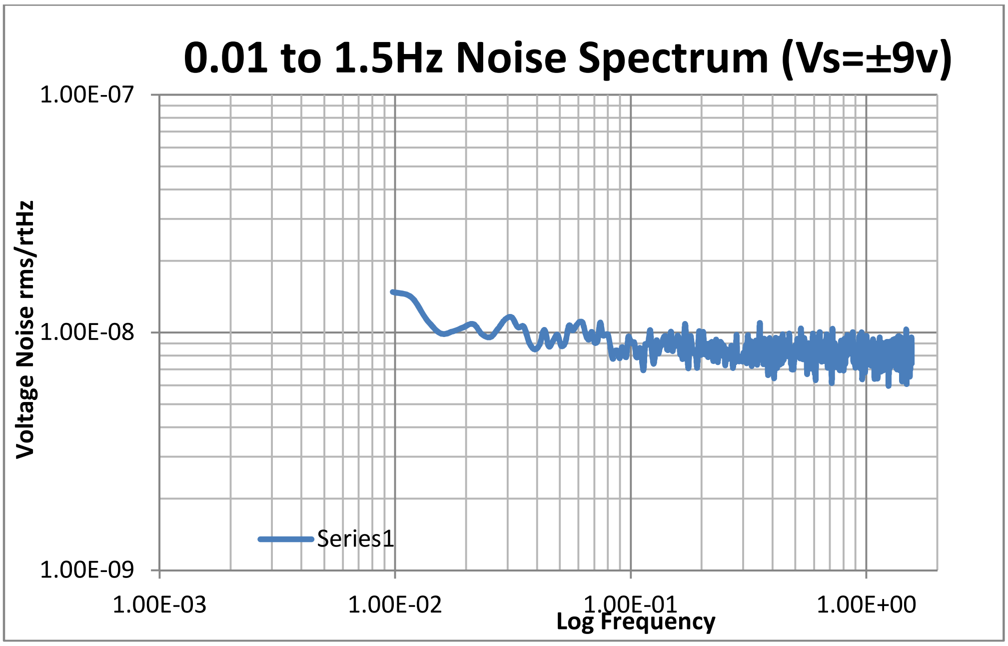
Voltage noise peak-peak (ie 6δ): 155nV
(cf to data sheet typical: from table 250nV, and from graph: 172nV)

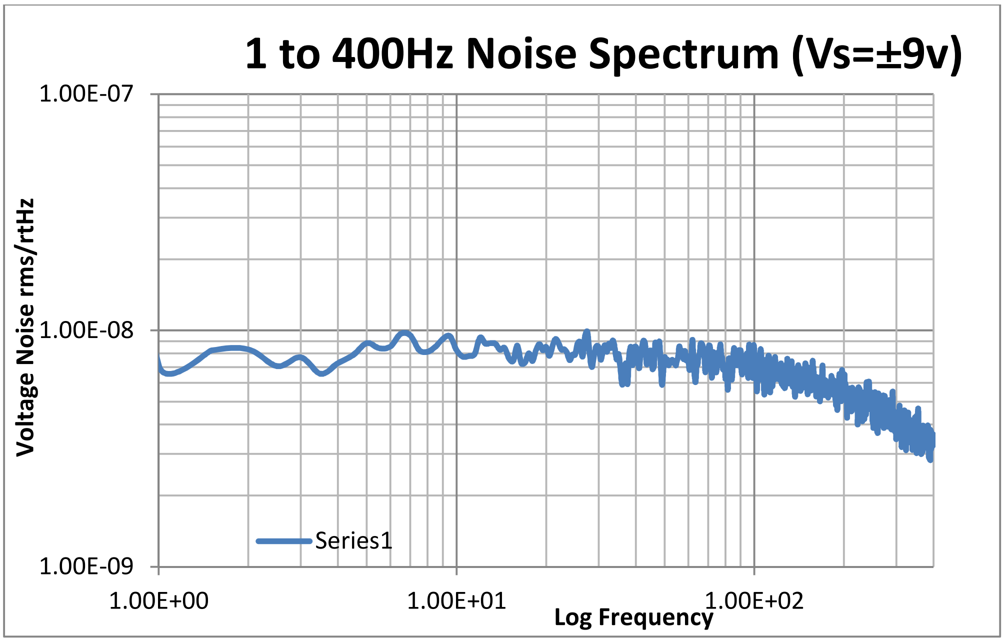
2.2 OPA188 #1 Voltage Noise Spectrum Test 1

Test conditions:
Vs: ±9v
Temperature: 23.5C.
In all data plotted below, the noise is input referred.



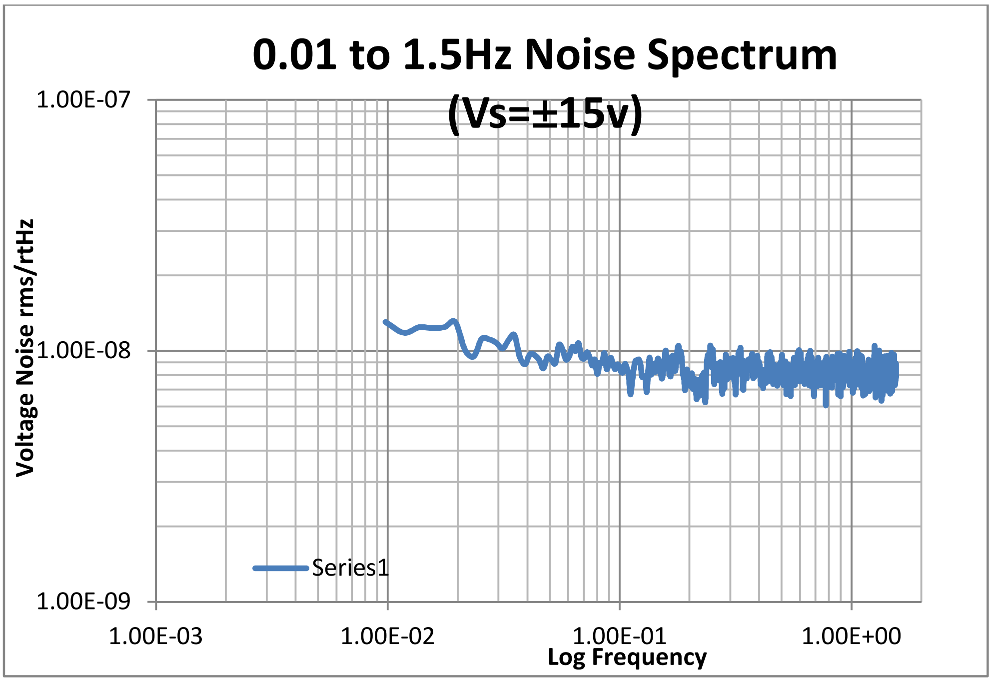
Noise spectrum from data sheet for comparison

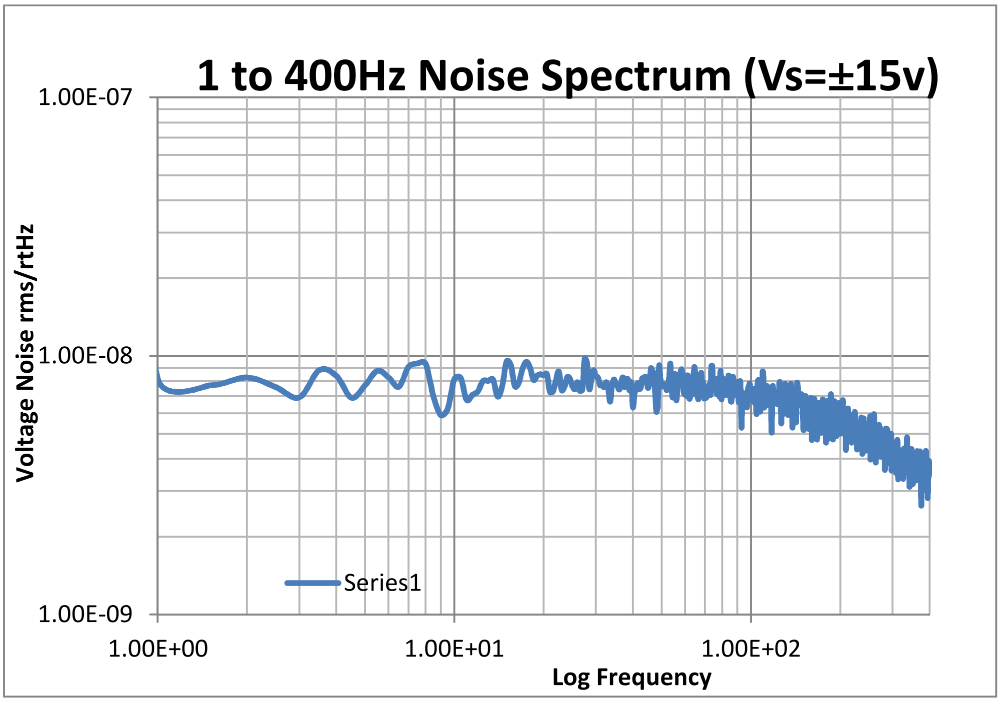




2.3 OPA188 #1 Voltage Noise Spectrum Test 2

Test conditions:
Vs: ±15v
Temperature: 21.5C.
In all data plotted below, the noise is input referred.





2.4 OPA188 #1 Current Noise Spectrum

Test conditions:
Vs: ±15v
Temperature: 22C

The current noise for this device is specified at 7fA/rtHz at 1KHz (the manufacturer provides no further data). This is too low to measure effectively with this system: The resistors required would be so large that their own noise dominates the measurement. In addition, the

auto-zero circuitry in the op-amp causes short transients in the bias currents (Auto zeroing occurs ~every 3uS, and in a normal high gain application the transients will be far above the operational bandwidth. The manufacturer however recommends a LPF on the device output to prevent feedthrough of these transients to the output via the feedback network. The manufacturer gives no further indication of the amplitude or nature of these transients).
It is believed that the high impedances ‘seen’ by the inputs in this test cause some disturbance to the auto-zero process (or the current transients, and high impedance cause disturbance of the input stage – cf to ‘audio rectification’ effect as commonly seen in RS or BCI EMC tests), causing output offsets to be higher than expected (for example: with R1=100R R2=100KR R3=R4=500KR the output offset is 1.59v. The absolute worst case one would expect based on the manufacturers room temperature data is 1.4v (0.16v typical).
The large impedances also cause premature GBW roll off: For example, with R1=100R R2=100KR R3=R4=500KR, the operational bandwidth is ~85Hz. Compare this to the case where R3=R4=0. Here the operational bandwidth is 2.1KHz, which is in agreement with the manufacturers GBW data.
In conclusion, the noise seen in the following tests is higher than expected (the resistor noise was expected to dominate, over both current and voltage noise, but the noise seen is even higher than this). It is believed that for optimum performance, this opamp should be operated with minimum impedance as seen looking out of each input, (which could well be the case in a standard high voltage gain application), and all that can be achieved by this test is to place an upper limit on the current noise within the 0.01 to 1Hz band.

Three current noise tests were conducted using sense setups as follows:

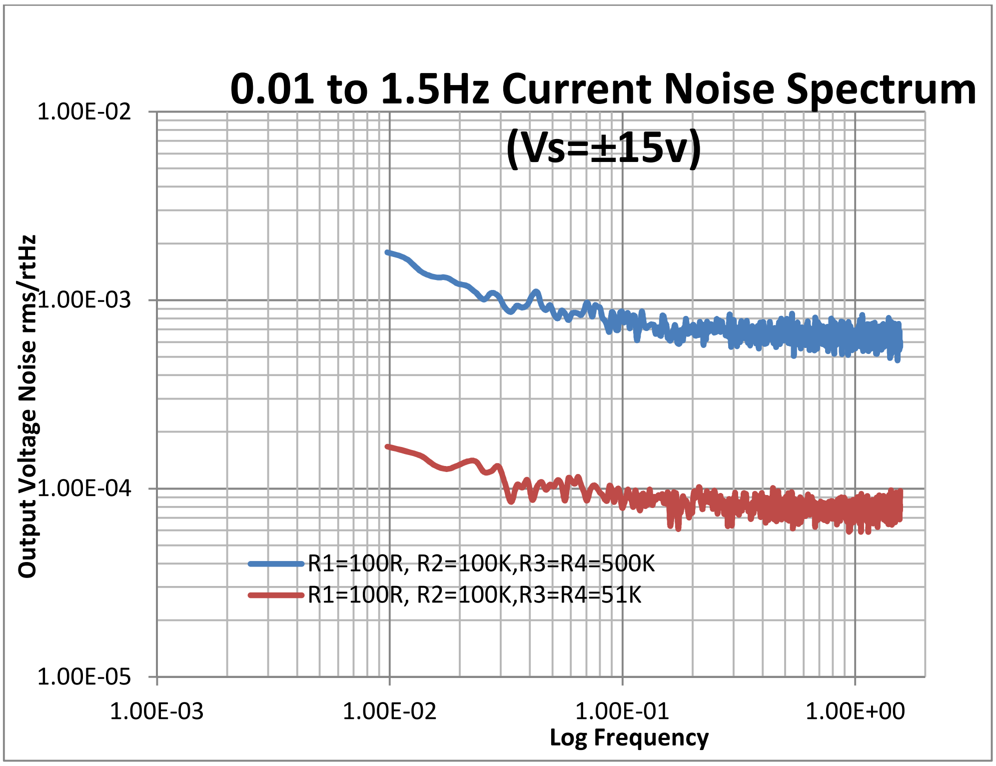
Test 1: R1=100R, R2=100K, R3=R4=500K

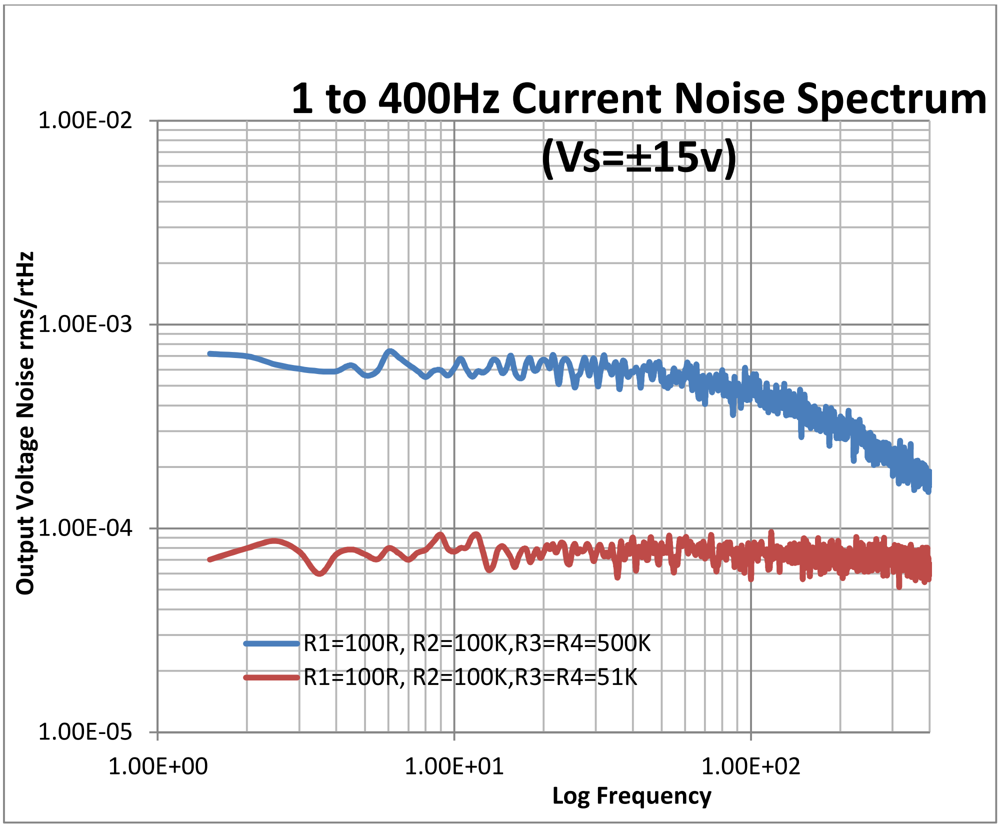
Test 2: R1=100R, R2=100K, R3=R4=51K
(Note in this case offset was reduced to 160mV which is still higher than expected, and the operational bandwidth is 720Hz which is still lower than expected, so these impedances are still higher than should be used for ‘optimum’ performance)

Test 3: R1=open, R2=100K, R3=R4=0
In this case the measured noise is below the DSA noise floor 7E-6V/√Hz at 0.01Hz, so this measurement is not included in the graph data below (it implies a limit on current noise of 70pA/√Hz – which is clearly incorrect – see results from test 1 and 2 below)

The data in the plots below are **output referred**, since the results can only be referred to the input as current noise if we are certain that the current noise dominates in all regions (which we are not).

However, from these plots, we can say that the upper limit of input referred current noise at 0.01Hz is ~2.5pA/√Hz. This implies that to keep the current noise contribution below the voltage noise (8.8nV/√Hz) would need the impedance seen by each input to be less than ~2.5K.


0.01 to 1.5Hz Current Noise Spectrum (Vs=±15v)
Output Voltage Noise rms/rtHz
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-03
1.00E-02
1.00E-01
1.00E+00
Log Frequency
R1=100R, R2=100K,R3=R4=500K
R1=100R, R2=100K,R3=R4=51K


1 to 400Hz Current Noise Spectrum (Vs=±15v)
Output Voltage Noise rms/rtHz
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E+00
1.00E+01
1.00E+02
Log Frequency
R1=100R, R2=100K,R3=R4=500K
R1=100R, R2=100K,R3=R4=51K

3 Results for OPA188#2

3.1 OPA188 #2 Voltage Noise 0.1 to 10Hz

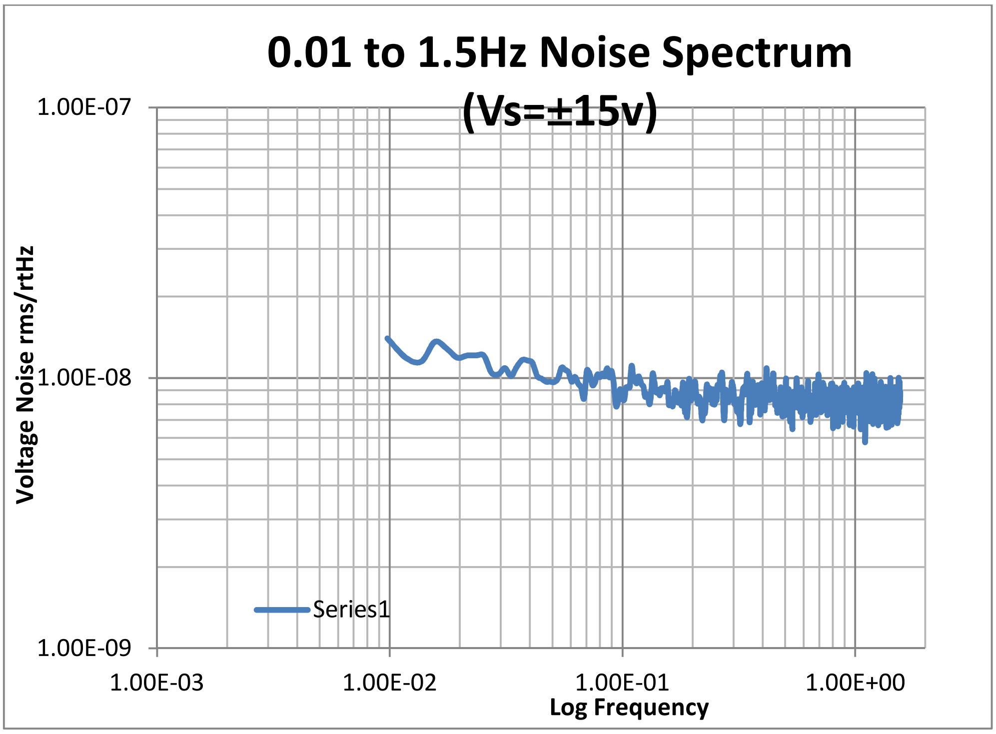
Test conditions:
Vs: ±15v
Temperature: 22C.

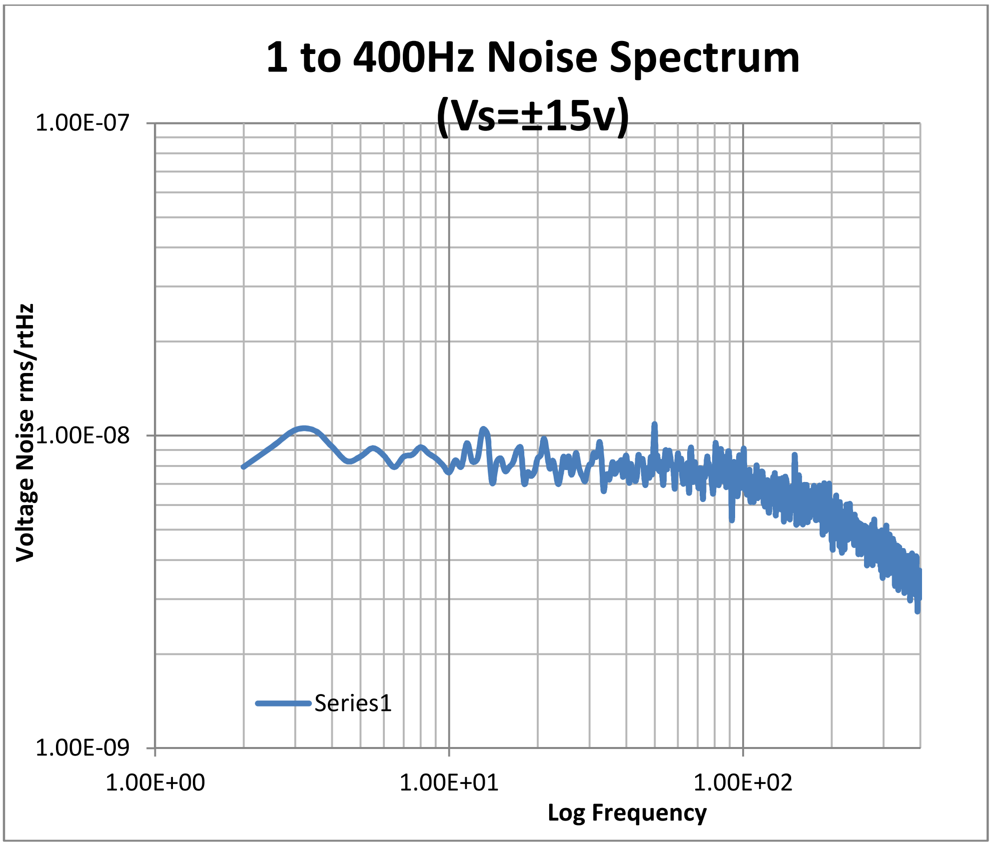
The noise of the device tested is as follows:
Voltage noise rms: 27.2nV
(cf to data sheet typical:40nV rms)

Voltage noise peak-peak (ie 6ẟ): 163nV
(cf to data sheet typical: from table 250nV, and from graph: 172nV)

3.2 OPA188 #2 Voltage Noise Spectrum

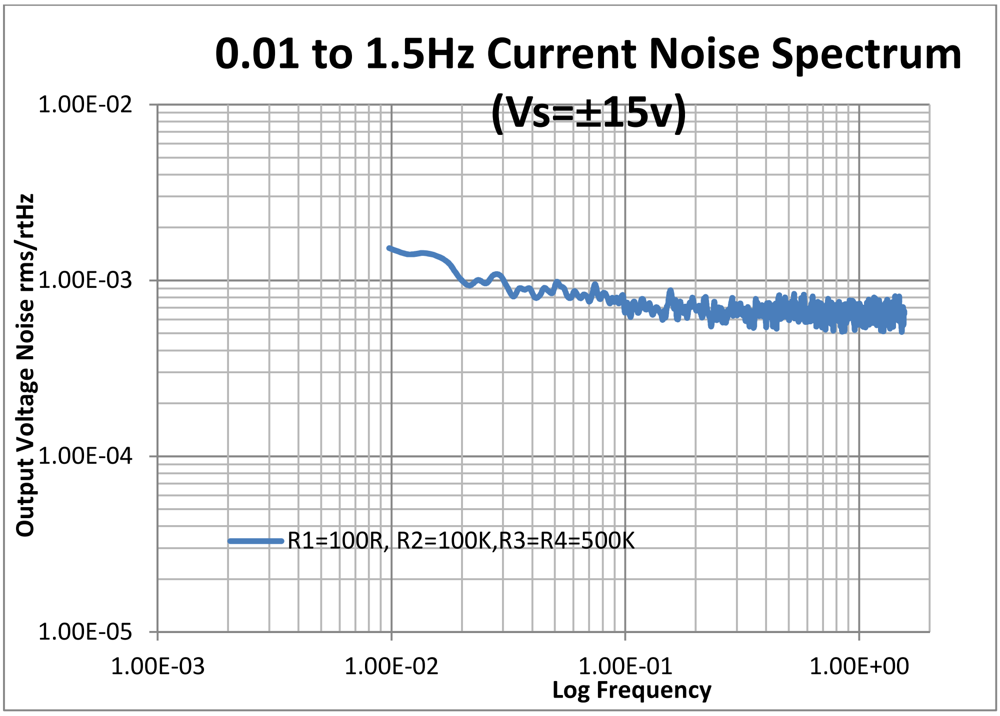
Test conditions:
Vs: ±15v
Temperature: 22.5C.
In all data plotted below, the noise is input referred.

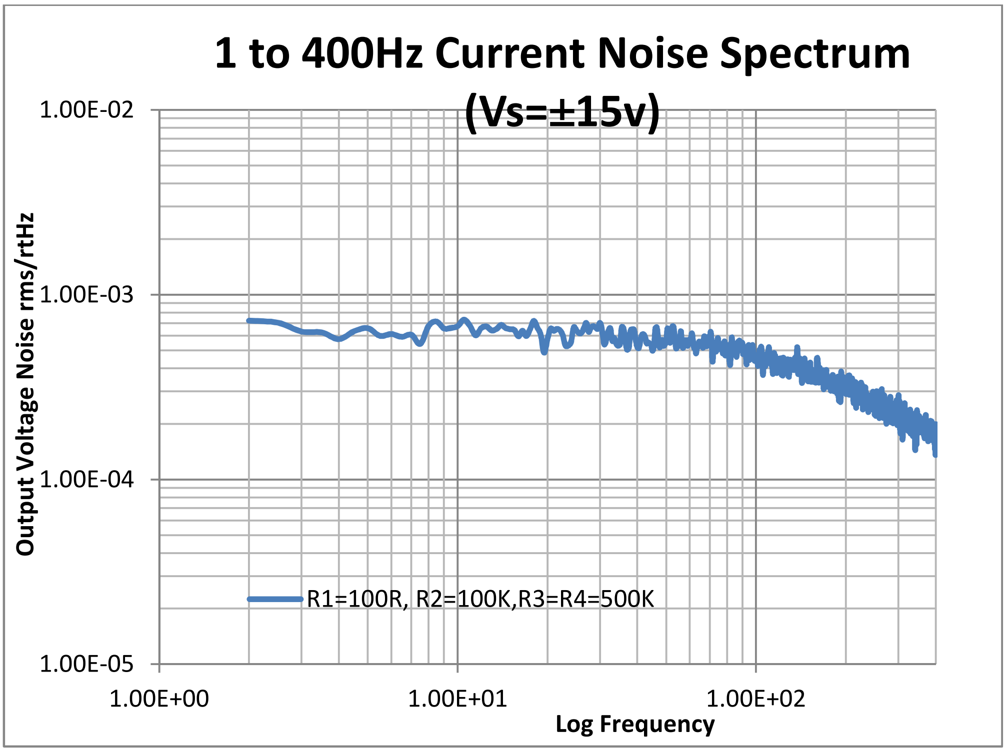




3.3 OPA188 #2 Current Noise Spectrum

Test conditions:
Vs: ±15v
Temperature: 22C
All data below is referred to the output (see explanation in section 2.4)





This places an upper limit on the current noise at 0.01Hz of 2.2pA/√Hz.

4 Results for ADA4528 #1

4.1 ADA4528 #1 Voltage Noise 0.1 to 10Hz

Test conditions:
Vs: ±2.5v
Temperature: 22C.

The noise of the device tested is as follows:
Voltage noise rms: 22nV

Voltage noise peak-peak (ie 6δ): 132nV
(cf to data sheet typical: 99nV)

4.2 ADA4528 #1 Voltage Noise Spectrum

Test conditions:
Vs: ±2.5v
Temperature: 22.5C.

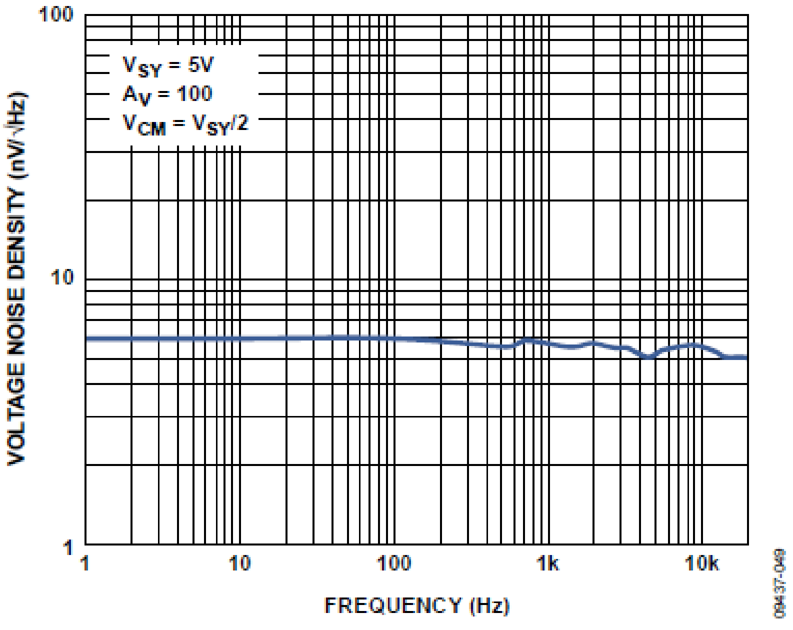
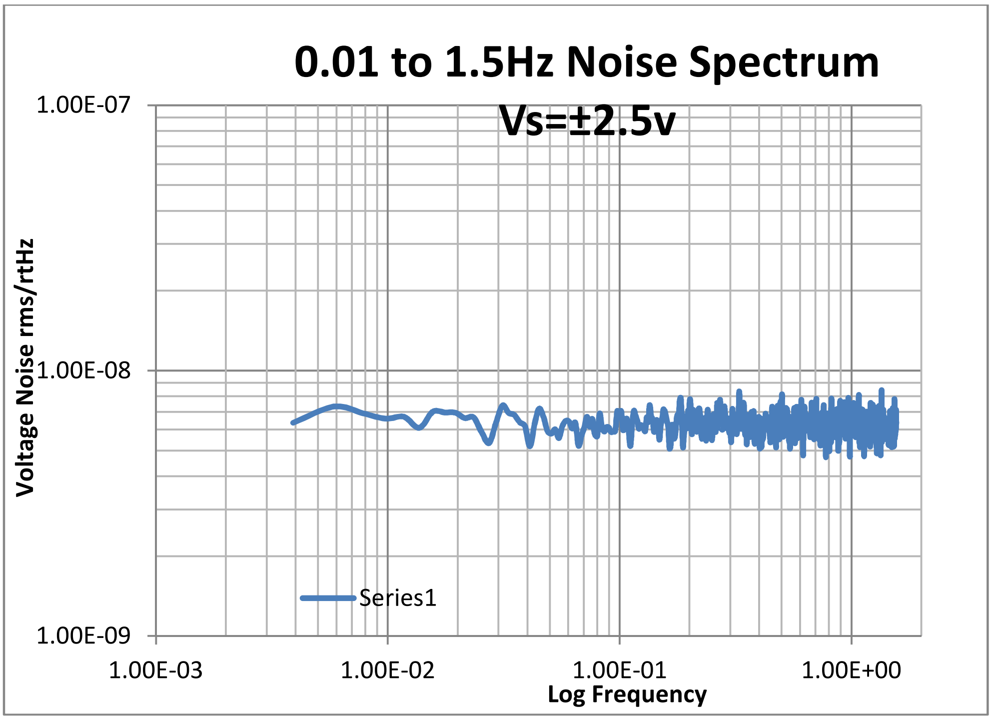
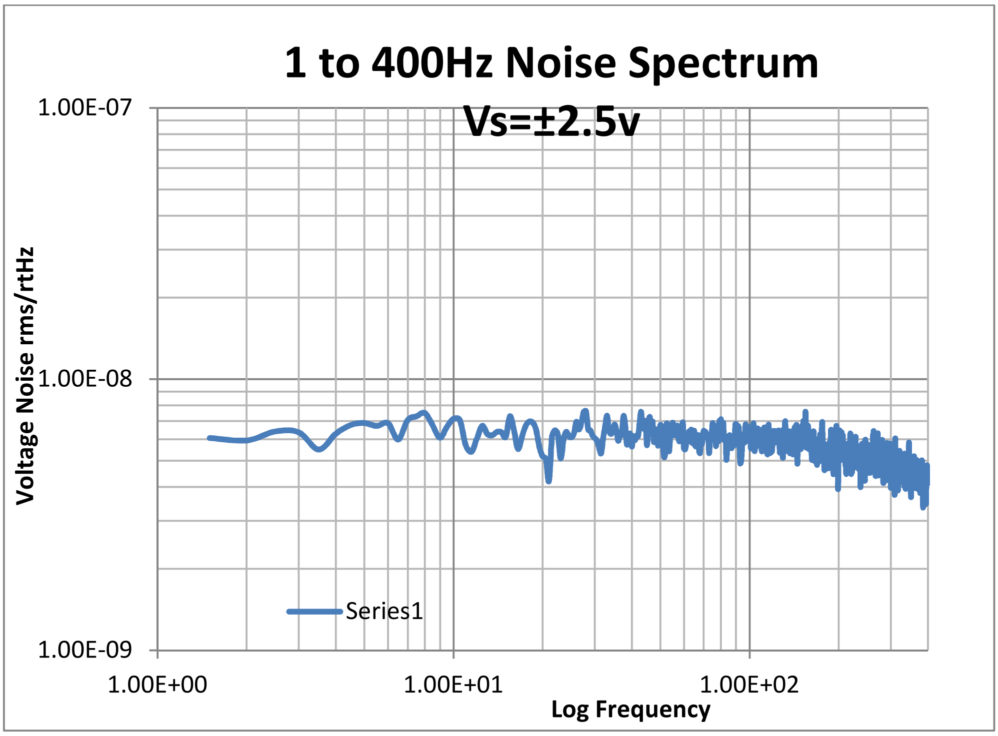


Figure 54. Voltage Noise Density vs. Frequency

Voltage noise data from data sheet for comparison





4.3 ADA4528 #1 Current Noise Spectrum

Test conditions:
Vs: ±2.5v
Temperature: 22C

As can be seen below, this device behaves in a much more predictable manner than the OPA188. The data below is in line with the manufacturers current noise data. The plots are referred to the input.

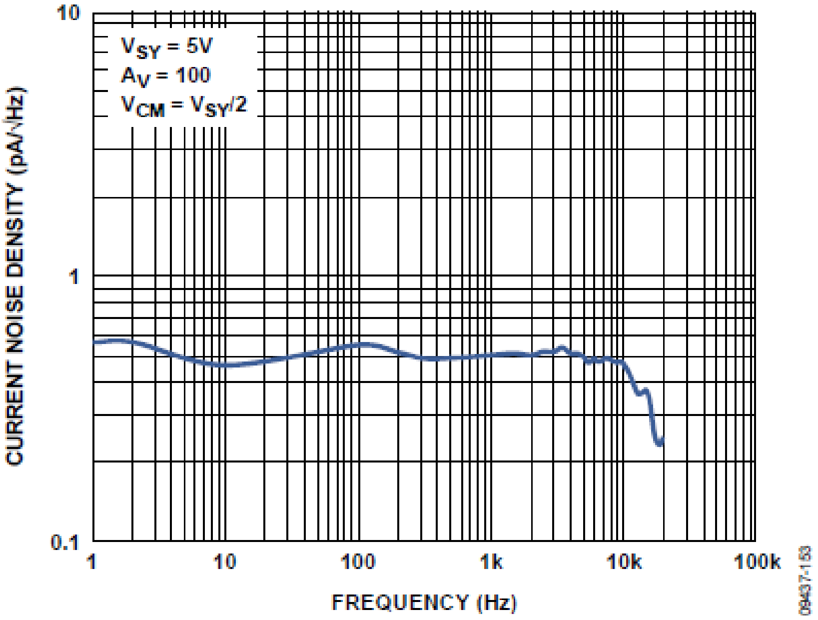
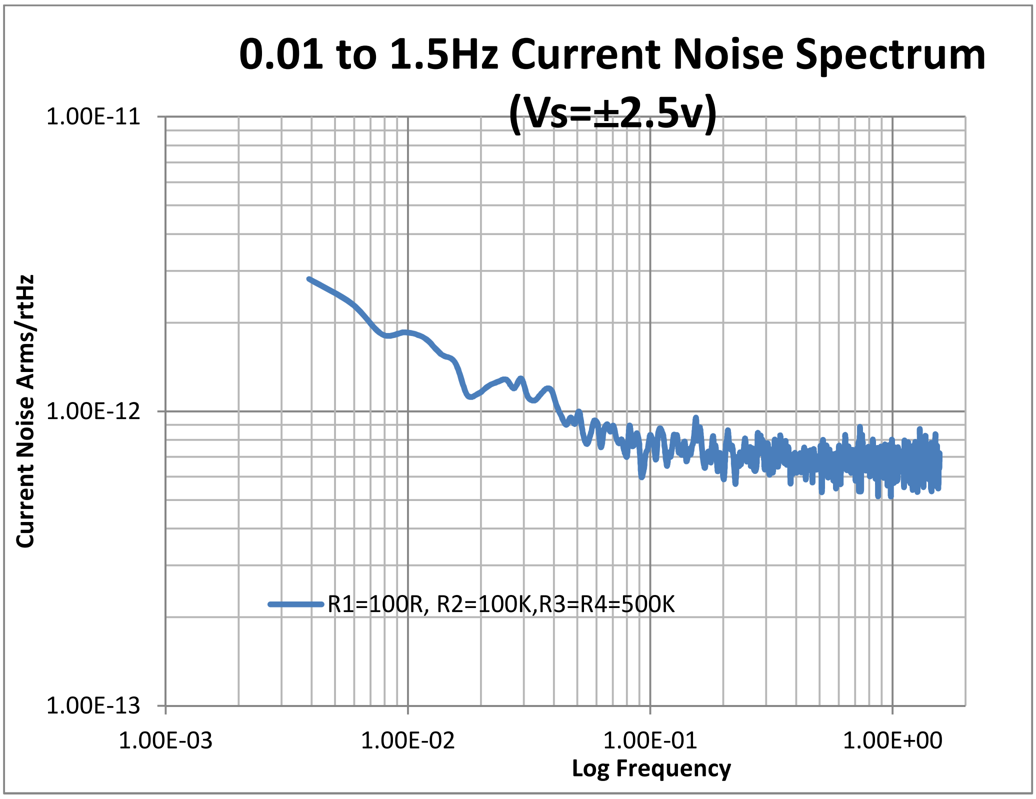
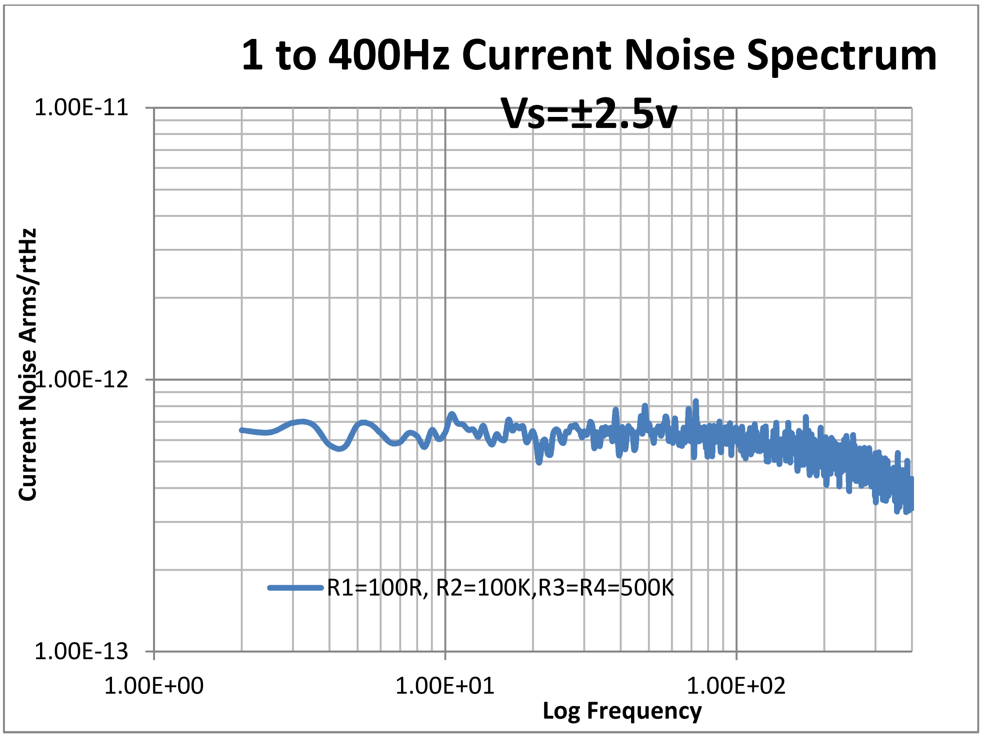


Figure 55. Current Noise Density vs. Frequency

Current noise from data sheet for comparison




1 to 400Hz Current Noise Spectrum
Vs=±2.5v
Current Noise Arms/rtHz
1.00E-11
1.00E-12
1.00E-13
1.00E+00
1.00E+01
1.00E+02
Log Frequency
R1=100R, R2=100K,R3=R4=500K

5 Results for ADA4528 #2

5.1 ADA4528 #2 Voltage Noise 0.1 to 10Hz

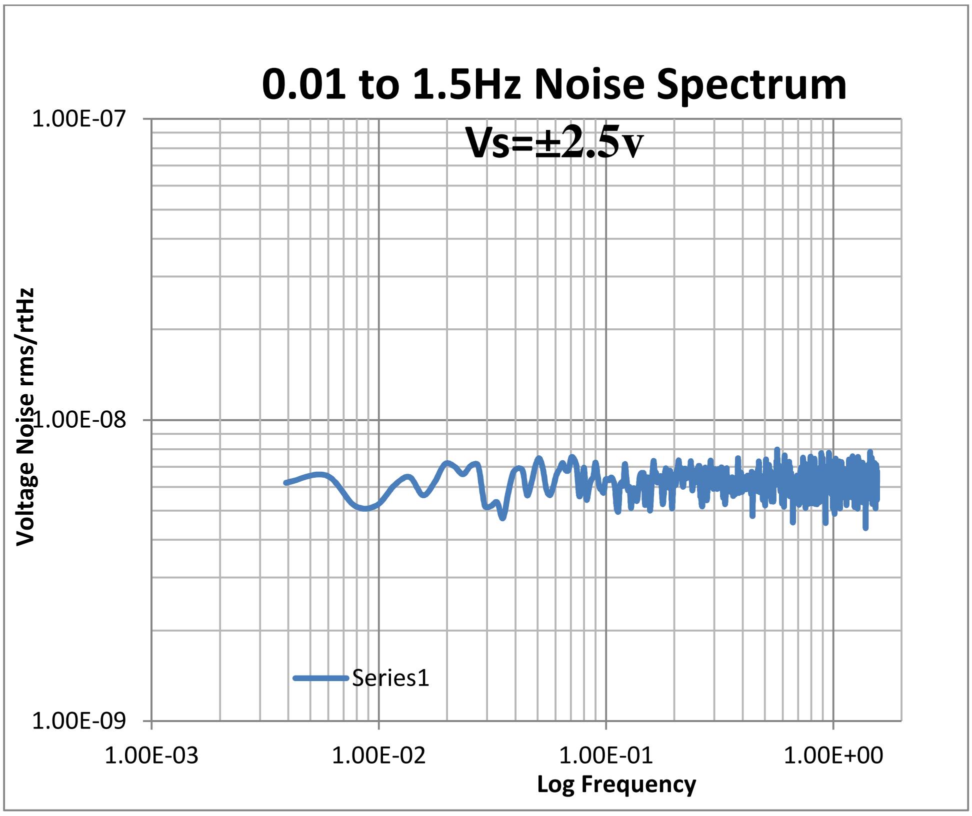
Test conditions:
Vs: ±2.5v
Temperature: 22C.

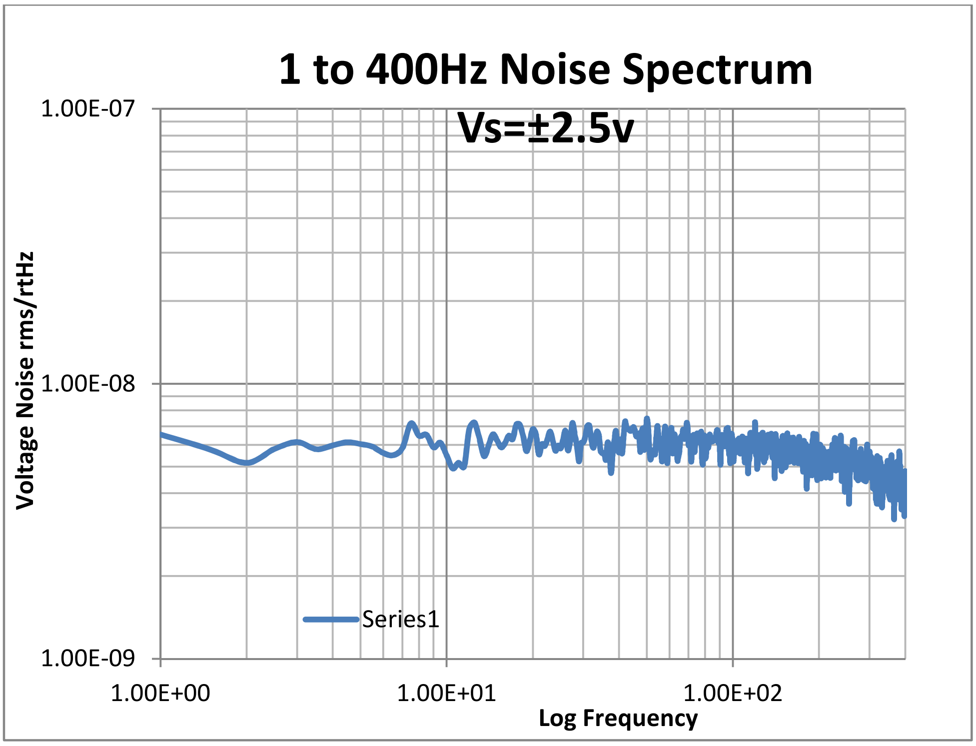
The noise of the device tested is as follows:
Voltage noise rms: 20.6nV

Voltage noise peak-peak (ie 6δ): 124nV
(cf to data sheet typical: 99nV)

5.2 ADA4528 #2 Voltage Noise Spectrum

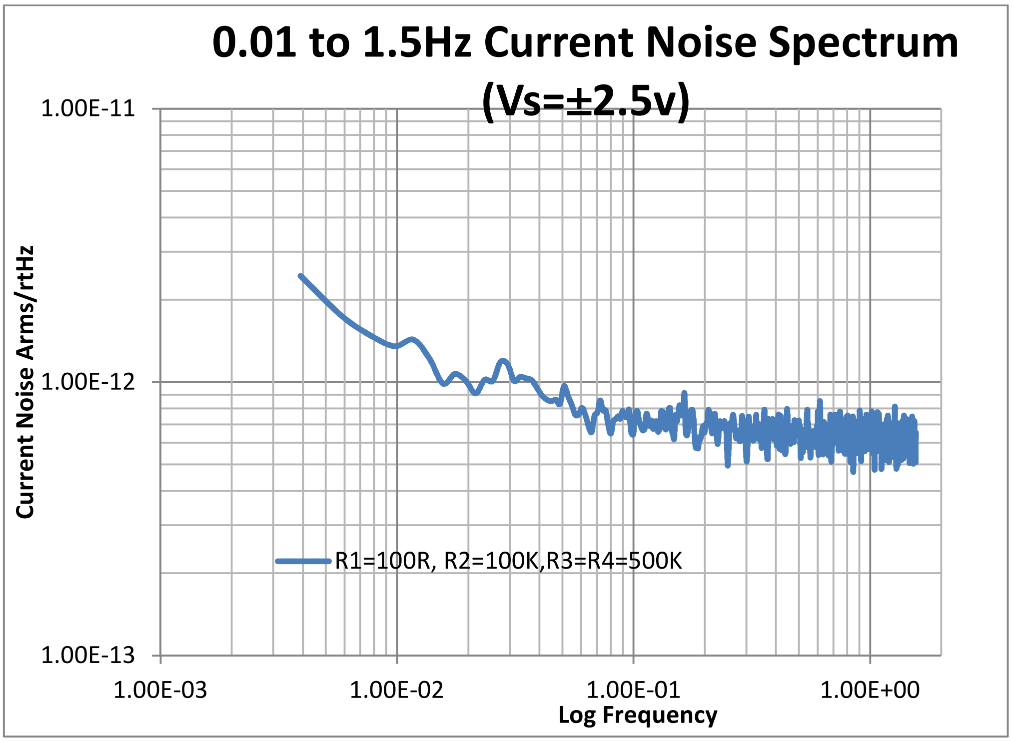
Test conditions:
Vs: ±2.5v
Temperature: 23C.

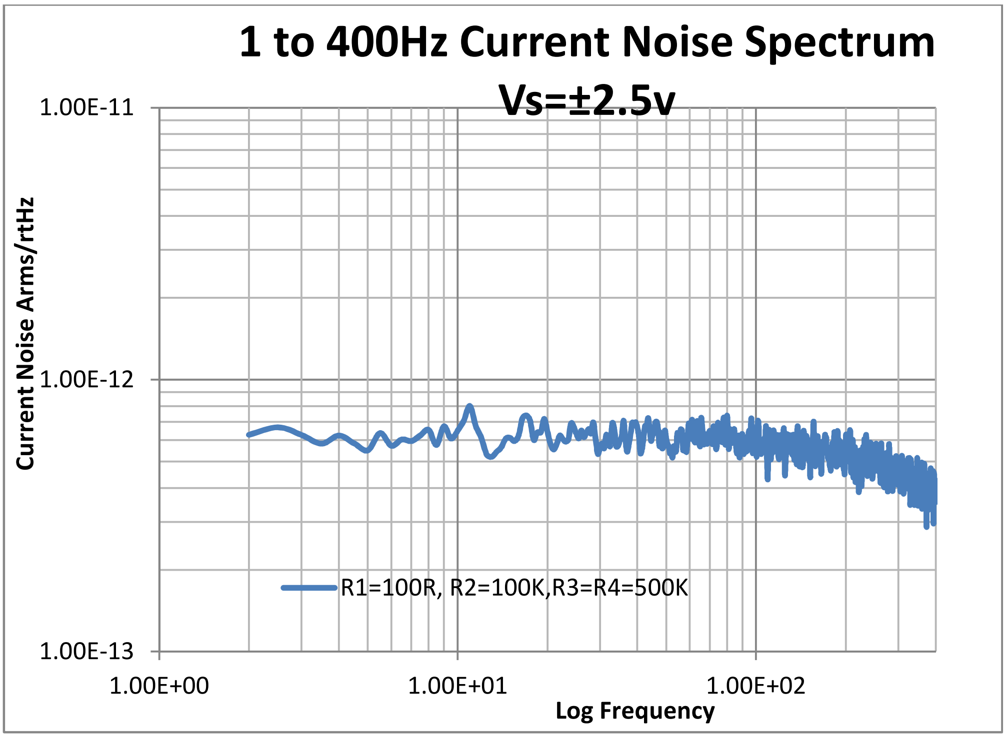




5.3 ADA4528 #2 Current Noise Spectrum

Test conditions:
Vs: ±2.5v
Temperature: 22.5C




1 to 400Hz Current Noise Spectrum
Vs=±2.5v
Current Noise Arms/rtHz
1.00E-11
1.00E-12
1.00E-13
1.00E+00
1.00E+01
1.00E+02
Log Frequency
R1=100R, R2=100K,R3=R4=500K

6 Results for CS3002 #1

6.1 CS3002 #1 Voltage Noise 0.1 to 10Hz

Test conditions:
Vs: ±2.5v
Temperature: 24C.

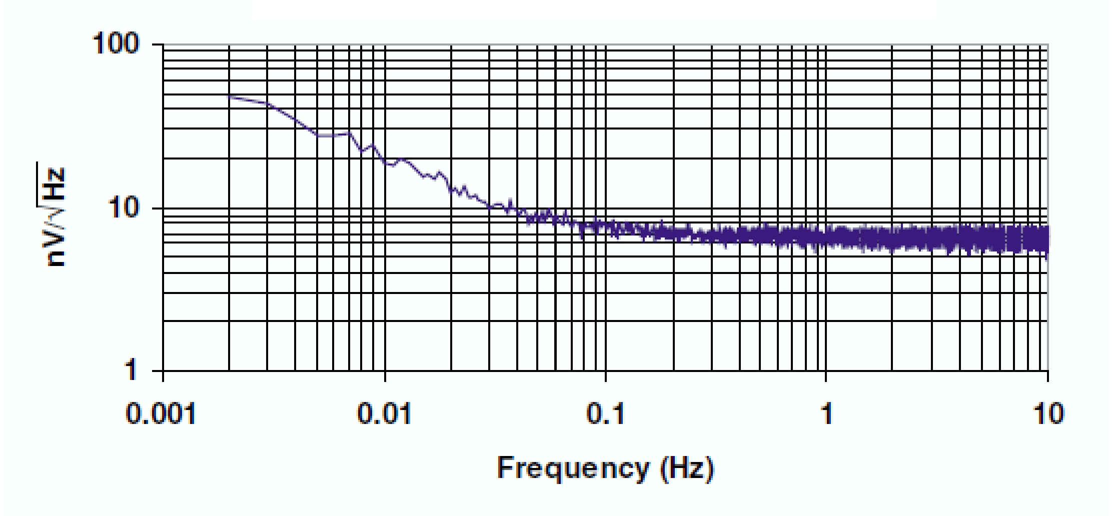
The noise of the device tested is as follows:
Voltage noise rms: 19.4nV

Voltage noise peak-peak (ie 6δ): 117nV
(cf to data sheet typical: 125nV)

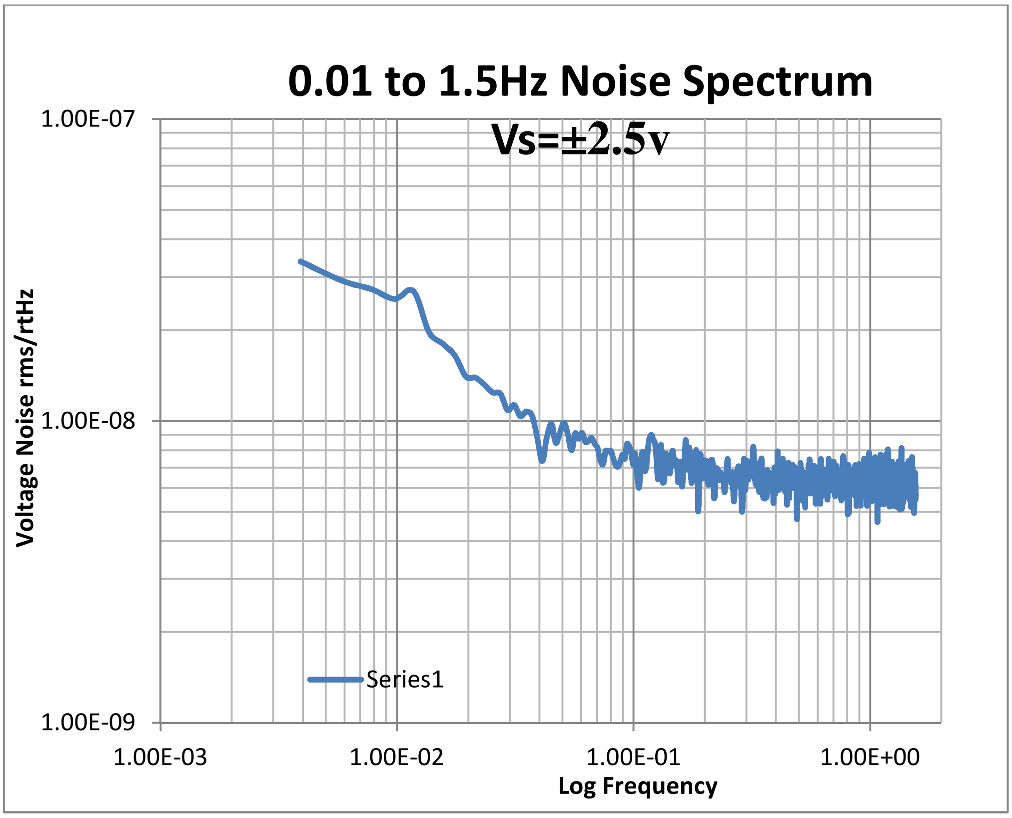
6.2 CS3002 #1 Voltage Noise Spectrum

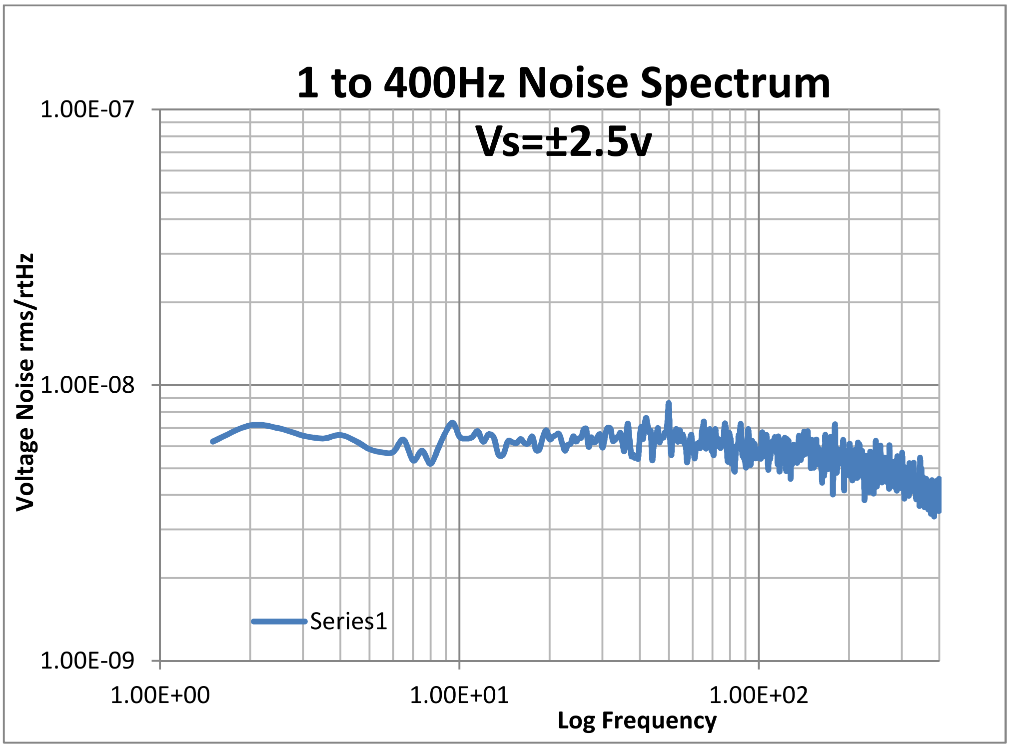
Test conditions:
Vs: ±2.5v
Temperature: 24C.

Note: This device was unstable with the feedback resistor used for voltage noise measurement, and required 4.7nF between output and inverting input for stability. This limits the voltage noise measurement bandwidth to 340Hz. However the 1/f corner frequency at around 80mHz is in agreement with the manufacturers device data. This instability is probably due to the unusually high open loop gain which is ~300dB at DC, rolling off at ***~100dB/decade*** over ~500 to 60KHz.



Voltage noise data from data sheet for comparison


0.01 to 1.5Hz Noise Spectrum
Vs=±2.5v
Voltage Noise rms/rtHz
1.00E-07
1.00E-08
1.00E-09
1.00E-03
1.00E-02
1.00E-01
1.00E+00
Log Frequency
Series1


1 to 400Hz Noise Spectrum
Vs=±2.5v
Voltage Noise rms/rtHz
1.00E-07
1.00E-08
1.00E-09
1.00E+00
1.00E+01
1.00E+02
Log Frequency
Series1

6.3 CS3002 #1 Current Noise Spectrum

Test conditions:
Vs: ±2.5v
Temperature: 22.5C

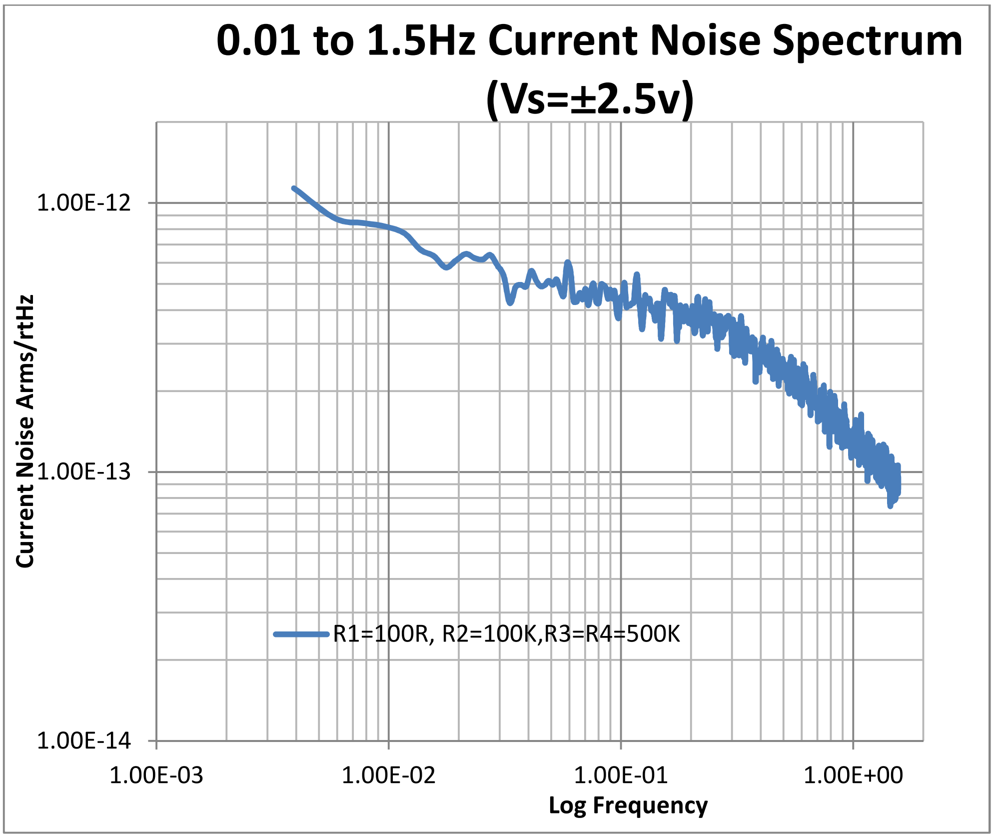
The device was unstable with the feedback resistor and the large input resistance used for the test, and required 1nF between the output and the inverting input for stability. This limits the noise bandwidth to 1.5KHz which is fine for this test, however the capacitors impedance will cause errors in the results as it approaches the sense resistor impedance (at ~320Hz).

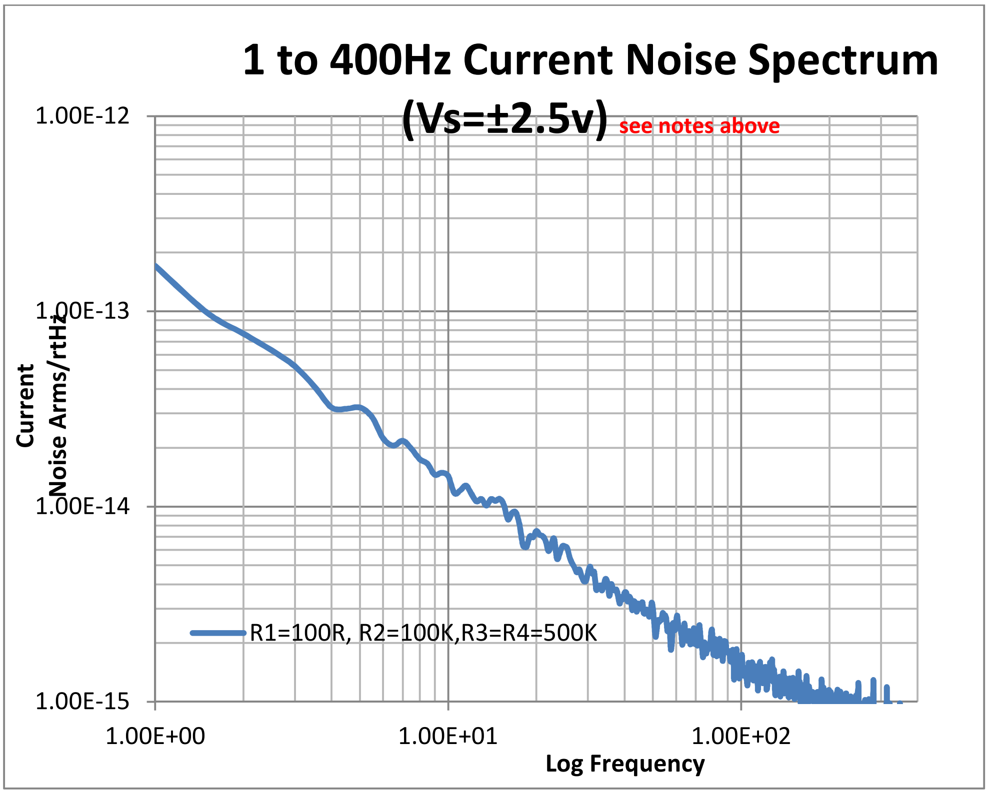
It is also clear that – like the OPA188, the large sense resistors cause issues with the device, in this case the response begins to roll off at around 250mHz, giving results above this frequency which are clearly incorrect with this setup. (This test setup is limited by the sense resistor noise, which on the noise plots below is equivalent to a white noise floor around 0.182pA/√Hz).

It is not totally clear from this data, but the current noise appears to flatten off at ~80mHz before the rolling off at ~250mHz. This effect is more pronounced on the second device tested (see below).

The manufacturer specifies 2pA/√Hz at 1Hz. It is clear however that even ignoring the roll off as the frequency increases beyond 250mHz , that the current noise is somewhat better than this.

Testing in transimpedance amplifier configuration (R1=open, R2=100K, R3=R4=0R) was not undertaken as in this arrangement, the noise floor is limited by the analyser to around 70pA/√Hz at 10mHz – see section 2.4 above).


0.01 to 1.5Hz Current Noise Spectrum (Vs=±2.5v)
Current Noise Arms/rtHz
1.00E-12
1.00E-13
1.00E-14
1.00E-03
1.00E-02
1.00E-01
1.00E+00
Log Frequency
R1=100R, R2=100K,R3=R4=500K


1 to 400Hz Current Noise Spectrum (Vs=±2.5v)
see notes above
Current Noise Arms/rtHz
1.00E-12
1.00E-13
1.00E-14
1.00E-15
1.00E+00
1.00E+01
1.00E+02
Log Frequency
R1=100R, R2=100K,R3=R4=500K

7 Results for CS3002 #2

7.1 CS3002 #2 Voltage Noise 0.1 to 10Hz

Test conditions:
Vs: ±2.5v
Temperature: 22C.

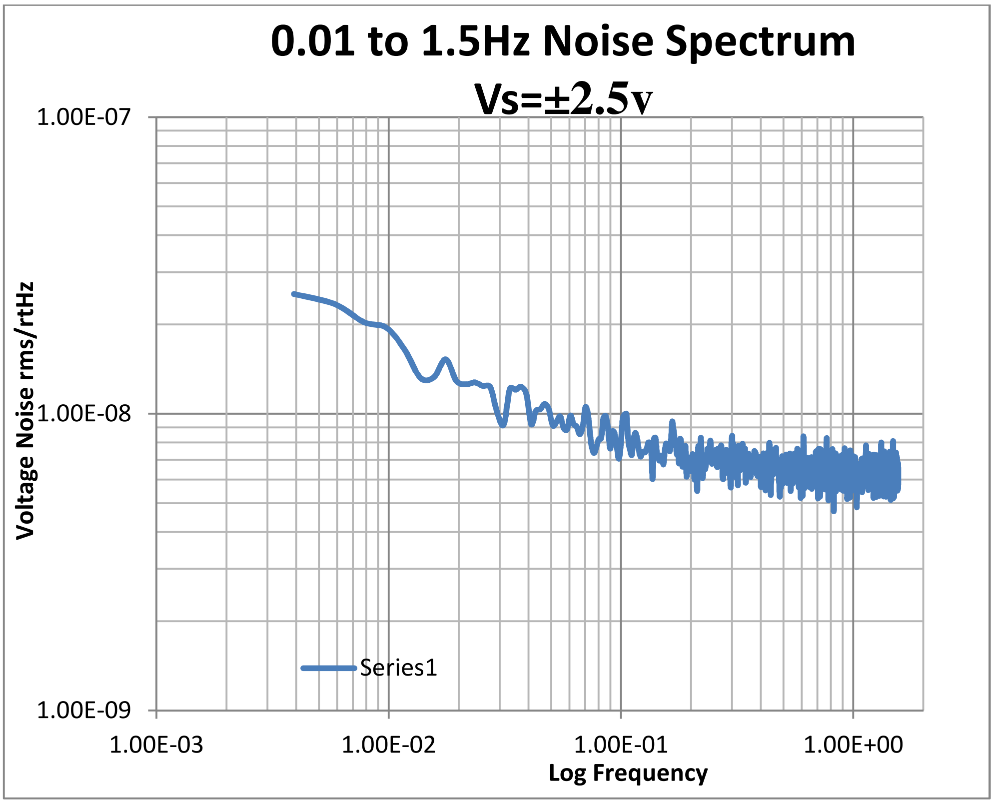
The noise of the device tested is as follows:
Voltage noise rms: 13.6nV

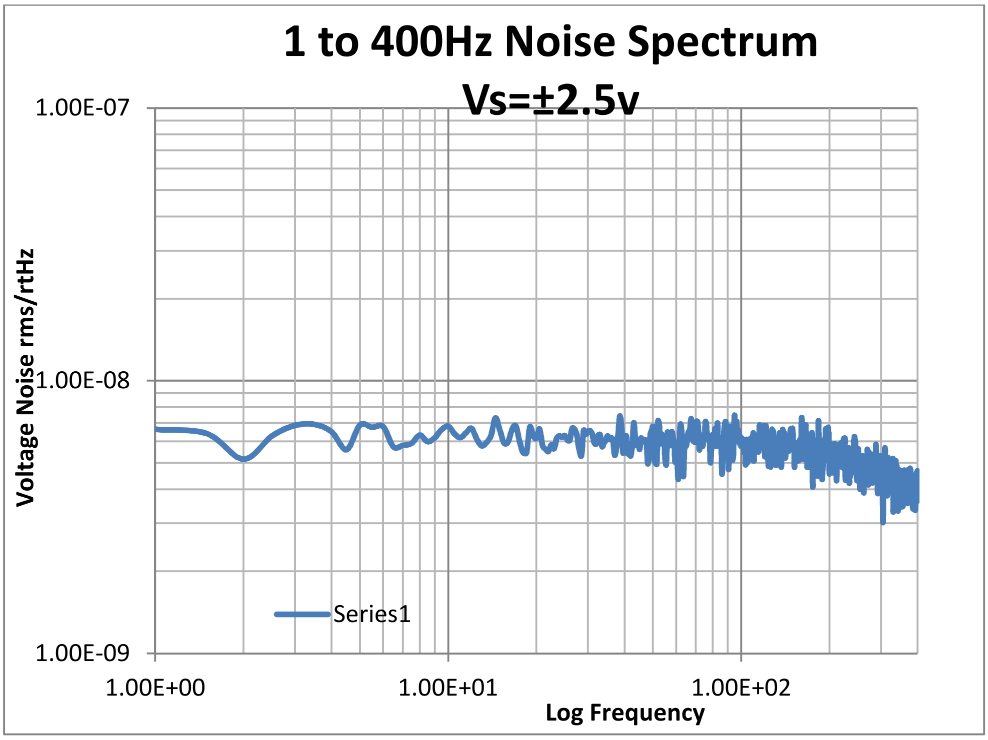
Voltage noise peak-peak (ie 6δ): 81.8nV
(cf to data sheet typical: 125nV)

7.2 CS3002 #2 Voltage Noise Spectrum

Test conditions:
Vs: ±2.5v
Temperature: 24C.

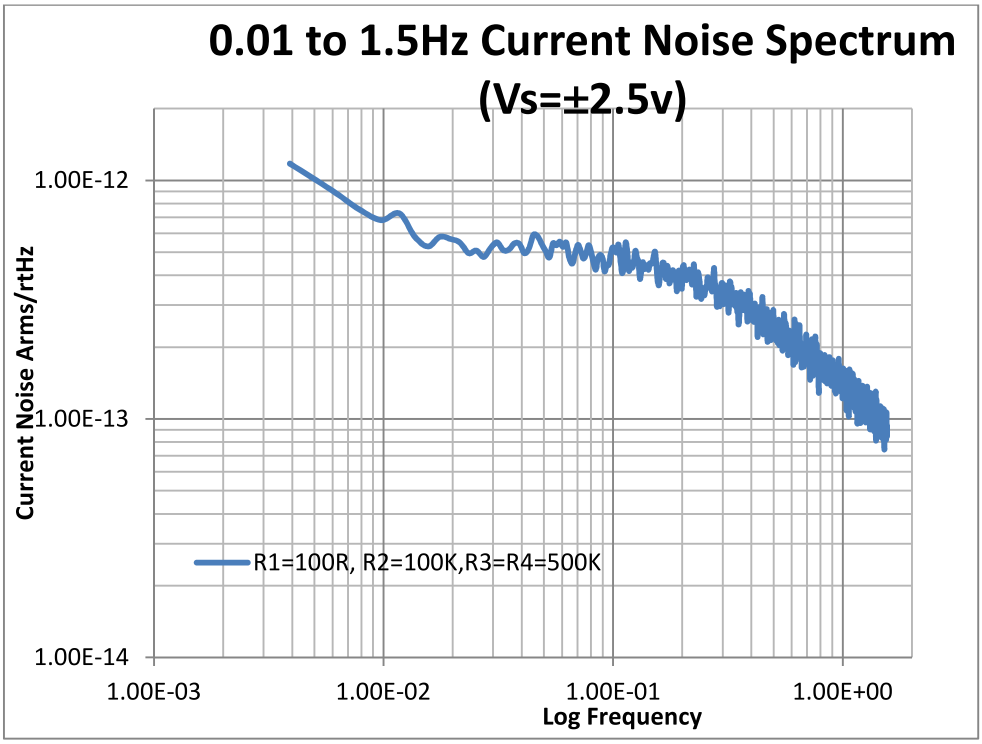
Note – again this device required stabilisation with 4.7nF between output and inverting input, and this limits the noise measurement as before to ~340Hz

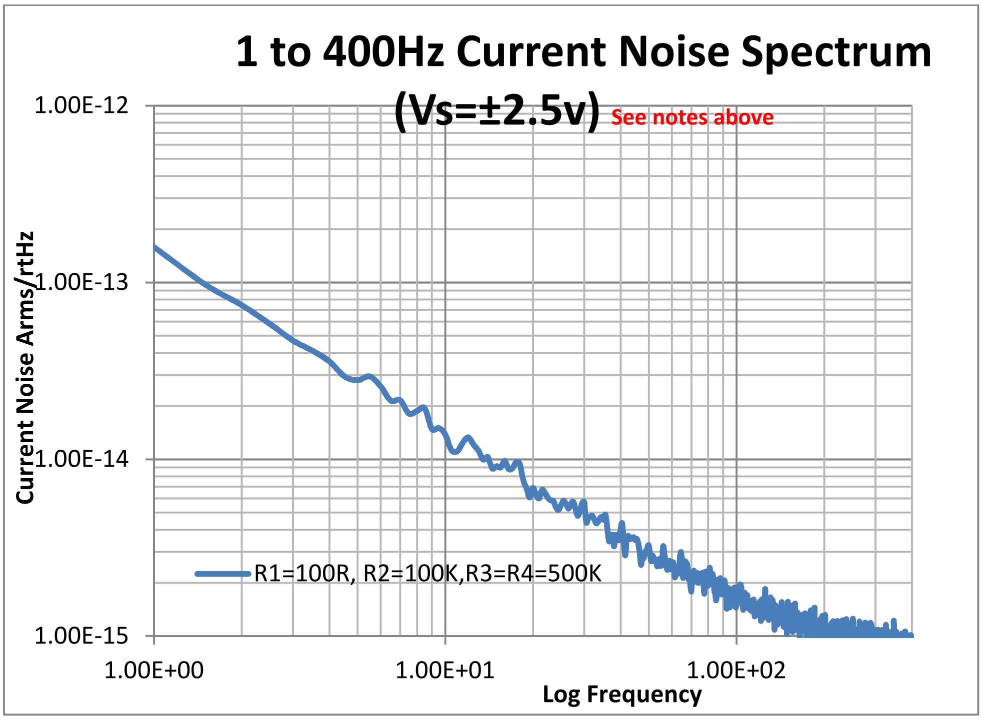




7.3 CS3002 #2 Current Noise Spectrum

Test conditions:
Vs: ±2.5v
Temperature: 22.5C
Note – again the device had to be stabilised with a 1nF capacitor between output and inverting input. Results are similar to the previous device except that the noise flattens off around 20mHz before the rolling off at ~200mHz. This roll-off is most likely caused by the large sense resistors (see 6.3 above), and therefore sets the upper limiting bandwidth for the measurement (results above this frequency are not valid).


0.01 to 1.5Hz Current Noise Spectrum (Vs=±2.5v)
Current Noise Arms/rtHz
1.00E-12
1.00E-13
1.00E-14
1.00E-03
1.00E-02
1.00E-01
1.00E+00
Log Frequency
R1=100R, R2=100K,R3=R4=500K


1 to 400Hz Current Noise Spectrum (Vs=±2.5v)
See notes above
Current Noise Arms/rtHz
1.00E-12
1.00E-13
1.00E-14
1.00E-15
1.00E+00
1.00E+01
1.00E+02
Log Frequency
R1=100R, R2=100K,R3=R4=500K

8 Results for OP180 #1

8.1 OPA180 #1 Voltage Noise 0.1 to 10Hz

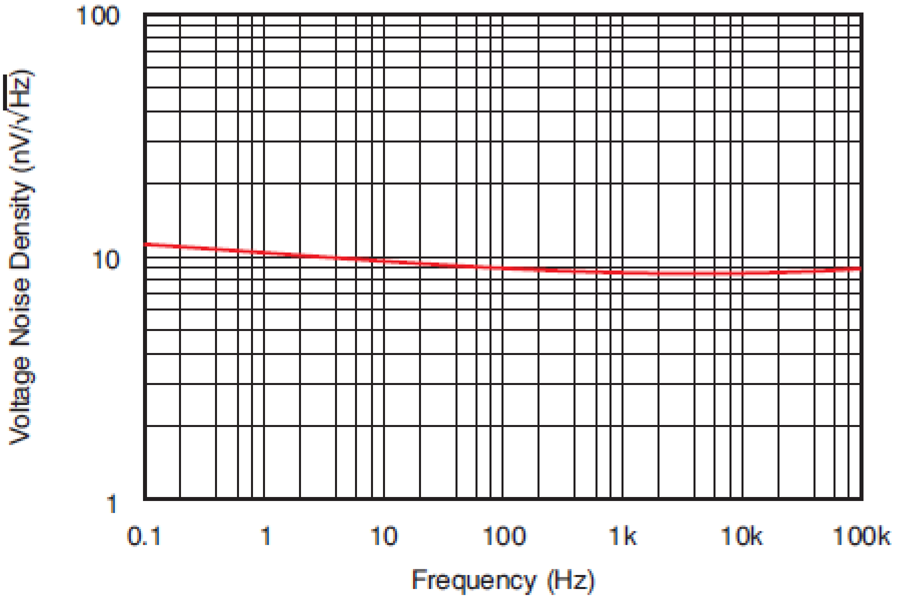
Test conditions:
Vs: ±2.5v
Temperature: 22C.

The noise of the device tested is as follows:
Voltage noise rms: 17.3nV

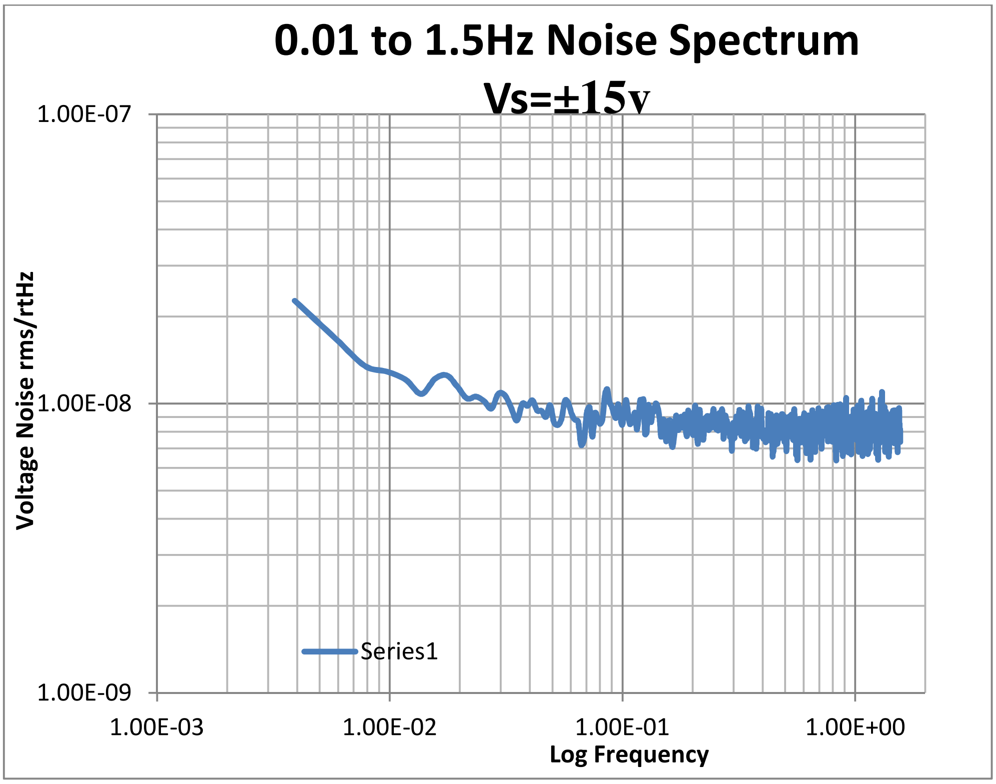
Voltage noise peak-peak (ie 6δ): 103.5nV
(cf to data sheet typical: 250nV)

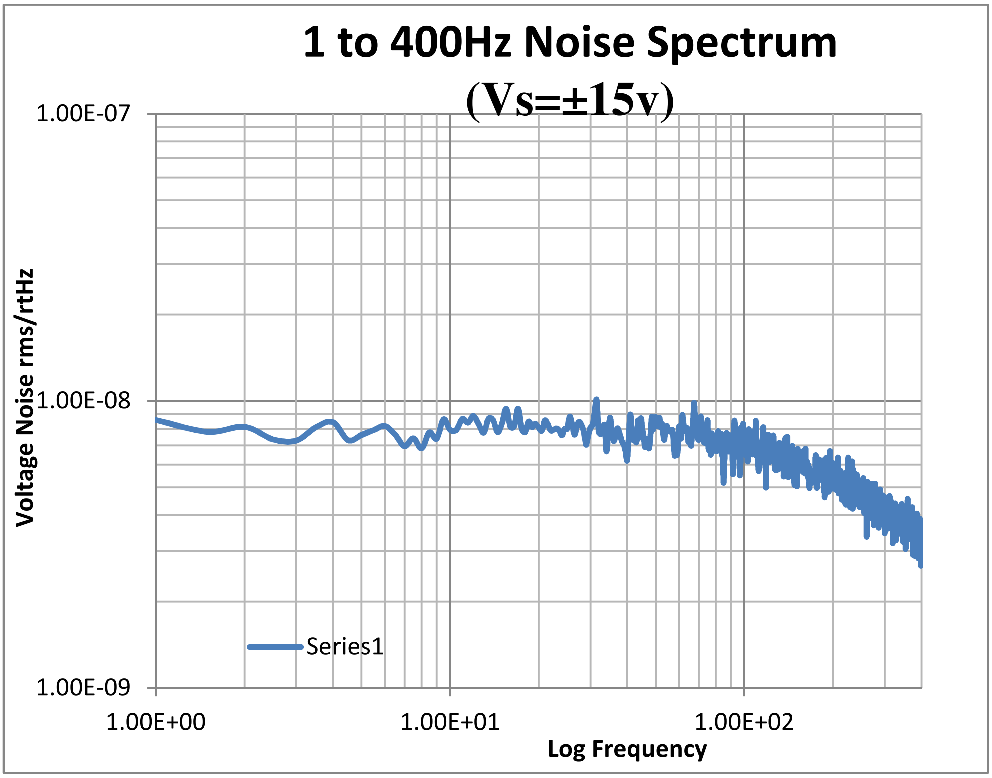
8.2 OPA180 #1 Voltage Noise Spectrum

Test conditions:
Vs: ±2.5v
Temperature: 22C.



Voltage noise data from data sheet for comparison

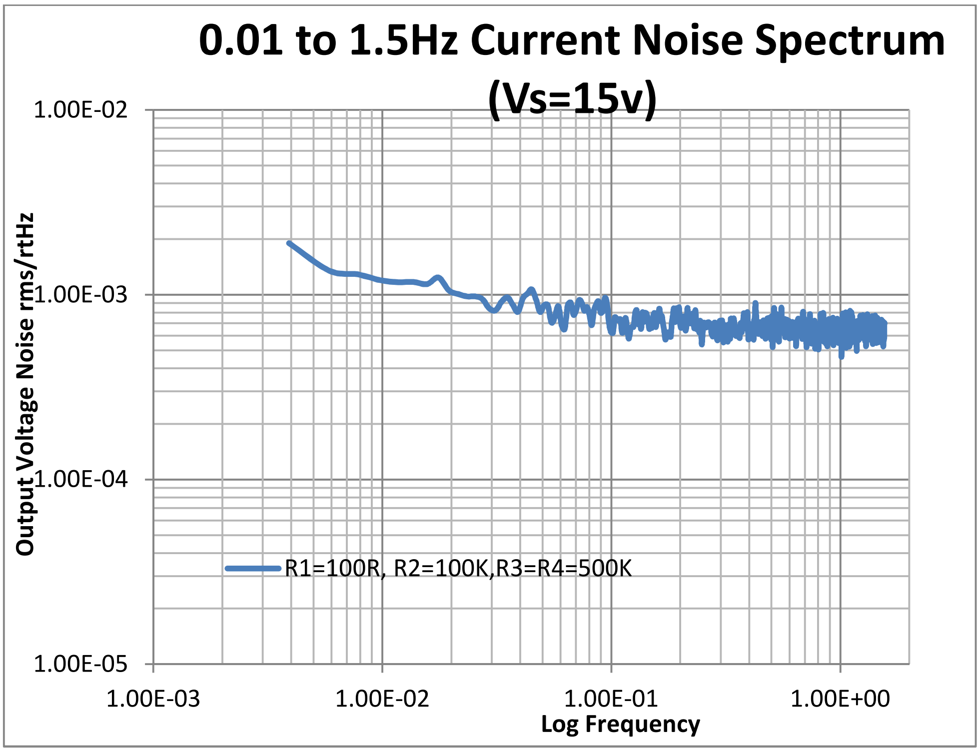


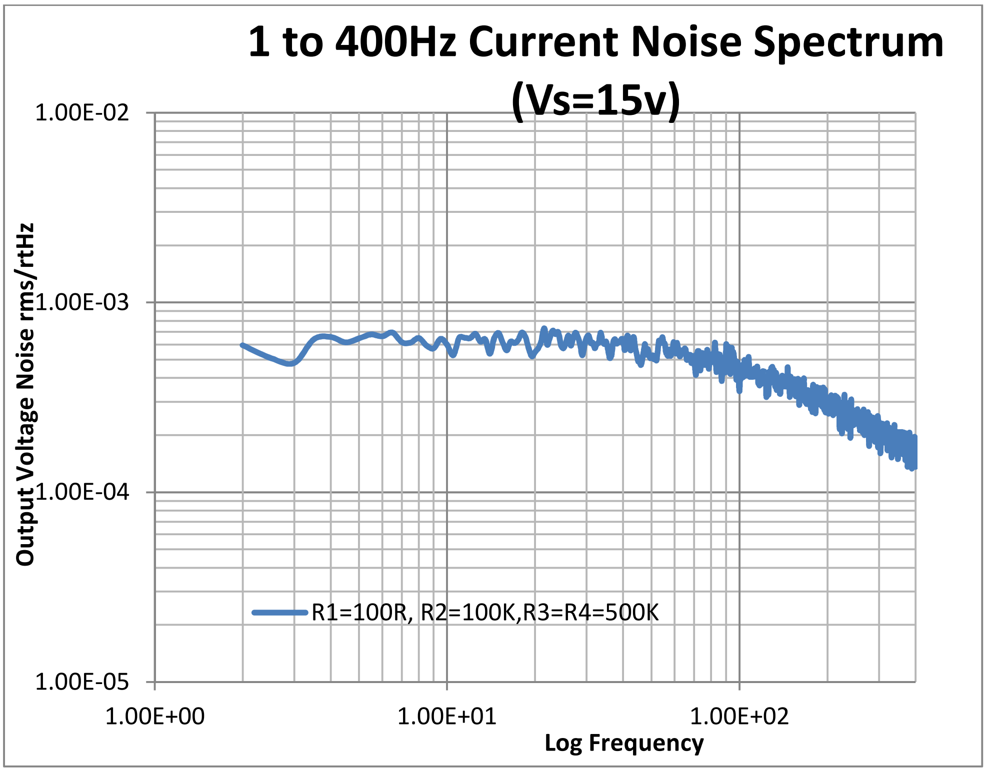


8.3 OPA180 #1 Current Noise Spectrum

Test conditions:
Vs: ±2.5v
Temperature: 22C

This device is from the same family of parts as the OPA188 previously tested as expected has very similar issues when used in circuits with high input impedances (Higher than expected levels of noise and offset voltage). Again since we are uncertain of the reason for this, the current noise spectrum is given below referred to the output, and from it we can infer an upper limit to the current noise of 1.7pA/√Hz at 10mHz)

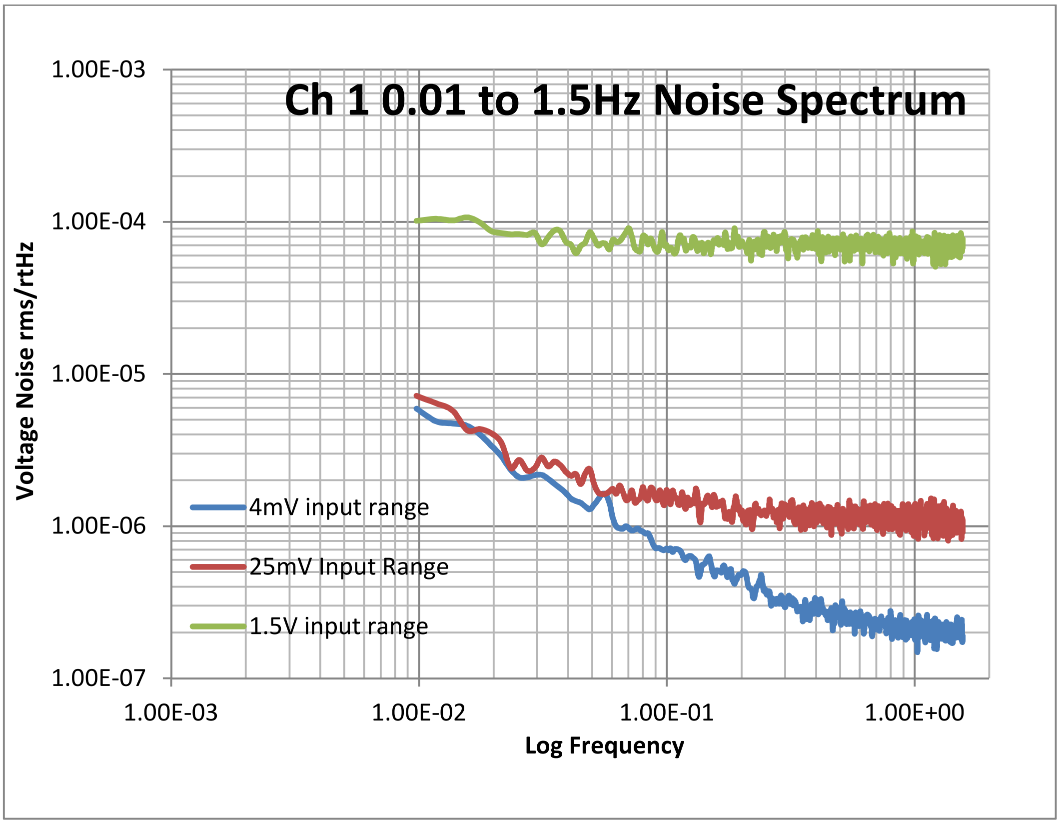


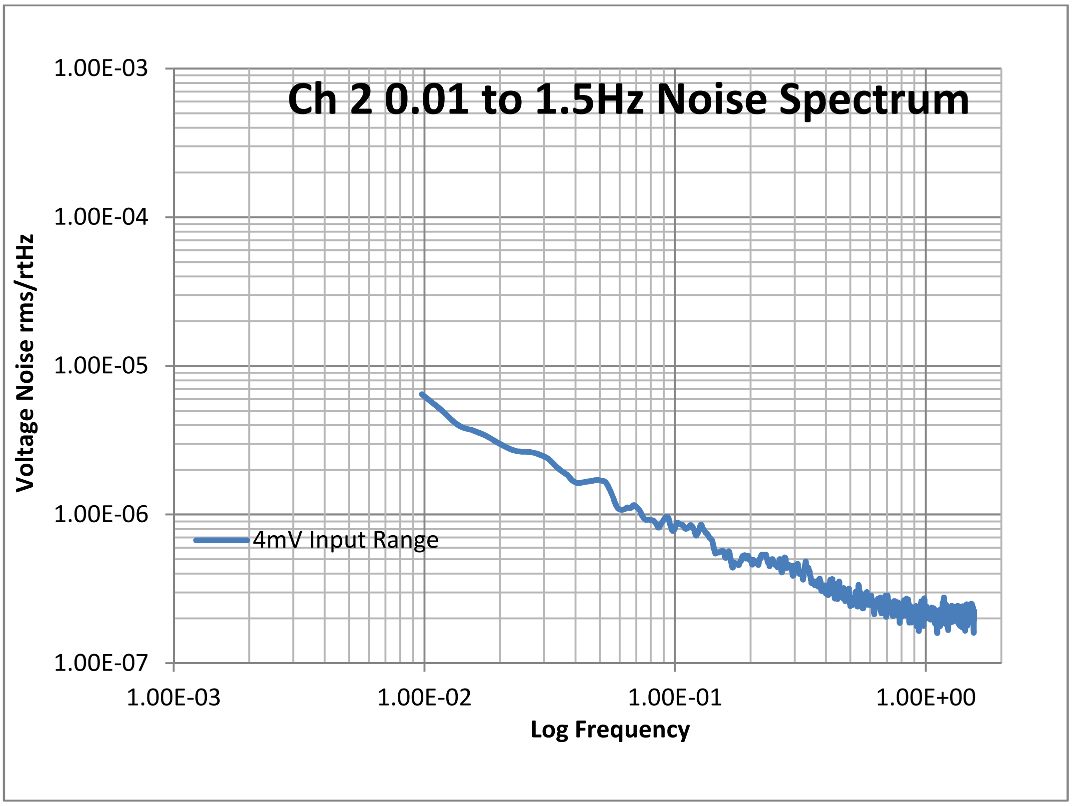


This device is clearly closely related to the OPA188, and may well be simply a different production grade of the same die. In noise terms it is very similar in performance to the 0PA188, and therefore no further devices were tested

Appendix A Agilent 35670A Noise floor PSD

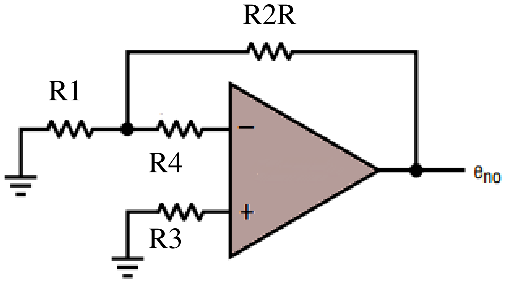
Device S/N: MY42507469. With various input range settings





Appendix B Noise Test Circuit Analysis

The generic circuit for noise analysis is shown below.
For Voltage noise measurements, R3 and R4 are not used, and are populated with zero ohm links.
For current noise measurements they are used to sense the current noise at each input.



In the following expressions, the noise is referred to the op-amp non-inverting input. It can be referred to the output by multiplying by the noise (non inverting) gain.

Resistor noise contribution from all components:-

$$v_{rni} = [4kt\frac{R_1R_2}{R_1+R_2} + 4ktR_3 + 4ktR_4]^{0.5}$$

Note for voltage noise measurement, R_3=R_4=0 so the last 2 terms disappear

Opamp noise contribution from voltage and current noise:-

$$v_{oni} = [{v_n}^2 + (i_{n2}R_3)^2 + (i_{n1}[\frac{R_1R_2}{R_1+R_2} + R_4])^2]^{0.5}$$

Note for voltage noise measurement, R_3=R_4=0, and these terms disappear. For current noise measurement, because of the high gain used, R_4>>R_1||R_2 , and the i_{n1} noise term reduces to $i_{n1}R_4$

k=Boltzmann constant
t = temperature
v_n=op-amp input referred voltage noise
i_{n1}=inverting input current noise
i_{n2}=non-inverting input current noise

The following Scilab script may be used to show how specific component selections may be used to make voltage or current noise dominate the total noise.

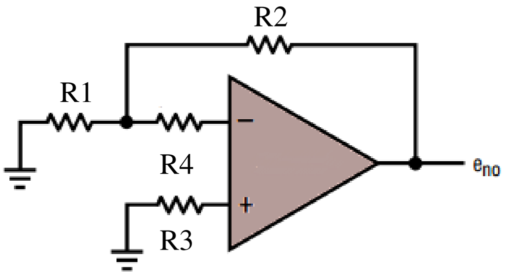
```
//*****************************************************************
//Program to allow investigation of noise sources in the
//opamp noise test jig per schematic E00142
//13/11/15 DMH
//Version 1.0
//*****************************************************************
clc;

//***********************
// Constants

k = 1.3806504E-23;     // Boltzmans const
t = 300;               // temperature in kelvin

//***********************
// Opamp Noise Parameters

x = input ("Select Amplifier (enter a ADA4528, b LT1677, c OPAx180, d CS3002 or e OPAx88)", "string")
if x== 'a' then
   // for ADA4528
   printf ('\n ADA4528 ');
   vn = 5.9E-9;   //input referred voltage noise in V/rtHz
   in = 0.5E-12;  //input referred current noise in A/rtHz
elseif x=='b' then
   // for LT 1677
   printf ('\n LT1677 ');
   vn = 3.2E-9;
   in = 0.3E-12;
elseif x=='c' then
   // for OPAx180
   printf ('\n OPAx180 ');
   vn = 10E-9;
   in = 0.01E-12;
   // ** Cant use circuit below to measure current noise - its too low -if you increase R3,4, the resistor noise
   // starts to dominate**
elseif x=='d' then
   // for CS3002
   printf ('\n CS3002 ');
   vn = 6E-9;
   in = 2E-12;
else
   // for OPAx88
   printf ('\n OPAx88 ');
   vn = 8.8E-9;
   in = 0.007E-12;
end

printf ('Vn = %3.3e V/rtHz  ',vn);
printf ('In = %3.3e A/rtHz\n',in);
printf('\n');
//***********************

// Circuit Components

x = input ("Voltage or Current Noise test (enter v or c)","string")
if x=='v' then
   printf ('\n Voltage Noise Test\n');
   //Use the following for voltage noise testing
   R1 = 10;       // Input resistor (input grounded)
   R2 = 100E3;    // Feedback Resistor
   R3 = 0;        // Non inverting input to Gnd
   R4 = 0;        // inverting input to Input resistor/Feedback resistor junction
else
   printf ('\n Current Noise Test\n');
   // Use  the following for Current noise testing
   R1 = 100;      // Input resistor (input grounded)
   R2 = 100E3;    // Feedback Resisor
```

```
    R3 = 500E3;      // Non inverting input to Gnd
    R4 = 500E3;      // inverting input to Input resistor/Feedback resistor junction
end

//************************
// Noise components referred to
// non inverting input

ResistorNoise = (4*k*t*((R1*R2/(R1+R2))+R3+R4))^0.5;

VoltageNoise = vn;

CurrentNoise = ((in^2)*((R3^2)+((R1*R2/(R1+R2))+R4)^2))^0.5;
printf('\n');
printf('Total Input Referred Resistor Noise     = %3.3e V/rtHz\n', ResistorNoise);
printf('Total Input Referred voltage Noise      = %3.3e V/rtHz\n', VoltageNoise);
printf('Total Input Referred Current Noise      = %3.3e V/rtHz\n', CurrentNoise);

TotalNoise =(ResistorNoise^2 + VoltageNoise^2 + CurrentNoise ^2)^0.5;

printf('\n');
printf('Total Input Referred Noise             = %3.3e V/rtHz\n', TotalNoise);

TotalOutputNoise = TotalNoise * (1+(R2/R1))

printf('\n');
printf('Total Noise at output               = %3.3e V/rtHz\n', TotalOutputNoise);

printf('\n');
printf('For current noise setup, you can calculate the actual current noise by \n');
printf('taking the output noise, and dividing by (1001x(rt2)xR) where [R=R3=R4]\n');
printf('\n');
printf('For voltage noise setup, calculate the actual voltage noise by \n');
printf('taking the output noise and dividing by 10001 \n');
printf('\n');
printf('If device current noise is very low ie ~10s of fA, then you need very large \n');
printf('resistors (~100s of MR) to get the current noise to dominate - OPAx188 and OPAx88\n');
printf('- This is not really practical!')
```

Appendix C **Resistor selection**

All resistors have a defined temperature coefficient (usually specified in the manufacturers data as a worst case for all values of that model type). For low noise applications select metal film, thin film or metal foil types etc with tempco <25ppm/C.
Resistors used in the noise tests above are all 10ppm/C or less.

To illustrate the effect of resistor temperature coefficient on noise performance, consider the voltage noise test case above:



R1=10R
R2=100KR
R3=R4=0R

A typical non controlled thermal environment (eg a laboratory) may have the following temperature characteristics (taken from real data):

$0.2K/\sqrt{Hz}$ at 10^{-3}Hz
$0.07K/\sqrt{Hz}$ at 10^{-2}Hz
$0.01K/\sqrt{Hz}$ at 10^{-1}Hz

If the op-amp has an offset voltage of 1mV, and we make R_2 alone a 100ppm/C resistor, then the additional (non-inverting) input referred noise caused by this temperature fluctuation will be

$$v_{ni} = v_{off} \frac{\delta R_2 \tilde{t}}{R_1 + R_2}$$

δR_2= R_2 resistance change per ºC in ohms
This gives:

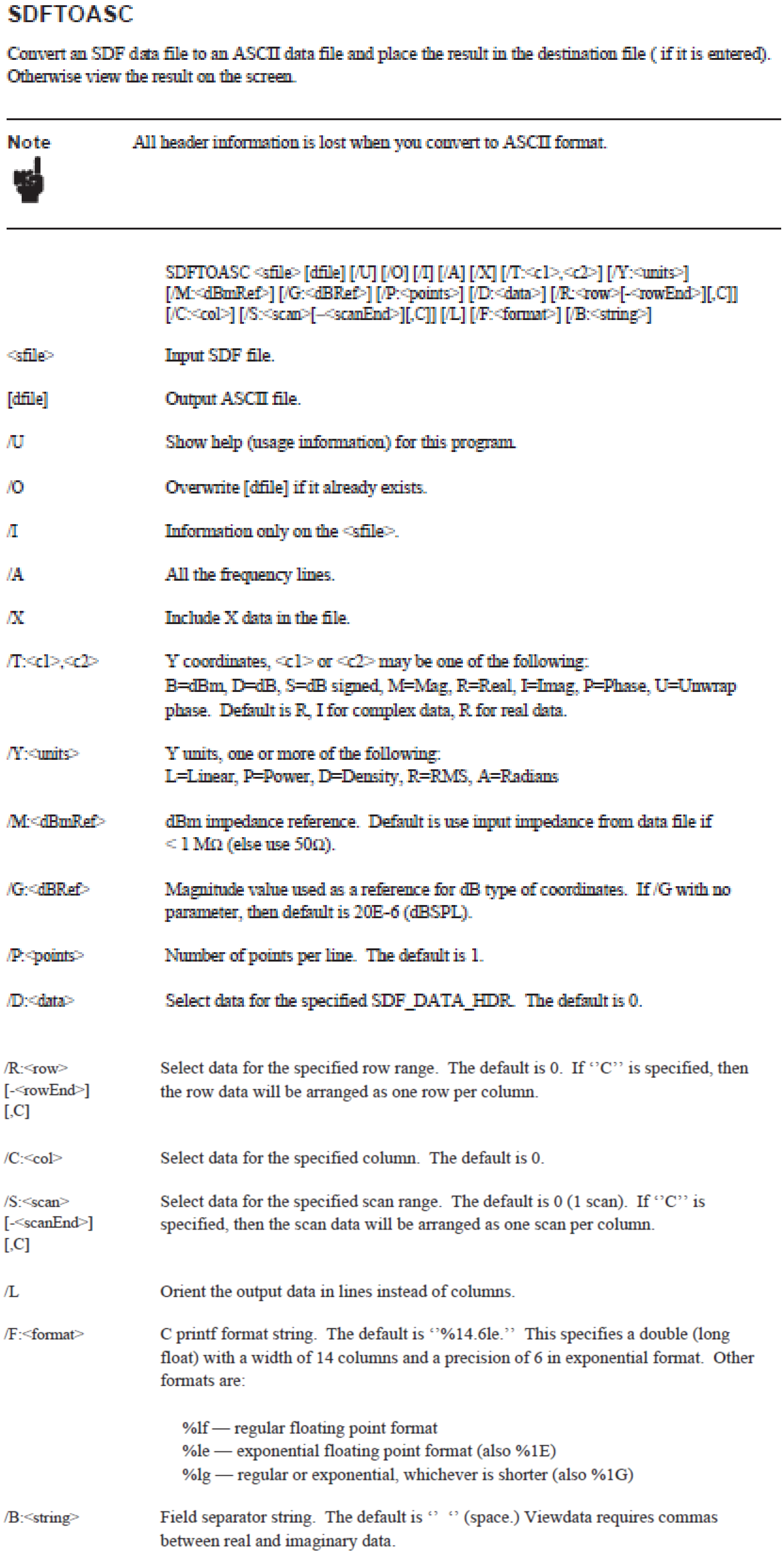
$20nV/\sqrt{Hz}$ at 10^{-3}Hz
$7nV/\sqrt{Hz}$ at 10^{-2}Hz
$1nV/\sqrt{Hz}$ at 10^{-1}Hz

This can clearly influence low frequency noise.

In addition, the pcb should be in an enclosure which shields it from air currents, and be allowed to thermally stabilise before the test. These measures not only reduce the above noise, but also noise caused by (dissimilar metal to metal) thermocouple effects within the circuit.

Appendix D **DSA data file conversion SDFTOAS.exe utility command switches**

(From Standard Data Format Utilities User Guide, courtesy of HP/Agilent)
This is a legacy utility and may require a DOS emulator such as DOSBOX to run)



SDFTOASC

Convert an SDF data file to an ASCII data file and place the result in the destination file (if it is entered). Otherwise view the result on the screen.

Note All header information is lost when you convert to ASCII format.

```
SDFTOASC <sfile> [dfile] [/U] [/O] [/I] [/A] [/X] [/T:<c1>,<c2>] [/Y:<units>]
[/M:<dBmRef>] [/G:<dBRef>] [/P:<points>] [/D:<data>] [/R:<row>[-<rowEnd>][,C]]
[/C:<col>] [/S:<scan>[—<scanEnd>][,C]] [/L] [/F:<format>] [/B:<string>]
```

<sfile>	Input SDF file.
[dfile]	Output ASCII file.
/U	Show help (usage information) for this program.
/O	Overwrite [dfile] if it already exists.
/I	Information only on the <sfile>.
/A	All the frequency lines.
/X	Include X data in the file.
/T:<c1>,<c2>	Y coordinates, <c1> or <c2> may be one of the following: B=dBm, D=dB, S=dB signed, M=Mag, R=Real, I=Imag, P=Phase, U=Unwrap phase. Default is R, I for complex data, R for real data.
/Y:<units>	Y units, one or more of the following: L=Linear, P=Power, D=Density, R=RMS, A=Radians
/M:<dBmRef>	dBm impedance reference. Default is use input impedance from data file if < 1 MΩ (else use 50Ω).
/G:<dBRef>	Magnitude value used as a reference for dB type of coordinates. If /G with no parameter, then default is 20E-6 (dBSPL).
/P:<points>	Number of points per line. The default is 1.
/D:<data>	Select data for the specified SDF_DATA_HDR. The default is 0.
/R:<row> [-<rowEnd>] [,C]	Select data for the specified row range. The default is 0. If ‘‘C’’ is specified, then the row data will be arranged as one row per column.
/C:<col>	Select data for the specified column. The default is 0.
/S:<scan> [-<scanEnd>] [,C]	Select data for the specified scan range. The default is 0 (1 scan). If ‘‘C’’ is specified, then the scan data will be arranged as one scan per column.
/L	Orient the output data in lines instead of columns.
/F:<format>	C printf format string. The default is ‘‘%14.6le.’’ This specifies a double (long float) with a width of 14 columns and a precision of 6 in exponential format. Other formats are: %lf — regular floating point format %le — exponential floating point format (also %1E) %lg — regular or exponential, whichever is shorter (also %1G)
/B:<string>	Field separator string. The default is ‘‘ ’’ (space.) Viewdata requires commas between real and imaginary data.