

# *DRAFT*

## (PART OF PART IV ON THE NBLNA)

### NBLNA Test Procedure

Testing a Narrow Band Low Noise Amplifier (NBLNA) for a Proton Precession Magnetometer

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In this note, I describe how we test a newly built NBLNA board. Then, I offer some ideas on less detailed testing methods using our Johnson noise test method with just an AC voltmeter and a couple of resistors.

#### **NBLNA DETAILED TESTING METHOD**

Initial setup:

On first powering the NBLNA board, look for the two high brightness LEDs to come on, showing proper polarity of the V+ and V- supplies. We do most of the testing at +/- 6 V, however, some testing, such as gain range, needs full rail voltages of +/- 15 V. We recommend normal operation anywhere from 6 V to 12 V, 15 V is okay too, but no higher. For no load, you should see a load current on each rail (V+ and V-) of about 7 or 8 milliamps.

Setting up a 10 uV input test signal:

Twist one side of two ¼ W 49.9 ohm resistors together and bend the leads so the twist can be screwed into the first terminal of the input terminal block (input common, analog ground), and the two resistor ends follow for input terminal V- (terminal 2) and V+ (terminal 3).<sup>1</sup> Next, connect the output of the signal generator (e.g. a hp 3325B synthesizer) to a step attenuator.<sup>2</sup> Then place a 49.9 ohm resistor across the binding posts of an AC voltmeter, such as a hp 400 GL, hp 400 FL or hp 400 F AC voltmeter, some of the few low cost instruments that can directly measure AC voltages down to 10 µV AC.<sup>3</sup> Vary the output amplitude from the signal generator in combination with a variable or step attenuator to set 10 µV AC (e.g. 10 mV out with about a 60 dB attenuator setting), which will become the input reference signal for initial NBLNA testing.<sup>4</sup>

General precautions:

When changing wiring at the NBLNA input terminals, turn the V+ and V- rail power supply off. Also, observe good anti-static practice, especially when working at the NBLNA inputs.

Frequency tuning span:

Apply the 10  $\mu\text{V}$  input test signal across one of the two 49.9 ohm input resistors (e.g. the resistor from the V- input to common input of the NBLNA board). Set the frequency tuning trimmer to full counter-clockwise. If you get the trimmer clicking sound, advance CW back a half turn or so. Change the signal generator frequency to find the lowest f. Next repeat the test for the full clockwise setting of the trimmer. This range can be moved by adjusting the fixed values of the multiple feedback active filter R10, R13, and R11, as well as by changing the values of the two film filter capacitors. Example: 1873 Hz to 2683 Hz. Now set your desired center frequency as determined by measurement, or by looking up your local value at one of the online geomagnetic modeling programs, such as the NOAA National Geophysical Data Center web resource.<sup>5</sup> Leave the center frequency set to your local value for the testing which follows. Set the desired center frequency by setting the exact desired frequency at the signal generator, then peak the output meter while tuning the frequency trimmer (R23, next to R11 and IC3). Example: 2,086 Hz.

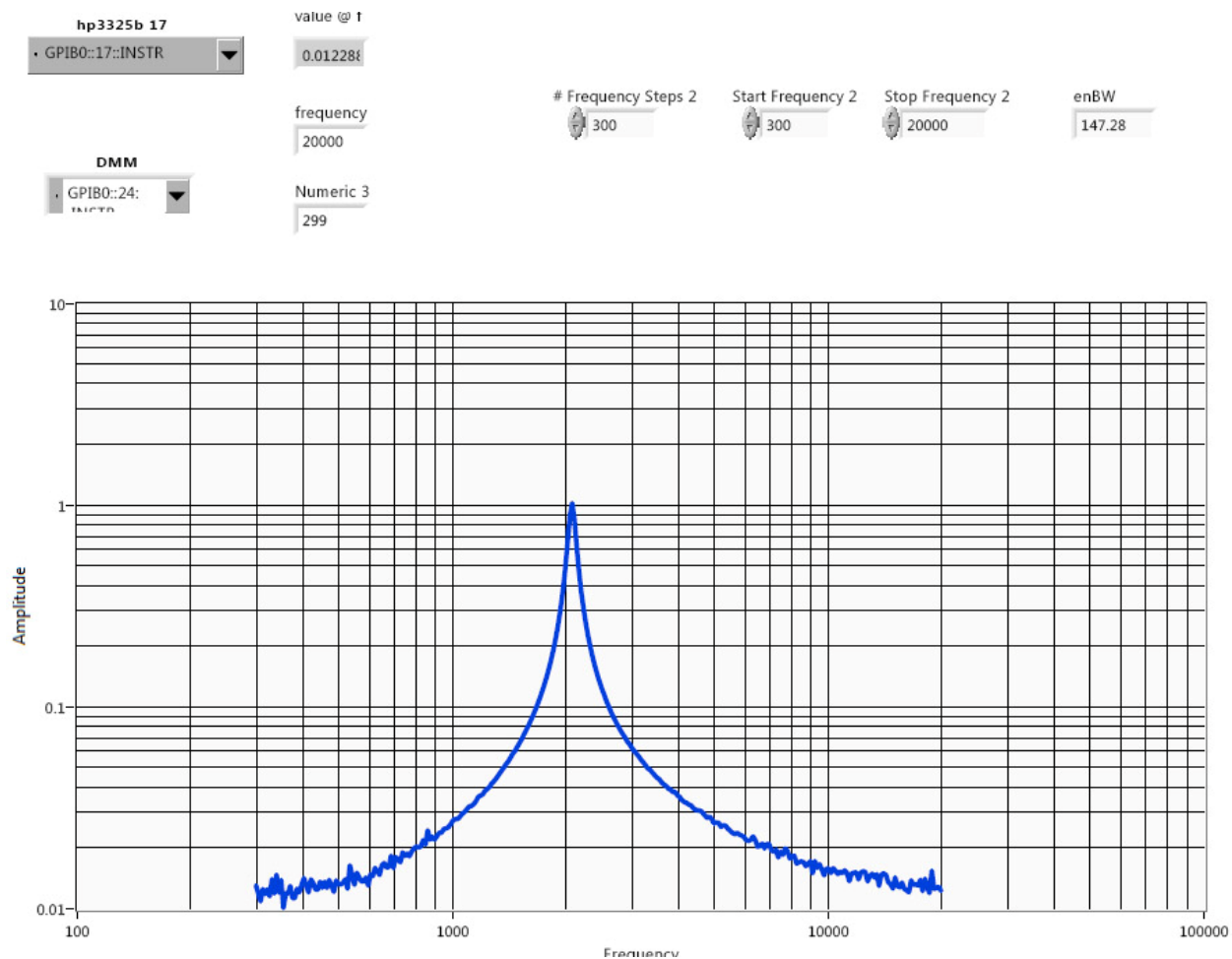
Gain Range:

Next, continuing to use the 10  $\mu\text{V}$  input test signal now set to the desired center frequency (e.g. 2086 Hz), we check the NBLNA available gain range. If available, use 3 ½ digit or greater resolution DMM for this measurement and setting. We use an Agilent 34410A for the remaining amplitude measurements and settings.<sup>6</sup> Set the gain trim to the lowest CCW setting and record the output voltage. Set the power supply voltage to +/- 15 V and repeat the measurement for full CW (Gain trimmer R12). Example: 3.94 V (gain 394,000) to 22.4 V (gain 2.2 million). Set the power supply voltage back to +/- 6 V and set the gain to 500,000 (5.00 V AC RMS, try to set to about +/- 5 mV, if possible), our nominal operating gain.

Keep this 500,000 gain setting for the remaining tests. Also, because of the relatively small amplitude input / output signals, for the remaining tests, the board should be mounted in a metal box with the cover at least tacked on over the test cables. The box should be connected to the box as “chassis ground” to analog ground, such as by the grounded corner mounting hole on the NBLNA board via a conductive mounting post.

Effective noise bandwidth:

Next we use a LabView based test setup<sup>7</sup> to do a piecewise integration for 300 test frequencies between 300 Hz and 20 kHz to directly measure the effective noise bandwidth. Alternatively, for a given filter (e.g. our cascade of single pole filters with the primary active multiple feedback filter, if the circuit is properly configured (i.e. no miswires), there is roughly a constant between the 3 dB bandwidth and the effective noise bandwidth. Example: 147 Hz:



For this same NBLNA board, the 3 dB bandwidth was measured using the standard low and high (above and below  $f_c$ ) -3 dB bandwidth points of 2037 Hz (lo) and 2130 Hz (hi) for a 3 dB bandwidth of 93 Hz<sup>8</sup>. Therefore, if you do not have a way to measure effective noise bandwidth, the conversion constant from 3 dB bandwidth to effective noise bandwidth is on the order of 1.6 times the 3 dB bandwidth for this circuit.

Noise floor testing (using an AC RMS voltmeter, a wire, and two resistors)

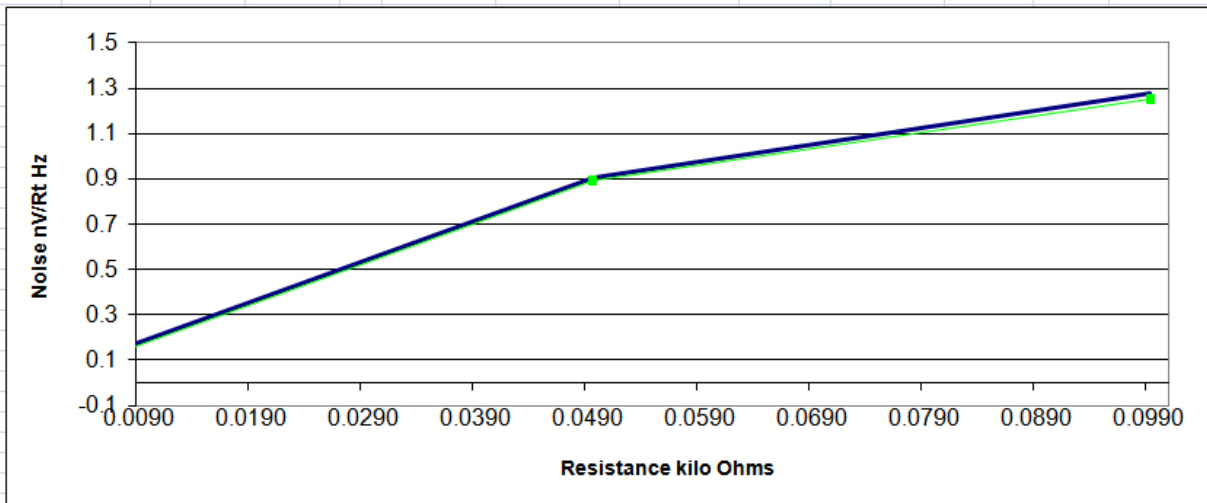
Next, to measure the noise floor and test the low noise capability of the NBLNA we compare test results for excess noise, measured for at least three data points, to the well known Johnson noise equation. This is essentially a reduced version of our JCan experiment noise experiment.<sup>9</sup> This testing is done with no input signal (turn off the signal generator and any other equipment on the bench not needed for this testing. Remove the two 49.9 ohm resistors used in the previous testing. Add a short (e.g. a bent cutoff component lead) from the V- to V+ input terminals (there is no connection to the input common for this testing). Record the output RMS voltage, preferably averaged, either by observation, or by an averaging routine such as is built in to the

Agilent 34410A DMM. Next place a 49.9 ohm resistor from the V- to the V+ input terminal (replace the tacked on cover) and record the output average RMS voltage. Once more repeat this test with a 100 ohm resistor. Using an ohmmeter (account for lead R either by making a four-wire Kelvin measurement, or by nulling the shorted leaded value) measure the actual resistance of the 49.9 ohm resistor and the 100 ohm resistor. Record the room temperature.

Now, enter the gain (500,000), the measured effective noise bandwidth (e.g. 147 Hz), and the other measured values into our noise worksheet (including the 20 kilo ohms value of the two NBLNA built in 10k bias resistors in the “input R field” of the worksheet).

Example - 1.6 nV / rt-Hz:

Noise Worksheet										
			Measured Data			Legend:		Entered Data		
Enter Resistor Under Test (kilo ohms)	Corrected R for input R	Theoretical 1 Hz NBW nV calc	AMP Vout AC mV	AMP Vout AC mV corrected for input noise	1 Hz NBW calculated from AMP Vout nV / Rt Hz calc		Enter AMP Gain	Enter AMP Bandwidth		
0.0000	0.00	0.0	9.92	0.0	0.0		500000	147	AMPLIFIER NOISE FLOOR nV / rt Hz 1.64	
0.0497	0.05	0.9	11.30	5.4	0.9					
0.0994	0.10	1.3	12.49	7.6	1.3					
Input R kilo ohms:		20000		Input Referred Noise (mV at output for shorted input)		9.92		Temperature degrees F		75.0
Calculated Temperature Centigrade		23.9		Calculated Temperature Kelvin		297				



Note that slewing the gain in this example to about 490,000 gives a better match suggesting that perhaps the actual gain during this test was somewhat lower than 500,000.

## REDUCED TESTING METHOD 1

One very effective way to characterize an NBLNA board is to measure the gain of the board, using a method such as described above. Then, skipping the effective noise bandwidth measurements, perform the several resistor noise test and fill in the noise worksheet. Now guess the effective noise bandwidth (e.g. 150 Hz) and view the separation between the measured noise curve and the actual noise curve. Change the effective noise bandwidth value until the two curves overlap. Assuming your other measured variables are correct, this is a very simple way to measure the effective noise bandwidth of an amplifier.

## REDUCED TESTING METHOD 2

Guess both the gain of the circuit (e.g. 500,000) and the effective noise bandwidth. Perform the noise test using resistors as described above. Vary both parameters until the theoretical noise curve matches the measured noise curve. Since this method varies two parameters with one equation, you cannot know the actual values, but can give a first indication if the NBLNA board is operating correctly.

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<sup>1</sup> If you are using an older signal generator with a 600 ohm output, use two 600 ohm resistors, i.e. match the test load to your signal generator.

<sup>2</sup> We use a Kay 837 or 839 50 ohm step attenuator. If you do not have a Kay 837 or Kay 839 attenuator, you can also use cascaded fixed attenuators or build your own “pad” attenuator using handbook tables. Use an attenuator impedance that matches your signal generator output impedance (e.g. typically 50 ohms or 600 ohms).

<sup>3</sup> Note that the 34410A cannot measure amplitudes below about 1 mV (or, the 34401A below 5 mV), so it is not directly useful for setting the initial 10  $\mu$ V reference voltage. You could use a calibrated fixed attenuator between the signal generator and the 34410A, but then the reference is set less directly. See:

<http://www.gellerlabs.com/34401A%20AC%20zero.htm>, Making Low Level AC Voltage Measurements below 1-5 mV with the Agilent™ 34401A and 34410A Digital Multimeters.

<sup>4</sup> If your signal level will not go below several tens or hundreds of  $\mu$ V AC, there is probably a ground loop somewhere in your test setup and/or lengths of unshielded wire with relatively large in-band interfering signals. Try disconnecting the input cable from the signal generator to the attenuator and see if the meter value drops to 10  $\mu$ V AC or less.

<sup>5</sup> <http://www.ngdc.noaa.gov/geomagmodels/IGRFWMM.jsp> .

<sup>6</sup> For AC measurements, the statistics display is particularly convenient. Reset the average for each new test setup.

<sup>7</sup> <http://www.gellerlabs.com/nBW%20Geller%20Tech%20Note.htm>, ON MEASURING THE EFFECTIVE NOISE BANDWIDTH OF A FILTER.

<sup>8</sup> Using a hp 400 EL with its convenient log scale. Any suitable AC meter can be used for this relatively high level measurement (e.g. set the input voltage at center frequency to give 1 V RMS at the NBLNA output for the 3 dB bandwidth testing (output down by about .707 (-3dB) on either side of the center frequency)).

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<sup>9</sup> <http://www.gellerlabs.com/JCan%20Parts%20and%20Kits.htm>