Noise Figure Measurements Below 10 MHz

Whitham D. Reeve

1. Introduction

Common commercial noise sources used in everyday lab work are specified and calibrated at intervals from a low frequency limit of 10 MHz to the source's upper frequency limit. I previously investigated extending the lower frequency limit of certain noise sources down to 2 MHz {Reeve26}. The present article provides examples of some amplifier noise figure measurements at lower frequencies using two of those noise sources and a spectrum analyzer with a noise figure measurement option.

A benefit of the noise figure measurements is that the amplifier gain is measured and displayed at the same time, so both noise figure and gain measurements are provided. Of importance to these measurements and also discussed are the somewhat specialized analyzer settings below 10 MHz.

---

2. Amplifier Descriptions

The amplifiers listed in table 1 and shown in figure 1 make up the measurement regimen. Most of these devices are of interest to me because they have frequency ranges that are compatible with the Callisto instruments used in the e-CALLISTO Solar Radio Spectrometer Network {eCALLISTO}.

Table 1 ~ Amplifiers used for noise figure measurements

Model	Datasheet Frequency range	Measured frequency range	Remarks
LWA FEE V2	20 to 85 MHz	2 to 200 MHz	Routinely used down to 5 MHz or lower
nenuFAR LNA	10 to 85 MHz	2 to 200 MHz	Not presently used in the USA
LNA-1 LNA	25 to 3000 MHz	2 to 3000 MHz	S/N 101, also 2 to 200 MHz
LNA-2 LNA	25 to 1000 MHz	2 to 1000 MHz	S/N 201, also 2 to 200 MHz
HP 8447A Modified	9 kHz to 3000 MHz	2 to 3000 MHz	S/N 9600, Wenteq ABL0300-00-3030 amplifier

The Callisto has a native frequency range of 45 to 870 MHz, but that is easily extended with an up-converter or down-converter whose intermediate frequency (IF) output is within the native frequency range. With an up-converter, the Callisto is an ideal instrument for use with the Long Wavelength Array (LWA) Antenna over a frequency range of 5 to 85 MHz. The noise figure measurements purposely extend below the amplifiers' datasheet frequency ranges shown in the table to see if they might be usable at the lower frequencies.

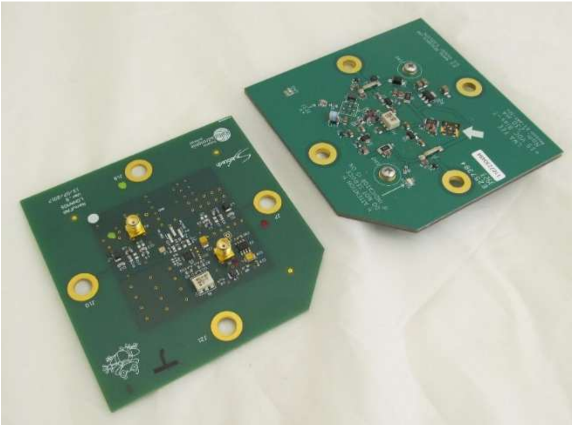


Figure 1.a ~ NenuFAR LNA (left) and LWA FEE V2 (right). Both amplifiers have the same dimensions but are different designs. The NenuFAR LNA is shown with the two SMA connectors pointed up and the LWA-FEE V2 is shown with the connectors pointed down. Both amplifiers have one amplifier on the top and other on the bottom to provide a dual polarization device. The dipole elements connect to the larger holes along the sides. A polarizing notch in one corner of the PCBs ensures the proper orientation when mounted in the hub of a crossed-dipole LWA Antenna.

Figure 1.b ~ LNA-2 (left) and LNA-1 (right). Both LNAs have an antenna connector and receiver connector. The 12 Vdc powering voltage is fed through the receiver connector from a bias-tee near the receiver. The weatherproof cover is plastic while the mounting base/bracket is aluminum. A mast clamp is used with the amplifiers to attach to a mast immediately below the antenna.

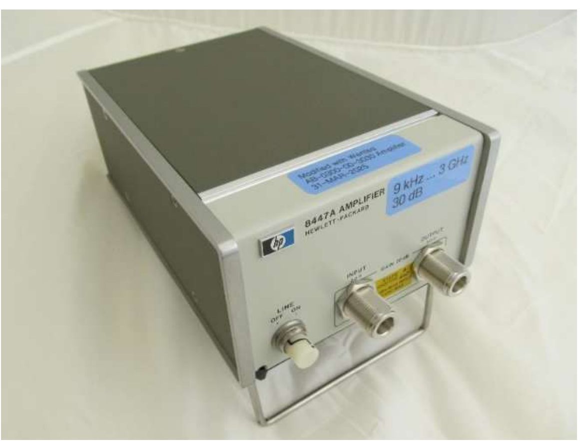


Figure 1.c ~ HP 8447A Modified. This is a lab amplifier and not intended for dedicated use with a receiver. This particular unit has been internally modified with a Wenteq ABL0300-00-3030 amplifier that replaces the original HP amplifier. The modification included replacing the original BNC-F connectors on the front panel with type N-F connectors as well as modifying the internal power supply for the lower voltage required by the Wenteq amplifier.

The Long Wavelength Array (LWA) Front End Electronics (LWA FEE) is used in the LWA and its many derivatives, all of which use the well-known tied-fork, crossed-dipole *LWA Antenna*. The nenuFAR LNA is another front end alternative for the LWA Antenna. It is electrically and mechanically compatible with this antenna, but its design is far different from the LWA FEE V2 and its frequency range extends to approximately 300 MHz. The nenuFAR uses an ASIC instead of the MMICs used in the LWA FEE V2. The noise figures of both front ends are measured under identical conditions while installed in the LWA FEE Test Fixture V2, which powers the amplifiers through the test fixture's built-in bias-tee. The LWA FEE V2 design documents and PCB EDA files are located at {LWAFEE}. No design documents are available for the nenuFAR amplifier but overall information is here {nenuFAR}.

The LNA-1 and LNA-2 are commercial products intended for use with broadband antennas such as Log Periodic Dipole Array antennas, Discone antennas or, at higher frequencies, parabolic dish antennas. The amplifiers are powered through a lab bias-tee (Mini-Circuits ZBT-4R2GW+). Two sets of measurements are provided, one that covers the amplifier's entire frequency range and another that covers from 2 to 200 MHz as a compatibility test for use with the LWA Antenna.

The HP 8447A Modified amplifier is a repurposed single-channel laboratory amplifier originally manufactured by Hewlett-Packard for many years starting in the 1970s. The original internal amplifier was not very reliable and I replaced it with a modern low noise amplifier manufactured by Wenteq. The Wenteq amplifier has the same or better operating specifications compared to the old HP internal amplifier. The two main enhancements are noise figure and frequency range. This amplifier normally is not used for operational observations but it could be.

---

3. Noise Source Selection

There are no rigid rules for selecting the noise source used in noise figure measurements. Guidelines published by Rohde & Schwarz, immediately below, are the most rigorous of the methods described here; two simpler methods are described later.

Guideline 1. $NF_{DUT} + G_{DUT} - NF_{SA} > 1\ dB$ (Alternative form: $NF_{DUT} + G_{DUT} > NF_{SA} + 1\ dB$) (1)

Guideline 2. $ENR_{NS} - NF_{DUT} > 5\ dB$ (Alternative form: $ENR_{NS} > NF_{DUT} + 5\ dB$) (2)

Guideline 3. $ENR_{NS} - NF_{SA} > 3\ dB$ (Alternative form: $ENR_{NS} > NF_{SA} + 3\ dB$) (3)

To use the guidelines, some basic knowledge of the amplifier, or Device Under Test (DUT) as it sometimes is called here, and spectrum analyzer is needed. First, estimates of the DUT noise figure and gain are needed for Guidelines 1 and 2. These may be estimated or obtained from the amplifier datasheet if available. If necessary, an initial estimate can be made and then updated after measurements but this is necessary only if the guidelines produce a far different ENR afterwards. This potentially could be an iterative process but more than an initial estimate usually is unnecessary. Commercial noise sources are available with only a few ENR values, typically 5 or 6, 15 and 21 dB, so some judgement almost always is needed. Table 2 summarizes the values obtained from the alternative form of Guidelines 1 and 2 for each amplifier.

Next, the analyzer noise figure is needed in Guidelines 1 and 3. The analyzer noise figure, NF_{SA}, is the composite of the internal preamplifier, which always is enabled for noise figure measurements, and the spectrum analyzer noise figures. The FPL analyzer noise figure with the preamplifier enabled was not explicitly determined in {Reeve26} but it can be found from the DANL specification in the datasheet or from the DANL measurements. The noise markers used to measure the FPL analyzer DANL take into account all corrections, in which case the analyzer noise figure is simply

$$NF_{SA} = DANL + 174 \quad (4)$$

where NF_{SA} is the spectrum analyzer noise figure with preamplifier enabled (dB), DANL is the Display Average Noise Level (dBm Hz^{-1}) and the constant 174 is the noise power spectral density at the reference temperature 290 K (dBm Hz^{-1}). It was determined in {Reeve26}, figure D2.a (see appendix of this article for a duplicate copy), the FPL DANL is not constant below 10 MHz, so the analyzer noise figure is separately calculated for several frequencies below 10 MHz (table 3). For frequencies between measurement points, the noise figure can be interpolated but this is not normally necessary.

Table 2 ~ Amplifier nominal noise figures and gains (assumed to be flat across the frequency range) and Guidelines 1 and 2.

Model	**DUT Noise figure (dB)**	**DUT Gain (dB)**	**Guideline 1 $NF_{DUT} + G_{DUT}$ (dB)**	**Guideline 2 NF_{DUT} + 5 dB**
LWA FEE V2	3	34	37	8
nenuFAR Front End	2	26	28	7
LNA-1 LNA	1	25	26	6
LNA-2 LNA	1	25	26	6
HP 8447A Modified	3	30	33	8

Table 3 ~ FPL analyzer noise figure measurements (NF_{SA}) calculated from DANL in {Reeve26} and Guidelines 1 and 3.

Frequency (MHz)	**DANL (dBm Hz^{-1})**	**NF_{SA} (dB)**	**Guideline 1 NF_{SA} + 1 dB**	**Guideline 3 NF_{SA} +3 dB**
2	–162.53	11.5	12.5	14.5
3	–164.36	9.6	10.6	12.6
5	–166.13	7.9	8.9	10.9
7	–166.75	7.3	8.3	10.3
≥ 10	–167.09	6.9	7.9	9.9

Results of the above analysis:

Guideline 1. $NF_{DUT} + G_{DUT} > NF_{SA} + 1\ dB$: 20 to 37 dB > 12.5 dB (2 MHz) to 7.9 dB (≥ 10 MHz) (Table 2 & 3) ✓

Guideline 2. $ENR_{NS} > NF_{DUT} + 5\ dB$: If ENR_{NS} = 15 dB > 6 to 8 dB depending on amplifier (Table 2) ✓

Guideline 3. $ENR_{NS} > NF_{SA} + 3\ dB$ If ENR_{NS} = 15 dB > 14.5 dB (2 MHz) to 9.9 dB (≥ 10 MHz) (Table 3) ✓

The above guidelines favor a 15 dB ENR especially at the lower frequencies. Above 2 or 3 MHz, a 5 or 6 dB ENR may be appropriate.

A simpler noise source selection can be made by using a rule of thumb (Reeve14}, which I will call a *Rule of Thumb*. I do not remember the source but it probably was published years ago in technical literature:

> The noise source ENR should be within about 10 dB of the device's noise figure. For example, a 5 dB ENR noise source may be used to measure noise factors up to about 15 dB, and a 15 dB ENR noise source should not be used to measure noise factors below approximately 5 dB or above approximately 25 dB.

This rule of thumb assumes the analyzer has an internal low noise preamplifier or an external low noise amplifier is used in the measurement setup. This method favors a 5 dB ENR noise source for the amplifiers to be measured here.

Keysight recommends using a 15 dB ENR noise source to measure noise figure up to 30 dB, and a 6 dB ENR noise source when the DUT has a very low noise figure or does not exceed 15 dB [Keysight18]. Keysight does not define *a very low noise figure* in their recommendations. This method favors a 5 dB ENR noise source for the amplifiers to be measured.

Based on the three above selection methods, either the HP 346B: s/n 2614A06872, with ENR = 15 dB or the HP 346A: s/n 2614A01751 with ENR = 5 dB may be used. For comparison, two sets of measurements are described later, one set for each noise source.

---

4. Instrumentation

The Rohde & Schwarz FPL1003 spectrum analyzer is used for the noise figure measurements. Its frequency range is 5 kHz to 3 GHz. This is the same analyzer used to measure the noise sources described in {Reeve26}. The FPL is equipped with the *Noise Figure* option (FPL1-K30) and *Additional Interfaces* option (FPL1-B5). It also is equipped with the *Preamplifier* option (FPL1-B22) that simplifies most noise figure measurements (an external low noise preamplifier usually is required if this option is not equipped).

The Noise Figure option provides signal processing and measurement displays that are tailored to noise figure measurements. The Additional Interfaces option includes a connector on the instrument's rear panel and an internal 28 Vdc source for controlling the hot and cold states of an external noise source.

As mentioned in the previous section, the HP 346A noise source with a nominal ENR of 5 dB and HP 346B noise source with a nominal ENR of 15 dB are used for all measurements. Both sources were calibrated within a couple months of their use here. The 28 Vdc noise source control cable from the analyzer rear panel was equipped with multiple ferrite beads to reduce common mode noise that might be conducted into the noise sources.

The noise source calibration certificate and sticker on the noise source itself show the calibration frequencies and corresponding ENRs but only down to 10 MHz. The ENRs at frequencies below 10 MHz are set to the value at 10 MHz as discussed in {Reeve26}. The ENRs were Saved in the FPL as an ENR Table from 0 Hz to the noise source upper frequency limit, which is 18 GHZ for both the HF 346A and HP 346B (figure 2). ENR tables for any number of noise sources can be entered this way. The analyzer interpolates the ENR values at frequencies not listed in the tables.

Prior to noise figure measurements, the FPL was calibrated using the *2nd Stage Correction* calibration procedure, which takes into account the inherent noise of the analyzer when calculating the measurement results. The procedure requires a noise source to be connected directly to the analyzer RF Input and controlled by the voltage source on the rear panel. This correction was done for each frequency range and measurement points combination. Each Calibration set was Exported to an XML file stored on a USB drive and then Imported as needed for measuring each amplifier frequency range. This avoids repetitive setup and calibration when making a series of measurements over different frequency ranges.

A variable linear power supply, Siglent SPD3303X, was used to provide the operating voltages necessary for the amplifiers. The nenuFAR operates from 5.5 to 16 Vdc and was measured at 12 Vdc input. The LNA-1 and LNA-2 use 12 Vdc supplied through the LPC-3 power coupler. The TSS-23ULN+ is setup on its evaluation board to use either 3 or 5 Vdc but it was measured with 5 Vdc input. The GALI-74+ may be operated from 7.0 to 15.0 Vdc depending on the bias resistance installed on the evaluation board; I used the bias resistor for 12.0 Vdc input that was supplied with the board.

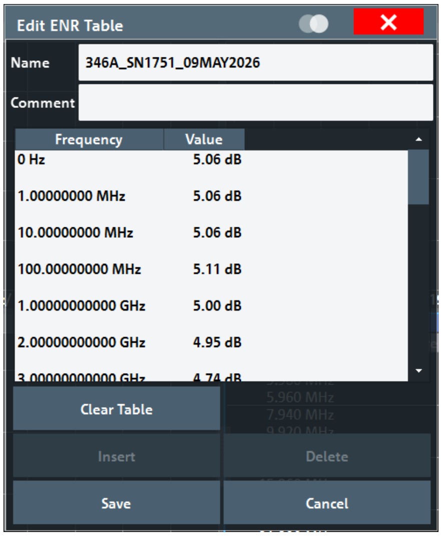


Figure 2 ~ Partial ENR table for the HP 346A noise source. ENR values below 10 MHz are according to {Reeve26} and for 10 MHz and above are from the calibration sticker on the noise source or the associated calibration certificate. A value is included for 0 Hz but any measurements with the FPL1003 spectrum analyzer under the conditions described in this article are valid only down to 2 MHz. The table is stored in the XML format and can be imported or exported. A similar ENR Table was populated for the HP 346B noise source.

---

4. Instrument settings

The following discussion applies to the FPL1003 analyzer described in the previous section but the concepts can be applied to other spectrum analyzers. There are some important parameters that must be considered when making noise figure measurements – frequency, resolution bandwidth (RBW) and sweep time.

Dedicated noise figure analyzers (NFA) typically have a 3 or 4 MHz resolution bandwidth filter, which is suitable for measurements at 10 MHz and above. The analyzer sweep rates are optimized for those bandwidths. When measuring noise figures below 10 MHz, lower RBW settings and longer sweep times are necessary to maintain measurement accuracy.

The FPL allows specific RBW and sweep times to be listed in a Frequency Table, which is then used for the noise figure measurements. The Frequency Table itself is manually or automatically populated based on the user specified frequency span and number of measurement points.

For frequencies ≥ 10 MHz, the default Sweep Time per frequency and RBW are 30 ms and 3 MHz, respectively. For frequencies < 10 MHz, the same product of Sweep Time per frequency and RBW is used, as in

$$Sweep\ Time_{Freq} \cdot RBW = 30ms \cdot 3MHz = 90 \cdot 10^{3} \tag{5}$$

It is intuitive that the RBW must be lower than the frequency being measured. For example, a 3 MHz RBW setting is not suitable for a measurement at 1 MHz because it would attempt measurements outside the filter frequency range. In this example, 250 kHz RBW would be suitable. The RBW depends on the filter characteristics including type or shape and number of poles. Specific filter details are seldom available for commercial spectrum analyzers but it is generally understood that the measurement frequency should be at least 3 times higher than the RBW. Factors higher than 3 may be used at the expense of longer sweep times, although most analyzers have only discrete sweep time and RBW settings and a compromise is almost always necessary.

With that in mind, the following may be used for noise figure measurements below 10 MHz:

$$RBW = f_{Meas}/(k) \tag{6}$$

$$Sweep\ Time\ =\ 90 \cdot 10^{3}/RBW \tag{7}$$

where f_{Meas} is the measurement frequency in Hz, k is a constant between 3 and 6, and sweep time is in s. The k values of 3 and 6 provide practical boundaries on the RBW. The RBW may be found by dividing the measurement frequency f_{Meas} by 3 and again by 6 and then selecting the nearest available RBW setting between the two results. RBW settings are available in the FPL analyzer in a 1-2-3-5 sequence. For example, if f_{meas} = 3.5 MHz, RBW_3 = 1.167 MHz and RBW_6 = 583 kHz. The nearest available RBW setting between the two is 1 MHz.

The Sweep Time in equation (7) applies to each individual frequency in the FPL Frequency Table. The available sweep time settings in the FPL are 1 ms to 8000 s, but the settings for noise figure measurements cover a much smaller range. For the noise figure measurements of interest here, the sweep time settings vary from 300 ms to 30 ms. The RBW and sweep time settings given in table 4 are based on equations (6) and (7). Note that either smaller RBW settings or longer sweep times may be used than those listed.

Table 4 ~ Resolution bandwidth and sweep time

Frequency f (MHz)	RBW	Sweep time	Remarks
1.0 ≤ f < 1.5	300 kHz	300 ms	Frequencies not useable with FPL unless an external preamplifier is used that covers them
1.5 ≤ f < 3.0	500 kHz	180 ms	2 MHz is lowest usable frequency with FPL internal preamplifier
3.0 ≤ f < 6.0	1 MHz	90 ms	
6.0 ≤ f < 10.0	2 MHz	45 ms	
10.0 ≤ f	3 MHz	30 ms	

For a frequency span f_{Span} and number of measurement points n_{Points}, the frequency spacing f is found from

$$f = f_{Span}/(n_{Points} - 1) \tag{8}$$

For example, if the measurement start and stop frequencies are 2 and 200 MHz, respectively, the frequency span is 198 MHz. If 101 points are to be measured, the frequency spacing or interval f = 1.98 MHz. The first measured frequency is 2.0 MHz and the next one is 3.98 MHz, and so on (figure 3). The frequency Table does not have to be incremental or evenly spaced. It could be manually filled with arbitrary frequencies if they are in the proper range and order, low to high, top to bottom, and the number of frequencies corresponds to the number of measurement points. After the measurement point frequencies are selected, the RBW and Sweep Times are determined as described above and entered in the table for each frquency.

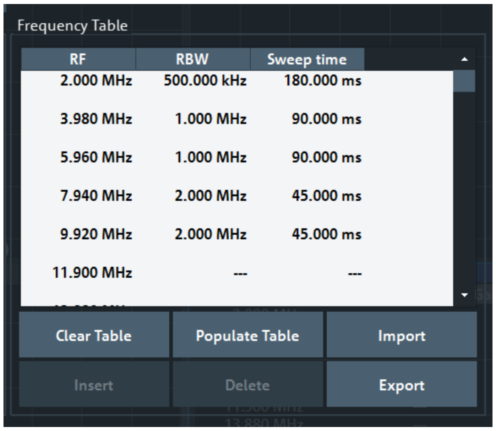


Figure 3 ~ Partial frequency table showing frequencies from 2.0 to 11.9 MHz. The RBW and Sweep times may be entered manually with the Insert/Delete buttons or automatically with the Populate Table button based on the frequency span (198 MHz) and number of measurement points (101) specified in another window. The automatic method ensures optimum settings predetermined by the instrument manufacturer. Note that the 11.900 MHz frequency point in this example shows a blank RBW and Sweep time with the — symbol. This is because I used the Populate Table button and this frequency point is set to default values of 3 MHz and 30 ms, respectively. All frequencies above 11.900 MHz (not shown in this image but in the Frequency Table) also are blank and use default values.

Four Frequency Tables were setup with the following ranges (see section 2): 2 to 200 MHz, 2 to 1000 MHz, 2 to 2000 MHz and 2 to 3000 MHz. The number of measurement points was set to provide approximately the same frequency spacing f in each table (table 5). The tables were Exported to an external USB Drive on the analyzer and then recalled as needed (they could just as easily have been stored on the analyzer’s internal SSD).

Table 5 ~ Measurement points and frequency spacings

Frequency range & span f_{span} (MHz)	Measurement points	Frequency spacing f (MHz)	Remarks
2 – 200 (198)	101	1.98	
2 – 1000 (998)	506	1.98	
2 – 2000 (1998)	1013	1.97	
2 – 3000 (2998)	1520	1.97	

Improved accuracy at higher frequencies is achieved by compensating for the losses in the coaxial cables or other devices used to connect the DUT to the noise source and analyzer. These are called Input Loss and Output Loss, respectively. However, the noise sources were connected directly to the DUT inputs and no cables were used. Also, since this article is concerned mostly with measurements below 10 MHz, in which the cable losses are negligible, no Output Loss setting was needed. No effort was made to determine cable loss effects on the measurements at the higher frequencies.

5. Measurements

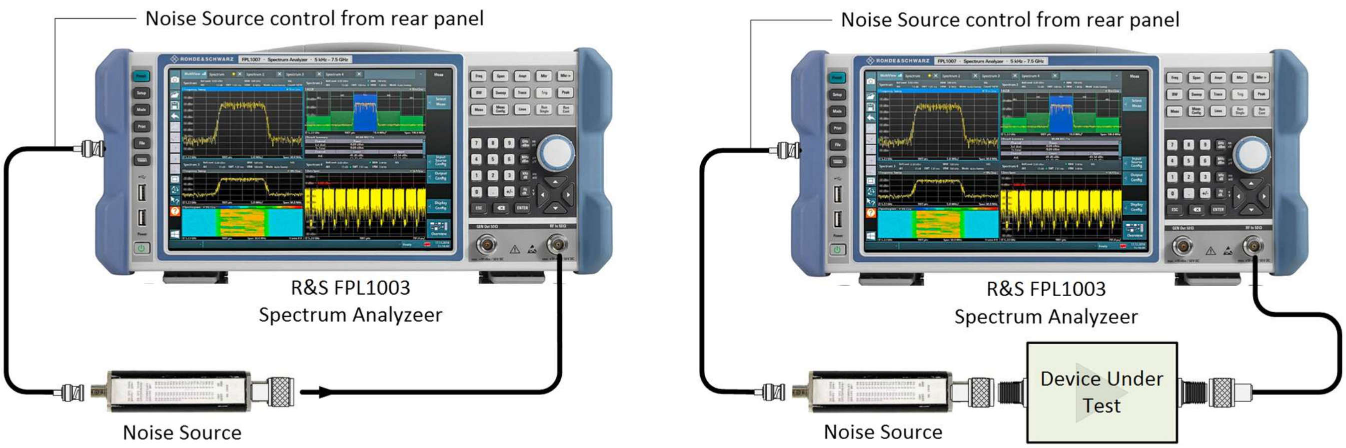
The 2nd Stage Correction (Calibration) was performed for each frequency span and each of the two noise sources discussed in the previous section. These were Saved as Calibration Result files and then Imported as appropriate for each amplifier. The saved Calibration Results were given unique filenames for easy identification such as CalibrationResults_346A_2-200MHz_YYYY_MM_DD_HH_MM.

Autoscale was used for the vertical scale in all plots, so some measurements appear magnified or compressed. The thicker trace in the noise figure plots is the actual measured value, and the thinner traces above and below it indicate the estimated uncertainties. Uncertainty was automatically calculated for each measurement by the FPL. No Averaging was used except on the HP 8447A Modified amplifier measurements.

The FPL supports only four markers in the Noise Figure mode. For several of the amplifier measurements, two markers were set at 45 and 870 MHz to mark the Callisto lower and upper native frequency limits. Another marker was set at a low frequency and one at a midspan frequency.

The calibration and measurement setups are shown in figure 4, and pictures taken during the lab measurements are shown in figure 5. The measurement results are shown in plot images with the noise figure in the upper frame and gain in the frame immediately below. The Marker Table is in the bottom frame. Two plots labeled a. (5 dB ENR) and b. (15 dB ENR) are shown for each amplifier (figures 6.a and 6.b through figure 11.a and 11.b). The Discussion section provides detailed comments about each measurement set.

Figure 4 ~ Setup schematic. <u>Left</u>: 2nd Stage Correction (Calibration); <u>Right</u>: Measurement



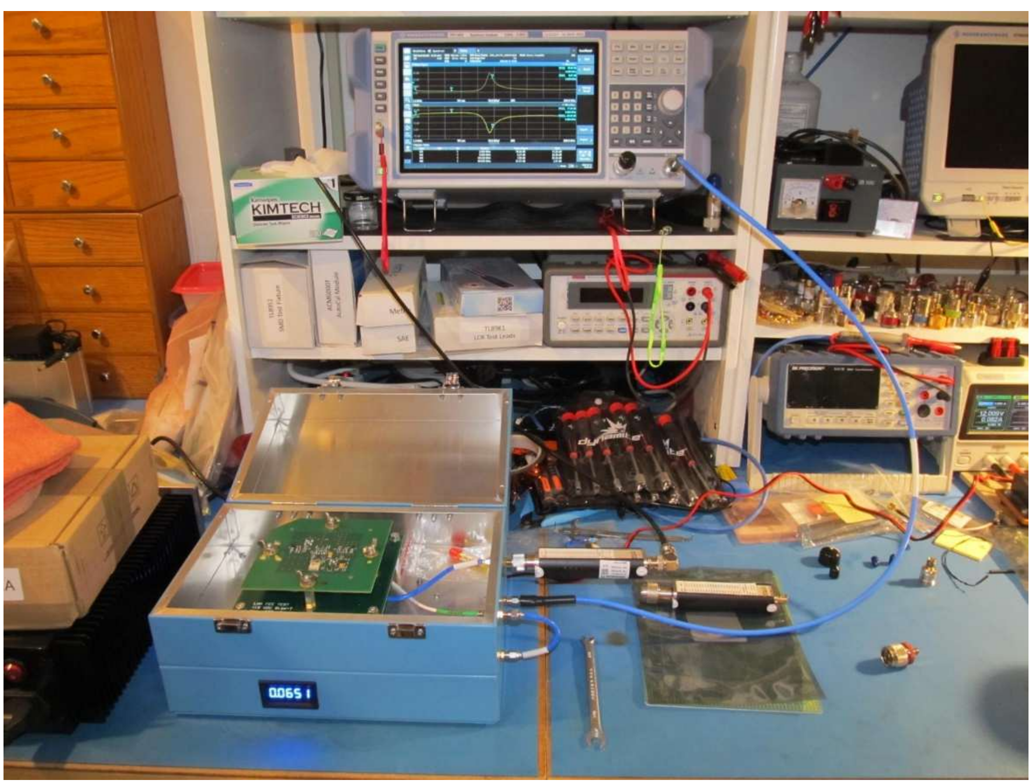


Figure 5.a ~ <u>Foreground</u>: NenuFAR LNA in test fixture before lid is closed and latched. The HP 346A noise source is connected with the HP 346B stands by. <u>Background</u>: FPL1003 analyzer.

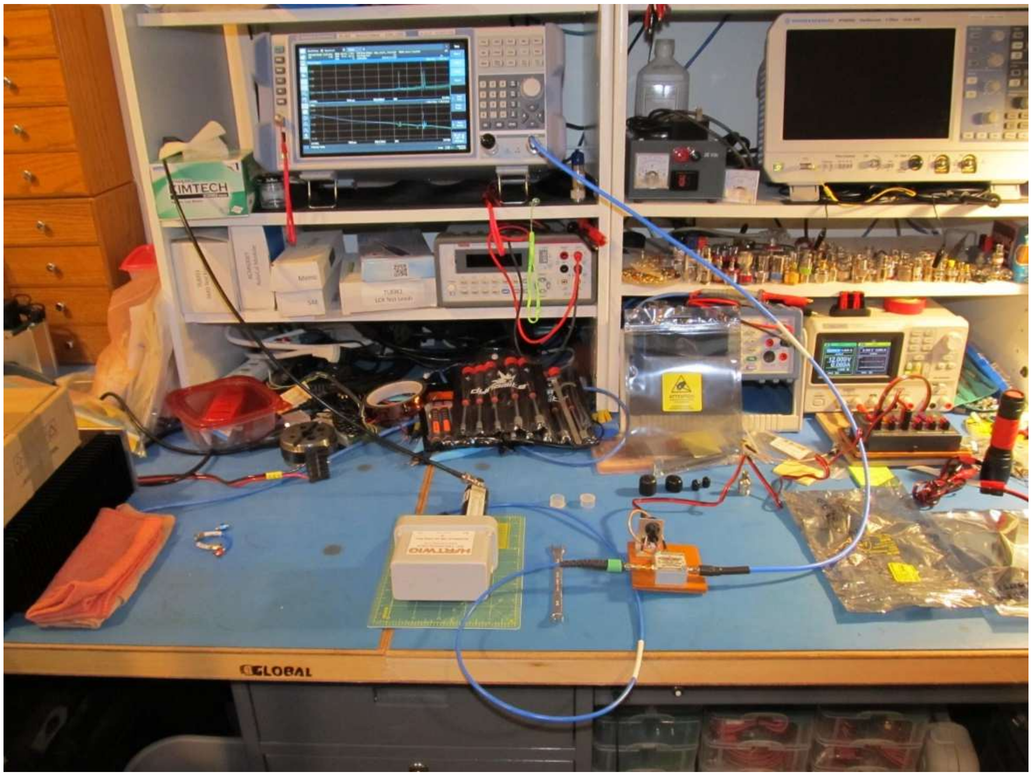


Figure 5.b ~ LNA-1 with lab bias-tee to right.

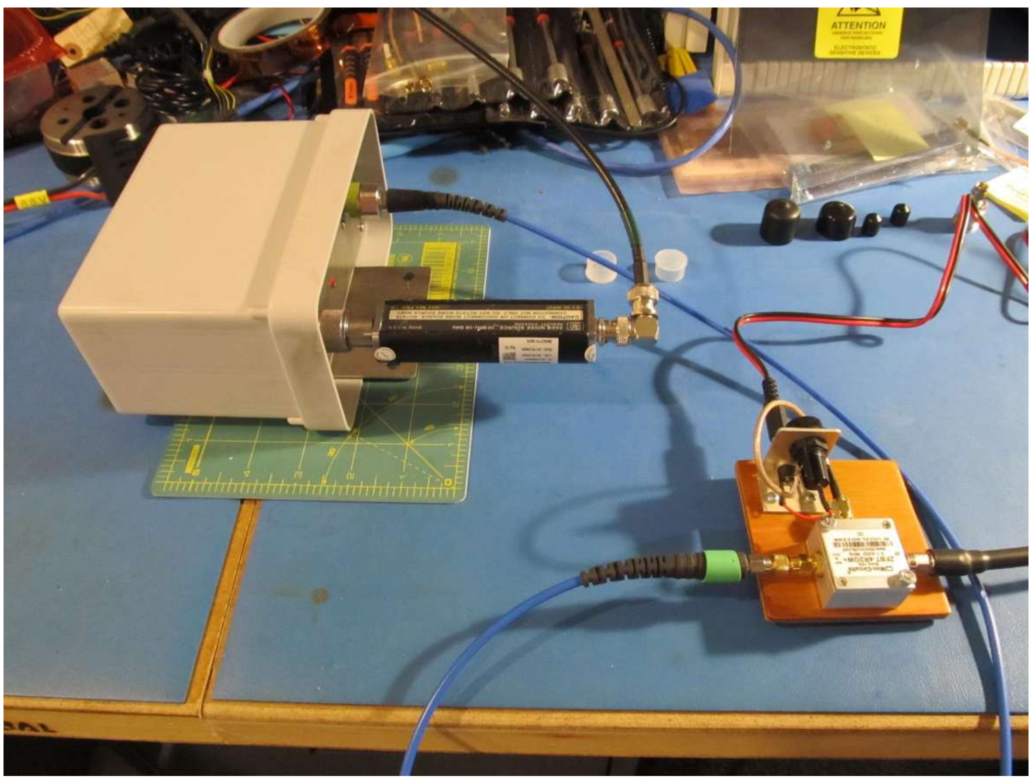


Figure 5.c ~ LNA-2 with HP 346B Noise Source and Bias-Tee.

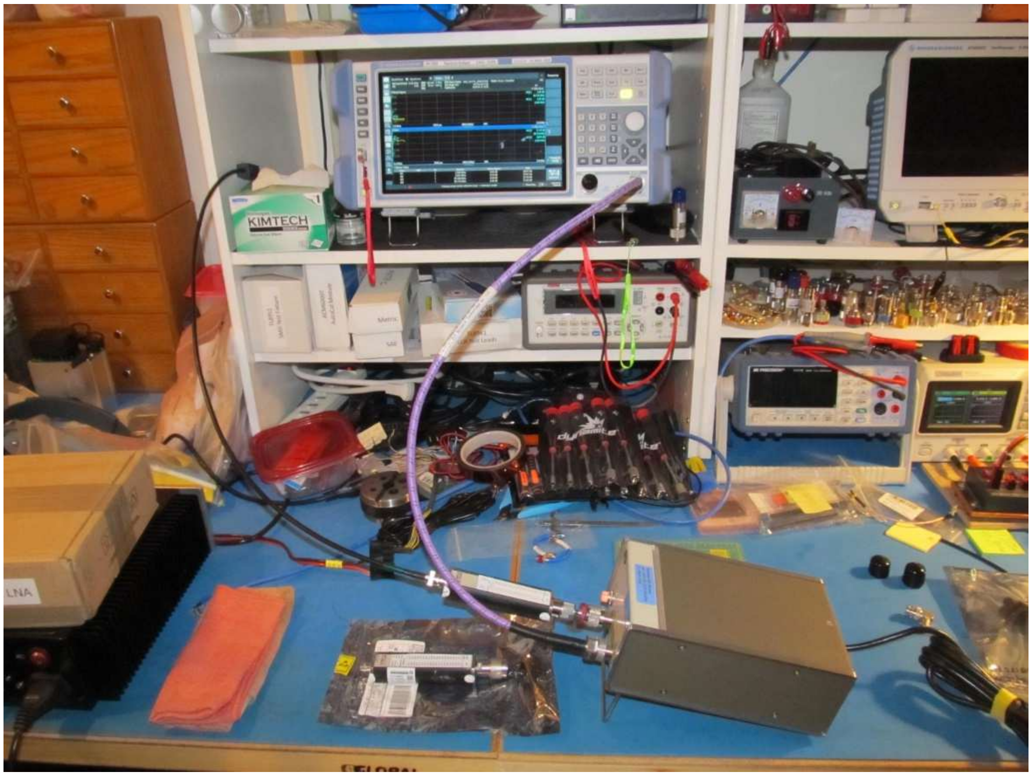
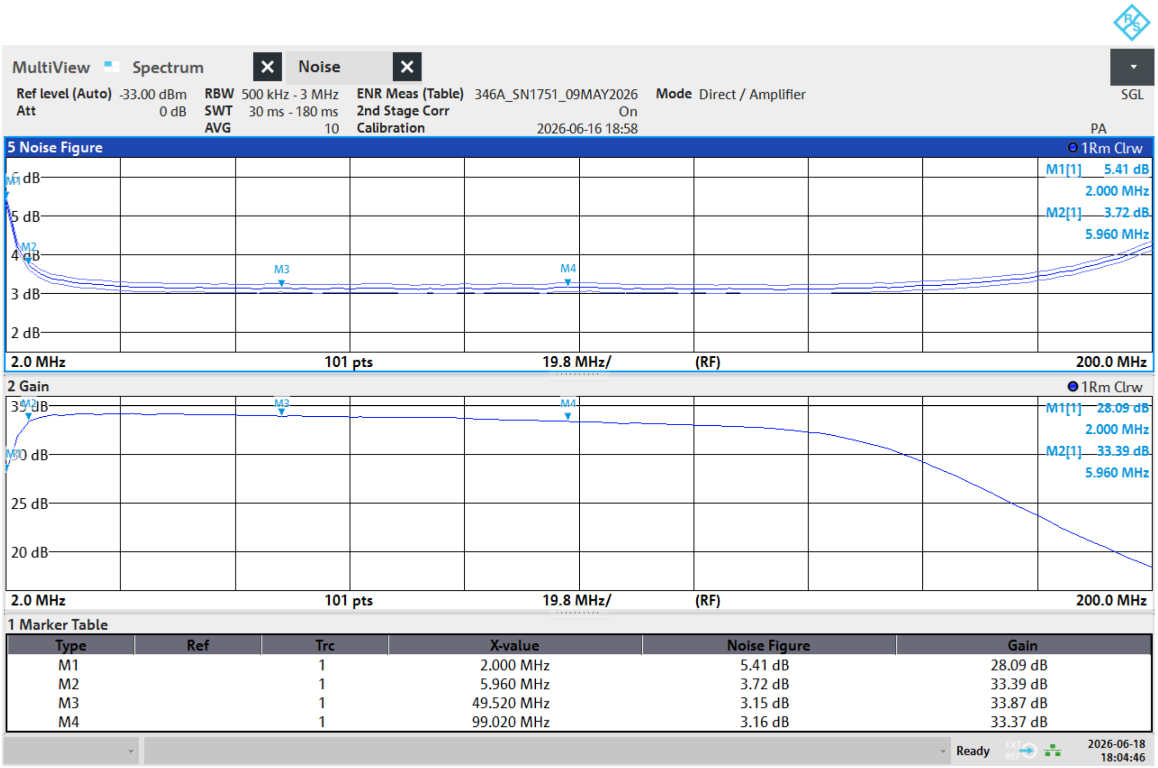


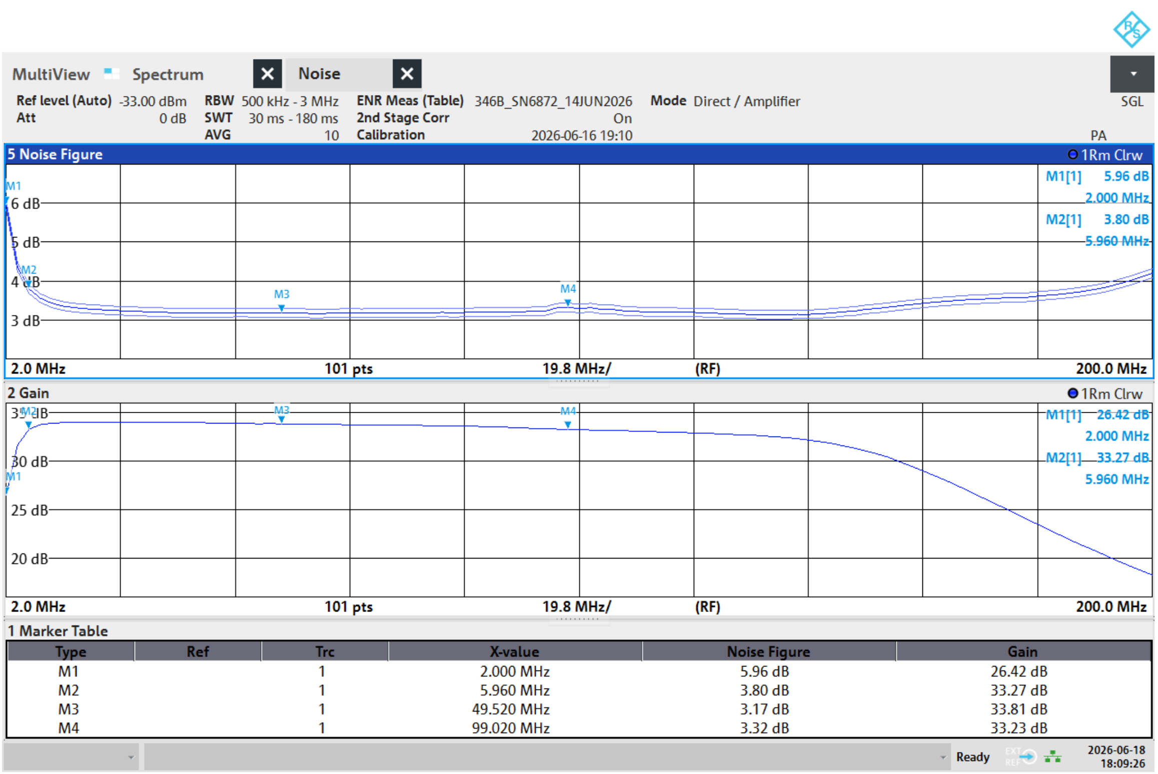
Figure 5.d ~ HP 8447A Modified showing HP 346A in use and HP 346B below.

Figure 6.a ~ LWA-FEE V2 (5 dB ENR)



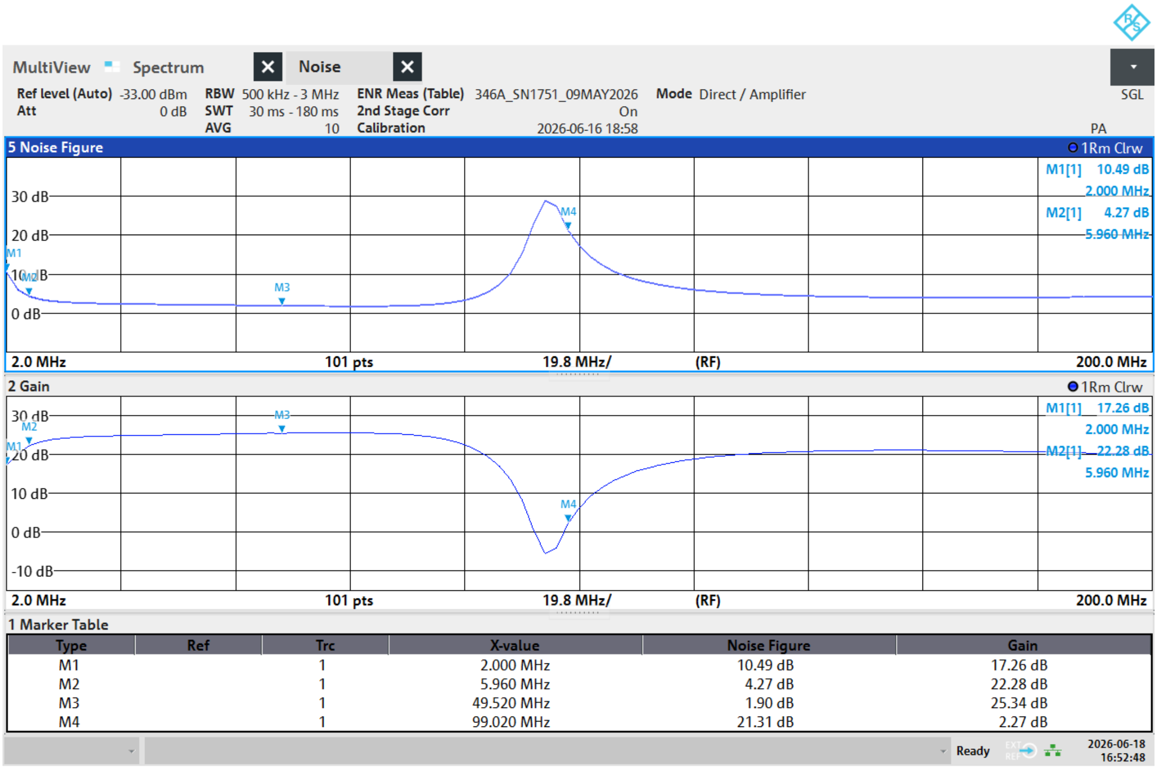
06:04:46 PM 06/18/2026

Figure 6.b ~ LWA-FEE V2 (15 dB ENR)



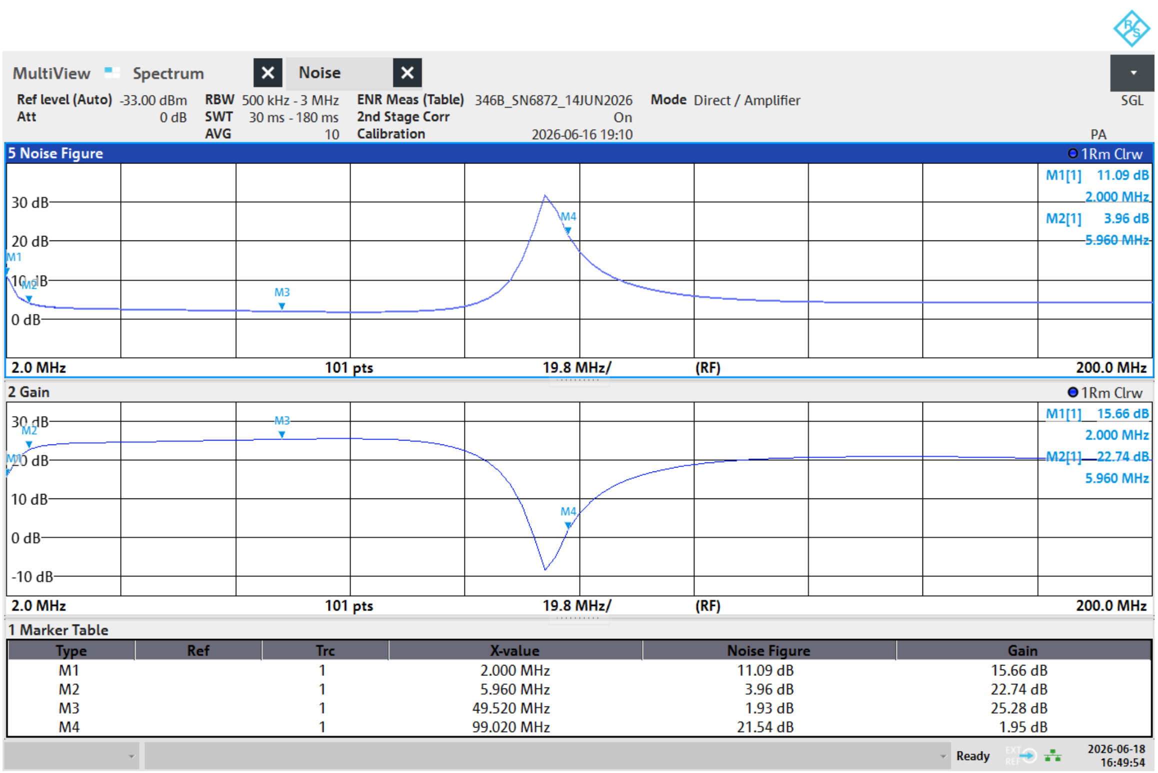
06:09:27 PM 06/18/2026

Figure 7.a ~ NenuFAR LNA (5 dB ENR)



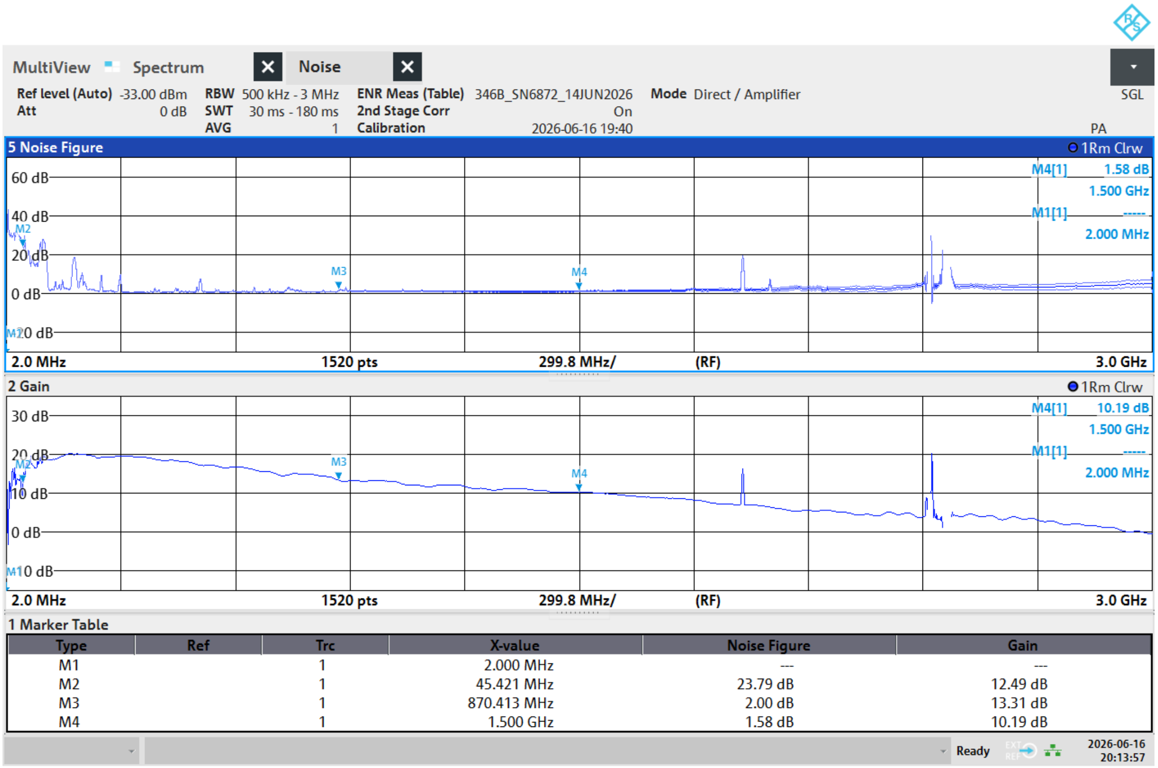
04:52:48 PM 06/18/2026

Figure 7.b ~ NenuFAR LNA (15 dB ENR). Note noise figure and gain difference with 346A above



04:49:54 PM 06/18/2026

Figure 8.a ~ LNA-1 LNA (5 dB ENR): 2 – 3000 MHz

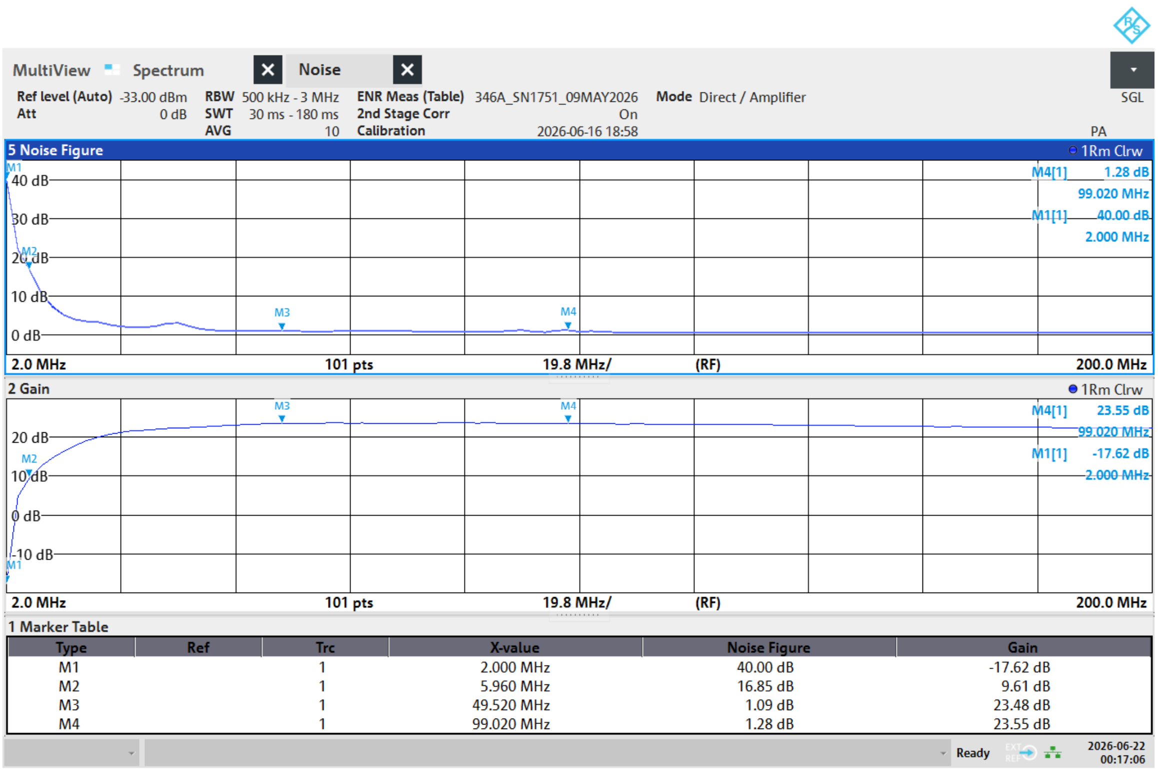


08:13:57 PM 06/16/2026

Figure 8.b ~ LNA-1 LNA (15 dB ENR): 2 – 3000 MHz

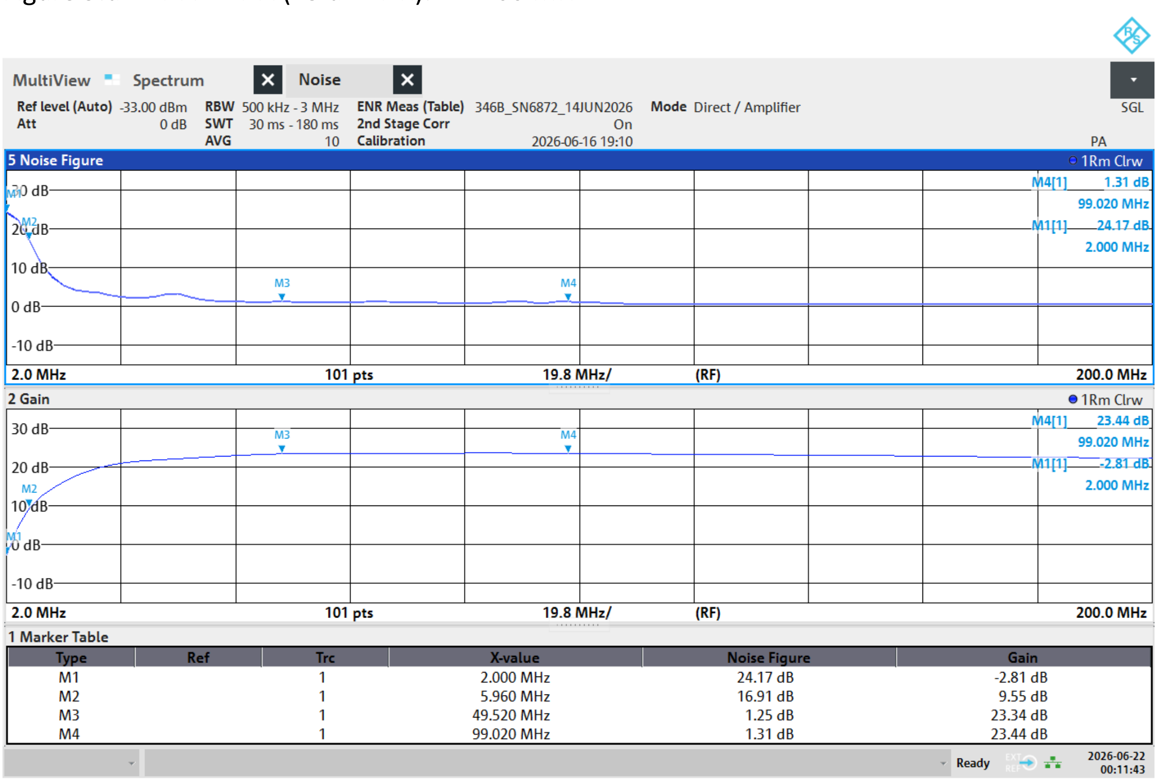
09:40:48 PM 06/16/2026

Figure 9.c ~ LNA-1 LNA (5 dB ENR): 2 – 200 MHz



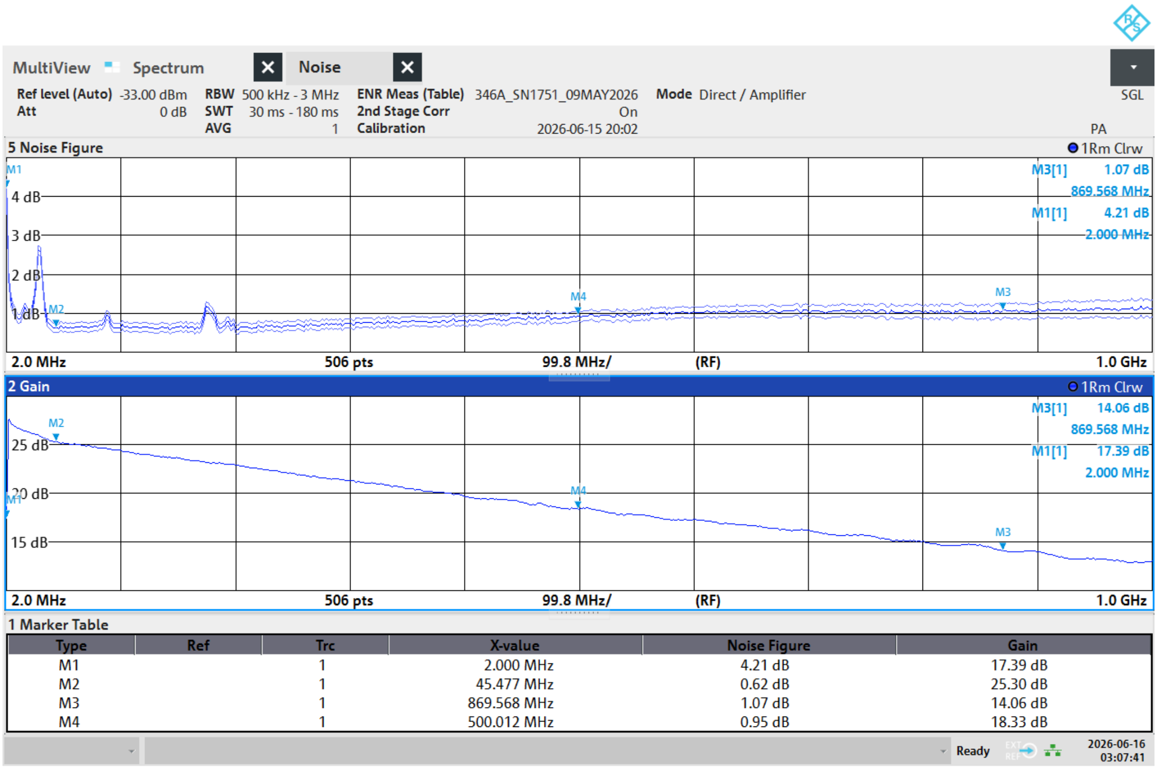
12:17:07 AM 06/22/2026

Figure 9.d ~ LNA-1 LNA (15 dB ENR): 2 – 200 MHz



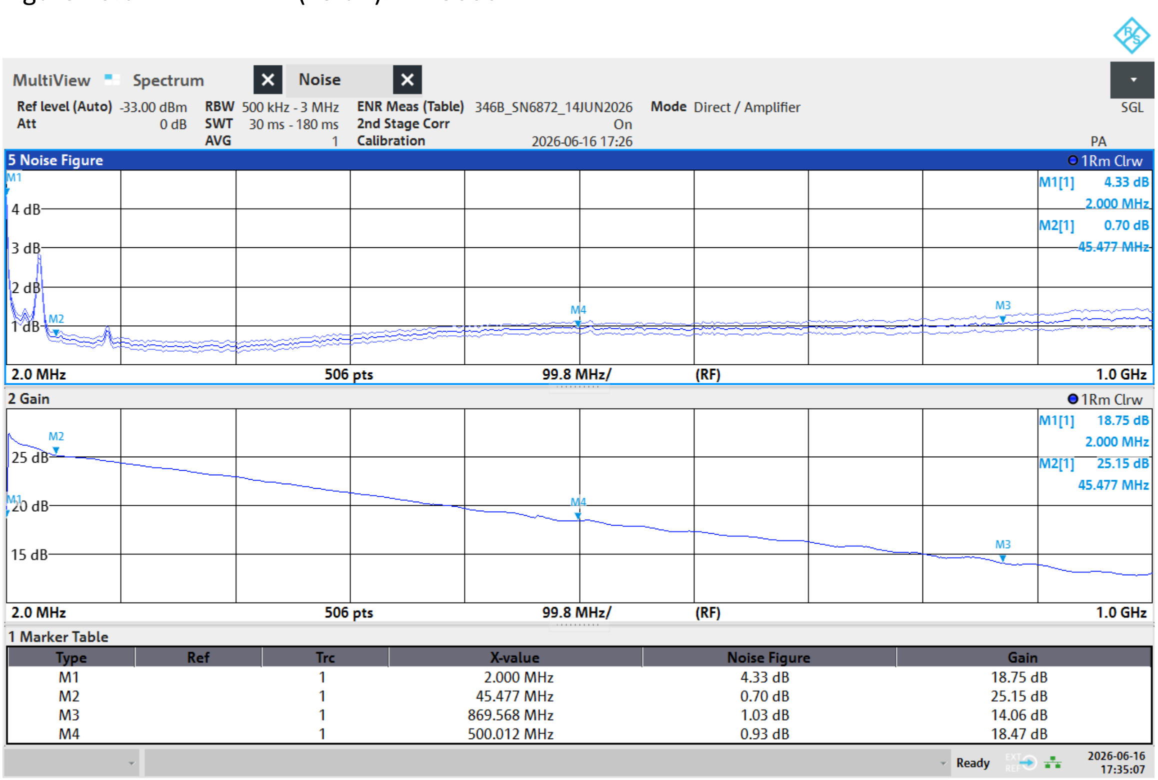
12:11:44 AM 06/22/2026

Figure 10.a ~ LNA-2 LNA (5 dB ENR): 2 – 1000 MHz



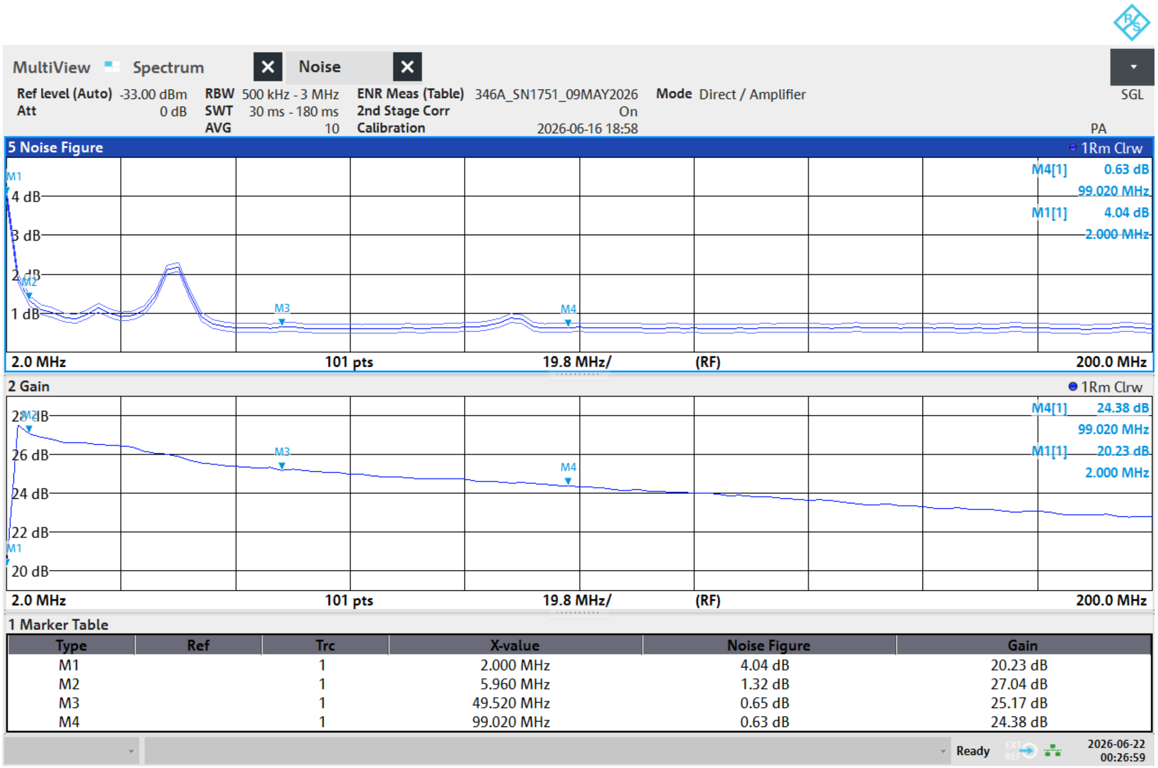
03:07:42 AM 06/16/2026

Figure 10.b ~ LNA-2 LNA (15 dB): 2 – 3000 MHz



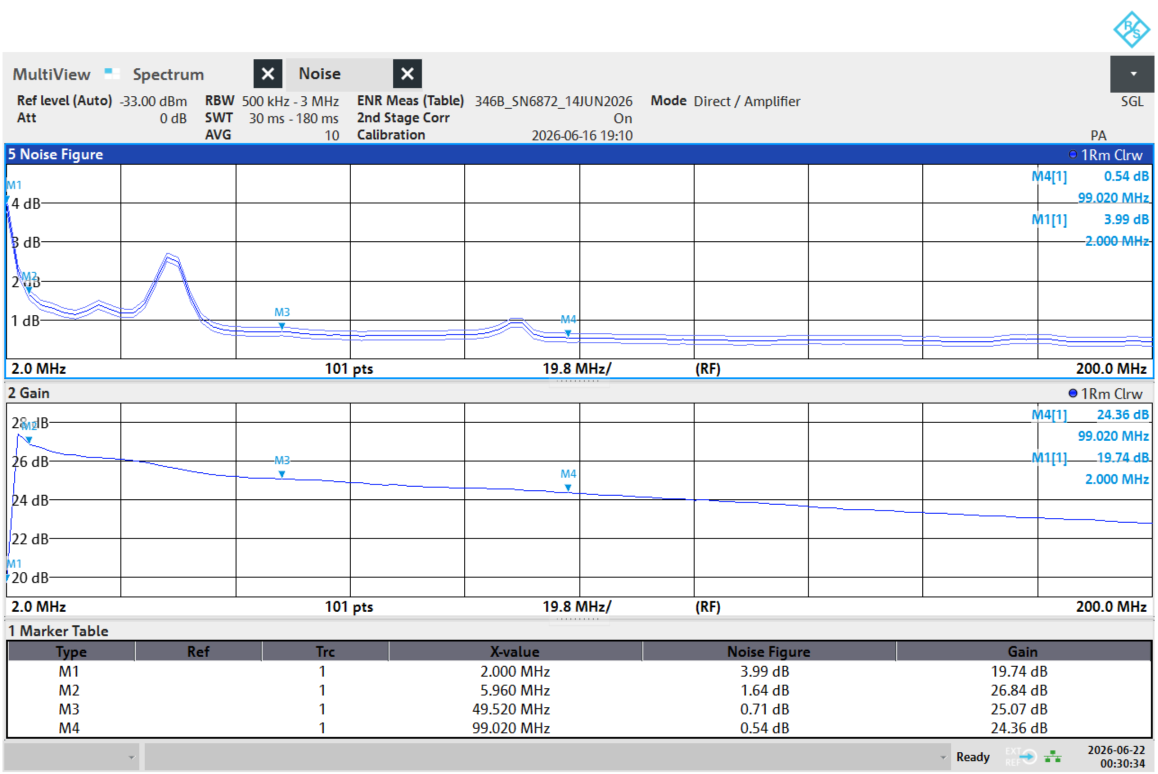
05:35:07 PM 06/16/2026

Figure 10.c ~ LNA-2 LNA (5 dB ENR): 2 – 200 MHz



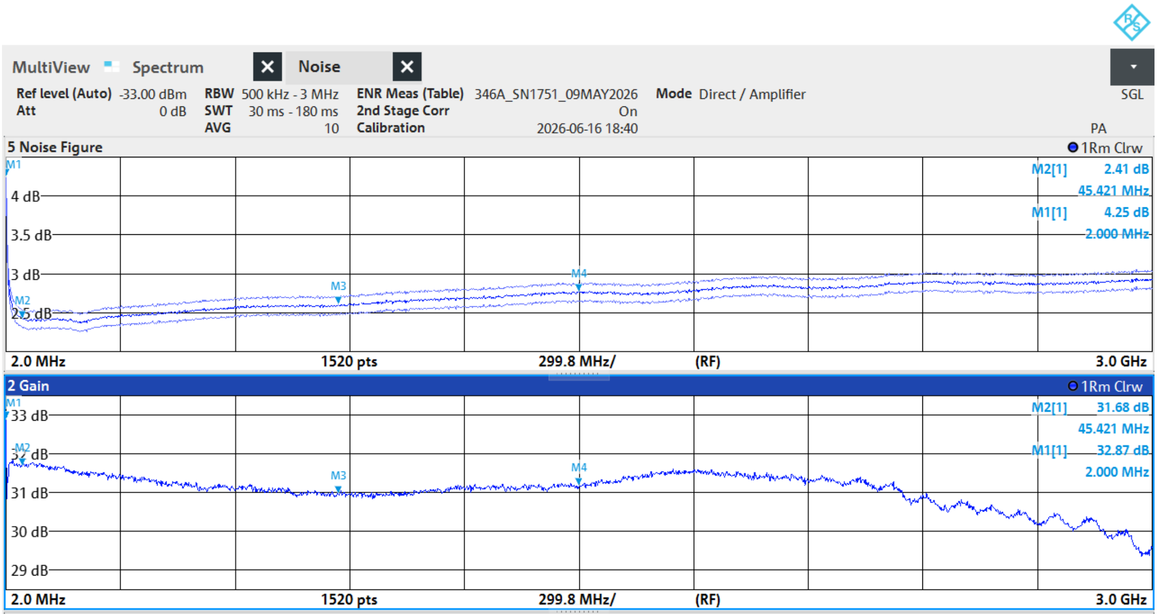
12:27:00 AM 06/22/2026

Figure 10.d ~ LNA-2 LNA (15 dB ENR): 2 – 200 MHz



12:30:35 AM 06/22/2026

Figure 11.a ~ HP 8447A Modified (5 dB ENR)

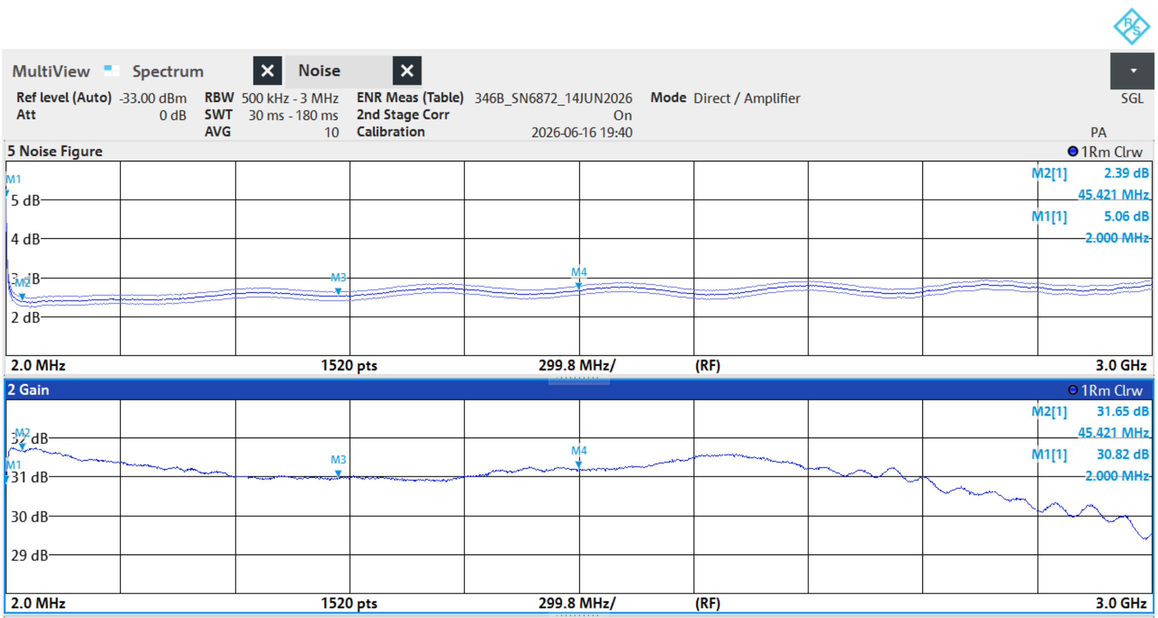


Type	Ref	Trc	X-value	Noise Figure	Gain
M1		1	2.000 MHz	4.25 dB	32.87 dB
M2		1	45.421 MHz	2.41 dB	31.68 dB
M3		1	870.413 MHz	2.60 dB	30.96 dB
M4		1	1.500 GHz	2.77 dB	31.16 dB

Ready 2026-06-18 02:35:11

02:35:11 AM 06/18/2026

Figure 11.b ~ HP 8447A Modified (15 dB ENR)



Type	Ref	Trc	X-value	Noise Figure	Gain
M1		1	2.000 MHz	5.06 dB	30.82 dB
M2		1	45.421 MHz	2.39 dB	31.65 dB
M3		1	870.413 MHz	2.53 dB	30.96 dB
M4		1	1.500 GHz	2.68 dB	31.19 dB

Ready 2026-06-18 03:48:56

03:48:57 AM 06/18/2026

6. Discussion

1. LWA-FEE V2: The noise figure and gain measurements are within a couple tenths dB at the marker frequencies with the two noise sources except at 2 MHz where the difference was 0.4 dB. However, the gain measurements at 2 MHz varied by a couple dB indicating measurement difficulties at that frequency. The gain measurements at higher frequencies were approximately 1 dB lower than gain measurements made with both a spectrum analyzer/tracking generator and vector network analyzer. Also, the noise figure measurements at 10 MHz and above were about 1 dB higher than measurements made with a different instrument, a Keysight N9917A Microwave Analyzer with Noise Figure option. This may have been due to the more involved calibration and measurements with the Keysight analyzer in which the test fixture losses were compensated.

The noise figure measurement with the 15 dB ENR noise source showed a very small bump near 100 MHz, which was not seen with the 5 dB ENR noise source, and it did not appear in the gain measurement. The probable source of the bump is FM broadcast band interference. The LWA-FEE V2 was measured while mounted in the LWA FEE Text Fixture with the lid closed and latched. If the lid was left open, FM broadcast and TV band interference was far more obvious in the noise figure measurements.

2. NenuFAR LNA: The NenuFAR LNA measurements were undertaken with the test fixture lid closed and latched; otherwise, interference was observed similar to the LWA-FEE V2. The noise figure and gain measurements at 2 MHz showed about the same variations as the LWA-FEE V2 with the two noise sources. The differences in the noise figure measurements with the two noise sources at the 6, 49 and 99 MHz marker frequencies were 0.3 dB or less.

3. LNA-1 LNA: The LNA-1 contains an unshielded amplifier in a plastic dome-like outdoor enclosure. This configuration was susceptible to radio frequency interference when undergoing the highly sensitive noise figure measurements. Several interfering frequencies were observed. The most prominent one was 30 MHz, which is the 3rd harmonic of the lab 10 MHz reference frequency. Interestingly, the reference frequency is a sinewave but it apparently has some distortion that produced the 3rd harmonic. The other interference in the LNA-1 measurements corresponded to TV station frequencies, 1900 MHz cellular band and 2.4 GHz in-house WiFi. Surprisingly, the interference from FM broadcast transmitters was almost indetectable.

A few attempt were made to reduce the interference by wrapping the LNA-1 in a cocoon of aluminum foil and anti-static bags but this effort had no effect. This might indicate that the interference is entering the amplifier some other way, but I was not able to mitigate it. Two sets of measurements were made on this amplifier, one set from 2 to 200 MHz and another from 2 to 3000 MHz. The lower frequency noise figure measurements showed a small (2 dB) interference bump at 30 MHz, and the measured noise figure at 2 MHz was unreliable due to the low gain at that frequency. From 6 MHz to 99 MHz, the markers read within a tenth dB for both noise sources. The higher frequency measurement set with the two noise sources showed a 1 dB difference at 870 MHz but only 0.05 difference at 1.5 GHz.

4. LNA-2 LNA: The LNA-2 amplifier is mounted in an enclosure similar to LNA-1 but the amplifier itself is enclosed in a machined aluminum enclosure. Even so, there was interference in the noise figure measurements from the 10 MHz lab reference (3rd harmonic) and TV station frequencies; FM broadcast band interference was small. These were approximately the same as in the LNA-1. Noise figure measurements with the two noise sources indicate very close agreement, less than 0.3 dB difference, in the 2 to 200 MHz measurement set and about 0.1

dB or less difference up to 500 MHz. It is interesting that interference from the 10 MHz lab reference frequency only appeared in the LNA-1 and LNA-2 and not any of the other amplifiers.

5. HP 8447A Modified: Although the 8447A Modified has relatively high gain (nominal 30 dB) and low noise figure (nominal 2.5 dB), the traces for both the gain and noise figure measurements were a little noisy when the 5 dB ENR noise source was used. The traces were less noisy with the 15 dB ENR noise source. Both measurement sets shown here used averaging (10) to reduce trace noise and this helped considerably. The noise figure measurements were within 0.1 dB at all four markers for both noise sources. The amplifier gain plots show a few tenths dB ripple from impedance mismatch above 2.1 GHz

---

7. Conclusions

The noise figure and gain measurements appear to be reliable down to at least 3 MHz. Some variations were noted at 2 MHz, which indicates either an error in the ENRs used at that frequency or a misapplication of the FPL internal preamplifier below its datasheet specification of 3 MHz. If it is necessary to make additional measurements below 3 MHz, an external preamplifier with the appropriate frequency response should be used.

The 5 and 15 dB ENR noise sources produced very similar results and the differences can be explained by the measurement uncertainties.

Ability to specify RBW and Sweep Time at each measurement frequency is essential.

Noise figure measurements involve very small power spectral densities and can be subject to interference from the ever-present FM broadcast band, television bands, cellular bands and local WiFi systems. Even the local reference frequency can cause interference. However, these generally are easily recognized and could be avoided by using specially designed Frequency Tables in the analyzer. It also is necessary to use high-quality cables to connect to the DUT. Ferrite beads on the cables can be used to reduce their antenna effects.

It is well known that noise figure measurements are difficult to make accurately.

Based on noise figure and gain measurements described above:

- LWA-FEE usable to at least 3 MHz
- NenuFAR LNA usable to at least 3 MHz
- LNA-1 amplifier may be usable to about 5 MHz
- LNA-2 amplifier usable to at least 3 MHz
- HP 8447A Modified usable to below 2 MHz

---

8. References

[Keysight18] Keysight 10 Hints for Making Successful Noise Figure Measurements – Application Note, 5980-0288E, 2018

{LWAFEE} LWA Front End Electronics (FEE) v2, https://github.com/lwa-project/Front_End

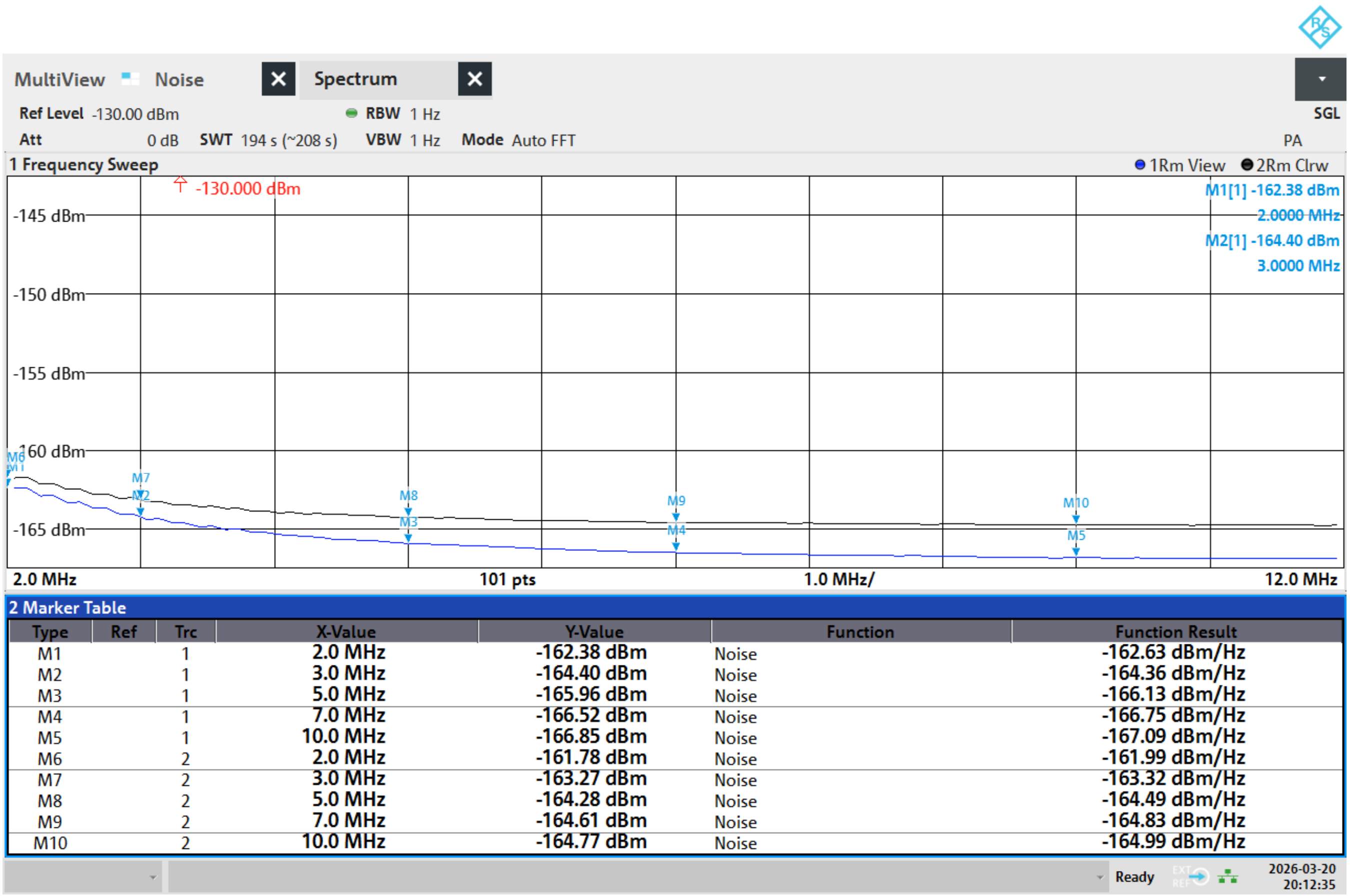
{Reeve14} Reeve, W., Noise Tutorial: Part V ~ Noise Factor Measurements, 2014, available at: https://www.reeve.com/Documents/Noise/Reeve_Noise_5_NFMeas.pdf

{Reeve26} Reeve, W., Noise Sources at Lower Frequencies, 2026, available at: https://www.reeve.com/Documents/Articles%20Papers/Reeve_NoiseSrcLFMeas.pdf

Appendix ~ FPL DANL Measurements

Reference: {Reeve26}:
Figure D2.a ~ HP 346A, s/n 2614A01751, ENR 5 dB (nominal), APC 3.5-M adapted to N-M, 2 – 12 MHz

Note: Markers M1 through M5 show the analyzer DANLs (noise source in the cold state, equivalent to 50 ohm termination) in dBm Hz^{-1} in the Marker Table far-right column.



Type	Ref	Trc	X-Value	Y-Value	Function	Function Result
M1		1	2.0 MHz	-162.38 dBm	Noise	-162.63 dBm/Hz
M2		1	3.0 MHz	-164.40 dBm	Noise	-164.36 dBm/Hz
M3		1	5.0 MHz	-165.96 dBm	Noise	-166.13 dBm/Hz
M4		1	7.0 MHz	-166.52 dBm	Noise	-166.75 dBm/Hz
M5		1	10.0 MHz	-166.85 dBm	Noise	-167.09 dBm/Hz
M6		2	2.0 MHz	-161.78 dBm	Noise	-161.99 dBm/Hz
M7		2	3.0 MHz	-163.27 dBm	Noise	-163.32 dBm/Hz
M8		2	5.0 MHz	-164.28 dBm	Noise	-164.49 dBm/Hz
M9		2	7.0 MHz	-164.61 dBm	Noise	-164.83 dBm/Hz
M10		2	10.0 MHz	-164.77 dBm	Noise	-164.99 dBm/Hz

08:12:36 PM 03/20/2026

Document Information

Author: Whitham D. Reeve

Revisions: 0.0 (Started document, 10 May 2026)
0.1 (Added guidelines, 13 May 2026)
0.2 (Added table images, 15 May 2026)
0.3 (Added FPL noise figure measurements, NF guide and noise source selection, 13 Jun 2026)
0.4 (Added more detail to Instrument Settings section and Measurements section, 14 Jun 2026)
0.5 (Added LNA-1, LNA-2 NF measurements 2-200 MHz, 21 Jun 2026)
0.6 (Added amplifier images and revised Noise Source Selection section, 23 Jun 2026)
0.7 (Edits, 29 Jun 2026)
0.8 (Work on Conclusions, 06 Jul 2026)
0.9 (Final edits and distribution, 18 Jul 2026)

File size: 12905894