Receiver Output Stability Analysis
Part II: Measurements

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2-1. Introduction

Part II presents stability measurements for several SDR and analog receivers and soundcards based on the concepts described in Part I. Part II focuses on receivers operating in the high frequency (HF) band, particularly the upper portion from 15 to 30 MHz, but the concepts and measurement methods apply to any total power receiver at any frequency.

The measurement results are grouped according to type of receiver and soundcard and briefly summarized in section 2-3. More details follow (table 2-1). Soundcards can potentially affect narrowband receiver stability measurements so they were measured separately in an attempt to determine those effects (a datalogger also was used). A complete set of measurements including Allan Deviation (ADEV) plots, Data Value plots (time domain) and Power Spectral Density plots (frequency domain) and detailed procedures are available from the author.

Table 2-1 ~ Categories, devices and associated section numbers

Category →	**Wideband SDR**	**Wideband Scanning**	**Narrowband**	**Soundcards**
Measurements	Sect. 2-4	Sect. 2-5	Sect. 2-6	Sect. 2-7
Receivers	RFSpace NetSDR RFSpace Cloud-IQ SDRPlay RSP AirSpy with SpyVerter	RF Associates FSX-5	Icom R-75 RF Associates Jove Receiver	See Section 2-6

The measurement results presented here are estimations and meant to demonstrate the methods and concepts and to provide a path for users who wish to make stability measurements under their own specific operational conditions. The results are not definitive for any particular receiver because of the many variables involved. It is important to note that I did not necessarily optimize receiver settings for ADEV measurements or for any particular operating condition or radio observation type. Optimization is particularly important with the SDR receivers in actual use. Also, temperatures were normal room temperatures, and night setback was used in one of the two measurement locations (temperature plots are provided in the next section). Temperature variations potentially can affect electronics performance and be detrimental to the ADEV measurements. Although not optimal, these measurement conditions probably are close to the actual operating conditions in many amateur radio astronomy observatories.

Two sets of measurements were taken for most of the receivers. One used a 50 ohm termination at room temperature (nominal noise temperature of 290 K) on the receiver RF input and the other used a noise generator on the RF input (see Part I for explanation). Two noise generators were used, the HOT-1 and RF-2050S (figure 2-1). Both are made by RF Associates and are high-quality devices designed for amateur radio astronomy applications. The HOT-1 originally was supplied with a single output of 23.1 million kelvins, but I packaged it with 0 to 50 dB attenuator having 1 dB steps to provide an adjustable output as described in {HOT-1}. The RF-2050S has 1.4 million kelvins maximum output and includes a built-in step attenuator with six settings in 3 dB steps. I set their outputs to a noise temperature nearest the galactic radio background at 20 MHz, which for the HOT-1 is 46 300 K and for the RF-2050S is 43 100 K.

Figure 2-1 ~ Noise generators RF-2050S (left) and HOT-1 (right). These units are designed for HF and low VHF amateur radio astronomy applications and include attenuators to adjust the output noise temperature. For scale, the width of the HOT-1 is about 150 mm.

Wideband receiver measurements went smoothly and the ADEV plots indicate that data averaging times of 1 h or more are possible. Some measurements of a given receiver indicated less than 1 h possibly due to temperature variations or other unknown factors. The external USB soundcard measurements were comparatively difficult and indicate poor ADEV performance (averaging provides no benefits at all). The analog narrowband receivers usually performed poorly when connected to a PC through one of the external soundcards. Some reasons for the poor performance of the external USB soundcards could be: 1) Soundcards must have an input power level above zero to provide meaningful output; 2) Noise is coupled through the USB port to the soundcard (discussed in section 2-6); 3) The software used to collect the data is not suitable because of lost data; 4) Temperature and power supply variations; 5) Soundcard drivers are inadequate; 6) Performance of the PCs or operating systems is limited. Except for 2) I have not done any investigation to determine which of these could be the cause.

As mentioned above, measurements were made with a 50 ohm resistance and noise generator terminations. When the noise generator is used, the ADEV measurements may actually be of the noise generator stability and not the receiver stability. However, in many cases the ADEV of a receiver with a 50 ohm termination is comparable to the ADEV with a noise generator termination, which indicates that the noise generator stability is at least as good as the receiver. However, their stabilities have not been quantified. Noise generators designed for laboratory applications may yield more accurate results.

2-2. Basic Measurement Considerations

General: Data collection and analyses depended on various software applications including Radio-Sky Spectrograph, Radio-SkyPipe II (referred to as Radio-SkyPipe or RSPII throughout this document), SDR#, SDRPlay2RSS, Microsoft Excel, ALAVAR and the text editor Notepad++. Measurements of some SDR receivers required two application programs running simultaneously, one to control the receiver, pre-process the I-Q data and produce the streaming output data (for example, SDR#) and another to display and store the data (for example, Radio-Sky Spectrograph). ALAVAR was used for all ADEV and related calculations and plots.

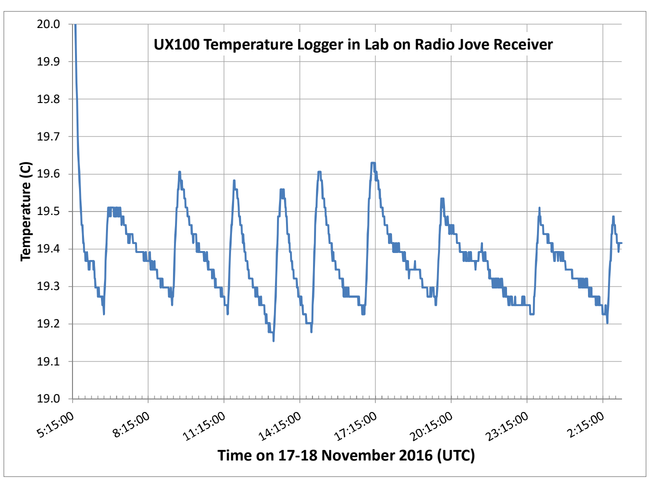
Most measurements were run for 24 h (about 90 000 s) more or less as determined by convenience. The measurement run lengths were a tradeoff between 1) obtaining sufficient data for the ADEV calculations (the more the better), 2) manageable file size (many data files approached or exceeded 1 GB and comma separated variable (.csv) data files approached or exceeded 1 million lines) and 3) the self-imposed need to finish the data collection within two months (during that time period four PCs were running measurements 24 h/d, 7 d/wk), and many measurements were repeated many times.

The ADEV is plotted with respect to multiples of the sampling interval ($n \cdot \tau_0$). Because sampling interval is an important parameter, it was determined by analyzing the differences between timestamps in the output data. Slight variations were noted in the sampling intervals, ranging from 0.5% to 10% depending on the software used to collect the data. It is not known how or if these variations affect the calculated ADEV.

The ADEV plots were visually interpreted to determine the maximum averaging time when Gaussian or white FM noise dominates – a straight line plot with slope near –0.5 ending in the so-called "knee" (see key plot at the end of this section). Although visual interpretations are somewhat subjective, the results are useful for estimating purposes. A few ADEV plot overlays were made from the calculated data to compare noise generator and 50 ohm termination measurements on one plot.

Some ADEV plots include 1-sigma (68.3% probability) error bars. It is noted that the error bar length increases at the high end of the time scales and plots often have a "hook" at that end. I believe this is because, as the averaging time increases, the number of points available for the ADEV calculation decreases and the possibility of a statistical error increases.

<u>Temperature variations</u>: It is well-known that temperature variations can affect hardware performance, particularly oscillator frequency and amplifier gain. In an attempt to determine these effects, I measured the temperatures at the two locations used for the ADEV measurements: The Radio Jove Receiver temperature was measured in the Laboratory and Cloud-IQ temperature was measured at the Receiver Station. In both cases, the temperature logger was placed on top of the receiver. Therefore, the logged temperatures are of the receiver enclosures as influenced by the receiver temperature and room ambient temperature. The temperature of the Radio Jove Receiver in the Lab was quite stable and varied only about ±0.25 °C from average with approximately 3 h cycle over a 22 h period (figure 2-1). In contrast, the temperature of the Cloud-IQ at the Receiver station varied much more. It is near a hot water baseboard heater and north-facing window and the room has a night-setback thermostat that lowers the temperature about 4 °C.



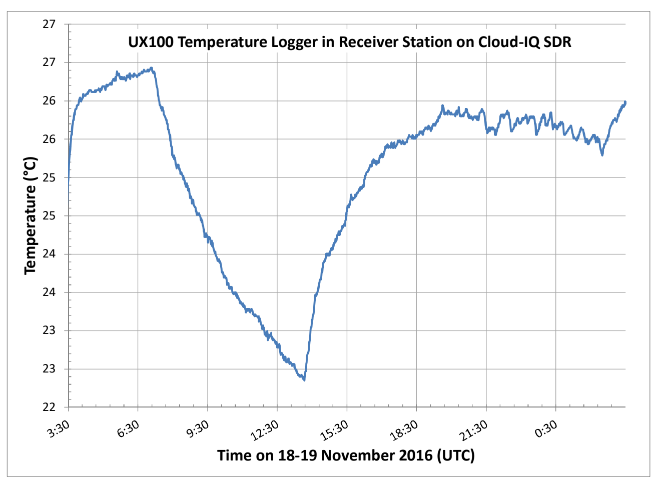


Figure 2-1 ~ Laboratory and Receiver Station temperature measurements for approximately 24 h duration. Note vertical scale differences. Left: Lab measurements show very small variations. The initial temperature spike is due to handling the logger prior to deployment; the temperature logger is "Launched" by a PC and then carried to its logging location (delayed launch was not used). Right: Receiver Station measurements show relatively wide variations. The higher temperature of the Cloud-IQ receiver enclosure and also the effects of room temperature night-setback are obvious in the plot. Normal cyclic temperature variations also can be seen in the plot after about 1700 UTC but they are not as obvious because of the scale.

The ALAVAR Data and ADEV plots do not indicate an obvious correlation with temperature, but that could be a matter of interpretation. Comparing the internal and external USB soundcard ADEV measurements indicates the external USB soundcards performed poorly at both locations, so their temperature performance probably is overshadowed by other factors. The one internal soundcard at the Receiver station performed much better than the external soundcards but not as well as two identical internal soundcards in the Lab where the temperature is more stable. This indicates that temperature variations did, in fact, affect the internal soundcard stability measurements and, by logical extension, the receivers used with them.

Wideband receivers: The wideband receivers covered here are categorized as two basic types: Software defined radio (SDR) receivers and Scanning receivers. The scanning receiver is considered wideband because of its sweep range, although the instantaneous bandwidth of each sweep channel is much narrower.

For two of the SDR receivers (RF Space Cloud-IQ and NetSDR) the data output sampling interval had to be ≥ 0.5 s due to software or PC limitations determined by experiment. For these two receivers, continuum measurements were made with sampling intervals of 0.5 and 1.0 s. Continuum is the total noise power in the displayed span setting of the receiver. The software produces data for average and peak continuum powers, and the Allan Deviation is calculated from the average power samples. For all measurements, these receivers were operated with their maximum bandwidth settings (35 MHz for the NetSDR and 61.44 MHz for the Cloud-IQ) but with 10 MHz span settings. The center frequency was set to 20 MHz.

For the other two SDR receivers (SDRPlay RSP and AirSpy), measurements were made on channelized data produced from the FFT of the receiver I-Q data. The FFT splits the receiver continuum of, say, 10 MHz into frequency bins or channels. Each bin has a bandwidth determined by the FFT frame size or length N and RF sampling rate f_S such that channel width $f_{Channel} = f_S / N$. Note that the RF sampling rate f_S is not the same as the data output sampling rate. The total number of channels $n_{Channels}$ displayed by the associated software depends on the frequency span f_{Span} where $n_{Channels} = N \cdot f_{Span} / f_S$. I made measurements using 50, 100 and 200 kHz channel widths. The Allan Deviation is calculated for only one of the FFT channels near 20.1 or 20.5 MHz. Both receivers have spurs or undesired responses at fixed distances from the center frequency and care was taken to avoid them when choosing the channel.

The spectral leakage that occurs across adjacent FFT channels can be reduced by windowing. Default window functions were used in all measurements involving the FFT. More rigorous comparison measurements would use the same window function, but I expect the effects on stability would be minor. The default settings are:

SpectraVue (Cloud-IQ and NetSDR):	Hanning (available for demodulation modes but not used)
SDR# (AirSpy):	Blackman-Harris 4
SDRPlay2RSS (RSP):	None (Blackman available)

The overall performance of the SDRPlay RSP and AirSpy receivers depends significantly on their gain settings. The SDR# software used with the AirSpy has three gain setting modes – *Sensitivity*, *Linearity* and *Free*. The RF, Mixer and IF gains are user adjustable in the Free mode. In the Sensitivity and Linearity modes, the Mixer and IF gains are preset (no information is available that describes how these are set but presumably they are optimized for the mode) and only the RF gain is user adjustable. I made measurements using both the Sensitivity and Linearity modes and used different RF gain settings for each mode, one near mid-range (9 out of 20 gain units) and another high-range but not maximum (18 out of 20 gain units).

The SDRPlay2RSS software used with the RSP has only a Preamplifier gain setting. The RSP gain is actually set as a reduction from maximum gain, in which a setting of 0 means maximum preamplifier gain. A higher setting provides higher attenuation of the input. I believe the gain reduction setting is in dB but I did not confirm. I experimented with gain settings and settled on a value (10 gain reduction units) that provided a noticeable change in the spectrum when the noise generator output was changed by ±1 dB from the galactic radio background setting (46 300 K for the HOT-1 noise generator). I then made a set of measurements with 10 gain reduction units and another set with 18 gain reduction units. The same gain setting was used for both the 50 ohm termination and noise generator termination.

The SDR# software plug-in for Radio-Sky Spectrograph used with the AirSpy receiver does not allow adjustable sampling intervals. It is fixed at 109.3 ms as determined from analyses of the timestamps in the data files (standard deviation = 0.5 ms). The SDRPlay2 RSP software used with the RSP allows the user to specify a sampling interval (Integration Time) and I always used 100 ms (the timestamps also indicated standard deviation = 0.5 ms).

The lower frequency limit of the AirSpy is 24 MHz so it requires an up-converter to cover frequencies near 20 MHz. I used the SpyVerter companion up-converter for these measurements. For comparison, I also made some ADEV measurements at 104 MHz without the SpyVerter, but the results are not included here (no obvious difference was noted).

The wideband scanning receiver (FSX-5) is inherently channelized and the frequency is rapidly and repetitively swept over the desired frequency band. For the measurements discussed here, the lower and upper frequency sweep settings were 15 and 30 MHz, respectively, with data collected for 50, 100 and 300 channels. The response of this receiver is reduced at 15 MHz due to its internal filtering but all ADEV plots were made for a single channel near 20 MHz. The channel center separation is inversely proportional to the number of channels for a given sweep range but the actual channel bandwidth is fixed at 30 kHz. Data was collected while scanning over the full frequency range so that any sweeping effects would be included in the measurements. The output data sampling interval τ_0 for this receiver depends on the number of channels setup in the software. For example, timestamp analyses showed 49.5 ms sampling interval for 100 channels and 146.7 ms for 300 channels. This receiver does not have user-adjustable gain.

<u>Narrowband receivers and soundcards</u>: Narrowband receivers have an analog audio output and require a soundcard or datalogger for digitization; thus, embedded in the measurements are both receiver and analog-digital converter (ADC) effects, which include quantization noise and any other noise or distortion produced by the soundcard. To determine the extent of these effects, I made standalone measurements (no receiver

connection) of several soundcards and a datalogger. These measurements indicate that the soundcard can limit the overall ADEV performance of the analog narrowband receivers.

For the standalone measurements I terminated the soundcard audio inputs with resistors equal in value to the Icom R-75 narrowband receiver's audio output impedance, 4.7 kohm. I used Radio-SkyPipe software for all narrowband receiver and soundcard measurements except the datalogger. Radio-SkyPipe was setup to use the same basic audio settings: Stereo, 12 kHz audio sampling rate with 16 bit resolution and 100 ms output sampling interval τ_0. Statistical analyses of the timestamps indicate the standard deviation of the intervals varied from 2 to 10 ms for Radio-SkyPipe. The datalogger, a LabJack U3-HV, used its own software application (LJLogUD v1.20), which was set for 100 ms data sampling interval. The standard deviation of the LJLogUD timestamps was about 8 ms. Note that I also did some measurements with the LabJack U3-LV but found it to be unsuitable because it accepts only unipolar inputs whereas as the U3-HV can accept bipolar inputs.

I encountered problems with Radio-SkyPipe skipping or temporary freezing during measurement runs. No data is recorded during skipping. The skipping did not occur on every run, and when it did it seemed to occur randomly. Also, it seemed to be worst with external USB soundcards and would last for less than 1 second to almost 30 seconds. It is possible the skipping seriously affects the ADEV calculations, but I was not able to determine the cause or effects. It is possible the Windows operating system would engage itself in a high priority activity such as virus scanning that prevented Radio-SkyPipe from sampling. It also is possible that setting Radio-SkyPipe for higher CPU priority would reduce this problem (available settings are *Normal*, *Above Normal*, *High*, and *Real Time*; Normal was used for all measurements).

As with the wideband receivers two sets of measurements were made on each of the narrowband receivers using a 50 ohm termination and a noise generator termination. The same noise temperature settings were used as previously mentioned.

<u>Output data</u>: The raw output data format varies with the software used to collect it. Radio-SkyPipe saves data in a proprietary format that must be exported to a columnar text file without the date information and with time stamps in the sssss.sss format, where "s" is seconds. These files are saved as *.dat files and can be directly loaded by ALAVAR. The .dat extension is used for convenience – the file contents are ordinary ASCII text. Radio-Sky Spectrograph also produces a proprietary data format but it first must be exported to a comma separated value *.csv file. Next, the data for the desired frequency channel column are copied and pasted into the NotePad++ text editor and saved as a *.dat file. This file can then be loaded by ALAVAR. SpectraVue software produces *.csv files with timestamp, average power and peak power columns. The powers are expressed in dB. The data from the average power column are converted to linear ratios after the measurement run and then copied and pasted into a text editor and saved as a *.dat file for loading in ALAVAR.

<u>ALAVAR</u>: The *.dat data file is first opened in the ALAVAR application program and then *Validated* by the software. For all measurements I set ALAVAR to "Remove Outliers" during *PreProcessing* to eliminate transients that occurred on some soundcard measurements when, for example, the monitor and keyboard were changed to a different PC with a KVM switch. I also set the *PreProcessing* to start at data row 5 to eliminate potential problems with the first sample in the file. More careful measurements would not disturb the PC and the "Remove Outliers" option would not be used. Prior to *Processing* the file, I set *Tau(0)* in ALAVAR to the output sampling interval used in the original measurements. I also unchecked all deviation plots except ADEV (ALAVAR

has a quirk in that HDEV is always displayed after *Processing*, but it can be removed by checking and then unchecking it).

The slope of the ADEV plot can be determined by using the ALAVAR *Fit with a Line* function and visual interpretation. When *Show the Line* and *Fixed Slope* are checked in the ALAVAR main window, the slope of the displayed straight fitted line can be adjusted to visually align with the plot. Alternately, ALAVAR's computed data, which is shown directly below the plot can be saved as a text file and used to determine the slope. However, where white FM noise dominates the output, it is convenient to simply fix the slope of the line-fit to –0.5 and plot it as an overlay on the data. ALAVAR allows customizing the format of its output plots but the settings are tedious and cannot be saved. Each time ALAVAR is closed and then re-opened, the plot formats must again be customized.

<u>Key to Reading ADEV Plots</u>: Details shown on each plot may include (figure 2-2)

- Receiver type (title)
- Soundcard (if standalone or used with narrowband receivers) (title)
- Channel number (if a soundcard was used) (title)
- Center frequency (title)
- Bandwidth setting (SDR receivers only) (title)
- Receiver mode (analog narrowband receivers only) (title)
- Input noise temperature in kelvin: "46k" indicates a noise temperature of 46 300 K and "43k" indicates 43 100 K
- If a noise temperature is not shown, the input was terminated with 50 ohms at 290 K; some plots show 50R to indicate this type of termination (title)
- Date of measurement (title)
- The horizontal scale is $n \cdot \tau_0$ in seconds. The value of τ_0 is indicated by the position of the first data point on the left side of the plot. The value of *n* typically varies from 2^0 to 2^{14} (more or less depending on measurement duration)
- Error bars may be shown on plot
- For the AirSpy, the annotation will show GLx or GSx to indicate the Linearity or Sensitivity gain setting value x
- For the SDRPlay RSP, the annotation will show GRx to indicate the Gain Reduction setting value x
- Some plots may show a straight-line with slope –0.5 overlaid on the linear portion of the plot
- All plots start at τ_0

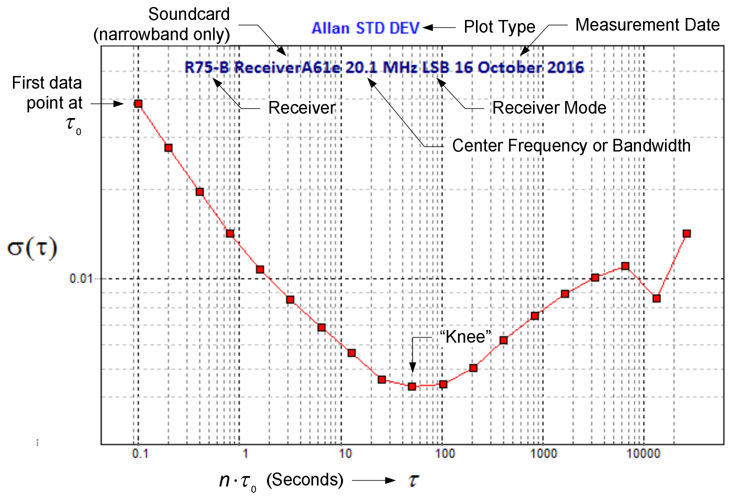


Figure 2-2 ~ Example ADEV plot with annotations. The information shown in the title will vary with the type of receiver and measurement conditions.

2-3. Summary of Measurements

1. SDRPlay RSP	**Value**
a. Tau	1000 to > 20 000 s (290 K), 400 to 1000 s (46 300 K)
b. CF/BW/FFT channel width	20 MHz/ 1.536 MHz/ 7.8 kHz
c. Output data sampling interval	100 ms
d. Software	SDRPlay2RSS & Radio-Sky Spectrograph
2. AirSpy-SpyVerter	
a. Tau	> 10 000 s (290 K), 1000 to > 200 000 s (46 300 K)
b. CF/BW/FFT channel width	20 MHz/10 MHz/50 kHz
c. Output data sampling interval	109 ms
d. Software	SDR# & Radio-Sky Spectrograph
3. RFSpace Cloud-IQ	
a. Tau	No measurements (290 K), 600 to 1000 s (43 100 K)
b. CF/BW/FFT channel width	20 MHz/61.44 MHz/10 MHz (continuum)
c. Output data sampling interval	0.5 and 1 s
d. Software	SpectraVue
4. RFSpace NetSDR	
a. Tau	No measurements (290 K), 200 to 2000 s (43 100 K)
b. CF/BW/FFT channel width	20 MHz/35 MHz/10 MHz (continuum)
c. Output data sampling interval	0.5 and 1 s
d. Software	SpectraVue
5. RF Associates FSX-5	
a. Tau	> 20 000 s (290 K), 5000 s (46 300 K)
b. CF/BW/channel width	20 MHz/15 MHz/50 kHz (30 kHz actual channel bandwidth)
c. Output data sampling interval	146.7 ms
d. Software	Radio-Sky Spectrograph
6. Icom R-75	
a. Tau	25 to 200 s (290 K), 100 to 2000 s (43 100 & 46 300 K)
b. CF/BW/channel width	20.1 MHz/2.8 kHz/2.8 kHz (LSB)
c. Output data sampling interval	100 ms
d. Software	Radio-SkyPipe II
e. Soundcard	LabA61eNo2 & ReceiverA61e
7. RF Associates Radio Jove Receiver	
a. Tau	1000 to > 20 000 s (290 K), 200 to > 20 000 s (46 300 K)
b. CF/BW/channel width	20.1 MHz (approximate)/3 kHz/3 kHz
c. Output data sampling interval	100 ms
d. Software	Radio-SkyPipe II
e. Soundcard	LabA61eNo2 & LabJack U3-HV (Note: Far better results with U3-HV)

Key:

Tau:	Averaging interval when white FM noise dominates
CF:	Center Frequency setting
BW:	Bandwidth setting
FFT channel width, Channel width:	Width of channel used in ADEV calculations
290 K:	Noise temperature of 50 ohm resistor termination
46 300 K & 43 100 K:	Noise temperature setting of noise generator termination

2-4. Measurement Results for Wideband SDR Receivers

SDRPlay RSP with SDRPlay2RSS and Radio-Sky Spectrograph, figure 2-3: The RSP is a software defined radio receiver that can process up to 10 MHz bandwidth. Its native frequency tuning range is 10 kHz to 2 GHz. The I-Q samples produced by the receiver are pre-processed by SDRPlay2RSS and then displayed and stored by Radio-Sky Spectrograph. Although this receiver is capable of processing 10 MHz bandwidth, I ran the measurements with reduced bandwidths of 1.5 and 5 MHz. The overall performance including ADEV performance of this receiver is sensitive to the gain setting; measurements were made with 10 gain reduction units and 18 gain reduction units as indicated below.

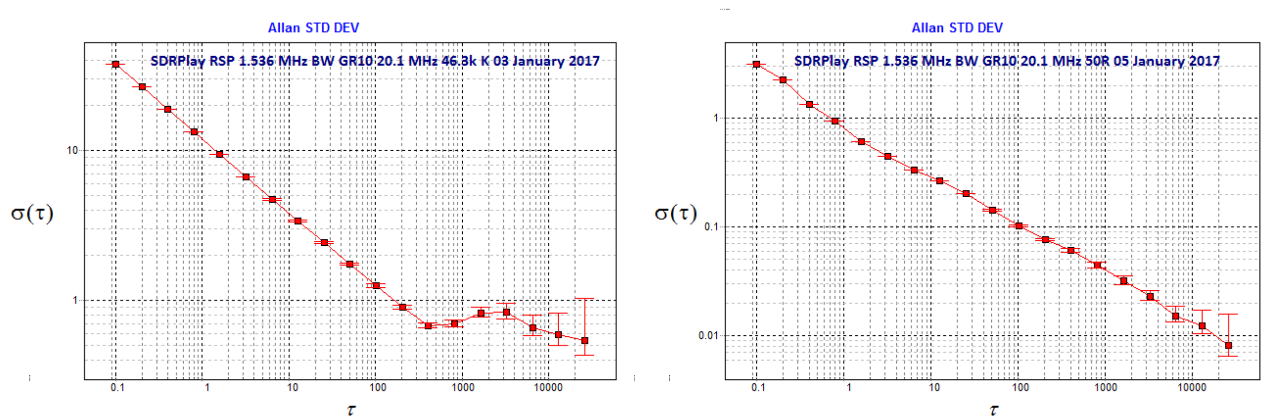


Figure 2-3a ~ SDRPlay RSP SDR Receiver with gain reduction set to 10 units, 1.536 MHz bandwidth and 20.1 MHz center frequency, 24 h measurement period and with 46 300 K noise generator termination (left) and with 290 K 50 ohm termination (right). The “knee” for the noise generator measurement is about 400 s but there is no apparent “knee” in the measurement interval for the 50 ohm termination. The measurements were made in the lab where the ambient temperature is quite stable.

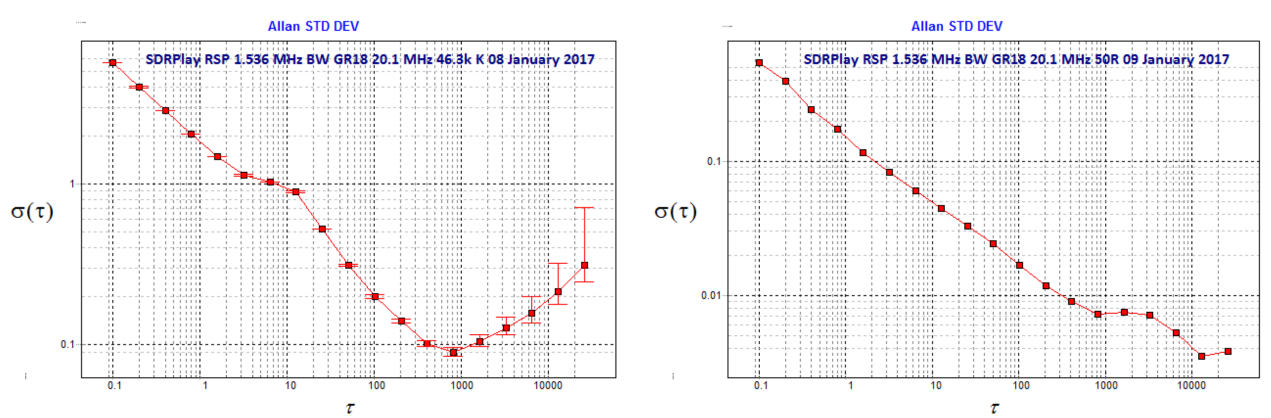


Figure 2-3b ~ SDRPlay RSP SDR Receiver with gain reduction set to 18 units. All other settings as in previous plots. Measurement with 46 300 K noise generator termination (left) and with 290 K 50 ohm termination (right). The “knee” for the noise generator measurement is about 900 s and an apparent “knee” at slightly more than 10 000 s for the 50 ohm termination. The measurements were made in the lab where the ambient temperature is quite stable.

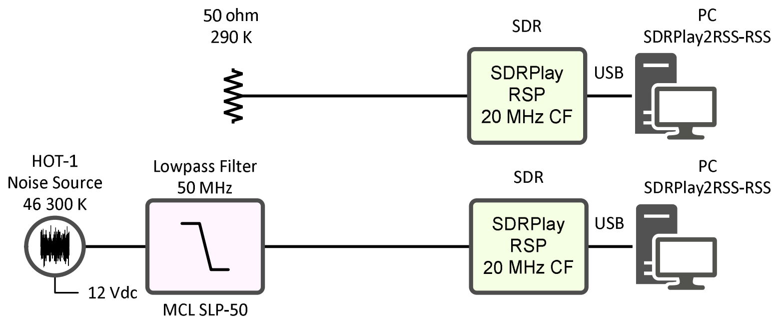


Figure 2-3c ~ Measurement configurations for SDRPlay RSP.

AirSpy and SpyVerter with SDR# and Radio-Sky Spectrograph, figure 2-4: The AirSpy is an SDR receiver that can process up to 10 MHz bandwidth, of which about 8 MHz are usable. The native frequency tuning range of the AirSpy is 24 to 1800 MHz, so I used the SpyVerter up-converter to allow measurements near 20 MHz. The I-Q samples produced by the receiver are pre-processed by SDR# and then displayed and stored by Radio-Sky Spectrograph. I ran the AirSpy measurements on a new Windows 10 PC, which handled the full bandwidth without problems. The overall performance including ADEV performance of this receiver is sensitive to the gain settings; measurements were made for a mid-range and high-range gain setting in Sensitivity and Linearity gain modes as indicated below. All AirSpy measurements were made in the Lab, which is a stable temperature environment.

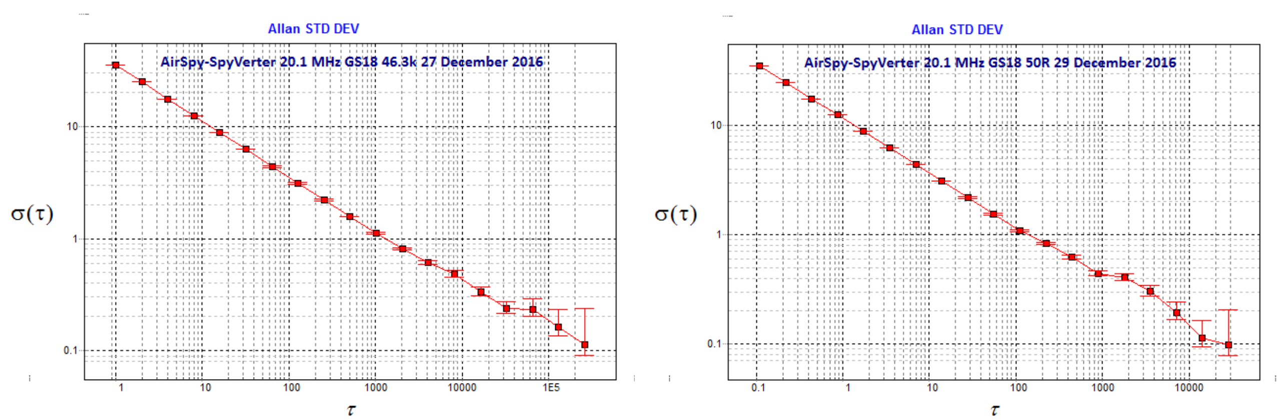


Figure 2-4a ~ AirSpy-SpyVerter SDR Receiver with Sensitivity gain mode and gain set near the high end (18 out of 20), 10 MHz bandwidth and 20.1 MHz center frequency. Measurement with 46 300 K noise generator termination over 72 h (left) and 290 K 50 ohm termination over 24 h (right). The "knee" for the noise generator measurement exceeds 200 000 s and for the 50 ohm termination exceeds 30 000 s. The measurements were made in the lab where the ambient temperature is quite stable.

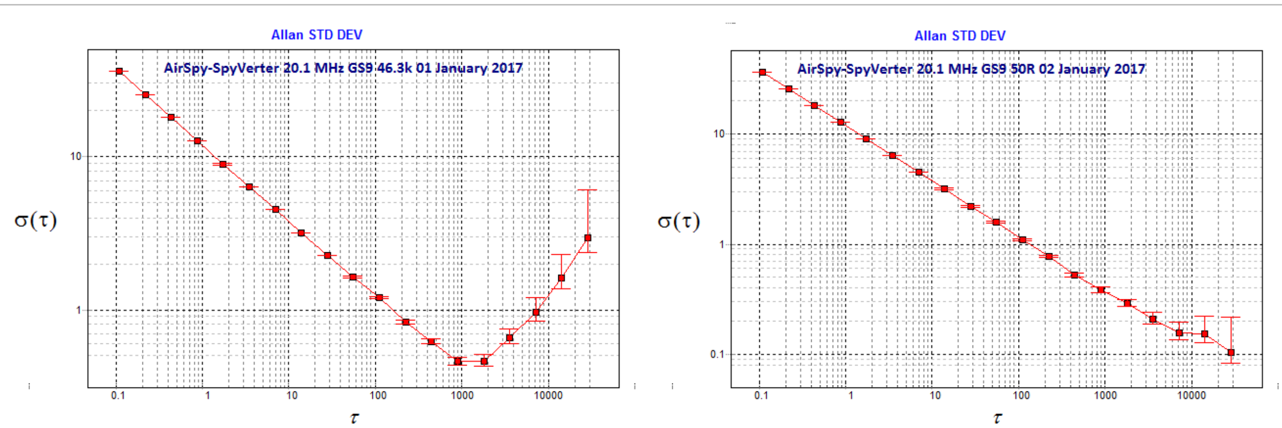


Figure 2-4b ~ AirSpy-SpyVerter SDR Receiver with Sensitivity gain mode and gain set near the mid-range (9 out of 20) , 10 MHz bandwidth, 20.1 MHz center frequency, 24 h measurement period and with 46 300 K noise generator termination (left) and 290 K 50 ohm termination (right). A "knee" is apparent for the noise generator measurement near 1000 s but is greater than 30 000 s for the 50 ohm termination. The measurements were made in the lab where the ambient temperature is quite stable.

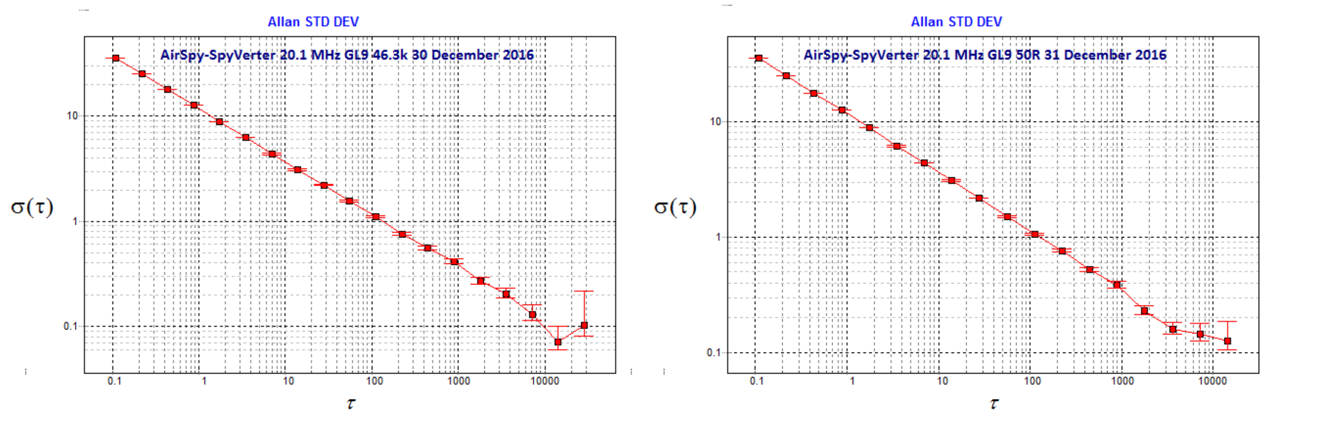


Figure 2-4c ~ AirSpy-SpyVerter SDR Receiver with Linearity gain mode and gain set near the mid-range (9 out of 20), 10 MHz bandwidth, 20.1 MHz center frequency, 24 h measurement period and with 46 300 K noise generator termination (left) and 290 K 50 ohm termination (right). There is an apparent "knee" for the noise generator measurement at about 11 000 s but is greater than 11 000 s for the 50 ohm termination. The measurements were made in the lab where the ambient temperature is quite stable.

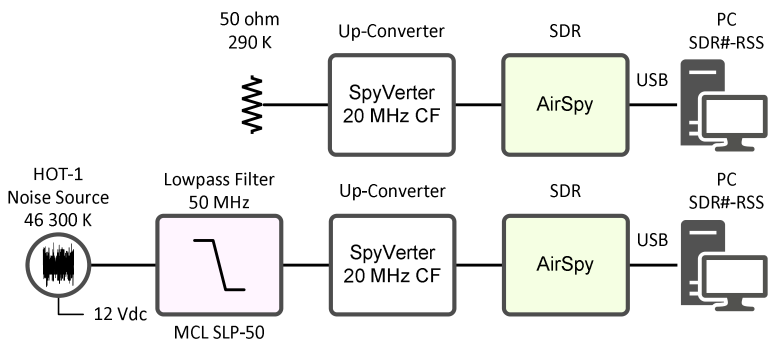


Figure 2-4d ~ Measurement configurations for AirSpy with SpyVerter.

<u>RFSpace Cloud-IQ with SpectraVue, figure 2-5</u>: The Cloud-IQ is an SDR receiver with an operating frequency range from 9 kHz to 56 MHz; it was run in the IQ-mode, which allows the full frequency range to be viewed in the SpectraVue software. Center frequencies of 20 and 25 MHz and a frequency span of 10 MHz were displayed. The Cloud-IQ ADC sample rate is 122.88 MHz. The receiver was set to the corresponding maximum bandwidth of 61.44 MHz with no decimation and maximum FFT frame size of 32k. The SpectraVue software can control RF input attenuators that may be set between 0 and 30 dB in 10 dB steps. Only the 0 dB attenuator setting was used. The receiver has an ADC overload indicator but it never illuminated during the measurements. The receiver is located near a baseboard heater and north-facing window and is in a room with night-setback temperature, which may account for the variations seen in the ADEV measurements below.

Continuum mode was used to collect the data. In continuum mode the total average and peak spectral powers in the displayed span are saved in dBFS (dB with respect to ADC full scale). Prior to loading the data into ALAVAR, I converted the average power dBFS values to equivalent linear ratios ($Linear \rightarrow 10^{(dB/10)}$) and then processed in ALAVAR. I experimented with various sampling intervals but could not obtain the correct number of samples per second for intervals less than 0.5 s, so I used 0.5 s and 1 s sampling intervals for all measurements.

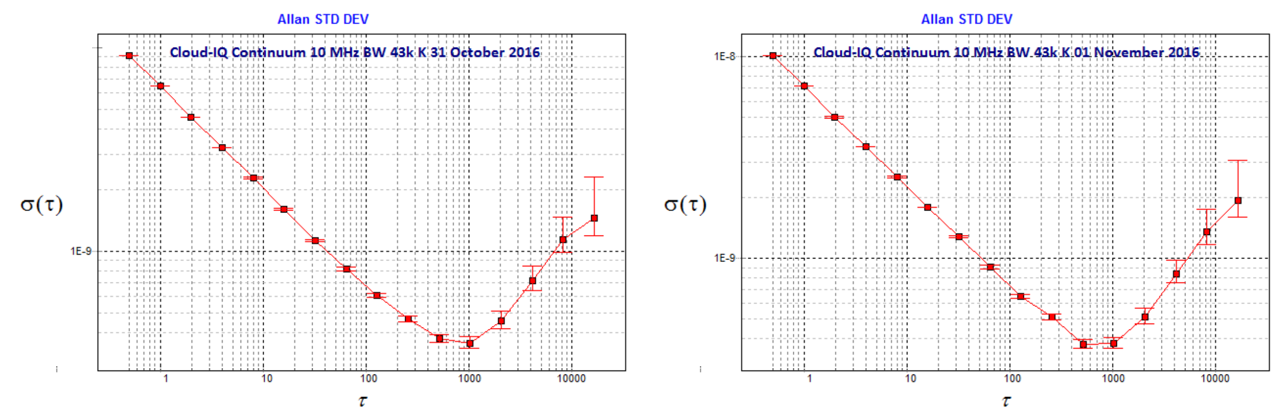


Figure 2-5a ~ Cloud-IQ SDR Receiver set to 61.44 MHz input bandwidth, 10 MHz displayed frequency span, 0.5 s sampling interval and 46 300 K noise generator. Measurements indicate an averaging interval of about 600 to 1000 s.

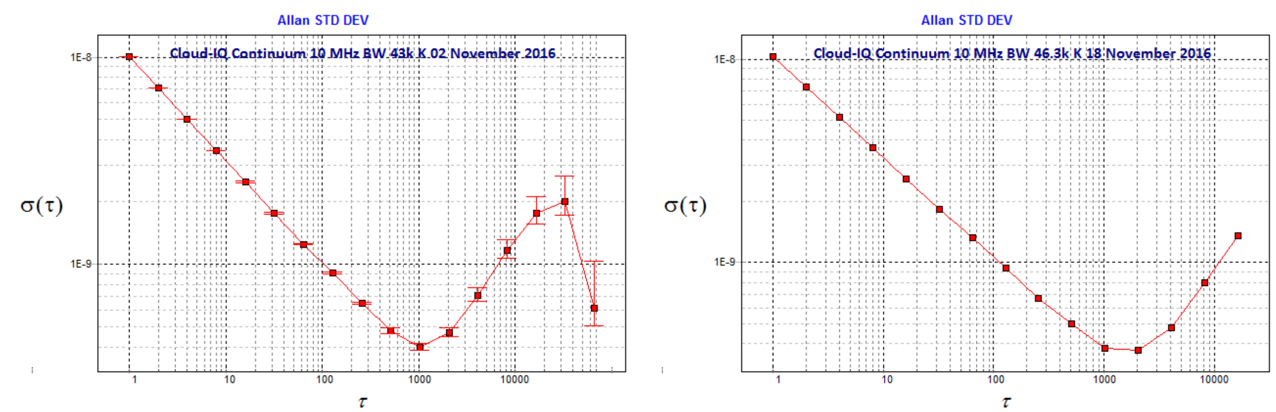


Figure 2-5b ~ Cloud-IQ SDR Receiver set to 61.44 MHz input bandwidth, 10 MHz displayed frequency span, 1 s sampling interval and 43 100 K noise generator (lower-right measurement used 46 300 K). Measurements indicate an averaging interval of about 1000 to 2000 s.

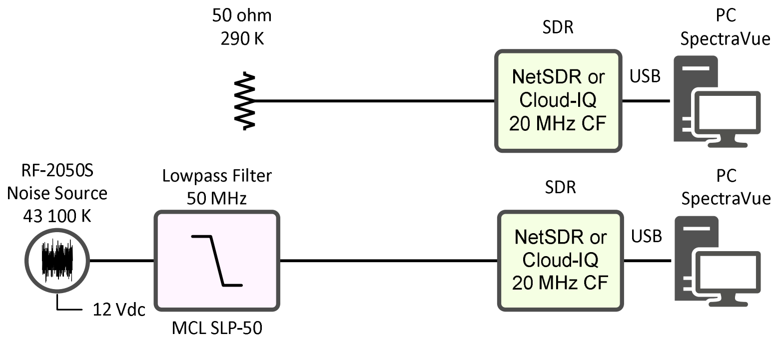


Figure 2-5c ~ Measurement configurations for Cloud-IQ.

RFSpace NetSDR with SpectraVue, figure 2-6: The NetSDR is an SDR receiver with a frequency range from 10 kHz to 34 MHz. Center frequencies of 20 and 25 MHz and a frequency span of 10 MHz were displayed. The receiver bandwidth was set to 35 MHz (real mode FFT). The ADC sample rate is 80 MHz. In real mode, there is no down-conversion (no decimation), and the usable bandwidth is approximately 34 MHz (85%). The software operation, including input attenuation, is very similar to the Cloud-IQ. Although the receiver can accept a 10 MHz reference clock input, no reference clock was used for these measurements. The receiver is located near a baseboard heater and north-facing window and is in a room with night-setback temperature.

The data recordings were made in Continuum mode. As with the Cloud-IQ, I experimented with various sampling intervals and ended up using 500 ms and 1 s. Prior to loading the recorded continuum data into ALAVAR, I converted the average power dB values to equivalent linear ratios as described for the Cloud-IQ.

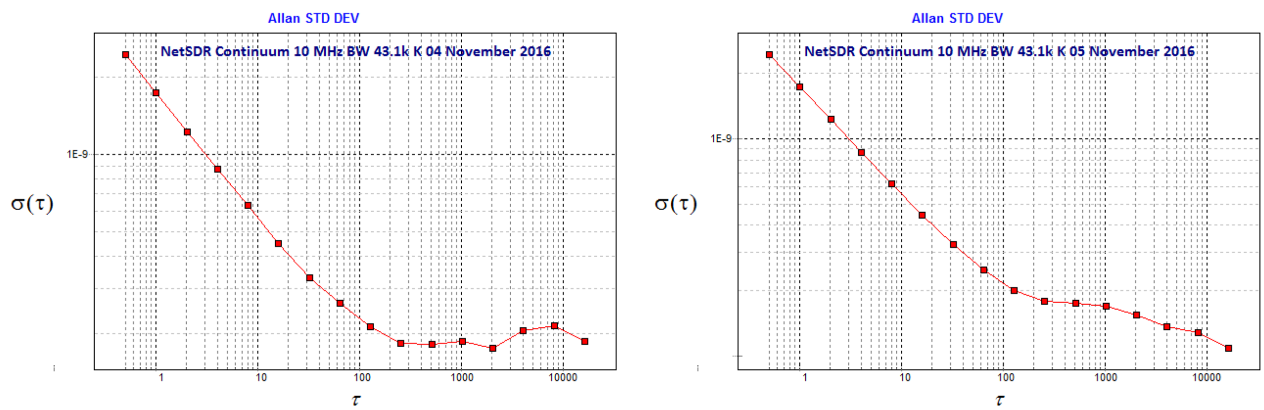


Figure 2-6a ~ NetSDR SDR Receiver set to 35 MHz bandwidth, 10 MHz displayed frequency span, 0.5 s sampling interval and 43 100 K noise generator termination. Measurements indicate an averaging interval of 200 s, although the right plot continues to drop after leveling out at 200 s.

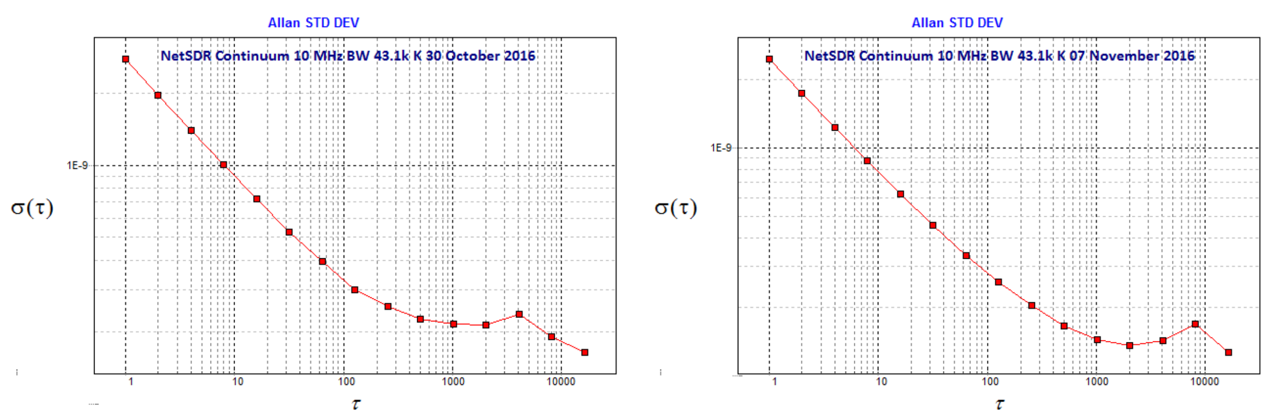


Figure 2-6b ~ NetSDR SDR Receiver set to 35 MHz bandwidth, 10 MHz displayed frequency span, 1 s sampling interval and 43 100 K noise generator termination. Measurements indicate an averaging interval of 1000 to 2000 s.

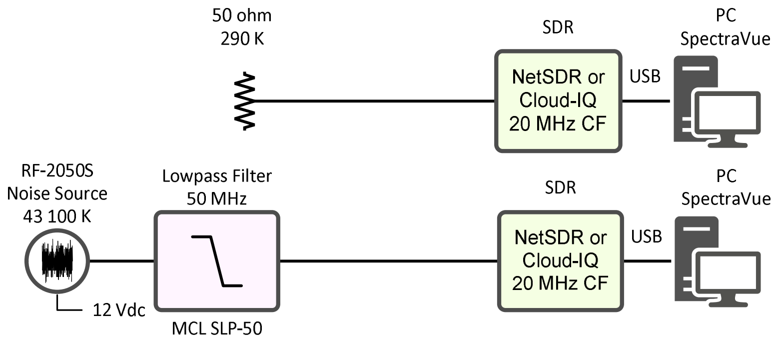
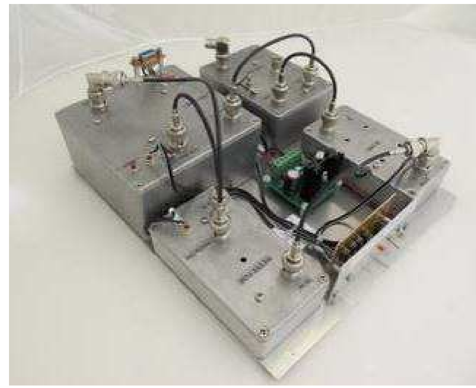


Figure 2-6c ~ Measurement configurations for NetSDR.

2-5. Measurement Results for Wideband Scanning Receivers



FSX-5 and Radio-Sky Spectrograph, figure 2-7: The FSX-5 is a sweep-type receiver with a tuning range of about 15 to 30 MHz. A logarithmic detector is used and its output is converted to a digital data stream by an on-board 12-bit ADC. The detection bandwidth of each channel is approximately 30 kHz. Various numbers of channels were used and the data associated with one of the channels is analyzed by ALAVAR. The image right shows the individual FSX-5 modules mounted on an aluminum plate. After the image was taken the modules were installed in a 2RU rack-mounted enclosure, which was the physical configuration for the measurements described here.

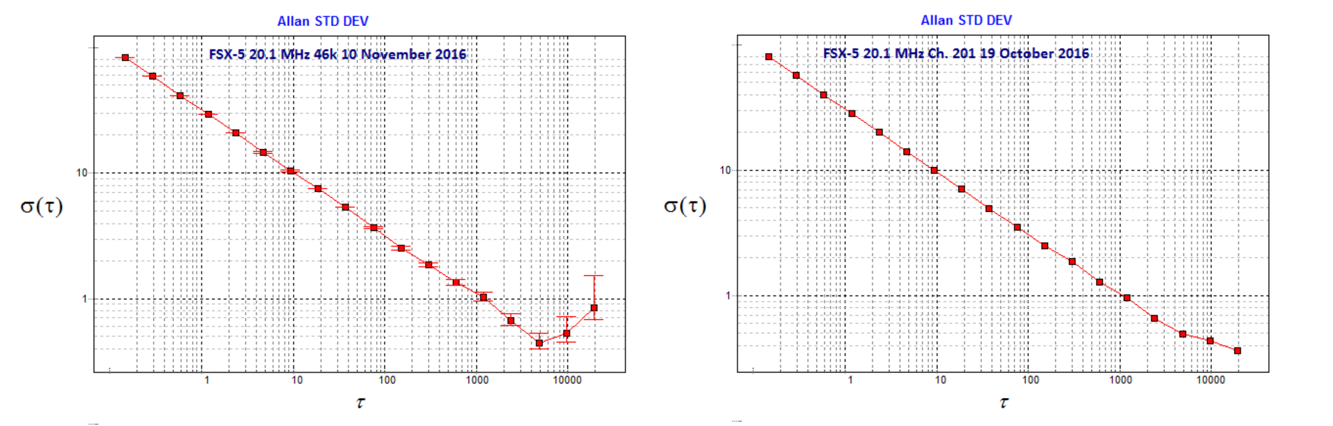


Figure 2-7a ~ FSX-5 Scanning Receiver, center frequency 22.5 MHz, 300 channels, 24 h measurement period and with 46 300 K noise generator termination (left) and 50 ohm termination (right). The “knee” is not apparent on the plot for 50 ohm termination but appears at about 5000 s for the noise generator termination.

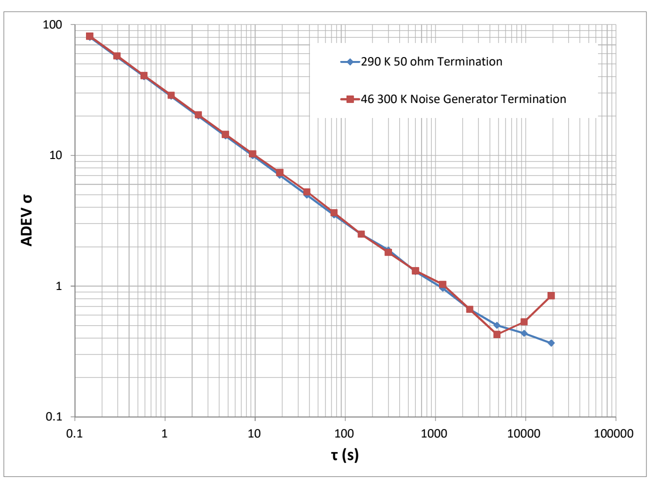


Figure 2-7b ~ Comparative ADEV plots of data from the above plots for the 50 ohm and noise generator terminations. The plots are almost identical for τ from 146.7 ms to about 3 600 s (1 h).

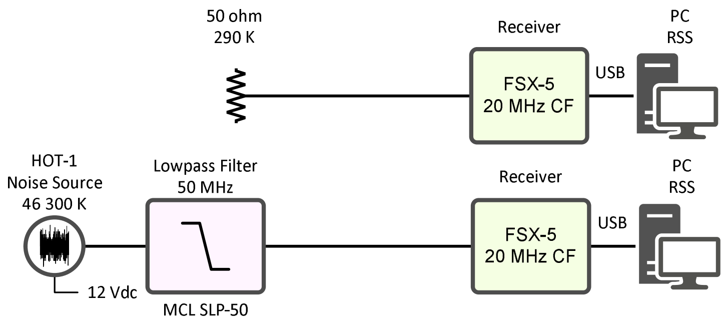


Figure 2-7c ~ Measurement configurations for FSX-5.

2-6. Measurement Results for Narrowband Receivers

Icom R-75 and Radio-SkyPipe II, figure 2-8: The R-75 is a narrowband superheterodyne general coverage receiver with a tuning range of 100 kHz to 60 MHz. Its detection bandwidth is selectable based on the installed IF filters and can vary from about 400 Hz to 15 kHz. For the measurements here, the receiver was tuned to 20.1 MHz and set for lower sideband (LSB, detection bandwidth approximately 2.8 kHz) with AGC Off and RF Gain set to maximum. The Recorder Output (REC) with 4.7 kohm output impedance was used for the measurements. Two R-75 receivers were measured and are indicated as positions A and B. R75-A was measured at the Receiver Station and in the Lab and R75-B was measured only at the Receiver Station. Radio-SkyPipe was set to sample the output audio waveform every 100 ms. Various soundcards were used, both internal and external; however, the results for the external USB soundcards (not shown) reflected the poor performance of the soundcard and not the receiver. The stability measurements made at the Receiver Station are believed to be influenced by the variable temperatures – the Lab measurements showed generally better performance. However, the overall results are quite variable for otherwise unknown reasons.

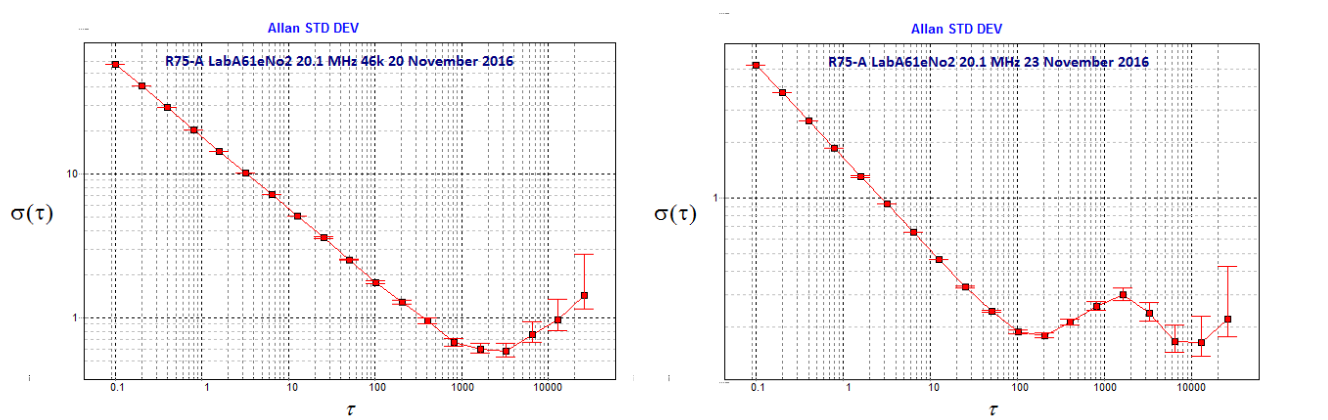


Figure 2-8a ~ Icom R-75 Receiver, position A (R75-A) and LabA61eNo2 PC internal soundcard, 24 h measurement period in the Lab with 46 300 K noise generator (left) and 50 ohm termination (right). Measurements indicate a longer averaging interval for the noise generator termination (2000 s) than the 50 ohm termination (200 s).

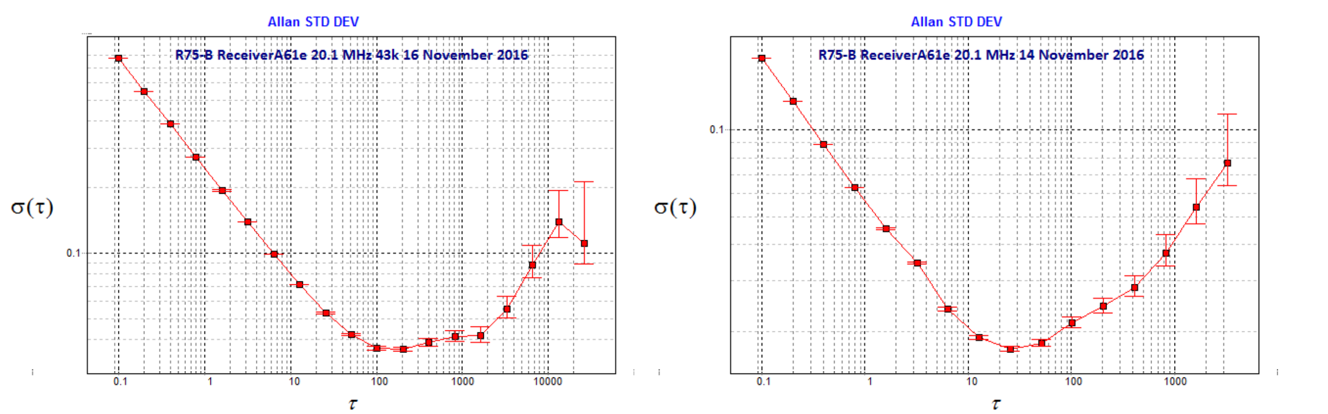


Figure 2-8b ~ Icom R-75 Receiver, position B (R75-B) and ReceiverA61e PC internal soundcard at the Receiver Station, 24 h measurement period with 43 100 K noise generator (left) and 50 ohm termination (right). ADEV varies by an order of magnitude from about 100 to 1000 s with the noise generator to 25 to 200 s with the 50 ohm termination.

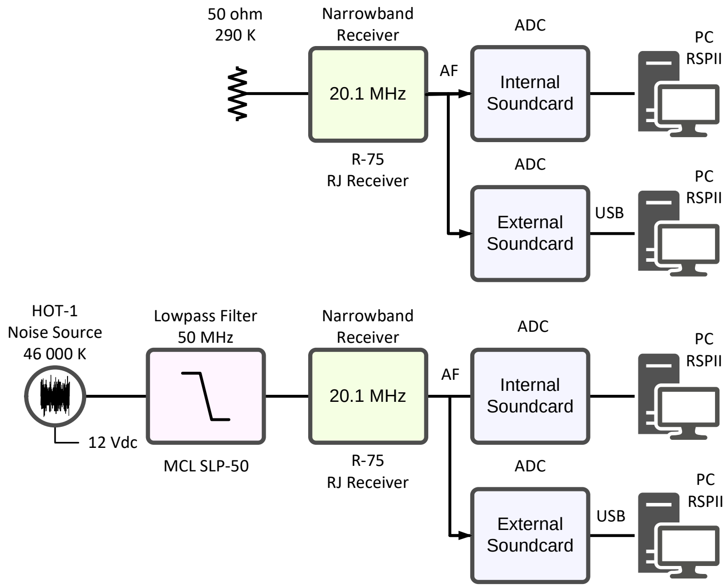


Figure 2-8c ~ Measurement configurations for Icom R-75. Some measurements used the LabJack U3-HV datalogger in place of an External USB Soundcard.

<u>Radio Jove Receiver and Radio-SkyPipe II, figure 2-9</u>: The Radio Jove Receiver is a direct conversion type with a narrow tuning range of about 200 kHz centered on 20 MHz. Its detection bandwidth is approximately 3 kHz and audio output impedance is 10 ohms. As with the R-75 receivers, the Radio Jove Receiver was connected to both internal and external USB soundcards and a datalogger, but the results with the external soundcards (not shown) had consistently poor performance corresponding to the soundcard's poor performance. Only four measurements are shown below, all made in the Lab where the temperature is stable. The datalogger provided consistently better results.

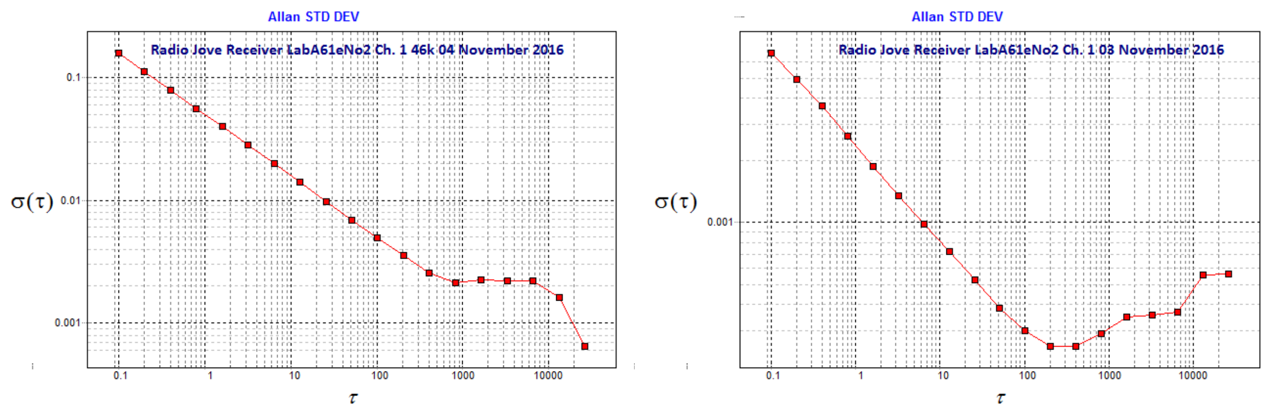


Figure 2-9a ~ Radio Jove Receiver and LabA61eNo2 PC internal soundcard, 24 h measurement period with 46 300 K noise generator termination (left) and 50 ohm termination (right). For these measurements the audio gain control was set to the 1 o'clock position. The averaging interval is about 1000 s for the noise generator termination but is reduced to about 200 s with the 50 ohm termination. Both measurements were made in the Lab, which has a stable temperature environment.

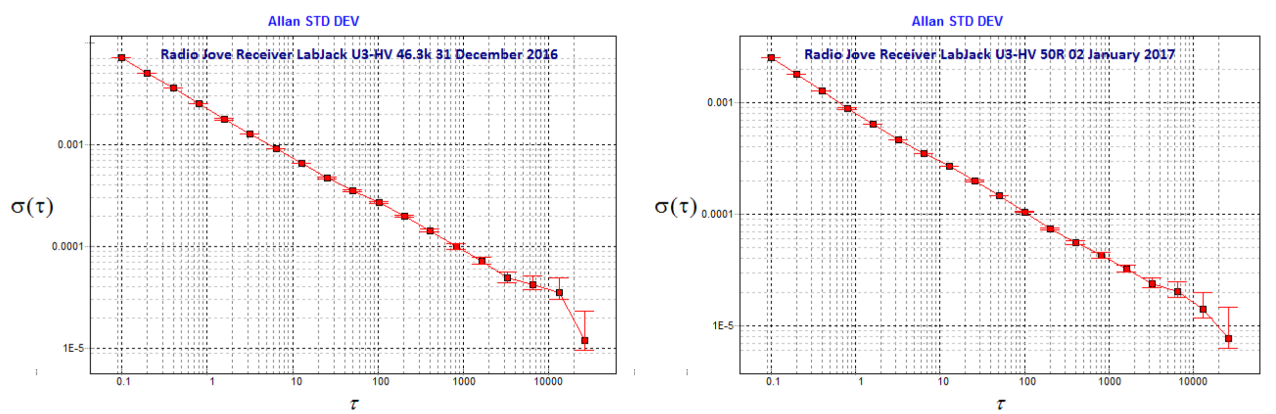


Figure 2-9c ~ Radio Jove Receiver and LabJack U3-HV datalogger, 24 h measurement period with 43 100 K noise generator termination (left) and 50 ohm termination (right). For these measurements the audio gain control was set to the 1 o'clock position. These measurements were made in the Lab, which is a stable temperature environment. For these measurements the averaging interval exceeds 20 000 s. The datalogger yields more consistent measurements than the internal soundcard.

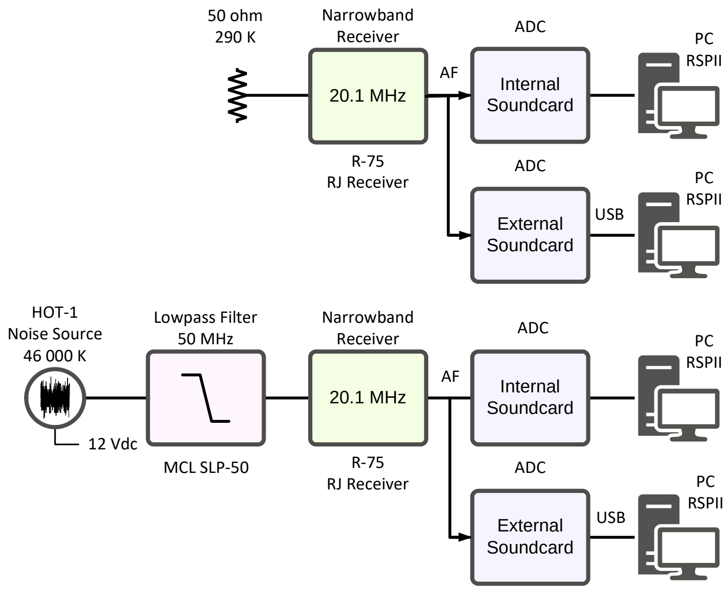


Figure 2-9d ~ Measurement configurations for Radio Jove Receiver. Some measurements used the LabJack U3-HV datalogger in place of an External USB Soundcard.

2-7. Measurement Results for Soundcards and Datalogger

Four different PCs with internal soundcards, three external USB soundcards, and one datalogger were used for the measurements (table 2-2). Three of the PCs use a Realtek audio codec and SoundMAX driver. These PCs were purchased new in 2007 and early 2008 with Windows XP but two were later upgraded to Windows 7. The LINE IN jack was used for all measurements. The fourth PC is a new Lenovo M900 Tiny PC with a Realtek HD audio codec and running Windows 10; however, neither the internal soundcard nor external USB soundcards would work with Radio-SkyPipe software on the Windows 10 PC, most likely because of incompatibilities.

Table 2-2 ~ Soundcards and Dataloggers. Radio-SkyPipe was used with all soundcards and LJLogUD was used with the LabJack datalogger. Radio-SkyPipe software would not work properly on the Windows 10 PC.

Internal Soundcard		**External USB Soundcard and Datalogger**	
Type	**Designation**	**Type**	**Designation**
Lenovo A61e	LabA61eNo2	StarTech ICUSBAUDIO7D	StarTech
Lenovo A61e	LabA61eW7	Unbranded (cheap)	No. 2 External USB Soundcard
Lenovo A61e	ReceiverA61e	Labjack U3-HV	U3
Lenovo M900 Tiny	M900-1		

The external USB soundcards were difficult to setup in Windows 7 for use with Radio-SkyPipe. In Windows XP I was able to use the LINE IN function in the soundcard driver but in Windows 7 only the Stereo Mixer function would work. All measurements involving soundcards used Radio-SkyPipe II software, v2.7.10. To ensure that the soundcard driver and Radio-SkyPipe software were setup and operating properly, I initially removed and reinserted the plug carrying the audio to the soundcard LINE IN jack to cause a transient. If the transient was visible, I assumed the setup was working properly and I could then configure a Scheduled Observation in Radio-SkyPipe. However, with soundcards running under Windows 7, removing the termination plug would disable the soundcard, causing Radio-SkyPipe to crash. I eventually resorted to connecting an audio frequency signal generator to the soundcard LINE IN jack through an interface adapter (figure 2-10). I checked response in Radio-SkyPipe by injecting a real signal from the adapter and then isolating the signal generator with toggle switches while retaining the resistive termination.

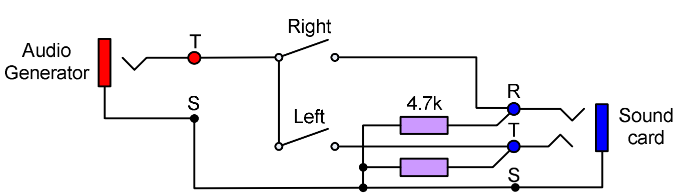


Figure 2-10 ~ Audio interface adapter provides stereo termination resistances of 4.7 kohm and allows isolation of the AF signal generator after it is ensured the soundcard setup is working properly.

Generally, Radio-SkyPipe was the only application program running at the time of measurements. I originally had setup Radio-SkyPipe to restart at 00:00 UTC but found that it often would produce unusable data when the measurement period spanned more than 24 hours. After several dozen measurements over a period of two months I then reset Radio-SkyPipe to record continuously (no restart at end of day) and had no further problems.

Most Radio-SkyPipe measurements used a 100 ms sampling interval, although I did take some measurements with 200 ms sample interval to see if that affected results (there was no obvious change).

The ADEV plots for the internal soundcards show that averaging times are reasonable but the plots for the external USB soundcards show no benefit to averaging (figure 2-11). I thought that noise coupled through the USB port might be part of the performance problem with the external soundcards, so I made one set of measurements with six extra clamp-on ferrite noise suppression beads on the USB cable (the cable already had one conformal ferrite bead attached). These beads suppressed any common-mode noise on the shielded cable but did not improve the ADEV performance.

The datalogger performed comparatively well (figure 2-12). The datalogger was setup as a simple voltage sampling device. Afterwards, I squared the datalogger voltage data to make it proportional to the noise power, saved the data and then loaded the file into ALAVAR.

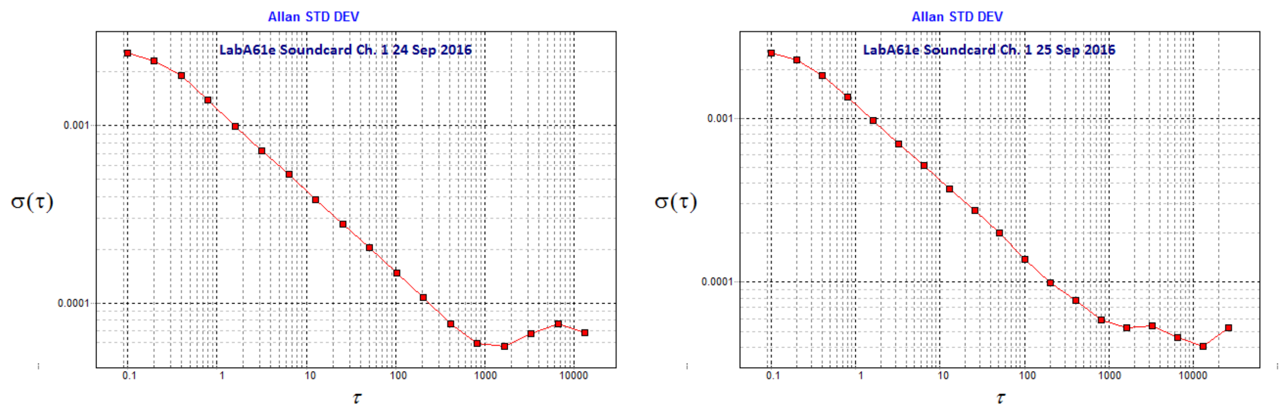


Figure 2-11a ~ LabA61eNo2 PC, Windows XP, internal soundcard LINE IN, stereo inputs terminated with 4.7 kohm resistors. Averaging possible for about 15 minutes.

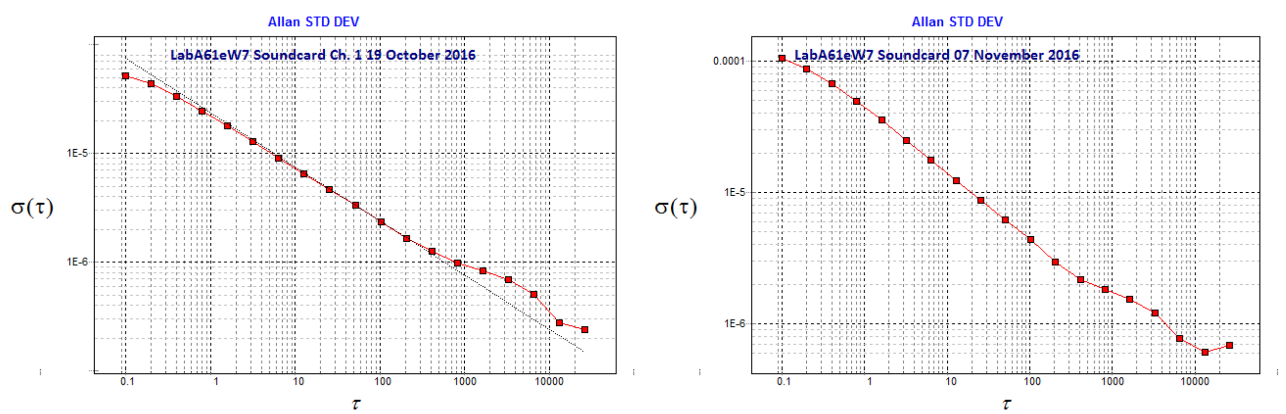


Figure 2-11b ~ LabA61eW7 PC, Windows 7, internal soundcard LINE IN, stereo inputs terminated with 4.7 kohm resistors. Averaging possible for several hours.

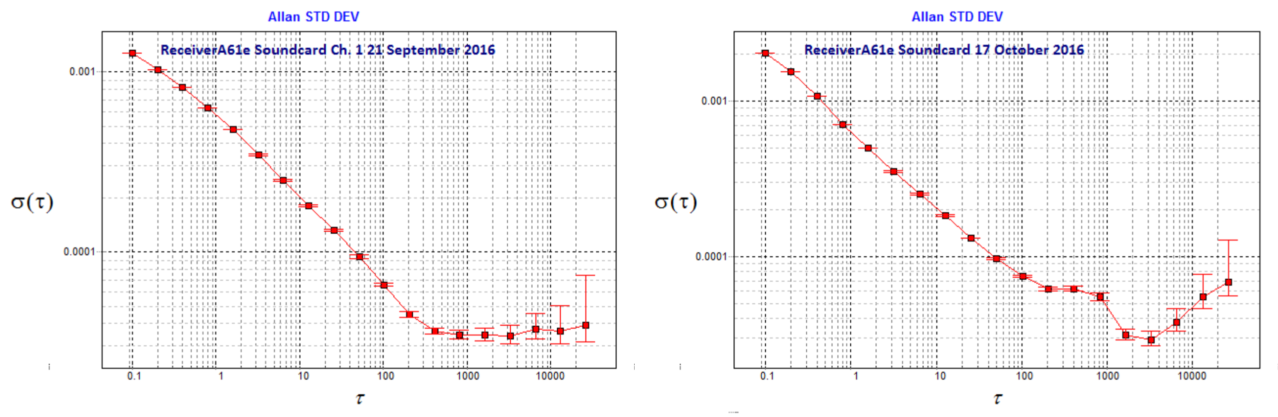


Figure 2-11c ~ ReceiverA61e PC, Windows 7, internal soundcard, LINE IN, stereo inputs terminated with 4.7 kohm resistors. This PC is subjected to a wider temperature variations than the other A61e PCs, apparently reducing allowable averaging to a few minutes.

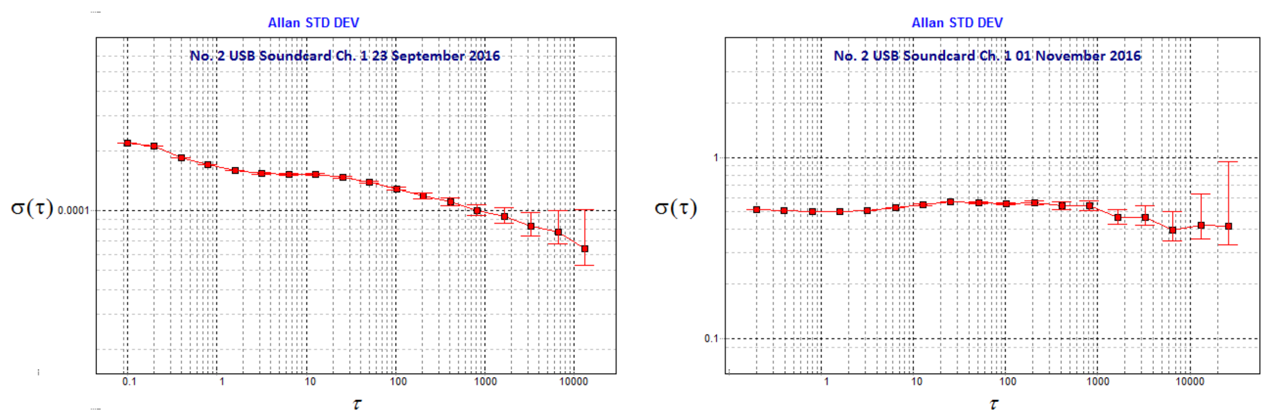


Figure 2-11d ~ No. 2 External USB soundcard, LINE IN, channel 1, stereo inputs terminated with 4.7 kohm resistors. Left: Sampling interval 100 ms. Right: Sampling interval 200 ms. Averaging provides no benefits.

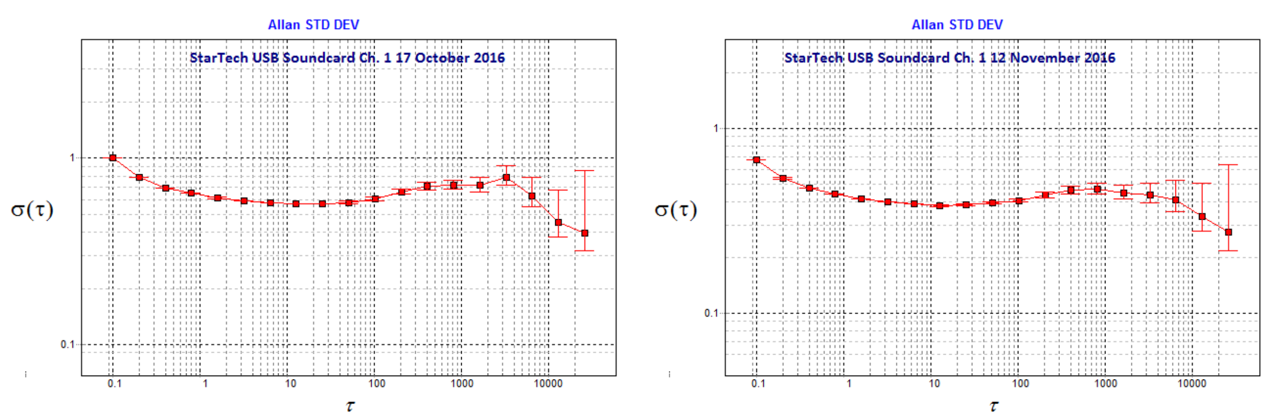


Figure 2-11e ~ StarTech model ICUSBAUDIO7D External USB soundcard, LINE IN, channel 1, stereo inputs terminated with 4.7 kohm resistors. Averaging provides no benefits.

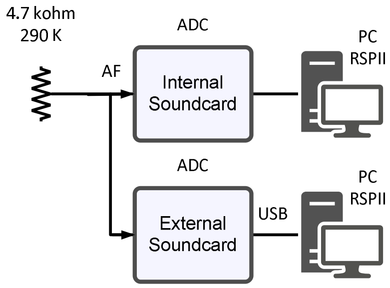


Figure 2-11f ~ Measurement configurations for Internal and External USB soundcards. One or the other soundcard is used during any given measurement session.

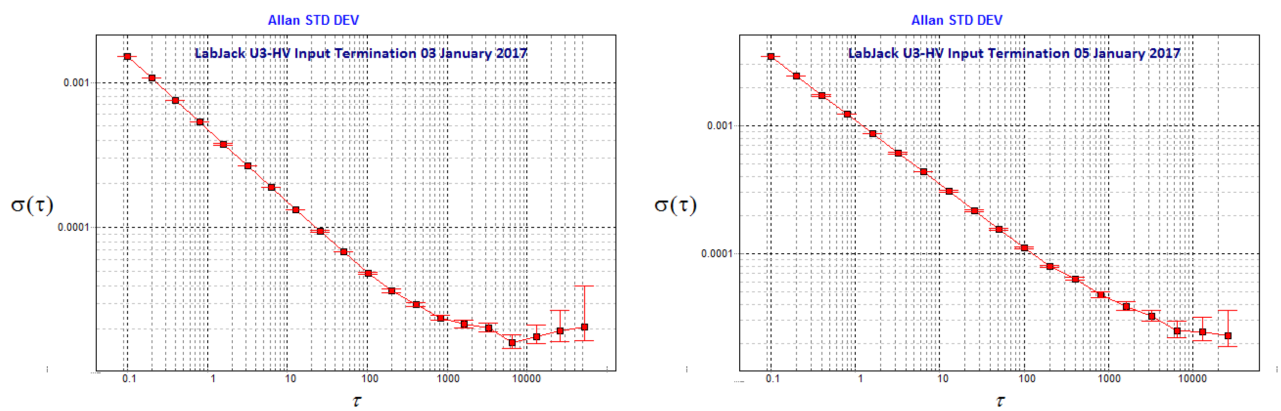


Figure 2-12a ~ LabJack U3-HV datalogger, input terminated with a 4.7 kohm resistor. The left measurement showing a possible averaging interval of approximately 6 000 s was made over a 48 h period and the right measurement with a possible averaging interval exceeding 20 000 s was made over a 24 h period.

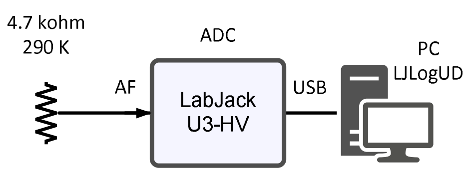


Figure 2-12b ~ Measurement configurations for the LabJack U3-HV datalogger.

2-8. Conclusions and Recommendations

Part I of this paper describes total power receiver stability measurement concepts based on the Allan Deviation (ADEV), which may be used to indicate the amount of averaging of the receiver output to reduce system noise. Part II describes specific methods and provides measurement results using a noise generator termination to simulate the galactic radio background. A 290 K resistor termination also was used in most cases for comparison.

The wideband receivers provided the best ADEV measurements. Depending on the receiver and setup, the averaging indicated by the Allan Deviations (τ) varied from 200 to over 30 000 s.

Some difficulties were encountered when measuring the Allan Deviations of the analog narrowband receivers. It was found that the ADEV performance of these receivers, which varied from 25 s to over 20 000 s, is largely determined by the soundcard or datalogger connected to the receiver audio output. The measurements showed that the datalogger provided by far the best and most consistent results and the USB soundcards provided the worst. Some variability may be due to the software used to sample the soundcard (the datalogger used different software than the soundcards).

Temperature variations and other unidentified environmental or setup factors also may have affected the measurements.

Based on these findings, it is recommended that measurements of a particular receiver be undertaken in a temperature controlled environment with the receiver configured for its actual operating conditions.

2-9. References & Web Links

{HOT-1} Reeve, W., Packaging the HOT-1 Noise Source, 2012, available here: http://www.reeve.com/Documents/Articles%20Papers/HOT-1Package_Reeve.pdf

Document information

Author: Whitham D. Reeve

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