WSPR

Measurement AGC impact on SNR
Discussion WSPR SNR calculation

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August 2021

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1 Summary

The WebSDR in Maasbree can be used as a reference for how well signals on the five available ham radio bands are received at your own location. But it can also be used for optimizing reception.

SNR indicates the quality of reception. However expressing accurately the SNR difference in dB's is difficult. That needs measuring multiple signals and noise levels over a long period of time on both locations at the same time. S-meters can only give rough estimates of SNR. WSPR is much better suited to perform such measurements.

Measurements with WSPR of differences in SNR showed sometimes large deviations (>10dB) from the expected values. Deviations could be traced back to the receivers. Significant deviating SNR were reported by WSPR between two receivers receiving exactly the same signal.
The main differences between both receivers was whether or not using the AGC.

Measurements have been done to confirm the impact of the AGC.
Results are reported in chapter 2.

The question was why the AGC causes such large errors in the reported SNR.
The way WSPR calculates the SNR is investigated and discussed in chapter 3.

Conclusions:

- For accurate SNR measurement the AGC has to be switched OFF.
- Deviations in SNR by the AGC are small for SNR up to and not much higher than 0dB (in 2500Hz).
- WSPR uses the average power spectrum in 300Hz over 114 seconds for calculating the SNR. This includes partially the noise without a WSPR signal and the AGC settling. Both contribute to a deviating SNR.
  This is the main reason for large deviating SNR when using an AGC.
- Fading and out-of-band signals can result in deviating SNR when using an AGC.
- The exact value of SNR deviation depends on the AGC behavior.
- For reliable SNR the “deep decode” option has to be disabled.
- Audio bandwidth has to be >=300Hz.

<u>With the AGC switched OFF and “deep decode” disabled WSPR is very well suited for measuring differences in SNR between receiving locations.</u>

2 Measurement of AGC impact

2.1 Motivation

Observation of significant deviating SNR reported by WSPR between two receivers receiving exactly the same signal.

2.2 Measurement setup

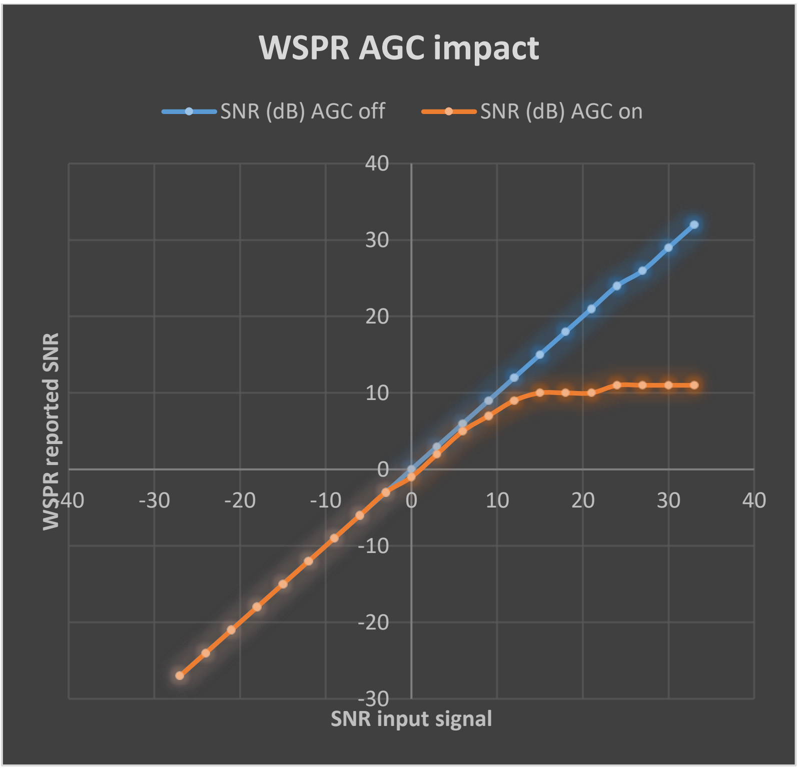
A 2 minutes long audio .wav file is made with my own WSPR signal. This of course is an ideal WSPR signal without any band noise and fading.
When played back noise (and fading) can be added in software (e.g. GNUradio) at any level. In that way the SNR can be set accurately to any value and you know exactly what is send to WSPR. A 1200Hz band pass filter sets the bandwidth. An AGC can be switch ON or OFF.

2.3 Measurement

The SNR is increased in 3dB steps and the SNR is measured with and without AGC.

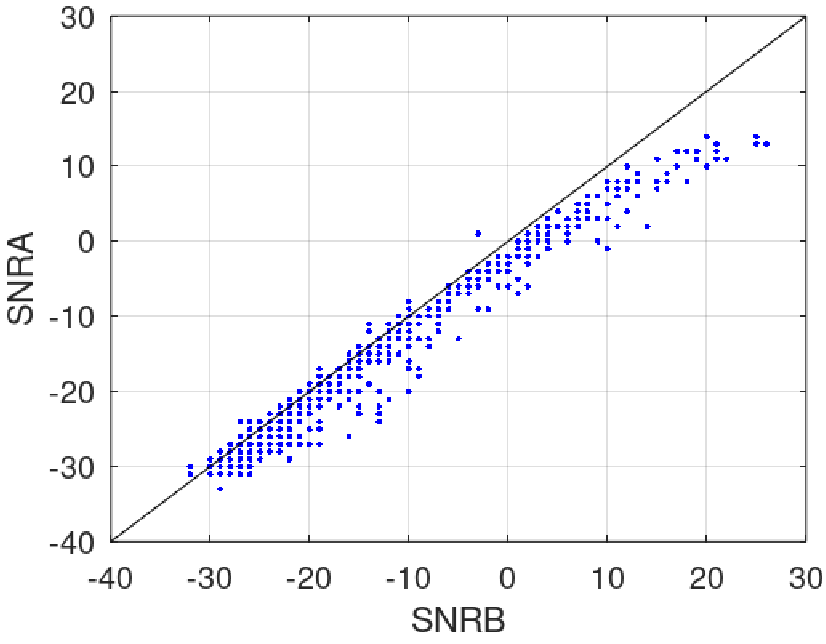
2.4 Results artificial signals

The reported SNR with the AGC ON and AGC OFF is plotted against the SNR of the input signal (x-axis). At about SNR=0dB the signal becomes strong enough to modulate the gain when using an AGC. That level depends on the audio bandwidth (1200Hz).
<u>Note: the signal is not fading. Only one single signal is present.</u>



2.5 Results real world signals

The next plot shows the same plot when using real world signals and two receivers. SNRA is the receiver using the AGC. SNRB is the receiver with no AGC.



2.6 Conclusion measurements

- Without AGC WSPR reports the SNR accurately.
- For SNR’s of 0dB and higher using an AGC results in an increasing deviating SNR.
- Up to a SNR not much higher than 0dB the deviation is limited.
- *For accurate SNR measurement the AGC has to be switched OFF.*

3 Discussion WSPR SNR calculation

WSPR source code is used to find out how WSPR calculates the SNR.
Source code:
https://sourceforge.net/p/wsjt/wsjtx/ci/master/tree/lib/wsprd/wsprd.c#l1056

3.1 WSPR SNR processing steps

1) The signal is measured in a **300Hz** bandwidth, +/-150Hz at 1500Hz.
2) Only the first **114 seconds** of each 2 minute period are used. This includes a short period without a WSPR signal present.
3) A short term 25% overlap (sliding) FFT (using a sine window over two symbols) is used for calculating the power spectra **
4) The **average power spectrum over 114 seconds** is calculated and smoothed.
5) The bins in the averaged power spectrum are sorted by increasing power level.
6) Noise level is estimated at the 30'th percentile.
7) A scaling factor is applied for a SNR in 2500Hz

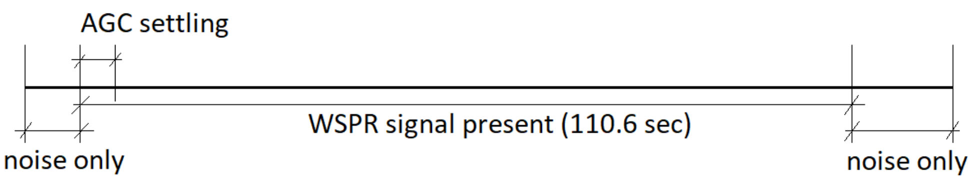
** 162 symbols in 110.6 seconds => window is 1.365 seconds

3.2 Verifying the WSPR processing with Matlab

Basically the same SNR processing is programmed in Matlab. In Matlab the processing can be better verified and explored.
Artificial 2 minutes long audio .wav files are made with GNUradio and my own WSPR signal. The audio files are processed by WSPR and by this Matlab script. The SNR reported by Matlab and by WSPR are equal for all audio files.

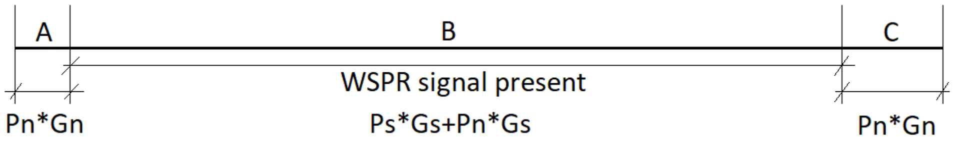
3.3 114 seconds WSPR signal with AGC ON.

We can distinguish 4 different periods in the 114 seconds signal.
- ~1 second with only noise
- <<1 second period in which the AGC settles at the start of the WSPR signal
- ~110.6 second period of the WSPR signal
- ~2 second period with only noise



3.4 Impact of the two noise-only periods with AGC ON

While the WSPR signal is not present the AGC sets the gain according the noise level.
The WSPR signal is present over 110.6 seconds. That leaves 114-110.6=3.4 seconds for the noise only part.



We can distinguish 3 time periods A, B and C in the total 114 second period assuming the AGC settling time is infinite short.
A: only noise just before the signal starts.
B: the WSPR signal is present with the noise
C: remaining period with only noise

Pn = the noise level
Gn = the AGC gain for noise only
Ps = the signal level
Gs = the AGC gain for signal with noise

In period A: noise level is $Pn \times Gn$
In period B: signal level is $Ps \times Gs$ + noise level is $Pn \times Gs$
In period C; noise level is $Pn \times Gn$

The contribution to the average power spectrum of the noise in A and C is:

$$K \times Pn \times Gn \qquad \text{with } K = (114-110.6)/110.6 = 0.03$$

The resulting SNR is:

$$SNR = Ps \times Gs / (Pn \times Gs + K \times Pn \times Gn)$$

The real signal to noise ratio SNRreal=Ps/Pn:

$$SNR = SNRreal / (1 + K \times Gn/Gs)$$

Suppose SNRreal=20dB. The AGC gain will be set about 20dB lower by the WSPR signal.

➔ $K \times Gn/Gs = 0.03 \times 1/0.01 = 3$ ➔ resulting SNR is SNRreal-6dB=14dB

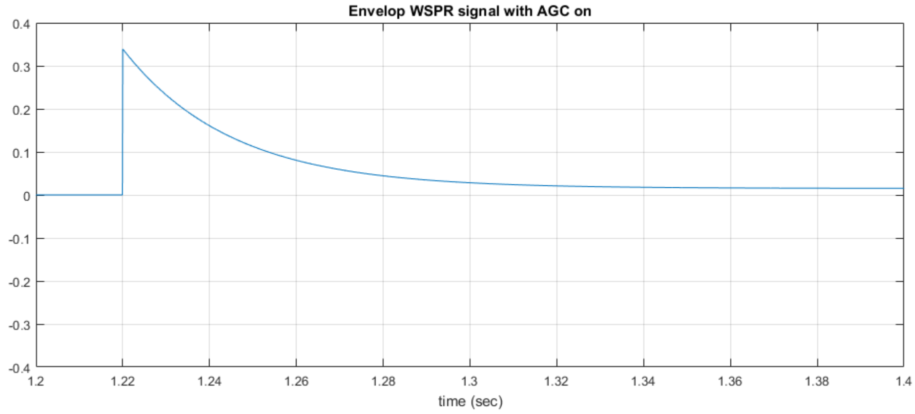
The AGC keeps $Ps \times Gs$ at a constant level for increasing signal levels. A higher signal level Ps has a corresponding lower AGC gain Gs.
As a result the SNR will approach an asymptote of 15dB set by K.
Of course that value depends on the AGC behavior for noise, WSPR signal and audio bandwidth!

<u>Note:</u> with the AGC switched OFF the noise in the no-signal periods increase the noise level with only 114/110.6 or 0.13dB.

3.5 Impact AGC settling time

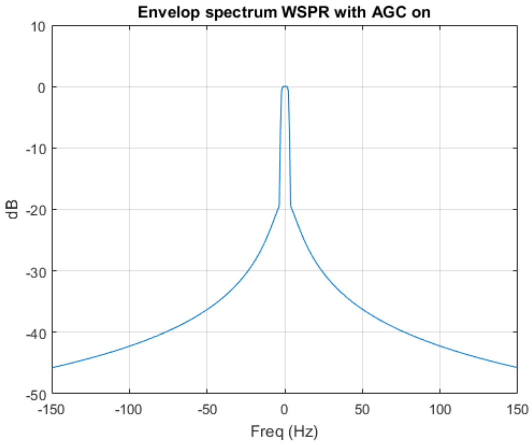
In the previous chapter the contribution of the settling time of the AGC is neglected (assuming an ultra-fast AGC).

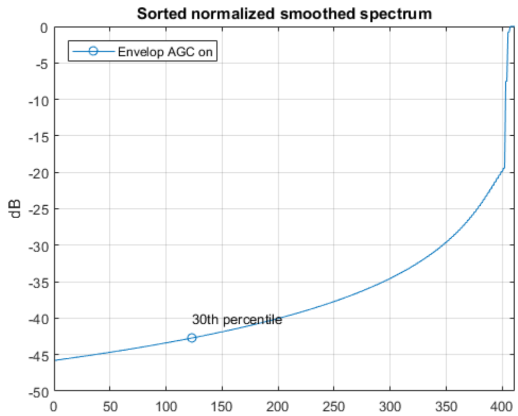
The next plot zooms in on the envelop of the WSPR signal during the settling time of the AGC.



At the start of the WSPR signal (at 1.22 seconds) the AGC will reduce the gain with the speed of the AGC.
The WSPR signal will start to decay and the AGC gain settles to Gs.
In effect the envelop amplitude modulates the WSPR signal.

The next plot to the left shows the power spectrum of the modulating envelop if it is calculated in the same way as the WSPR signal.



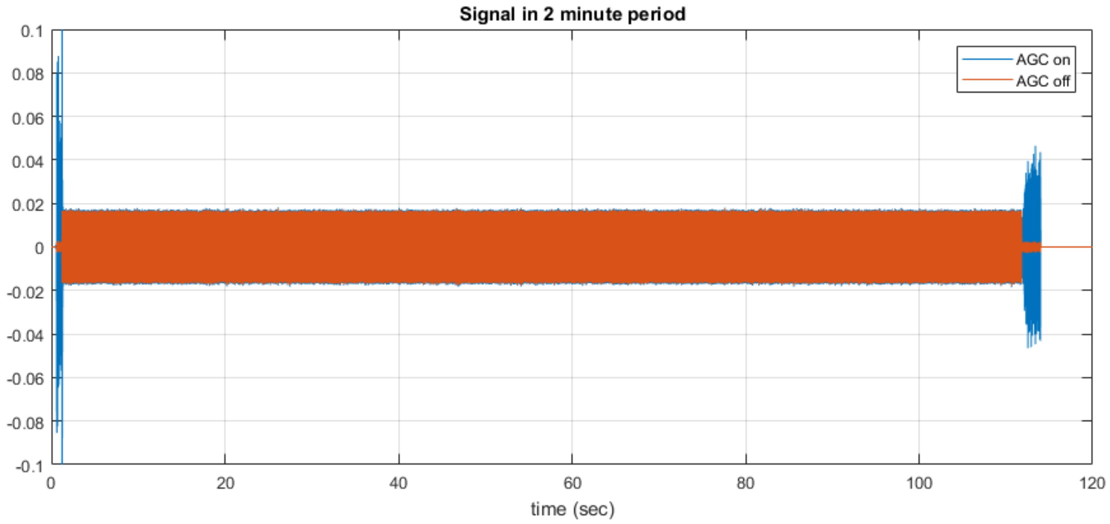


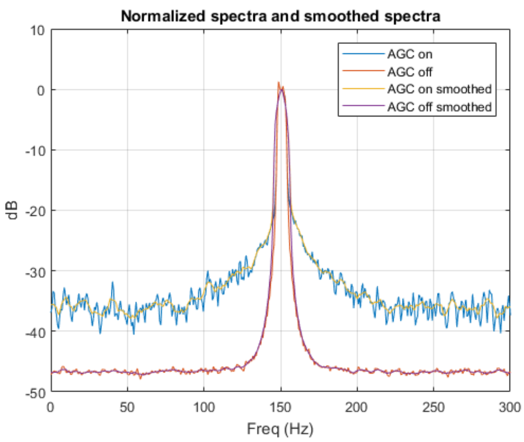
The spectrum of the modulating envelop converts to side bands of the WSPR signal.
<u>The modulation is not noise, but is increases the “noise” floor in the spectrum.</u>

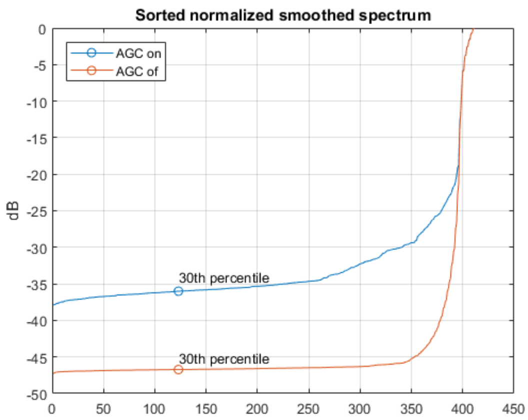
The plot to the right shows the sorted power spectrum.

3.6 Matlab plots of a WSPR signal with a +21dB SNR

3.6.1 Using the full 114 second period







The first plot shows the WSPR signal over time with AGC ON and OFF.
In the last 6 seconds the WSPR signal is made zero. Only the first 114 seconds are used by WSPR.

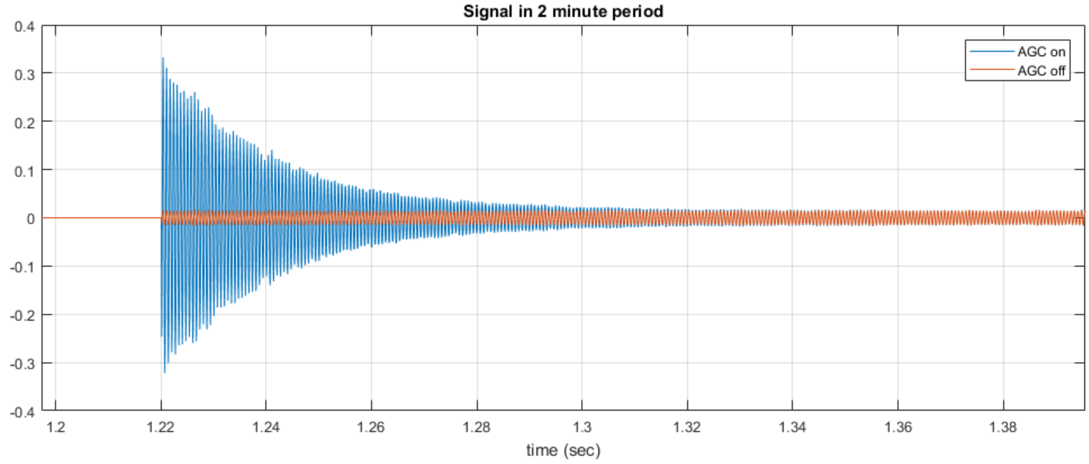
The AGC is set for an equal amplitude of the signal with and without AGC.
In the first second and in the last few seconds the noise level is much higher with the AGC ON.
The orange trace (AGC OFF) shows the noise level without AGC.

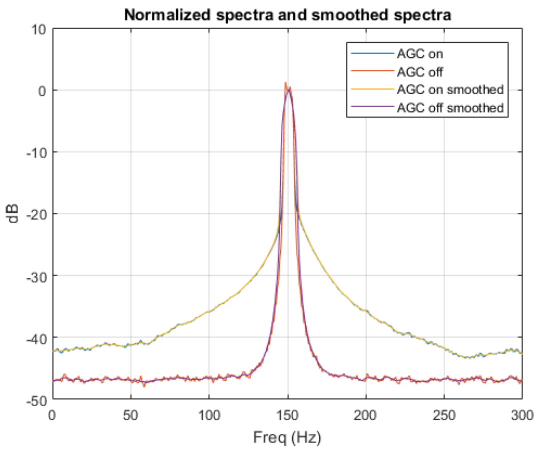
The normalized average power spectra are plot in the second plot to the left.
The signal frequency is 1500Hz and shows up in the middle of the plot. The spectra are normalized to the maximum level.
The AGC increases the noise level over about 10dB.

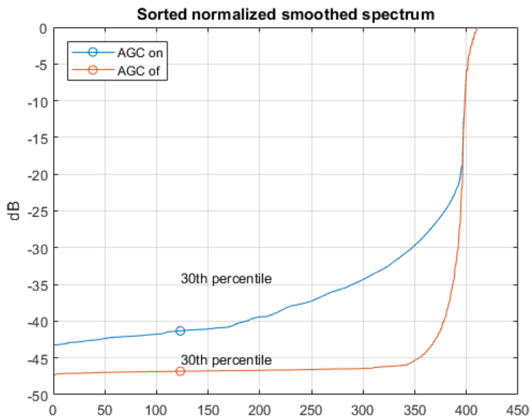
The normalized smoothed and sorted average power spectra are in the plot to the right.
WSPR sorts the smoothed spectra according increasing amplitude.
300Hz bandwidth is 411 bins of the FFT. The 30th percentile, the 123th bin, is selected as representing the noise level.

Deviation caused by using the AGC is 11dB.

3.6.2 Selecting the WSPR signal is present including AGC settling period.





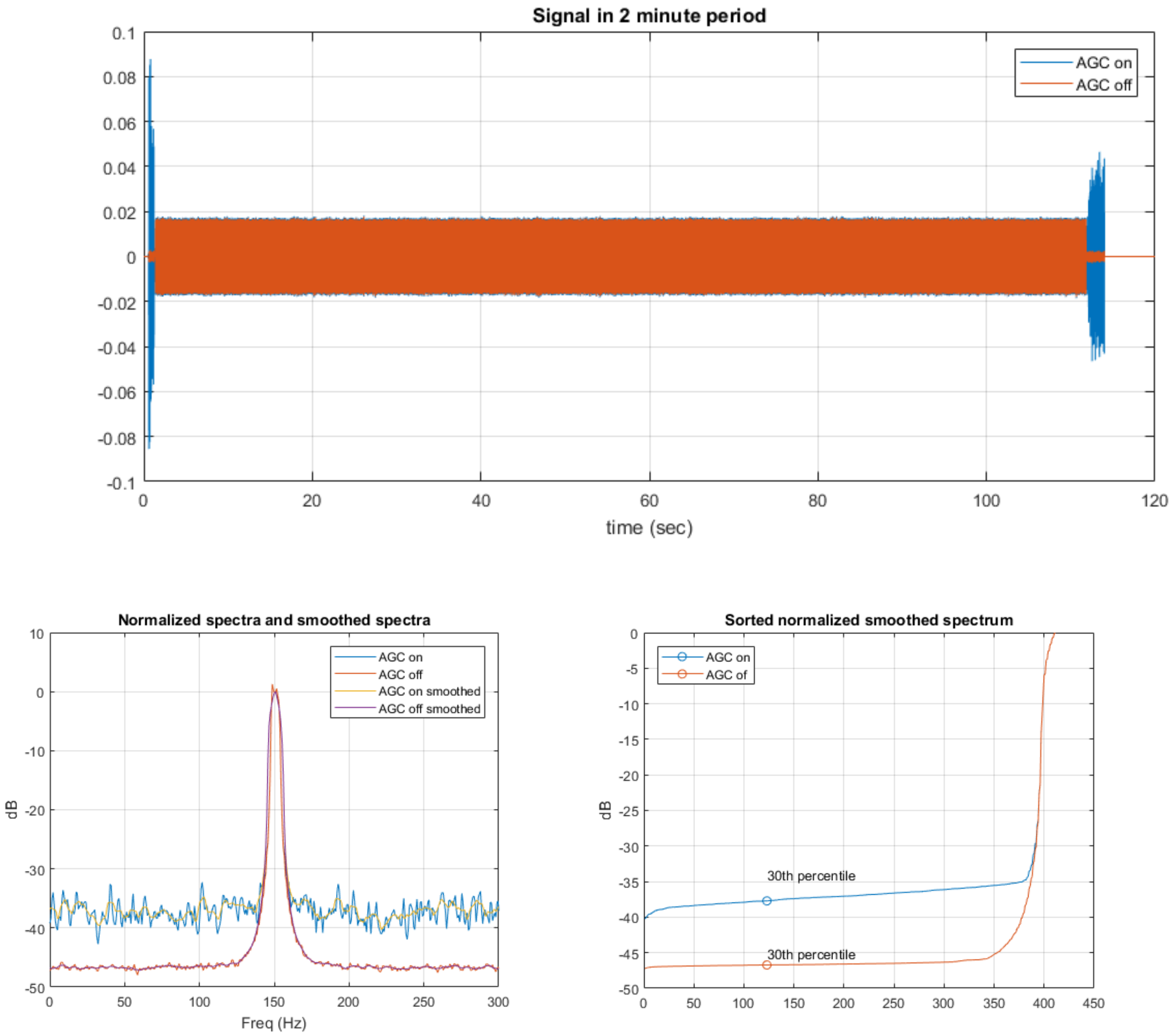


The first plot shows the settling of the AGC gain at the start of the WSPR signal.
<u>In the noise-only periods the signal is multiplied by zero.</u>

In the spectra we still see a deviating “noise” floor caused only by the settling of the AGC. The AGC modulates the WSPR signal. The deviation in SNR depends on how fast the AGC reacts. But it depends also on the selection for the 30^{th} percentile.

Deviation caused by the AGC settling is 5.5dB.

3.6.3 Selecting 114 second without the AGC settling period.

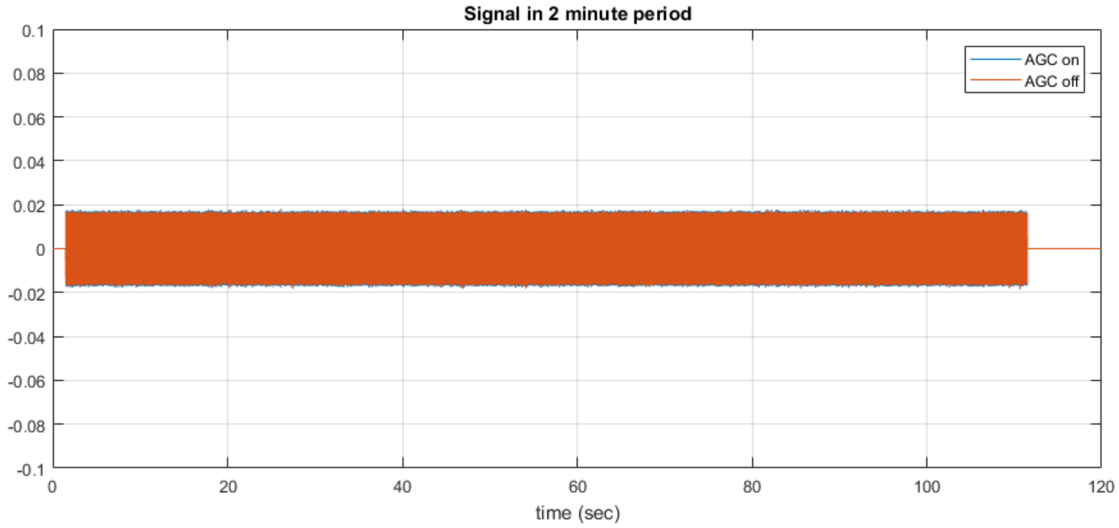


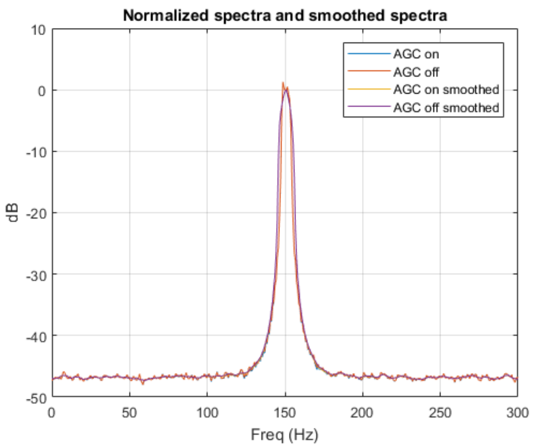
The first plot now shows the full 114 seconds without the settling period of the AGC.
<u>In the AGC settling period the signal is multiplied by zero.</u>

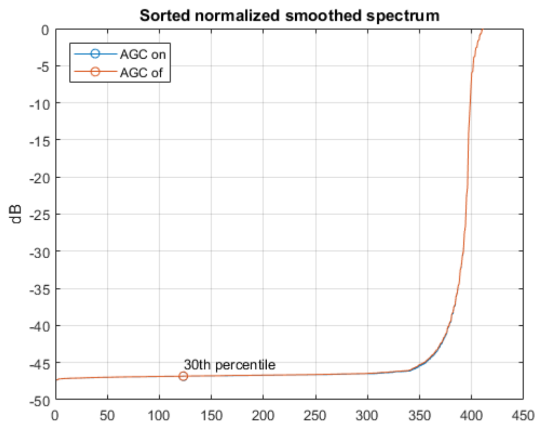
In the spectra we see again a deviating “noise” floor caused only by the noise before and after the WSPR signal.

Deviation caused by the noise before and after the WSPR signal is 9dB.

3.6.4 Selecting the WSPR signal is present and AGC settled period.







The first plot shows again the WSPR signals over time with the AGC ON and OFF.
<u>In the AGC settling period and noise-only periods the signal is multiplied by zero.</u>

As expected the noise level is not changed by the AGC.

3.7 Fading signals and AGC ON

Reported SNR can be affected by the AGC even when using only the time period when the signal is present and the AGC settled. As in 3.6.4.
Fading signals with high SNR will modulate the AGC gain. The gain follows the fading amplitude.
A changing AGC gain will not cause the SNR to deviate at each moment.
However the contribution to the average power spectrum is changed.

At a lower signal level the SNR is lower. The AGC will increase the gain, because of the lower signal level. The higher gain increases the contribution of the lower SNR to the average power spectrum.

➔ A lower SNR gets a higher contribution, a higher SNR a lower contribution. The resulting SNR will be lower depending on the fading.

3.8 Out-of-band signals in the audio pass band and AGC ON

Strong non-WSPR signals outside the 200Hz WSPR band will also modulate the AGC gain.
In that way they modulate in time the contribution to the average power spectrum.
If the WSPR signals fade it will give rise to a deviation in reported SNR also.
Because the amplitude of non-WSPR signals are not correlated with the fading of WSPR signals, deviations will normally be small.
However it makes sense, when using an AGC, to reduce the audio bandwidth, but not lower than 300Hz. See also: https://owenduffy.net/blog/?p=10474

3.9 Deep decodes

WSPR has the option for "deep decodes".
However it does not looking deeper in the noise. It is nothing more than an educated guess based on what is received already. It uses that info when a reasonable match is found and fills in the call and locator.
So the call can be wrong. But also the SNR will be unreliable. Decodes are at least questionable.
That is why the Maasbree WebSDR hasn't enabled the WSPR deep decode.

3.10 Conclusions WSPR SNR calculation

For accurate SNR measurement the AGC has to be switched OFF.

Deviations in SNR by the AGC are small for SNR up to and not much higher than 0dB (in 2500Hz).

WSPR uses the average power spectrum in 300Hz over 114 seconds for calculating the SNR.
This includes partially the noise without a WSPR signal and the AGC settling.
Both contribute to a deviating SNR.
This is the main reason for large deviating SNR when using an AGC.

Fading and out-of-band signals can result in deviating SNR when using an AGC.

The exact value of SNR deviation depends on the AGC behavior and audio bandwidth.

The accuracy of SNR is not guaranteed when selecting the period** the WSPR signal is present and the AGC settled. Fading still can cause deviating SNR.
However it would significantly reduce the error in the reported SNR for high SNR.
** For that we have to assume all WSPR signals are fairly accurately timed.