Phase Noise Measurement of Oscillators with the DSA815TG to -150 dBc

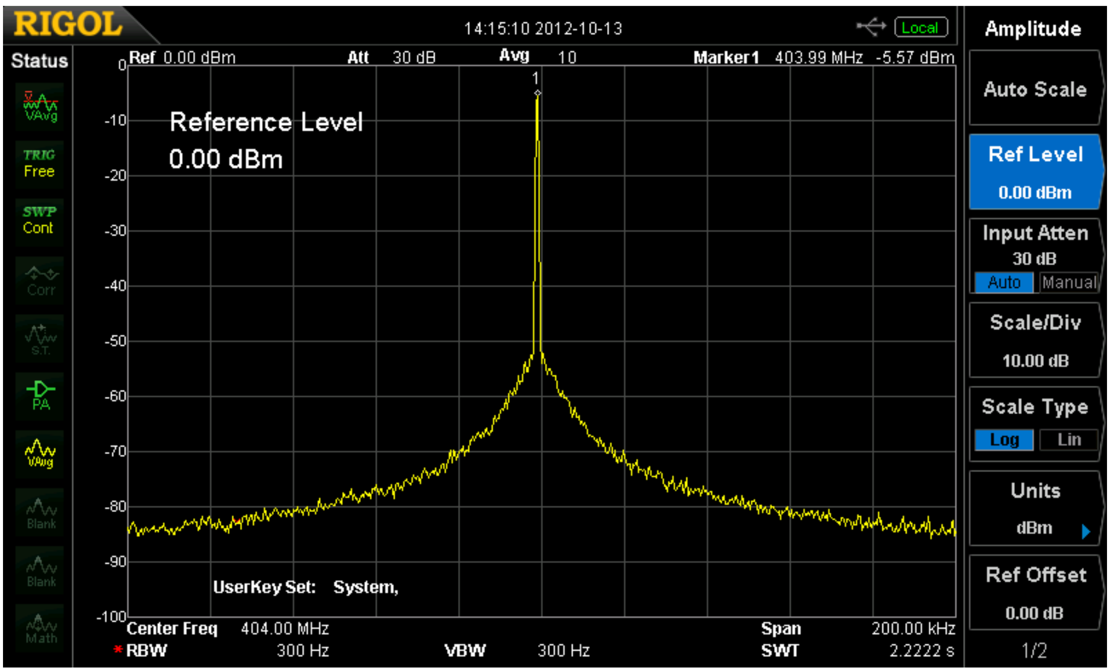
Introduction:

Recently, Jos Disselhorst PA3ACJ and Antoon Milatz PA3BWE wrote an article in this magazine about the Rigol DSA815-TG spectrum analyzer. In this article Jos and Antoon have given an introduction to this new new instrument and its many features. In this article I describe a method to use the DSA815-TG and some simple tools for phase noise measurements on oscillators. Normally there is very specific and expensive equipment is required for measurements of carrier phase measurements. With the additional tools with the DSA815-TG, it is possible to measure the phase noise near the carrier to -150 or -160 dBc / Hz.

Phase Noise:

The quality of the oscillator is often expressed as the level of noise in the sidebands in addition to the carrier wave. This noise is caused by small phase changes in the oscillator circuit. You will see oscillator specifications such as -120 dBc /Hz at an offset of 25 kHz from the carrier. What does this mean now?

At 25 kHz from the carrier, there is a noise level such that, as you would measure with an instrument with a 1 Hz bandwidth, this noise is at a level of 120 dB below the level of the carrier. The indication dBc is a relative value, and means that the value relative to the carrier. See Fig. 1



Figuur 1, Showing a 404 MHz oscillator signal and its the phase noise sidebands

Reciprocal Mixing:

If the phase noise of an oscillator is high, this could have adverse effects on the strong signal behavior of a receiver. That adverse effect is called reciprocal mixing.

By reciprocal mixing something strange happens in the mixer input of the receiver. The tasks of LO and RF are equally turned whereby a very strong signal on the RF port and will behave itself as LO energy of the LO signal in the intermediate frequency mixing. The LO then behaves like the received RF signal. Hence it is used for this purpose, the term "reciprocal".

Why oscillator phase noise in this case such an important specification? Suppose you have a 2 meter SSB receiver that receives a signal DX on 144 315 MHz, with a 3 kHz wide intermediate frequency of 10.7 MHz. The local oscillator in the receiver is then, for example, at 144,315 - 10.7MHz, which is corresponds to 133,615 MHz. The signal is mixed in the mixer to the intermediate frequency of the receiver, and is further amplified and detected to an audible signal. The DX signal is S2, a level of 0.2 50 UV on the input of the receiver. Expressed in dBm is -135dBm.

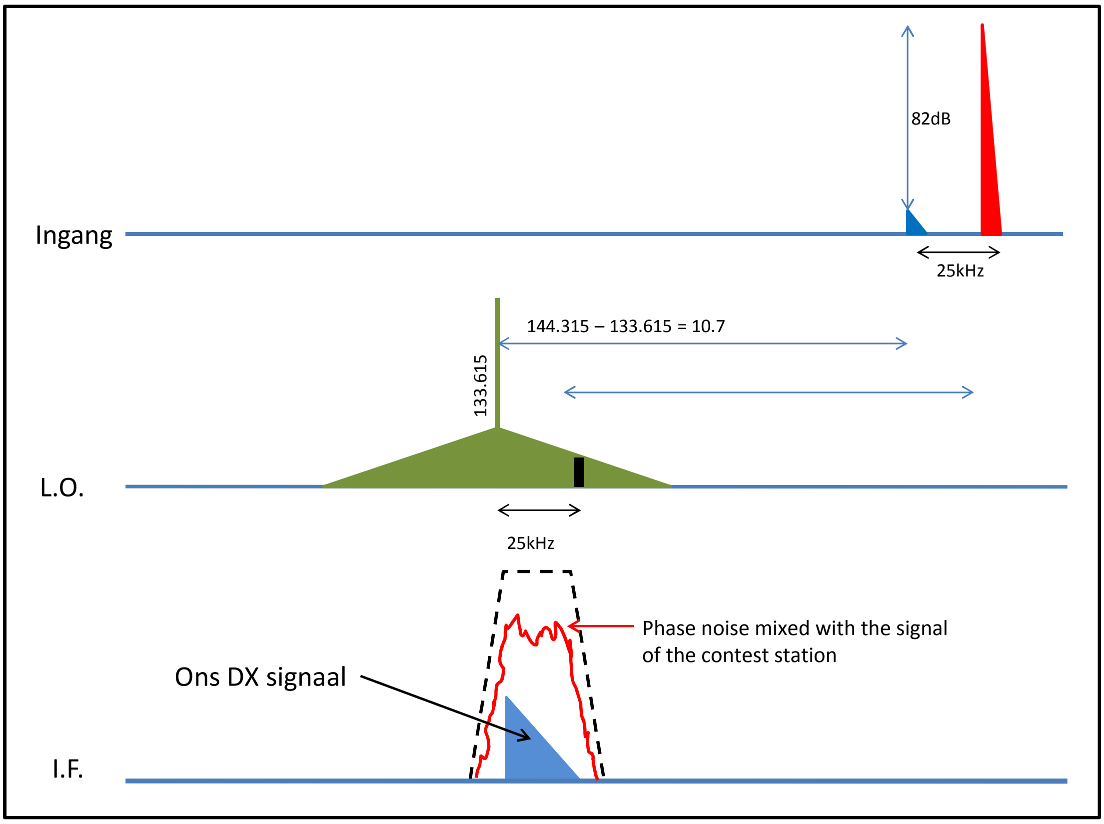
The DX signal is received during a VHF contest and 25 kHz up a local club station busy by calling CQ. Their signal produces a strong signal at the input of the receiver of S9 + 40dB, which corresponds to a level of -53dBm, 82dB stronger than the signal DX! with this the signal strength comes from the contest station as LO work.

What does the mixer with these two signals as the local oscillator in the receiver an SSB phase noise specification of -100dBc / Hz? The intermediate-frequency bandwidth of the receiver is 3kHz. If then we take the level of phase noise at 25 kHz and convert to 3 kHz bandwidth as follows:

$$\text{Phase Noise } (BW@3kHz) = \frac{100dBc}{Hz} + 10 * Log(3000)$$

In a 3kHz bandwidth, the phase noise of the LO now to lie on a level of -65.3 dBm / 3 kHz (-100 + 34.7). Set the mixer has a 6 dB conversion loss. After mixing, DX is the signal at 10.7 MHz at a level of only -141 dBm. The contest station at 25 kHz delivers remote at the receiver input a level of -53dBm. If this signal is going to blend in the mixer with the SSB phase noise power in the sideband of the LO, there is a second mixing product in the intermediate frequency chain, which in view of the strength of the signal above the -141 dBm to lie, and the DX signal is inaudible.

Figure 2 shows e.e.a. transparent.



Figuur 2

The red signal, the contest station, is 82 dB stronger than the DX at the receiver input. The phase noise, to 25 kHz from the LO, mixes with the contest station that at 25kHz from our DX station state and there is a second very disturbing signal recovered at the intermediate frequency.

3rd order intercept point and reciprocal mixing a receiver:

The large signal behavior of a receiver is generally represented by the 3rd-order IP (Intercept Point) specification. In addition to a good large signal behavior of the input in order to prevent unwanted intermodulation products, it is therefore also of great importance that the phase noise of the local oscillator in the receiver is very low. All effort to build a perfectly designed RF input stage with a very high IP3 specification can still be negated if the LO is much noise in the sidebands.

The measurement of the SSB phase noise:

Often, the phase noise figures are low, of the order of -100 a -150 dBc / Hz, which is 100 to 150 dB lower than the LO power. Such a measurement can not be carried out directly with a spectrum analyzer, because the dynamic range is insufficient for this. But going with a simple trick though.

What do you need in addition to the spectrum analyzer?

- An additional signal generator having a low phase noise

- A double balanced mixer

- A crystal filter, preferably with two 50 Ohm ports, or a filter with adaptable to networks 50 Ohm. See Figure 3. (Note: the bandwidth of the filter is not as important. The greater the attenuation of the filter and the sharper the edge of the filter on the side of the carrier, however closer you can measure the carrier)

- A low-noise amplifier with a gain of 20 - 30dB and a noise figure of 1dB up

- A step attenuator in steps of 10dB to 120dB

In order now to be sure that the additional signal generator has a low phase noise, the generator itself is first measured, and then the OUT [Oscillator Under Test]. The generator must have a typical phase noise value around 10dB lower than the number we want to measure.

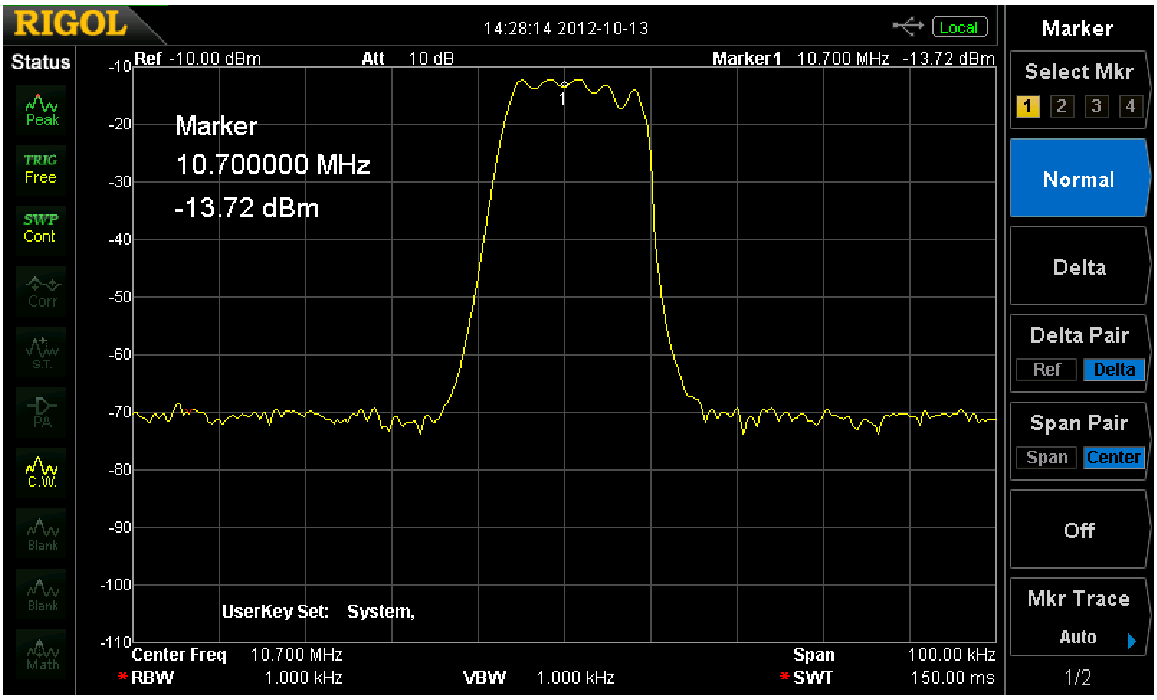
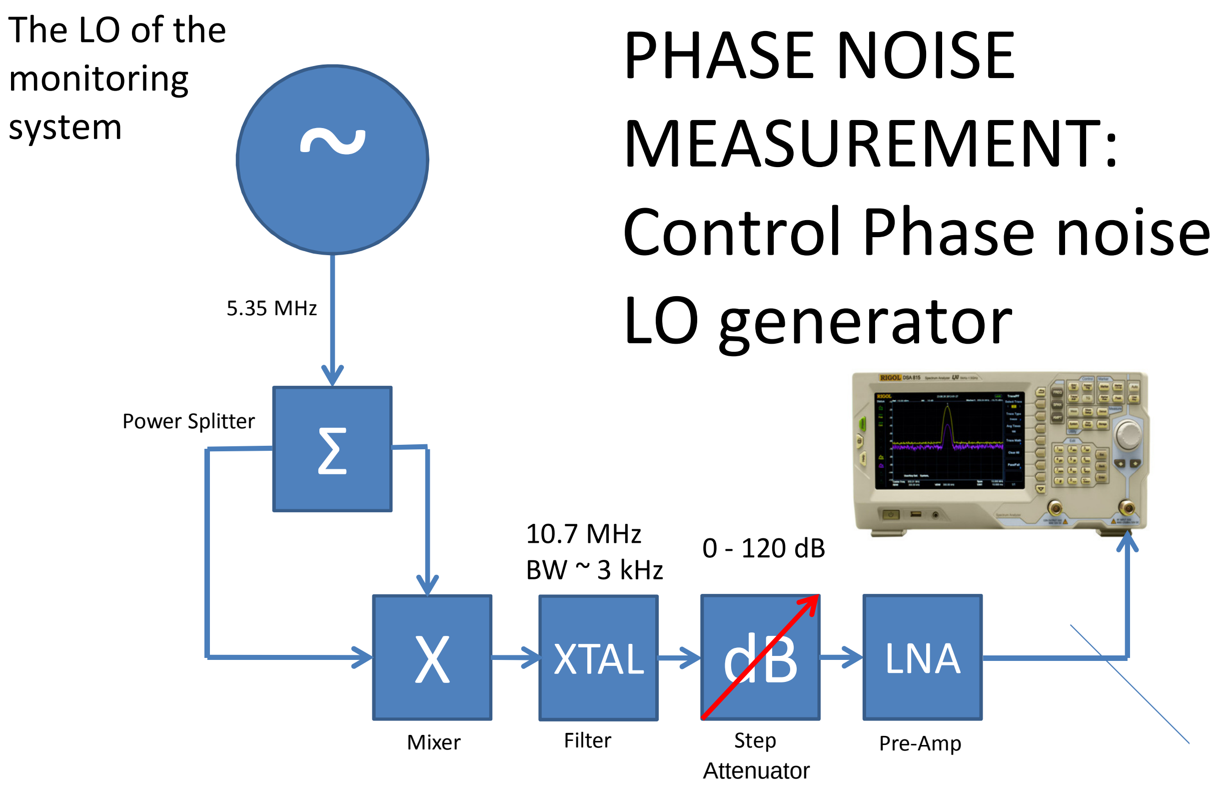


Figure 3. Pass band of the 10.7MHz, 15 kHz crystal filter



Figuur 4

In order to measure the phase noise of the own-LO generator is built up of the arrangement of Figure 3. How does this measurement work?

Stap 1 Set the attenuator to 100dB

Stap 2 **For the Reference Measurement:**

Set the generator at 5:35 MHz and having a level of + 10dBm.

The signal from the generator is split into two branches which are mixed with each other in the mixer. At the output of the mixer are then a DC signal, and 2 * 5:35 MHz = 10.7 MHz. That is, in the middle of the pass band of the filter.

Set the spectrum analyzer as follows:

Frequency	10.7 MHz
Span	100 kHz
Attenuation	0 dB
Pre-amplifier	On
Resolution Bandwidth	100 Hz
Reference Level	As required

Stap 3 Measure the signal strength of the signal with the marker, and record it. In our measurement a level of -68 dBm was used. This is the reference value of the measurement, under the conditions with 100 dB in the step attenuator, and a RBW of 100Hz.

Stap 4 We want to measure the phase noise at 25 kHz from the carrier. The signal generator is now shifted 12.5 kHz (up or down does not matter). The signal will disappear from view because the product mix is now 2 * 5.3625 = 10 725 kHz. This frequency is outside the pass band of the crystal filter.

Stap 5 Set the step attenuator up to 0dB. A plate as shown in is then visible.

What has happened now. The arrangement now measures a noise band of 3 kHz wide (the bandwidth of the crystal filter). Now the mixer product of 10 725 kHz is outside the filter and the passage is now 100dB !! The sensitive system now shows the output from the generator 25 kHz from the carrier. We measure the noise level in this band of about -95 dBm

What is the dBc / Hz value of the generator? We count it as follows.

1) The measurement noise is 27 dB lower than the reference measurement of -68 dBm - 27 dB
2) We have 100dB attenuation removed -100 dB

Apparently, the noise at a distance of 25 kHz measured with a 100Hz bandwidth -127 dBm. In order to the dBc / Hz value arrive this result is corrected with an additional 20dB which follows from 10log (100/1) = 20 dB, in other words how much extra noise is still in a 100Hz bandwidth compared to the desired 1Hz bandwidth.

The result of the measurement is therefore -147 dBc / Hz. The LO and RF signal is now coming from the same source. The result is thus also 3dB worse than expected and the phase noise at 25 kHz from the carrier leads to -150dBc / Hz.

Now we know that the generator has this value, the arrangement with may no longer phase-to-noise levels are measured to -140dBc / Hz without the phase-noise of the LO generator affects the measurement.

The measurement of the sideband phase noise of 404 MHz oscillator with this set-up:

The Reference Measurement:

The LO of the arrangement will be adjusted to 414.7 MHz and with the right number dBm in order to steer the mixer. The attenuator is set to its maximum value (100dB). Because the oscillator to be measured generates a frequency of 404MHz, the mixed product will be in the middle of the crystal filter come to lie.

Now adjust the spectrum analyzer off in such a way, the frequency 10.7 MHz is in the middle of a width (SPAN) of 50 kHz. From the measurement of this oscillator (Figure 1), we know that the output power is -5 dBm. However, this value as a result of attenuation and reinforcement of all the elements in the preparation did not display correctly.

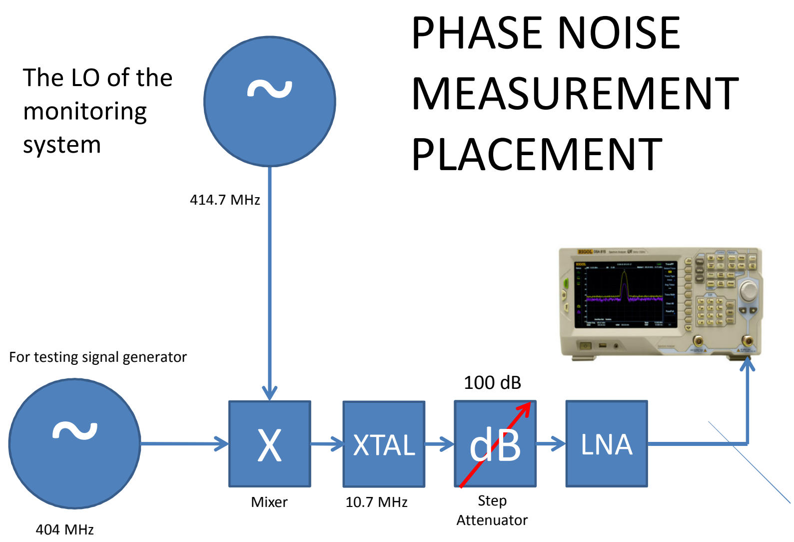
We can adjust the read-out of the analyzer by means of the "Reference Offset" and does such a manner that this level is sometimes measured. You see at the bottom right of the analyzer to the reference offset is 78dB. This value compensates for the effect of the following elements of the arrangement:

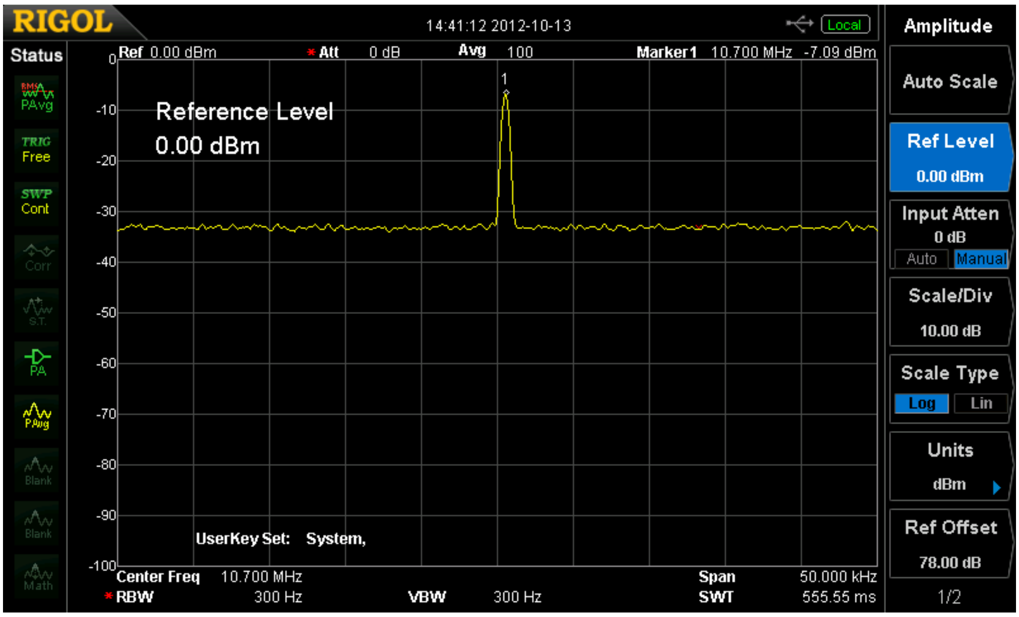
- The Conversion lLoss of the Mixer - 6dB
- The Loss in the Filter - 4dB
- The Gain of the LNA + 32dB
- The Attenuator - 100 dB

This chain provides a loss of at 78dB. By means of the reference offset to be set by + 78dB dBm be all values in the screen re-calculated with this value.

*For clarity, **because it is a relative measurement of the absolute levels are not important, however, by using this offset measurement is mi transparent.***

Of course, all other settings are now also used again as during measurement of the generator itself. This provides the reference measurement, outcome -7dBm. (see Figure 5)





Figuur 5. Reference measurement of the carrier wave

Stap 2:

The measurement of the phase noise. Suppose we want at a distance of 25 kHz to 404 MHz measure the phase noise of this generator is 404 MHz. Before the establishment of the LO should be changed to 414 725 MHz. What happens now is that the piece of spectrum 404 025 MHz +/- 7.5 kHz (the bandwidth of the XTAL filter in the measuring arrangement is, after all, 15kHz), is mixed and allowed to pass through the filter. The carrier, which during the reference measurement in the center of which was has now disappeared and falls outside the passband of the crystal filter.

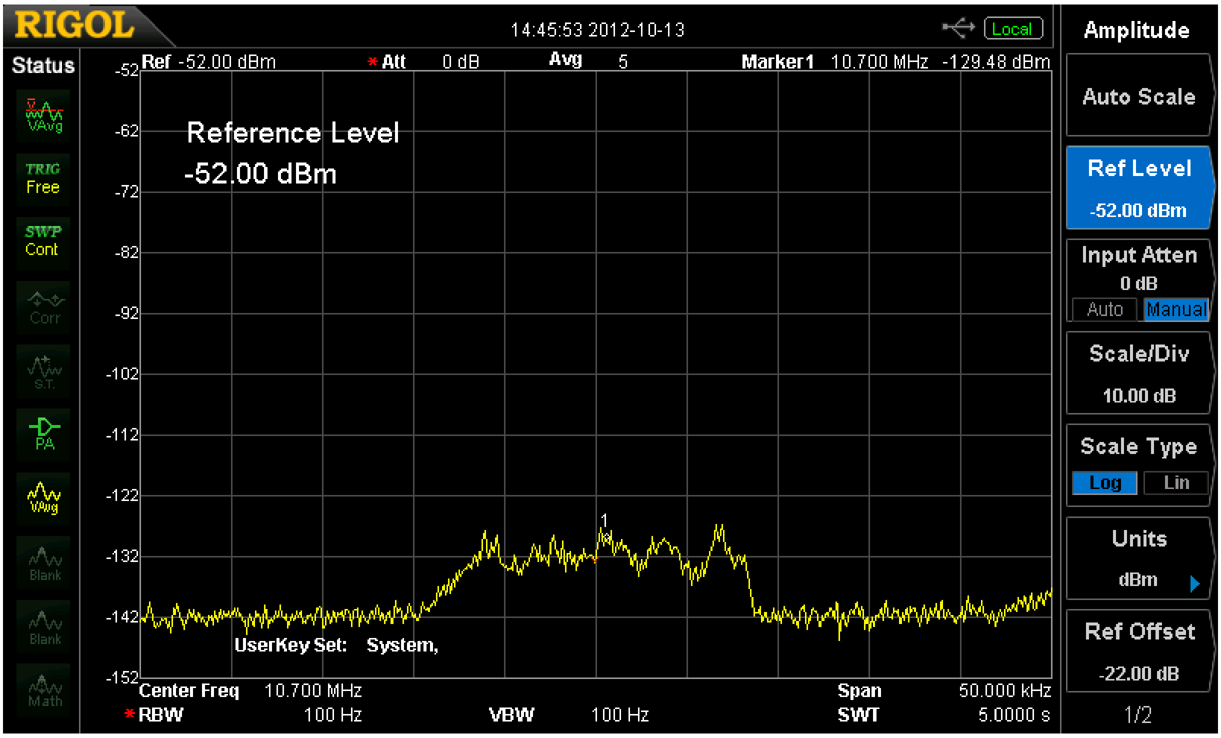
After this alignment you see nothing at first, then only the noise of the Spectrum Analyser itself! This is in order that the phase noise is much lower than the carrier, more than about 100 dB lower. The attenuator is now changed from 100dB to 0dB so that the arrangement is sensitive 100dB!

We have most of the reading of the analyzer with + 78dB to offset the loss of the mixer circuit, filter, attenuator and LNA nullify. As we have just released the attenuator of 100dB to 0dB set, we must set these offset again.

The new value of this offset is now 78-100 = -22dB. See Figure 6, bottom right of the screen.

Then comes the following picture in the picture, which is a part of the phase noise of the generator is at a distance of 25 kHz of the carrier. You will see the noise in the transmission characteristics of the filter (see

Figure 3)



Figuur 6. Measurement of the phase noise

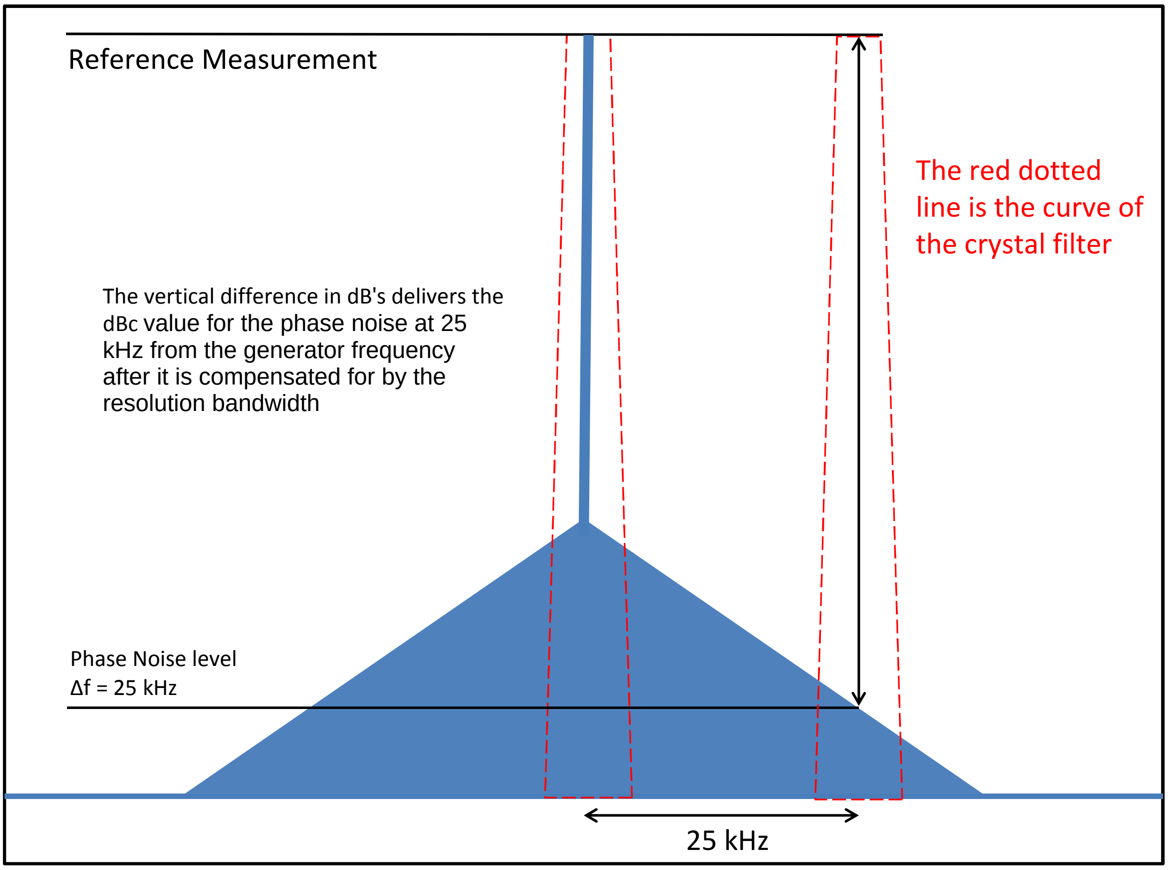
The marker1 in the screen indicates that he is now at a level of -129dBm (the marker value top right of the screen). The measurement we performed with a bandwidth of 100Hz. this setting is shown in the bottom left of the screen (RBW 100Hz).

After compensation of this measurement to 20dB as a result of the bandwidth in order to get the value in 1Hz bandwidth by means of the formula:

$$RBW\ compensation\ (BW@100Hz) = 10 * Log(100) = 20dB$$

This results in a final value of -149dBc / Hz at 404MHz for this oscillator at a distance of 25kHz from the carrier.

Schematically, the measurement is as shown in the diagram below.



Conclusion: A low-cost spectrum analyzer can be used by incorporating a number of readily available auxiliary components to build a phase noise measurement setup. The vertical offset of the shell with the external attenuator yields a dynamic range in to measure dBc / Hz values of up to -160dBc / Hz.