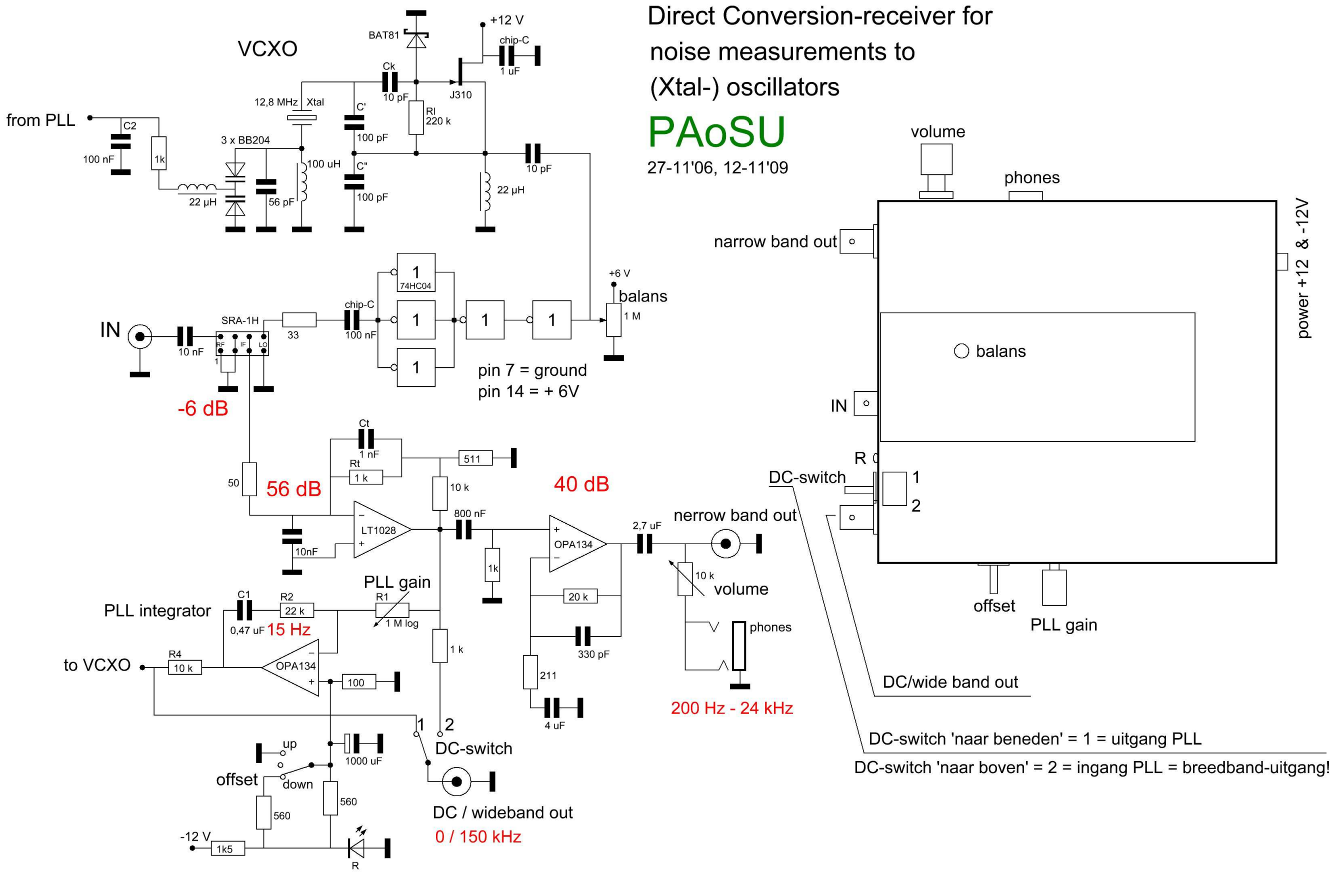
Direct Conversion receiver for noise-measurements

Introduction

One of the best methods to measure close-in noise of an oscillator is to use a reference oscillator on the same frequency as the DUT (= the oscillator to be measured in this case) and to put their outputs in a mixer. The spectrum of the output of this mixer is a direct measure for the close in noise of both oscillators. If the reference oscillator noises, say, 10 dB less than the DUT, the low frequency output could be examined with a LF-spectrum analyzer or a narrow band voltmeter.
For this the two oscillators must be locked in frequency and fase.

The diagram

The theory of this kind of measurement could be found in the literature and on Internet e.g.:.
http://www.wenzel.com/documents/measuringphasenoise.htm
The used diagram has been shown below.



The resolution of the figure is that high that it could be enlarged until you can read the details.

The VCXO

The VCXO is running with a 12.8 MHz Xtal in this diagram. The output to the mixer should be +17 dBm. This frequency is used to measure LO’s for the 80-meter band with a 9 MHz IF. This oscillator has been explained extensively on this website.
To measure Xtal oscillators at 11.2896 MHz, the VCXO should be tunable over about 400 Hz to lock it with the DUT. In this document I will stick to an oscillator of 11.2896 MHz as been used in many CD-players. The $K_v \approx 35$ Hz/V in the range of 4 – 9 volt.

The input

The input (IN) comes from the DUT. In our case an 11.2896 MHz Xtal cock oscillator. The level should be 0 dBm for the mixer SRA1H.

Post mixer amp

The post mixer amplifier determines the noise figure of the receiver. With low impedances an LT1028 op amp noises less than a 50 Ω resistor, so that this circuit hardly will be outscored. The bandwidth of this amp has been limited to 150 kHz because in our applications the noise further from the carrier than 150 kHz is of no concern. Its gain is 56 dB.

Nerrow band amp

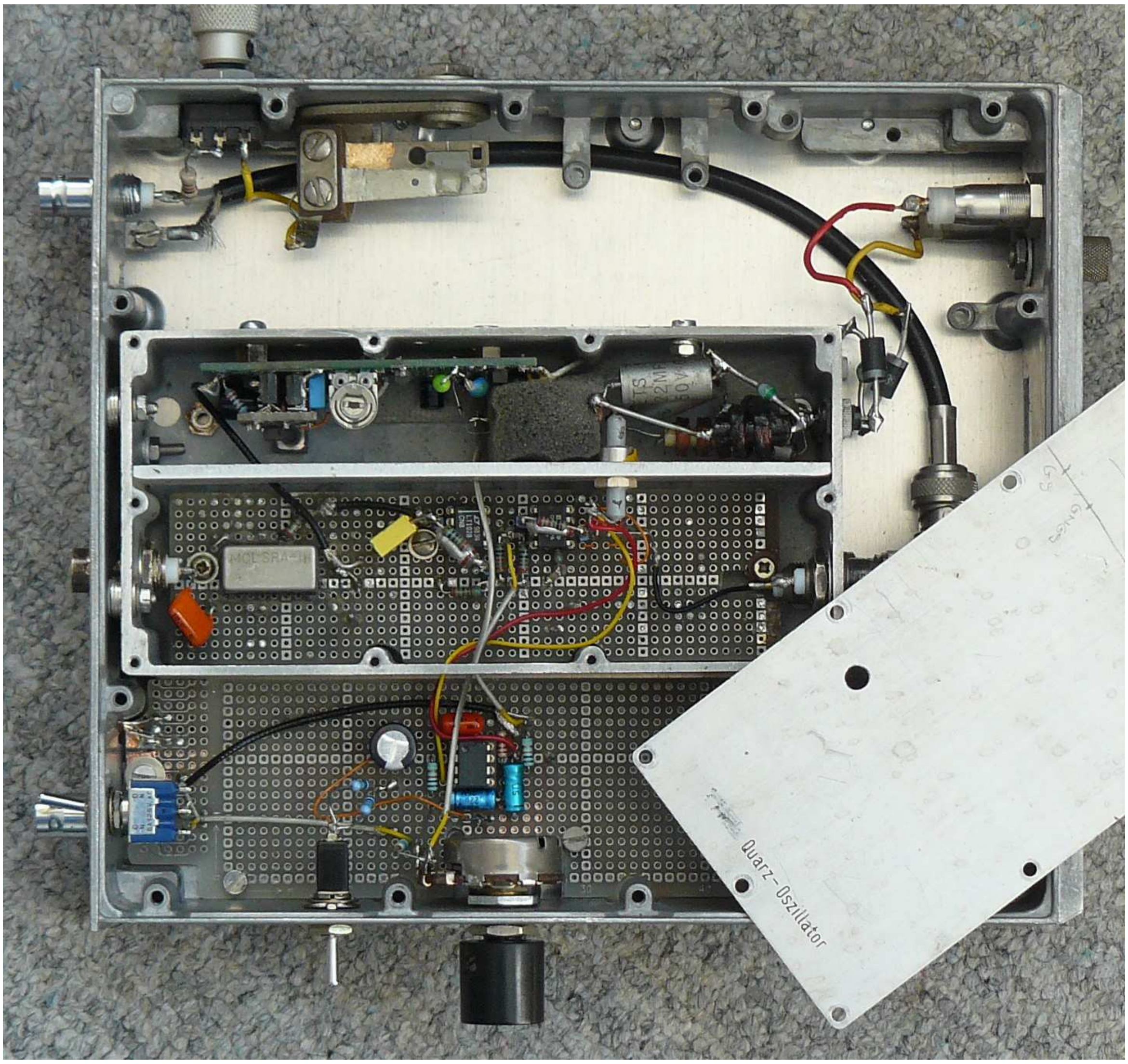
The following narrow band amp (200 Hz to 24 kHz) has been equipped with an OPA134. This stage amplifies 40 dB. This frequency range is important for LO's (Local Oscillators) in radio receivers. The extra gain serves eg. DUTs with low output levels and very low noise Xtal-oscillators.

The PLL integrator

The OPA134 is a very low noise op amp in high impedance environments, so that it is very applicable in a PLL integrator. Its bandwidth is about 15 Hz (is **not** the loop bandwidth!) so that lock time could be long. To 'help' the loop find the right frequency of the VCXO, the offset up/down switch has been added. In case the PLL-gain is set to maximum. During the following noise measurements this poti is turned back to minimal gain being the optimal gain for loop stability.

The DC switch

The DC switch connects the DC/wideband output B&C-connector to the output of the LT1028 for the wide band noise (~50 Hz – 110 kHz) for further treatment, or to the output of the PLL integrator for examination of frequencies within the PLL-loop being 0 – 50 Hz. These frequencies appear to be the most interesting for clock oscillators in digital audio applications.



The control devices correspond with the drawing above. The lid of the inner box has been taken off.

Spectrum analyzer

This receiver has been equipped with a headphones output plug beside a B&C for measurements. **Use this possibility** for the ear is able to detect strange noise and birdies much easier than the most beautiful LF spectrum analyzer! Even the loop-stability can be jugged with this audio by the colour of the noise!

The building

has been carried out in two aluminum boxes. The lager one encloses the smaller one. In the small box are located: the VCXO (in the upper compartment of the small box), the mixer, the LT1028, and the OPA134 nerrow band amp.
The PLL-integrator has been kept outside the small box.

Power supplies

For the plus- and minus 12 volt supplies, batteries should best be used. They are isolated from the mains, so that strange feed back (hum modulation) via the input cables will be prevented.

Input level

For the adjustment of the input level, a 50 Ω step attenuator should be used. Together with an AC voltmeter or calibrated receiver the level has to be adjusted to 0 dBm. Be careful not to overdrive the mixer! Not only to prevent damage but also to make the found values reliable.

Dimensioning

To get a stable and reliable PLL, some calculations should be carried out. To save the readers trouble, they are left out here. The user of this instrument should know that the loop bandwidth of this circuit is about 50 Hz, so that the wide band output is from 50 Hz to 110 kHz if the PLL-gain is set to minimum and the DC-switch on 2. To investigate the low frequencies < 50 Hz the DC-switch should be set to position 1. **For the *comparison* of Xtal-clock-oscillators for digital audio purposes, this situation is prevalent.**

Calibration

Calibrated measurement with low noise Xtal-oscillators is only possible if the input level has been set to 0 dBm. This should be established with a 50 Ω (stap) attenuator.
[0 dBm = 1 mW = 225 mV over 50 Ω.]
If the DUT (or a signal generator) is tuned at a frequency of about 1 kHz lower or higher than the VCXO: the 1 kHz output of the DBM (SRA-1H) in case is -6 dBm, the output of the LT1028 should become -6 +56 = 50 dBm = 70.7 V (if measured on a high input impedance voltmeter). Of course the LT1028 can't manage this, so that the input attenuation should be enlarged with -50 dB so that the output of the LT1028 becomes 225 mV (or eg. 2,25 V if the attenuation is enlarged to -30 dB).
The output of the OPA134 becomes 0 dBm if the input attenuation is enlarged to 90 dB.

Calculations

The noise bandwidth of the wideband output was measured as 110 kHz!
The noise bandwidth of the narrow band output was measured as 21 kHz (200 Hz – 21.2 kHz).
The loop bandwidth is 50 Hz.

If the noise from a 50 dB attenuated DUT should give 225 mV RMS output at the wide band output, the strength of the SSB-noise is – 6dBm. (Mind that the noise arises from **two** sidebands). To find the figure in dBc/Hz@??, this figure should be corrected so that the correction factor
$CF_{110} = 10 \log 1.1 \cdot 10^5 = 50.4$ dB. This means that the side band noise should become:
-6 + 50 – 50.4 = -6 dBc/Hz@??
What should be filled in for the ?? ? Mind that the slope of the noise (30 dB/octave) in this region (50 Hz to 110 kHz) mainly arises from the noise at 50 Hz so that the noise could staid to be: -6dBc/Hz@50Hz.

The noise bandwidth of the narrow band output was measured as 21 kHz so that
$CF_{21.7} = 10 \cdot \log 21 \cdot 10^3 = 43$ dB.

Using a PM2451

The old Philips PM2451 is an AC voltmeter up to 7 MHz **with a dB-scale** which has been calibrated for 600 Ω. (If measuring noise, the meter behaves as a RMS-meter within 0.1 dB!)
This means that 0 dB corresponds with 1 mW into 600 Ω :: 0.775 (0.7745966) volt.

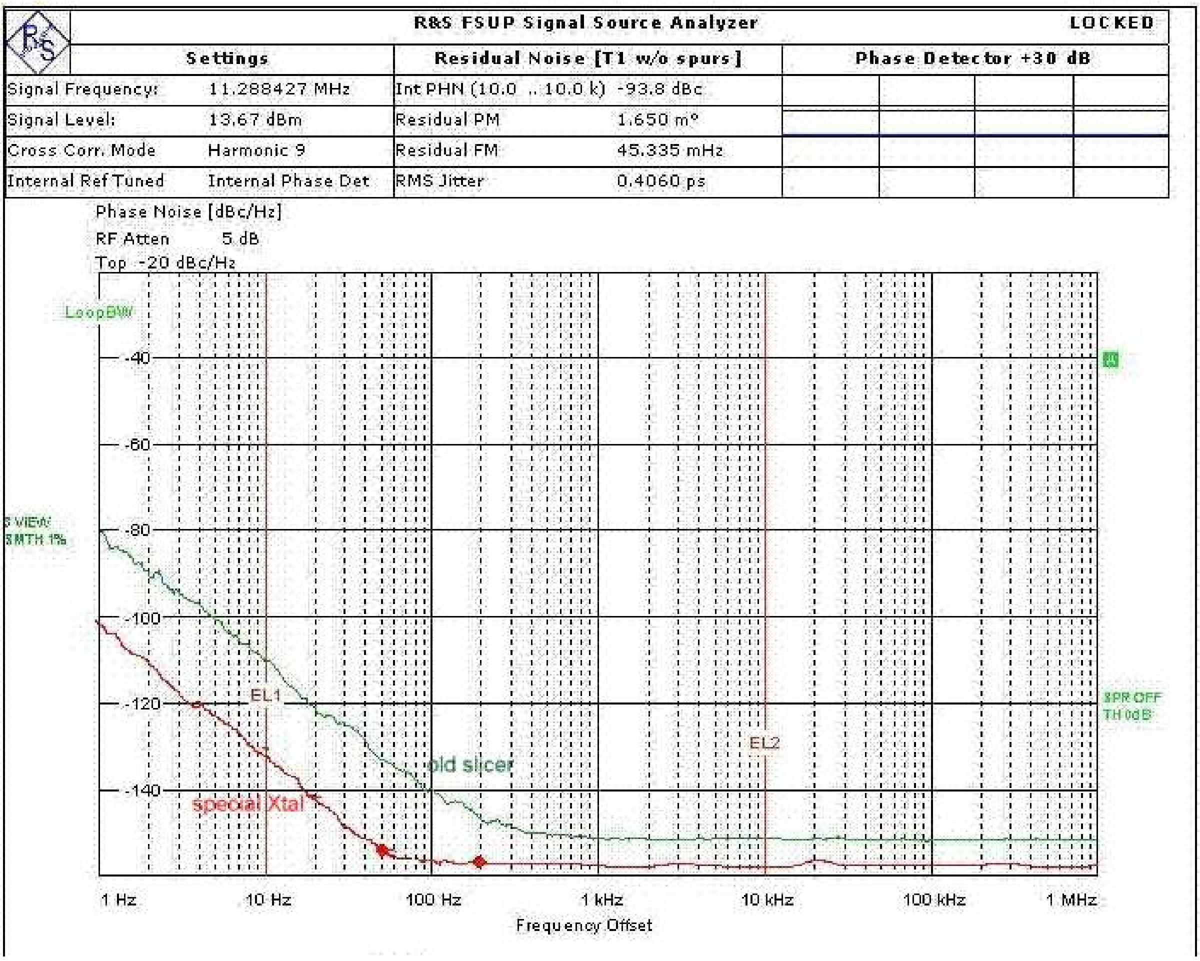
The difference in voltage between 0 dB over 50 Ω and 0 dB over 600 Ω is 3.4641016 which is 10.8 dB, say, 11 dB.
So, compared to our 50 Ω-measurements the PM2451 indicates 11 dB too little.

Consequently, as an example: if a 0 dBm input signal shows -20 dB on the PM2451 connected to the **wideband** output, the noise to carrier distance will be:
the input level: 0 dBm minus
the meter rash: -20 dB plus
too little rash: 11 dB minus
single sideband: 6 dB minus
total gain (DBM and LT1028): 50 dB minus
CF_{110}: 50 dB is: 50 dB yields:
0 – 20 + 11 – 6 – 50 – 50 = -115 dBc/Hz@50Hz.

If a 0 dBm input signal should show -20 dB on the PM2451 connected to the narrow band output, the noise to carrier distance will be:
0 – 20 +11 - 6 - 90 - 43 = -148dBc/Hz@200Hz.

Conclusion:
*For the wideband measurements one should subtract **95 dB** from the meter rash,=with the nerrow band measurements one should subtract **128 dB** from the meter rash, to find the carrier to noise distance in dBc/Hz at respectively 50 and 200 Hz from the carrier*.

Surprisingly these figures correspond with measurements with the old tunable low frequency meter and analyzer PSM-11 of Wandel & Goltermann (15 Hz – 200 kHz with a band width of 8 Hz), and measurements with the R&S FSUB Signal Source Analyser (see below).



The upper curve correspondents to both oscillators (the VCXO and the DUT) with an LT1016 as slicer and the lower curve with a 74HC04. The red dots correspond with the DC-receiver measurements.

Mind that the figures found above have nothing to do with the calculated examples. Both, the VCXO and the DUT were low noise rutgerS'Clock oscillators as treated elsewhere on this website. Mind that with the DC-receiver **both** oscillators (with about the same noise figures) had been examined……

Locking the DUT with the VCXO

The capture range of the VCXO is about 400 Hz. To assure that the DUT oscillates in that range, a very good trimmer of about 50 pF could be put in series with the Xtal. There is still another phenolme-non: DC-offset of the mixer (= DBM SRA-1H). The LT1028 has been DC-coupled to the mixer with a gain of 56 dB. This means that there will be some DC-offset, which should be minimized with the balance potentiometer. In my case the minimum offset is -200 mV. This should be corrected at the + input of the PLL-integrator. If the offset switch is in the middle this offset is corrected **in this case.**
The voltage from the PLL to the VCXO should be between 4 and 9 volt for proper operation. This should be examined at the DC output (with an oscilloscope). If the voltage is to low one has to switch to “up”, if the voltage is to high, switch to “down”. In both cases the voltage will change slowly until the VCXO has been locked. If the frequency of the DUT is out of the capture range, the trimmer in series with the Xtal of the DUT must be changed (the offset switch is in the middle) until the VCXO will lock. Turn the trimmer until the voltage is about 6.5 volt.

In this situation the measurements have to be carried out at the wideband and narrowband outputs. The output voltage at the wideband output should not ‘swing’ more than, say, 0.3 dB in case of Xtal-oscillators.
For Xtal-clock-oscillators for digital audio one should also look at the DC-output with the AC-input of an oscilloscope! Make the sensitivity as high as possible. There should be no ‘irruptions’ and the near subsonic frequencies should not be higher than some milli volt.
Another nice possibility is to connect a LF amp with loudspeaker output to the DC-output. Below you could see the swing of the cone with a bad and a good Xtal:

Bad Xtal movie:

Good Xtal movie:

Microphony

There is still another phenomenon: microphony. Xtals are sensitive to vibrations in the range of some hundred hertz to some kilohertz and impulses. This counts for the VCXO as well as for the DUT. On the photograph of the DC-receiver is shown that the Xtal has been packaged in polyether foam (gray in the middle of the upper box within the small box) besides it has been packaged into a piece of lead. It is advised to do the same with the Xtal in the DUT for best performance. The three connections (one to the can) are made of thin 90 degrees bend (short) wires to minimize structure-born noise.
Even with this arrangement the DC-receiver should be ‘isolated’ from structure-born noise of the table it lays on with a pillow below it.

Even coaxial cables could be (very) microphonic! At least the cables from the DUT to the attenuator and to the input should be examined on this. Listen to the headphones and beat on them!