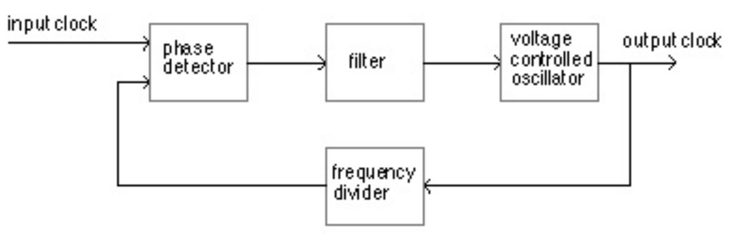
Some jitter measurements

During the design of our DAC it became apparant that CD transports have an audible impact. The main cause for this is jitter, which basically is a result of the transport <-> SPDIF channel <-> data and clock recovery chain, but also of implementation issues around and inside a DA convertor chip. If you use the data and clock signal from the recovered SPDIF signals directly, the conversion doesn't take place equidistant in time, and hence the output signal is distorted. For this reason an additional PLL can be used, to reclock the data and clock signals initially recovered from the SPDIF.

A schematic overview of a PLL is given in the following figure:



What follows now is a rough description of how this PLL works. A phase detector compares an input clock (in our case the recovered clock signal from the SPDIF) with a clock generated by a voltage controlled oscillator (VCO). By filtering the output signal of the phase detector, 'fast changes' in phase between input clock and output clock are ignored. Depending on the characteristics of this filter, the output clock frequency of the VCO will follow the input clock slow or quickly (related to the so-called loop bandwidth). A frequency divider enables the possibility to use a VCXO which generates an output clock frequency that is a multiple of the input clock.

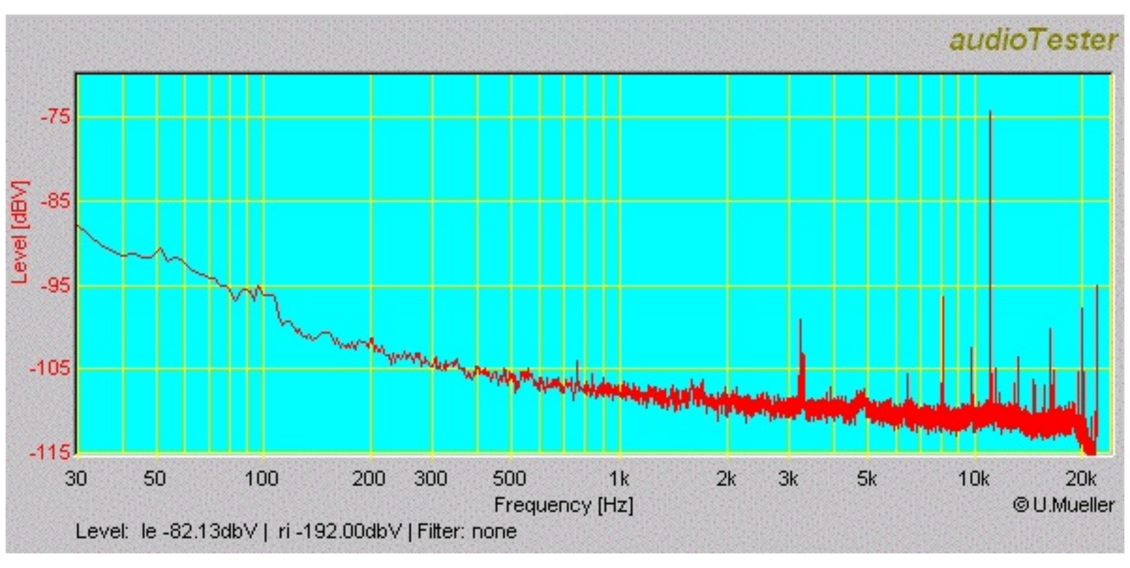
If the VCO delivers a stable output clock signal, and the filter is defined such that the output clock follows the input very slowly (in our case the loop bandwidth is about 2 a 3 Hz), the output of the phase detector is related to the power spectrum of the jitter. We use a Raltron VCXO, which if provided a stable input voltage, measures 3ps jitter.

A suitable point to look at the spectral contents of the jitter is directly after the phase detector. It has the advantage that you don't have to include the spectral contents of the clock signal itself, which makes jitter difficult to measure close in the area of the clock signal.

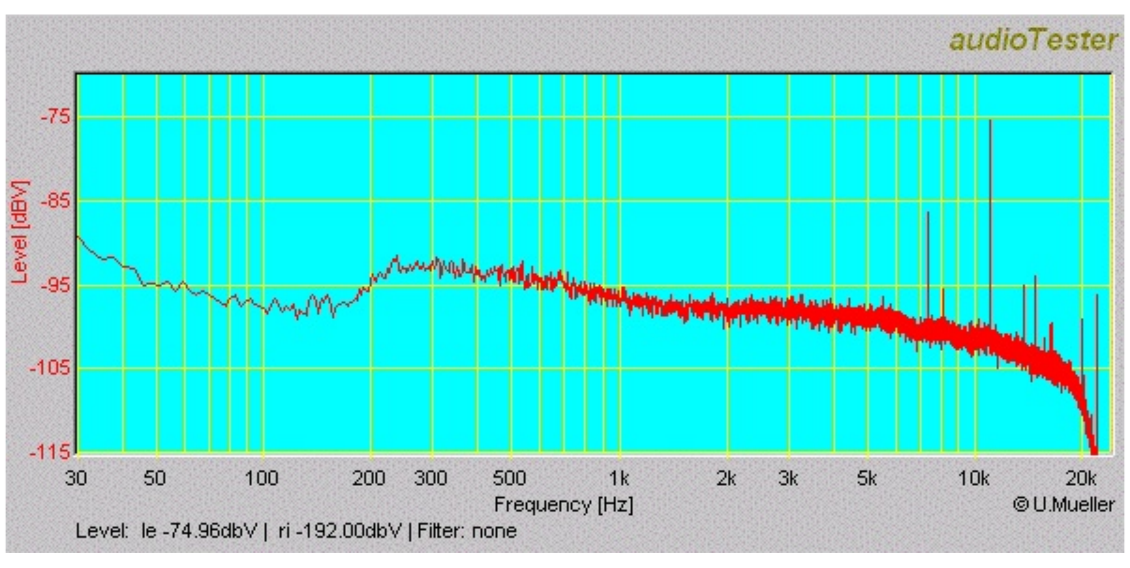
Another nice idea is just to LISTEN to this signal. When you just have a valid input clock signal, this output sounds like noise. We did have some very interesting observations when we tried out several CD transports (e.g. a TEAC VDRS-10, a Philips CD850). With the TEAC, playing an ordinary audio CD (Shirley Horn, You won't forget me), the audible characteristics of the noise changed a bit. With the Philips playing the same CD, the noise characteristics changed, but you could also hear the music itself very softly in this signal!!! This implies that the data signal is correlated in the clock signal!!!

The following figures show some measurements of the output signal of the phase detector, when playing a CD containing pink noise as a signal (track 2 of the AES/EBY QAM CD, 422 204-2). The measurements have been made with a Compacq laptop, and a simple sound card. This means that the measurements have no value in absolute sense (a lot of garbage in the spectra is coming from the Compacq laptop itself, quantisation will be not so linear, quality ad accuracy of the FFT performed, etc.). The measurements are suitable for relative comparison though! Most measurements have been verified with multiple measurements, to see whether they deviate from eachother, which is not the case.

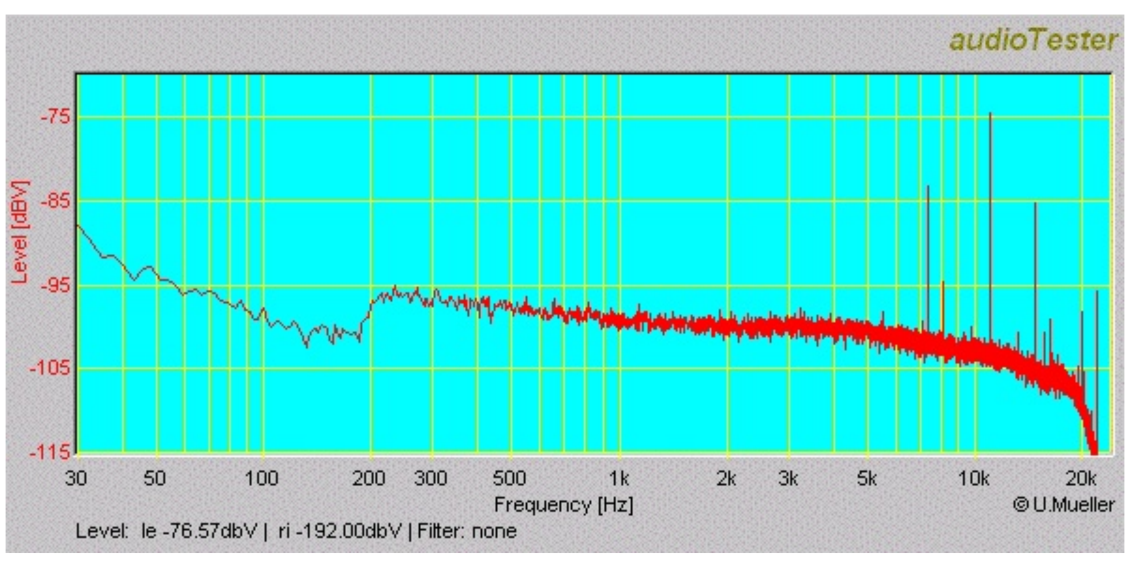
For reference, the garbage introduced by the Compacq has been measured by shortcutting its input. You'll see some spikes that should be ignored in the remaining figures. Also, the zero-level is not constant.



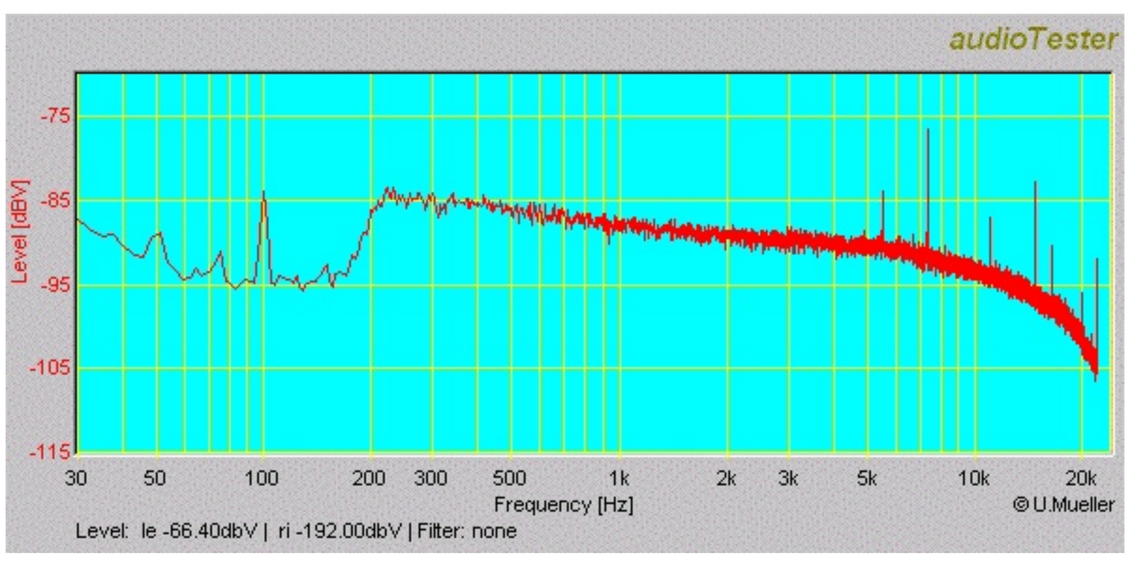
The first figure shows the results when playing the noise track on a Marantz CD player. Most spikes originate from the Compacq.



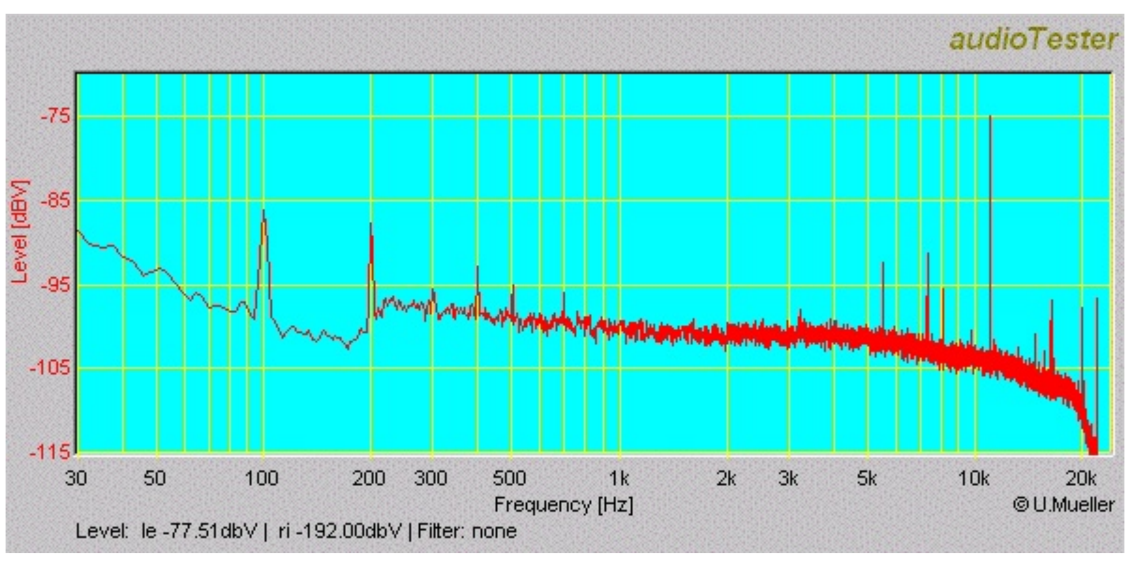
The second figure is from a Micromega player. You can see some lower spectral contents from 200-1000Hz, and there is a spike at 15kHz.



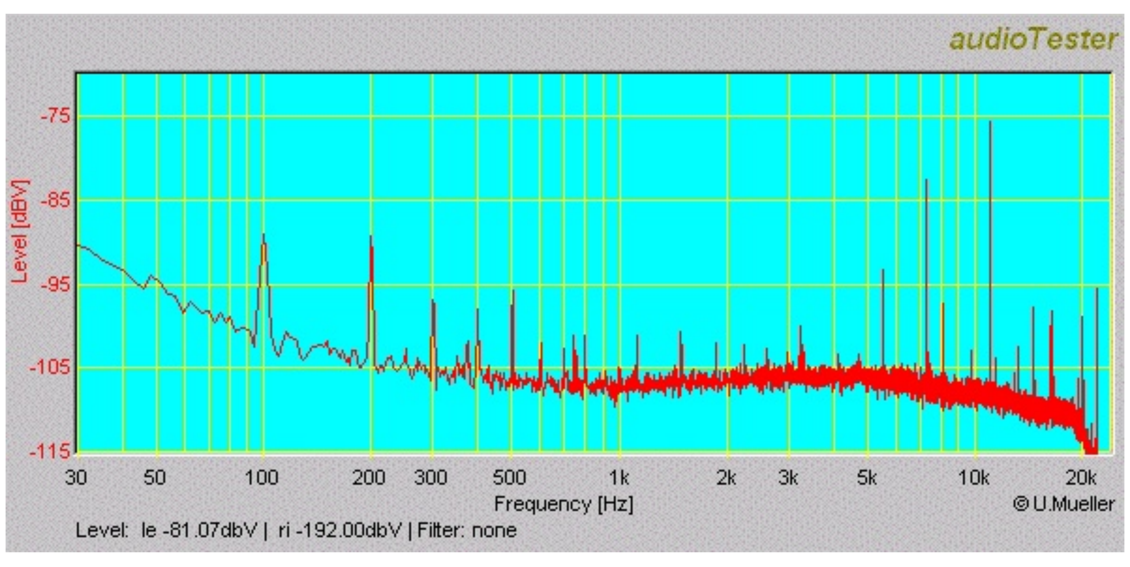
The third figure is from a CEC players. From this figure you can see that the average level of jitter is higher than the former two. You can also se a 100Hz spike, probably due to bad supply rejection.



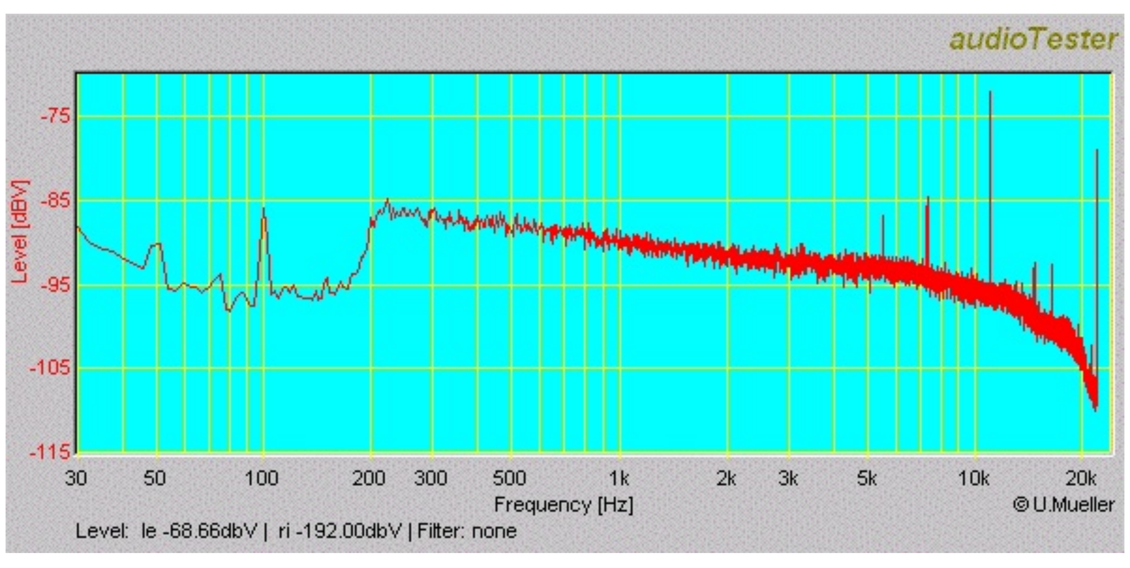
The fourth figure is from a TEAC. There are some spikes at multiples of 50 Hz (supply frequency).



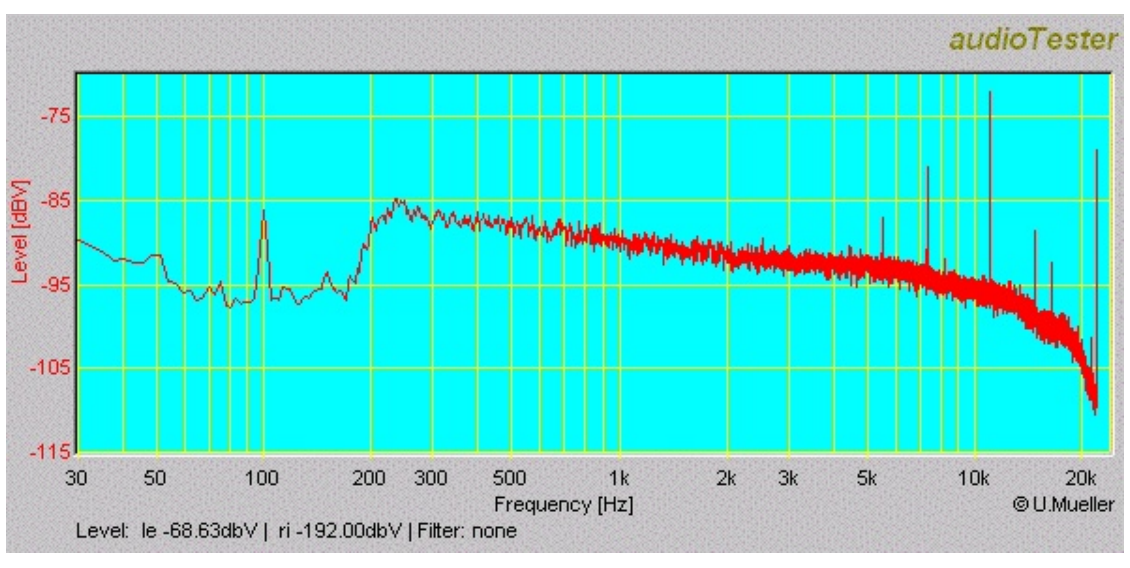
The fifth figure is from the same TEAC, but now with the info display of this transport (time info, track info) enabled. A lot of spikes appear...



Because we can also hear differences between different brands of CD-Rs playing on the same CD player, we measured the phase comparator output to look at this situation as well. The following picture is from a Philips Premium Silver, where the previou pink noise track has been recorded upon (using a Plextor PX-412 and an Apple Macintosh), played on a CEC CD transport. This resulted in the following figure:



The next picture is the same info, but then at a Ricoh. The measurements have been performed a couple of times, but the spike at 7kHz was a repeatable difference between the two measurements:



This leads us to some conclusions:

- Differences between transports and CD-Rs can easily be measured and heard after the phase comparator.
- In some cases the data signal is correlated with the retrieved clock from the SPDIF signal, in other cases it is not.
- The signal can be used for relative comparisons. E.g,, modifications to transports can be measured, and we do find a clear correlation between audible improvements of a CD transport, and these measurements.
- It is difficult to conclude from these pictures which transport sounds 'the best'. Ofcourse this is a matter of preference. The CEC did sound 'the best' to all of the people attendind the tests, but Guido also was able to improve it drastically by changing some parts of the CEC design (e.g., changing the Crystal Oscillator - see CD-player upgrade II, and scroll down a bit for more details).
- Cleaning up the conversion clock is necessary, to eliminate transport dependent effects during DA conversion.
- To be able to draw conclusions about the absolute jitter performance, better measurement equipment must be used.

In the near future, we'll hope we can use some Audio Precision equipment from a friend, to be able to measure these effects very precisely.