

Grimm Audio Test equipment

When aiming for the highest possible performance, testing becomes a problem in itself. Even the best available test gear will only approach the performance of the device under test. In addition, commercially available test equipment is designed to work in a very wide range of situations and compromises must be necessarily made. To get around this problem, Grimm Audio is building its own arsenal of test circuits for very narrowly defined applications. In each instance, the resolution obtained is at least an order of magnitude better than what is achieved by the very best general-purpose analysers.

+60 dB low noise low distortion wideband amplifier

The noise performance of standard regulator circuits is rather average. A typical “7805” regulator injects noise levels varying from 60uV to 1.5mV (20-20kHz, unweighted) into the audio circuits they power. The better sounding LM317 fares hardly better at 90-120 uV or around 20uV (-94dBV) when the adjust pin is decoupled. These figures vary wildly depending on manufacture and output current. Also, input ripple attenuation is 65dB to 80dB at best, found only at frequencies of 100Hz or below. One need not look further to explain the sonic differences between regulators. Yet, the power rails are rarely probed with anything better than an oscilloscope (noise floor = 0.5mV) or a millivolt meter (50uV) at best.

The discrete shunt regulators used throughout the AD1 are quieter by orders of magnitude.

The noise level hovers around -124dBV (0.6 uV), which outstrips the capabilities of a millivolt meter by some 40dB, and is even quieter than the inputs of an Audio Precision System 2 test set. PSRR of the shunt regulators is around 120dB up to well beyond the audio band. To be able to measure these figures and optimize the shunt supplies we designed a +60dB head-amplifier. Input noise is at -136dBV, input impedance is high at 330kOhm. Gain can be adjusted from +20 to +60 dB in 10dB steps. It is battery powered to minimize ground interferences. Bandwidth is 6MHz at +20dB, shrinking at higher gain of course but still a healthy 150kHz at +60dB.

Very Low Frequency (VLF) nanovoltmeter

All active analogue circuits suffer some form of flicker (1/f) noise. The effect of this noise on clock oscillators is to produce low-frequency jitter (wander), the effect of which on sound has been greatly underestimated. Published audible jitter limits have so far been derived from monaural listening tests on tones. A simple listening test establishes that the minimum audible jitter on stereophonic material is orders of magnitude lower. No standard test equipment is available covering the sub-10Hz frequency range. We designed a VLF voltmeter with a bandwidth of 0.1Hz-30Hz that will reliably measure down to 100nV (full scale bottom range). Equivalent input noise (shorted inputs) is some 10nV (-160dBV) in wide mode (0,1-30Hz), and only 2.5nV (-172dBV) between 1-10Hz.

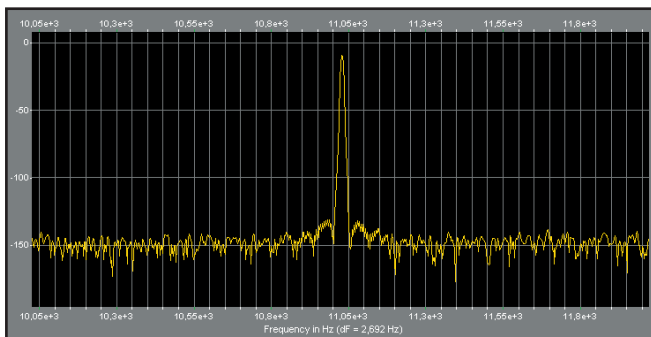
Jitter meter

The VLF nanovoltmeter addresses one cause of jitter. To measure jitter directly we have long relied on a Wavcrest test set. Again, the fact that this instrument is designed to measure jitter at any thinkable clock frequency ultimately limits the noise floor to around 3ps. It appears that discrete jitter components well below this figure can still lead to audible degradation. To say that clock stability is a decisive factor in digital audio is nearly an understatement.

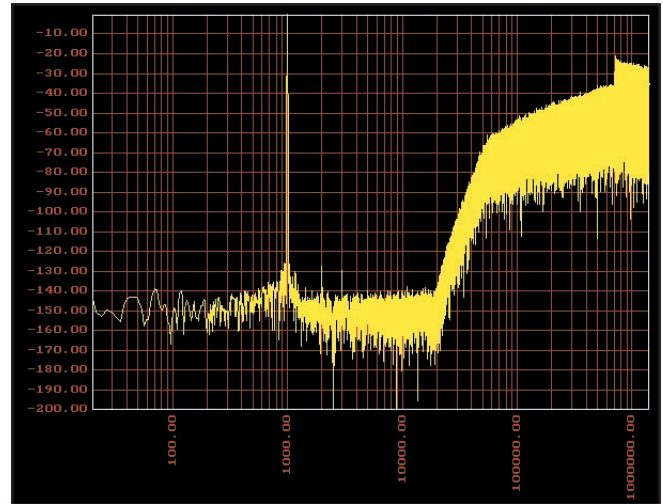
Again, building a jitter test circuit geared specifically towards the clock frequencies used in the AD1 provides the required resolution. The phase comparator outputs a very useful 10mV per picosecond, which can easily be observed on an oscilloscope screen or spectrum analyzer. This instrument allows us to track down all kinds of factors that influence the oscillators performance. Production units can be tested thoroughly as well.

High-stability 11.025 kHz oscillator

Observing clock jitter on a completed converter is most easily done by injecting a spectrally pure 11.025kHz signal into the input and making a long FFT analysis of the digital data. Harmonic distortion is not an issue, phase noise is. The test oscillator consists of a high-stability time base, a divider chain and a



Audio spectrum of AD1 with high-stability 11.025kHz oscillator and 100ns jittered external clock. The lack of sidebands proves the PLL is performing very well (the small rise in noise around the tone is caused by the FFT window).



Audio spectrum of AD1 with 0dB tone, measured on the DSD stream.

lowpass filter. Although the sensitivity of this test is much less than a direct measurement on the internal clock, it is an effective verification tool for finished products.

DSD Test software

No standard test equipment is available to analyse DSD audio. AD1 performance tests are done using a data logger and a math routine to display FFT and THD+N results.

Interpreting our jitter graphs

The spectrum is an FFT of the jitter measured between the AD1 clock and a reference oscillator that is made to track the AD1 clock over the long term. The phase error between the two is measured, expressed in seconds and then FFT-transformed.

The plot has two scales. This has *nothing* to do with the fact that this is a jitter measurement. It's just a clarification that helps interpret a spectrum whenever both steady state signals (sine waves) and noise are on the same plot. Every point on the spectrum represents a tiny portion of the spectrum. Suppose we are receiving a 1V 1kHz sinewave signal with 1mVrms white noise inside the 20kHz band. That is a SNR of 60dB. Suppose the spectrum analyser measures points (bins) with a bandwidth of 10Hz. A 1V sinewave measured through a 10Hz bandpass filter tuned to 1kHz still comes out as 1V. If the noise measured across 20kHz is 1mV, only 10/20000 of the noise power will pass through a 10Hz wide filter. Since voltage is proportional to the square root of power, the noise measured across 10Hz is $1\text{mV}/\sqrt{20\text{kHz}/10\text{Hz}}=22\text{uV}$.

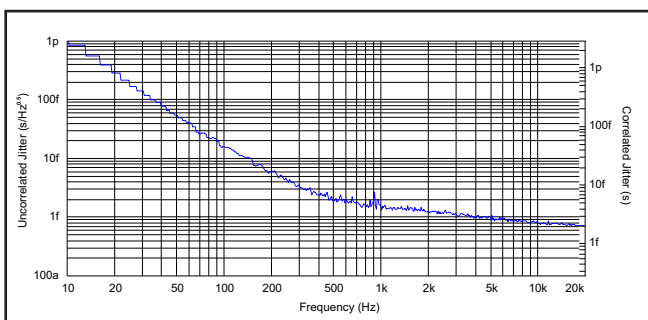
The spectrum analyser will show the sinewave as 1V but the noise floor at 22uV. When reading this graph, one could be misled into thinking that the signal to noise ratio is $1\text{V}/22\text{uV}=93\text{dB}$! If we do not know what the detector bandwidth is, noise measurements are meaningless. In radio engineering, spectral analysers always put "Resolution Bandwidth x Hz" (RBW x Hz) on the screen and on the printout. This gives the reader this important missing bit of information. When an RF

engineer reads a spectral plot, he will read tones (sharp spikes on the spectrum) directly, and for smooth curves (noise) he will normalise the reading to a standard bandwidth of 1Hz. The correction factor is $\sqrt{1\text{Hz}/\text{resolution bandwidth}}$. From there, the noise level can be recomputed to any desired bandwidth.

In the above example, the resolution bandwidth is 10Hz, and the noise reading is 22uV. Converting to 1Hz means 10 times less energy or 3.16 times less voltage. So, the noise in the signal is written $7\text{uV}/\sqrt{\text{Hz}}$.

In audio, this way of thinking is almost unknown. FFT spectral plots are presented without further information concerning resolution bandwidth (in FFT lingo this is called "bin width" and equals sampling rate over number of points, corrected by a factor dependent of window shape). The majority of people will read the noise floor straight off an FFT plot without even realising they're 30dB off. It's unlikely that adding a line to an FFT plot stating the RBW will remedy this, so we decreed from now on to normalise jitter plots directly to seconds/sqrt(Hz) (see AES preprint 6122).

Unfortunately, jitter is often not noise-like. Quite often you will see discrete tones appearing. Now one can either normalise to $\text{s}/\sqrt{\text{Hz}}$ or absolute seconds, but not both unless RBW is exactly 1Hz. In the case of this jitter plot, $\text{RBW}=9\text{Hz}$, so to us the best solution seems to add a second scale on the right hand side which is calibrated in ps. The scales are offset by a factor $\sqrt{\text{RBW}}=3$. When reading rms values of tone-like jitter, read using the right hand scale.



Jitter measurement of AD1 clock