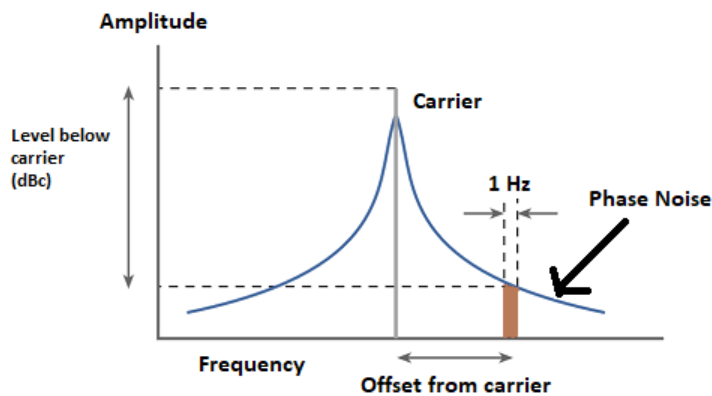


THE WELL TEMPERED MASTER CLOCK

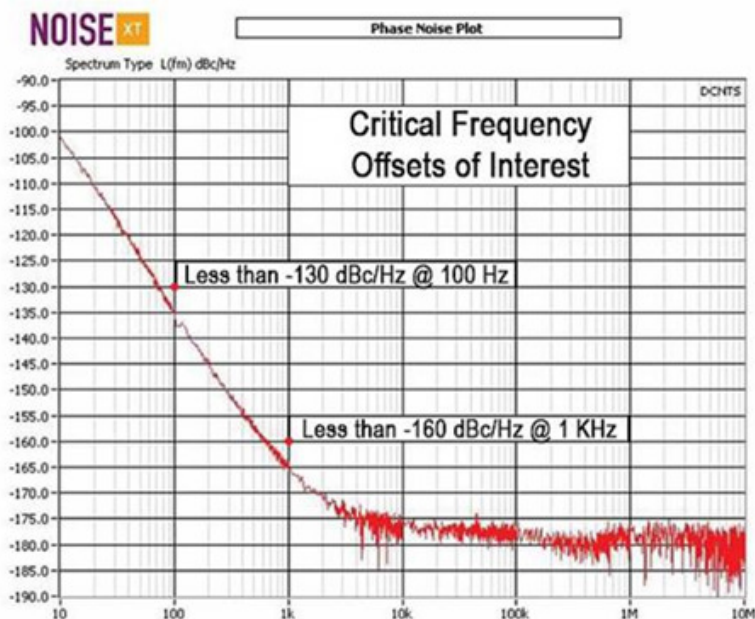
What is phase noise?

Phase noise is defined as the noise arising from the rapid, short term, random phase fluctuations that occur in a signal. These random fluctuations are caused by time domain instabilities called as phase jitter.

Phase noise is the noise spectrum that is seen spreading out on either side of a signal as a result of the phase jitter. In most radio receiver applications the phase noise is quoted in terms of single sideband phase noise. The phase noise spreads out equally either side of the carrier but only one side is measured - hence the name single sideband phase noise.



Phase noise is a kind of specification which indicates short time frequency stability in the frequency domain. The unit of phase noise is dBc/Hz @ offset frequency, for example: -130 dBc/Hz @ 100 Hz offset. This means when frequency offset is 100 Hz , the phase noise is -130 dBc/Hz . A higher absolute value of the phase noise is better.

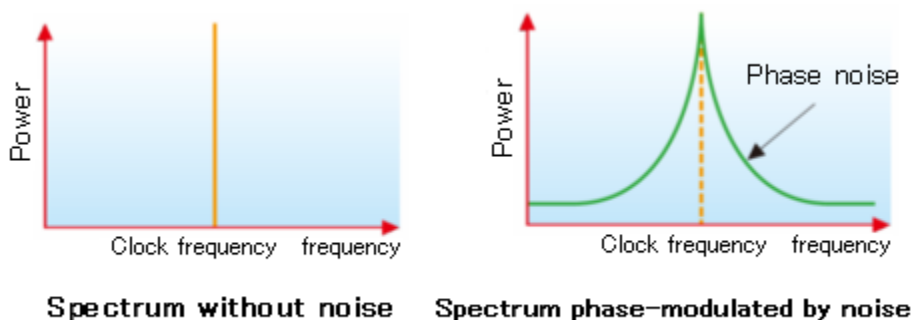


How the phase noise of the master clock affects the digital to analog conversion?

Taken from: Relationship between audio equipment and crystal oscillator Sound quality and clock phase noise (NDK website)

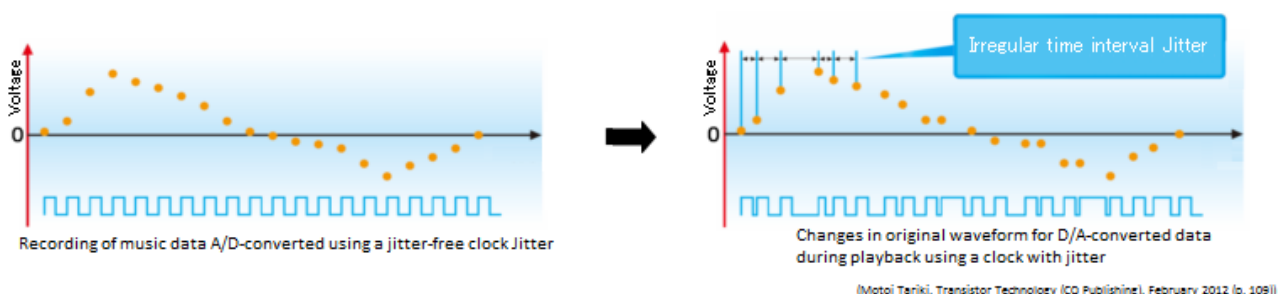
Faithful reproduction of high-resolution sound sources requires precise digital signal processing and analog sound output with reduced deterioration of the sound source in the digital audio device. This conversion accuracy depends on the noise characteristics (i.e., frequency components outside the target frequency) of the clock frequency of the audio device used.

The clock frequency spectrum for a circuit with zero noise has the form of a straight line (Figure 1, right). However, real-life spectra are modulated by noise, and are characterized by an extra frequency component nearby (Figure 2, right) known as phase noise.



(Motoi Tariki, Transistor Technology (CQ Publishing), February 2012 (p.109))

The phase noise of a clock frequency influences DAC and makes the time interval irregular. This phenomenon is called jitter (see the figure below).



(Motoi Tariki, Transistor Technology (CQ Publishing), February 2012 (p. 109))

In digital audio devices, the phase noise of the master clock influences DAC due to jitter, thereby impeding high-fidelity audio reproduction. To enhance sound reproducibility, a crystal oscillator for a master clock with superior phase noise characteristics (i.e., low jitter) is necessary.

Phase noise is expressed as frequency component levels measured outside a crystal oscillator's original frequency, and is based on the component level of the original frequency. Offset frequency is the departure from the original frequency, and is normally measured in the range of 1 Hz - 1 MHz.

Frequency stability (the characteristic by which frequency does not change over an extended period) is generally seen as an important property of crystal oscillators. However, audio devices require short-term rather than long-term stability.

Why short-term rather than long-term stability?

Because our brain is very sensitive to the timing errors, it's able to perceive short time errors, even femto-seconds discrepancy. Timing errors in digital to analog conversion are much more deleterious than harmonic distortion because they alter our perception of space.

Try to put an obstacle between you and another person. You will find that you can no longer understand exactly where he is calling you from. The same thing happens in the digital to analog conversion, the data are delayed or anticipated causing a time distortion compared to how they were recorded when converting from analog to digital.

Why phase noise and not jitter?

Because phase noise is an absolute measurement while jitter depends on the integration bandwidth.

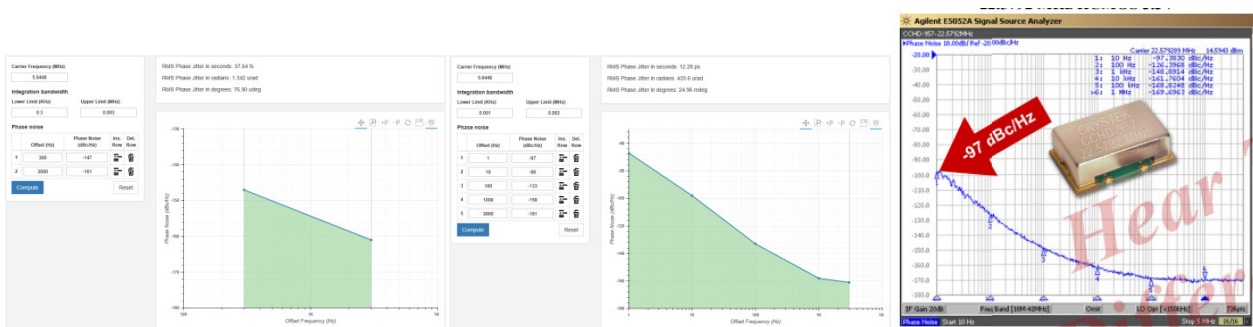
Jitter is a useful parameter for telecommunications but it does not say enough for digital audio because it does not show the spectrum of the noise.

It's a standalone number that does not help much to understand the short term stability of an oscillator, while the phase noise plots shows the whole spectrum of the noise and mostly they help a lot to know the behavior of the oscillator close to the carrier, that's what we are looking for digital to analog conversion.

To understand the concept you can look at the following figures. The first shows the jitter calculated with a integration bandwidth suitable for telecommunication, the result is 37.84 fs. The second one shows the jitter calculated with a larger bandwidth suitable for digital audio, now the result is 12.28 ps.

What a difference!

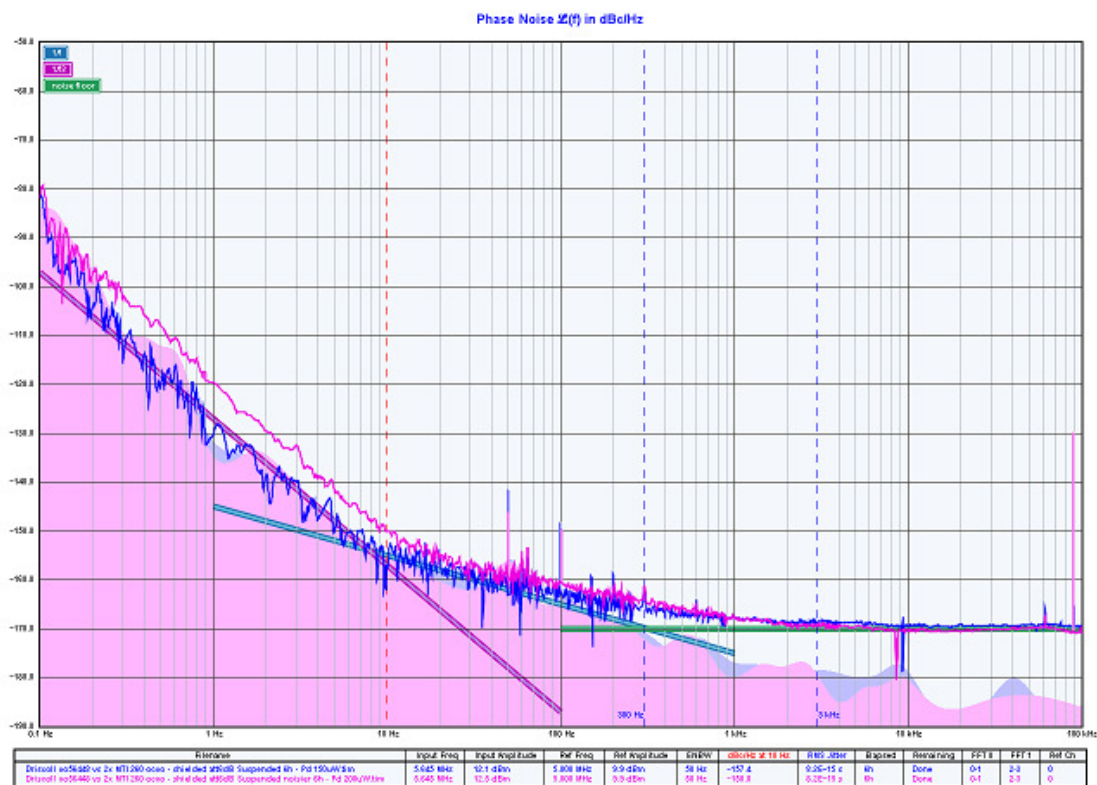
Obvious, changing the integration bandwidth the calculated jitter varies a lot making it useless to understand the quality of an oscillator. The third figure shows the phase noise plot of an oscillator, now with the whole spectrum of the noise it's easy to compare two oscillators superimposing their phase noise plot. The comparison becomes absolute, there is no uncertain margin.



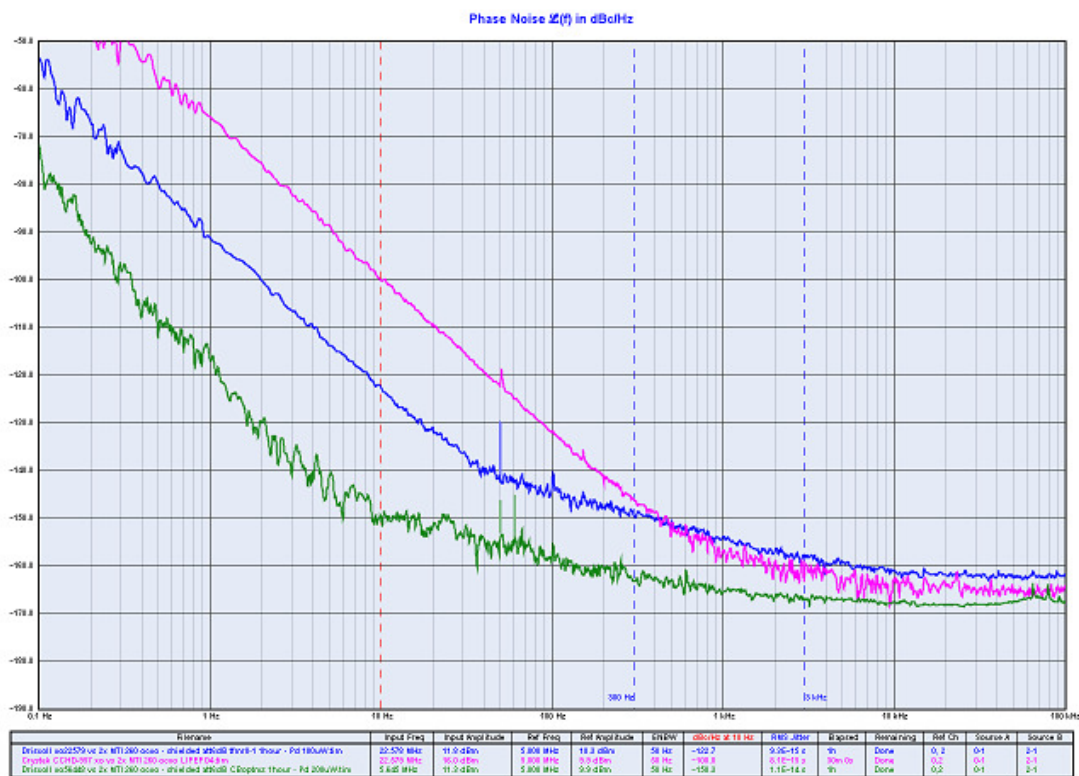
How to read phase noise plots?

It's very simple, since you are looking for the best short term stability you should look at the close-in phase noise, at 10 Hz and below from the carrier. Referring to the below figure you should pay attention to the part of the curve named 1/f³ and also at the 1/f part of the plot. The noise floor is

much less important in audio application because any decent oscillator has a phase noise better than -130dBc in that region.



Comparison between oscillators is even simpler, as it is sufficient to overlap the plots to identify the most performing one. In the below figure the green plot identifies the best of the three oscillators because its phase noise is far less than the other two.



TWTMC-DRIXO New Driscoll oscillator

It's a state of the art oscillator to be used as the master clock for digital to analog conversion. It is the best oscillator of this GB together with the new Differential one (TWTMC-EXO).

The output of this oscillator is sine wave therefore it needs a sine to square converter to be connected to digital devices such as FIFO or DAC (for example the TWTMC-STS).

Oscillator type: Driscoll

Frequencies: 5.6448 MHz, 6.144 MHz, 11.2896 MHz, 12.288 MHz, 22.5792 MHz, 24.576 MHz

Output: 50 Ohm sine wave (+16 dBm to +18 dBm)

Crystals: SC-Cut overtone only

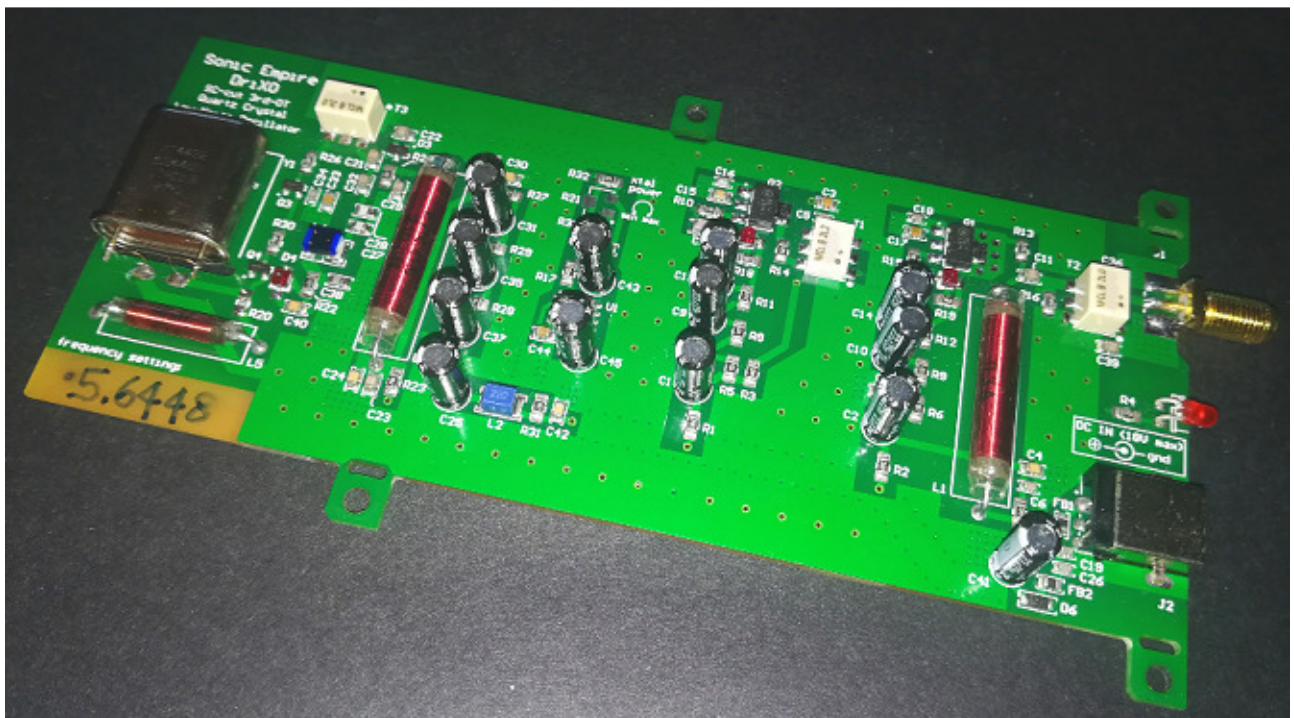
Board size: 151mm x 75mm (excluding SMA connector)

Power supply: 12-18 Vdc 60 mA

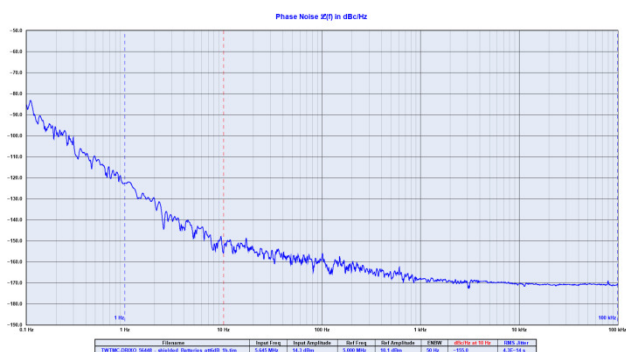
Suitable box: Hammond 1455J1601 (Mouser part 546-1455J1601)

Board options: finished and semi-finished

Note: supplied without crystal and box



The following figures show the measured phase noise of the Driscoll oscillator at different crystal frequencies: 5.6448 MHz, 6.144 MHz, 11.2896 MHz, 22.5792 MHz, 24.576 MHz.



TWTMC-DRIXO 5.6448 MHz phase noise



TWTMC-DRIXO 6.144 MHz phase noise



TWTMC-DRIXO 11.2896 MHz phase noise



TWTMC-DRIXO 22.5792 MHz phase noise



TWTMC-DRIXO 24.576 MHz phase noise

There are 2 available options for this oscillator:

- finished boards (fully assembled and tested)
- semi-finished boards (users have to solder a few parts, mostly TH)

The BOM for semi-finished board is available at post #3008 on the diyaudio.com thread: The Well Tempered Master Clock - Building a low phase noise/jitter crystal oscillator.

TWTMC-EXO New Differential oscillator

It's a state of the art oscillator to be used as the master clock for digital to analog conversion. It is the best oscillator of this GB together with the new Driscoll one (TWTMC-DRIXO).

The output of this oscillator is sine wave therefore it needs a sine to square converter to be connected to digital devices such as FIFO or DAC (for example the TWTMC-ST5).

Oscillator type: Differential

Frequencies: 5.6448 MHz, 6.144 MHz, 11.2896 MHz, 12.288 MHz, 22.5792 MHz, 24.576 MHz

Output: 50 Ohm sine wave (+11 dBm to +16 dBm)

Crystals: SC-Cut overtone only

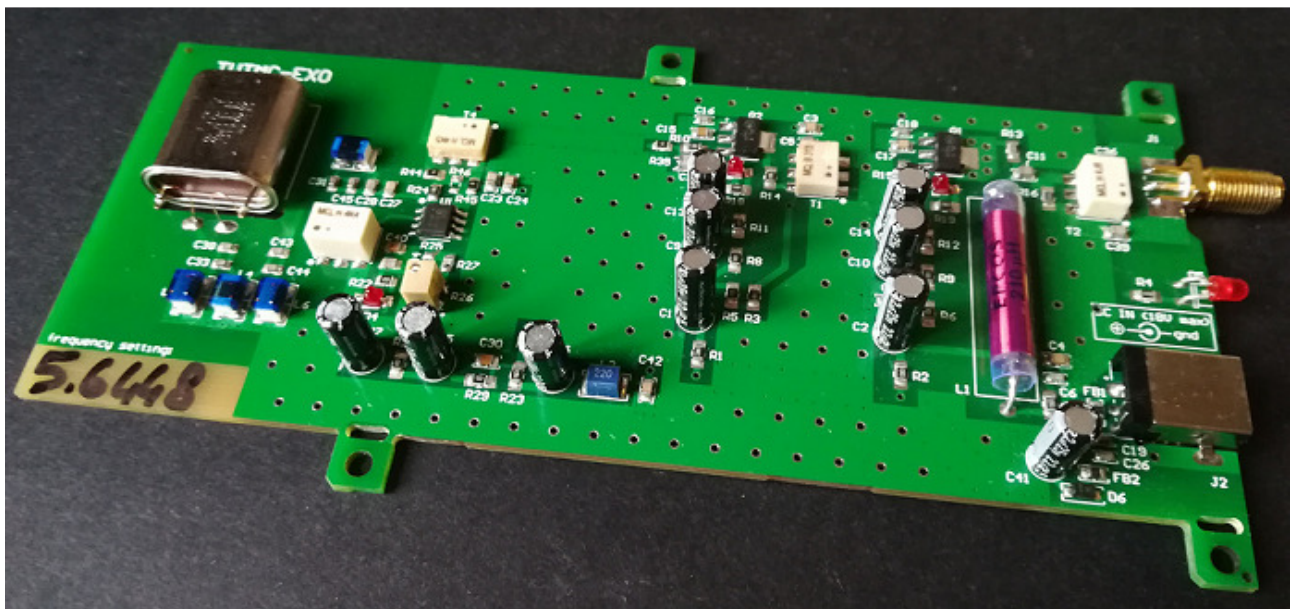
Board size: 151mm x 75mm (excluding SMA connector)

Power supply: 12-18 Vdc 60 mA

Suitable box: Hammond 1455J1601 (Mouser part 546-1455J1601)

Board options: finished and semi-finished

Note: supplied without crystal and box



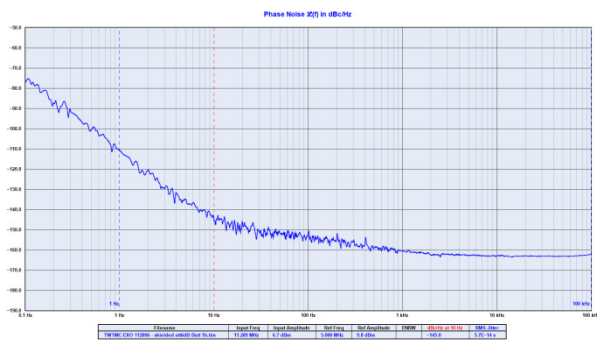
The following figures show the measured phase noise of the Differential oscillator at different crystal frequencies: 5.6448 MHz, 6.144 MHz, 11.2896 MHz, 22.5792 MHz, 24.576 MHz.



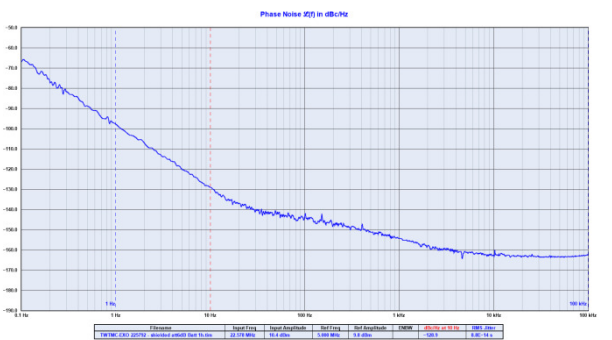
TWTMC-EXO 5.6448 MHz phase noise



TWTMC-EXO 6.144 MHz phase noise



TWTMC-EXO 11.2896 MHz phase noise



TWTMC-EXO 22.5792 MHz phase noise



TWTMC-EXO 24.576 MHz phase noise

There are 2 available options for this oscillator:

- finished boards (fully assembled and tested)
- semi-finished boards (users have to solder a few parts, mostly TH)

The BOM for semi-finished board is available at post #3009 on the diyaudio.com thread: The Well Tempered Master Clock - Building a low phase noise/jitter crystal oscillator.