Wow and Flutter Measurement using Multi-Instrument

By Dr. Wang Hongwei

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The objective of this article is to explain how wow and flutter is measured in Multi-Instrument as well as the theory behind. Sophisticated mathematics is intentionally avoided in this article in order to make it easily understood by most software users.

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1. Introduction

The sound recording and reproducing techniques had evolved from analog approaches, such as those used by phonograph cylinders, disc phonographs and taper recorders, into digital approaches using CDs or solid state memories as the recording mediums since 1980s. However, till today, the analog technique based devices have not vanished, as evidenced by the considerable new sales of turntables and vinyl records. Some audiophiles still love to listen to them.

2. What is Wow and Flutter?

Flutter, wow, drift, and scrape flutter are all forms of distortion in analog recording and reproducing systems that use a moving medium. These are caused by undesired frequency modulation introduced into the signal by an irregular motion of the recording medium during the recording, duplicating, and reproducing processes. The measurement of wow and flutter quantifies the amount of frequency wobble (caused by speed fluctuations) present in subjectively valid terms. For example, when a 3150 Hz tone is replayed, the measured instantaneous frequency should be constantly 3150 Hz under ideal circumstances. However, with wow and flutter in the real world, the instantaneous frequency would vary constantly around some mean value (not necessary to be 3150 Hz). In other words, there are back-and-forth frequency deviations from that mean value over time.

Drift refers to frequency modulation of the signal in the range below approximately 0.5 Hz resulting in distortion which may be perceived as a slow changing of the average pitch.

Wow refers to frequency modulation of the signal in the range of approximately 0.5 Hz to 6 Hz resulting in distortion which may be perceived as a fluctuation of pitch of a tone or program.

Flutter refers to frequency modulation of the signal in the range of approximately 6 Hz to 100 Hz resulting in distortion which may be perceived as a roughening of the sound quality of a tone or program.

Scrape Flutter refers to frequency modulation of the signal in the range above approximately 100 Hz, which is caused by stick-slip motion (stiction) of the tape. It results in distortion which may be perceived as a noise added to the signal – that is, a noise not present in the absence of a signal. It is also called “friction noise” or “stiction noise”.

Different standards exist for wow and flutter measurement, such as CCIR, DIN, NAB and JIS. AES6-2008 (r2012) is followed here. It is compatible with IEC 60386, IEEE Std-193, CCIR 409-2, and DIN 45507. The standard test frequency is 3150 Hz. Other test frequencies such as 3000 Hz can also be used.

Wow and flutter in analog domain has its counterpart in digital recording and reproduction, that is, the variation in sampling clock timing, often referred to as jitter. The measurement of clock jitter will be described in another article.

3. Wow and Flutter Frequency Weighting

During wow and flutter measurements, the acquired signal is demodulated first to obtain the instantaneous frequency deviation from the average frequency. The instantaneous frequency deviation, as a function of time, is then weighted according to the subjective perception of human ears. Psychoacoustic researches have shown that the perception of wow and flutter varies with the modulating frequency. The weighting curve is shown as follows. It can be seen that the weighted wow & flutter mainly accounts for modulating frequencies in the range of 0.2 Hz ~200Hz, with the highest weighting factor at 4 Hz to which the human ears are most sensitive. In other words, the “Drift” and “Scrape Flutter” are greatly suppressed by the weighting factor, leaving only the “Wow and Flutter” prominent. An unweighted option is also provided in the software. In order to measure accurately the 0.2 Hz modulating frequency, a sampling duration of at least 5 seconds is required.

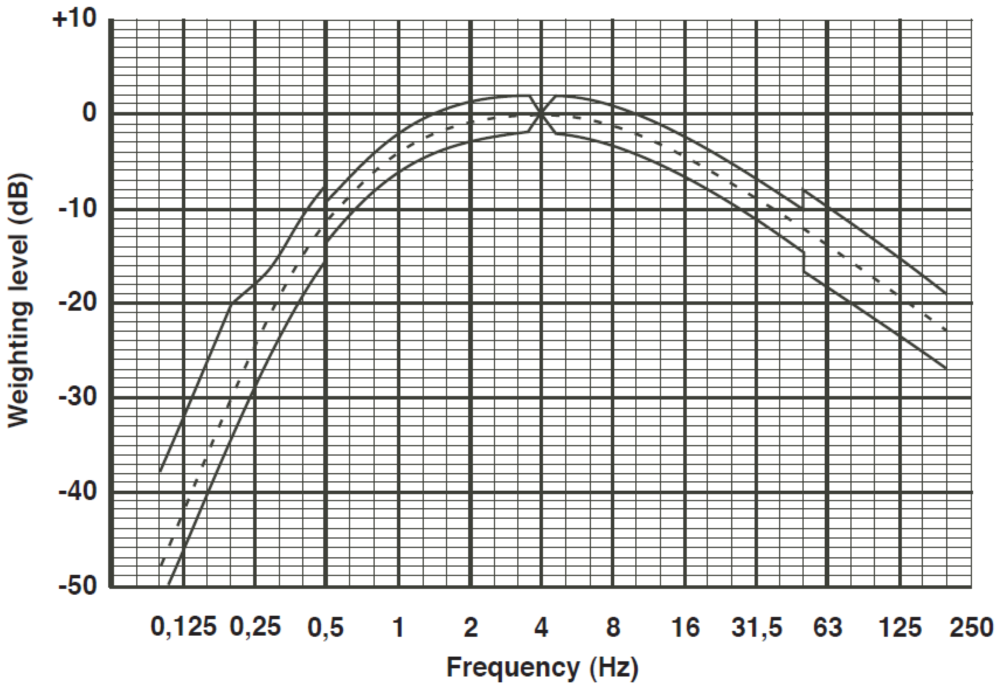

Fig. 1 Modulating Frequency Weighting Curve

4. How is Wow and Flutter Expressed?

Wow and flutter (W&F) is often expressed in terms of peak or RMS value of the frequency deviation. The former is adopted in AES6-2008(r2012) while the latter is used in JIS. Both are measured in Multi-Instrument. The peak wow and flutter value here is not the maximum value in its conventional context. It is a peak value determined through a so-called “2-Sigma” statistical method as shown below. In this method, the cumulative time for which the instantaneous frequency deviations exceed the peak wow and flutter in the positive or negative direction is equal to 5% of the total time.

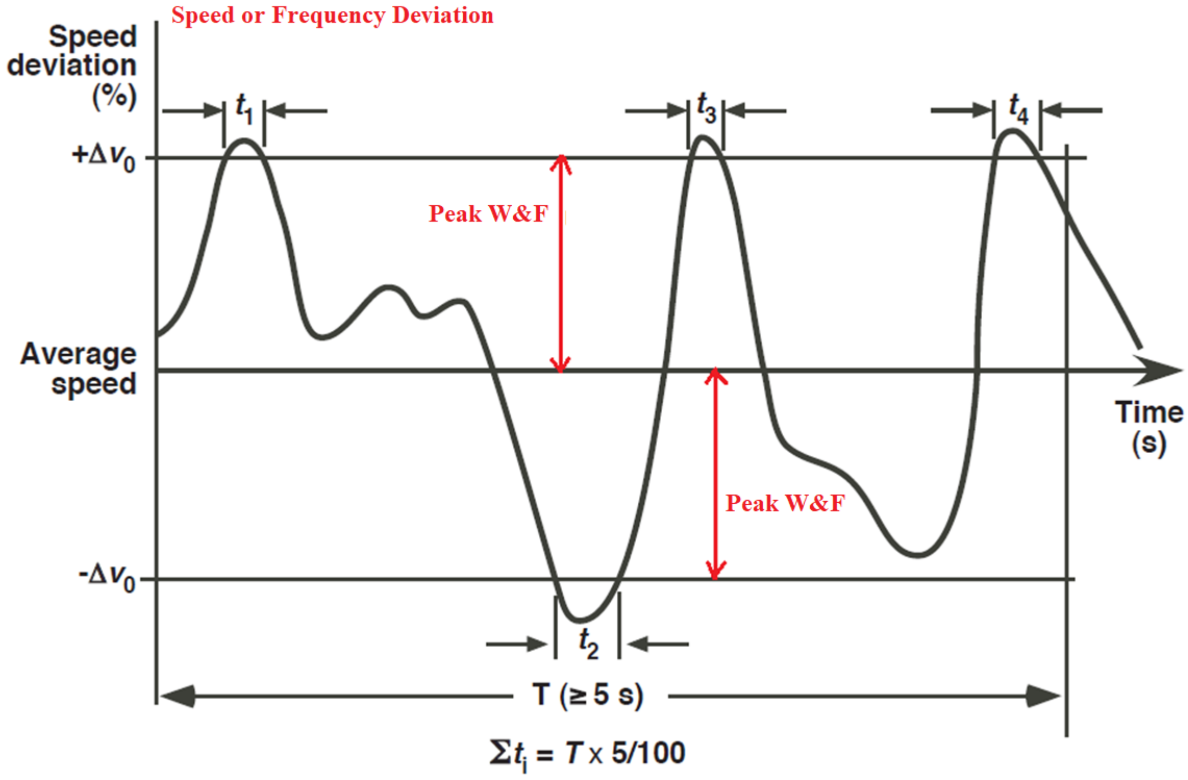

Fig. 2 Example of 2-Sigma calculation method

This method is recommended by AES. If the frequency deviation follows a Gaussian distribution with a mean μ and a standard deviation σ, then the probabilities of its values falling within [μ-σ]~[μ+σ] and [μ-2σ]~[μ+2σ] are about 68% and 95% respectively, as illustrated in the following figure. This is why the method is called "2- Sigma".

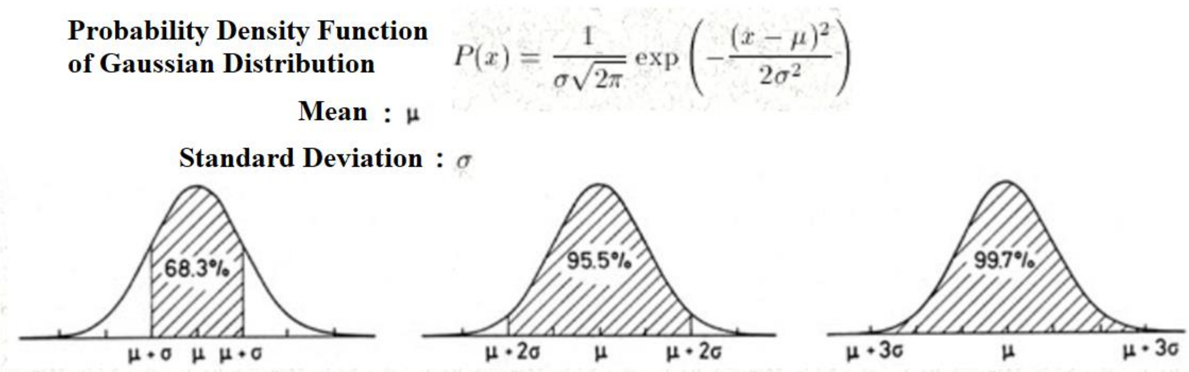

Fig. 3 The area contained between the limits μ±σ, μ±2σ, μ±3σ in a Gaussian distribution

Multi-Instrument provides the following drift, wow and flutter readings:

1. Peak and RMS Wow and Flutter, 0*~400Hz (weighted), 0*~0.4×[Test Frequency] Hz (unweighted)
2. RMS Wow, 0.5~6Hz (weighted and unweighted)
3. RMS Flutter, 6~400Hz (weighted), 6~0.4×[Test Frequency] Hz (unweighted)

4. RMS Drift, 0.05*~0.5 Hz (unweighted always)

*The lowest frequency is equal to 1/[Sampling Duration]. For example, if the [Sampling Duration] is 10 seconds, then the lowest frequency measurable is 0.1 Hz.

5. Measuring Method

Normally, recording devices and reproducing devices are measured separately. When a reproducing device is under test, the wow and flutter of the recording device must be much better than that of the reproducing device so that its residual can be ignored. For example, when measuring a turntable, the wow and flutter of the test signal on the vinyl record must be kept negligibly small. On the contrary, when a recording device is under test, the wow and flutter of the reproducing device must be much better than that of the recording device.

When replaying the 3150 Hz test signal from a vinyl record or tape on a reproducing system, under ideal conditions without any wow and flutter, the measured signal should be a constant 3150 Hz signal, as shown as follows. The measured unweighted peak wow and flutter is 0.000%.

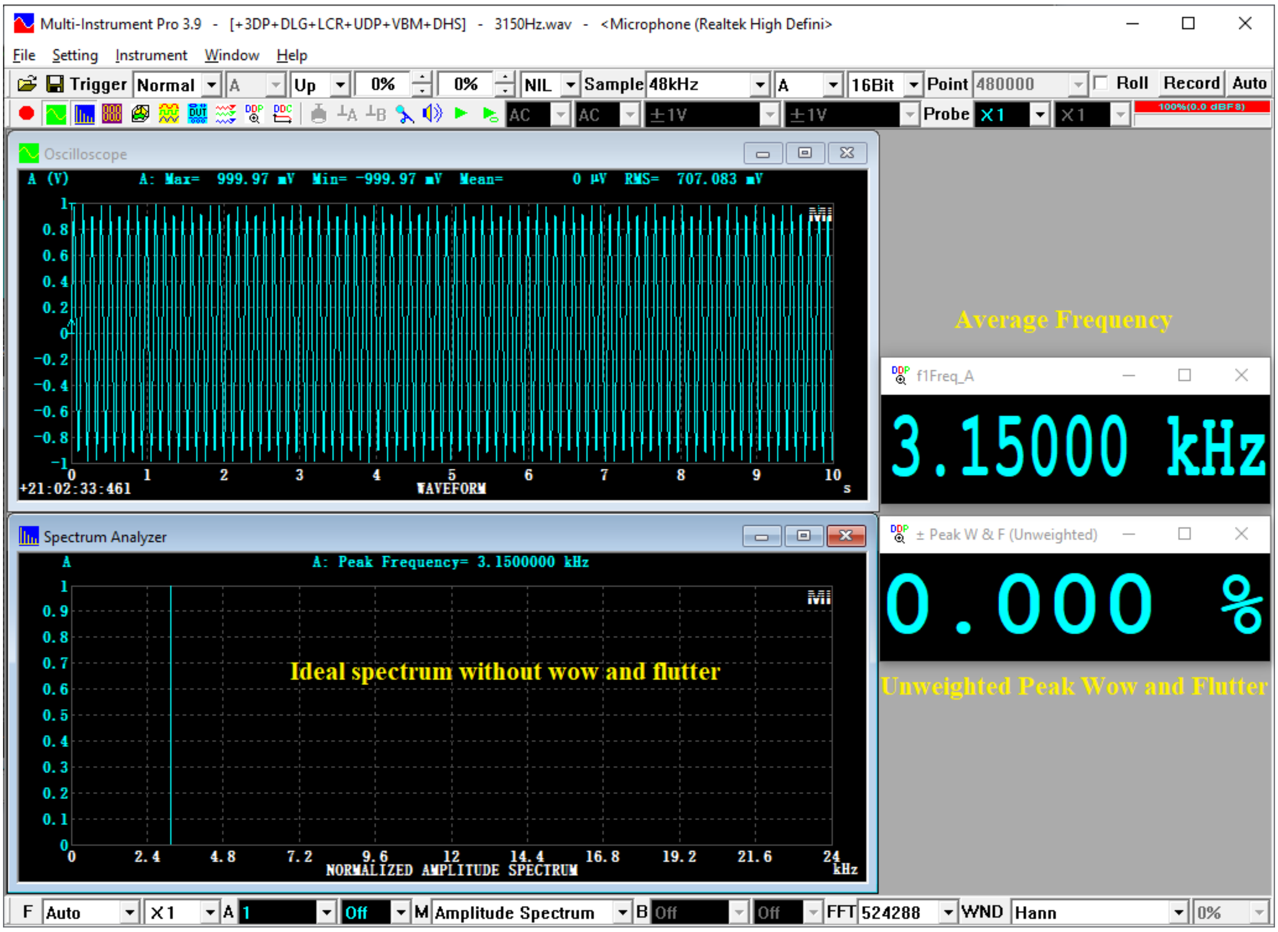

Fig. 4 Spectrum and unweighted peak wow & flutter of an ideal 3150 kHz signal

In the real world, due to the wow and flutter of the device under test, the measured signal would be a FM signal with a carrier frequency around 3150 Hz. The following figure shows a 3150 Hz test signal from a turntable. The measured unweighted peak wow and flutter is 0.495%. Note that the measured average frequency is 3129 Hz, which deviates from 3150 Hz. This average frequency deviation can be removed by adjusting the average speed of the motor and is not accounted for in the wow and flutter measurements.

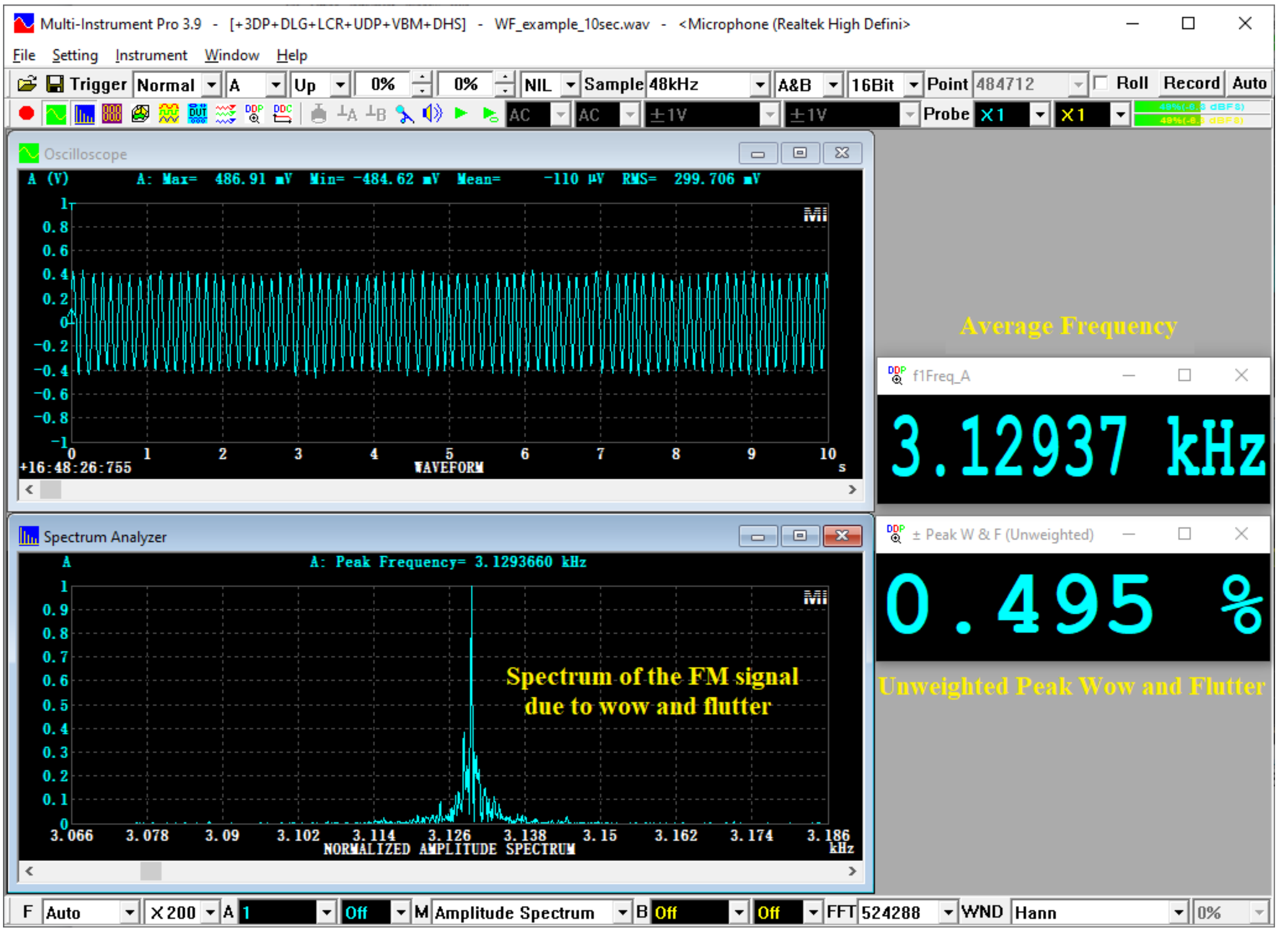

Fig. 5 Spectrum and unweighted peak wow & flutter of a 3150 kHz signal from a turntable

In Multi-Instrument, to measure the wow and flutter, set the Oscilloscope frame width (a.k.a. record length or sweep time) to be at least 5 seconds (10~60 seconds is recommended). Right click the Spectrum Analyser window, select [Spectrum Analyzer Processing] and tick "Wow and Flutter" (see Fig. 6). By default, the measured results are weighted. If the "Unweighted" option is ticked, then the results will be unweighted. FFT size is recommended to be equal to or greater than the record length. A window functions such as Hann, Kaiser 6~20, Blackmann Harris 7 is recommended. This two parameters will only affect the measurement of the average frequency used as the denominator in the wow and flutter percentage calculation. If the Multimeter window is opened and set to frequency counter mode, then the counted frequency instead of the peak frequency measured in the Spectrum Analyzer will be used. The reason for this arrangement will be explained later. DDP Viewers can be used to display the measured results: WowAndFlutter, WowAndFlutterRMS, WowRMS, FlutterRMS, DriftRMS. Of course, the simplest way is to load the preconfigured wow and flutter measurement panel setting file and start measuring directly without any hassle.

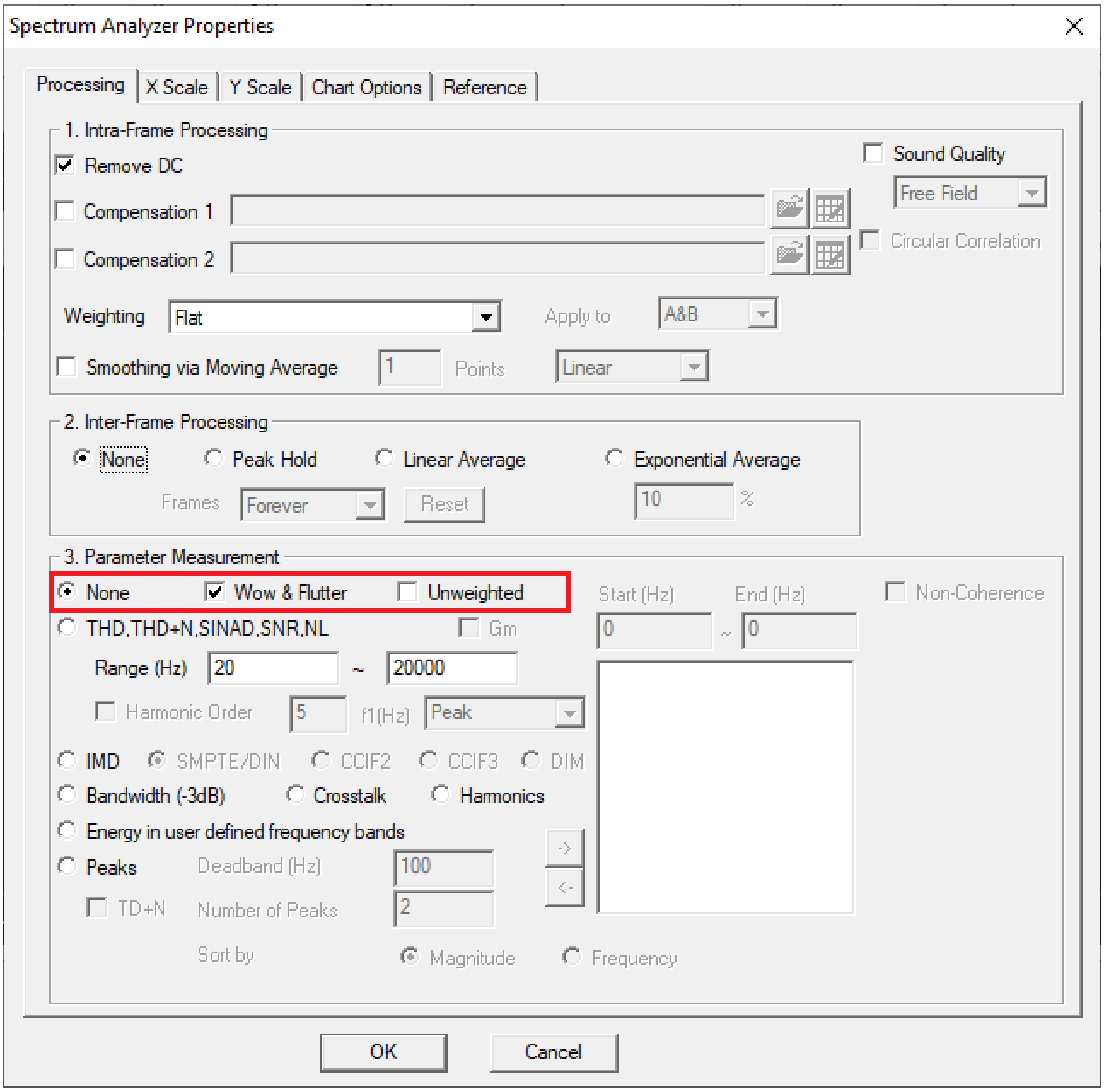

Fig. 6 Wow and Flutter Measurement Settings

The signals displayed in the Oscilloscope in Figs. 4 and 5 are the original FM signals, which must be used for the above automated wow and flutter measurements. It is also possible to manually demodulate the FM signal and show the demodulated wow and flutter waveform in the Oscilloscope. However, in this case the above automated wow and flutter measurement will give wrong readings and thus the option in Fig. 6 should be disabled.

The following figure shows the FM demodulated signal in Fig.5. It represents the frequency deviation (%) vs time. It can be obtained by right clicking the Oscilloscope window, selecting [Oscilloscope Processing] and then setting the signal processing flow in the Oscilloscope as follows:

Step 1: 312.9 Hz ~ 5945 Hz band pass filter. This is to band limit the FM signal, but it should allow the highest possible frequency deviation to pass through.

Step 2: FM demodulation. Carrier frequency is set to the actually measured 3129 Hz. FM sensitivity is intentionally set to 3129 Hz/V so that a frequency deviation of 3129 Hz (100% wow and flutter) corresponds to 1 V, or a frequency deviation of 1 Hz (0.032% wow and flutter) corresponds to 0.00032 V.

Step 3: Remove DC in the demodulated signal and then apply a 1565 Hz low pass filter. The cutoff frequency should be at least less than ½ of the measured test frequency while allowing the highest demodulated flutter frequency to pass through.

From the demodulated signal in the following figure, the unweighted peak wow and flutter can also be estimated to be around 0.495%.

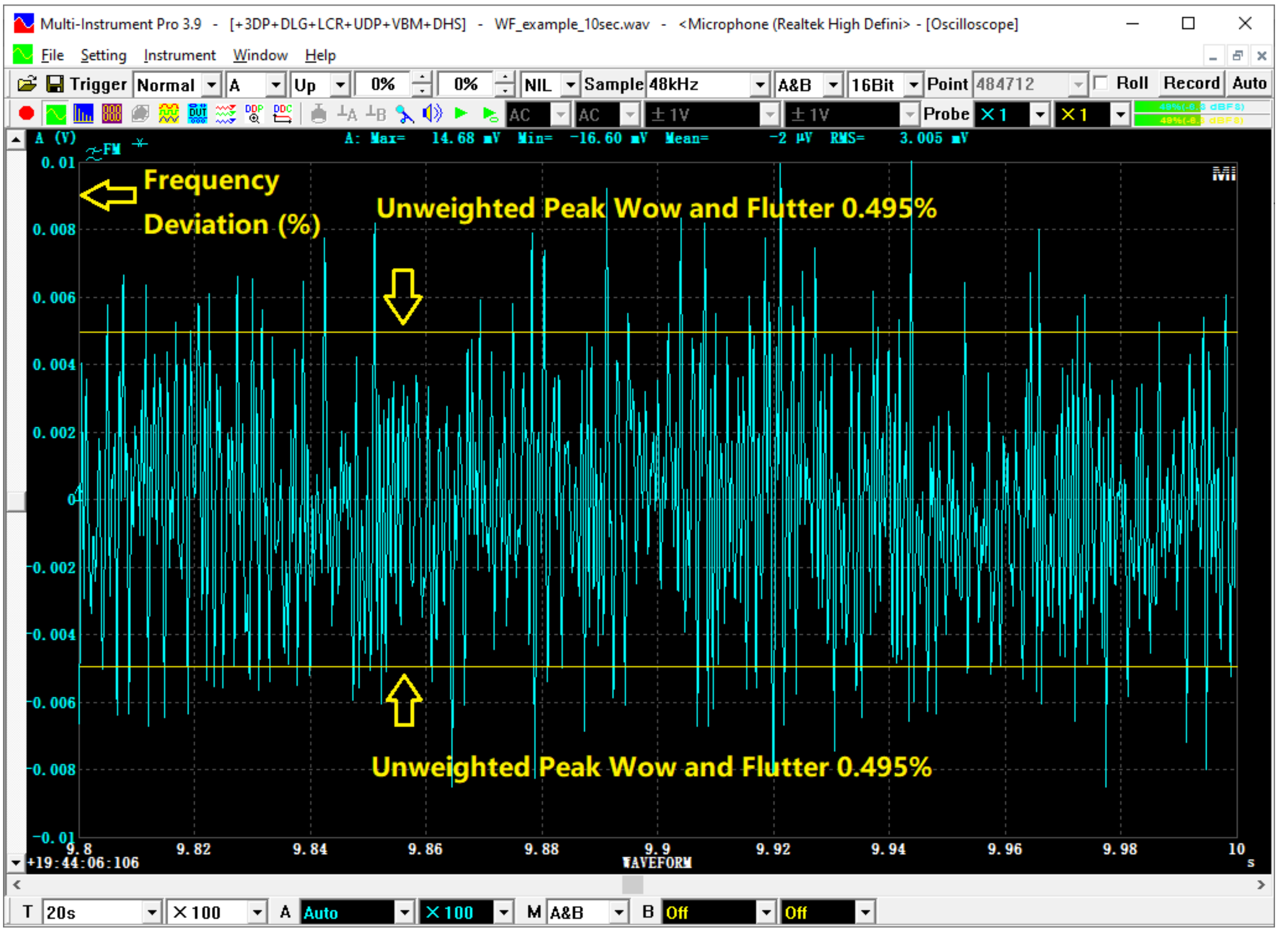

Fig. 7 Frequency deviation vs time of a measured 3150 kHz signal from a turntable

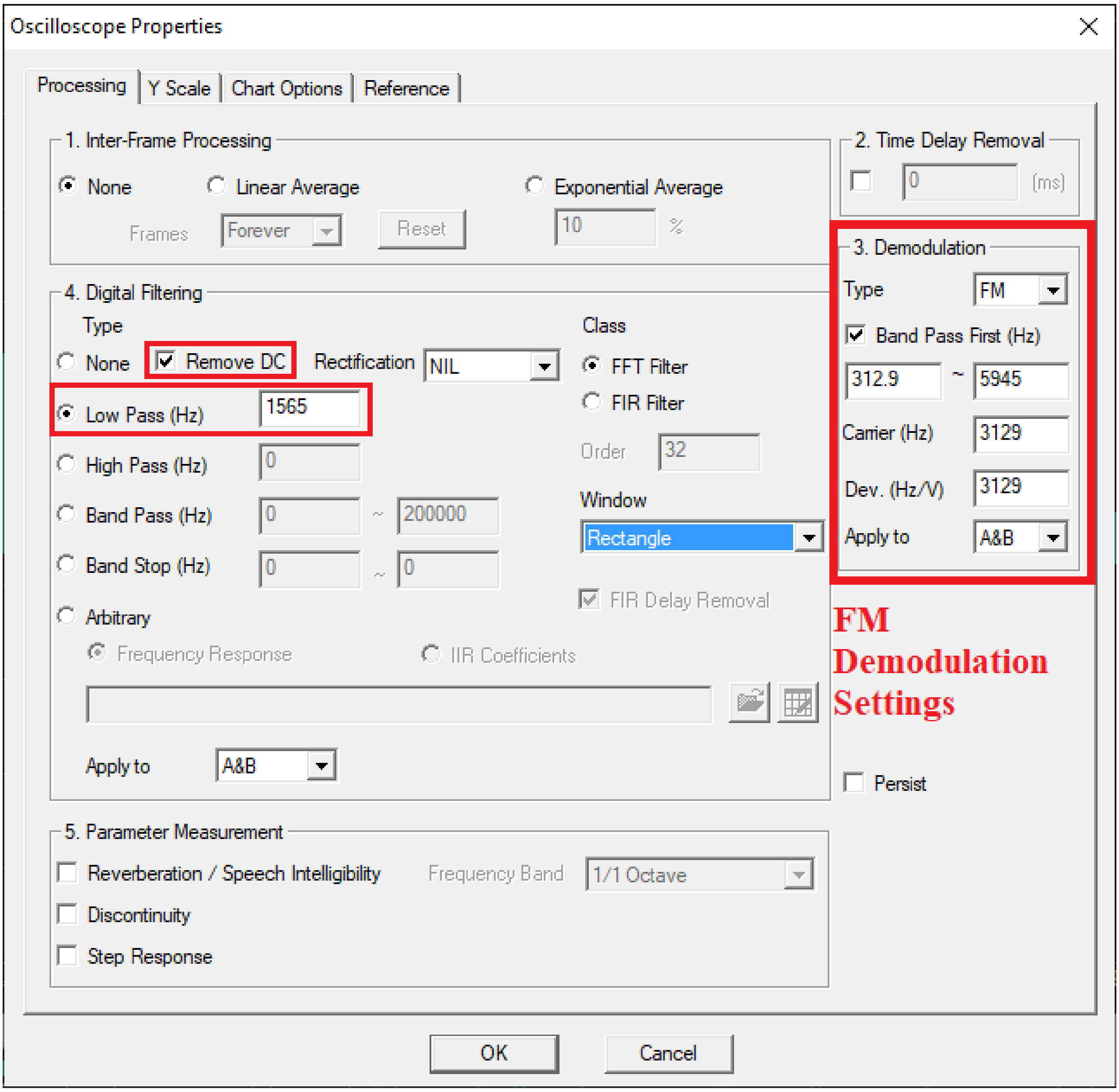

Fig. 8 FM demodulation settings to get the demodulated wow and flutter waveform

6. Measuring Hardware

Conventional analog wow and flutter meter is expensive and bulky. With an ordinary inexpensive ADC hardware such as a sound card, wow and flutter can be accurately measured through software using digital signal processing algorithm. The measurement accuracy, to a great extent, depends on the degree of jittering of the sampling clock and noises. The following figure shows the unweighted residual wow and flutter of a Focusrite Scarlett Solo sound card measured through a loopback test.

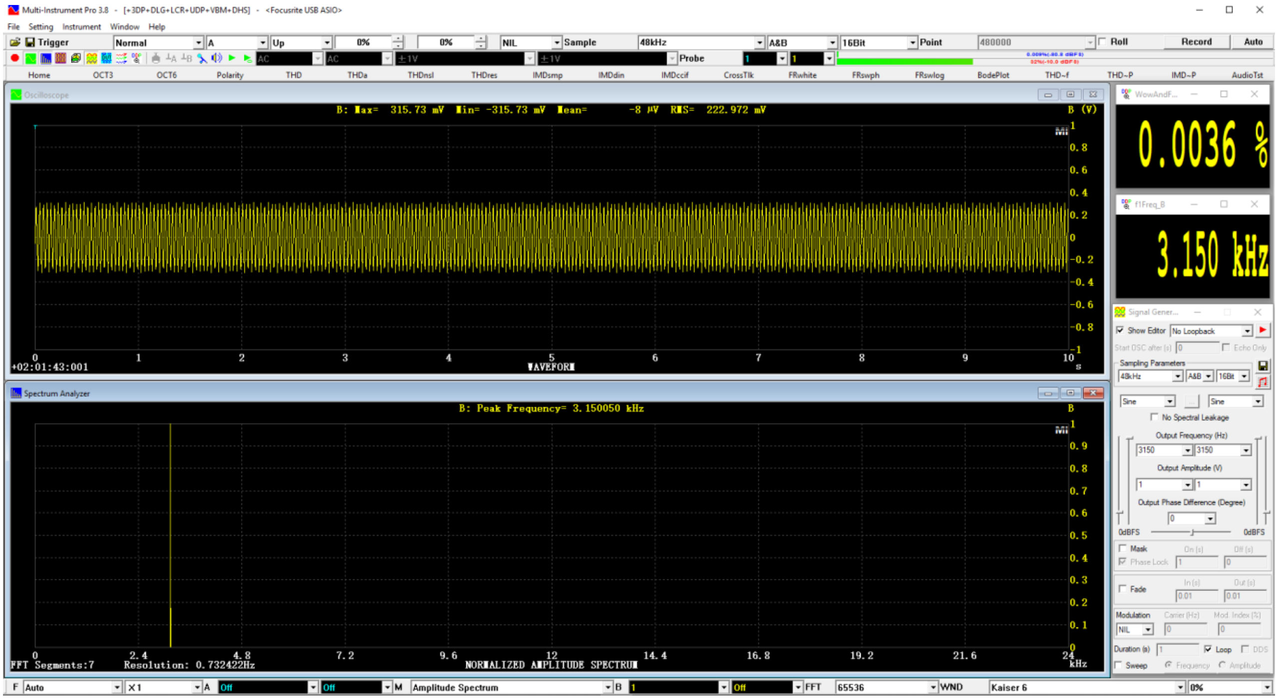

Fig. 9 Unweighted residual peak wow and flutter of a Focusrite Scarlett Solo sound card measured through a loopback test

The following figure shows the unweighted residual wow and flutter of a M-Audio Mobile Pre sound card measured through a loopback test.

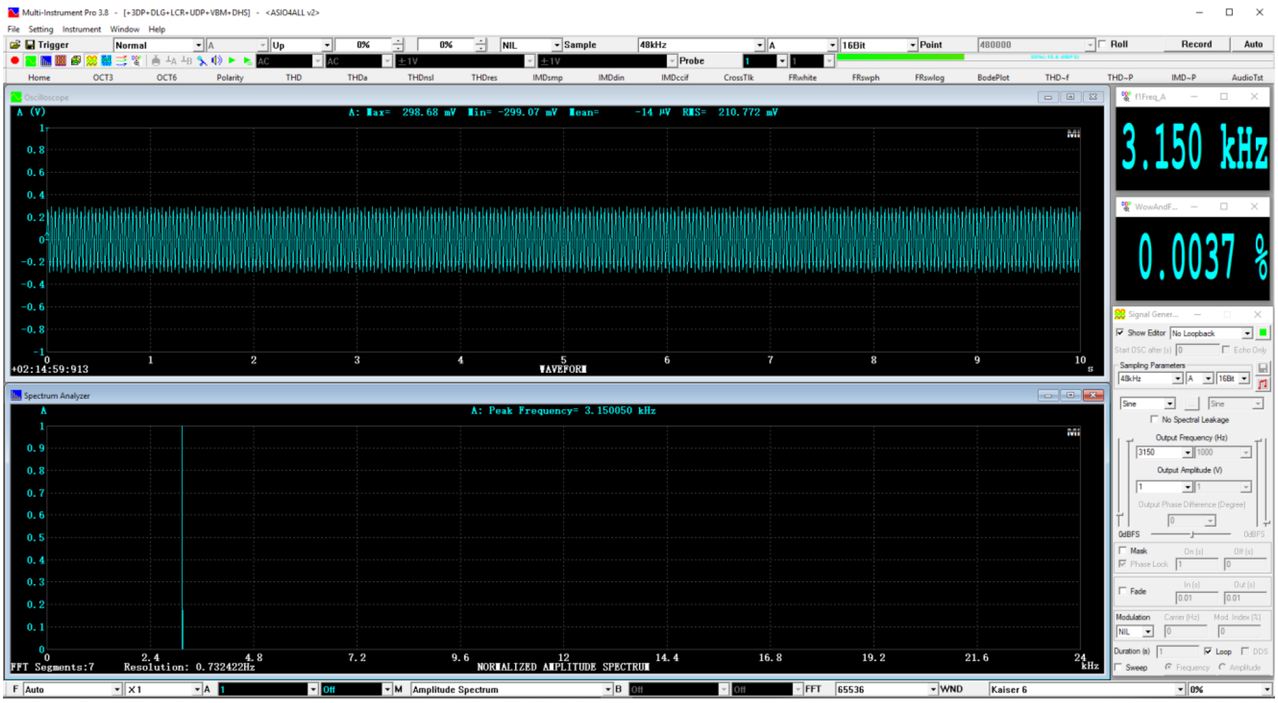

Fig. 10 Unweighted residual peak wow and flutter of a M-Audio Mobile Pre sound card measured through a loopback test

It can be argued that in the above loopback tests, the jitter of the ADC and DAC sampling clocks correlated as they were from the same sound card. The following figure used the M-Audio Mobile Pre as the ADC and Focusrite Scarlett Solo as the DAC and measured the combined unweighted residual peak wow and flutter through a loopback test.

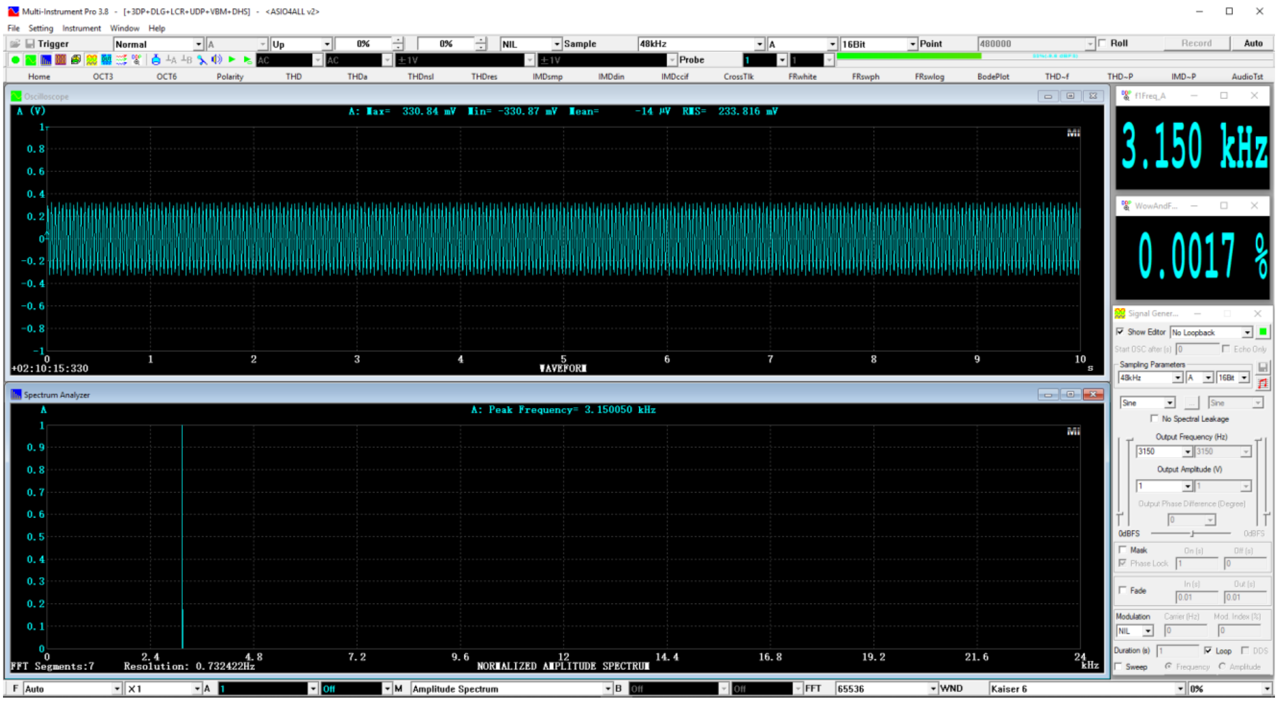

Fig. 11 Combined unweighted residual peak wow and flutter of a Focusrite Scarlett Solo sound card (DAC) and M-Audio Mobile Pre sound card (ADC) measured through a loopback test

The wow and flutter of an ordinary turntable would be in the order of 0.x%, or 0.0x% for the best ones. It can be inferred from the above loopback test results (0.0036%, 0.0037%, 0.0017%) that a sound card would be sufficient to measure the wow and flutter of a turntable.

The most convenient and cost-effective measuring hardware would be sound cards. If the turntable under test has line outputs, they can be connected directly to the line inputs of a sound card, or the mic inputs after attenuation. If the turntable has phono outputs only, then a phono preamp should be inserted between the turntable and sound card. Some sound cards such as USB Phono Plus and Audio Genie II accept phono inputs. They can be connected to the phono outputs of a turntable directly.

A vinyl recording is made with the low frequencies reduced and the high frequencies boosted in order to limit the excursions the cutter needs to make when cutting a groove in order to increase the recording density as well as SNR at high frequencies. On playback the opposite occurs to obtain an overall flat frequency response. The recording and playback frequency responses are called RIAA equalization curves, as shown below.

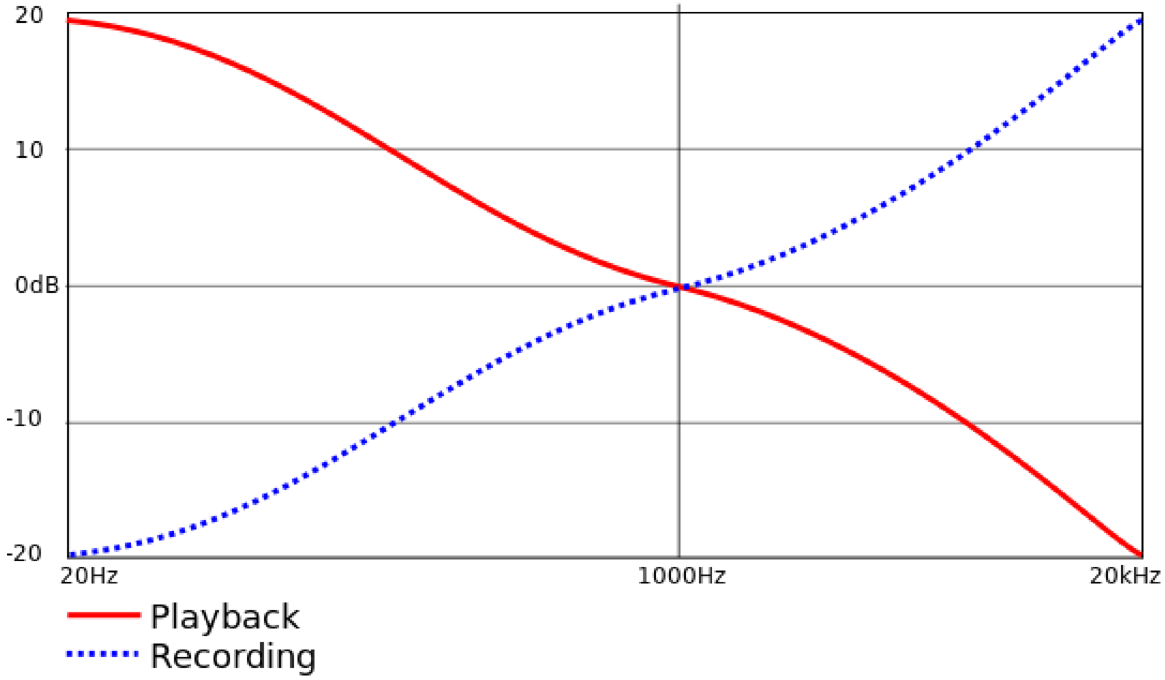

Fig. 12 RIAA equalization curves

7. FM Demodulation Algorithm

To measure wow and flutter, the instantaneous frequency deviation needs to be obtained first through FM demodulation. The frequency deviation is then weighted according to Fig. 1. Finally the peak wow and flutter is found through the aforementioned 2-Sigma method as shown in Fig. 2.

There are a few digital FM demodulation methods. Here we use quadrature demodulation. Assuming I(t) is the original signal and Q(t) is its Hilbert transform. Then we can construct a complex analytical signal I + jQ. The instantaneous amplitude, frequency and phase can then be derived as follows:

$$Instantaneous\ Amplitude = \sqrt{I^2 + Q^2}$$

$$Instantaneous\ Phase = \arctan\left(\frac{Q}{I}\right)$$

$$Instantaneous\ Angular\ Frequency = \frac{\mathrm{d}\left(\arctan\left(\frac{Q}{I}\right)\right)}{dt} = \frac{1}{\left(1+\left(\frac{Q}{I}\right)^2\right)} \times \frac{d\left(\frac{Q}{I}\right)}{dt}$$

$$= \frac{1}{\left(1+\left(\frac{Q}{I}\right)^2\right)} \times \left(\frac{1}{I} \times \frac{dQ}{dt} - \frac{Q}{I^2} \times \frac{dI}{dt}\right) = \frac{I\times\frac{dQ}{dt} - Q\times\frac{dI}{dt}}{I^2+Q^2}$$

AM, FM or PM demodulation can be performed based on the above formulae. For wow and flutter measurement, FM demodulation is required. For discrete-time signals, we need to change differentials to differences in the above instantaneous angular frequency formula. The differencing operation is very sensitive to high frequency noise, therefore band limiting must be performed first. Once the instantaneous frequency is obtained, the instantaneous frequency deviation can be calculated by subtracting the measured average frequency.

Discrete Hilbert transform can be implemented in time domain (approximated by a Hilbert FIR filter). It can also be done in frequency domain using FFT. The latter is simpler. Our objective here is not to get the Hilbert transform Q(n) from I(n), but the entire complex analytical sequence I(n) + jQ(n). The steps are as follows. First, we perform FFT on I(n). The coefficients of the positive frequencies are multiplied by 2 in order to retain the original signal amplitude, while those of the negative frequencies are set to zero. The coefficients for DC and Nyquist frequency should be kept intact. Then we perform IFFT to obtain the complex analytical signal.

The following figure shows the conjugate symmetry of the FFT results of a real number sequence I (n).

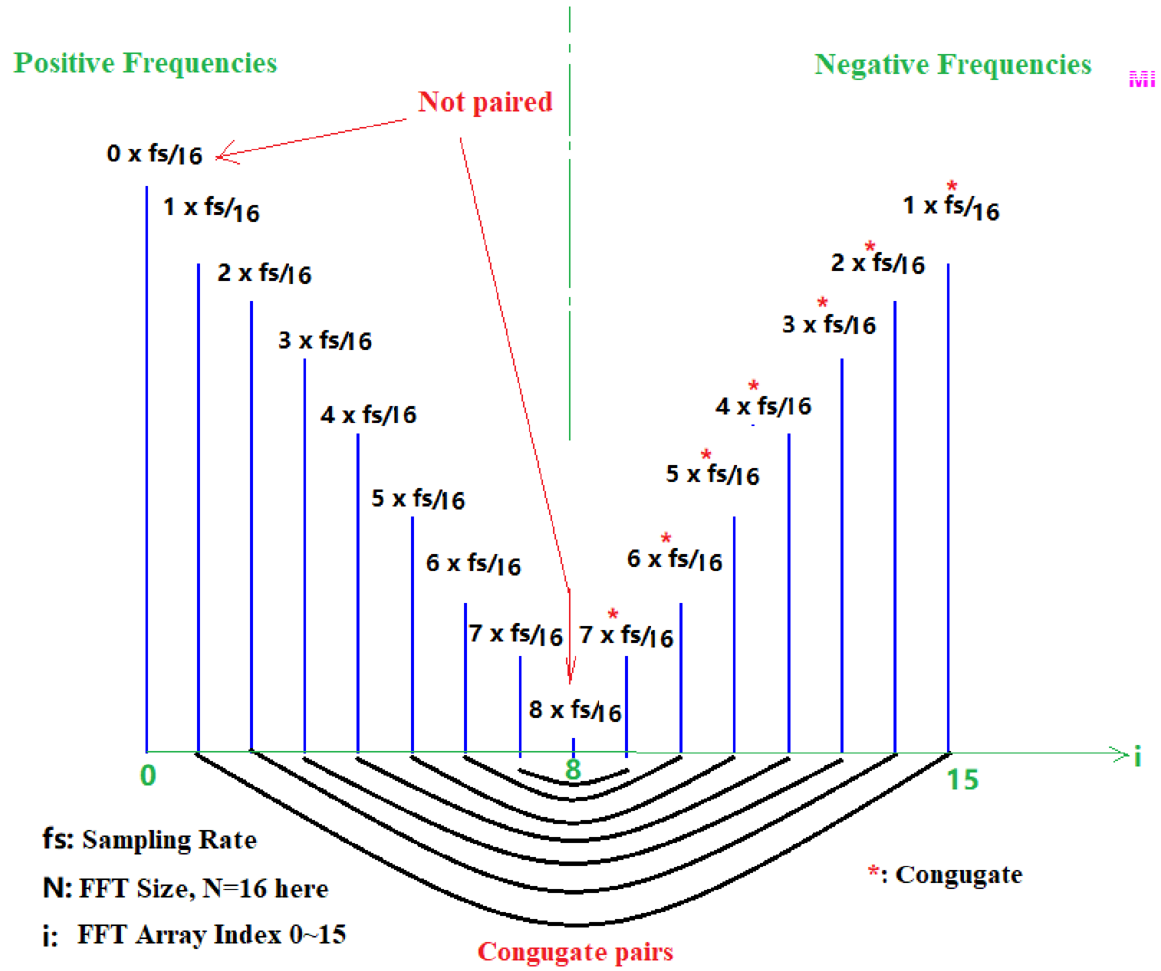

Fig. 13 FFT results of Real Number Sequence I (n)

The following figure shows the single-sided spectrum of the complex analytic signal constructed from the real number sequence I(n). It can be seen that the spectrum of an analytic signal does not have negative frequency components.

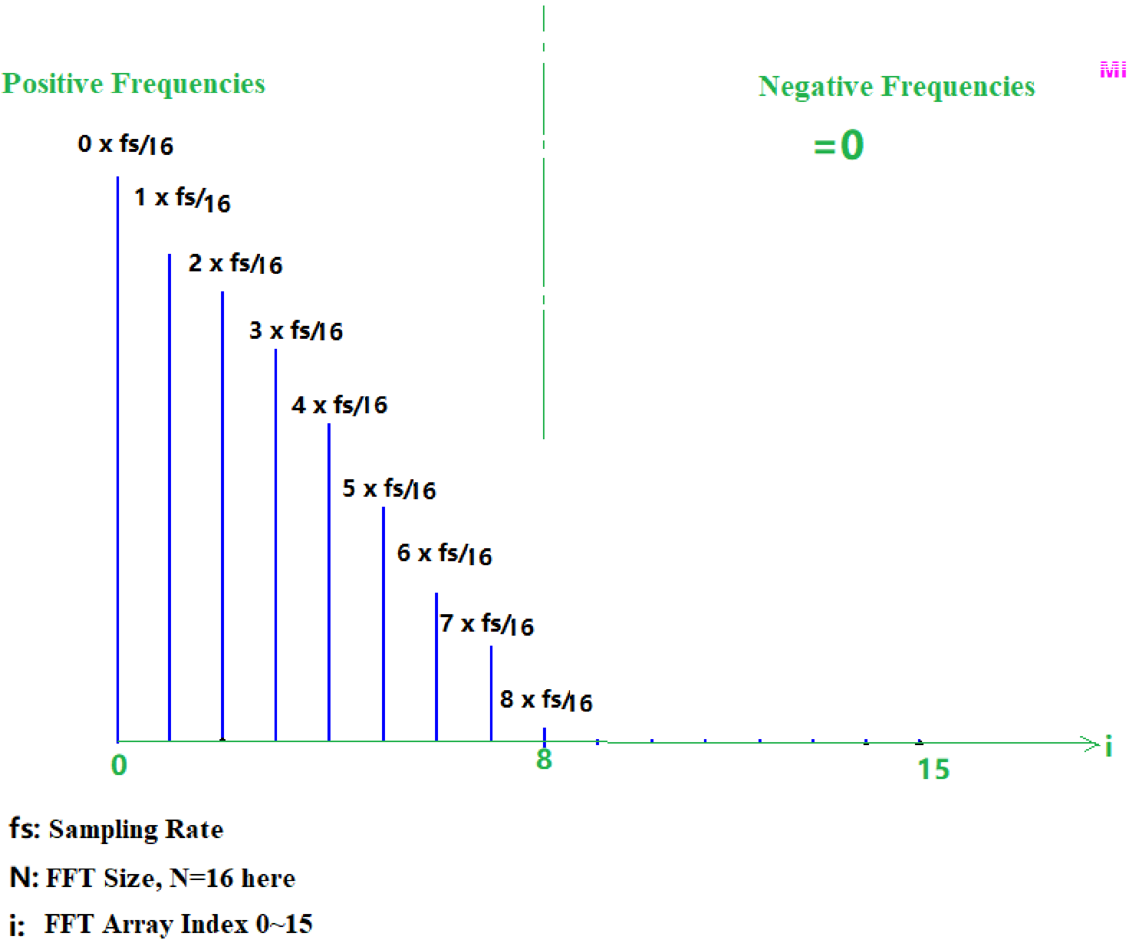

Fig. 14 Spectrum of Analytic Signal I + jQ, where Q is the Hilbert transform of I

The following figure shows a FM modulation and demodulation example. A FM signal with a carrier frequency 10 kHz, maximum frequency deviation 3 kHz, modulating frequency 1 kHz and amplitude 0.5V is generated from the signal generator and fed into both channels of the Oscilloscope through software loopback (iA=oA, iB=oB), as shown in Fig. 17. The following FM demodulating settings (see Fig. 16) are set in the Oscilloscope processing properties: carrier frequency 10 kHz, FM modulating sensitivity 6000 Hz/V (i.e. 6000 Hz frequency deviation corresponds to 1V, 3000 Hz frequency deviation corresponds to 0.5V). The demodulation is performed on Ch. A (cyan) only while Ch. B (yellow) displays the original FM signal for comparison. Their spectra are displayed in the Spectrum Analyzer (see Fig. 15).

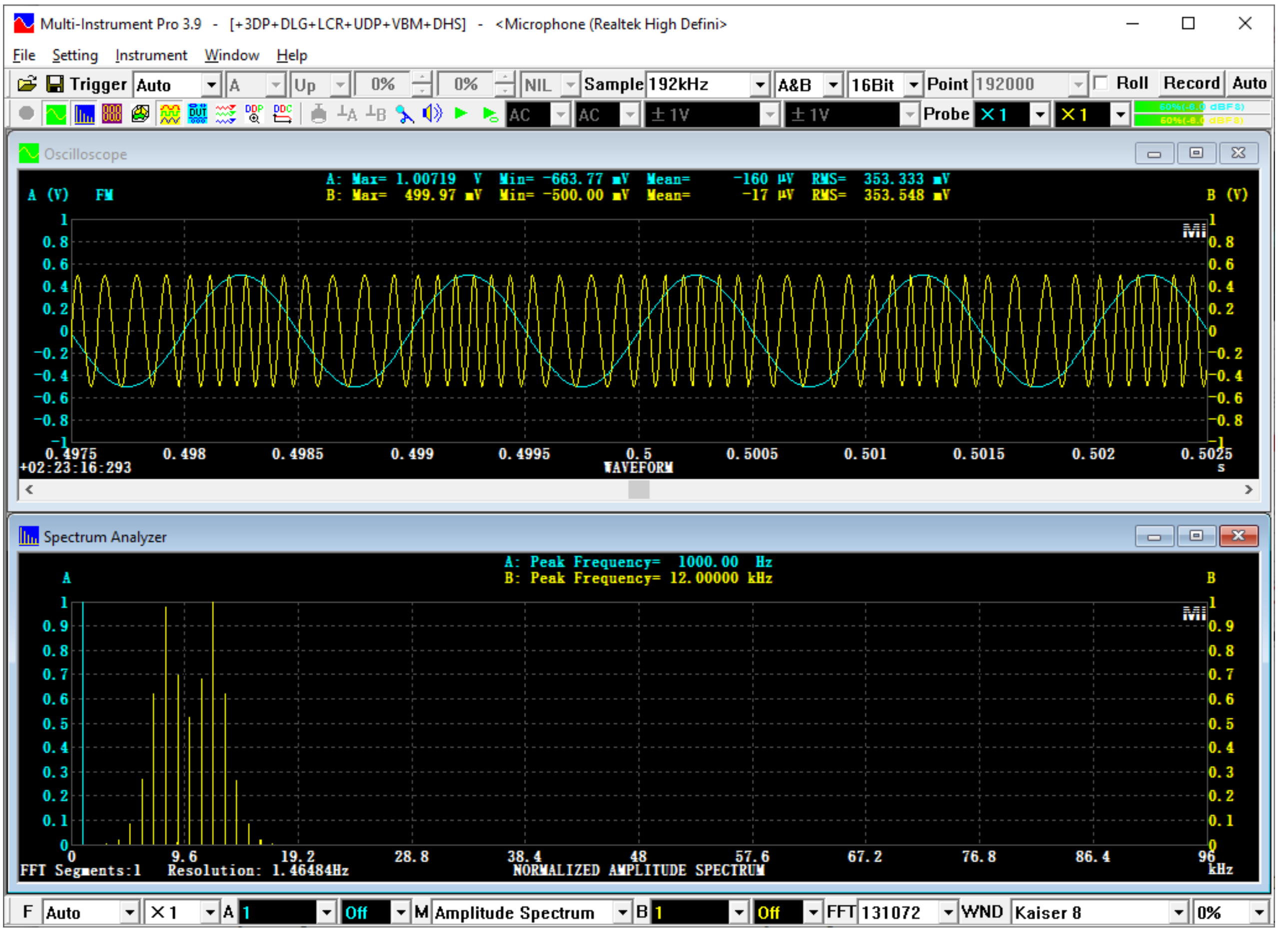

Fig. 15 Comparison between a FM signal and its demodulated counterpart

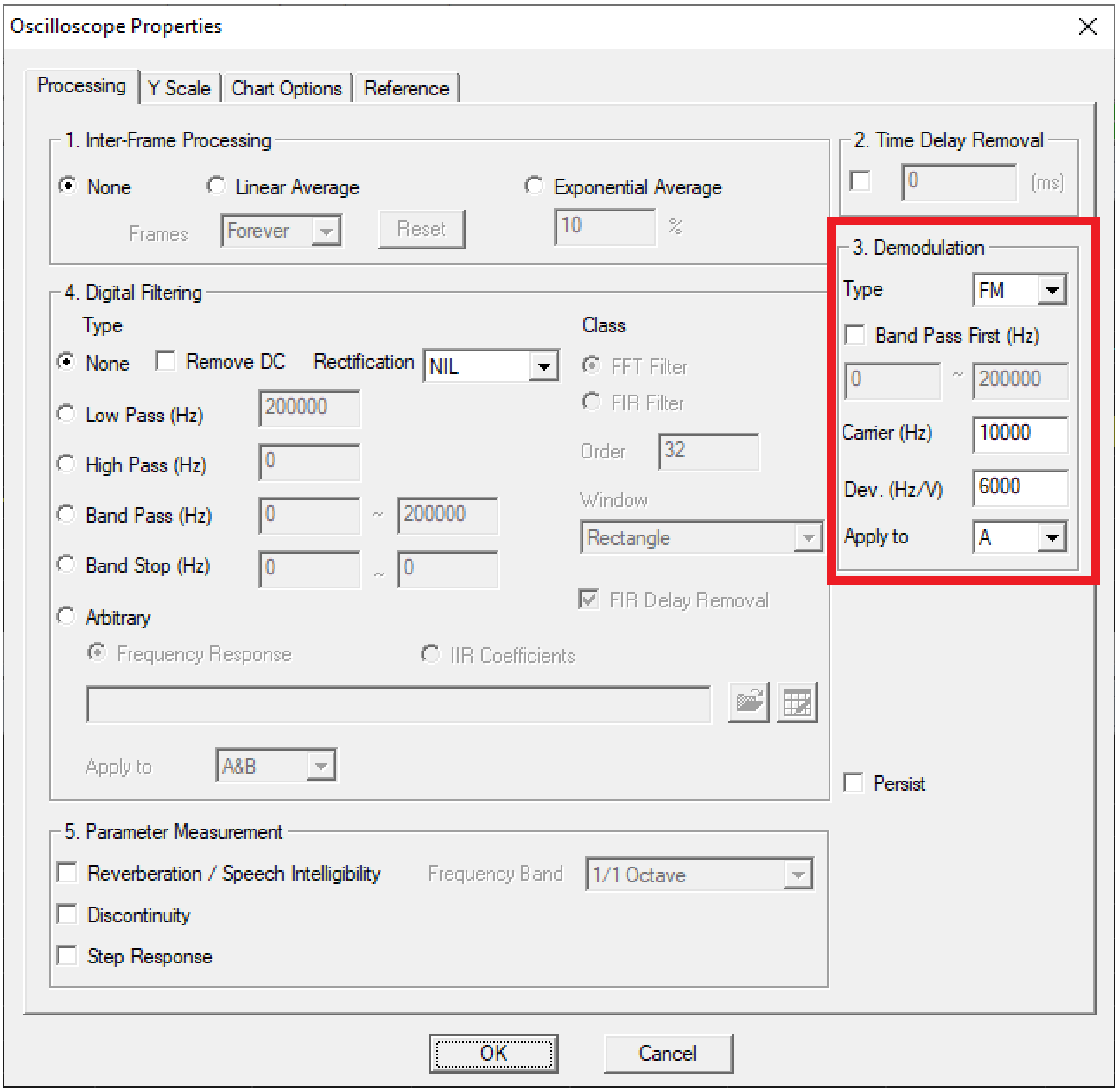

Fig. 16 FM Demodulation Settings

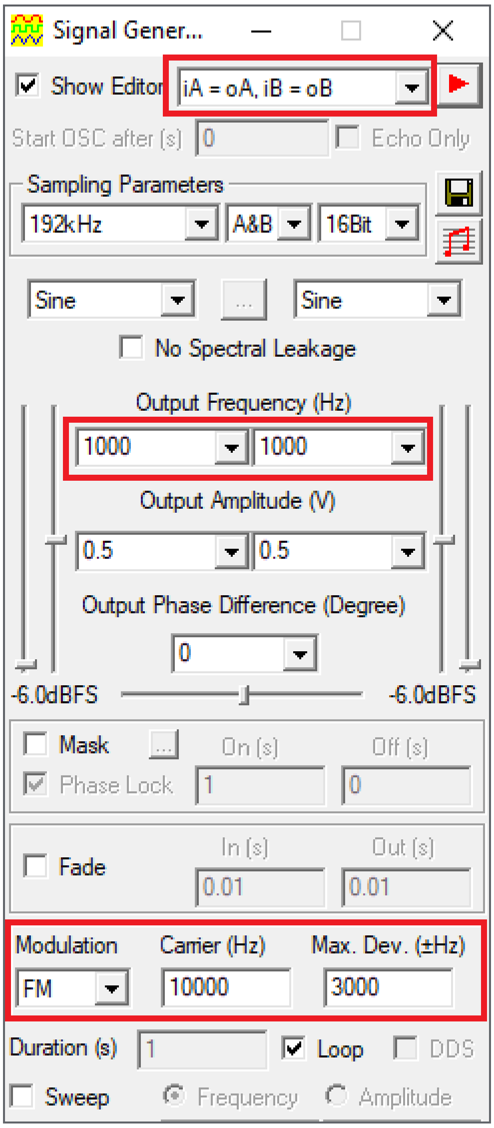

Fig. 17 FM Signal Generation Settings

8. Methods to Get Average Frequency of Test Signal

The average frequency of the un-demodulated test signal is used to derive the instantaneous frequency deviation after the instantaneous frequency is obtained. It is also used to normalize the detected peak frequency deviation to a percentage. Its former effect is effectively removed through a DC removal process after demodulation, leaving only the relative instantaneous frequency fluctuations. Therefore the measured average frequency will only affect the normalization operation in the last step.

There are two methods to get the average frequency of the un-demodulated signal in Multi-Instrument. One is to use the peak frequency detected in the Spectrum Analyzer. The other is to use the counted frequency in the Multimeter. The latter will take precedence if the Multimeter is opened and set to frequency counter mode. A FM signal spans a frequency range and the peak frequency in that range may not be located at the center. This measurement error in the Spectrum Analyzer usually increases with the degree of wow and flutter. Typically, for 1% wow and flutter, the error is less than 1%. Thus, there is generally no need to correct this error. On the other hand, the frequency counted by the frequency counter of the Multimeter reflects the true average frequency. When the wow & flutter is lower than 1%, there is little difference between these two methods.

The figure below show a software generated 3150Hz test tone with a max. frequency deviation of 315 Hz modulated at 4 Hz (i.e. about 10% peak wow and flutter). The peak frequency detected in the Spectrum Analyzer is 3.45 kHz while the frequency measured by the frequency counter is 3.15 kHz. It can be seen from the spectrum that the peak frequency is not located at the center of the frequency band, and this causes a measurement error of 9.5%. The modulating signal in the real world is not a pure sinewave, the eccentric distribution of the spectral energy is much more moderate and thus the measurement error is usually much lower than that.

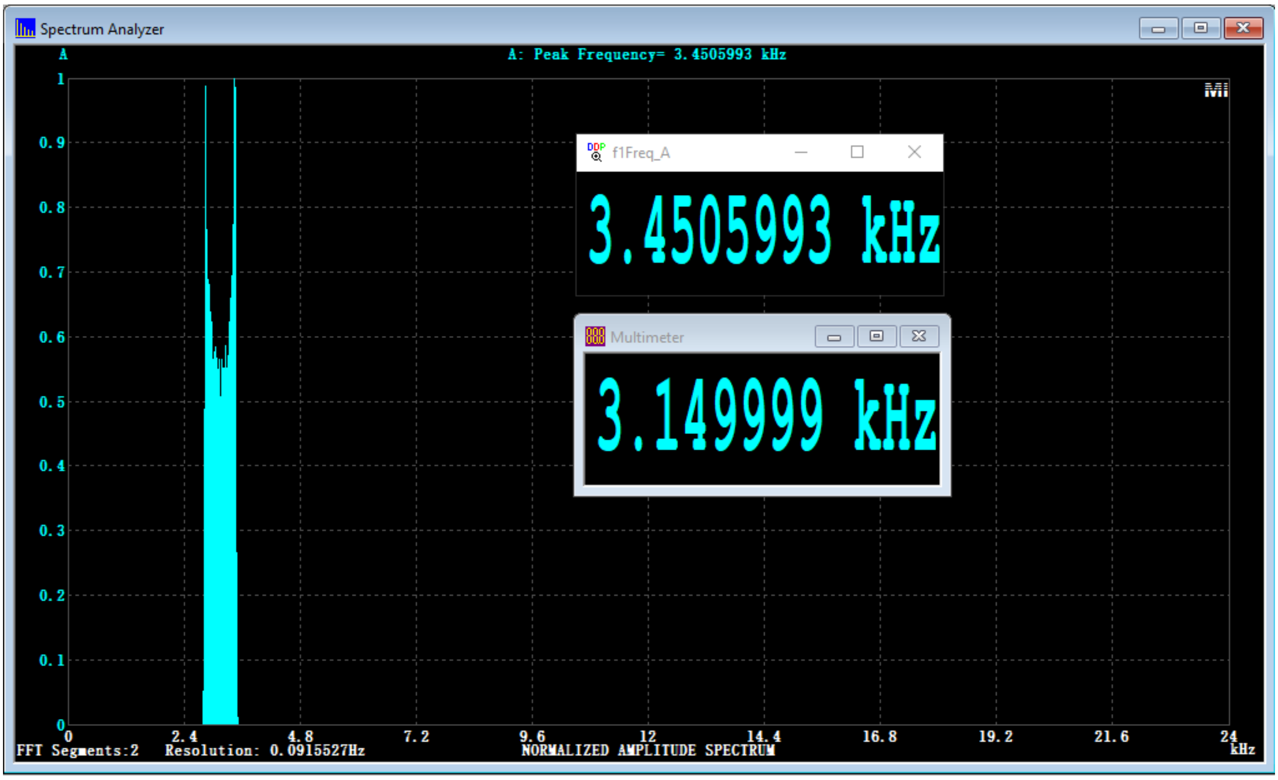

Fig. 18 Comparison between the peak frequency in Spectrum Analyzer and the counted frequency in Multimeter (Max. frequency deviation 315 Hz, modulated at 4 Hz, FFT resolution 0.092 Hz)

The figure below show a software generated 3150Hz test tone with a max. frequency deviation of 31.5 Hz modulated at 4 Hz (i.e. about 1% peak wow and flutter). The peak frequency detected in the Spectrum Analyzer is 3.13 kHz while the frequency measured by the frequency counter is 3.15 kHz. The measurement error of the former is reduced to 0.6%, which is quite acceptable.

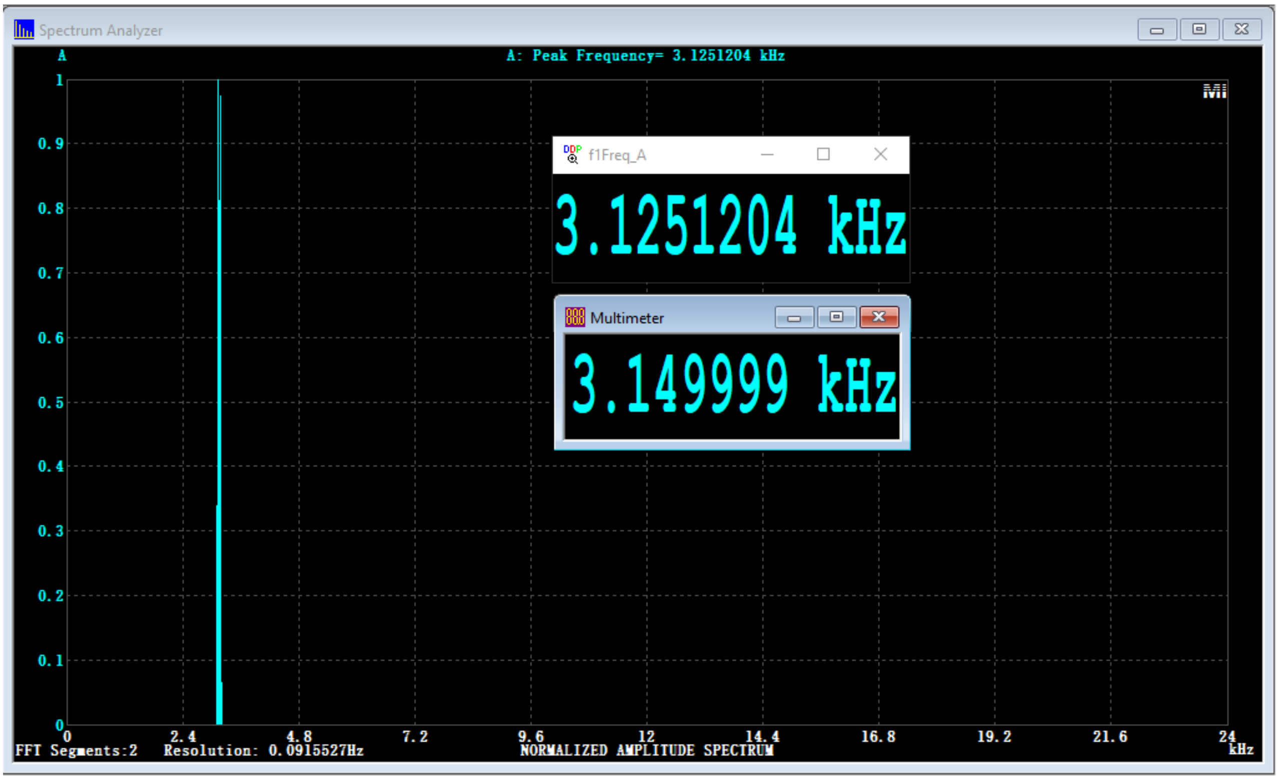

Fig. 19 Comparison between the peak frequency in Spectrum Analyzer and the counted frequency in Multimeter (Max. frequency deviation 31.5 Hz, modulated at 4 Hz, FFT resolution 0.092 Hz)

In conclusion, when the wow and flutter is greater than 1%, it is recommended to open the Multimeter window and set it to the frequency counter mode to get the average frequency accurately. This in turn will help to measure the wow and flutter more accurately. Or to keep things simple, always keep that window open regardless of the wow and flutter magnitude.

9. Verification of Wow and Flutter Measuring Device

There is no calibration factor involved in the above measurement method. To check the accuracy of a wow and flutter measuring device, a test signal with a known wow and flutter value should be used. The most convenient way to generate this test signal is through a sound card. To check the measuring software only, a test wave file can be used. The duration of the test signal has to be at least 5 seconds as the modulating frequency to be measured can be as low as 0.2 Hz. In practice, 10~60 seconds is recommended. The test signals can be generated using the FM signal generation function in Multi-Instrument. The following are a list of 30-second-long test wave files for free download.

1) www.virtins.com/3150Hz.wav

   Carrier frequency 3150 Hz, no frequency modulation, unweighted and weighted peak wow & flutter values are both 0%.

	W&F Peak	W&F RMS	Drift RMS	Wow RMS	Flutter RMS
Theoretical (unweighted)	0.00000%	0.00000%	0.00000%	0.00000%	0.00000%

Measured (unweighted)	0.00010%	0.00006%	0.00000%	0.00000%	0.00006%
Theoretical (weighted)	0.00000%	0.00000%		0.00000%	0.00000%
Measured (weighted)	0.00000%	0.00000%		0.00000%	0.00000%

2) www.virtins.com/3150HzModulatedBy4HzAt0.00997Percent0.315Hz.wav
Carrier frequency 3150 Hz, modulating frequency 4 Hz, max. frequency deviation 0.315 Hz, unweighted and weighted peak wow & flutter values are both: 0.315 / 3150 × sin(0.95×90°) = 0.00997%.

	W&F Peak	W&F RMS	Drift RMS	Wow RMS	Flutter RMS
Theoretical (unweighted)	0.00997%	0.00707%	0.00000%	0.00707%	0.00000%
Measured (unweighted)	0.00994%	0.00707%	0.00002%	0.00707%	0.00013%
Theoretical (weighted)	0.00997%	0.00707%		0.00707%	0.00000%
Measured (weighted)	0.00996%	0.00706%		0.00706%	0.00007%

3) www.virtins.com/3150HzModulatedBy4HzAt0.0997Percent3.15Hz.wav
Carrier frequency 3150 Hz, modulating frequency 4 Hz, max. frequency deviation 3.15 Hz, unweighted and weighed peak wow & flutter values are both: 3.15 / 3150 × sin(0.95×90°) = 0.0997%

	W&F Peak	W&F RMS	Drift RMS	Wow RMS	Flutter RMS
Theoretical (unweighted)	0.0997%	0.0707%	0.0000%	0.0707%	0.0000%
Measured (unweighted)	0.0996%	0.0707%	0.0002%	0.0707%	0.0008%
Theoretical (weighted)	0.0997%	0.0707%		0.0707%	0.0000%
Measured (weighted)	0.0996%	0.0706%		0.0706%	0.0007%

4) www.virtins.com/3150HzModulatedBy4HzAt0.997Percent31.5Hz.wav
Carrier frequency 3150 Hz, modulating frequency 4 Hz, max. frequency deviation 31.5Hz, unweighted and weighted peak wow & flutter values are both: 31.5 / 3150 × sin(0.95×90°) = 0.997%

	W&F Peak	W&F RMS	Drift RMS	Wow RMS	Flutter RMS
Theoretical (unweighted)	0.997%	0.707%	0.000%	0.707%	0.000%
Measured (unweighted)	0.997%	0.707%	0.002%	0.707%	0.008%
Theoretical (weighted)	0.997%	0.707%		0.707%	0.000%

Measured (weighted)	0.996%	0.706%		0.706%	0.007%

5) www.virtins.com/3150HzModulatedBy4HzAt9.97Percent315Hz.wav
Carrier frequency 3150 Hz, modulating frequency 4 Hz, max. frequency deviation 315 Hz, unweighted and weighted peak wow & flutter values are both: 315 / 3150 × sin(0.95×90°) = 9.97%

	W&F Peak	W&F RMS	Drift RMS	Wow RMS	Flutter RMS
Theoretical (unweighted)	9.97%	7.07%	0.00%	7.07%	0.00%
Measured (unweighted)	9.97%	7.07%	0.02%	7.07%	0.08%
Theoretical (weighted)	9.97%	7.07%		7.07%	0.00%
Measured (weighted)	9.96%	7.06%		7.06%	0.07%

6) www.virtins.com/3150HzModulatedBy0.8HzAt0.0499Percent3.15Hz.wav
Carrier frequency 3150 Hz, modulating frequency 0.8 Hz, max. frequency deviation 3.15 Hz, unweighted peak wow & flutter value: 3.15 / 3150 × sin(0.95×90°) = 0.0997%, and weighted peak wow & flutter value: 0.5 × 0.0997% = 0.0499%, where 0.5 is the weighting factor provided by AES (refer to Fig. 1).

	W&F Peak	W&F RMS	Drift RMS	Wow RMS	Flutter RMS
Theoretical (unweighted)	0.0997%	0.0707%	0.0000%	0.0707%	0.0000%
Measured (unweighted)	0.0996%	0.0709%	0.0046%	0.0707%	0.0001%
Theoretical (weighted)	0.0499%	0.0354%		0.0354%	0.0000%
Measured (weighted)	0.0498%	0.0354%		0.0354%	0.0000%

7) www.virtins.com/3150HzModulatedBy20HzAt0.0506Percent3.15Hz.wav
Carrier frequency 3150 Hz, modulating frequency 20 Hz, max. frequency deviation 3.15 Hz, unweighted peak wow & flutter value: 3.15 / 3150 × sin(0.95×90°) = 0.0997%, and weighted peak wow & flutter value: 0.508 × 0.0997% = 0.0506%, where 0.508 is the weighting factor provided by AES (refer to Fig. 1).

	W&F Peak	W&F RMS	Drift RMS	Wow RMS	Flutter RMS
Theoretical (unweighted)	0.0997%	0.0707%	0.0000%	0.0000%	0.0707%
Measured (unweighted)	0.0996%	0.0707%	0.0000%	0.0000%	0.0707%
Theoretical (weighted)	0.0506%	0.0359%		0.0000%	0.0359%

Measured (weighted)	0.0506%	0.0359%		0.0000%	0.0359%

8) www.virtins.com/3150HzModulatedBy0.2HzAt0.003Percent3.15Hz.wav
Carrier frequency 3150 Hz, modulating frequency 0.2 Hz, max. frequency deviation 3.15 Hz, unweighted peak wow & flutter value: 3.15 / 3150 × sin(0.95×90°) = 0.0997%, and weighted peak wow & flutter value: 0.0296 × 0.0997% = 0.0030%, where 0.0296 is the weighting factor provided by AES (refer to Fig. 1).

	W&F Peak	W&F RMS	Drift RMS	Wow RMS	Flutter RMS
Theoretical (unweighted)	0.0997%	0.0707%	0.0707%	0.0000%	0.0000%
Measured (unweighted)	0.0996%	0.0709%	0.0709%	0.0025%	0.0001%
Theoretical (weighted)	0.0030%	0.0021%		0.0000%	0.0000%
Measured (weighted)	0.0031%	0.0027%		0.0012%	0.0000%

Taking the above 4) and 7) as examples, the measured unweighted and weighted peak wow & flutter are shown as follows. It can be seen that both results match their theoretical values exceptionally well.

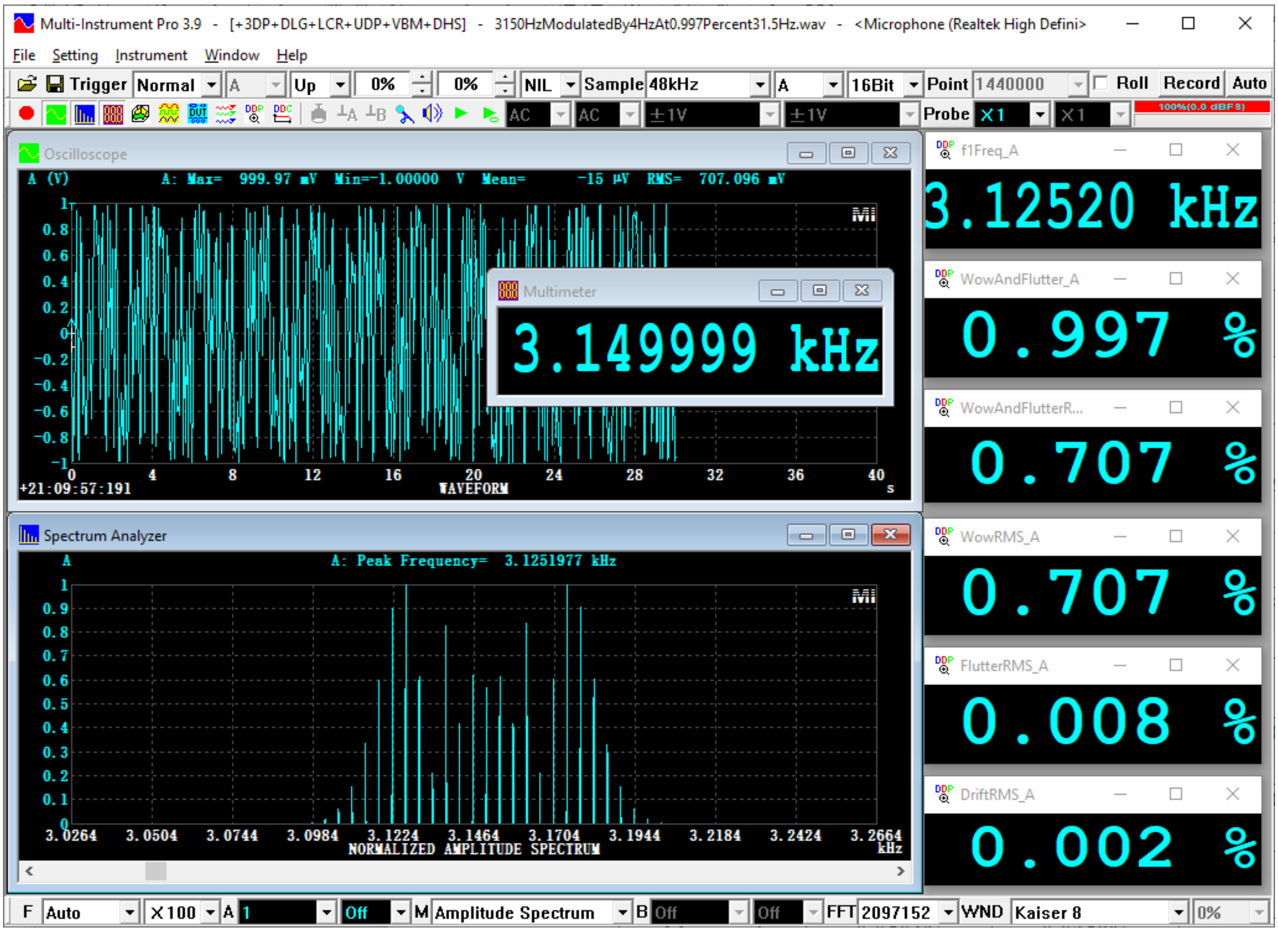

Fig. 20 The measured unweighted wow and flutter of Test Signal 4 (Note: The average frequency of the test signal is obtained through the frequency counter mode of the Multimeter)

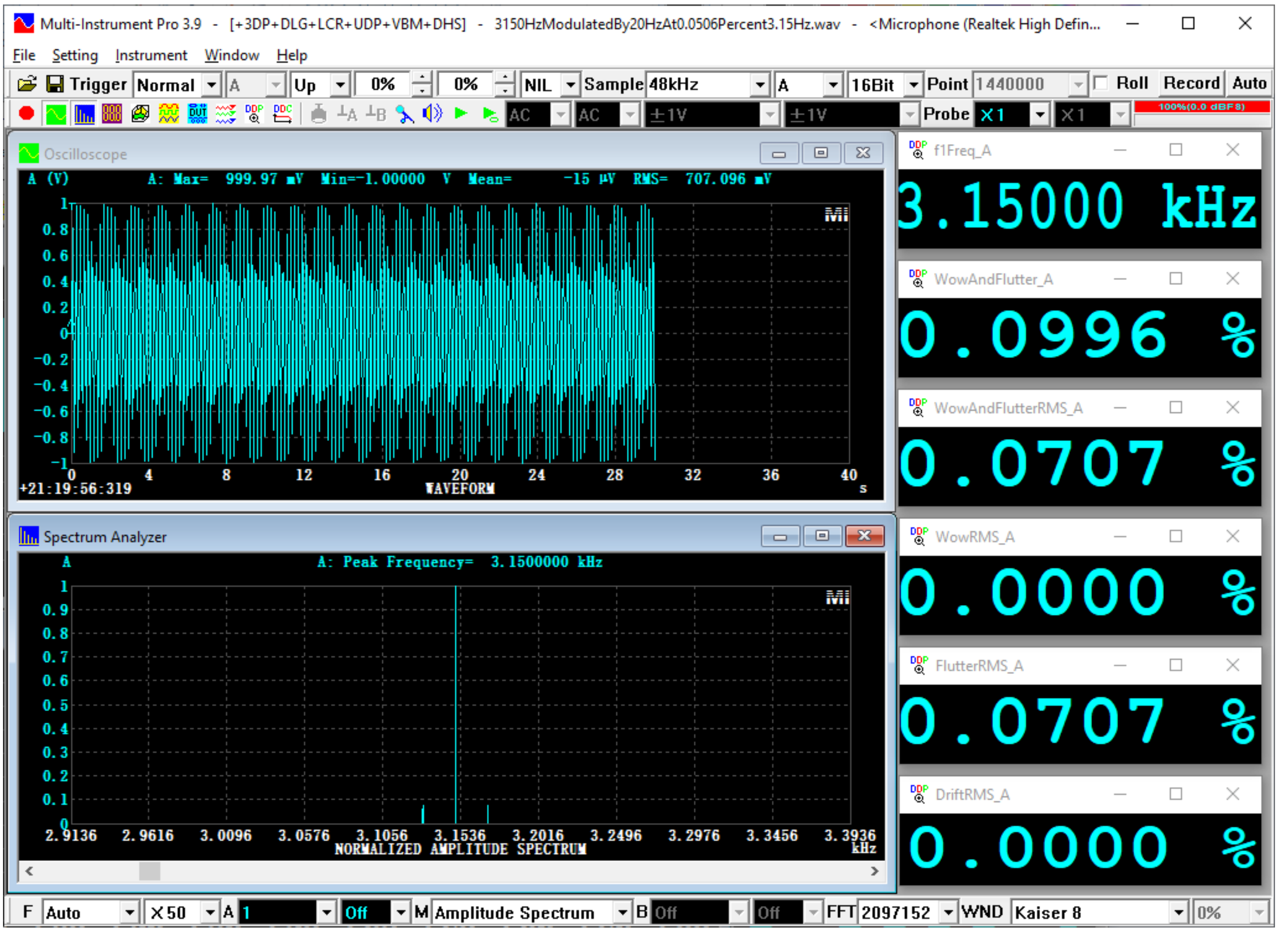

Fig. 21 The measured unweighted wow and flutter of Test Signal 7

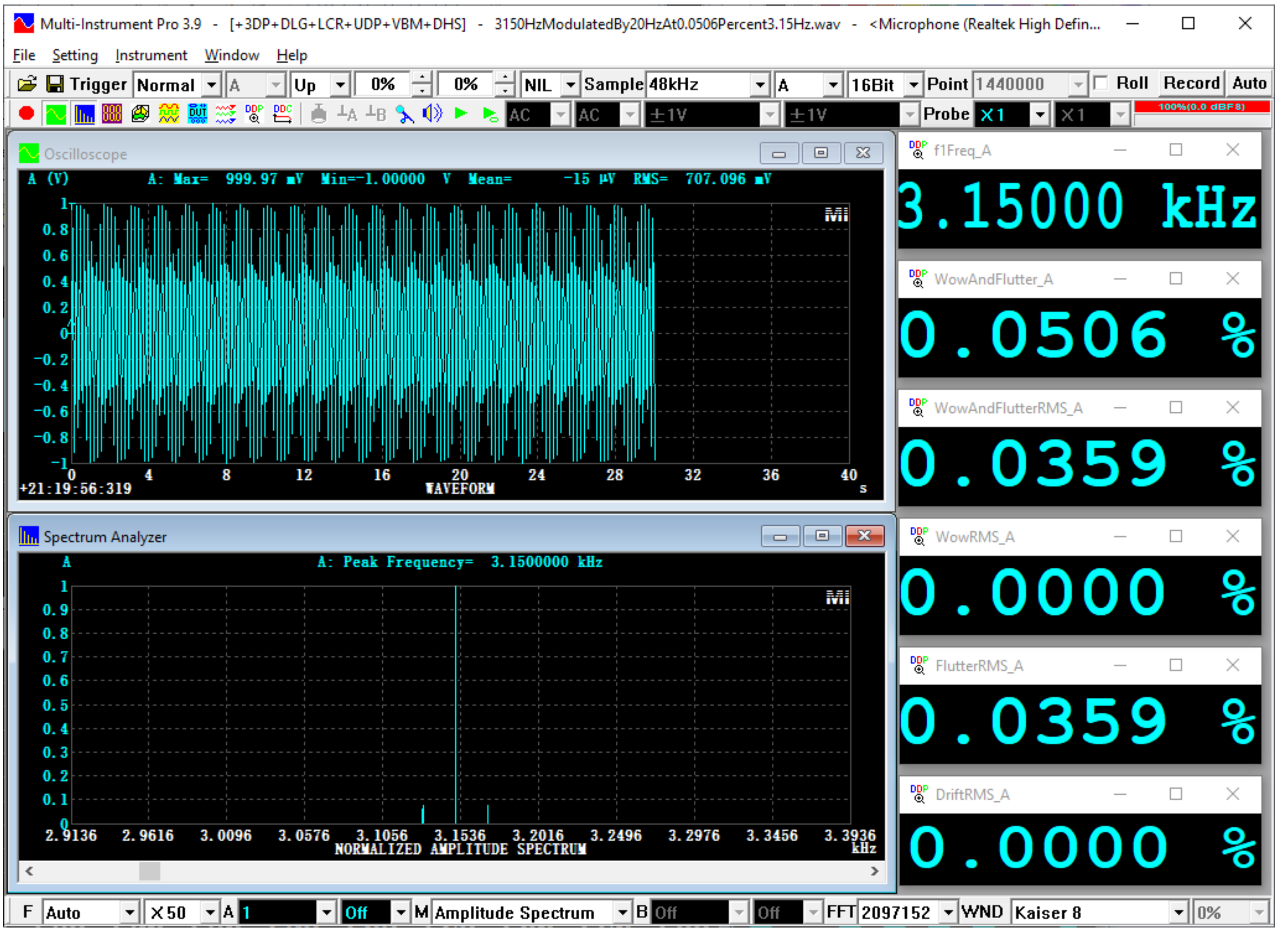

Fig. 22 The measured weighted wow and flutter of Test Signal 7

10. Summary

Wow and Flutter measurement instrument using obsolete analog demodulation techniques is bulky and expensive. Software using digital demodulation techniques together with a piece of inexpensive ADC hardware such as an ordinary sound card provides a very cost effective way to accurately measure the wow and flutter of an analog medium player. Moreover, it is self-proven and calibration free.

