Polarity Check for Speakers, Microphones and Amplifiers using Multi-Instrument

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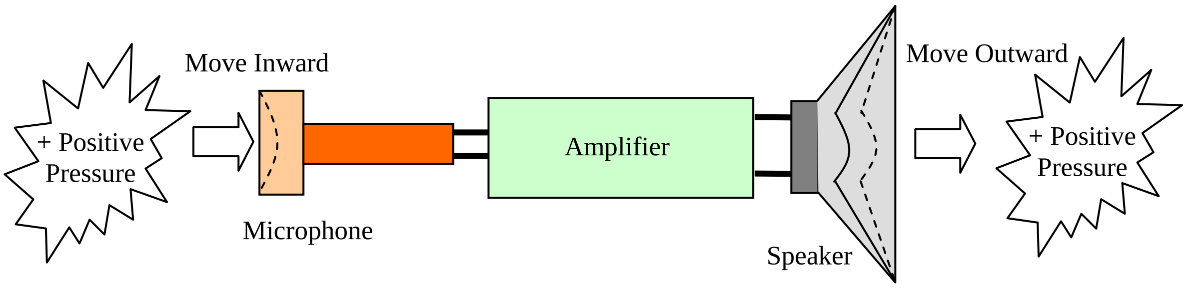
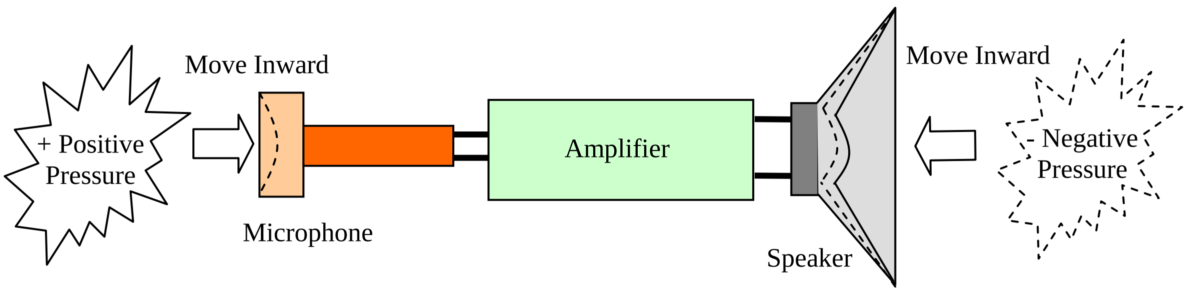
1. Absolute & Relative Polarity and Why They Are Important

A typical sound system consists of microphones, audio amplifiers and speakers. All these components have a polarity. The polarity of a microphone refers to in-phase and out-of-phase condition of voltage developed at its terminals with respect to the sound pressure of a sound wave causing the voltage. The positive or in-phase terminal is the terminal that has a positive potential with respect to a positive sound pressure at the front of the diaphragm of the microphone (inward movement). The polarity of an amplifier refers to the in-phase and out-of-phase condition of its output voltage with respect to its input voltage. If the two voltages are in-phase, then it is a non-inverting amplifier, otherwise, an inverting amplifier. The polarity of a speaker refers to the in-phase and out-of-phase condition of sound pressure developed at its front with respect to the voltage applied at its terminals. The speaker will produce a positive sound pressure (outward movement) at its front if a positive voltage is applied between its positive and negative terminals.

The polarity definitions for microphones and speakers are consistent. If a microphone, an amplifier and a speaker are connected in-phase one by one, the absolute polarity is maintained. That is, a positive sound pressure on the microphone is reproduced as a positive sound pressure by the speaker. For instance, the plosive "P" sound from a vocalist sends an initial positive air pressure wave toward the microphone, which responds with an initial inward movement of the microphone diaphragm, away from the vocalist. The speaker then sends an initial positive pressure wave outward, toward the listener.

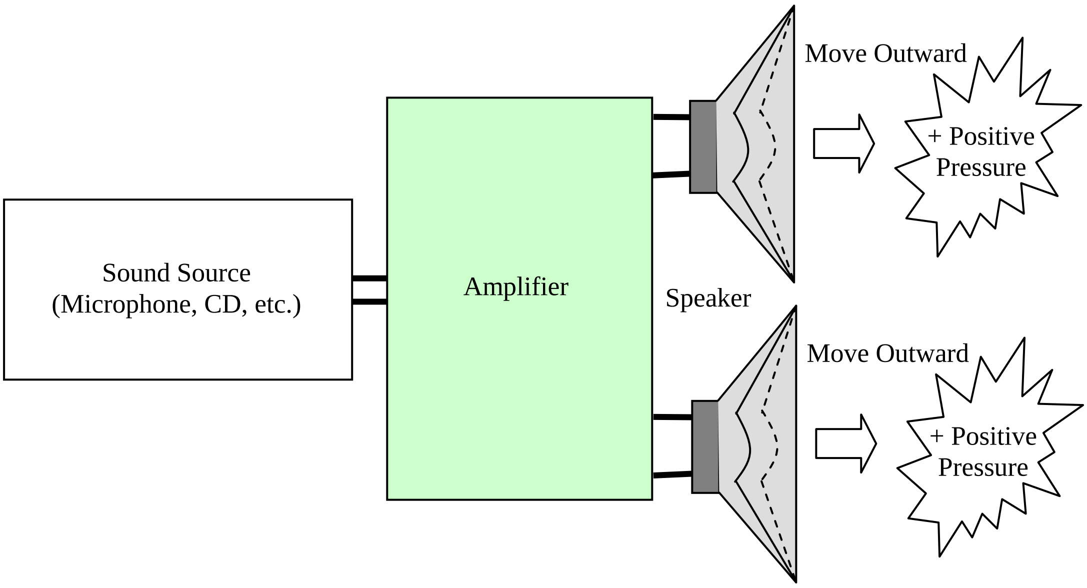


Absolute Polarity Maintained

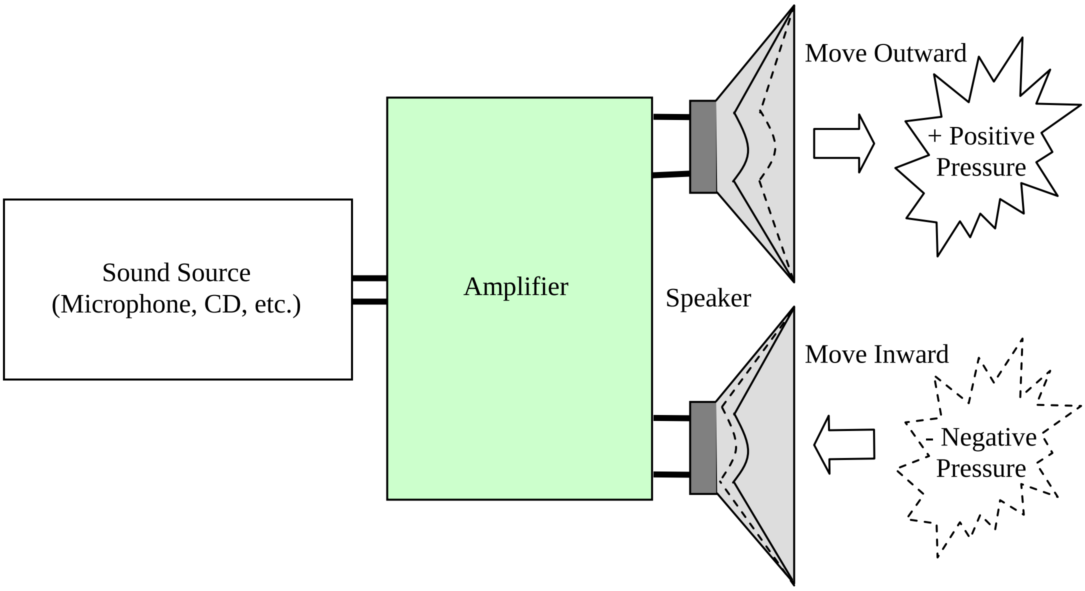


Absolute Polarity Inverted

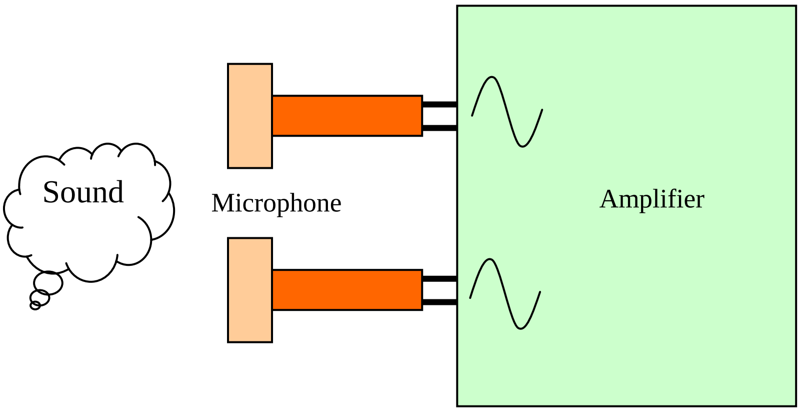
The human auditory system is not sensitive to absolute polarity except for very low-frequency and high impulse sounds such as percussion. Thus maintaining the absolute polarity is generally not a priority in practice, although it is absolutely good if it is achieved. It is the relative polarity that has significant impact on the perceived sound when multiple microphones, amplifier(s) and speakers are used. For sound reproduction, maintaining relative polarity means that all speakers are polarized the same as one another, without regard as to whether they have correct absolute polarity. The reproduced sound field will be messed up if the speakers are out of phase. For example, if two speakers are emitting the same tone, and one of them is in a state of inverted polarity, those tones, when combined at a given spatial point, will cancel each other. This effect is stronger at lower frequencies and will result in loss of bass and destroy the original stereo imaging. Similarly, maintaining the relative polarity of microphones is of great importance for sound recording. For example, when two microphones are used to record a single sound source, it is imperative that they respond to a positive pressure on their diaphragms in the same way. If the polarity of one of the microphones is reversed, the tone will become very thin and lack bass when the two outputs are mixed together. Even if the microphones are panned hard left and right for a stereo effect, if their polarity is not consistent, the sound will appear to be unfocused and vague, and difficult to localize in the stereo sound field.



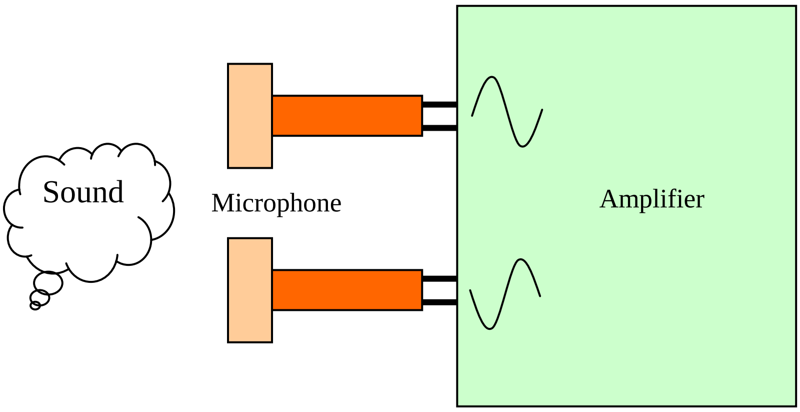
Relative Polarity Maintained in Sound Reproduction



Relative Polarity Inverted in Sound Reproduction



Relative Polarity Maintained in Sound Recording



Relative Polarity Inverted in Sound Recording

It should be noted that the sound cancellation effect of out-of-phase connection is sometimes used purposely for noise cancellation in recording (using microphones) and sound reproduction (using speakers).

2. How to Test Polarity

When interconnecting different types of acoustic and audio components together in a sound system, maintaining the relative or absolute polarity may not be a simple task without proper testing tools.

2.1 Speaker Polarity Test using a Battery

Speaker polarity test is probably the easiest. You can connect a 1.5V battery to the speaker under test momentarily and observe the movement of the speaker. If it moves outwards initially, then the positive wire from the battery is connected with the positive terminal of the speaker. This method, however, is not practical if the movement of the speaker is not discernible (e.g. tweeters) or cannot be seen (e.g. horns, or already sealed inside a speaker box).

2.2 Polarity Test using Multi-Instrument

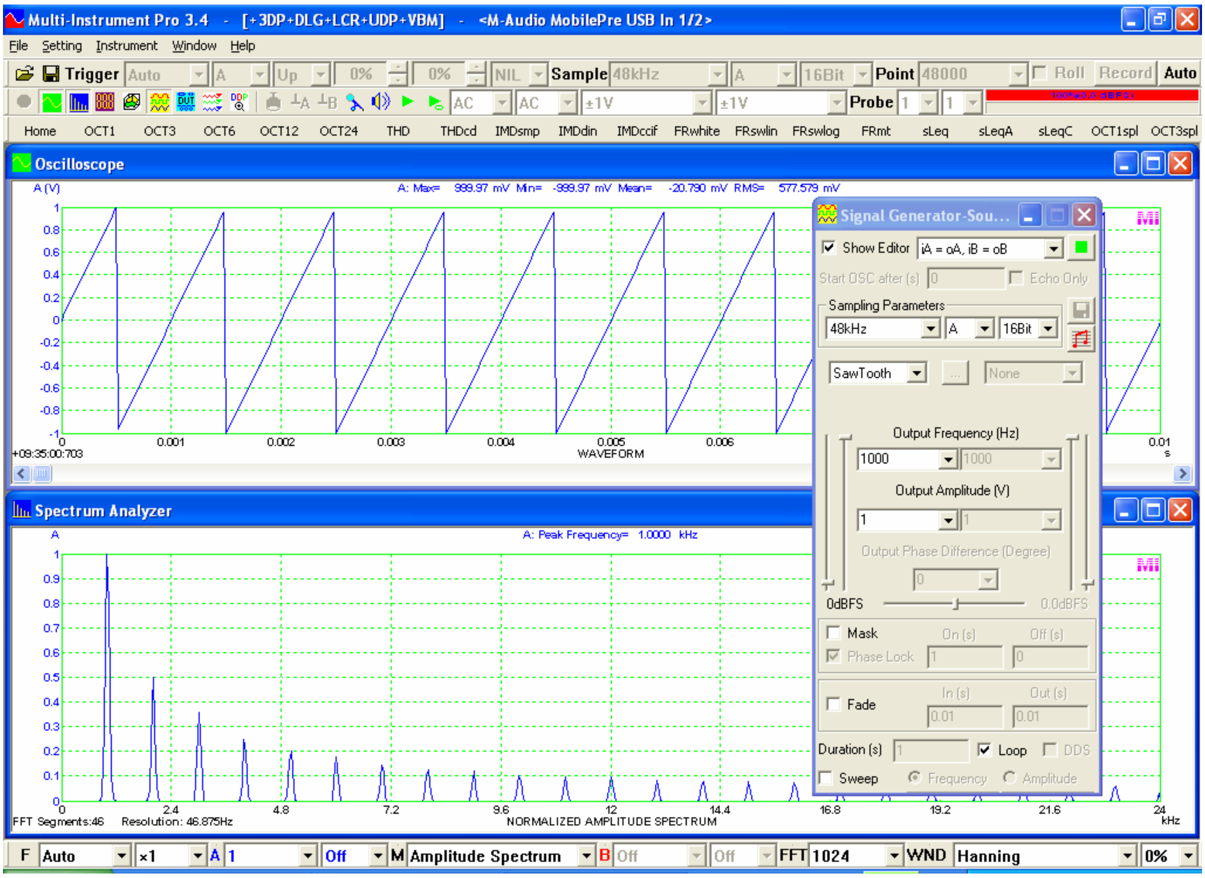
Multi-Instrument (downloadable from www.virtins.com or www.multi-instrument.com) is a powerful PC based multi-function virtual instrument software. It contains many virtual test and measurement instruments such as an oscilloscope, a spectrum analyzer and a signal generator. With Multi-Instrument and the PC sound card, it is easy to check the polarity of microphones, amplifiers, speakers, or a combination of them. You just need to feed a periodic signal with an asymmetric waveform that looks significantly different if inverted, or a burst signal with a known initial phase, from the signal generator or a CD to the Device Under Test (DUT) and check the output from the DUT on the oscilloscope. The output from the DUT can be fed to the input of the oscilloscope directly for the case of an electrical output (e.g. by an amplifier) or through a microphone and its pre-amplifier for the case of an acoustic output (e.g. by a speaker). From the waveform displayed on the oscilloscope, the relative polarity of the DUT can be readily determined.

In the following sections, we will discuss a few types of signals that can be used for polarity test and their pros and cons. You may choose one or more from them for your polarity tests.

2.2.1 Periodic Asymmetric Waveforms

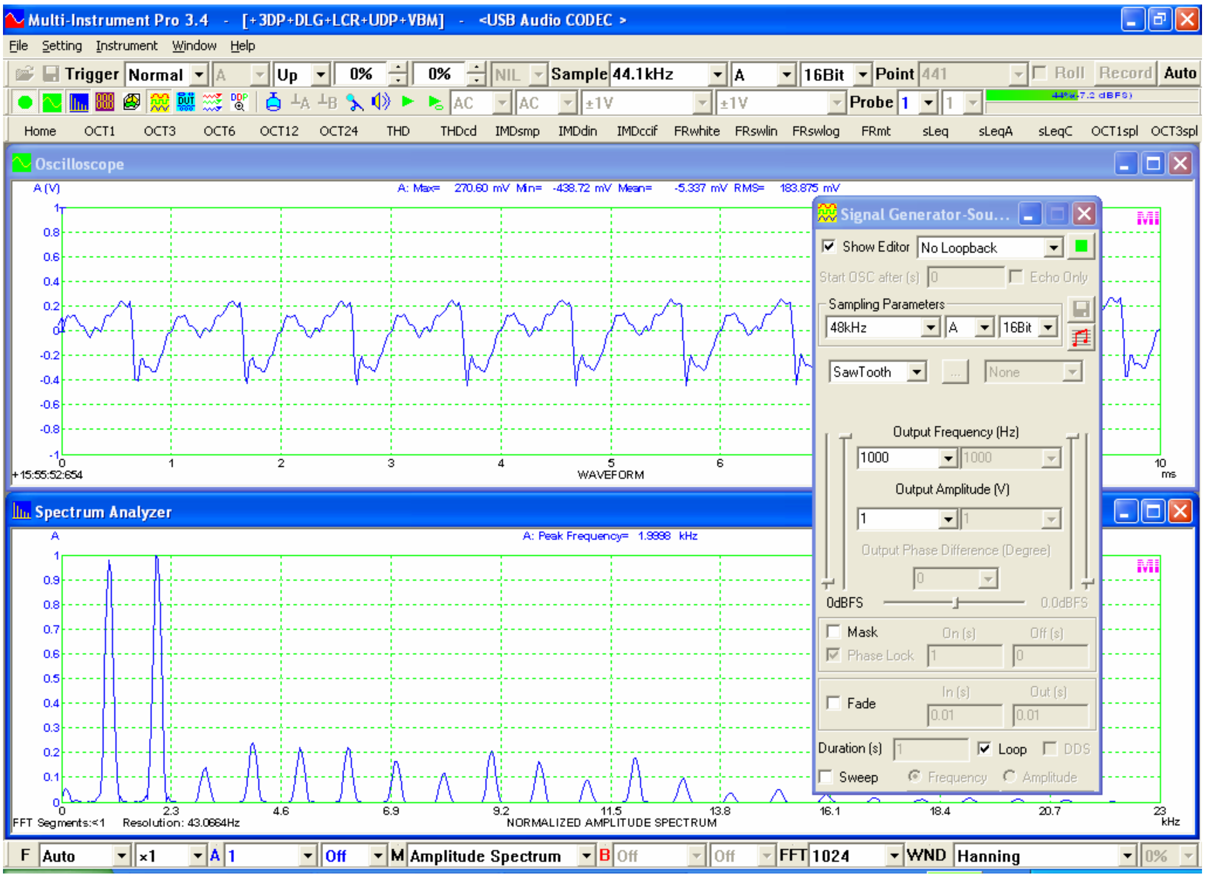
2.2.1.1 Sawtooth (or Ramp Up)

The sawtooth wave is so named based on its resemblance to the teeth of a saw. The convention is that a sawtooth wave ramps upward and then sharply drops. If inverted, the wave ramps down and then sharply rises. Its spectrum contains the fundamental frequency and an infinite number of even and odd harmonics. The amplitude of the N^{th} order harmonics is $1/N$ of that of the fundamental frequency. The following figure shows an ideal 1 kHz sawtooth wave and its spectrum.

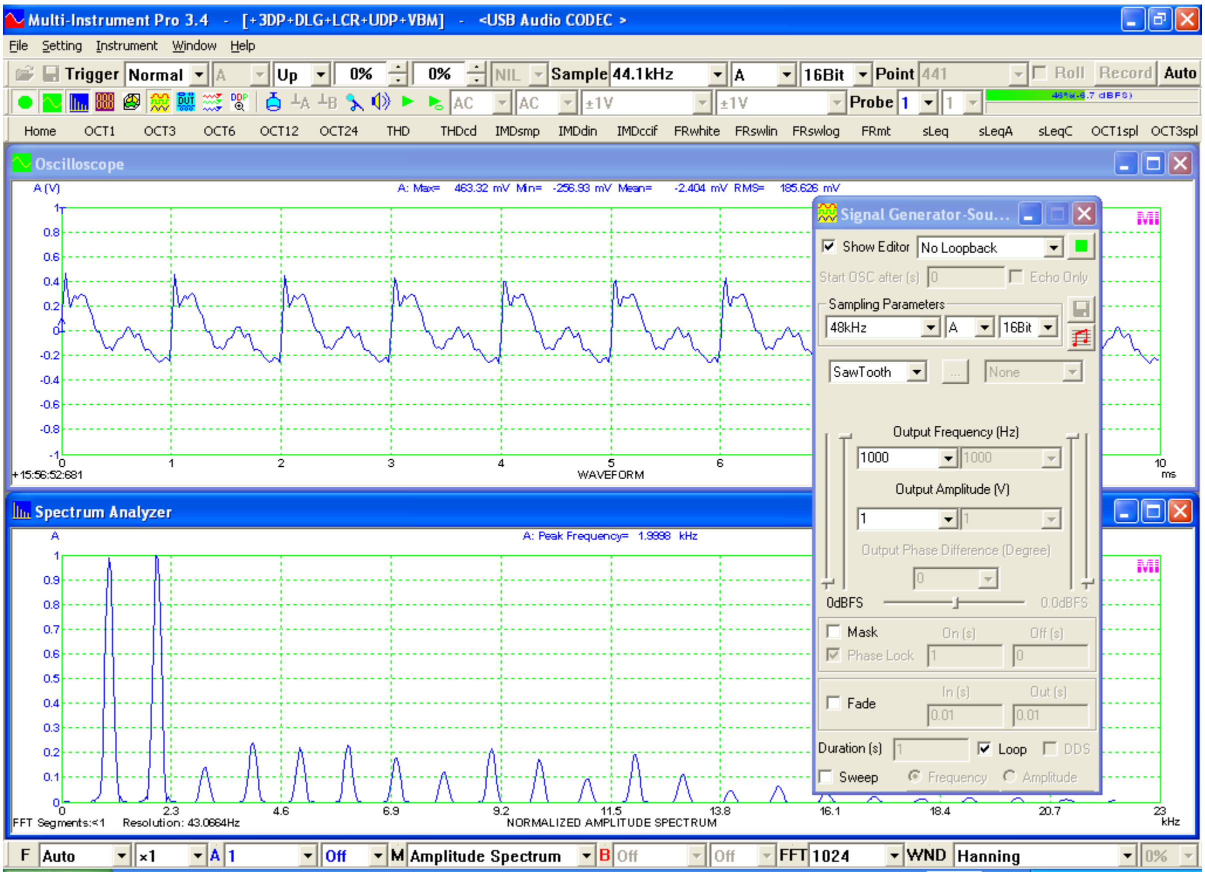


Ideal 1kHz Sawtooth Wave

In practice, an ideal sawtooth wave from the source is always reshaped by the system's overall frequency response including both magnitude and phase responses. The system here refers to both the DUT and the measuring setup. If the system involves any acoustic path, then the sound reflection from the surrounding surfaces will also play a part in the overall frequency response and thus the captured waveform. If the measured waveform is deformed too much, it may be difficult to differentiate its non-inverted and inverted states. The following two figures show a 1 kHz sawtooth wave measured from a computer speaker without and with polarity inversion using VT RTA-168B (www.virtins.com/VT-RTA-168.shmtl).



Measured 1kHz sawtooth wave from a computer speaker

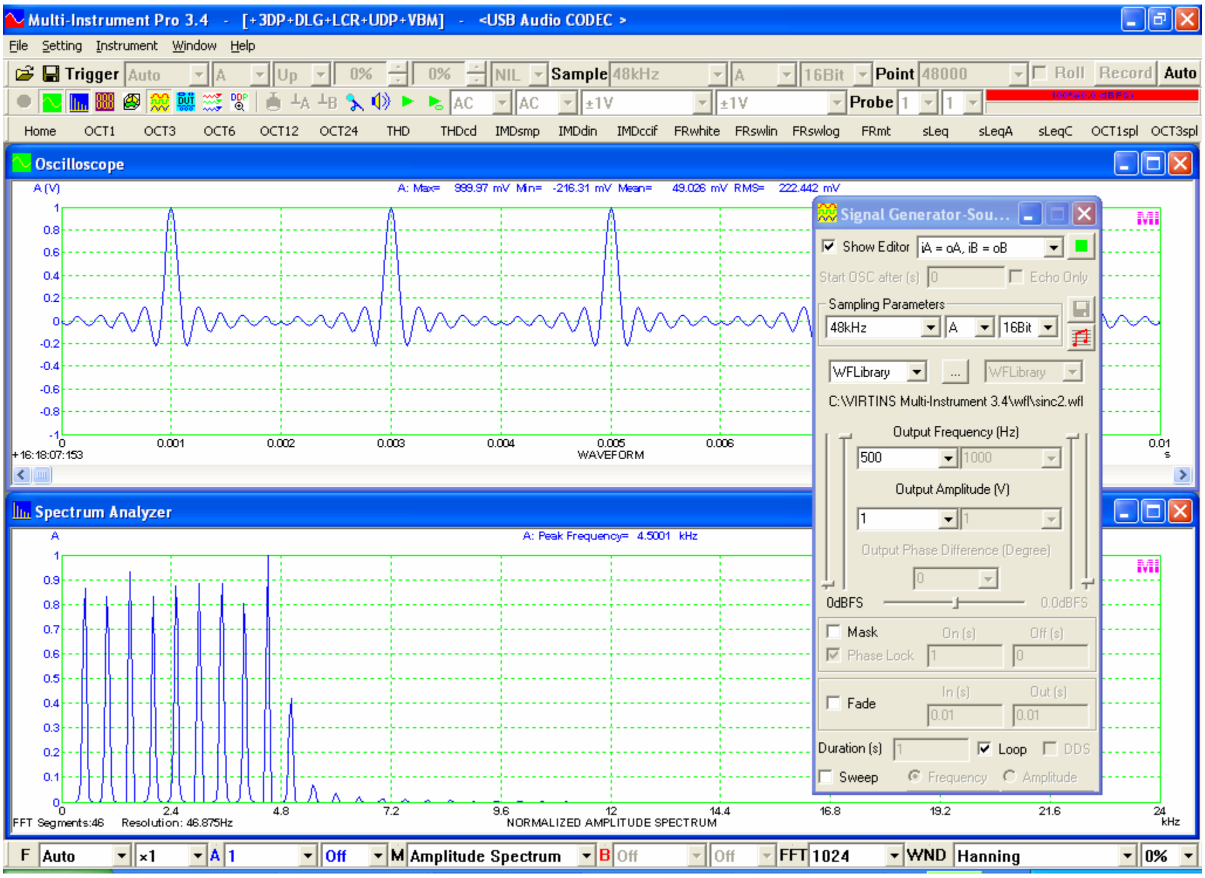


Measured 1kHz sawtooth wave from a computer speaker with its polarity inverted

It can be seen from the above two figures that the measured sawtooth waveform is distorted quite badly as compare to its ideal shape due to the limited bandwidth of the DUT, un-equalized frequency response, phase response of the DUT as well as sound reflection from the surrounding enclosure, etc.. Nevertheless, the polarity can still be identified.

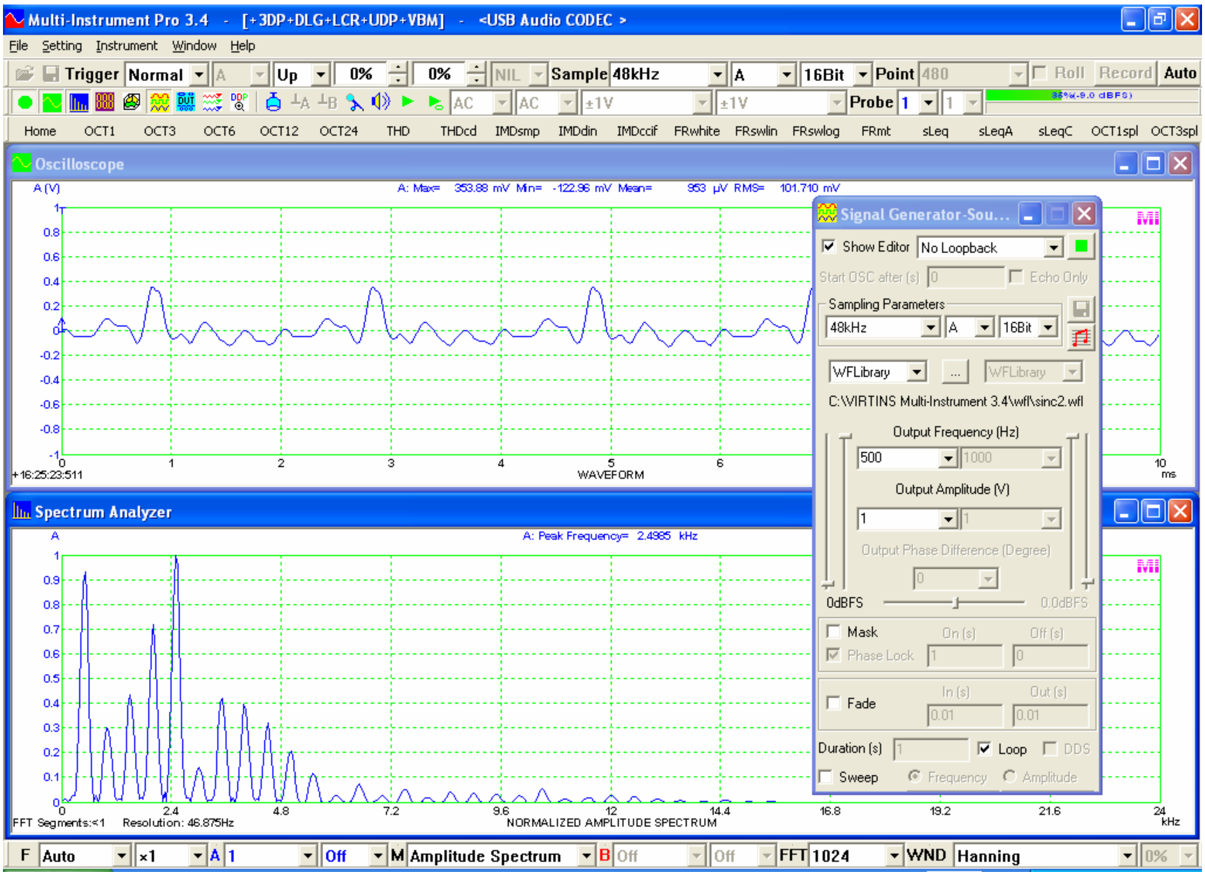
2.2.1.2 Truncated Sinc

The spectrum of an ideal sinc wave (with an infinite length) is a rectangle function. When generated by a signal generator, the ideal sinc wave is truncated symmetrically and repeated at a certain frequency. The spectrum of the generated sinc wave contains the fundamental frequency and a limited number of even and odd harmonics, depending on how many peaks exist in a cycle of the truncated sinc waveform. All these harmonics have the same magnitude as the fundamental frequency. The following figure shows a 500 Hz truncated sinc wave and its spectrum in ideal condition. The truncated sinc wave is generated from sinc2.wfl in the wave file library using WFLibrary function of the signal generator of Multi-Instrument. It contains the fundamental and 2^{nd} ~10^{th} order harmonics. If sinc1.wfl is used instead, the harmonics will go up to the 50^{th} order.

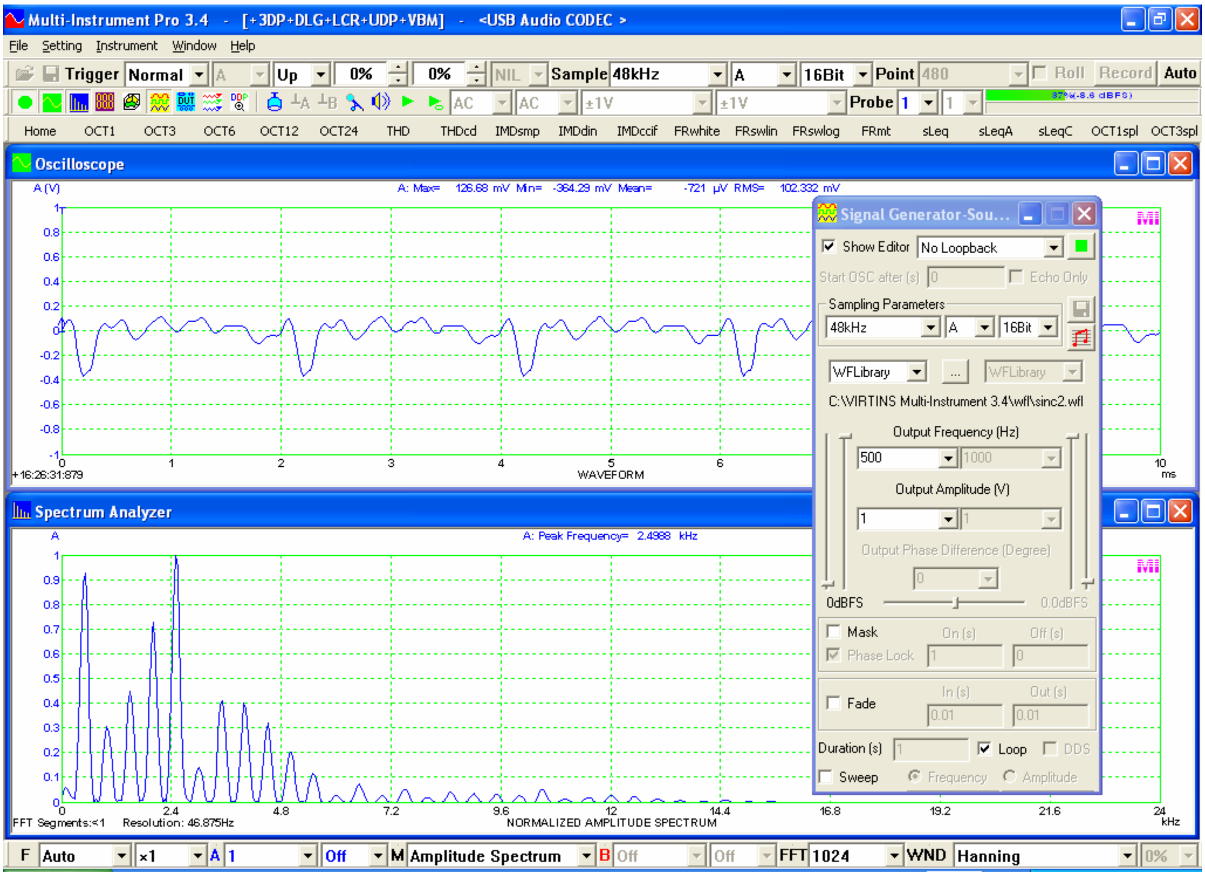


Ideal 500Hz truncated sinc wave

The following two figures show a 500Hz sinc wave measured from a computer speaker without and with polarity inversion using VT RTA-168B.



Measured 500Hz truncated sinc wave from a computer speaker

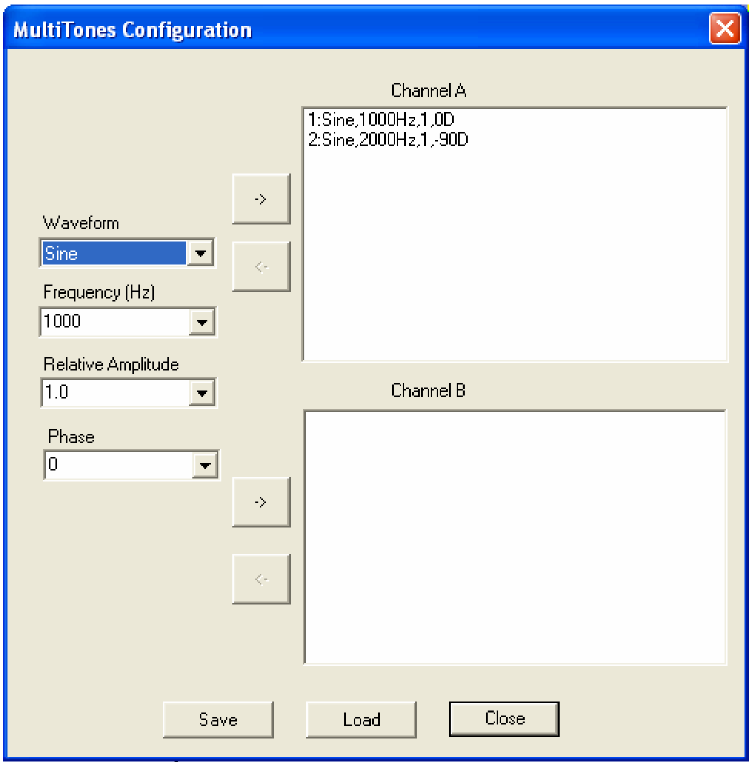


Measured 500Hz truncated sinc wave from a computer speaker with its polarity inverted

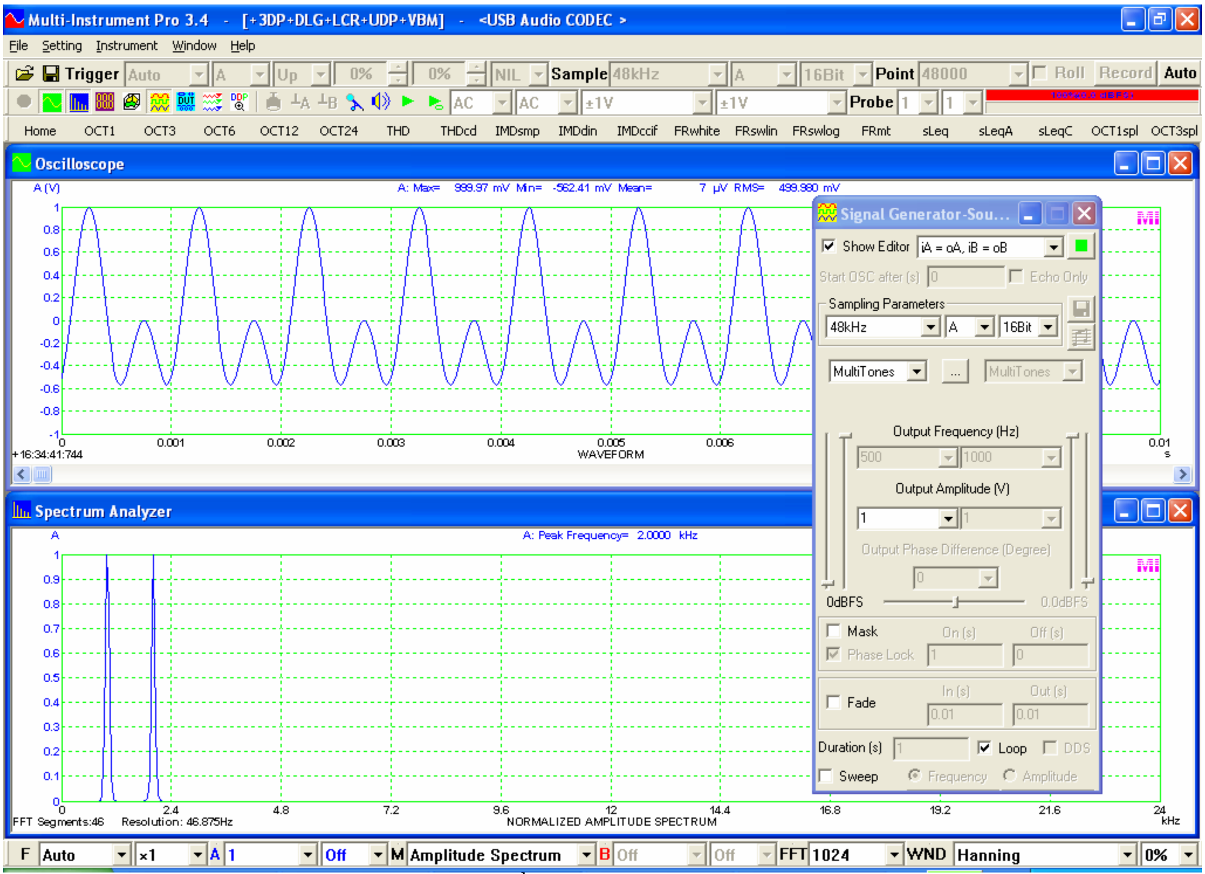
It can be seen from the above two figures that the measured sinc waveform is distorted quite obviously as compare to its shape under ideal condition due to the limited bandwidth of the DUT, un-equalized frequency response, phase response of the DUT as well as sound reflection from the surrounding enclosure, etc.. Nevertheless, the polarity can still be identified.

2.2.1.3 Sinc-like MultiTones

A sinc-like multitone signal is a summation of the fundamental frequency with a phase shift of 0° and a limited number of even and odd harmonics, each of which has the same amplitude as that of the fundamental and a phase shift of -90°×(N-1), where N is the order of the harmonics. It is a truncated and repetitive version of the ideal sinc wave. Here we create the simplest one of such kind – a 2nd-order sinc-like multitones: 1 kHz sine wave with a phase shift of 0° + 2 kHz sine wave with a phase shift of -90°.

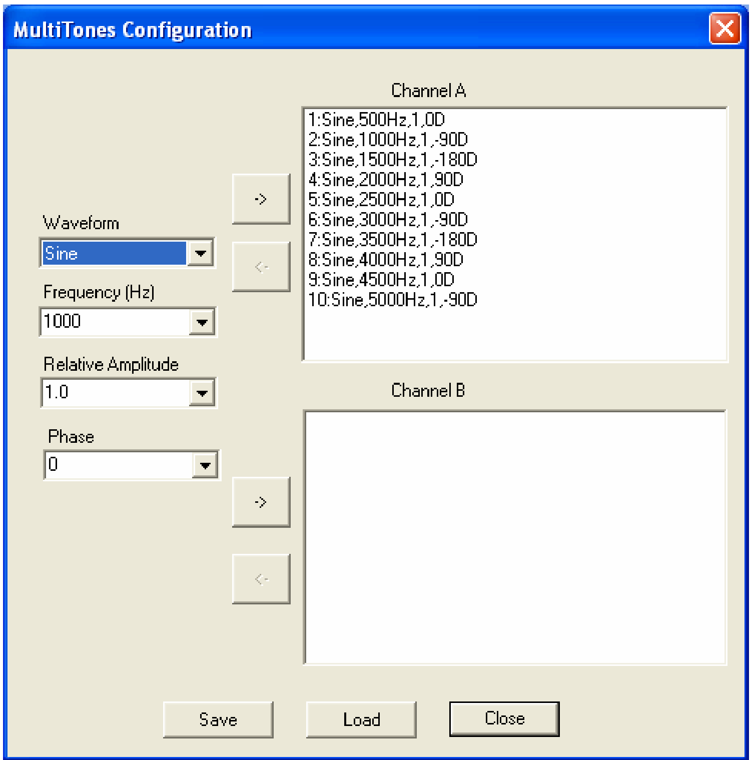


1kHz 2nd-order sinc-like multitone configuration

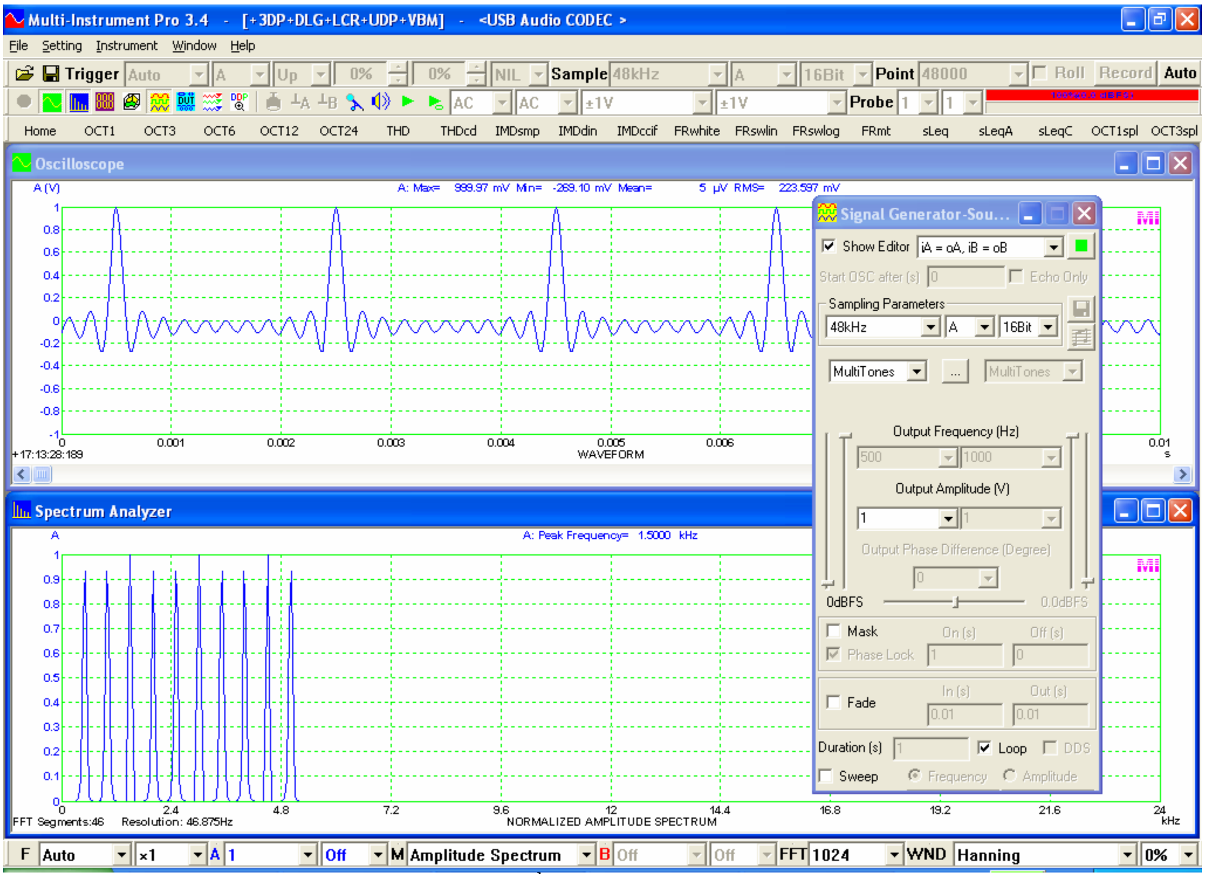


Ideal 1kHz 2nd-order sinc-like multitones

The following is a 500Hz 10th-order sinc-like wave, almost the same as the example in the previous section.



500Hz 10nd-order sinc-like multitone configuration



Ideal 500Hz 10^{nd}-order sinc-like multitones

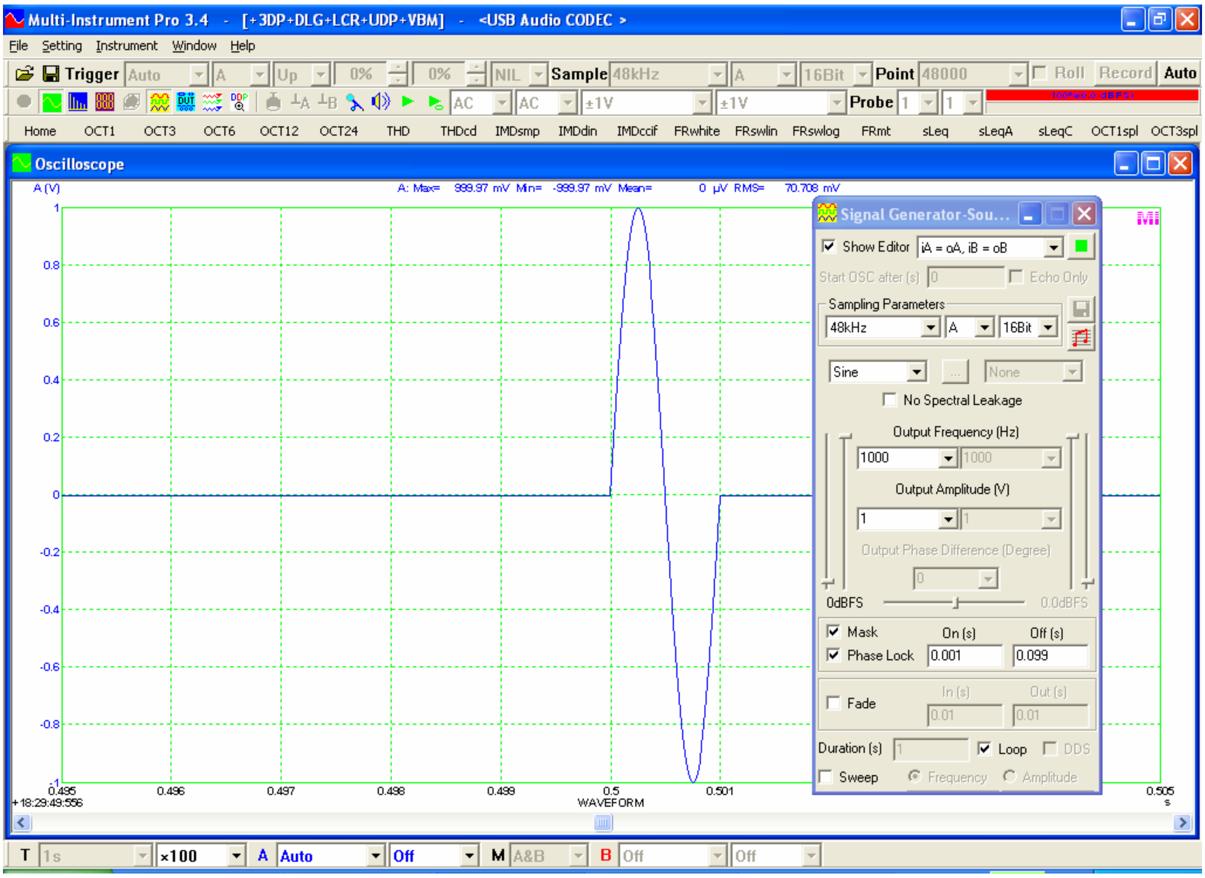
All sinc-like multitones are asymmetric with respect to the x axis. If it is not easy to identify the polarity from the captured waveform due to the deformation mentioned previously, then a high-order multitone signal can be used. One good feature of the sinc-like waveform is that the polarity can be determined by just comparing the absolute value of the Maximum and Minimum without using advanced waveform analysis methods. This feature can be used in automated polarity tests.

2.2.2 Burst Signals with a Known Initial Phase

A burst signal has two states: silent and burst. Thus it is easy to identify the initial phase at the front of the burst. Both a single or multiple bursts can be used. If a single burst is used, then the oscilloscope must be set to the single trigger mode and trigger condition must be set properly in order to capture the single burst. Here we use multiple bursts to check polarity so we do not have any chance to miss them. Any waveform, symmetric or asymmetric, can be used as a burst to check the polarity as the initial phase of the burst can be observed at its front.

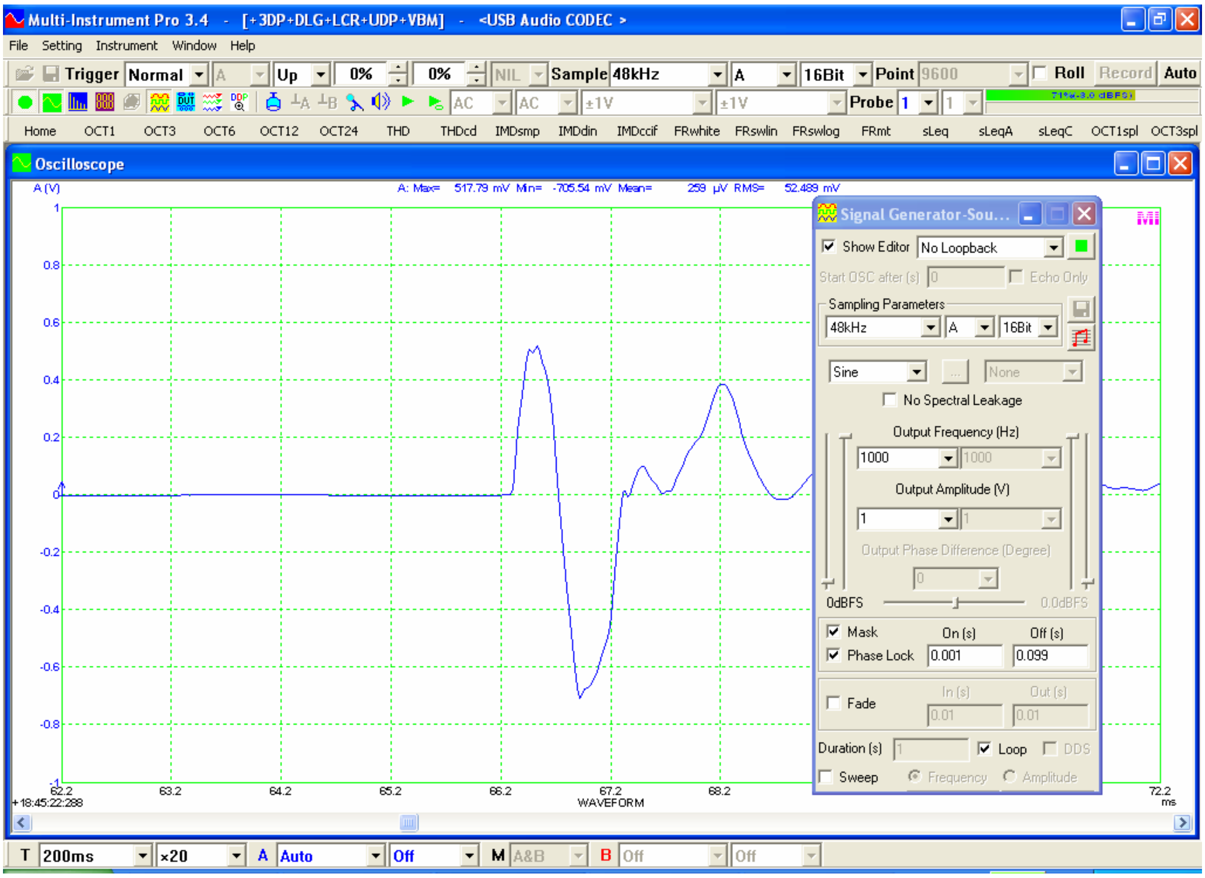
2.2.2.1 Sine Burst

We can generate a sine burst containing one cycle of 1 kHz sine wave every 0.1 s (see figure below). Note that the mask period of the signal generator in Multi-Instrument is set to 0.1 s with On = 0.001 s and Off = 0.099 s and the Phase Lock option is ticked. It masks on and off a continuous 1 kHz sine wave and ensures each burst starts at a predefined initial phase.

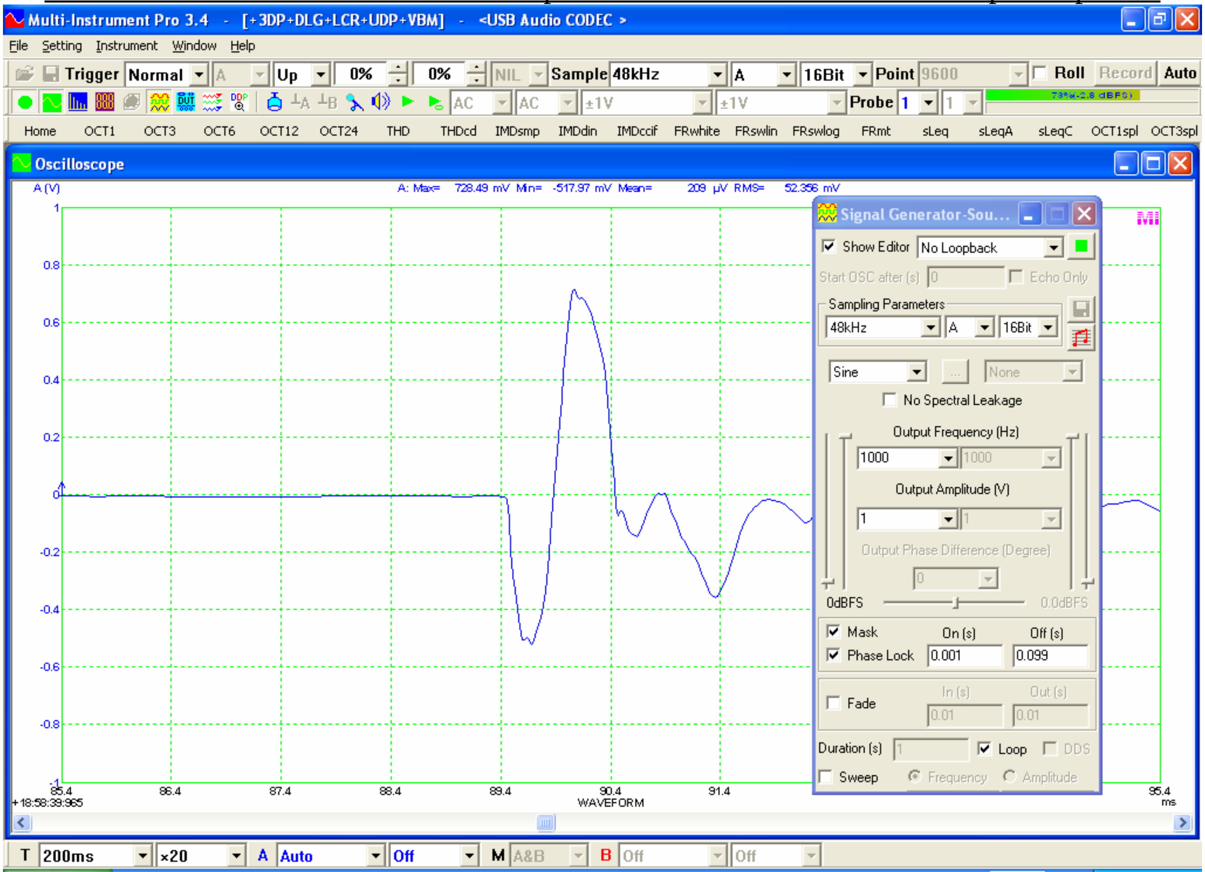


Ideal 1 ms 1 kHz sine burst at a repetition rate of 100 ms

The following two figures show the above burst measured from a computer speaker without and with polarity inversion using VT RTA-168B.



Measured 1 ms 1 kHz sine burst at a repetition rate of 100 ms from a computer speaker

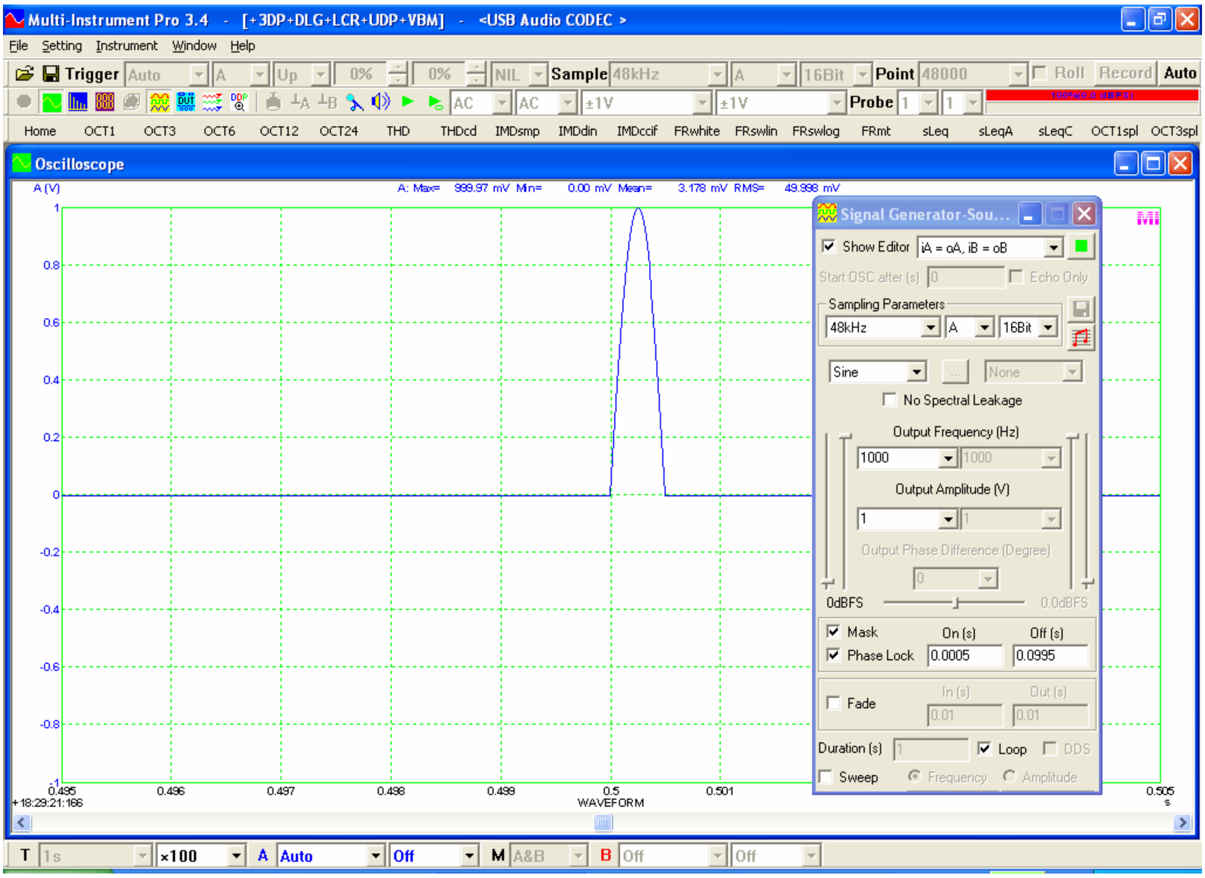


Measured 1 ms 1 kHz sine burst at a repetition rate of 100 ms from a computer speaker with its polarity inverted

It can be seen from the above two figures that the measured sine burst has a quite good sine shape until after the first cycle. This is because the frequency response of the system does not affect the shape of a pure sine wave. Moreover, sound reflection from the surrounding enclosure will usually arrive later after the first cycle, so it will not change the shape of the first cycle. Thus, the waveform captured is not very sensitive to the relative position of the measuring microphone in front of the speaker, in contrast to the cases of using periodic asymmetric waveforms.

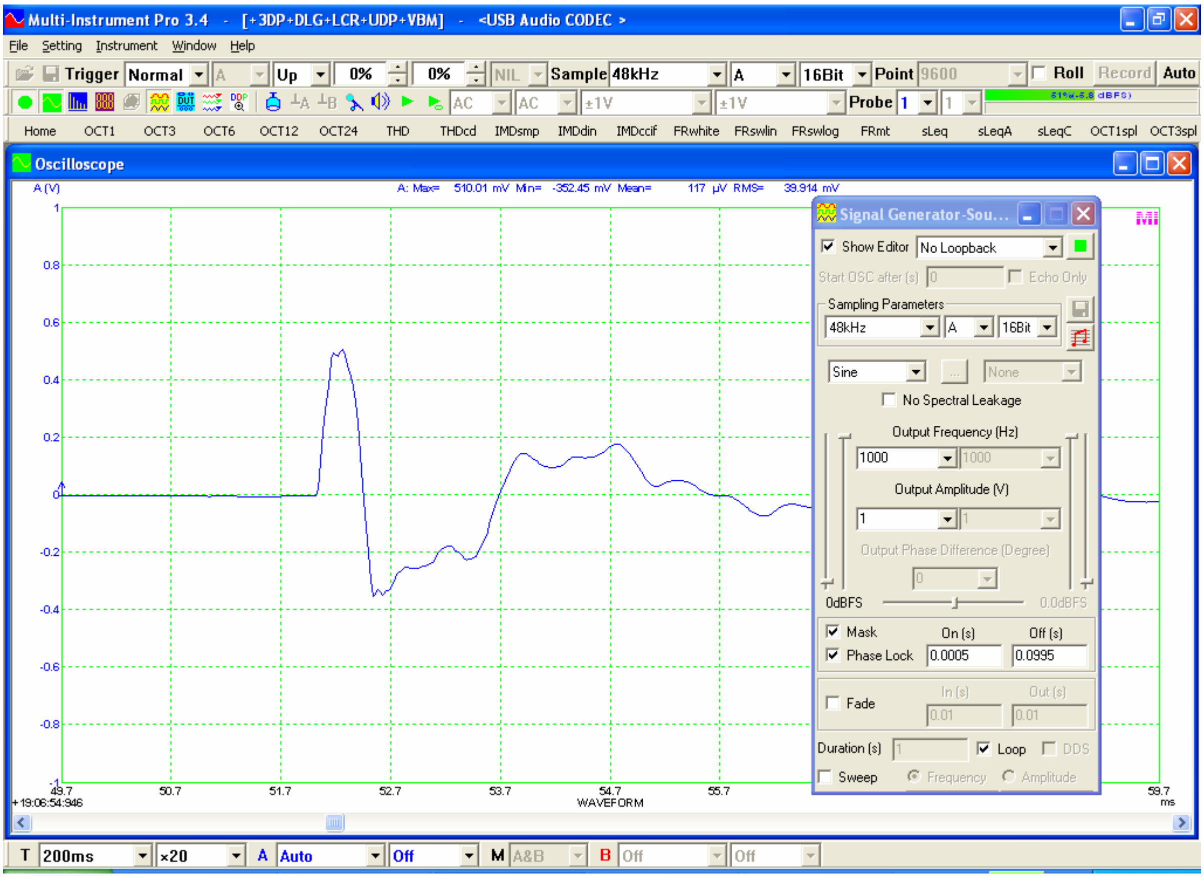
2.2.2.2 Half Sine Burst

We can generate a half sine burst containing a half cycle of 1 kHz sine wave every 0.1 s (see figure below). Note that the mask period of the signal generator in Multi-Instrument is set to 0.1 s with On = 0.0005 s and Off = 0.0995 s and the Phase Lock option is ticked. It masks on and off a continuous 1 kHz sine wave and ensures each burst starts at a predefined initial phase.

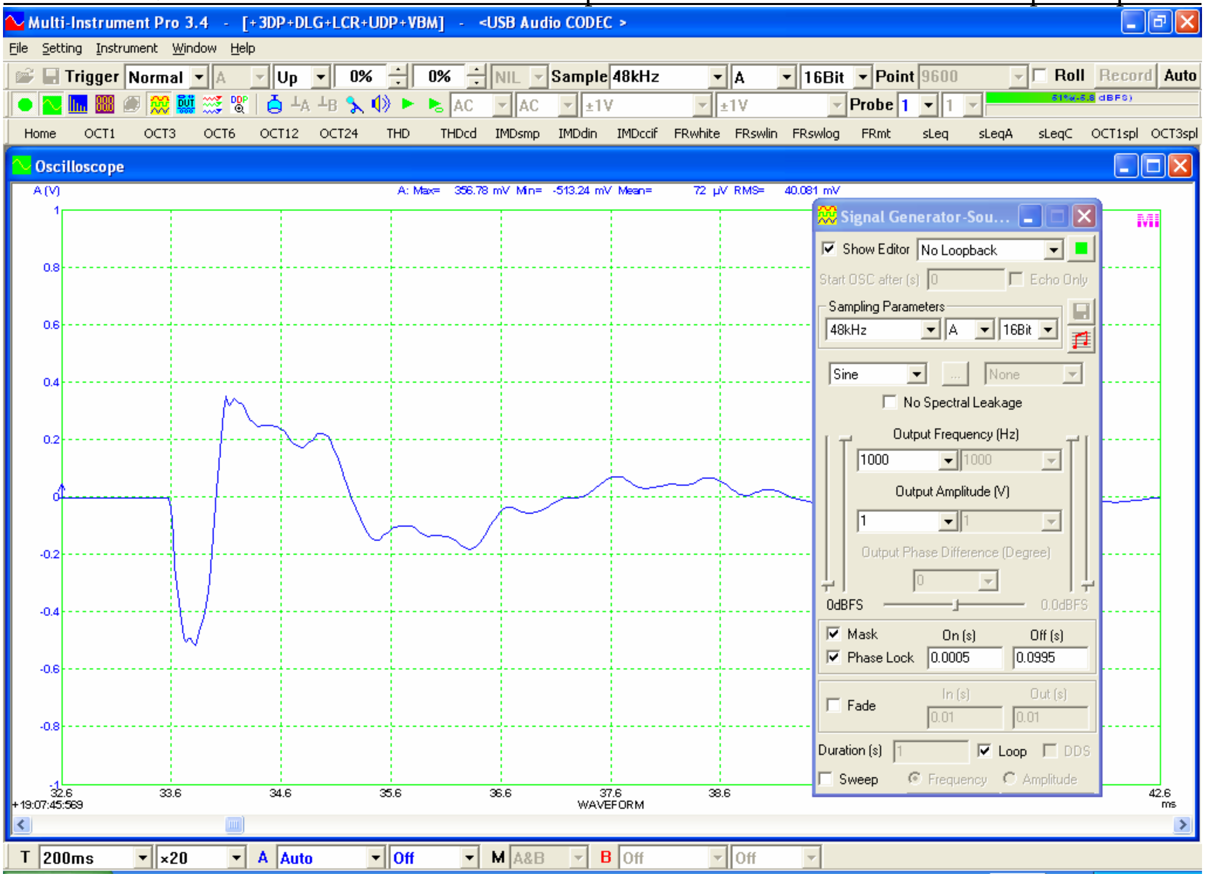


<u>Ideal 0.5 ms 1 kHz half sine burst at a repetition rate of 100 ms</u>

The following two figures show the above burst measured from a computer speaker without and with polarity inversion using VT RTA-168B.



Measured 0.5 ms 1 kHz half sine burst at a repetition rate of 100 ms from a computer speaker

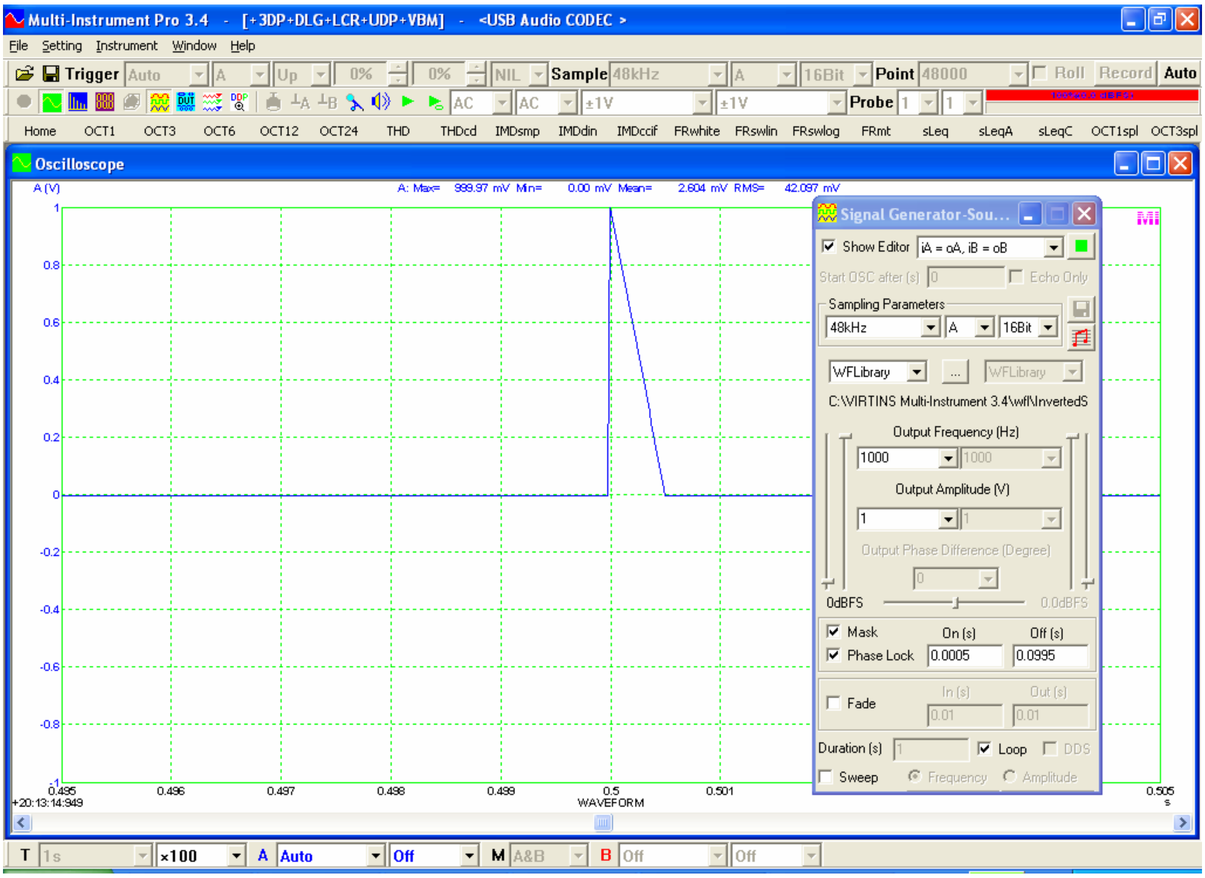


Measured 0.5 ms 1 kHz half sine burst at a repetition rate of 100 ms from a computer speaker with its polarity inverted

It can be seen from the above two figures that the measured half sine burst has a quite good sine shape until after the first half cycle. This is because the frequency response of the system does not affect the shape of a pure sine wave. Moreover, sound reflection from the surrounding enclosure will usually arrive later after the first half cycle, so it will not change the shape of the first half cycle. Thus, the waveform captured is not very sensitive to the relative position of the measuring microphone in front of the speaker, in contrast to the cases of using periodic asymmetric waveforms. One good feature of the half sine burst is that the polarity can be determined by just comparing the absolute value of the Maximum and Minimum without using advanced waveform analysis methods. This feature can be used in automated polarity tests.

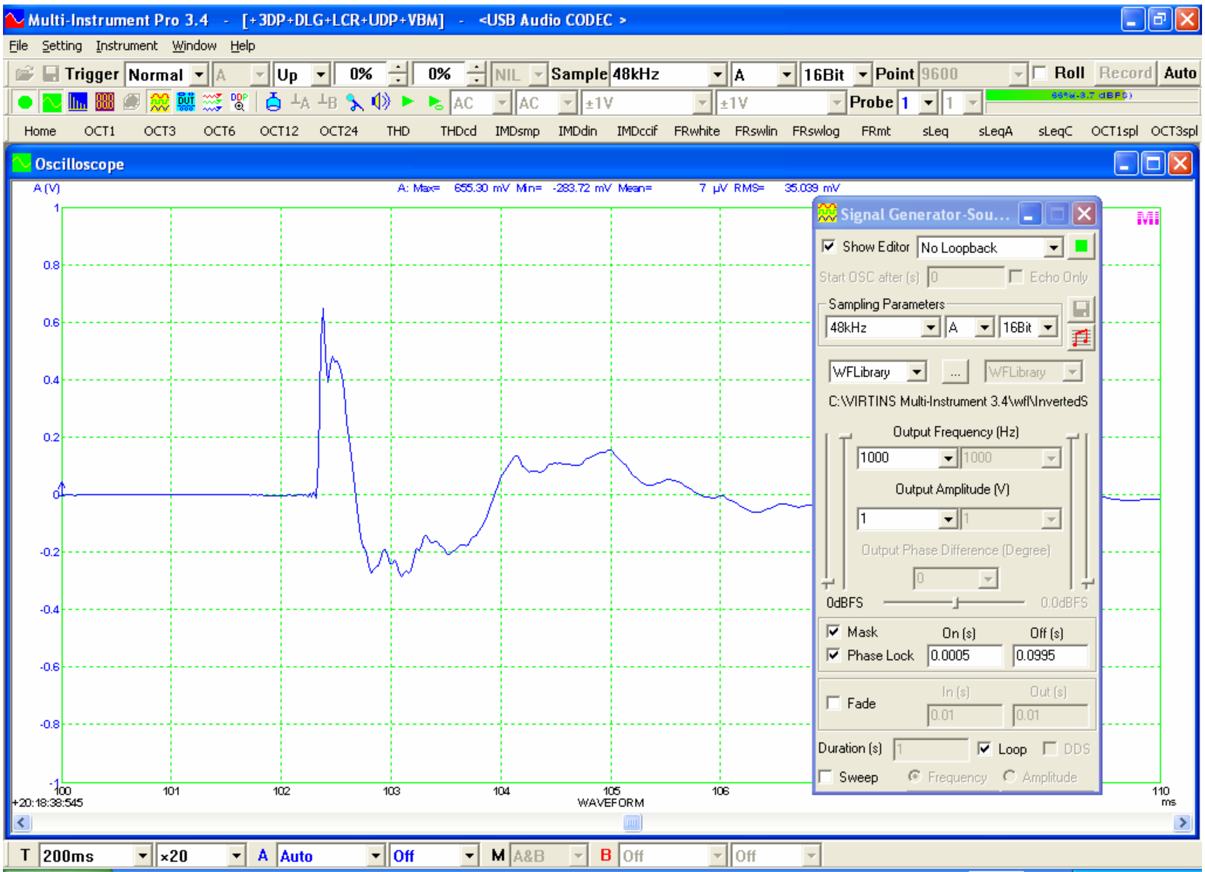
2.2.2.3 Half-Inverted-Sawthooth Burst

We can generate a half inverted sawtooth (Ramp Down) burst containing a half cycle of 1 kHz inverted sawtooth wave every 0.1 s (see figure below). Note that the mask period of the signal generator in Multi-Instrument is set to 0.1 s with On = 0.0005 s and Off = 0.0995 s and the Phase Lock option is ticked. It masks on and off a continuous 1 kHz inverted sawtooth wave and ensures each burst starts at a predefined initial phase. The inverted sawtooth wave is generated from InvertedSawtooth.wfl in the wave file library using WFLibrary function of the signal generator in Multi-Instrument.

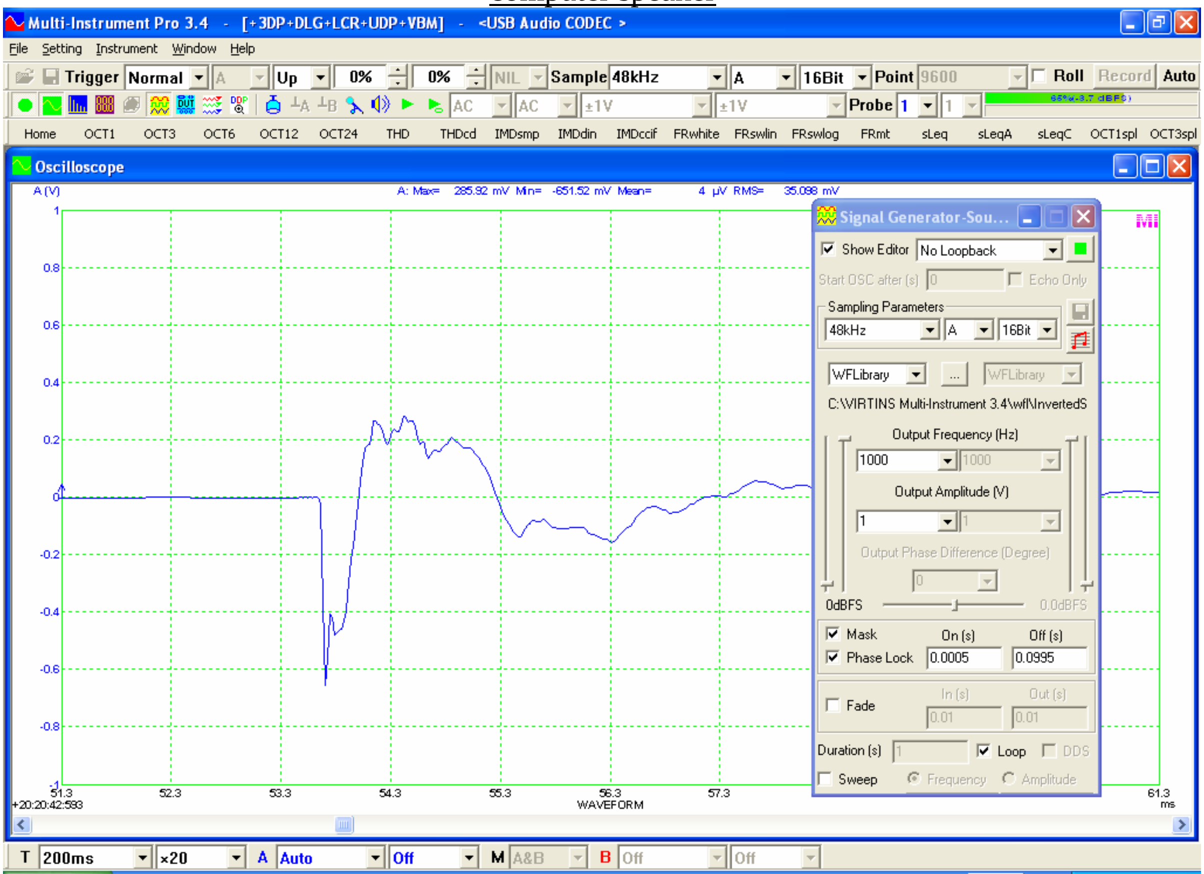


<u>Ideal 0.5 ms 1 kHz half inverted sawtooth burst at a repetition rate of 100 ms</u>

The following two figures show the above burst measured from a computer speaker without and with polarity inversion using VT RTA-168B.



Measured 0.5 ms 1 kHz half inverted sawtooth burst at a repetition rate of 100 ms from a computer speaker



Measured 0.5 ms 1 kHz half inverted sawtooth burst at a repetition rate of 100 ms from a computer speaker with its polarity inverted

It can be seen from the above two figures that the measured half inverted sawtooth burst has a quite correct shape until after the first half cycle. Sound reflection from the surrounding enclosure will usually arrive later after the first half cycle, so it will not change the shape of the first half cycle. Thus, the waveform captured is not very sensitive to the relative position of the measuring microphone in front of the speaker, compared with the cases of using periodic asymmetric waveforms. One good feature of the half inverted sawtooth burst is that the polarity can be determined by just comparing the absolute value of the Maximum and Minimum without using advanced waveform analysis methods. This feature can be used in automated polarity tests.

2.2.3 Which Test Signal Is The Best?

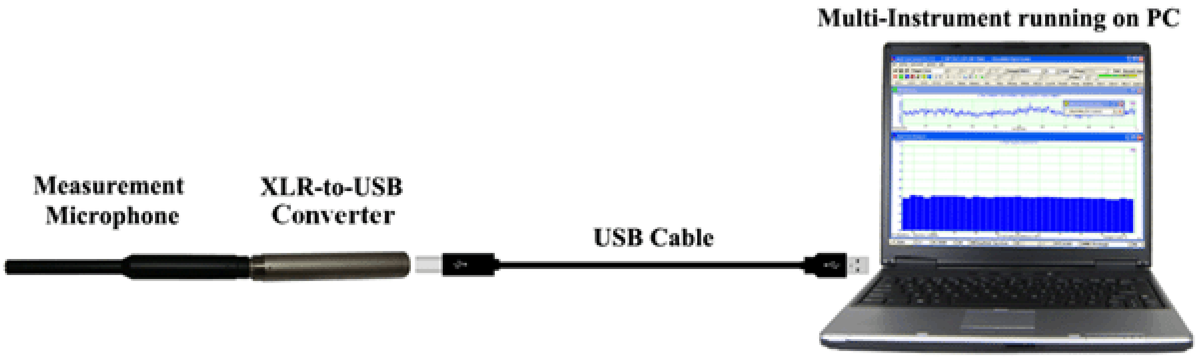
Its depends. For polarity tests, which do not involve any acoustic components, using a periodic asymmetric signal such as sawtooth or sinc, is simpler. Otherwise, a burst signal is preferred as the effect of sound reflection can be ruled out and the frequency response of the system does not have significant impact on recognizing the initial phase of the burst. Half sine and half inverted sawtooth (Half Ramp Down) bursts are recommended as they create significant difference between the heights of the positive and negative peaks. The polarity can be readily determined by comparing these two heights without looking at the captured waveform, which is a good feature for automated polarity tests.

You may need to change the frequency of the test signal so that it is more or less within the bandwidth of the DUT.

2.3 Absolute Polarity Calibration

In the previous section, we have discussed using different test signal to check the polarity of the DUT. If you want to test the absolute polarity, then the measuring tool must be calibrated, e.g. using a DUT with known polarity. The basic speaker polarity test using a battery can be used to make a reference speaker. The initial movement of the speaker, if it can be seen under the stimulation of a burst tone (you can slow down the repetition rate of the burst if necessary), can also be used to check the absolute polarity of a speaker. To make a reference microphone, utter a plosive "P" sound, which creates a positive air pressure before the microphone, and observe the initial phase of the waveform captured by the oscilloscope.

VT RTA-168 (www.virtins.com/VT-RTA-168.shtml) comes with the absolute polarity calibrated. A positive air pressure on the measurement microphone will result in a positive waveform in the oscilloscope of Multi-Instrument, provided that the waveform inversion button  in the Instrument toolbar is not pressed down.



VT RTA-168

2.4 How to Check a Stereo System's Polarity by Ears

First of all you need to make sure that the left and right speakers are located correctly. You can either use the signal generator of Multi-Instrument or the audio test CD that comes with VT RTA-168 to check. On the signal generator panel, Channel A is left and Channel B is right. In the audio test CD, there are two test tracks for this purpose, one reads "left" and "right" and the other reads "left", "right", "middle" and "surround", from the respective speakers if they are placed correctly.

Then, if you stand in the middle of the left and right speakers and play a mono sound such as a pink noise, white noise, frequency sweep, a tone or any sound containing bass. If the polarity of the speakers is correct, then the perceived sound should come from the middle of the left and right speakers. Otherwise, the perceived sound will be thin and lack bass and will not converge to a single source. The signal generator of Multi-Instrument allows you to generate stereo tones with a phase shift. You can use this feature to check how it sounds like if the two tones are in-phase (0°) or out-of-phase (180°). The audio test CD that comes with VT RTA-168 also contains quite a few in-phase and out-of-phase stereo sound samples.

2.5 How to Create an Audio Test CD using Multi-Instrument

Just set all the signal parameters including signal duration on the signal generator panel of Multi-Instrument first, and then press the save button . It will be saved as a WAV file. You can then create an Audio Test CD from the saved wave files.

2.6 How to Create a Polarity Tester with Color Display in Multi-Instrument

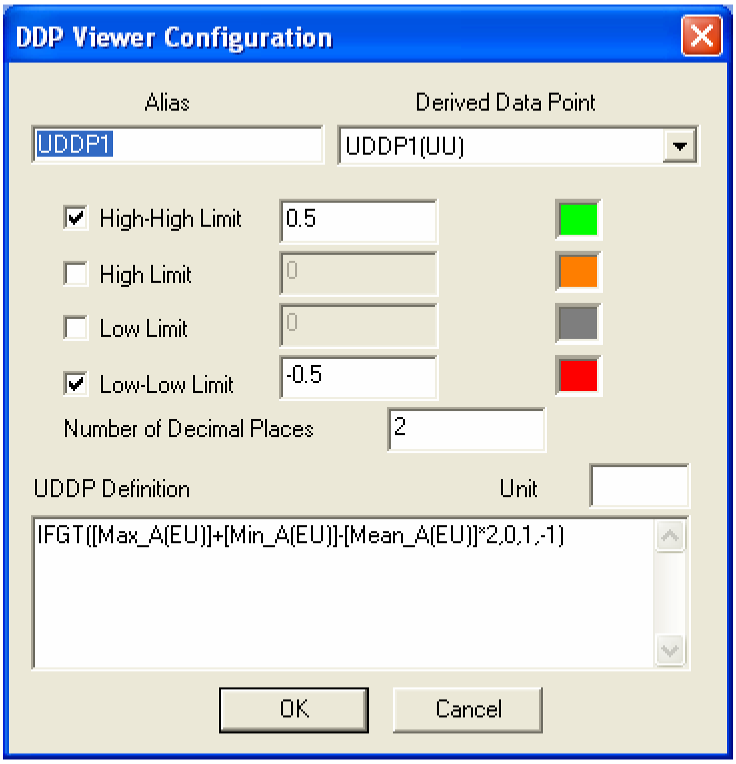
It is very handy if we can use color to indicate different polarity in Multi-Instrument. This can be done using DDP Viewer.

The configuration of the DDP Viewer is shown in the figure below. A User Defined Derived data Point (UDDP) is defined using the formula:

IFGT([Max_A(EU)]+[Min_A(EU)]-[Mean_A(EU)]*2,0,1,-1)

where: [Max_A(EU)], [Min_A(EU)] and [Mean_A(EU)] represent the maximum, minimum and mean, respectively.

The formula defines that if [Max_A(EU)]-[Mean_A(EU)] is greater than [Mean_A(EU)]-[Min_A(EU)], then the value of the formula is 1, otherwise –1.

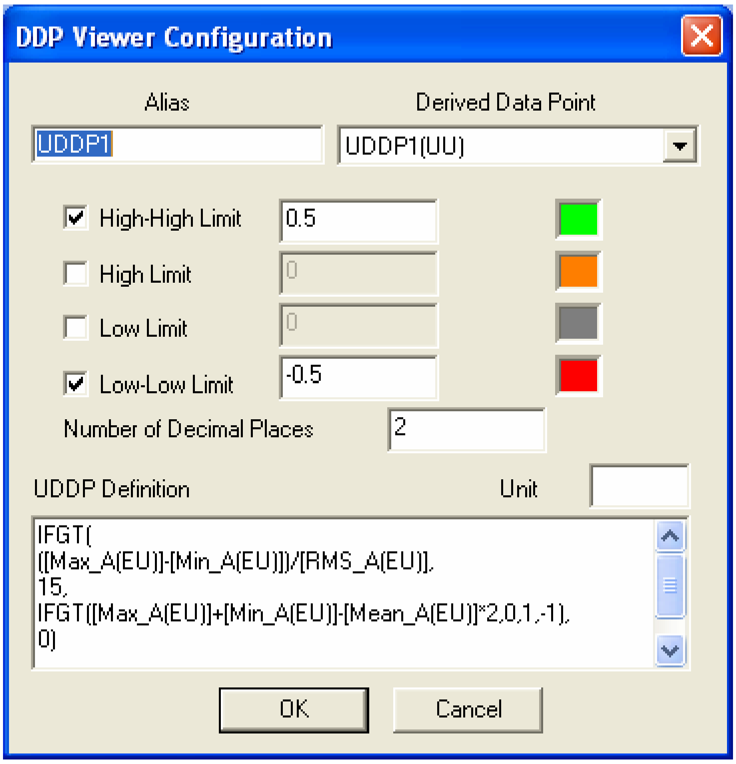


The alarm color is used to indicate polarity. When the value is less than –0.5, red color will be displayed (for VT RTA-168, this means negative polarity). When the value is greater than 0.5, green color will be displayed (for VT RTA-168, this means positive polarity). The above formula, however, will always indicate a polarity, either negative or positive, even if the test signal is not present in captured data. This will cause confusion. One way to check the presence of a burst signal is to use the crest factor, which is defined as the ratio of the peak to the RMS. The modified configuration of the DDP Viewer is shown in the figure below. A User Defined Derived data Point (UDDP) is defined using the formula:

IFGT(
([Max_A(EU)]-[Min_A(EU)])/[RMS_A(EU)],
15,
IFGT([Max_A(EU)]+[Min_A(EU)]-[Mean_A(EU)]*2,0,1,-1),
0)

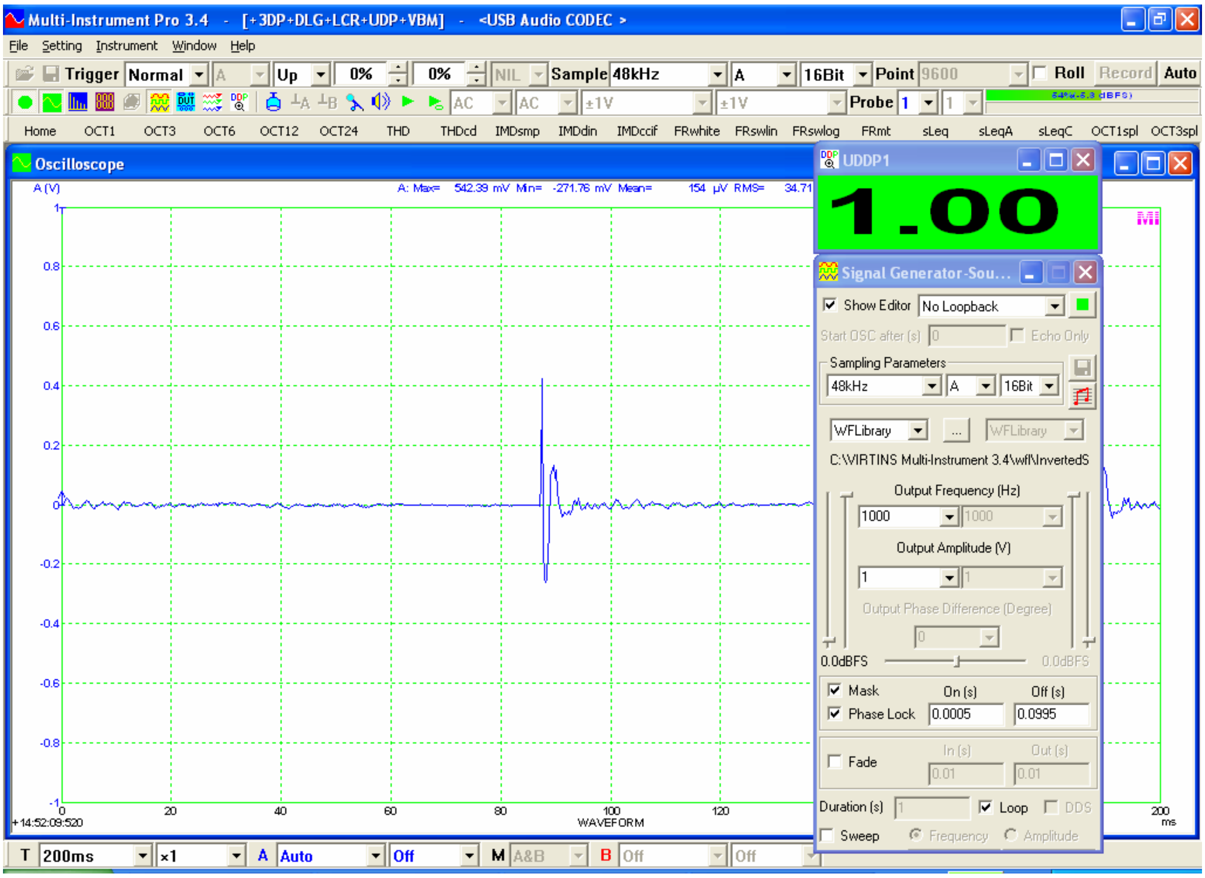
where: [Max_A(EU)], [Min_A(EU)], [Mean_A(EU)] and [RMS_A(EU)] represent the maximum, minimum, mean and RMS, respectively.

The formula defines that if the modified crest factor ([Max_A(EU)]-[Min_A(EU)])/[RMS_A(EU)] is greater than 15, an indication of the presence of the test signal, then the value of the formula is IFGT([Max_A(EU)]+[Min_A(EU)]-[Mean_A(EU)]*2,0,1,-1) which is either 1 or -1, otherwise 0.

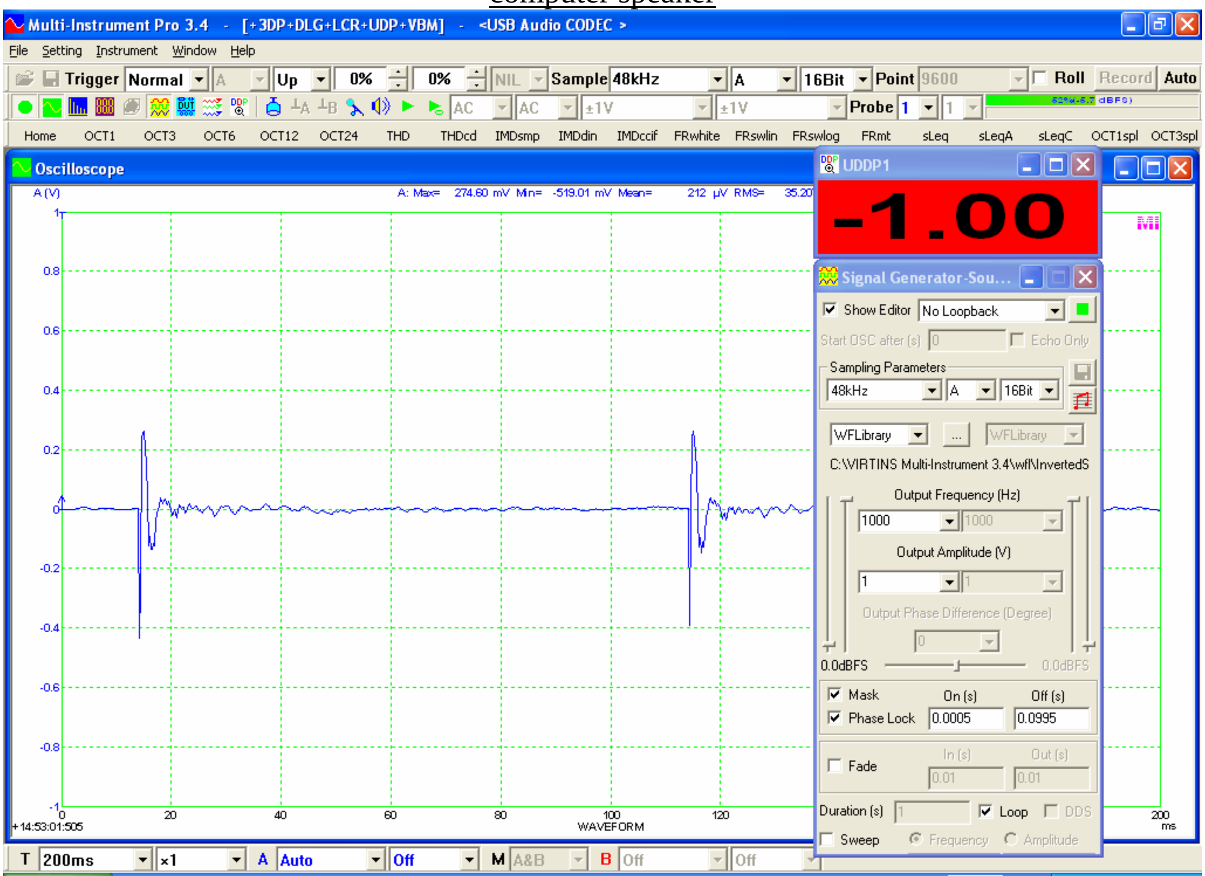


In the \PSF subdirectory of Multi-Instrument, there are two pre-configured polarity test Panel Setting Files: Polarity_Tester.psf and Polarity_Tester_WithCrestFactorCheck.psf. They use the setting described above and a half inverted sawtooth burst signal. You can load one of these settings via [Setting]>[Load Panel Setting].

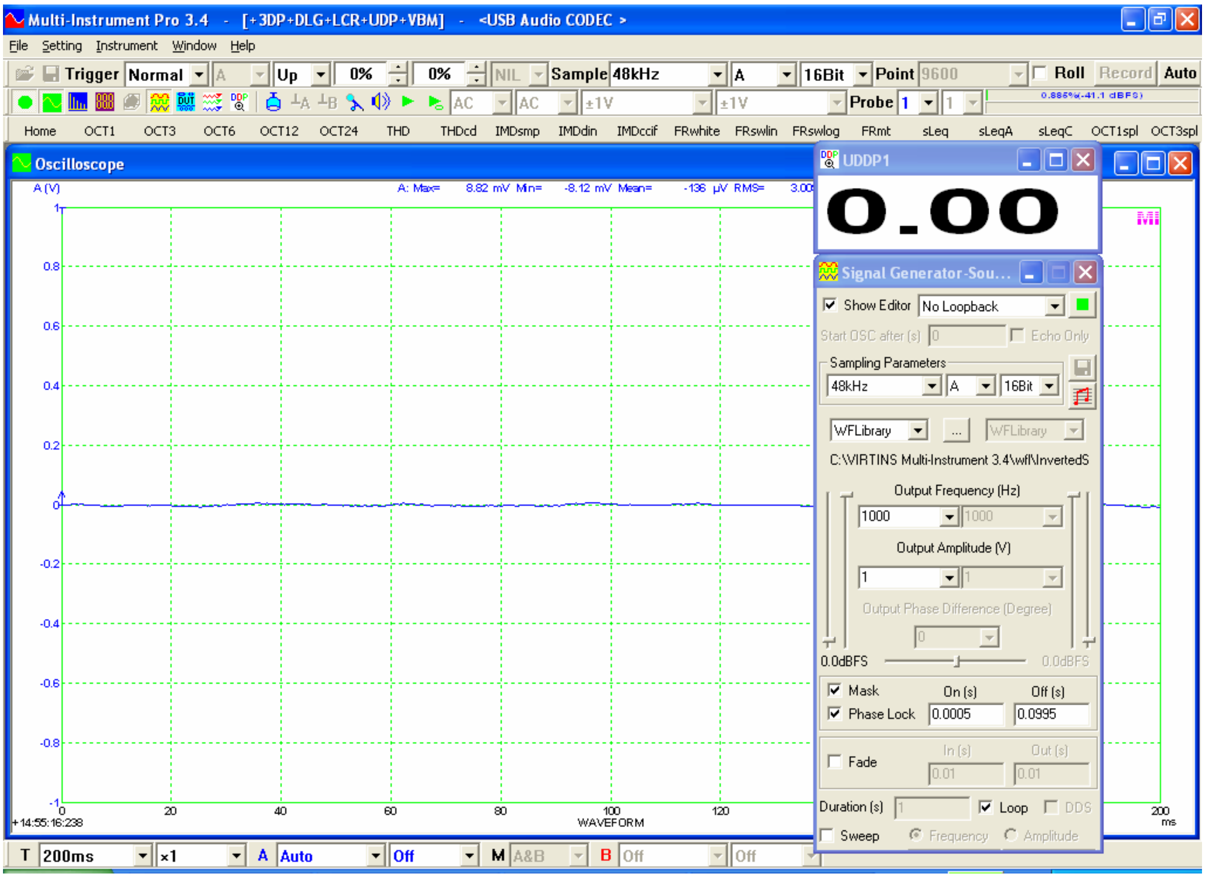
The following three figures show a half inverted sawtooth burst signal measured from a computer speaker under different conditions using VT RTA-168B.



Measured 0.5 ms 1 kHz half inverted sawtooth burst at a repetition rate of 100 ms from a computer speaker



Measured 0.5 ms 1 kHz half inverted sawtooth burst at a repetition rate of 100 ms from a computer speaker with its polarity inverted



same setting when no test signal or the test signal is not strong enough

