

## MLS SPL calibration using sinewave

By Bohdan Raczynski

Maximum Length Sequences (MLS) are easy to generate digital sequences, and possess interesting properties, that make them really interesting in the field of acoustic measurements.

Being digital signals with binary +1/-1 levels, its root-means-square (RMS) level is, theoretically, equal to its peak level – meaning, that the crest factor is unity (CF=1). This is exactly what we would need for generating maximum power from our amplifiers and loudspeakers, used for Room Impulse Response (RIR) measurements in large concert halls and venues.

The measurements can be affected by:

1. Background noise
2. Nonlinearities
3. Time variance in the system under test.

### Background Noise

Theoretically, and MLS provides the maximum excitation level for a given amplitude (low crest factor) and therefore the highest obtainable SNR. However, in practical applications, the digital MLS stream must be low-pass filtered before it's delivered to the loudspeaker, and this process will degrade the crest factor (CF).

Some sources quote deterioration in CF as large as 10-12dB, however, I have measured the CF on my sound card, and the results are shown below. The CF is somewhat dependant on sampling frequency and the length of MLS signal. Here are some examples measured on Delta1010LT sound card:

MLS length	Sampling	Vpp	Vrms	Crest Factor
64k	48k	7.25V	1.91V	5.60dB
64k	96k	6.56V	1.84V	5.02dB
132k	48k	7.25V	1.74V	6.30dB

Please note that the crest factor for sine-wave is 3dB. Therefore, the deterioration of CF due to using MLS signal is only about 3dB. The available SNR will be reduced by the same amount.

However, the common practice to improve the SNR is to average repeated measurements. The SNR improves by approximately 3dB if the number of averaged measurements is doubled. So, two consecutive measurements will improve the SNR by 3dB, four consecutive measurement will improve the SNR by 6dB and so on.

It may be interesting to visualize the MLS and sine-wave with identical CF and RMS values – see Figure 1.

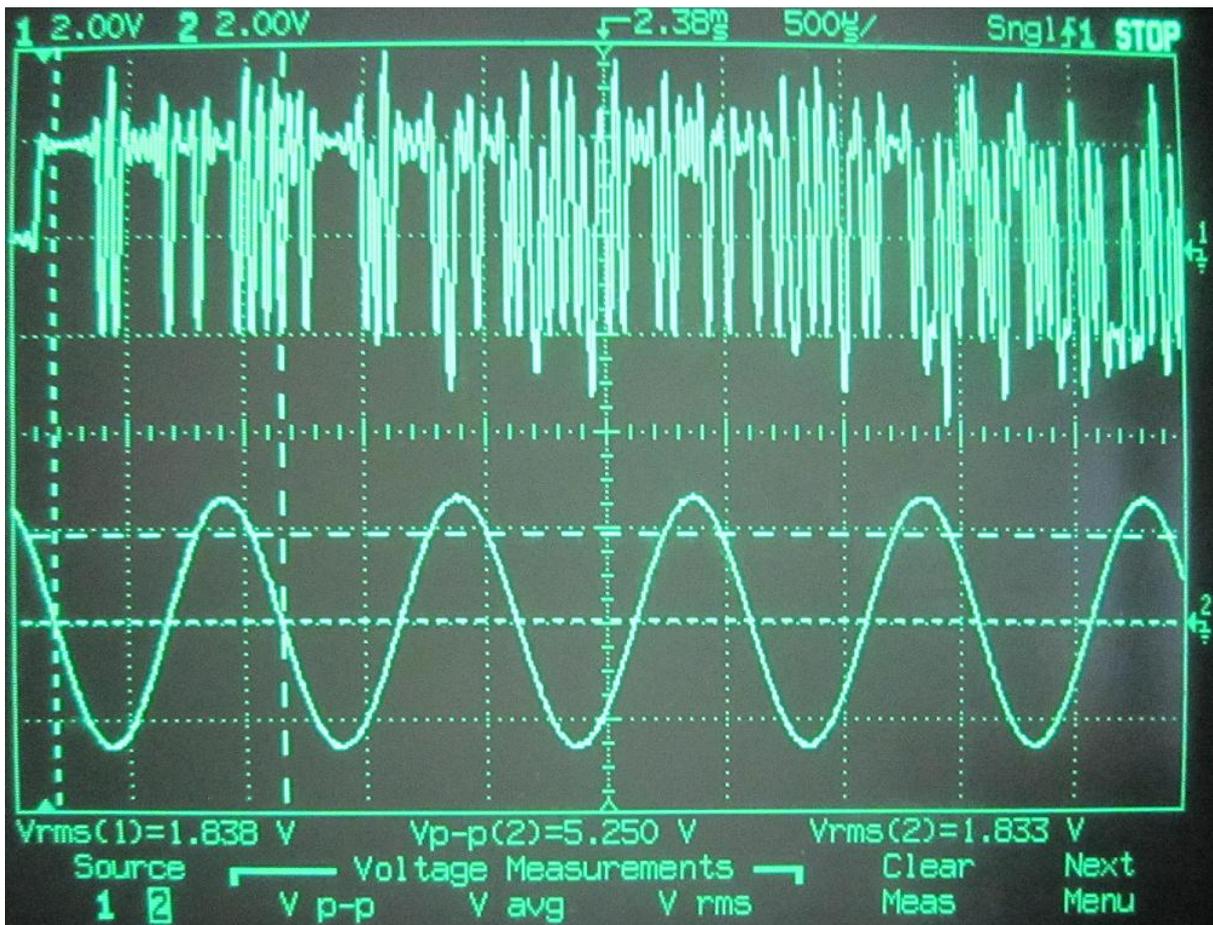


Figure 1. MLS and sine-wave (1000Hz) with almost identical RMS values.

## Nonlinearities

If the system to be measured exhibits nonlinearities, the measured impulse response will be affected. The nonlinearities manifest themselves as small spikes along the decaying tail of the impulse response.

The position of these spikes can not be predicted, however, for a particular system, the appearance of these spikes is directly linked to a particular MLS sequence used, and repeated measurements will always see them in the same location- so they can not be reduced by simple averaging.

There exists quite effective way of dealing with nonlinearities in MLS systems. The idea is to perform repeated measurements using different, cyclically distinct, MLSs, so that the nonlinearity peaks will pop up in different locations. Then simply apply averaging. Each time the number of averages is doubled, the noise due to nonlinearities is reduced by approximately 6dB. Even a relatively small number of repetitions will push the nonlinearity peaks into the noise floor, so there is no need to be concerned about them any more.

It is possible to provide an MLS scheme which is capable of largely eliminating nonlinearities. However, I have not encountered any instances, where such scheme would be needed.

## **Time variance**

Time variance can be divided into:

1. Inter-periodic – effects that occur between two measurements, for instance, slow temperature changes.
2. Intra-periodic – effects that occur within an MLS measurement period, like wind and clock jitter.

Slow temperature changes are typically not a problem in loudspeakers driven at 1Watt/1meter measurement scenarios.

Wind can be a factor in outdoor measurements, so there is an obvious need to avoid windy conditions – this would be true for any type of measurements.

## **MLS Advantages**

1. MLS- related signals have a SNR improvement proportional to their period length.
2. They can be used in noisy environment or at low excitation level.
3. Relative high noise immunity and an efficient correlation algorithm have significantly improved RIR measurements, acoustic impedance-tube measurements, absorption coefficients in reverberation chamber even with rotating diffuser, in situ measurements of sound insulation of noise barriers, acoustic surface reflection functions, both indoor and outdoors, measurement of head-related transfer functions and hearing aids, applications in underwater acoustics and landmine detection.
4. The interest in MLS measurement technology has also stimulated investigations on its advantages, such as high-transient noise immunity.
5. Spectrally, MLS signal more closely resembles real musical signal, while sine-wave is just a single spike on the frequency spectrum.
6. Analogue gated sweep is a single-channel, amplitude only measurement, so does not provide phase information. Phase must be recovered with high degree of probability using HBT. However, HBT only works for single driver measurements (because it's minimum-phase). Therefore you can not measure the phase response of a loudspeaker system - which is typically non-minimum phase.
7. On the other hand, the MLS system is dual-channel, will measure phase of anything you throw at it, and even has "coloured" MLS version to measure tweeters without feeding low-frequency spectrum into the driver (driver protection).

## Can MLS system be calibrated for DIY?

Process discussed here sets out to determine “efficiency” of the driver. Typically, a 1Watt signal is fed into the driver, and a calibrated measurement microphone picks up the sound at 1 meter distance. The result is presented as some value in decibels. For instance, Efficiency = 95dB would indicate very efficient driver, while Efficiency of 80dB would indicate rather inefficient driver.

Before we bring the MLS into the discussion, it's worth mentioning, that the Efficiency of a driver is one of the most basic parameters of a driver, and is typically always provided by the manufacturer.

Secondly, the Efficiency can be easily calculated from TS parameters of the driver. So if it's missing from the specs, then can be easily calculated – see formulas 2.34, 2.35, 2.36 and 2.37 in “Testing Loudspeakers” by Joseph D’Appolito.

Clearly, we are trying here to duplicate something that has already been done by the manufacturer.

OK, but the above process relies solely on sine waves used for measurements. Now, we can feed a sine wave into the MLS system and discover what happens.

## Measurement System Set-up

Here is a simple idea: Assuming, that sine-wave and the MLS signal have the same RMS values - Is the MSL system going to respond with ***the same SPL level***, when a sine-wave OR MLS is fed into it?.

In order to check the MLS signals, I have used SoundEasy V20 in loopback mode. For sine wave comparisons, I have injected a 1000Hz sine wave from external generator right into the MLS input port of the sound card. Both signals were monitored by a digital storage CRO – see Figure 1. Smoothing was 1/12oct, MLS length = 131071 and sampling frequency was 48kHz. These parameters are important – see Figure 2 below.

When the sine wave was used as an input signal, I have used symmetrical Blackman-Harris windows of 20ms length, centered at 10ms – see Figure 3 below. My arbitrary voltage level was RMS = 0.0dB, or 1.8V.

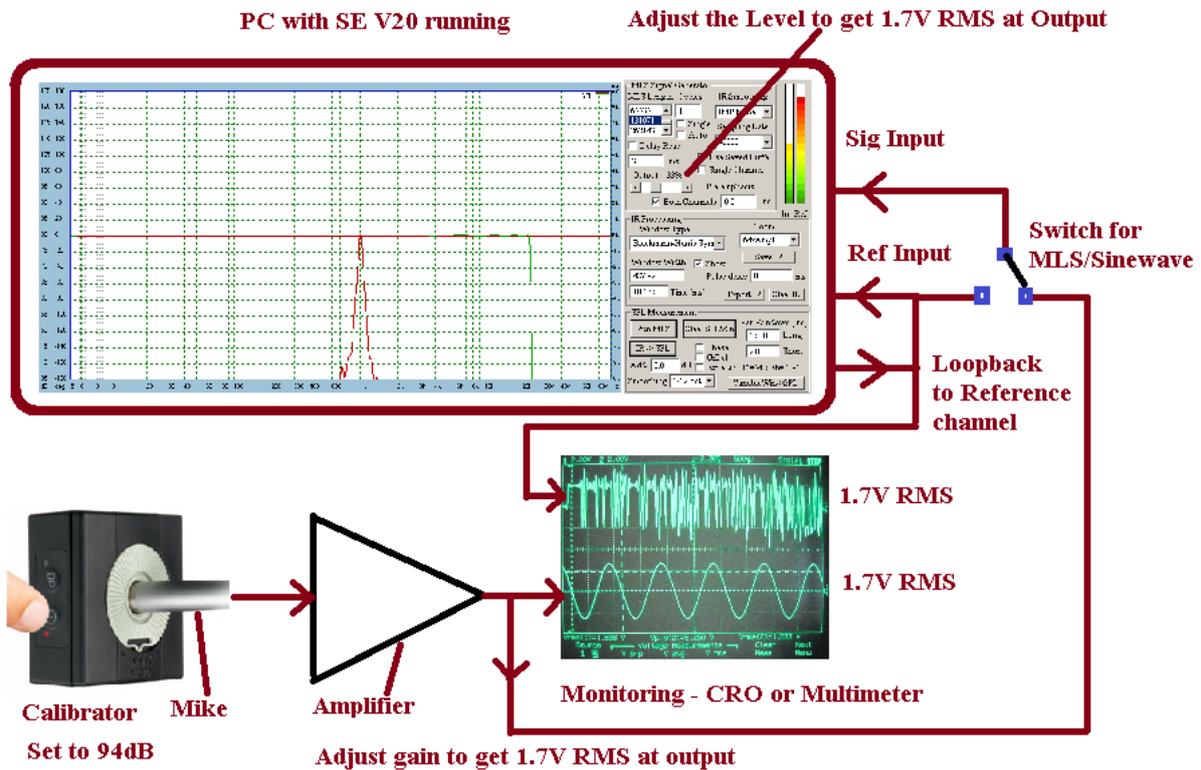


Figure 2. Measurement system diagram.

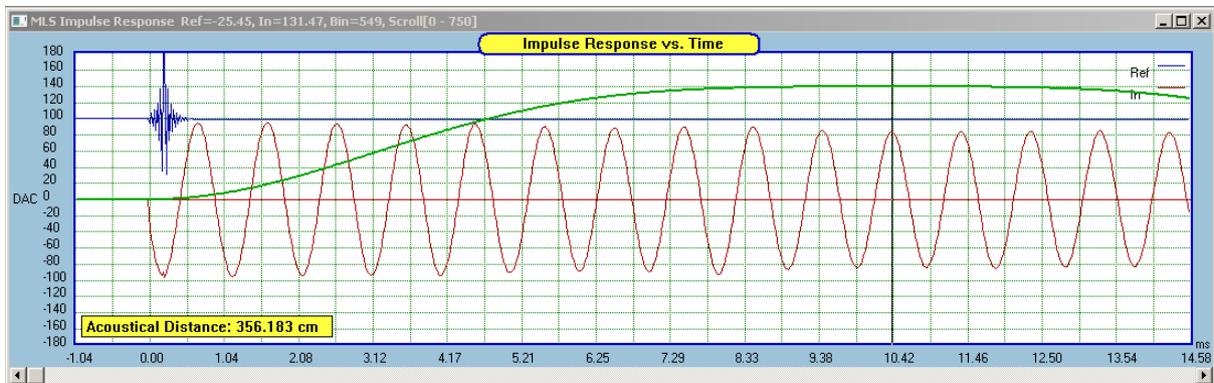


Figure 3. Sine wave RMS = 0.0dB (1.802V), Blackman-Harris 10ms long, set at 10ms, Amplitude Zoom=64

When the MLS was used as an input signal, I have used standard Blackman-Harris windows of 100ms length, located at 0ms – see Figure 4 below. My voltage level was RMS = 0.0dB, or 1.801V. (must be very similar as for sine wave).

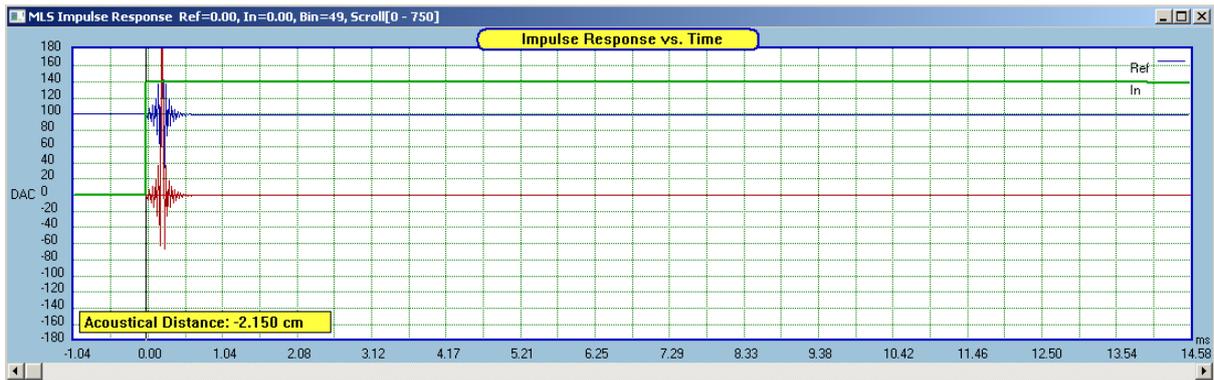


Figure 4. MLS generator at 33% (1.79V RMS). Blackman-Harris 100ms long, set at T=0. Amplitude Zoom=1

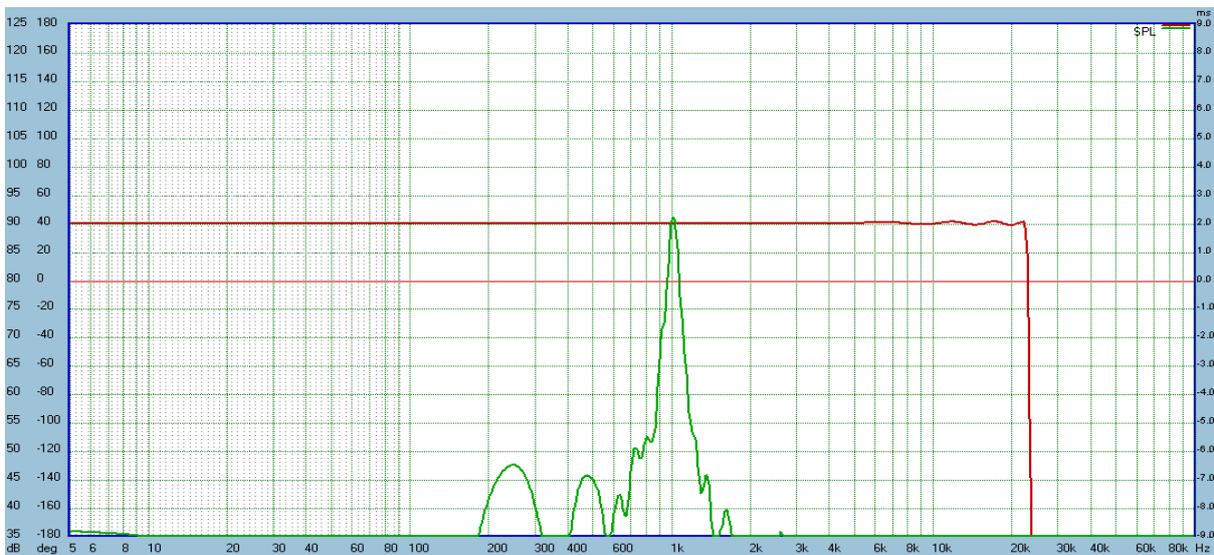


Figure 5. Green – sine wave response after FFT, Brown – MLS response after FFT.

**Note, almost the same level of 90dB.**

In the next step, the levels of both signals were reduced by 10dB, and the measurements were repeated.

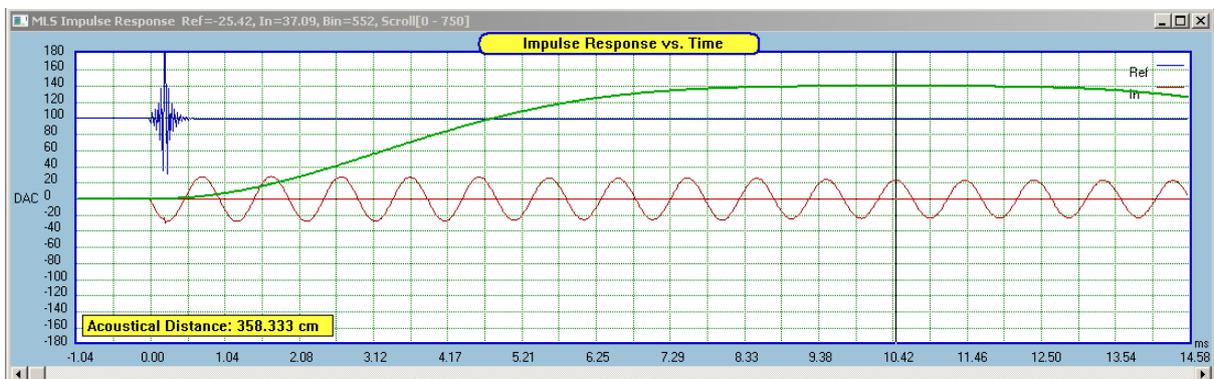


Figure 6. Sine wave RMS = -10dB (0.554V), Blackman-Harris 10ms long, set at 10ms, Amplitude Zoom=64

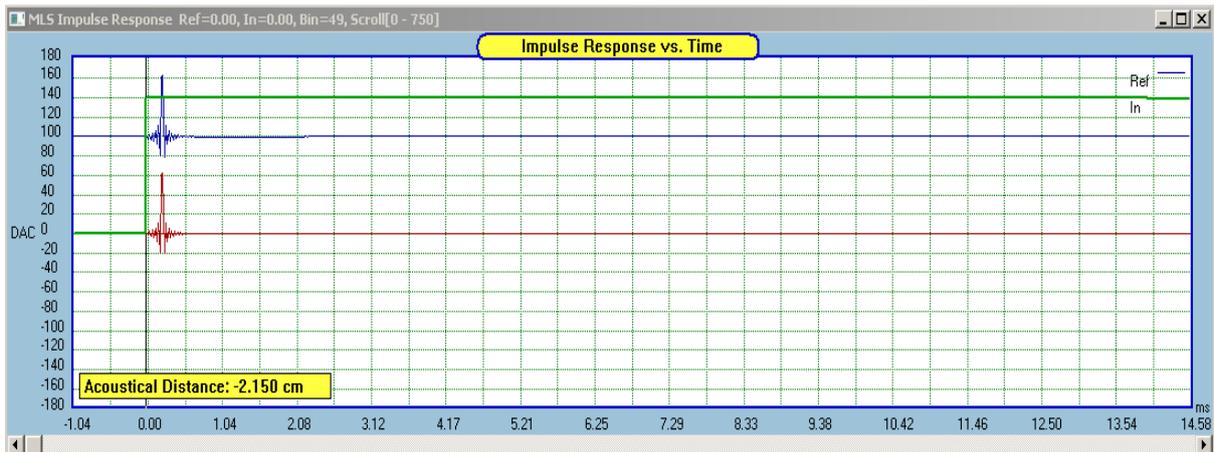


Figure 7. MLS generator = -10dB (or 11% or 0.556V) Blackman-Harris 100ms long set at T=0. Amplitude Zoom=1



Figure 8. Brown – sine wave response after FFT, Green – MLS response after FFT. Note, almost the same level of 80dB.

Interestingly, I can feed an MLS signal with a given RMS level, OR a sinewave with the same RMS level, and BOTH signals will manifest themselves at the same level on the SPL plots.

The process is linear. I could reduce the level of both signals by -10dB, and obtain the same 10dB reduction in both SPL displays.

## Further investigation

It strongly recommended to conduct some investigation of your PC+MLS system in order to confirm the findings shown below.

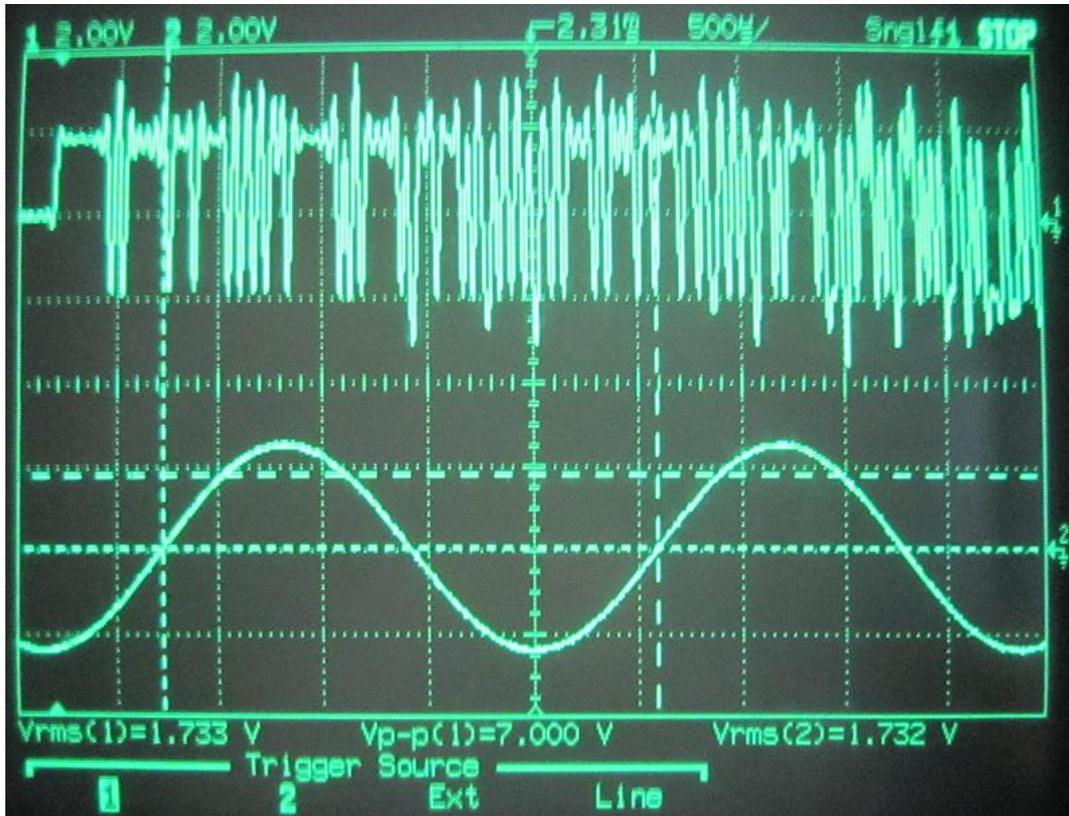


Figure 9. MLS and sine-wave (300Hz) with identical RMS values.

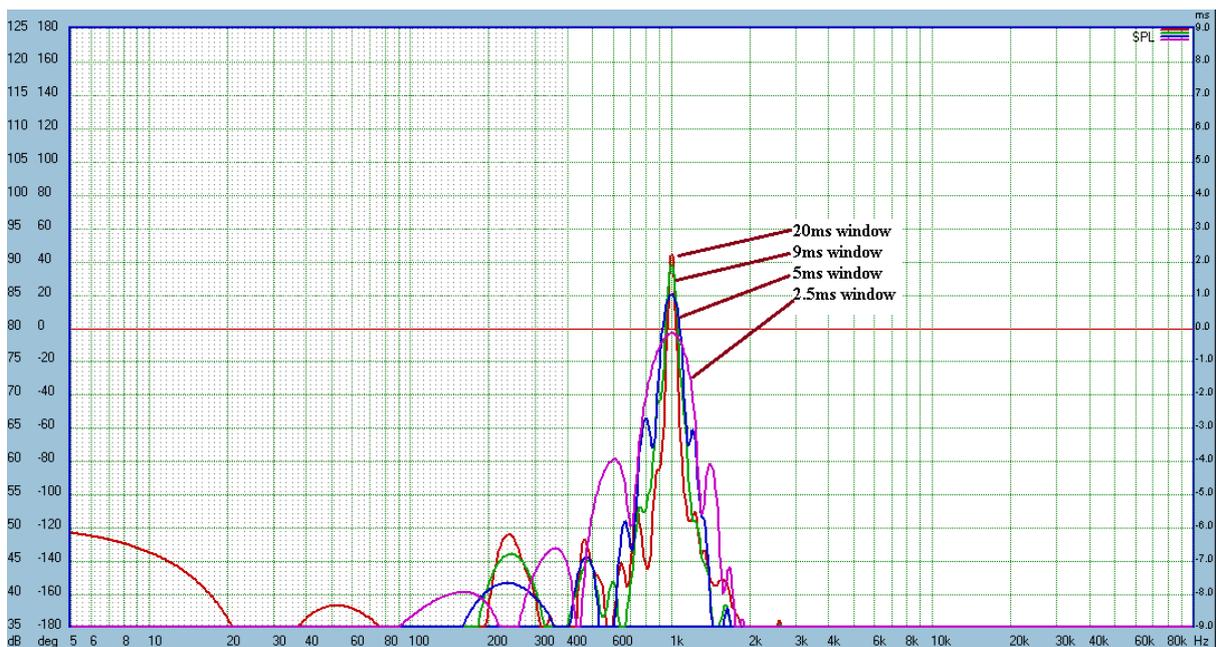


Figure 10. The shape and height of the peak is related to the width of the symmetrical Blackman-Harris window.

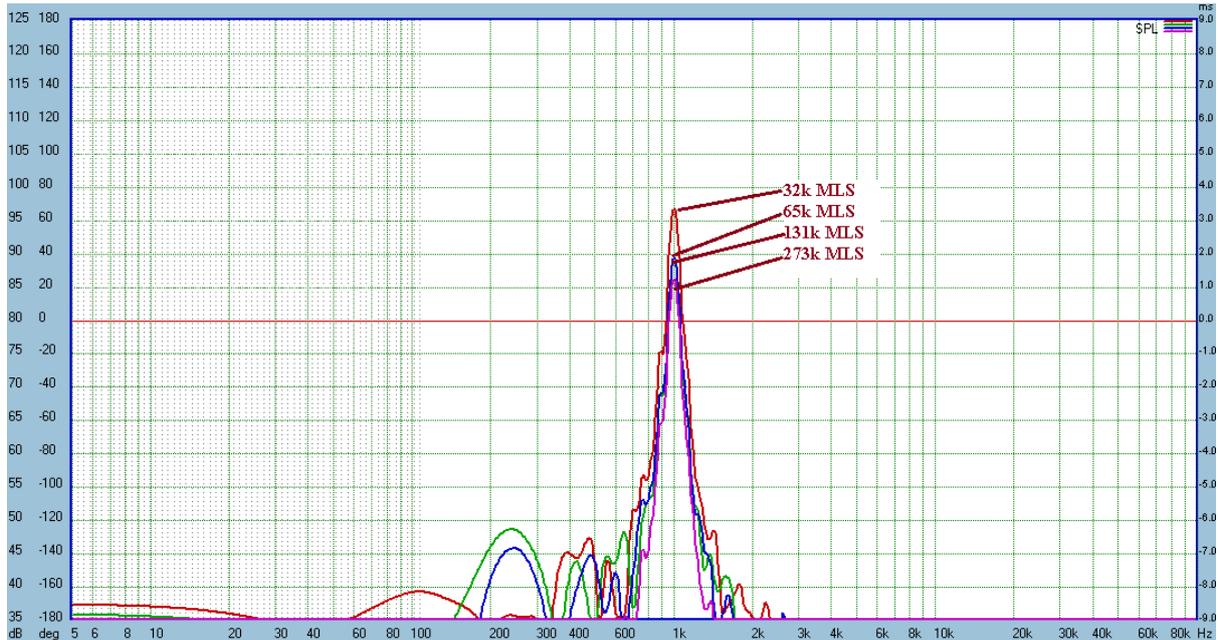


Figure 11. The shape and height of the peak is related to the width of the length of MLS. Recommended length is 65k or 131k. Window is 9ms Blackman-Harris window.

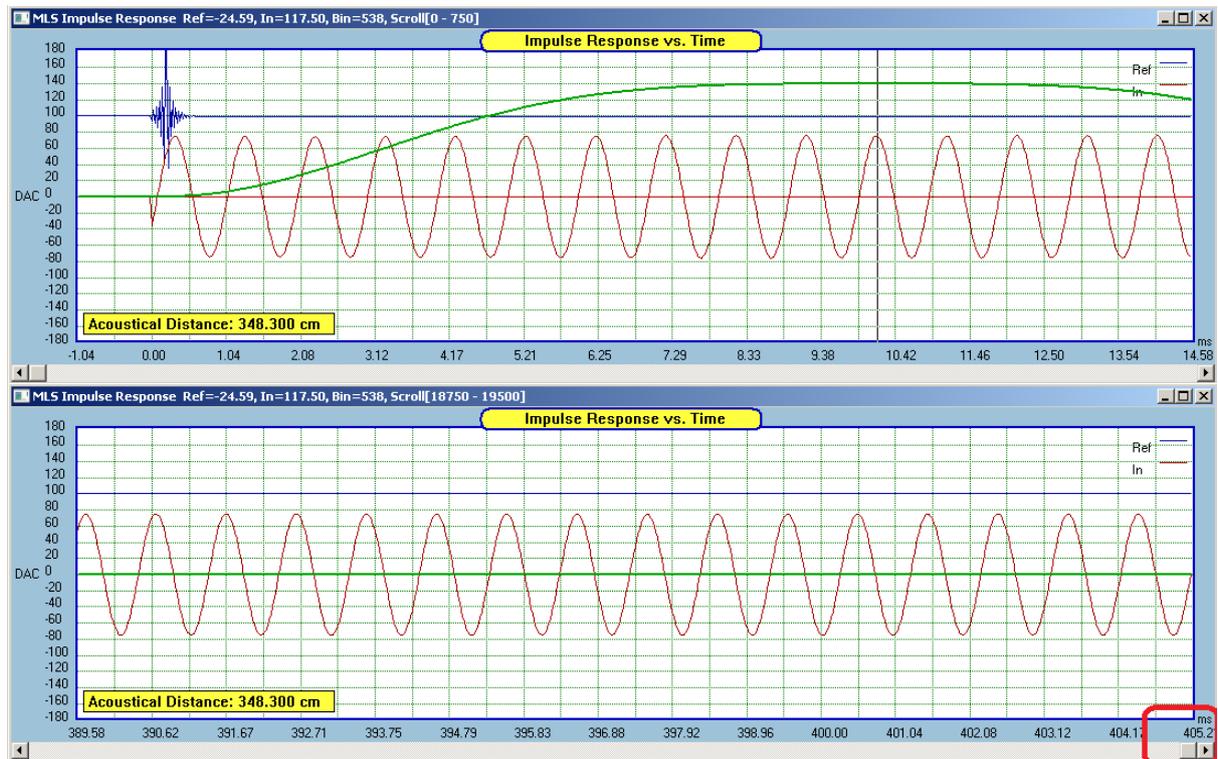


Figure 12. Captured sine-wave may fluctuate in amplitude after passing through Hadamard-Walsh Transform. Scroll through the captured Signal buffer to make sure, that the largest amplitude of the sine-wave is being windowed.

## Fast Hadamard Transform

The Fast Hadamard Transform (FHT) is used in MLS system to reorder received MLS sequence back into the impulse response of the DUT.

However, the reordering process, when applied to the received sine-wave was causing unwanted amplitude fluctuations. It was then decided to replace the FHT by simple vector scaling process when sine-wave was fed into the MLS system.

As a result, a checkbox, "Calibration" was introduced in MLS system which allows the user to switch the MLS system into sine-wave calibration mode.

## Proposed Calibration Sequence

Investigation into MLS system calibration conducted so far indicated, that regardless of the input signal, be it MLS sequence or sine-wave, the MLS measurement system can be modified to maintain its linearity. This is very important, as it allows us to propose a calibration method using an inexpensive, 1000Hz / 94dB microphone calibrator:

<http://www.bksv.com/products/transducers/acoustic/calibrators/4231>

### Quick and easy

In five seconds you can have a definitive calibration check. There are few options – simply click a microphone into place, press the button and it is done.

There is no need to remove the protective leather case to use it, and you don't have to spend time ensuring the fit is exact. Because of the 1000 kHz calibration frequency, there is no need to use filters for different weighting networks.

### Pocket-sized

This compact unit gives you a battery-operated sound source wherever you need it.



### Features

- Conforms to EN/IEC 60942 (2003) Class LS and Class 1, and ANSI S1.40 – 1984
- Robust, pocket-sized design with highly stable level and frequency
- Calibration accuracy  $\pm 0.2$  dB
- 94 dB SPL, or 114 dB SPL for calibration in noisy environments
- Extremely small influence of static pressure and temperature
- Sound pressure independent of microphone equivalent volume
- 1 kHz calibration frequency for correct calibration level independent of weighting networks
- Fits Brüel & Kjær 1" and 1/2" microphones (1/4" and 1/8" microphones with adaptor)
- Switches off automatically when removed from the microphone

Figure 13. 1000Hz / 94dB microphone calibrator

The calibration process described below is based on capabilities of the available hardware as follows:

1. Maximum undistorted input signal = 10Vpp (for Delta1010LT)
2. MLS crest factor = 6dB (for Delta1010LT)
3. Sinewave crest factor = 3dB
4. Calibration signal from microphone = 1000Hz at 1.0volt. This includes any microphone amplifier.

Let's consider the sine-wave first, with the voltages delivered by the Calibrator.

1 Vrms = 1.42Vp = 2,84Vpp - This voltage will be delivered to the MLS system when 94dB calibrator is used. The system should be able to handle +6dB level as well, so:

2Vrms = 2.84Vp = 5.68Vpp - This voltage will be delivered to the MLS system when 94dB + 6dB level arrives, so it's well within the 10Vpp input capabilities of the Delta1010LT sound card.

However, we will be using MLS pulse train **with 6dB crest factor**, so let's have a look at the MLS situation: 1Vrms = 2Vp = 4Vpp - This voltage will be delivered to the MLS system when 94dB SPL level is received. The system should be able to handle +6dB level as well, so:

2Vrms = 4Vp = 8.0Vpp - This voltage will be delivered to the MLS system when 94dB + 6dB level arrives, so it's well within the 10Vpp input capabilities of the Delta1010LT sound card.

**First, please enter 0.00 value as the "Calibration" factor into the Preferences screen.**

**Step 1 – Feed the 1.0Vrms signal from the Calibrator, with MLS system in Calibration Mode.**

MLS Settings for sine-wave input – please note the "Calibration" checkbox is ON.

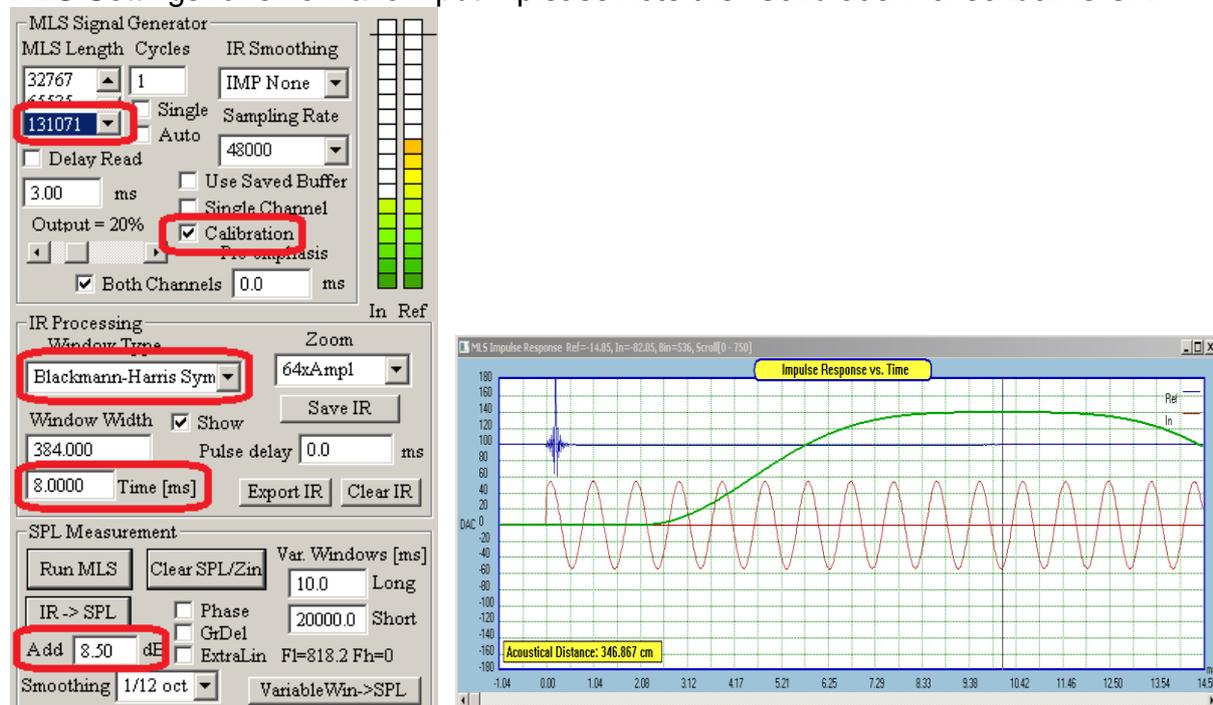


Figure 14. Major settings for sine-wave input – note the "Calibration" checkbox.

When the 1V rms sine wave from the calibrator is fed into the MLS system in "Calibration" mode, an 8.5dB is added to the SPL plot to bring it to the required 94dB level – see Figure 15 below.

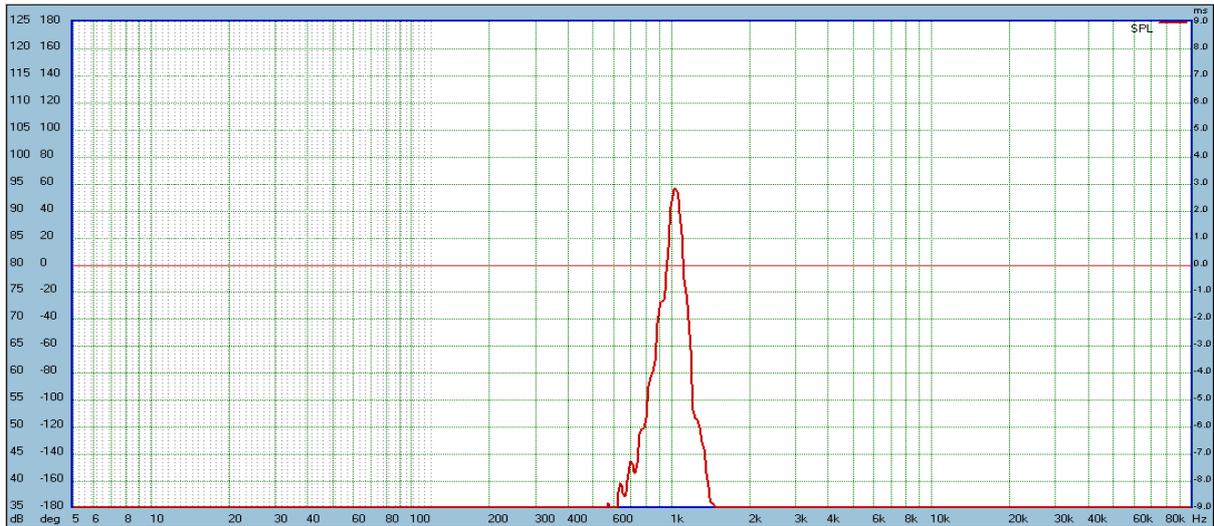


Figure 15. Modified MLS system response to sine-wave input.

## Step 2 – Feed the 1.0Vrms signal from the Delta1010LT MLS system.

When the 1Vrms MLS signal from the Delta1010LT output is fed into the MLS system, the same 8.5dB is added to the SPL plot to bring it to the required 94dB level – see Figure 17 below.

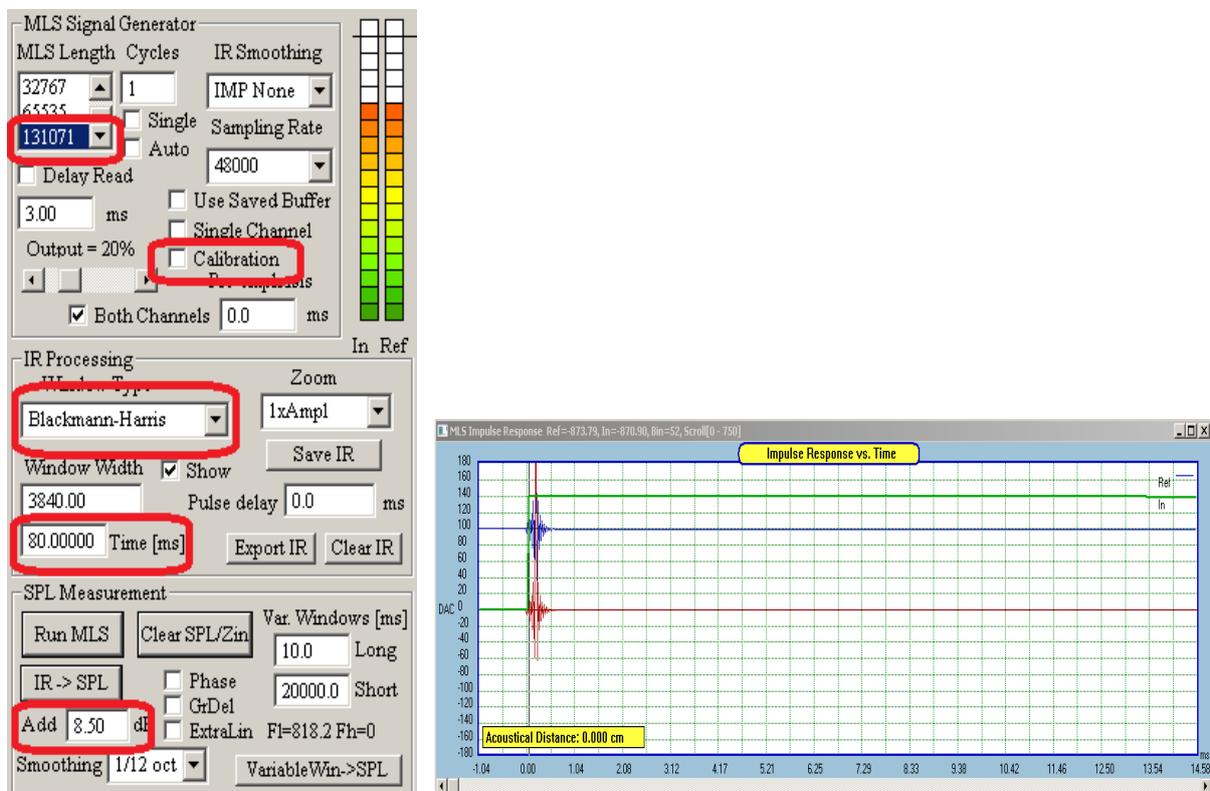


Figure 16. Major settings for MLS input – note the “Calibration” check box NOT checked.

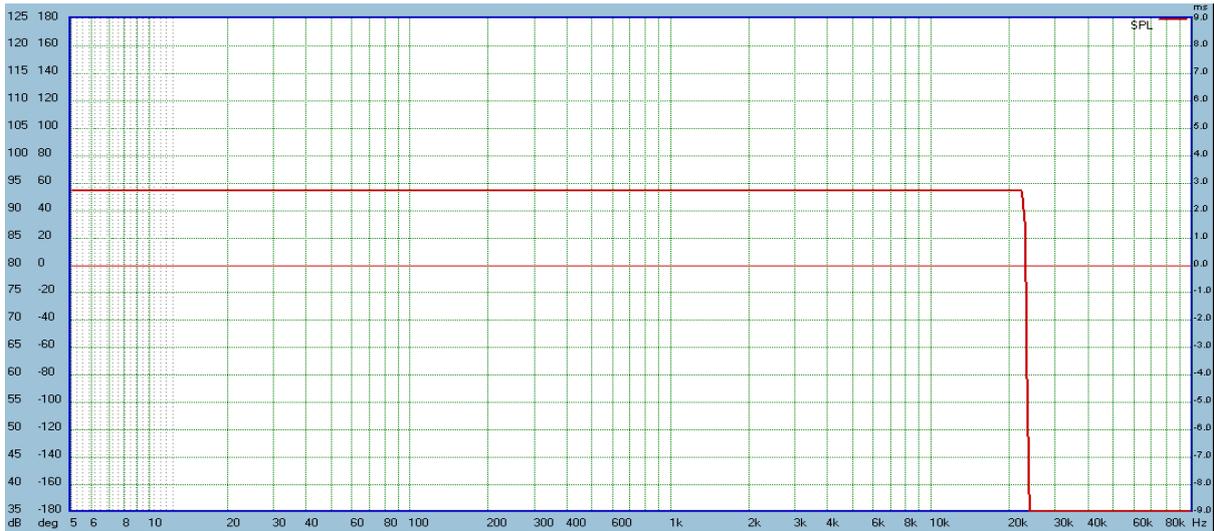


Figure 17. MLS system response to MLS signal input.

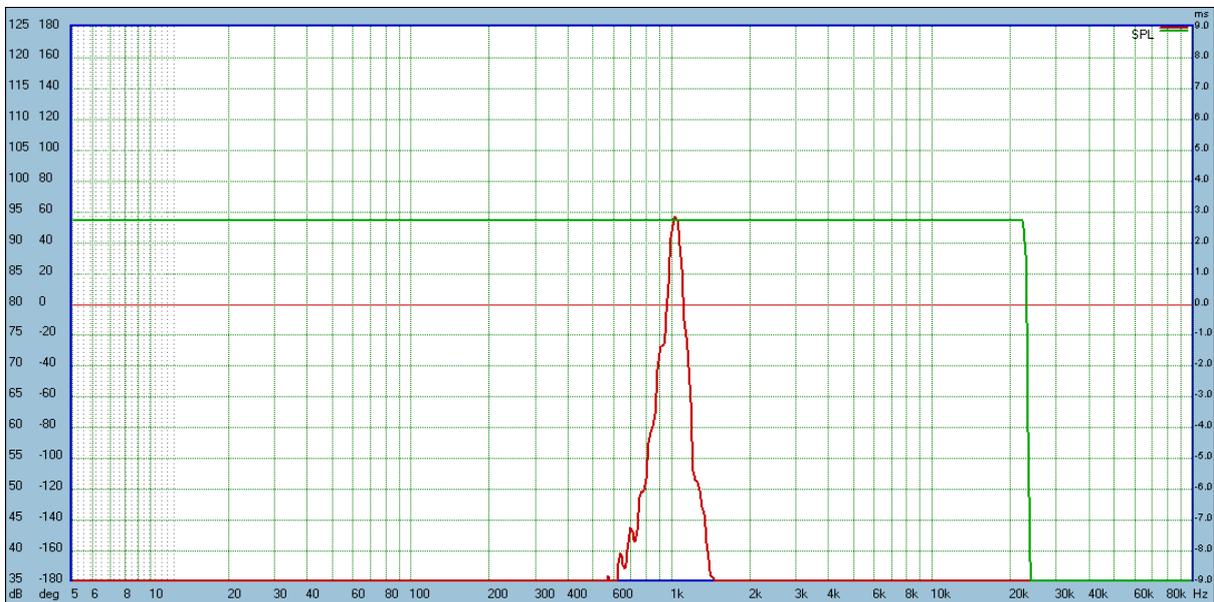


Figure 18. Both, MLS and sine-wave signals overlapped on the same plot.

As it can be observed from the Figure 18, the SPL plots are quite close to each other. It is estimated from the plots, that the accuracy of the sine results tracking the MLS results in the process described above is about +/- 1dB.

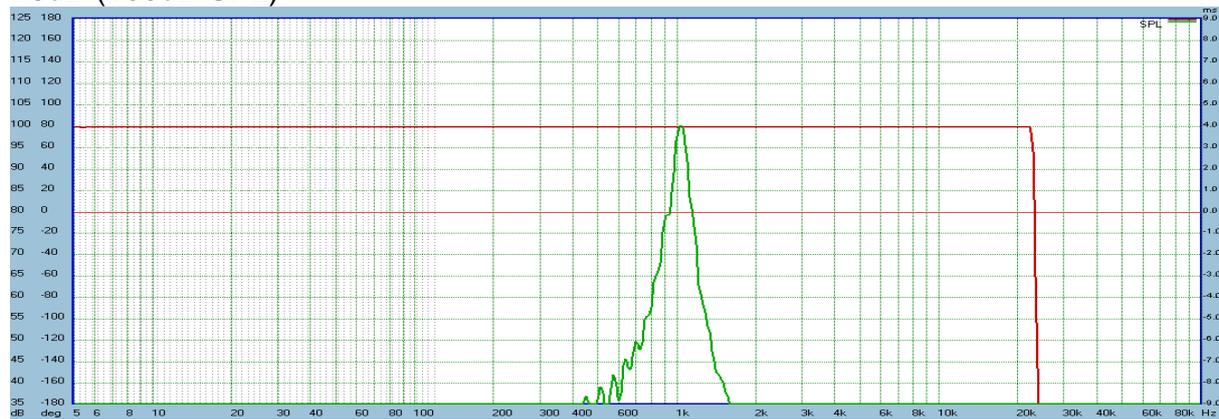
Environment		
Temperature		
Speed of Sound	344.00	m/s
Calibration	8.50	dB

Finally, please transfer the added decibel value as the “Calibration” factor into the Preferences screen. This value is now saved into the Preferences file, and you are free to use the “Add” data field in the MLS TAB as usual – see above.

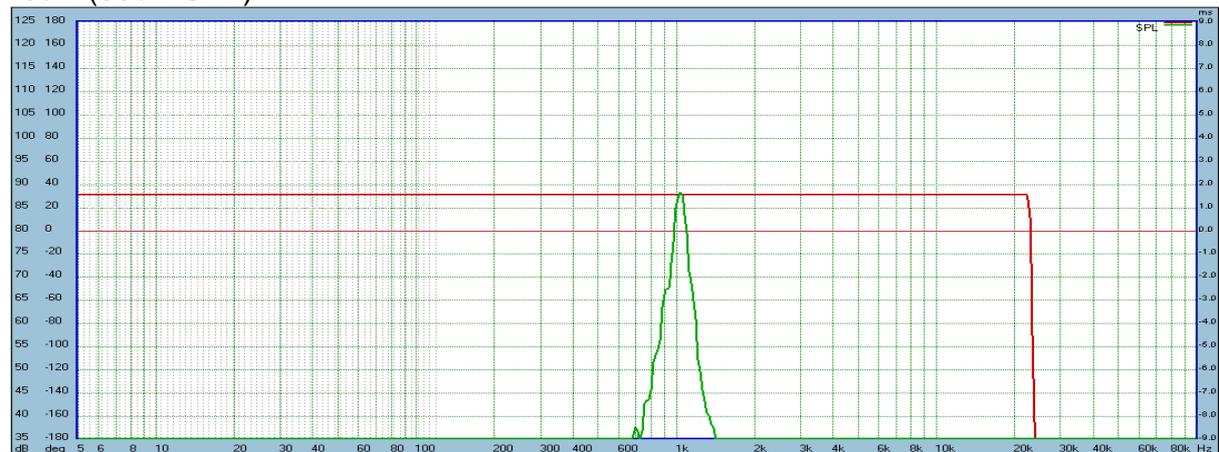
## Linearity check

Final check for tracking accuracy between MLS and sine-wave inputs are shown below. Both signals were increased by +6dB, then decreased by -6dB and finally by -20dB. As observable from the figures below, excellent tracking has been achieved. Each time the system uses sine-waves, it must be switched to "Calibration" Mode.

### +6dB (100dB SPL)



### -6dB (88dB SPL)



### -20dB (74dB SPL)

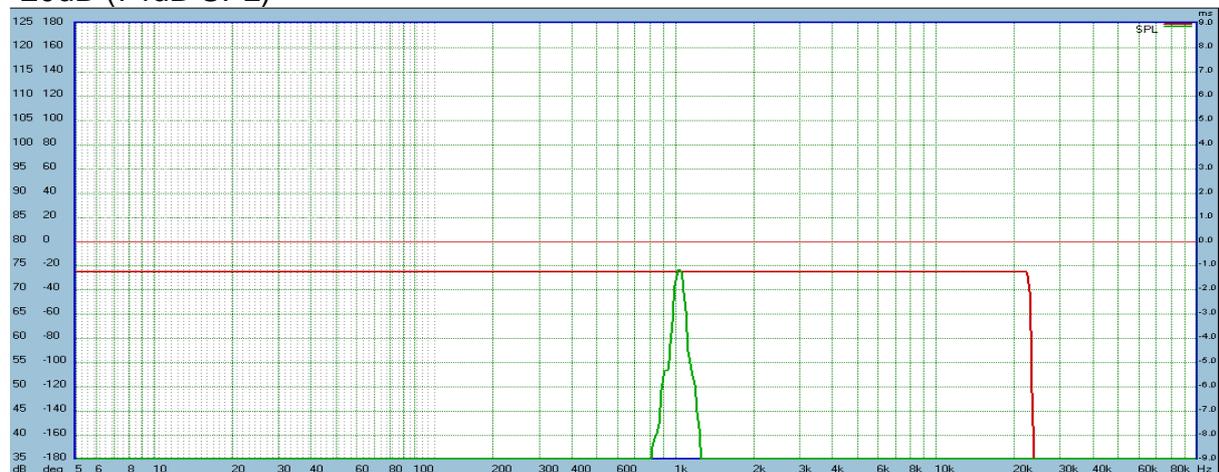


Figure 19. +6dB, -6dB and -20dB linearity check.

### Step 3 – Set the MLS signal at 1Watt and feed it to the loudspeaker

Built-in “Reflection-Free Path” calculator may help you with locating the first surface reflection, and that should assist you in selecting FFT window length for suppressing the reflections showing on impulse response.

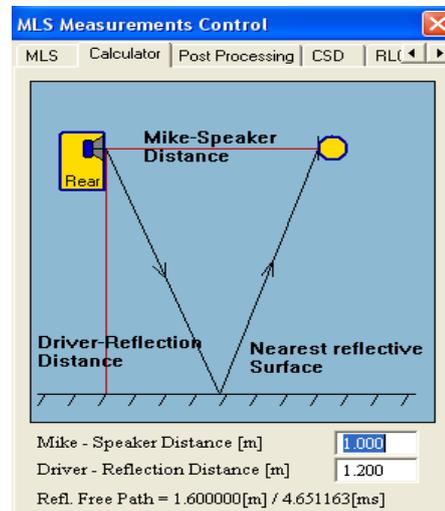


Figure 20. Calculator assisting with estimating FFT windowing.

RMS value of an AC current can be measured using a very rudimentary multimeter. I had a good success even with an old, analogue multimeter such as Micronta 22-204C



Figure 21. Multimeter used to measure 2.83Vrms for 1W/1m at 8ohm measurements

I set it to 5VAC range. It shows a very good agreement for RMS values with my digital CRO. The 1W RMS at 8ohm is 2.83V. So for instance, while my CRO is showing 2.85Vrms, the Micronta shows almost 2.9Vrms. The 2.9Vrms at 8ohms = 1.05Watt, so it's close enough for me.