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Silence Sweep: a novel method for measuring electro-acoustical devices

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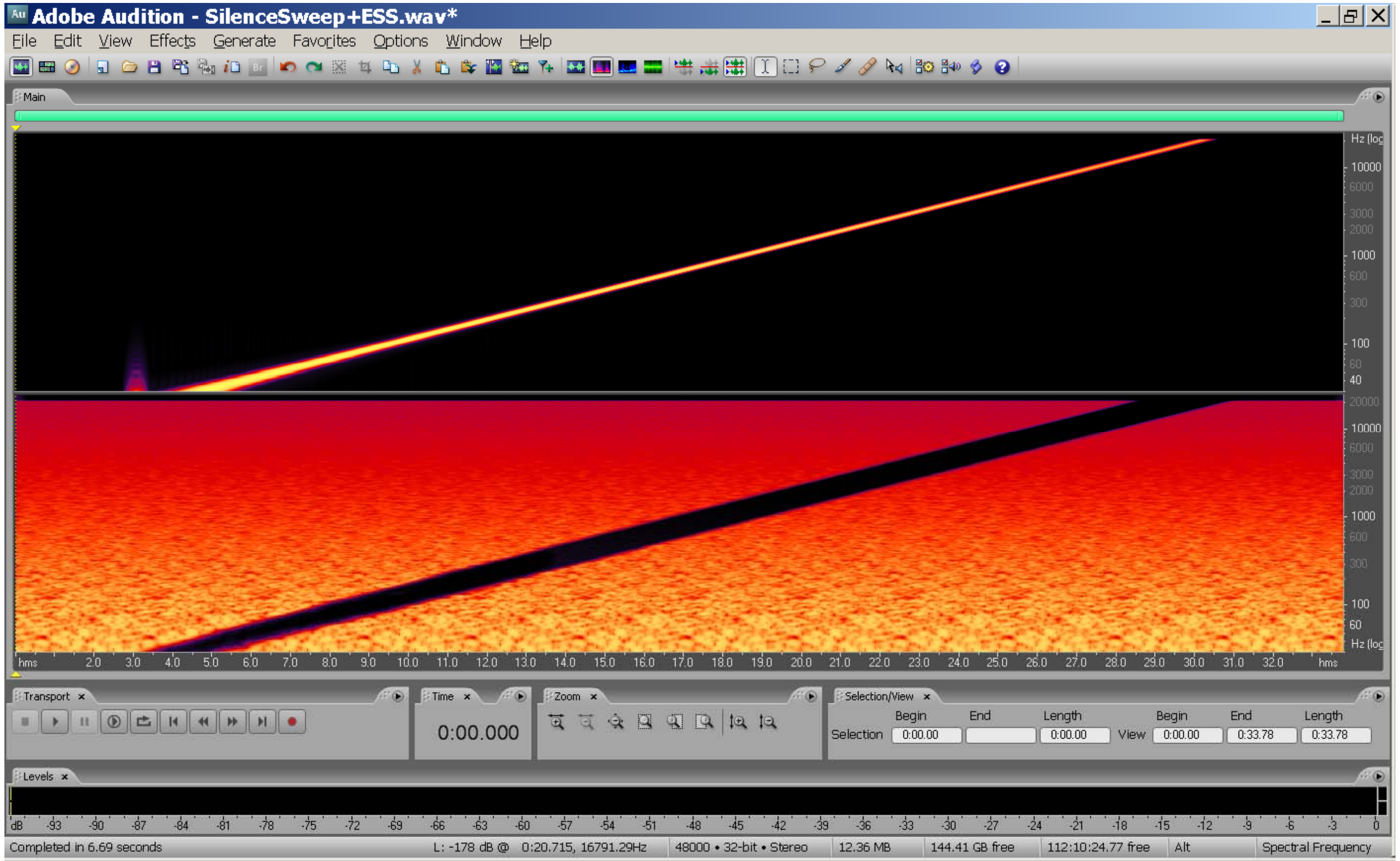
Introduction

- **A Silence Sweep test signal is basically the "negative image" of an Exponential Sine Sweep signal:**

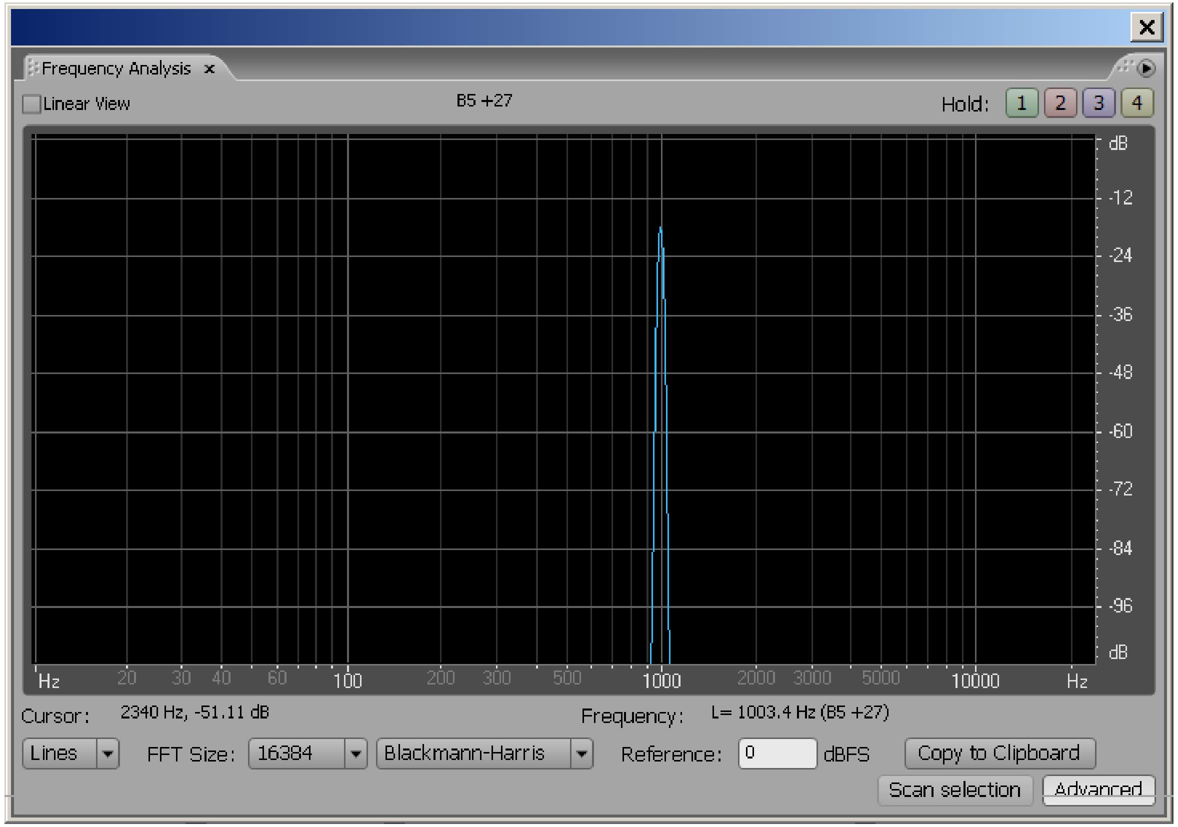


Exponential Sine Sweep

Silence Sweep

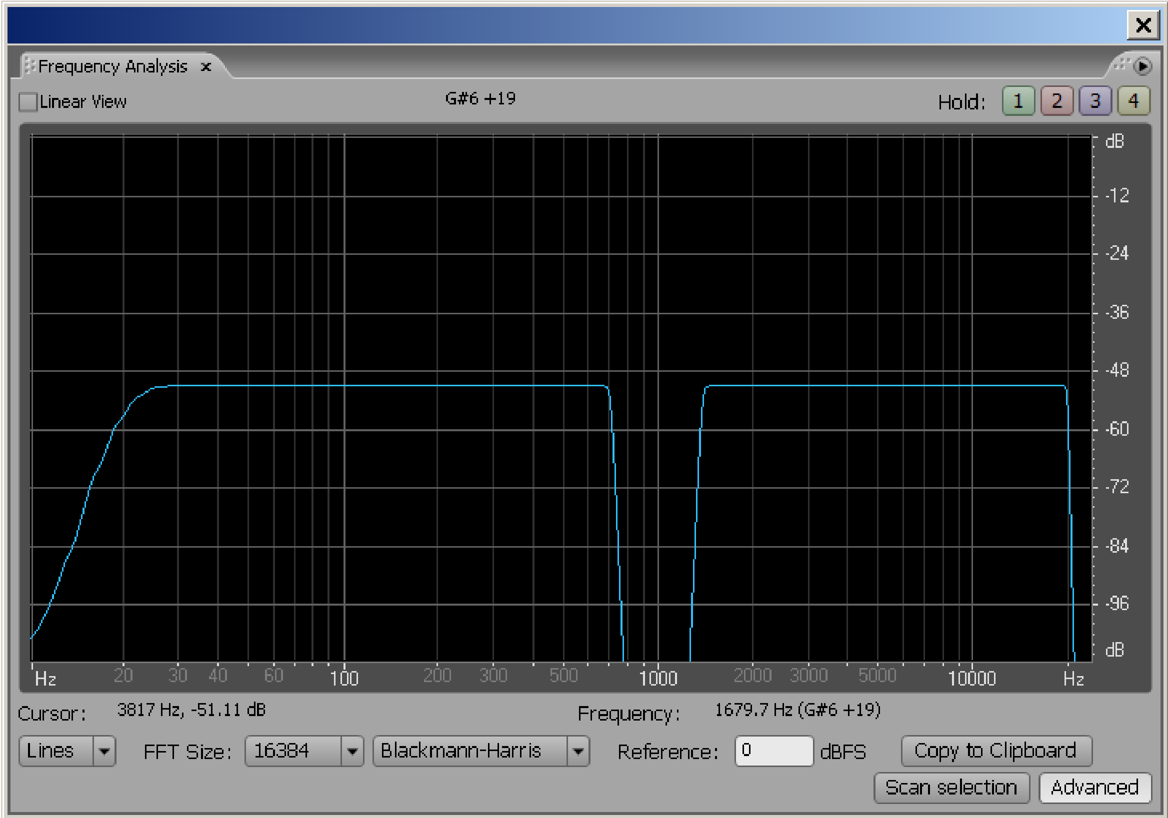
Introduction – ESS signal

- In the ESS signal, at a given instant we have energy only in a narrow frequency band:

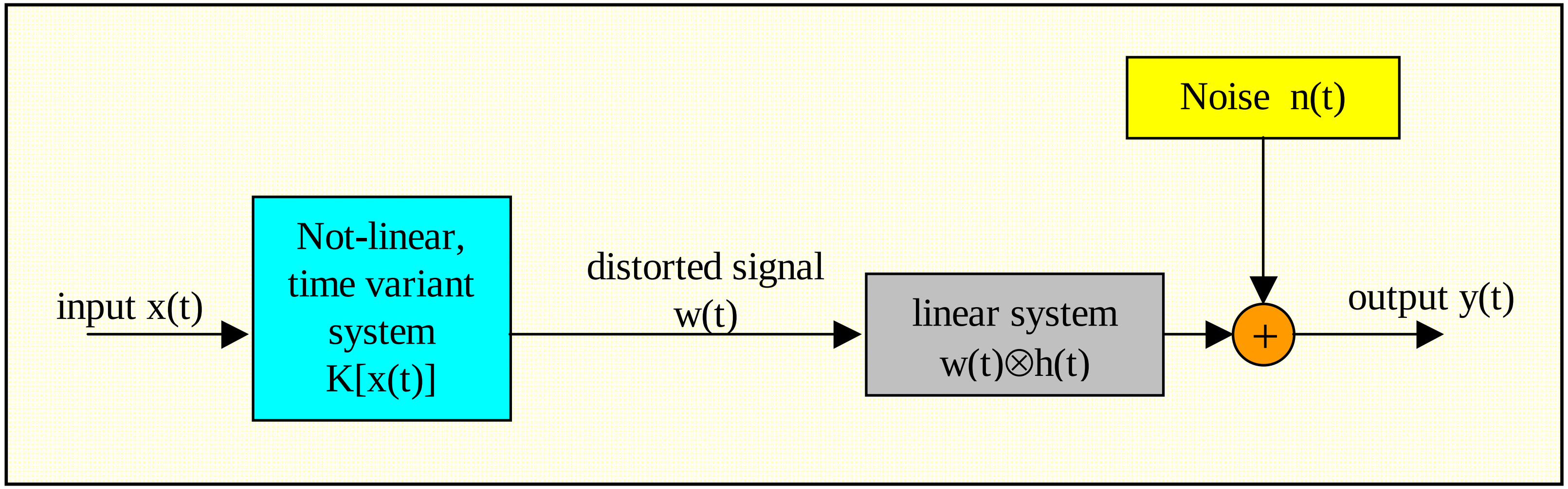


Introduction – Silence Sweep

- **In the Silence Sweep signal, at a given instant we have energy in the whole spectrum, EXCEPT in a narrow frequency band:**



Signals and System



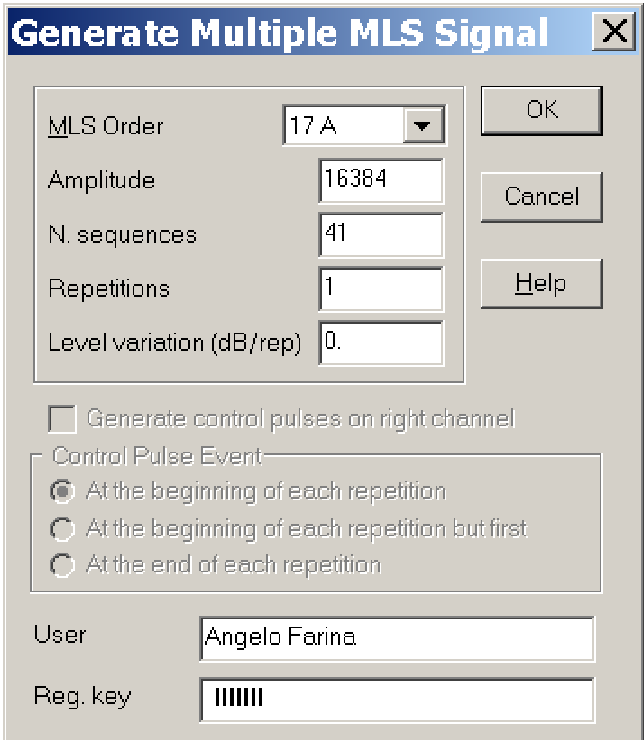
- We apply the test signal to a system under test, which generally comprises a not-linear part (for example a loudspeaker), a linear system, and introduces some noise
- By measuring the ouput of the system, we would like to assess the linear transfer function, the amount of not-linear distortion, and the amount of noise

ESS vs. Silence Sweep

- The ESS signal is great for measuring the linear transfer function, without artefacts caused by not-linear distortion and by noise, which can be almost completely rejected
- Furthermore, ESS allows for measuring with great accuracy the Harmonic Distortion products, and consequently also the THD (Total Harmonic Distortion)
- However, ESS does not measure other types of distortion, such as intermodulation, as the system is fed with just one frequency at any instant.
- Furthermore, inharmonic artefacts such as rub and buzz, rattling, etc. are not measured by ESS, which instead removes them as if they were noise unrelated with the signal.
- The Silence Sweep method, instead, provides assessment of exactly those quantities which are missed with ESS: intermodulation, inharmonic distortion and noise.
- So the two methods should be used together, for a complete characterization of a sound system

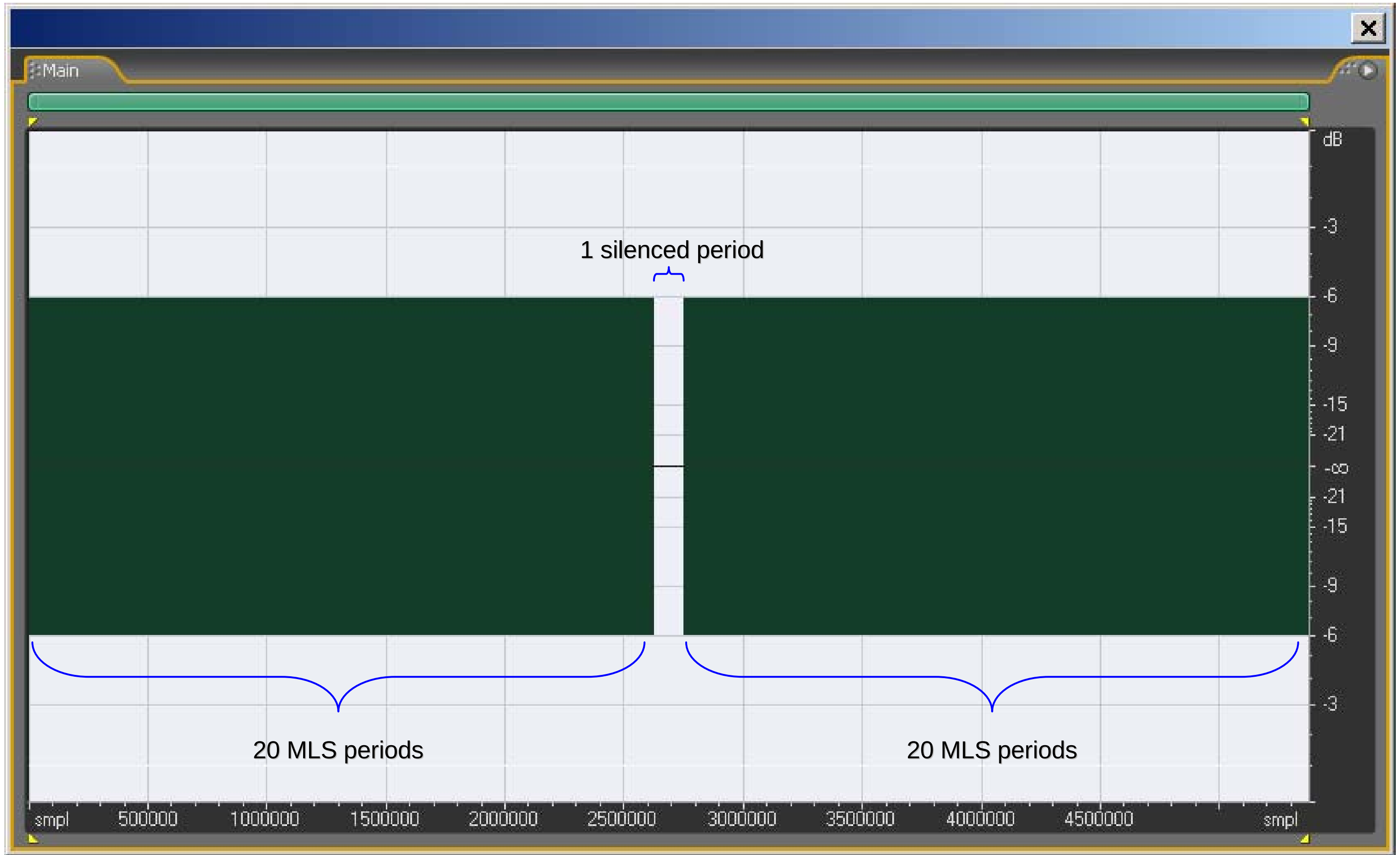
How to generate the Silence Sweep

- **The basic idea was to first generate a wide-band noise, and then apply a band-reject filter with variable center frequency**
- **This approach did work badly. It was difficult to have real silence in the suppressed band, and the high-order filter was causing distortion at the corner frequencies**
- **So a new method was developed, based on employing an exponential sine sweep as stretching filter, which is applied to a sequence of MLS signals, with one sequence missing.**
- **We first generate a MLS signal:**



The interrupted MLS sequence

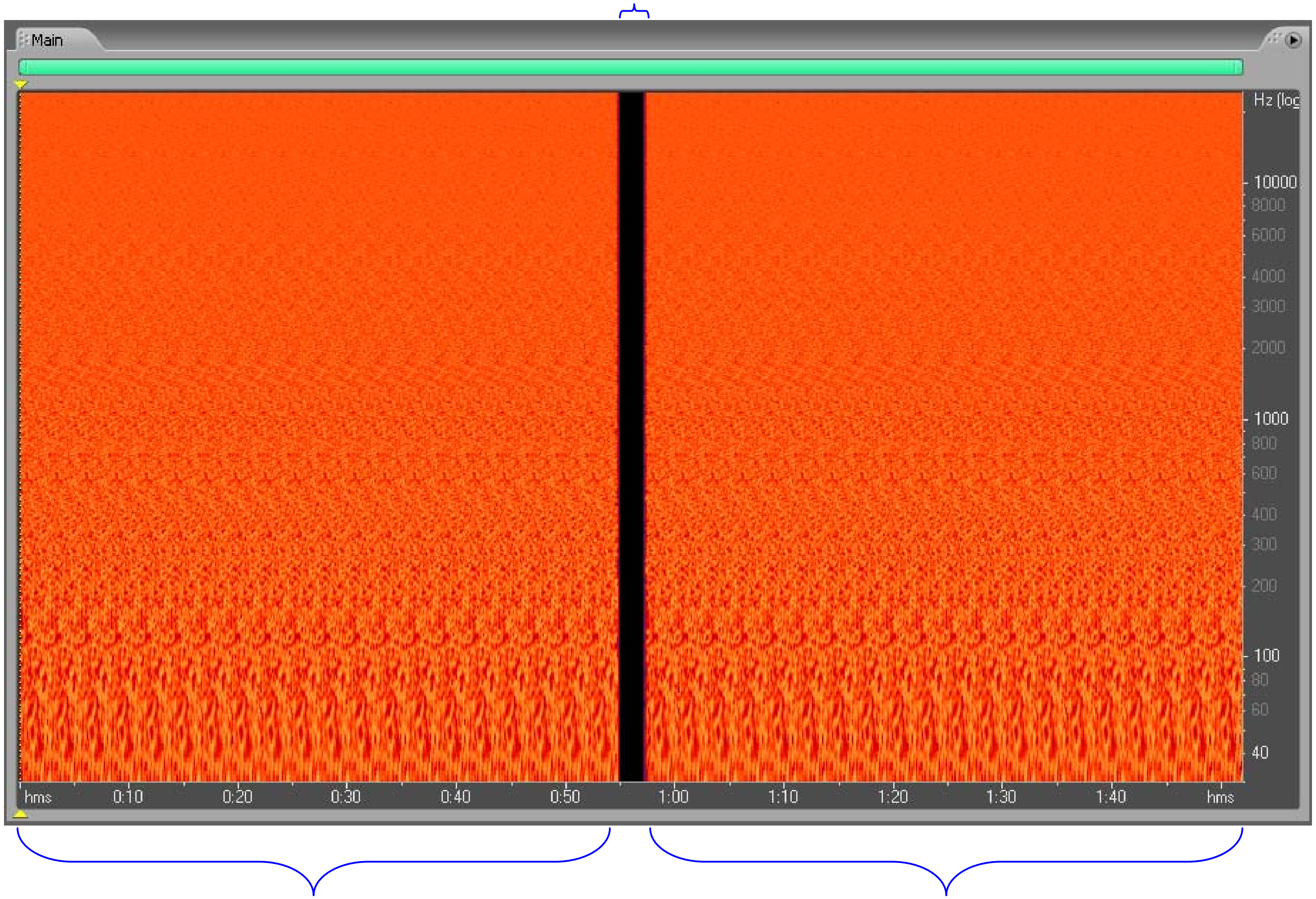
- **We now silence the central repetition of the MLS sequence, so that we will have 20 sequences, one silenced sequence, and other 20 sequences, as shown here:**



The interrupted MLS sequence

- **The spectrogram now is as follows:**

1 silenced period

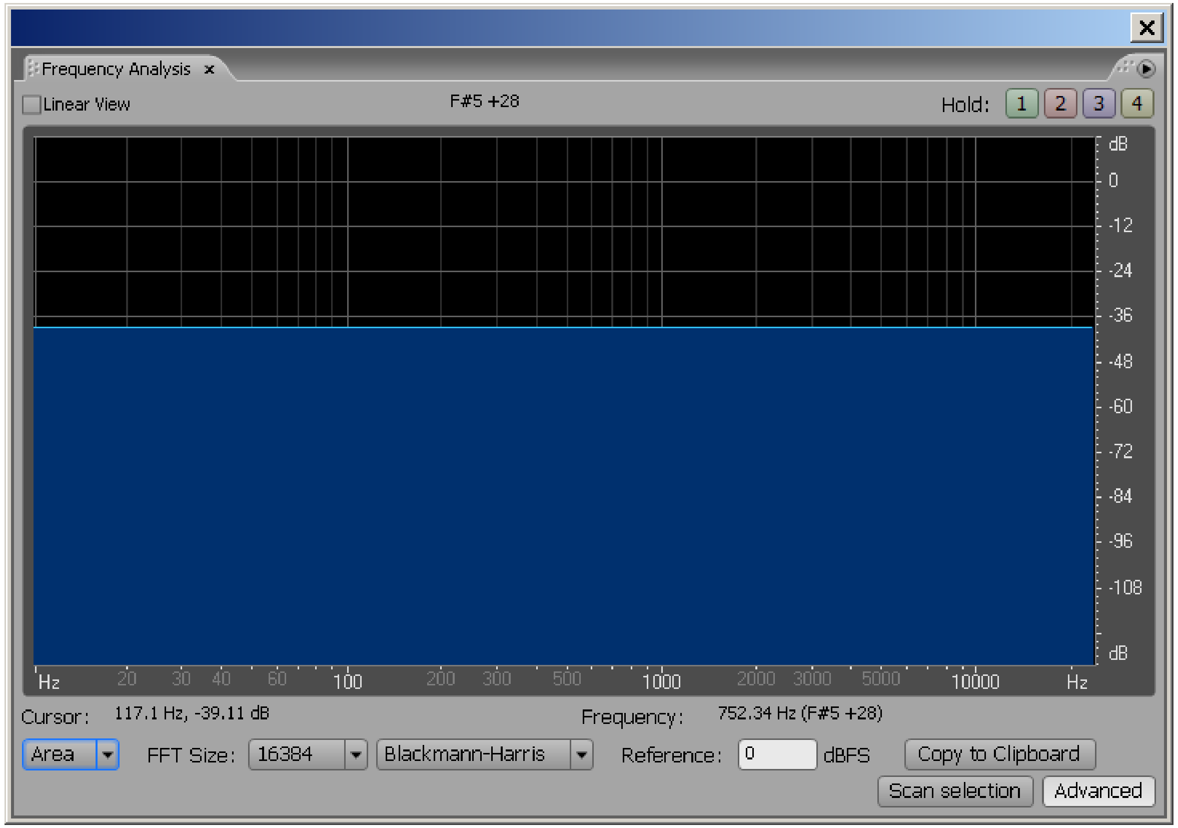


20 MLS periods

20 MLS periods

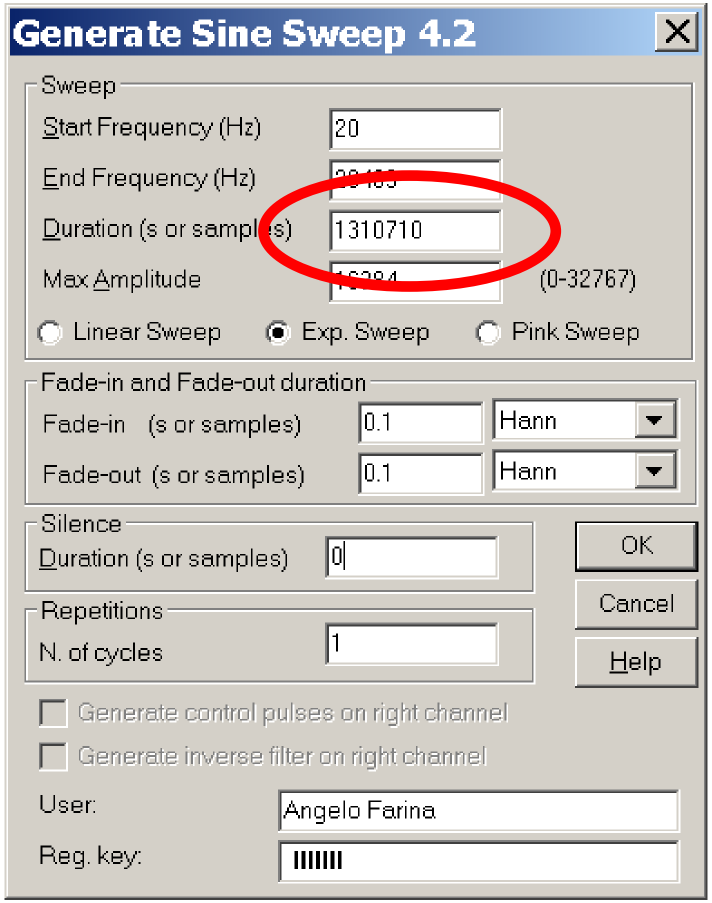
The interrupted MLS sequence

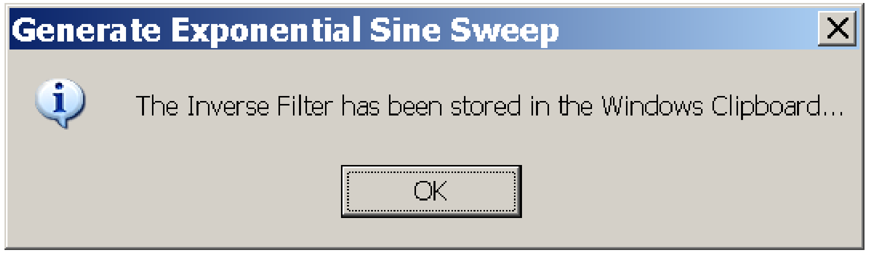
- **And, of course, the spectrum of the MLS signal is white:**



The ESS signal

- **We now generate an Exponential Sine Sweep signal, to be used both as a test signal and as the time-stretching filter for creating the Silence Sweep starting from the previously-generated interrupted MLS sequence:**

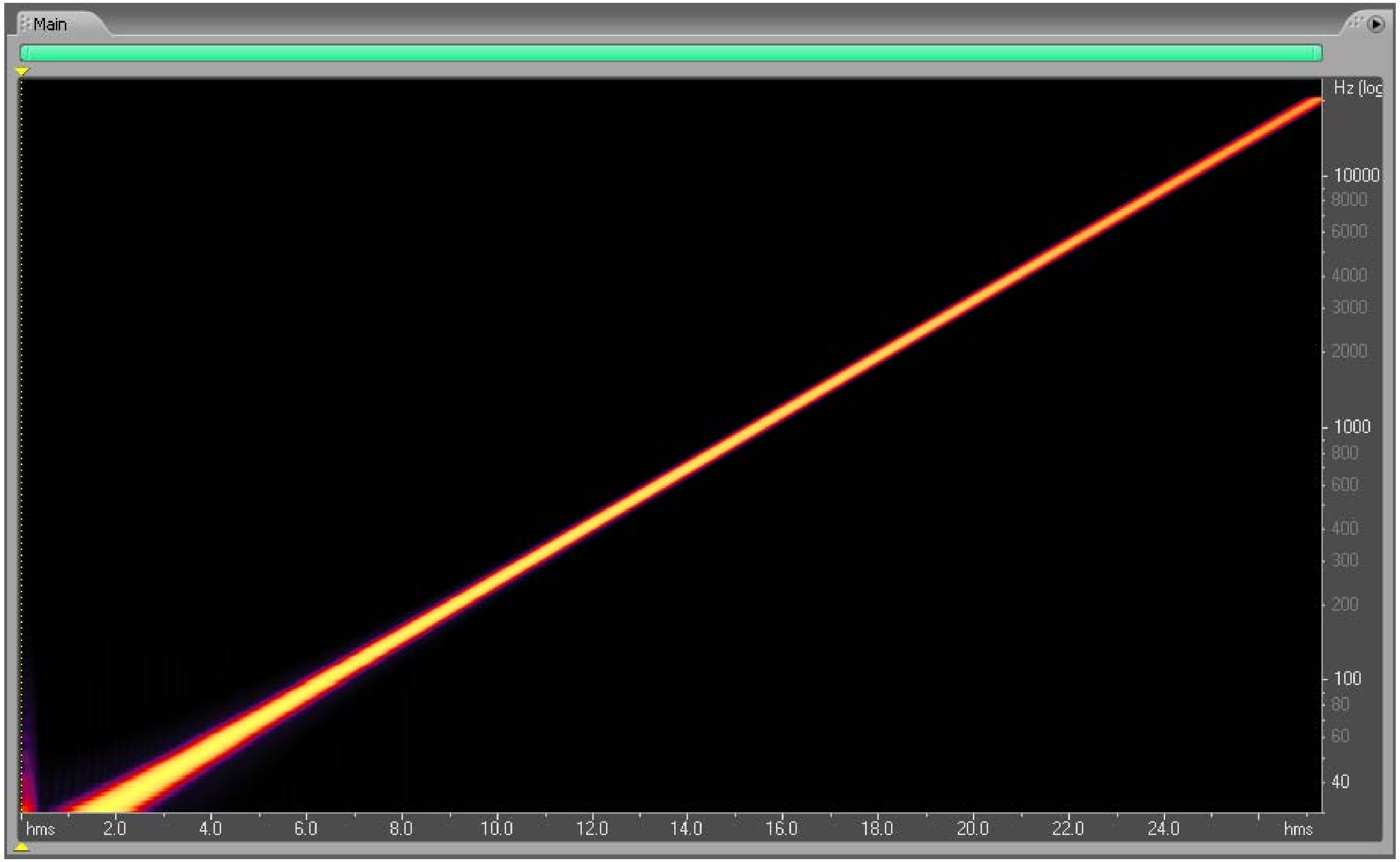




- **Note that the Duration of the ESS is exactly equal to 10 MLS sequences**

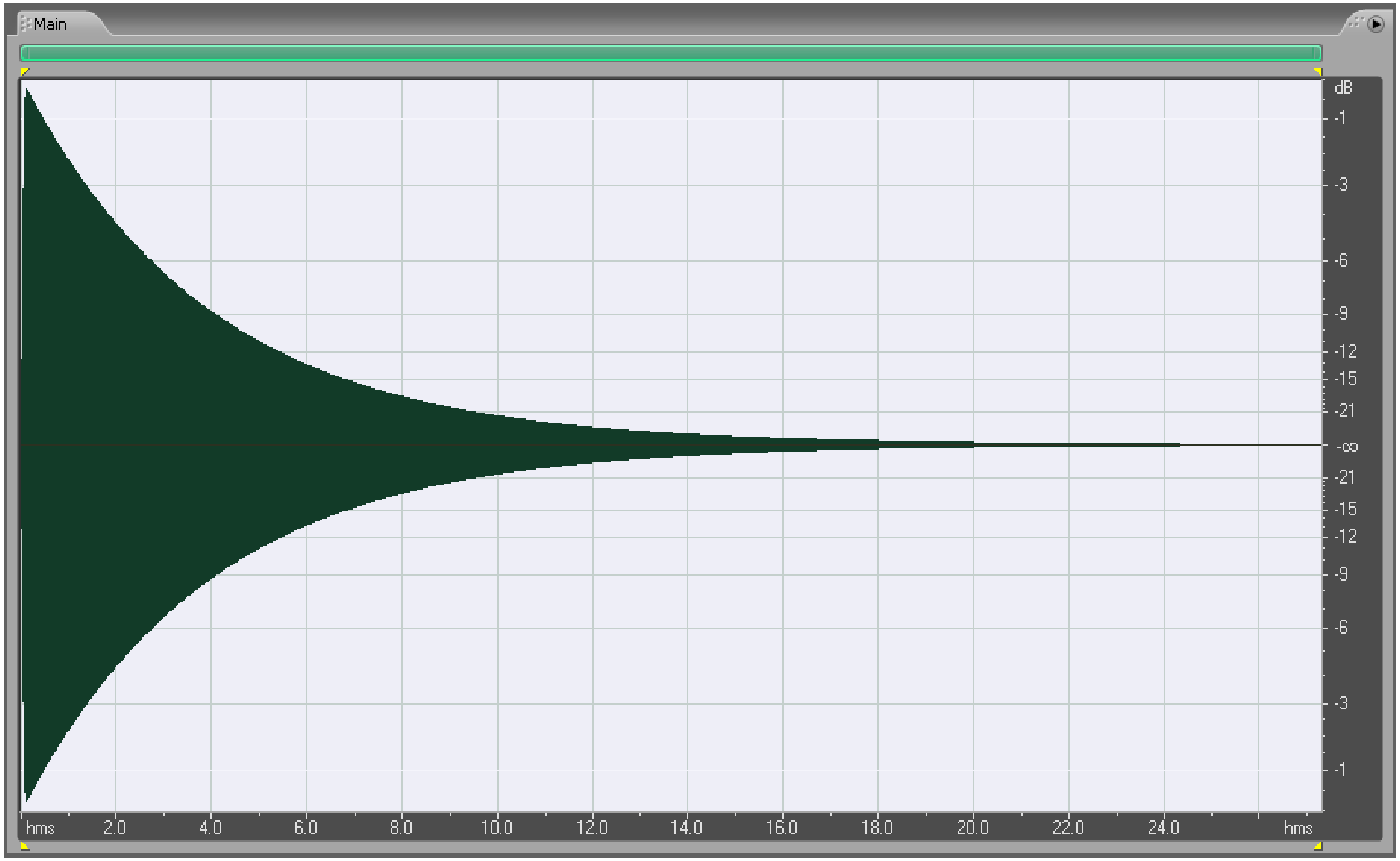
The ESS signal

- **This is the spectrogram of the ESS signal:**



The Inverse Sweep

- Of course, during the generation of the ESS, the Aurora plugin did also create automatically its matched inverse filter, which is stored on the Windows clipboard. We retrieve it from there, and we save for later use:

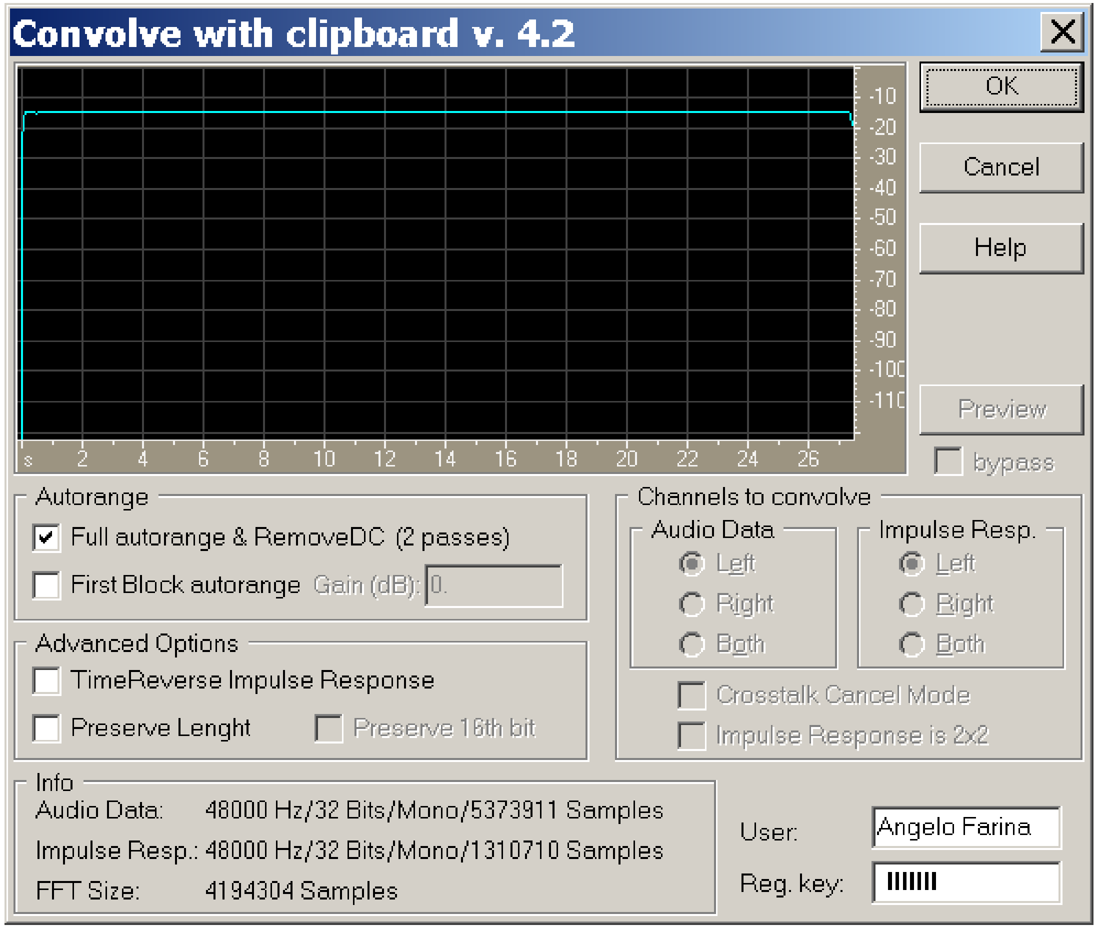


The Inverse Sweep

- **And here is the sonogram of the inverse filter, from which it is quite clear that it is substantially the time-reversal of the original ESS signal, with some amplitude modulation.**

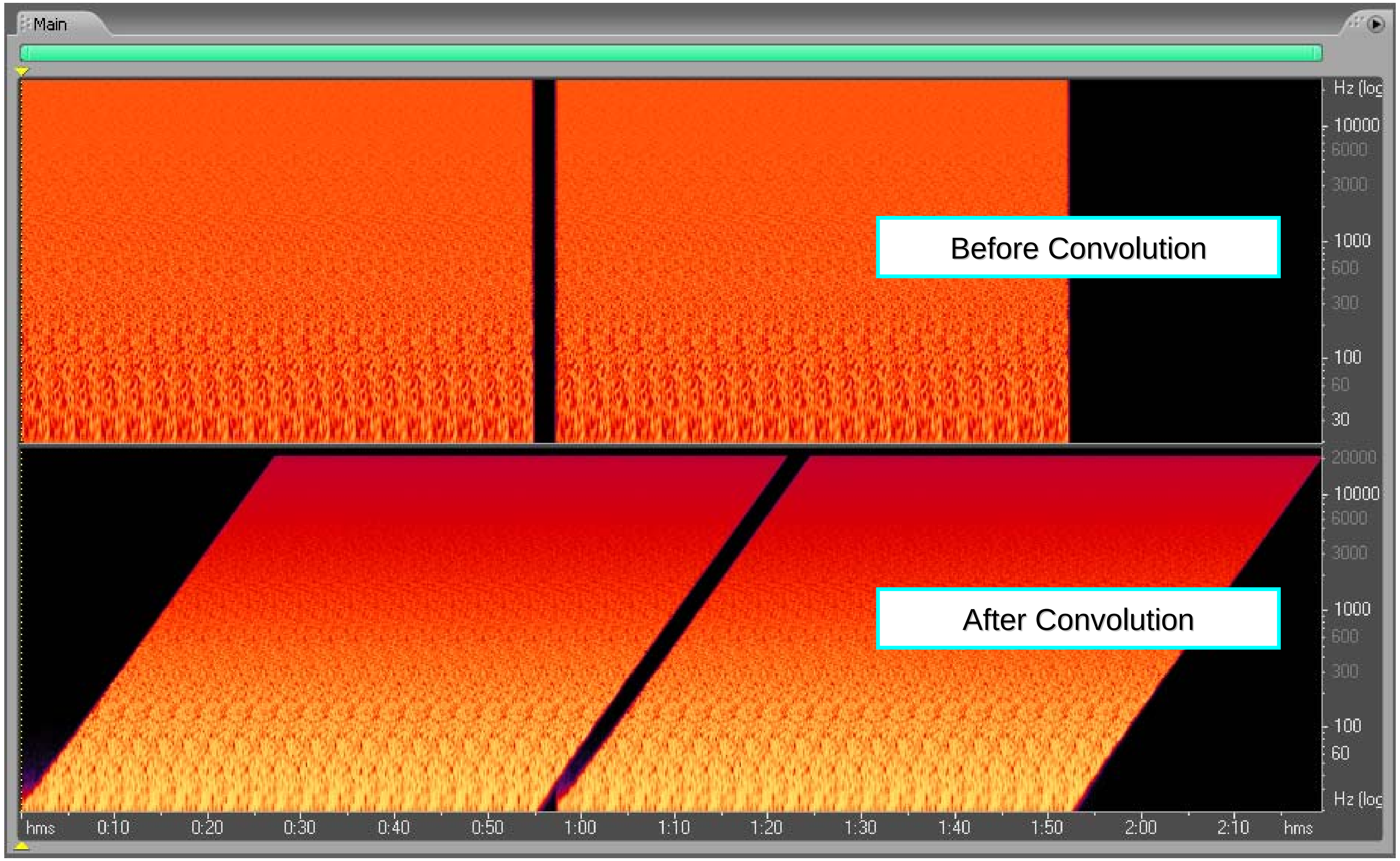
Generation of the Silence Sweep

- **The Silence sweep is generated by convolving the interrupted MLS signal with the Exponential Sine Sweep. So we first copy to the Windows clipboard the ESS, then we display the interrupted MLS, and we invoke the "Convolve with Clipboard" Aurora plugin:**



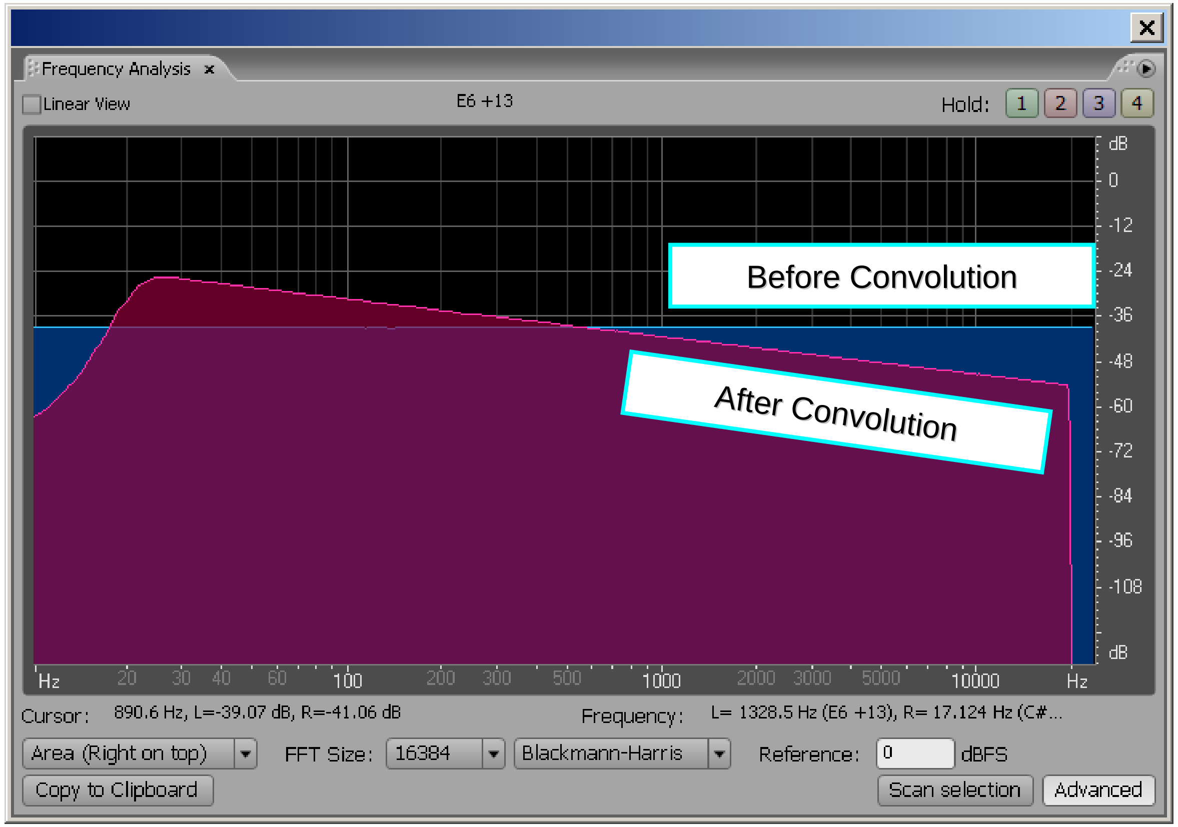
Generation of the Silence Sweep

- **After the convolution is done, the silence gap is now stretched in time, as shown in the following picture:**



Generation of the Silence Sweep

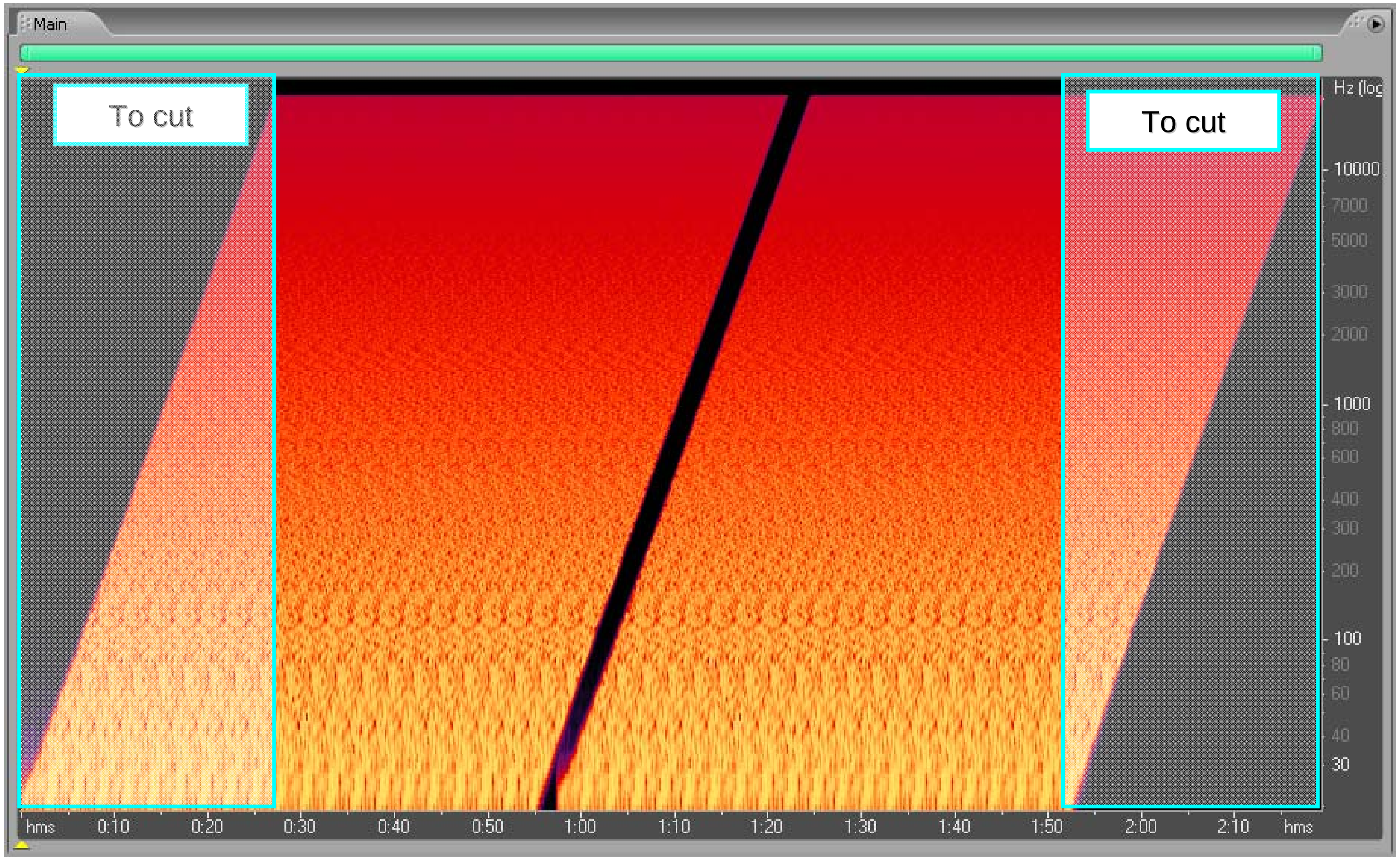
- **Furthermore, the spectrum of the MLS signal has now changed from full-band white to band-limited pink:**



- **A pink spectrum has well-known advantages for most transducers**

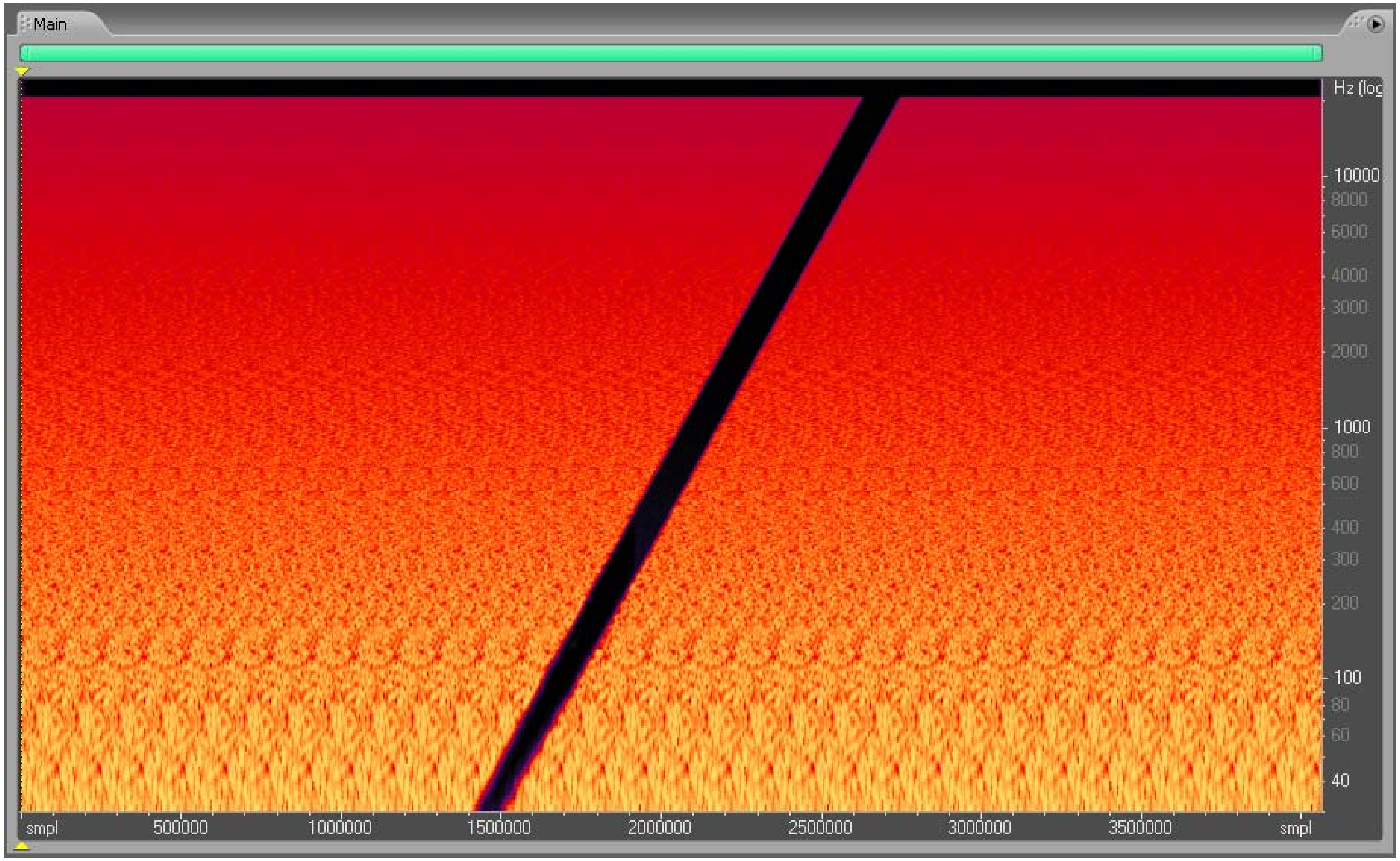
Generation of the Silence Sweep

- **Finally, we cut away the beginning and end of the convolved signal**



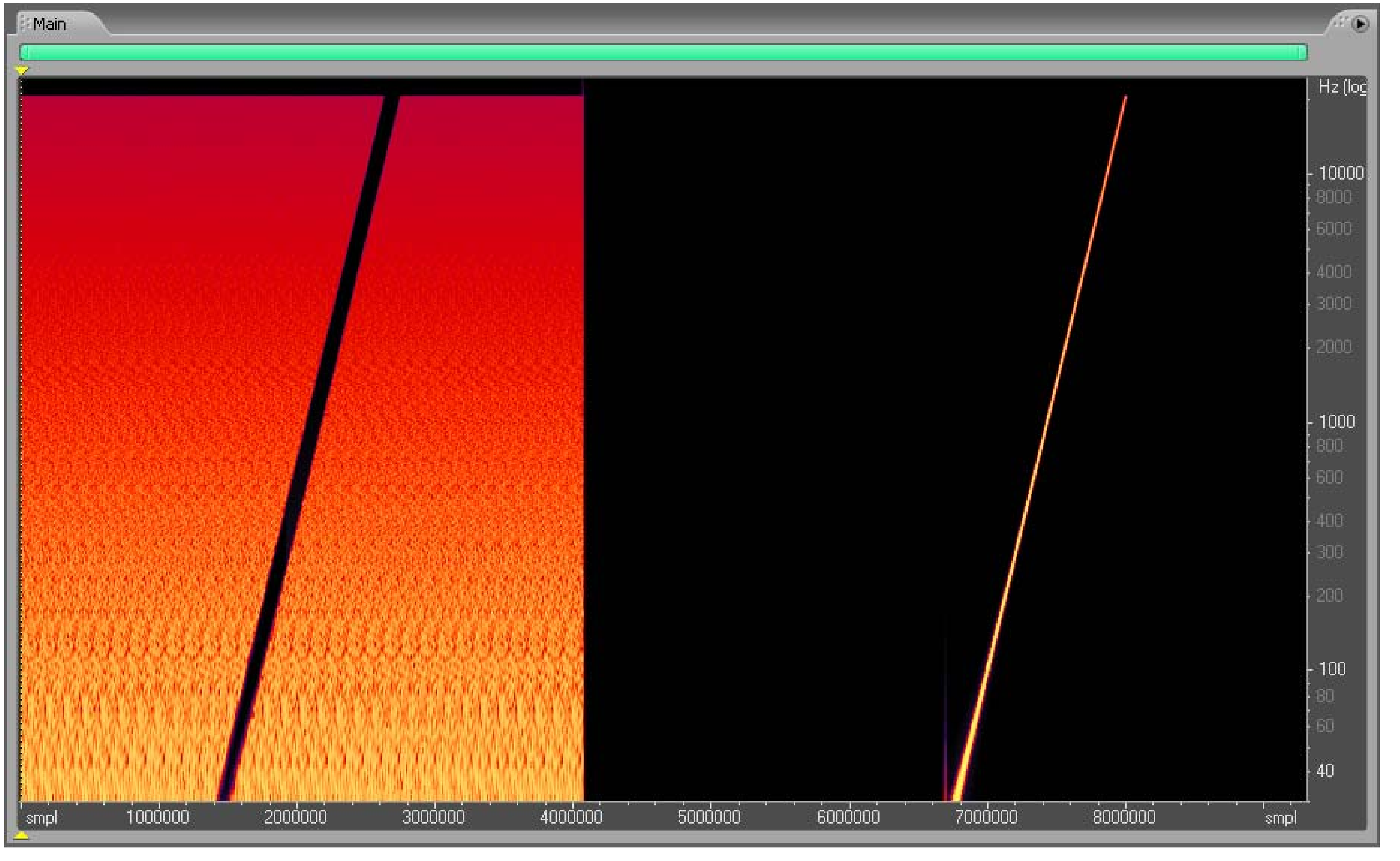
Generation of the Silence Sweep

- **And we get our final test signal:**



Silence Sweep + ESS

- **For a complete test, it is advisable to employ a longer test signal, containing the Silence Sweep, a piece of silence, and finally a traditional ESS signal:**



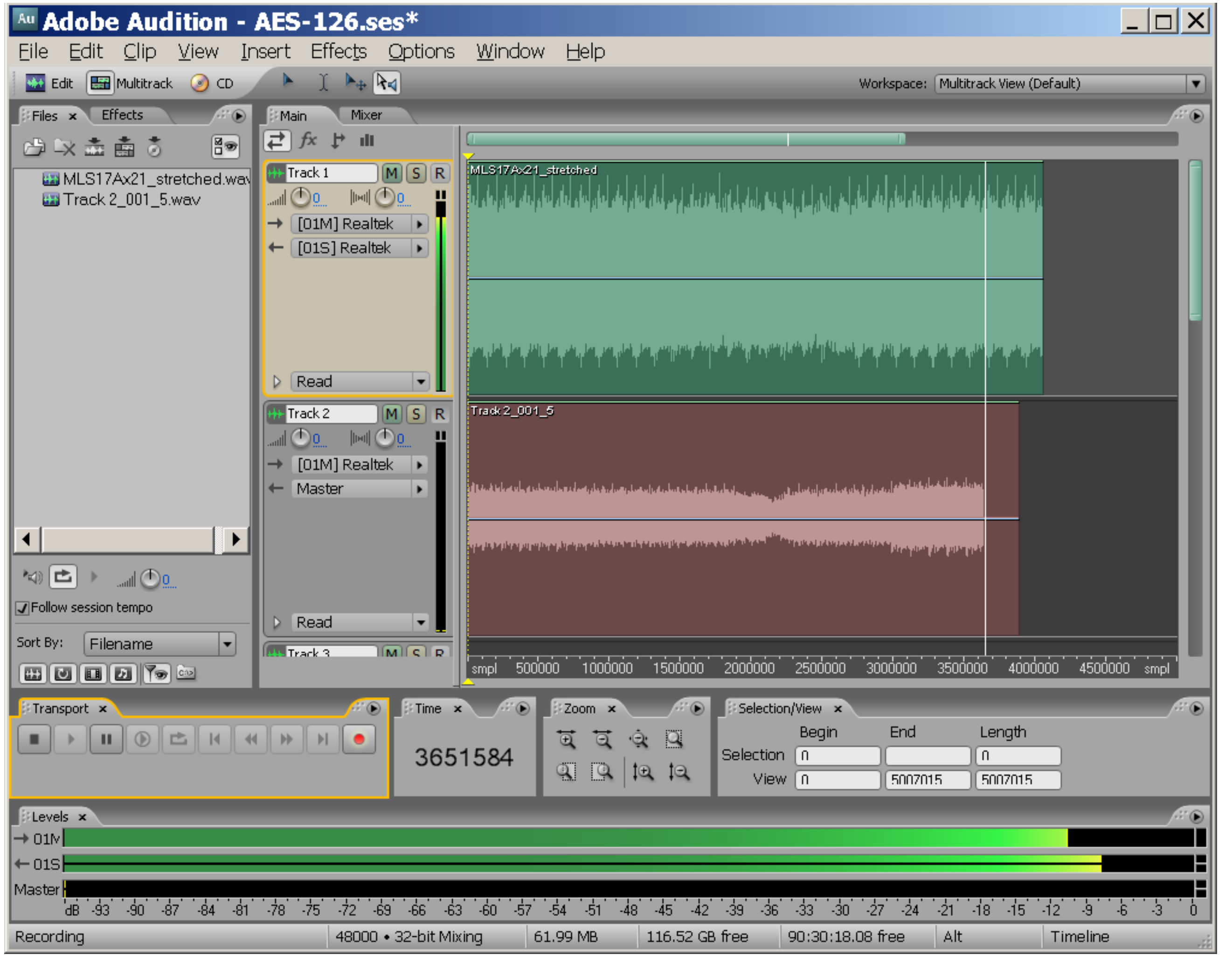
Usage of the Silence Sweep

- We now employ the Silence Sweep signal for measuring the transfer function of an headset placed over a dummy head:

- For simplicity we only measure one of the two ears

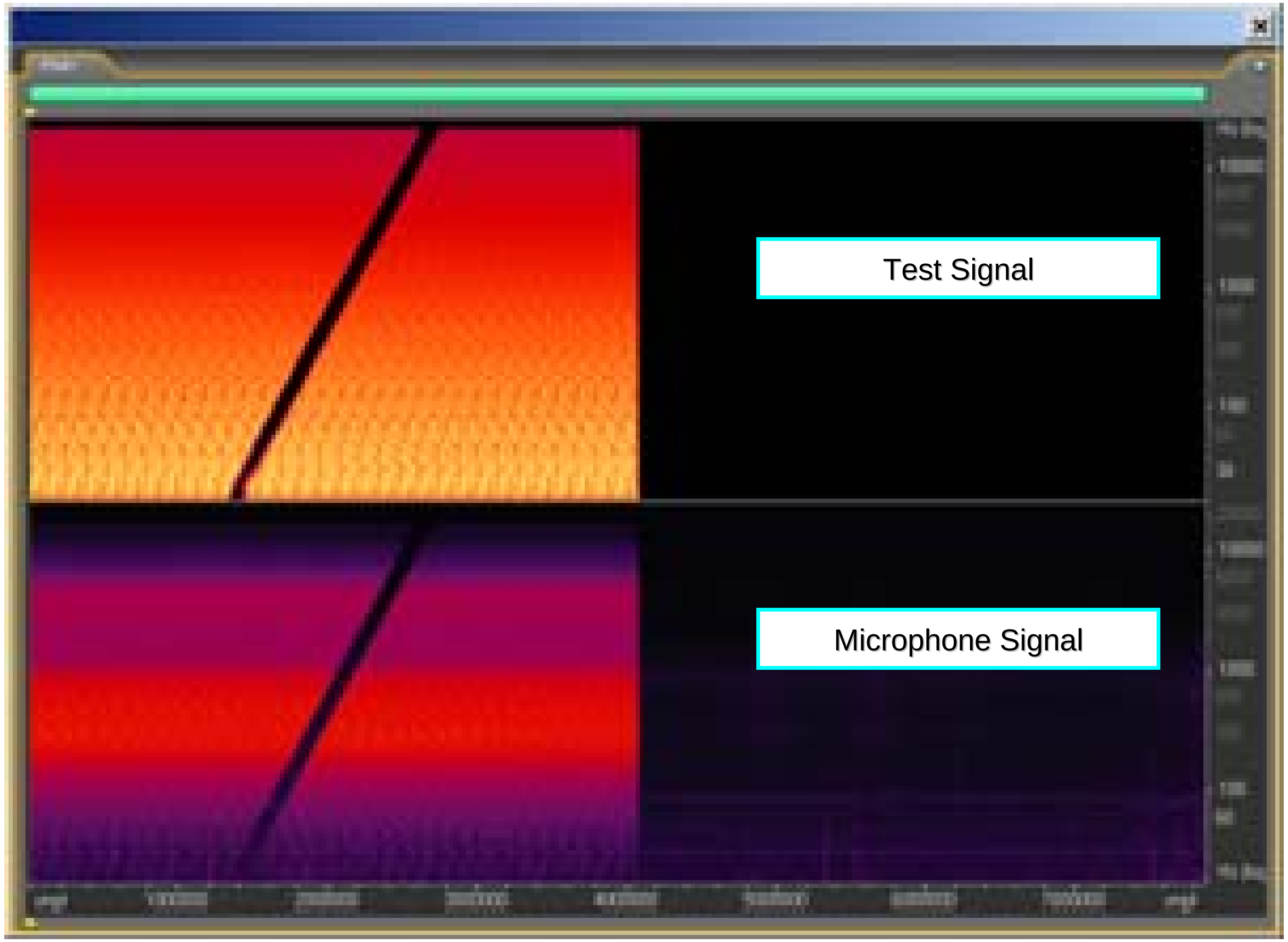
Usage of the Silence Sweep

- **In Adobe Audition, we place the Silence Sweep on the first track, which will be played, while we record the Left in-ear microphone on the track 2:**



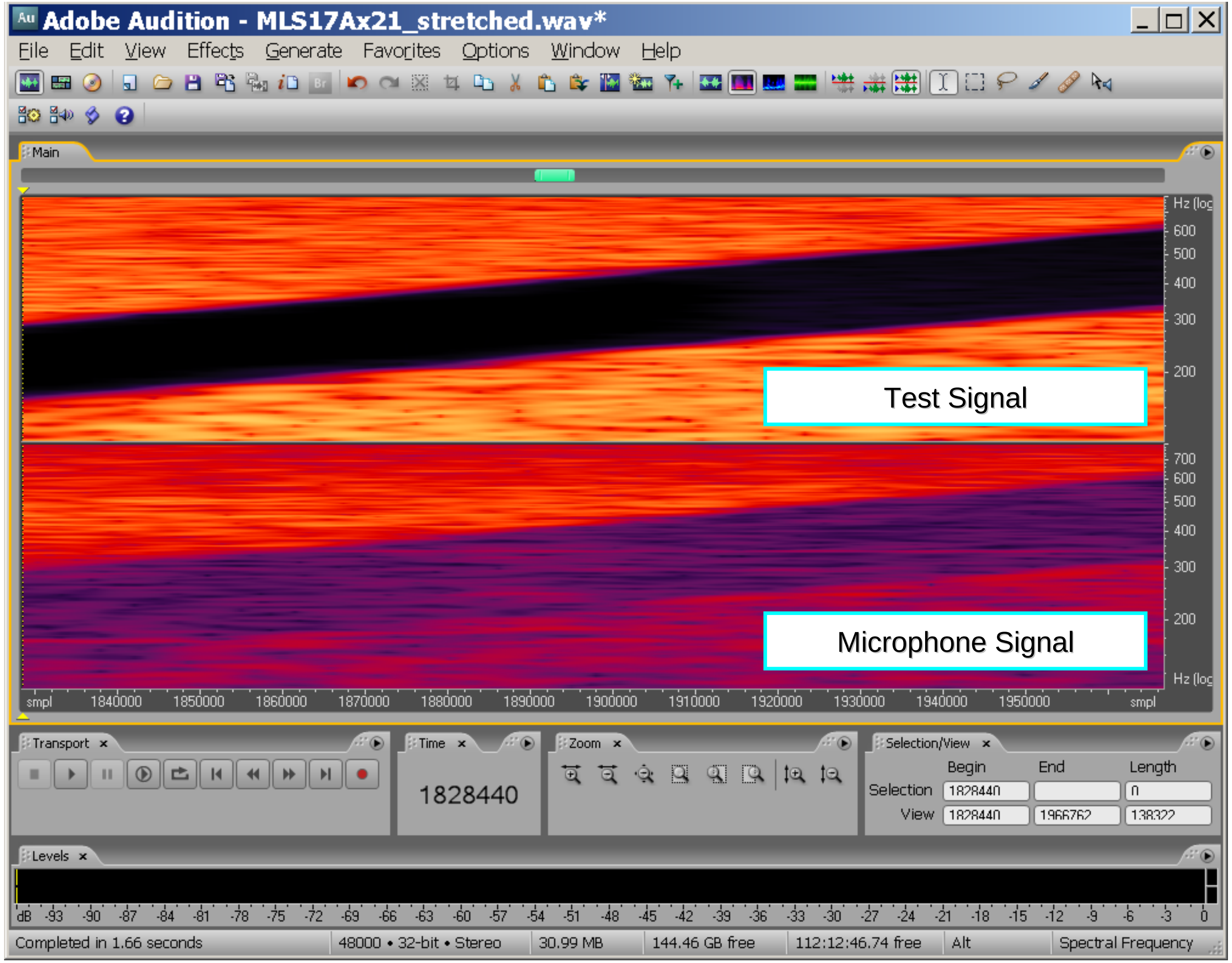
Usage of the Silence Sweep

- **This is the comparison between the spectrograms of the Silence Sweep test signal and the signal recorded by the microphone**



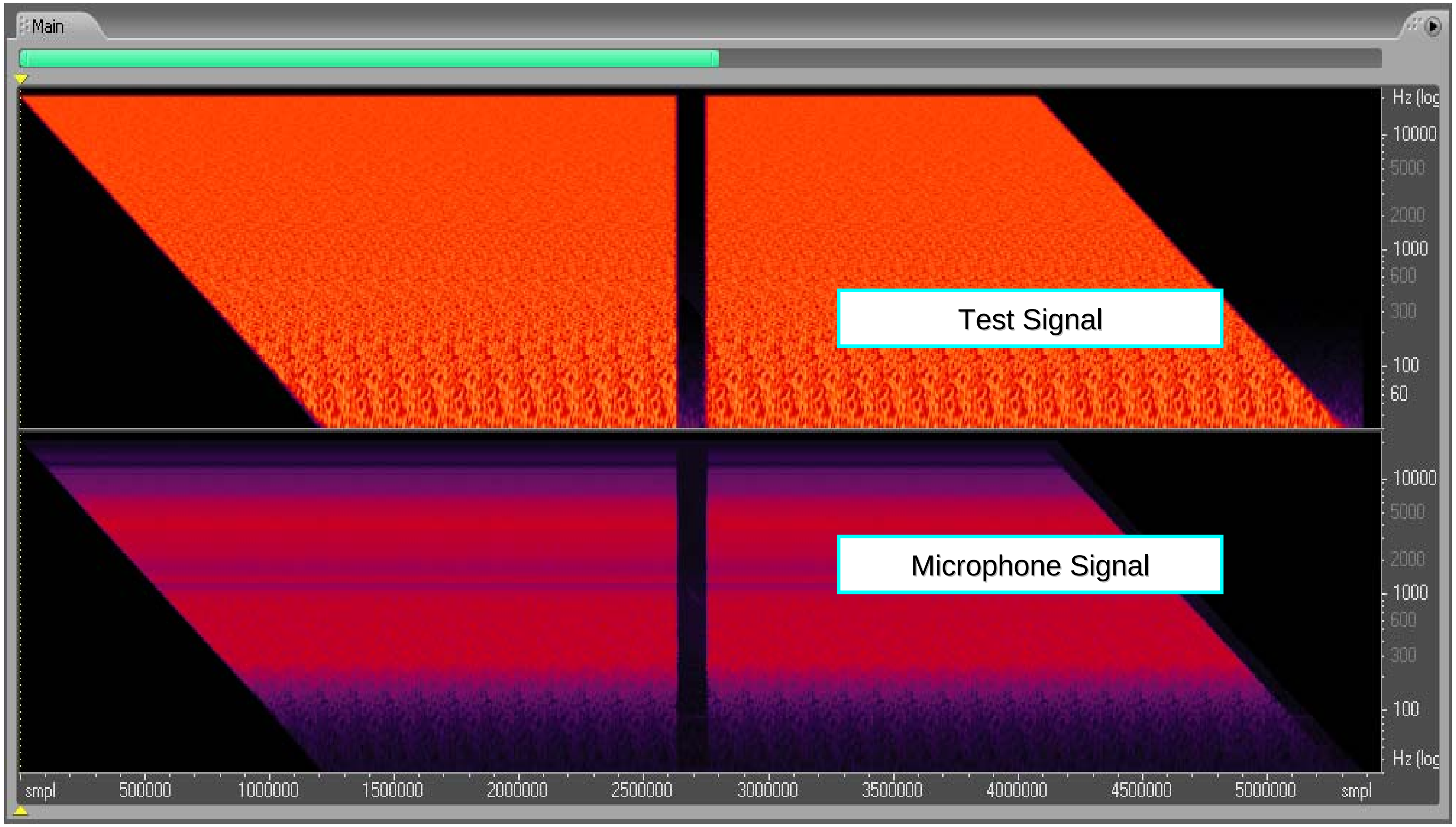
Usage of the Silence Sweep

- **A closer look shows that the signal in the silenced band is now contaminated by noise and distortion products**



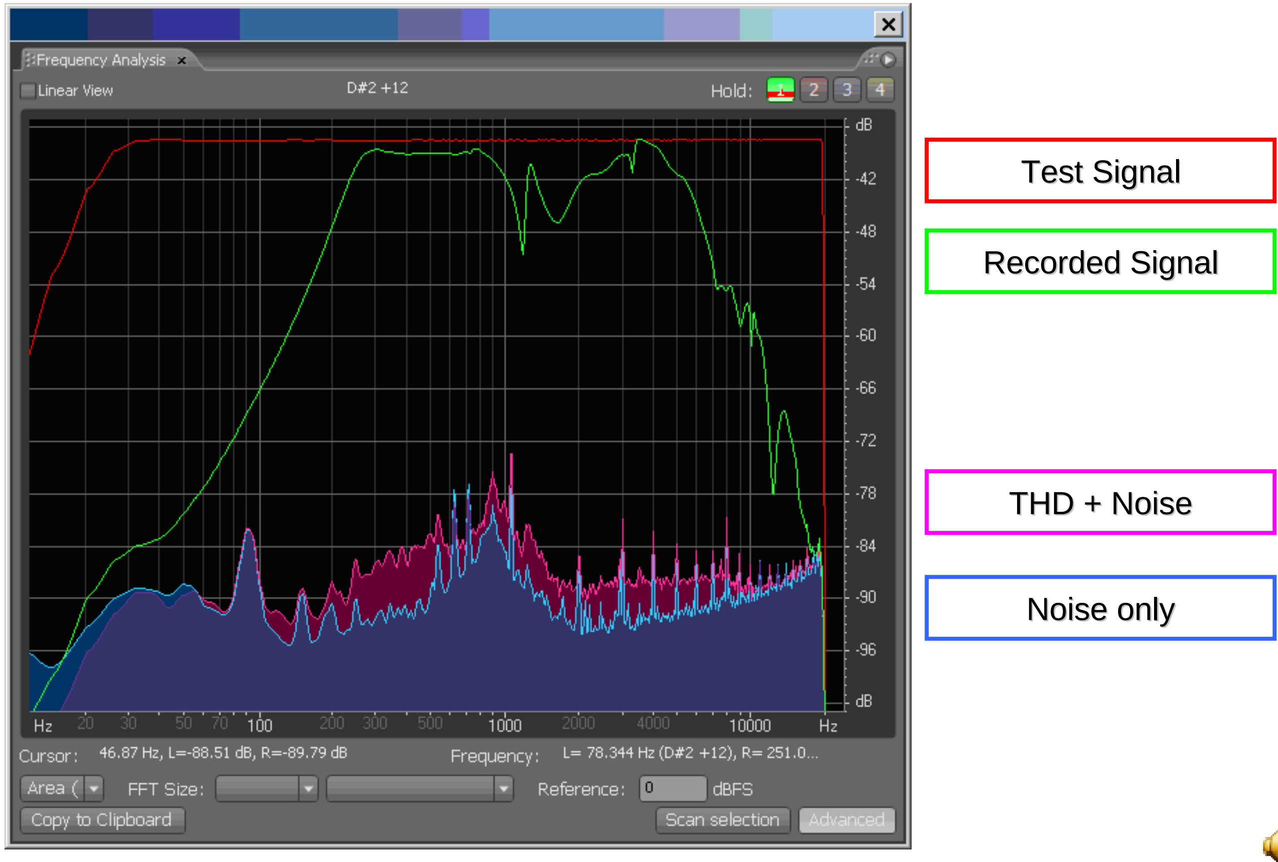
Processing of the signals

- **We now convolve the recorded signals with the Inverse Sweep generated previously. This de-stretches the silence sweep, transforming it back to a period of silence at a well defined time:**



Analysis of the results

- **We can now analyze separately a time segment when the signal was active and the following, during which there was no signal, and the system's response is only due to background noise and distortion. Also the segment at the end, where the background noise was captured, can be analyzed, providing info on the background noise only.**
- **The following figure shows the spectra obtained when performing this comparison:**



Advanced analysis

- We can do a more advanced analysis, exploiting the fact that we did employ MLS signal instead of a "normal" white noise. After proper deconvolution, each MLS sequence becomes an impulse response:

Advanced Analysis

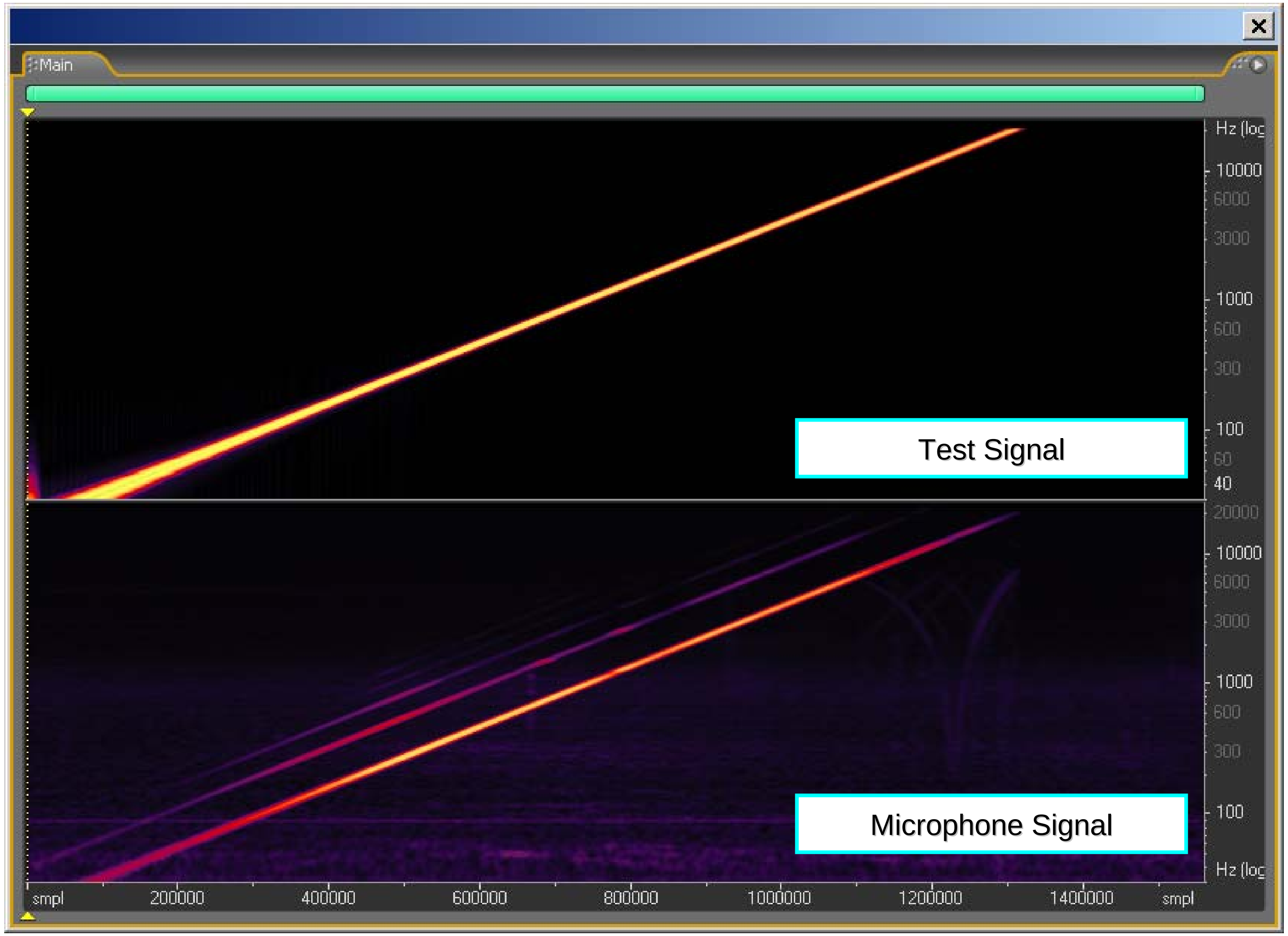
- **The spectra obtained form the impulse responses are cleaner and more repeatable than those obtained by analyzing directly the noise signals:**

Test Signal

Recorded Signal

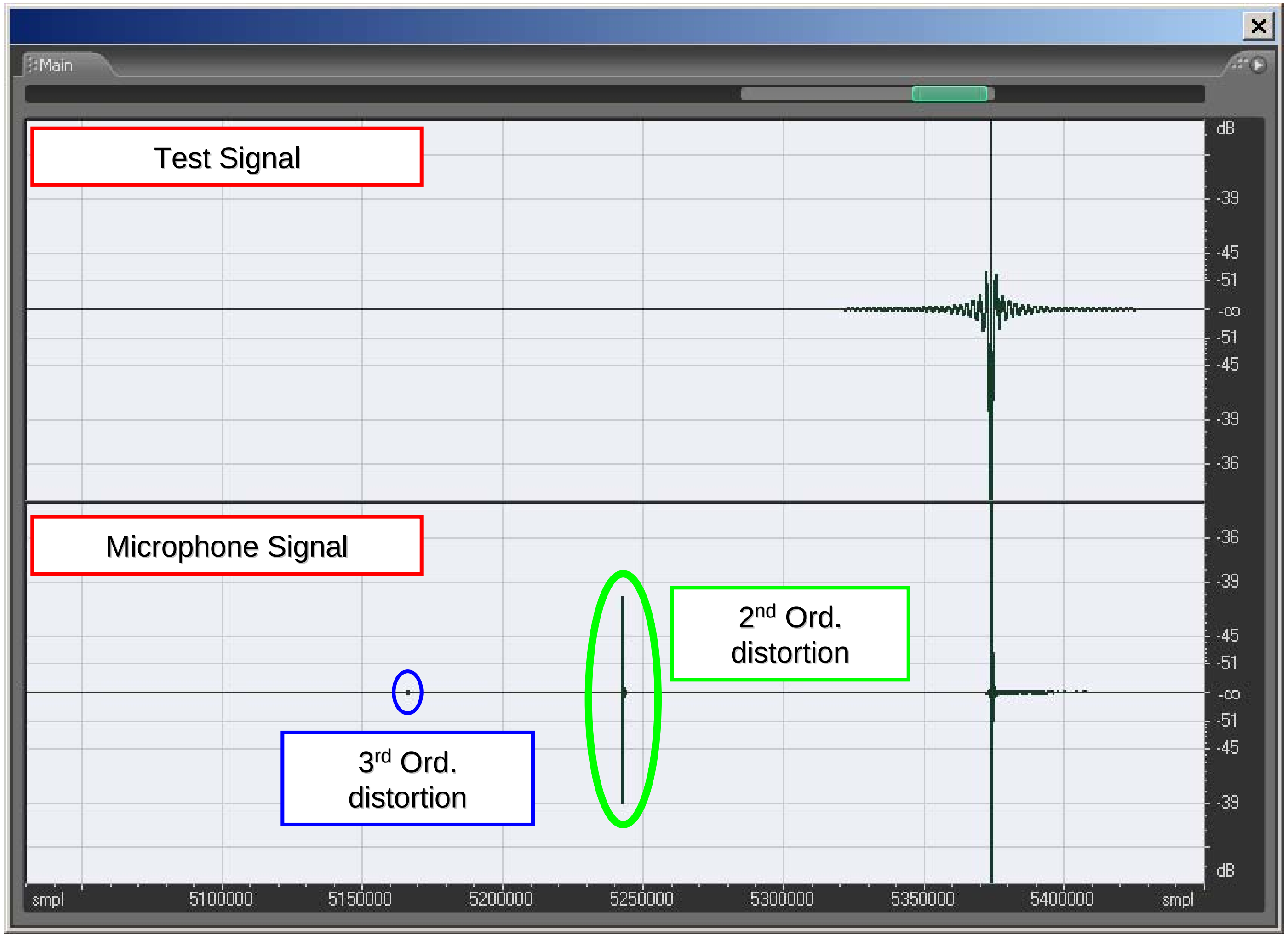
ESS analysis

- **A further step is based on analyzing also the ESS signal, which was played and recorded after the Silence Sweep signal:**



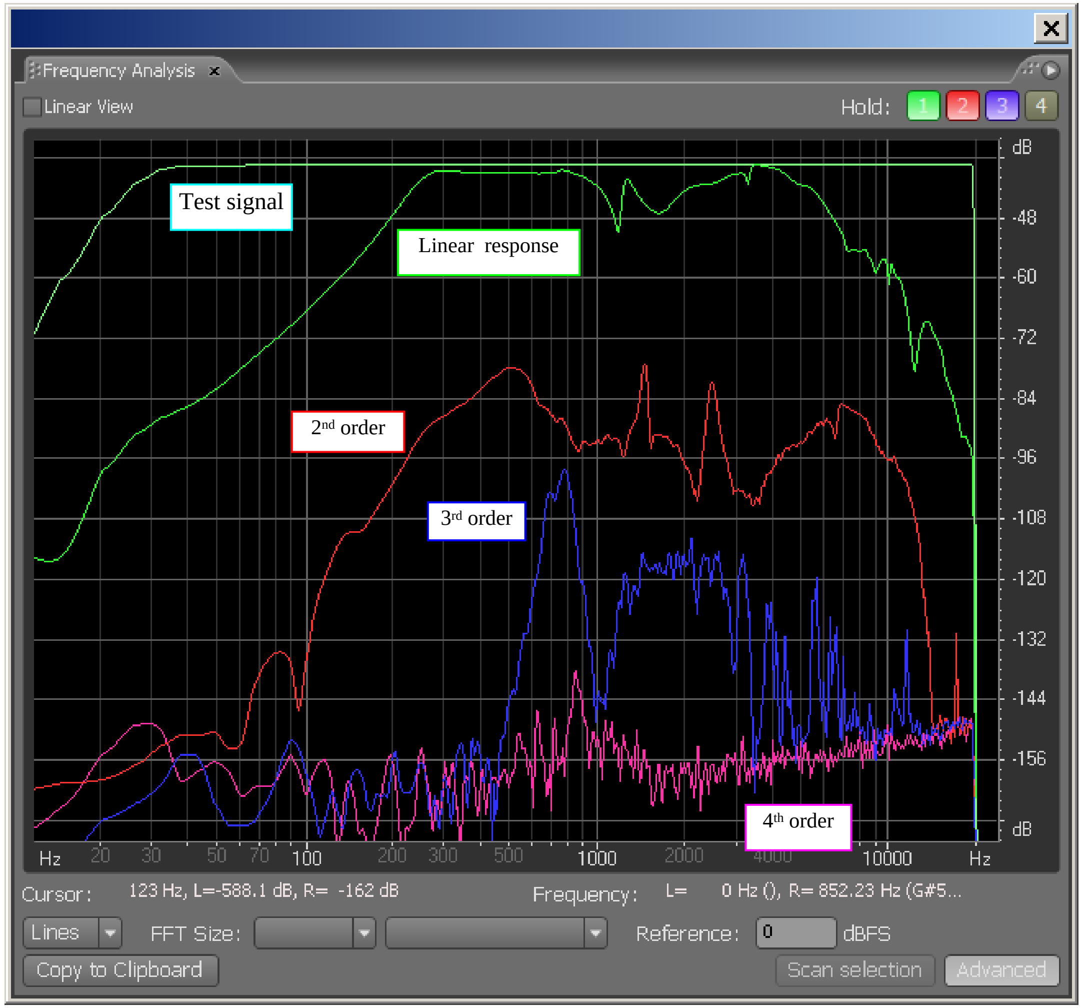
ESS analysis

- While convolving the Silence Sweep with the Inverse Sweep, also the following ESS signal has been de-stretched, so that it is now as here:



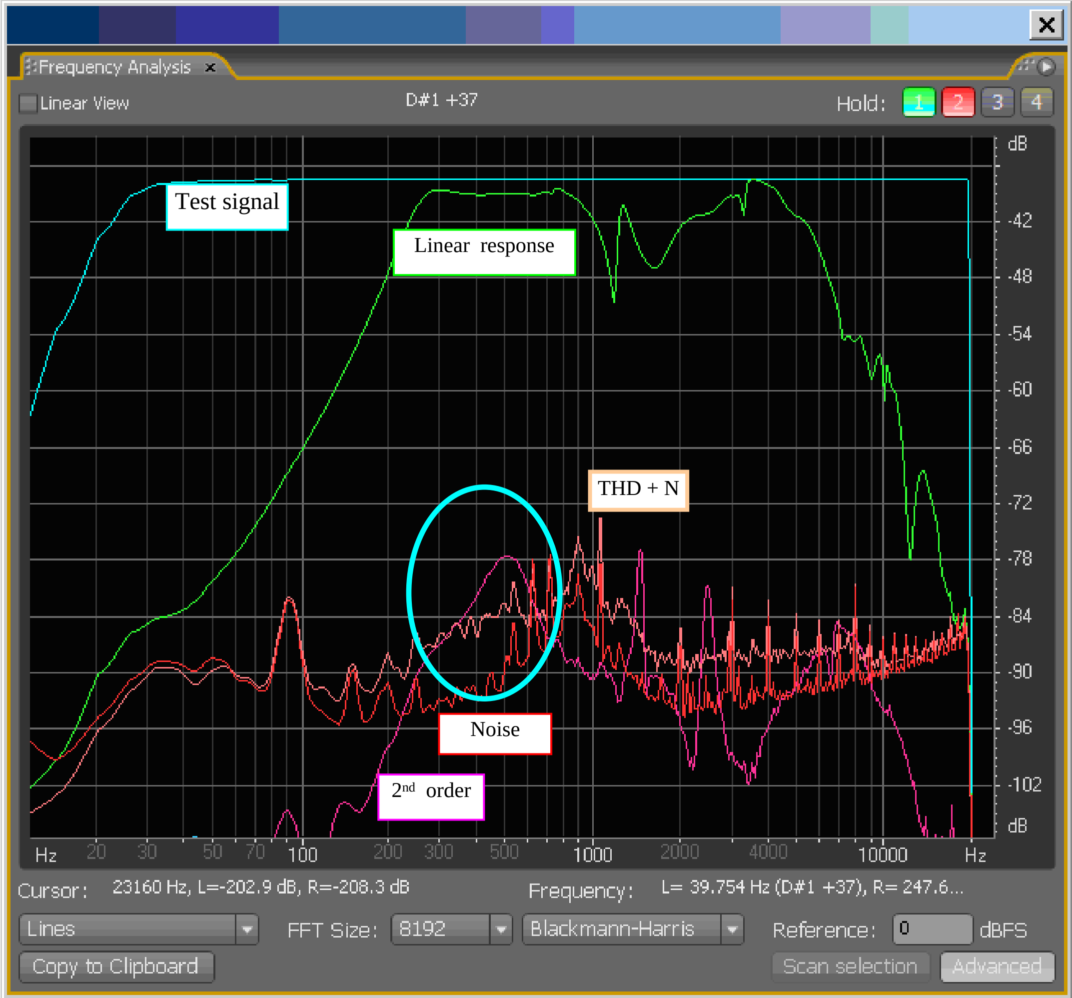
ESS results

- **After selecting the proper time segments for the various harmonic orders, we can analyze the corresponding spectra:**



ESS plus Silence Sweep results

- **And finally, for getting a complete display of the results, we can compare the results of the ESS measurement with those of the Silence Sweep:**



Discussion

- Are these results sensible?
- How can the 2^{nd} order harmonic distortion be larger than the THD+N in a certain frequency range around 500 Hz?
- Does it make sense to employ the same RMS amplitude for testing our system with the Silence Sweep and with the ESS signals?

- Considerations:
- As the ESS signal concentrates all the energy in just a narrow frequency band, it is more easily causing harmonic distortion (and this explains the "strange" result above).
- It appears that, for meaningful tests, the amplitude of the ESS and Silence sweep signals should NOT be the same. Instead, they should model the real amplitude of musical or speech signals
- For music, it is known that typical digital recordings are usually processed in such a way that they have a crest factor of approximately 8 to 12 dB
- Some further research is needed for assessing if this is the appropriate offset to be applied also between the amplitude of the ESS and of the Silence Sweep signals.

Conclusion

- The Silence Sweep is a completely new method
- Some of its implications are still unclear also to its inventor
- Further research is needed for understanding completely the information collected inside the "silenced band"
- The method shows the potential for a quick test, providing information on not-linear behaviour such as inharmonic distortion and intermodulation
- A complete test signal including an ESS, a Silence sweep and a small piece of silence can provide the complete characterization of a not-linear system with noise

Acknowledgements

- This research was partially supported by Audio Precision, who gently donated a complete measurement system for performing comparisons and reference measurements.

- I apologize for not being present at the 126 AES conference by person, due to health problems.
- For questions you can contact me by Skype:

angelo.farina

Or by phone: **+39 331 5918321**

I will be online for the duration of the scheduled session, although I do not know how much voice I will have….