State Scientific Center
of the Russian
Federation

CCAUV/15-43

VNIIFTRI

National Research Institute for
Physical-Technical and Radio Engineering Measurements

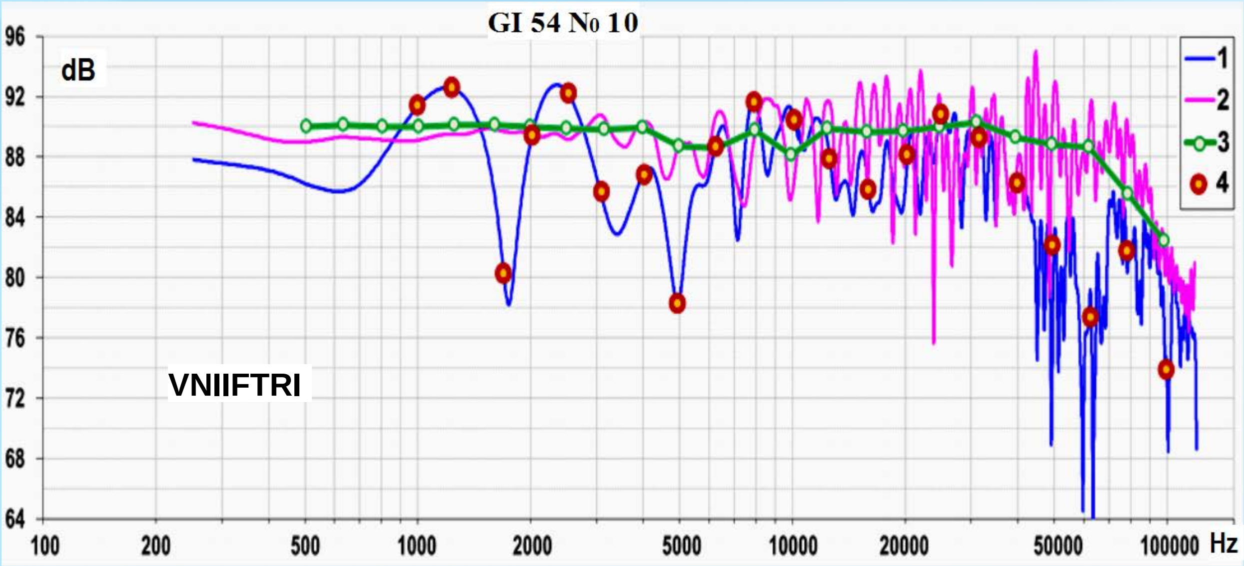
Using the water tank transfer function to suppress the reverberation distortion of the signal during calibration of an underwater sound receiver

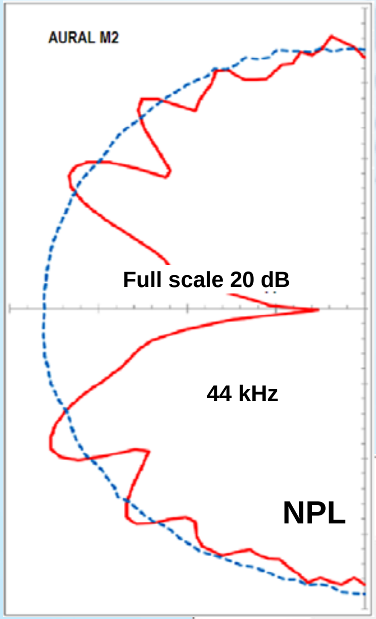
A.E. Isaev, I. V. Chernikov (VNIIFTRI, Russia)

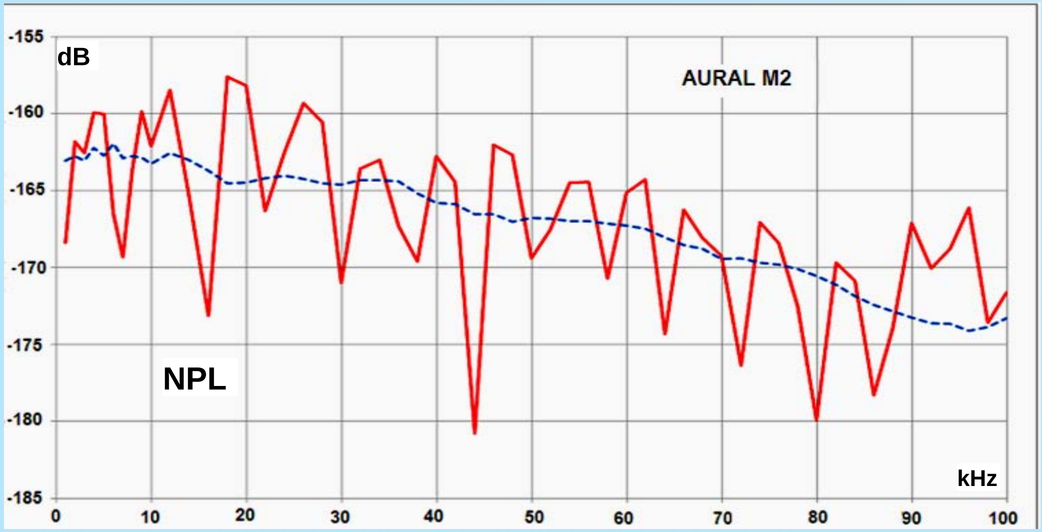
Examples of the hydrophone carrier (or suspension) system design

VNIIFTRI

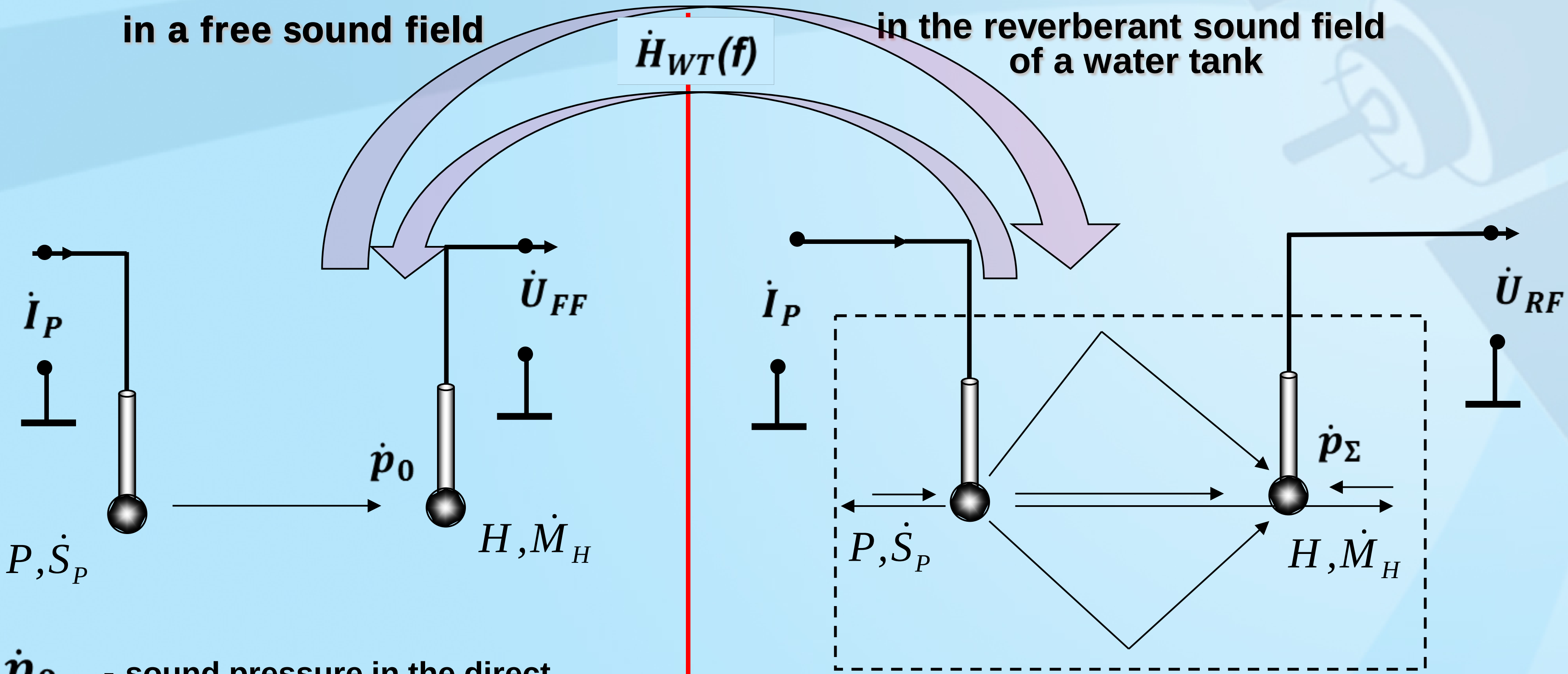
Influence of the carrier (suspension) system design on the response of the measuring system







The four pole model of the projector-receiver pair



$\dot{p}_0$ - sound pressure in the direct wave of the projector

The transfer impedance of the projector-receiver pair in a free sound field:

$$\dot{Z}_{FF} = \frac{\dot{U}_{FF}}{\dot{I}_P} = \dot{S}_P \dot{M}_H$$

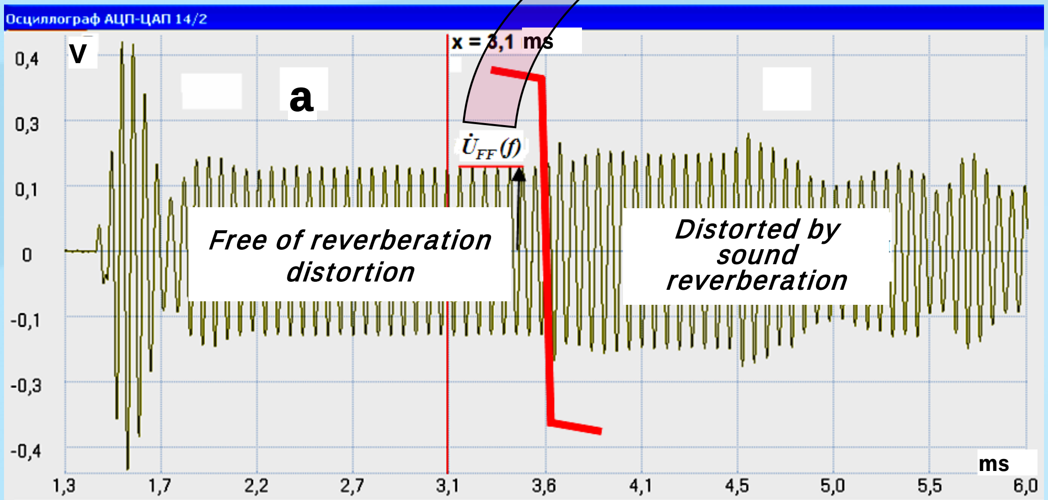
The total sound pressure at the receiving point:

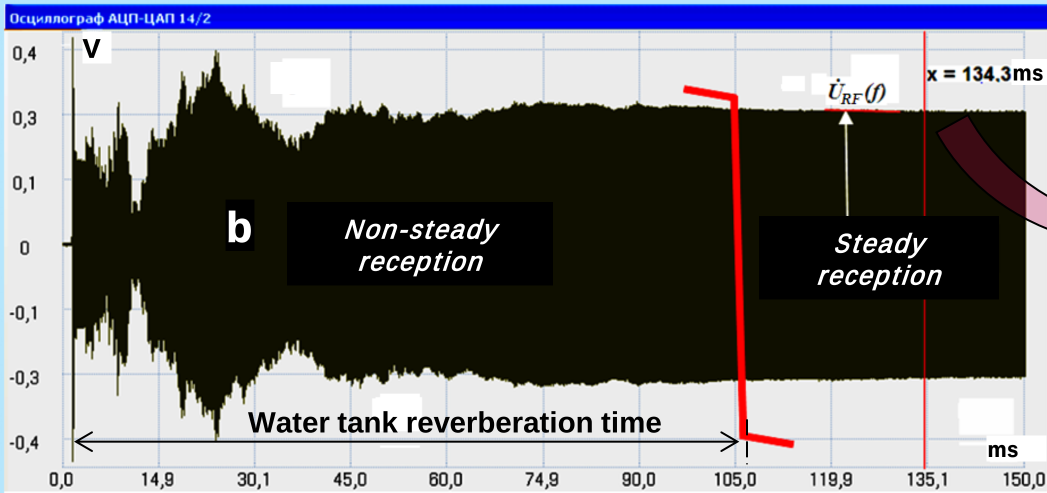
$$\dot{p}_\Sigma = \dot{p}_0 + \dot{p}_{R_\Sigma}$$

The output voltage of the receiver

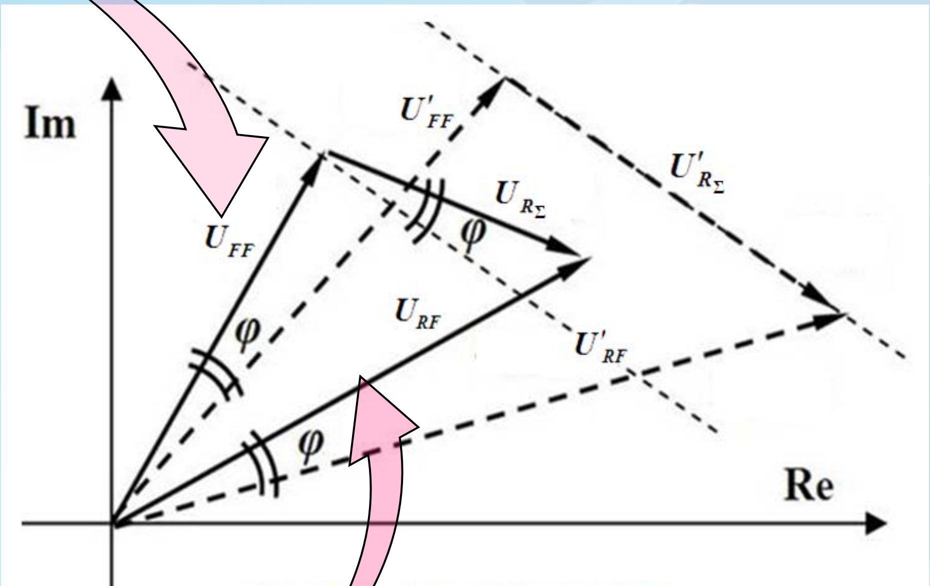
$$\dot{U}_{RF} = \dot{U}_{FF} + \dot{U}_{R_\Sigma}$$

The four pole model of the projector-receiver pair in the reverberant sound field of a water tank





Oscillograms of the receiver output voltage in the reverberant sound field of a harmonic signal in areas: free of reverberation distortion, distorted by sound reverberation, non-steady and steady reception



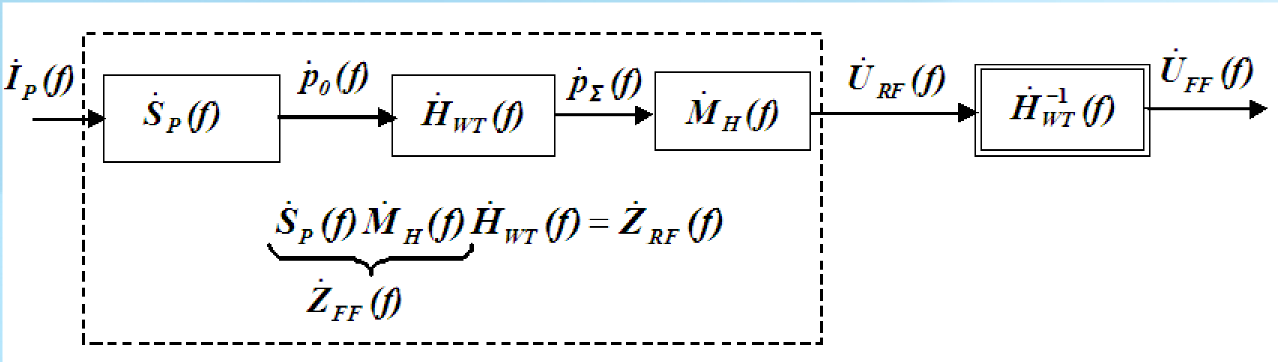
Vector diagram of the receiver output voltage

$$\frac{\dot{U}_{RF}}{\dot{U}_{FF}} = \frac{\dot{p}_0 + \sum_i \dot{p}_{R,i}}{\dot{p}_0} = \dot{H}_{WT}$$

The transfer impedance of the projector-receiver pair in the reverberant sound field of a water tank:

$$\dot{H}_{WT} = \frac{\dot{U}_{RF}}{\dot{I}_P}$$

The four pole model of the projector-receiver pair for measurements in a water tank



The Water Tank Transfer Function (WTTF) is a complex function that depending on the frequency establishes the ratio between the sound pressures in the reverberant and free sound fields at the receiving point:

$$\dot{H}_{WT}(f) = \frac{\dot{p}_{\Sigma}(f)}{\dot{p}_0(f)} = \frac{\dot{U}_{RF}(f)}{\dot{U}_{FF}(f)}$$

The transfer impedance of the projector-receiver pair in the reverberant sound field is the product of the pair transfer impedance in the free sound field and the WTTF:

$$\dot{Z}_{RF}(f) = \dot{Z}_{FF}(f)\,\dot{H}_{WT}(f)$$

Formula for the experimental determination of the WTTF

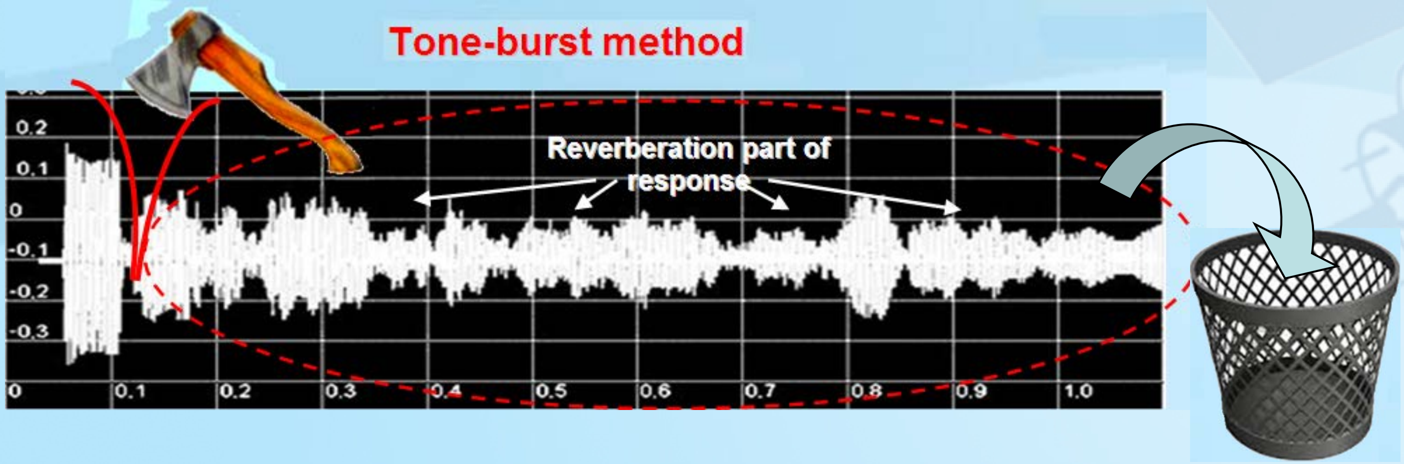
$$\dot{H}_{WT}(f) = \frac{\dot{Z}_{RF}(f)}{\dot{Z}_{FF}(f)}$$

The receiver output voltage in the free sound field

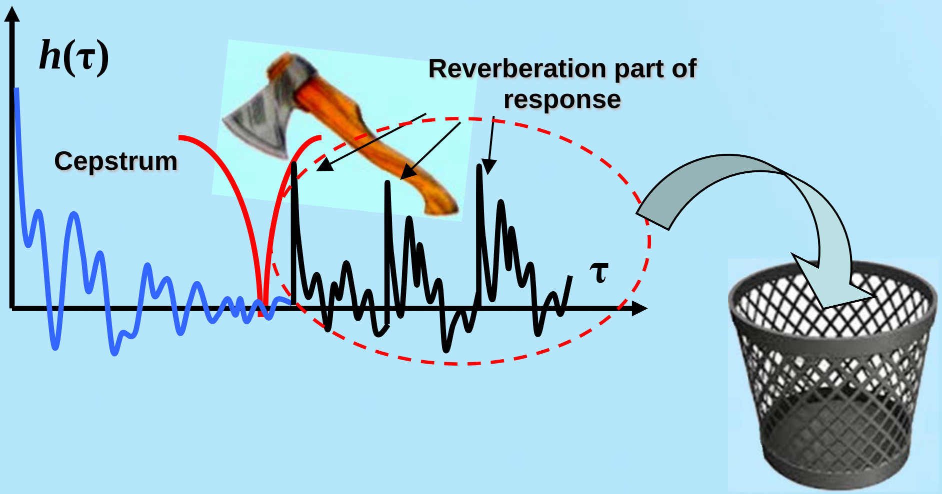
$$\dot{U}_{FF}(f) = \dot{U}_{RF}(f)\dot{H}_{WT}^{-1}(f)$$

The traditional approach to free-field calibration

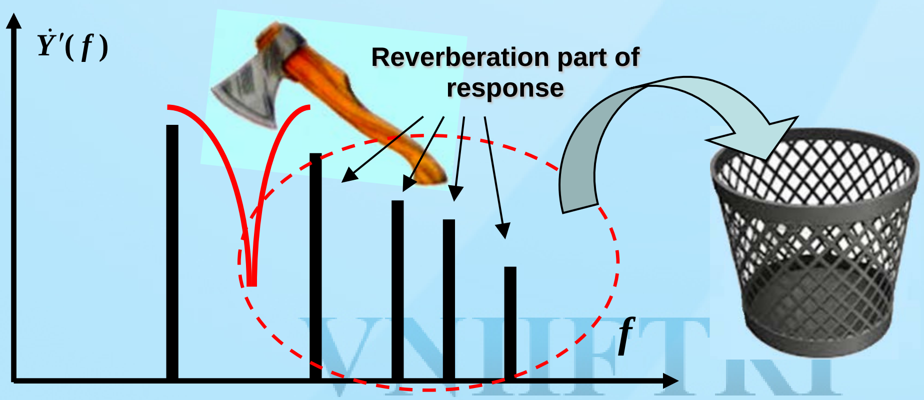
Tone-burst method



Homomorphic postprocessing



Time delay spectrometry



Measurement formulas

WTTF determination in the reverberant sound field of a noise signal

Experimental data: $\dot{I}_i(f)$, $\dot{U}_{RF_i}(f)$ *i=1,m*

Processing:

1 $|\dot{I}_i(f)|^2 = \dot{I}_i(f)\dot{I}_i(f)^*$, $\dot{U}_{RF_i}(f)\dot{I}_i(f)^*$

2 $\langle|\dot{I}_i(f)|^2\rangle$, $\langle\dot{U}_{RF_i}(f)\dot{I}_i(f)^*\rangle$

3 $$\dot{Z}_{RF}(f) = \frac{\langle\dot{U}_{RF_i}(f)\dot{I}_i(f)^*\rangle}{\langle|\dot{I}_i(f)|^2\rangle}$$

4 $$\dot{H}_{WT}(f) = \frac{\dot{Z}_{RF}(f)}{CMWA[\dot{Z}_{RF}(f)]}$$

Free-field measurements using the WTTF

1 $\dot{U}_{FF}(f) = \dot{U}_{RF}(f)\dot{H}_{WT}^{-1}(f)$

2 $u_{FF}(t) = F^{-1}[\dot{U}_{FF}(f)]$

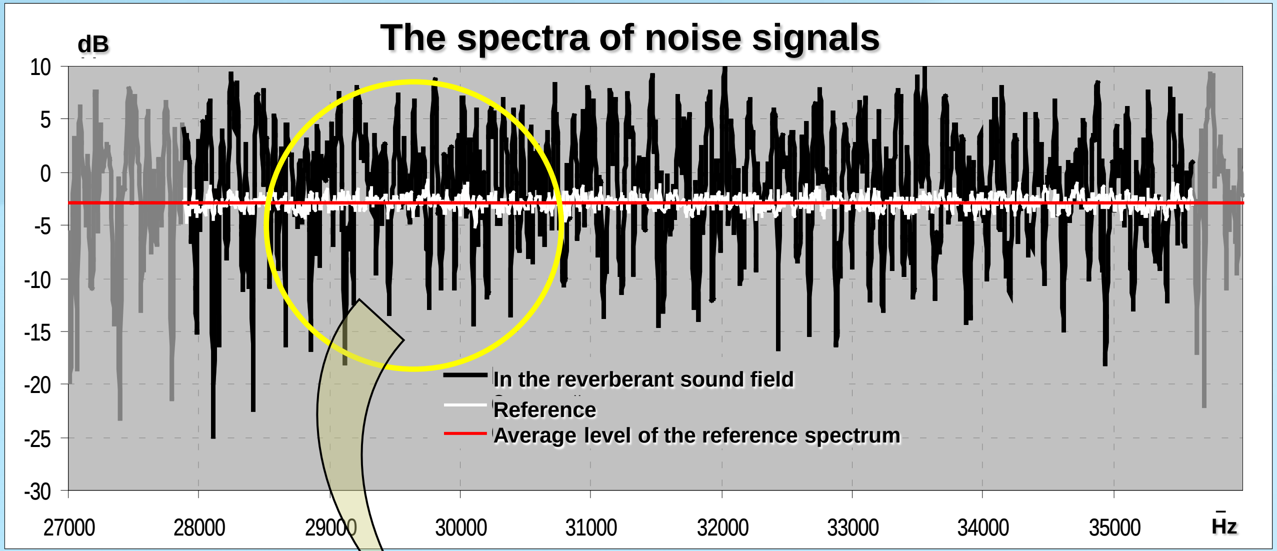
Reference signal

3 $\dot{U}_{REF}(f) = \dot{I}_P(f)\dot{Z}_{GET55}(f)$

4 $u_{REF}(t) = F^{-1}[\dot{U}_{REF}(f)]$

Experiments on the suppression of the reverberant distortion of spectra

Reception of white noise

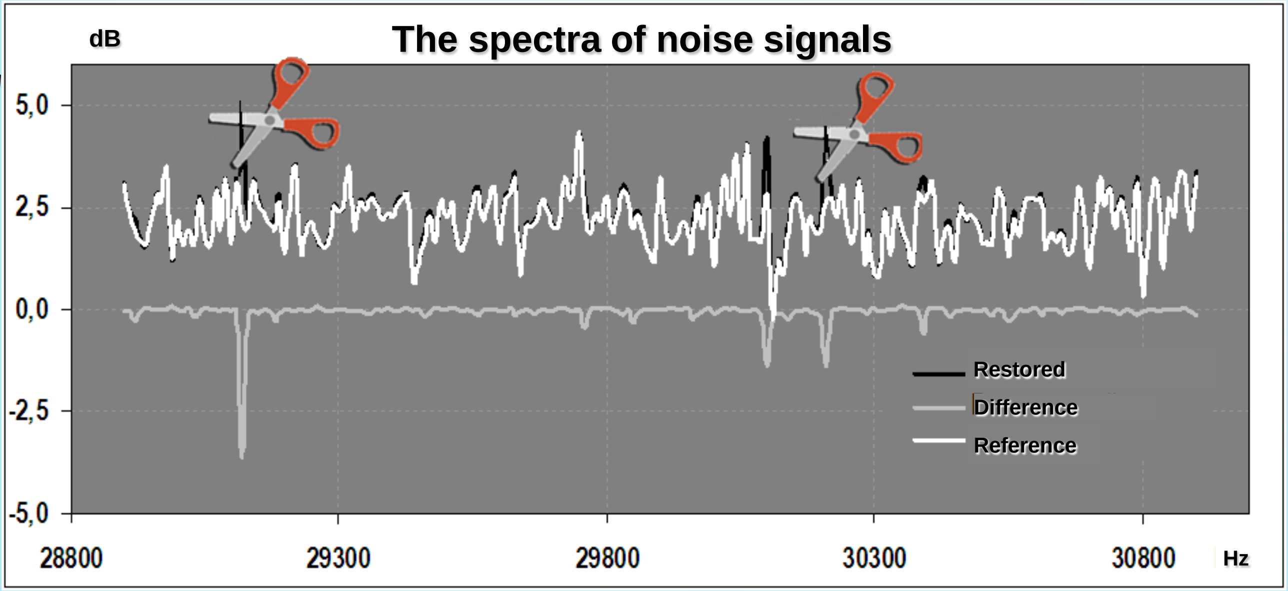


The spectrum of the noise signal at the receiver output in the reverberant sound field of a water tank

The reference spectrum and the average level of the reference spectrum

The reference, restored, and difference spectra

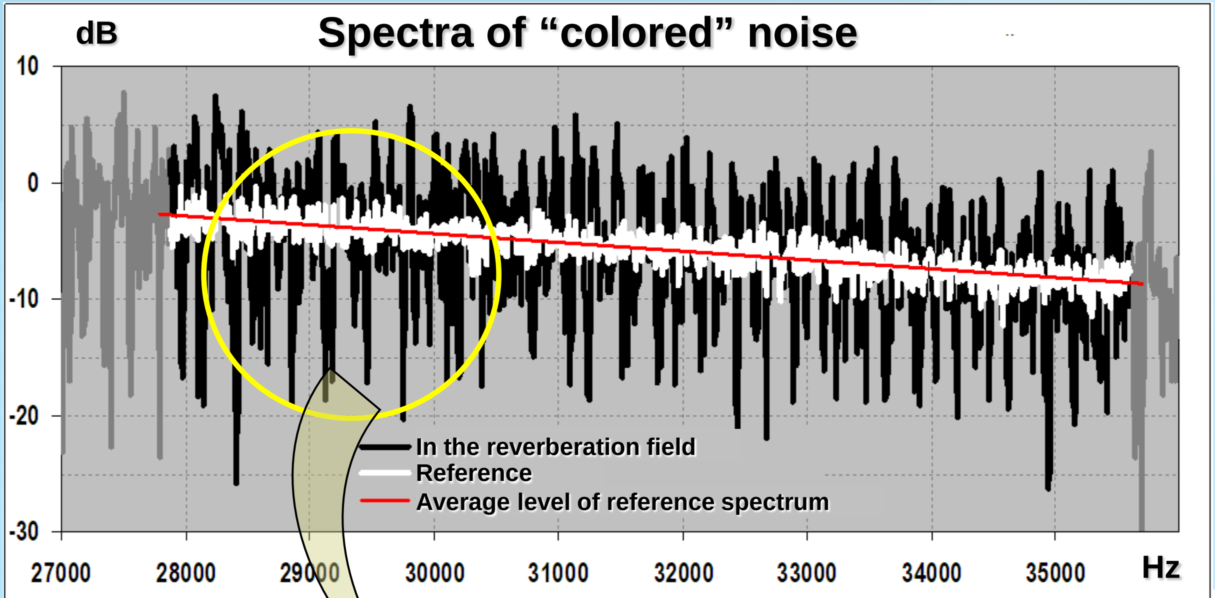
$$\left|\dot{H}_{WT}(f)\right|^{-1}$$



The difference of SPL values in 1/3 octave frequency bands of the reference and restored signals is less than 0.3 dB, which is comparable with tolerances for the effective bandwidth of 1/3 octave filters of class 1

Experiments on the suppression of the reverberant distortion of spectra

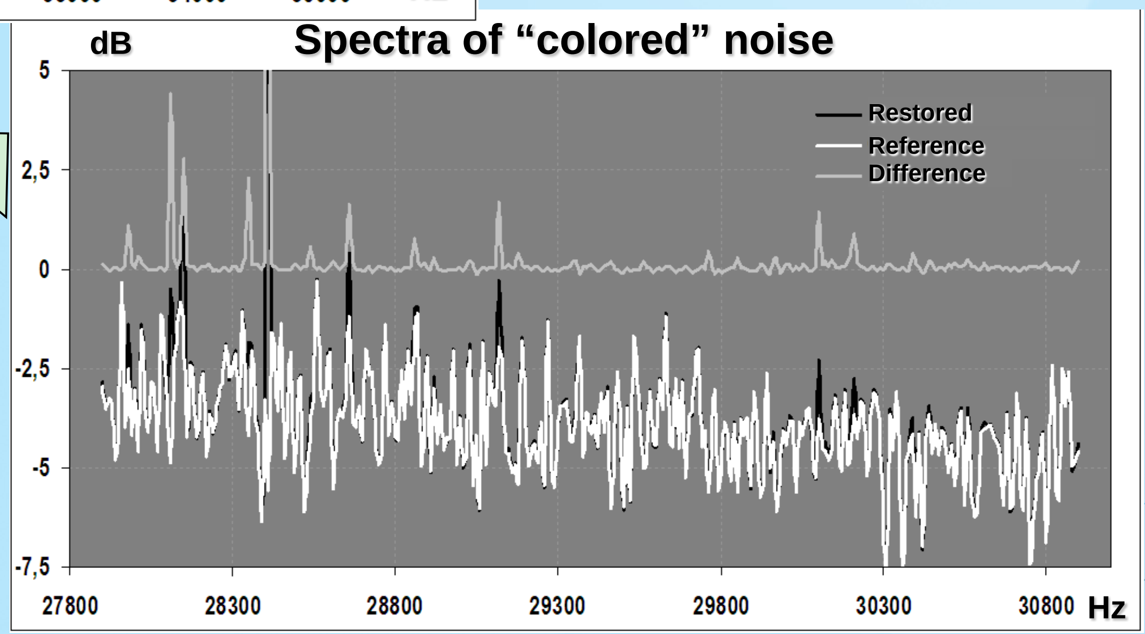
Reception of "colored" noise



The spectrum of the noise signal in the water tank reverberant field, the reference spectrum and the direct line of the reference spectrum average level

The reference, restored, and difference spectra

$$\left|\dot{H}_{WT}(f)\right|^{-1}$$

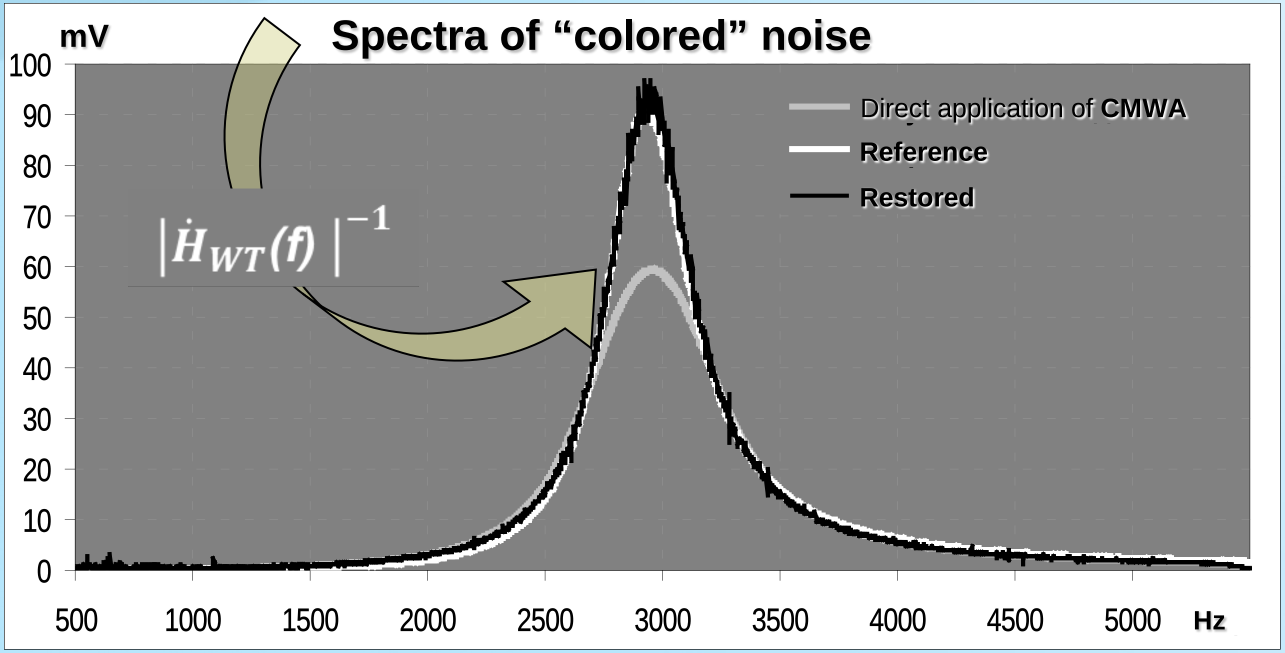


The difference of SPL values in 1/3 octave frequency bands of the reference and restored "colored" noise is less than 0.26 dB

The "trimming" of the spectrum reduces the difference to 0.1 dB

Experiments on the suppression of the reverberant distortion of spectra

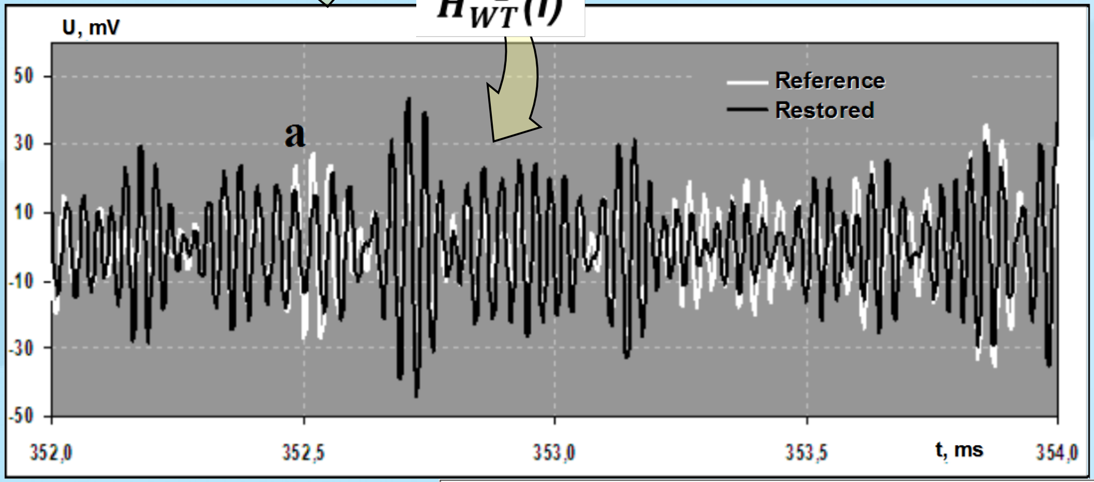
Reception of bell-shaped spectrum



The spectrum restored using the WTTF, the reference spectrum, and the frequency response obtained by direct application of CMWA processing

Restoring the waveform of the noise signal in a water tank with a reverberation time of 500 ms (time domain)

$\dot{H}^{-1}_{WT}(f)$

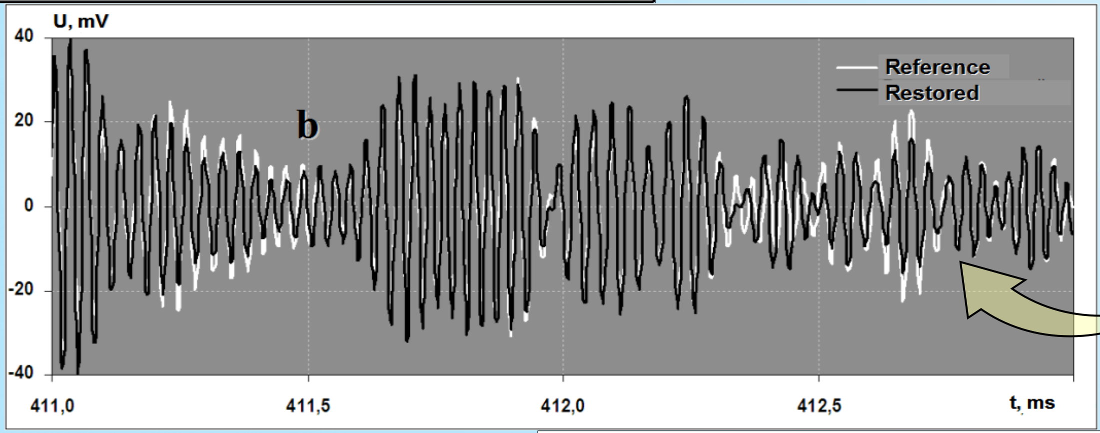


Time interval from 351 ms to 359 ms

Correlation coefficient of the reference and restored signals 0.82

Time interval from 408 ms to 416 ms

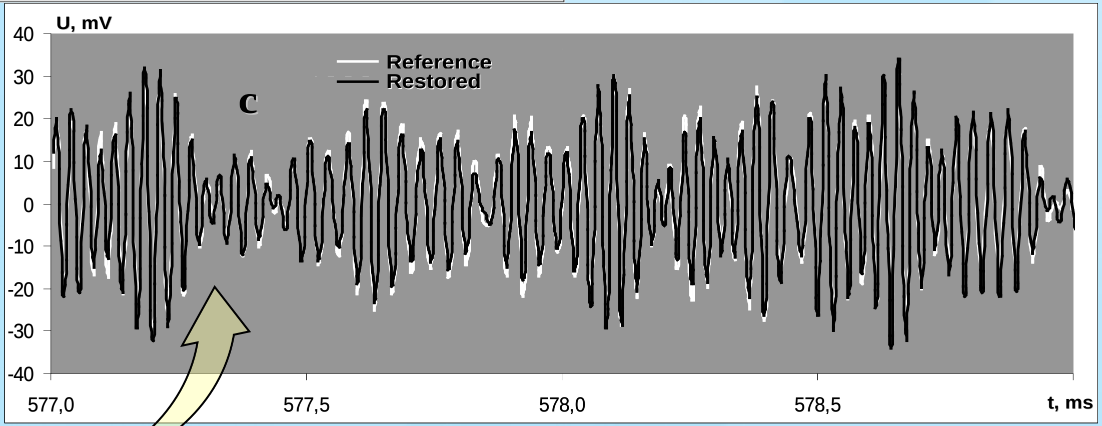
Correlation coefficient 0.96



$\dot{H}^{-1}_{WT}(f)$

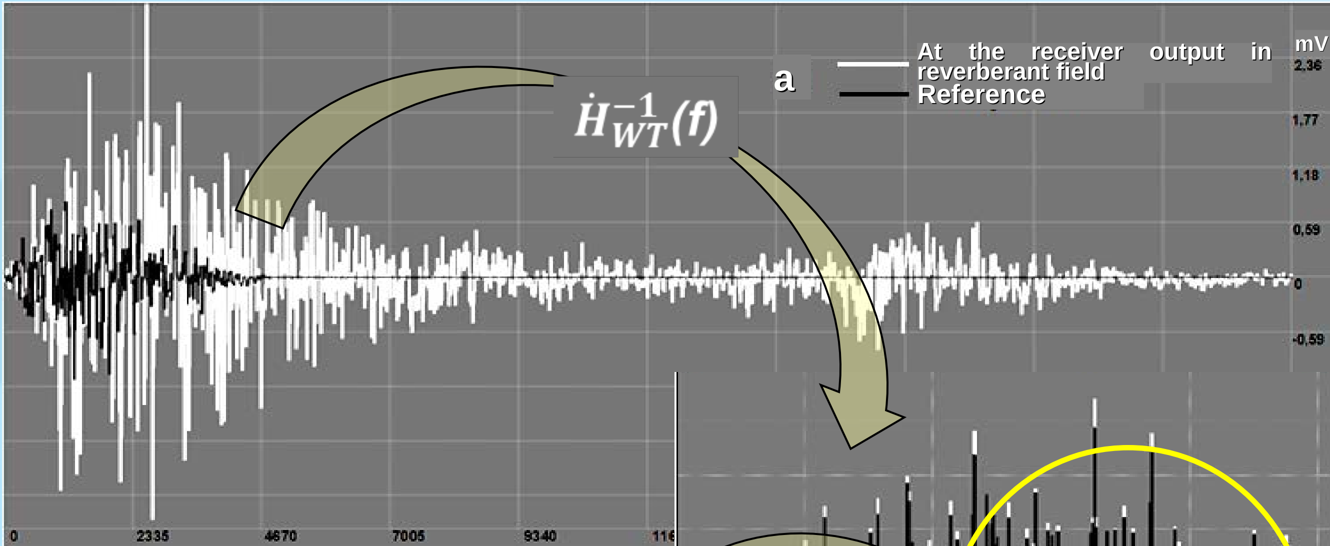
Time interval from 574 ms to 582 ms

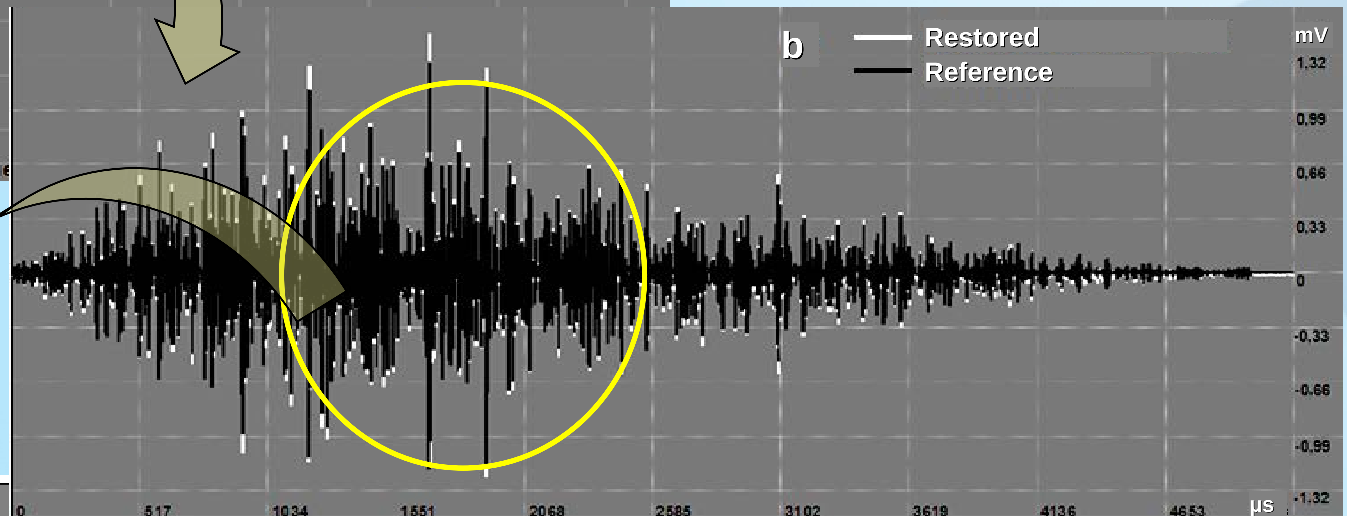
Correlation coefficient 0.99



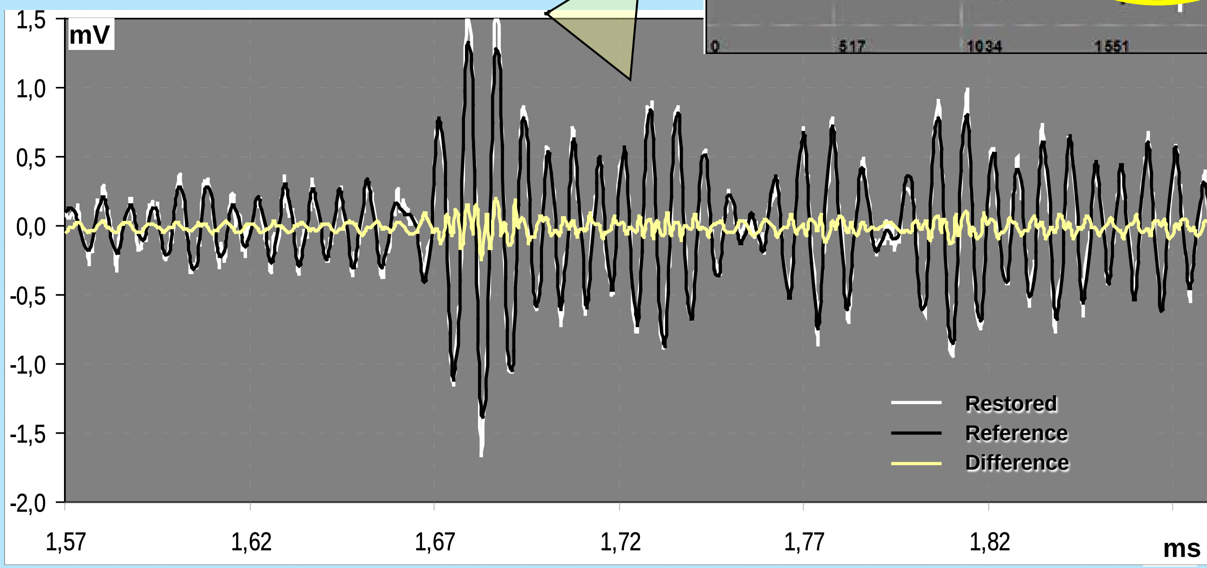
$\dot{H}^{-1}_{WT}(f)$

Restoring the form of a pulsed sound (time domain)





Waveforms of pulse signals: the receiver output in the reverberant sound field, the reference and restored signals



Differences of peak-to-peak values of the reference and restored pulses ≤ 13,5%

The discrepancy in the sound exposure ≤ 1%

The reference, restored and difference pulse signals in the neighborhood of the peek-to-peek value

CONCLUSIONS

Using the WTTF to suppress the reverberation distortion of the signal allows us to:

- circumvent the limitation of the time-frequency uncertainty relation during signal reception under conditions complicated by sound reverberation in a laboratory water tank;

- use in laboratory calibration of a underwater sound receiver noise signals similar to the signals measured when the receiver is used for its intended purpose.

The experiments on suppressing the reverberation distortion of the spectrum and waveform of stationary noise and pulsed sound have shown the possibility of:

- suppressing the reverberation distortion of the noise signal spectrum with quality comparable to the tolerances for the effective bandwidth of 1/3 octave filters of class 1

- restoring the free-field waveform of stationary noise (correlation coefficient 0.99)

- restoring the free-field waveform of pulsed sound with uncertainties of peak-to-peak values of 13.5% and the level of sound exposure not more than 1%

Thank you for your attention!

REFERENCES

1. A.E. Isaev, I.V. Chernikov. Laboratory Calibration of an Underwater Sound Receiver in the Reverberation Field of a Noise Signal. *Acoustical Physics, 2015, Vol. 61, No. 6, pp. 699–706*

2. A.E. Isaev, I.V. Chernikov. The use of reverberation sound fields for metrology work in a laboratory water tank. *Measurement techniques. (In the stage of publication). - 2015, - No 12.*

3. A.E. Isaev, I.V. Chernikov. Reverberant sound fields in a laboratory water tank and their use for metrology purposes. *Proceedings of 3-rd International Conference and Exhibition on Underwater Acoustics «UACE 2015», Crete, Greece, 2015, pp. 211 - 217.*

4. A.E. Isaev et al. The calibration of underwater sound receiver using the laboratory water tank transfer function. *Almanac of modern metrology. FSUE "VNIIFTRI." No 4, 2015, pp. 67-111. In Russian.*