Applications for Time-synchronized Noise Compensation (TNC)

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Introduction

Acoustic measurements in noisy environments (e.g. cars) often face the problem of separating the signal to be measured from the background noise. In [1] a very efficient method was proposed to reduce the disturbing noise by subtraction of signals in the time domain (Time-synchronized Noise Compensation (TNC)). The contribution explained the principle of TNC for the application of laboratory tests of ICC systems. Further investigations on TNC applications have been carried out and are introduced in the current paper. This includes the measurement of noise dependent frequency response or loudness rating, double talk attenuation in receiving direction and also the measurement of echo components, such as talker echo loudness rating or echo measurements on analogue two-wire interfaces. Furthermore, the practical limits influencing the performance of TNC have been investigated and are discussed.

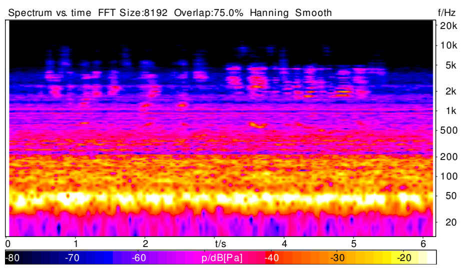

Figure 1a: Speech and noise (spectrum vs. time); recorded at the backseat of a vehicle equipped with an ICC system.

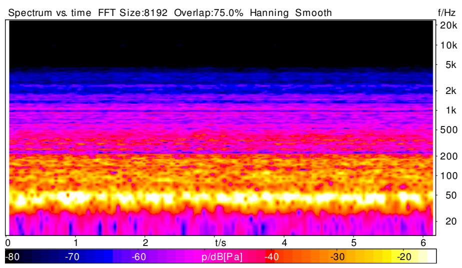

Figure 1b: Noise (spectrum vs. time) recorded at the backseat of a vehicle equipped with an ICC system.

Principle of TNC

The basic idea of TNC is the reproducible generation of an impairing signal simultaneously to a test signal in a laboratory setup. The signal to be analyzed consists of the test signal and the superposed impairing signal. The impairing signal recorded previously without test signal is then subtracted from the measured signal in the time domain. In this way the signal to be measured is preserved but the disturbing components for the analyses are efficiently removed. The transmitted test signal can be analyzed without the impairing signal. When applying TNC to compensate background noise, the playback of the background noise has to be synchronized to the playback of the test signal. **Figures 1a** to **1d** show an FFT vs. time representation of a speech signal (test signal) measured at the backseat of a vehicle equipped with an in-car communication (ICC) system [1]. Since ICC systems are excited by driving noise, measurements have to be carried out under noisy conditions. **Figure 1a** shows the three-dimensional spectrum of the signal consisting of speech and noise. **Figure 1b** shows only the noise spectrum (reference recording). The processed signal after application of the TNC algorithm is shown in **figure 1c**: background noise is reduced by more than 30 dB, the speech spectrum is clearly recognizable. For comparison, the clean speech signal without background noise is provided in **figure 1d**. The difference between the active speech level [2] of the original clean speech and the processed signal after TNC is less than 0.1 dB.

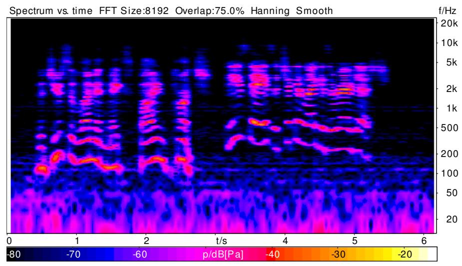

Figure 1c: Speech (spectrum vs. time) after TNC application.

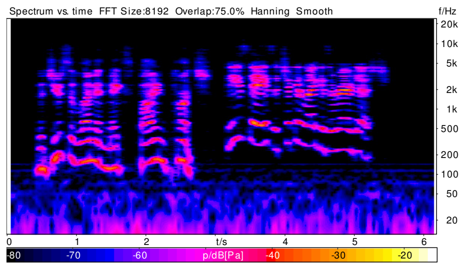

Figure 1d: Original clean speech (spectrum vs. time).

Practical Applications

Loudness rating and frequency response in noise

Similar to ICC systems current eCall systems often provide a noise dependent volume control. The receiving loudness rating (RLR) of these systems is automatically adapted via automatic gain control or automatic volume control respectively to provide sufficient signal to noise ratio for any background noise level while maintaining a comfortable volume under silent conditions. It is possible to measure the variation of the loudness rating depending on the background noise level by the application of TNC. **Figure 2** (right) shows the basic setup for measurement of background noise dependent parameters in the vehicle. **Figure 3a** shows the frequency response of an eCall system under silent conditions with a corresponding RLR of 0.9 dB. When a typical eCall road noise (as defined in ITU-T Rec. P.1140 [3]) is applied, an RLR of -11.5 dB can be measured on this system (**figure 3b**). However, the result in **figure 3b** is not accurate, as the background noise also contributes to the RLR result to an unknown extent. After applying TNC to the measured signal, the correct RLR of the eCall system under these noisy conditions can be determined to -9.6 dB. The corresponding frequency response curve (**figure 3c**) shows exactly the same characteristic as in **figure 3a** which is simply shifted by 10.5 dB.

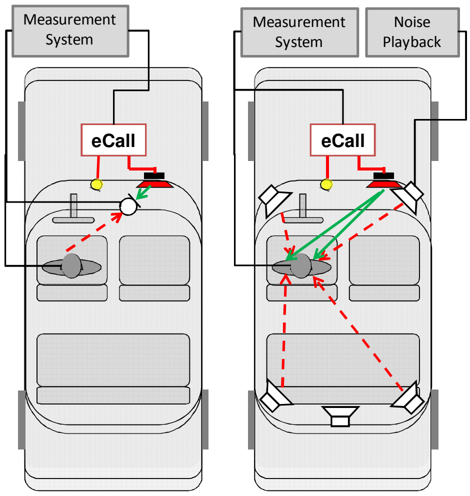

Figure 2: Setup for measurements in the vehicle for double talk (left) and under background noise conditions (right).

Double talk in receive

Another practical application of TNC is the measurement of double talk attenuation in receiving direction of hands-free devices. Double talk measurements require the simultaneous application of two test signals, the downlink signal and the near end signal via the artificial mouth. **Figure 2** (left) shows the measurement setup in a vehicle cabin. When near end (red) and far end signal (green) are played back in the cabin, both signals are recorded at the HATS which influences the double talk attenuation measurement. Therefore, the influence from the near end signal has to be minimized. Typically the measurement is carried out using a measurement microphone close to the loudspeaker of the hands-free terminal. In this case the level of the near end signal is low compared to the loudspeaker signal level and does not affect the determination of the double talk attenuation. **Figure 4a** shows the measured sensitivity in receive of an eCall system under double talk conditions. The magenta curve represents the sensitivity during double talk, the black curve shows the equivalent sensitivity under single talk conditions (no signal emitted by the near end). Both sensitivity curves show a similar behavior indicating no double talk attenuation. However, for some hands-free implementations the speaker is capsulated and not accessible. In these cases it is not possible to minimize the near end speaker signal by microphone positioning sufficiently. **Figure 4b** shows the measurement results when the microphone cannot be positioned close enough to the loudspeaker. The level of the near end signal significantly distorts the measurement results, a potential attenuation in receive cannot be detected due to the gain induced by the near end signal. After applying TNC, the near end influence on the double talk sensitivity is removed, both curves show a similar behavior and the correct double talk attenuation can be determined (**figure 4c**).

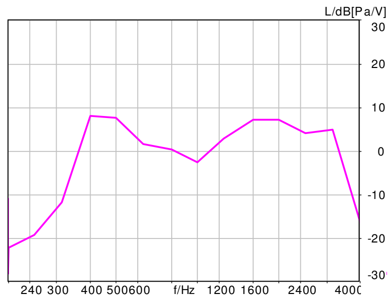

Figure 3a: frequency response in downlink direction of an eCall system under silent conditions (corresponding RLR of 0.9 dB).

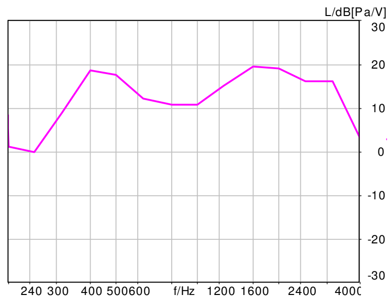

Figure 3b: frequency response in downlink direction of an eCall system under background noise conditions (road noise, corresponding RLR of -11.5 dB).

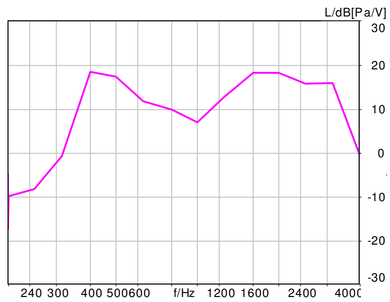

Figure 3c: frequency response in downlink direction as determined by the TNC algorithm of an eCall system under background noise conditions (road noise).

Acoustic measurement of talker echo loudness rating

In a typical end-to-end setup the determination of the talker echo loudness rating (TELR) is of interest in order to categorize the echo performance of the complete system. TELR is typically calculated (SLR + RLR + echo loss) since the level of the near end sidetone is several magnitudes higher than the expected echo level. However, by subtracting the sidetone via TNC, the sidetone level can be attenuated by up to 60 dB, thus making the acoustic measurement of TELR possible. **Figure 5** shows the principle setup for the determination of talker echo loudness rating. In order to rate the performance of TNC in this setup, an echo simulator has been applied to the far end in **figure 5** that allows to chose dedicated echo attenuations. **Table 1** shows the measured TELR compared to the calculated TELR values.

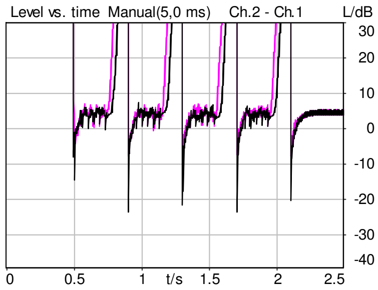

Figure 4a: Level vs. time sensitivity, recorded close to the speaker of the device under test: single talk (black) and double talk (magenta).

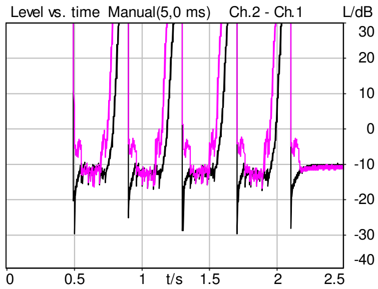

Figure 4b: Level vs. time sensitivity, recorded at the HATS: single talk (black) and double talk (magenta).

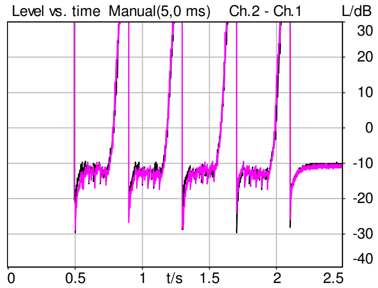

Figure 4c: Level vs. time sensitivity from recording at HATS after TNC application (magenta) and the recording under single talk conditions (black).

In this test it can be observed that the measured TELR exceeds the calculated value due to the influence of the AGC of the near-end mobile phone in receiving direction which is not taken into account by the calculation based on SLR and RLR. Furthermore, the results indicate that the attenuation of the near end sidetone using TNC is sufficient to carry out valid TELR measurements. Moreover the examples show, that the calculation of TELR may even be misleading as it is based on standard sensitivities.

Electric measurement of echo in two-wire environment

A similar approach can be taken to measure the echo of landline telephones in a two-wire environment. The basic setup is shown in **figure 6**. The analog hybrid, necessary to connect the analog phone, couples back a hybrid echo to the measurement system ("Hybrid Echo E1" in fig. 6). Since this echo level, originated at the hybrid is typically higher than the far end echo level from the phone to be tested (far end echo, "Acoustics Echo E2" in fig. 6), echo measurements are inaccurate or even impossible in such a setup. Applying TNC to the recording allows the accurate measurement of far end echo E2 by compensating the near end hybrid echo E1. Again, tests were carried out simulating different far end echo attenuations E2. Some exemplary results are provided in **table 2**. Row 2 shows the measured echo without TNC, which is dominated by the echo E1 originated at the hybrid. Row 3 shows the result after compensating the hybrid echo by TNC. TNC makes it possible to exactly measure the echo loss that has been generated by the echo simulator. Thus, the application of TNC enables echo measurements in analog two-wire connections.

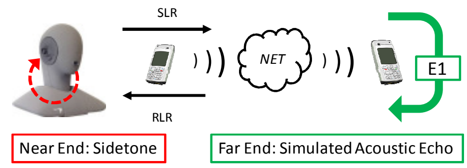

Figure 5: Setup for the determination of talker echo loudness rating.

Figure 6: Setup for the determination of echo attenuation in a two-wire environment.

Table 1: Talker Echo Loudness Rating

Echo Loss E_1 [dB]	**12.0**	**24.0**	**30.0**	**42.0**
Calculated TELR [dB]	22.0	34.0	40.0	52.0
Measured TELR [dB]	22.2	35.6	42.0	59.1

Table 2: Electric measurement of two-wire echo

Echo Loss E2 [dB]	∞	**50**	**40**	**30**	**20**
Measured Echo E1+E2 [dB]	24	24	24	24	19
Measured Echo E2 (TNC) [dB]	57	50	40	30	20

Practical limits

Several investigations have been carried out concerning the variables that could decrease TNC performance. The goal of TNC is to reduce the disturbing noise or signal components from measured signals, so that the level of the signal of interest is high against the level of the disturbing signal. This requires very high correlation between the two recordings of the disturbing noise. If both recordings are carried out acoustically, this correlation is influenced by the signal to noise ratio of the playback system, non-linear distortions introduced by acoustic transduces and also the frequency content of the signal to be compensated, since the correlation of the two signals decreases with increasing frequency. Verification tests have been performed in a typical measurement chamber for measuring telecommunication devices. The chamber was equipped with a background noise system according to ES 202 396-1 [4] which has been equalized using a 70 dB(A) pink noise as the calibration signal. The ambient noise in the chamber has been determined to 28 dB(A). TNC was applied for four different test signals in order to rate the performance of TNC: a stationary car noise (full size car 130, as defined in [3]), pink noise, white noise and also a forest noise which consists mostly of bird tweeds at 36 dB(A) signal level (nature one_forests_binaural [], attenuated by 5 dB).

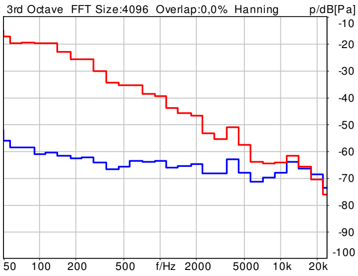

Figure 7a: spectrum of test signal (red) and residual signal (blue) determined by TNC, full size car 130 km/h.

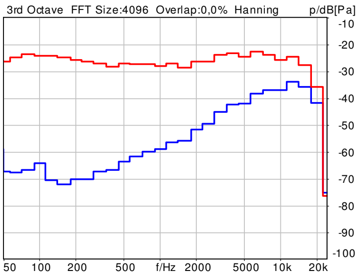

Figure 7b: spectrum of test signal (red) and residual signal (blue) determined by TNC, pink noise.

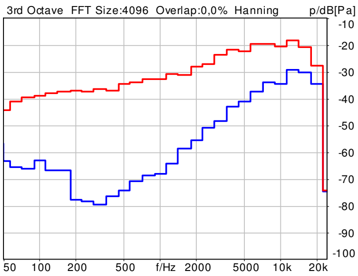

Figure 7c: spectrum of test signal (red) and residual signal (blue) determined by TNC, white noise.

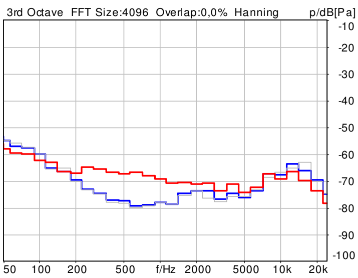

Figure 7d: spectrum of test signal (red) and residual signal (blue) determined by TNC, forest.

Table 3: Noise level reduction

Noise	**Car**	**Pink Noise**	**White Noise**	**Forest**
Level [dBSPL(A)]	67.0	81.0	82.0	36.0
Level [dBSPL]	86.0	84.0	84.0	47.0
TNC atten. [dB]	27.4	16.2	15.3	2.8

Table 4: Influence of time-alignment errors

Delay [No. of samples (21µs)]	**0**	**1**	**2**	**3**	**5**	**10**
TNC atten. [dB]	27.4	24.3	21.6	19.4	16.2	11.3
Loss (dB)	-/-	-3.1	-5.8	-8.0	-11.2	-16.1

Table 3 shows the results of these tests. **Figures 7a** to **7d** show the third octave spectra of the test signals (red curve) and also those of the residual signals after TNC (blue curve). As expected, TNC performs best with car noise, where low frequencies are dominant (**figure 7a**). The performance with pink noise of a similar level (**figure 7b**) is significantly worse due to higher frequencies being more prominent. The performance with white noise which contains even more high frequency content is slightly worse but in a similar range (**figure 7c**). The bad performance of the forest noise (**figure 7d**) can be explained by a combination of the rather high frequent noise and the low test signal level.

Using the same test environment, further studies have been undertaken to rate the influence of the accuracy of the synchronization. If measurement signal and noise signal are emitted by different physical sources, the noise signal has to be triggered by the measurement system. The accuracy of the time-alignment has a direct influence on the performance of TNC. Tests have been carried out using the full size car 130 test signal [4]. In order to rate the influence of trigger errors, one of the two measured signals has been delayed by a variable number of samples (at 48 kHz sampling rate). **Table 5** shows the results depending on the number of samples delayed. As expected, the attenuation achieved by TNC decreases with higher synchronization error.

Conclusion

Time-synchronized noise compensation has been introduced as a method to increase the SNR of measured signals under the premise that the disturbing noise or signal can be played back synchronous to the measurement. Several application examples have been proposed where TNC permits determination of acoustic parameters in presence of noise which otherwise would be heavily distorted. In order to investigate the robustness of TNC, tests have been performed using noises with a different spectral distribution and noise levels. The influence of time-alignment accuracy has been determined by performance tests with delayed compensation signals. The test results show that, within the given limits, TNC is an efficient method to accurately perform measurements under poor SNR conditions which cannot be performed conventionally.

References

[1] U. Muesch, F. Kettler: Instrumental Testing of In-Car Communication Systems, DAGA 2015.

[2] ITU-T Rec. P.56: Objective measurement of active speech level (12/2011)

[3] ITU-T Rec. P.1140: Speech communication requirements for emergency calls originating from vehicles (06/2015)

[4] ETSI ES 202 396-1: Speech quality performance in the presence of background noise (06/2015)

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