Comparative Study of Speech Intelligibility Inside Cars

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Goals

- Evaluation of the acoustical confort inside a car, in terms of speech intellegibility
- Objective rating of both electroacoustical devices (sound system) and of natural communication between passengers
- Evaluation of the bi-directional performances of hands-free communication systems

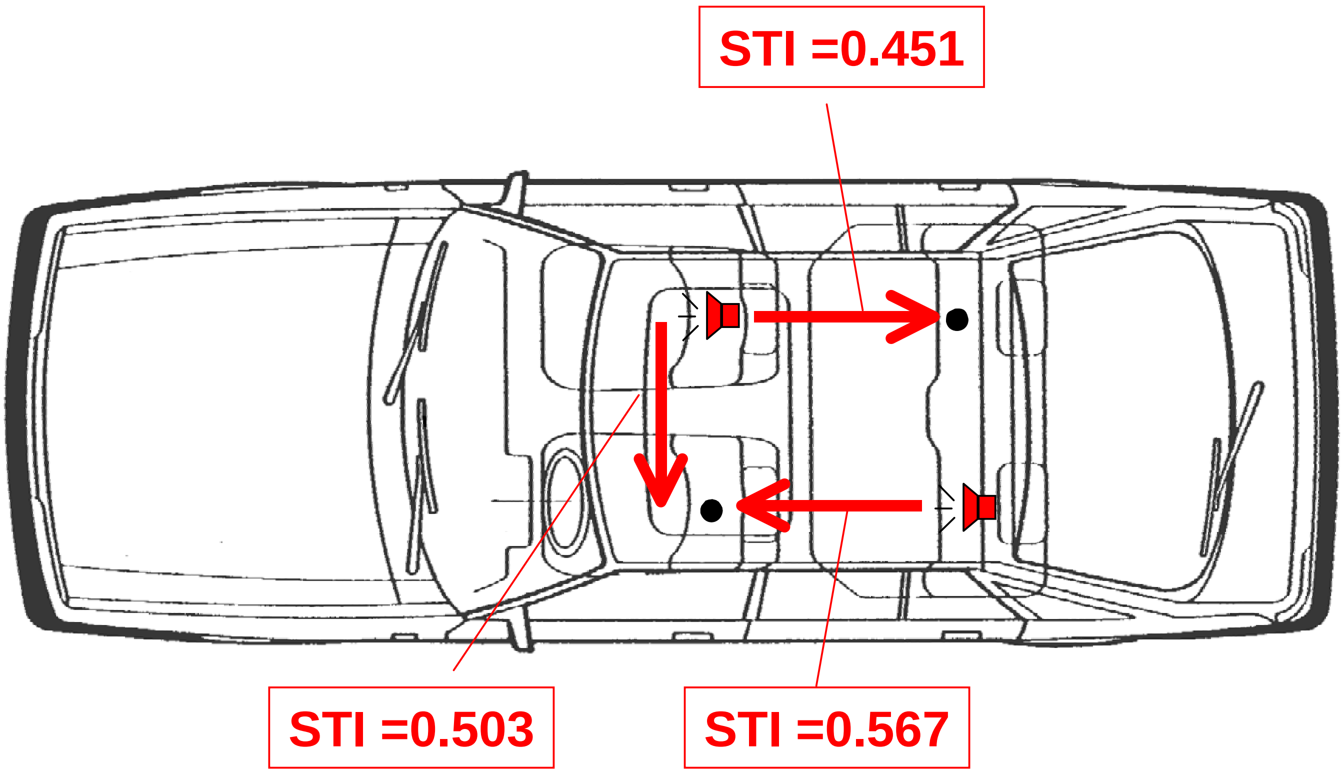
Details :

- The sound is recorded inside the car running on the road, by means of a binaural microphonic probe. For passenger-to-passenger communication, the test signal is generated through a mouth simulator, installed in a separate torso simulator.
- The test is performed according to IEC standard n. 60268-16 (STI), in the MLS-based implementation.

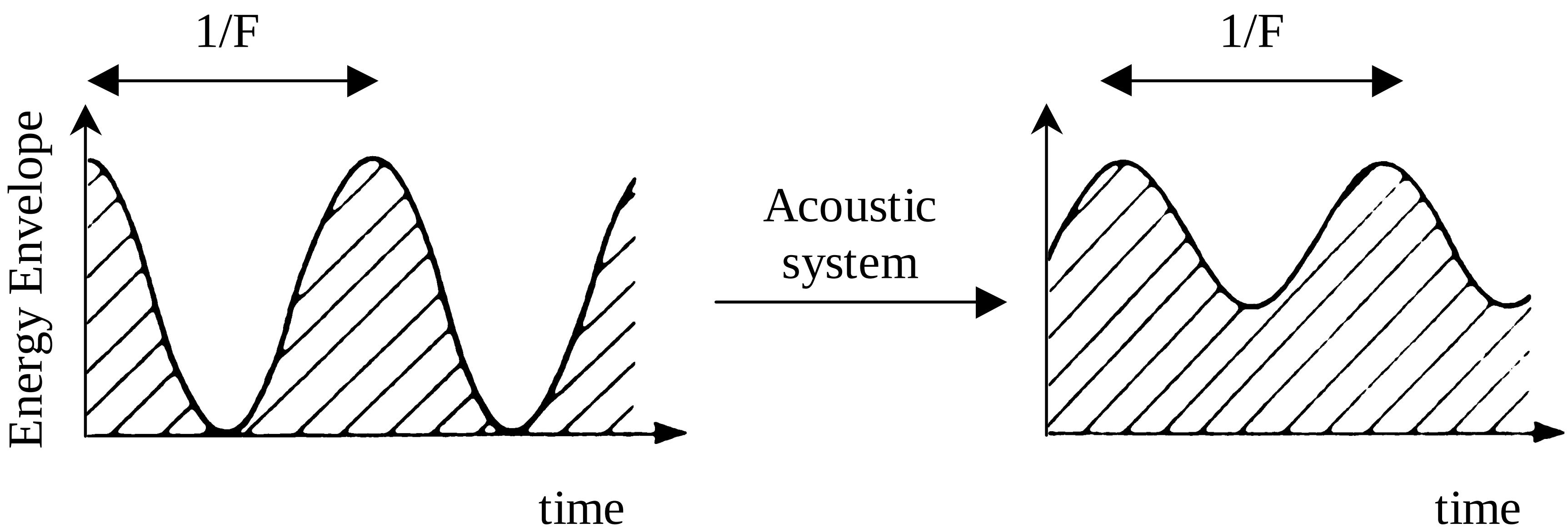
Methods

- Three kinds of tests are employed:

1. Front seat passenger ➔ Driver
2. Rear seat ➔ Front seat on the same side
3. Front seat ➔ Rear seat on the same side



The STI Method



The STI method is based on the MTF concept: a carrier signal (one-octave-band-filtered noise) is amplitude modulated at a given modulation frequency with 100% modulation depth. At the receiver, the modulation depth is reduced, due to noise, reverb, echoes, etc.

MTF from Impulse Response

- It is possible to derive the MTF values from a single impulse response measurement:

To compute each value of *m(F)* from the impulse response *h(t)*, an octave-band filter is first applied to the impulse response, in order to select the carrier's frequency band *f*. Then *m(F)* is obtained with the formula

$$m(F) = \frac{\int_0^\infty h_f^{\,2}(\tau) \cdot \exp(-j \cdot 2 \cdot \pi \cdot F \cdot \tau) \cdot d\tau}{\int_0^\infty h_f^{\,2}(\tau) \cdot d\tau}$$

Background noise

- If the background noise is superposed to the impulse response, the previous method already takes care of it, and the MTF values are measured correctly
- However, in some cases, it is advisable to perform a noise-free measurement of the IR, and then insert the effect of the noise with the following expression:

$$m(F) = m'(F) \cdot \frac{1}{1 + 10^{\left(\frac{L_{noise} - L_{signal}}{10}\right)}}$$

- This makes it possible to measure the impulse response in the laboratory, and then to perform just the noise measurement with the car running over the road

Transducers: binaural microphone

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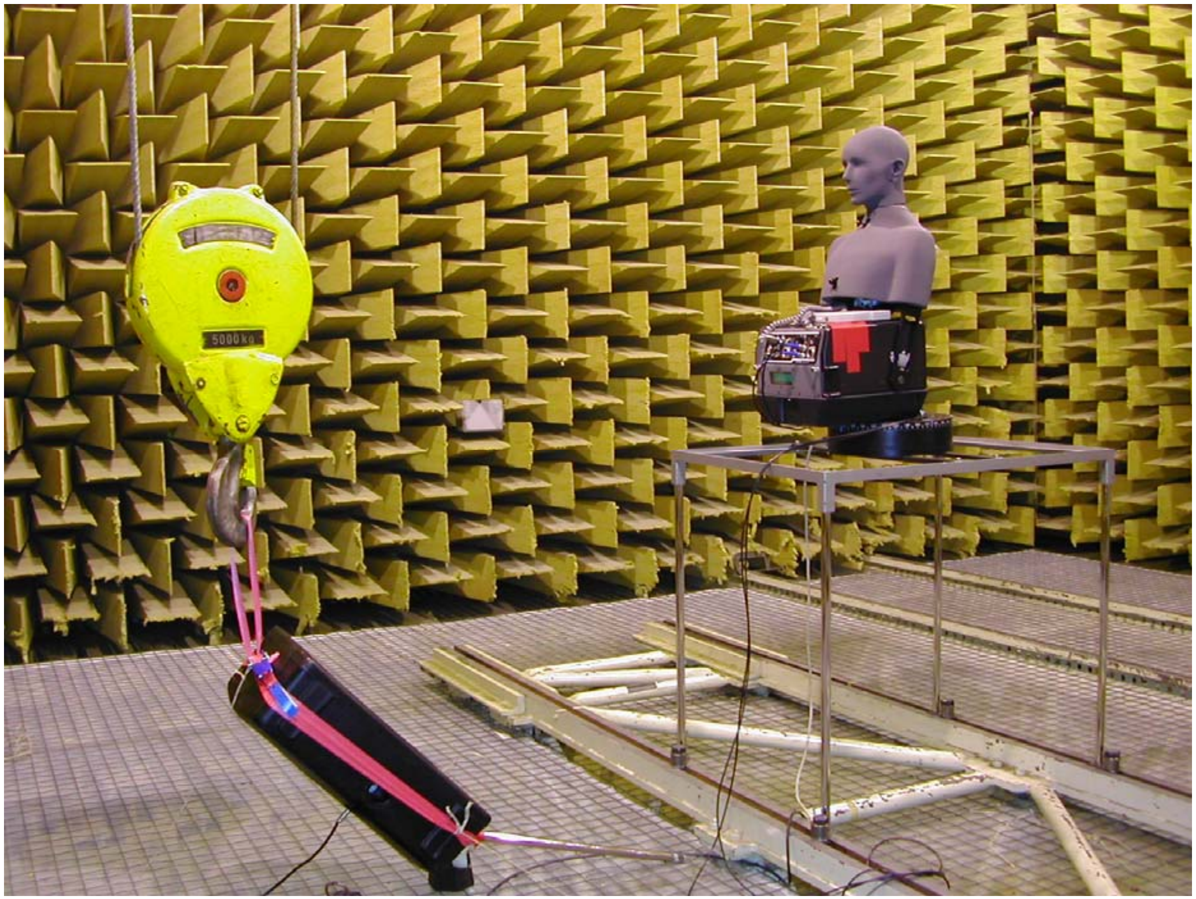
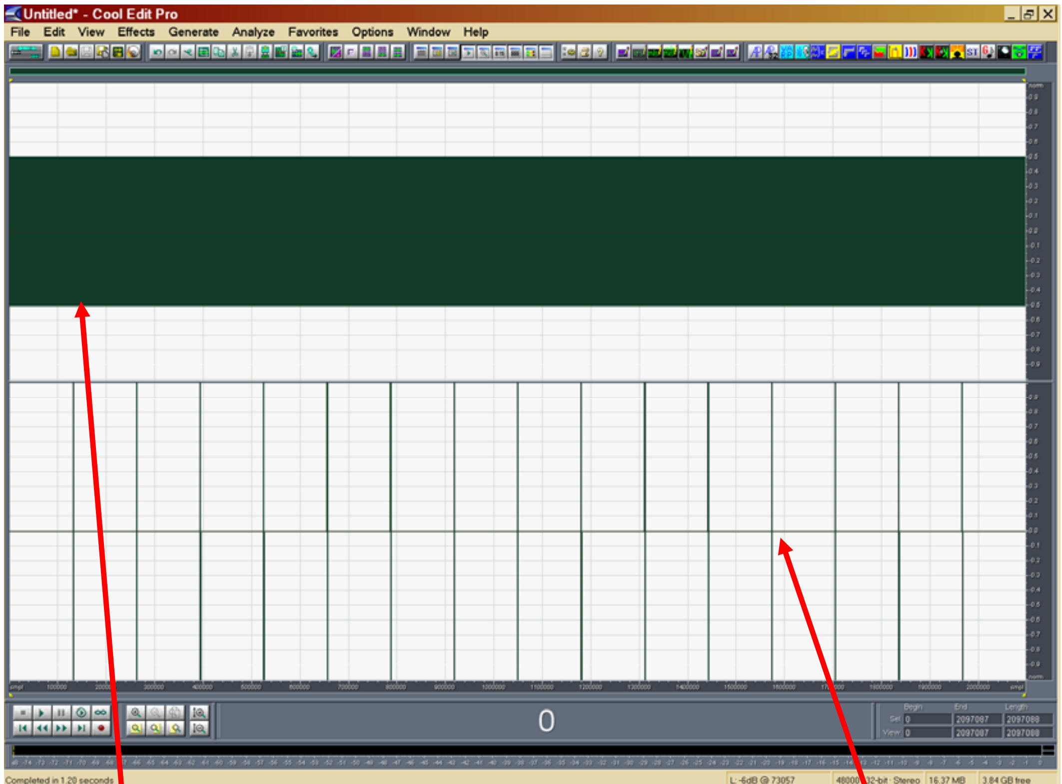


- A Cortex head and torso simulator was selected, after careful comparative tests performed in an anechoic chamber, which demonstrated its superiority to other binaural microphones (Neumann, B&K, Head Acoustics)

Transducers: mouth simulator

- The mouth simulator was built inside a ellipsoidal dummy head, employing low-cost parts. Its compliance with the ITU recommendation was confirmed by means of anechoic directivity tests.

Directivity measurements

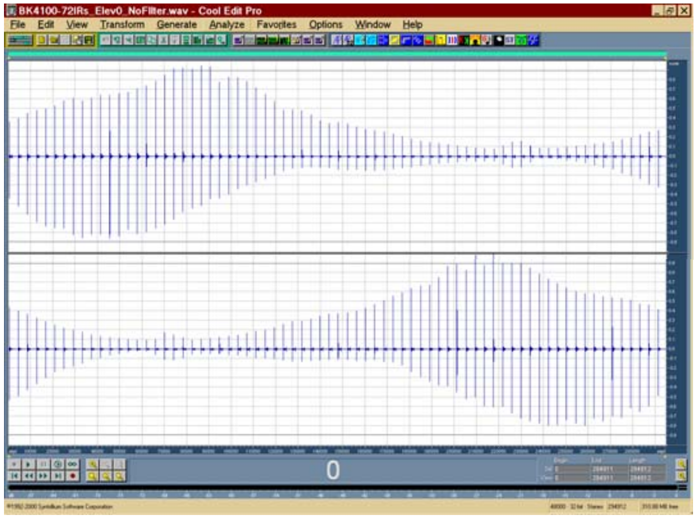


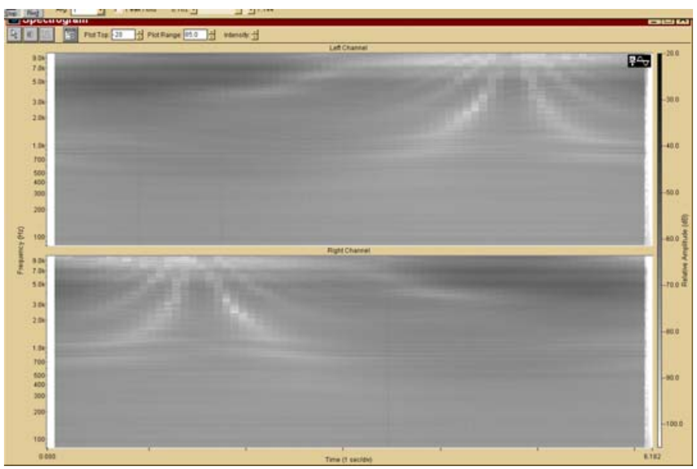
- In both cases, the anechoic directivity measurements were performed employing a rotating table, directly synchronized with the sound board employed for measuring the impulse response. The Aurora software generates the required pulses on the right channel, which cause the rotating board to advance.

Continuous MLS signal

Pulse every 8 MLS periods

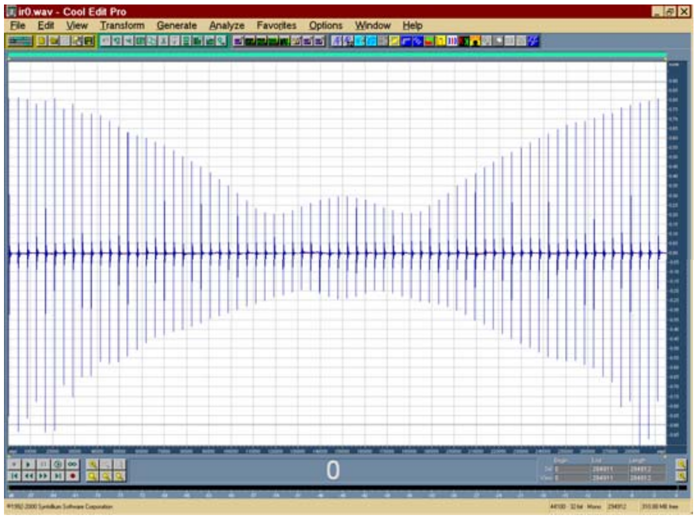
Directivity of the binaural microphone

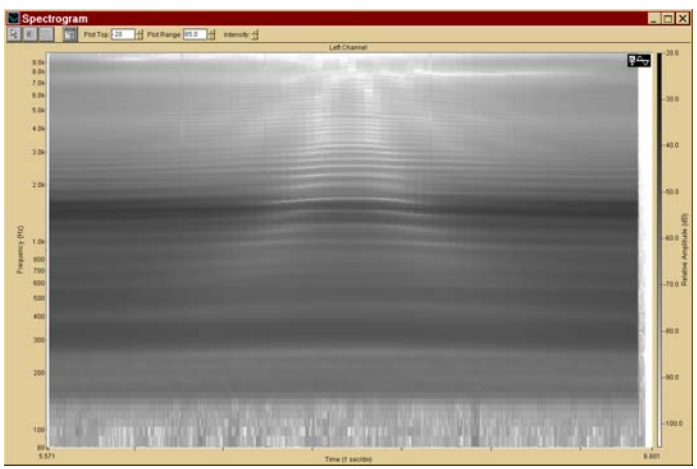




- The simmetry revealed to be quite good, and the listening test of the sequence of impulse responses gives the impression of a pulsive source rotating around.

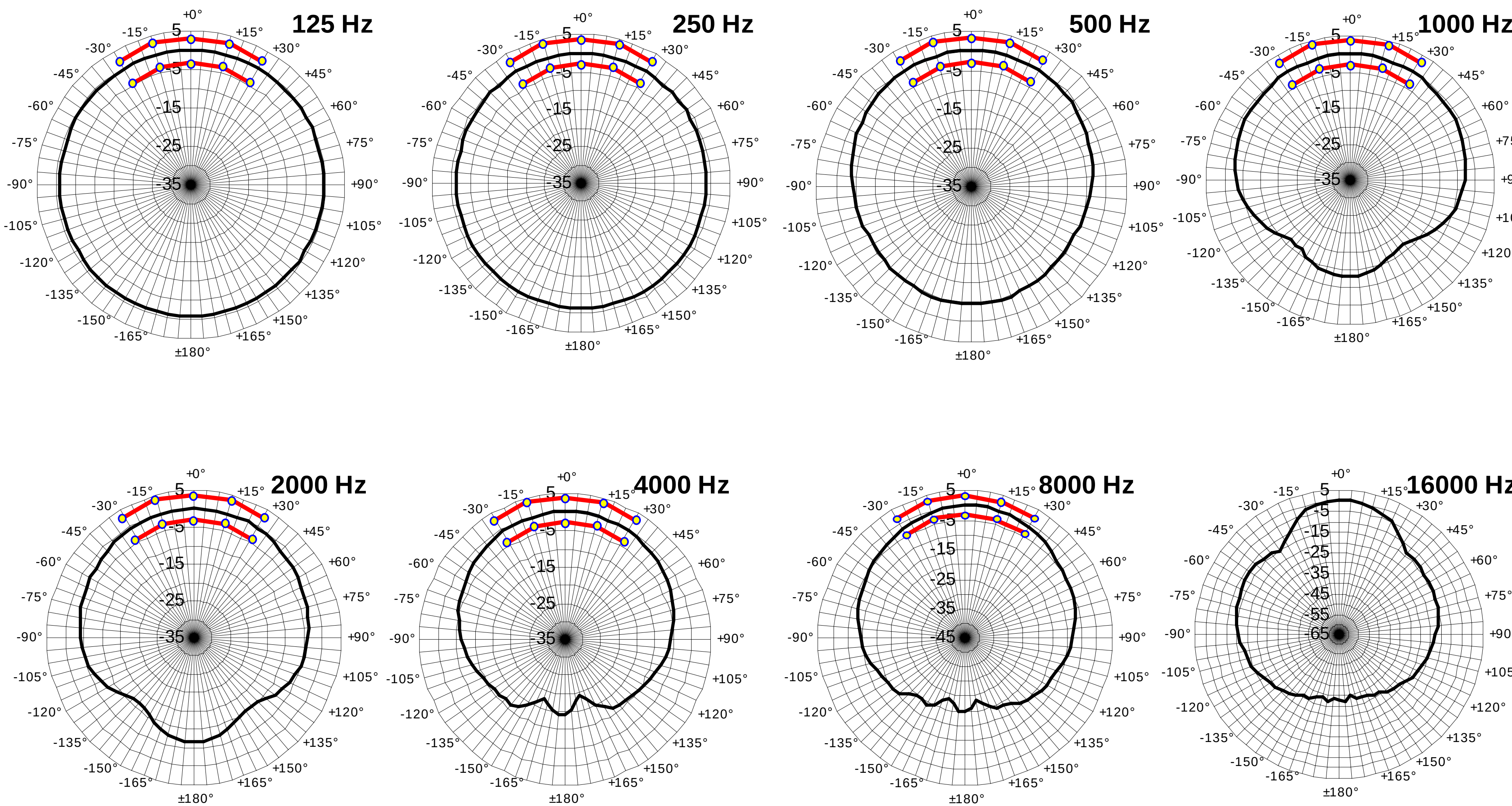
Directivity of the mouth simulator



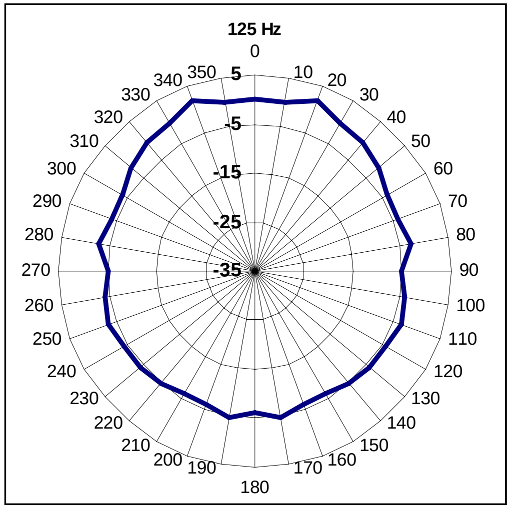


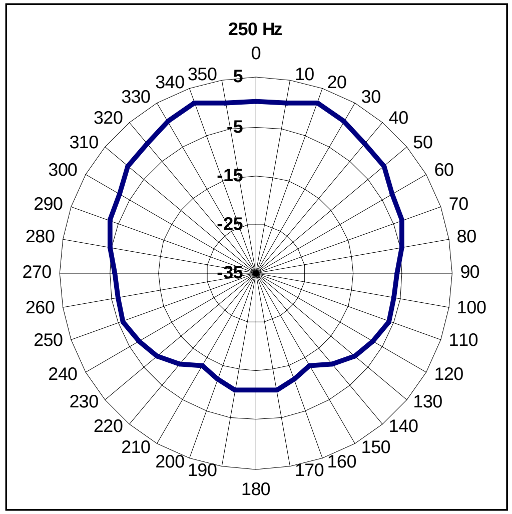
- The amplitude varies smoothly, and respects the directivity mandated by ITU recommendation.
- Nevertheless, the sound is heavily coloured, as shown by the horizontal stripes in the lower plot.

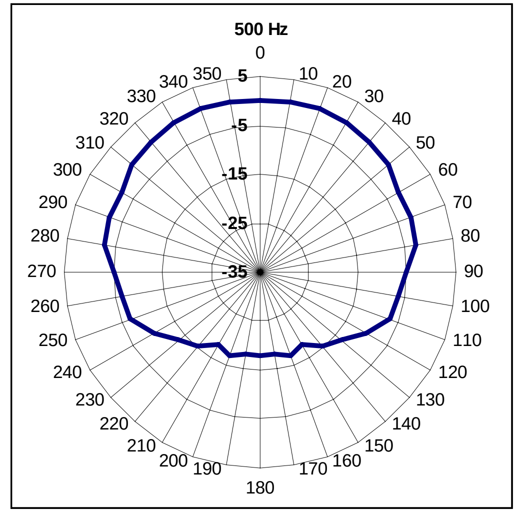
Directivity of the mouth simulator

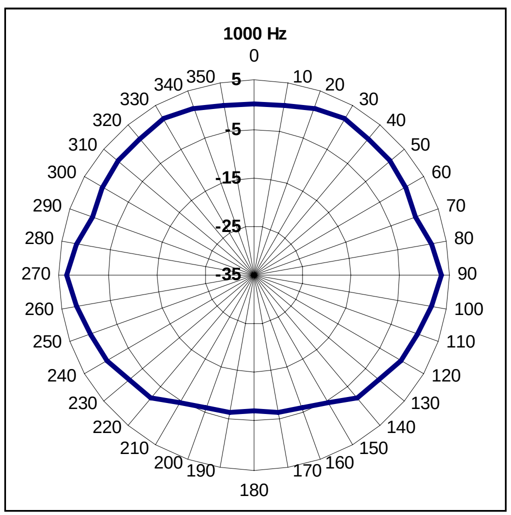


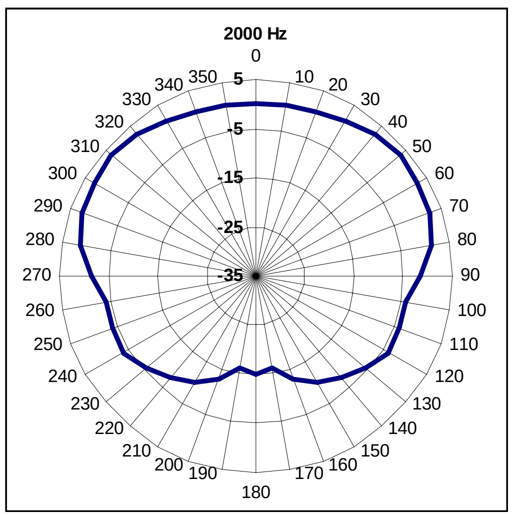
Directivity of a real human (I. Bork, PTB)

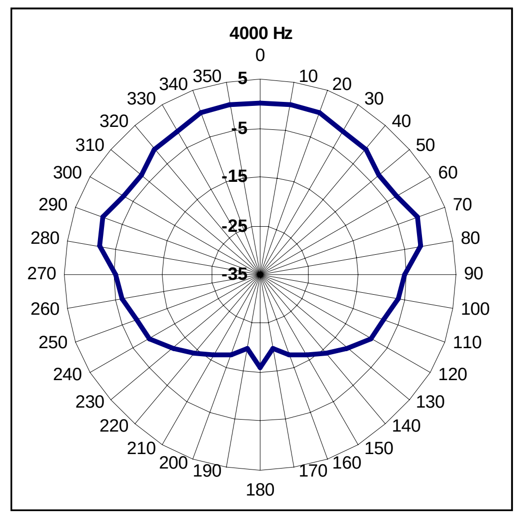




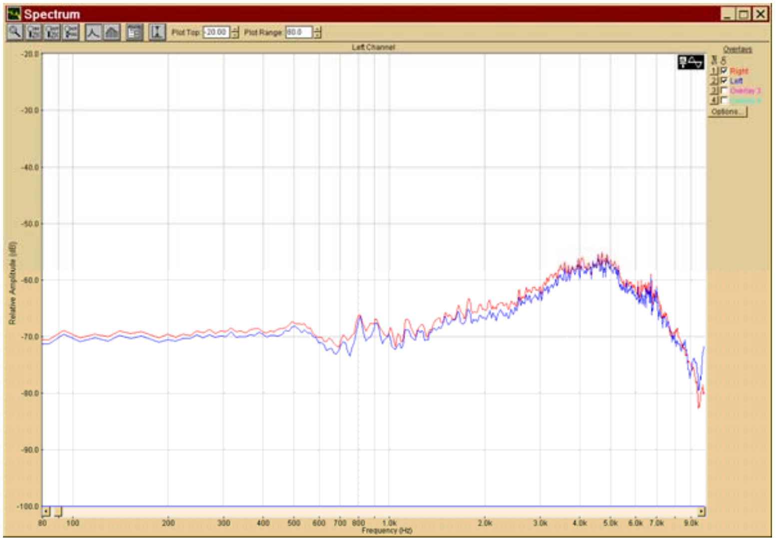






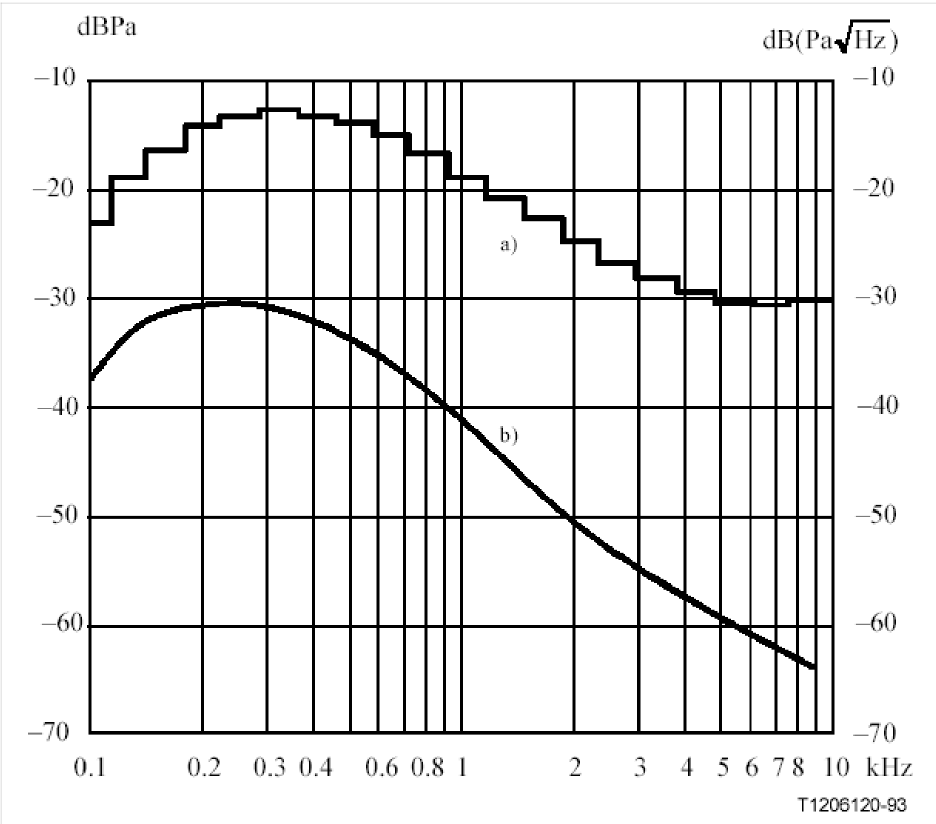


Frequency responses



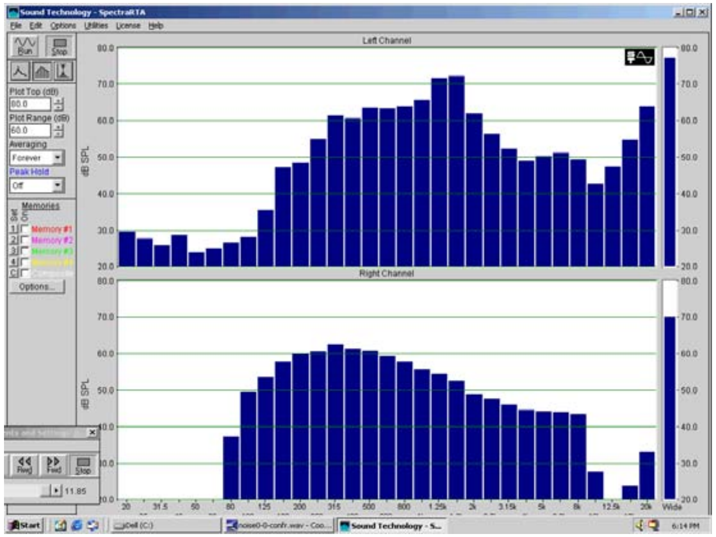
- The binaural microphone exhibit the typical response of a dummy head, with significant boost around 4-5 kHz.
- The mouth simulator is flat between 200 and 1000 Hz, and requires substantial equalization outside this interval

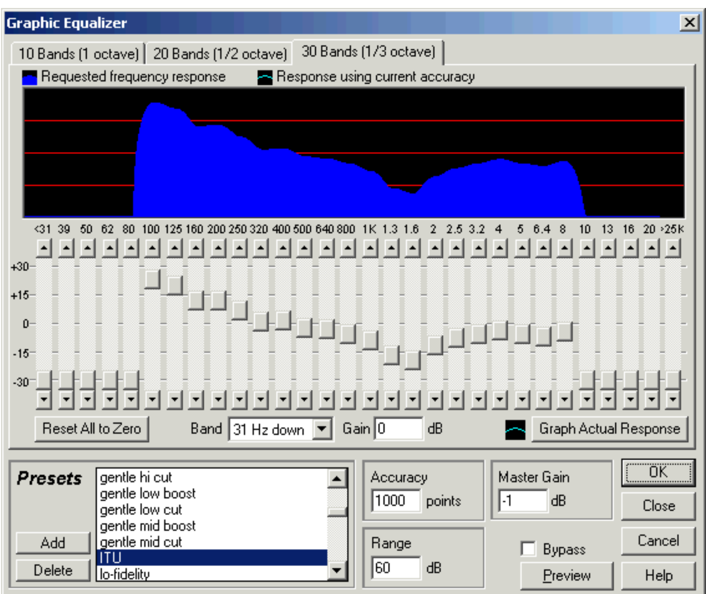
Equalization of the mouth simulator



- The spectrum of the emitted test signal should correspond to the prescriptions of ITU T-P50 Recommendation.
- The overall SPL should be 67 dB(A) at 1m, on axis, for STI standard measurements

Equalization of the mouth simulator





- The MLS signal is prefiltered, so that the frequency response, measured at 1m in front of the mouth, complies with the IEC spectrum.
- The filtering is performed by means of the grahic equalizer incorporated in Cool Edit Pro.

Measurement example (no noise)

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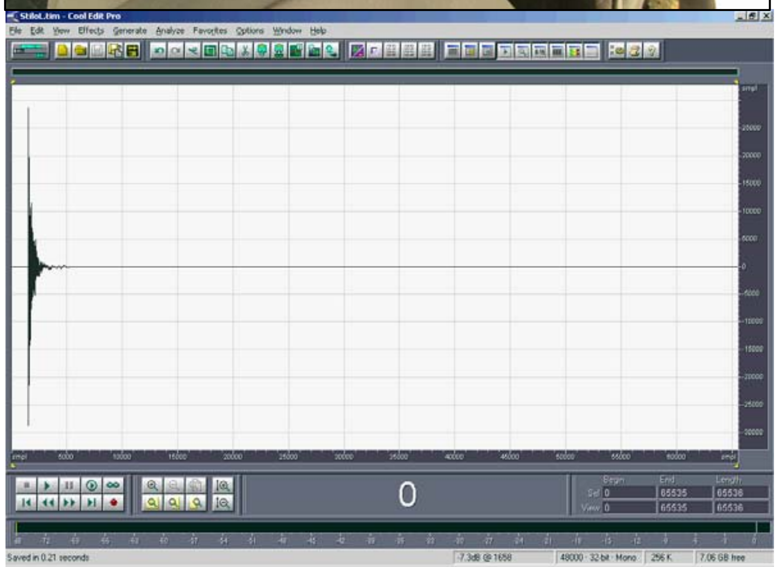


MLSSA - FROZEN

MTF Matrix (Uncalibrated)

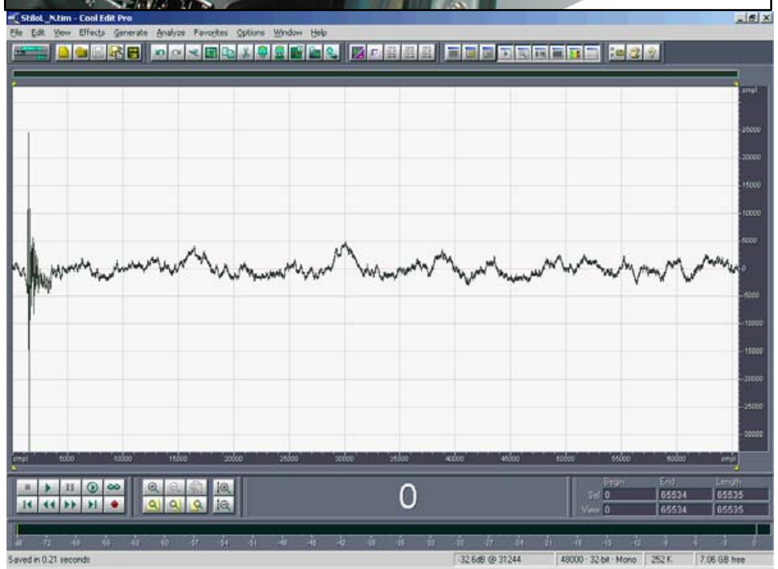
Frequency-Hz	125	250	500	1000	2000	4000	8000
level dB-SPL	65.9	71.4	69.9	76.9	76.8	78.5	82.5
m-correction	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.63	0.993	0.997	0.996	0.999	0.999	1.000	1.000
0.80	0.991	0.997	0.996	0.999	0.999	1.000	1.000
1.00	0.988	0.996	0.995	0.999	0.999	0.999	1.000
1.25	0.984	0.995	0.993	0.999	0.998	0.999	1.000
1.60	0.976	0.993	0.991	0.998	0.998	0.999	0.999
2.00	0.967	0.990	0.989	0.997	0.997	0.999	0.999
2.50	0.954	0.987	0.986	0.996	0.997	0.998	0.999
3.15	0.935	0.983	0.982	0.995	0.995	0.997	0.998
4.00	0.908	0.976	0.976	0.993	0.994	0.995	0.997
5.00	0.875	0.968	0.969	0.990	0.991	0.993	0.995
6.30	0.834	0.957	0.959	0.986	0.988	0.989	0.992
8.00	0.792	0.942	0.946	0.979	0.982	0.984	0.988
10.00	0.762	0.925	0.929	0.969	0.974	0.975	0.982
12.50	0.747	0.908	0.906	0.955	0.963	0.962	0.972
octave MTI	0.870	0.967	0.969	0.996	0.998	0.998	1.000

STI value= 0.974 (0.991 modified) ALcons= 0.9% Rating= EXCELLENT

ESC to exit, F1 to print, Shift-F1 to dump. MLSSA: STI

- The measured IR is saved as a TIM file, and processed with MLSSA

Measurement example (noise)



MLSSA - FROZEN

MTF Matrix (Uncalibrated)

Frequency-Hz	125	250	500	1000	2000	4000	8000
level dB-SPL	82.2	88.2	84.0	81.9	75.5	68.1	67.9
m-correction	1.000	1.000	0.999	0.999	0.999	0.998	1.000
0.63	0.659	0.951	0.928	0.949	0.885	0.676	0.820
0.80	0.653	0.951	0.928	0.949	0.886	0.676	0.820
1.00	0.641	0.951	0.926	0.950	0.886	0.677	0.819
1.25	0.623	0.951	0.924	0.950	0.886	0.677	0.817
1.60	0.606	0.949	0.920	0.950	0.885	0.675	0.816
2.00	0.602	0.946	0.916	0.948	0.882	0.670	0.816
2.50	0.607	0.940	0.911	0.946	0.879	0.671	0.818
3.15	0.621	0.934	0.903	0.946	0.880	0.676	0.817
4.00	0.620	0.930	0.897	0.943	0.880	0.666	0.812
5.00	0.556	0.923	0.891	0.936	0.877	0.670	0.815
6.30	0.516	0.914	0.876	0.935	0.873	0.666	0.811
8.00	0.532	0.899	0.862	0.928	0.868	0.662	0.809
10.00	0.458	0.885	0.846	0.912	0.860	0.658	0.802
12.50	0.489	0.866	0.823	0.895	0.850	0.648	0.795
octave MTI	0.550	0.878	0.819	0.898	0.785	0.602	0.713

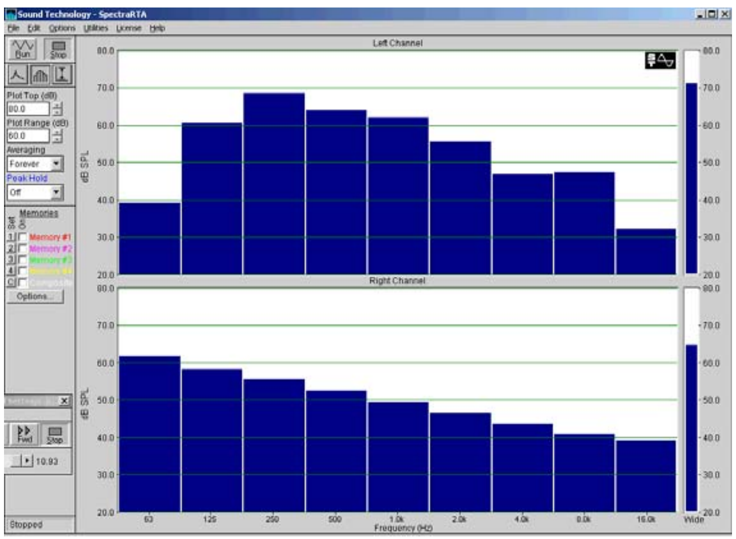
STI value= 0.744 (0.775 modified)   ALcons= 3.0%   Rating= GOOD

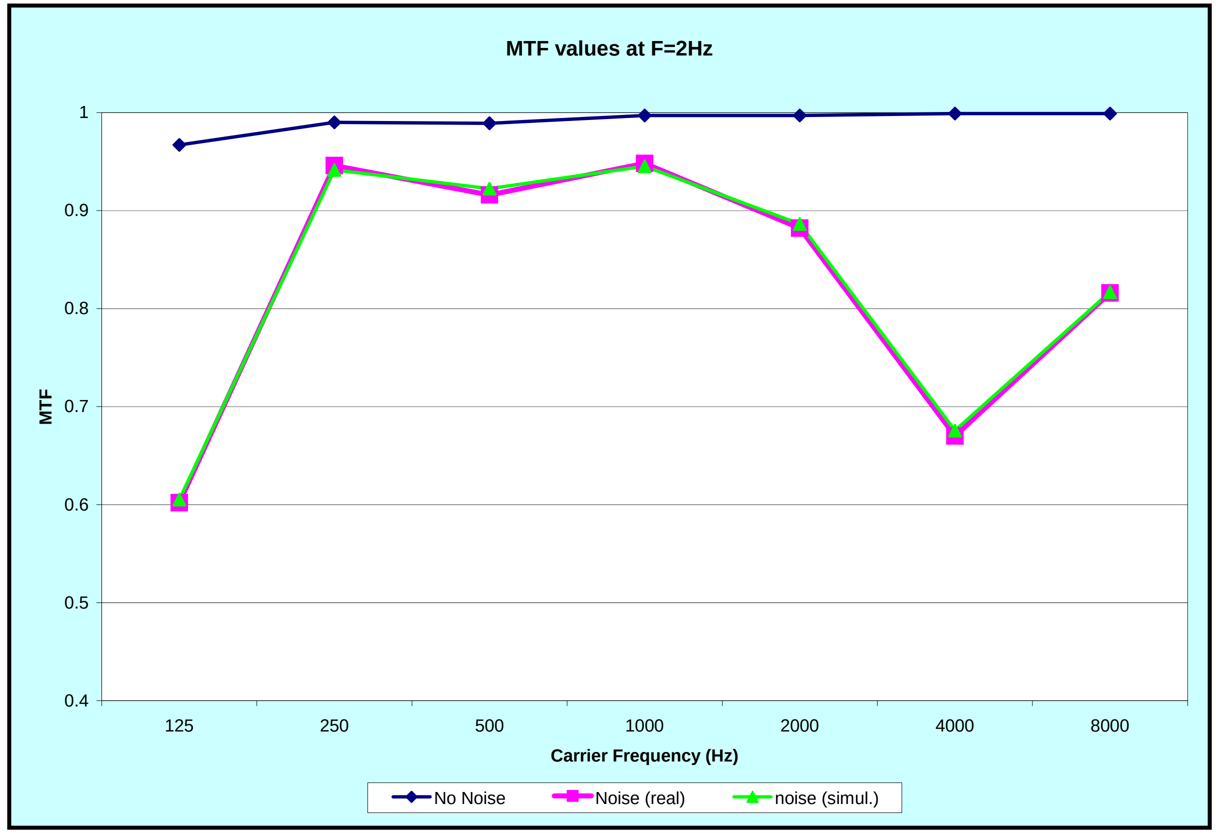
ESC to exit, F1 to print, Shift-F1 to dump.   MLSSA: STI

- The measured IR is saved as a TIM file, and processed with MLSSA

Verification of noise simulation

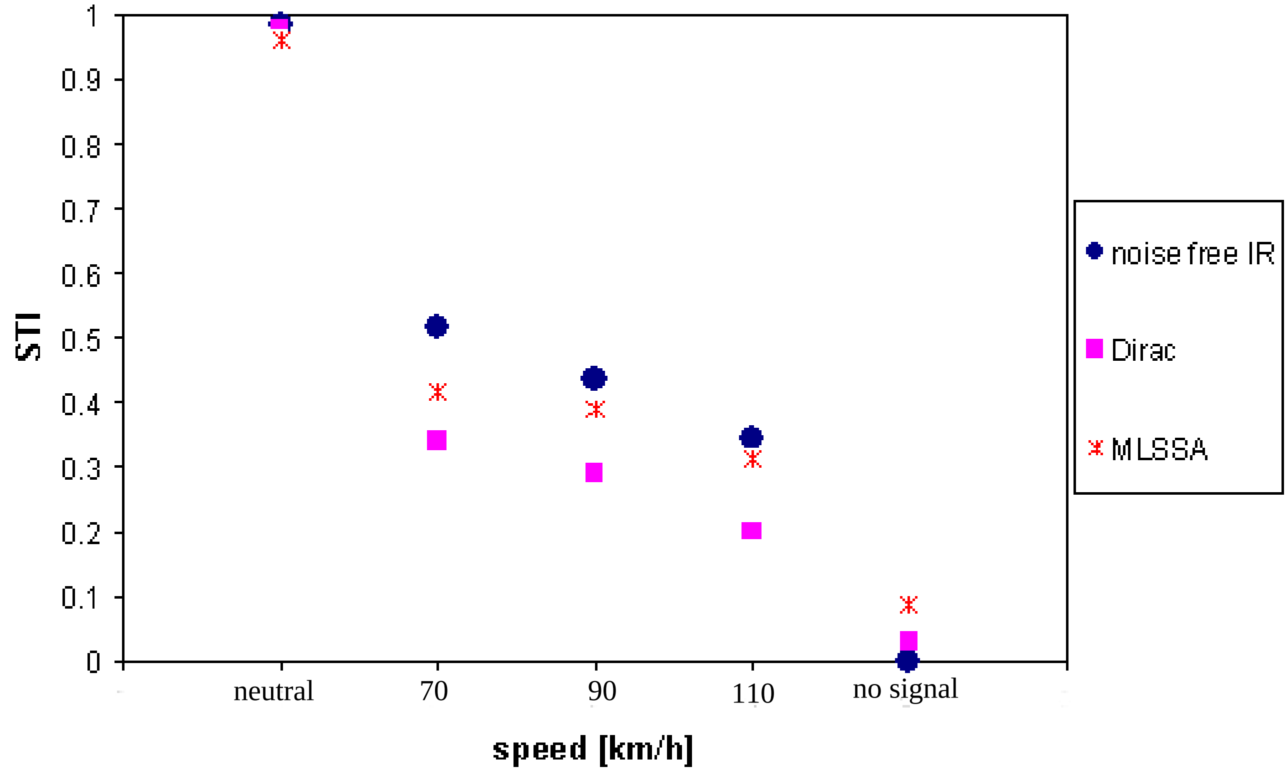
- The values of m(F) obtained by the measurement without noise were corrected for the S/N ratio, and compared with the m(F) values measured with noise





Experimental results on a test car

- The same car was measured at different speeds, employing two different software tools (DIRAC and MLSSA), and, with the latter, also with artificial noise compensation applied to the noise-free measurement.



Analysis of the results on a test car

- The measurements derived by artificial background noise correction of noise-free impulse responses revealed to provide, on average, slightly higher values of STI and much lower standard deviation of the results.

Results at 70 km/h

Table 1: *Averages and standard deviations of STI computed with different techniques.*

Techniques	Average	Standard Deviation
DIRAC (real noise)	0,345	0,033
MLSSA(real noise)	0,460	0,030
MLSSA (noise free IR)	0,518	0,003

Conclusions

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- The hardware and software developed allows for quick and reliable measurement of STI in cars.
- The background noise can be present during the actual measurement: however, it is possible to add its effect later, in two different ways:
  - Mixing a noise recording over the re-recorded MLS signal, prior of IR deconvolution (yet to be assessed)
  - Correcting the MTF values with the theoretical relationship, knowing the levels of the signal and of the noise (ideal method when only the noise spectral values are known, and no recording is available)
- The methodology developed, however, allows also for the creation of sound samples, containing speech (convolved with the noiseless IR) and background noise: these sound samples can be employed for listening tests.