Speech Intelligibility

MEASUREMENT WITH THE XL2 ANALYZER

Public Address (PA) systems in buildings like airports, railway stations, shopping centers and concert halls have to clearly inform persons in danger about escape information and directions in case of an emergency. Using the XL2 Analyzer, it is possible to determine the intelligibility of the messages spoken through the PA by measuring at all public points within the building.

Speech Intelligibility is the measure of how accurately people understand a spoken message. The XL2 measures the speech intelligibility according to the standard IEC 60268-16:2020 (edition 5). STI and STIPA are the most established methods for measuring speech intelligibility. STIPA is an optimized version of STI dedicated to portable measurement instruments. This application note explains the principles behind these methods.

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Introduction

XL2 Audio and Acoustic Analyzer

Public Address (PA) systems in building complexes have to inform members of the public about escape directions in case of emergency. Such public buildings include airports, railway stations, shopping centers and concert halls. However, if such announcements are misunderstood due to poor system quality, tragic consequences may result. Therefore, it is essential to design, install and properly verify the speech intelligibility of such sound reinforcement systems. In addition, common public announcement systems may have legal or contractual requirements regarding the level of speech intelligibility, such as in medical, industrial or commercial environments.

The XL2 Acoustic Analyzer offers reliable measurement of the Speech Transmission Index (STI) within 15 seconds. Besides the single value STI or CIS (= Common Intelligibility Scale) test result, a detailed view of the modulation indices and individual band level results is provided.

The measurement meets the standard IEC 60268-16 standard (edition 5.0 released in 2020). The XL2 also supports noise corrections, automated averaging of measurements and the older standard editions 2, 3 and 4.

The intelligibility of speech depends on:

- Signal-to-noise ratio
- Psychoacoustic masking effects
- Sound pressure level
- Ambient noise level
- Reverberation time RT60
- Reflections
- Frequency response
- Distortion

CAN I BUY STIPA FOR MY XL2 ANALYZER?

Yes, STIPA is an optional function for the XL2 Audio and Acoustic Analyzer. Any XL2 user may obtain a STIPA license. With the license key you may download the activation key for your XL2 Audio and Acoustic Analyzer. Ask your local representative for purchasing details. Enter your license key at https://my.nti-audio.com.

Standards

The ISO 7240-16/-19 standard requires the verification of electroacoustic sound systems for emergency purposes. Realistic circumstances shall ascertain a measurable minimum level of speech intelligibility in case of an emergency. Therefore, speech intelligibility from a regulatory view is not a subjective measurement, but can be verified with several, more or less complex methods that have been standardized in IEC 60268-16.

International Standards:	
CEN/TS 54-32	Fire detection and fire alarm systems
ISO 7240	Fire detection and alarm systems, section 16 & 19
IEC 60268-16	Objective rating of speech intelligibility by speech transmission index
EN 50849	Sound systems for Emergency purposes
EN 60849	First international standard based on BS 60849; replaced by DIN EN 50849

National regulatory bodies recommend or require maintaining a minimum speech intelligibility.

National Standards:	
AS 1670.4	Australia: Fire detection, warning, control and intercom systems
NFPA 72	US: National Fire Alarm Code (2010 edition)
BS 5839-8	Great Britain: Fire detection and alarm systems for buildings; code of practice for the design, installation and servicing of voice alarm systems
VDE 0828-1	Germany: Electroacoustic Emergency Systems with application regulation described in standard DIN VDE 0833-4 and VDE V 0833-4-32
UFC 4-021-01	Design and O&M: Mass Notification Systems

STIPA Test Signal

The standard STIPA signal is based on random noise limited to the bands contained in a male speech spectrum.

> Use only the original NTi Audio test signal for speech intelligibility measurements with the XL2.
>
> Other signals may not seamlessly loop, thus causing wrong measurement results! Compressed formats, like MP3 or similar, must not be used.

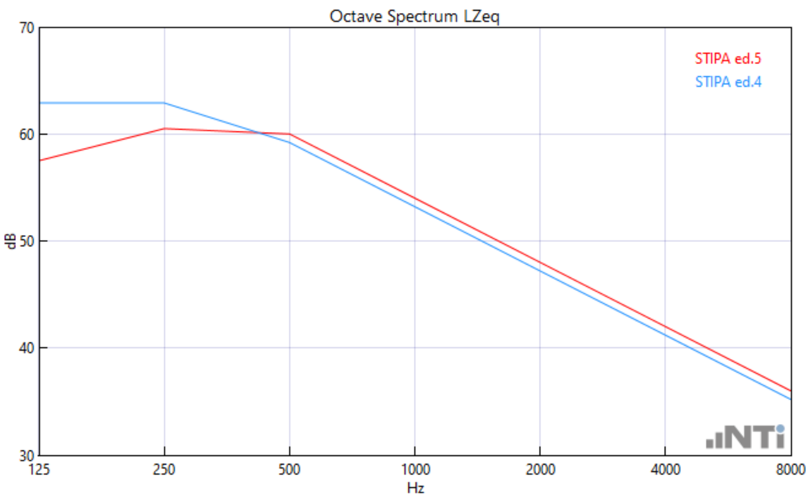


Figure 1: Spectra of STIPA Test Signal Ed. 4 and 5

Signal Source

Choose the applicable STIPA test signal source.

NTi Audio TalkBox

The NTi Audio TalkBox simulates a person talking at a precise acoustic level, enabling the measurement of the complete signal chain including the microphone.

— Place the NTi Audio TalkBox in front of the microphone at the typical position of the talking person's head.

— Select Track #1 for the STIPA test signal.

— Toggle the Output Mode to loudspeaker symbol; you should hear the STIPA test signal.

Minirator MR-PRO

The Minirator MR-PRO is used for electrical signal injection into Public Address systems that commonly use alarm messages from a hard drive (systems without a microphone).

TalkBox

NTi Audio TalkBox

The NTi Audio TalkBox is required for PA systems with voice microphones.

It simulates a person talking at a precise acoustic level, enabling the measurement of the complete signal chain including the microphone. It offers a calibrated acoustic sound source, emulating the speech levels of a person speaking in a normal or in an emergency situation.

The use of the NTi Audio TalkBox is advisable if

— Regulations require a complete end-to-end system check including the microphone; this is, in any event, the most realistic system check.

— No input is available for an electrical test signal.

— The level of the test signal is not clearly defined.

— The characteristics of the speaker's and listeners' acoustical environments are not negligible.

— The characteristic, sensitivity and frequency response of the speaker's microphone is not known, but needs to be considered.

— For any other reason it is desirable to test the entire signal chain under real conditions.

The standard STIPA signal is based on a band-limited random noise of a male speech spectrum. The TalkBox is also capable of delivering White and Pink Noise and other special signals, and is thus a very useful tool for overall system tuning and testing.

How to use the NTi Audio TalkBox

— Place the NTi Audio TalkBox in front of the microphone at the typical position of the talking person's head.

— Select Track #1 for the STIPA test signal.

— Toggle the Output Mode switch to the loudspeaker symbol; you should now hear the STIPA signal.

> ℹ In case the typical microphone-speaker distance D is less than 10 cm, then use the STIPA test signal A with 70 dB @ 1 m, and set the TalkBox to a measurement distance of approx. "D * 3" away from the microphone (e.g. distance D = 5 cm -> measurement distance = 15 cm). This simulates the actual speaker level at close distances and prevents unwanted near-field effects.

Minirator MR-PRO / MR2

Minirator MR-PRO

The Minirator MR-PRO is used for electrical signal injection into Public Address systems that commonly use alarm messages from a hard drive (PA systems without a microphone).

How to set the Minirator output level

— Determine the LAeq of the voice signal for at least 40 sec unless the signal is a recorded announcement of shorter duration.

— The measured level is corrected by an empirically-derived factor of 3 dB in order to obtain an estimate of the real speech level. This compensates for the silent parts of the speech signal, e.g. the gaps between words (in accordance with IEC 60268-16:2020, Annex J4).

— Power ON the STIPA test signal on the Minirator.

— Increase the volume, until the announcement level at the same measurement position = LAeq + 3 dB.

— Execute the STI measurements with the XL2 Analyzer.

STI Measurements – Getting Started

PREPARE FOR THE TEST

The XL2 reads the electronic data sheet of the connected NTi Audio measurement microphone and switches the 48 V phantom power automatically ON.

— Connect the measurement microphone to the XL2.

— Switch ON the XL2.

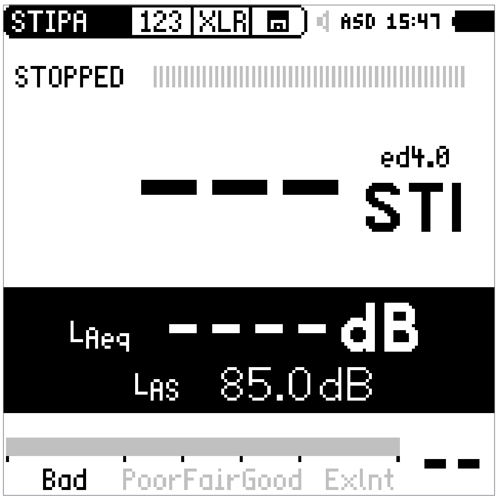
The 48 V phantom power indication in the upper menu bar changes to ASD; the XL2 is now ready for acoustic measurements.

— Position the XL2 at the measurement location by using a microphone stand or tripod.

— Select the STIPA measurement function in the XL2 measurement menu.

— Prepare the environment for the measurement; for instance, mute all sound sources to establish silence.

No impulsive noise (traffic, doors slamming, etc.) shall occur during the speech intelligibility measurement, including speech and other noises in the vicinity of the measuring microphone.



Start STIPA Test Signal

Select the STIPA signal source according to your application requirements.

— Switch ON the STIPA test signal at the signal source.

— Set the acoustic sound pressure level of the PA system to simulate the typical announcement level; e.g. LAS = 85 dB.

Start the Measurement

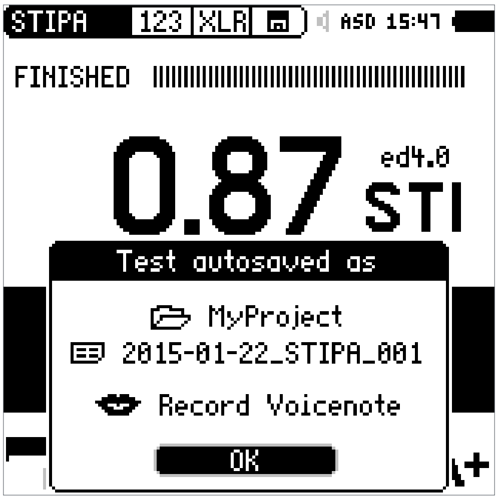
— Press Start.

The progress bar switches to **RUNNING**. The test result tendency is shown at the bottom of the screen, as **Bad**, **Poor, Fair, Good** and **Exlnt (Excellent)**.

The following minimum intelligibility values, measured across all applicable areas, apply in accordance with the ISO 7240-19:2007 standard:

— mean: 0.50 STI

— minimum: 0.45 STI



Stop the Measurement and Save the Results

After 15 seconds the speech intelligibility measurement finishes automatically. The progress bar indication switches to **FINISHED** and the final test result is displayed. The measurement result is stored automatically.

— Switch OFF the STIPA test signal.

— Press Enter to confirm. The measurement data is stored on the SD-card in ASCII format.

The measurement is completed.

QUALIFICATION SCALE “A+” TO “U”

The STI value is shown as a letter of the qualification scale below, which informs about the typical STI requirements for dedicated applications.

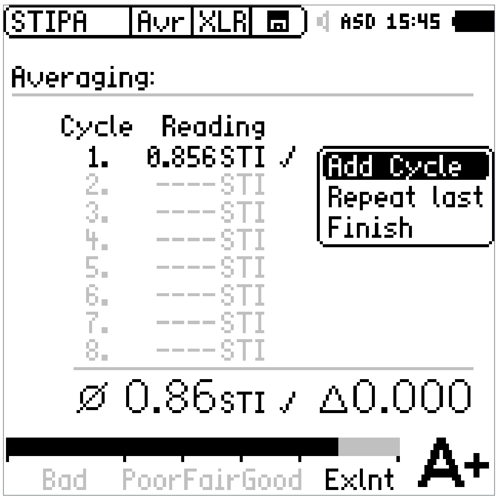
Band	STI Range	Examples of typical uses
A+	> 0.76	recording studios
A	0.72 - 0.76	theatres, speech auditoria, parliaments, courts
B	0.68 - 0.72	theatres, speech auditoria, parliaments, courts
C	0.64 - 0.68	teleconference, theatres
D	0.60 - 0.64	class rooms, concert halls
E	0.56 - 0.60	concert halls, modern churches
F	0.52 - 0.56	PA in shopping malls, public offices, cathedrals
G	0.48 - 0.52	PA in shopping malls, public offices
H	0.44 - 0.48	PA in difficult acoustic environments
I	0.40 - 0.44	PA in very difficult spaces
J	0.36 - 0.40	not suitable for PA systems
U	< 0.36	not suitable for PA systems

Averaging of STI Results

The IEC 60268-16 standard recommends the averaging of two or three sequential results that were taken at the same measurement location.

The German VDE 0833-4 Standard requires a minimum of three sequential measurements at a single position in case STI < 0.63.

The XL2 Analyzer offers automated averaging of two to eight speech intelligibility results, based on these standard requirements.

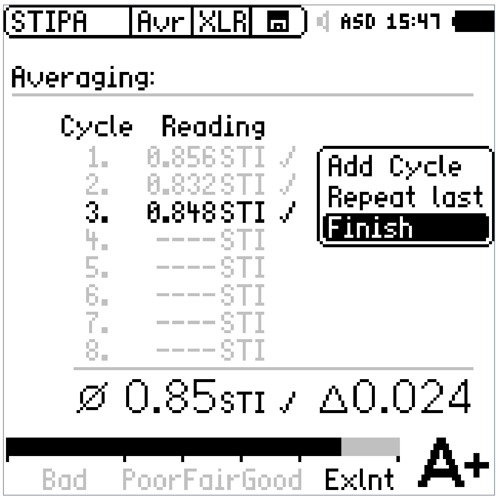


Start Averaging

— Select the averaging page **Avr.**

— Turn the rotary wheel to select the parameter START NEW and press enter.

The first measurement is labeled **Cyc. 1 and** starts automatically.



Add Cycles

— Press enter to confirm **Add Cycle**.

— Repeat the measurement at the same position as required.

The XL2 executes further measurements and adds them to the list.

Finish

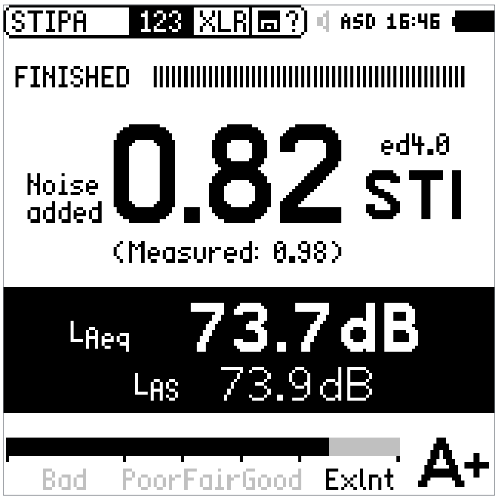
— Choose **Finish** to end the averaging.

The speech intelligibility average and the deviation is displayed for documentation.

Display of STIPA Numeric Result Page

The symbol Ø indicates that the averaged STI value is displayed.

Ambient Noise Correction



Measuring the STI under realistic environmental conditions is often not feasible. For instance, playing the test signal in a railway station at emergency levels during peak hours would irritate passengers. Additionally, at rush-hour the characteristics of ambient noise might be highly impulsive, while a pre-requisite for accurate STIPA measurements is a negligible impulsivity in the ambient noise. Under such circumstances the STIPA measurement should be shifted to a more suitable time of the day, e.g. during the night.

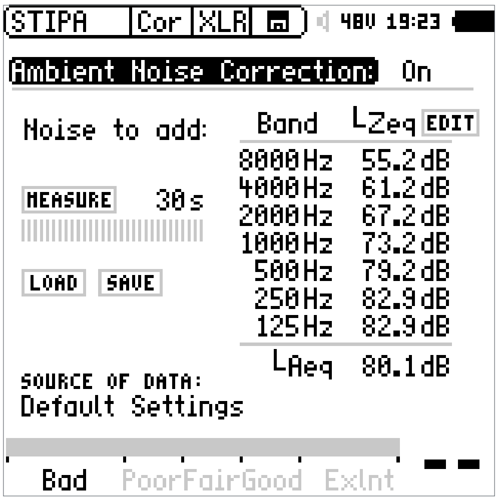
Ambient noise affects the speech intelligibility. The ambient noise correction has to be applied when the signal-to-noise ratio is lower than 15 dB in any octave band.

Measurement sequence:

- First, measure the realistic ambient noise, e.g. during day time.
- Second, measure the speech intelligibility STIPA, e.g. at night.

> This sequence simplifies the STIPA measurement as follows: The XL2 immediately displays the STIPA result with ambient noise correction. The result provides a guideline if further measurements at the same location are required. For more details see the chapter “STIPA Measurement Hints” in this application note.

If no ambient noise correction has been carried out on-site with the XL2 Analyzer, you can still post-process your measurement data on the PC. The NTi Audio STI Report combines the STIPA measurement taken under quiet conditions and the actual ambient noise caused by the public, e.g. during day-time. This emulates the expected STIPA value under real-life conditions.



Enable Ambient Noise Correction

— Select the correction page **Cor**.

— Turn the rotary wheel to select the parameter **Ambient Noise Correction** and press Enter.

The correction is enabled and the XL2 displays this screen.

> You may adjust the ambient noise band levels and the **LAeq**.

Commissioning New PA Systems

New Public Address systems are often commissioned prior to the grand opening. Thus, the actual ambient noise caused by the public is not yet available. In this case, you may simulate the real-life condition using ambient noise data from one of the following methods:

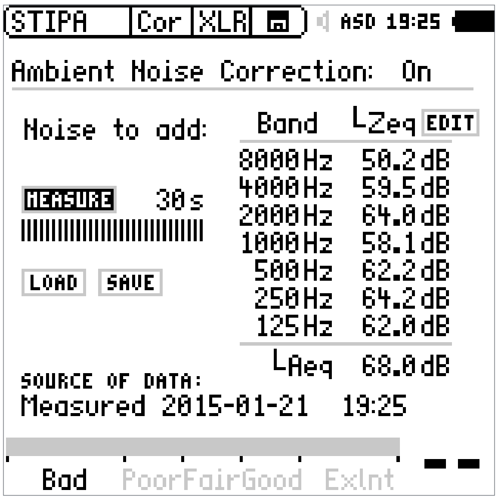
— Utilize a suitable reference noise file

- Measure the ambient noise at another similar project and store this as the reference noise file.
- Select the parameter **Load** with the rotary wheel and press Enter.
- Select the reference noise file, as ambient noise correction for your speech intelligibility measurements.

— Edit actual noise data

- Select the parameter **Edit** or the **LAeq** level with the rotary wheel and press Enter .
- Turn the rotary wheel to adjust the noise level.
- Press Enter to continue the setup.

— Measure the actual ambient noise after the opening of the public area, and verify the STI readings.



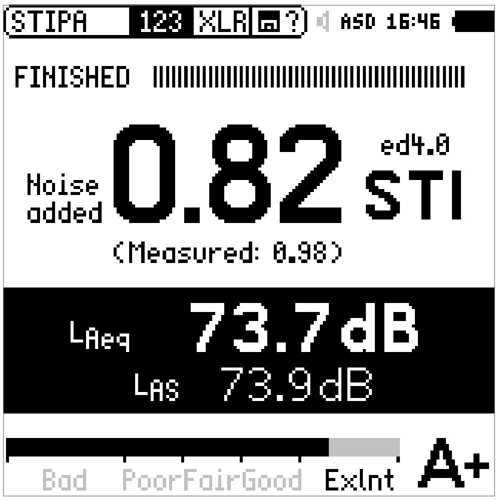
Measuring Ambient Noise

— Position the microphone at the STIPA measurement point.

— Select **Measure** (without any test signal present).

The XL2 measures the ambient noise and displays the LEQ octave band result.

> You may edit the noise data.



STI Measurement

— Select the STIPA result page **123**.

— Execute the speech intelligibility measurement.

The XL2 displays the corrected speech intelligibility result in large font. The actual measured result is listed below in smaller font.

ANNOUNCEMENT LEVEL

The speech intelligibility shall be measured at the announcement level.

The announcement level shall exceed the ambient sound pressure level by a minimum of 10 dB. This shall apply at all places within the listener zone, where warning signals are conveyed to building occupants. The measured announcement level shall not be less than 65 dBA nor more than 105 dBA at the listener position. A louder announcement is not always better; the speech intelligibility reduces gradually at levels exceeding 80 dBA.

The announcement level measurement itself takes 60 seconds at each position in accordance with ISO 7240. Here the NTi Audio TalkBox serves as an excellent reference speaker. It generates prerecorded announcements or your own messages at the specified sound pressure level into the voice microphone for any time you require and until you have completed the verification at all measurement positions. Your own announcement signals may be loaded onto the memory card and are seamlessly looped.

Recommended Ambient Noise

The following table lists the typically applicable ambient noise levels in accordance with the Austrian TRVB S 158 - 2006 standard.

Area Type	Sound Level LAeq (dB)	Area Type	Sound Level LAeq (dB)
Airport		Libraries	
- check in, departure / arrival hall	59-72	- reading area quiet	35-45
- gates	54-64	- reading area noisy	50-60
- custom area	63-71	- reception	50-60
- passages	59-70		
- waiting area departure	49-64	Manufacturing facilities	
		- monitoring stations	70-75
Aisles		- common manufacturing	80-85
- with carpet	28-32	- heavy industry	95->105
- quiet without carpet	45-55		
- noise without carpet	66-76	Markets	
		- quiet	47-63
Bus station		- noisy	63-80
- quiet	58-68		
- noisy	63-73	Offices	
		- Single person office	40-50
Conference room	40-45	- Open-plan office quiet	50-70
Concert halls, cinemas, theaters	60-75	- Open-plan office noisy	70-85
Courtrooms	40-50		
Exhibition hall	63-73	Public Areas	50-64
Hotels / Motels			
- service support areas	55-65	Restaurant	
- sleeping room, TV off	28-35	- quiet	55-65
- sleeping room, TV on	60-70	- noisy	68-78

Area Type	Sound Level LAeq (dB)	Area Type	Sound Level LAeq (dB)
Railway		Shops	
- waiting area	54-65	- quiet	50-60
- service area	60-66	- noisy	65-75
- platform electric train	60-72	- shopping centre	70-75
- platform diesel train	75-85		
		Sport facilities	
Restaurants		- quiet	60-72
- customer area	72-75	- noisy	72-82
- kitchen	65-75	- squash	60-80
		- ice-skating hall	69-80
Schools		- swimming hall	72-79
- classroom, quiet	56-68	- swimming area kids	81-87
- classroom, noisy	64-72	- bowling	78-85

STI Report

The STI Reporting Tool creates measurement reports according to these standards:

— AS 1670.4

— CEN/TS 54-32:2015

— DIN EN 50849:2017

— IEC 60268-16

— ISO 7240-19:2007

— VDE V 0833-4-32:2016 (VDE 0828-1:2017-11)

STIPA Summary Report

Report according to IEC 60268-16{ed4}, chapter 7.6.4 and DIN VDE 0833-4{2007-09}, appendix F.6

Project	Waiting Room
Comments	Measured in empty room with TalkBox
Standard	IEC 60268-16 ed4.0 2011

All		Arithmetic mean lav	STI	0.58	
		Standard deviation σ	STI	0.06	
		lav - σ	STI	0.52	G
1	**Position**		STI	0.58	E
	STIPA File	AltbFlur_STIPA_000 (Altb_Flur, 1)			
	Noise File	XL2_V2x_RTA_APPEND_SLM_008 (MyLocation, 1)			
2	**Position**		STI	0.57	E
	STIPA File	AltbFlur_STIPA_000 (Altb_Flur, 2)			
	Noise File	XL2_V2x_RTA_APPEND_SLM_008 (MyLocation, 2)			
3	**Position**		STI	0.60	D
	STIPA File	AltbFlur_STIPA_000 (Altb_Flur, 3)			
	Noise File	XL2_V2x_RTA_APPEND_SLM_008 (MyLocation, 3)			
4	**Position**		STI	0.54	F
	STIPA File	AltbFlur_STIPA_000 (Altb_Flur, 4)			
	Noise File	XL2_V2x_RTA_APPEND_SLM_008 (MyLocation, 1)			
5	**Position**		STI	0.52	F
	STIPA File	AltbFlur_STIPA_000 (Altb_Flur, 5)			
	Noise File	XL2_V2x_RTA_APPEND_SLM_008 (MyLocation, 2)			
6	**Position**		STI	0.52	F
	STIPA File	AltbFlur_STIPA_000 (Altb_Flur, 6)			
	Noise File				

The STI Report is free to download on the XL2 support website https://my.nti-audio.com for all registered users (enable all macros when opening the document).

Measurement Positions and Number of Measurements

The ISO 7240-19:2007 standard specifies to measure the speech intelligibility at the number of measurement points equal or greater than listed in the following table:

Area [m2]	Minimum number of measurement points
< 25	1
25-100	3
100-500	6
500-1500	10
1500-2500	15
> 2500	15 per / 2500 m^2

— The distance between measurement points shall not exceed 12 m.

— The measurement points shall be equaly distributed throughout the area.

— No more than one-third of the points shall be located on the axis of a loudspeaker.

— The measurement microphone should be maintained approximately 1.6 m (5 ft) from the floor to represent standing individuals and 1.2 m (4 ft) for seated individual as appropriate.

AUSTRALIA

— One measurement is sufficient in case STI > 0.56.

— Take a minimum of two measurements if the reading is < 0.56 STI.

— Take a third measurement in case the two measurements differ by more than 0.03 STI.

— Take the two measurements that are closest in score and calculate the average to determine the final speech intelligibility at the individual measurement point.

— The measurements shall be made at a sufficient number of representative points in each area of coverage.

— Calculate the arithmetical average ‘Iav’ of the intelligibility values on the STI and the standard deviation σ^2.

— The relation between the arithmetical average and the standard deviation shall be: $Iav - \sigma^2 > 0.50$ STI. If the result is within $\pm\sigma^2$ of the limit, then the measurements should be repeated at a larger number of measurement points.

— The mean value of intelligibility and its 95% confidence interval, over the whole area of coverage shall be calculated.

GERMAN VDE0833-4 STANDARD

STI > 0.63	One single measurement is sufficient.
STI < 0.63	Execute three sequential measurements for this measurement position. — If the maximum result deviation of these three measurements is > 0.03 then further three measurements shall be executed. — If the maximum result deviation of these measurements is > 0.05 then the cause of this instability shall be evaluated and removed. — The arithmetic average of the executed three or six measurements has to be reported.

An STI > 0.63 ensures that the speech intelligibility is higher than 0.5 with a confidence level of 95%.

Continuous Level-dependent Auditory Masking

The masking function emerged through the various editions of the IEC60268-16 standard as follows:

ed2.0	old edition released in 1998, with fixed masking function
ed3.0	old edition released in 2003 with stepped level dependent auditory masking function
ed4.0	old edition released in 2011, with continuous level dependent auditory masking function
ed5.0	actual edition released in 2020, with continuous level dependent auditory masking function (identical to edition 4.0)

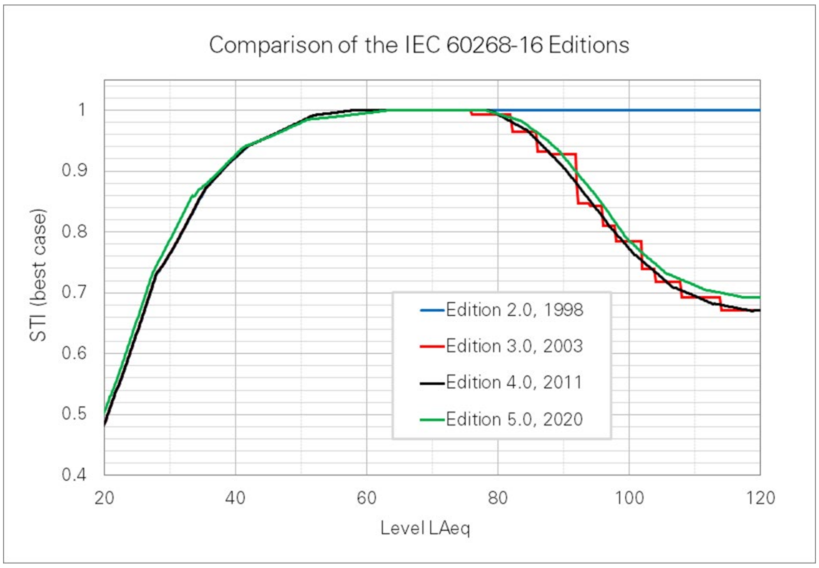


Figure 2: Comparison of STIPA Masking Curves

Best intelligibility is achieved at message levels in the range of 70..80 dBSPL. At higher sound pressure levels the ear triggers a self-protection mechanism, which is reflected in a reduced intelligibility index. For example, an STI of 1 at 70 dBSPL may be down to 0.7 STI at a higher sound pressure level.

Measurement Hints

AMBIENT NOISE

The ambient noise has to be sufficiently constant during the measurement. A signal-to-noise ratio of 15 dB or higher is recommended to achieve best speech intelligibility. Impulsive ambient noise during the measurement, such as speech, causes severe measurement errors. The STIPA result is usually too high.

Fluctuating noise is detected by measuring the direct STI in the absence of the test signal. Carry out these measurements at least at a representative set of locations. If the STI is too high (e.g. STI > 0.2), the measurement results are likely to be erroneous. Then the STIPA measurement should be carried out without this noise being present. Utilize the ambient noise correction for such instances.

At locations with varying conditions (e.g. public areas with few people and other areas with crowds) the worst-case STIPA results should be measured. Consult the local regulations (e.g. the NFPA code in the U.S.) for directives concerning measurement locations and number of required STIPA measurements under which circumstances.

STI MEASUREMENT

- The intelligibility index is measured in the range from 0 to 1, whereby 1 is perfect. The minimum intelligibility requirement including measurement uncertainty is typically 0.5. In areas where the occupants are familiar with the alarm messages, a minimum intelligibility of 0.45 STI can be assigned.
- The variation of STIPA test results should be not more than 0.03 STI at one test position. In case you find the deviations higher than 0.03 STI, then verify and eliminate the causes for these discrepancies and repeat the measurement (e.g. measure STIPA during night time).

— Low STIPA readings can be caused by
  - Excessive sound reverberation, echoes or reflections
  - Poor speaker directivity or speaker coverage
  - Speaker level setting incorrect; e.g. low signal-to-noise ratio.

WHAT TO DO IF THERE IS MUCH IMPULSIVE NOISE

In a 24/7 production environment or near a highway, impulsive noise may be permanently present and STIPA measurements should not be carried out. In such instances the onsite conditions have to be simulated in a laboratory for STIPA testing:

— The real noise spectrum should be measured e.g. with the XL2 Audio and Acoustic Analyzer SLM function, averaging over a sufficient period of time.

— A diffuse sound field of non-impulsive noise with same frequency shape and octave band levels as measured has to be generated in the laboratory.

— The real speaker-listener environment has to be acoustically reproduced as close as possible in the laboratory.

— Then the actual STIPA measurement can be carried out; no post processing is required.

This approach is also mandatory for systems that include Automated Gain Control (AGC), if such systems cannot be tested in the original environment without annoying members of the public.

MEASUREMENT CONFIGURATION

Simulate the emergency situation as close as possible:

— Position the microphone at 1.0 to 1.2 meters above ground in sitting areas or 1.5 to 1.8 meters in standing areas (typical positions are not directly in front of the speakers).

— The person taking the measurements should be out of the acoustic field, so as not to affect the measurement results. For this purpose the measurement microphone can be mounted on a microphone stand and connected with the ASD Cable to the XL2.

— An earlier draft of the VDE 0833 standard defines measurements to be carried out in a grid from 6 x 6 meter up to 12 x 12 meter. For example, large areas like exhibition halls may use a 12 x 12 meter grid. The measurement points have to represent the area under test!

CD PLAYER

Only high-quality CD Players should be used to reproduce the STIPA test signal as only limited time-shifts (±20 ppm) ensure reliable STIPA test results. Pitch control and shock protection should be disabled. We recommend that only professional CD Players be used. Verify the time shift of the CD Player with a 1 kHz test signal:

— Insert the NTi Audio Test CD into the CD Player and start track #1, which is the 1 kHz test signal.

— Connect the XL2 directly to the audio output and measure the signal frequency in RMS/THD+N mode. The displayed frequency should be in the range from 0.99998 kHz to 1.00002 kHz.

STIPA test signals from other test system manufacturers may sound similar but are not compatible. Only the NTi Audio STIPA test signal CD V1.1 or higher should be used in combination with the XL2 Analyzer.

SPEECH INTELLIGIBILITY IN REVERBERANT SPACES

Send the announcements via directed speakers to the public area. Any non-directed sound returns as reflections and reduces the speech intelligibility.

Who can and should conduct STI measurements?

Even though the STIPA method is complex, the measurement of STIPA using the XL2 Audio and Acoustic Analyzer is very simple. Operators with a basic acoustic knowledge can easily conduct these measurements. The instrument’s internal storage ability also simplifies the measurements in larger buildings, where many measurements must be taken at many locations. The detailed access to the measured MTF (Modulation Transfer Function) matrix enables experts to post-process all measurement data.

Further Information:

For further information please visit www.nti-audio.com.

Detailed information on speech intelligibility measurements are contained in the IEC60268-16 (2020. edition 5.0) standard, which also describes the test procedures and the requirements in practice.

Appendix

SUBJECTIVE ANALYSIS METHODS

Although frequency response, reverberation, distortion, signal-to-noise ratio or loudness are related to intelligibility, the conventional measurements of these parameters together only marginally relate to intelligibility. When added issues, such as directionality of drivers and the environment conditions are taken into consideration, the question is: How well a spoken message can be understood at different locations?

The fundamental approach to measuring intelligibility is to let a trained human speaker read a number of existing or synthetic words, whereas a representative number of listeners individually write down what they believe they understood. The statistical analysis of these notes results in a value representing the percentage of words being understood correctly. Standardized procedures according to this method are PB-words, CVC or SRT (Speech Reception Threshold). However, conducting such tests is rather time-consuming and costly, and, in some hazardous locations, even impossible. Therefore, these methods are mainly used to verify alternate measurement methods.

TECHNICAL METHODS

As early as 1940, Bell Laboratories started to develop measurement technologies to determine the intelligibility of speech. Nowadays, highly-developed algorithms such as SII (Speech Intelligibility Index) and various forms of the STI (Speech Transmission Index) objectively quantify speech intelligibility measurement.

These techniques consider many parameters which are important for intelligibility such as

- Signal-to-noise ratio
- Psychoacoustic masking effects
- Sound pressure level
- Ambient noise level
- Reverberation time RT60
- Reflections
- Frequency response
- Distortion

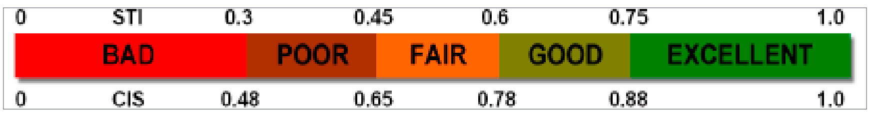


Figure 3: Speech Intelligibility may be expressed by a single number value. Two scales are most commonly used: STI (Speech Transmission Index) and CIS (Common Intelligibility Scale)

The basic principle of STI measurement consists of emitting synthesized test signals instead of a human speaker's voice. The speech intelligibility measurement acquires this signal and evaluates it as it would be perceived by the listener's ear. Extensive investigations have evolved the relationship between the alteration of speech characteristics and the resulting speech intelligibility. These findings are incorporated into the speech intelligibility meter that is able to display the intelligibility result as a single number between 0 (unintelligible) and 1 (excellent intelligibility).

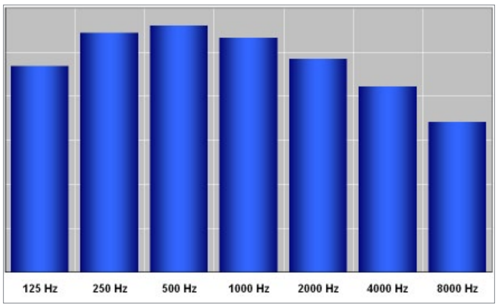


Figure 4: Average octave band spectrum of a male speaker

Speech Model

First of all, measuring the speech intelligibility requires a model for speech signals. For instance, speech may be described as how a frequency spectrum evolves over time. Superimposition of spectra defines the long-term speech frequency spectrum. The intensity of each frequency modulates over time.

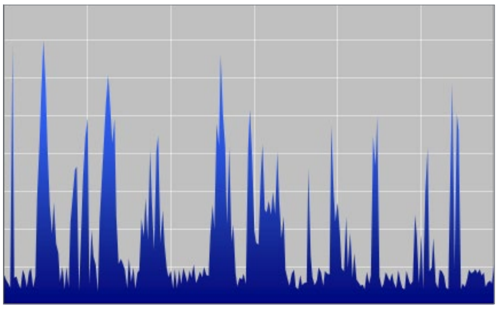


Figure 5: Envelope of a speech signal (250 Hz band).

Time Modulation

Level of frequency components varies, i.e. is "modulated" by the speaker. Figure 3 shows the envelope of a speech signal in the 250 Hz octave band. The shape of the envelope is given by averaging the time evolution of the speech content.

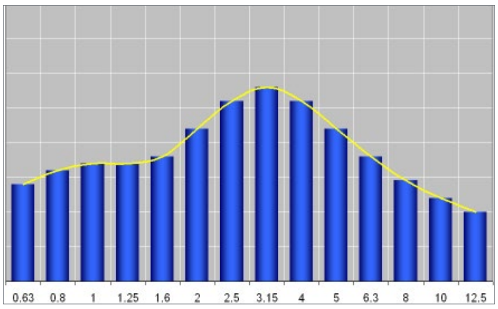


Figure 6: Frequency spectrum of the envelope (250 Hz band).

Frequency Spectrum

The spectral analysis of a male voice averaged over a longer time results in a typical characteristic as shown in Figure 2.

Analyzing the spectra of time modulation intensity shows that a speaker modulates the speech spectra with frequencies in the range from 0.1 Hz to 24 Hz. A set of modulation frequencies from 0.63 Hz to 12.5 Hz sufficiently represents these modulations.

MODULATION TRANSFER FUNCTION (MTF)

High speech intelligibility requires that the spectral intensity modulation and the overall spectrum be preserved at the listeners' ears. Therefore, the three core intelligibility measurement methods STI, RASTI and STIPA are based on measuring the MTFs (Modulation Transfer Functions) in 7 octave bands. For each octave band, one MTF quantifies the degree of preservation of the intensity modulations in this band. These functions quantify how much the intensity modulations are preserved in 7 octave bands, thereby covering the long-term speech spectrum.

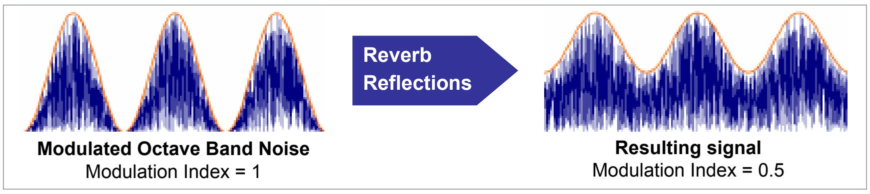


Figure 7: Reverberation, ambient noise and reflection are responsible for degrading the modulation index.

Figure 8 shows the MTF of one octave band. This is derived from measuring the 1/3rd octave modulation frequencies, thus resulting in 14 frequencies between 0.63 Hz and 12.5 Hz. Each modulation transfer function determines how well the modulations are preserved in the associated octave band.

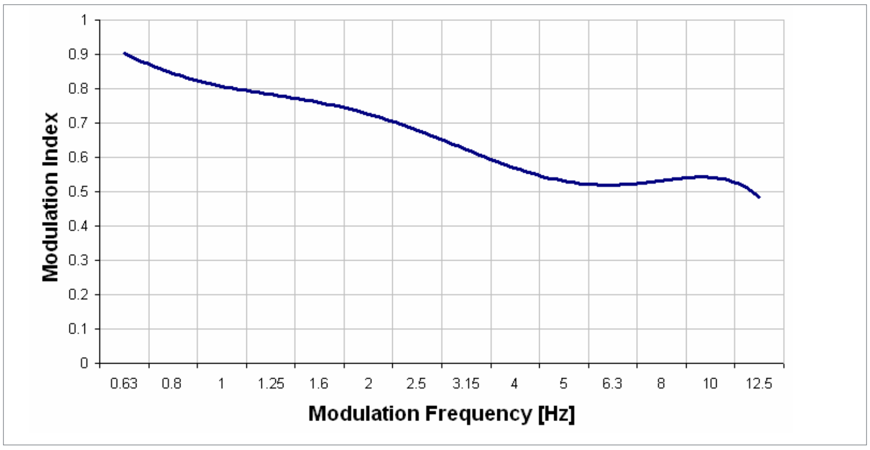


Figure 8: Modulation Transfer Function for one octave band.

Based on the MTF results as well as sound pressure level, the hearing threshold of the octave band, frequency response and psycho-acoustic effects (masking effects), it becomes possible to reliably determine the preservation of speech intelligibility from speaker to listener. The calculations are based on extensive and profound evaluations and comparisons with subjective methods.

Measuring the complete MTF – as required for STI – is rather time consuming. 14 * 7 = 98 individual measurements must be executed. Therefore, different approaches have been developed to reduce test duration and to enable speech intelligibility measurements with portable instruments.

TNO in the Netherlands has verified the correlation of the STIPA method offered by the XL2 Analyzer to the full STI to within ±0.03 STI.

STI SPEECH TRANSMISSION INDEX

The STI result is based on the full set of 98 measurements. Since this approach requires a rather long test period, it is less frequently applied in practice. However, STI represents the most detailed method to measure the preservation of speech intelligibility during transmission and is mostly used if alternative approaches don't provide reliable results due to unfavorable environmental conditions.

		Modulation Frequencies													
		0.63 Hz	0.8 Hz	1 Hz	1.25 Hz	1.6 Hz	2 Hz	2.5 Hz	3.15 Hz	4 Hz	5 Hz	6,3 Hz	8 Hz	10 Hz	12.5 Hz
Octave Bands	125 Hz	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	250 Hz	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	500 Hz	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	1 kHz	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	2 kHz	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	4 kHz	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	8 kHz	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Figure 9: STI considers all 14 modulation frequencies and all 7 octave bands resulting in 98 modulation index results.

In practice, the STI result is mostly calculated from the impulse response (MLSA) that has been acquired e.g. with a PC-based system. This approach is much quicker, but requires post-processing with spectral frequency weighting and lot of experience. The measurement assumes a linear behavior of the setup, i.e. there must be no non-linear processing or conditions, including compressors or limiters and close-to-zero wind speeds, which is a rather rare situation. Microphone and speakers are not allowed to be moved during measurement. As handheld instruments aren't fixed during measurement, it doesn't make sense to support MLS testing in handheld instruments.

RASTI - ROOM ACOUSTICS SPEECH TRANSMISSION INDEX

Effective with the standard IEC60268-16, edition 4.0, 2011, is RASTI no longer a permitted method for speech intelligibility measurements.

RASTI has been developed for special cases, such as a human lecturer speaking into a small room without echos, but not for electro-acoustic systems. In order to reduce the test time required for each STI measurement, a faster method called RASTI was developed. However, both the ability to comprehensively test and the resistance to outside interference are compromised. This leads to poor correlation between subjectively evaluated STI and RASTI. For a long period RASTI was the only method available for measuring the quality of speech transmission with a portable instrument, and has been extensively utilized to measure public announcement systems in the aviation industry, despite the compromises.

RASTI acquires only a few segments of a complete MTF table, and represents an extreme simplification of STI. Therefore, tight restrictions must be met to acquire reliable speech intelligibility results with RASTI. Furthermore, the RASTI result does not consider significant parameters such as the frequency response, echoes or frequency-dependent reverberation times. For a RASTI measurement, only two simultaneously-generated frequency bands are considered, i.e. the 500 Hz and the 2 kHz band which are then modulated with four and five frequencies respectively.

Octave Bands	Modulation Frequencies													
	0.63 Hz	0.8 Hz	1 Hz	1.25 Hz	1.6 Hz	2 Hz	2.5 Hz	3.15 Hz	4 Hz	5 Hz	6,3 Hz	8 Hz	10 Hz	12.5 Hz
125 Hz														
250 Hz														
500 Hz			✓			✓			✓			✓		
1 kHz														
2 kHz	✓			✓			✓			✓			✓	
4 kHz														
8 kHz														

Figure 10: RASTI uses 9 different modulation frequencies in 2 octave bands. The yellow marked octave bands and modulation frequency.

RASTI is normally used only to quantify the intelligibility index of the channel between two persons.

STIPA - SPEECH TRANSMISSION INDEX FOR PUBLIC ADDRESS

A rising awareness of security issues, new technological developments and the shortcomings of RASTI triggered the speaker manufacturer Bose to develop a new method for speech intelligibility measurements of PA installations. The result of these efforts is STIPA, which allows quick and accurate tests with portable instruments.

STIPA applies a simplified procedure to calculate the MTF. But STIPA determines one MTF by analyzing all seven frequency bands, whereby each band is modulated with two frequencies.

Supposing that no severe impulsive ambient noise is present and that no massive non-linear distortions occur, the STIPA method provides results as accurate as the full STI method. If however impulsive ambient noise is present during the normal system operation hours, it is usually possible to mitigate the effects by also acquiring a measurement at a more favorable time e.g. under slightly different conditions in the area, or during the night time - and to calculate an unbiased overall measurement by using the results of both test cycles.

The old and already replaced revision IEC60268-16:2003 described a STIPA method where the 125 Hz band and 250 Hz band are combined and the yellow marked modulation frequencies are not considered.

Octave Bands	Modulation Frequencies													
	0.63 Hz	0.8 Hz	1 Hz	1.25 Hz	1.6 Hz	2 Hz	2.5 Hz	3.15 Hz	4 Hz	5 Hz	6,3 Hz	8 Hz	10 Hz	12.5 Hz
125 Hz			✓							✓				
250 Hz														
500 Hz	✓							✓						
1 kHz						✓							✓	
2 kHz				✓							✓			
4 kHz		✓							✓					
8 kHz							✓							✓

Figure 11: STIPA specified in old IEC60268-16:2003 standard (replaced by 2011 edition).

The handheld NTi Audio analyzers offer sufficient processing power for more precise speech intelligibility measurements than standardized. The NTi Audio STIPA method (verified by TNO) considers all 7 octave bands and all 14 modulation frequencies resulting in more accurate speech intelligibility results. This method has been standardized in IEC 60268-16, edition 4 (2011) and edition 5 (2020).

Octave Bands	Modulation Frequencies													
	0.63 Hz	0.8 Hz	1 Hz	1.25 Hz	1.6 Hz	2 Hz	2.5 Hz	3.15 Hz	4 Hz	5 Hz	6,3 Hz	8 Hz	10 Hz	12.5 Hz
125 Hz					✓							✓		
250 Hz			✓							✓				
500 Hz	✓							✓						
1 kHz						✓							✓	
2 kHz				✓							✓			
4 kHz		✓							✓					
8 kHz							✓							✓

Figure 12: NTi Audio STIPA Method (standardized in IEC 60268-16, edition 4 (2011) and edition 5 (2020).

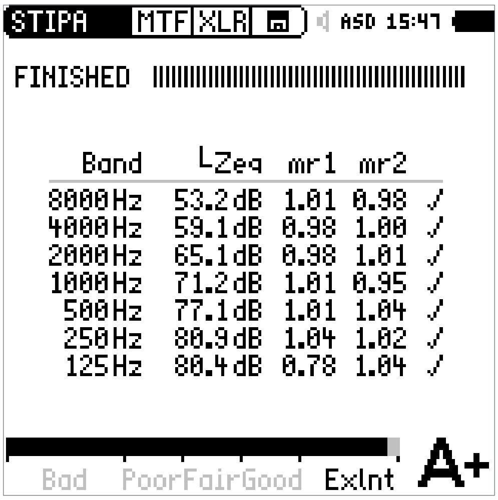


Figure 13: Modulation Transfer Function Results presented by XL2 Analyzer

STIPA Modulation Ration mr1, mr2

For good speech intelligibility it is mandatory that the integrity of the transmitted voice signal modulations are preserved. Therefore STIPA is based on measuring the MTF (Modulation Transfer Function). This function quantifies the degree to which the voice modulations are preserved in individual octave bands. The STIPA method determines the MTF by analyzing the seven frequency bands. Each band is modulated with two frequencies, resulting in the modulation ratio mr1 and mr2:

— mr1: modulation frequency 0.63 Hz to 2.5 Hz

— mr2: modulation frequency 3.15 Hz to 12.5 Hz

The mr levels should be as close as possible to the value of 1.00 for perfect intelligibility - as lower the value is as less modulation has been transmitted.

All indexes together combined with psycho-acoustic models provide the single-value speech intelligibility result.

HOW DOES STIPA COMPARE TO STI?

STI measured in public address systems can be very time consuming. A complete set of 98 measurements of modulation transfer functions (MTF) has to be obtained and summed. Due to the complex nature and the time required, almost no really useful STI measurement systems were available for years. With the appearance of MLS based systems, STI was more often obtained, as it can be calculated out of the transfer function, as long as the entire system is strictly linear and synchronous. Microphone and speaker are not allowed to move during the measurements, which prohibits employment of handheld instruments. Thus it doesn't make sense to support MLS measurements in handheld instruments. Alternatively, by using the dedicated STIPA test signal, measurements can be accomplished with handheld instruments.

STIPA, a derivative of FULL STI, has been developed specifically to cope with the non-linear processing environment common to advanced sound systems, and to reduce the measurement time required to a practical level. The results of the STIPA measurement method and the Full STI method correlate by approx. 99% at common evacuation installations. Typically, with FULL STI, the maximum deviation is about 0.02 STI. With STIPA the maximum deviation is approximately 0.03 STI for repeated measurements.

CALCULATION OF % ALCONS FROM STIPA MEASUREMENT

Alcons (%) = 10^((1-STI)/0.45)

The calculation of STIPA based on Alcon measurements is not reasonable due to the difference in the measurement principles.

STIPA NOW

STIPA (Speech Transmission Index for Public Address systems) supports fast and accurate tests with portable instruments. Portable STIPA analyzers, e.g. NTi Audio's XL2 Audio and Acoustic Analyzer, are able to evaluate speech intelligibility within 15 seconds per room position and are thus well suited for wide-area measurements and high productivity.