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Research Paper

Effect of Power Amplifier Distortion on the Speech Transmission Index for Public Address Systems

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The effect of the power amplifier on speech intelligibility in public address systems is often marginalised – i.e. it is assumed that it does not introduce significant signal distortion. This approach is justified when the linear range of the amplifier is used. The large crest factor of the speech signal and economic considerations mean that the amplifier also works in the non-linear range. In this paper, the effect of power amplifier distortion on the speech transmission index for public address systems (STIPA) is presented. In the first step, this influence was evaluated by measurements for Class AB and D amplifiers. Then, a computer model of the public address system based on the direct STIPA method, taking into account the non-linear properties of the amplifier, was proposed. Using the computer model, the optimum amplifier driving values were determined taking into account the reverberation time and interfering noise.

Keywords: speech transmission index; power amplifier; public address system.

1. Introduction

Public address systems intended for the transmission of messages must provide adequate speech intelligibility. In the author's experience, many designs of such systems do not take into account the effect of the power amplifier on the final parameters of the system – i.e. it is assumed that the amplifier will be able to drive the loudspeaker signal close to its rated power, while at the same time the effect of amplifier distortion on the speech intelligibility will be negligible.

This paper evaluates the effect of power amplifiers on the speech transmission index for public address systems (STIPA). STIPA is a simplified version of STI, developed by HOUTGAST and STEENEKEN (1973; 1980; 2002). The method has been continuously developed, resulting, among other things, in successive editions of IEC 60268-16 (2020). STIPA was chosen because it is the most popular method used in Europe to assess the speech intelligibility of public address systems. This is due, among other things, to the fact that nowadays formal requirements for voice alarm systems (VAS) (CEN/TS 54-32, 2015) or railway passenger information systems (European Commission, 2014) are determined by STIPA values. Due to the different properties of the STIPA and speech signals (BRACHMAŃSKI, 2015), the results obtained for the STIPA signal should not be directly related to the speech. However, work by STEENEKEN and HOUTGAST (2002) suggests that a good correlation is to be expected in this respect. For the formal reasons mentioned above, knowledge of the amplifier's effect on the STIPA signal may be more important than its effect on speech intelligibility.

The STIPA algorithm shows that the frequency response of even budget amplifier designs in the 1/1 octave bands range from 125 Hz to 8 kHz and the resulting signal-to-noise ratio (SNR) should not adversely affect the STI values obtained.

Seemingly, the same might be true for non-linear distortion. The most popular measure used to evaluate non-linear distortion is the total harmonic distortion (THD). The THD values of modern power amplifiers given in the specifications are so small that they should also not affect the STI values obtained. The same is true of other measures of non-linear distortion such as modulation distortion, difference-frequency distortion, or dynamic intermodulation distortion (IEC 60268-2, 1987). The effect of non-linear system properties on speech intelligibility is most often analysed in terms of centre clipping and peak clipping distortion.

Licklider's research (1946) suggests that centre clipping, also known as crossover distortion, can have a significant impact on speech intelligibility. Centre clipping occurs when the amplitude of low level parts of the signal is reduced. This distortion can be the effect of corroded contacts (IEC 60268-16, 2020), is a disadvantage of Class B power amplifiers (Ballou *et al.*, 2015), occurs in carbon microphones (Steeneken, Houtgast, 2002) (nowadays practically not used) and it can be the effect of using an expander or its special case – noise gate in the signal chain (Dobrucki, 2011). For large values of this kind of distortion, the STI model should not be used (Steeneken, Houtgast, 2002).

The effect of peak clipping on speech intelligibility is relatively small (Licklider, 1946). To digitise the speech signal, it has even been allowed to use so called infinite peak clipping, which consists of transforming the speech signal into a sequence of pulses with equal amplitudes (Licklider, Pollack, 1948). Such distortion results in an unnatural sound and its effect on speech intelligibility is more complex. It appears that the reduction of word intelligibility can be relatively small (up to 80–90%) but after a long period of auditory accommodation (Brachmański, 2015). In some applications, this may be acceptable, but in others such as VAS, it is unacceptable. It should also be remembered that Licklider's research was carried out using tube amplifiers whose properties when operating at high amplitudes are different from solid state amplifiers. Furthermore, speech intelligibility in these works was assessed by subjective methods, while STIPA is an objective method. The effect of peak clipping on STIPA in modern solid-state amplifiers, especially those implemented in Class D, may therefore differ significantly from the results of Licklider's work. Steeneken and Houtgast (2002) have shown that STI can predict the speech intelligibility of peak clipped speech.

It follows from the above considerations that for a properly designed, manufactured, and (implemented in the system) contemporary power amplifier, operating in the linear range, its effect on the obtained STIPA values should not be expected. This was confirmed by measurements later in the paper. In practice, however, it may turn out that large public address systems or those intended to provide high sound levels, work with signals that require operation in the non-linear range of the amplifier. Therefore, when designing the public address system, peak clipping should be taken into account.

The fundamental problem is to determine what the maximum value of amplifier output power can work with so that it does not adversely affect the speech transmission index. It may seem that such power is the rated power of the amplifier, i.e. the power that is determined by the specifications of professional power amplifiers, based on the distortion limited output power. Such power can be measured according to IEC 60268-3 (2018) using a sinusoidal signal for THD ≤1%. However, the speech signal is more difficult to transmit in the signal chain than the sinusoidal signal (Dziechciński, 2014). This is due, among other things, to the fact that the crest factor (CF), i.e. the ratio of the signal's peak value to its RMS value, is higher than for a sinusoidal signal. For a speech signal, the crest factor ranges from 12 dB in sources concerning audiology (Chasin, Russo, 2004) to 24 dB in sources concerning audiobooks or podcasts (ECMA TR/105, 2012). For the STIPA signal used in this study, it is 14 dB. The crest factor of the sinusoidal signal is 3 dB, so at the same peak value, the RMS value of the speech signal will be, depending on the adopted information source, from 9 dB to 21 dB (for STIPA signal 11 dB) lower than that of the sinusoidal signal. By driving the power amplifier so that it does not cut off the peaks of the speech signal, the power obtained at its output would therefore be 8 to 126 times lower than its rated power. This means that the amplifier would have to be between 8 and 126 times the effective power of the signal that we would like to deliver to the loudspeaker! This type of approach for public address systems would not only be uneconomical, but it would also pose a risk of damaging the loudspeaker. This problem is partly solved by appropriate monitoring of the signal level at the input of the power amplifier. Quasi-peak meters, which do not take into account the very short pulses present in the signal, are used to determine the limiting amplitude of the input signal. Quasi-peak meters are described, among others, in IEC 268-10 (1991) and, according to the terminology used therein, are called peak programme meters (PPM). The integration time of type I PPMs is 5 ms. For the STIPA signal used in the study, the PPM value was 6.5 dB lower than its peak value determined as "true peak" (this method was used to determine the peak value of the signals in this work) according to ITU-R BS.1770 (2015). This work will check whether PPM meters are a good tool for signal control from the point of view of the optimal amplifier driven by STIPA signal.

In the first stage of the research, the effect of amplifiers working at and above the STIPA signal limit (a maximum signal level that does not introduce peak clipping) was measured. The results obtained at this stage can therefore be used to assess the effect of the amplifier distortion on STIPA for ideal other elements of the transmission channel.

In the second stage of research, the measurement results were used to extend the computer model of the public address system proposed by Dziechciński

(2019) to determine the STI, taking into account nonlinear properties of the system and time varying interfering noise. This extended model was in turn used at the third stage of the study to assess the effect of peak clipping of the power amplifier, taking into account interfering noise and reverberation time.

2. Amplifier measurements

Class D amplifiers currently dominate in public address systems. Class AB amplifiers are gradually being replaced by Class D and are now mainly used for high end applications – e.g. in studio monitors or household applications. Class A is mainly used in audiophile and headphone amplifiers and will not be considered in the analysis. Three different types of amplifiers working in classes AB and D were used for the research. The selected amplifiers were produced by various manufacturers, they varied in power and quality, and did not have built-in protection in the form of limiters or other dynamic processors. The powers of the studied Class D amplifiers are relatively low, but the integrated circuits used in them can be used to design amplifiers with a much higher power. The parameters of the amplifiers used in this study were determined under IEC 60268-3 (2018). The band of analysis was limited to the frequency range in which the speech transmission index is determined (89–11 200 Hz). The obtained results and other information on the tested amplifiers are presented in Table 1.

Based on the results of the amplifier measurements, the STIPA signal levels used for the tests were determined. The measurements were made using a high accuracy measurement system in which a generator operating synchronously with the analyser reproduced the digitally prepared STIPA signal. This ensured a very high repeatability of STI results. The analysis time was 18 s. Auditory effects in the analyser were turned off so that the signal level did not affect the STI values. STI values were determined with an accuracy of 0.001 (the typical resolution of STI measurements is 0.01). For each level, the measurement was performed at least twice, and if the differences were measurable (larger than 0.0005), a third measurement was made. The final result for a given level of driving was the average of the STI measurements. The obtained results of the effect of amplifiers' driving on STIPA are presented in Fig. 1. $L_{\text{in,ov}}$ = 0 dB (0 dB "overdrive") means that the peak value of the STIPA signal on the amplifier input is equal to the peak value of the sinusoidal signal, which gives distortion limited output power. The crest factor of the STIPA signal used in this work is equal to 14.0 dB, so its RMS value is 11.0 dB lower than the RMS value of a sinusoidal signal with the same peak value. This means that the output power of the STIPA signal for $L_{\text{in,ov}}$ = 0 dB is 11 dB lower than distortion limited output power of amplifier.

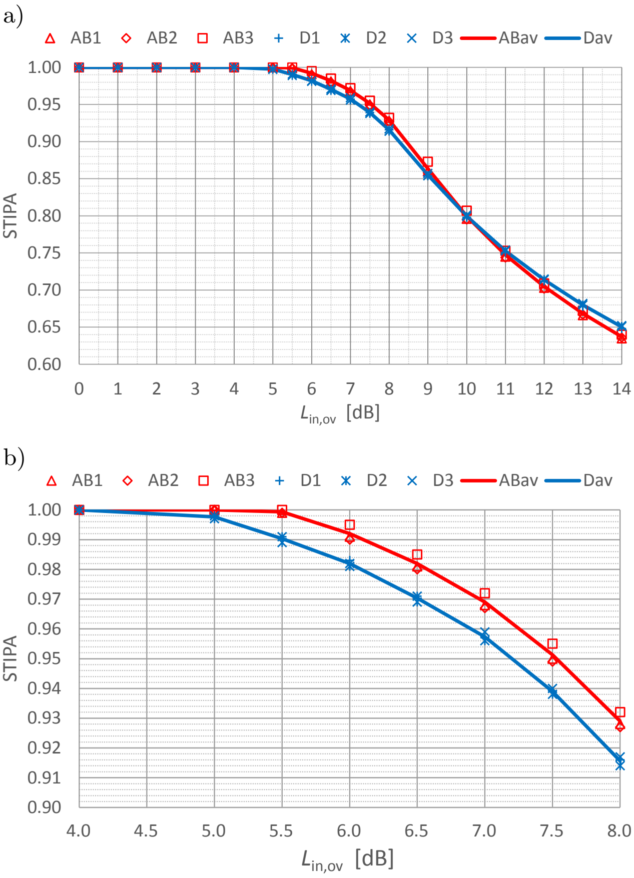

Fig. 1. Measurement results of the effect of amplifiers driving on STIPA: a) 0 dB ≤ $L_{\text{in,ov}}$ ≤ 14 dB, b) 4 dB ≤ $L_{\text{in,ov}}$ ≤ 8 dB.

Table 1. Parameters of the tested amplifiers.

Amplifier symbol	AB1	AB2	AB3	D1	D2	D3
Class of operation	AB	AB	AB	D	D	D
Distortion limited output power P_n (THD = 1%, Z = 8Ω) [W]	61	68	119	8	37	35
Frequency response (89–11 200 Hz) [dB]	±0.02	±0.02	±0.05	±0.01	±0.2	±0.5
Signal-to-noise ratio (89–11 200 Hz) [dB]	106	98	81	74	82	95
Total harmonic distortion [%]	0.008	0.08	0.02	0.9	0.1	0.04
Modulation distortion (180 Hz, 7 kHz) [%]	0.03	0.2	0.1	3.5	0.4	0.25
Difference frequency distortion (7 kHz, 125 Hz) [%]	0.006	0.04	0.02	0.8	0.1	0.07

The effect of drive on STIPA for different amplifiers in a given class was very similar (Fig. 1). For Class D amplifiers, the maximum difference in STIPA values for a given $L_{\mathrm{in,ov}}$ was 0.004. For Class AB, the differences were larger, but for the practically relevant range $L_{\mathrm{in,ov}} \leq 8$ dB, the maximum was 0.006. Therefore, the average STIPA values for a given class of amplifiers were used for further analysis. The effect of overdrive on STIPA for Class AB and Class D amplifiers differs slightly. Overdrive has no measurable effect on STIPA for $L_{\mathrm{in,ov}} \leq 5.0$ dB for Class D amplifiers and $L_{\mathrm{in,ov}} \leq 5.5$ dB for Class AB amplifiers. Above these values, up to $L_{\mathrm{in,ov}} = 8$ dB, the STIPA values for Class AB amplifiers are 0.01 higher.

To facilitate analysis, the signal output power (P_{out}) was normalised to the distortion limited power of the amplifier (P_n). The normalised level of the output power of the amplifier $L_P = 10\log(P_{\mathrm{out}}/P_n)$ – depending on the STIPA signal driving – is shown in Fig. 2. The differences between the normalised output power levels depend not so much on the Class of the amplifiers as on the tested type of amplifier. In the case of Class D, the maximum difference between the tested models did not exceed 0.1 dB, and in the case of Class AB it was 0.4 dB. Therefore, the average L_P value from the obtained values for the six tested amplifier models will be used for analysis.

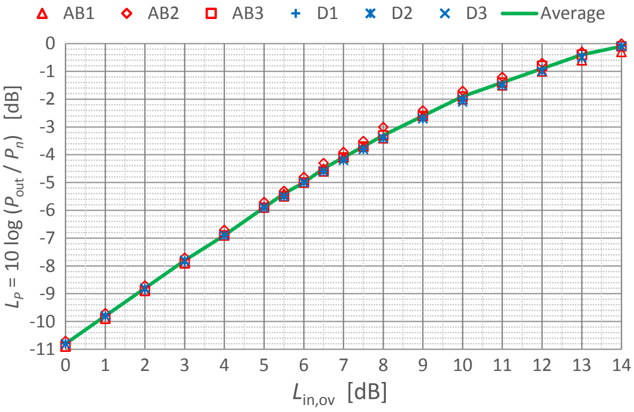

Fig. 2. Measurement results of the effect of amplifiers driven by STIPA signal on the output power level.

The results obtained for the electrical output can be directly related to an acoustically ideal sound propagation environment, i.e. with zero reverberation time and negligible interfering noise level. Under these conditions, a STIPA signal at the amplifier output with its rated power will ensure category C according to IEC 60268-16:2020 (STI = 0.66 ± 0.02), i.e. high speech intelligibility. The highest category A+ (STI > 0.76) is obtained for $L_{\mathrm{in,ov}} = 10.5$ dB and in this case $L_P = -1.7$ dB (68%). To ensure that the amplifier provides STI = 1.00, it is possible to overdrive it to max. 5 dB ($L_{\mathrm{in,ov}} = 5$ dB) which corresponds to $L_P = -5.9$ dB (26%).

The effect of the amplifier on the STI taking into account the reverberation time and interfering noise will be discussed later in the paper, based on analysis performed using a suitably prepared computer model of the public address system.

3. Public address system model

The model proposed by Dziechciński (2019) for computer simulations is based on the direct STIPA measurement method. Its general idea is very simple: a software implemented STIPA generator and analyser complying with the requirements of IEC 60268-16 are used for calculations, while the transmission channel can be modelled using different methods and taking into account different factors, depending on the problem under analysis. In this study, the effect of the amplifier distortion on STIPA was mainly assessed, therefore a simplified version of the model presented in Fig. 3 was used.

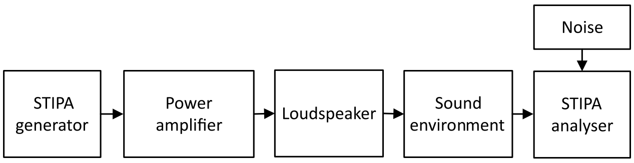

Fig. 3. Block diagram of the computer model used in this work.

It is assumed that the model will use a loudspeaker that does not introduce any linear or non-linear distortion but is only a transducer of an electrical signal to an acoustic signal. The acoustic environment was modelled by the reverberation time (T). The influence of the reverberation time on the modulation index m_k (according to IEC 60268-16) for larger source-receiver distances is described by formula (1):

$$m_k(f_m) = \frac{1}{\sqrt{1+\left(\frac{2\pi f_m T}{13.8}\right)^2}}, \tag{1}$$

where f_m is the modulation frequency.

This situation is therefore simplified, as the influence of the directional properties of the loudspeakers on the STI will not be considered in the analysis. However, the obtained results can be used in the prescriptive design method for VAS, e.g. CEN/TS 54-32 (2015).

Two interfering noise spectra were used for the analysis: a male speech spectrum according to IEC 60268-16:2020 and a pink noise spectrum. In practice, these are two extreme spectral cases – male speech is one of the least adverse interfering noise spectra and pink noise is one of the most adverse for STI. The effect of white noise, often used in telecommunications related analysis (Brachmański, 2015) was not applied, because it is unlikely to be present in public address systems and interfering noise with relatively high levels. It was assumed that the effect of noise on modulation indices (according to IEC 60268-16) is described by Eq. (2):

$$m_k(f_m) = \frac{1}{1 + 10^{-\mathrm{SNR}/10}}. \tag{2}$$

The system model used in the previous publication (Dziechciński, 2019) did not take into account the non-linear properties of the amplifier, so it is necessary to develop a new version of its model.

4. Power amplifier model

The amplifier model developed must reflect as closely as possible the results of measurements of the effects of amplifier clipping on STIPA and output power level. Model parameters should be available in typical power amplifier specifications. The model is to consider only symmetrical peak clipping. It is simplest to model it as a limiter where the output signal $y(n)$ is equal (Eq. (3)):

$$y(n) = \begin{cases} U_p, & x(n) > U_p, \\ x(n), & -U_p \le x(n) \le U_p, \\ -U_p, & x(n) < -U_p, \end{cases} \tag{3}$$

where $x(n)$ is the input signal and U_p is the peak value of the distortion limited output voltage equal to (Eq. (4)):

$$U_p = \sqrt{2 \cdot P_n \cdot Z}, \tag{4}$$

where P_n is the distortion limited output power and Z is the rated load impedance for which the output power is specified.

The Rapp model (Rapp, 1991) commonly used to model solid state RF amplifiers (Levanen *et al.*, 2012) was also verified. This model is described by Eq. (5):

$$y(n) = \frac{G \cdot x(n)}{\left(1 + \left(\frac{G \cdot x(n)}{Up}\right)^{2p}\right)^{-2p}}, \tag{5}$$

where G is the gain in the linear range and p is the smoothness factor. The best correlation with STIPA measurements was obtained for $p = 320$ for Class AB amplifiers and $p = 280$ for Class D amplifiers. The differences between the results of modelling and measurements of the output power level were similar for both numerical models and comparable with the spread of measurement results for particular types of amplifiers. The effect of the amplifier on STIPA obtained by modelling compared with the measured results is shown in Fig. 4. The analysis was performed independently for Class AB and Class D amplifiers. The differences between the Rapp model and the limiter are noticeable only for high overdrive values and for such levels a better correlation with measurements is provided by the Rapp model. Both numerical models perform better for Class D amplifiers. Up to 7 dB overdrive, for Class D, the differences between STIPA modelling and measurements are less than 0.002, so they can be considered negligible, while for higher overdrive values they are less than 0.01 STI, which should also be considered a satisfactory result. For Class AB, the maximum difference between measurement and modelling for the Rapp model is also close to 0.01 STI.

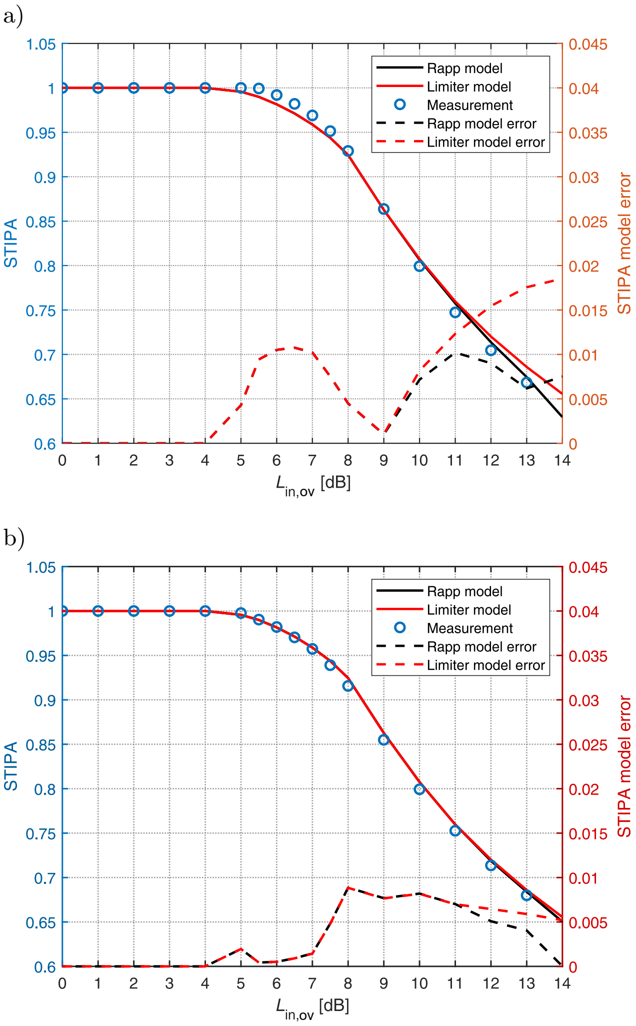

Fig. 4. Effect of the amplifier on STIPA obtained by modelling compared with measured results for: a) Class AB, b) Class D.

The advantage of the limiter model is the possibility to assess the number of peak clipped samples of the STIPA signal depending on the amplifier driving (Fig. 5). $L_{\mathrm{in,ov}} = 5$ dB is 0.7% of the peak clipped samples, and for $L_{\mathrm{in,ov}} = 8$ dB it is already 5% of the signal samples. This explains why for $L_{\mathrm{in,ov}} \le 5$ dB the effect of amplifier distortion on STIPA is negligible.

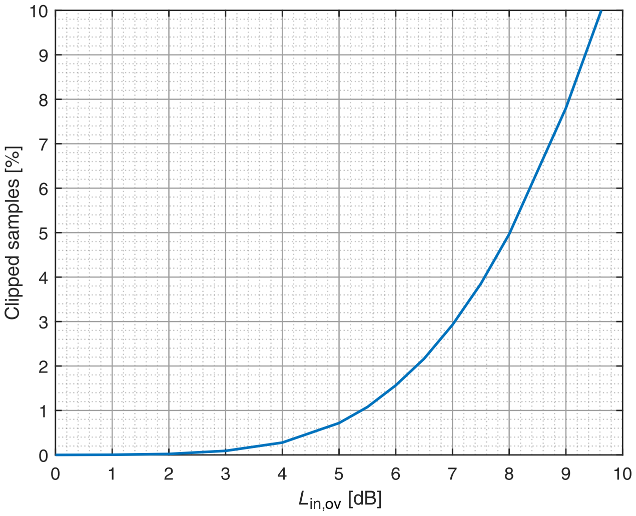

Fig. 5. Effect of amplifier drive on the number of peak clipped samples.

5. Effects of amplifier on STIPA including reverberation time and interfering noise

The analysis of the effect of the amplifier on STIPA (taking into account the reverberation time and interfering noise) will be performed by computer simulations using the model described in Sec. 3 for Class D amplifiers, modelled with the Rapp model. According to the analysis in Sec. 2, for Class AB amplifiers, one can expect STI values to be higher by 0.01 for overdriving in the range of 6–8 dB. The analysis will be performed mainly for the signal level $L_{\mathrm{Aeq},s}$ = 75 dB or noise level $L_{\mathrm{Aeq},n}$ = 65 dB and reverberation time up to 1.3 s, i.e. the limit values for the prescriptive design method according to CEN/TS 54-32 (2015).

In an ideal acoustic environment, overdriving the amplifier by $L_{\mathrm{in,ov}} > 5$ dB reduces the STI. For an acoustic environment with noise, increasing $L_{\mathrm{in,ov}}$, increases SNR. Thus, it may be that if the increase in STI resulting from increased SNR is larger than the degradation in STI resulting from amplifier overdrive above $L_{\mathrm{in,ov}} > 5$ dB, the resultant STI will increase. The use of an ideal power amplifier is the reference point for the analysis. The effect of SNR on STIPA for such a case is shown in Fig. 6. In the case where the reverberation time is equal to zero, the effect of SNR on STIPA is the most significant. For male speech ambient noise, STI increases linearly for SNR within ±15 dB. This follows from Eq. (2) and the STI algorithm. This situation is shown in red in Fig. 6a. In this case, the slope of the curve is 0.033 STI/dB. As can be seen in Fig. 6, the larger the reverberation time, the smaller the effect of SNR on STI (the slope of the curve is smaller). For pink noise (Fig. 6b), the slopes of the curves are smaller than 0.033 STI/dB.

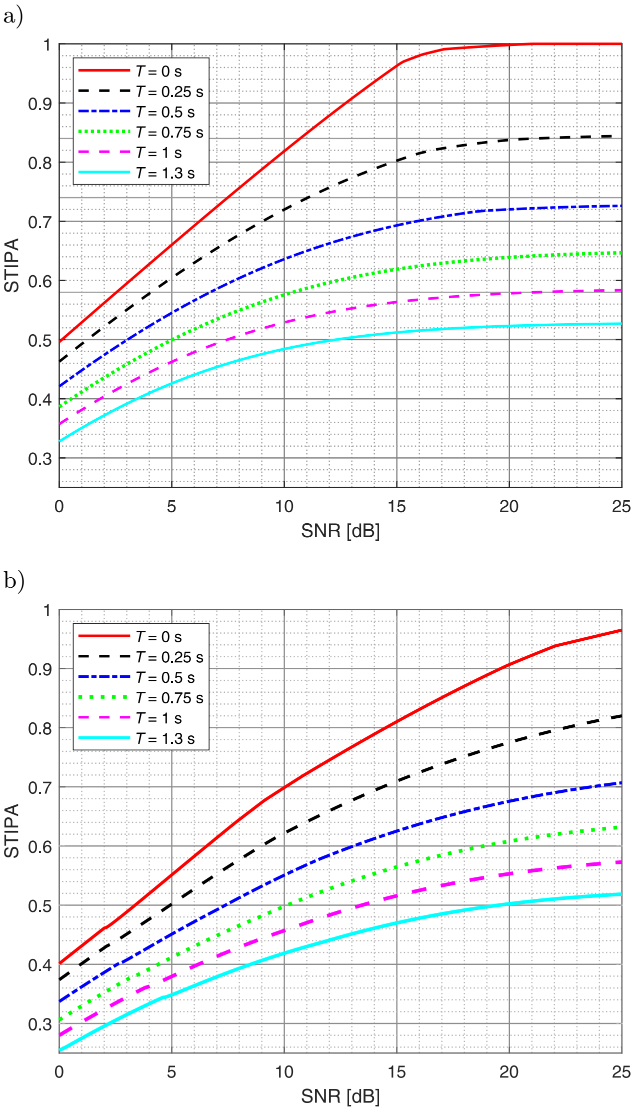

Fig. 6. Effect of signal-to-noise ratio on STIPA for an ideal amplifier and selected values of reverberation time, signal level $L_{\mathrm{Aeq},s}$ = 75 dB and two interfering noise spectra: a) male speech, b) pink noise.

For Class D amplifiers in the $L_{\mathrm{in,ov}}$ range of 5 dB to 8 dB (Fig. 1), the slope of the curve is 0.027 STI/dB and so it can be expected that the optimum amplifier drive will lie in this range. This was tested for the noise level $L_{\mathrm{Aeq},n}$ = 65 dB, i.e. the limit value for the prescriptive design method from CEN/TS 54-32 (2015) and a system designed to achieve SNR = 10 dB, so $L_{\mathrm{Aeq},s}$ = 75 dB. Assuming the safe drive of the amplifier, its power should be selected so that the required sound level is obtained for $L_{\mathrm{in,ov}}$ = 5 dB (L_P = −5.9 dB). The results of computer simulations for such a case are presented in Fig. 7. In these simulations, the influence of auditory effects was also taken into account. Consequently, in the absence of noise, STIPA has values lower than 1.00 already for a $L_{\mathrm{in,ov}}$ = 4 dB driving level. This is not due to the introduction of distortion by the amplifier but is a result of the auditory masking and the associated effect of the signal level

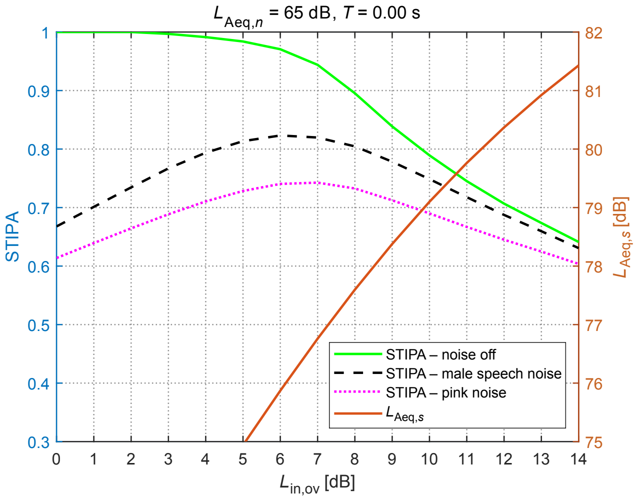

Fig. 7. Effect of the amplifier driving on STIPA for reverberation time T = 0 s and interfering noise level $L_{\mathrm{Aeq},n}$ = 65 dB.

on STI (Fig. 8). In the presence of noise, the maximum STI is obtained for $L_{\mathrm{in,ov}}$ = 6 dB in the case of male speech noise and $L_{\mathrm{in,ov}}$ = 7 dB for pink noise.

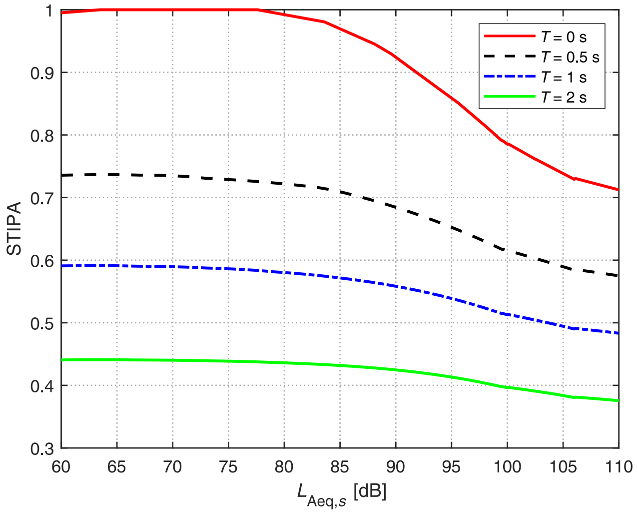

Fig. 8. Effect of the signal level on STIPA.

The results of computer simulations for reverberation time T = 1 s and the other parameters as in the previous example are shown in Fig. 9a. The effect of amplifier overdrive on the range of STIPA changes is smaller in this case, but still significant. The optimum drive levels have not changed.

If the required STIPA value is relatively small compared to the reverberation time of the room, it is possible to drive the amplifier to higher levels. In this case, less powerful amplifiers can be used in the system, which can have a significant economic impact in the case of large systems. For interfering noise and reverberation time as in the previous example, assuming that the required STI value is 0.50 and the noise has a male speech spectrum, it is possible to use an amplifier with twice less power in the system. The results of the analysis for this case are shown in Fig. 9b.

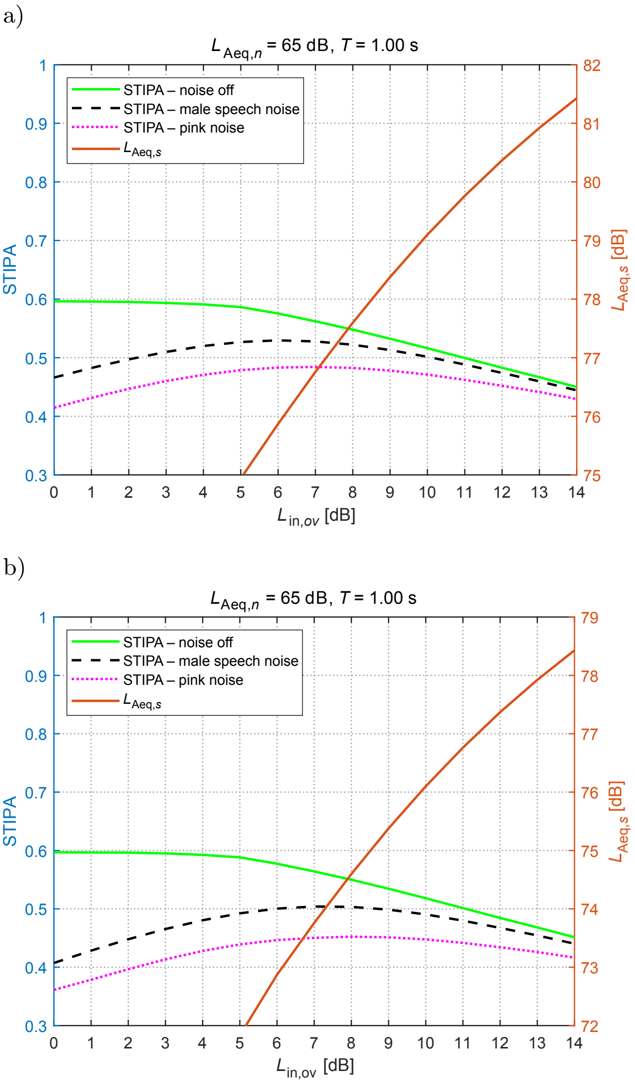

Fig. 9. Effect of the amplifier drive on STIPA for reverberation time T = 1 s and interfering noise level $L_{\mathrm{Aeq},n}$ = 65 dB for: a) an amplifier selected so that the required sound level of the system is obtained for $L_{\mathrm{in,ov}}$ = 5 dB, b) for an amplifier with two times less power.

The shape of the STI ($L_{\mathrm{in,ov}}$) characteristics and the optimum levels of driving can be influenced by the operation of the public address system with high sound levels. The influence of the sound level on STIPA is largest for zero reverberation time (Fig. 8) and for such a case the analysis was performed, the result of which is shown in Fig. 10. This analysis was performed for the interfering noise level $L_{\mathrm{Aeq},n}$ = 95 dB. This is the highest value of the interfering noise level the author has encountered in design practice. In comparison with the noise level $L_{\mathrm{Aeq},n}$ = 65 dB (Fig. 7), the effect of the amplifier driving on the range of STIPA changes is in this case smaller, but still significant. The optimum driving levels have not changed.

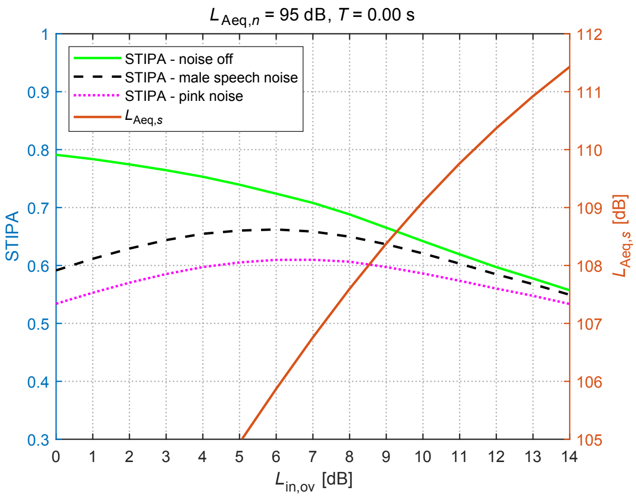

Fig. 10. Effect of the amplifier driving on STIPA for reverberation time T = 0 s and interfering noise level $L_{\mathrm{Aeq},n}$ = 95 dB.

6. Discussion

For the six types of tested power amplifiers of Class AB and D, the influence of STIPA signal drive on STI values was very similar. In the research, it was assumed that the amplifiers' driving will be referred to the level $L_{\mathrm{in,ov}}$ = 0 dB, which corresponds to the maximum peak value of STIPA signal, not distorted by the amplifier. For $L_{\mathrm{in,ov}} \leq 5$ dB the effect of the amplifier on the STI is not measurable. The amplifier output power level L_P (output power normalised to the power limited by distortion) for $L_{\mathrm{in,ov}}$ = 5 dB is equal to −6 dB. This means that when designing public address systems, it is safe to assume that the power amplifier will be able to drive $^1/_4$ of its rated power to the loudspeaker.

For analysis of the effect of the amplifier distortion on STIPA in the presence of reverberation time and noise, the computer model proposed by Dziechciński using the direct STIPA method was extended to a non-linear amplifier model. The amplifier was modelled as a limiter and according to Rapp model. These models gave similar results, but the Rapp model provided a better correlation with the measurement results and it was used for further analysis.

The exemplary analysis was mainly performed for the limit values of the prescriptive design method for voice alarm systems of CEN/TS 54-32 (interfering noise level $L_{\mathrm{in,ov}}$ = 65 dB, signal level $L_{\mathrm{in,ov}}$ = 75 dB, reverberation time $T \leq 1.3$ s).

In the presence of noise, with an assumed SNR = 10 dB, the maximum STI is obtained for $L_{\mathrm{in,ov}}$ = 6 dB for male speech noise and $L_{\mathrm{in,ov}}$ = 7 dB for pink noise. The reverberation time does not affect the optimum value of the overdrive, but the larger it is, the smaller the range of variation of STI as a function of overdrive.

In rooms with low reverberation times in relation to the required STI values, for economical reasons, even higher $L_{\mathrm{in,ov}}$ values can be used, which will enable the use of amplifiers with lower power. However, taking into account the STI ($L_{\mathrm{in,ov}}$) characteristics obtained from the measurements, it seems that the $L_{\mathrm{in,ov}}$ values should not be higher than 8 dB. This means that when designing public address systems, the maximum assumed power with which an amplifier can drive a loudspeaker should not be higher than $^1/_2$ of its rated power.

A PPM meter used for a STIPA signal will indicate overdrive for $L_{\mathrm{in,ov}}$ = 7.5 dB. Therefore, it is not an ideal tool for checking a signal chain from an STI point of view, but it can be useful.

The results obtained in this study should also be taken into account at the stage of STI measurements in public address systems. One of the elements of the measurement procedure is to increase the STIPA signal level (in relation to the message level) by 3 dB. In the case of using dynamically compressed messages and a precisely adjusted system, it is possible to introduce additional distortions and therefore to underestimate the STI measurement results.

7. Summary

The study concluded that the optimum range of amplifier output power for the STIPA signal is between $^1/_4$ and $^1/_2$ of their rated power. However, when assuming values higher than $^1/_4$ power at the design stage, it should be verified that this will not adversely affect the STI in a particular case.

The analysis carried out did not take into account several factors connected with STIPA signal processing in the signal chain, which may additionally influence the optimum amplifier driving. These factors include equalisation or dynamic processors. Their influence on STI will be analysed in the future. It is also planned to assess the effect of these elements not only on STI but also on the quality of signal and subjective assessment of speech intelligibility.

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