Frequency weighting of airborne sound signals

Tones with the same sound pressure level, but different pitch, are perceived with different loudness by the human ear. This frequency-dependent sensitivity curve of the human ear can be reproduced with weighting filters. For airborne sound signals, four different weighting curves were designed: A-, B-, C- and D-weighting (see figure 1).

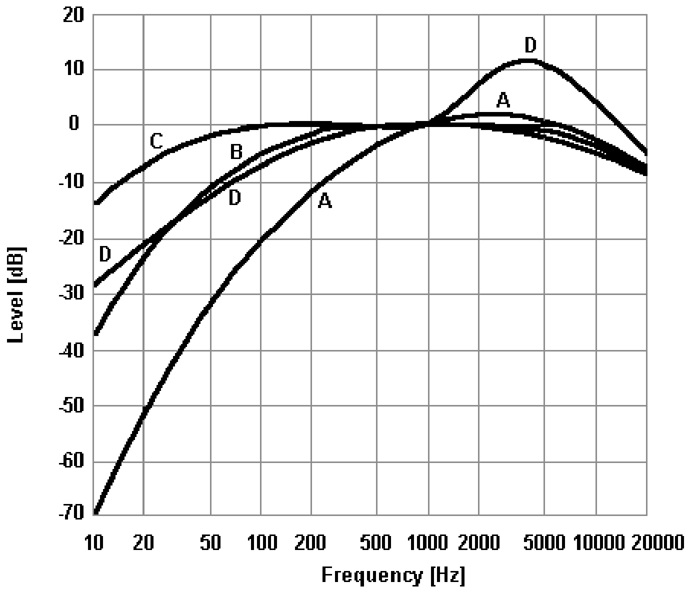

Figure 1: Frequency weighting curves

The curves of these weighting filters are supposed to represent the inverted equal-loudness-level contours (according to ISO 226). Since the progression of equal-loudness-level contours depends on the sound pressure level, different weighting curves have been defined for different sound pressure levels. The A-weighting curve corresponds to the constant loudness curve at approx. 20-40 phon, the B-weighting curve is for the 50-70 phon range and the C-weighting curve for 80-90 phon. The D-weighting complies with the curves showing the same loudness level at very high sound pressures.
In practice as well as in laws and regulations, e.g., regarding noise protection, the A-weighting curve is almost exclusively used. Although initially only intended to be used with quiet sounds, the A-weighting is now also used with louder sounds. The C-weighting is used with higher sound pressure levels as well as for an enhanced consideration of low frequency sound components. Both the B-weighting and the D-weighting are generally no longer used and are only mentioned here for the sake of completeness.
The result of a weighted level analysis, e.g., using the A-filter, is the A-weighted sound pressure level. In diagrams, the application of a specific weighting filter is often indicated by a corresponding suffix to the physical quantity of the sound pressure level, e.g., *L(A)* in *dB(SPL)*.
Details on the implementation of a frequency weighting in ArtemiS SUITE[1] using a Pool Project can be found in the present Application Note. The descriptions also apply to other projects of ArtemiS SUITE, e.g., the Automation Project.

[1] The descriptions in this Application Note refer to ArtemiS SUITE 9.1. The general procedures also apply to other versions. However, the scope of functionality and the user interface may differ.

Applying weighting functions in a Pool Project

In a Pool Project, a frequency weighting can be applied at various points in the signal processing chain. Frequency weighting can be performed in the Filter Pool prior to an analysis, or in the Analysis Pool within the actual analysis (available, e.g., for the 1/n octave analysis, the FFT analysis or the level analysis). In the Filter Pool, the weighting is performed in the time domain. In the Analysis Pool using FFT-based analyses, the frequency weighting is performed in the frequency domain, whereas the weighting for non-FFT-based analyses, e.g., in the Filter Pool, is performed in the time domain.

With the ***Frequency Weighting*** element in the Filter Pool, either all or only selected channels of a signal are filtered prior to the analysis. The advantage of using this element is that the frequency weighting can be applied to each channel individually. This means that in a multi-channel file, the airborne sound channels can be A-weighted, while all other channels, such as acceleration or rpm, remain unaffected. That way, weighting can be restricted to those channels for which A-weighting actually makes sense. Figure 2 shows the Properties window of the ***Frequency Weighting*** element.
After the frequency weighting in the Filter Pool, the desired analysis can be selected in the Analysis Pool.

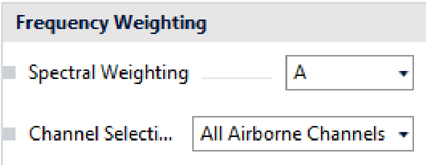

Figure 2: Properties window of the *Frequency Weighting* in the Filter Pool

The other possibility to apply A-weighting can be found directly in the Properties window of many analysis functions. Figure 3 shows the Properties window of the averaged FFT analysis. In the ***Spectral Weighting*** field, you can select A-weighting, for example.

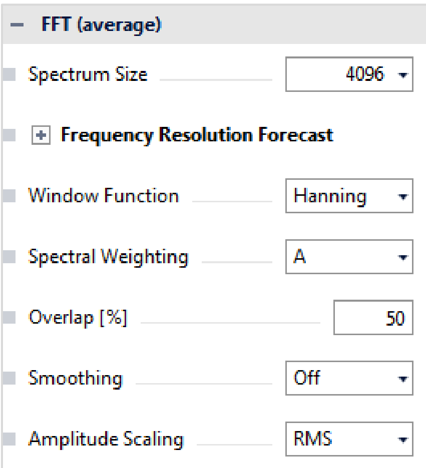

Figure 3: Properties window of the averaged FFT analysis

Frequency weighting in the Filter Pool is thus performed in the time domain, whereas the A-weighting of the FFT analysis is simply added in the frequency domain after the actual Fourier transformation[2]. Usually these different approaches lead only to minimal differences in the result.
Figure 4 shows the result of an FFT analysis calculated with a Hanning window function. The diagram contains two curves: for the blue curve, A-weighting was applied in the Filter Pool, i.e., in the time domain prior to the analysis, whereas for the light blue curve, A-weighting was added after the Fourier transformation. The difference between the two curves is small and only seen at the low frequencies.

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[2] This applies only to frequency weighting in FFT-based analyses, i.e., not for time-dependent ***Level vs. Time*** analyses, for example.

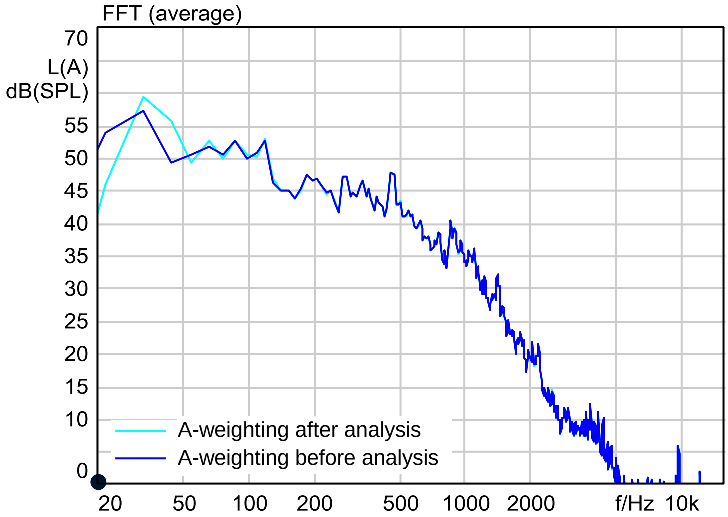

Figure 4: Averaged FFT analysis (Hanning window) with A-weighting before (blue curve) and after the analysis (light blue curve)

Special applications

Review of window functions for FFT analysis

For the Fourier transformation, the signal must be temporally segmented ("windowed"). This is achieved by subdividing the original signal into several blocks with N sample values each. In the analysis of the signal blocks, a periodic continuation of the time domain signal is implied. At the edges of the signal section, this can lead to points of discontinuity if the respective block does not contain a whole-numbered multiple of a period. These points of discontinuity cause frequencies to show up in the spectrum that were not present in the original signal. This "leaking" of signal energy to neighboring frequencies of the original frequency is referred to as the leakage effect. By suitable windowing techniques using window functions dropping smoothly to zero at their edges, this effect can be reduced. Since the choice of the window function has an effect on the analysis result, the appropriate window function for the respective application must be chosen. For many applications, the Hanning window is suitable, because it reduces the leakage effect very well. Other window functions are optimized for special applications. For example, the Kaiser-Bessel window has a very good frequency resolution and should therefore be used to separate tonal components with very different levels.

When using the rectangular window, the signal is simply split into smaller sections, but the sections are not faded in and out. In case of signals whose spectrum contains distinct frequency bands with relatively high levels, using a rectangular window leads to inaccurate analysis results. Figure 5 shows the result of an FFT analysis of a signal with a strong low-frequency component. The red curve shows the result of the FFT analysis with a rectangular window. The green curve shows an FFT analysis of the same signals, but this time using a Hanning window to reduce the leakage effect. The sound examined is the same as in figure 4. However, for the FFT analysis in figure 5, no frequency weighting has been applied yet.

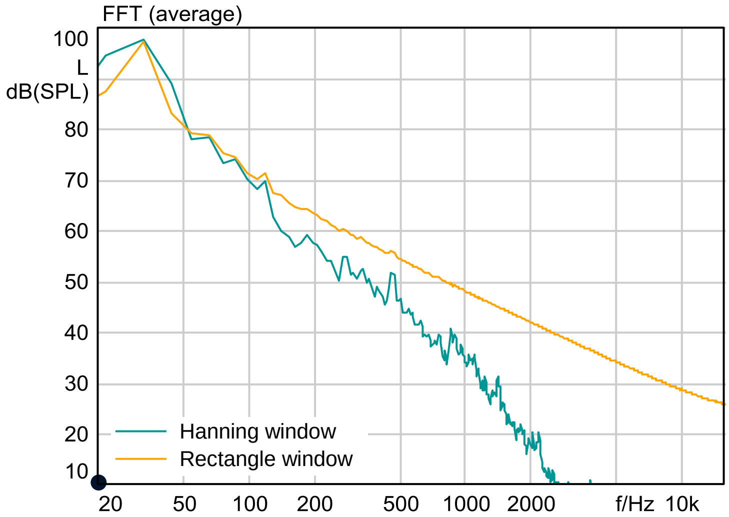

Figure 5: Averaged FFT analysis with rectangular (orange) and Hanning windowing (green)

It is clearly visible that with the rectangular window, the strong low-frequency component of the signal dominates the higher frequency ranges as well and masks the underlying actual spectrum. Using the Hanning window reduces this effect significantly.
For signals with individual prominent frequency ranges, the rectangular window is not suitable. Generally, using a rectangular window is only advisable for special applications (e.g., the analysis of pseudo-noise). However, using the rectangular window may be necessary in some cases, e.g., to ensure comparability with other analysis results.

Applying A-weighting

The above example regarding the rectangular window illustrates very well that the difference between A-weighting in the time domain and in the frequency domain can be significant in some cases: when no proper windowing function is used for calculating the FFT analysis, and only a rectangular window is used, the differences between the results become much more obvious. Figure 6 shows the results of the same FFT analysis as in figure 4, except that a rectangular window has been used this time.
It is clearly visible that the difference between the two curves is stronger without a proper windowing function. This is due to the fact that the leakage effect already shown in figure 5, which occurs when using a rectangular window, cannot be avoided if the A-weighting is applied only after the analysis in the frequency domain. However, if the A-weighting is performed before the analysis in the time domain, the strong low-frequency component is reduced prior to the FFT analysis, which in turn reduces the negative effect of the rectangular window significantly.

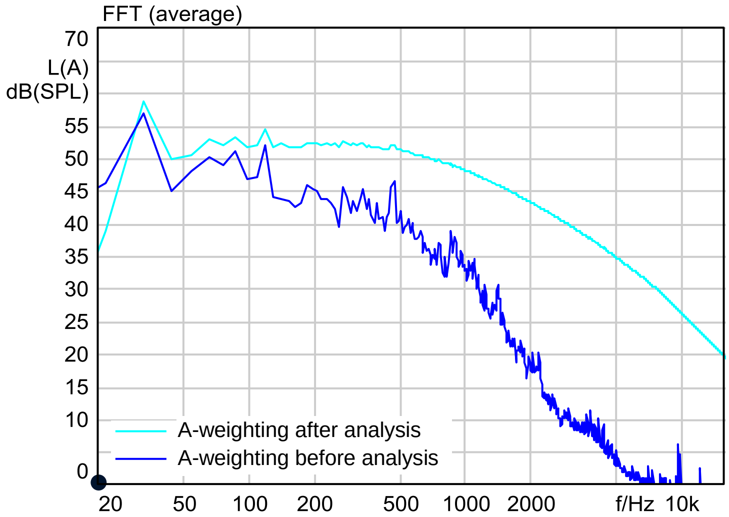

Figure 6: Averaged FFT analysis (rectangular window) with A-weighting before (blue curve) and after the analysis (light blue curve)

Summary

In most cases, the decision whether frequency weighting is applied in the time domain or in the frequency domain has only a minor influence on the analysis result. However, the influence on the result can become significant in the case of special signal forms or with the use of inappropriate analysis parameters, e.g., a wrong windowing function.

Notes

For the calculations presented in this Application Note by means of a Pool Project, you need the following ArtemiS SUITE modules: **ASM 00** ArtemiS SUITE Basic Framework (code 5000) and **ASM 01** ArtemiS SUITE. If you want to use the weighting curves by means of other projects, e.g., with an Automation Project or a Standardized Test Project, you may need other modules. Your HEAD acoustics representative will gladly provide you with further information.

Do you have any questions or remarks? Please write to:
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We look forward to receiving your response!