

Using the new psychoacoustic tonality analyses *Tonality (Hearing Model)*¹

As of ArtemiS SUITE 9.2, a very important new fully psychoacoustic approach to the measurement of tonalities is now available. ***Tonality (Hearing Model)***, based on the **Hearing Model of Sottek**, has been developed due to considerable and growing concern from the Information Technology and automotive sectors about errors of existing tonality metrics to quantify tonalities in technical sounds according to perception (sometimes they are not resolved, other times over-emphasized or falsely presented). The new method automatically considers the threshold of hearing and the relationship of tonality perceptions to psychoacoustic loudness levels, and provides a high time resolution to measure transient and rapidly changing tonalities. **Uniquely, it can also present the strength and the frequency of (maximum) tonality vs. time, RPM or other reference quantity.** The method was published in the Information Technology acoustic standard ECMA-74, 15th Edition (June 2018).

The method *Tonality (Hearing Model)* offers several analyses:

1. ***Specific Tonality (Hearing Model)*** – average spectrum of psychoacoustic tonality
2. ***Specific Tonality (Hearing Model) vs. Time or RPM*** – spectrum of psychoacoustic tonality vs. time or RPM
3. ***Tonality (Hearing Model) vs. Time or RPM*** – strength of the maximum psychoacoustic tonality at a given instant as a function of time or RPM
4. ***Tonality (Hearing Model) Frequency vs. Time*** – frequency of (maximum) tonality (at each instant) vs. time

Although these tools are straightforward with very minimal settings to be decided upon, their power is very great. Careful study of this Application Note will pay dividends in getting full use of *Tonality (Hearing Model)*.

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A brief background of tonality measurement

(details may be looked up in the ArtemiS SUITE Help System)

Previous tonality metrics, currently in use, are:

1. Tone-to-Noise Ratio (ECMA-74)
2. Prominence Ratio (ECMA-74)
3. DIN 45681 Tonality
4. Tonality vs. time (Aures/Terhardt)

The first three listed methods are hybrids, in that they use the critical bandwidth (a psychoacoustic factor) but operate with sound pressure, not psychoacoustic loudness. They do not consider the cavum conchæ resonance of the ear (an acoustic amplifier of approximately 12 dB at about 4 kHz affecting perceived loudness) and are not based on the calculation of psychoacoustic loudness. The fourth method (Aures/Terhardt) is psychoacoustic in concept but incompletely implemented.

The *Tone-to-Noise Ratio* and *DIN 45681 Tonality* can operate only on discrete tones. **Although discrete tones can cause the perception of tonality, so can other factors: elevated regions of**

¹ These analyses require **ASM 16** ArtemiS SUITE Advanced Psychoacoustics (code 5016).

narrowband noise (such as caused by resonances), impure tones, steep discontinuities in noise spectra without discrete tones, and conjunctions of pure or impure tones with the other mentioned phenomena.

In the ECMA-74 standard to date, the *Tone-to-Noise Ratio* and *Prominence Ratio* are only to be applied to pure tones. Due to its mode of operation, the *Prominence Ratio* may be used with or without restriction to pure tones; it can often be more effective without the tones restriction.

The *Aures/Terhardt Tonality* method has a psychoacoustic basis but yields no spectral information, only the relationship of tonal to non-tonal loudness as a function of time. Due to the lack of spectral information and the high resolution in time, the results are often difficult to interpret. Thus, this method is seldom useful.

The *Tone-to-Noise Ratio*, *Prominence Ratio* and *DIN 45681 Tonality* all require very high resolution in frequency, which results in very low resolution in time. Brief, transient or short-term frequency-shifting tonalities are therefore either under-represented or not captured at all.

In many product sectors, quieter and quieter products are being developed and marketed. An increasingly evident flaw in the extant tonality methods is indicating and penalizing significant tonality magnitudes not actually associated with perception, from sound situations near or below the threshold of hearing.

Tonality (Hearing Model)

The method *Tonality (Hearing Model)* employs only psychoacoustic loudness, and determines the loudness of tonal and non-tonal components of sounds by means of the running (updating) autocorrelation function. The method has been tested by jury evaluations with many participants and a wide variety of technical sounds having a wide variety of spectral shapes, event timings/variations and loudness levels. As with other psychoacoustic metrics, accurate calibration of the presented sound pressure signals is very important.

Due to its psychoacoustic accuracy, *Tonality (Hearing Model)* may for the first time in tonality measurement be relied upon for automatic, intervention-free determination of tonalities according to how they would be perceived, without the requirement for listening which is in the current standard descriptions for use of *Tone-to-Noise Ratio* and *Prominence Ratio*. Due to the frequent unavailability of calibrated acoustic playback, the listening requirement can impose difficulty due to a necessity for direct audition.

Tonality (Hearing Model) automatically includes the threshold of hearing and the relationship of tonality perceptions to loudness levels. It operates at $\frac{1}{2}$ critical bandwidth direct spectral resolution but yields finer frequency-of-tonality detail. It provides both high time resolution and high frequency resolution. The inter-measurement time interval is approximately 5 ms at the highest signal frequencies and approximately 40 ms at the lowest frequencies, with four steps in time resolution between the 5 ms and 40 ms frequency-dependent time resolutions. Although calculations are made at $\frac{1}{2}$ critical bandwidth resolution, the precise frequency of tonality is determined from the spectrum of the updating autocorrelation function permitting the analysis *Tonality (Hearing Model) Frequency vs. Time* to present a resolution of approximately 3 Hz at the lowest signal frequencies and approximately 24 Hz at the highest signal frequencies. The *Specific Tonality (Hearing Model)*, an average measurement, and *Specific Tonality (Hearing Model) vs. Time* or *RPM*, are of course displayed at the $\frac{1}{2}$ critical bandwidth resolution.

Results with various tonality methods on real-world sounds

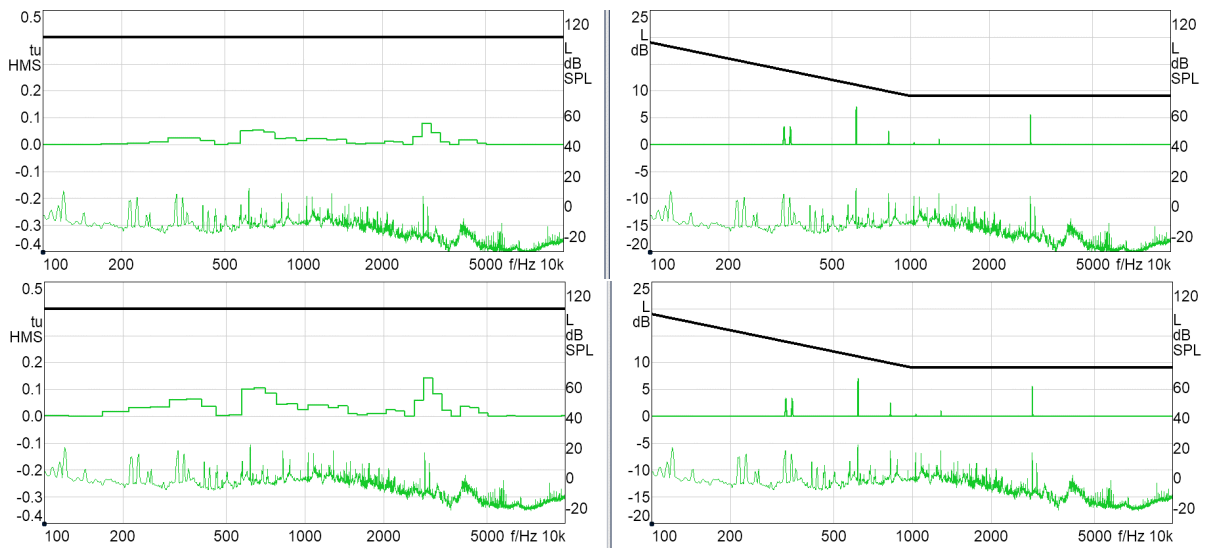


Figure 1: An Information Technology product sound (steady): comparison of specific tonality by *Tonality (Hearing Model)* (left panels) and *Prominence Ratio* (tones-only, right panels). Upper: original sound pressure level. Lower: same recording, sound pressure raised 10 dB. **Note: no change in the *Prominence Ratio* result, but change in the psychoacoustic tonality result matching the perception change.** The black horizontal line in the left panels is the tolerance for reportability of prominent tonality according to ECMA-74, at and above the value 0.4 tu(HMS) (Tonality Unit according to the Hearing Model of Sottek). The black line in the right panels is the tolerance for reporting tonality according to ECMA-74 for the *Prominence Ratio*.

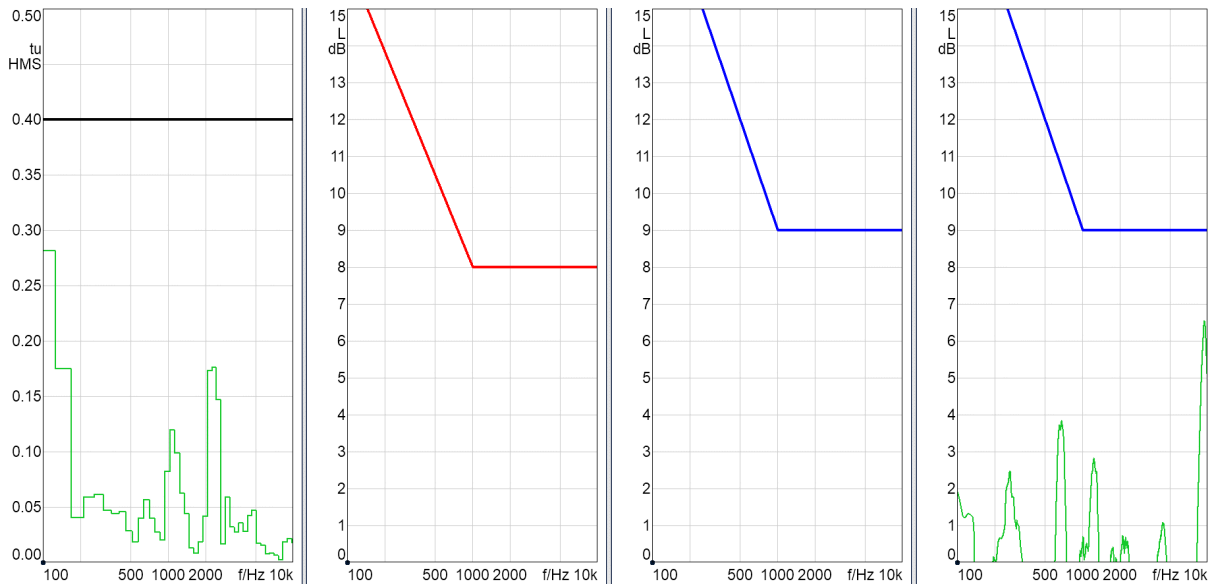


Figure 2: For a printer printing a sequence of pages, here is the average spectrum of tonality (specific tonality) by, left to right: *Tonality (Hearing Model)*, *Tone-to-Noise Ratio*, *Prominence Ratio* (tones only) and *Prominence Ratio* (not selecting for tones only). The tolerance lines for reportable tonal prominence are shown, color-coded by analysis type.

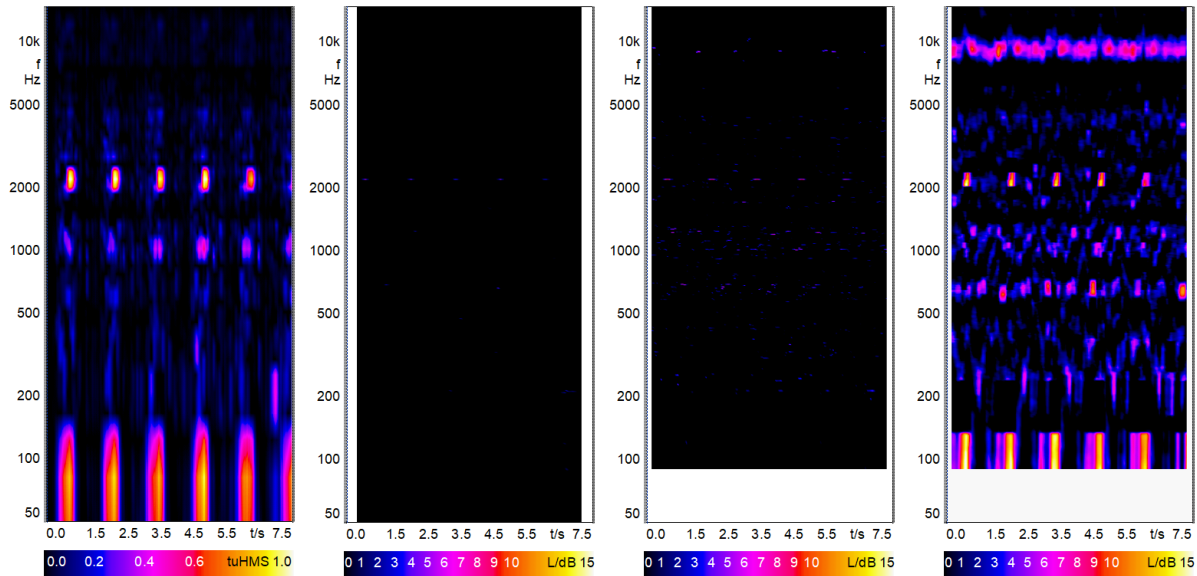


Figure 3: For the same printer sound, here are the same measures versus time. Note that the maximum tonality magnitude during the brief events is much higher than that shown in the average specific tonality graph of Figure 2, due to the short duty cycle. Also note that the pure-tone methods greatly under-represent the tonalities. The *Prominence Ratio* displays a prominent tonality around 10 kHz which is inaudible at this loudness, hence does not appear in the psychoacoustic tonality result. This printer also has a significant audible transient tonality near 85 Hz (see Figures 2 and 4) not reported by the older methods.

Capabilities of *Tonality (Hearing Model)*

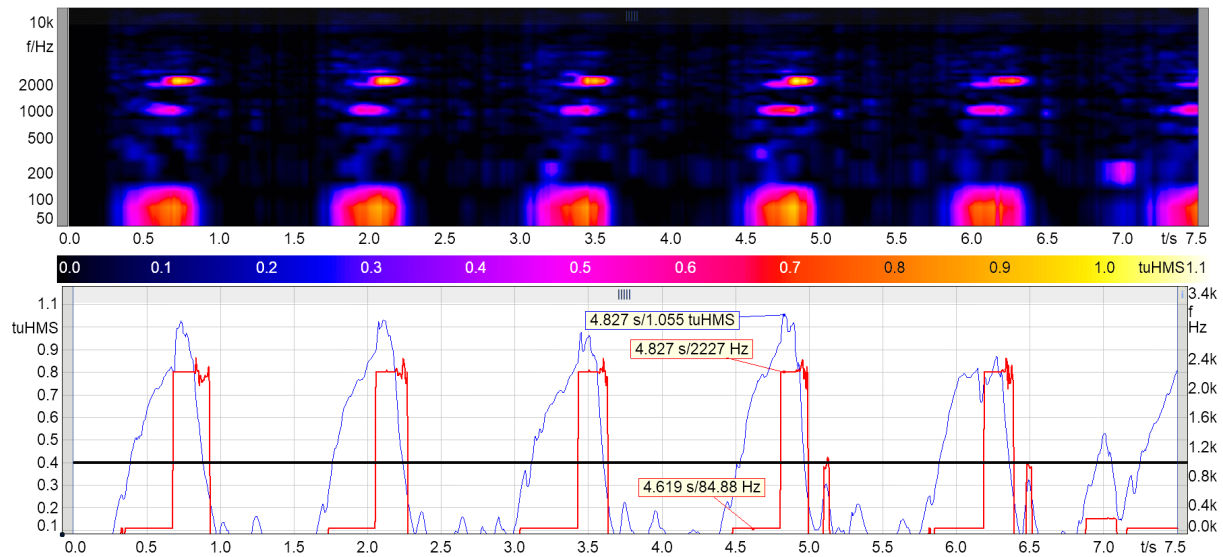


Figure 4: (same sound as in Figures 2 and 3) Unlike other tonality measures, *Tonality (Hearing Model)* can present the magnitude of maximum tonality vs. time (blue, lower panel) and frequency of maximum tonality vs. time (red). It is very informative to view these relationships. Note: where the tonality frequency changes, the graphic transition is a vertical line.

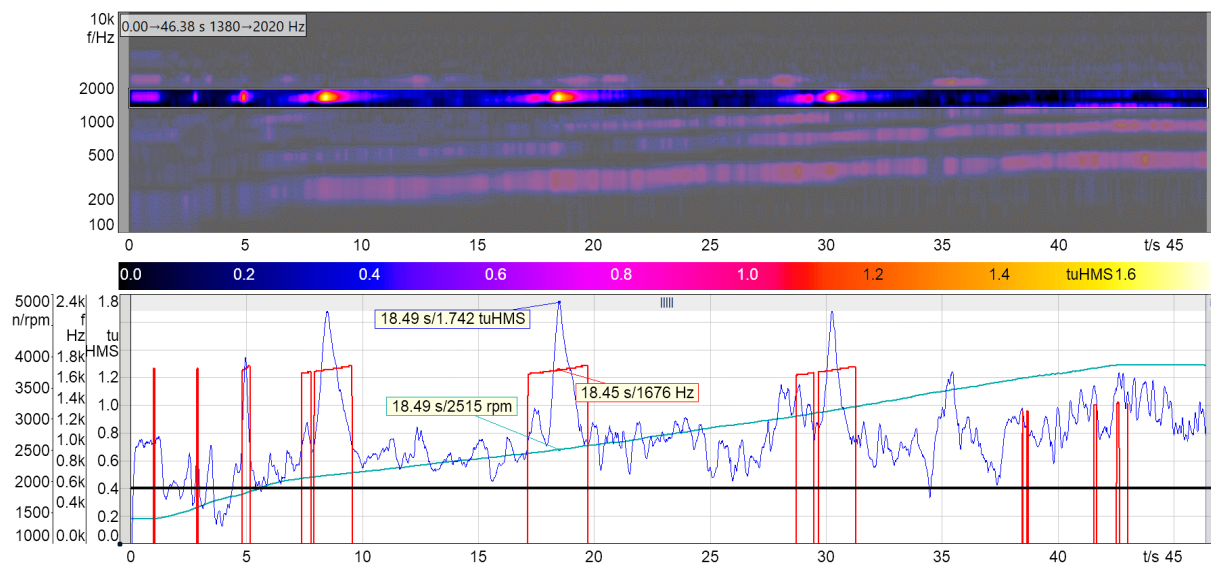


Figure 5: Information Technology fan run-up with a very strong narrow resonance. The RPM history is also shown. All *Tonality (Hearing Model)* analyses have a properties setting for the displayed frequency range (please see the next topic in this Application Note concerning the few applicable settings); this setting is after the calculation of full-band psychoacoustic tonality. In this figure, the frequency range for the tonality in the lower window is as highlighted on the *Specific Tonality (Hearing Model) vs. Time* spectrogram in the upper window. Clearly, fan orders are exciting the strong fixed-frequency resonance. Restricting the presented frequency range assists in measuring particular tonalities. Also regarding the frequency readout, please see the next topic in this Application Note, ***Tonality (Hearing Model)* analyses and properties in ArtemiS SUITE Projects, Figure 9, about the frequency of maximum tonality vs. time.** This analysis has an adjustable threshold, of default value 0.1 tu(HMS). Because these are very strong tonalities, the threshold was set here to 0.7 tu(HMS).

Tonality (Hearing Model) analyses and properties

The *Tonality (Hearing Model)* analyses are among the least settings-intensive analyses of any kind. There are essentially no properties settings associated with the tonality calculation. One does not need to select a Fourier block size, a method, etc., just select the analysis and make use of the minimal properties indicated here for each analysis:

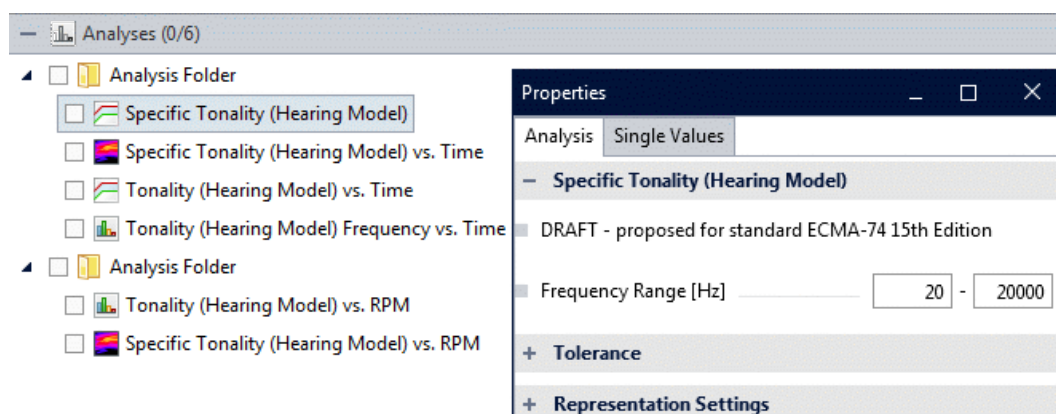


Figure 6: *Specific Tonality (Hearing Model)*: the only adjustable property is the (post-calculation) frequency range.

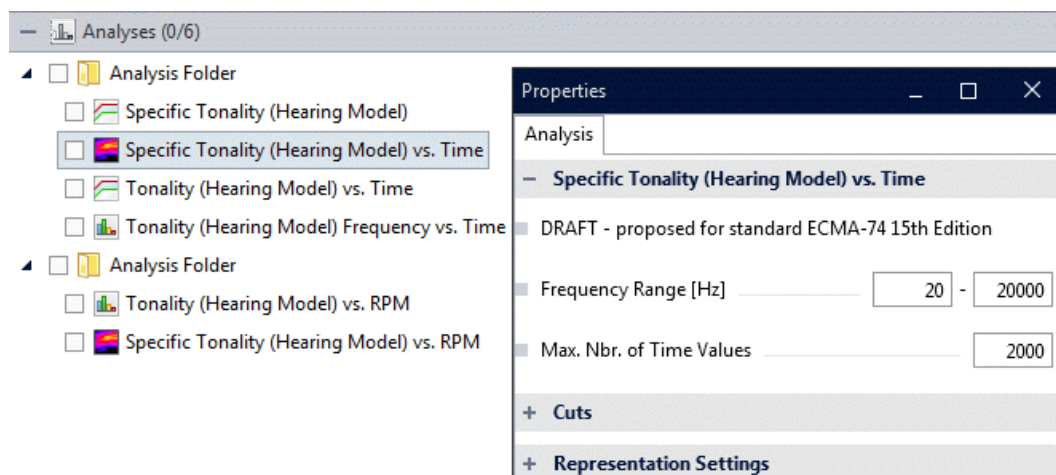


Figure 7: *Specific Tonality (Hearing Model) vs. Time*: the only adjustable properties are the (post-calculation) frequency range and (as with all 3-axis analyses vs. time) the maximum number of displayed time values. It is recommended in this case to set the max. number of time values to match your horizontal screen resolution.

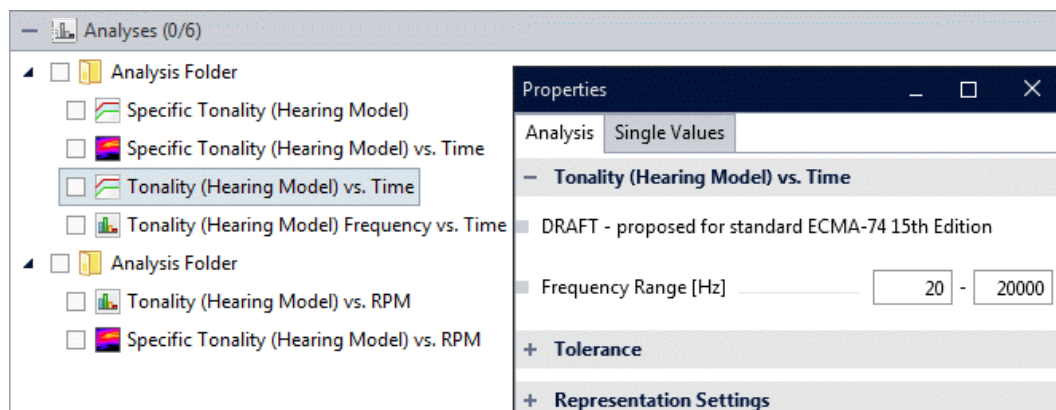


Figure 8: *Tonality (Hearing Model) vs. Time*: the only adjustable property is the (post-calculation) frequency range. Depending on the selected frequency range, this analysis result may be associated with different tonality frequencies as the time axis progresses. **Significant changes of the magnitude (and/or frequency) of maximum tonality, and/or interaural binaural differences in the magnitude and/or frequency of maximum tonality, can indicate sound quality issues requiring attention.**

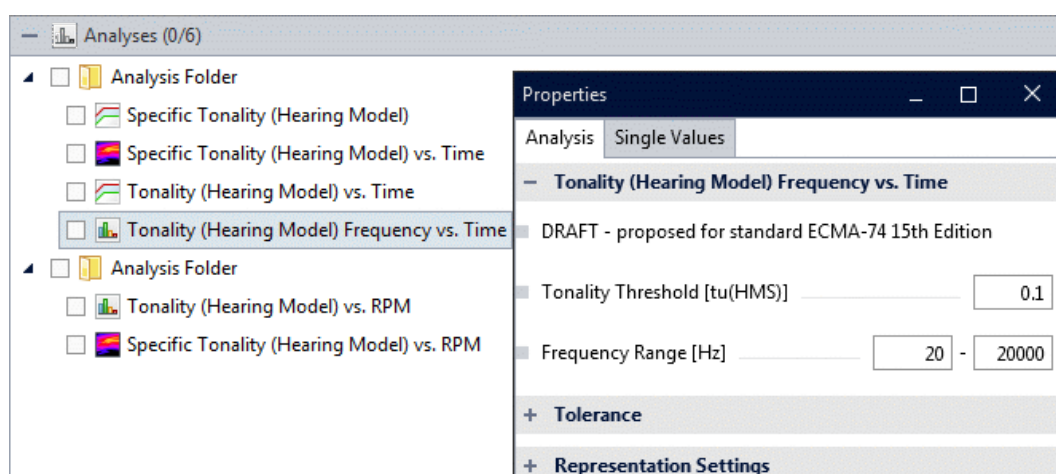


Figure 9: *Tonality (Hearing Model) Frequency vs. Time*: Frequency of maximum tonality as a function of time. There are two adjustable properties: Tonality threshold (default 0.1 tu(HMS) – lower-valued tonalities show 0 frequency). You may set this threshold as you require. The other adjustable property is the (post-calculation) frequency range.

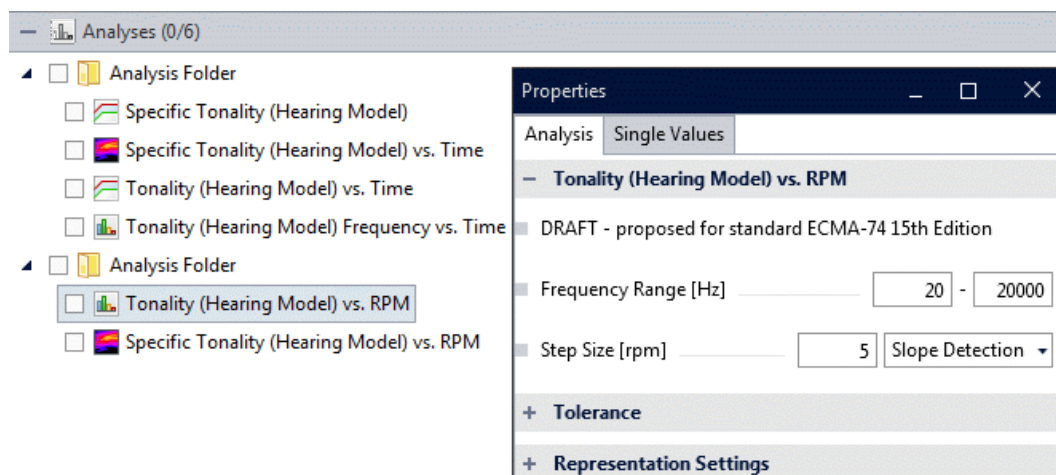


Figure 10: *Tonality (Hearing Model) vs. RPM*: This is like the *Tonality (Hearing Model) vs. Time*, except the abscissa is RPM or other reference quantity. In addition to the adjustable property of (post-calculation) frequency range, you may as with any analysis vs. RPM, set the step size and the slope rule.

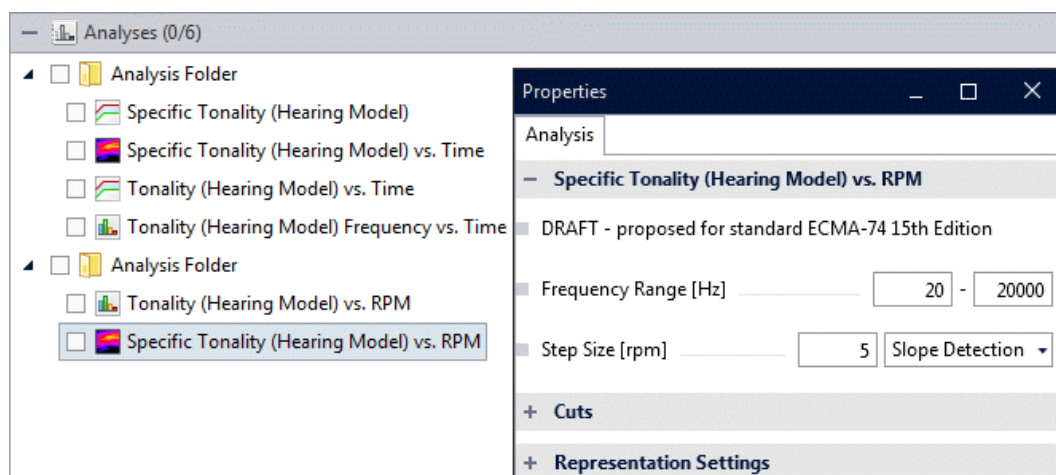


Figure 11: *Specific Tonality (Hearing Model) vs. RPM*: See the comment immediately above.

The *Tonality (Hearing Model)* calculations are performed at sampling rate 48 kHz. In ArtemiS SUITE it does not matter what the sampling rate of files is; if not 48 kHz an automatic resampling occurs inside this tool.

Using *Tonality (Hearing Model)* analyses: two practical examples

The *Tonality (Hearing Model)* can provide much more information than other methods. Ability to display the magnitude vs. time and the frequency vs. time of maximum tonality is not available in other tonality analyses. For multichannel data (especially binaural data) the readout of results of two or more channels superimposed (as in Figures 12 and 13) can reveal inter-channel relationships significant in perceiving tonal events.

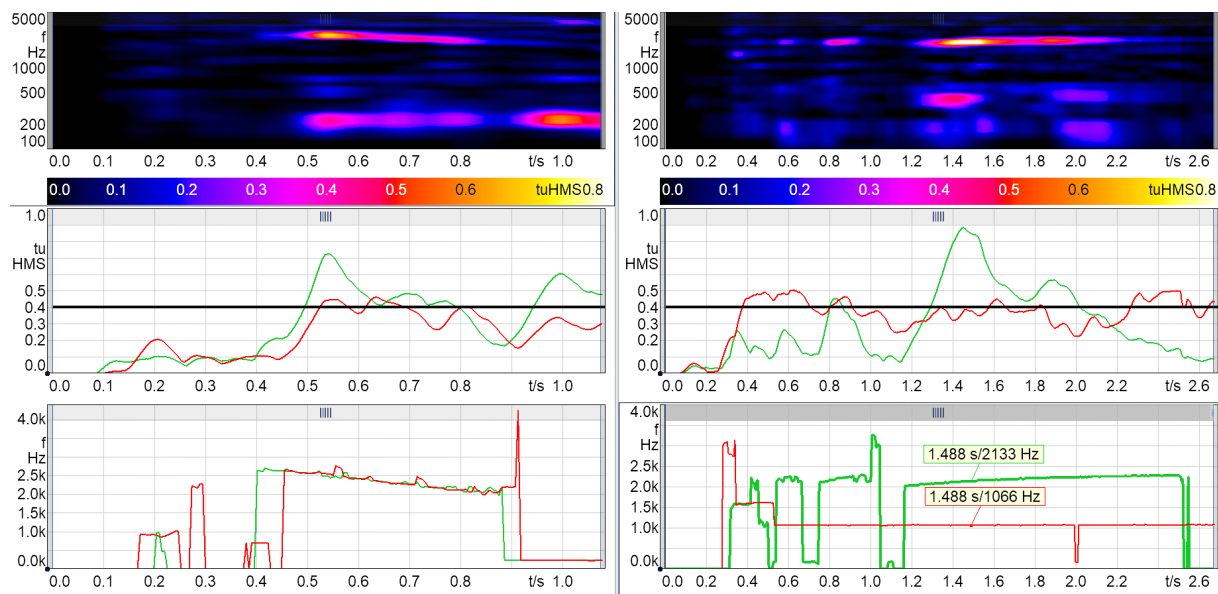


Figure 12: (Both sets of results are from binaural recordings: left ear green, right ear red in the lower two panels each side.) Left panels: an internal combustion engine starter motor disengage/spin-down tonality, duration 0.4 second. Right panels: an Information Technology device run-up. Top-to-bottom: specific psychoacoustic tonality vs. time (left ear shown); Middle: psychoacoustic tonality (maximum) vs. time, both ears; Bottom: frequency of maximum tonality vs. time, both ears.

In Figures 12 and 13, the left panels measure a short-duration tonality very difficult or impossible to measure using the previous methods. The (maximum) tonality vs. time and frequency of (max.) tonality vs. time indicate reasonably-expected similarity of both quantities between the left and right ears of the binaural recording. (In both the left and right panels in Figure 12 the *Specific Tonality (Hearing Model)* vs. *Time* spectrogram is of the left ear only.) The right panels (an IT device run-up) reveal a very different situation: the source is extremely directive, so the magnitudes (briefly) and the frequencies (for a longer time) of maximum tonality vs. time differ strongly between the two ears. The hearer's attention is activated more strongly by this unusual interaural condition, and the sound is therefore evaluated more negatively than would be expected just by the tonality measurements of one or the other ear alone, or of data from a single microphone. Figure 13 shows, for the IT device run-up (upper right panel), the results for the right ear only – compare to Figure 12.

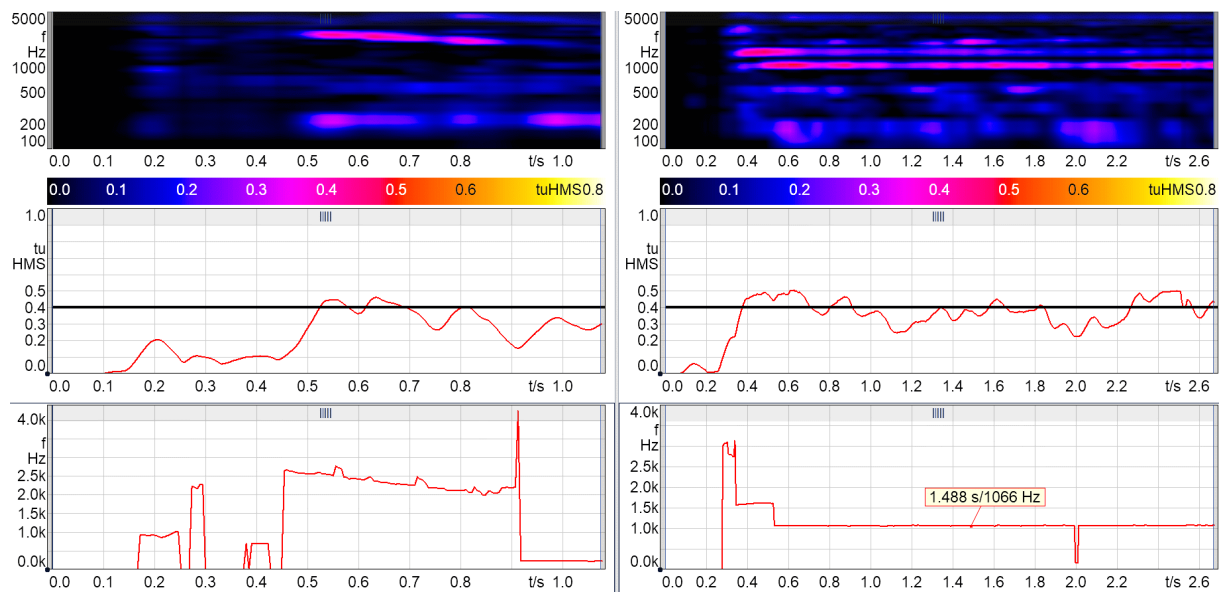


Figure 13: Only the right ear result is now shown in all panels. Particularly in the upper right panel, note the very different tonality history compared to the Figure 12 upper right panel. The dominant tonality shown in the *Specific Tonality (Hearing Model) vs. Time* left ear data in the Figure 12 upper right panel is barely evident, and other tonalities not evident (therefore not perceived) in the left ear are strongly indicated and perceived in the right ear.

Note that because the tolerance for reportable prominent tonality according to ECMA-74 in *Tonality (Hearing Model)* is a constant, 0.4 tu(HMS) (the horizontal black line in Figures 12 and 13 and elsewhere), it can also be applied against a time or RPM abscissa, not only against a frequency abscissa. You may generate these tolerance lines yourself in ArtemiS SUITE using a Tolerance Scheme or please contact us and we will transmit them to you.

In our opinion, this new advanced psychoacoustic tool, *Tonality (Hearing Model)*, is one of the most powerful and universally applicable psychoacoustic developments of HEAD acoustics. It can measure essentially all perceivable tonalities in a reliable way, and can provide much more information than other methods. We hope that with this Application Note we have given you the guidance to make full use of psychoacoustic tonality measurement.

Do you have any questions or comments?
Please write to SVP-Support@head-acoustics.com.
We look forward to receiving your feedback!