In this regard an assumption is made: the frequency region of interest appears to be below 10 kHz. The reasoning for this is found in the lower sensitivity of the ear at higher frequencies and in our measurements; they show little sound energy emitted above 10 kHz. Consequently the minimal wave length of the noise equals 3.4 cm (340 m/s divided by 10 kHz). The overall dimensions of the transformers of interest are smaller than 20 cm (2 kW power range and smaller). Therefore, beam forming (lobing) of the emitted sound will occur at high frequencies. One might ask under such conditions whether the emitted sound energy should be measured (reflective sound chamber) or the sound pressure level (only in one predetermined direction in an absorbing sound chamber). Our measurements on many toroidal transformers indicated that acoustical beam forming occurs. Especially the high frequency sound is emitted into the transformers rotational symmetrical axis direction, where the microphone is placed. This microphone position ensures that the noise is measured under the "worst case" condition. It is our opinion that this condition should be the standard for measuring transformer noise. When noise is heard and this noise is directed to our ear, we should measure this maximum noise level. Consequently we can accurately measure the noise in an absorbing type of sound chamber, under the stringent condition that the microphone is placed on the "worst case" spot.

A "standard" metal case is emulated inside the sound chamber, by placing the noisy transformer on a metal plate, thickness of 2 mm, dimensions 40 by 40 cm, with the edges folded over 90 degrees downward. The edges give the plate its stiffness and this emulates the mounting plate of a transformer in a case. At the four corners of the plate, rubber supports are mounted to allow for free movements of the plate. Figure 6 shows the detailed construction. When we measure the noise in this way, we actually measure the noise from the transformer plus the noise emitted by the plate, beamed in the vertical direction right into the microphone placed above. This configuration indeed is "the worst case" situation where the maximum sound pressure level is measured due to lobing of the noise.

The distance to Sound Pressure relation from microphone to noisy transformer is well known for the "far field" condition, where a doubling of the distance -r- will cause a 6 dB drop in the Sound Pressure Level. For practical reasons we measure at a standard distance of 0.5 m. Assume that we measure at a certain frequency a Sound Pressure Level of 32 dB. At 1 meter distance, under the "far field" condition, the noise level will be 6 dB lower at 32 - 6 = 26 dB. In fact, at any reasonable distance -r- in the "far field", the noise level can be measured and converted to a level at 1 meter by means of the well known formula 2-1.

$$SPL_{at\ 1\ m} = SPL_{at\ r\ m} + 20\log r \tag{2.1}$$

We tested at three frequencies whether or not the "far field" condition is vallid in our actual noise test chamber. Figure 8 shows the Sound Pressure Levels of 200, 650 and 2000 Hz as function of the distance -r-, to be compared with the shown ideal 20log(1/r) "reference". For 200 Hz, at an equal or larger distance than 50 cm, the "far field" behaviour is found, while for 650 and 2000 Hz, within the accuracy of the measurements, the ideal "far field" behaviour is closely matched. For frequecies above 200 Hz we therefore safely can use the "far field" formula's for predicting Sound Pressure Levels at distances larger than 0.5 m.

Figure 9 shows an example of the noise spectrum measured at 0.5 m distance from a typical noisy transformer. In this case the time to frequency domain conversion is performed by the LibertyAudioSuite system, but similar results were measured with the MLSSA system. It is clearly visible that at each frequency the level is different. To standardize the measurement, a frequency weighting curve is needed for, taking the acoustic properties of the ear into account. There already exists such a weighting function. Figure 10 shows these standardized Balanced Noise Criterion Curves (abreviated to NC-curves), which are internationally accepted for the weighting of acoustical noise levels in studio's and working and living environments. Table 1 shows some noise levels as they occur in different environments. In these NC-curves it is clearly visible that the ear is not very sensitive at low frequencies, while the very high frequency sensitivity loss is not accounted for. In our specific case this is no problem and needs no further study due to the little amount of very high frequency sound emitted by noisy transformers.

The noise levels measured and the NC-curves can be combined into one picture as shown in Figure 11. In this specific example, the transformer produces at 0.5 m (our distance of measurement) less noise than the NC-30 curve. This means that we can quantify the noise by: NC30 [dB,0.5m] or NC24 [dB,m], the later having the advantage of using SI-units, and is therefore preferable.