Measurements on Studio Microphones

4617 (B-7)

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**Presented at
the 103rd Convention
1997 September 26–29
New York**

AN AUDIO ENGINEERING SOCIETY PREPRINT

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Abstract

Over the last few years there has been much discussion about special new measurements of studio microphones. This paper will examine the present standards. We will furthermore present the results of a number of special measurements such as difference-frequency distortion measurements, special noise patterns, development in proximity effects of pressure gradient transducers as a result of frequency and distance. These measurements are currently in the discussion phase and have not yet been standardized.

Introduction

Over recent years, a number of groups and panels have increasingly devoted themselves to discussing future measurements and ways of reporting the technical data and performance of studio condenser microphones. These groups are national as well as international standardization committees, studio microphone manufacturers and, last but not least, the users.

The aim of an international committee, of course, is to develop and offer rules with worldwide validity which have been (previously) agreed by the national committees involved, and thus to enable comparable measuring results to be used everywhere. However, where many committees are involved, it is always a long and difficult process to reach a consensus.

In 1996, independently of the existing national standardization committees, the AES Working Group
SC-04-04 on microphone characterization was set up to bring the above groups more closely together and to discuss ways of giving users more detailed information on studio microphones. This working group meets twice a year in the framework of the respective AES conventions. Between meetings it uses the Internet to discuss topical issues quickly and simply within a large group of interested parties.

We wish to contribute to this discussion by explaining some of the lesser known details of standardized measurements and showing some results of measurements which are not standardized for microphones. These are

- Difference-frequency distortion measurements
- Self-noise levels
- Proximity effects.

1. Existing standards

In 1963, the German standard DIN 45 591 'Mikrophon-Prüfverfahren, Meßbedingungen und Meßverfahren für Typprüfung' ('Test conditions and testing procedures for microphones for type tests') was published. [1]
It stipulates electrical and acoustic test conditions and gives information on possible interference sources and uncertainties with regard to measurements. The different microphone types are explained, along with the consequences for measurement which are associated with different microphone characteristics. It also describes the spherical sound field, the progressive wave and the diffuse sound field and gives information on their implementation and testing. It then explains how amplitude frequency responses, directional characteristics and the directivity factor of microphones can be determined. For measurements of electrical microphone characteristics it explains the weighted and unweighted self-noise levels and output impedance, and it closes with explanations of a number of 'other' characteristics such as equivalent air volume of a condenser microphone, magnetic stray factor and permissible climatic conditions.

A literature list with 17 references rounds off this microphone compendium, which is still a valuable source. The latest version of this standard was published in February 1974.

DIN 45 593 'Mikrophone, Angabe von Eigenschaften' ('Microphones; classification of the characteristics to be specified'), which was first published in 1960, specifies in tabular form what details a manufacturer should give on microphones. A distinction is made between 'studio microphones' and 'other microphones', and it is stipulated whether the data should be labeled on the microphone itself or be specified in accompanying documents.

To make these standards internationally known and accessible, all of the major elements of DIN 45 591 and DIN 45 593 were published in 1972 as publication 268-4 of the International Electrotechnical Commission (IEC). They can be found in part 4, 'Microphones' of publication 268, 'Sound System Equipment'. [2]
Many additions and improvements have been made since 1972, and they were published in April 1997 in a draft revision of the IEC 268-4. The revised standard will be published as IEC 60268-4. Fundamental information on measurements is mainly contained in part 1, 'General' of IEC 268 (= IEC 268-1) and in part 2, 'Explanation of general terms and calculation methods' (= IEC 268-2).

The standards quoted so far especially define what microphone characteristics should be measured, and they give information on the conditions which must be created or taken into account. One example, which has already been mentioned, is the definition of the sound field within which the microphone is placed during the measurement.

This will be presented in detail in the section 'proximity effect developments of pressure gradient transducers as a result of frequency and distance'. For many measurements, further definitions are still required.

A much-discussed example is the 'weighted self-noise level' of microphones which has already been mentioned and will be dealt with in detail in the section 'Self-noise level'.

It should also be mentioned that the power supply to condenser microphones is defined in part 15 of IEC 268, 'Preferred matching values for the interconnection of sound system components' and in DIN 45 595 (A-B supply system) and DIN 45 596 (Phantom supply system).

For the moment, this will be enough to give us a brief introduction to existing standards - although we could, of course, fill a book with the subject.

Each of the standards quoted contains references to additional literature and standards. These documents are therefore a valuable reference book on the subject.

2. Difference-frequency distortion measurements

In IEC 268-4, an overload sound pressure is only defined in very general terms: 'The maximum sound pressure of a plane sound wave at which the amplitude non-linearity of the microphone does not exceed a specified limit ...'.

For studio condenser microphones, the maximum sound pressure level is normally defined as a total harmonic distortion (THD) less than 0.5 % on the basis of measurements of just the circuitry.
Direct measurement of THD for pressure transducers (microphones with omnidirectional characteristic) is only possible, for example, in a small pressure chamber. In such a setting, correspondingly high sound pressures can be generated with a sufficiently low level of distortion, at least for some frequencies, to measure the very small non-linearities of these microphones.

This does not, however, apply to pressure gradient transducers, i.e. to unidirectional microphones. For realistic measuring results, these transducers must not be measured in a chamber of this type.

2.1. Measuring methods

The direct measurement of total harmonic distortion in a free sound field is not possible because any loudspeaker will produce far more harmonics than any condenser microphone at the sound pressure levels which are of interest here.

It was therefore suggested a number of years ago to obtain information on distortions of the complete microphone by using difference-frequency distortion measurements. [3]

With this method, distortions can be analyzed by measuring a frequency component (the 80 Hz difference frequency) which is not contained in the loudspeakers' test signals. Therefore the loudspeakers' inherent distortion will have no effect (within certain limits) on the microphone being tested.

In the draft of the new version of IEC 268-4 (IEC 60268-4), difference-frequency distortion of second order has actually been included and placed alongside the measurement of THD.

A general description of the measuring methods for total harmonic distortion and difference-frequency distortion can be found in IEC 268-2 and in DIN 45 403 'Messung von nichtlinearen Verzerrungen in der Elektroakustik' ('Measurement of non-linear distortions in electroacoustics').

2.2. Measuring set-up

With regard to microphones, a measuring set-up such as that shown in Figure 1 can be used:

Two signal generators feed signals via power amplifiers to two loudspeakers which are positioned such that the angle of incidence of both sound waves at the microphone is exactly the same. The signals used can be some discrete frequencies or sliding sine waves. The frequency spacing between both signal is always 80 Hz. The 80 Hz component is filtered out of the microphone output signal with a very narrow band and is related to the exciting signal amplitudes (effective values).

2.3. Amount of work required for measuring

The measuring procedure itself can be largely automated by using a computer program. But the measuring set-up is more complex than Figure 1 leads us to expect:
- The microphone and each loudspeaker must be calibrated.
- The position of the loudspeakers in relation to the microphone can be critical, depending on the type of microphone, and therefore it must be adjusted with a great deal of care.
- If physically different microphones are to be compared with each other, this must be taken into account when setting up the measuring equipment. A common reference plane is advisable, e.g. the plane of the respective microphone diaphragms.
- For measurements over a wide frequency range, it is possible that the features of choosen type of loudspeaker are not sufficient. For the frequency range we wished to test, i.e. from 250 Hz to 20 kHz, we therefore had to work with two different types of loudspeaker. That meant twice the amount of adjustment and calibration work, and it also made it necessary to combine the respective partial data in the program.

2.4. Causes of distortions

The main causes of distortions in microphone capsules are the non-linearities of the acoustic impedances and, in microphones with AF circuitry, their square-law transducer response.

The acoustic impedances are partly dependent on the frequency because of frequency-dependent air particle velocities, and partly on the direction of the diaphragm excursion.

Distortions due to the square-law transducer response are very small. Any resulting difference-frequency distortions are proportional to $1/\omega$ and are therefore negligible in the frequency range presented here and with a circuitry of the right dimensions.

It is different with the impedances of the air in front of and behind the diaphragm and in the slots and holes drilled in the back electrode. In pressure gradient transducers, there are also impedances in the time delay network, which controls the directional characteristic (e.g. cardioid characteristic) behind the back electrode.

An assessment of the different influencing factors shows that we can limit ourselves to difference-frequency distortions of second order. [3]

2.5. Results

Figures 2 to 4 show some results. [4]
The top curve shows the 0° frequency response for each of the microphones (left hand scale, dB), the other curves show the respective difference-frequency components for this frequency response.

Part A of the figures shows the respective difference-frequency distortion of second order as a percentage (right hand scale, %), part B shows the same results as a sound level in dB.

All measurements were made at a sound pressure level of 107 dB at the microphone resulting from the two loudspeaker signals.
Difference-frequency distortions are proportional to modulation. Therefore it is simple to calculate difference-frequency levels for other sound pressure levels.

2.5.1. Pressure transducers

In Figure 2, a pressure microphone capsule is tested which has been manufactured unchanged for about 25 years. In the course of time it has been used as a transducer for the different generations of our miniature microphones with omnidirectional characteristic. From 1964 it was part of the tube microphone KM 63, from 1966 it was used in the KM 83 (circuitry with one FET and output transformer), and since 1988 it has been used in the KM 130 with a more complex semiconductor circuitry without output transformer. All three microphones have a diameter of 21 mm.

With this capsule type, the difference-frequency distortions are extremely small, and negligible in comparison with the difference-frequency distortions of the respective circuitry.

The diaphragm spacing for pressure transducers is smaller than for pressure gradient transducers, so that very little air is enclosed. The air mass and the diaphragm mass are small, and so is the diaphragm compliance, with the result that the transducer is 'high-tuned'. The restoring force of the diaphragm, on the other hand, is large.

As the air particle velocity is frequency-independent at a constant sound pressure, that also applies to the resulting non-linearities.

These are typical characteristics of condenser pressure transducers, and on the whole they lead to very small distortions. [5]

2.5.2. Single diaphragm pressure gradient transducers

Figure 3 shows a pressure gradient capsule which is also 21 mm in diameter. This capsule was also used from 1964 in a tube amplifier (KM 64), from 1966 in a FET amplifier (KM 84), and since 1988 with transformerless circuitry as KM 140.

Here, acoustic distortions in the capsule are already predominant from about 1 kHz, and the influence of the circuitry used therefore diminishes.
In contrast to pressure transducers, greater enclosed masses of air operate in pressure gradient capsules because of their greater diaphragm spacing and the time delay network connected.

At a constant sound pressure, the pressure gradient and thus the air particle velocity increase with increasing frequency. Therefore, as the frequency increases, its distortions also become more important.

2.5.3. Double diaphragm pressure gradient transducers

Another pressure gradient transducer is shown in Figure 4. This is a double diaphragm capsule with a diameter of 34 mm. This capsule was also first used in a tube microphone, the U 67. Since 1967 it has been integrated in the U 87, which works with an FET and an output transformer.

With this gradient transducer, the greater distortion as the frequency increases can also be observed. In addition to the distortion development which is similar to Figure 3, a relative maximum can be seen here in the 4.5 kHz range. This originates from the time delay network inside the capsule which delays the sound pressure from the one diaphragm to the rear of the other diaphragm to such an extent that a cardioid characteristic results for each system on its own. At this so-called transition frequency, the air particles reach a maximum velocity, so that the non-linearities of the air have their greatest effect here, too.

2.5.4. The human ear

It is perhaps also interesting in this respect that a difference-frequency distortion of the order of magnitude of 1 % is created in the human ear at the sound pressure levels of 107 dB that are used here. [6]

3. Self-noise level

Regarding microphone noise, there are sometimes uncertainties about its causes.

3.1. Causes of noise

It is often suggested that inherent noise is a phenomenon which is only related to electronic components. That would mean, for example, that condenser microphones would create inherent noise, but not dynamic microphones. That is incorrect.

All atoms and molecules are in a constant state of movement resulting from thermal energy. This means, for example, that the diaphragm of a microphone is excited by moving air molecules even without any sound pressure stimulation. A further consequence is that a resistor is subject to a noise voltage which depends on its rating and temperature even without any electric current flowing through it. Both of these factors cause even dynamic microphones to create inherent noise. Measuring results will be reported below.

3.2. Standards

In relation to the existing standards, the terms 'weighted' and 'unweighted' self-noise level were mentioned.

The unweighted self-noise level is measured in the frequency band 31.5 Hz to 20 kHz with a permissible level deviation of ± 0.5 dB.
In order to copy the strong dependence of our sense of hearing on frequency, noise voltages (self-noise levels) are measured with weighting filters so that the measured value corresponds as closely as possible to the subjective 'noise impression'.

The filter characteristics are standardized, as are the dynamic characteristics (time constants) of the measuring instrument with which the alternating voltage of the self-noise is measured.

Depending on the standard used, the noise is measured with different weighting curves and time constants, which leads to very different results, and often causes great uncertainty.

3.2.1. DIN 45 405

In 1962, the German standard DIN 45 405, 'Geräusch- und Fremdspannungsmesser für elektroakustische Breitbandübertragung' ('Noise level measurement in sound systems') was published. This standard (last edition: 1967) defined, among other things, the weighting curve shown in Figure 5 (a) and a 'quasi peak meter'. Therefore, many data sheets from European manufacturers include the remark 'DIN 45 405, quasipeak' for the self-noise level.

From November 1983, this weighting curve in DIN 45 405 was changed as shown in Figure 5 (b), and thus brought in line with CCIR Recommendation 468. As a result of the stronger weighting of noise spectrum above 1.5 kHz, the self-noise level of a microphone appears to be inferior by about 4.4 dB. [7]

When DIN 45 405 is quoted, it is important to note when the respective details were prepared. This also prevents potential misinterpretations when comparing older technical data with those for more recent products.

3.2.2. CCIR 468

Reference to CCIR 468-3, on the other hand, is unambiguous and refers to the weighting curve shown in Figure 5 (b) and the use of a 'quasi peak meter'. More recent data sheets sometimes define such values as 'weighted peak' or as 'dBq'.
Use of an RMS meter, which does not conform to the standard, produces measuring results which are about 4 dB lower, and therefore apparently better.

3.2.3. IEC 179 and DIN IEC 651

Completely different measuring results, but again results that appear to be more favorable, are achieved by using the standards IEC 179 and DIN/IEC 651. Here, the weighting curve shown in Figure 5 (c) is used, known as the 'A-weighting'. The noise voltage is measured as an effective value, not as 'quasi peak'. For a microphone, this leads to self-noise levels which are 11 to 12 dB lower than when measured according to CCIR 468-3.

To compare measuring results according to the different standards, Figure 5 shows the corresponding values for a studio microphone.

3.3. Equivalent sound pressure level

In our consideration of the standards relevant to microphone measurements, the different weighting standards have been explained.

It has been shown that the measured value of the self-noise level of a microphone is heavily dependent on the measuring procedure used.

In data sheets, the self-noise is normally not expressed as a voltage; with the aid of the sensitivity of the microphone, it is converted to an equivalent sound pressure level. The reference point is the sound pressure of the threshold of audibility, 20 µPa.

The equivalent noise pressure level is a fictitious quantity which assigns the noise voltage measured at the microphone to a sound pressure which would generate this voltage at the output of a microphone that was otherwise noise-free. This means that the microphone's self-noise level can be directly compared with the sound pressure levels to be recorded.

The user can then decide whether this value is suitable for the recording situation or whether the microphone's self-noise level may impair quiet passages, or even mask them completely.

The result of this conceptual model is called 'equivalent sound pressure level due to inherent noise' or 'equivalent self-noise level' and expressed in dB or dB-A.

3.4. Results

High quality studio condenser microphones have a weighted equivalent self-noise level of 10 to 16 dB-A (IEC 179 and DIN/IEC 651) or 22 to 28 dBq (CCIR 468-3).

A 'typical' dynamic microphone with an output impedance of 200 Ohms has, at room temperature, a weighted noise voltage of about 0.3 µV rms according to DIN/IEC 651, or 1.3 µV according to CCIR 468-3. At a sensitivity of 1.8 mV/Pa, this corresponds to a weighted equivalent self-noise level of 18 dB-A or 31 dBq.
Thus, dynamic microphones are not free from inherent noise. Their 'equivalent sound pressure level due to inherent noise' is actually higher than that of high quality condenser microphones.

Figure 6 shows a table with the weighted equivalent self-noise level of a number of microphones. As in previous figures, microphones from different circuitry generations, using the same capsule each, are shown.

The noise level of all microphones with a substitute capacitance instead of the capsule would be 0.5 to 0.8 dB lower because the diaphragms move due to the molecular movement of the air described above.

3.5. Special noise patterns

In addition to unweighted and weighted measurement across the entire audio frequency range, the noise spectrum is sometimes determined. Here, third octave analysis is normally used in order to obtain stable values. Figure 7 shows the noise spectrum of a large diaphragm studio microphone.

This type of measurement can be used, for example, for comparison with our threshold of audibility or with the existing noise spectrum in a recording studio. The figure shows the recommended minimum requirements for the acoustic self-noise spectrum for German radio and television broadcasting stations. [8]

4. Proximity effect developments of pressure gradient transducers as a result of frequency and distance

According to IEC 268-4 (1972), the frequency response of a studio microphone should be measured in an 'undisturbed free sound field with a wavefront perpendicular to the reference axis of the microphone', and 'the microphone should be placed in a plane-wave free sound field'.
In the April 1997 draft for the IEC 268-4 revision, the general requirement of a 'plane-wave free sound field' is restricted to the 'low frequency range for the measurement of pressure gradient microphones'. Some manufacturers use the proximity effect [5] of pressure gradient transducers to simulate 'better' microphone performance at low frequencies.

In justification, it is argued that the plane-wave free sound field would not meet practice.

In acoustics, any geometric dimension must be assessed in relation to the length of sound waves. In relation to a wavelength of 3.4 m at 100 Hz, microphones are often in the near field of a sound source. If the distance is less than one wavelength, the wavefronts are curved rather than plane. Thus, the sound pressure changes to a higher degree with distance than according to the 1/r law of the plane-wave free sound field. This results in a greater pressure gradient as the driving force for the diaphragm, and leads to a lesser bass roll-off than is normal for any pressure gradient microphone due its physical design.

Figure 8 shows frequency responses of a cardioid pressure gradient microphone in a plane-wave free sound field and with curved wavefronts at different distances from the loudspeaker in an anechoic room. This relative boost of the lower frequency components with increasing proximity to a sound source is well known as 'proximity effect'. But it occurs not only in practical applications where it is deliberately used for effect, for example, by singers, it also occurs in the measuring rooms of microphone manufacturers.

Only very few acoustic measuring rooms are large enough to create a sound field conforming to the standards for frequencies of less than about 100 Hz. Therefore, the measurements must be corrected in accordance with the sound field conditions in the measuring room in order to obtain data which correspond to the standards and give the user a meaningful characterization of the microphone.
Valuable instructions for such corrections can be found in [9].
When comparing the low frequency response of microphones from different manufacturers it must therefore be known whether the data originate from a sound field with plane wavefronts, or whether they have been presented with the appropriate corrections.
Pressure transducers do not react to the curvature of the wavefronts, and are therefore not critical with regard to these effects.

5. Conclusion

The results discussed here are, of course, only a small cross-section of possible tests of microphones. In order to come close to the 'sound' of a microphone, an infinite range of tests would certainly be needed.

The discussions and measuring results of microphones mentioned above could and should have the effect of stimulating efforts to develop new methods of measurement, and also of encouraging a new examination of the existing standards. Only microphone data in accordance with the standards make it possible to compare different types, and are therefore helpful and useful for the user.

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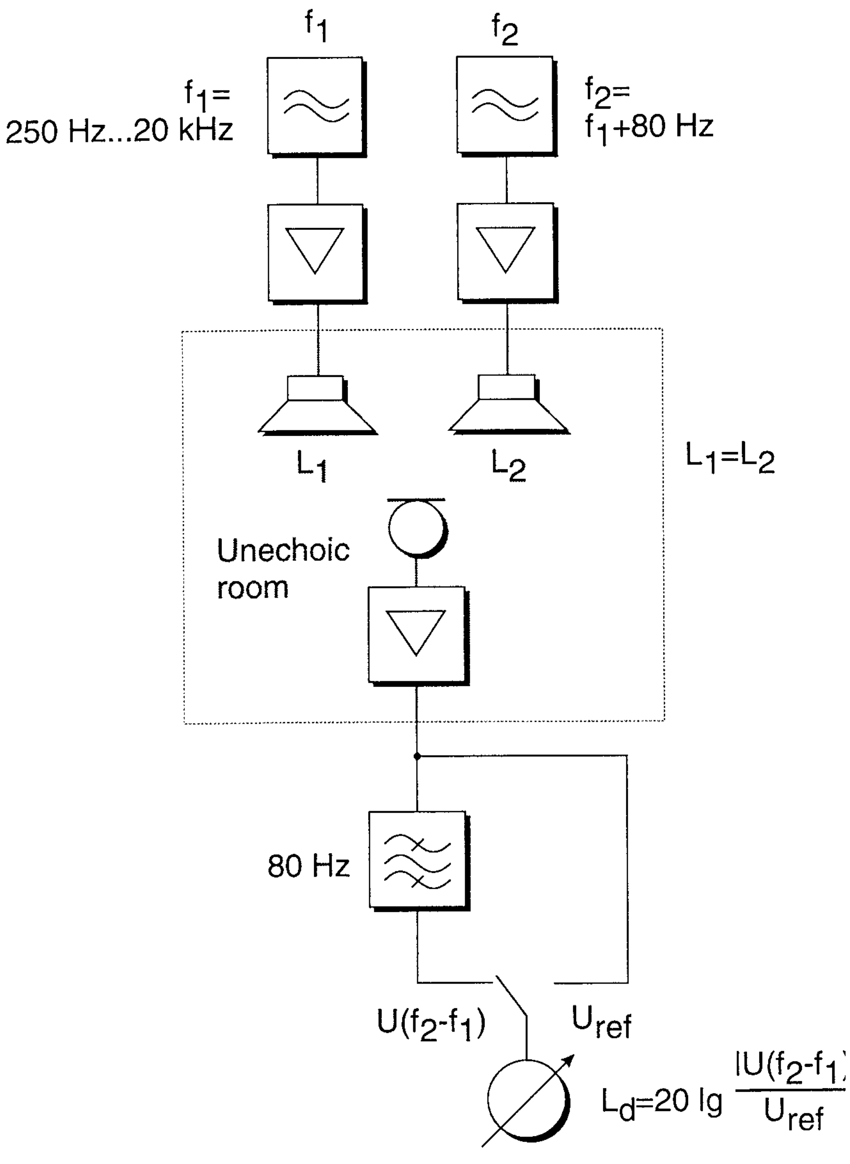


Fig. 1: Setup for Difference Frequency Distortion Measurement

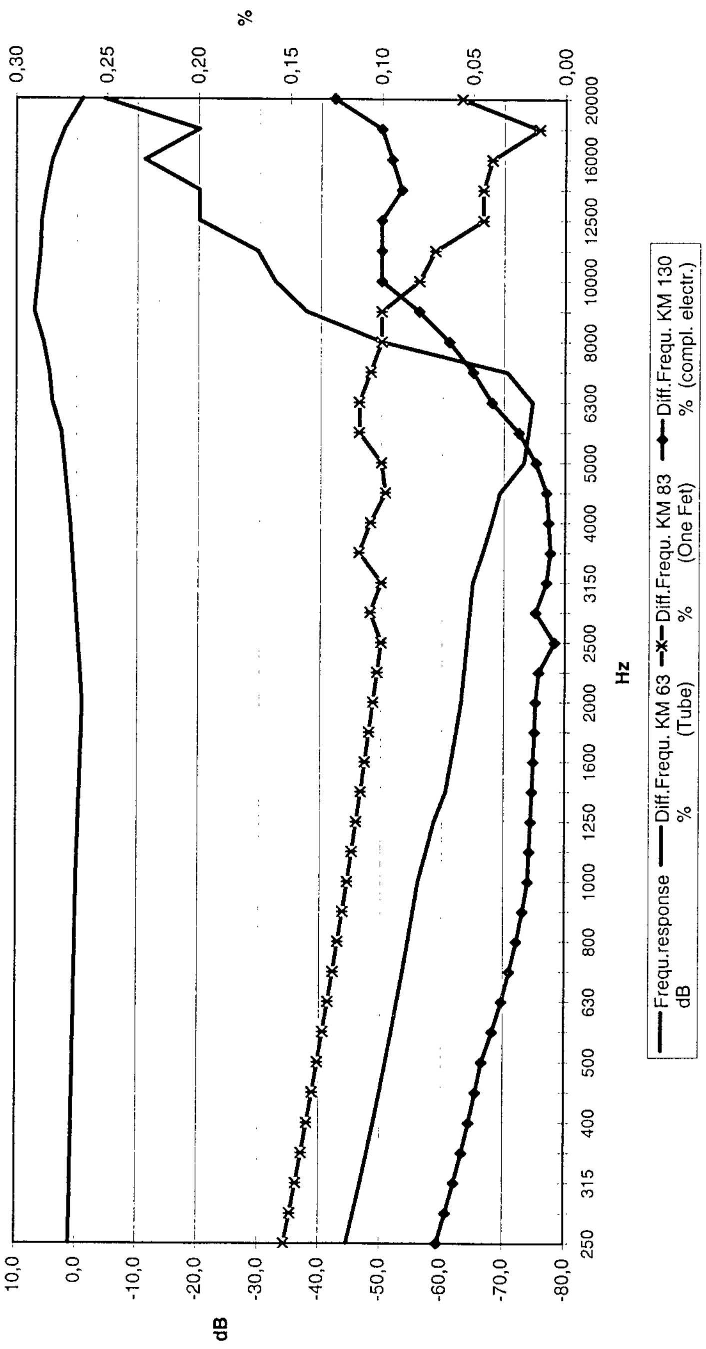


Fig. 2a Difference Frequency Factor at 107 dBSPL, Miniature Pressure Microphones KM 63, KM 83, KM 130

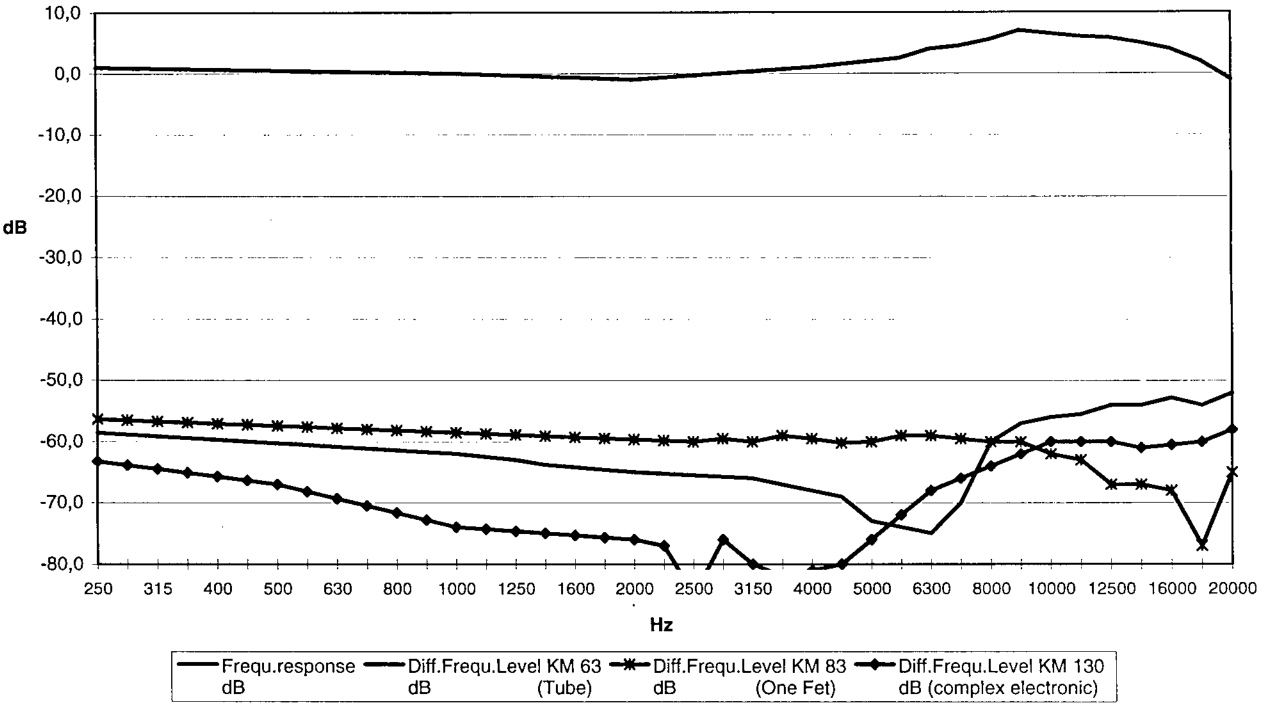


Fig. 2b Difference Frequency Level at 107 dBSPL, Miniature Pressure Microphones KM 63, KM 83, KM 130

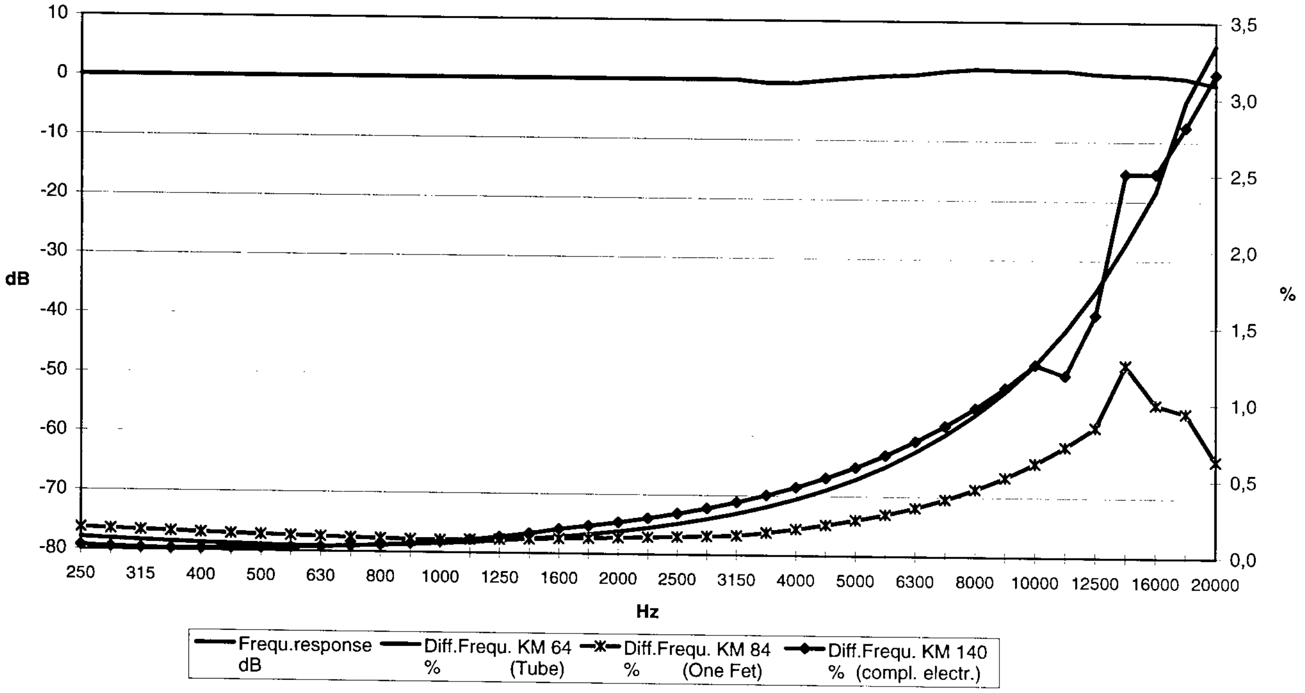


Fig. 3a Difference Frequency Factor at 107 dBSPL, Miniature Pressure Gradient Microphones KM 64, KM 84, KM 140

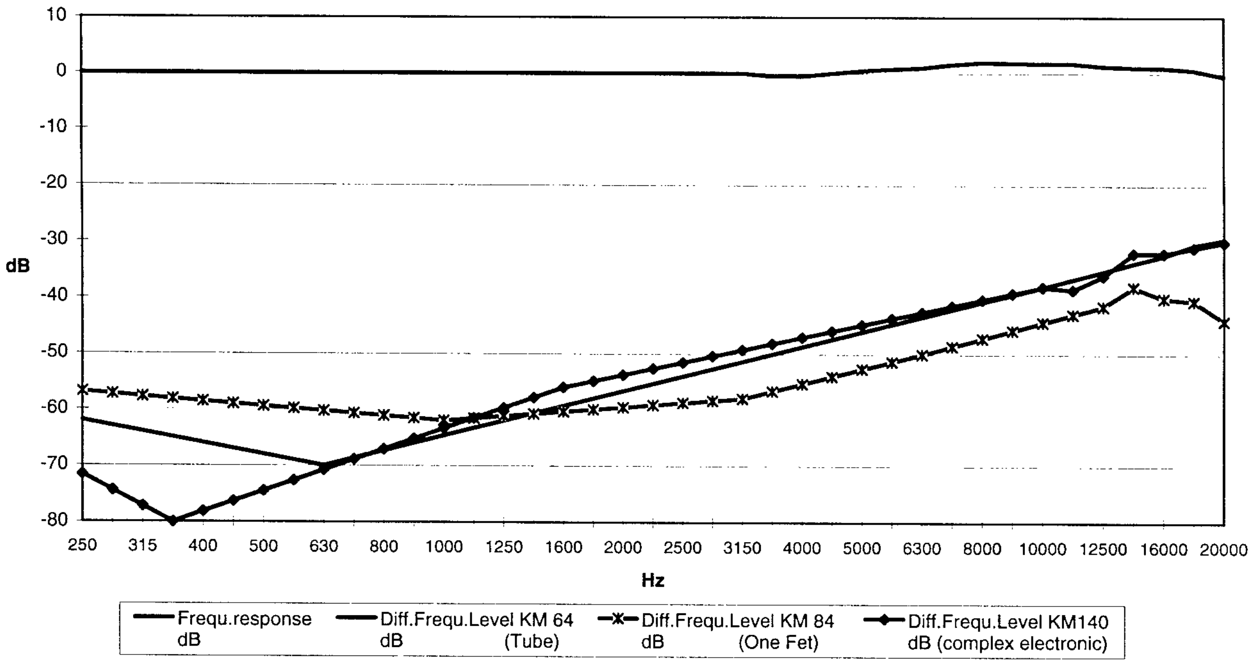


Fig. 3b Difference Frequency Level at 107 dBSPL, Miniature Pressure Gradient Microphones KM 64, KM 84, KM 140

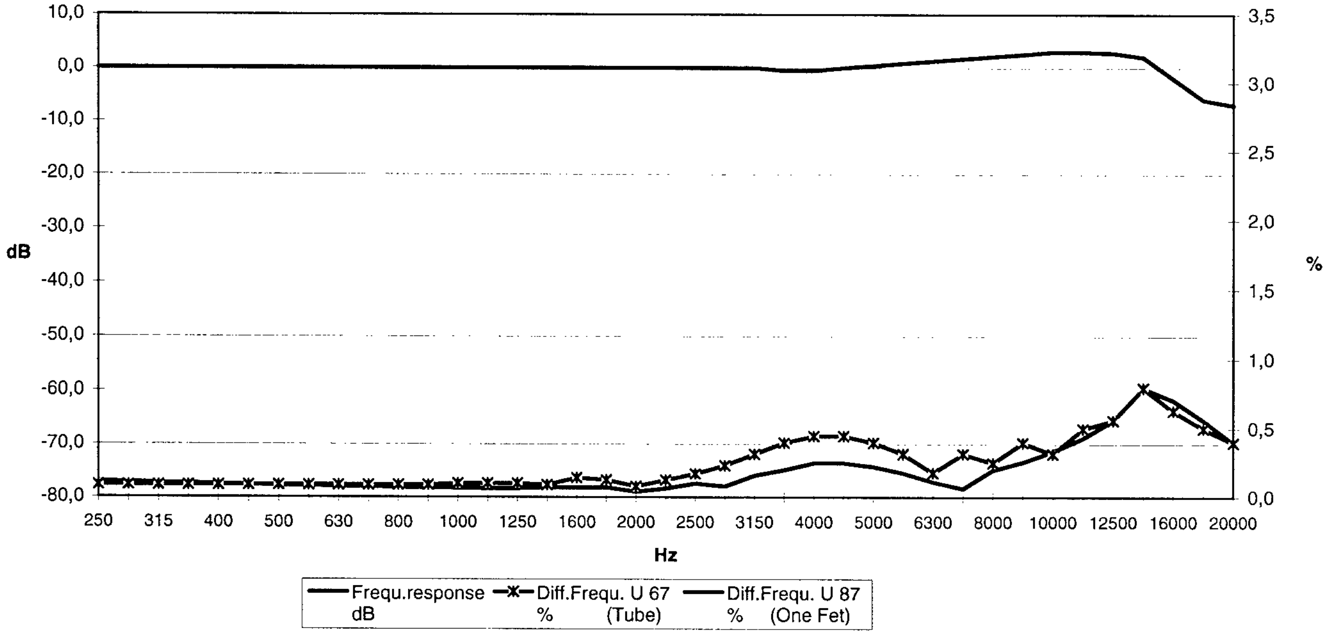


Fig. 4a Difference Frequency Factor at 107 dBSPL, Large Diaphragm Pressure Gradient Microphones U 67, U 87

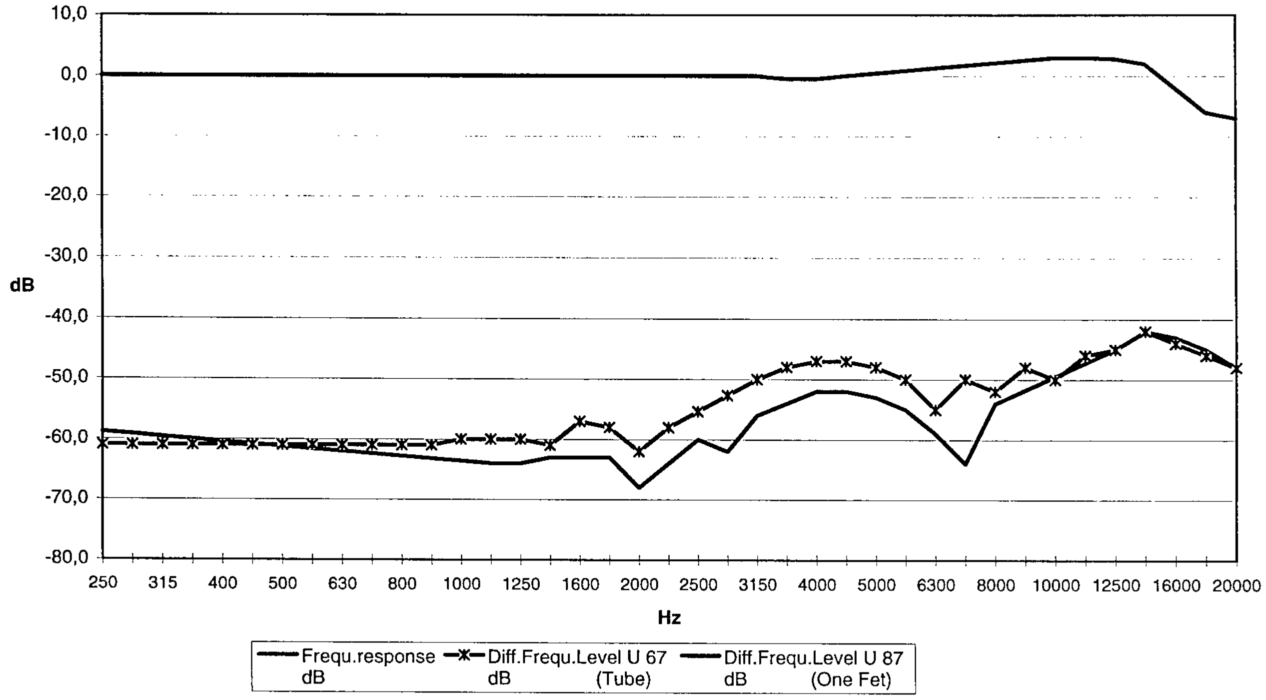
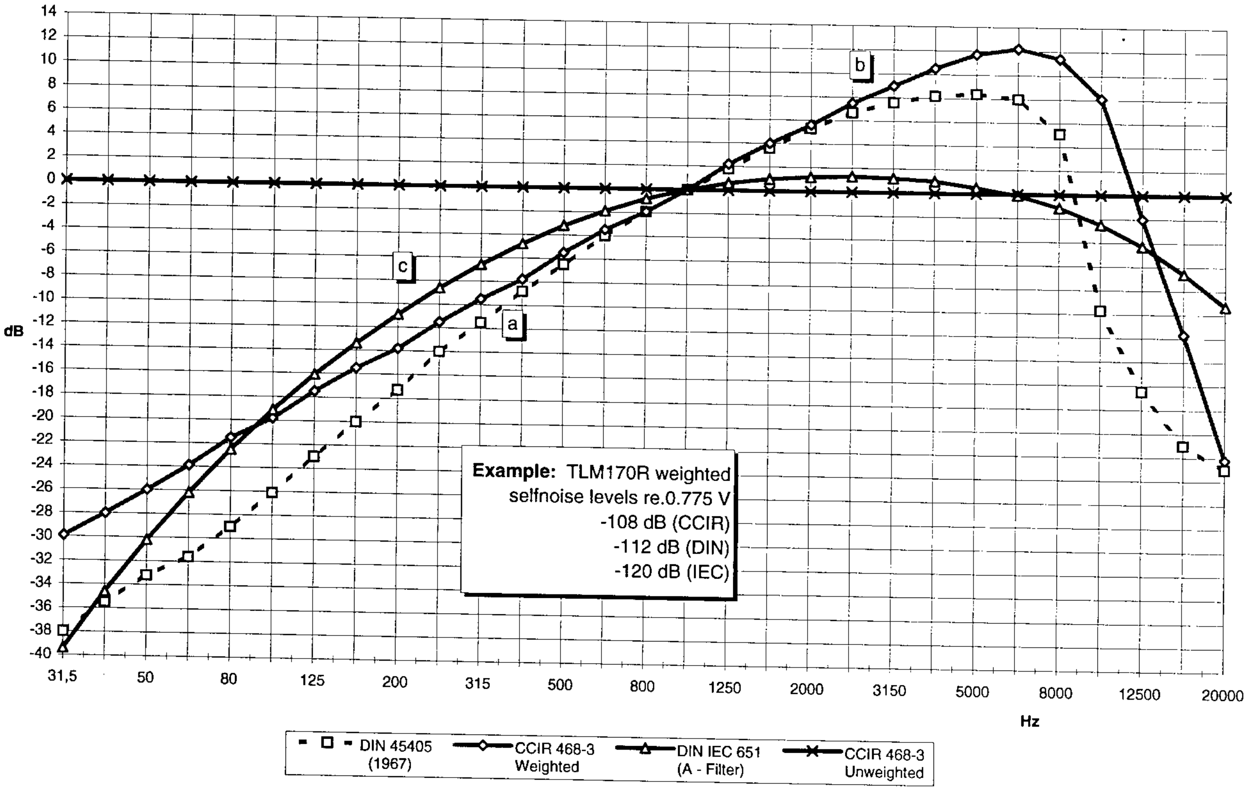


Fig. 4b Difference Frequency Level at 107 dBSPL, Large Diaphragm Pressure Gradient Microphones U 67, U 87



Example: TLM170R weighted selfnoise levels re.0.775 V
-108 dB (CCIR)
-112 dB (DIN)
-120 dB (IEC)

Fig. 5 Different Weighting Filter Curves

Microphone (Cardioide)	CCIR 468-3 dBq	DIN/IEC 651 db-A	Capsule Type
KM 64	33	21	KK 84
KM 84	28	17	Single membrane, 21 mm diameter
KM 140	25	16	
U 67	28	17	K 67
U 87	29	18	Double membrane, 34 mm diameter
U 87A	23	12	
U 47	26	14	K 49
M 49	36	25	Double membrane, 34 mm diameter
M149 Tube	25	13	
U 89	28	17	K 89
TLM 170	26	14	Double membrane, 28 mm diameter
TLM 193	21	10	

Fig. 6 Equivalent loudness level due to inherent noise of some condenser microphones

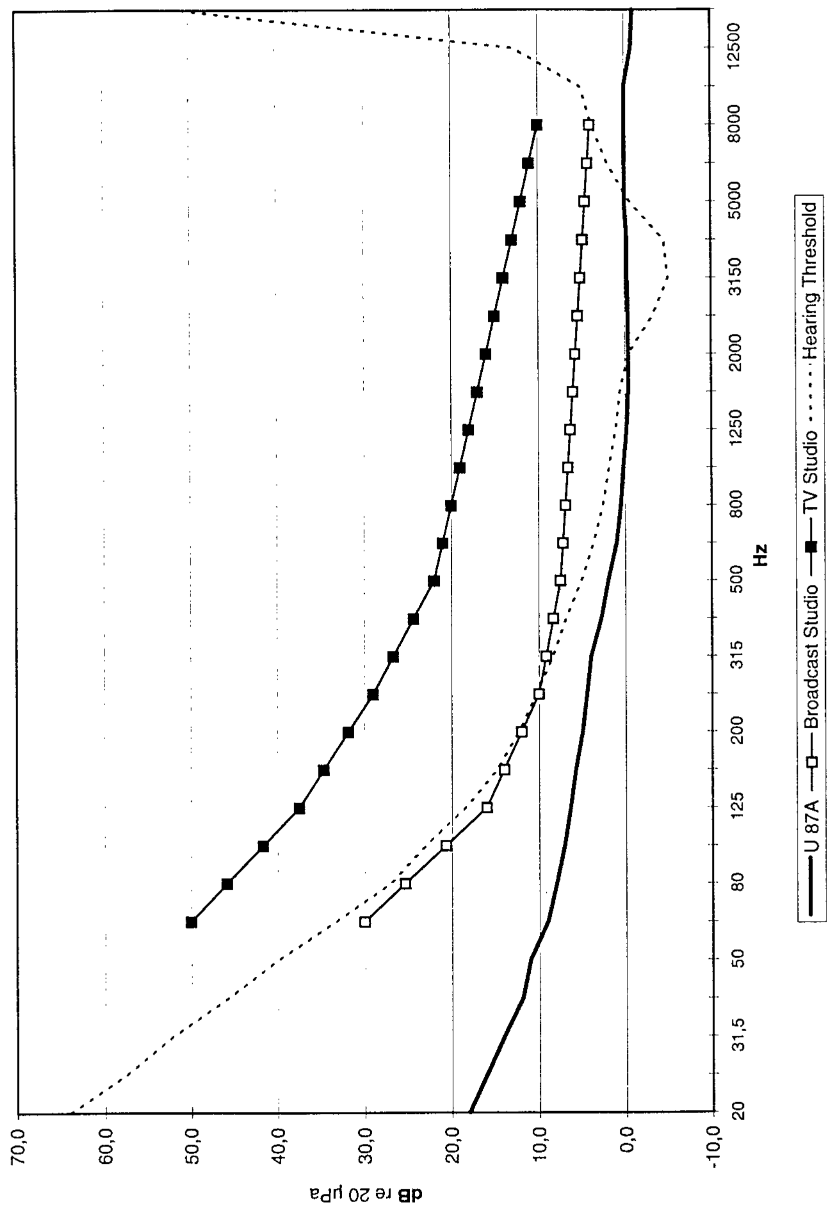


Fig. 7 Self-noise level of a studio condenser microphone compared to hearing threshold and max. studio background levels [8]

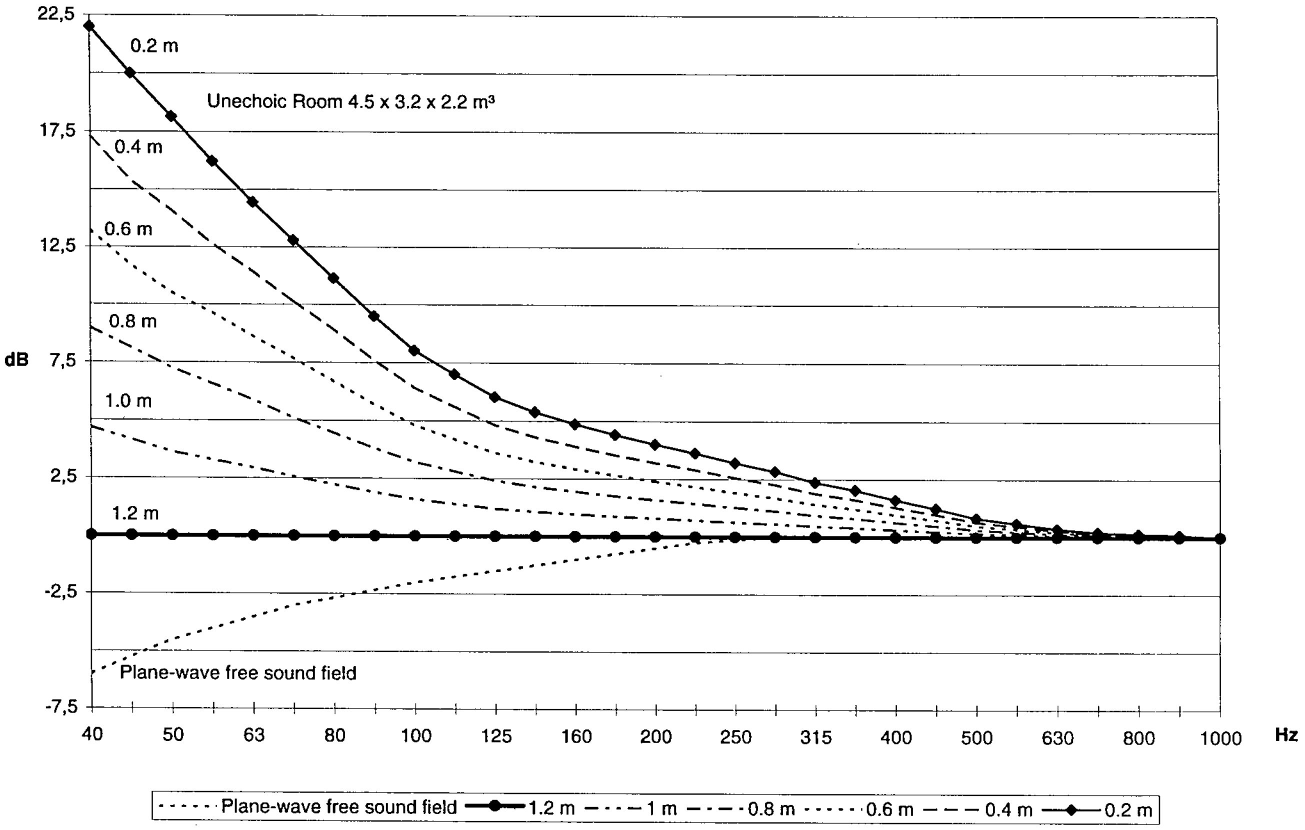


Fig. 8 Promitity effect of a cardioid microphone at different distances to the loudspeaker ref. 1.2 m, in comparison with frequency response in a plane-wave free sound field.