Programme Material Analysis

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1. Abstract

The paper describes an analysis of programme material available on Compact Disc (CD). The primary analysis is the average power distribution as a function of frequency. The programme material was initially divided into ten groups including a group for speech. The results have been compared to the International Electrotechnical Commission standard (IEC-268) for the Simulated Programme Signal and its use in power rating loudspeakers.

2. Introduction

The analysis was prompted over concern that the power tests used for power rating loudspeakers are not adequate. During the design and production of a loudspeaker it undergoes certain power tests to determine the loudspeakers power ratings and its 'life expectancy'. There are three tests using a simulated programme signal,

(i) Short Term Maximum Power
The maximum power that can be applied to the loudspeaker system for a period of 1 s without causing any permanent damage. The test is repeated 60 times with 1 minute between applications of the signal.

(ii) Long Term Maximum Power
The maximum power that can be applied to the loudspeaker system for a period of 60 s without causing any permanent damage. The test is repeated 10 times with 2 minutes between applications of the signal.

(iii) Rated Noise Power (Power Handling Capacity)
The power that can be applied to the loudspeaker system for a period of 100 hours without causing any significant change in system parameters observed a period 24 hours after the test.

The tests are described extensively in the IEC publication 268-5. The signal used in the tests is the Simulated Programme Signal as specified in the IEC publication 268-1 (described in section 3, below). Loudspeaker specifications generally quote the systems power handling capacity or the long term maximum power that can be applied, however, some now quote the short term maximum power.

The test signal is based on data collected pre-1980 from analogue recordings [1], which, due to the nature of the operating system, have restricted dynamic range and bandwidth compared to digital systems, namely CD, which has become the most popular audio medium post-1980. Also, many new forms of programme material have appeared, for example Hip-Hop, which obviously differ from the above test signal quite significantly. Locally, Bang & Olufsen have experienced breakdowns in loudspeaker systems in the market place caused by the user playing extreme pieces of programme material at high levels. These pieces of material differ substantially from the test signal currently used. Some analysis has been made on CD material, for example by Greiner and Eggers [2], but these have been general and too small an analysis.

The purpose of this study was to produce an average power spectrum for different groups of programme material and then combine this data to give an overall average power spectrum for programme material sourced from CD. Also investigated was a short term peak power spectrum and the variation between the groups. The results are compared to the existing simulated programme signal.

3. Existing Simulated Programme Signal (IEC 268-1, 1985)

Described in the standard as, quote, "A signal, whose mean power spectral density closely resembles the average of the mean power spectral densities of a wide range of programme material, including both speech and music of several kinds, is stationary weighted Gaussian noise without amplitude limiting". The average power spectrum of the simulated programme signal is shown in figure 1.

The signal can be obtained from pink noise with a suitable filter network. For the purpose of the power tests the signal is clipped, and uninterrupted, the signal shall have a peak-to-r.m.s. ratio between 1.8 and 2.2 (3 dB). The signal is clipped so that suitably small amplifiers can be used for the tests. For example, with the signal unclipped, if the loudspeaker has a power handling capacity of 200 W, then for the short term maximum power test to be performed without clipping due to amplifier limitations the amplifier required would be of huge proportions. In most cases only the long term maximum power and power handling capacity tests are performed.

4. Programme Material

The population of material available on CD is huge. This population was reduced into ten groups of programme material for the study.

1	Symphonic	(large orchestra)
2	Chamber	(small orchestra including quartets etc.)
3	Opera	(including choir with and without accompaniment)
4	Pop	(including soft rock and electronic pop)
5	Heavy	(hard rock, heavy metal and thrash)
6	Hip-Hop	(including techno and dance)
7	Jazz	
8	Blues	
9	Folk	(including easy listening and country and western)
10	Speech	

The groups were chosen based on those categories found in larger music stores and are such that it is straight forward to classify any piece of material and that vastly different styles of material do not occur in the same group. A separate group for movie sound was not included because most soundtracks are available on CD and the music can be classified into the groups already identified and dialogue falls into the speech group. Some soundtrack material has been included in the study.

5. Speech

A long term average speech spectrum has been well documented previously [3], but for the purpose of this study the data was not entirely suitable. The spectrum was only determined for the 63 Hz to 16 kHz third octave bands and was also measured under anechoic conditions. To enable comparison with other data in this study, information of the power spectrum was required over the full audio bandwidth together with peak spectral information and statistical analysis. I also wanted the information to represent broadcast studio situations as radio or television speech is not transmitted from an anechoic environment. To satisfy this, a set of speech recording were made in the Bang & Olufsen IEC listening room with Danish subjects with the speech recorded onto Digital Audio Tape (DAT) using the CD sampling rate of 44.1 kHz. Both male and female subjects from a wide age range were used. The previous work [3] shows that there are little differences between languages, therefore using only a single language for the measurements is valid. In addition to the recordings, some speech material was taken from CD. The average power spectrum for the speech material in this study in compared to the previously determined spectrum in figure 2. The two spectra are very similar in the bands were both results are quoted.

6. Selection of Programme Material

Most of the CDs for the study were selected from a large collection at Bang & Olufsen, additional discs were loaned from employees or bought specially for the study. The collection at Bang & Olufsen was only previously arranged into classical, jazz, opera and popular music with no further ordering within these groups, selection was made at random. Other material was accepted on the basis that it fell into the required category and the artist had not been previously included.

It was decided not useful to analyse complete CDs as they most likely contain many tracks recorded by the same band or orchestra and using the same equipment thus would be correlated to some extent. Therefore, it was decided to select a single track from each CD at random. The selection was made using a random number generator. Justification for analysing a complete track rather than a sample from the track is that users of loudspeakers do not listen to an extract of a piece, they would listen to a complete track.

Within the classical groups, symphonic and chamber, a composer may have been included more than once, for example Mozart, but no two tracks were taken from the same composition. In the opera group several tracks may have been taken from the same opera, but it should be noted that the operas span three or four CDs which include tens of tracks featuring different performers. Within the other groups, any particular artist was only included once. Compilation CDs have been used, although tracks accepted are those taken directly from the original artists album.

7. Real-Time Analysis of Programme Material

The programme material was analysed using a real-time third octave analyser. Processing was performed entirely in the digital domain. The material was sourced from a Bang & Olufsen Beosystem 2300 CD player equipped with a digital output in S/P DIF format. The signal was converted to I^2S format and then to 16-bit parallel via an audio input interface and format conversion board prior to input to a digital signal processor. The DSP was a 40 MHz floating-point Motorola DSP96002 board from Loughborough Sound Images, UK. The host PC was a Compaq SystemPro LT.

The operation of the system was as described below,

The input data was stored in left and right channel circular buffers each of length 3 x 16k. This data was Hanning windowed in blocks of 32k with a 50 % overlap to give equal weighting to all parts of the time signal. The information was then Fast Fourier Transformed using a 32k FFT giving 16k taps equally spaced at 44100/32768 Hz (~1.35 Hz) in the frequency domain. Within each third octave band the spectral energy was then summed and normalised to give 1 W for a full-scale in-band sinusoid, the result being stored in memory. Therefore for every 16k of data (~0.37 s) for each channel the following actions occur,

The latest 32k of data was Hanning windowed and FFT'ed.
The spectral energy in each third octave band was summed.
The energy was normalised.
The result was summed into memory.

The highest of these short term power levels that occurred in each band was also stored giving the Short Term Peak Power Spectrum (STPPS). The data that has been summed was averaged at the end of the analysis period to give the Average Power Spectrum (APS). Both are expressed in dB and given for each channel of the CD. The total spectrum power of each average power spectrum was also calculated. The system has equal weighting to all parts of the incoming time signal and has a flat power response in the frequency domain. The final results are downloaded to the host PC and are of the following form,

Centre Frequency (Hz)	Left APS (dB)	Right APS (dB)	Left STPPS (dB)	Right STPPS (dB)
20	-75.1	-72.0	-49.9	-44.7
25	-72.3	-72.2	-52.1	-47.0
...	...	...	...	...
16000	-71.7	-76.3	-55.2	-59.3
20000	-76.9	-81.6	-59.7	-65.7
Total Power	-26.2	-25.8		

8. Preliminary Analysis and Post Real-Time Calculations

We have so far identified groups of programme material we wish to analyse and we have a real-time system from which to obtain and average power spectrum and short term peak power spectrum for each piece of material or track. It was now necessary to determine just how much material to include and how to best combine the data to give meaningful results for each group. To solve these problems a preliminary analysis was performed which included a single track from each of the ten groups. The conclusions of this initial analysis are detailed below,

8.1. Normalisation of Track Data

To enable combination in any form of the different track data, the data must be normalised to a reference level. The data for each track was normalised to yield a total power of 0 dB in the average power spectrum of both left and right channels. For example, with the track information in the table above, each third octave band level in both the average power spectrum and the short term peak power spectrum of the left (right) channel would be increased by 26.2 dB (25.8 dB).

8.2. Left and Right Channel Information

For the ten tracks considered, an overall average power spectrum was calculated for left and right channels separately. The average was an average of the powers in Watts in each third octave band given by,

$$\bar{P} = 10\log\left\{\frac{1}{n}\sum_{i=1}^{n} 10^{\frac{P_i}{10}}\right\} \qquad \textbf{Eqn 1}$$

Where, $\bar{P}$ is the overall average power and P_i is the power in dB of the i^{th} track and n is the number of observations, in this case n is equal to ten. The result after ten tracks was that the left and right data was almost identical (the difference was < 0.5 dB in any band). It should be noted that essentially the left and right information is correlated for a particular track. Therefore, in subsequent calculations the left and right data has first been normalised then combined into a single spectrum for the average power and short term peak power with the equation,

$$P = 10\log\left\{\frac{10^{\frac{P_{left}}{10}} + 10^{\frac{P_{right}}{10}}}{2}\right\} \qquad \textbf{Eqn 2}$$

8.3. Individual Track Duration

The data from each of the ten tracks was now combined with equal weighting and by time weighting each set according to the track duration. The difference between the two resulting spectra was again small and verified that each track could be taken as a single observation irrespective of duration.

8.4. Confidence Interval

For the group, confidence intervals can be calculated in each third octave band for the average power spectrum and short term peak power spectrum. We can assume the data is normally distributed, this is valid because the data is taken at random from a very large population of data. The standard deviation for the n tracks was given by,

$$s = \frac{1}{n-1}\sum_{j=1}^{n}(P_j - \bar{P})^2 \qquad \textbf{Eqn 3}$$

A 95 % confidence interval was then calculated,

$$k = 10\log\left\{\frac{1.960s}{10^{\frac{\bar{P}}{10}}\sqrt{n}} + 1\right\} \qquad \textbf{Eqn 4}$$

Where k is the interval in dB (0 dB for no uncertainty). Therefore, if the test was repeated 100 times with n new tracks each time then 95 out of the 100 new averages would lie in the range,

$$\bar{P} - k \le \bar{P}_{new} \le \bar{P} + k \qquad \textbf{Eqn 5}$$

8.5. Number of Observations

With the calculations outlined it was necessary to determine a number of CDs and hence tracks to analyse. The variation of the average power spectrum with number of tracks analysed was investigated for the ten tracks of the preliminary analysis. The variation was noted in the third octave bands with the narrowest and widest confidence intervals. The most variation was found in the 20 Hz band and it was clear that the average after ten tracks had not become stable in all bands. Therefore it was decided to consider 40 tracks in each group.

8.6. Summary of Operations and Calculations Within a Group

- CDs were selected.
- A track was selected at random from each CD.
- The real-time analysis was performed on each track.
- The average power spectrum and short term peak power spectrum were normalised.
- The left and right channel data was averaged using Eqn 2.
- The data for the 40 tracks was then averaged to give a single average power spectrum and short term peak power spectrum for the group using Eqn 1 with n equal to 40.
- The confidence intervals were calculated for each of these spectra with Eqn's 3 and 4.

Additionally, in each third octave band there is a ratio between the average power spectrum and the short term peak power spectrum, effectively a peak-to-r.m.s. ratio. It was found that this ratio was almost independent of frequency, hence a single peak-to-r.m.s. ratio for each group of programme material can be quoted by taking an average of the ratios from each of the 31 third octave bands. Therefore,

- A peak-to-r.m.s. ratio was calculated for each group of programme material.

9. Group Results

The results for each of the ten groups of programme material are shown in figures 3 - 12. Each graph shows the average power spectrum with the confidence intervals in each third octave band shown as upper and lower limit bars together with the IEC simulated programme signal power spectrum. Both spectra have a total spectrum power of 0 dB. The short term peak power spectrum has not been shown for clarity although the average peak-to-r.m.s ratio for each group is quoted below.

Programme Material Group	Average peak-to-r.m.s. Ratio (dB)
Symphonic	17.1
Chamber	14.2
Opera	15.8
Pop	10.6
Heavy	9.2
Hip-Hop	8.2
Jazz	13.5
Blues	10.8
Folk	11.3
Speech	12.9

10. Combination of Group Data

The ten group results are very useful individually, although it was now necessary to combine the average power spectrum for each group in a way that sensibly reflects an average loudspeaker lifetime. This is a very difficult task and indeed there are many ways in which the data could be combined with equally valid results. The most obvious way would be to obtain information of what percentages an average person listens to each group in their lifetime. This information could be obtained by making a survey , but to obtain valid results the survey would have to include a huge number of people taken from all age groups and nationalities. This task would be time consuming and expensive. Therefore, two options were pursued in this study, primarily for comparison to see how sensitive the result was to different methods of combination. The methods were,

- To take each of the ten groups equally.
- To weight each group according to a sensible estimate of the breakdown of time to which the average person listens to each group during their lifetime.

10.1. Equal Weighting of Group Data

The total average power spectrum was calculated from the group averages using,

$$\bar{P}_t = 10\log\left\{\frac{1}{N}\sum_{i=1}^{N} 10^{\frac{\bar{P}_i}{10}}\right\} \qquad \textbf{Eqn 6}$$

Where N was the number of groups (10). The standard deviation on the total mean was calculated using,

$$s_t = \sqrt{\frac{1}{N^2 n}\sum_{j=1}^{N} s_j^2} \qquad \textbf{Eqn 7}$$

Where s_j is the standard deviation of the j^{th} group average power and n is the number of observations in each group (40). The confidence intervals in dB of the final result were given by,

$$k_t = 10\log\left\{\frac{1.960 s_t}{10^{\frac{\bar{P}_t}{10}}} + 1\right\} \qquad \textbf{Eqn 8}$$

10.2. Time Weighting Group Data

The breakdown of time not only includes CD, but all loudspeaker sources such as radio and television. Several people from the Electroacoustics Department at Bang & Olufsen were asked to make a sensible breakdown, the results are given below (expressed as a percentage of time),

Programme Material Group	Percentage of Time	Weighting Factor W
Symphonic	2.5	0.0250
Chamber	1.5	0.0150
Opera	2	0.0200
Pop	37.5	0.3750
Heavy	4	0.0400
Hip-Hop	7.25	0.0725
Jazz	6	0.0600
Blues	4.25	0.0425
Folk	10.25	0.1025
Speech	24.75	0.2475

The data was combined with the weighting factors and the weighted average power spectrum was given by,

$$P_{t_{wgt}} = 10\log\left\{\sum_{i=1}^{N} W_i 10^{\frac{\bar{P}_i}{10}}\right\} \qquad \textbf{Eqn 9}$$

The standard deviation on the weighted average value was given by,

$$s_{t_{wgt}} = \sqrt{\frac{1}{N^2 n} \sum_{j=1}^{N} W_j s_j^2} \qquad \textbf{Eqn 10}$$

The confidence intervals were given by,

$$k_{t_{wgt}} = 10 \log \left\{ \frac{1.960 s_{t_{wgt}}}{10^{\frac{p_{t_{wgt}}}{10}}} + 1 \right\} \qquad \textbf{Eqn 11}$$

The two final average power spectra are shown in figures 13 and 14 with their confidence intervals and the IEC simulated programme signal. This data is also tabulated in section 16.

11. Discussion

A total of 28 hours 57 minutes and 4 s, or 400 tracks, of programme material has been analysed and for each group the results are stable and are independent of time. The results show many significant differences between the ten groups but also reveal important similarities between some of the groups. The ten groups can be grouped as follows based on these similarities,

- Those groups containing almost entirely mid-band energy.

They are symphonic, chamber, opera and speech. The energy is centred around the 500 Hz third octave band. The average level in this band is approximately 8 dB below the total spectrum power. Either side of the 500 Hz band the average power spectrum falls away at ~7 dB per octave. The spectra exceed the IEC signal between 200 Hz and 2.5 kHz. This category contains the largest average peak-to-r.m.s. ratios. Symphonic has the highest ratio of 17.1 dB (51.3), with opera 15.2 dB (33.1), chamber 14.2 dB (26.3) and speech 12.9 dB (19.5). The speech average power spectrum determined for this study is very close to that determined previously [3], figure 2. However, below the 63 Hz band there is low frequency noise present which will more accurately represent a broadcast studio environment.

- Those groups with evenly distributed energy.

They are pop, jazz, blues and folk. These groups have very similar average power spectra which falls by approximately 1 dB per octave with increasing frequency between the 80 Hz and 5 kHz third octave bands. Below this the energy falls at ~15 dB per octave and above 5 kHz falls at ~7 dB per octave. The average peak-to-r.m.s. ratio ranges between 10.6 dB (11.5) and 13.5 dB (22.4) for this category.

- Those groups with extreme high or low frequency energy.

They are the heavy and hip-hop groups. The heavy group average power spectrum contains peak energy between the 80 Hz and 160 Hz third octave bands and in the 2.5 kHz band. The energy in these bands is ~12 dB below the total spectrum power. The hip-hop average power spectrum contains most energy around the 63 Hz band and is ~9 dB below the total power. This spectrum contains large amounts of energy up to the 10 kHz band and is almost flat between 250 Hz and 8 kHz. Both spectra fall away rapidly below the 50 Hz third octave band. These two groups have the lowest average peak-to-r.m.s. ratios of 9.2 dB (8.3) and 8.2 dB (6.6).

Figures 13 and 14 show the final results of combining the ten groups of programme material. The equally weighted and time weighted average power spectra are very similar even when time weighting of up to 37.5 % has been applied. The difference between the spectra does not exceed 1.6 dB in any band and only 6 bands have a difference greater than 1.0 dB. Both spectra are quite close to the IEC simulated programme signal power spectrum above the 50 Hz third octave band. Only below this band is there significant difference. The un-weighted and time weighted spectra are ~10 dB below the IEC signal in the 20, 25 and 31.5 Hz bands and are ~5 dB below in the 40 Hz band. The spectra also dip below the IEC signal between 1 kHz and 5 kHz with the largest deviation being 3.1 dB. The statistical confidence of the final results is extremely good. The largest interval is +/- 1.4 dB, but generally the intervals are less than +/- 0.4 dB. Most variation occurred at the extremes of the frequency range giving the wider confidence intervals.

It should be noted that the peak-to-r.m.s. ratios quoted are not the maximum ratio that will have occurred. This is because there exists a time constant over which the short term powers are measured, in this case ~0.37 s. A shorter time constant would have given greater peak values. However, with the knowledge of the initial average power spectrum (before normalisation) from each track and the maximum recordable level it was clear that the values calculated in this study are very close to the maximum peak-to-r.m.s. values that could have occurred.

12. Conclusion

The primary aim of the project was to calculate an average power spectrum for programme material available on CD and to compare the results to the existing IEC Simulated Programme Signal. The results show that the newly determined spectrum is similar to the IEC spectrum (figures 13 and 14). This result is virtually independent to time weighting of the different groups of programme material, therefore an extensive study into more accurate weighting is not required.

For a long term average, in terms of frequency, the existing IEC signal stresses the loudspeaker under test more than would occur with programme material particularly at very low frequencies (below 40 Hz).

For the purpose of the shorter duration tests (Short and Long Term Maximum Power), these should represent a worst-case scenario rather than the long term average i.e. using a signal that represents the worst-case programme material. The worst-case groups are the heavy and hip-hop groups. They contain large amounts of low and high frequency energy which stresses loudspeakers most and experience has shown that it is this type of material that most frequently causes breakdowns. A more suitable signal for the shorter tests is one that contains more low and high frequency energy. Based on the results of this analysis a new power spectrum has been suggested for use in the Short and Long Term Maximum Power tests. This spectrum is tabulated in section 16 and is compared to the existing IEC spectrum in figure 15. It contains significantly less power below 40 Hz but an increase of ~3 dB in the 50 and 63 Hz bands (power doubling).

Between 1 kHz and 6.3 kHz there is 1 - 2 dB less power and in the 10 kHz and 12.5 kHz bands there is 2 dB more power.

The peak-to-r.m.s. ratios for the programme material groups are much higher than the ratio used in the existing power tests. Even the more compressed hip-hop material has a ratio of 8.2 dB which compared to the 3 dB currently used is an increase of 3.3 times. Hence, using the 3 dB peak-to-r.m.s. ratio does not represent programme material.

To summarise,

- The **spectrum** of the IEC Simulated Programme Signal **is** suitable for the Rated Noise Power test (Power Handling Capacity).
- The **spectrum** of the IEC Simulated Programme Signal **is not** suitable for the Short or Long Term Maximum Power tests (a new power spectrum is suggested).
- The **peak-to-r.m.s ratio** used in the power tests **is not** representative of programme material (a greater peak-to-r.m.s. ratio would be more representative).

13. Further Work

Additional analysis will be concentrated upon determining a suitable signal for the Short and Long Term Maximum Power tests and also a more adequate peak-to-r.m.s. ratio for each of the tests. Subsequently experimental tests can be performed to investigate how the power specifications would be affected by any changes. Also available from the study are cumulative distributions of the short term power levels in each third octave band for each track analysed. At present this data has not been processed but could be used for further investigations, for example into L_{10} the level exceeded for 10 % of time etc.

14. Acknowledgements

In addition to myself the following people participated in the project and their help was greatly appreciated, Knud Bank Christensen, Gert Munch, Villy Hansen, Soren Bech, Jan Larsen and Jan A. Pedersen all from the Electroacoustics Department at Bang & Olufsen A/S.

15. References

[1] Refer to the report 'Compatible Power Rating of Power Amplifiers and Loudspeakers for Speech and Music Programme', AEEG/EP-2201, a paper of the 65th AES Convention, London, February 1980, by Philips Electroacoustics Department.

[2] 'The Spectral Amplitude Distribution of Selected Compact Discs', R.A.Greiner and J. Eggers, from the Journal of the AES, April 1989.

[3] 'An International Comparison of Long-term Average Speech Spectra' from the Journal of the Acoustical Society of America, Vol. 96, No. 4, Page 2108, October 1994.

16. Tabulation of Data

Centre Frequency (Hz)	APS (Equal Weighting) (dB)	Confidence Interval (+/- dB)	APS (Time Weighted) (dB)	Confidence Interval (+/- dB)	Suggested Power Spectrum (dB)
20	-37.4	+/- 1.4	-35.8	+/- 0.5	-38.0
25	-35.0	1.1	-33.7	0.4	-32.0
31.5	-30.7	1.0	-29.2	0.4	-25.5
40	-23.7	0.7	-22.7	0.2	-19.0
50	-16.7	0.7	-15.8	0.2	-12.9
63	-14.4	0.4	-14.0	0.1	-12.4
80	-13.3	0.4	-13.0	0.1	-12.4
100	-12.9	0.3	-12.5	0.1	-12.4
125	-13.2	0.3	-12.8	0.1	-12.5
160	-12.7	0.3	-12.5	0.1	-12.5
200	-12.2	0.2	-11.2	0.1	-12.5
250	-12.3	0.3	-11.3	0.1	-12.5
315	-11.8	0.2	-11.6	0.1	-12.5
400	-11.1	0.2	-11.0	0.1	-12.6
500	-10.7	0.2	-10.8	0.1	-12.6
630	-11.0	0.2	-11.5	0.1	-12.7
800	-12.0	0.3	-12.8	0.1	-12.8
1000	-13.2	0.3	-14.3	0.1	-13.2
1250	-12.6	0.3	-14.9	0.1	-13.7
1600	-14.6	0.3	-15.4	0.1	-14.4
2000	-15.4	0.3	-16.1	0.1	-15.2
2500	-15.3	0.4	-16.4	0.1	-15.9
3150	-17.1	0.3	-18.0	0.1	-16.7
4000	-18.8	0.3	-19.1	0.1	-17.7
5000	-20.8	0.4	-20.7	0.1	-18.7
6300	-21.3	0.5	-21.0	0.1	-19.7
8000	-22.5	0.4	-21.8	0.1	-21.0
10000	-24.2	0.4	-23.6	0.1	-22.5
12500	-26.3	0.6	-25.9	0.2	-25.0
16000	-30.3	0.7	-29.7	0.3	-30.0
20000	-36.9	1.0	-36.5	0.3	-37.0

Note,

- APS = Average Power Spectrum
- Each power spectrum has a total spectrum power of 0.0 dB.
- Preferred third octave band centre frequencies are shown.

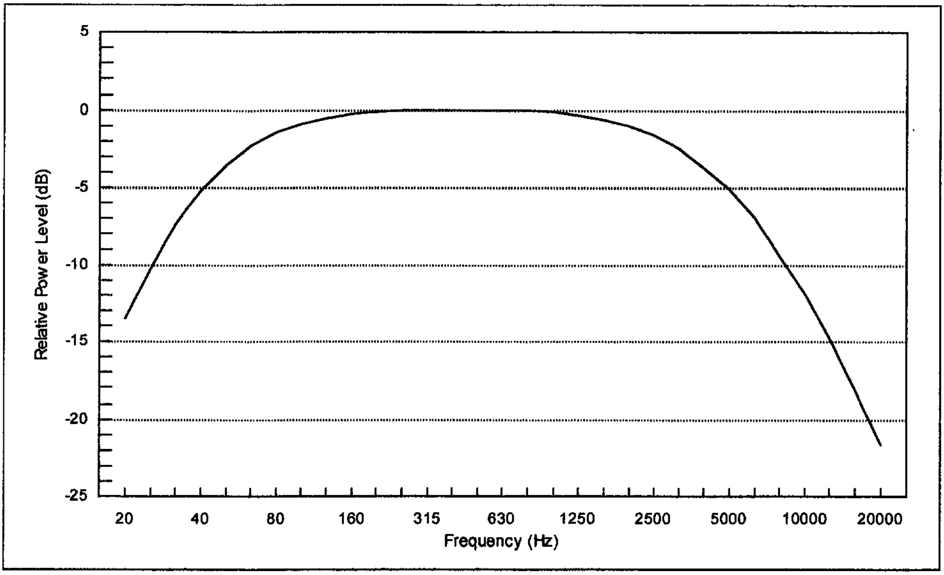

Figure 1 Average Power Spectrum of IEC 268-1 Simulated Programme Signal.

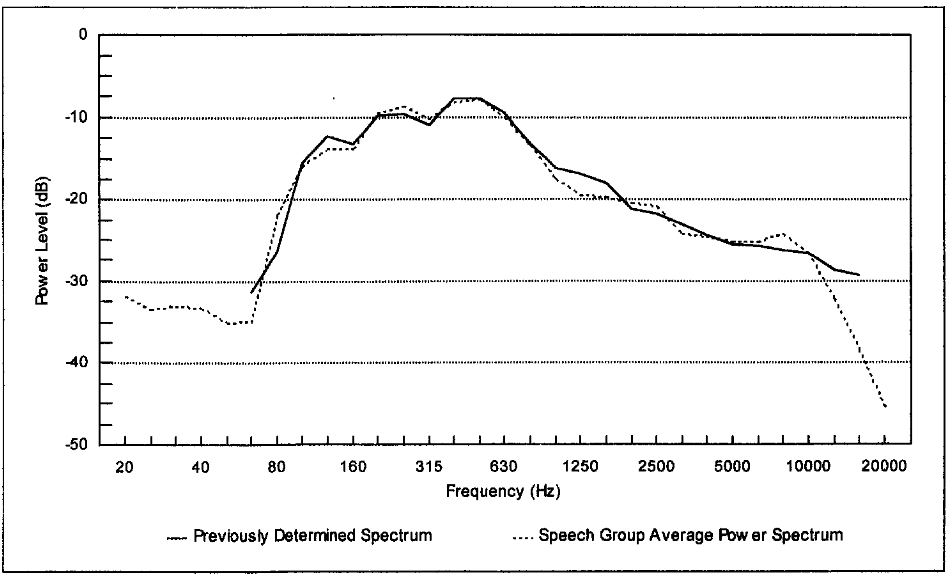

Figure 2 Comparison of newly measured speech spectrum with previously determined spectrum.

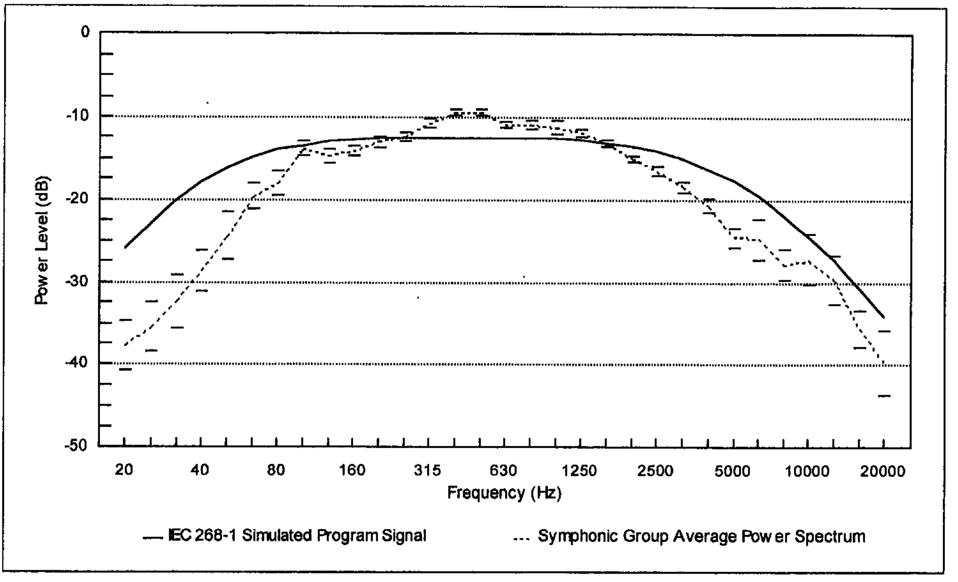

Figure 3 Average Power Spectrum of Symphonic Group

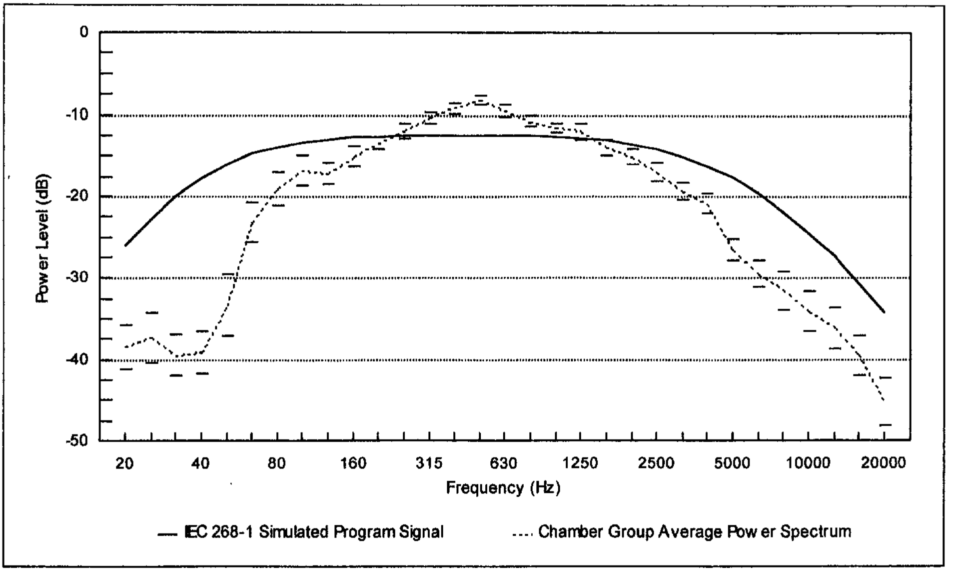

Figure 4 Average Power Spectrum of Chamber Group

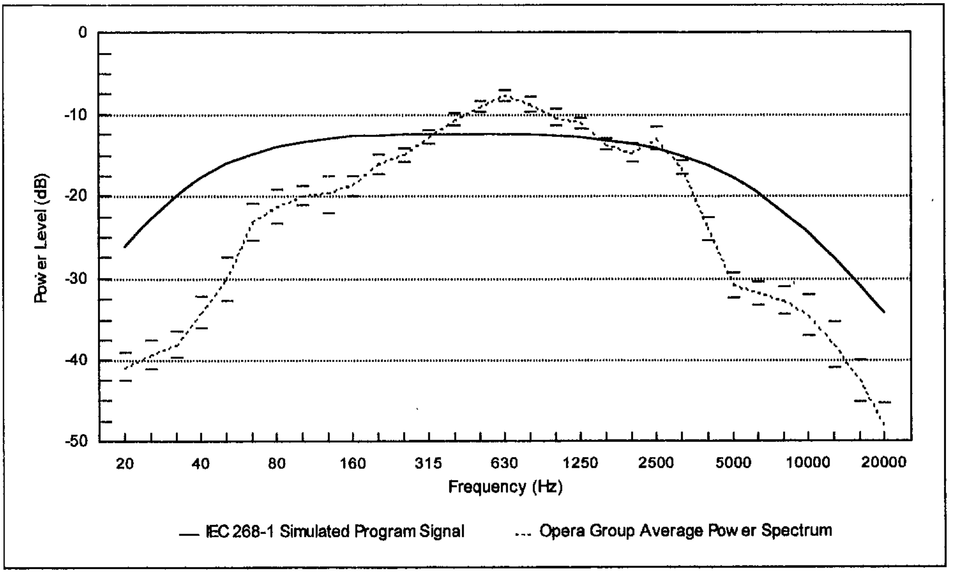

Figure 5 Average Power Spectrum of Opera Group

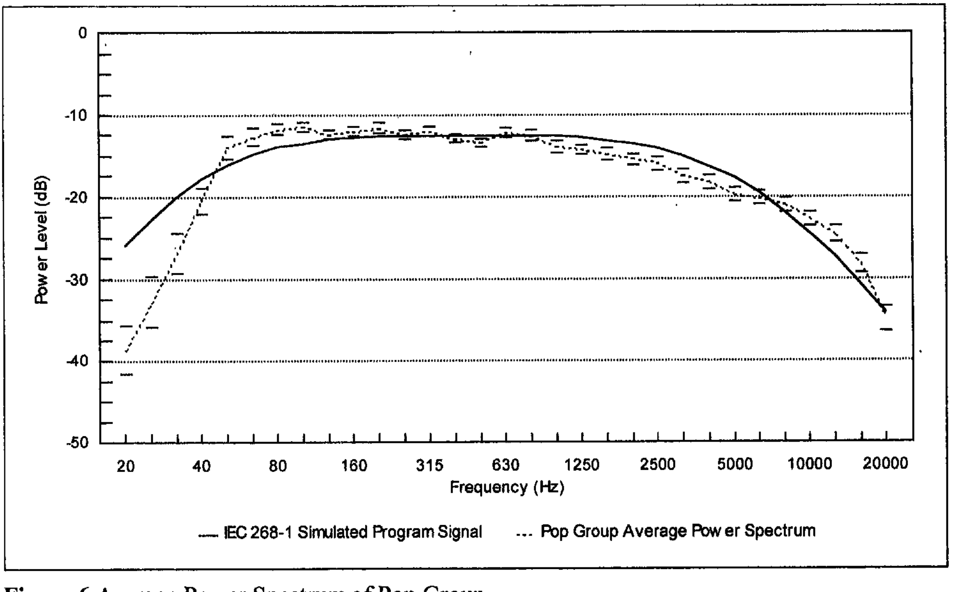

Figure 6 Average Power Spectrum of Pop Group

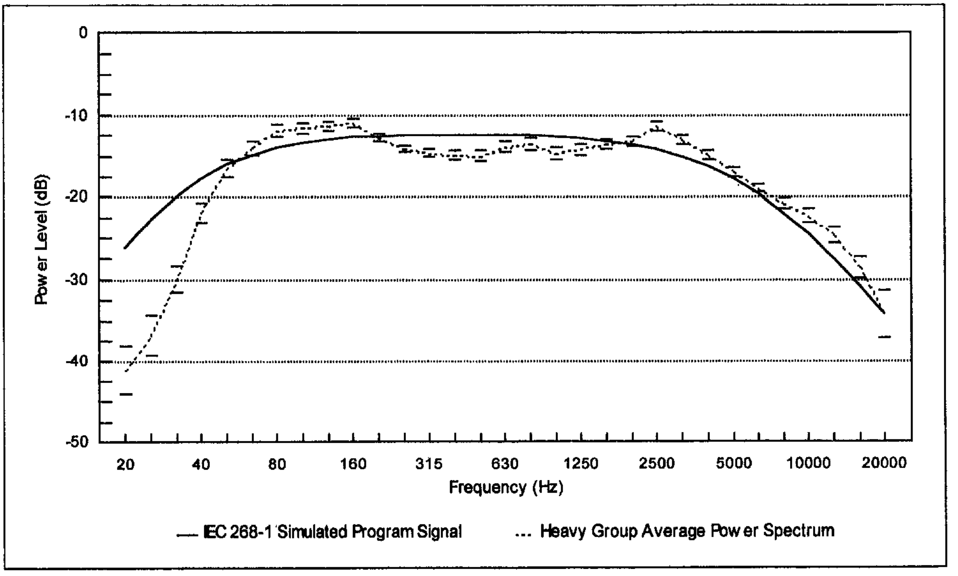

Figure 7 Average Power Spectrum of Heavy Group

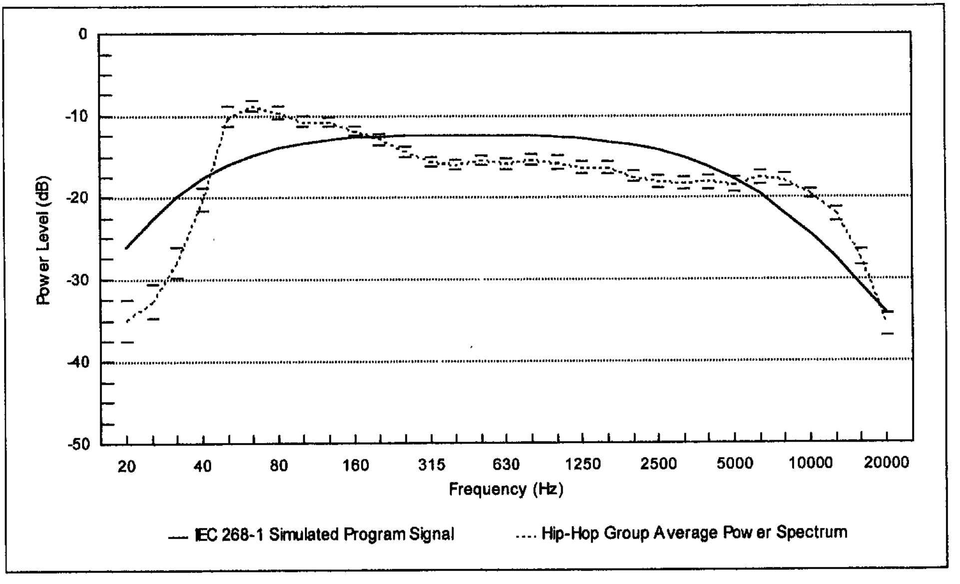

Figure 8 Average Power Spectrum of Hip-Hop Group

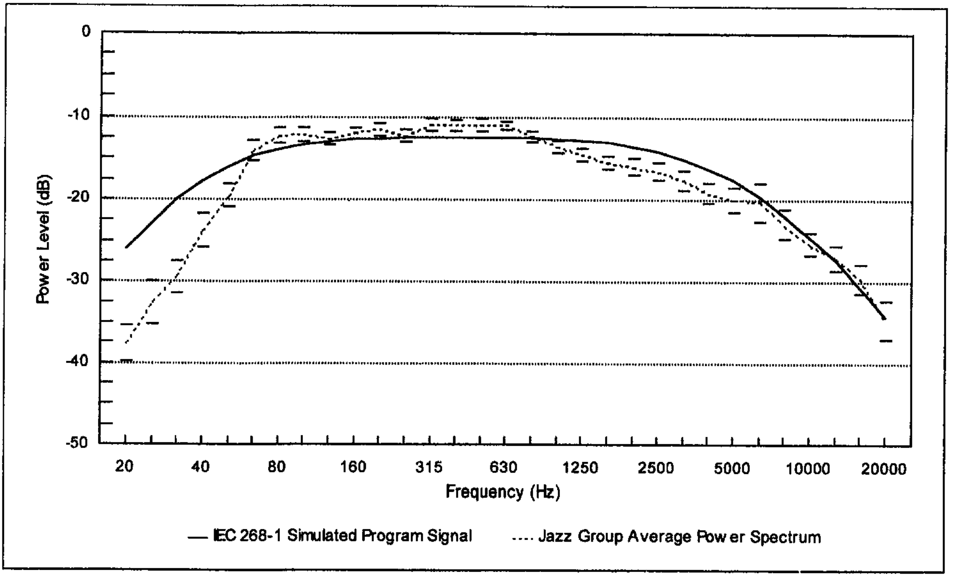

Figure 9 Average Power Spectrum of Jazz Group

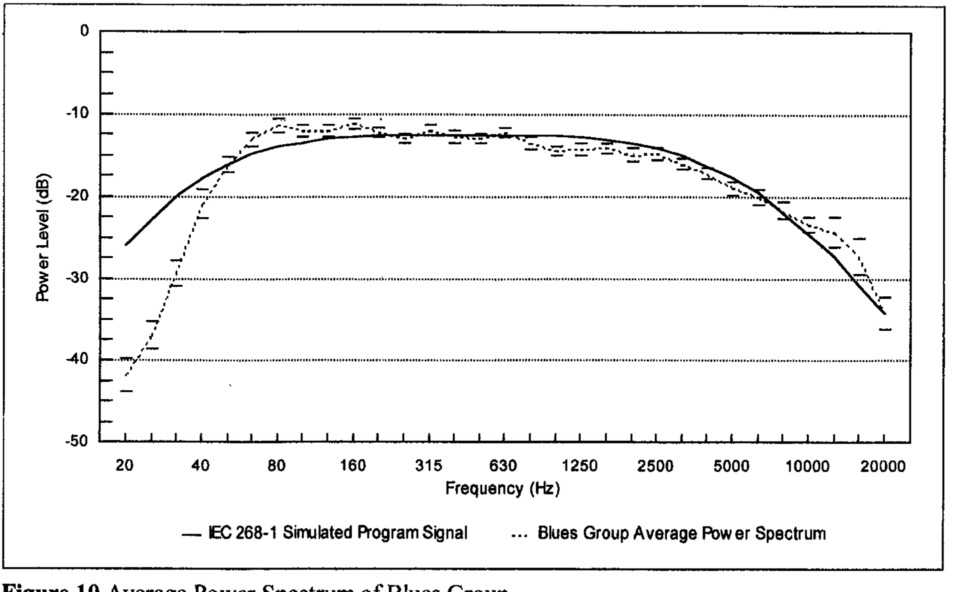

Figure 10 Average Power Spectrum of Blues Group

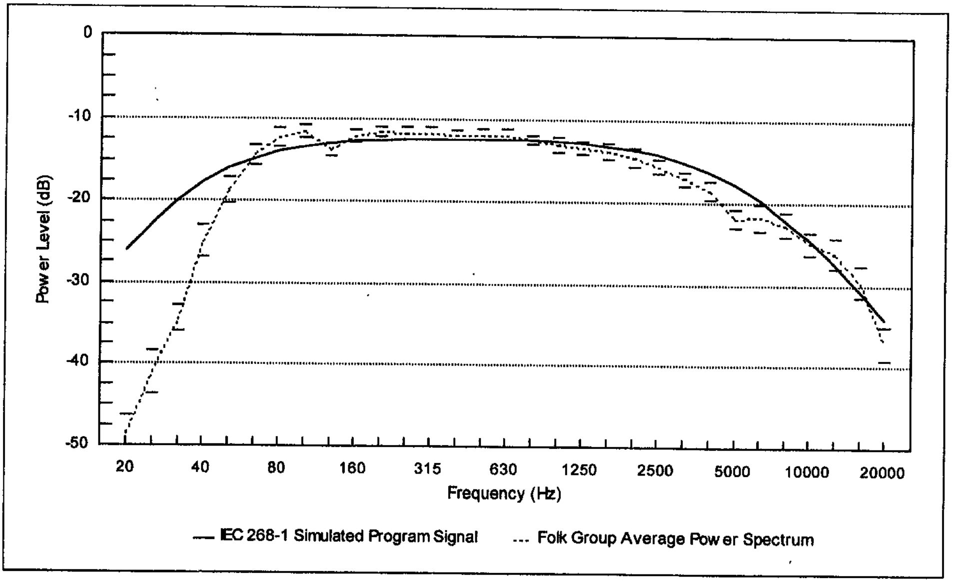

Figure 11 Average Power Spectrum of Folk Group

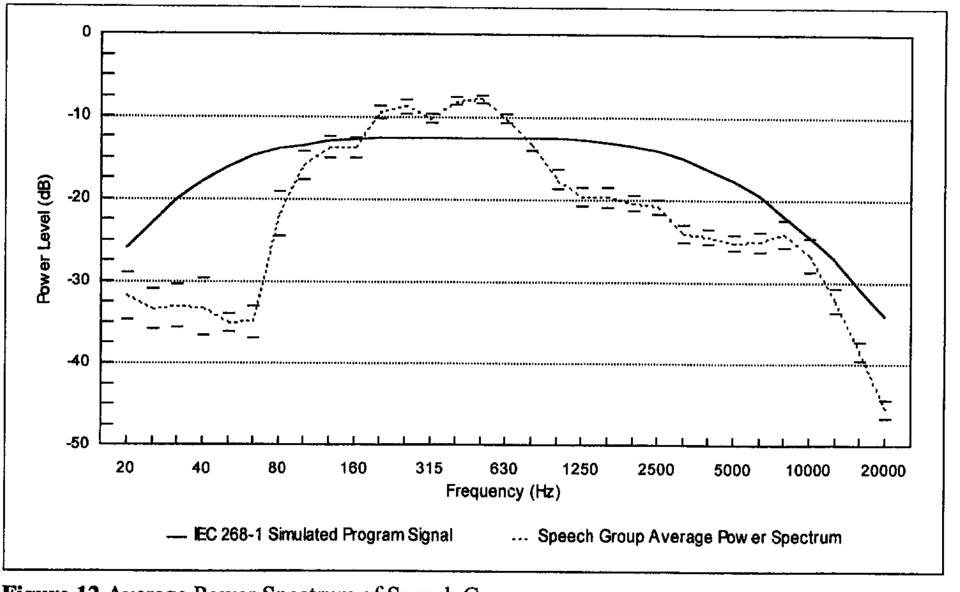

Figure 12 Average Power Spectrum of Speech Group

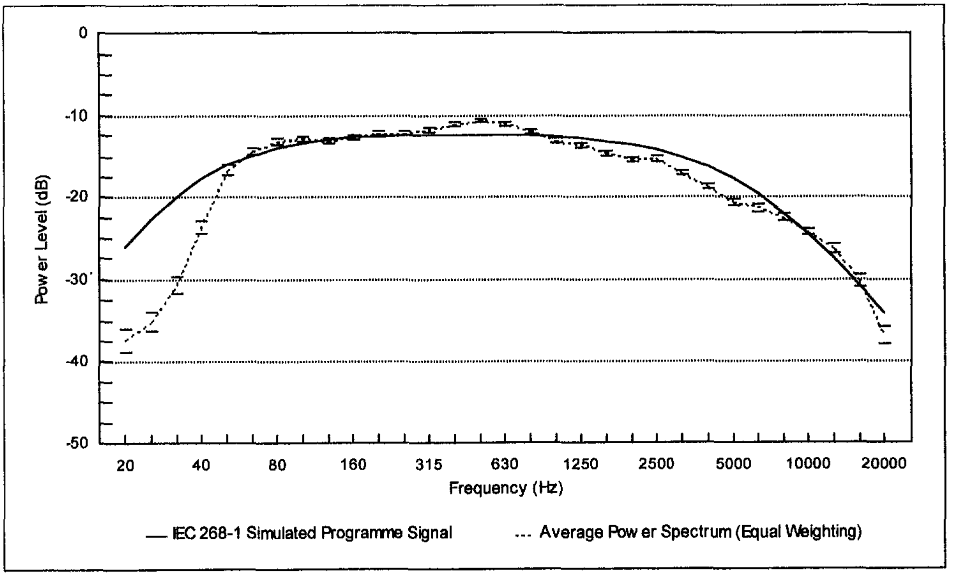

Figure 13 Average Power Spectrum (Equally Weighted)

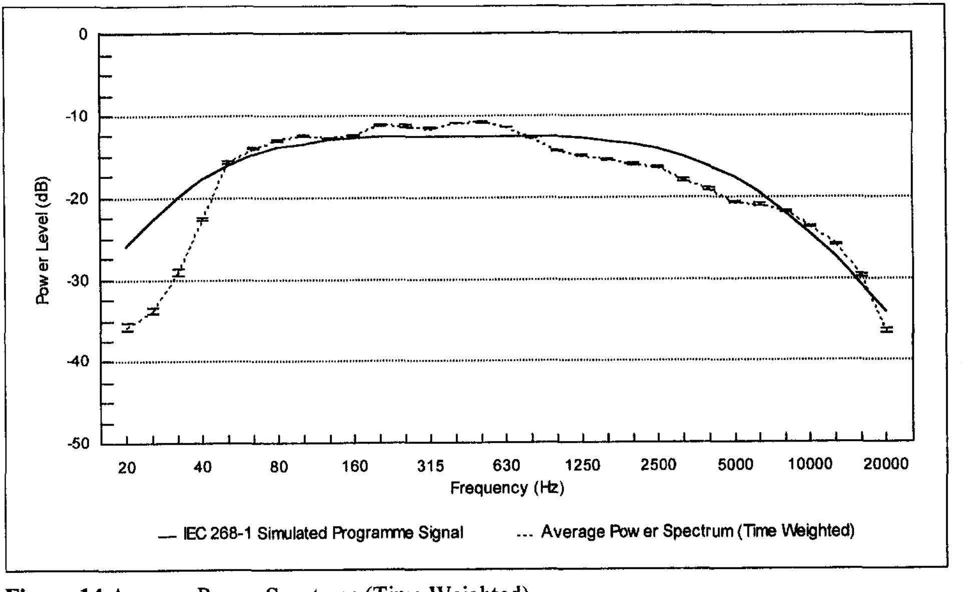

Figure 14 Average Power Spectrum (Time Weighted)

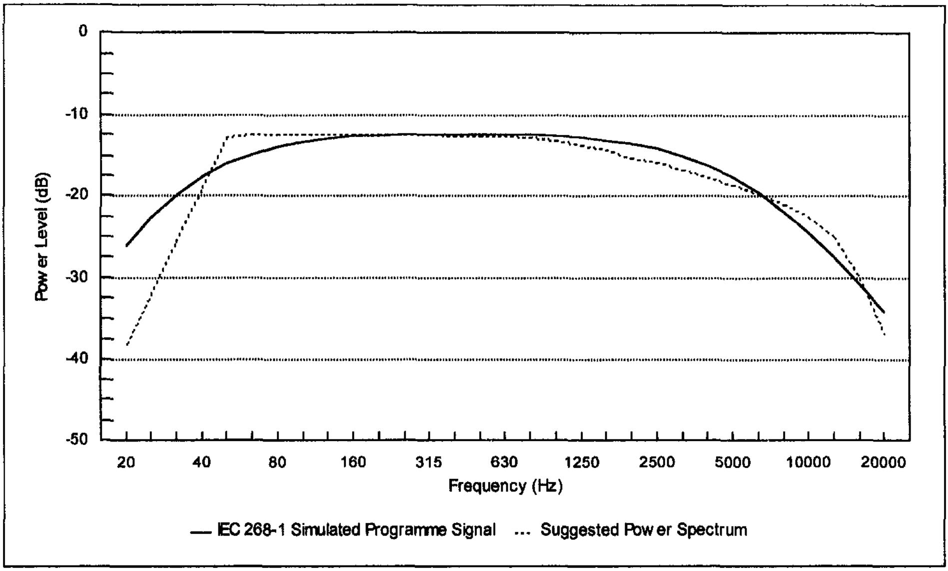

Figure 15 Suggested Power Spectrum