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Non-linear crosstalk in personal computer based audio systems

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ABSTRACT

International Electrotechnical Commission (IEC) and AES standards provide comprehensive tests for the performance of audio analogue to digital (ADC) and digital to analogue (DAC) converters for both consumer and professional applications. It is usually assumed that the ADC is more likely to degrade audio sound quality than the DAC. Tests on two samples of a professional quality PC based audio system are presented that show that a stereo DAC can introduce unexpected non-linear effects. These results suggest that a future revision of the standards should include a measure of inter-channel non-linear cross talk in the stereo DAC. Results are presented and an intermodulation distortion (IMD) loop test proposed to enable this measurement to be made with precision.

1. INTRODUCTION

The investigation presented in this paper arose from research by the authors into the precision measurement of the non-linear distortion of measurement-class microphones. Two-tone intermodulation distortion (IMD) tests (or 'difference-frequency' tests [1]) of the microphone were undertaken in an anechoic chamber using two loudspeakers, one for each tone. It is well known that this approach ameliorates the effects of non-linearity in each loudspeaker [2]. The test arrangement is depicted in Figure 1.

The PC based instrumentation made use of one analogue input channel and two analogue output channels of a professional quality 24 bit ADC-DAC 48 kHz sampling multi-channel unit. The loudspeakers (LS) were arranged in the anechoic chamber so that the sound waves from each sum at the microphone (Mic.) under test. Intermodulation in the signal from the microphone is expected to be produced only by the microphone. Non-linearity in the waveform from each loudspeaker will produce only harmonics of the test signal so will not introduce intermodulation distortion.

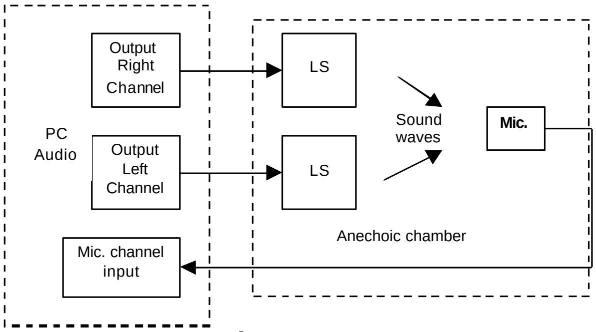

Figure 1 Microphone IMD test arrangement

However, unexpectedly large frequency and amplitude dependent IMD effects were observed in the microphone test results. This required further tests to determine whether the microphone or the instrumentation generated the IMD. The linearity and cross talk of the PC based system (referred to in this paper as UNIT 1) had been tested previously using the methods specified in the existing and emerging standards for PC based audio systems [3, 4] and on that basis was believed to be suitable for the microphone tests. The microphone tests were repeated with a different ADC-DAC system of similar specification to UNIT1 (referred to in this paper as UNIT 2) to try to eliminate the possibility of UNIT 1 producing the IMD. When UNIT 2 was used the microphone results were closer to those expected from theory. This indicated that some aspect of UNIT 1 was at fault. It was initially suspected that it could have been due to a fault having occurred in the microphone amplifier or ADC of UNIT 1. The true source of the problem was identified in the experimental investigation reported next.

2. TEST METHODS

Conventional loop tests for inter-channel cross talk and linearity were undertaken for both UNIT1 and UNIT 2 using readily available test software for PC based audio equipment [5].

2.1. loop test

This test required two external cables to connect or ‘loop’ one DAC channel pair to one ADC channel pair. Manufacturer’s data sheets for each unit revealed that a stereo output pair was generated by one stereo DAC integrated circuit and that a stereo input pair was handled by one stereo ADC integrated circuit. This ensures close matching of the left and right channels of the stereo pair. Test waveforms were synthesised by the host software in WAV format and replayed through the PC audio interface. Signals from the ADC were stored in a WAV format file and analysed to obtain the results of the loop test.

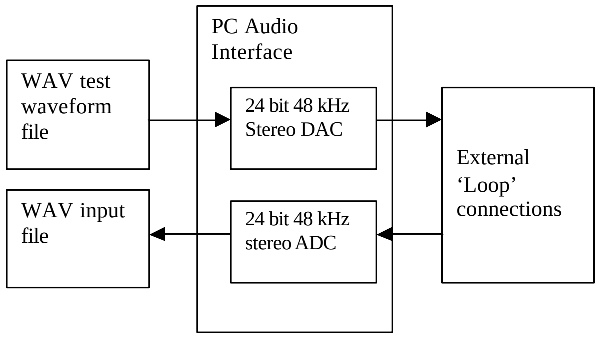

Figure 2 PC audio loop test

Linear cross talk in a stereo ADC is specified [3] when one channel is excited below overload. If a test signal of frequency F1 is applied to one channel with the other silent, linear cross talk appears in the other ‘silent’ channel as a component at the same frequency F1. Non-linear cross talk requires that the ADC input is greater than its full scale range. Signals that appear in the ‘silent’ channel during overload are then due to non-linear cross talk. As the DAC input cannot be overdriven this method cannot be used to measure non-linear cross talk with DACs. The noise and crosstalk results are presented in TABLE 1 and indicate that both stereo ADC-DAC systems had passed these aspects of the loop test.

	UNIT 1	UNIT 2
Frequency response (from 40 Hz to 15 kHz), dB:	+0.31, -0.30	+0.02, -0.12
Noise level, dB (A):	-114.7	-116.6
Dynamic range, dB (A):	113.8	116.3
Stereo crosstalk, dB:	-114.7	-117.0

Table 1 Loop test results

These particular tests did not indicate a problem with either UNIT1 or UNIT 2. Non-linearity appeared to be the main issue and this was investigated in more detail as follows.

For microphone measurements, ADC linearity was believed to be more important than DAC linearity. The loop test measured the sum of both ADC and DAC non-linearity so did not provide enough detail. Accurate measurements of the ADC total harmonic distortion (THD) required first that harmonics generated by the DAC be reduced. This was achieved by inserting a passive low pass filter in the external loop. A more precise measurement of ADC distortion was made and Figure 3 shows the spectrum of this result for UNIT1.

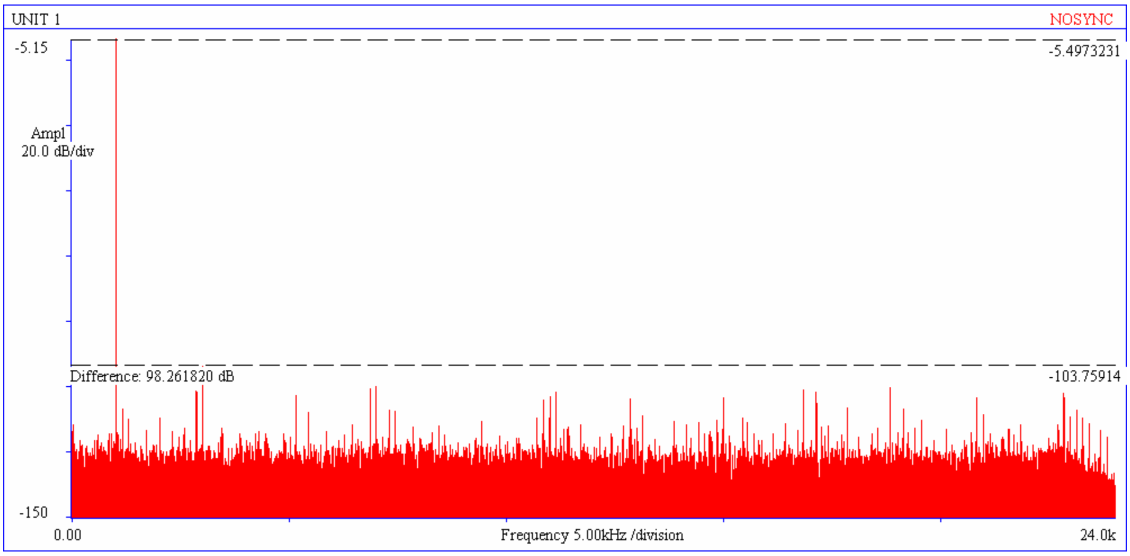

Figure 3 1 kHz THD test for UNIT 1

It was calculated using a 65536 point FFT with custom windowing [6]. This window provided a side-lobe suppression of better than 300 dB so was suitable for testing 24 bit systems with all practical values of FFT length. The THD calculated from figure 3 was 0.004 % at 1 kHz. As this was close to that of UNIT 2 (0.002%) the ADC was unlikely to be the source of the problem.

The ADC THD at 1 kHz was sufficient for the microphone measurements and did not give an indication of the source of the problem. DAC linearity was not thought to be an important issue as the microphone IMD test was expected to be insensitive to non-linearity generated in each of the two output channels. IMD measurements would be sensitive to crosstalk but the standard tests indicated that this was not a problem.

Further tests using IMD were undertaken to see if the non-linearity of the ADC became worse at higher frequencies. An IMD analogue test signal was generated by using the left and right output channels and summing the outputs linearly. In principle this should provide an IMD test signal that was not limited by DAC non-linearity so can measure the ADC performance with precision. This method is described next.

2.2. Single channel IMD loop test

IMD test waveforms were synthesised and analysed using PC based commercially available software [6]. Figure 4 depicts the test arrangement:

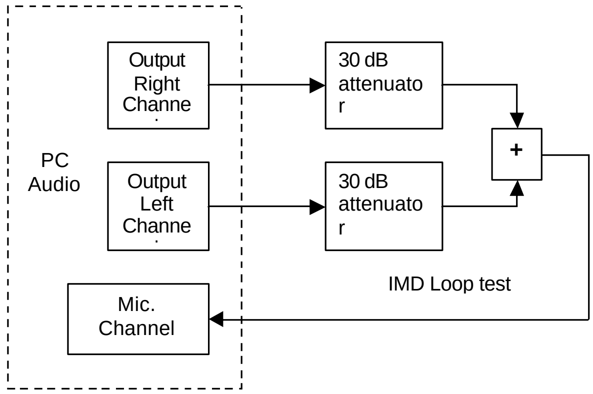

Figure 4 IMD loop test

Sine wave signals of nominally equal amplitude were generated at the output of each channel. The microphone amplifier was set to a gain of 30 dB approximately. Passive summing was used to maintain linearity and 30 dB passive attenuators enabled the outputs of the two DACs to be isolated by at least 60 dB. The gain of the microphone amplifier was then set to ensure that the ADC was driven to near full scale range at maximum input. IMD was measured with a 70Hz difference frequency at octave centre frequencies ranging from 250 Hz to 16 kHz. Measurements were repeated with the digital test waveform amplitude reduced in 5 dB steps from -0.1 dBFS to –20.1 dBFS. 0 dBFS corresponded to the digital full scale range of the DAC. The amplitude in the legends of figure 5 and 6 is relative to the DAC digital input full scale of -0.1 dBFS.

Only one channel of the stereo ADC had so far been used for IMD testing. The next part of the investigation used both channels of the ADC in order to eliminate the possibility of the microphone amplifier, ADC or summing network introducing the non-linear crosstalk.

2.3. Two channel IMD loop test

The test configuration depicted in Figure 2 was used again but now with each channel driven by one of the two tones. No summing network was used and neither ADC was overdriven. Left and right ADC output waveforms were summed in the analysis software so producing the equivalent of the IMD loop test without analogue summing. As only one tone was present in each analogue input channel, ADC and amplifier non-linearity cannot generate IMD. Frequency dependent IMD has been observed with only one ADC channel so it also cannot be caused by non-linear crosstalk between two ADC channels. If, therefore, when F1 is applied to the left channel and F2 (less than F1) to the right channel it is observed that a signal at a frequency F1-F2 appears in the ADC output of both left and right channels then this must be due to non-linear cross talk between DAC channels and to no other mechanism.

These test methods can therefore enable the source of the IMD to be identified and the results are described next.

3. IMD RESULTS

The IMD test methods have been described earlier. The results of applying the MD test to a stereo pair, calculated after summing the ADC outputs digitally, are presented next.

Figure 5 shows that the second order IMD value is proportional to the centre frequency of the waveform. At high signal frequencies it also very sensitive to amplitude so may be caused, for example, by a slew rate limitation in the circuitry.

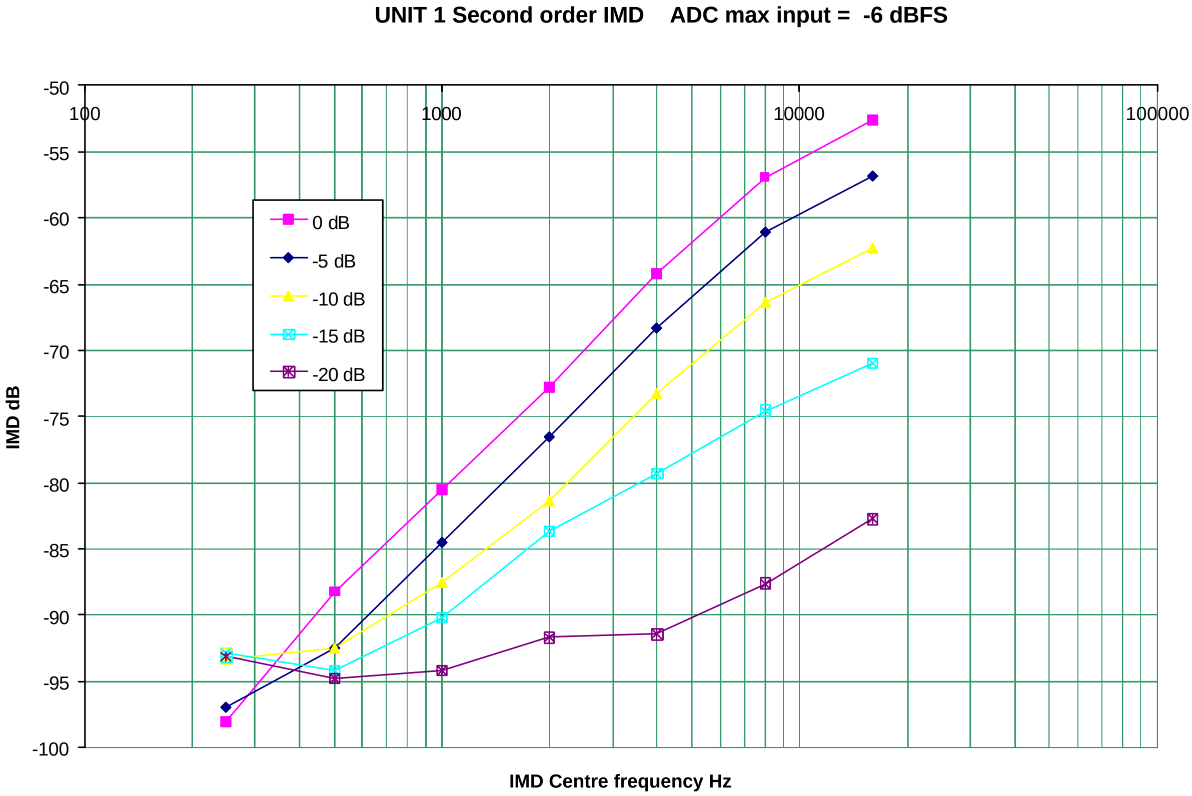

Figure 5 UNIT 1 IMD test results

In contrast with Figure 5, the IMD results for figure 6 indicate that non-linear cross talk is not obviously frequency dependent. The results indicate that the analogue noise floor of the unit may be a limit.

The results of Figure 5 and 6 are close to the results obtained using the configuration of Figure 2. The results of these tests have now demonstrated that non-linear cross talk between the channels of the stereo DAC was responsible for the frequency dependent IMD.

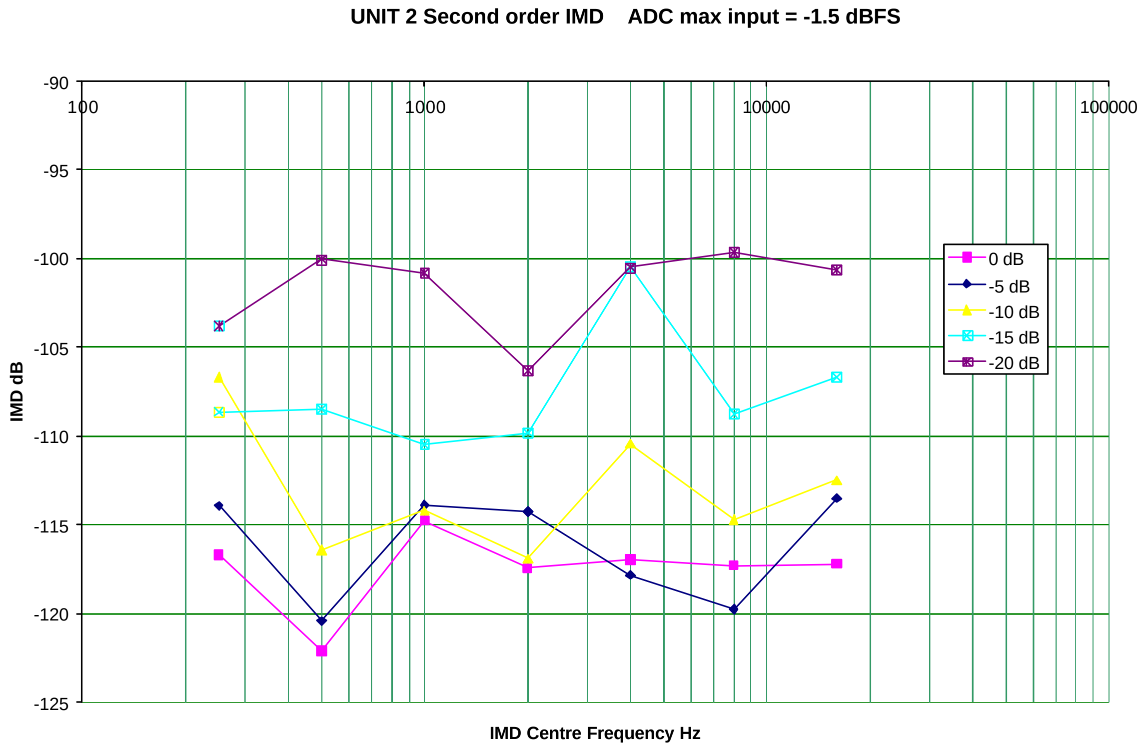

Figure 6 UNIT 2 IMD test results

If this stereo non-linear cross talk test is first used to check DAC performance then it is clear that the IMD loop test of figure 4 can then be used to measure the IMD of each ADC. IMD cross talk results will then indicate the limit of ADC measurement precision.

4. CONCLUSIONS

The main conclusion of this investigation is that non-linear cross talk in a stereo DAC is an important problem that has not been addressed by existing standards [3,7]. Test methods have been described that enable this effect to be measured without using expensive commercial audio test and measurement hardware.

Precision measurement of microphone non-linearity can be limited by non-linear cross talk in the DACs used to generate the test signals. This is an issue for microphone manufacturers to be aware of if they are using test systems that employ a stereo DAC. Clearly, frequency dependent non -linear cross talk between the channels of a stereo DAC could degrade sound quality so is an issue that should be considered in audio reproduction systems.

It is recommended that non-linear cross talk measurements of PC based audio systems should be made with both channels driven by single tones of an IMD pair. It is also recommended that the use of an external passive summing network is included in IMD tests of stereo DACs and ADCs. This will provide greater precision in frequency dependent IMD testing of an ADC without the need for external filters and would facilitate the application of the new IEC standard for dynamic specification of ADCs through the use of low cost test equipment [8].

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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