Objective-Subjective Correlation of Measurements of Audio Non-linearity

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Background

- Director at Signal Conversion Ltd

Cardiff University (to 2015): Professor EE

University of California: Visiting Professor EE

Swansea University: Lecturer electronic engineering (EE)

NHS: Senior Medical Physicist (Velindre hospital)

BBC Engineering Research Department: Senior Engineer

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Audio non-linearity Research

- When non-linearity is present in audio circuits or systems the quality of the reproduced sound may be impaired
- It would be convenient is some objective measure of the non-linearity could be used to estimate, with reasonable accuracy, the degree of subjective impairment that the reproduced sound would suffer
- This would then reduce the need for listening tests in the quality assessment of the systems
- It has long been recognised that the conventional total harmonic distortion measurements are not in good agreement with the results of subjective listening tests

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Audio non-linearity Research

- A sine wave is the conventional test signal for measuring audio non-linearity but how often do we listen to sine waves?
- First investigations focussed on listening to the reproduced 1 kHz sine wave and relating the amplitude of the harmonics to their subjective annoyance value; THD is a linear sum of harmonic power
- 1950: Shorter “The influence of high order products on non-linear distortion”
- 1961: Wigan “New distortion criterion”

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Weighting of harmonic powers

- Each concluded that the THD should be weighted so that higher order harmonics have more power. Though each had a different equation for the weighted THD they both recommended that the weighting of n^{th} harmonic power is proportional to n^2 .
- Theory (Brockbank and Wass)can predict the total distortion power T generated by a multi-tone (100) test signal if the n^{th} harmonic power of a sine wave test is known (t_n).
- $T = 2^{n-1}$. n!. t_n and hence the harmonic weighting is n! 2^{n-1}
- N = 2, Wigan/Shorter 4; BandW 4;
- n = 3, Wigan/Shorter 9; BandW 24; (3.2 . 2.2)
- n = 4, Wigan/Shorter 16; BandW 192;(4.3.2 . 2.2.2)
- Multi-tone test signals may give better subjective-objective agreement but some distortion power may be lost in the measurement process and so reducing the weighting factor

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Intermodulation distortion

- Distortion power measured when two or more sine waves are used as the test signal.
- Enables the complete audio bandwidth to be tested by sweeping the pair of tones over the frequency range
- Amplitude-probability density function may not be representative of real audio signals
- Special type of multi-tone signal (psuedo random ‘noise’) can be produced that is a good model of real audio signals so should give better subjective-objective agreement

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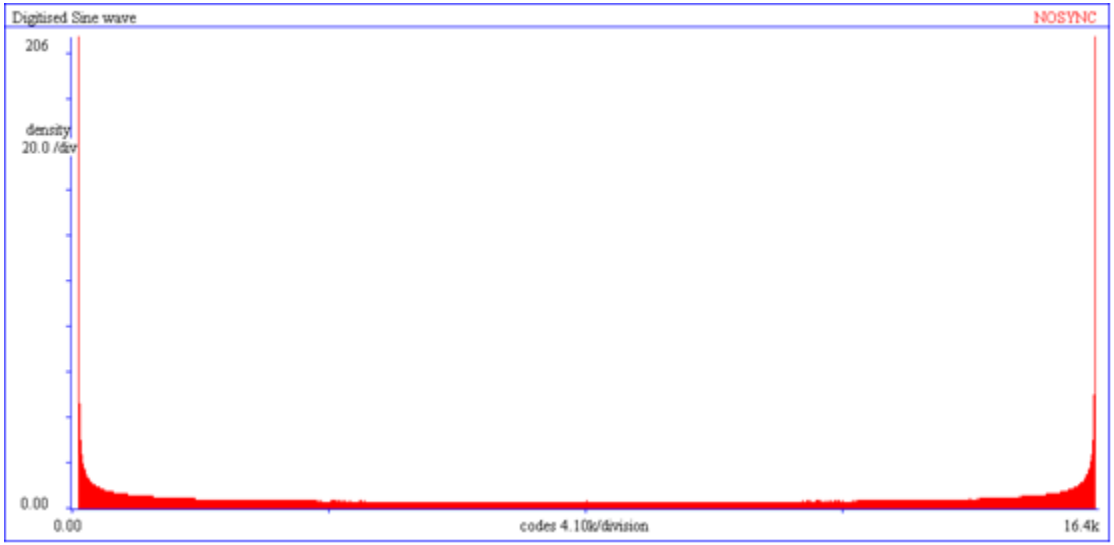
Sine wave Amplitude Probability Density Function



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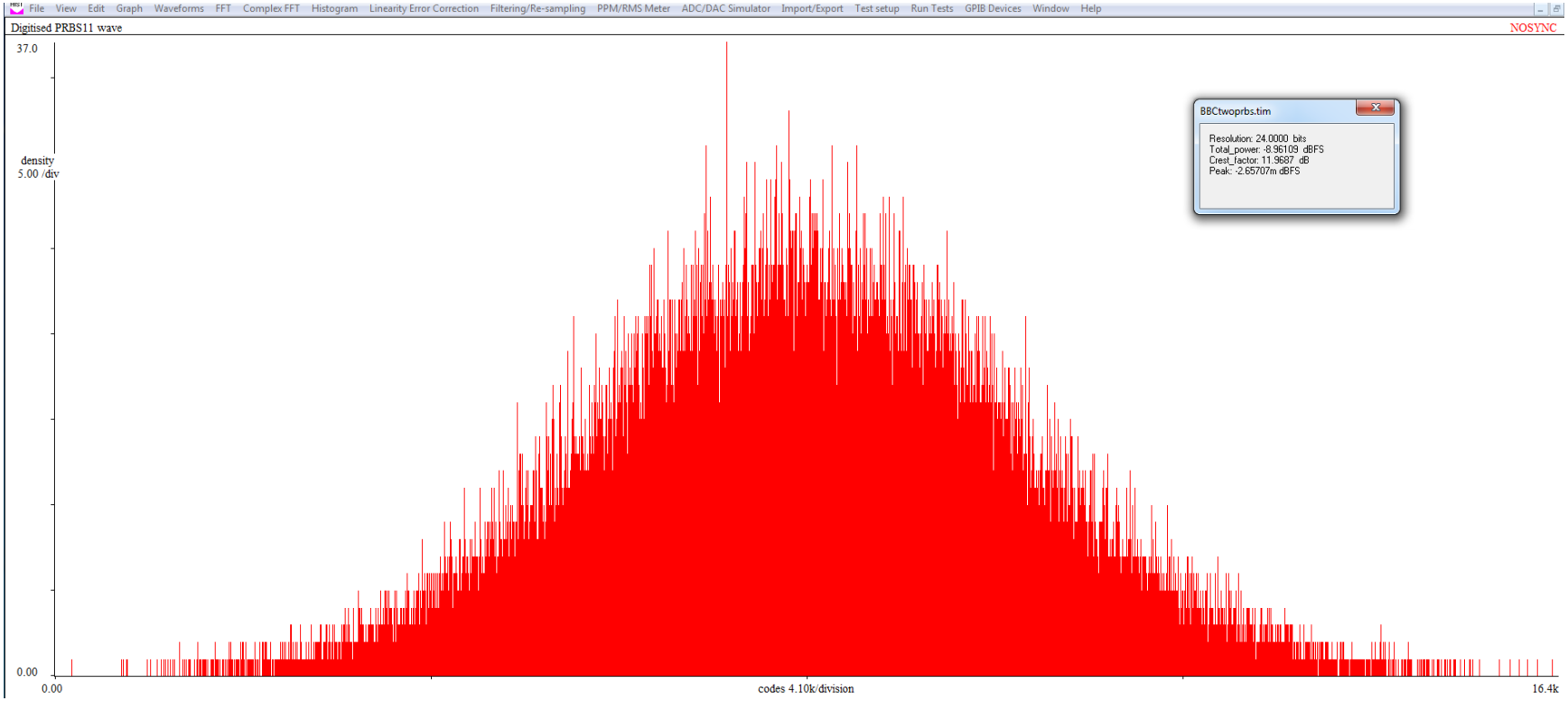
Amplitude probability density function of pseudo random signal



Sensitivity

- We are more likely to hear amplitude non-linearity for certain low level sounds
- Solo piano and is sensitive to low level amplitude non-linearity
- Orchestral recording much less sensitive to amplitude non-linearity
- Speech is a sensitive test for amplitude non-linearity

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CCIR 6 point impairment scale

The Six-Point Subjective Impairment Scale

GRADE	IMPAIRMENT
1	Imperceptible
2	Just perceptible
3	Definitely perceptible but not disturbing
4	Somewhat objectionable
5	Definitely objectionable
6	Unusable

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Test circuits

The Test Circuits

NUMBER	DESCRIPTION
1	Operational amplifier type '741
2	BBC transistorised amplifier type AM7/4
3	BBC thermionic amplifier type GPA/4A
4	Low-emission version of circuit 3

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Publications

- BBC RD - University of Surrey Collaborative PhD 1974-77
- Part of my Audio non-linearity research at BBC RD that generated BBC patent and award of 1976 IEE Gyr and Landis prize
- Researchgate.net : join to see my self archived audio related publications

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Research gate

- Measurement of alternative ENOB without a sine wave (IEEE 2015)
- Audio non-linearity: A comb filter method for measuring distortion (BBC RD 1974)
- Audio non-linearity: an initial appraisal of a double comb filter method of measurement (BBC RD 1976)
- A new distortion measurement (Wireless World 1978)

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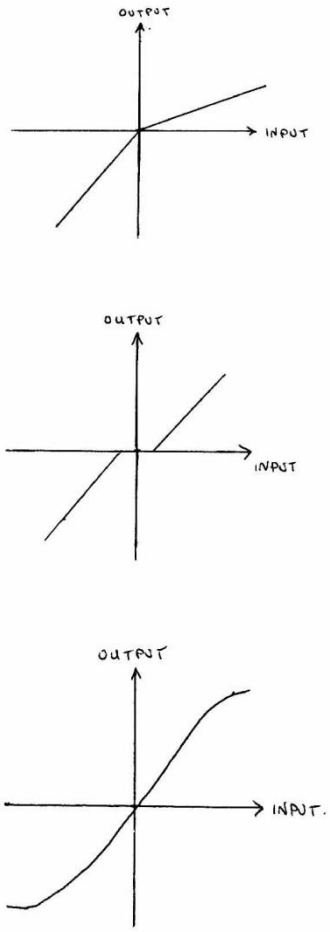
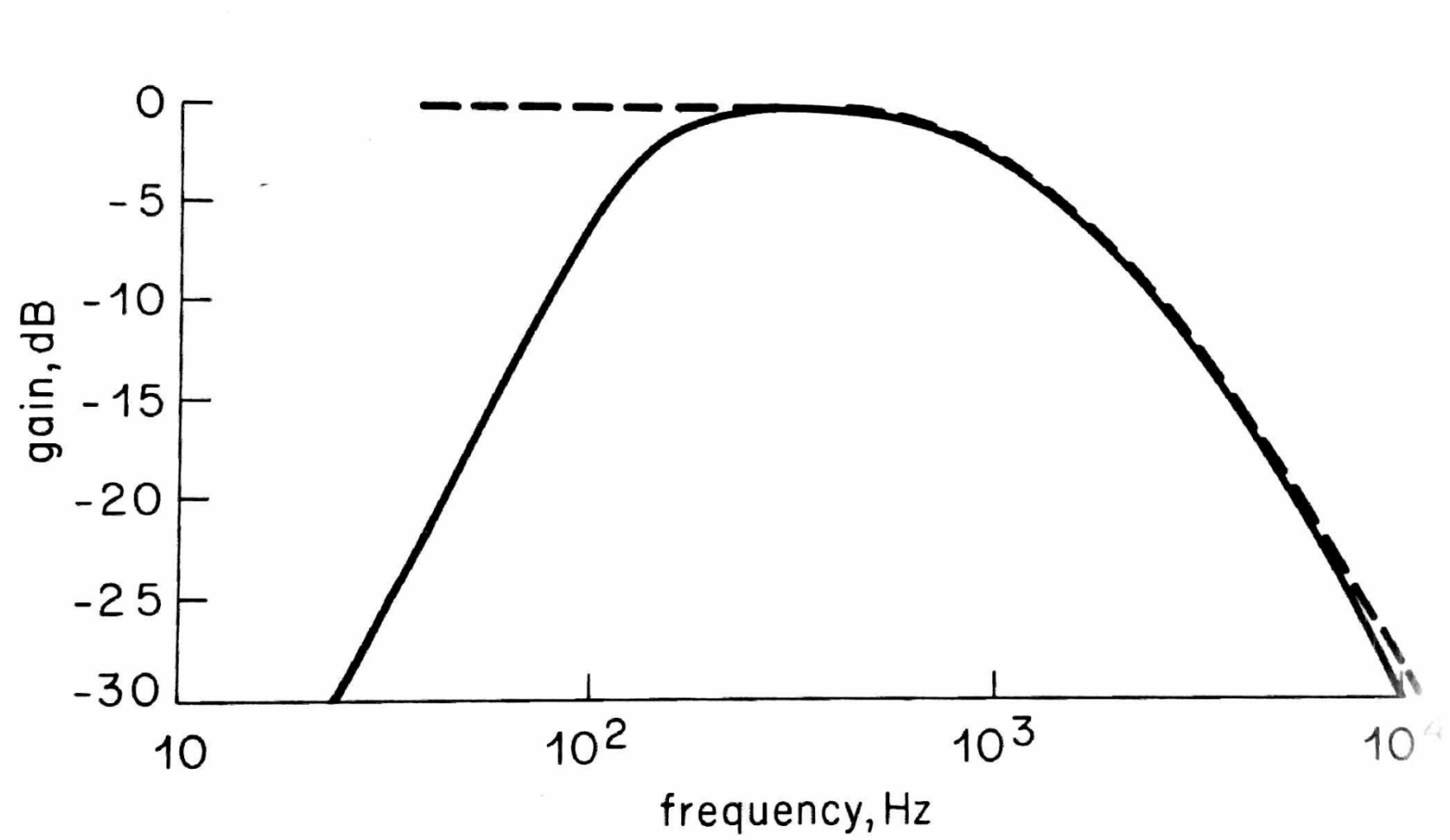
Typical amplifier input-output gain



CCIR average program spectrum



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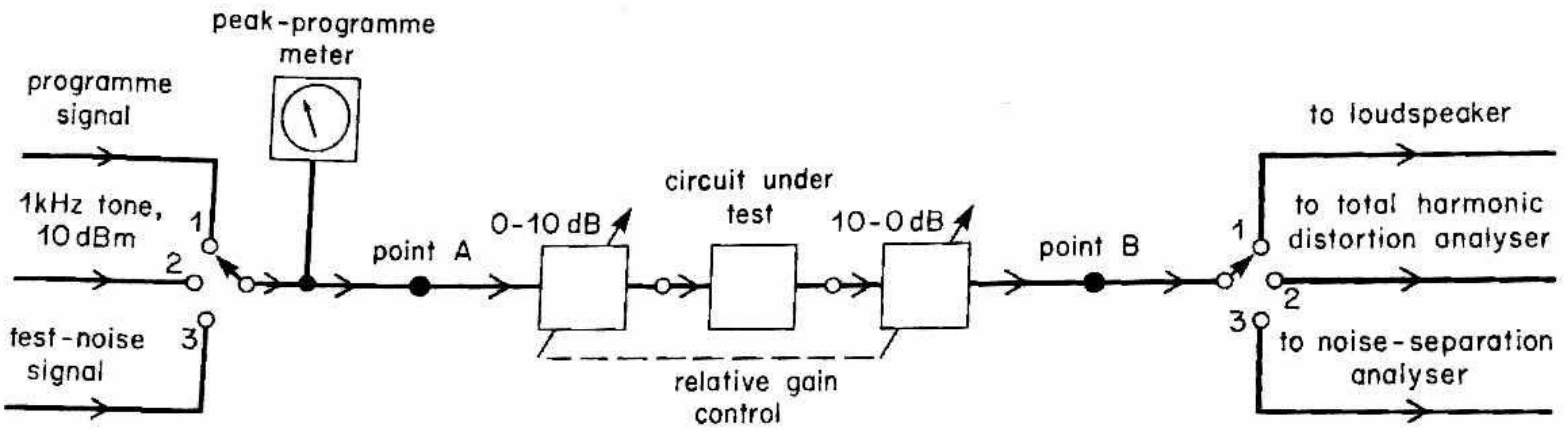
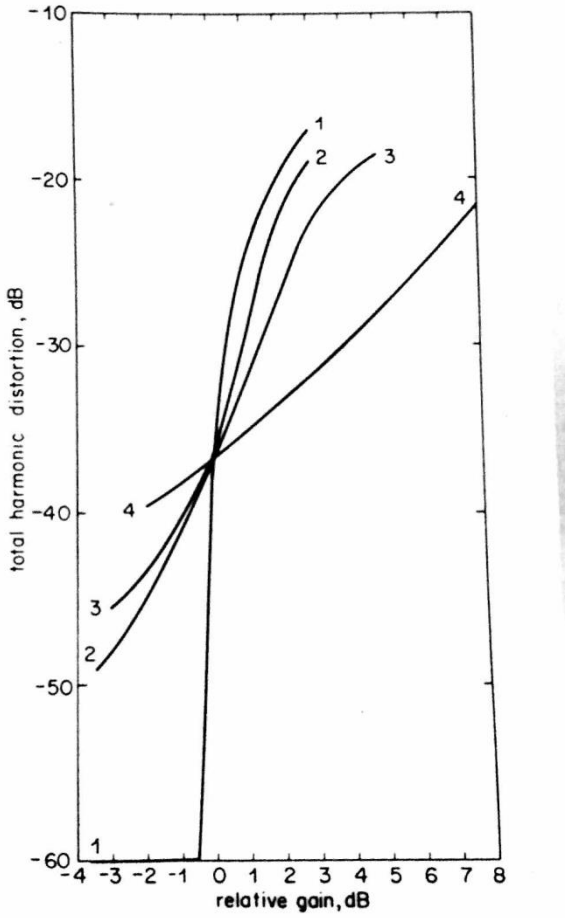
Subjective-objective experiment relative gain control



THD test results for amplifiers 1-4



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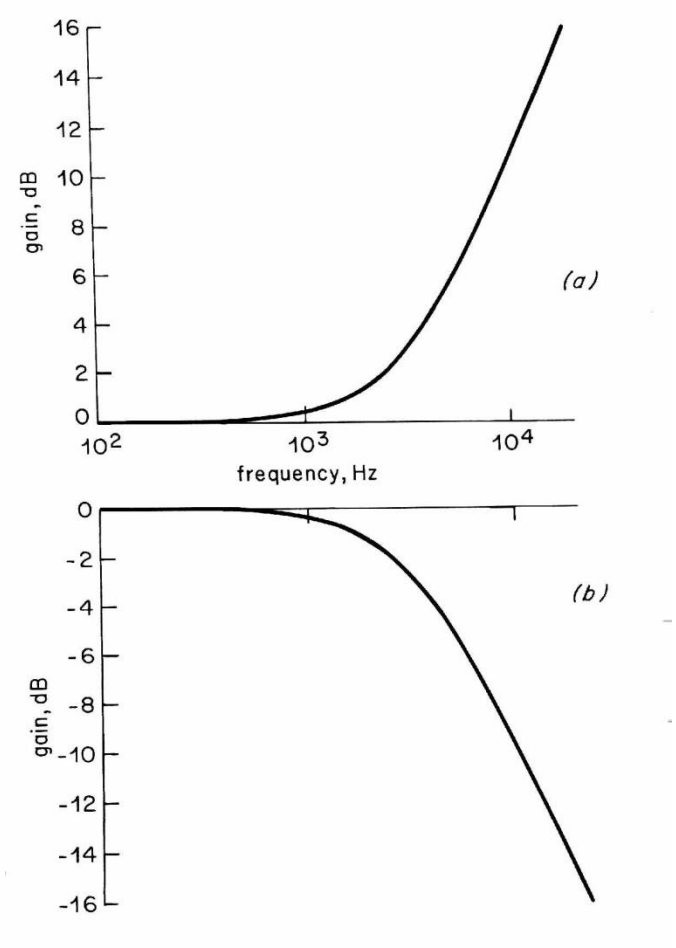
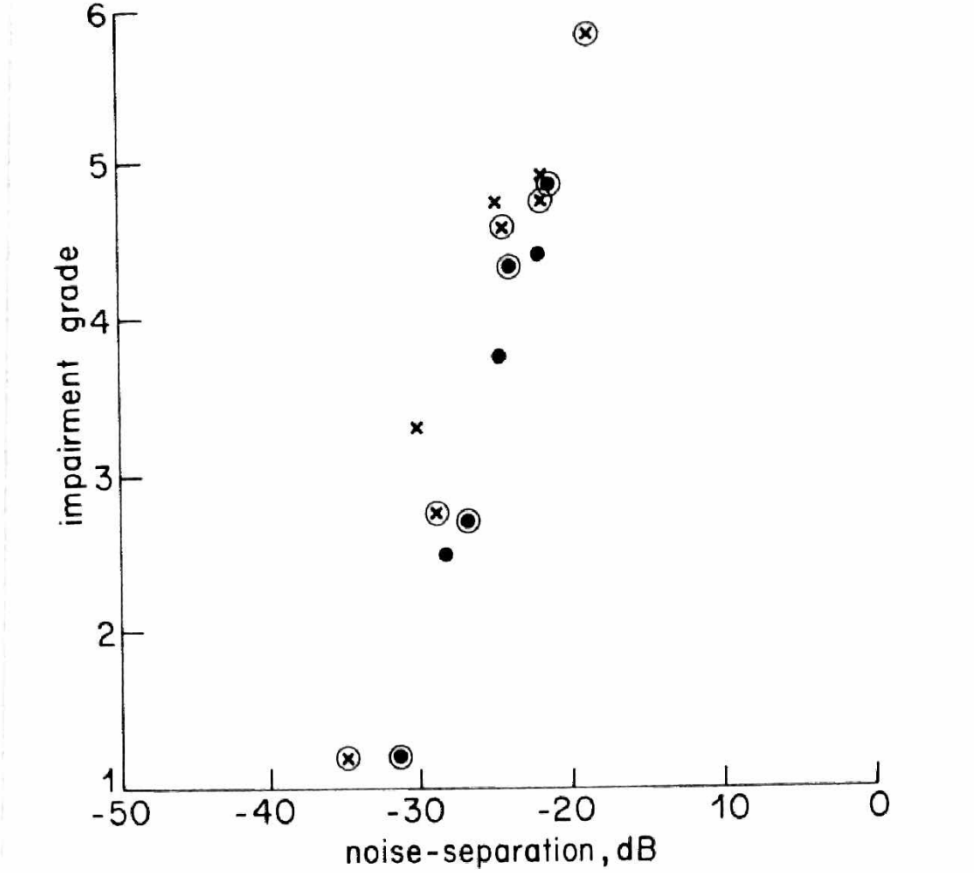
FM pre and de emphasis



Subjective-objective correlation amplifiers 1 and 2 with/without FM pre-emphasis



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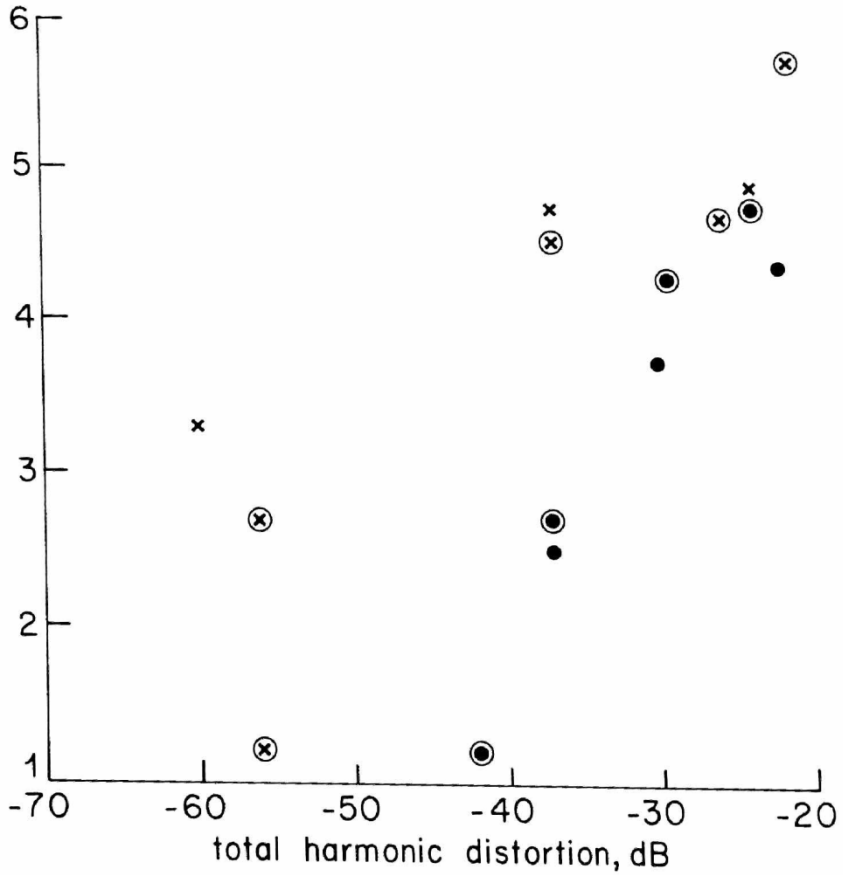
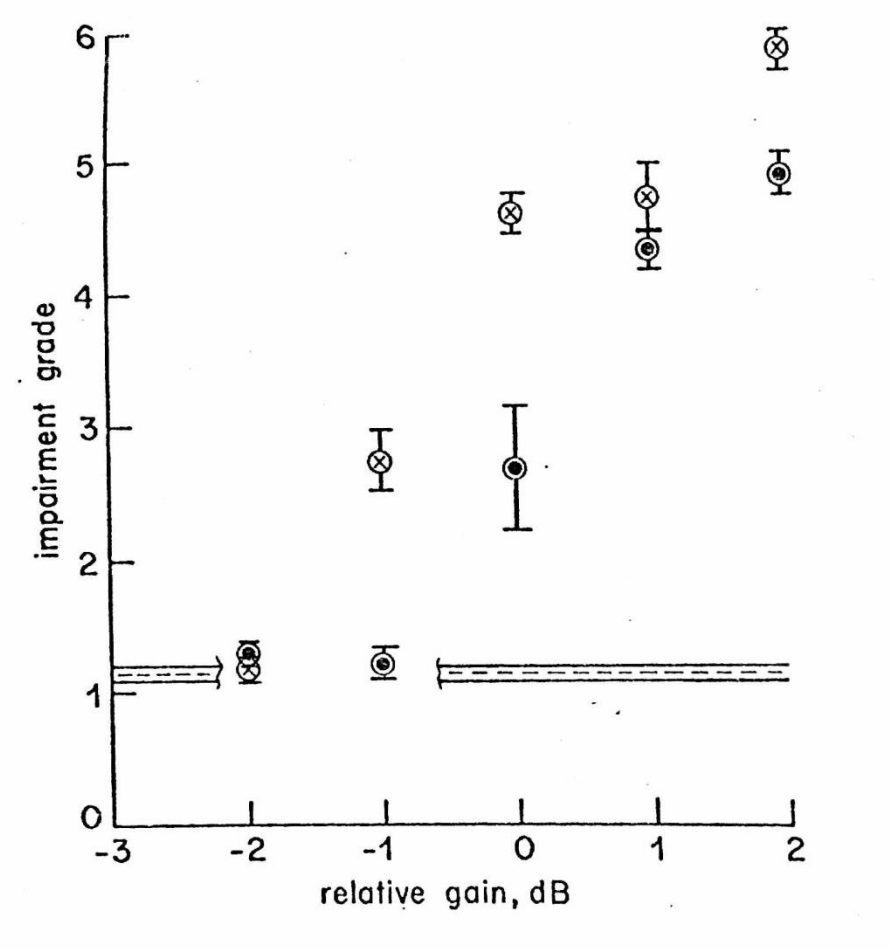


Subjective impairment vs relative gain solo piano



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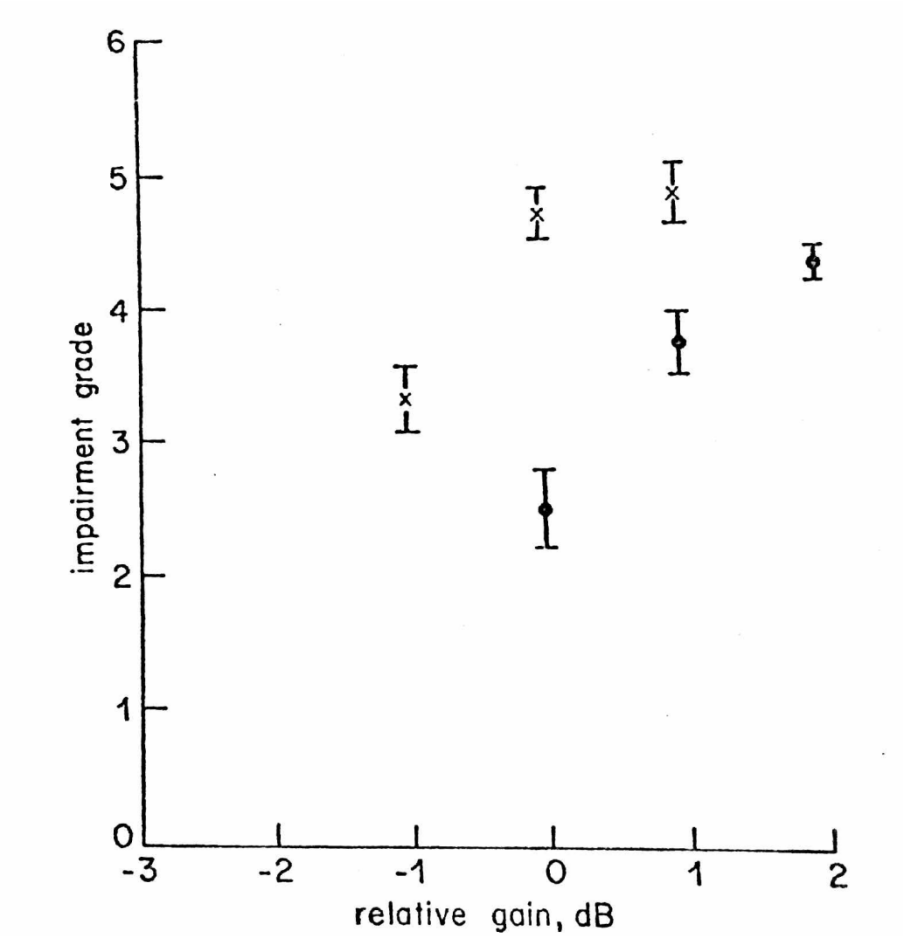
Subjective impairment vs relative gain male speech



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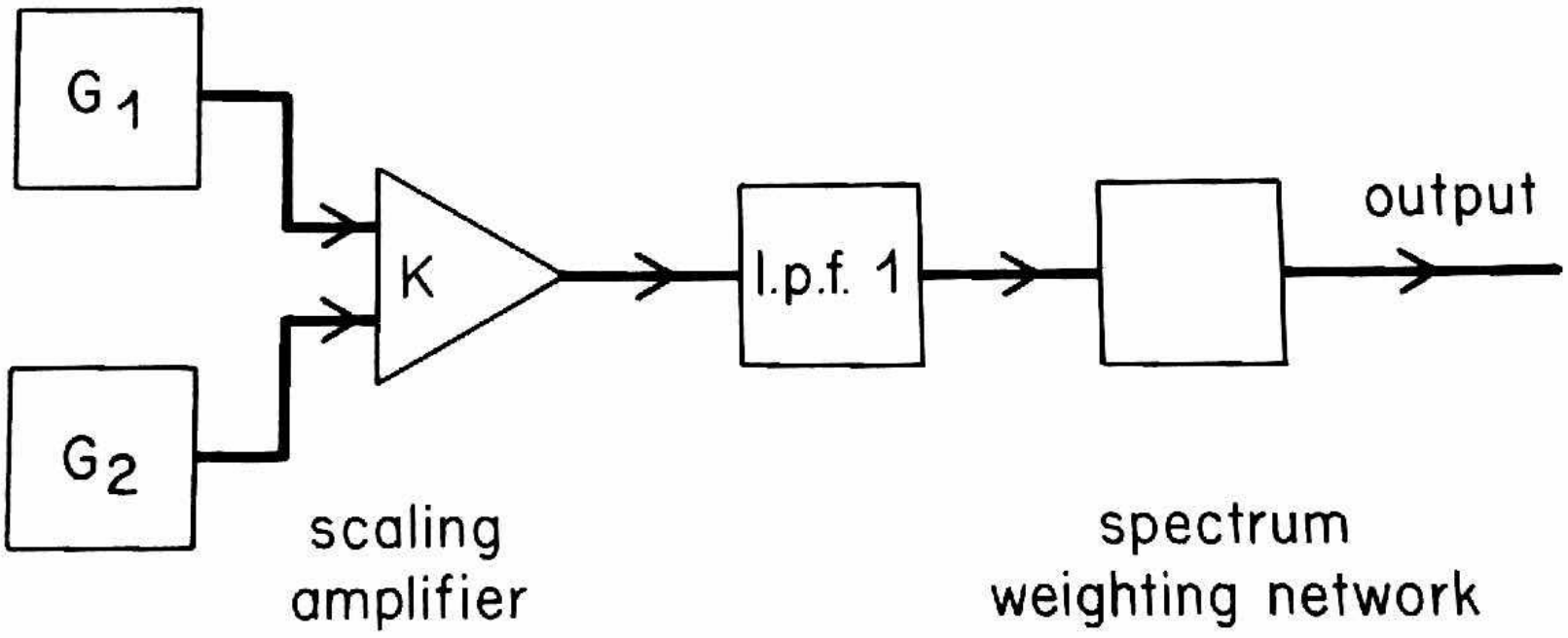
DCF Test signal generator



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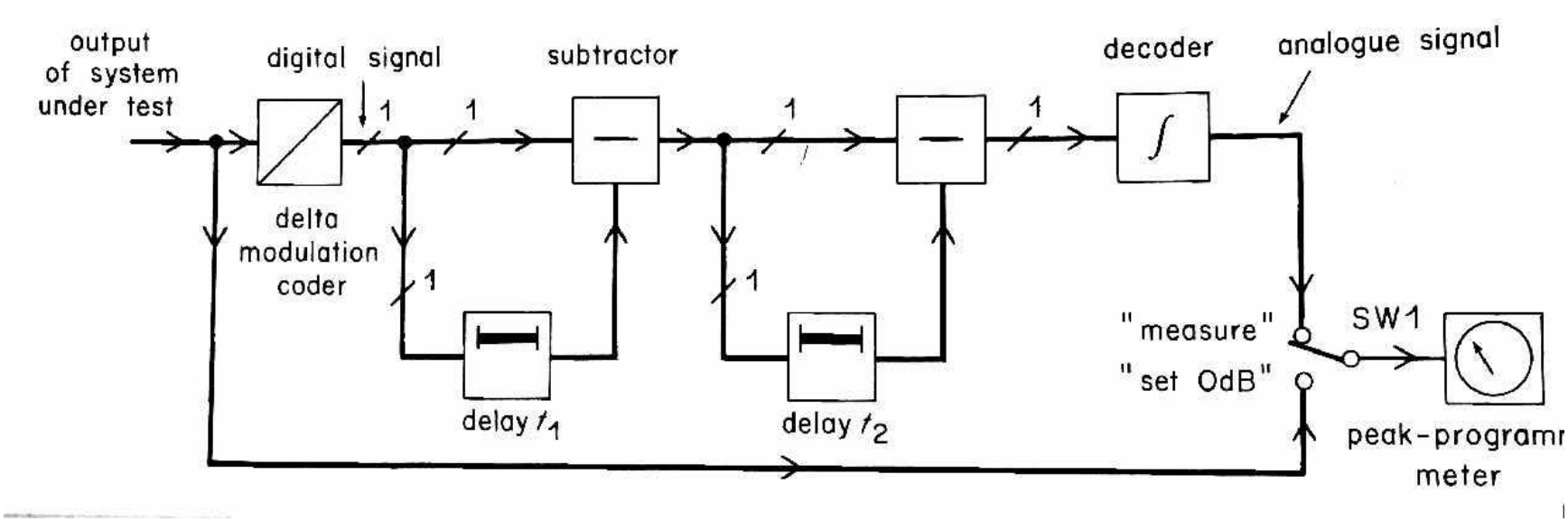
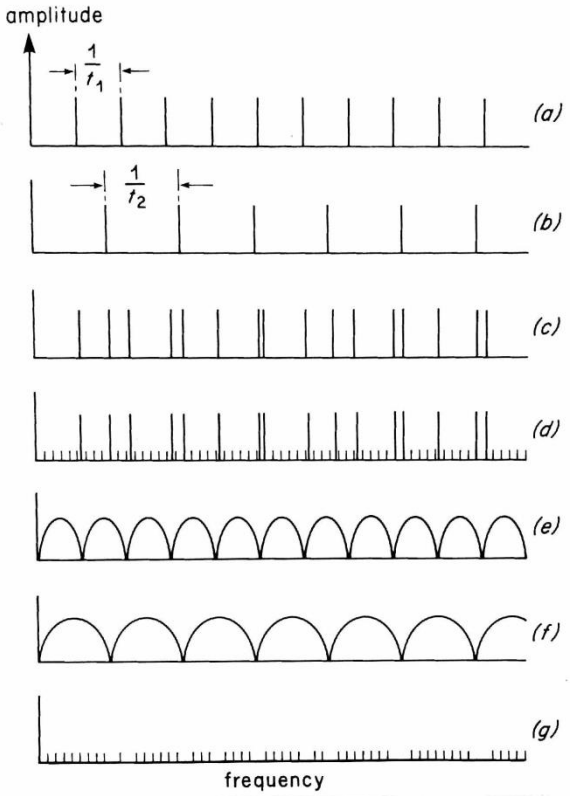
DCF test signal analyser



Spectra in DCF tests



t_1 = repetition period of m-sequence G_1
t_2 = repetition period of m-sequence G_2
(a) m-sequence G_1 (b) m-sequence G_2 (c) Test signal
(d) signal from system under test (e) First comb response
(f) second comb response (g) Output from comb filters

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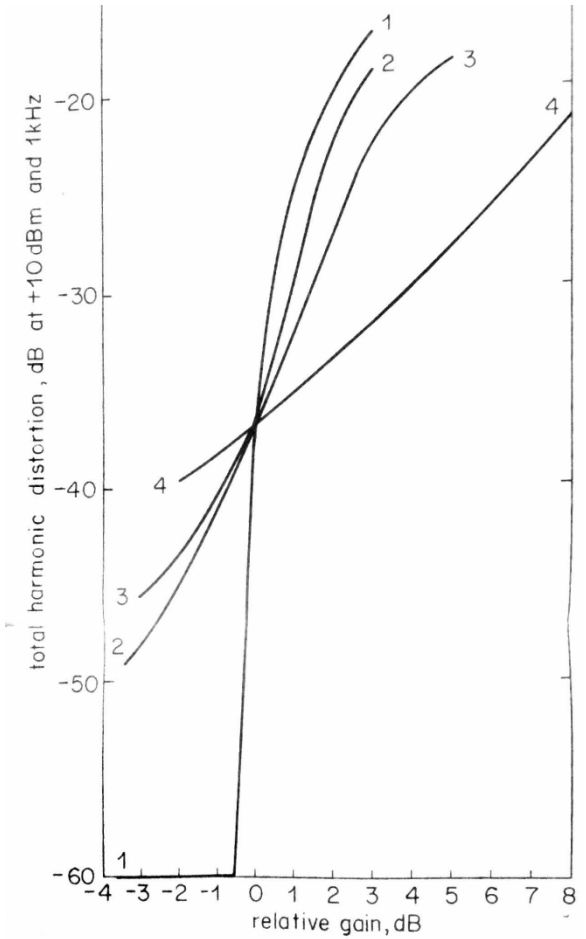
THD vs relative gain amplifiers 1-4



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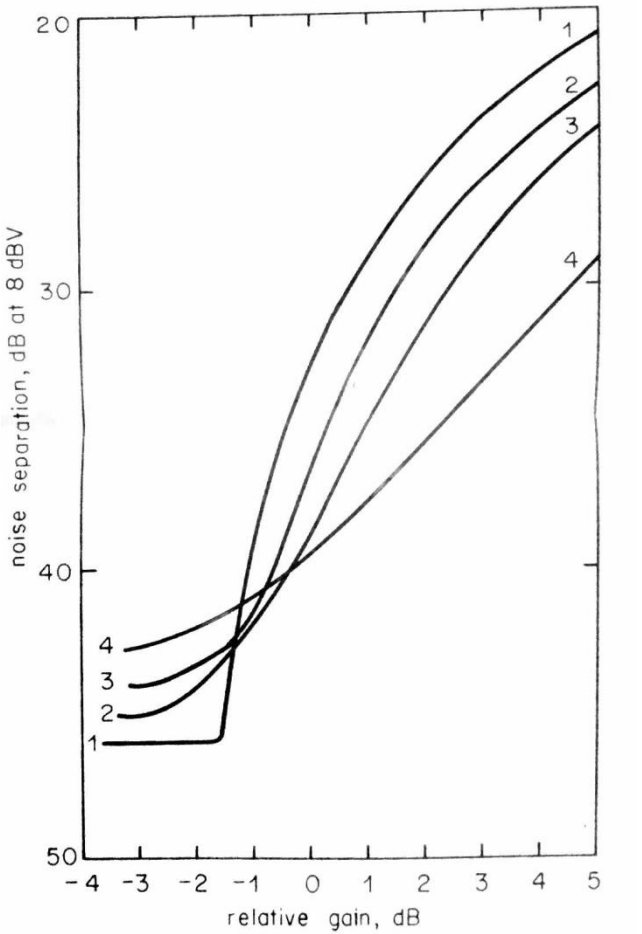
DCF ‘noise separation’ vs relative gain



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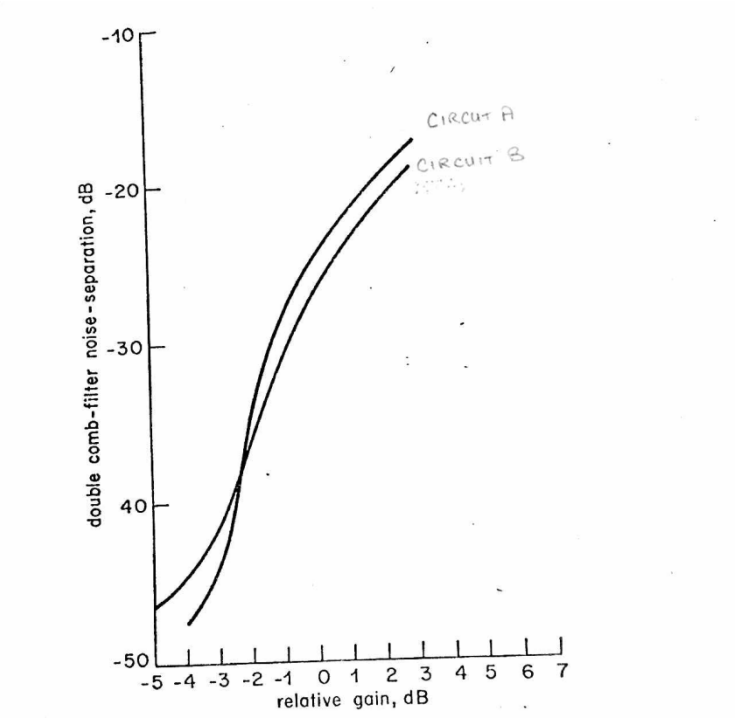
DCF circuits 1 and 2 with pre and de emphasis



- Double comb-filter noise-separation versus relative g
for test circuits with pre and de-emphasis.

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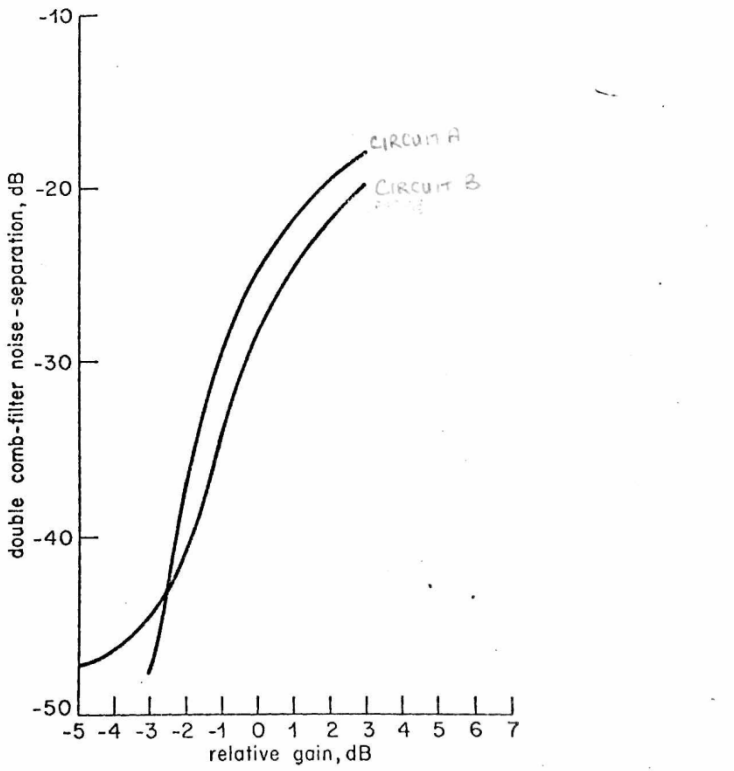
DCF circuits 1 and 2 without pre and de emphasis



Double comb-filter noise-separation versus relative gai
for test circuits without pre and de-emphasis.

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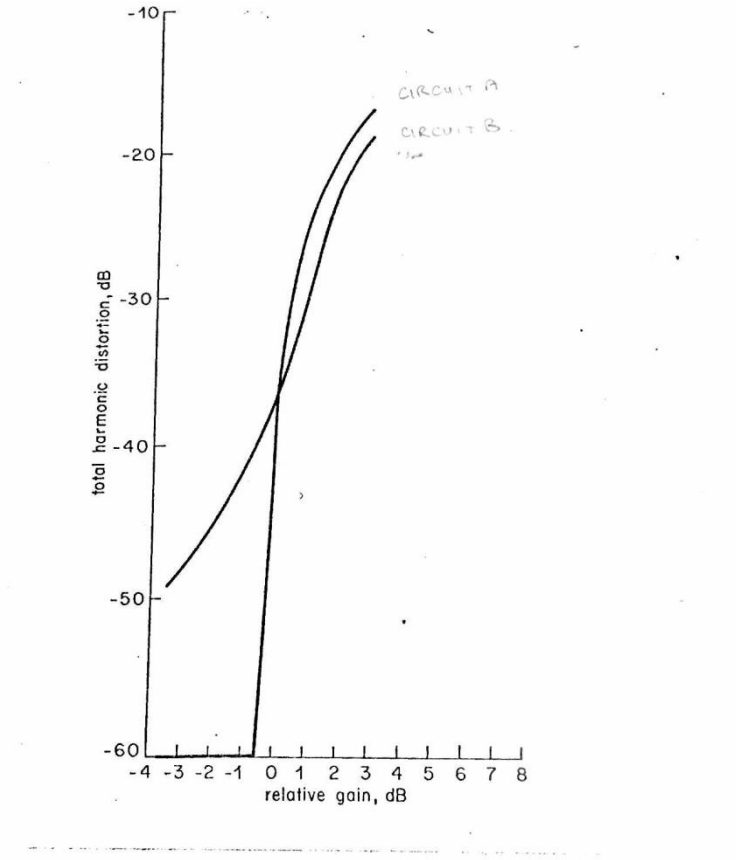
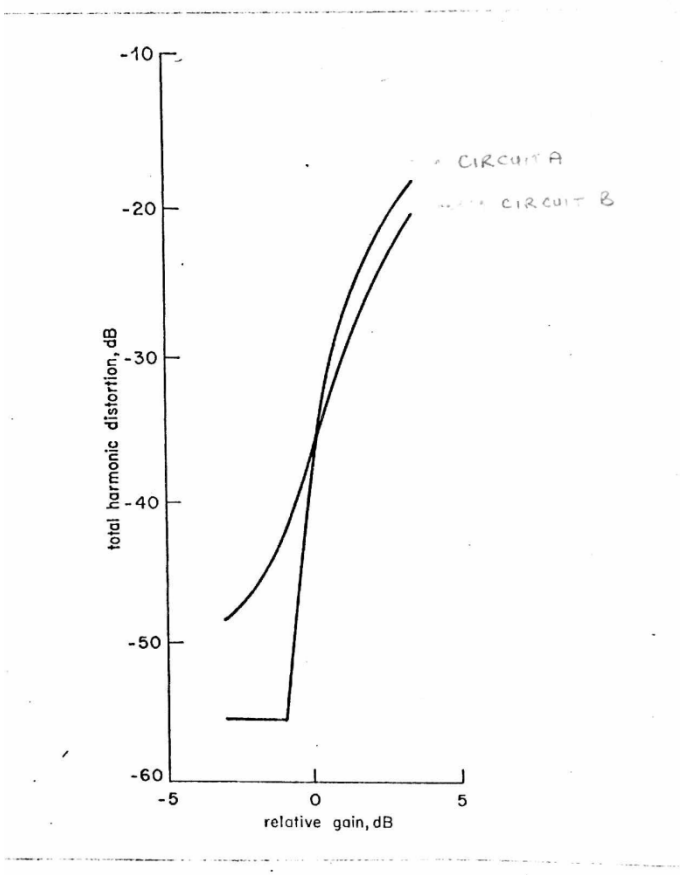
THD for circuits 1 and 2 without pre and de emphasis



Total harmonic distortion versus relative gain for test circuits without pre and de-emphasis.

THD for circuits 1 and 2 with pre and de emphasis



- Total harmonic distortion versus relative gain for test circuits with pre and de-emphasis.

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Amplifier 3 and 4

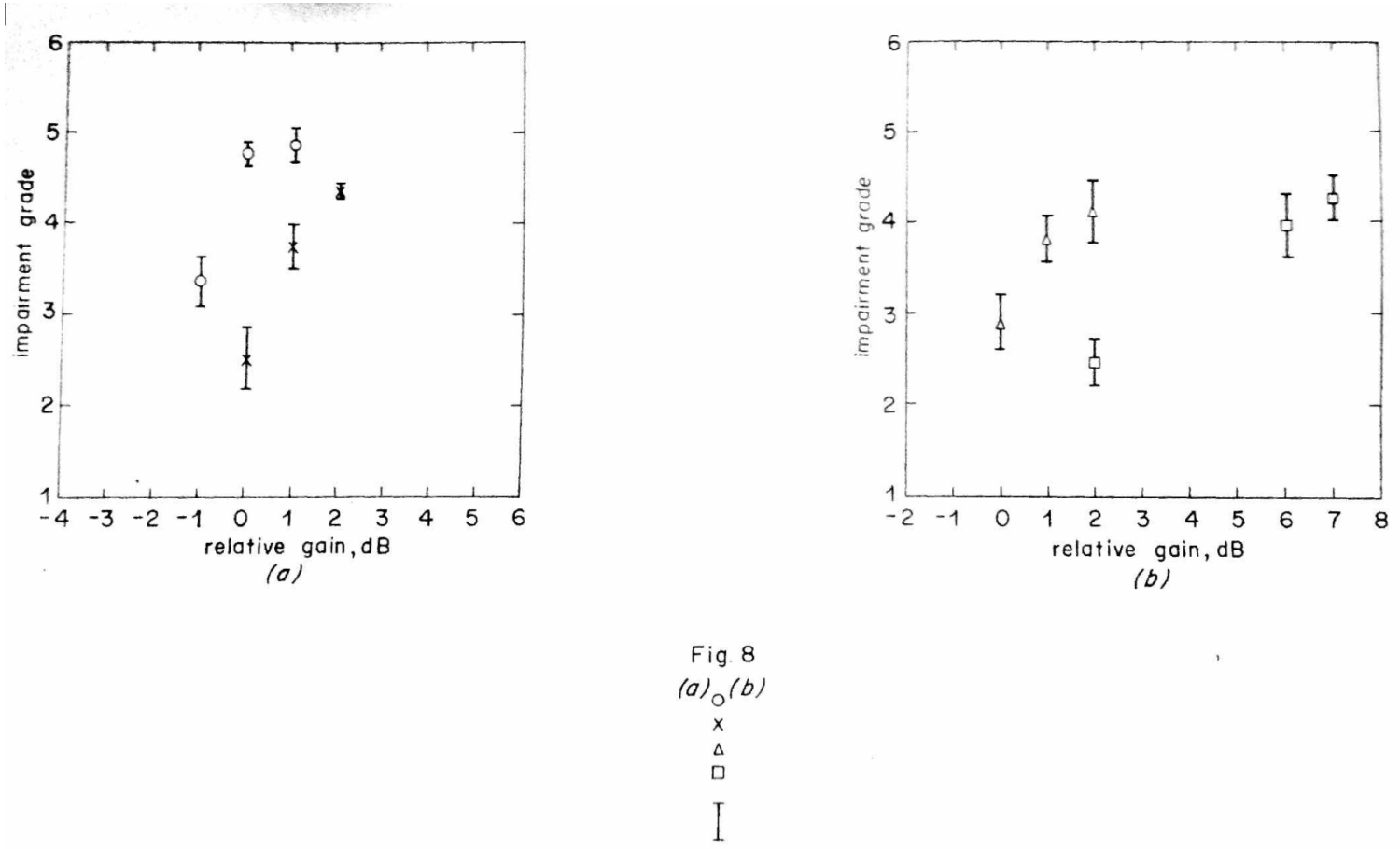

Fig. 8
(a) ○ (b)
×
△
□

Amplifier 3 and 4

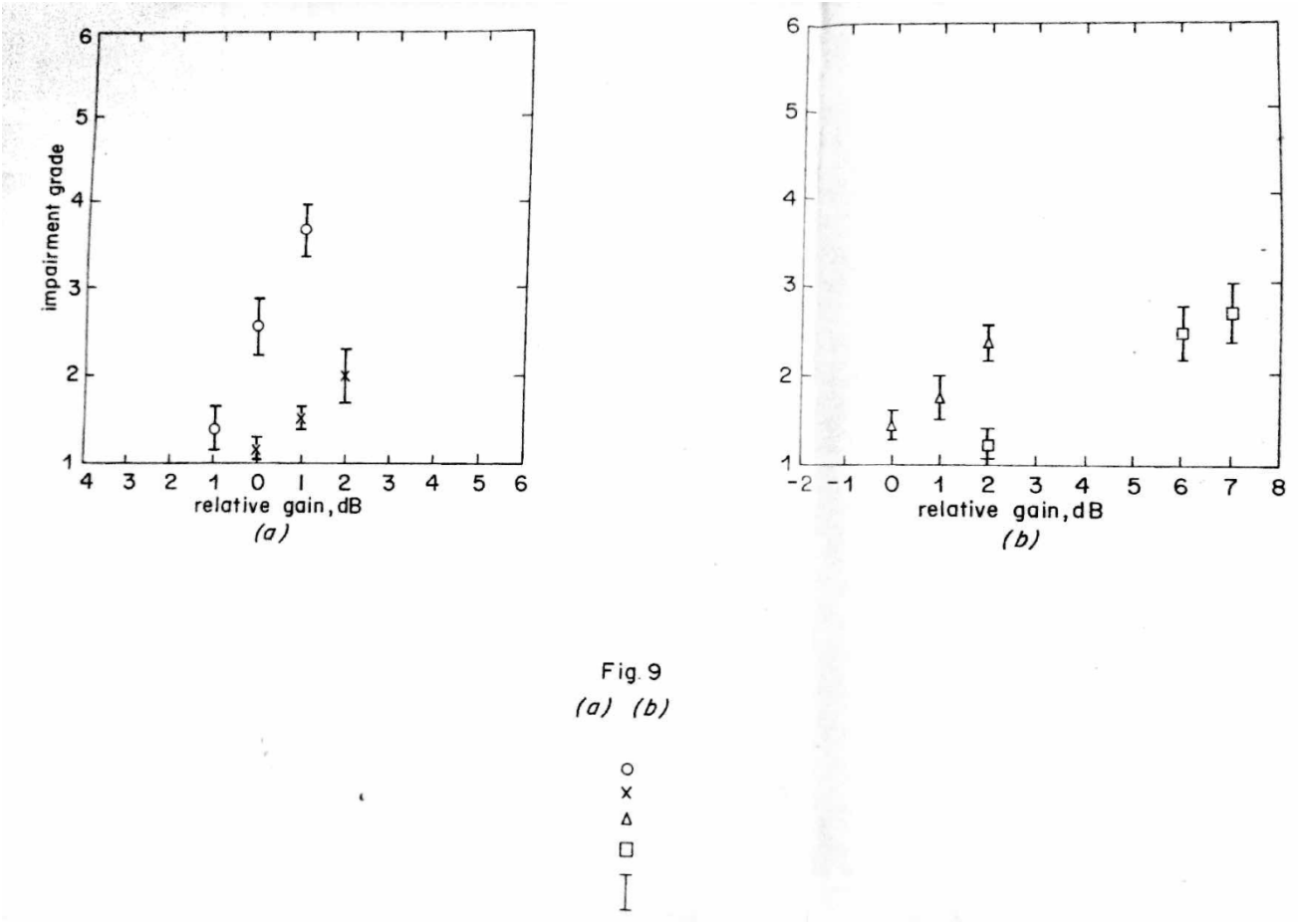

Fig. 9
(a) (b)

How easy is to use it now for testing audio non-linearity?

Signal Conversion Ltd WinSATS software makes is easy.

- Any software that plays and captures digital audio waveform files from a sound card or iphone can make the files needed for the measurement
- The DCF method is also used for very high precision measurements of non-linearity in acoustic and electronic circuits

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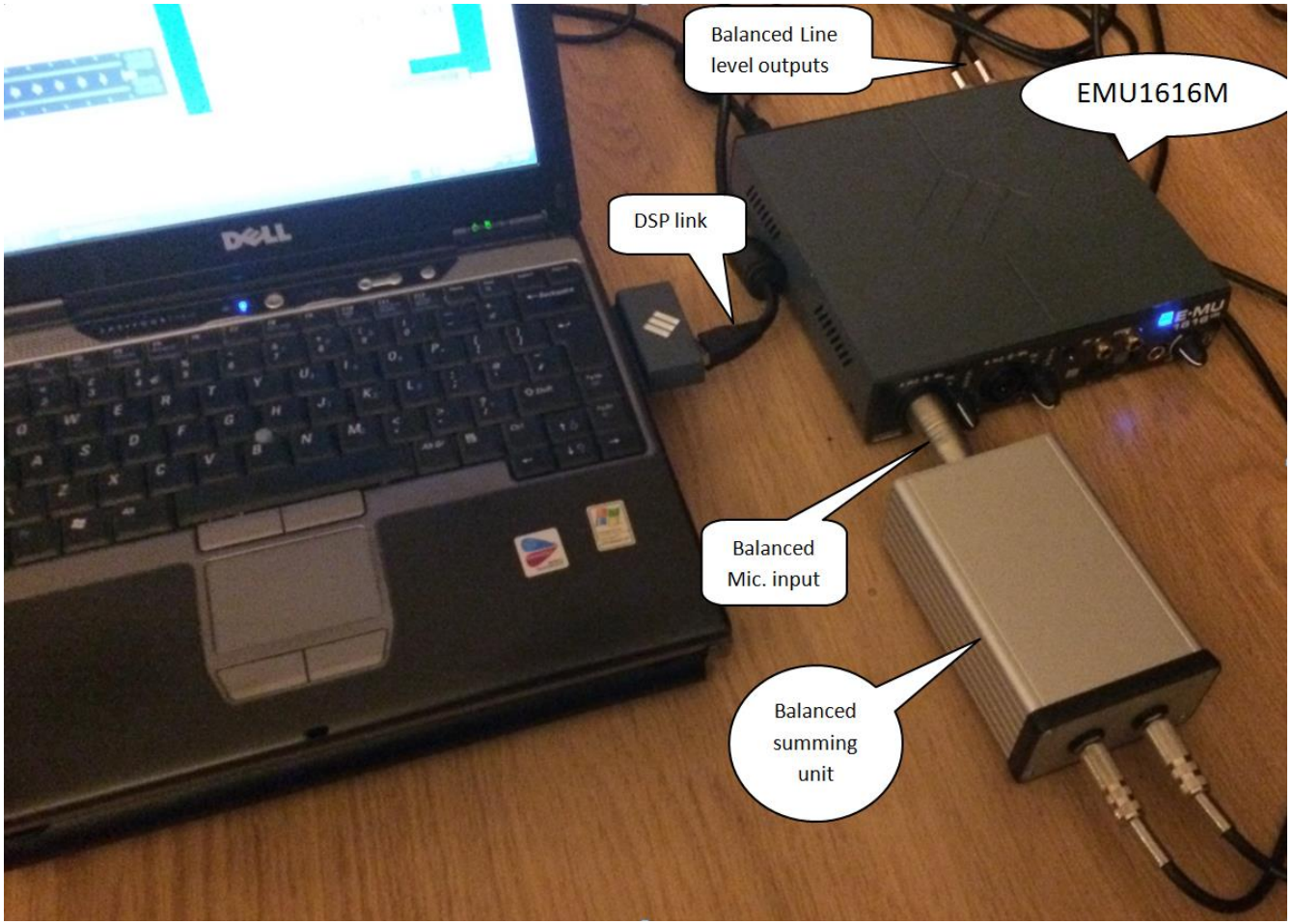
WinSATS and PC audio DCF measurement



Analogue to Digital Converter (ADC) test standards

IEC standard 60748-4-3 (Dynamic tests for analogue to digital converters) specifies a wideband routine test for non-linearity using two pseudo random signals.

Sometimes known as the Double Comb Filter (DCF) method.

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DCF also used for testing circuits, microphones and loudspeakers

- All must have an ADC and digital signal processing.

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DCF test method

In principle it offers unlimited precision in measuring in-band and out of band non-linearity.

Coefficient values of non-linear transfer function can be determined.

Waveform processing only: no FFT, low DSP overhead so minimum power

Digitally generated multi-tone test signals

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DCF Multi-tone test signal: Pseudo random bit sequences

- Periodic Sequence of 1's and 0's
- Generated using ***n*** flip-flops with selective feedback
- Sequence length = $2^n - 1$
- Multi-tone Spectrum is harmonics of base frequency
- Base Frequency = Clock frequency / Sequence length

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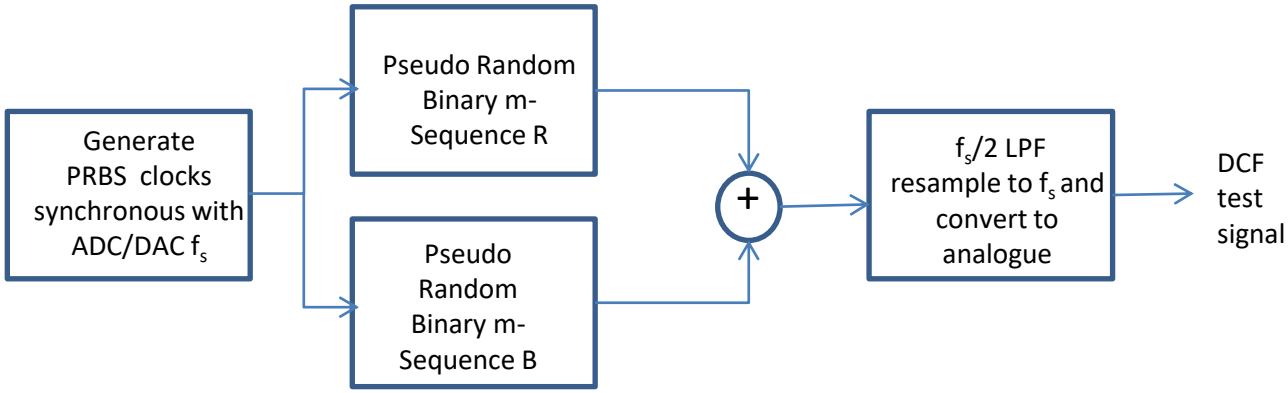
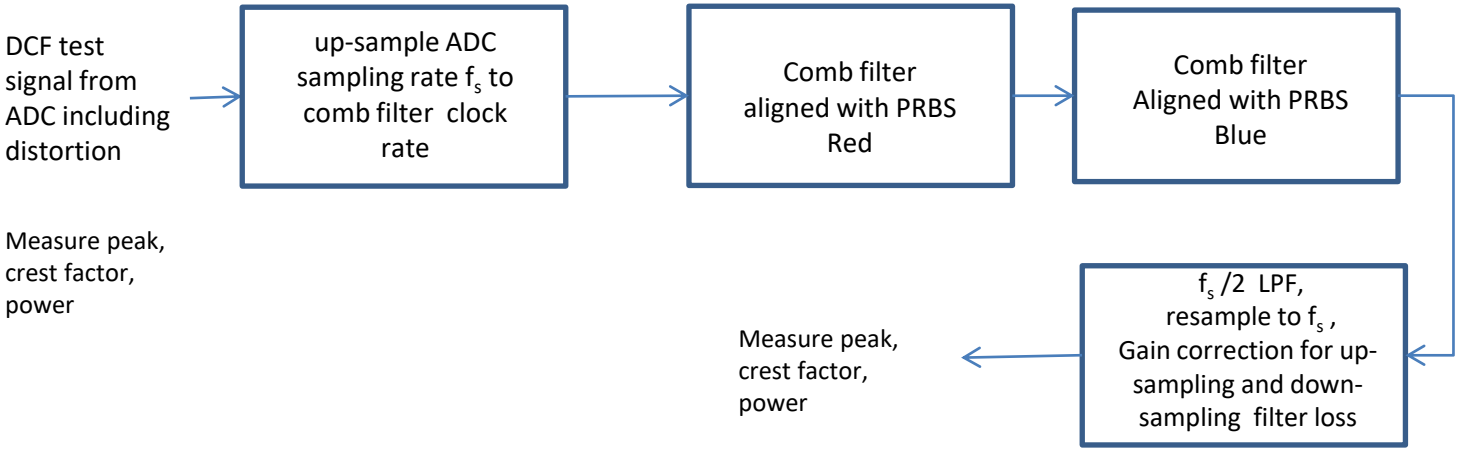


Synchronous DCF test signal generator



Signal processing for DCF measurement

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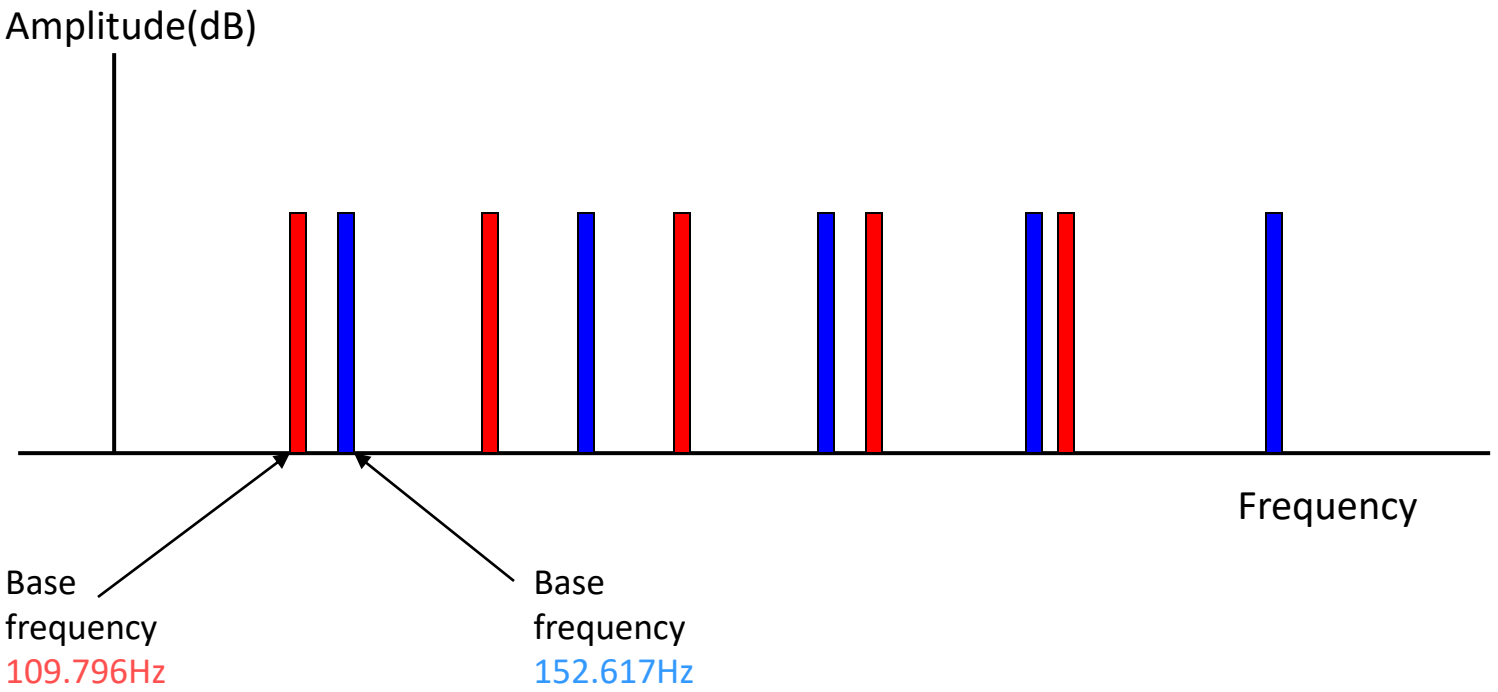
Test Signal Generator



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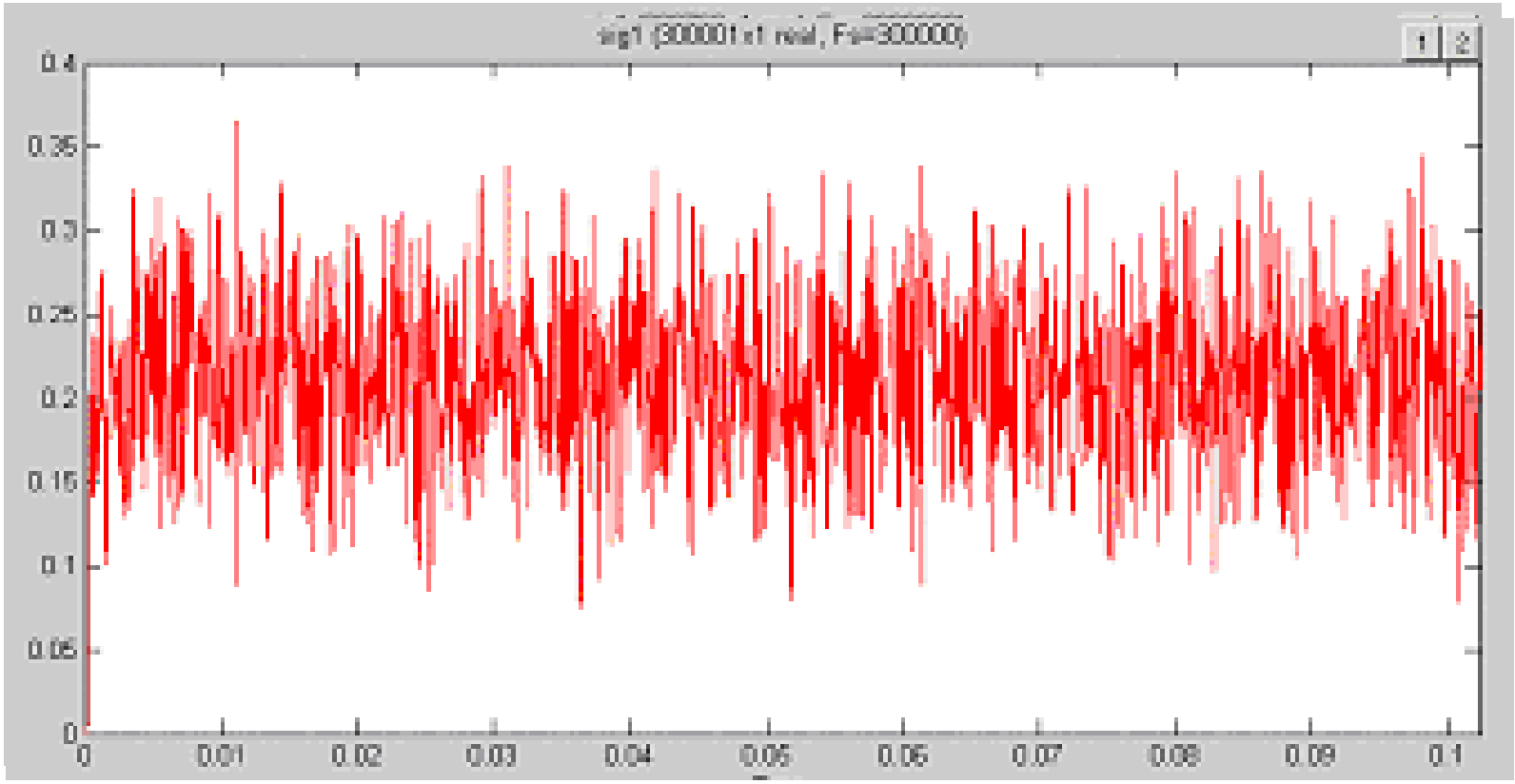
Generator Waveforms



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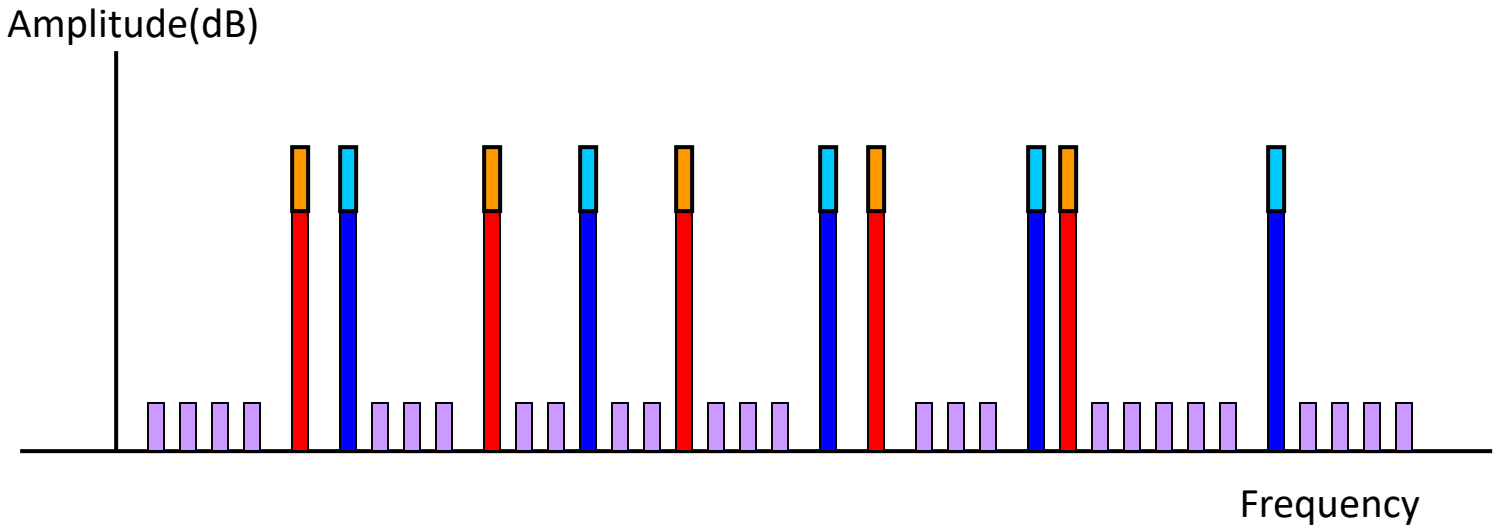
System Under Test

Distortion spectra generated by ADC/DAC under test appears *between* test signal and *on top* of test signal



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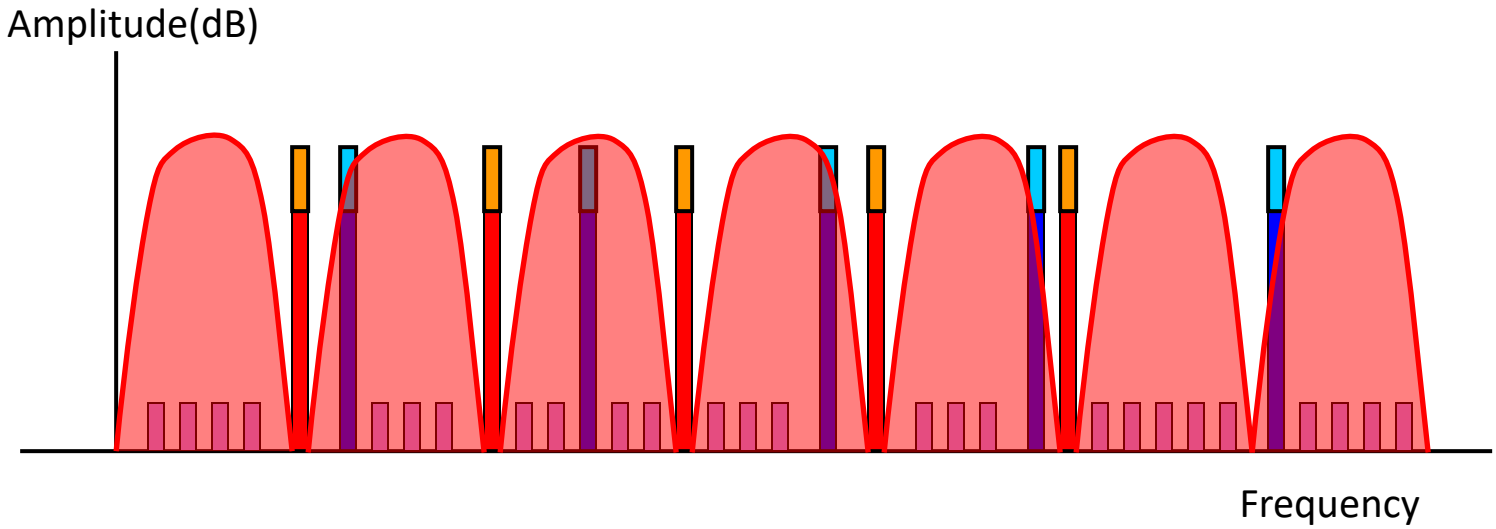
Test Signal Analyser

Red comb filter aligned with Red prbs spectrum



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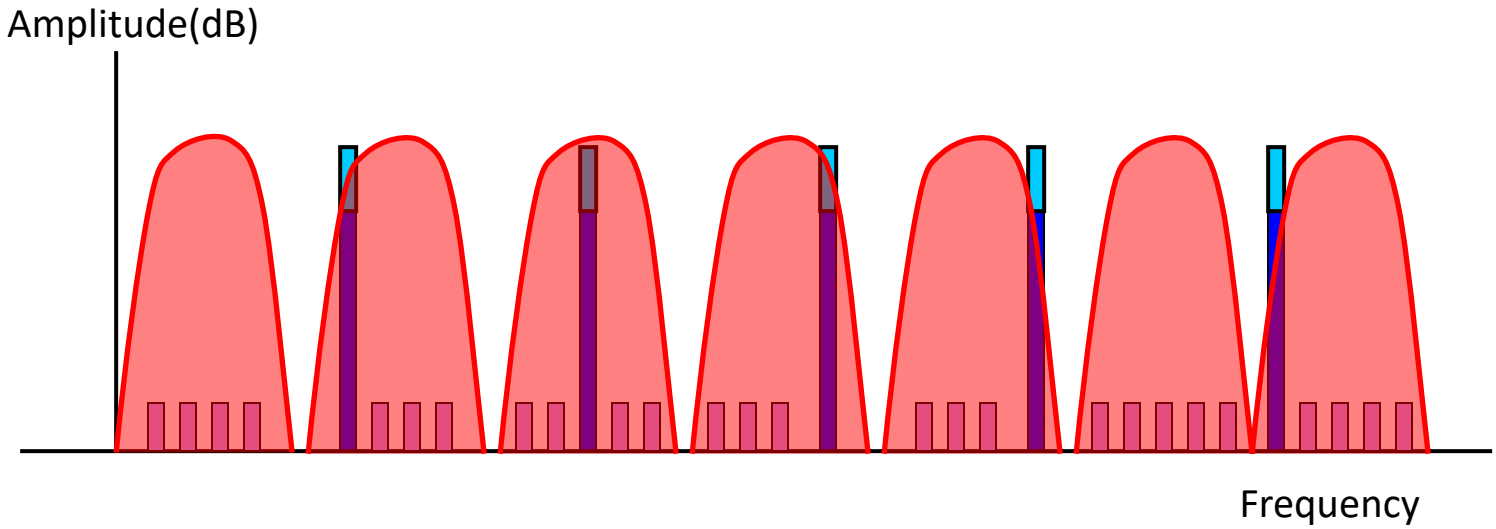
Test Signal Analyser

- Red PRBS spectrum removed



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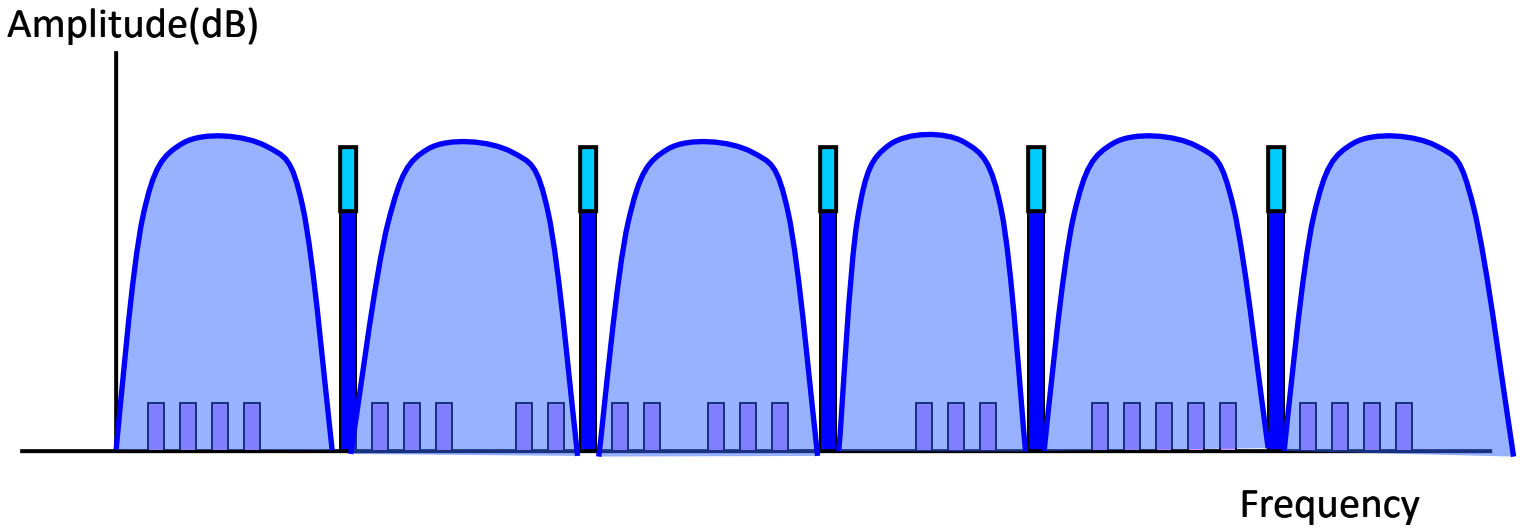
Test Signal Analyser

Blue comb filter aligned with blue PRBS spectrum



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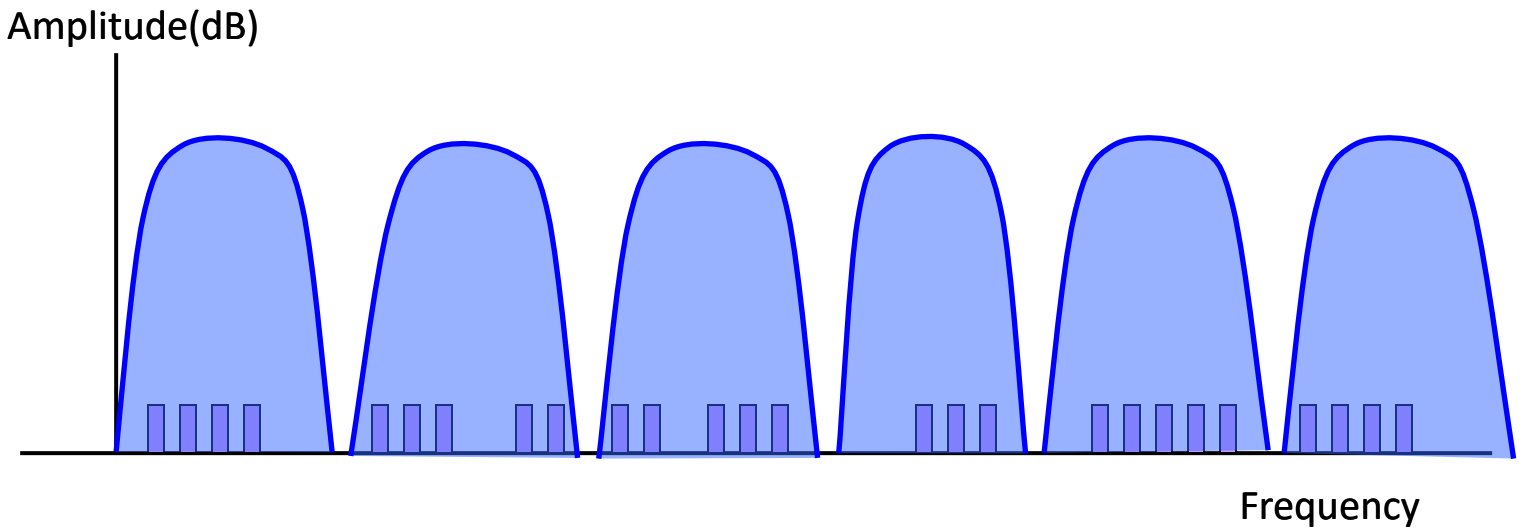
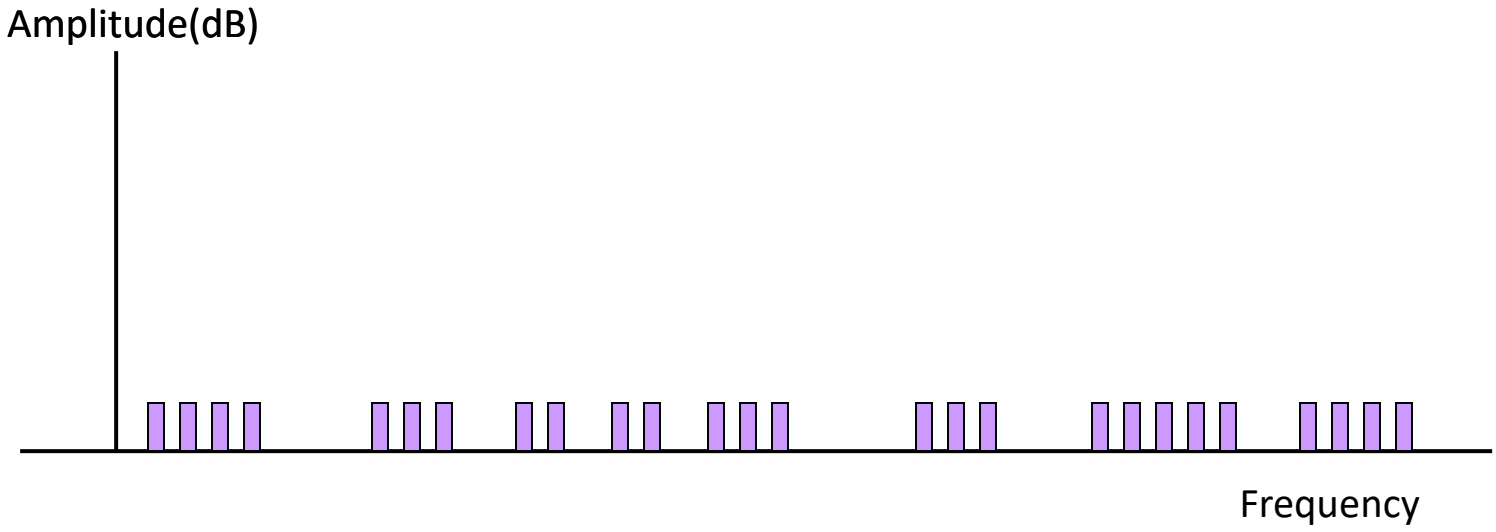
Test Signal Analyser

- Blue PRBS removed



Distortion Analyser

Distortion power measured in time domain;
no windowing, fast as no FFT



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Questions?

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https://www.signalconversion.com