Application Note

A2 • Rapid Test

Comparing Conventional vs. Multitone Testing

TABLE OF CONTENTS

ABSTRACT

Most of us are familiar with conventional (i.e. sequential) audio testing. We know the troubles and the possible sources for measurement failures. But by having accepted and applied the rules of how to measure an audio parameter for a long time, we even may have forgotten its limitations and drawbacks.

In contrast to this well known path, the new approach of multitone testing may puzzle us first. But fortunately, it is as simple as the standard way of measuring, as soon as we have understood the basic principles behind this technique. Multitone testing of course has its own limitations, but also some important advantages in comparison to the conventional approach with its single sine wave stimulus.

This application note describes the basic principles of conventional and multitone testing. It explains, in which terms these two measuring methods may be compared against each other. We will understand, that a direct (mathematical) relation between the acquired results does not always exist. However, it is shown that at least in qualitative terms, the measurement results may be compared, thus allowing to establish similar Good/No-Good criteria for both approaches. Finally, the most important difference between both methods is pointed out, the *overall test duration* for a certain number of measurements.

This document was written for new users of RAPID-TEST, who are not yet acquainted with the differences between conventional or multitone testing.

Assumptions

Although the subsequent investigations and statements refer to A2/A2-D and RAPID-TEST, they are also valid for all similar test instruments, since the physics to be considered is always identical.

Furthermore, this application note has been restricted to the most basic aspects of conventional and multitone testing, since a concise survey could fill dozens of heavy folders about this topic.

Finally, this note deals with the five core audio measurement functions only, i.e. Level, Distortion, Noise, Phase and Crosstalk, as well as the required overall time duration of a measurement.

FUNDAMENTALS

This chapter explains the basics of audio analysis, particularly the two topics of this application note, i.e. single- and multitone testing. Furthermore, a summary on the most important selection criteria is given, providing helpful information about the optimum test method to be used for any specific application.

Audio Signal Analysis

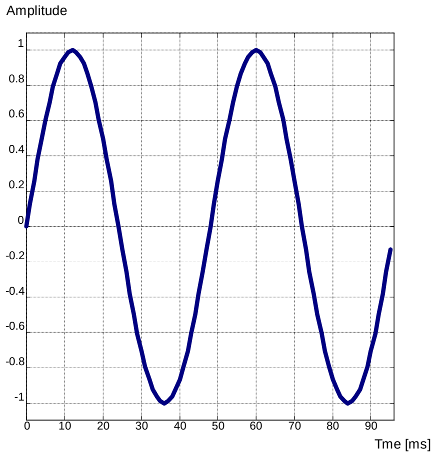
Most audio signal measurements are performed by stimulating the device to be tested with a test signal and analyzing the transmitted signal as soon as it has passed the device. One must be aware that the result of this evaluation consists of a few core quantities only, all of them relating to the capabilities of the human hearing sense.

- The most commonly used parameter is *Level*. Normally, it indicates the complete energy content of the signal, expressed as RMS value. Alternatively, by using a narrow bandpass filter, the *Level Selective* value results, considering the energy of a small band around the fundamental signal frequency only.
- Both the *Harmonic Distortion* (*THD+N* or *SINAD*) and *Intermodulation Distortion* (*IMD*) test refer to new signal components (i.e. frequencies) that are generated by the DUT. To measure them, the fundamental signal must be suppressed by using a narrow-band rejection filter, so that the new components come through only.
- The *Noise* measurement is normally done with a quasi-peak detector, measuring those audible components (spikes) of the incoming signal, which will not appear in the Level result due to their low energy contents.
- *Phase* and *Crosstalk* are important for the characterizations of dual-channel devices in order to identify the differences between the two channels.

Keep in mind, that there is one more property to be considered for any kind of measurement, the *time* (or *group*) *delay* of the signal on its way through the DUT. This parameter indicates the time passing between the moment the test signal has been sent by a generator and the time when the analyzer has received it.

Conventional Measurements

In practice, most audio tests are based on the use of a sine signal with one specific frequency.



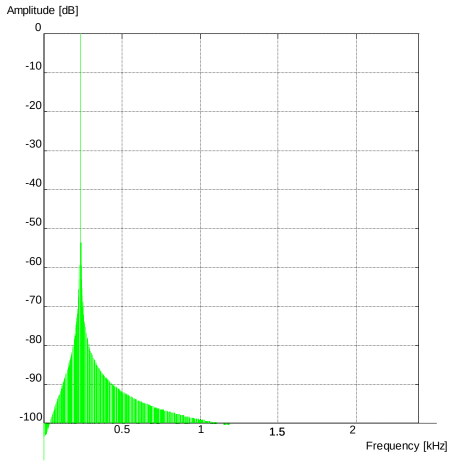


Fig 1 Time Plot & Spectrum of Single Tone Signal

In order to get a characterization over the complete frequency range, the generated signal must be swept through the band of interest, i.e. its frequency has to be increased (or decreased) stepwise, while at every step a measurement is executed.

For instance, the frequency response of a DUT in the audio range can be evaluated with a single tone test signal starting at 20Hz and ending at 20kHz, with a user-defined number of steps in between.

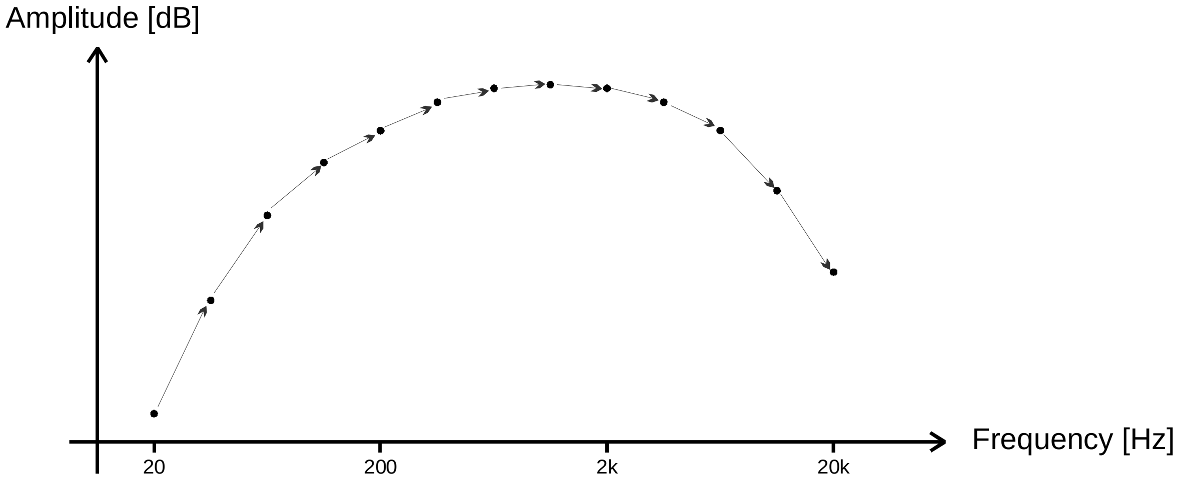


Fig 2 Example of Single-Tone Level Sweep over 13 Frequencies

Multitone Testing

In contrast to the single sine method, the multitone approach bases on the simultaneous transmission of several sine signals with different frequencies. This means, that the test signal comprises not only one, but different sine signals, which are transmitted all together at a time.

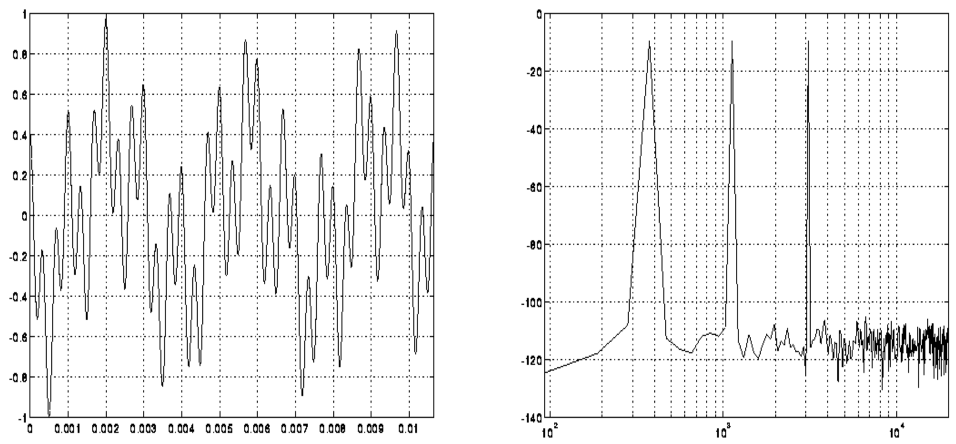


Fig 3 Time Plot & Spectrum of a Multitone Signal with 3 Frequencies (Signal Bins)

The level plot of a multitone analysis corresponds to the received amplitude values at the defined frequencies of the received signal.

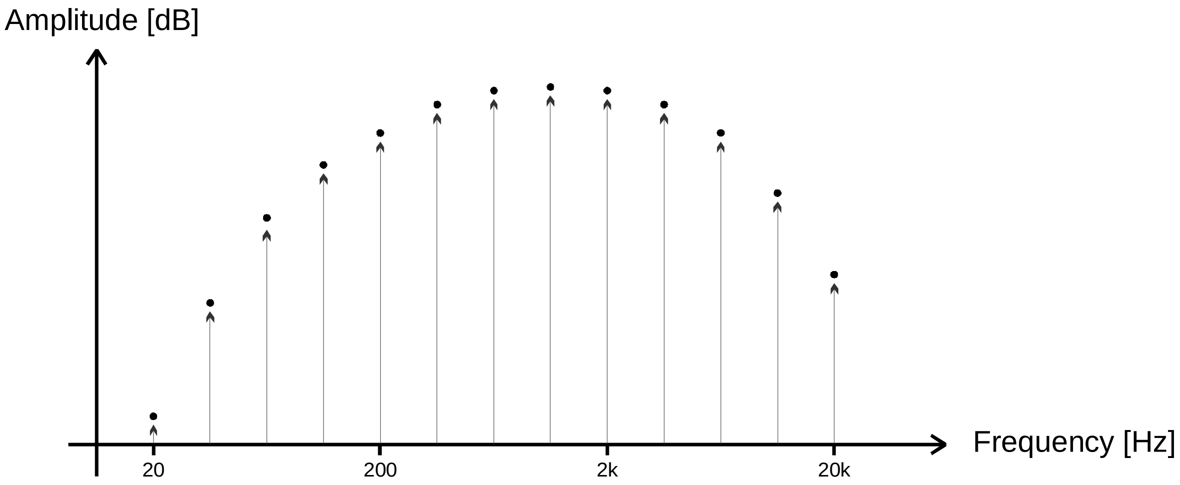


Fig 4 Example of 13-Bin Multitone Level Plot

Alternatively, the principle of a multitone test, providing five measurement results, all acquired in parallel at a time, may be described by following picture.

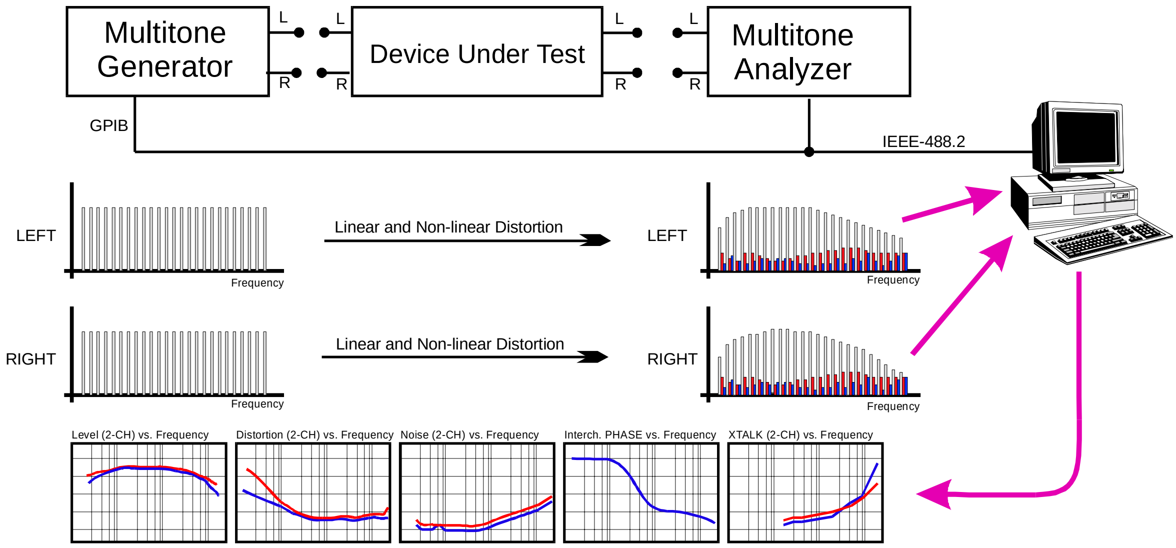


Fig 5 Multitone Test Principle

The multitone burst is transmitted through the DUT to the analyzer. The latter extracts the raw data by FFT analysis out of the received time signal and uploads them to the controlling device. The PC then allows to calculate and to display the different audio parameter plots.

Bins & Signal Bins

Before we start to discuss the multitone technique, it is vital to understand some basics of digital signal generation and especially the meaning of two terms, *bin* and *signal bin*.

First, a discretely generated time signal of limited length can comprise certain frequencies only. These frequencies f_n are given by the *blocklength*, i.e. the number of samples which build the signal, as well as the sampling frequency f_s.

$$f_n = n * \frac{f_s}{blocklength} \quad \text{with } n = 1, 2, 3, ...$$

Equation 1 Possible Frequencies of a Time Signal

In the multitone world, these possible frequencies have been named *bins*. However, a practical multitone signal will almost never comprise all possible frequencies, but a user-defined selection of them only. These actually set bins are called *signal bins*.

Furthermore, the bins and signal bins are normally not described by their frequencies, expressed in Hertz, but instead by their *bin number*. This value is obtained by numbering all possible frequencies starting with the lowest possible value (0Hz, i.e. DC, with the bin number 0). Alternatively, the bin numbers can be calculated according to

$$BinNo = \frac{Blocklength * f_n}{f_s}$$

Equation 2 Bin Number Calculation

Example

At a blocklength of 1024 and a sampling rate of 48kHz, the frequency of 562.5Hz corresponds to bin number 12.

Application Criteria

This chapter deals with the main characteristics of the two measurement principles, in order to support the user to choose the best approach for the actual application.

Signal Definition

The signal definition with RAPID-TEST is easy - you simply choose the frequencies you are interested in, by selecting the corresponding bin numbers. Consequently, after signal transmission, the instrument returns the measured results at all these frequencies.

However, depending on the DUT and the required measurement function, one normally has to optimize some characteristics of the multitone signal, as e.g. its level, frequencies and phases.

Bandwidth

The available frequency range of the transmission path always has to be considered. It is defined by the minimum and maximum frequency which can pass through the DUT. For instance, it would be useless to investigate telecom devices such as cellular phones - typically providing a bandwidth of 300Hz to 3kHz - with a test signal of 20kHz.

Number of Samples

The analysis of every audio parameter has to be optimized by the appropriate choice of the test signal(s). For instance, a detailed frequency response requires more frequencies to be measured than a crosstalk test, where few frequencies in the higher frequency range are of interest only.

Number of Signal Bins

The question about the optimum number of signal bins to be set for a certain test depends on several parameter.

- In most industrial applications, it is necessary to check a few 3 to 5 selected core frequencies only. Usually, this already allows a Good / No-Good decision, providing enough security that all faulty samples are found.
- From another point of view, one may take into account the specific demands of the different measurement functions. The level and phase measurement may require a larger number of signal bins in order to get a precise representation of the frequency and phase response. On the other hand, the distortion, noise and crosstalk test should be restricted to a few signal bins only, resulting in more meaningful measurement values.

Crest Factor

When measuring a DUT with a test signal of e.g. $5V_{RMS}$, we usually don't think about the peak value of the signal, since we are used to have enough headroom (e.g. twice the signal level, i.e. 10V). This makes sense when we remember that the peak level of a sine wave equals approximately 1.41 times its RMS value ($5V_{RMS} = 7.07V_p$).

However, things are different when working with (multitone) signals that are put together by two or more sine waves with different frequencies. In such cases, the resulting time signal, which is obtained by adding its components, will show a much larger difference between its RMS and peak value.

This effect is shown in ***Fig 6***, where three sine waves with $5V_p$ have been added to a new. signal. The peak value of this new signal is 3 times as high compared to the single sine waves, while its RMS value differs by a factor of 1.73 only vs. the single curves!

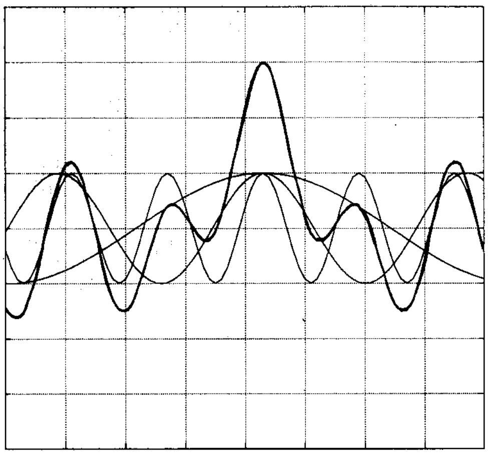


Fig 6 3-bin Signal @ 5V / Div.

The problem of a high signal peak value is that we need more headroom. For instance, the shown 3-bin signal would need somewhat like $20V_p$!

Fortunately, by optimizing the phase relations between the three signals, one may end up with a much smaller peak level of the multitone signal (see below).

In order to allow the characterization of a signal, a relationship between its peak and its RMS level had to be established, the so-called Crest factor C_f. It indicates the ratio of the peak level of the signal to its RMS level. Consequently, a high Crest factor corresponds to a signal having a high peak voltage compared to the average signal level.

$$C_f = \frac{V_p}{V_{RMS}}$$

Equation 3 Crest Factor Calculation

A single sine wave has a Crest factor of $\sqrt{2} = 1.41$. Consequently, no measures have to be taken concerning the Crest factor when working with conventional test methods.

On the other hand, different multitone signals have different Crest factors, depending on the number of signal bins and the phase relations between them. For instance, the Crest factor of a multitone signal with 31 signal bins may vary in the range from ≥ 2 to almost 8, depending on the chosen phase relations only.

Furthermore, it is vital to know that the higher the Crest factor of a multitone signal, the poorer the signal-to-noise ratio of the measurement. This can be explained easily when considering the shape of a multitone signal with a high Crest factor, i.e. a bad phase selection.

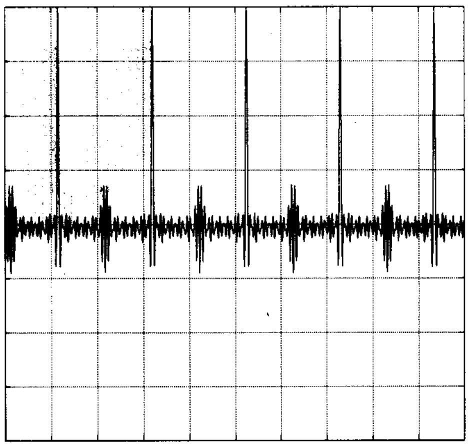


Fig 7 Multitone Signal with High Crest Factor

As you can see, the peak value of the signal is far above its average (RMS) level. Obviously, when transmitting such a signal through a DUT, one must adapt the peak voltage of the signal to the max. allowable voltage of the DUT in order to avoid clipping. Consequently, the RMS voltage of the signal becomes very small, thus coming closer to the noise floor of the transmitted signal.

So let's have a look on the same multitone signal, but this time with optimized phase relations between its signal bins, displayed in ***Fig 8***.

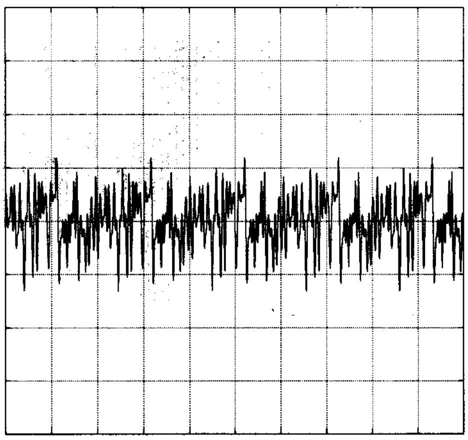


Fig 8 Multitone Signal with Low Crest Factor

This time, the difference between the peak voltage of the signal and its RMS level has become much smaller.
This does not only reduce the necessary headroom for signal transmission, but also improves the signal-to-noise ratio by far.

At this point it may be of special interest for the user to know that NTI provides an unique tool for the Crest factor optimization of a multitone signal. This feature is part of RT-EVAL, the evaluation software package for an easy access to RAPID-TEST. Please contact your local NTI representative to get your copy.

Correlation to Real-World Signals

One important question about audio measurements concerns the correlation between the acquired results and the behavior of the DUT under real-world conditions. For instance, one could argue that a DUT being stimulated with a single frequency only, may behave differently as soon as a mixture of several frequencies is applied.

In practice, this topic nowadays becomes increasingly interesting with the fast growing number of audio equipment using data reduction techniques as e.g. CODECs. These modules transmit the audible components of a signal only by using masking effects corresponding to the human ear perception characteristics (see RAPID-TEST application note ***Cellular Phone Testing***).

From this point of view, all measurement principles basing on a single sine tone transmission suffer under the drawback of a poor correlation to human speech, music or similar signals.
On the other hand, the demand for a good correlation between the test signals and real-world conditions imply the application of multitone or similar testing techniques.

Overall Test Duration

Depending on the actual application, the required time for a complete measurement might be a critical factor. For instance, for high-volume production the test duration must be kept as short as possible.

In order to evaluate the overall test duration, i.e. the time between sending off the test signal and receiving it back, a couple of influencing factors have to be considered.

- The *number of measurement functions* to be acquired.
- The *number of measurements*. Obviously, a test comprising several single measurements which are executed one after the other, proportionally prolongs the overall test duration.
- The *group delay*. This parameter indicates the time it takes for a signal to pass through the whole signal path. Please notice that in some cases, the value for the group delay varies with the frequency of the test signal.
- The *signal duration*. This parameter is given by the longest period length occurring in the test signal as well as the minimum settling time of the DUT.

Consequently, following rough approximation for the complete test duration may be given.

$$t_d = NoOfFunc * NoOfMeas * (t_{group} + t_{signal})$$

Equation 4 Overall Test Duration

With t_d = overall test duration, *NoOfFunc* = number of measurement functions, *NoOfMeas* = number of measurements, t_{group} = average group delay and t_{signal} = average signal duration.

Applied on the two approaches, it can be said that both the group delay and the signal duration are almost constant, thus providing no possibility to reduce the overall test duration. Consequently, it is the number of audio parameter and the number of measurements which allow to influence this parameter.

- With the conventional approach, the number of measurements equals the number of steps in a sweep. This means, that the higher the required resolution of a sweep is, the longer the whole measurement takes. Additionally, for each different audio parameter, the complete procedure has to be repeated.
- On the other side, a multitone burst ideally has to be transmitted once only. Furthermore, the multitone approach enables the analysis of several audio parameter at a time after having transmitted a single multitone test signal. In other terms, the values for both *NoOfFunc* and *NoOfMeas* always equal 1.

Fig 9 shows the typical overall test duration, acquired with a single tone stimulus. For this graphic, it has been assumed that a single measurement needs approx. half a second, and that for the acquisition of several audio parameters at identical frequencies, an automated remote control software has been used. In practice, i.e. under the control of a human operator, the values would become even larger.

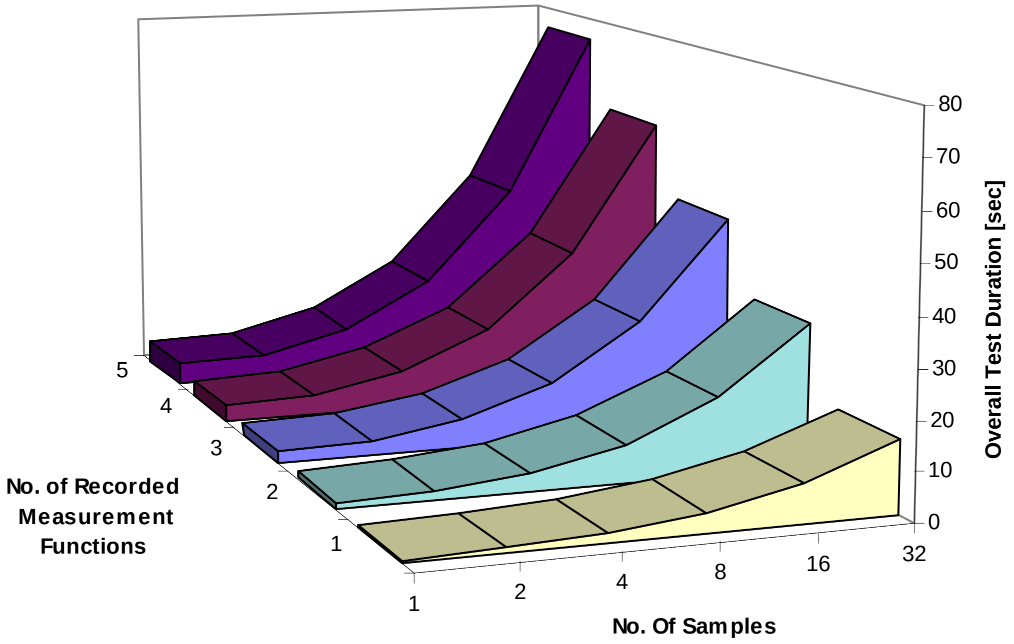


Fig 9 Typical Overall Test Duration for Conventional Measurements

On the other hand, the *overall test duration* of a multitone acquisition would typically last *1 second* only, regardless of the number of samples or recorded measurement functions.

Result Acquisition & Interpretation

One of the most important craters when comparing conventional vs. multitone measurement techniques is the interpretation of the acquired results. For instance, a service technician working in the field, wants to get results which can be understood immediately and compared easily with other values. On the other hand, in an automated environment, where well-defined tests are repeated thousands of times, it is no obstacle when the acquired results must be considered more thoroughly.

Conventional Approach

As long as the DUT is stimulated with a single sine wave only, the interpretation of the recorded measurement results is straightforward.

- The ratio between the sent-out signal level and the received one at the same frequency, directly corresponds to the attenuation / amplification factor of the DUT.
- The received distortion (THD, SINAD), i.e. those signal components, which have a different frequency as the one of the transmitted signal, are caused by the DUT or the transmission line.
- The same conclusion is valid for noise, phase and crosstalk measurements, supposed that the generator provides a sufficiently 'clean' sine signal.

Multitone Approach

The interpretation of measurement results acquired from a multitone burst transmission is as easy as with the conventional approach.

- In the Level mode, just the amplitude of the signal bins is measured,
- for Distortion and Noise analysis, certain bin levels between the signal bins are added up,
- the Phase result is obtained by comparing the signal bins on both channels, and
- for Crosstalk analysis the impact of the signal bins onto the other channel is investigated.

However, as soon as we have to cope with a DUT producing nonlinear distortion, the situation changes a little. Due to the intermodulation products, caused by these nonlinearities, it becomes impossible to evaluate the origin of any received (signal) bin level. Therefore, the interpretation of the results is not always as straightforward as we are used from the conventional method.

Fortunately, this does not compromise the meaningfulness of multitone measurement results, as it will be shown in chapter ***Measurement Functions*** (see page ***13***).

Pros & Cons

	Single Tone	Multitone
Signal definition	👍 **simple**	☞ requires some knowledge
Correlation to real-world signals	👎 poor	👍 **good**
Test duration	☞ Increasing with number of measurements	👍 **Independent from number of measurements**
Interpretation of results	👍 **easy**	☞ requires some knowledge

Table 1 Pros & Cons

This first overview about the characteristics of the two measurement principles unveils their typical applications.

- Conventional (single tone) tests are mainly used for applications where an easy and well-known interpretation of the results is required, and where time is not the limiting factor of the test.
- Multitone measurements play a major roll at all applications where a high test speed is of prime importance.

Measurement Functions

The subsequent chapters describe the different aspects of conventional vs. multitone testing applied on the five most commonly used audio measurements - Level, Distortion, Noise, Phase and Crosstalk.

Level

The frequency response of a DUT, i.e. the extent by which every transmitted signal component is attenuated or amplified, is one of the most important characteristics of any audio equipment. Fortunately, it is measurable in an easy way, and allows a rather straightforward interpretation of the acquired results.

With a conventional equipment, one simply has to move (sweep) the frequency of the stimulating signal through the band of interest.
On the analyzer side, the incoming signal may be either measured as broadband input level or as selectively, i.e. after being fed through a narrow bandpass filter. In the latter case, noise, which has been introduced in the test circuit, will be eliminated. Anyway, the characteristic of the results will be almost identical in most applications.

Similarly to the level selective mode, a multitone test instrument will extract the received signal level for every signal bin (frequency) of the transmitted test signal. The only thing we have to keep in mind is the possibility, that due to nonlinearities of the DUT some intermodulation products might fall onto the signal bins, too. Fortunately, even if this effect happens, its impact can be neglected in almost all cases.
Consequently, in most cases a multitone test will provide identical results as a conventionally acquired measurement.

Distortion

In opposition to the level measurement, the distortion or THD+N characteristic of a DUT normally looks very different depending on the used test method. To understand this, it is necessary to have a closer look at the two different approaches.

In a conventional test instrument, the distortion result will be measured by notching out the signal level at the sent-out (i.e. fundamental) frequency with a narrow-band rejection filter. All remaining signal components, i.e. the harmonic distortion and the noise are added up, thus building the THD+N value.

$$THD + N = \frac{U_{Distortion+Noise}}{U_{Signal+Distortion+Noise}}$$

Equation 5 THD+N Definition

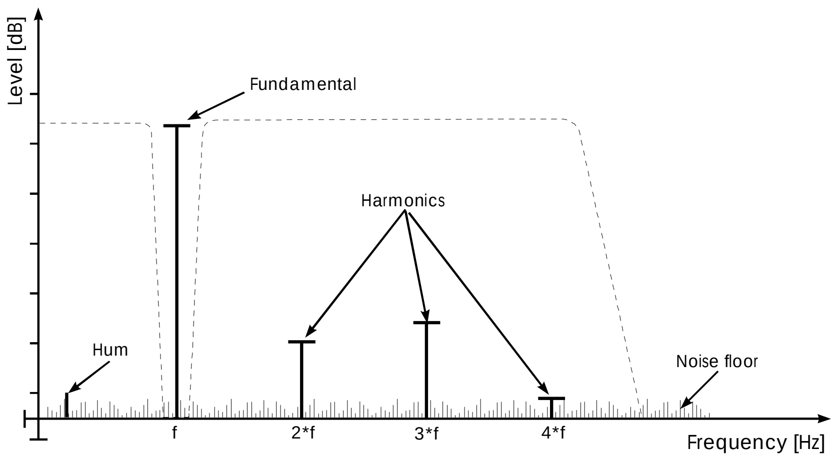


Fig 10 Conventional THD+N Acquisition

With a multitone test instrument, things are completely different. Here, the analyzer sums up all bins between each two signal bins, thus resulting in *n+1* distortion values (where *n* is the number of signal bins).

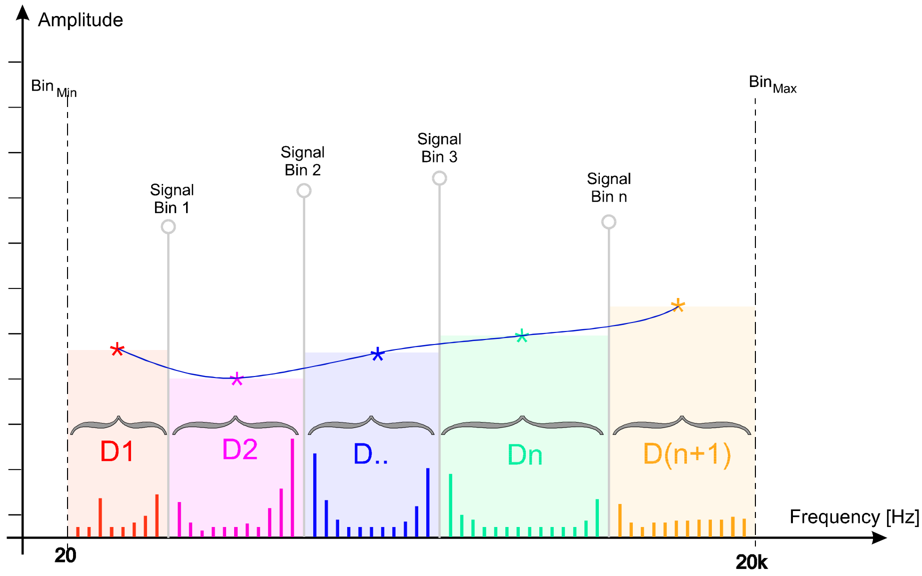


Fig 11 Multitone Distortion Acquisition

Consequently, these results may be called the TD+N values of the considered bands, i.e. the sum of all distortion plus noise.
Please notice the absence of the word 'harmonic' in this description. This is because of the numerous intermodulation products, that make the identification of the origin of any received signal component impossible.

THD+N Measurement

Sometimes, the operator of RAPID-TEST has to prove for a new application, that the THD+N (Total Harmonic Distortion + Noise) value of a DUT is the same, regardless if measured with a conventional test system or with RAPID-TEST. In order to provide the required result for such a comparison, the subsequent steps have to be executed.

1. Select a single test frequency f_{test} with which you want to stimulate the DUT.
2. Transmit a single-bin RAPID-TEST signal with this frequency and get the distortion result.
3. Calculate the THD+N result with the subsequent formula

$$THD + N\,[\%] = \frac{\sqrt{D_1[V]^2 + D_2[V]^2}}{\sqrt{D_1[V]^2 + L_1[V]^2 + D_2[V]^2}} * 100$$

with D_1 = distortion between 20Hz and the f_{test}, D_2 = distortion between f_{test} and 20kHz and L_1 = received level result.

The result of this procedure must be almost identical to the one of a conventionally acquired measurement. However, due to possible frequency shifts produced by the DUT, the values might differ slightly from each other.

Overview

- The THD+N measurement of the A2 uses a single sine tone as stimulus, and sums up all received signal components, except the fundamental one, over the complete frequency range.
- The RAPID-TEST instrument calculates the TD+N values for all frequency bands between the signal bins, by summing up all signal components in these bands.
- A direct relation between the distortion results of these two principles, in terms of a mathematical formula or similar, cannot be established. However, a DUT, that produces low distortion result when tested with RAPID-TEST, will as well show a very low THD+N value if conventionally tested.
- The smaller the number of signal bins is, the easier becomes a comparison between a multitone and a conventional measurement result.

Noise

The noise measurement is acquired almost identically to the distortion, however, with one major difference: its result is calculated by summing up the odd bins only in the respective frequency bands. But what does this mean? To give an answer, it is necessary to have a closer look on the FFT analysis which is performed on the incoming time signal.

As stated in chapter ***Bins & Signal Bins*** (p. ***6***), the available frequencies of a multitone signal (bins), are given by the number of samples (blocklength) for one FFT. Therefore, one could expect that a multitone signal, which has been generated with a blocklength of 512, should be analyzed with the same blocklength as well. However, in practice the blocklength of the analyzer is twice as high as of the generated signal (1024 instead of 512), providing a twice as high frequency resolution of the resulting spectrum.

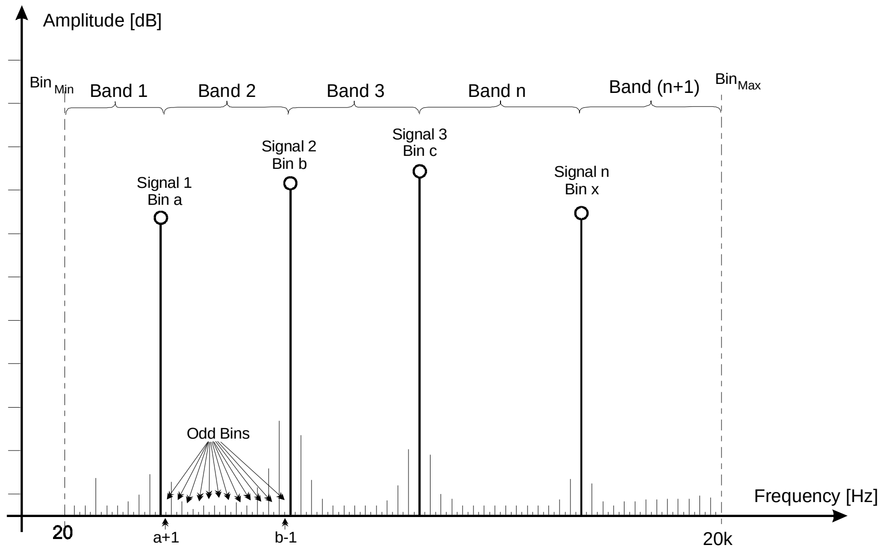


Fig 12 Multitone Noise Acquisition

Since distortion products are always integer multiples of their fundamentals, they must always fall onto the *even* bins.
On the other hand, the received results from the *odd* bins must represent the noise, that was generated by the DUT itself.
This explains how to extract a noise value out of a received multitone signal.

Remains the question, how a conventional system measures noise. The answer is rather simple. According to the international standards, noise is measured by feeding the incoming signal through a special circuit, which transforms its low-energy peaks into a signal with detectable RMS value.

- Conventional noise analysis measures the quasi-peak Voltage of the incoming signal.
- The noise result of RAPID-TEST is acquired by summing up the odd bins of the analyzed signal.
- A direct relation between the results of these two principles, in terms of a mathematical formula or similar, cannot be established. However, under the assumption, that the noise of a *stimulated* DUT is measured, the results are qualitatively comparable

NOTE ***Please notice, that the multitone approach allows to measure Idle Noise, i.e. the noise being generated by the DUT in the presence of the test signal, while for a conventional noise measurement, the inputs of the DUT must be muted.***

Phase

Concerning the phase measurement, things are quite easy, since the conventional and the multitone method proceed in an almost identical way. In both cases, the phase difference between the two input channels is measured for each frequency.

The only difference concerns the recording of a complete phase response. With multitone testing, this may be acquired in one step, while with a single sine stimulus, the signal frequency has to be swept through the frequency band of interest. In any case, both methods provide the same results.

Crosstalk

The principle to characterize the crosstalk between two signal lines is almost identical in conventional as in multitone test instruments. The system transmits a signal through one channel only and calculates the ratio between this signal and the measured input signal of the alternate channel.

Both approaches provide the same results. However, there is a difference between the two methods, since RAPID-TEST can generate and analyze different signal bins on its two channels.
This allows the instrument to acquire the crosstalk results for both channels in parallel, by transmitting two multitone signals with different signal bins at a time, and to measure the crosstalk from ChA → ChB and ChB → ChA in one step only.

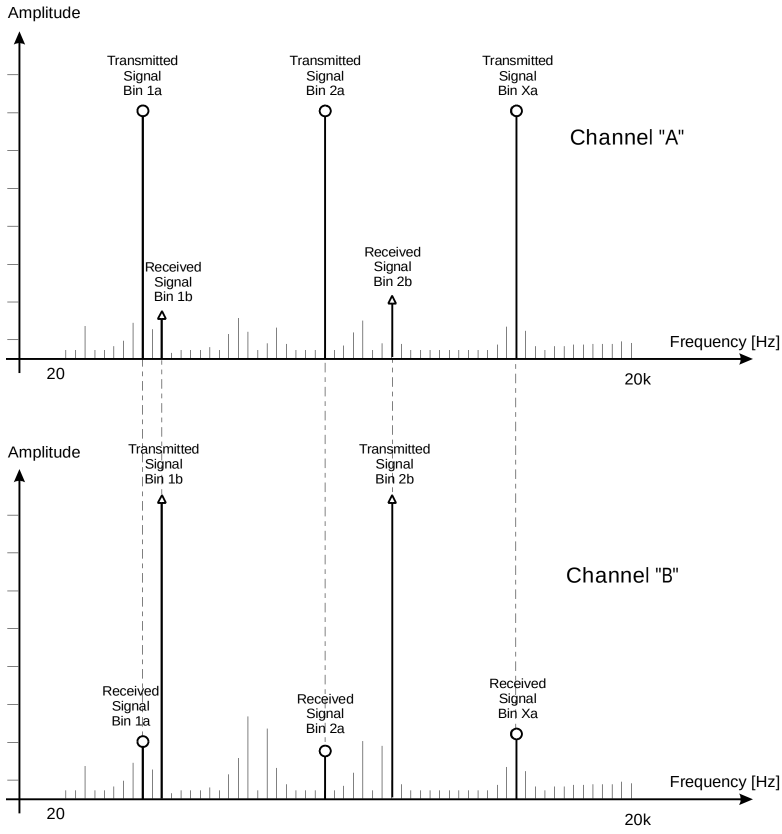


Fig 13 Multitone Crosstalk Acquisition

CONCLUSION

Comparability Overview

Table 2 provides a rough overview on how good the five measurement functions, investigated in this application note, can be compared if acquired with the conventional or multitone approach

	Conventional (single tone)	***Multitone***	***Comparability***
Level	broadband level or level selective	levels of received signal bins	**Good**
Distortion	THD+N of complete frequency range	TD+N of bands between signal bins	**Qualitatively only**
Noise	quasi-peak weighted noise	sum of odd bins between signal bins	**Poor**
Idle Noise	not possible	same as Noise	**-**
Phase	phase difference between input signals	phase differences at the received signal bins	**Good**
Crosstalk	crosstalk at generated signal frequency	crosstalk at signal bins	**Good**

Table 2 Comparability Overview

Summary

Both the conventional approach with single-tone stimulus and the multitone signals are equal methods to measure the five core audio parameter Level, Distortion, Noise, Phase and Crosstalk. As long as the respective backgrounds are known, the interpretation and comparison of the results is possible and easy.

The main advantage of multitone vs. conventional testing is the superior *speed* of the first method. Therefore, RAPID-TEST is the ideal choice for all applications where some core measurement functions shall be evaluated in a minimum of time.