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83

TIME DELAY SPECTROMETRY — AN UPDATE OF THE CLASSICAL SWEPT SINE MEASUREMENTS

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INTRODUCTION

The purpose of measuring in time and frequency domains falls generally into two different classes:

A. To exploit the information in a **signal** representing some physical phenomenon i.e. we have access to the **output only**.

B. To evaluate the function of **systems** i.e. where we generally both can access **an input and an output**.

When looking for an optimized measuring method, this basic classification should always be kept in mind.

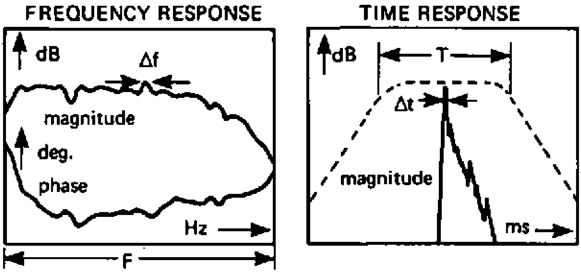
Historically signal analysis in the frequency domain, has been performed with a single narrow band filter swept through the relevant frequency range. Used with a suitable signal source — wideband-noise or a sinewave — the same filter now constitutes a measuring set-up suitable for system analysis.

For signal analysis the advent of modern real time parallel analyzers represents a major step forward in reducing measuring time and increasing overall quality of the results. This justified and unconditioned success of parallel analysis for signals, has tempted many to use parallel analyzers in connection with a wide band signal source as the ultimate solution also in the case of system analysis.

However, if a classic swept sinewave in connection with a single narrow band filter is used in the optimized way described as "Time Delay Spectrometry" the instrumentation outperforms any other technique with respect to measuring time and quality of results in terms of ability to reject disturbing correlated and uncorrelated noise.

OPTIMIZED SYSTEM ANALYSIS

To optimize a system analysis in terms of measuring time and quality of results, two considerations are essential. The signal to noise ratio of the measurement determines the amount of random spread in the results. It is generally proportional to the energy entered into the system through the test signal.



$$\Delta t = \frac{1}{F} \qquad \Delta f = \frac{1}{T}$$

$$T = \frac{B}{S} \qquad S = \frac{F}{T_s}$$

$$F \cdot T = B \cdot T_s$$

Fig. 1. Time-frequency relationships and TDS formulae. B is tracking filter bandwidth. T_s is sweep time and S is sweep speed

It is important not to waste time by collecting more information than required. This necessitates a careful segmentation in both frequency and time. The width of the frequency window F and time window T defines the amount of information collected $F \cdot T$. Observing the time-frequency uncertainty principle $F \cdot T$ can be expressed as either $^F/_{\Delta f}$ or $^T/_{\Delta t}$ where Δf and Δt represents the resolution in the two domains. (Fig.1.)

SEGMENTATION

In traditional swept sine measurements, the choice of a suitable frequency range F (e.g. 20 — 20000 Hz) is one of the most obvious things to do and current instrumentation has extensive facilities for satisfying any desire for segmentation. However, the choice of an appropriate time window has been given very little consideration.

An appropriate segmentation in the time domain can for example, provide the free-field frequency response of a loudspeaker in a much simpler and cheaper way than using expensive anechoic rooms. Any late reflections or other undesired signals are simply cut out by a suitably selected time window T.

Through the relation $\Delta f = {}^1/_T$, a well defined time window results in a well defined frequency resolution, in contrast to the highly subjective guesses of Δf often encountered in classical swept sine measurements. It should be noted that a time window already exists in every measurement. In the case of a traditional swept sine analysis, it is such a complex function of the instantaneous sweep rate and the swept filter bandwidth B, that the time window and the frequency resolution in general is unknown. To obtain a satisfying frequency resolution in this case, the sweep rate is kept so low that the resultant smear, in connection with the chosen filter bandwidth B, is negligible. As a result valuable measuring time is wasted, and the final frequency resolution still remains a subjective judgement.

TIME DELAY SPECTROMETRY — TDS

In TDS, the excitation is a sine sweep of a duration equal to the measuring time. As such, it represents the optimum excitation type in terms of the amount of energy put into the system under test. Combined with a constant bandwidth filter B swept linearly with frequency and synchronized with the excitation, a well defined time window is established. With a proper delay or frequency offset between sine generator and filter, the time window can be adjusted to compensate delays in the

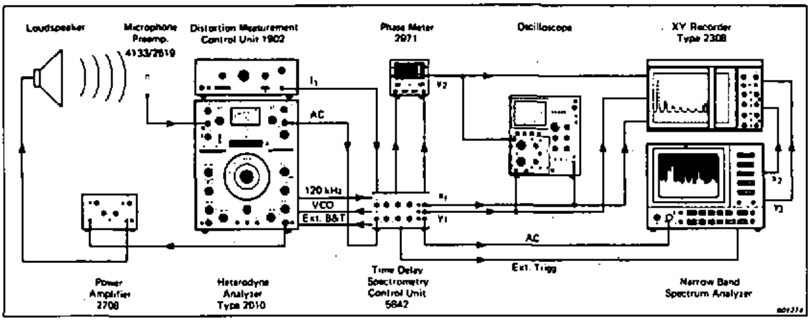


Fig.2. TDS system used for loudspeaker development. The same arrangement is used for other types of measurements by exchanging the microphone and loudspeaker systems for the appropriate transducers and amplifiers

system, and pick up any relevant segment of the time response. Observing that the time window is fixed — and user selectable to suit the measuring purpose — well specified frequency resolution Δf is a result through-out the frequency range.

In TDS the information of the system (FT) is picked up by a scanning filter B working during the total sweep time T_s. The basic formula for TDS can then be expressed as: $FT = BT_s$

It is very important to note that a smaller tracking filter B results in less noise being picked up at the direct expense of prolonged measuring time T_s. Therefore, where alternative measuring techniques may require complex averaging of may measurements, to obtain the desired S/N ratio, TDS would use a longer T_s and smaller B.

The only limitation in the described implementation of TDS is the minimum sweep time possible: $T_s \geqq FT^2$. For a detailled discussion see ref. [1].

TDS INSTRUMENTATION

As swept sinewave generators and tracking constant bandwidth filters have been available for years, essentially, TDS just represents a very powerful way of using them. Basically the present B & K system (Fig.2) consists of a precision voltage controlled sine generator and a BFO, syncronized with a constant bandwidth tracking filter. The frequency F is selected in the conventional manner, and an additional controlbox facilitates the setting of the time window T by selecting a proper set of B and T_s, paying due attention to the signal to noise requirements.

The measuring results from the tracking filter now represents the frequency response as a function of time. A straight forward Log magnitude and phase detection makes the frequency response ready for display on an oscilloscope screen. An FFT analyzer transforms directly the frequency response into magnitude vs. time, the so called Energy Time Curve (ETC), which has proved to be a most valuable display format for system time responses.

The TDS system offers substantial advantages over other techniques especially in acoustic designs where unwanted reflections and random noise are present. As an example Fig.3 shows hard copies of results from a loudspeaker measurement. Before read-out the results were available on the oscilloscope screen (frequency response) and the FFT (time response) for monitoring. In this case the total measurement time was only two seconds.

SUMMARY

TDS represents a logical optimization of the classical swept sine measurements. Especially in measuring acoustic systems where reflections and random noise are problems, TDS has demonstrated outstanding performance. A large number of measurements traditionally requiring an anechoic chamber, can now be performed in normal laboratory environments. Typical measuring time of a few seconds and live frequency and time display brings the term "Real time acoustic design" to a practical reality.

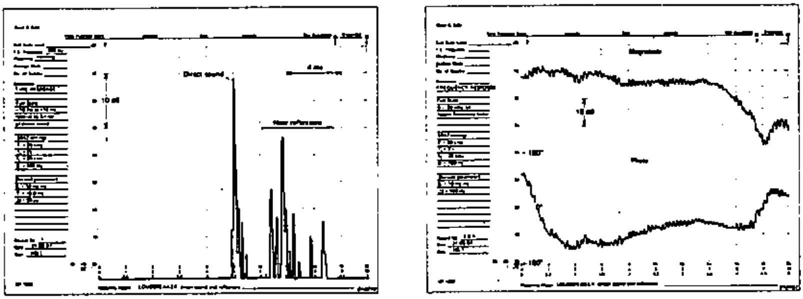


Fig.3. An example of possible display formats with the B & K TDS system, showing time response (left) log. magnitude and phase response vs. lin frequency (right) of a commercial loudspeaker and zoom reflections within a 10 ms time window. The total measuring time: 2 seconds

REFERENCES

[1] System Analysis and Time Delay Spectrometry, B & K Technical Review, No.1 & 2, 1983.