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DESCRIPTION OF A COMPUTER BASED TIME DELAY SPECTOMETRY UNIT

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Time Delay Spectometry is a time selective measuring technique primarily suited to making transfer-function measurements in both time and frequency domains on devices having a well defined input and output. TDS falls into the general class of two-port measurements methods where the test system generates a test signal which is sent to the device under test, and the resultant output of the device is analyzed. TDS is also one of the general class of measurement techniques that can simulate free-field measurements in a reflective environment ie. get measurement results as if you are in an anechoic reflection-free environment, but measured under "real-world" reflective conditions.

TDS was invented by Richard Heyser, a staff scientist at the Jet Propulsion Labs associated with California Institute of Technology. He first described the technique in a Audio Engineering Society paper in 1967 (2). Many subsequent papers and articles by he and others have appeared since that describe the process and the measurements. See the short reference list at the end of this article for further reading.

Two manufacturers are currently licensed to supply measurement systems using the patented TDS technique: Bruel and Kjaer and Crown International. B&K supplies a TDS control unit which in conjunction with other pieces of their test equipment forms a complete TDS test system. Crown supplies a completely self-contained portable instrument that can make all TDS measurements.

The TDS technique uses a swept sinewave test signal, where the instantaneous frequency is linearly related to time. This low crest-factor sinewave is applied to the device under test during the whole of the measurement/test interval (Fig.1). The test signal characteristics maximize the amount of test energy injected into the system under test for a given peak signal level. The resultant output of the system is analyzed with a dual set of tracking bandpass filters that are matched to the characteristics of the test signal. The bandpass filters can be offset in time to tract any type of delayed output the test system might present. Information on the magnitude of frequency response and phase (or real and imaginary) is completely preserved in the TDS process.

There are a number of competing test methods to TDS. These can be broadly grouped in two catagories: those which can and cannot simulate free-field measurements. A partial list of traditional methods that cannot simulate free-field measurements includes:

1. Slow swept sinewave test signal with broadband tracking filer,
2. As in number 1. but with a tracking bandpass filter, but with no time offset capability,
3. White noise test signal with constant bandwidth spectrum analyzer,
4. Pink noise test signal with real-time spectrum analyzer.

All these methods can measure frequency response but with no phase information. No time related information can be measured with these techniques. All four methods require a reflection free environment to make accurate measurements, and with the exception of number 2. require a very quiet test site for good dynamic range.

A partial list of competing techniques that can simulate free-field measurements inclues:

1. Tone burst test signal using time grating techniques (3.),
2. Impulse test signal with single-channel FFT spectrum analyzer,
3. White noise random (or psuedo-random) excitation with dual-channel FFT spectrum analyzer used to compute the cross-spectrum and other related quantities and,

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4. As in number 3. but using non-random excitation signals such as music or program material.

All these techniques can measure frequency response magnitude, while only the last three include phase and time information. While TDS and the three FFT techniques can yield the same measurement data in the same situation, the basic difference between the various techniques lies in the measuring time required for a given rejection of correlated (reflections) and uncorrelated (background) noise, and the crest factors of the test signals.

Refernce (1.) shows a theoretical comparison between TDS and the first three techniques with respect to measurement times in the presense of correlated and uncorrelated noise. The study shows that if background noise can be neglected, as in a anechoic chamber, the FFT techniques can be extremely fast. However, if tone burst or FFT techniques are used to gather measurement information in noisy situations, and most real-world situations are noisy, the data gathering time can get very long because a considerable amount of time averaging is required to minimize the noise effects. In the case of impulse excited FFT, the very high peak-to-average ratio of the test signal can place very high demands on the device under test, stressing it into non-linear behavior. With the exception of making tests in a noise free environment, TDS is found to beat all other techniques in measurement time if background noise is significant.

With regard to reflections, all the different techniques are obliged to obey the same physical constraints regarding frequency resolution and low frequency performance. To resolve frequency to a resolution of F_R, you must listen for a time window of $F_R = \frac{1}{T}$. Time window T can be increased to improve F_R, but you are going to need a larger measurement space so no reflections enter the time window during the measurement.

The TDS test technique can be used to measure a number of conventional parameters, and due to the inherent time selective capability of TDS, these measurements can be done on systems containing significant time delays.

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These measurements include:

1. Frequency Domain Measurements:

    Magnitude response

    Phase response

    Group delay

    Nyquist plot of magnitude-phase

2. Time Domain Measurements:

    Impulse response

    Transient response

Additionally a number of TDS related measurements can also be made:

1. Frequency Domain Measurements

    Energy-Frequency Curve

2. Time Domain Measurements

    Impulse and Doublet response

    Energy-Time Curve

3. Joint Frequency-Time Domain:

    Frequency Time Curve

    Erergy-Frequency-Time Curve (3D)

Samples of various TDS generated displays are shown at the end of this paper.

In conclusion, Time Delay Spectrometry offers a number of advantages for making measurements on sound systems, electro-acoustic devices, architectural spaces, and other related application areas. These advantages include: outstanding noise rejection characteristics, short measurement times, least stressful test signal, and the ability to make measurements in "real use" situations. TDS allows easy evaluation of systems, devices, or structures where time delay is inherent in their operation. Evaluation of reflections and echos is acoustic spaces is particularly straightforward.

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REFERENCES

(1.) H. Biering, O.Z. Pedersen, "Free-Field techniques. a comparison of time selective free-field techniques with respect to frequency resolution, measuring time, and noise induced errors." Paper presented at the 68th convention of the Audio Engineering Society, Hamburg 1981. Copy available from B&K, Denmark.

(2.) R.C. Heyser, "Acoustical Measurements by Time Delay Spectrometry," J. Audio Eng. Soc., P.370 (1967 Oct.)

(3.) H. Moller, "3-Dimensional Acoustic Measurements Using Gating Techniques," Bruel & Kjaer Allication Note.

(4.) H. Biering, O.Z. Pedersen, "System Analysis and Time Delay Spectrometry," Bruel & Kjaes Technical Review (in two parts, 1983)

(5.) R.C. Heyser, "Loudspeaker Phase Characteristics and Time Delay Distortion," J. Audio Eng. Soc., (1969 April)

(6.) G. Stanley, "TDS Computing," Audio Magazine, (1983 Nov.)

(7.) G. Stanley, "A Microprocessor Based TEF Analyzer," Paper presented at the 72nd convention of the Audio Engineering Society, Anaheim 1982.

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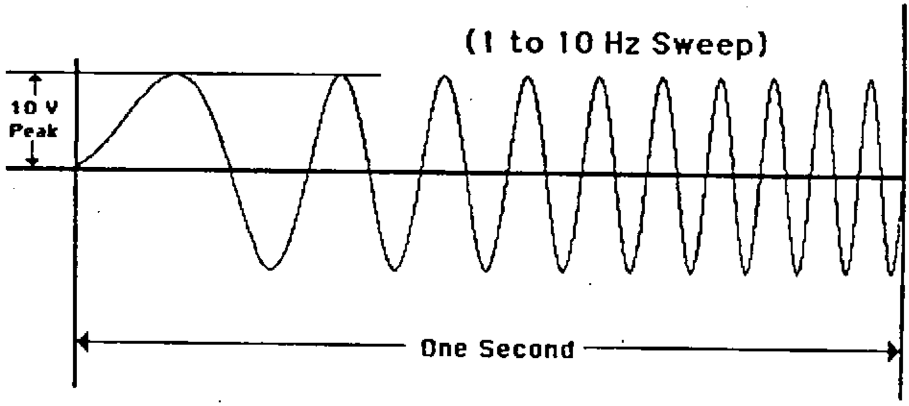
TDS SWEPT SINEWAVE TEST SIGNAL

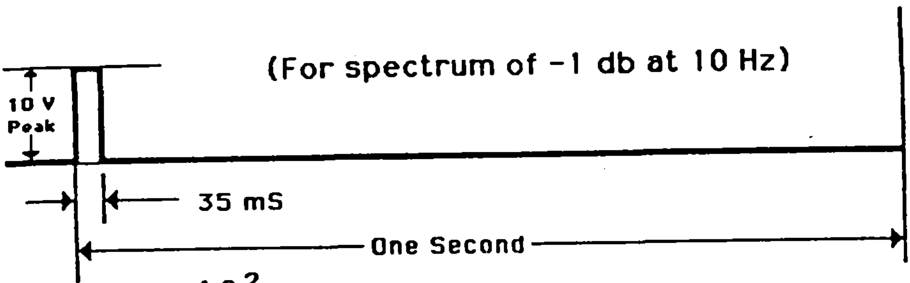


$$\text{Power} = \frac{10^2}{8} \times 0.707 = 8.8 \text{ Watts} \quad \text{(8 Ohm Load)}$$

Figure 1. The swept sinewave that TDS uses as an excitation test signal. The graph shows a one second sinewave sweep that covers the frequency range of 1 to 10 Hz. The frequency is swept linearly with time. Note that the signal exists for the whole measurement interval of one second. With the indicated 10 volt peak limitation the voltage would generate roughly 9 watts into a ficticious 8 ohm loudspeaker load.

FIG 1

PULSE EXCITED FFT MEASUREMENT TEST SIGNAL



$$\text{Power} = \frac{10^2}{8} \times (0.035) = 0.44 \text{ Watts} \quad \text{(8 Ohm Load)}$$

Figure 2. The pulse source that the impulse excited FFT method uses as a test signal. A pulse of about 35 millisecs width is required to have a flat spectrum to 10 Hz which duplicates the frequency range covered in Fig. 1. With the indicated 10 volt peak pulse limitation the voltage would generate roughly 0.5 watts into a ficticious 8 ohm loudspeaker load. This level is roughly 1/20th the power (-13 dB) provided by the TDS test signal with the same peak level and measurement time. If the frequency range is extended to 20 kHz, with the same measurement time, this power ratio increases to roughly 40,000 to 1 (46 dB) in favor of TDS! This is because the pulse has to be narrowed to about 18 microsecs whitch generates only about 220 microwatts of power while the TDS test power stays as before.

FIG 2

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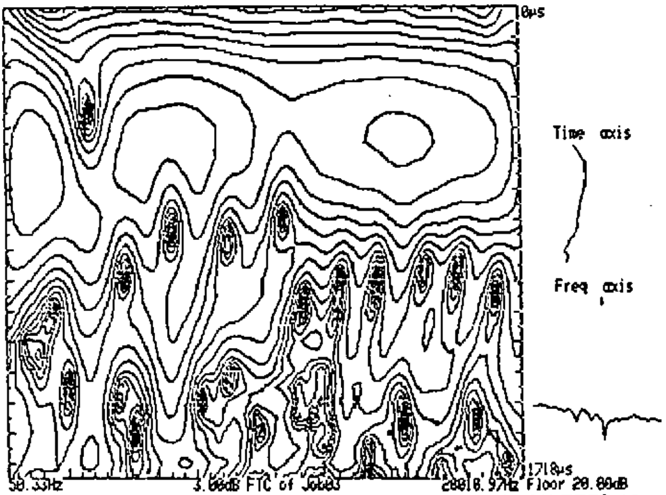


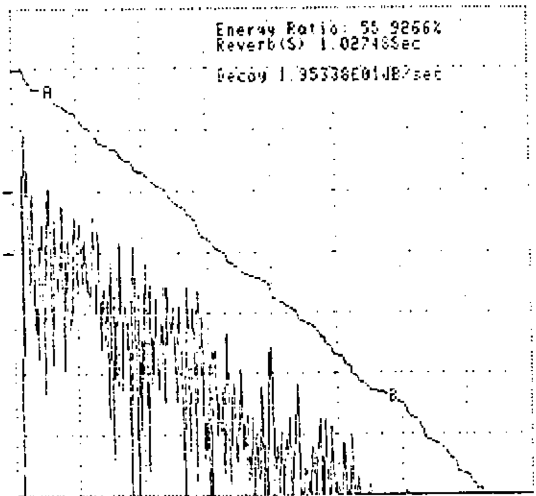
FTC, FREQUENCY TIME CURVE

HORIZONTAL

FREQUENCY:	50.33Hz to 20010.97Hz
SCALE:	5443.79Hz/inch & 2143.23Hz/cm 499.02Hz/tic & 2495.08Hz/ticmajor

VERTICAL

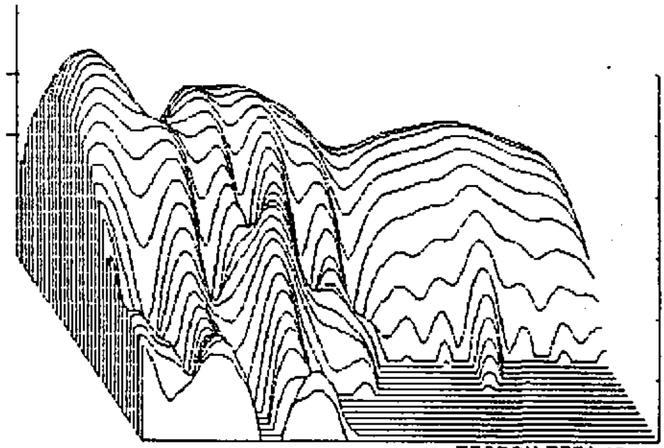
TIME:	1718E-6 sec or 1.9413 Feet (bottom)
THRU:	0E-6 sec or 0.0000 Feet (top)
SCALE:	-6E-6 sec or -0.0077 Feet/raster -55E-6 sec or -0.0625 Feet/tic -488E-6 sec or -0.5514 Feet/inch -1239E-6 sec or -1.4007 Feet/cm
RESOLUTION:	4.210621E-01 Feet & 2.68369E03Hz
SWEEP RATE & BANDWIDTH:	10734.76Hz/sec & 4.00000Hz
INPUT CONFIGURATION:	Balanced with 66dB of input gain & 18dB of IF gain.



TECRON TEF® 10

ETC, ENERGY TIME CURVE

VERTICAL:	6dB/div with base of display at 52.0dB 0dB is located at .00002 Pa
HORIZONTAL:	0 microseconds or 0 Feet to 799618 microseconds or 905.167 Feet
SCALE:	2.4748E+02 Feet/inch or 9.7434E+01 Feet/cm. 2.18623E+5 microseconds/inch or 86072 microseconds/cm.
LINE SPACING:	2004.05 microseconds or 2.26859 Feet
LINE WIDTH:	2725.51 microseconds or 3.08528 Feet
SWEEP RATE:	100.19Hz/Sec
SWEEP RANGE:	1000.12Hz to 1499.11Hz
WINDOW FILE NAME:	A:HAMMING.W8T
INPUT CONFIGURATION:	Balanced with 54dB of input gain & 21dB of IF gain.



3-D TIME, ENERGY, FREQUENCY

VERTICAL: 6dB/div with base of display at 60.3dB
OdB is located at .00002 Pascals

HORIZONTAL: 50.33Hz to 20011.00Hz
SCALE: 5457.44Hz/inch or 2148.60Hz/cm.

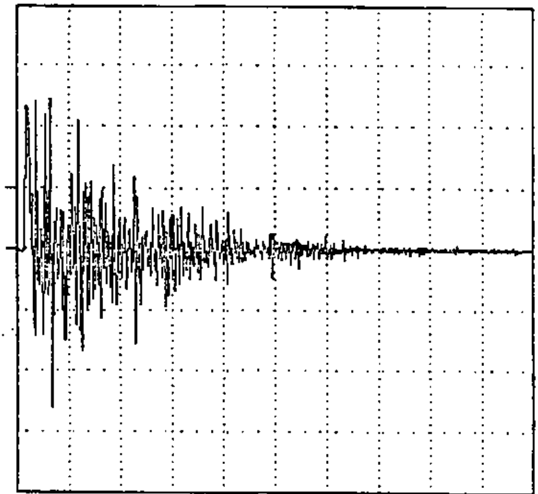
RESOLUTION: 4.2106E-01 Feet & 2.6837E+03Hz

TIME OF TEST: 1718 microseconds 1.9418E+00 Feet (front)
TO 0 microseconds 0.0000E+00 Feet (back)
-55 microseconds/step or -6.263850144909E-2 Feet

SWEEP RATE & BANDWIDTH: 10734.80Hz/Sec & 4.0000E+00Hz

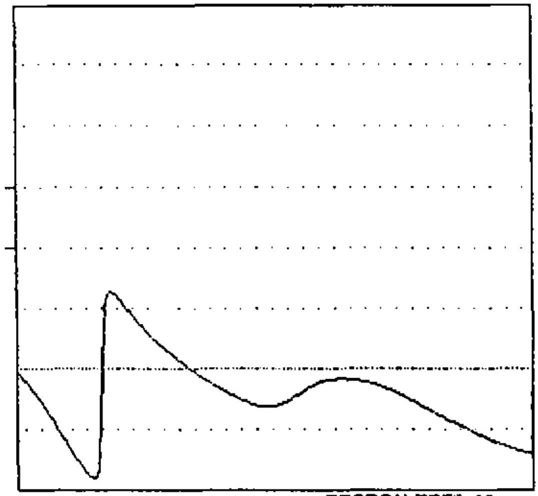
INPUT CONFIGURATION: Balanced with 66dB of input gain & 18dB of IF gain.

REMARKS: The remarks area can be very useful. It can be used as a scratch pad for yourself noting any unique test conditions. It can also be used to give a non-technical explanation of the display for inclusion in a proposal or document showing the improvements you had made to the system and/or environment.



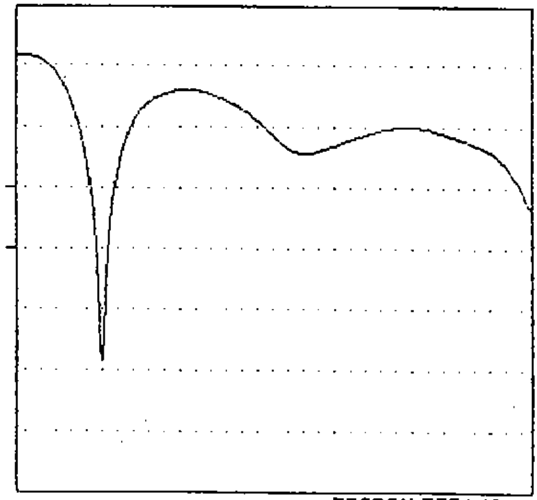
IMPULSE RESPONSE

VERTICAL:	Linear amplitude
HORIZONTAL:	0 microseconds or 0 Feet to 799618 microseconds or 905.167 Feet
SCALE:	2.4748E+02 Feet/inch or 9.7434E+01 Feet/cm. 2.18623E+5 microseconds/inch or 86072 microseconds/cm.
LINE SPACING:	2004.05 microseconds or 2.26859 Feet
LINE WIDTH:	2725.51 microseconds or 3.08528 Feet
SWEEP RATE:	100.19Hz/Sec
SWEEP RANGE:	1000.12Hz to 1499.11Hz
WINDOW FILE NAME:	A:HAMMING.W8T
INPUT CONFIGURATION:	Channel 1 Balanced with 54dB of input gain & 21dB of IF gain.



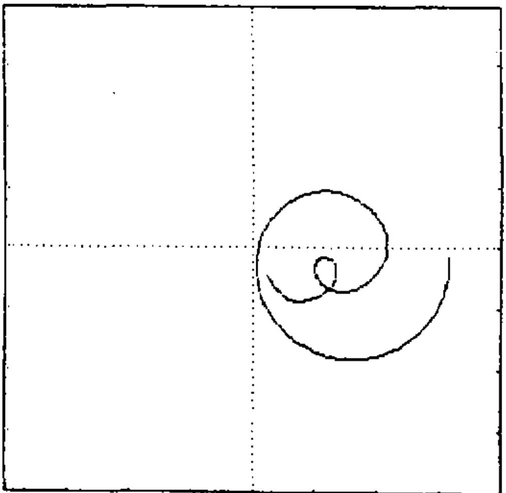
PFC, PHASE FREQUENCY CURVE

VERTICAL:	45 degrees/div. 0 degrees is at the dashed horizontal line.
HORIZONTAL: SCALE:	50.33Hz to 20011.00Hz 5457.44Hz/inch or 2148.60Hz/cm.
RESOLUTION:	4.2106E-01 Feet & 2.6837E+03Hz
TIME OF TEST:	456 microseconds, 5.1473E-01 Feet
SWEEP RATE & BANDWIDTH:	10734.80Hz/Sec & 4.0000E+00Hz
INPUT CONFIGURATION:	Balanced with 66dB of input gain and 18dB of IF gain.



EFC, ENERGY FREQUENCY CURVE

VERTICAL:	6dB/div with base of display at 42.3dB 0dB is located at .00002 Pascals
HORIZONTAL: SCALE:	50.33Hz to 20011.00Hz 5457.44Hz/inch or 2148.60Hz/cm.
RESOLUTION:	4.2106E-01 Feet & 2.6837E+03Hz
TIME OF TEST:	456 microseconds, 5.1473E-01 Feet
SWEEP RATE & BANDWIDTH:	10734.80Hz/Sec & 4.0000E+00Hz
INPUT CONFIGURATION:	Balanced with 66dB of input gain & 18dB of IF gain.
REMARKS:	there is a major drop in amplitude at the lower mid-range frequencies. We believe this is caused by a reflection off of the balcony.



NYQUIST PLOT, PHASE AMPLITUDE PLOT

RESOLUTION:	4.2106E-01 Feet & 2.6837E+03Hz OdB of automatic screen gain.
FREQUENCY RANGE:	50.33Hz to 20011.00Hz
TIME OF TEST:	456 microseconds, 5.1473E-01 Feet.
SWEEP RATE & BANDWIDTH:	10734.80Hz/Sec & 4.0000E+00Hz
INPUT CONFIGURATION:	Balanced with 66dB of input gain & 18dB of IF gain.