MODERN AUDIO AND ACOUSTICAL TEST AND MEASUREMENT

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OUTLINE

- Overview of Audio Precision
- Audio test and measurement
  - Scope of audio test
  - Test instrument requirements
  - Digital audio
- Acoustical measurement
  - MLS
- Specialized techniques
  - Windowless DFT
  - Multi-tone testing
- Conclusions

COMPANY OVERVIEW

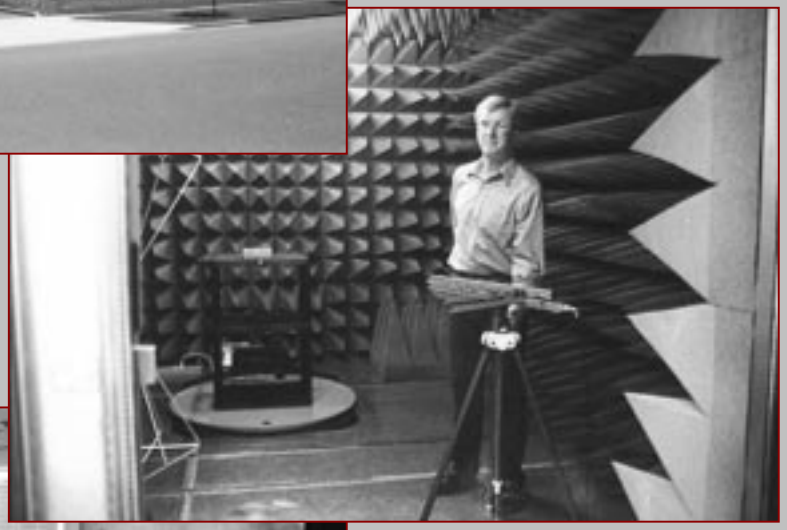
- Founded 1984
- Four employees of Tektronix, Inc.
- System One (1985)
  - PC-based
  - Outperformed rival instruments
  - Dual domain capability added 1989
  - Over 5,000 sold to date
- System Two (1995)
  - Better analog performance
  - Comprehensive digital measurements
- System Two Cascade (1999)
  - Higher performance converters
  - Large increase in DSP power
  - Up to 192 kHz sampling rate

COMPANY OVERVIEW II

- Currently 55 employees:
  - Hardware engineering
  - DSP engineering
  - Software engineering
  - Technical support and training
  - Assembly and production test
  - Marketing
  - Sales
  - Administration
- Units made to order
- Boards printed, stuffed locally
- Assembly, calibration, test performed in-house
- Worldwide sales representatives

COMPANY OVERVIEW III

AP building,
Beaverton, OR



EMI and acoustic
test chamber

Training room

AUDIO MEASUREMENT

- Analog audio characteristics:
  - Frequency response
  - Noise
  - Distortion (THD, IMD)
  - Crosstalk
  - Output level
- Additionally for digital audio:
  - Low-level linearity
  - Noise modulation
  - Effect of interface imperfections:
    - Jitter
    - Noise
    - Risetime

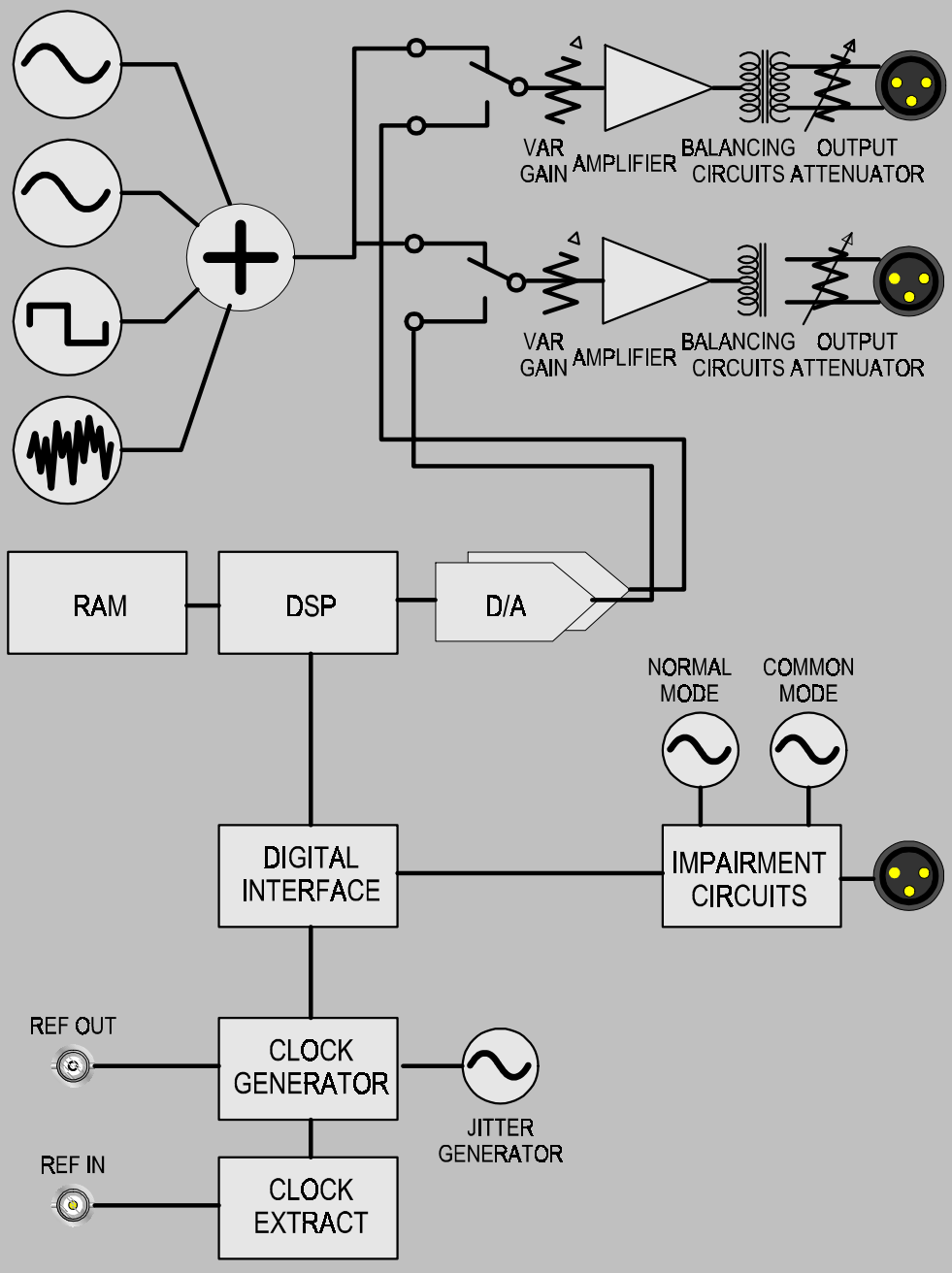
AUDIO MEASUREMENT II

- Audio test by stimulus/response
  - Low-distortion sine generation:
    - Analog THD 0.00003 % (-130 dB)
    - Digital THD 0.000001 % (-160 dB)
    - Frequency response, THD, crosstalk
  - Other signals:
    - Dual sine (IMD)
    - Sine+square (TIM)
    - Multi-tone (fast characterization)
  - Noise generation:
    - White, pink, true- or pseudo-random
- Interface test by impairment
  - Jitter generator
  - Noise generator
  - Variable risetime generator
  - Cable simulator

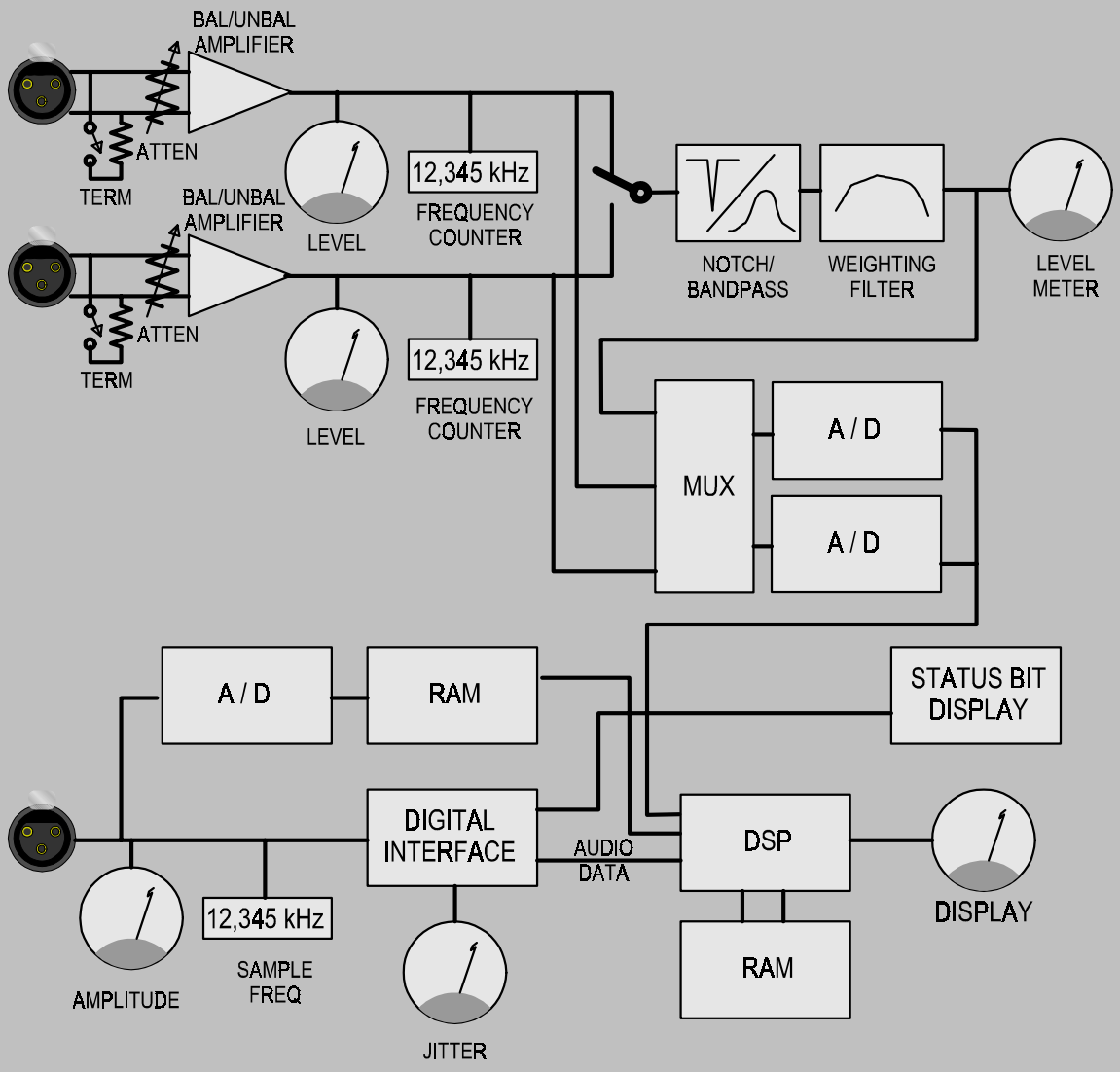
DUAL DOMAIN MEASUREMENT

- Analog in, analog out:
  - Amplifiers, tape recorders
  - A/D and D/A converters linear to ~18 bits — not optimal
    - Analog generator, analyzer
    - Converters used only if needed
- Digital in, digital out
  - Processors, sample rate converters
    - Digital generator, analyzer
- Analog in, digital out
  - A/D converters
    - Analog generator, digital analyzer
- Digital in, analog out
  - D/A converters, AC-3 decoders
    - Digital generator, analog analyzer

SIGNAL GENERATION



SIGNAL ANALYSIS



ACOUSTICAL TEST WITH MLS

- Frequency response measurement techniques:
  - Swept sine with RMS measurement
    - Very high accuracy
    - No rejection of room reflections
  - Impulse excitation
    - Fast
    - Poor signal-to-noise ratio
  - Time delay spectrometry (TDS)
    - Room reflections filtered out
    - Difficult to implement
  - Maximum-length sequence (MLS)
    - Easy to implement
    - High signal-to-noise ratio
    - Room reflections windowed out
    - Distortion can cause problems

MLS OVERVIEW

- Uses maximum-length pseudo-random binary excitation $x(k)$
- Property of $x(k)$, length N:

$$\Phi_{xx} = x(k) \otimes x(k) = N\delta(k) - 1$$
$$\approx C\delta(k)$$

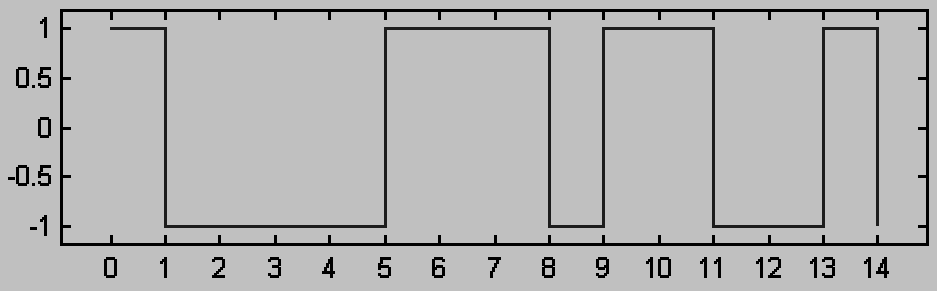
- Apply $x(k)$ to device under test (DUT), measure output $y(k)$:

$$y(k) = h(k) * x(k)$$

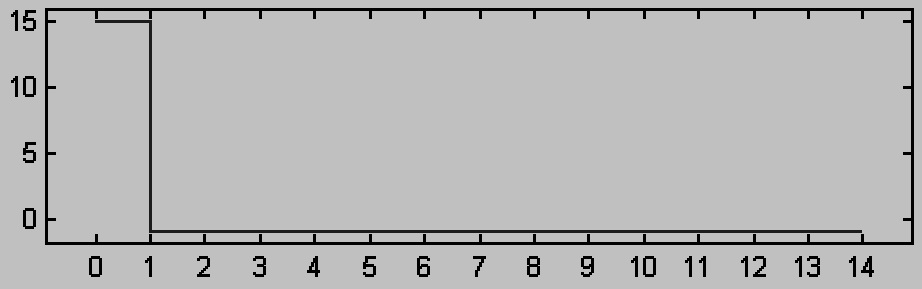
- Cross-correlate with $x(k)$:

$$y(k) \otimes x(k) = h(k) * x(k) \otimes x(k)$$
$$\approx h(k) \otimes \delta(k)$$
$$= h(k)$$

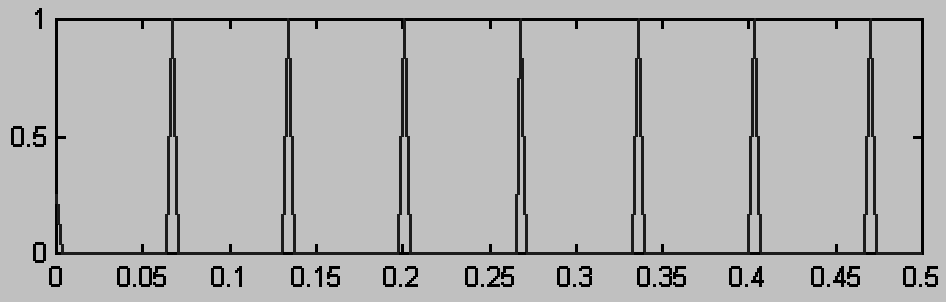
MLS EXAMPLE



Length 15 MLS



Circular autocorrelation



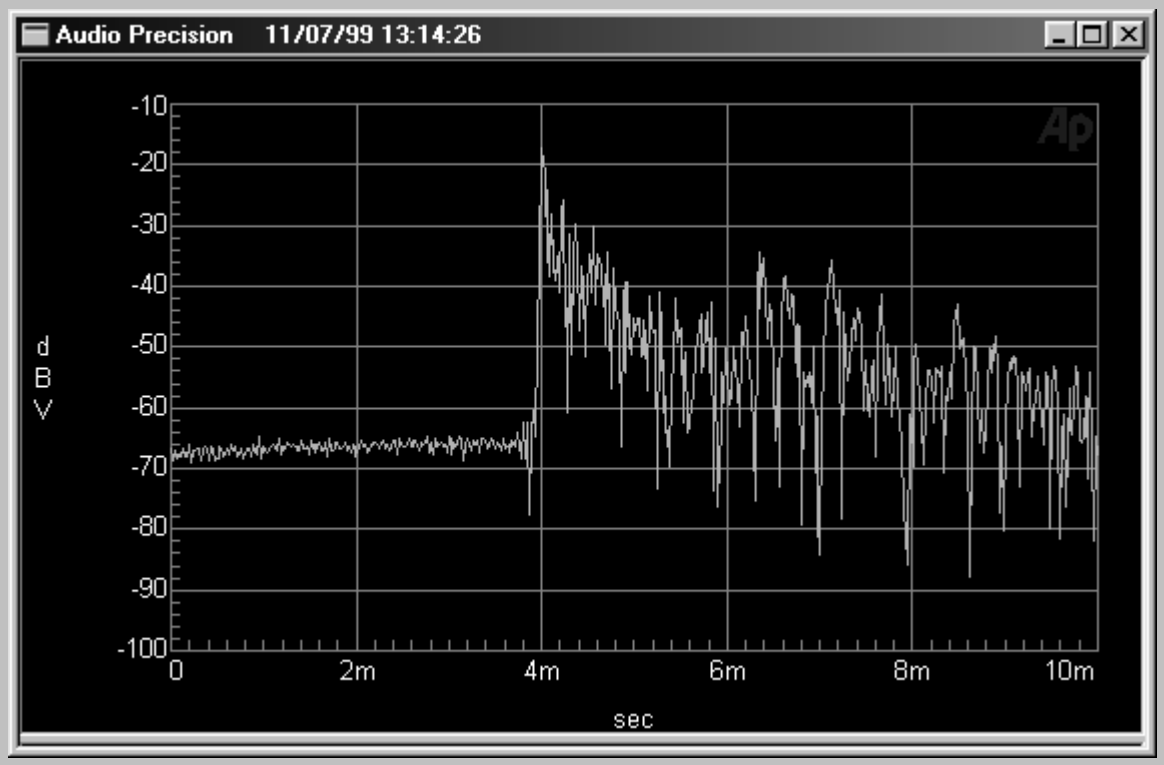
Spectrum of circular autocorrelation

FAST MLS ALGORITHM

- Problem: Slow cross-correlation
- Solution: Fast Hadamard Transform (FHT)
  - Same structure as FFT
  - 'Twiddle factors' are all unity
  - Only addition needed
  - No bit-reversed addressing
- Problem: FHT only for Sylvester-type, 2^N Hadamard matrices
- Solution: Permute and zero-pad measurement matrix:

$$\Phi_{xy} = \frac{1}{N} P_2(S_2(H_N(S_1(P_1(Y)))))$$

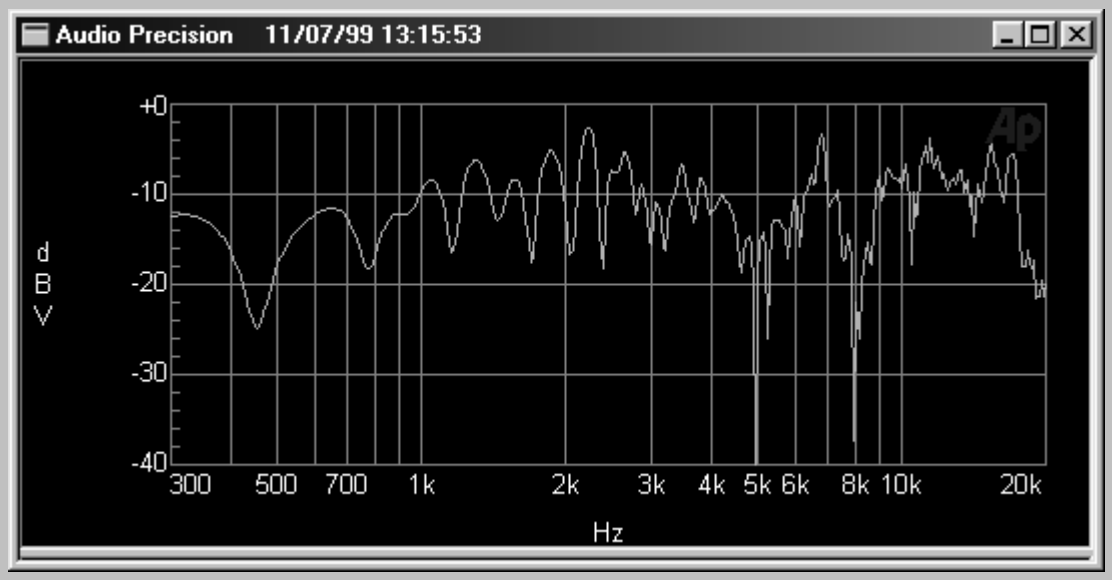
TIME WINDOWING



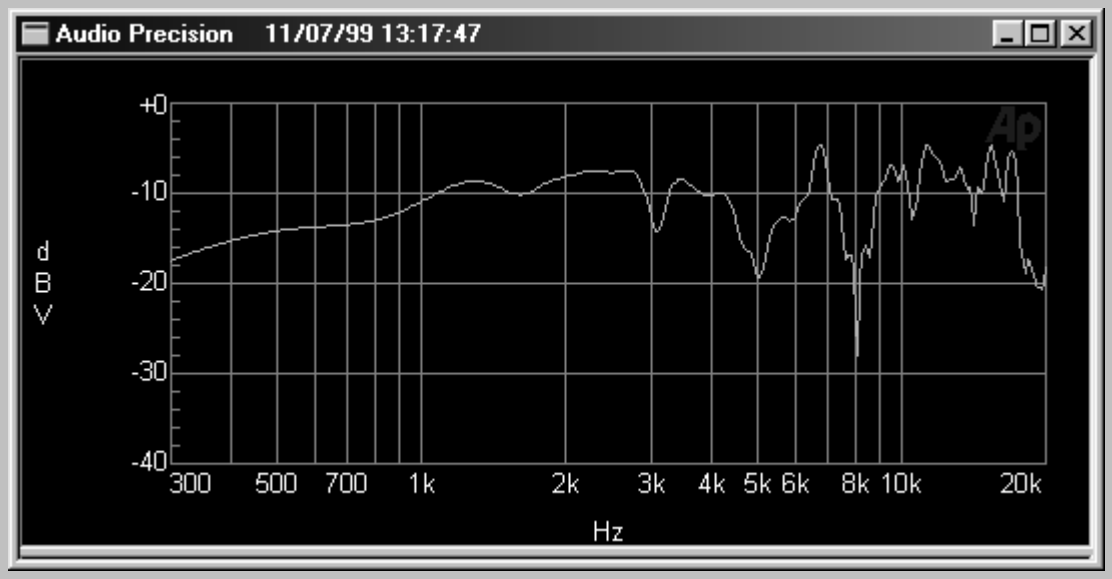
Impulse response of monitor speaker

- Typical acoustical set-up has direct + reflective signal paths
- Reflections skew measurements
- Window out all but direct path

WINDOWED MLS RESULTS



Frequency response, entire record



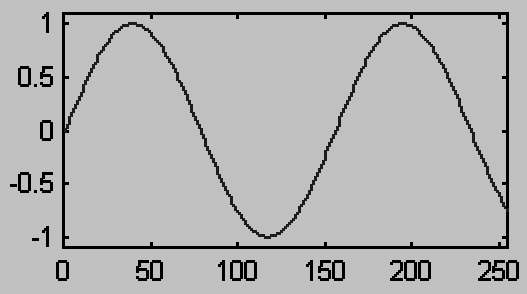
Frequency response, direct path only

INTRODUCTION TO DFT

- Discrete Fourier Transform (DFT):

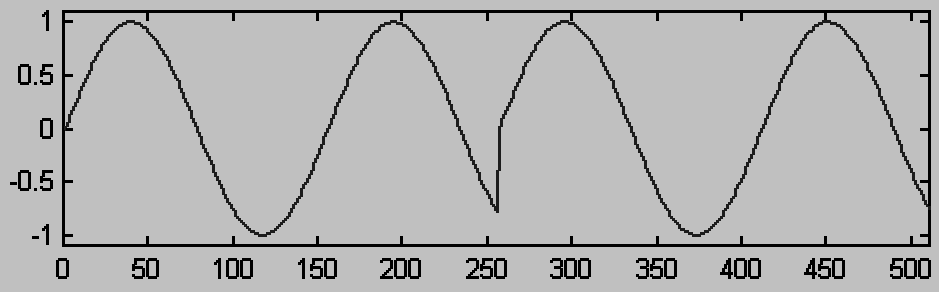
$$X[k] = \sum_{n=0}^{N-1} x[n] e^{-j2\pi kn/N}$$

- Frequency samples of continuous Fourier transform (CFT)
- Twiddle factors inherently circular so DFT is also circular

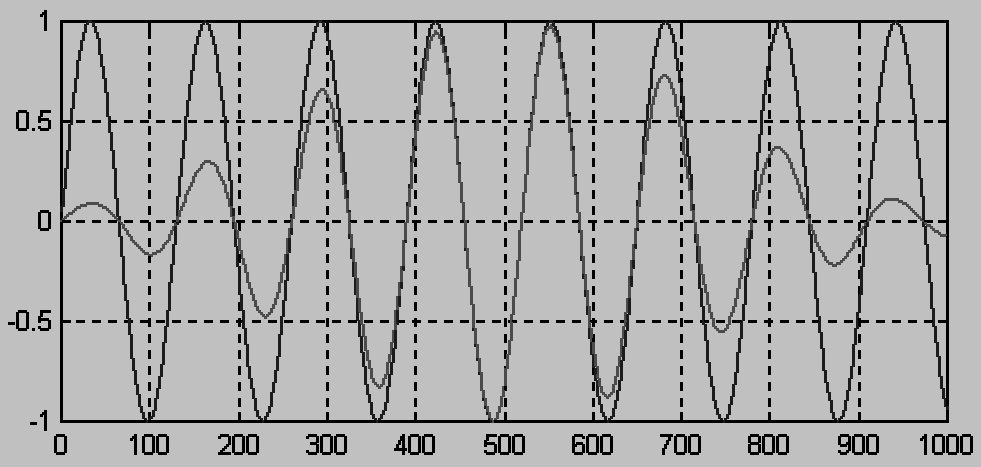


Input signal

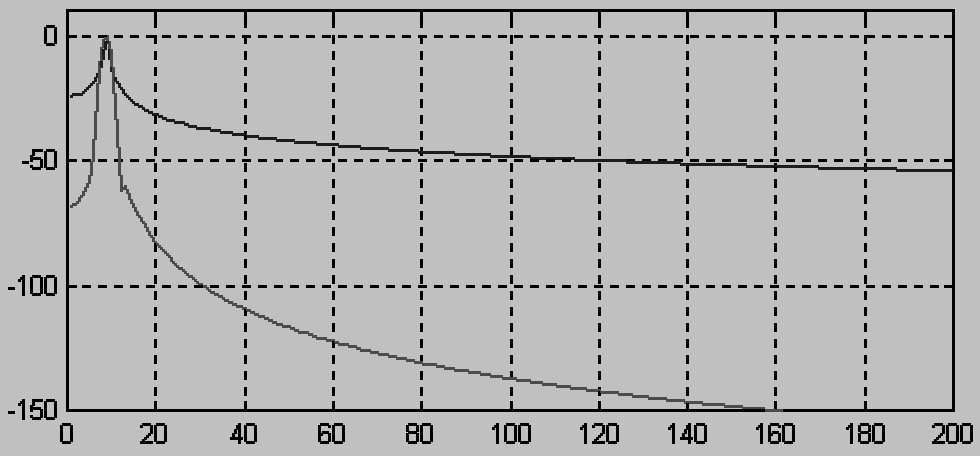
What DFT sees



WINDOW SOLUTION



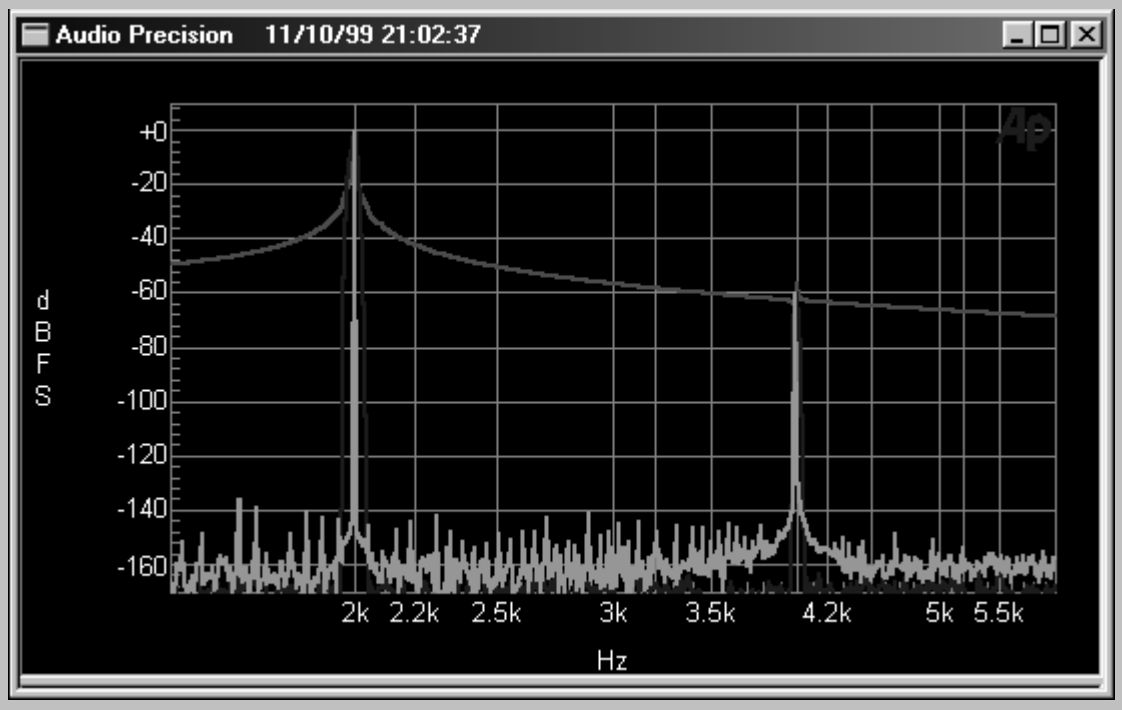
Windowed and non-windowed acquisitions



Windowed and non-windowed DFTs

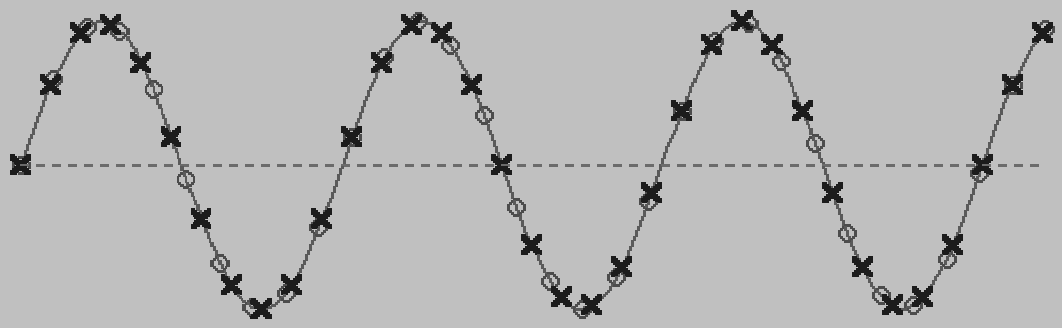
RATE CONVERSION SOLUTION

- Resample acquisition at new, synchronous sample rate
- Use interpolating FIR filter
- No windowing needed

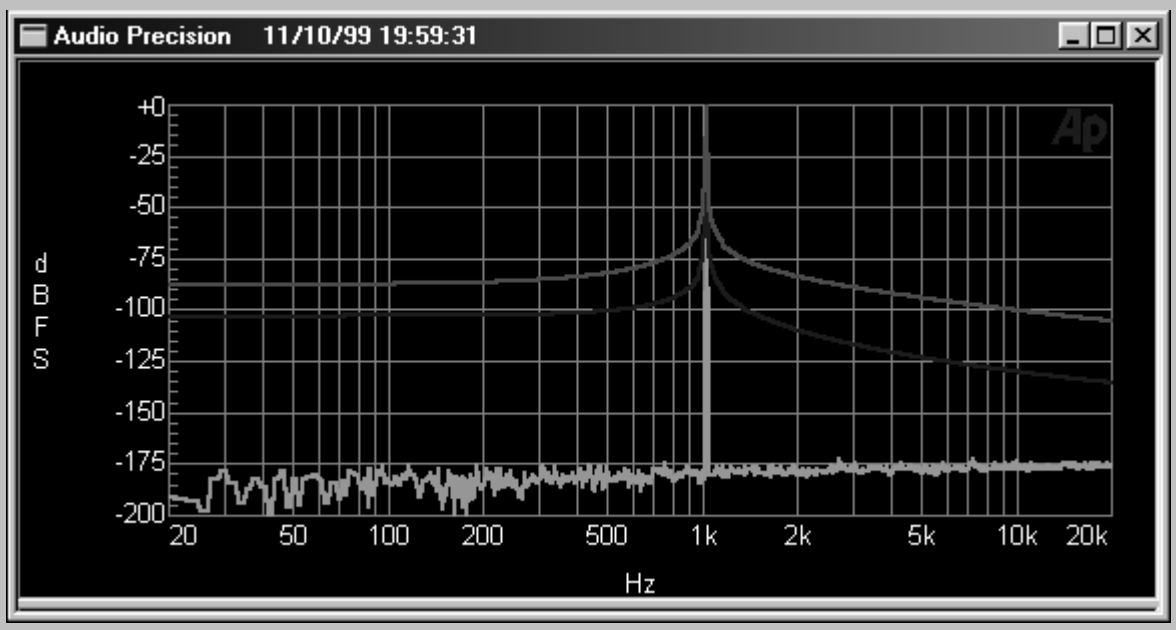


Unwindowed, windowed, and corrected FFTs

RATE CONVERSION



Interpolate underlying waveform at new points

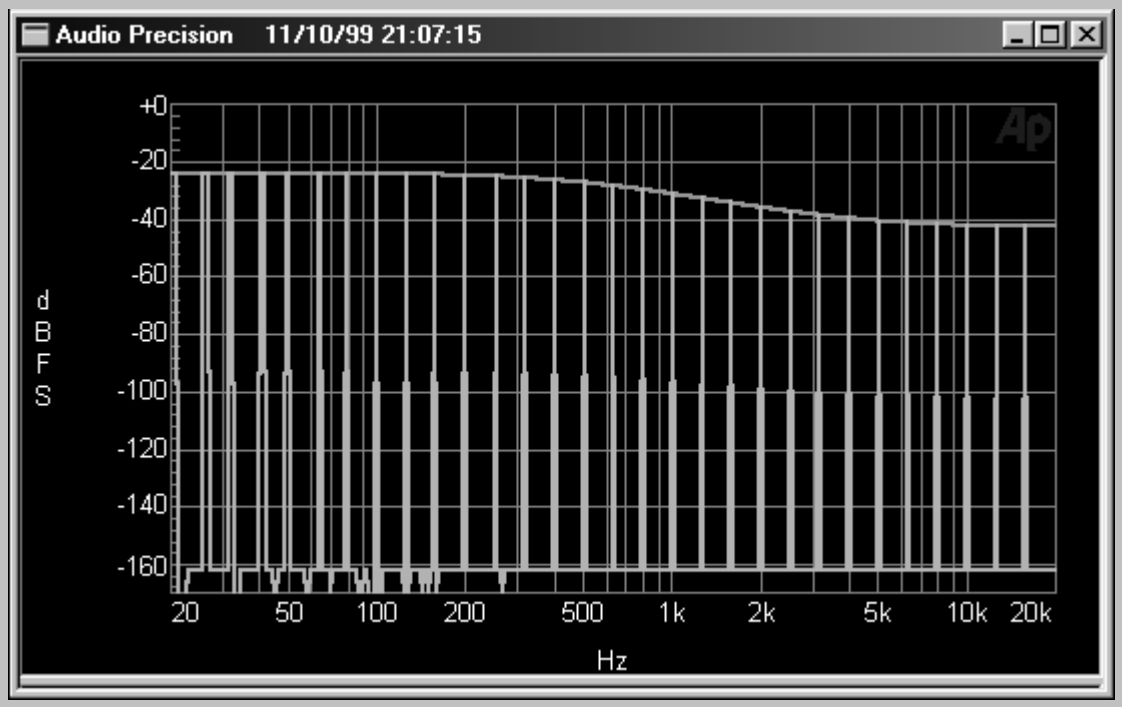


Frequencies off by 0.005 bin, 0.05 bin

FAST AUDIO TESTING

- Multi-tone audio testing:
  - Apply many tones to device at once, typically 31 for third-octave results
  - Process FFT of device output:
    - Input bins → frequency response
    - Other bins → total distortion + noise
  - If analyzer FFT length 2× generator FFT length, get 'empty bins'
    - Bins contain no signal or distortion
    - Measure noise with signal present
    - Good for effects processors
    - Doesn't work if frequencies shifted
  - Stereo testing:
    - Inter-channel phase, gain imbalance
    - Crosstalk
- Very fast characterization method

FASTTEST OUTPUT



Response of J17 digital de-emphasis filter

- Phases of tones scrambled to minimize crest factor
- Non-linear optimization problem

THE FUTURE OF AP

- Loudspeaker tester
  - Based around DSP + converters
  - New DSP code:
    - 1/*N*th-octave smoothing
    - Warble tones
    - Noise cancellation
- Low-cost production tester
- More…

THE FUTURE OF TK

- Beer drinking, reminiscing
- Texas Tech game tomorrow