Fast Audio-Band Measurement Using Log-Swept Chirp Signals

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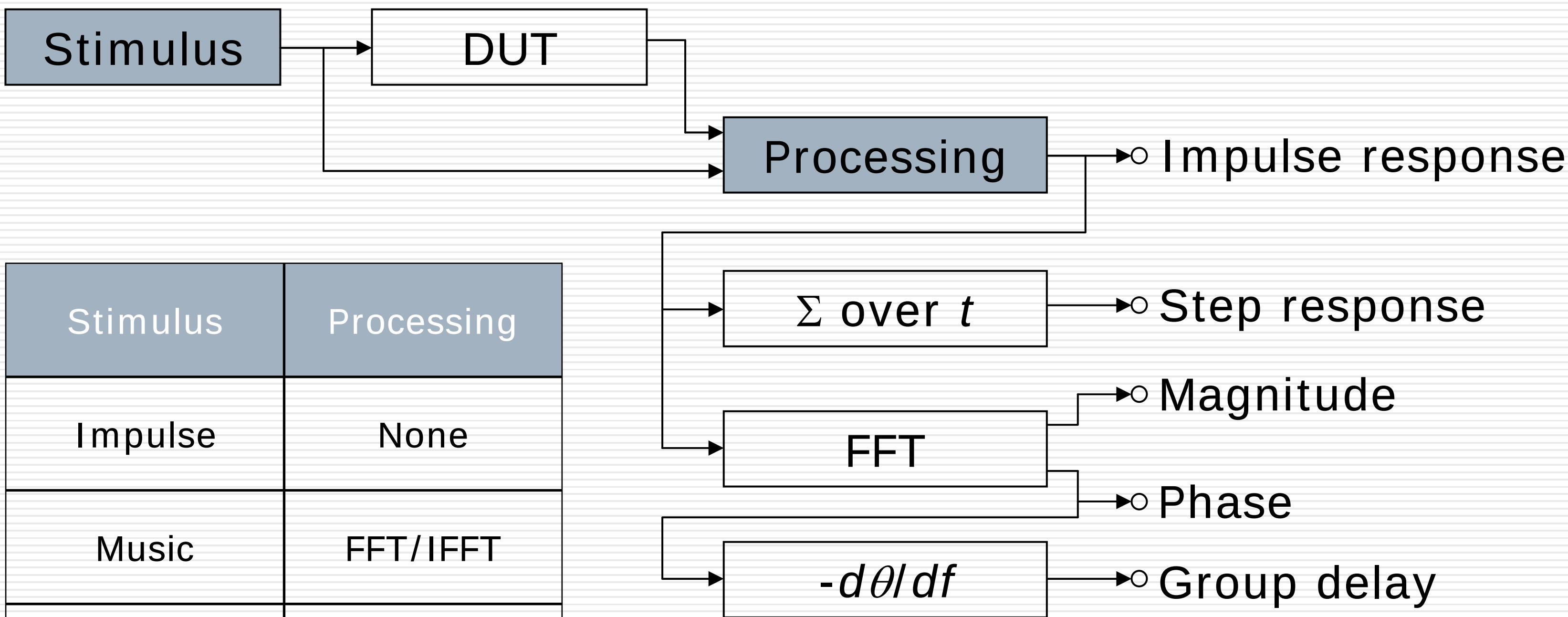
Impulse Response (IR)

- Time-domain description of LTI system
- From IR we can derive:
  - ⇨ Magnitude vs. frequency
  - ⇨ Phase vs. frequency
  - ⇨ Group delay vs. frequency
  - ⇨ Step response vs. time
- Frequency domain resolution depends only on length of captured IR
- No need to wait for device to settle

IR Measurement Techniques

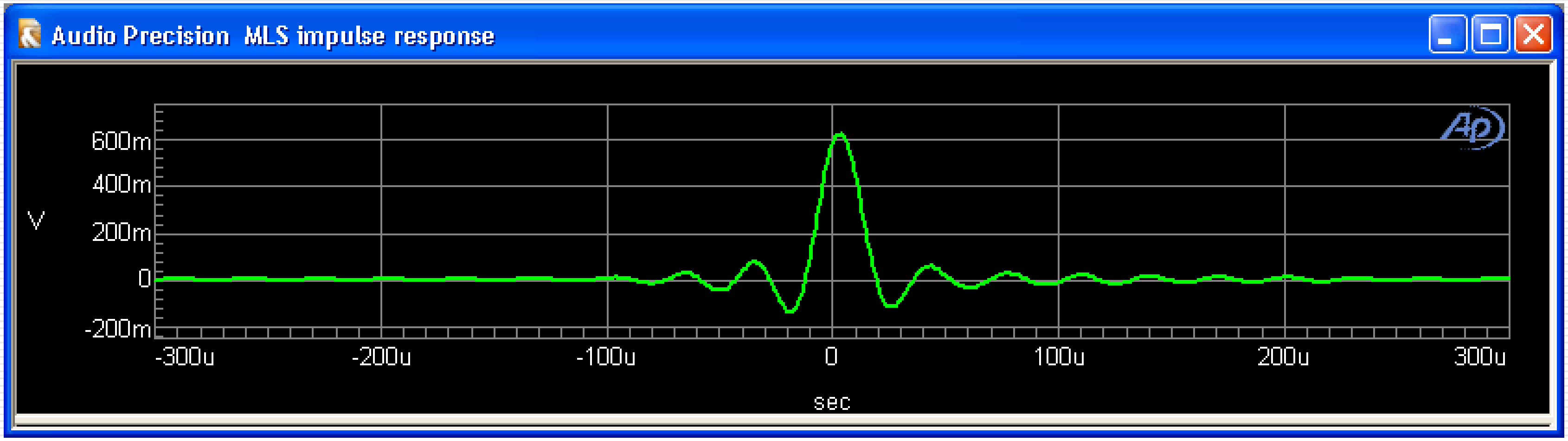
- Apply impulse, capture response
  - No post-processing needed
  - But signal-to-noise ratio (SNR) is very low
- Apply any wideband signal, deconvolve
  - Can use music, for instance
  - Forward and inverse transforms needed
  - SNR depends on energy at each frequency
- Maximum length sequence (MLS)
  - Fast Hadamard Transform has low cost
  - High SNR due to low crest factor; SNR is constant with frequency (white stimulus)

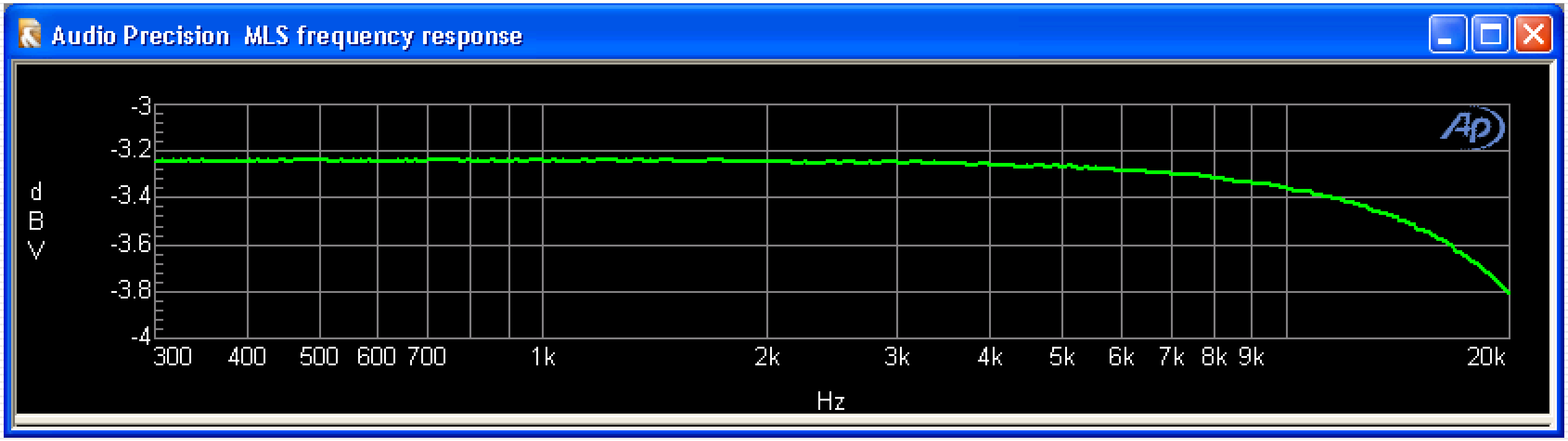
Deriving results from IR



Stimulus	Processing
Impulse	None
Music	FFT/IFFT
MLS	FHT

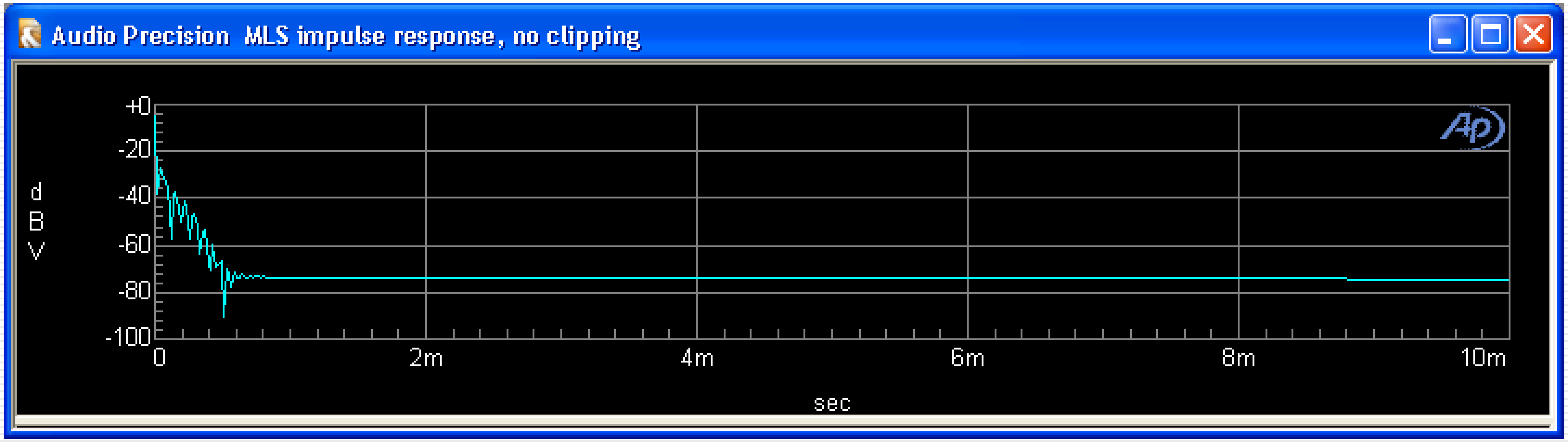
MLS impulse, frequency response





Distortion

- Real-world systems have distortion
  - ⇨ Corrupts impulse response
  - ⇨ Plus, it would be nice to measure it



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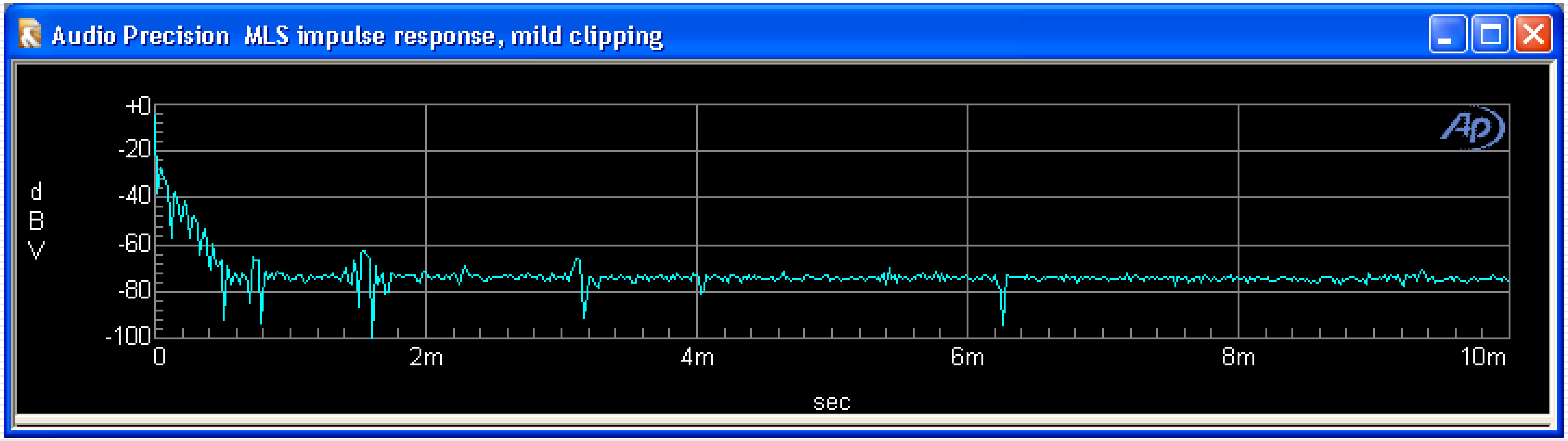


The log-swept chirp stimulus

- Basic form:

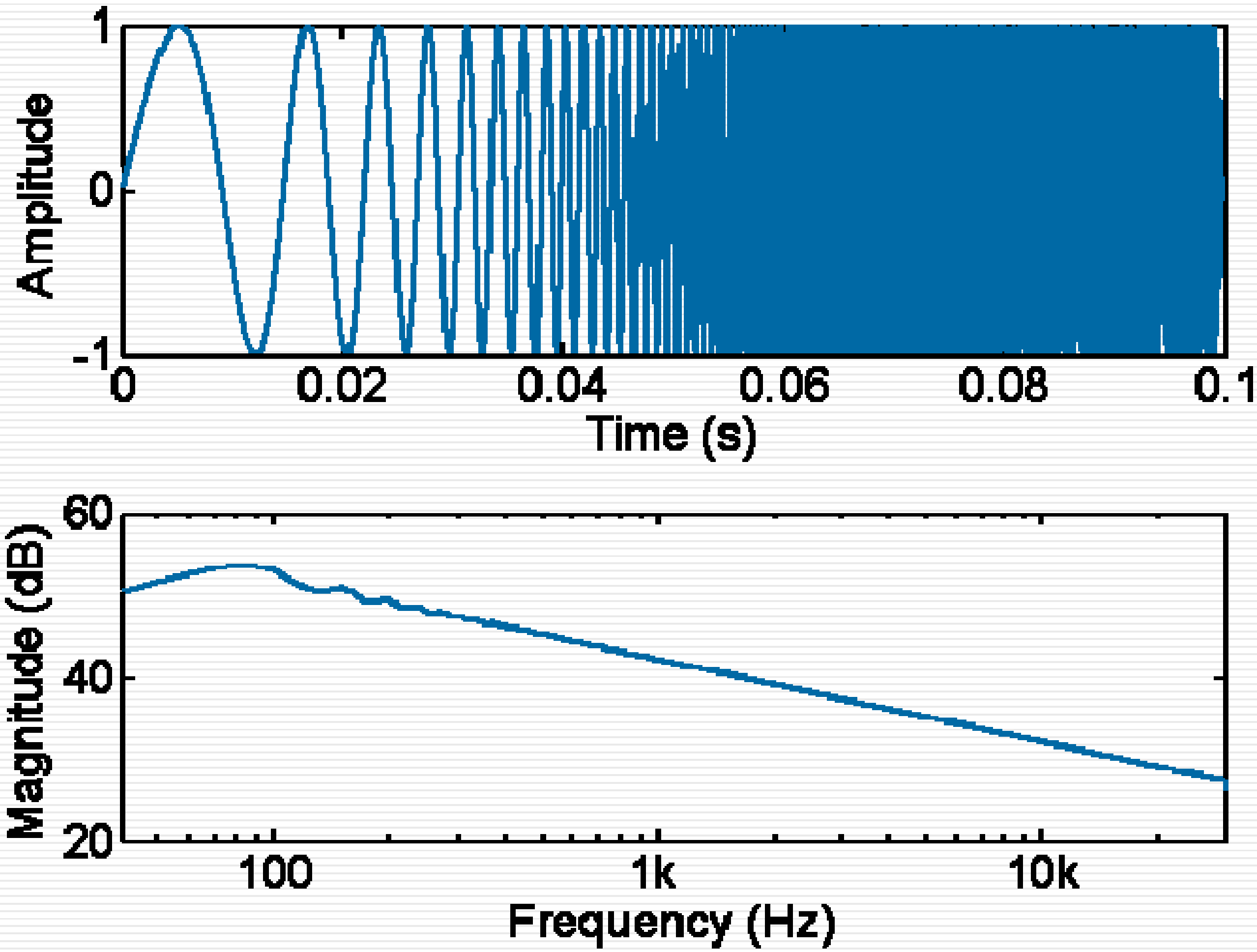
$$x(t) = \sin\left(\frac{2\pi f_1 T}{\ln(f_2/f_1)}\left[\exp\left(\frac{\ln(f_2/f_1)t}{T}\right) - 1\right]\right)$$

where:

- ⇨ T is total length (s)
- ⇨ f_1, f_2 are lower and upper frequencies

- Wideband, low crest factor

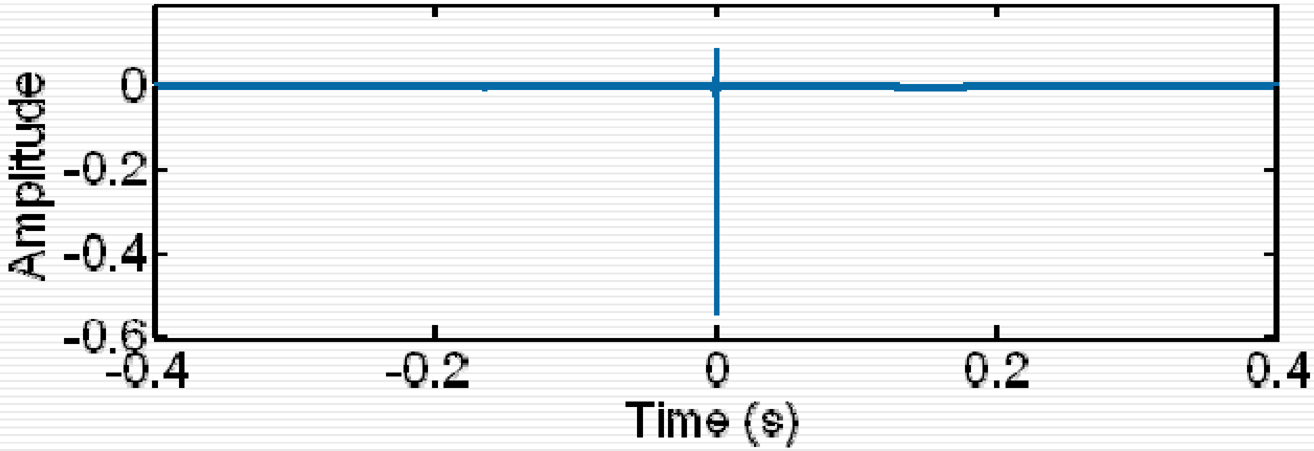
Chirp characteristics



Constant level in time domain — distortion generation like static sine

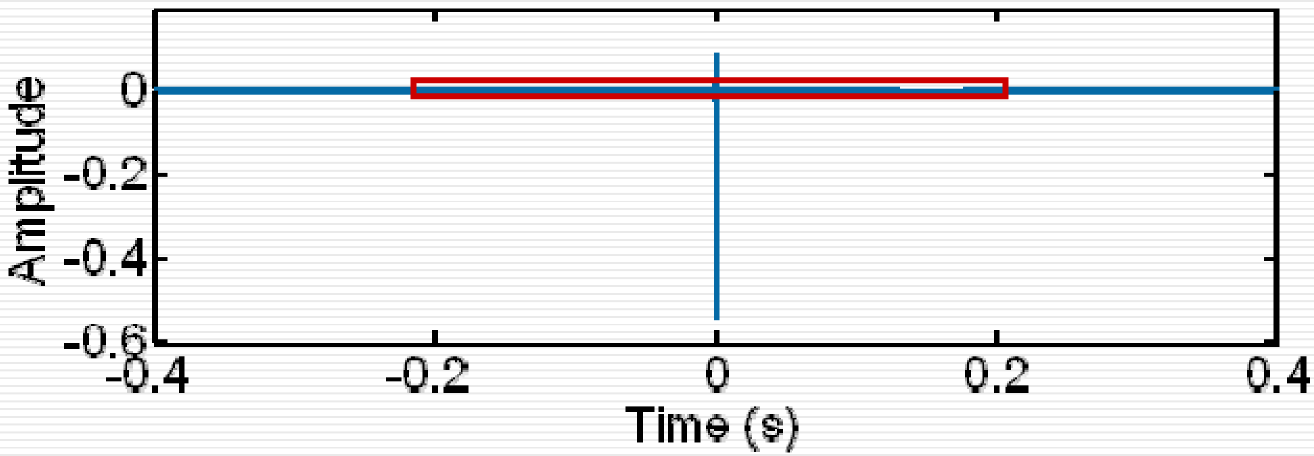
Energy (SNR) falls with frequency

Measured impulse response



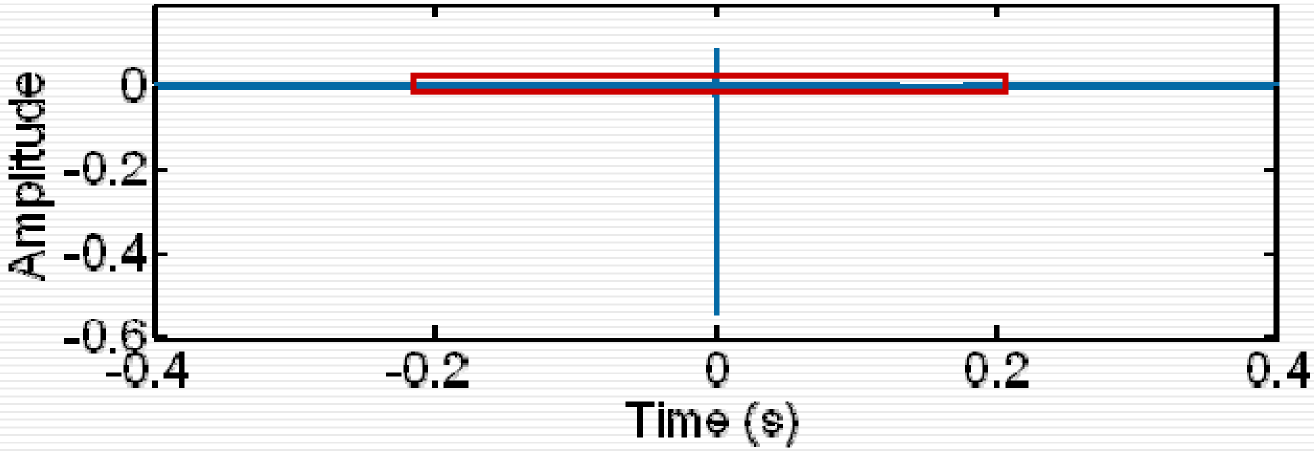
Deconvolved impulse response

Measured impulse response

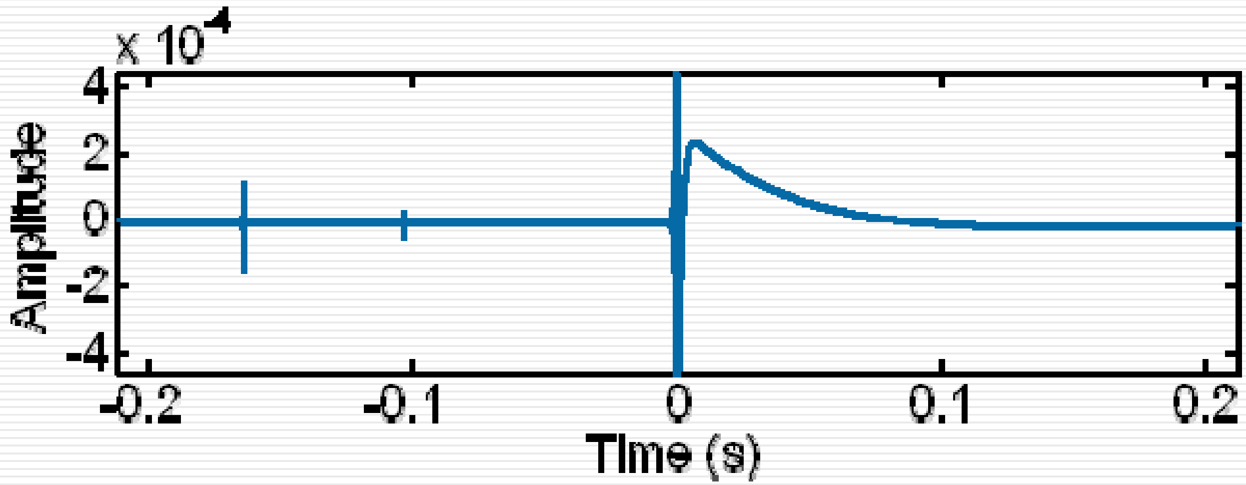


Deconvolved impulse response

Measured impulse response



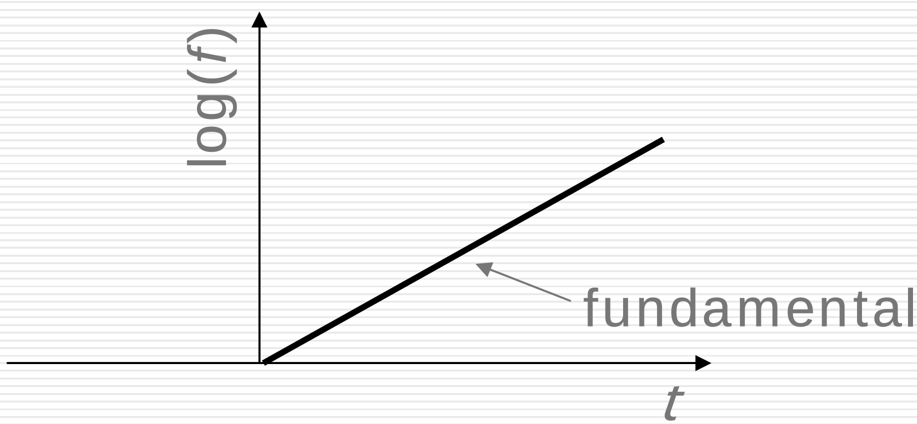
Deconvolved impulse response



Zoomed in — 2HD and 3HD products visible

Distortion generation

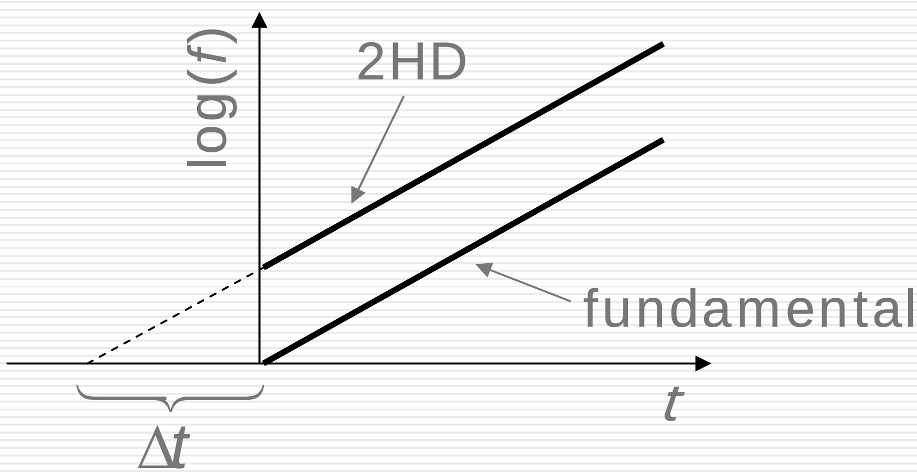
- Stimulus frequency *f* increases exponentially in time
  - ⇨ DUT's linear response does the same



Time (s)	Freq (Hz)
0.0	20
0.1	40
0.2	80
0.3	160

Distortion generation

- Stimulus frequency *f* increases exponentially in time
  - ⇨ DUT's linear response does the same
  - ⇨ Harmonics appear as if advanced in time



Time (s)	Freq (Hz)	2HD (Hz)
0.0	20	40
0.1	40	80
0.2	80	160
0.3	160	320

What is deconvolution?

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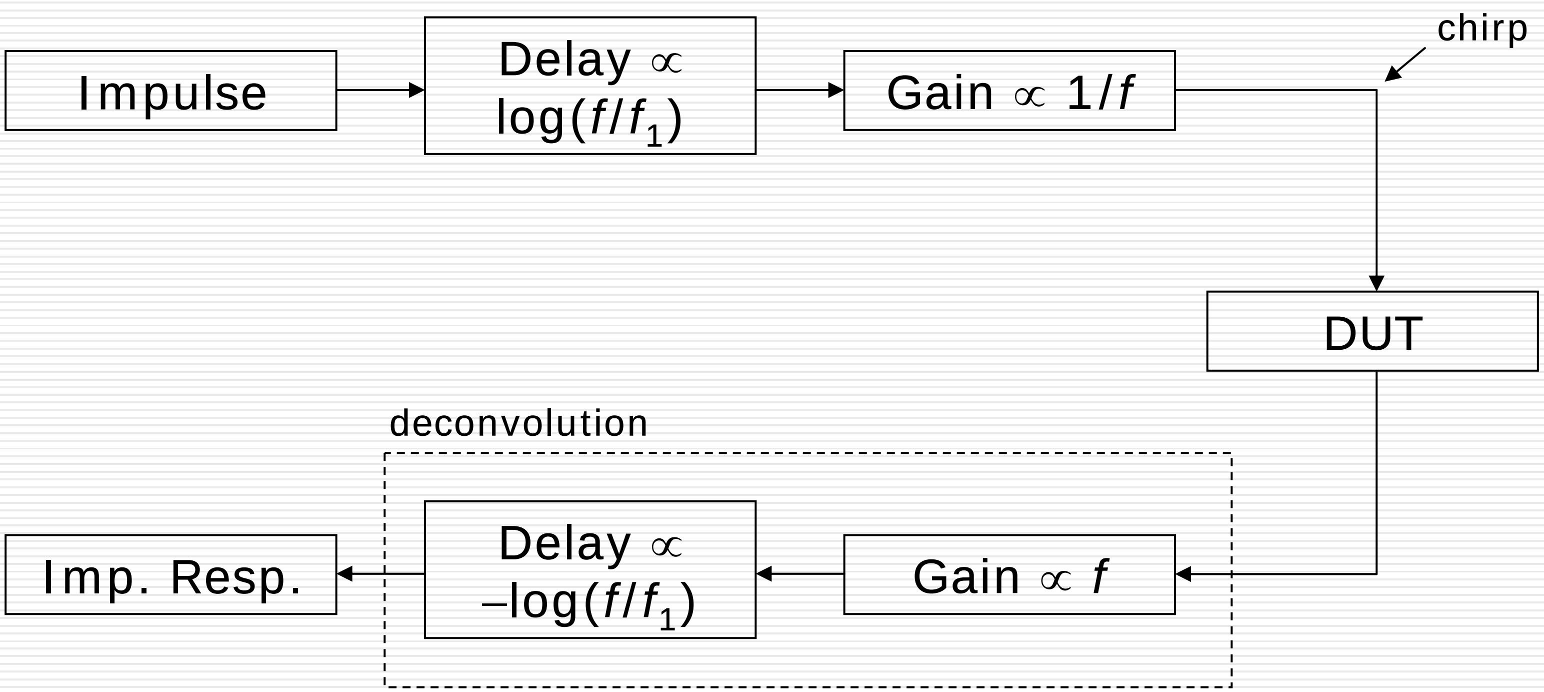
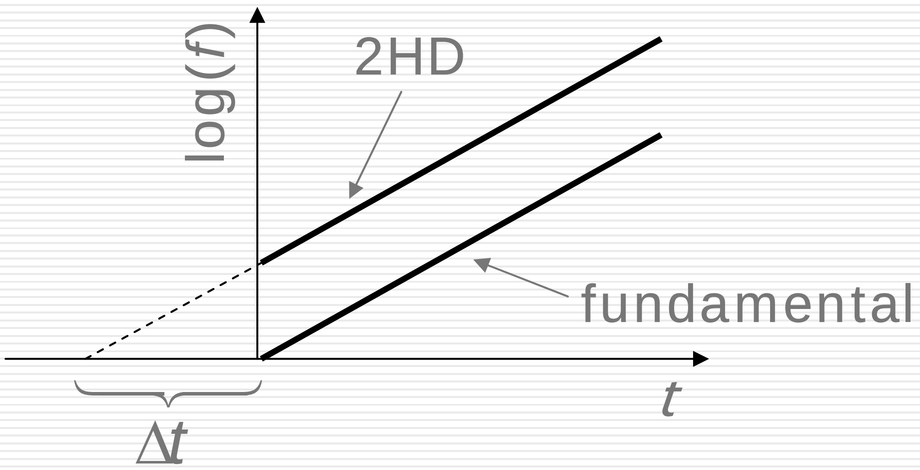


- Chirp is a stretched, EQed impulse
  - ⇨ Deconvolution de-EQs and de-stretches

Effect on harmonic products

- As with linear response:
  - ⇨ De-EQ restores frequency balance
  - ⇨ De-stretch collapses to impulse response
- Time advance separates HD products

At output of DUT



Effect on harmonic products

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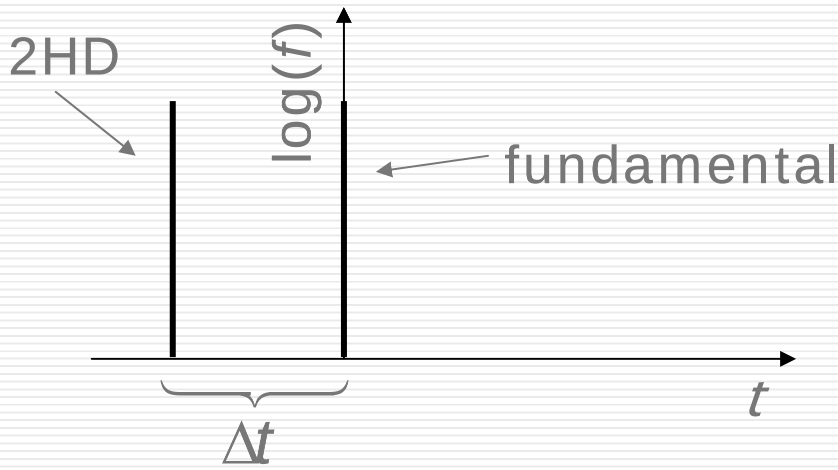
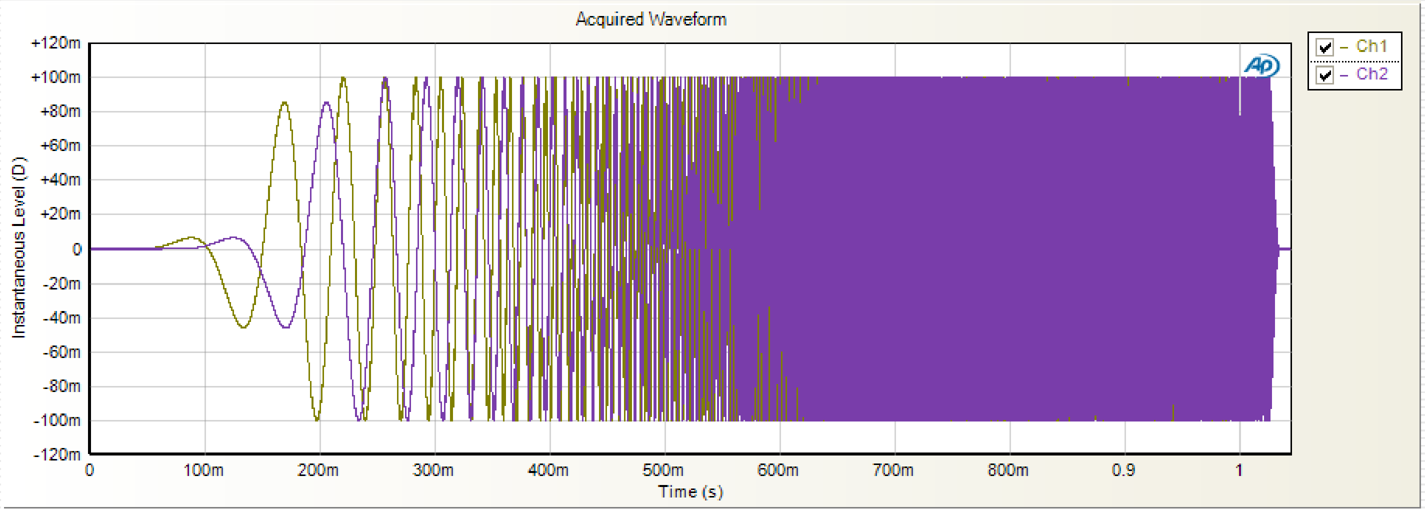
After deconvolution

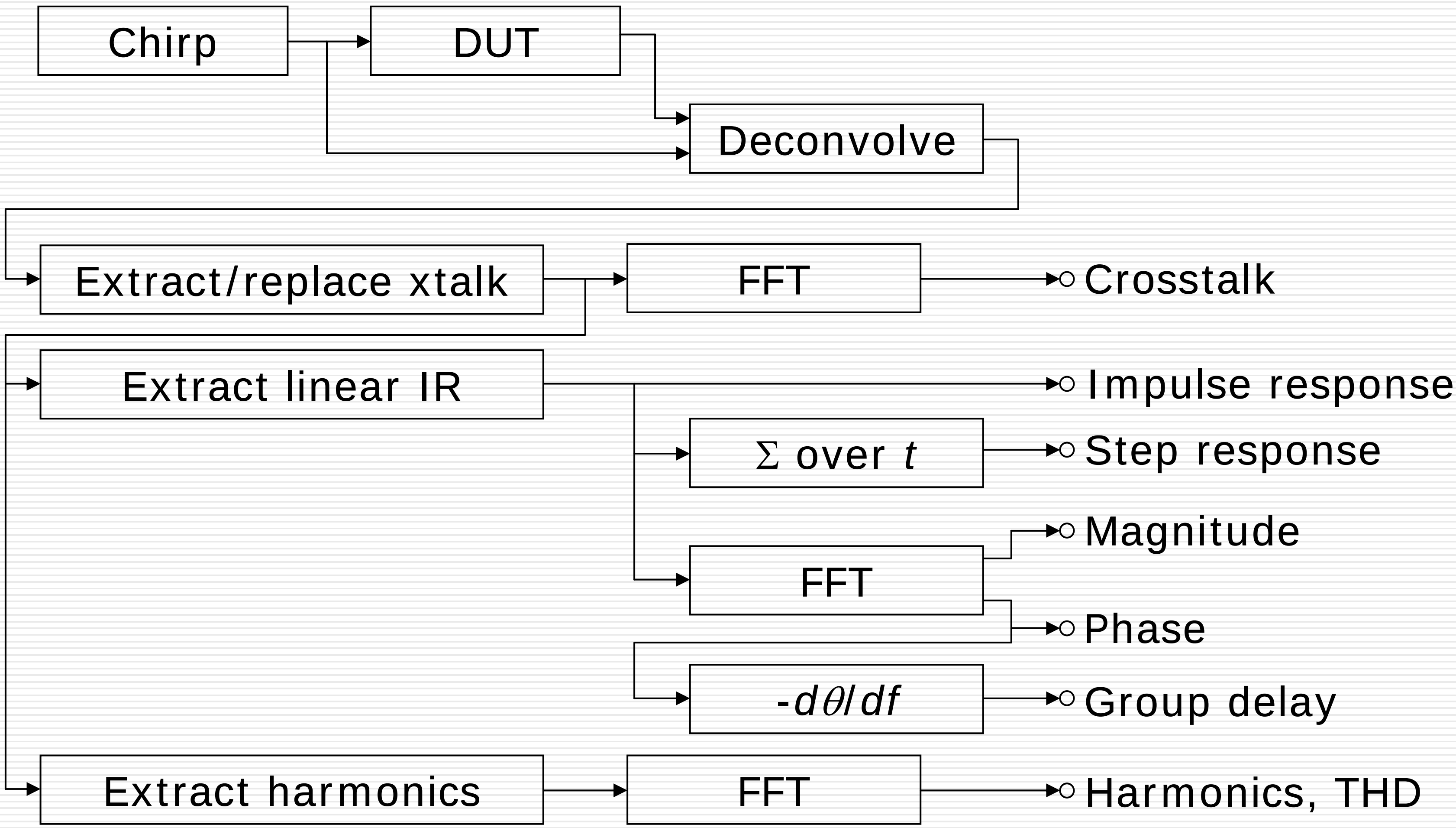


Crosstalk measurement

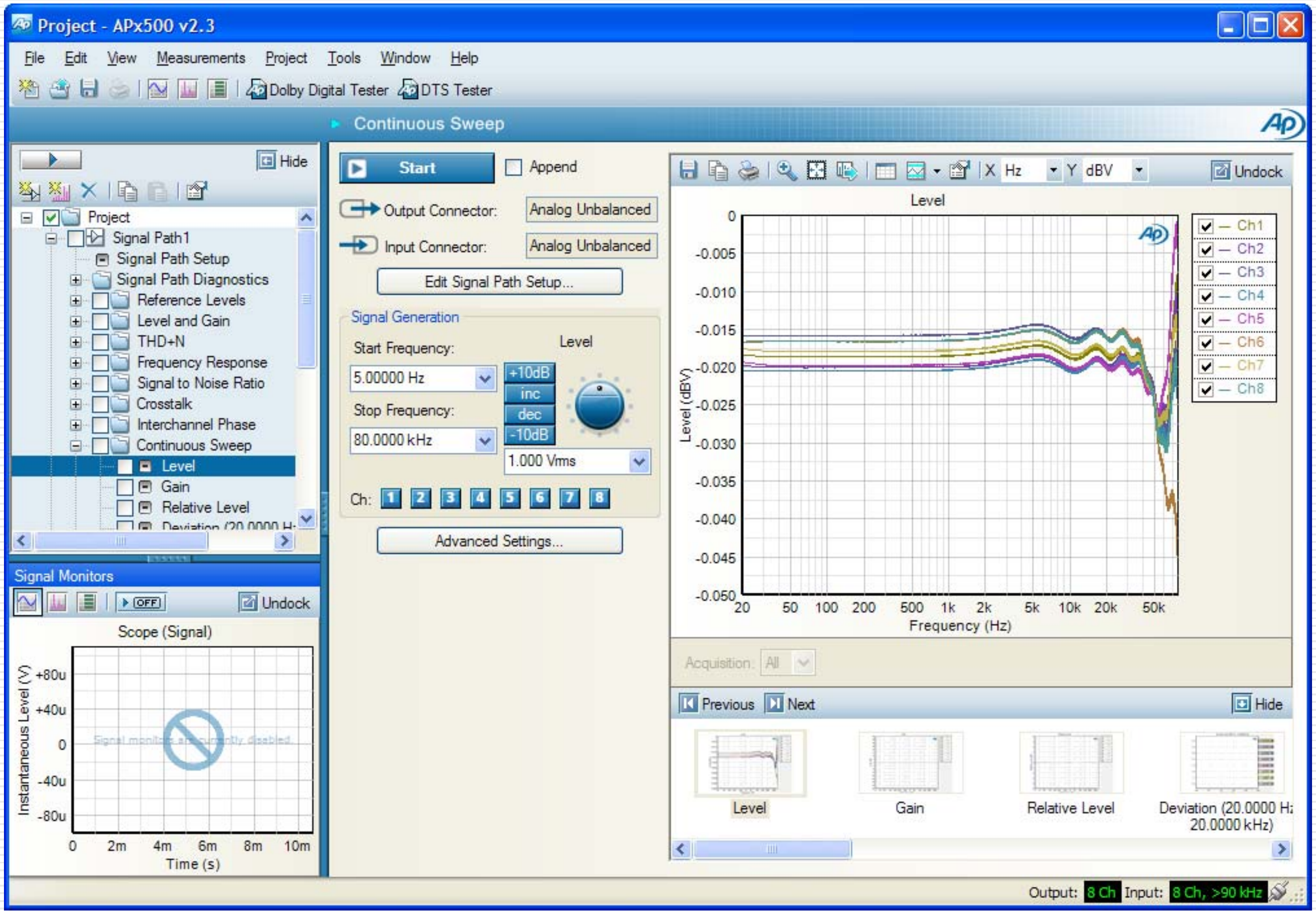
- Chirps separated in time on each channel
  - Crosstalk products from other channels advanced or delayed in impulse response
  - Works with any stimulus (LTI property)



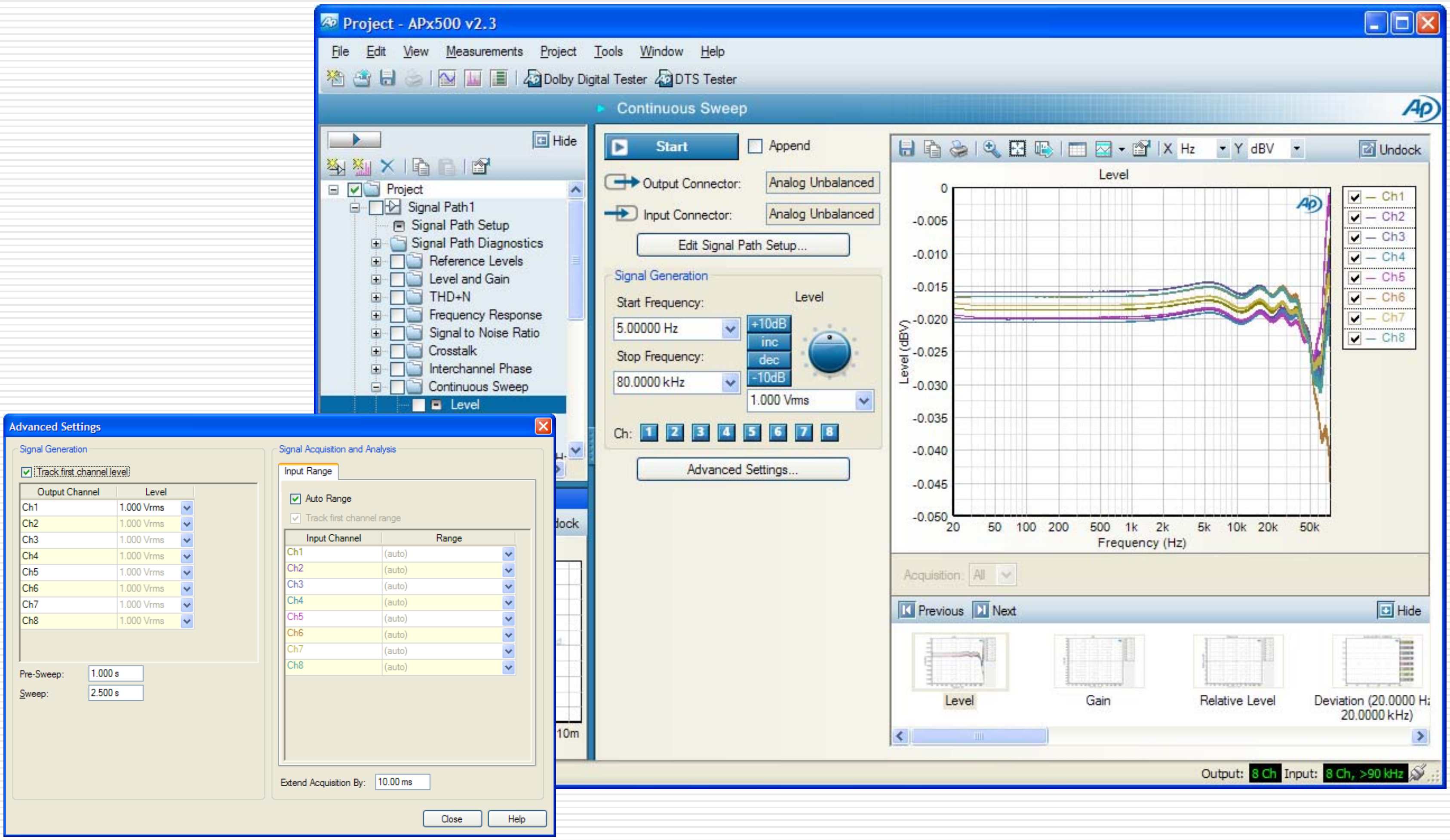
Deriving results from chirp



APx implementation



APx implementation



Why chirp is important to APx

- Speed
  - APx equipment is used on production lines
  - Time is always at a premium
  - Very short (<1 second) chirps
  - All measurements (14) at same time
  - High SNR: ideal for frequency response, distortion validation

Why chirp is important to APx

- Comparability
  - Users of audio analyzers don't like surprises
  - They do like sine waves
  - Chirp stimulus *is* a sine wave
    - Linear and non-linear products are directly comparable to stepped sines
  - Linear, distortion, crosstalk measurements all in close agreement with stepped sine
  - Chirp is not a "tough sell"

Future challenges for chirp

- Bandwidth restriction
- LF and severe crosstalk
- Different channel delays
- External
- SNR
- THD+N
- Interfering signals
- Clipping behaviour

In conclusion...

Grazie mille,
Prof. Farina!