



Unraveling Zero Crossing and Full Spectrum What does it all mean?

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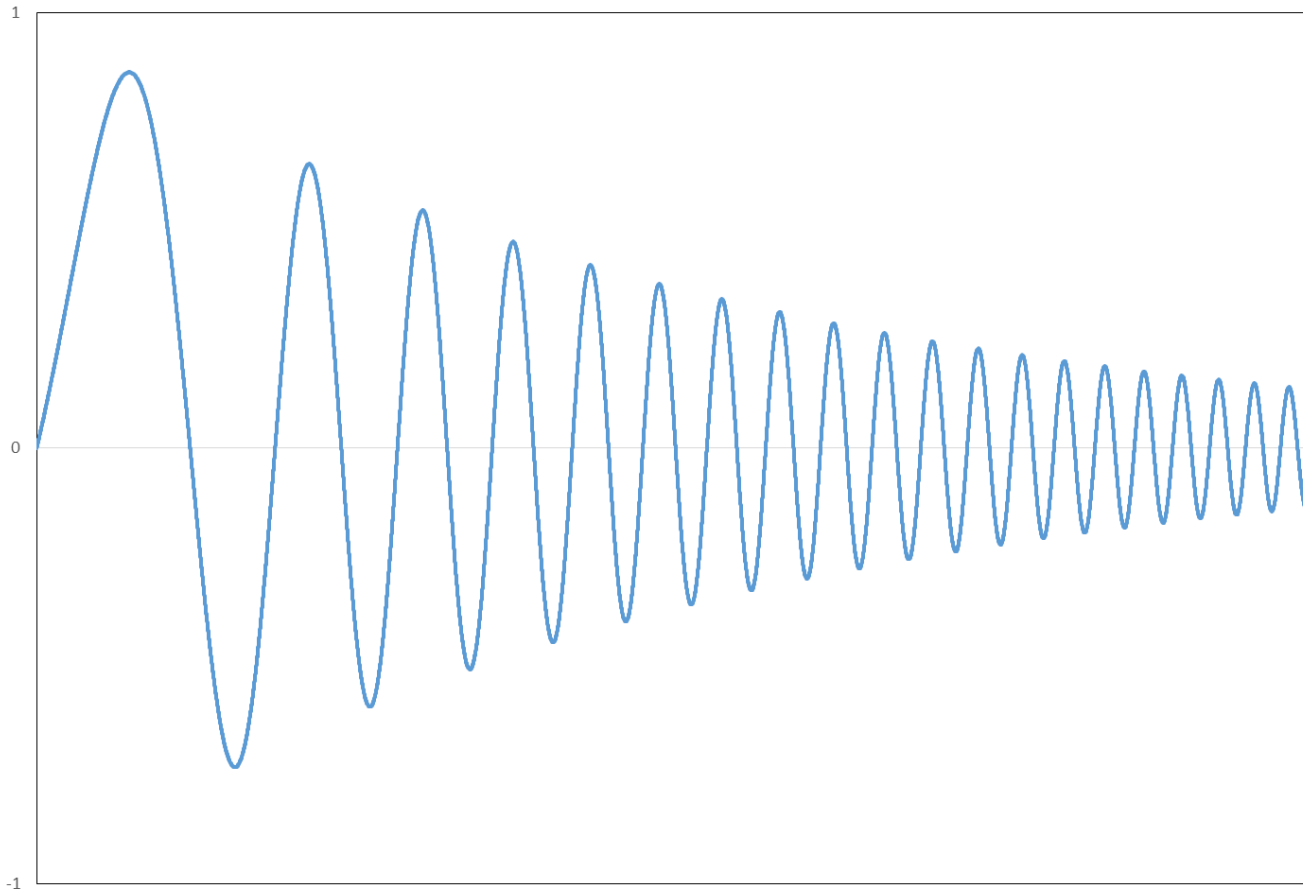
March 29, 2017





Let's start with a sound wave...

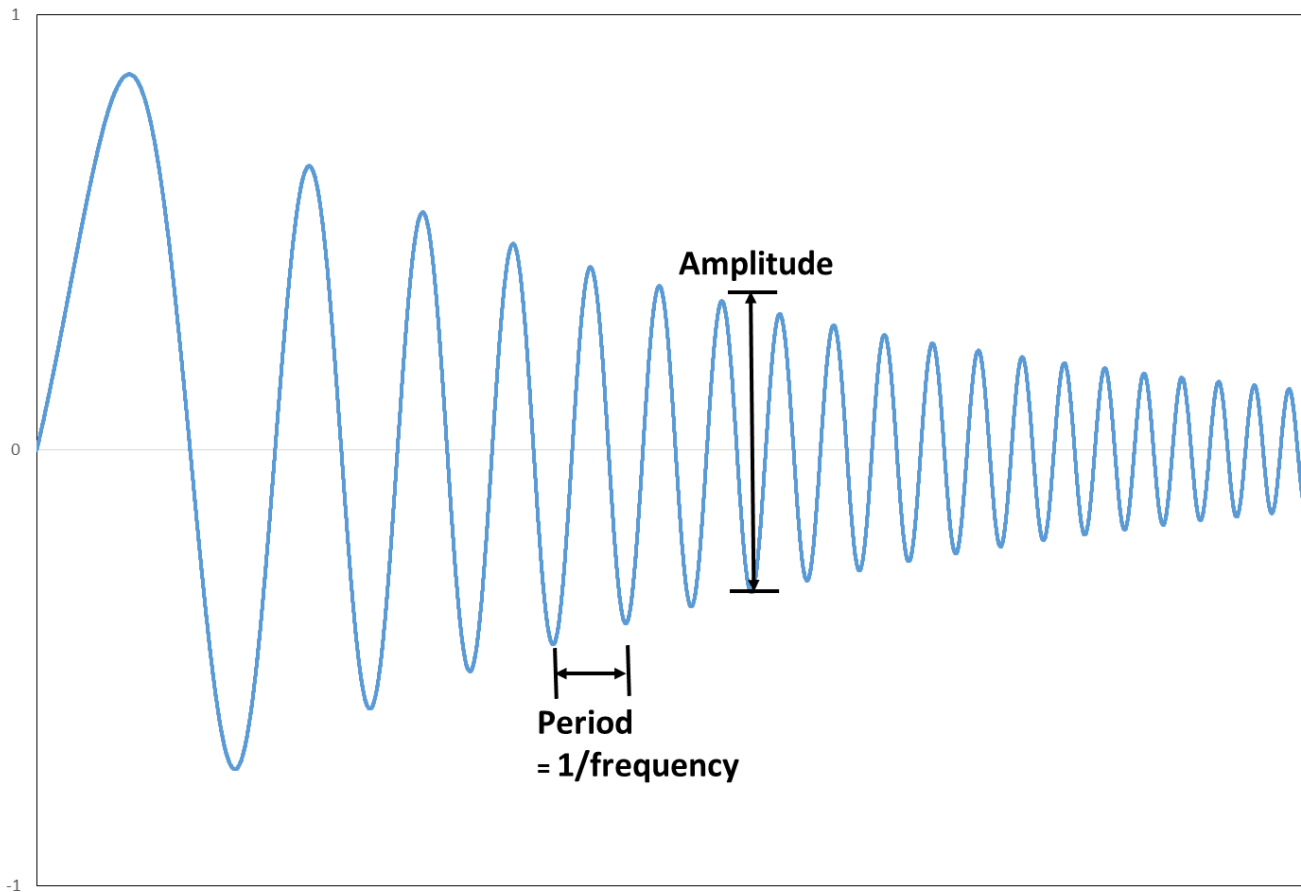
Oscillogram - Time Domain Representation of Sound Pressure Wave





Let's start with a sound wave...

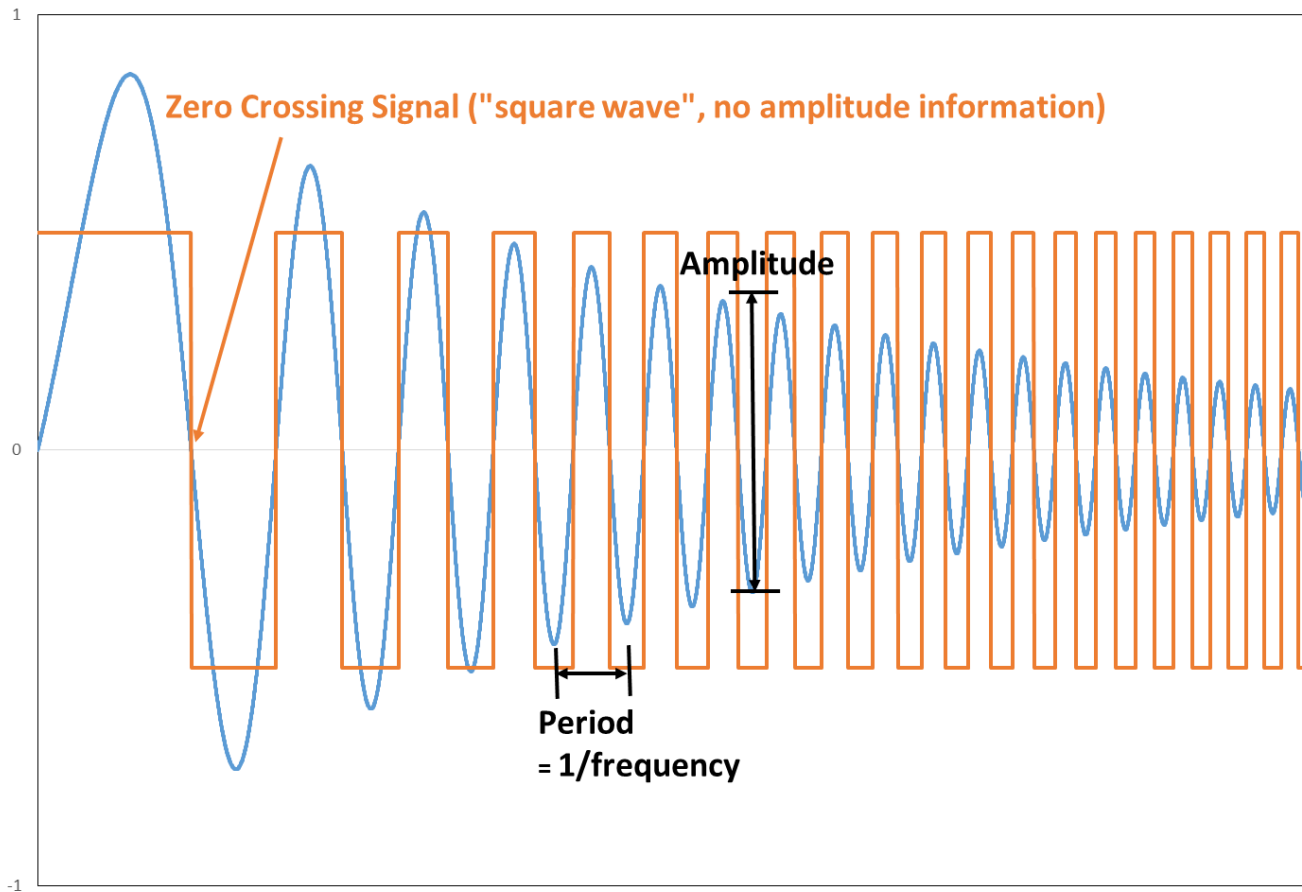
Oscillogram - Time Domain Representation of Sound Pressure Wave





Zero crossing - observe the “zero crossing points”

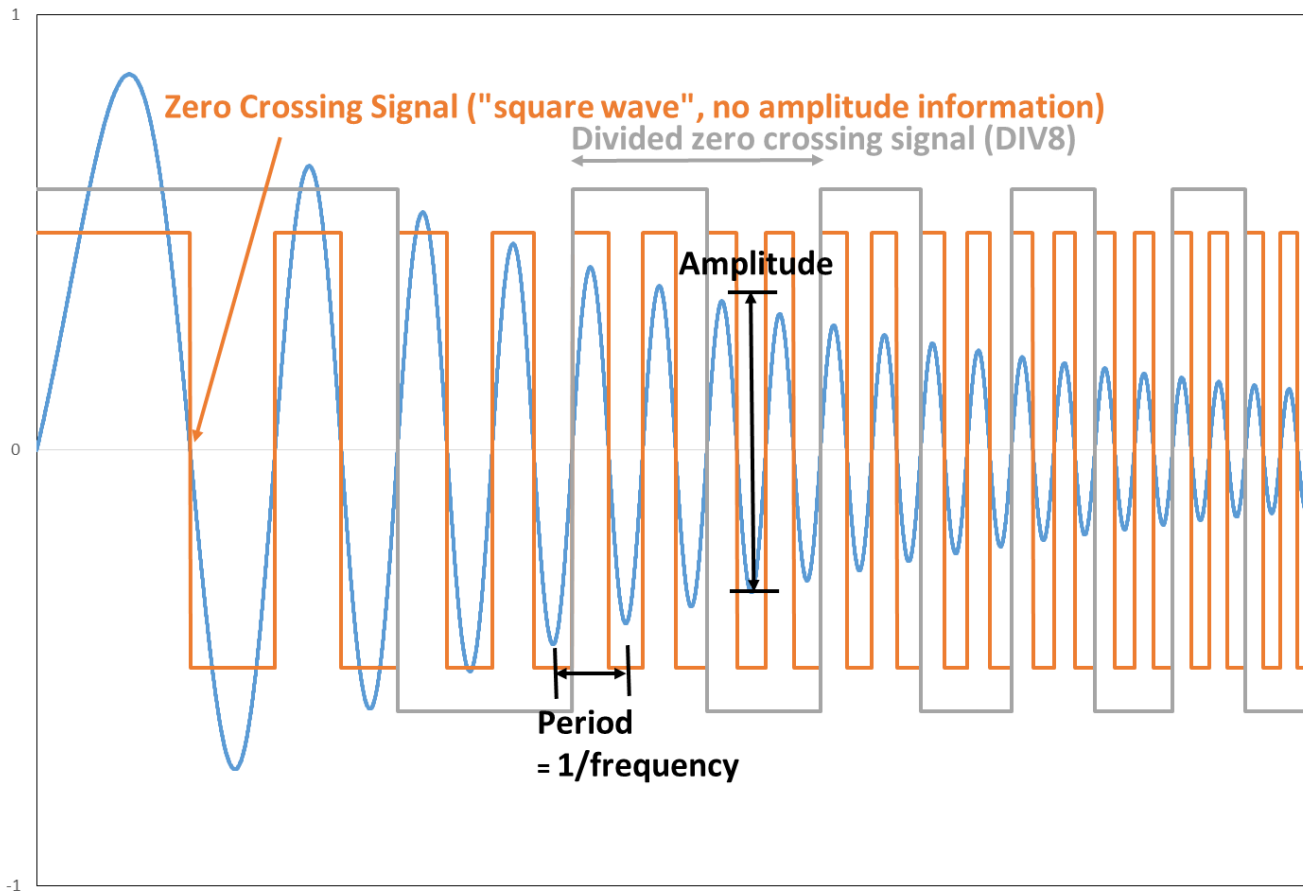
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Zero crossing – Division Ratio (each Nth crossing)

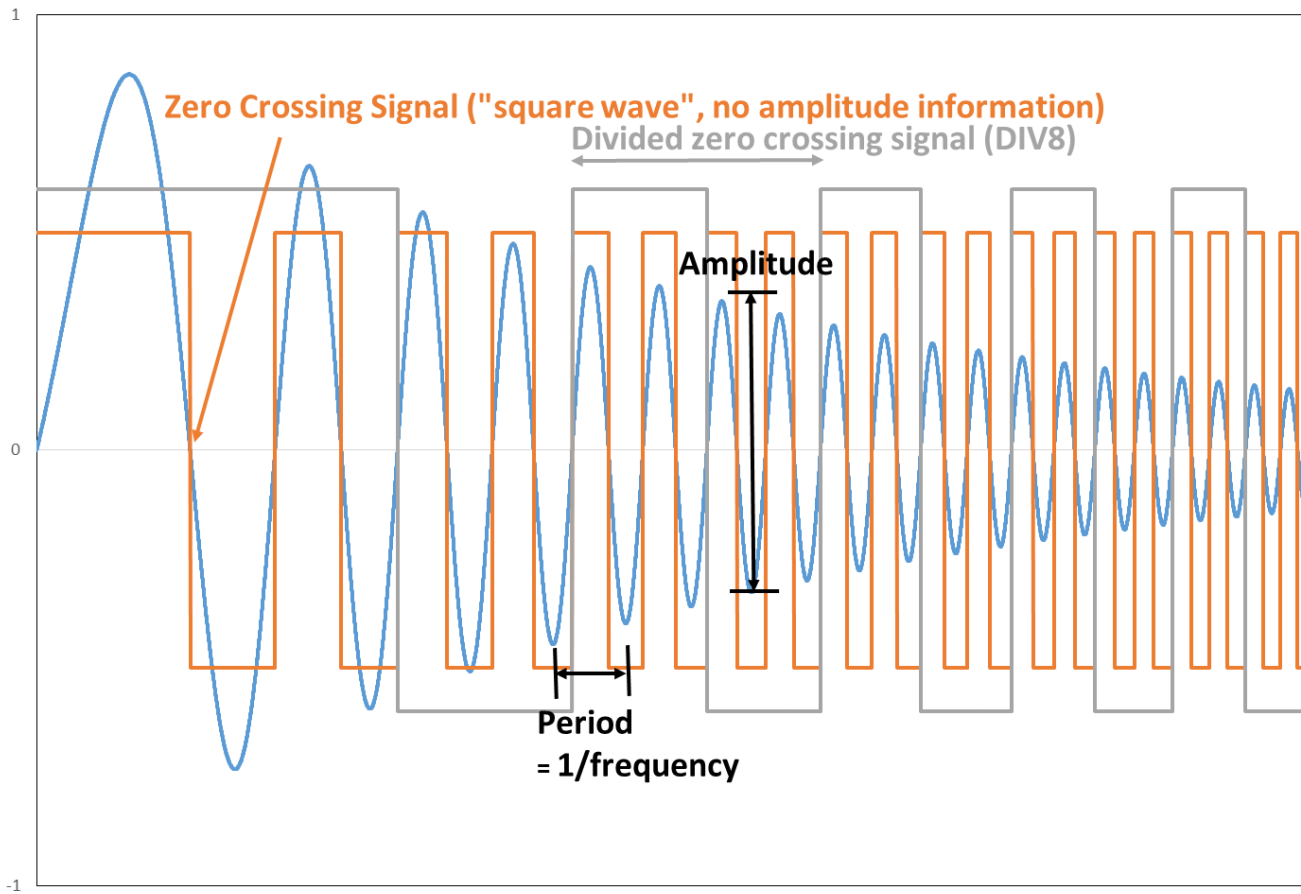
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Zero crossing – Division Ratio (each Nth crossing)

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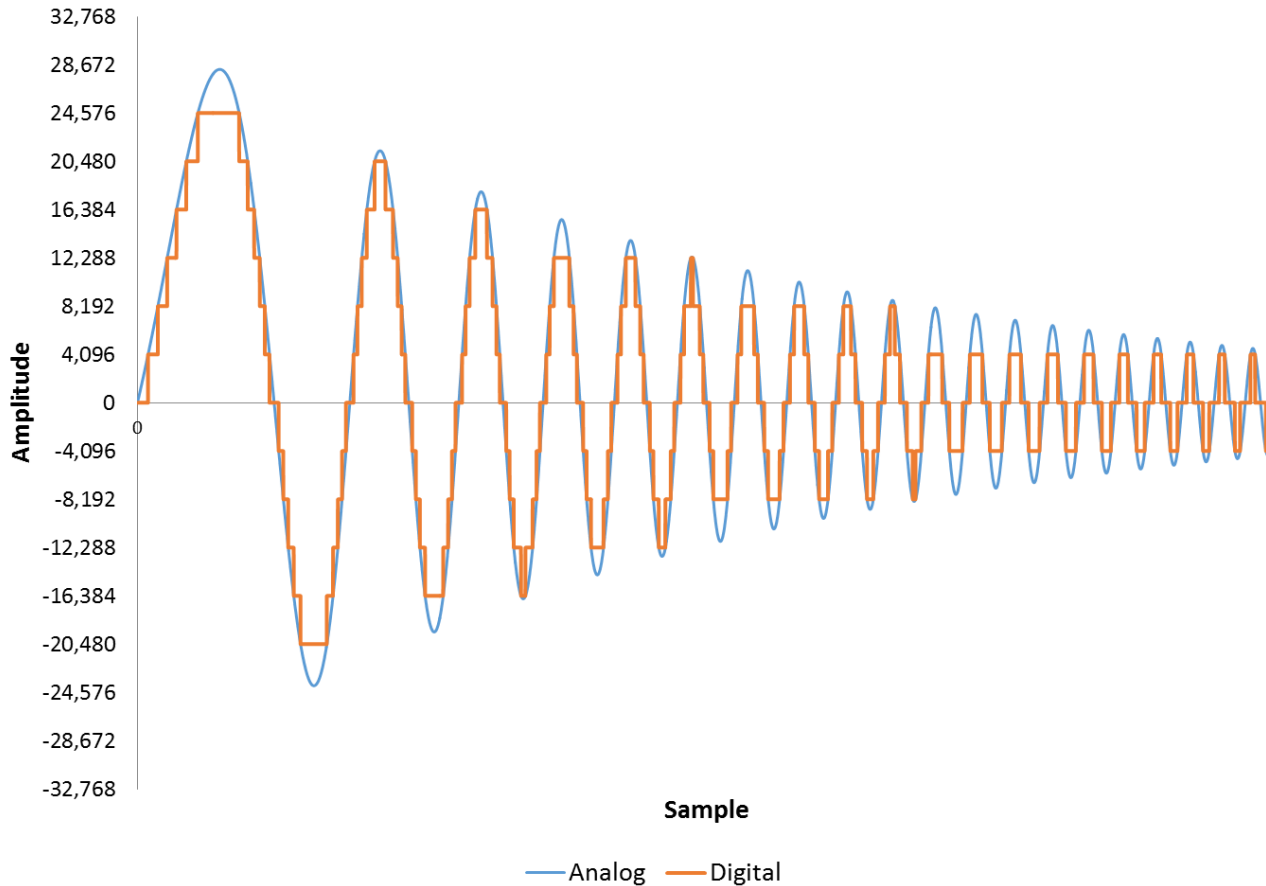


- ▶ Measure crossing times in discrete microseconds
- ▶ Division ratio trades off frequency vs. time resolution



Full Spectrum – Digitize the Analog Signal

Full Spectrum (digital sampling)

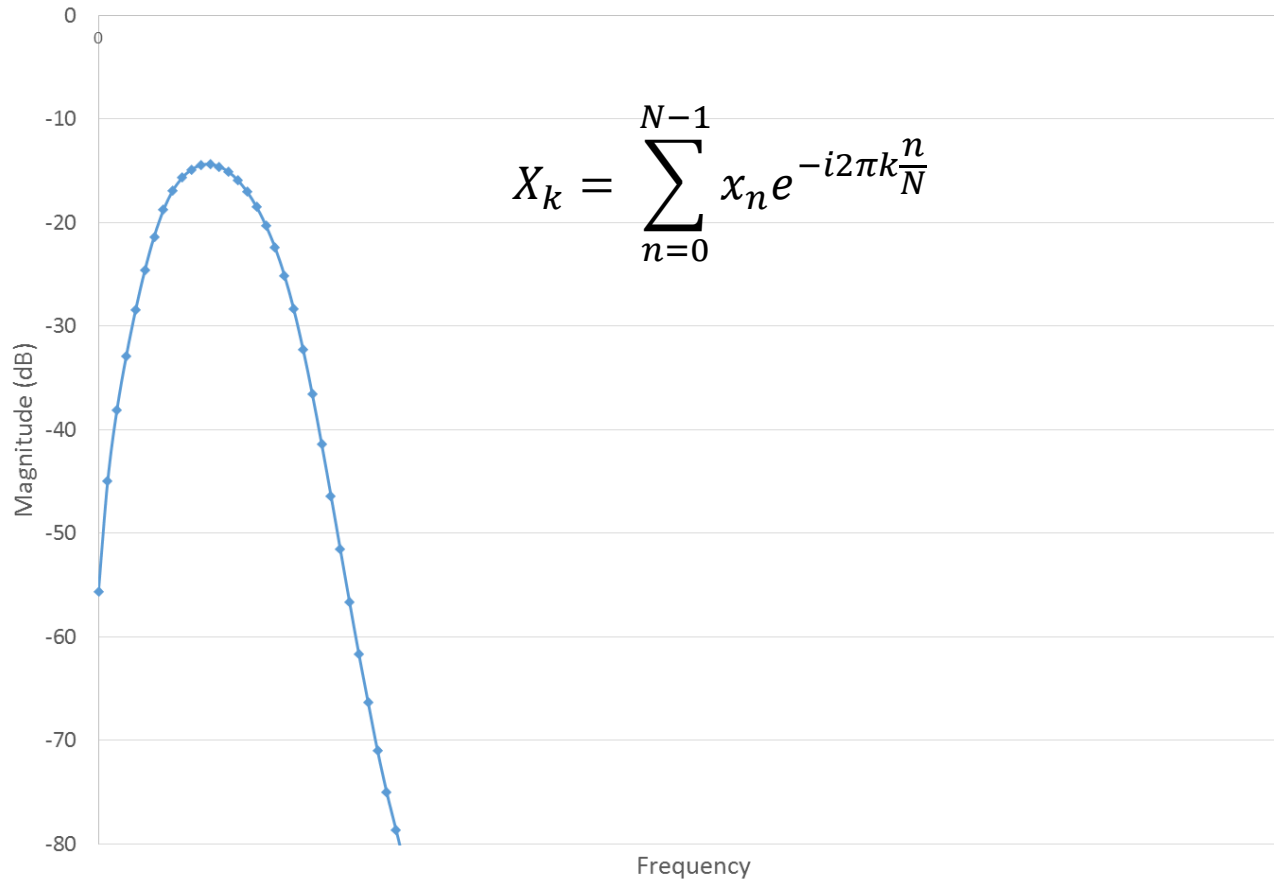


- ▶ Measure discrete voltage levels at a discrete sample rate
- ▶ Resolve frequencies up to $\frac{1}{2}$ sample rate (Nyquist)
- ▶ 16-bits = 96dB



Full Spectrum Analysis – “Fourier Transform”

Fourier Transform

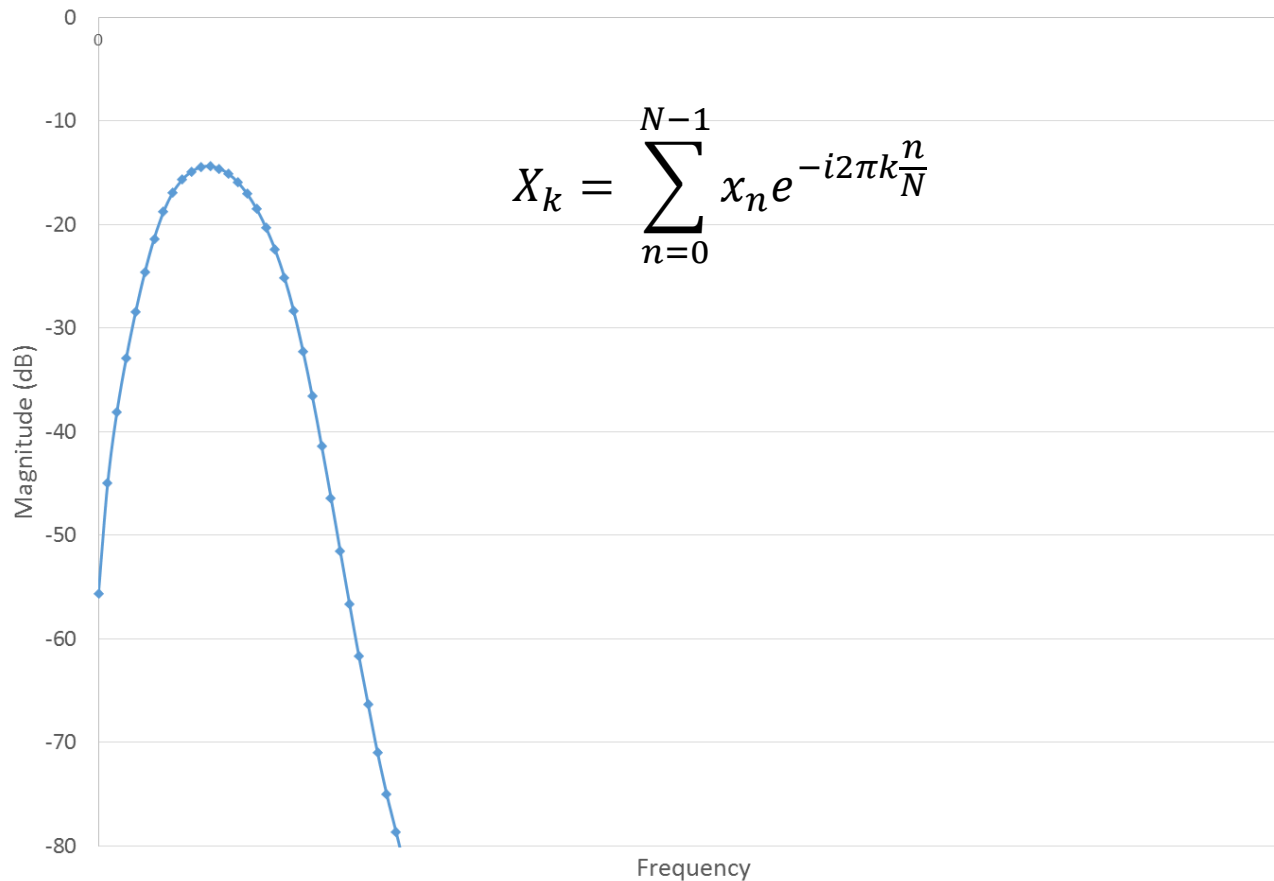


- Transforms N discrete time-domain samples into $N/2$ frequency bins with amplitude information



Full Spectrum – “Discrete Fourier Transform”

Fourier Transform

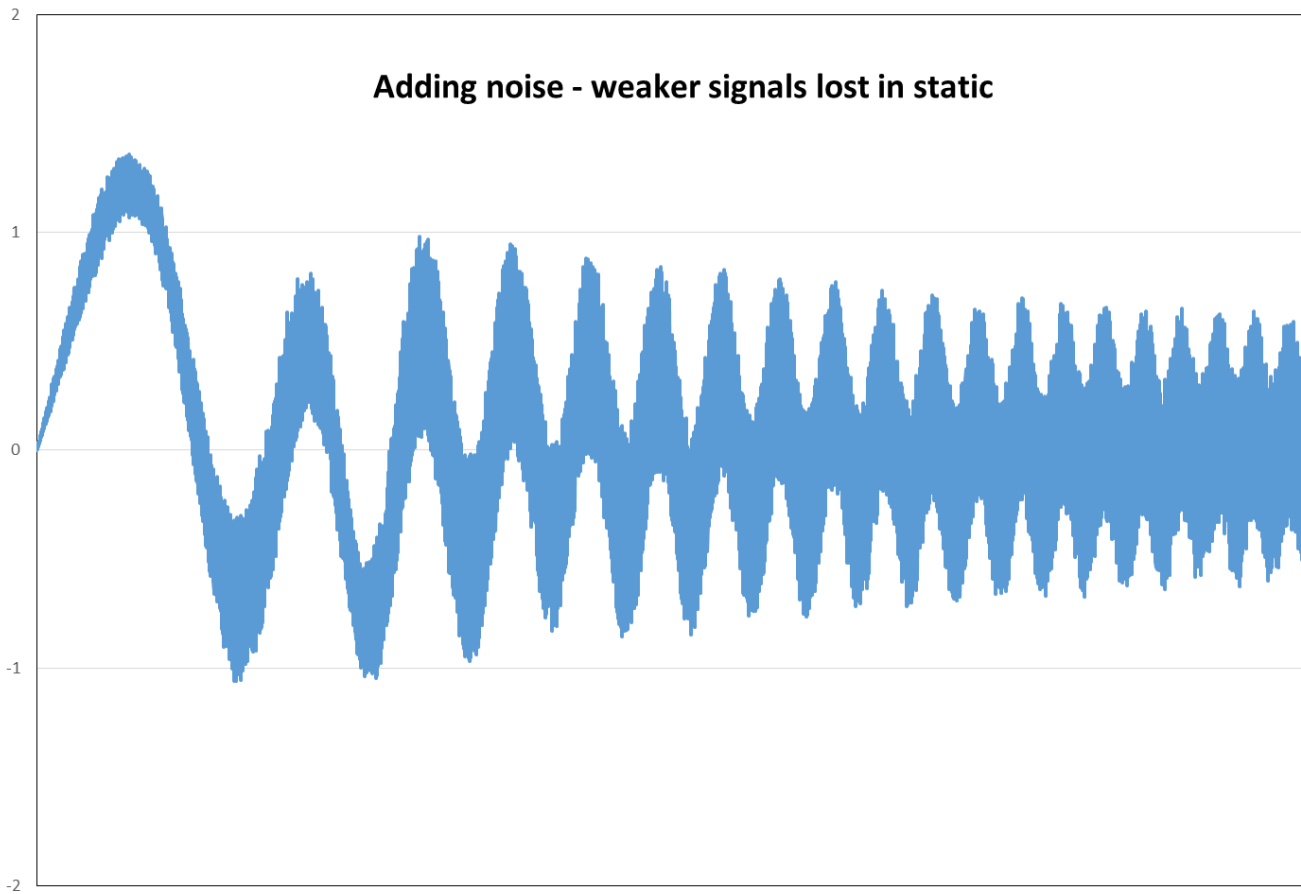


- ▶ Transform size N trades off between frequency and time resolution (just like division ratio in ZC)



Now consider a noisy sound wave...

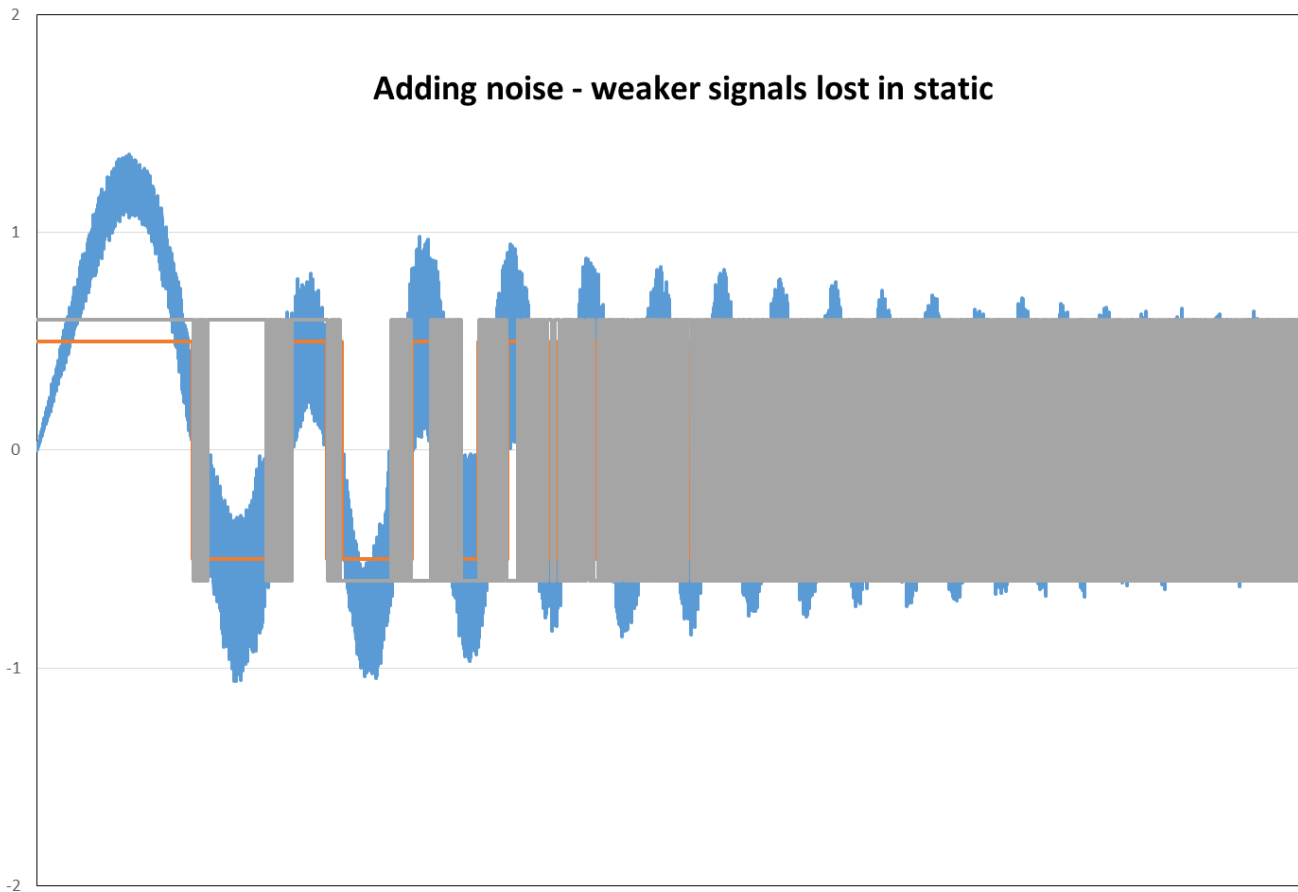
Oscillogram - Time Domain Representation of Sound Pressure Wave





Now consider a noisy sound wave...

Oscillogram - Time Domain Representation of Sound Pressure Wave

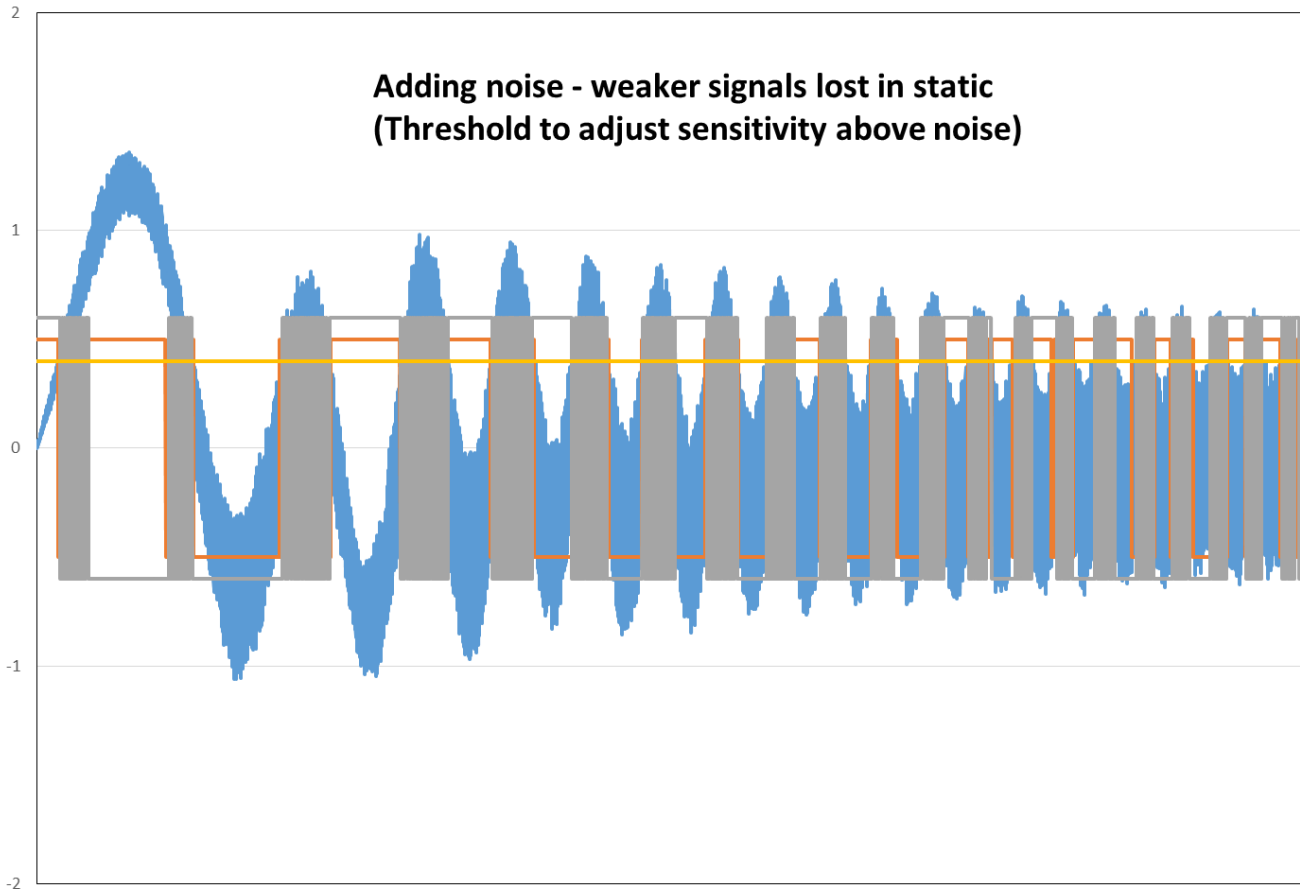


- ▶ In zero crossing, the signal is lost in the noise if the noise amplitude is larger than the signal's.



Now consider a noisy sound wave...

Oscillogram - Time Domain Representation of Sound Pressure Wave

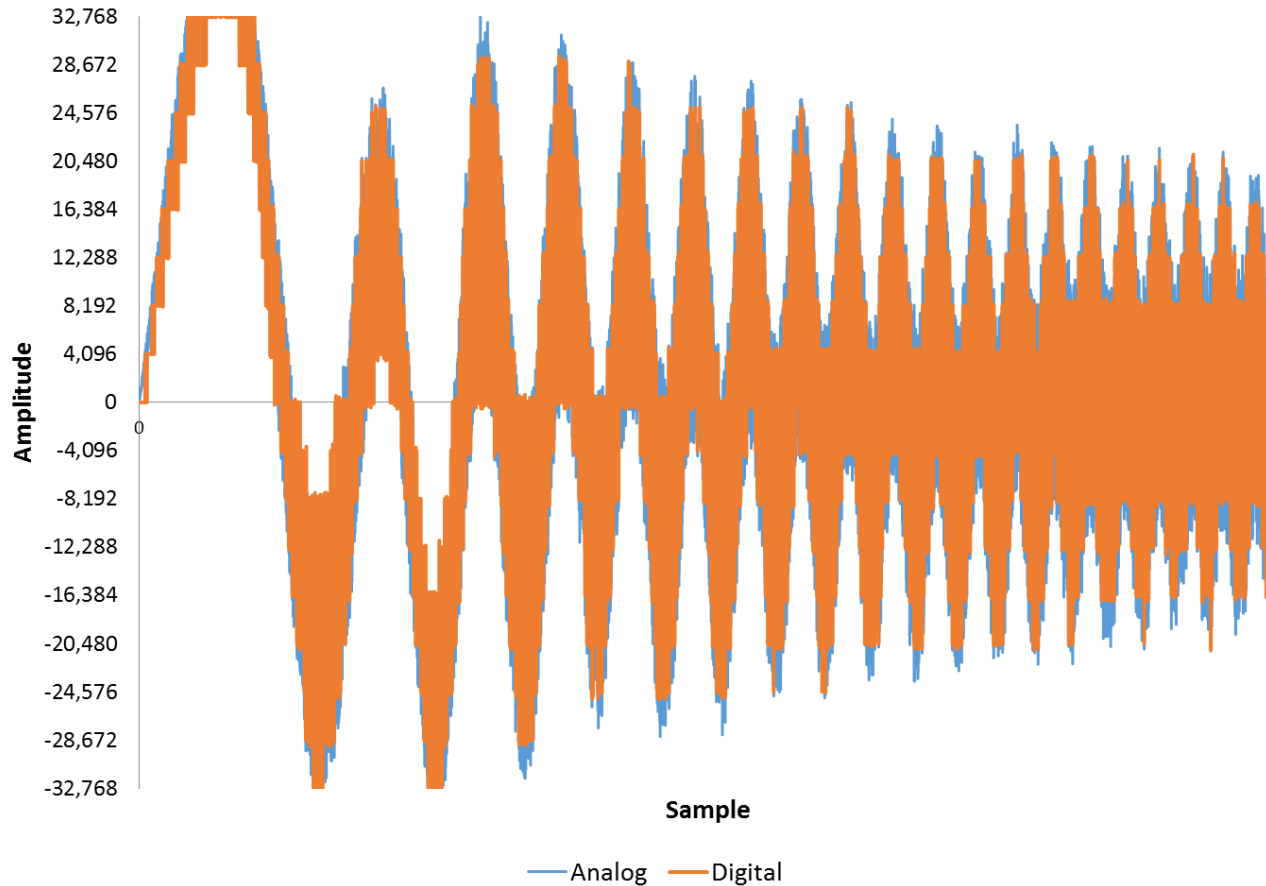


- ▶ A threshold (instead of zero) can reduce sensitivity above the noise.
- ▶ But signals below the threshold won't be detected



Now consider a noisy sound wave...

Full Spectrum (digital sampling)



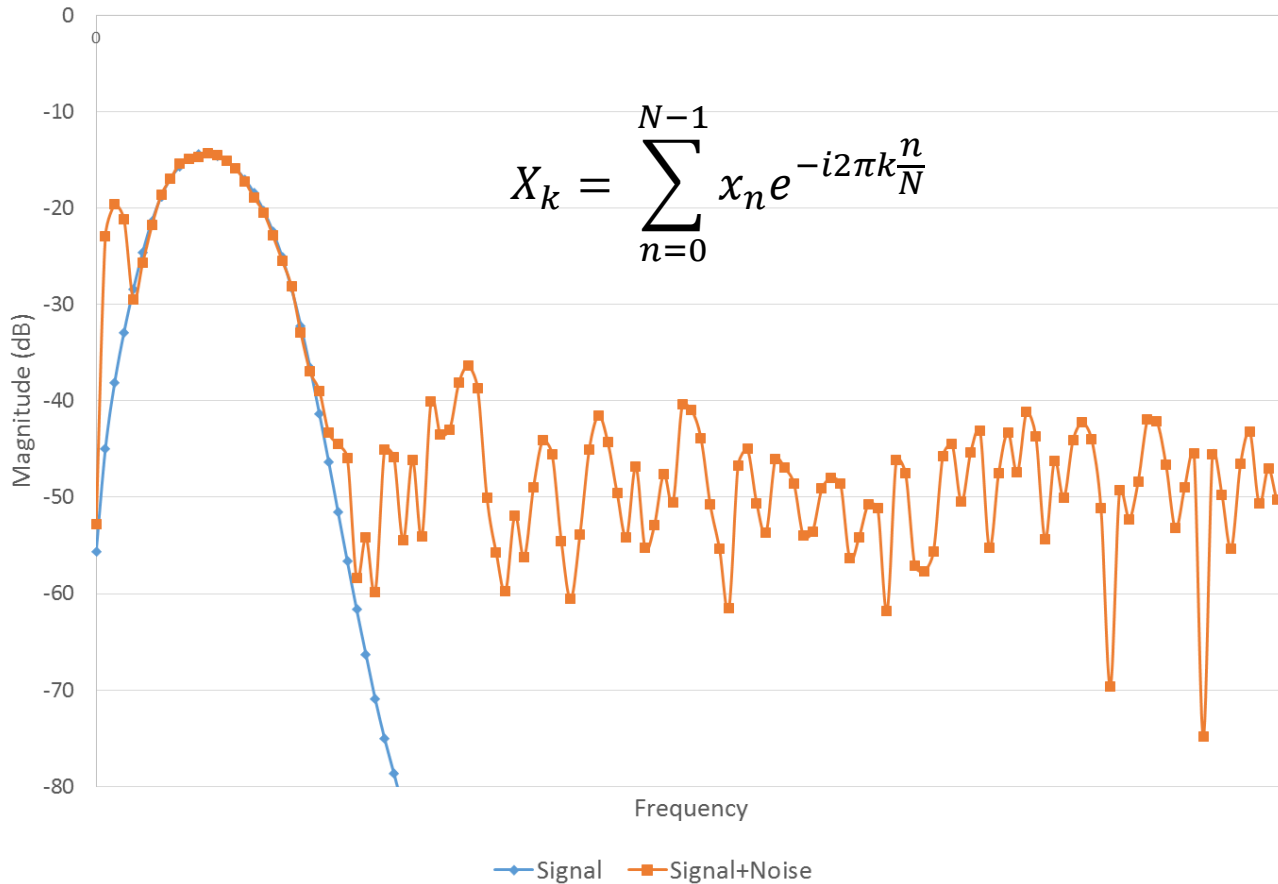
- ▶ In full spectrum, signal and noise are both represented faithfully within dynamic range



Now consider a noisy sound wave...

Fourier Transform

$$X_k = \sum_{n=0}^{N-1} x_n e^{-i2\pi k \frac{n}{N}}$$



- ▶ In full spectrum, noise power is divided and spread out among the frequency bins.



Signal to Noise Ratio (SNR)

- ▶ Signal to Noise Ratio determines “How far can I detect a bat?”
- ▶ White noise (e.g. self-noise of microphones) power is distributed across the frequency bandwidth.
- ▶ A native zero crossing detector has a large frequency bandwidth (e.g. 20-120kHz = ~100kHz bandwidth)
- ▶ Full spectrum analysis with Fourier transforms has a narrow frequency bandwidth (~1kHz bins)
- ▶ $10 \log_{10}\left(\frac{1,000}{100,000}\right) = 20\text{dB}$ full spectrum advantage over zero crossing
- ▶ About 2.3 to 2.6X further detection distance
 - ▶ (20-100kHz, 20°C, 50% R.H., FG sensor)

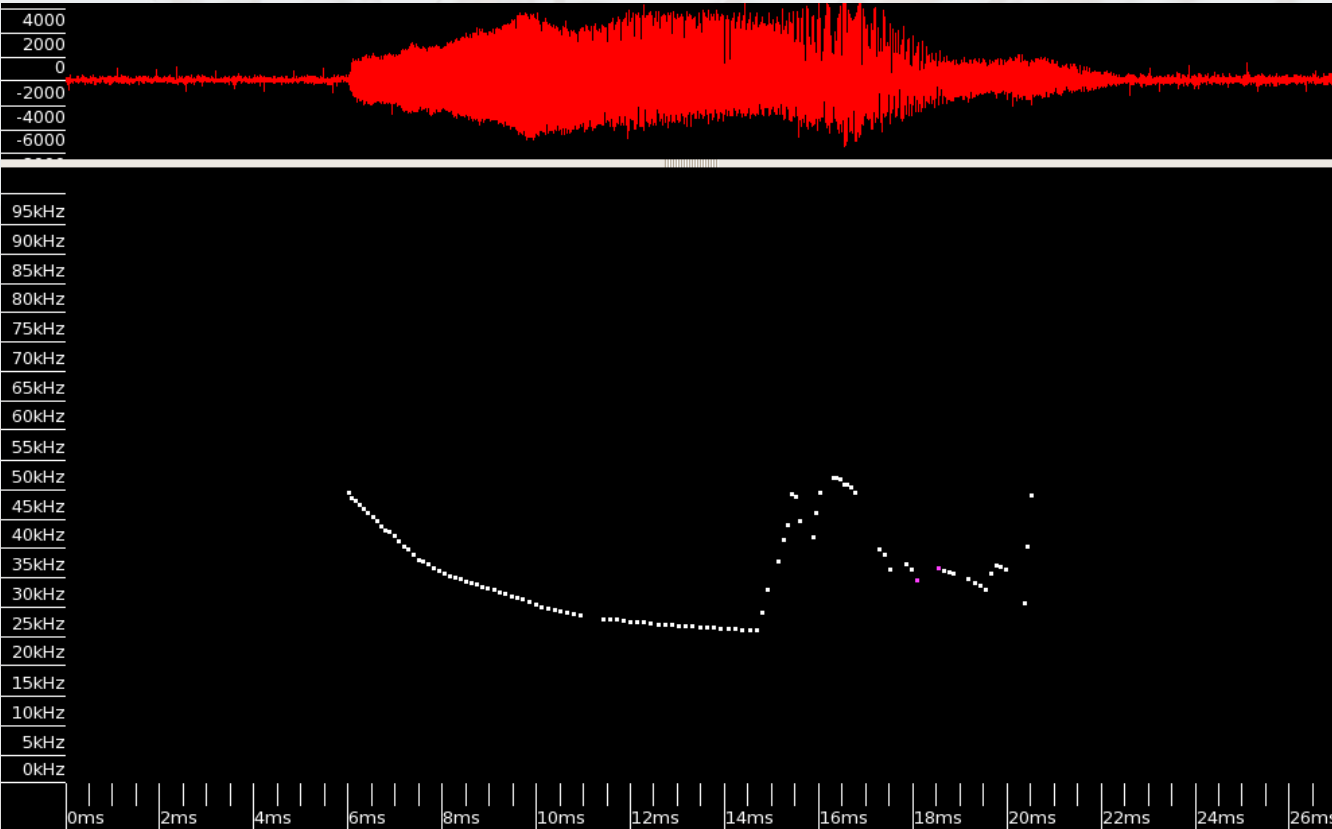


Native Zero Crossing vs. Zero Crossing Analysis

- ▶ Not the same thing!
- ▶ Recording in Zero Crossing has ~20dB disadvantage compared to recording in Full Spectrum (but has much lower power consumption and storage requirements making it attractive for some applications)
- ▶ Zero Crossing analysis from Full Spectrum recordings can have the same Full Spectrum advantage
- ▶ (Can also filter out insects, etc.)



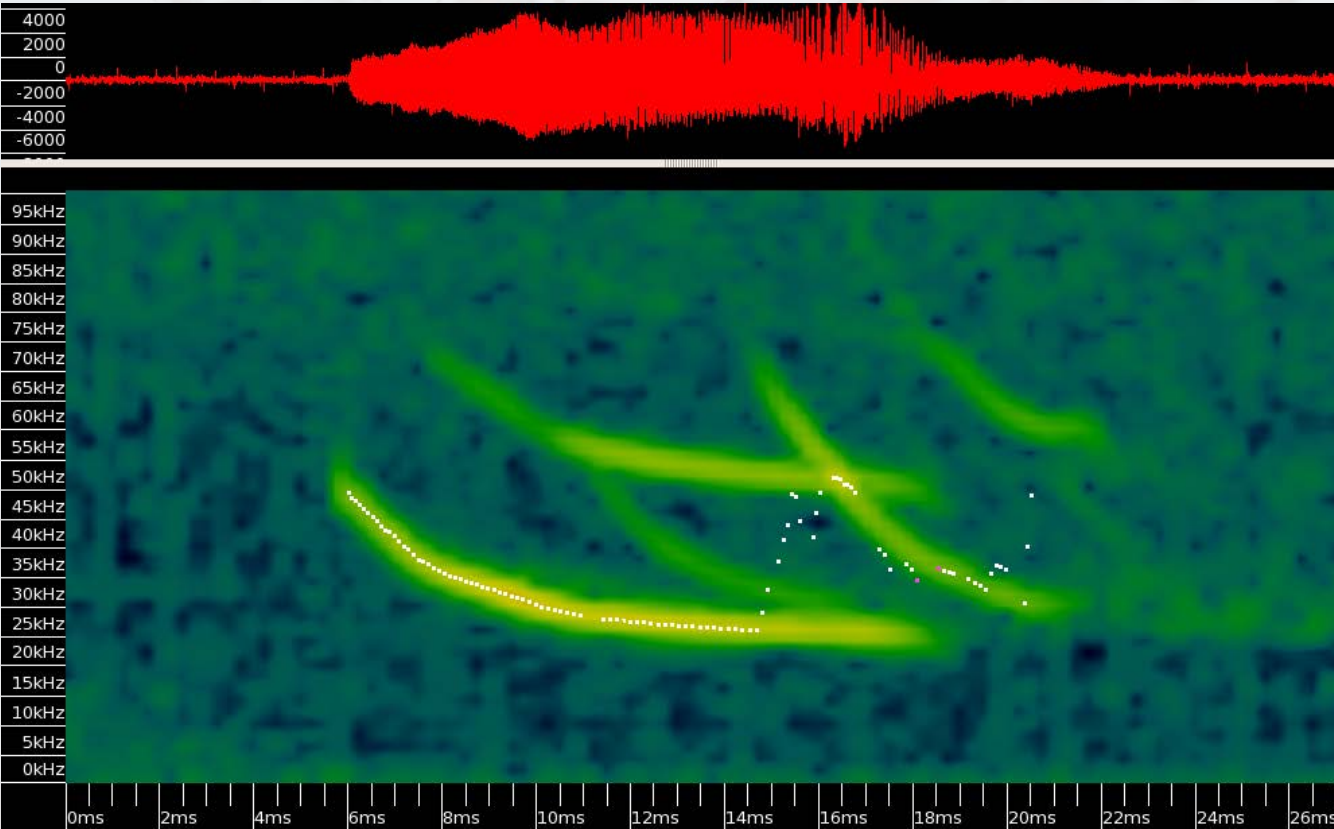
Example: Native Zero Crossing vs. Full Spectrum



► What is going on here?



Example: Native Zero Crossing vs. Full Spectrum

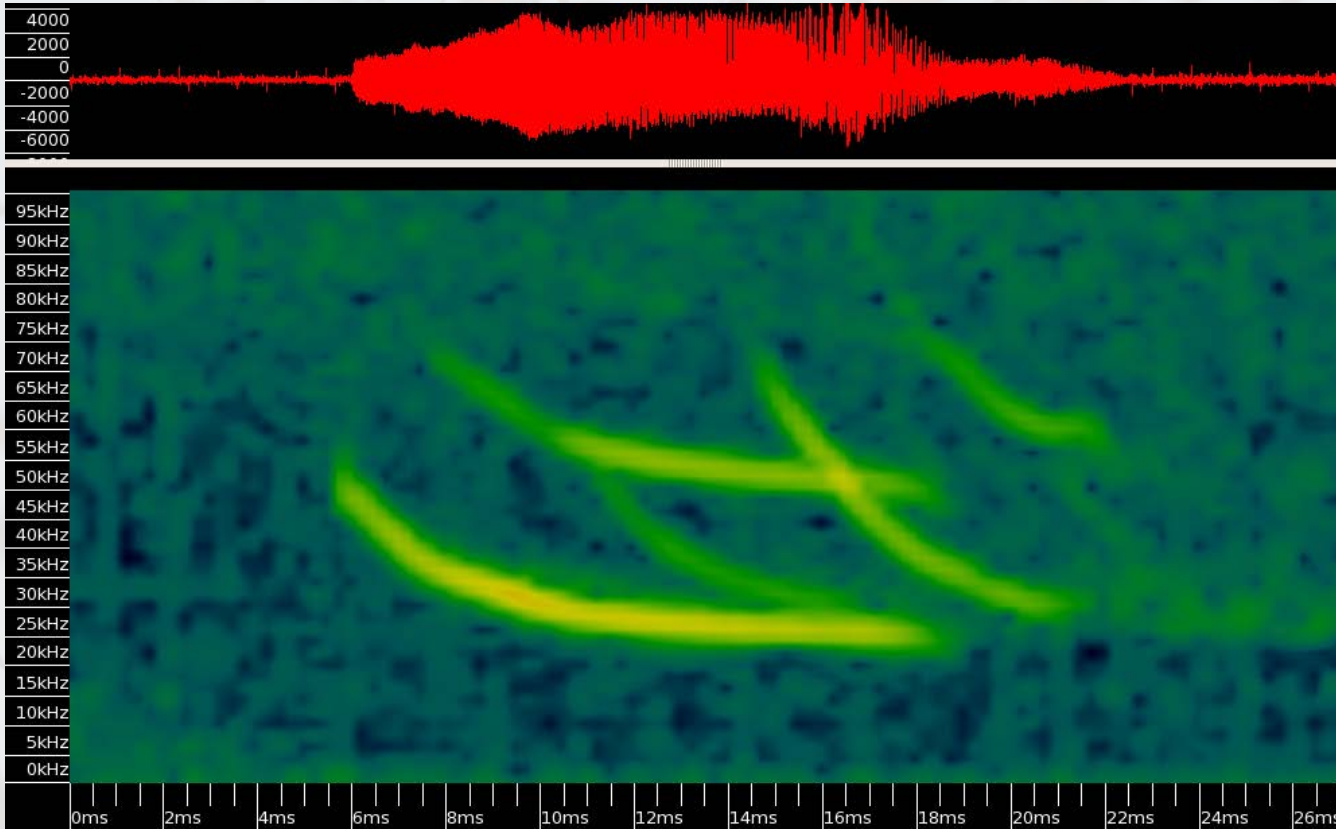


- ▶ Native zero crossing interference from echoes, harmonics, other bats, background noise



Example: Native Zero Crossing vs. Full Spectrum

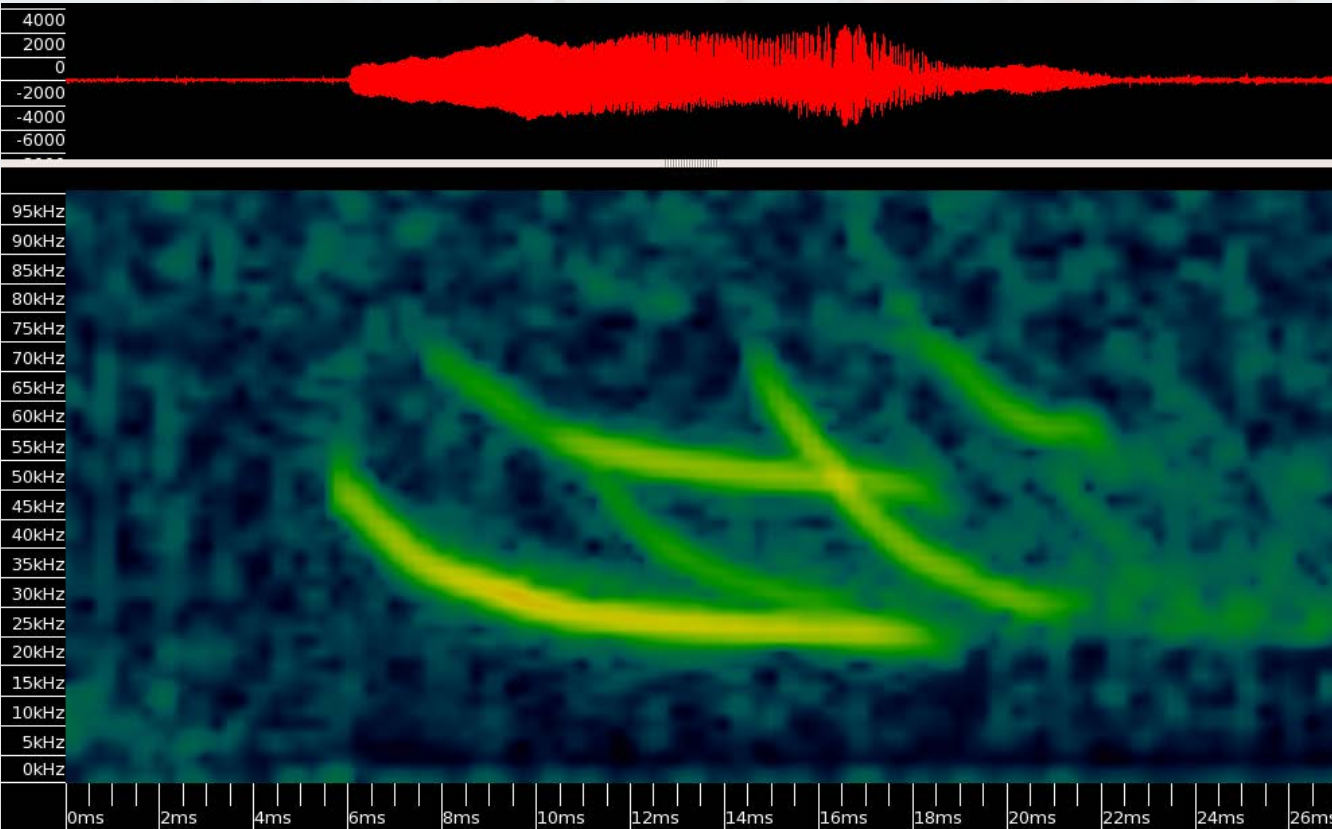
- ▶ Original full spectrum recording





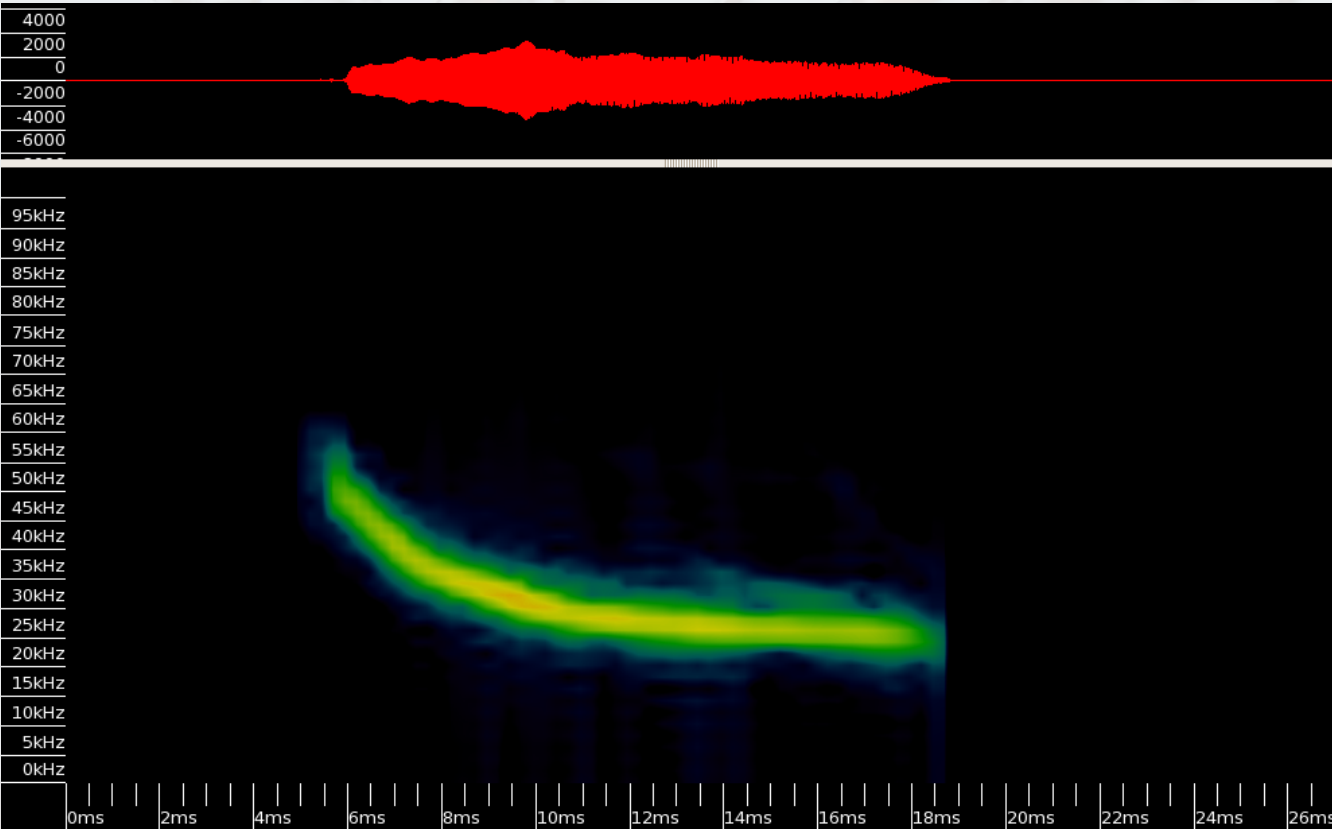
Example: Native Zero Crossing vs. Full Spectrum

- ▶ Background noise reduced using sophisticated Digital Signal Processing techniques





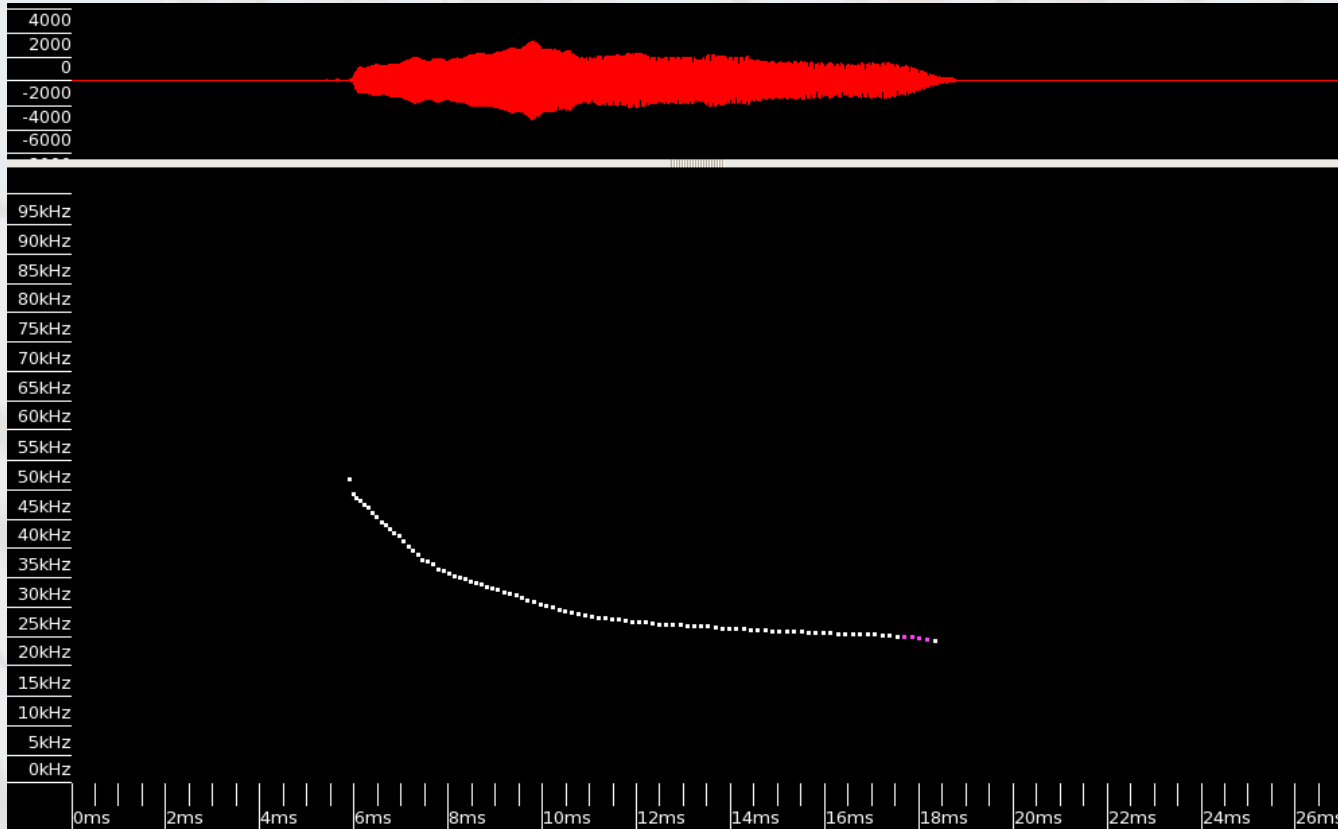
Example: Native Zero Crossing vs. Full Spectrum



- ▶ More DSP techniques eliminate harmonics and echoes
- ▶ What is left (just the bat, no noise)



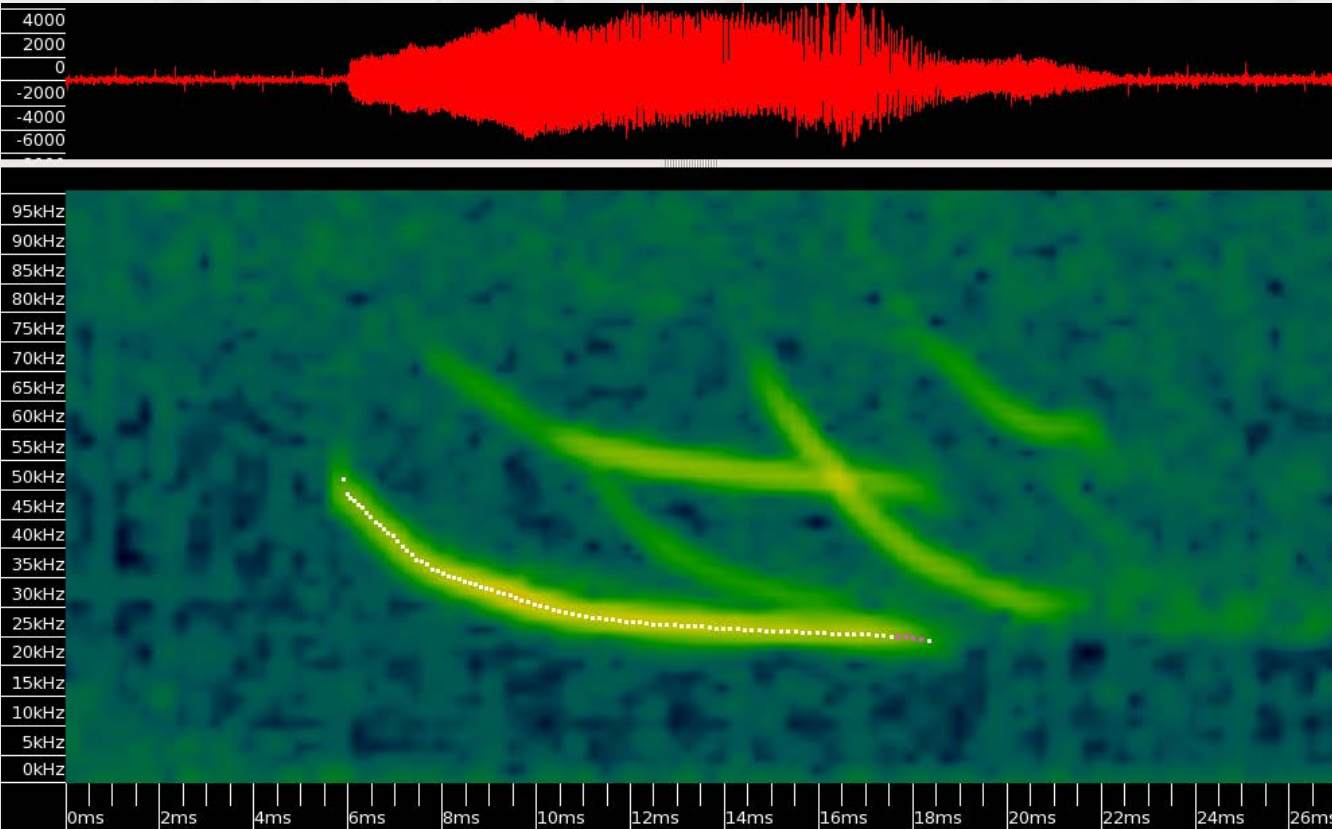
Example: Native Zero Crossing vs. Full Spectrum



- ▶ Zero crossing of enhanced full spectrum signal has full spectrum advantage
- ▶ Kaleidoscope does this!



Example: Native Zero Crossing vs. Full Spectrum

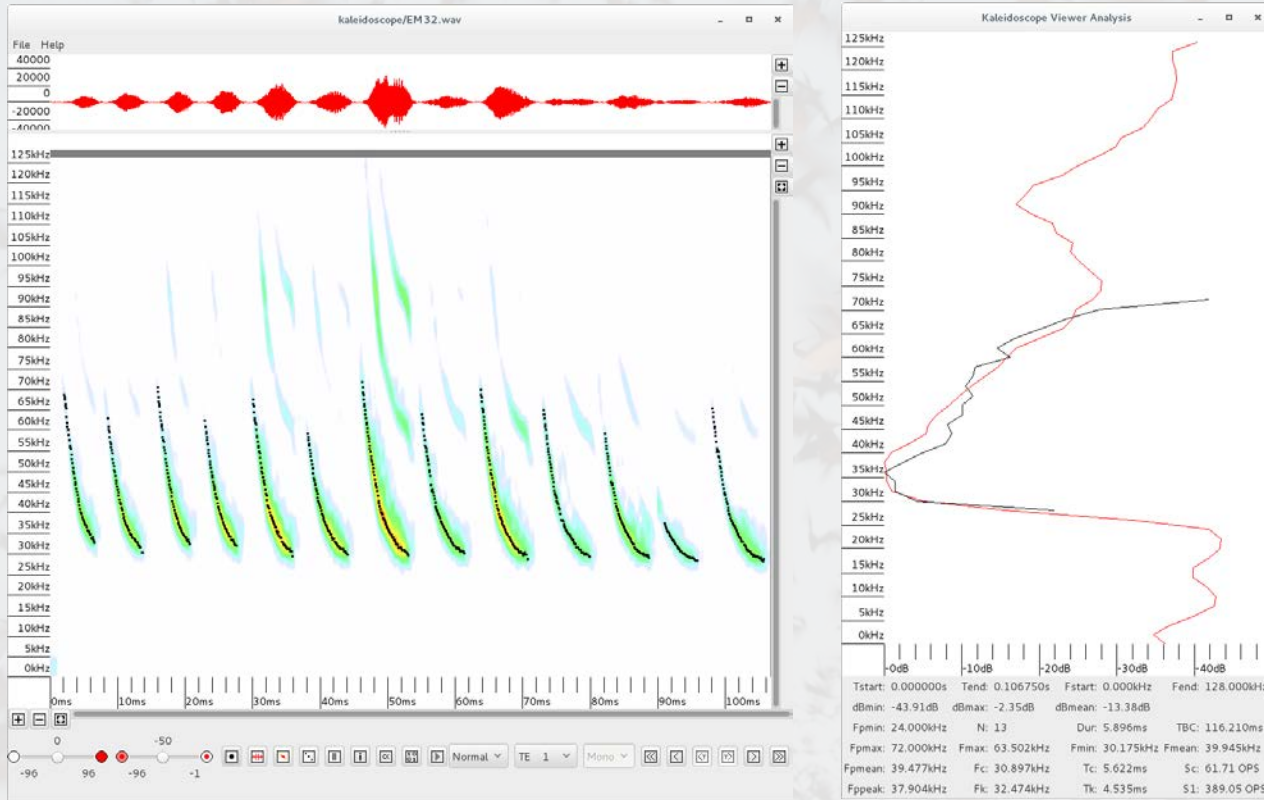


- ▶ Zero crossing of enhanced full spectrum signal has full spectrum advantage
- ▶ Kaleidoscope does this!



ZC vs. FS for species identification

- ▶ We notice an apparent correlation between call shape and power distribution. (Thanks Cori Lausen and Chris Corben!)





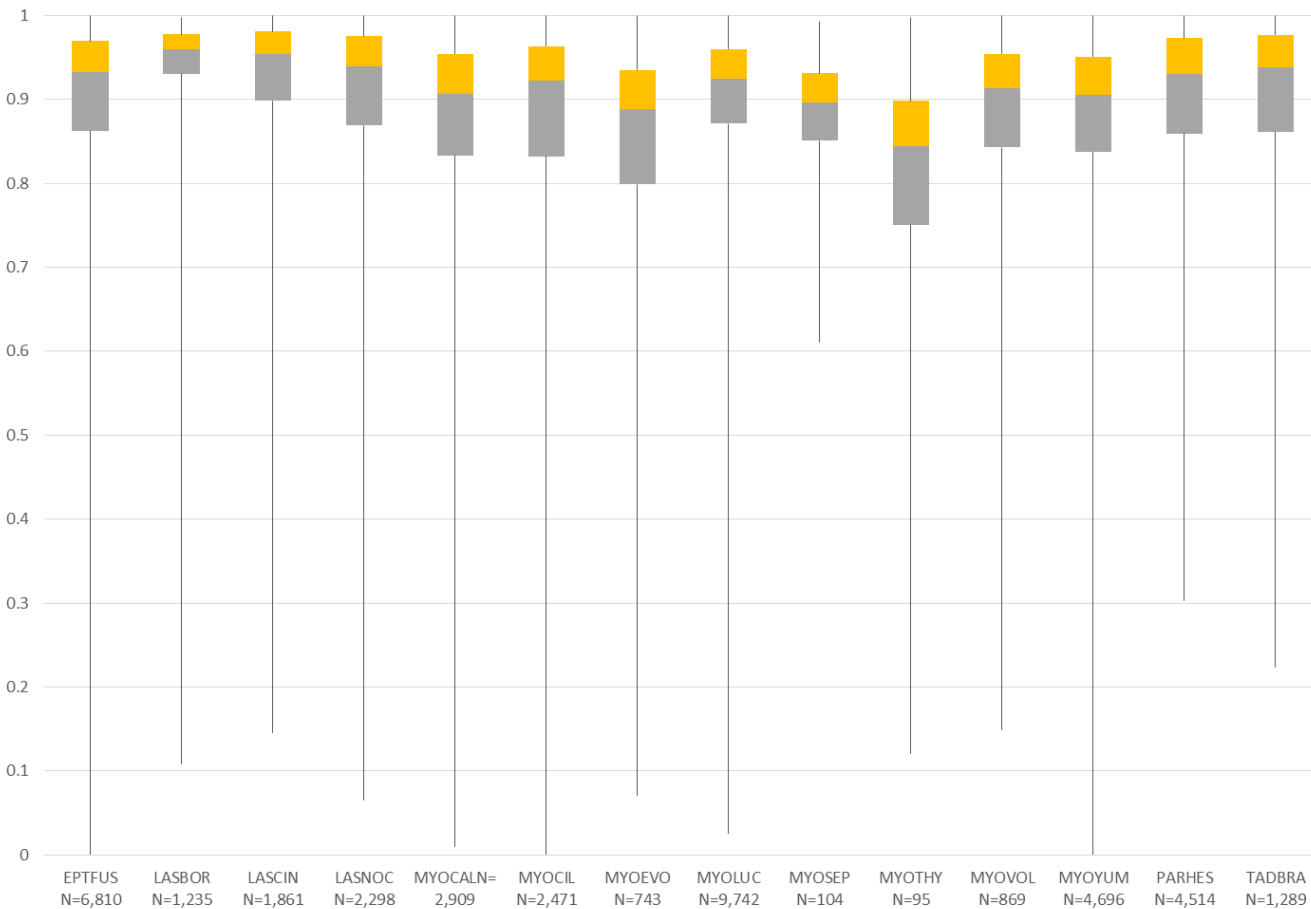
ZC vs. FS for species identification

- ▶ Let's try to calculate correlations on full spectrum recordings
 - ▶ For full spectrum, we divide the frequency bandwidth into ~2kHz bins, calculate power spectra in each bin in dB normalized to 0dB at the peak.
 - ▶ We convert to zero crossing and calculate the log of dot times spent in each frequency bin, normalized to 0dB at the peak
 - ▶ We calculate the R^2 correlation between the two curves by bin number and dB value



Correlation of ZC call shape vs. FS power spectrum

R² Correlation between measured power spectrum and that predicted by call shape



- ▶ Across many species, most of the pulses have power spectra predicted by call shape.
- ▶ Many pulses are not correlated. Why?



Conclusions

- ▶ Recording in full spectrum is superior (by $\sim 20\text{dB}$) to recording in zero crossing, all else being equal
- ▶ Zero crossing analysis of full spectrum signals can enjoy the same 20dB advantage as full spectrum analysis
- ▶ Zero crossing does not have amplitude information from the original signal
 - ▶ Maybe some amplitude information is helpful to identify some bat species
 - ▶ But... microphone frequency response and atmospheric absorption may have a larger effect on amplitude information.
 - ▶ And... call shape may predict amplitude information
 - ▶ More study needed!



Thank you!

- ▶ Questions?
 - ▶ This presentation can be found at:
 - ▶ <http://www.wildlifeacoustics.com/downloads/zcfs.pdf>
 - ▶ ian@wildlifeacoustics.com