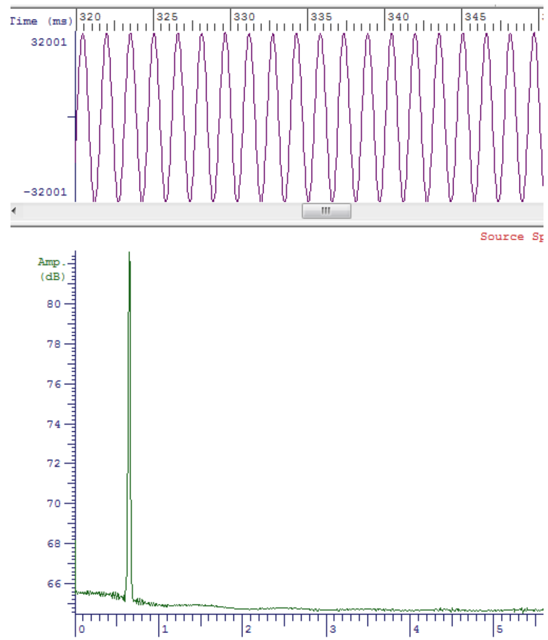
Signals & Systems for Speech & Hearing

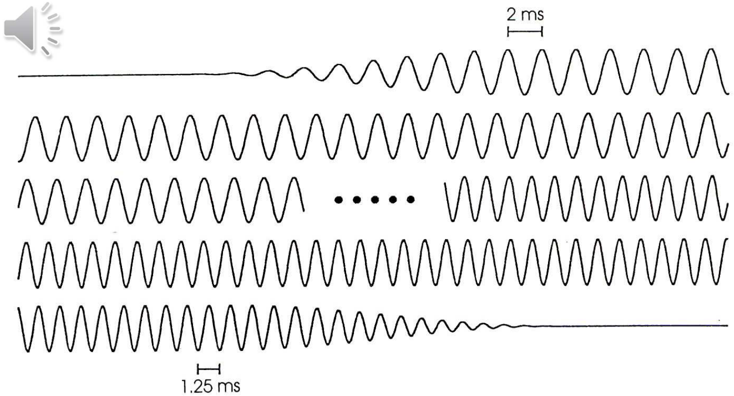
Week 9

Spectrograms

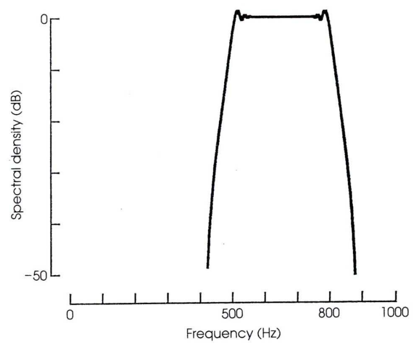
Representing signals in the time and frequency domains



A *frequency-modulated* (FM) tone 500-800 Hz over 400 ms

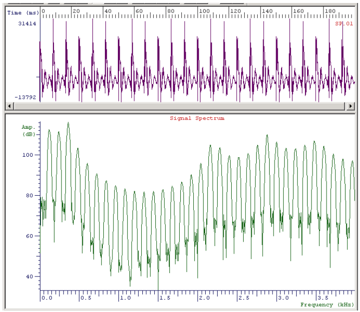


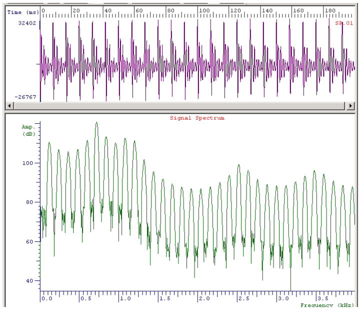
Spectrum of a frequency-modulated tone



Is the percept of a sweeping frequency captured by the spectrum?

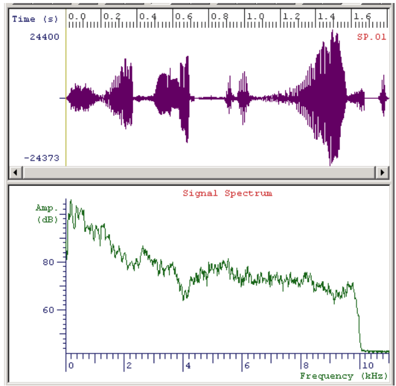
Two vowel-like sounds

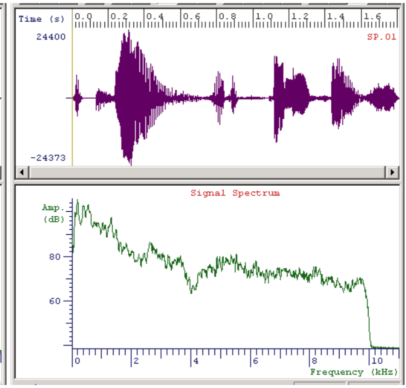




Spectra distinguish the vowel-like sounds well

Normal speech and reversed speech …





Why is the spectrum not good enough?

Conclusion

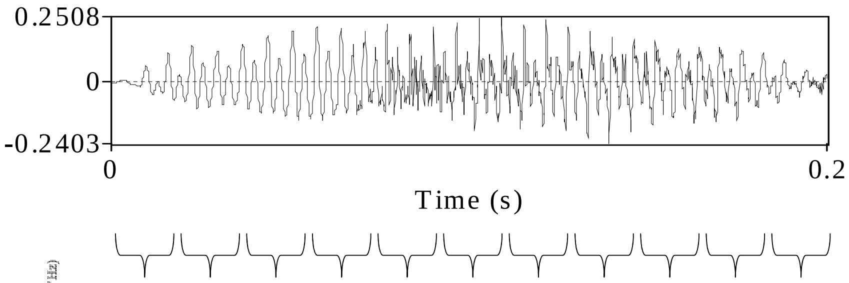
- If the characteristics of a signal do not change with time, then we can describe them adequately with a spectrum
- However many interesting signals *do change* over time (speech, for example!)

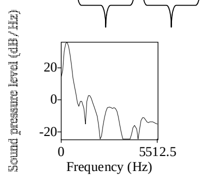
→ **So we need some way to show how the spectrum of a signal changes with time (the missing dimension from a spectrum)**

Solution I: Time-domain analysis

Step 1

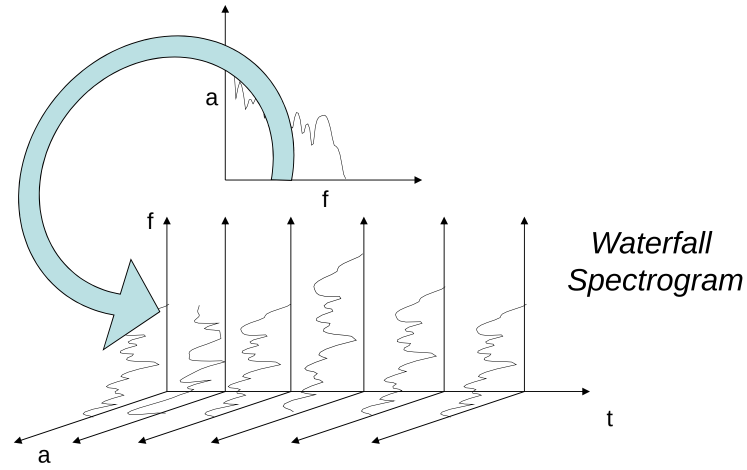
see rtSpec



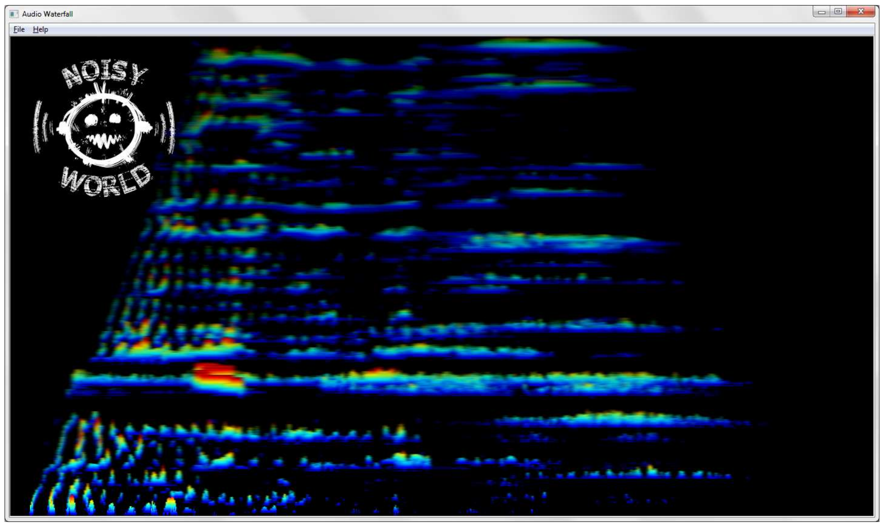


... o.k. but too many spectra ...

Step 2

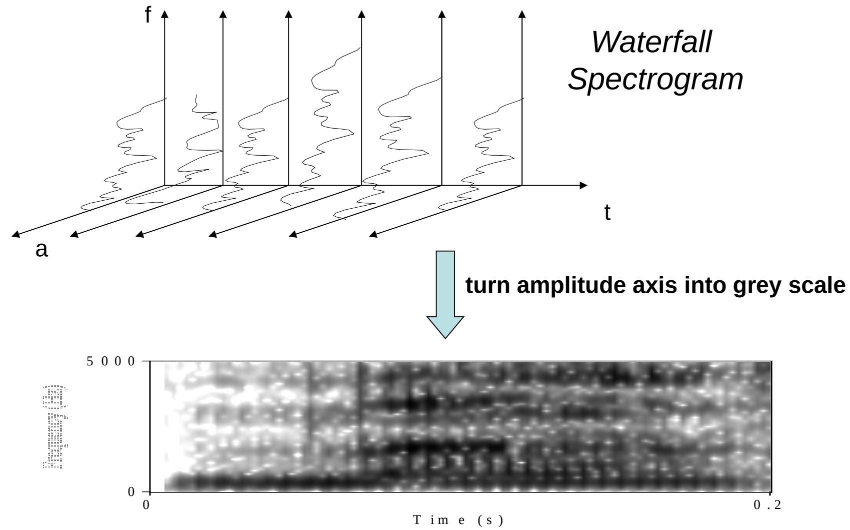


A colourful example



ftp://ftp.phon.ucl.ac.uk/pub/sfs/wauderfall/wauderfall100.exe

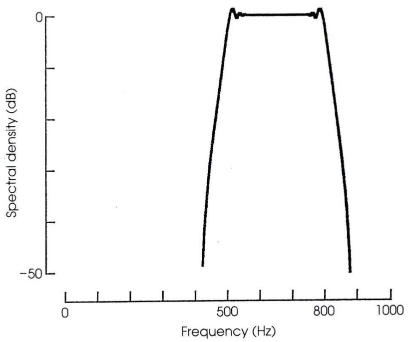
Step 3



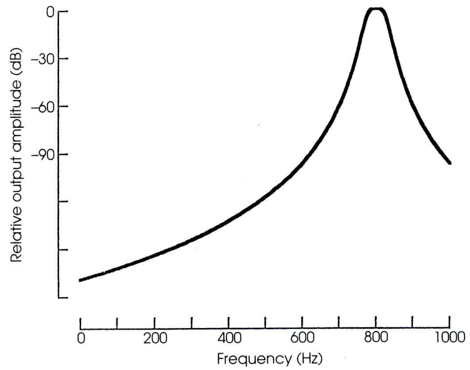
- The time-domain analysis lends itself readily to digital techniques, so is very common, but …
- How was this done back in the day? (A technique which is still useful in digital signal processing.)

Solution II: Frequency-domain analysis

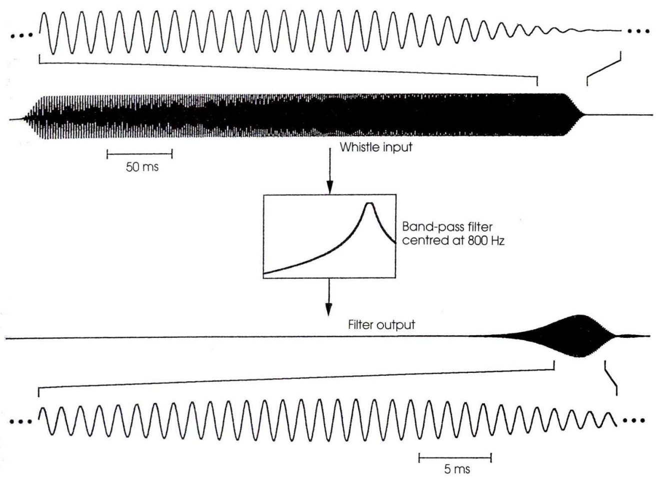
Remember the spectrum of a frequency-modulated tone:



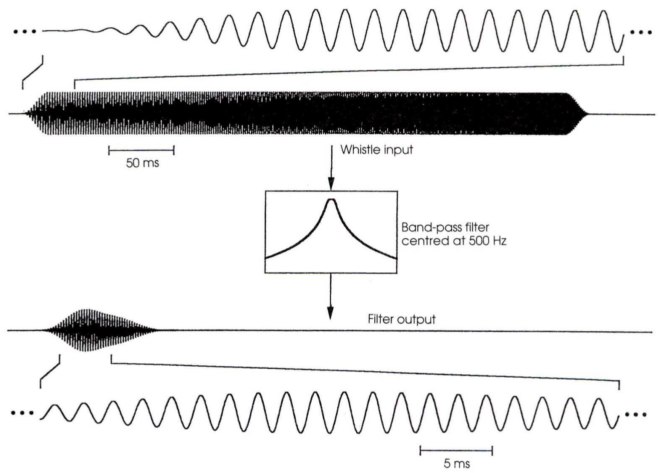
Analysis with a bandpass filter



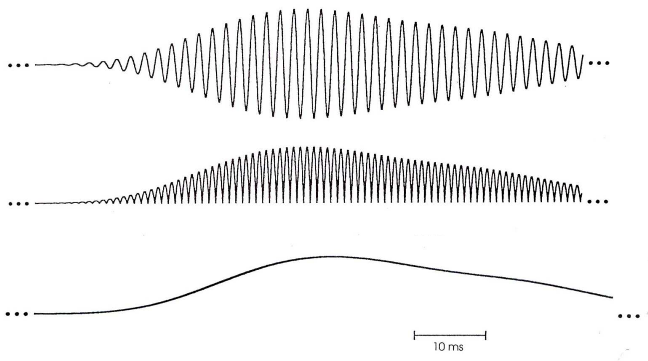
Output of a bandpass filter centred at 800 Hz



Output of a bandpass filter centred at 500 Hz

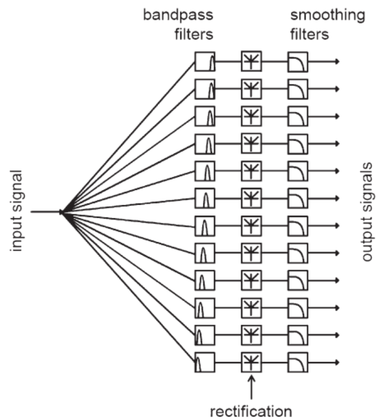


Losing temporal detail: Rectified and smoothed output



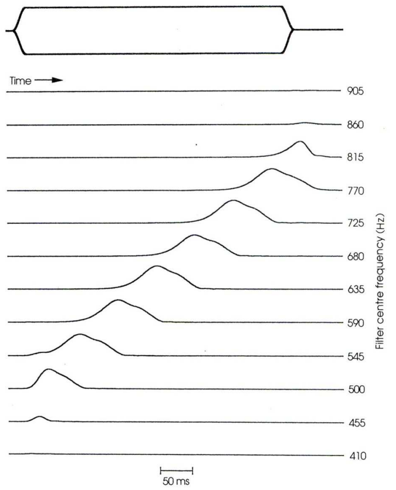
resulting in a simple measure of how overall energy in this wave fluctuates over time

Line up more filters with varying center frequency: A filter-bank

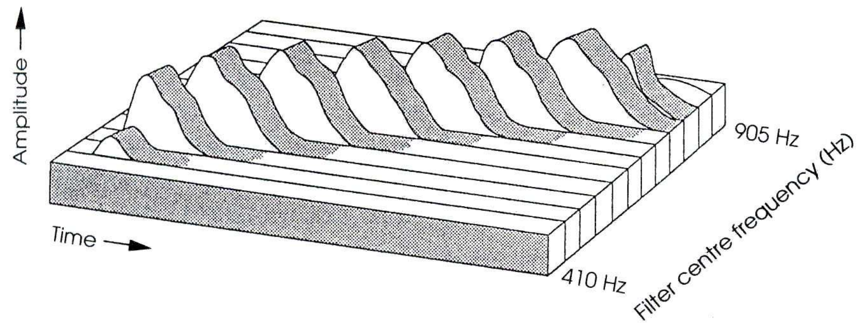


Plot each individual filter output simultaneously over time

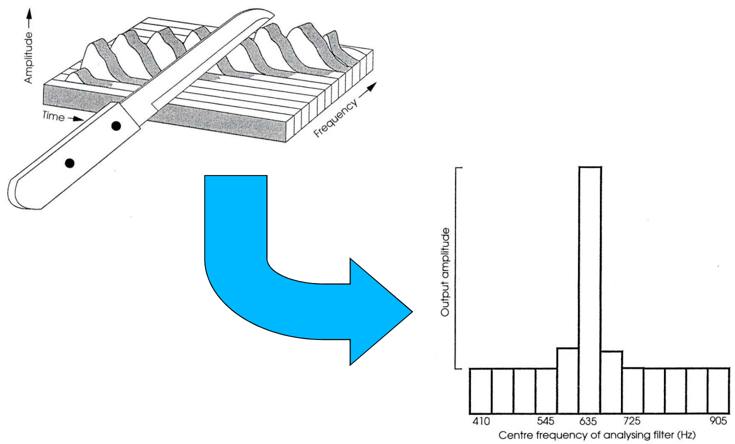
Again:
A spectrogram!



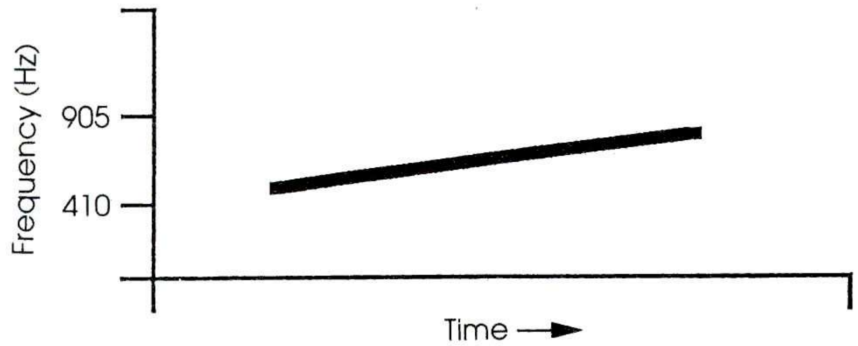
Three dimensional plot of the output (Spectrogram)



Each slice from the spectrogram is a spectrum:

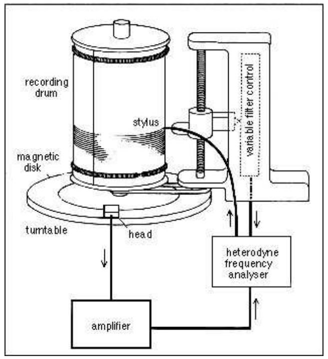


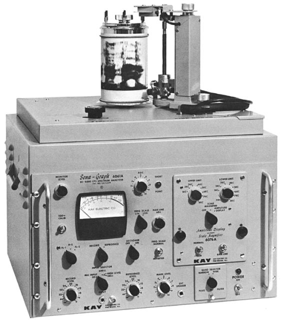
Convert the cake by mapping the height of the wave onto darkness of the trace



Early ways of producing spectrograms

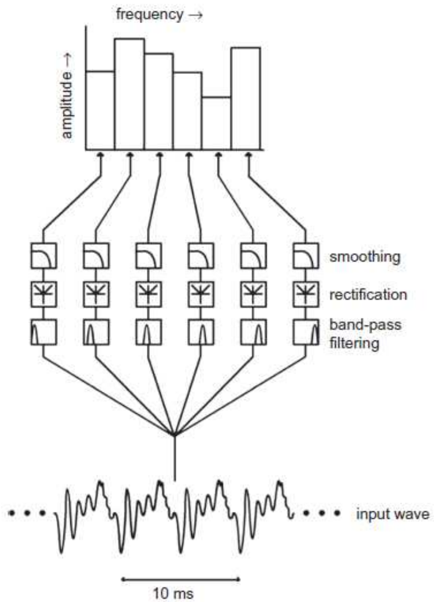
Thermo spectrograph using a filter with variable centre frequency:





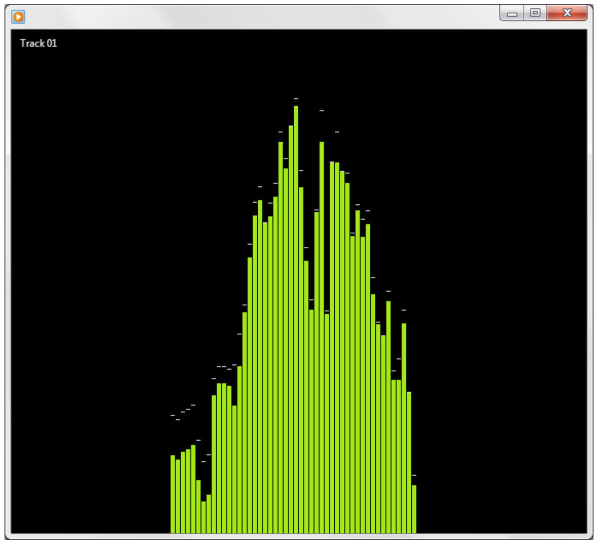
Left from: http://emsah.uq.edu.au/linguistics/teaching/ling2005/pic/spectrograph.jpg

A similar approach based on a filter bank

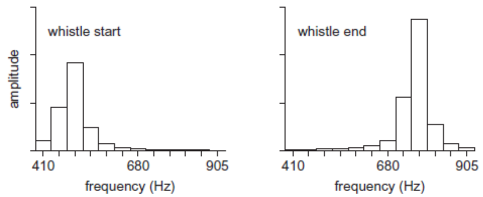


To get something like this

But this is still a movie

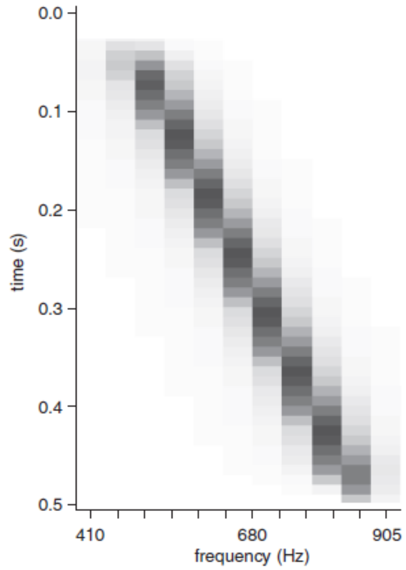


Back to (boring!) whistles

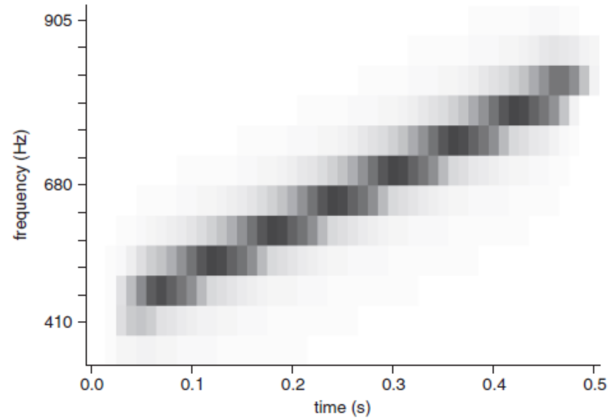


map spectral amplitude into the darkness of the trace

Stack them up on the page …



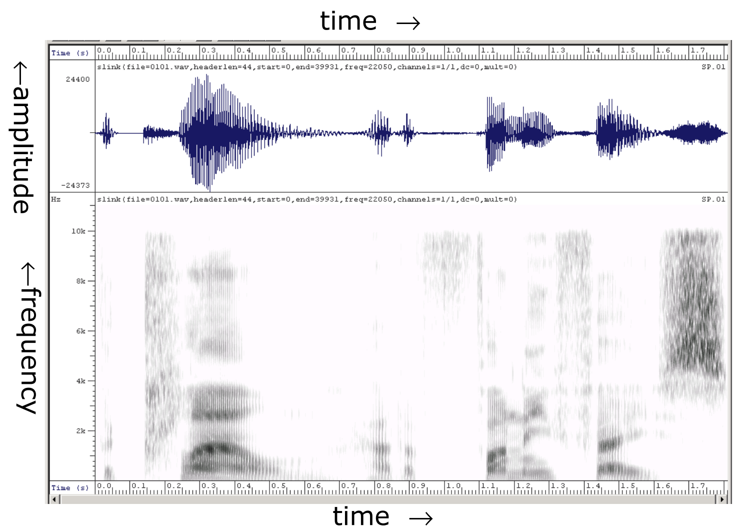
and rotate



Spectrograms are …

- Graphs of the frequency content of a signal plotted as a function of time
- **Time** is along the horizontal axis
- **Frequency** is along the vertical axis
- **Amplitude** of any component present in the signal at any given time and frequency is displayed on a grey-scale (white=low, black=high)

Layout of a waveform & spectrogram



Two reasons to study spectrograms

- As a good way to review signals & systems, involving waveforms, spectra, filtering, etc.
- More importantly: The most commonly used way to investigate and display complex signals, especially used for …
  - Speech, of course
  - Animal communicative sounds

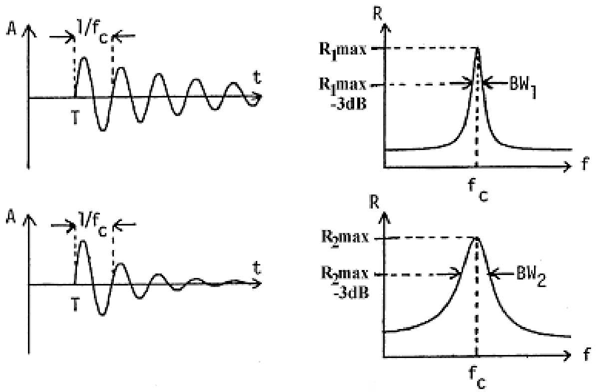
Many choices to make in generating a spectrogram

- One choice is absolutely essential, concerning the filter bank
- filter *bandwidth*
  - essentially infinitely variable
  - usually choose one of two options
    - wide-band or narrow-band (relative to the spacing or harmonics in the human voice)
    - historically, 45 or 300 Hz

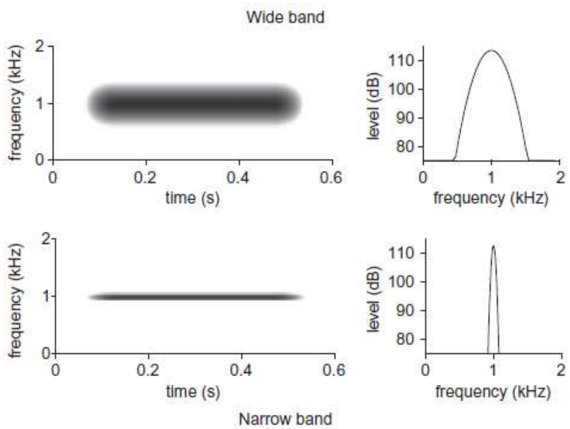
Remember!

Effects of wide- and narrow-band filtering on a signal:

- Wide band filters (bad frequency resolution)
  - short ringing (good temporal resolution)
- Narrow band filters (good frequency resolution)
  - long ringing (bad temporal resolution)

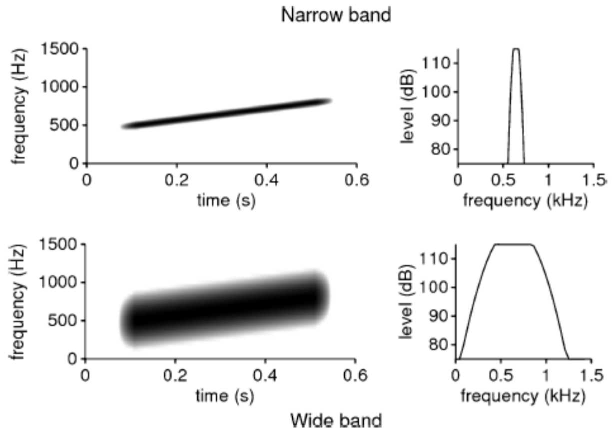


A 1-kHz sinusoid



Note the spectral *sections* at right

The FM sweep

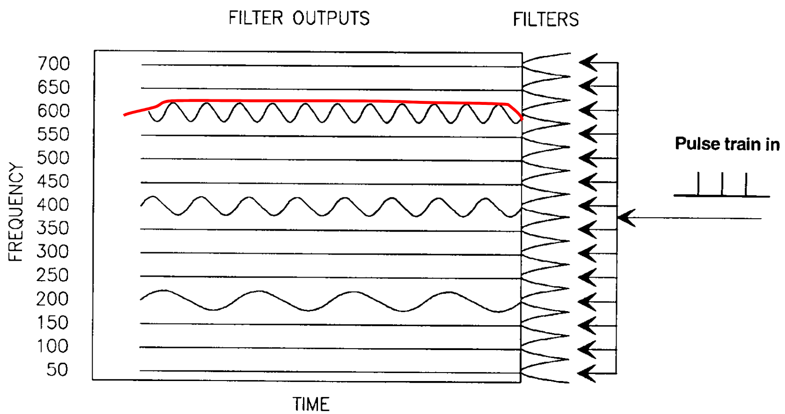


A more interesting example:

A pulse train

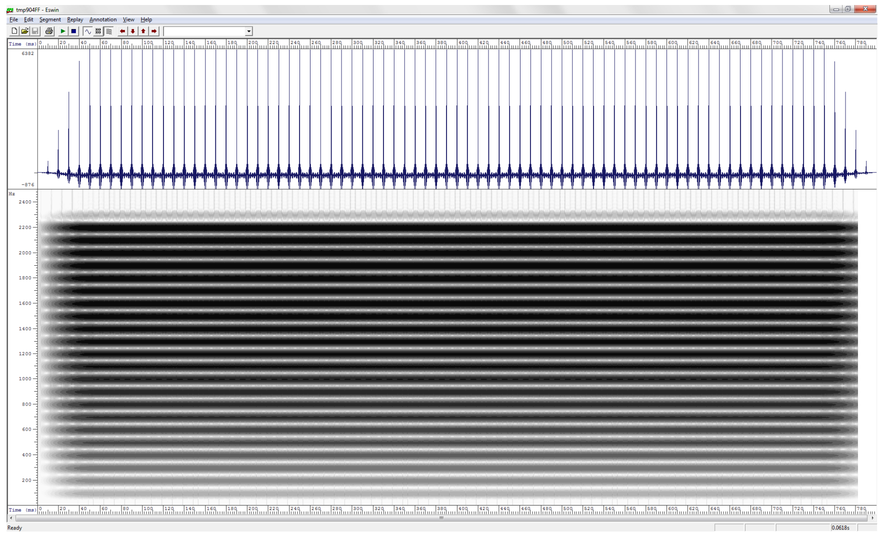
(narrow pulses at 100 Hz)

The easier case: Narrow bandwidth filters

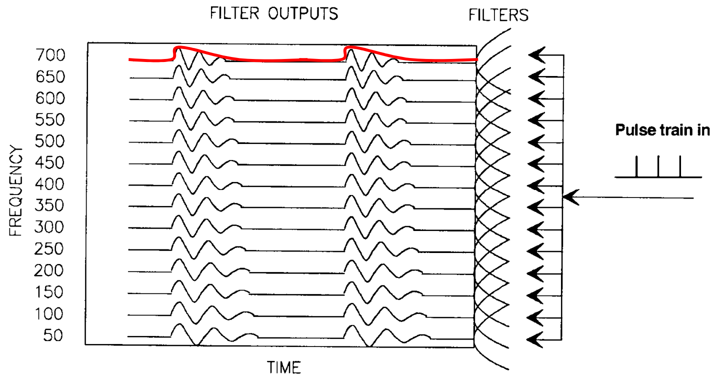


need to rectify, smooth & convert to darkness

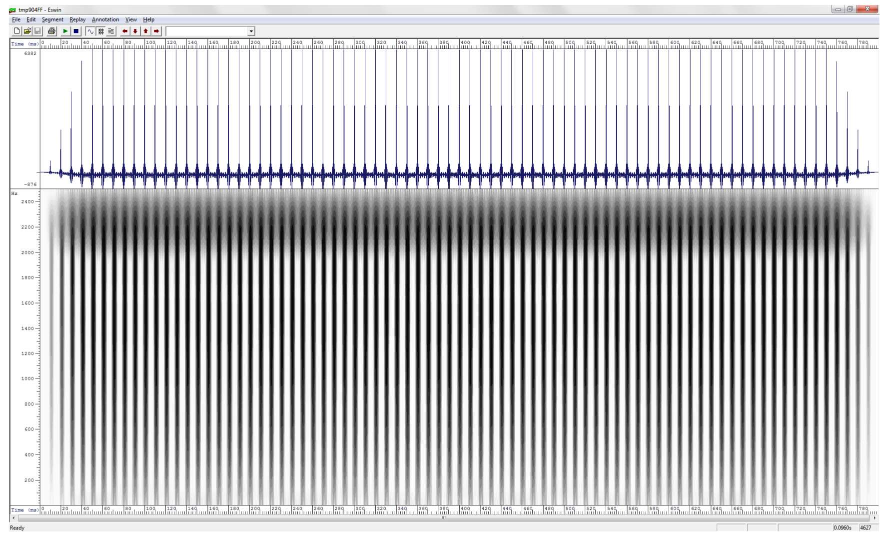
The real thing



Wide bandwidth filters



The real thing



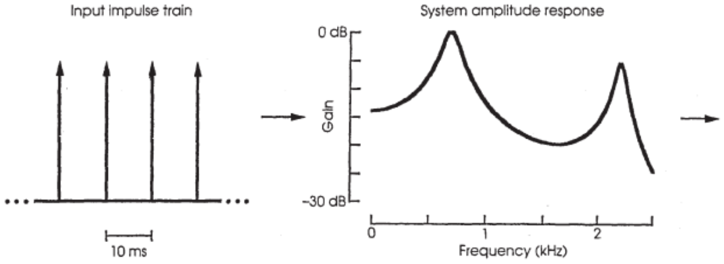
Narrow-band spectrograms

- Analyse with narrow band-pass filters
- About 45 Hz wide (≈ 20 ms ringing)
- Narrower than harmonic spacing (typical voice F0 > 70 Hz)
- Each filter “sees” single harmonic or nothing
- Get spectrogram showing harmonics

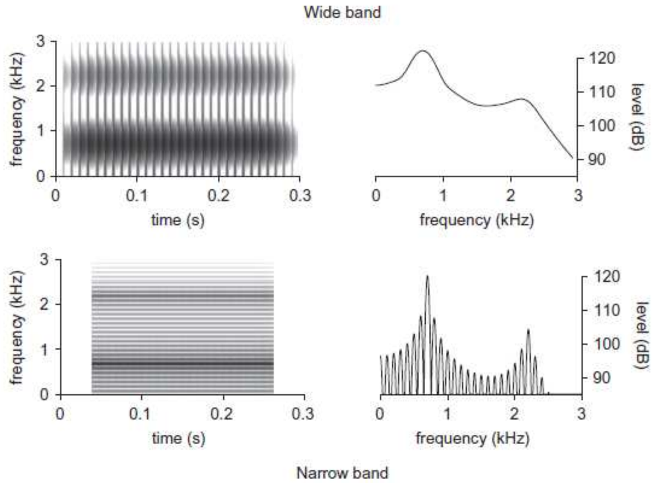
Wide-band spectrograms

- Analyse with wide band-pass filters
- About 300 Hz wide (≈ 3 ms ringing)
- Wider than typical harmonic spacing
- Each filter “sees” changes within pitch period, because of interaction of harmonics
  - related to beats
- Get spectrogram showing “striations”

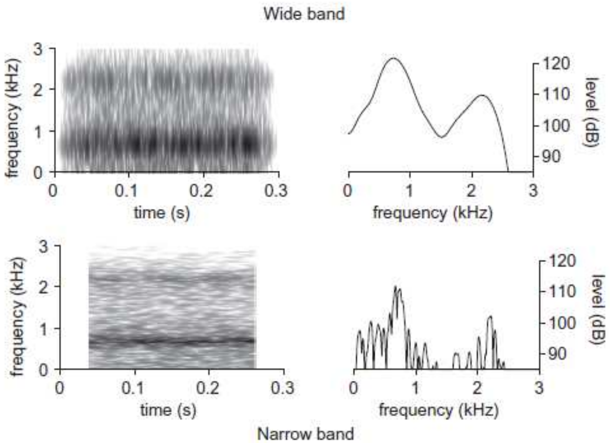
A pulse train through two resonators



A pulse train through two resonators



White noise through the same two resonators



Wide & Narrow Summary

- Wide-band analysis
  - Good for time resolution
  - Poor for frequency resolution
- Narrow-band analysis
  - Poor for time resolution
  - Good for frequency resolution