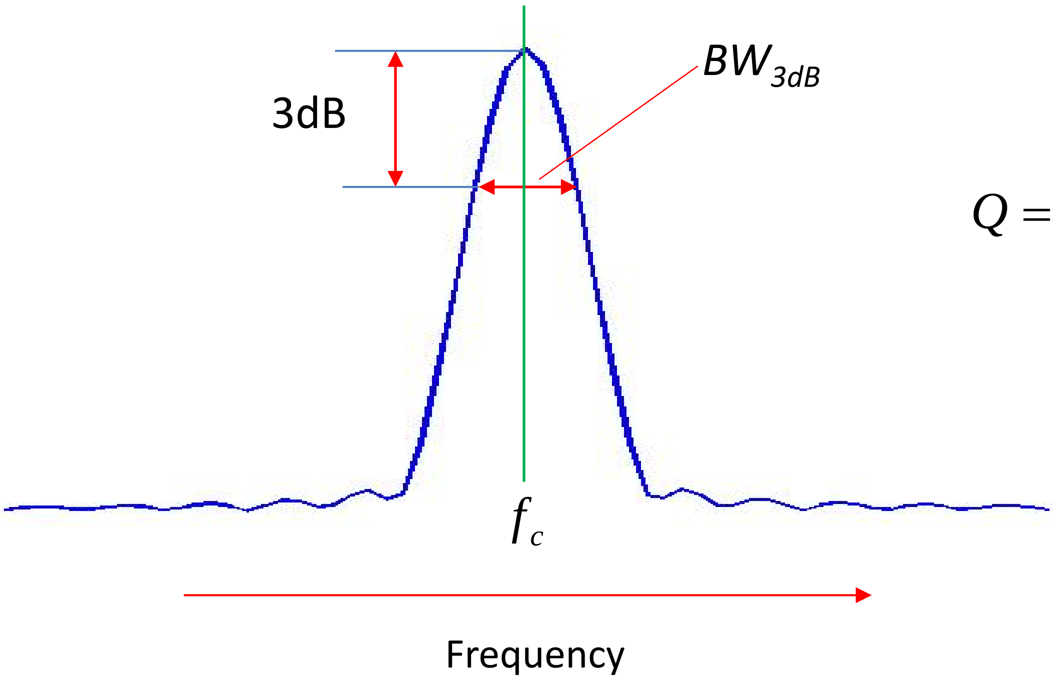
Broadband Acoustics

John Horne
University of Washington

What is Broadband?



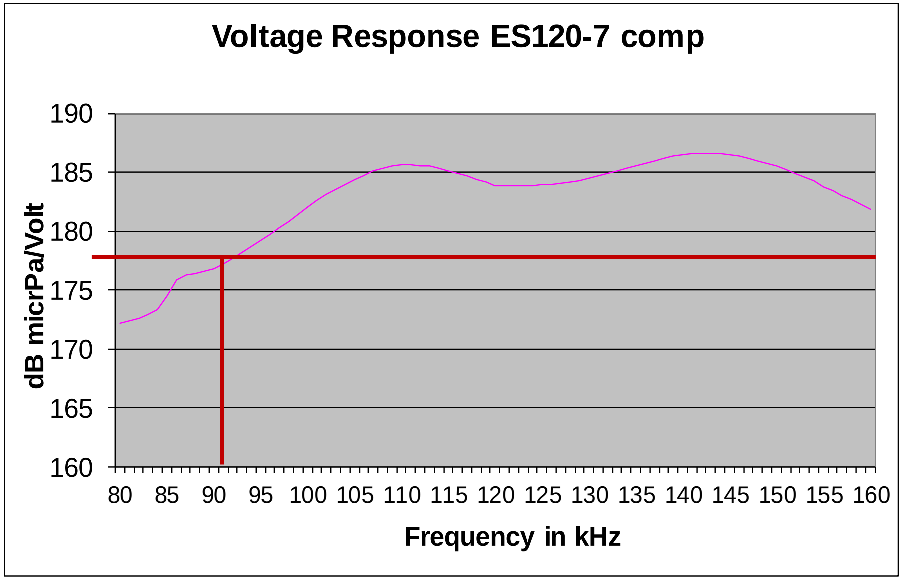
$$Q = \frac{f_c}{BW_{3dB}} \Rightarrow \begin{cases} >10 & \text{narrow band} \\ \text{in between} & ?? \\ <3 & \text{broadband} \end{cases}$$

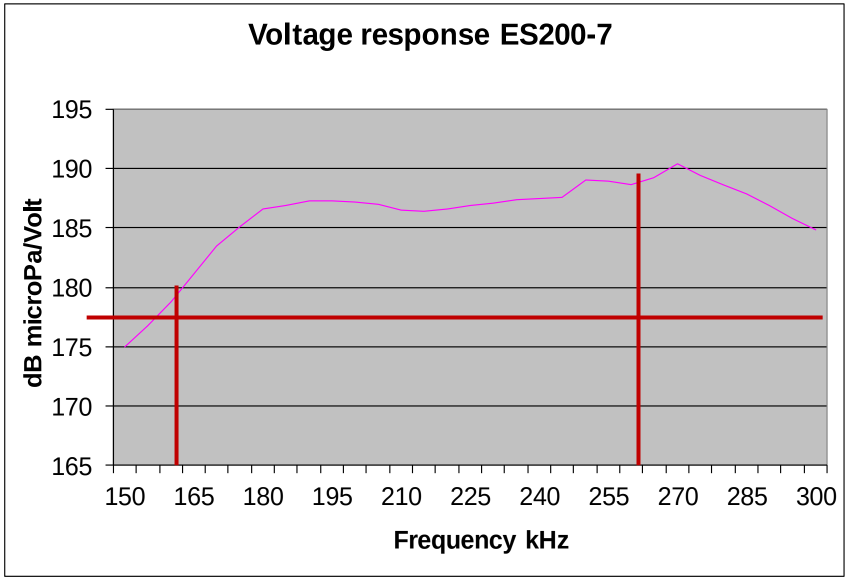
Advantages of Broadband compared to Narrowband:

- Higher signal to noise ratio (SNR)
- Higher signal temporal resolution (target characterization)
- Continuous frequency band (more information for target classification)

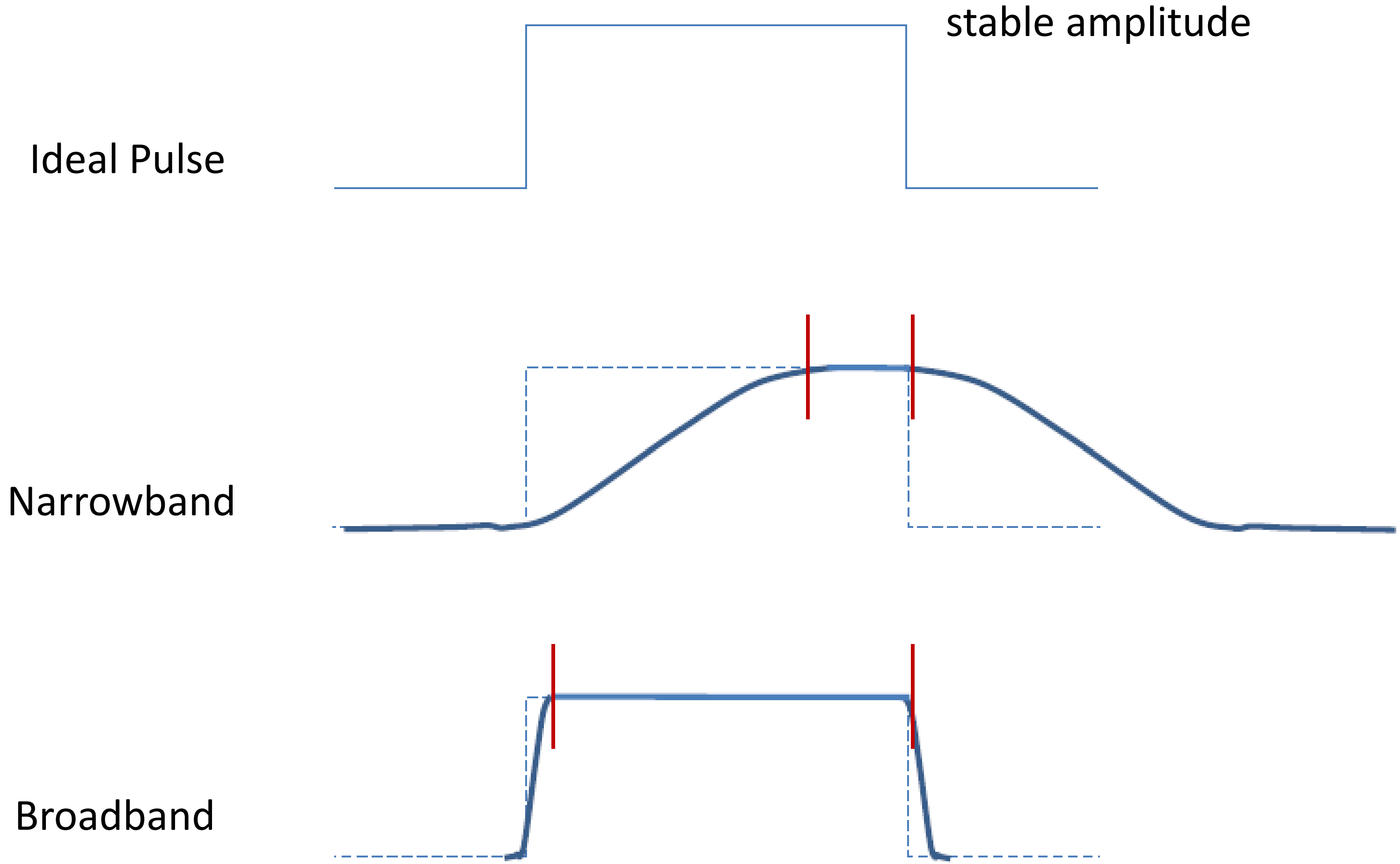
Broadband Transducers

	ES18	ES38-7	ES70-7C	ES120-7C	ES200-7C	ES333-7C
Nominal frequency [kHz]	18	38	70	120	200	333
Nominal opening angle [deg]	11	7	7	7	7	7
Nominal max TX power [W]	2000	2000	750	250	150	50
Approx. frequency band [kHz]	18	34 – 45	45 – 95	90 – 170	160 – 260	280 – 450





Acoustic Pulses

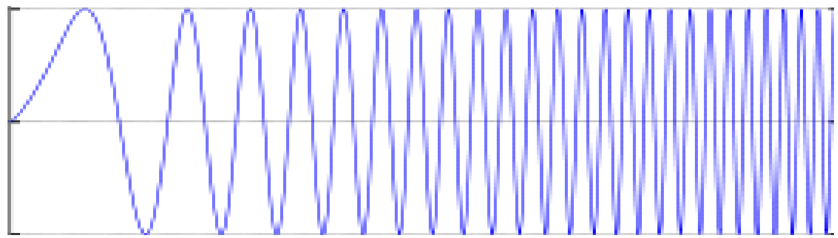


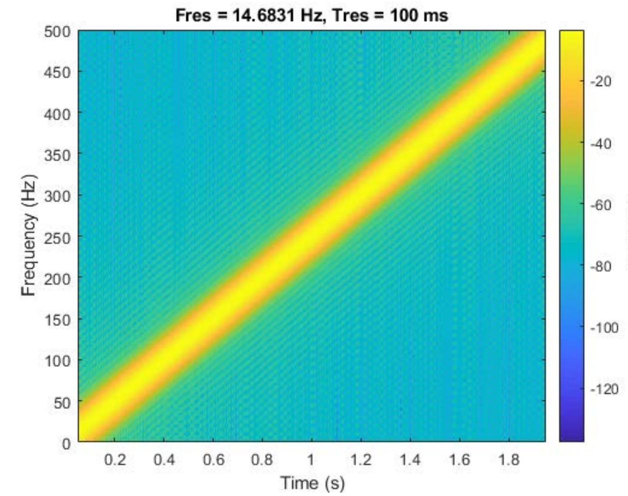
Broadband Pulse Types

CHIRP pulses: energy distributed across frequencies

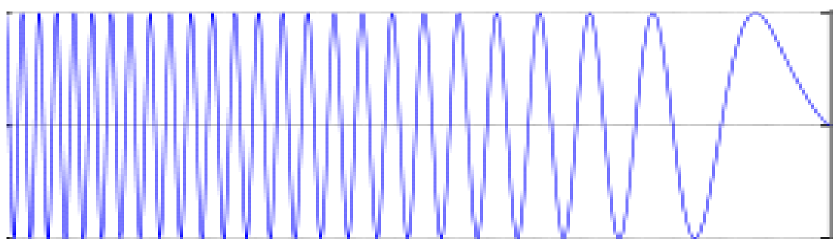
Linear

up-sweep

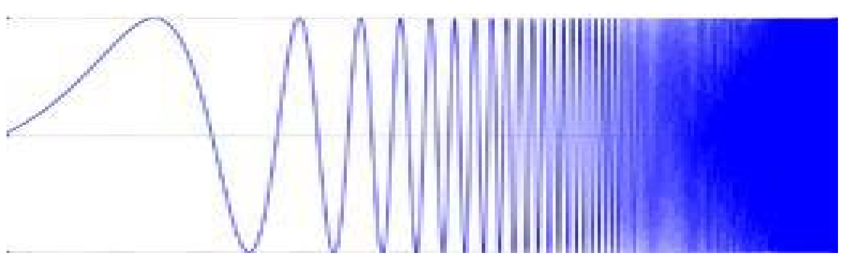


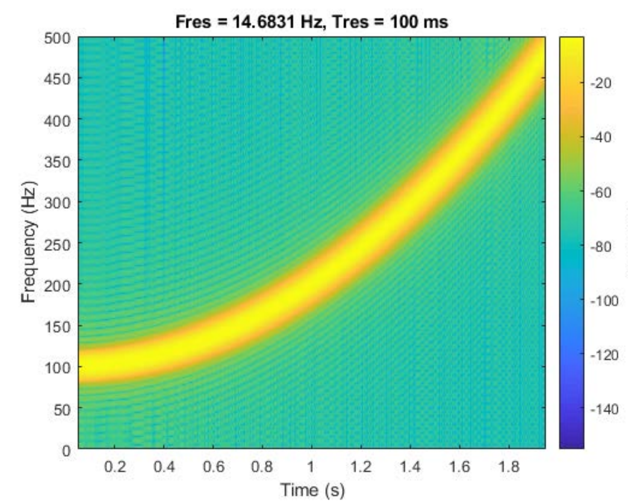


down-sweep



Exponential
up-sweep

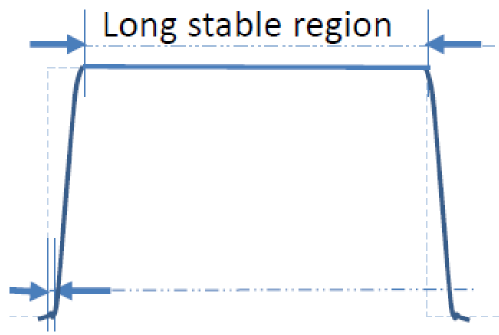


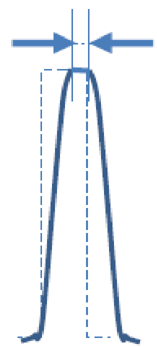


Improving Signal Resolution

Continuous wave target resolution: $\Delta r = \frac{c\tau}{2}$ Shorten pulse duration

Broadband target resolution:





BUT short broadband pulses have uneven distribution of frequencies

Broadband Solution: Matched Filter – a filter with bandwidth matching the pulse duration (aka Pulse Compression)

So What? Enables decoupling of known signal from unknown noise, maximizes SNR

Continuous wave

$$SNR = \frac{A_{rms}^2}{BWxN_0}$$

Broadband

$$SNR = \frac{A_{rms}^2 T}{BWxN_0}$$

where: A=Amplitude, BW= bandwidth, N_0= spectral density of noise, T = period of filter

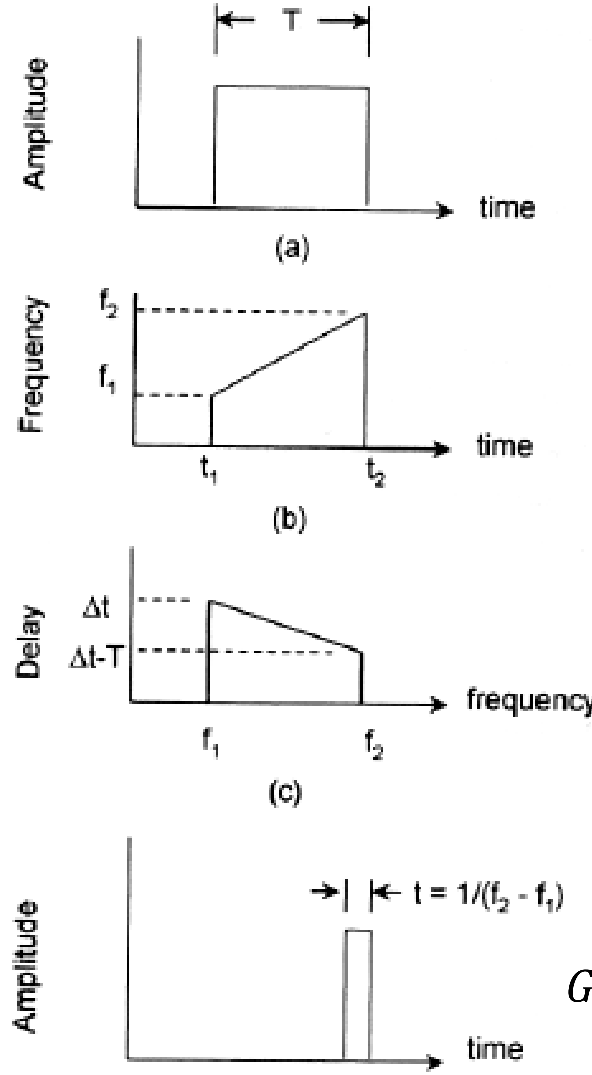
Matched Filter: Pulse Compression

Input pulse echo envelope

Input pulse frequency envelope

Matched filter time delay

Output pulse echo envelope



Gain in SNR:

$$G_{dB} = 10\log_{10}(BW) + 10\log_{10}(T)$$

$(f_2 - f_1)$

Adding a Matched Filter

Time series of echo returns:

$$x(t) = s(t) + n(t)$$

$s(t)$: signal

$n(t)$: noise

Apply a filter *a(t)* to the time series:

$$y(t) = x(t) * a(t) = s(t) * a(t) + n(t) * a(t)$$

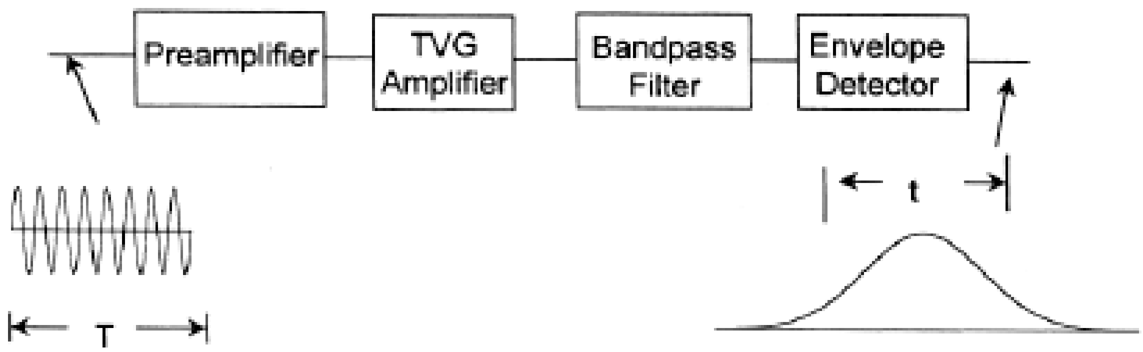
$$a(t) = k\, s(-t)$$ A time-shifted signal

$$y(t) = k\, r_{ss}(t) + k\, r_{ns}(t)$$

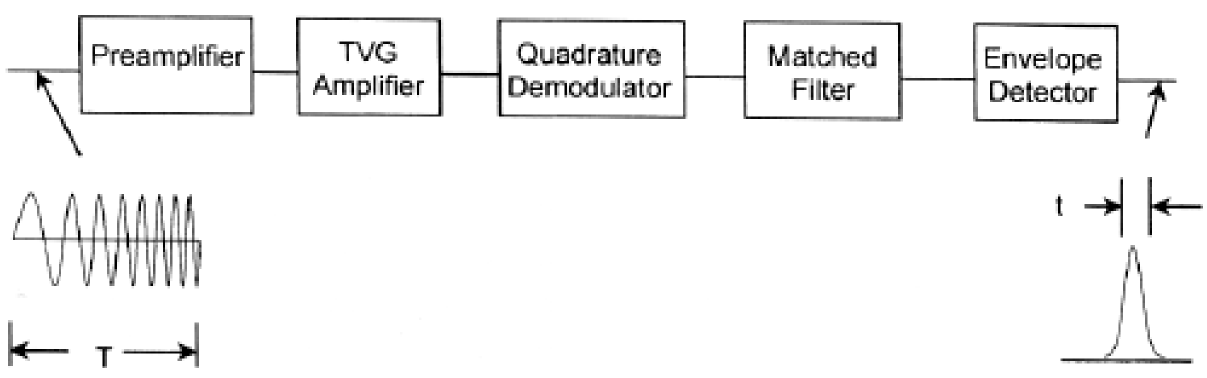
where $r_{ss}(t)$ is the auto-correlation function of the signal and $r_{ns}(t)$ is the cross-correlation function of the noise and the signal, which approaches to zero for a white noise, i.e. $r_{ss}(t) \gg r_{ns}(t)$.

Signal Processing

Continuous wave or Tone burst



Broadband



Challenges When Using Broadband

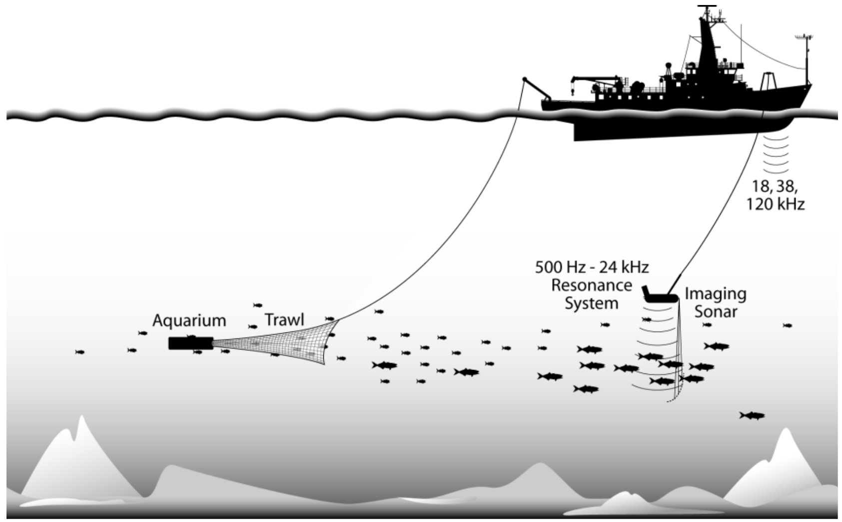
1. Frequency-dependent beam width (affects integration volumes)
2. Non-linear effects: harmonics (avoided using up or down sweeps)
3. Large increases in volume of data (EK60 0.2 GB/hr; EK80 CW 1.67 GB/hr; EK80 FM 41.67 GB/hr)
4. Data processing time

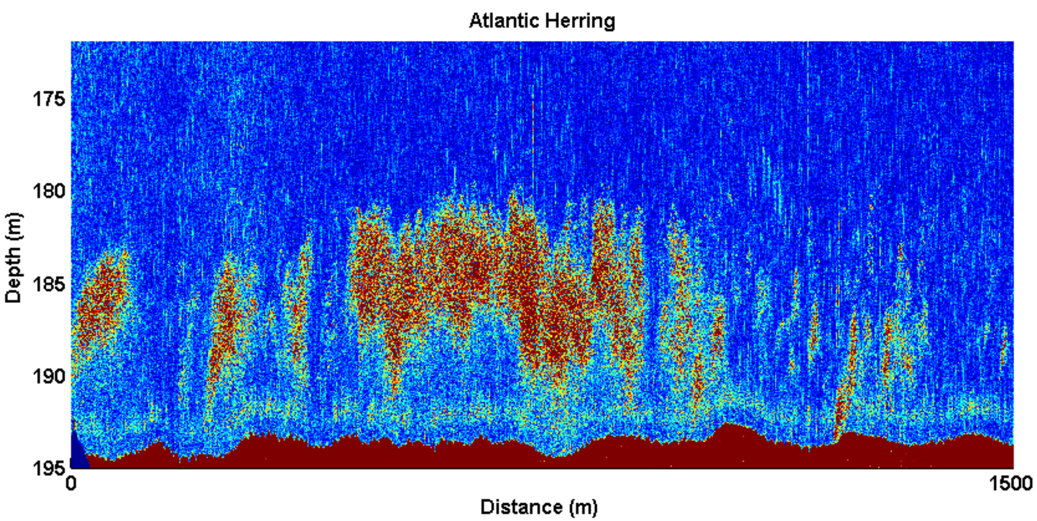
Example Broadband Systems

EdgeTech

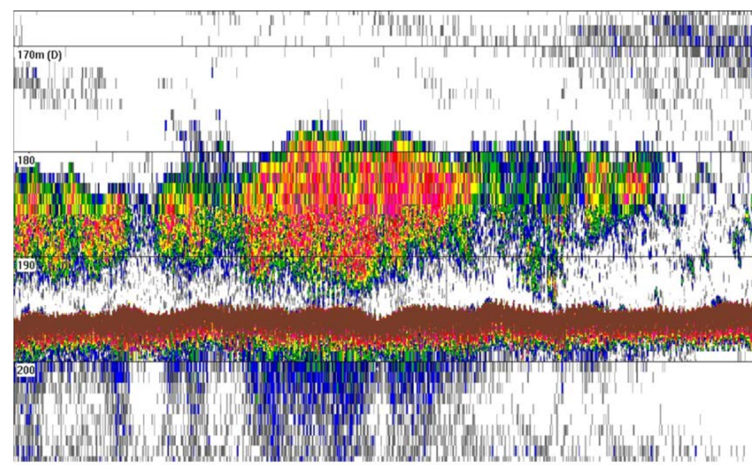
Simrad EK80

Herring Survey: Gulf of Maine



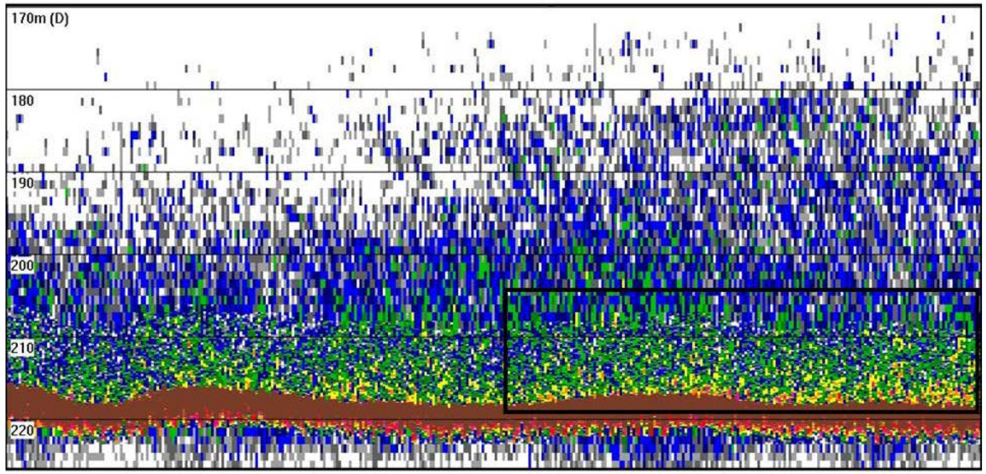


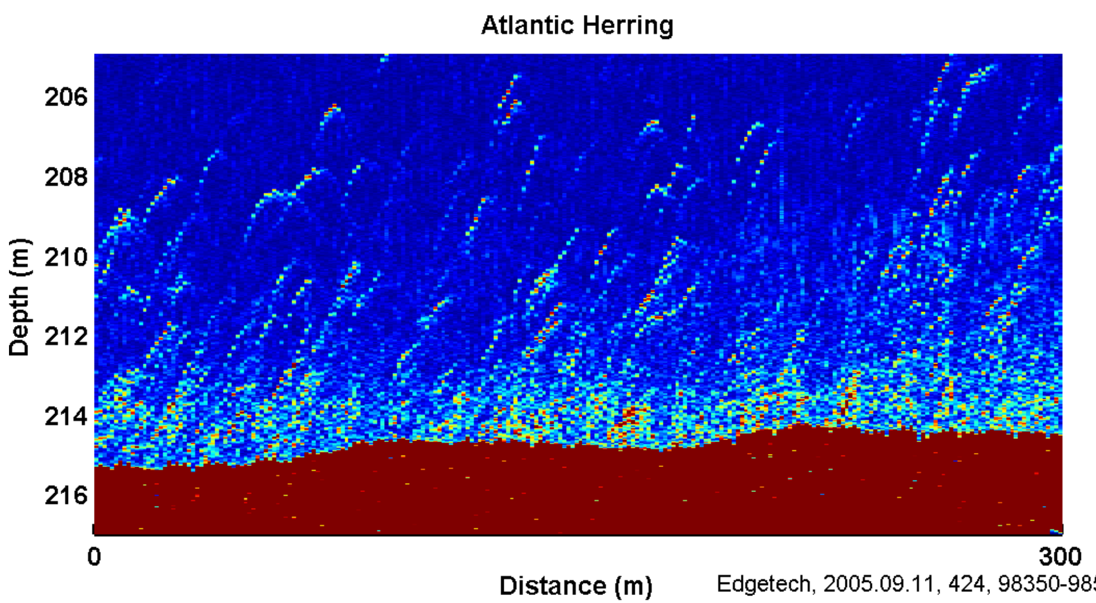
120 kHz narrow band



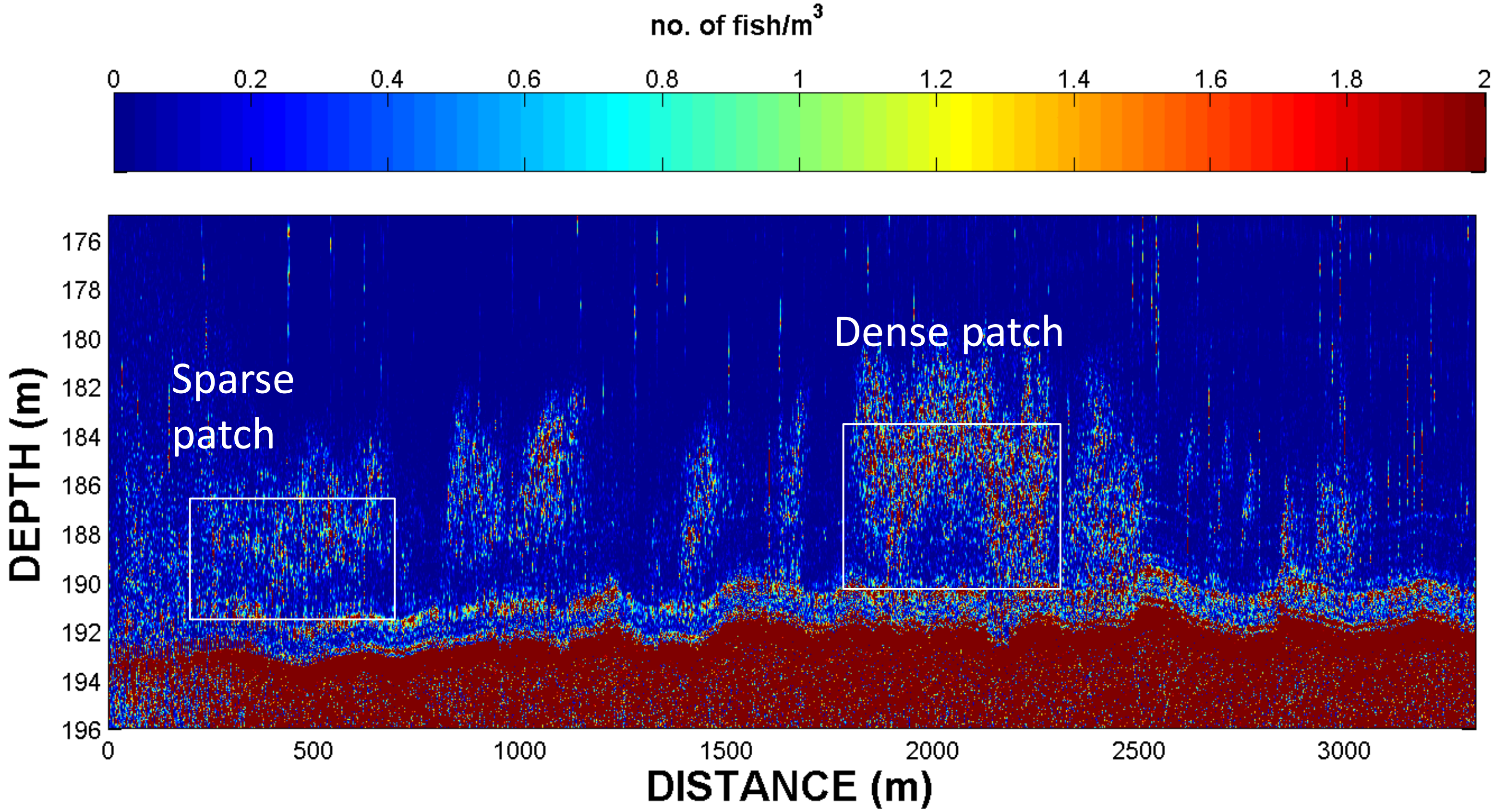
Improved Target Resolution

120 kHz narrow band

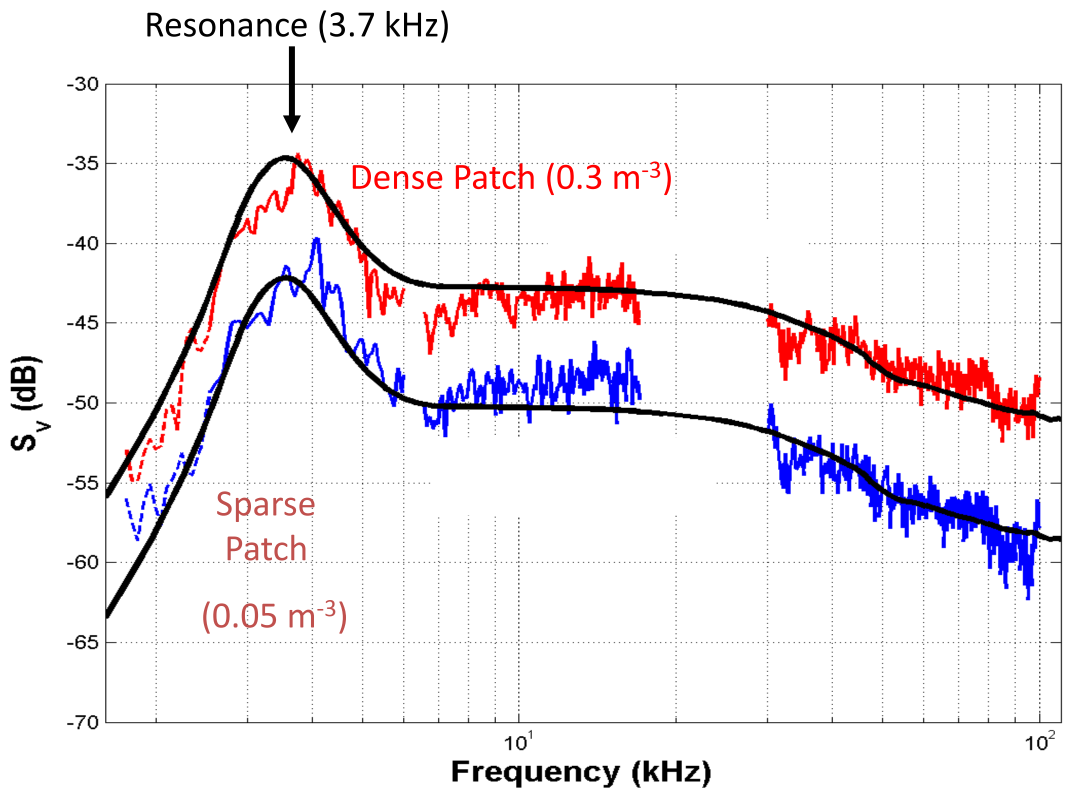




Herring Survey: Fish Density and ID



Herring Classification: Resonance



Difference in echo amplitude is due to difference in fish density, not size, orientation, or distribution of fish

EK80 70 kHz Broadband Echogram