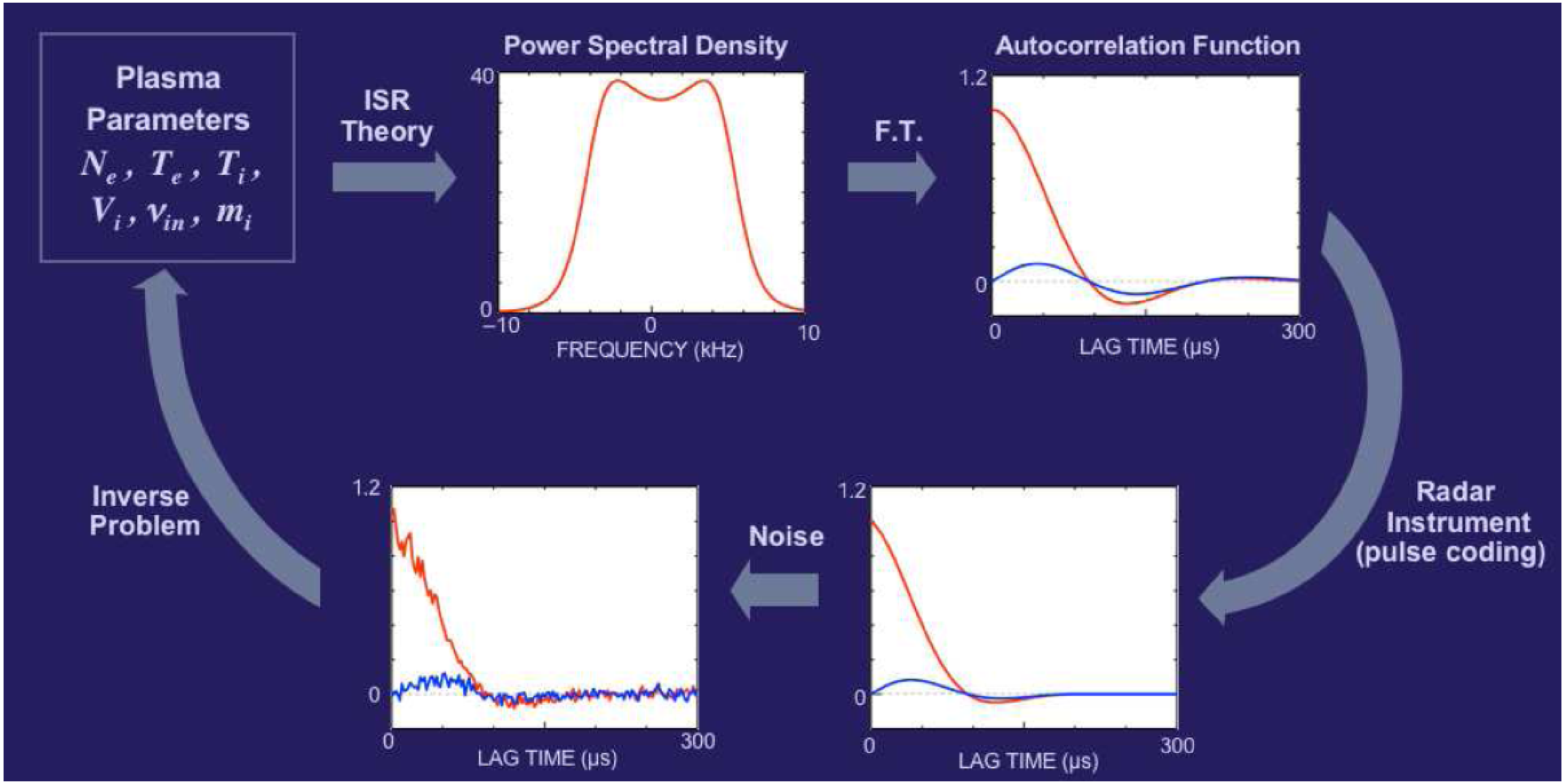
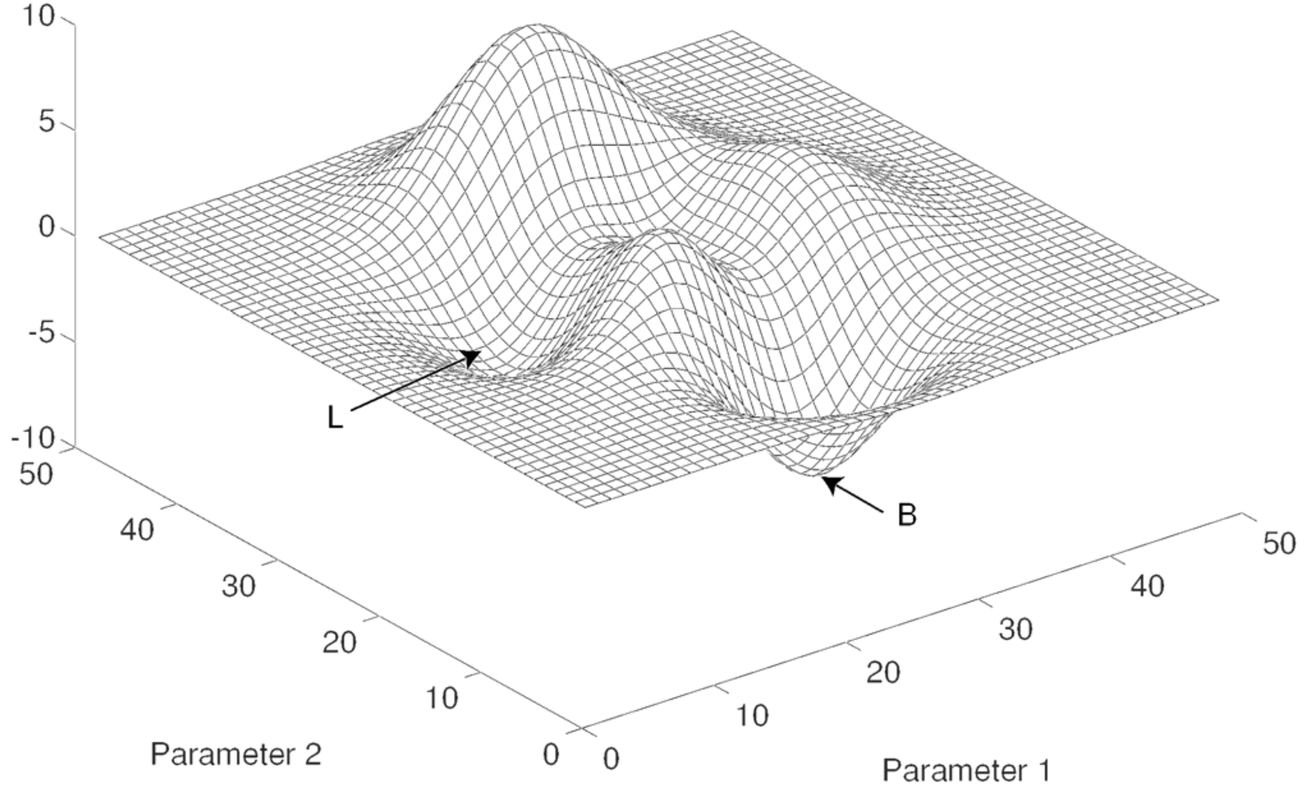
ISR Practicalities: Data Reduction

NB: Power spectrum (freq domain) <-> Autocorrelation function (time domain)

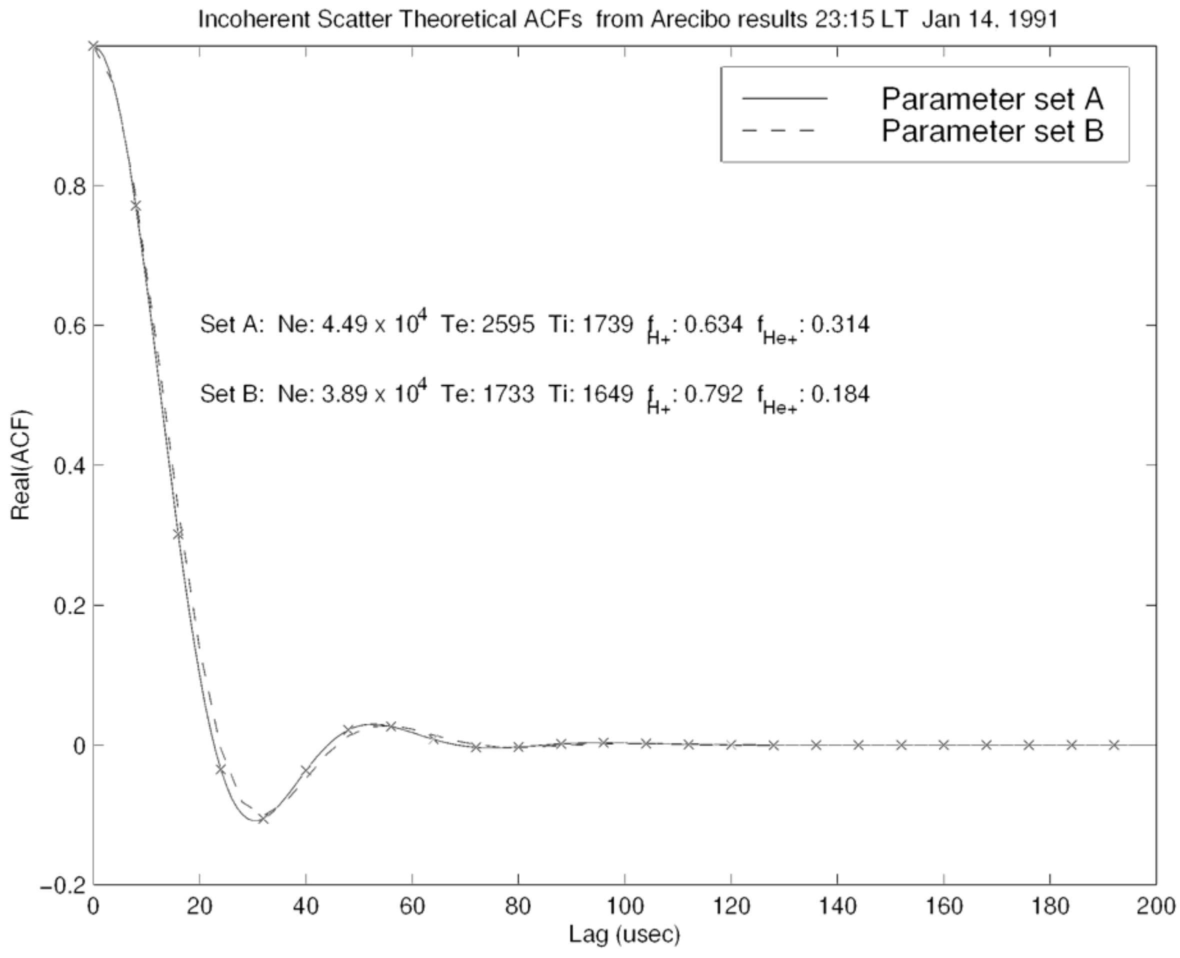


Incoherent Scatter Fit Ambiguities

L, B might both be valid parameter solutions. Might need to use constraints on the parameters to decide which one.



Incoherent Scatter Parameter Ambiguity Example



Incoherent Scatter Experiment Parameters

At a fundamental level, we must select

- Waveform type
- Inter-pulse period (IPP) or pulse repetition frequency (PRF)

Our choices will be dictated by the desired measurement and medium properties.

Most often, the choice is driven by a fundamental characteristic of scatterers (whatever their nature) – their correlation time. This is equivalent roughly to the power spectral width in the Fourier domain.

Note as well that since time is equivalent to distance, the scatterers also have a characteristic correlation length.

Target Correlation Time

- If the correlation time is long, we can assemble Doppler information from multiple target returns.
- If the correlation time is short, we need to obtain all the Doppler information from a single target return as the Doppler is changing fast (in fact, so fast that it changes as we illuminate it with a single radar pulse!).

Overspread vs Underspread Targets

Focus first on selection of the interpulse period (IPP).

Two requirements:

Avoid range aliasing (don’t confuse multiple pulse returns):

$$T \geq \frac{2L}{c}$$

Avoid frequency aliasing (sample fast enough to catch the whole spectrum):

$$T \leq \frac{1}{BW}$$

Underspread targets: both are possible since bandwidth of targets is small (coherent plasma waves, planetary radar, mesosphere-stratosphere-troposphere radar).

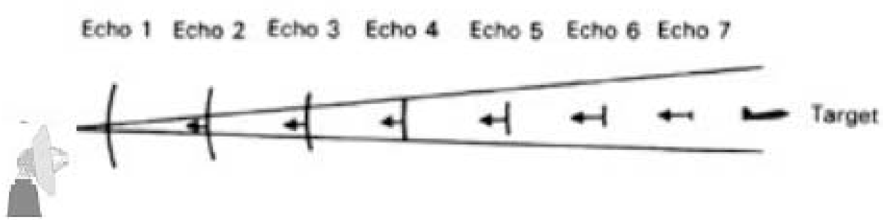
Overspread targets: both are not possible as target bandwidth is high (incoherent scatter).

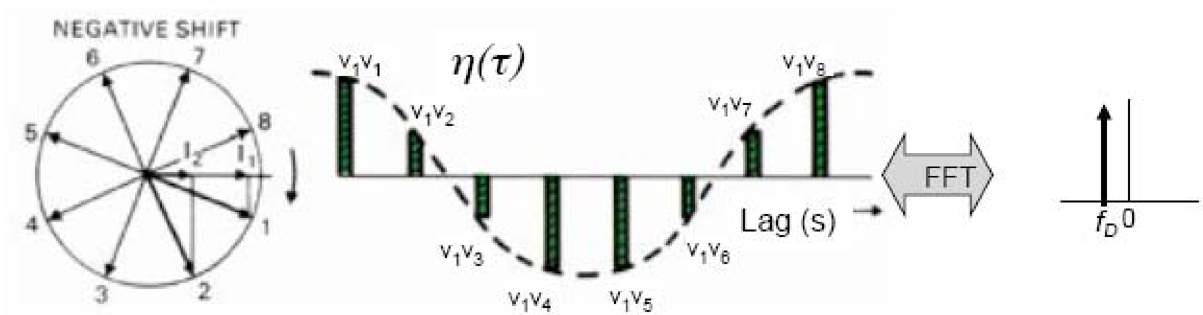
Underspread Case

Case 1

$1/f_d >> \tau$ (Doppler period much larger than pulse width)

- Assume phase is constant over one pulse, so only need to sample signal once per pulse to get Doppler information.
- Result: Need to transmit multiple pulses to determine Doppler.
- Need only satisfy the constraint that PRF>$2f_d$



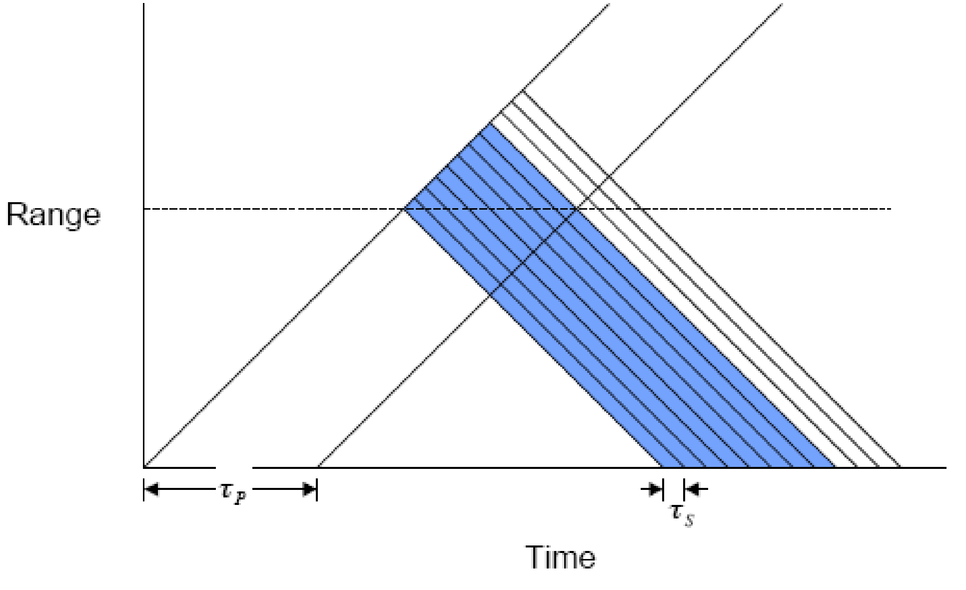


Overspread Case

Case 2

$1/f_d < \tau$ (Doppler changes significantly during one pulse)

- Must sample multiple times per pulse
- Result: Doppler can be determined from single pulse.



Selecting A Modulation Pattern

The other choice is to select the right transmitted waveform. This depends on:

- Temporal correlation time of the incoherent scatter signal

- Fundamental plasma parameter changes over
    - Spatial scales
    - Temporal scales

Ultimately, the choices of IPP and waveform define the number of independent statistical samples we get of the remote physical process per unit time.

This can be thought of as the “speed” of the measurement.

Some Modulation Pattern Guidelines

• Ionosphere has a characteristic length over which parameters remain unchanged – this sets the maximum pulse length usable and hence the maximum ACF lag measurable (i.e. frequency resolution). Recall the scale height.

• Within this characteristic length, the plasma ACF has a characteristic correlation time set by the plasma parameters themselves – sets the zero crossing and first ACF minimum, which determines how far out on the ACF it's useful to measure.

• Receiver bandwidth is set by the lag step or lag resolution (i.e. maximum Doppler spectral extent) in our usual overspread case – but that sets the thermal noise level (and ultimately SNR).

• Tradeoffs of all of these take place depending on a particular experiment..

Available Modulation Patterns

- Short pulse: cross-section profile only – area under spectrum; no Doppler resolution

- Long pulse: can measure ACF when modest spatial resolution is needed.

- Amplitude domain phase code (Barker code): cross-section only, but with better spatial resolution.

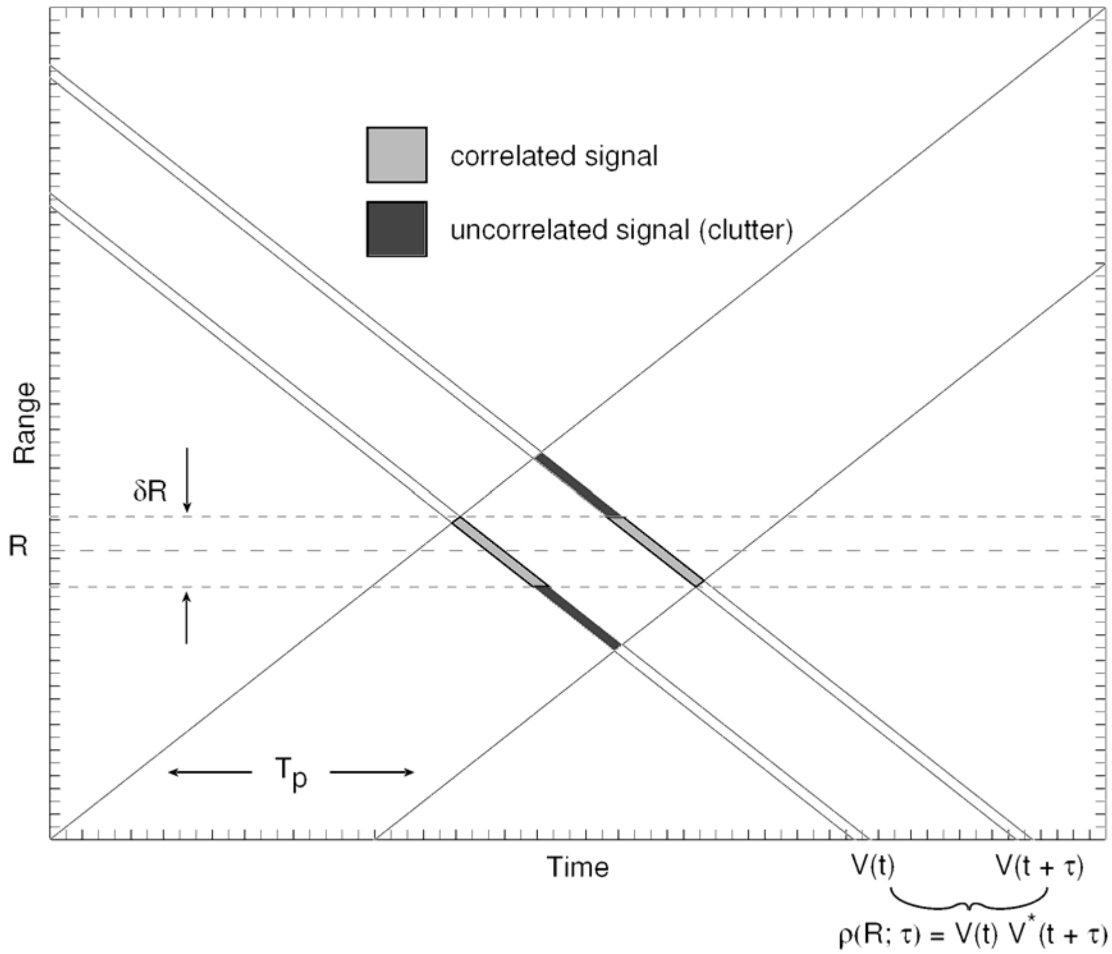
- Set of codes, each one a phase pattern (alternating code): measure ACF with good SNR and high spatial resolution. Penalty is more complex signal processing.

At Poker Flat, most used waveforms are long pulse, Barker code, alternating code.

Long Pulse: Range-Time Diagram

As lag increases, correlated signal goes down and uncorrelated signal (clutter = noise) goes up. Bad statistics!

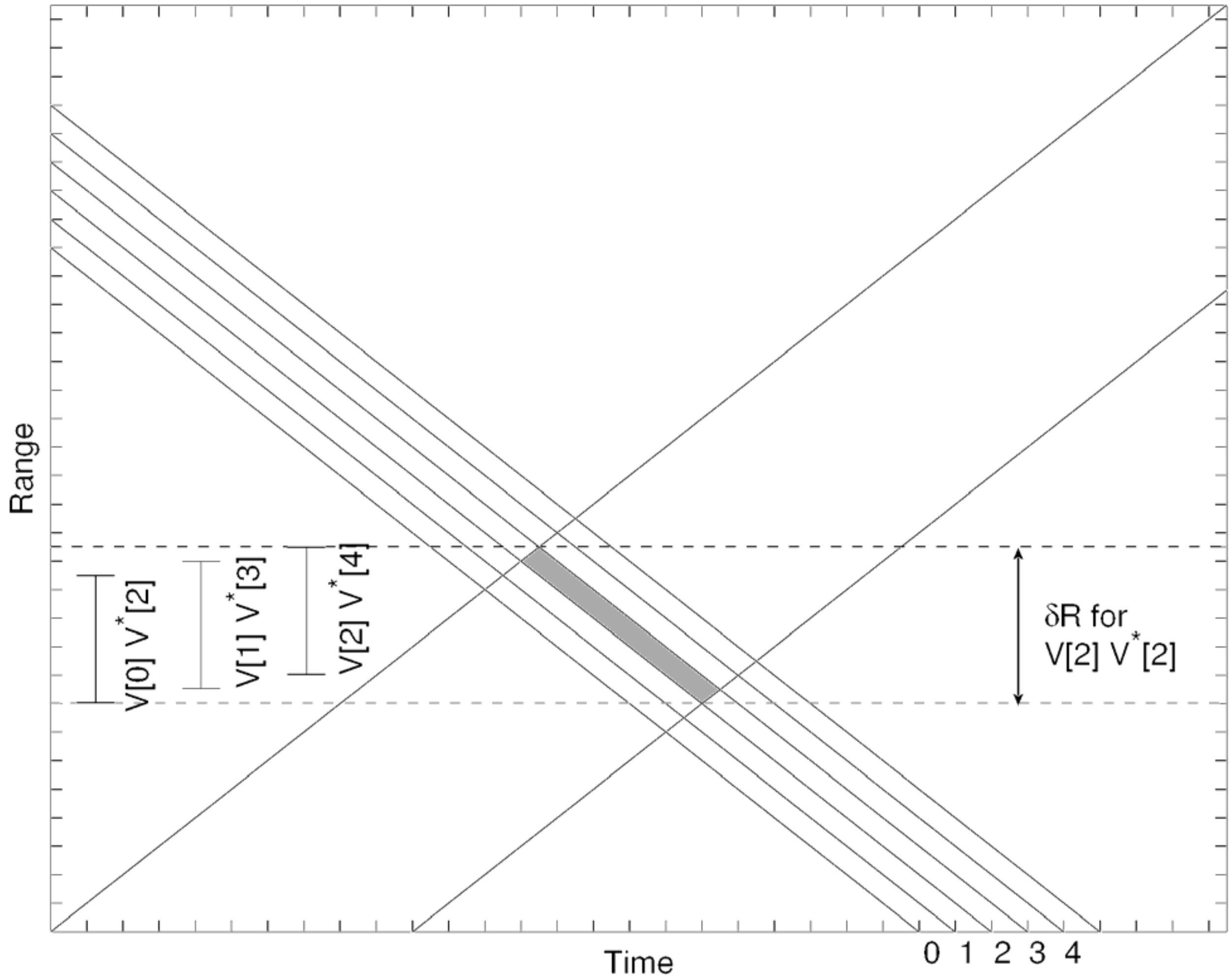
Altitude resolution of individual ACF lags not uniform as a function of lag!



Can't measure ACF at lags larger than pulse length (which sets frequency resolution in your measured power spectrum)*

- This is true for any pulsed waveform when we are overspread! (note mismatched RX filter)

Long Pulse: Improving Statistics



But note that final altitude resolution is still the size of the transmitted pulse (i.e. zero lag).

Pulse Compression: Defining A Measurement Problem

$$\Delta h \sim \Delta t \sim \frac{1}{BW_{pulse}}$$

So a 1 msec pulse gives a ~ 1 kHz bandwidth. And you might need a 1 msec pulse to get adequate frequency resolution depending on the plasma conditions. But this has a poor range resolution (150 km).

Suppose we want to measure in the E region, where things change on km scales. This won't work.

We need a wider bandwidth pulse (better height resolution).

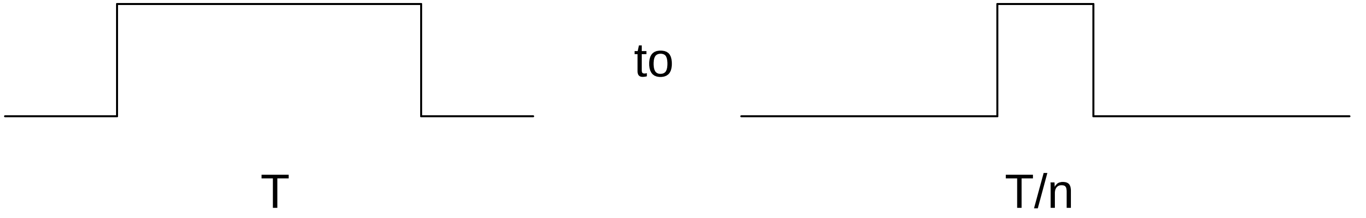
BUT just using a shorter pulse will get us not very far out on the ACF. Poor spectral resolution, and the illuminated volume is smaller so poorer SNR.

Worse yet, the correlation time is getting longer as we go to lower altitudes (spectra is narrower because temperature is lower). So our need for longer lags is even more acute.

Pulse Compression: The Solution

We need a waveform which is:
• Long enough to meet our max lag requirements and provide total energy in the return sufficient for good SNR;
• Short enough in range resolution that we can measure a stationary ionosphere (in physical parameters).

We can do this by modulating the transmitted waveform with a known frequency or phase pattern. This will widen the transmitted bandwidth. Upon reception, if we match filter with the known imposed pattern, we can compress the pulse in space (good spatial resolution, good SNR) while retaining the long lag measurement features (good spectral resolution).



Pulse Compression Modulation Possibilities

• Frequency modulation within the pulse – e.g. linear frequency modulation. Delay samples to reassemble energy upon reception.

• Phase modulation – gives equivalent results. Polyphase modulation possible, but most common mode is binary (+ or -) phase modulation.

In either case, target must remain stationary (i.e. its parameters controlling power spectral or ACF shape must not change) over the entire frequency or phase modulation waveform. If not, assumptions are no longer valid and decoding errors occur (i.e. energy does not get reassembled correctly).

Barker Code: High Resolution Power Measurements

Barker codes are a nice mathematical set for phase modulation. Decoding (matched filter) done in amplitude domain by multiplying voltages by the known code pattern. Maximum compression for n=13 code.

Unavoidable sidelobes, but n*n to 1 power compression.

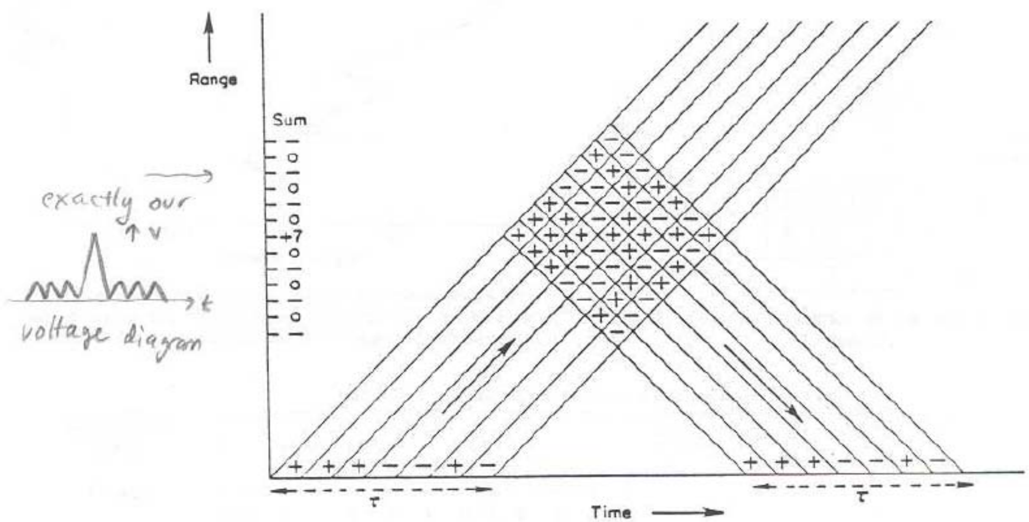
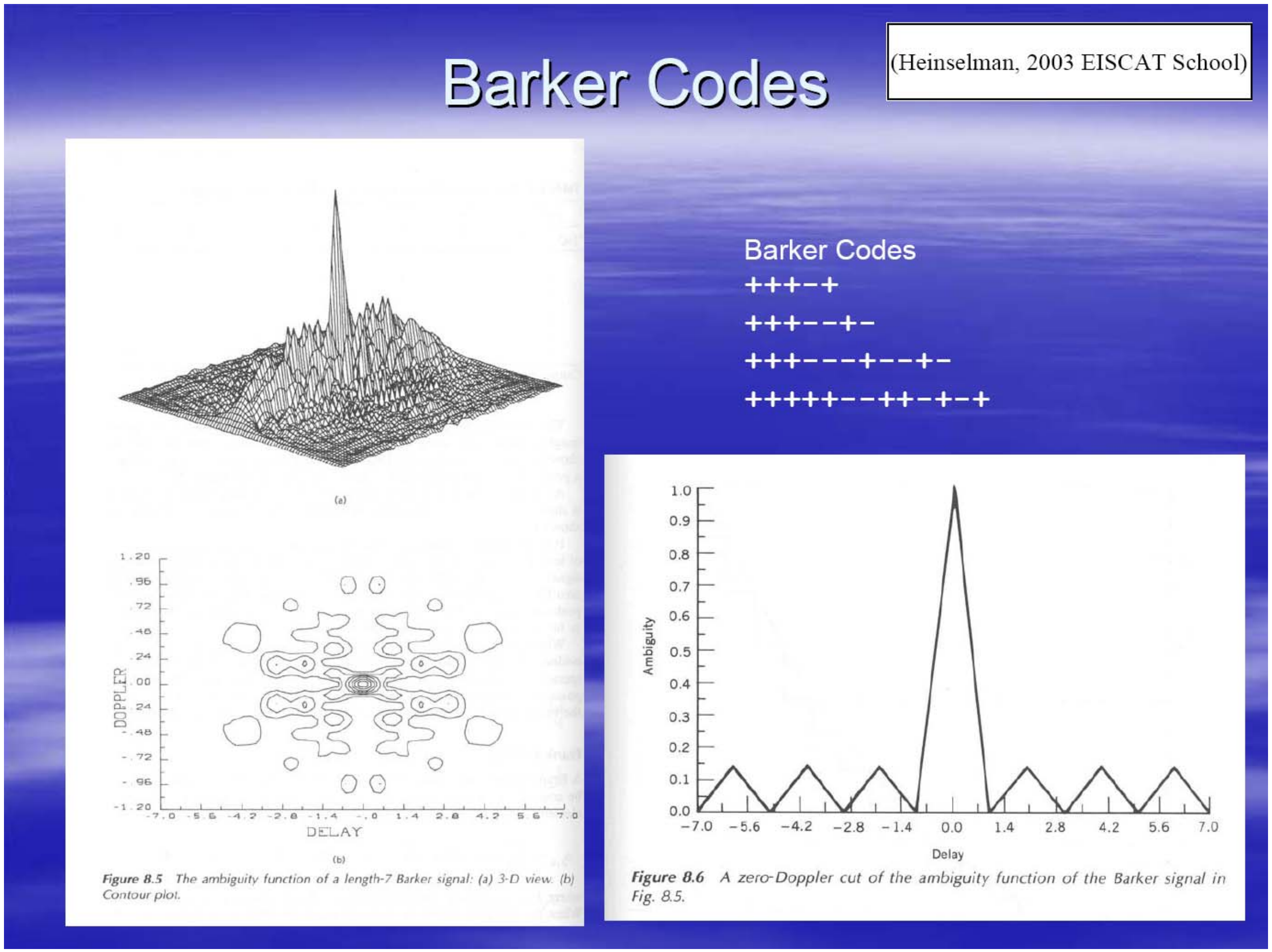


FIG. 9. Range–time diagram for a Barker-coded pulse, which is split into seven elements with + or − phases, as shown. The contributions of the 49 cells are obtained by multiplication, as shown. Only at the central range do these consistently add up to give a sum of +7 contributions. At the other ranges the sums are zero or −1, so nearly all the signal comes from the central range.

Barker Codes



Alternating Codes

Barker code was one modulation pattern repeated identically for each pulse (and decoded in the voltage domain).

What if we used a set of codes, each with a different sidelobe pattern?

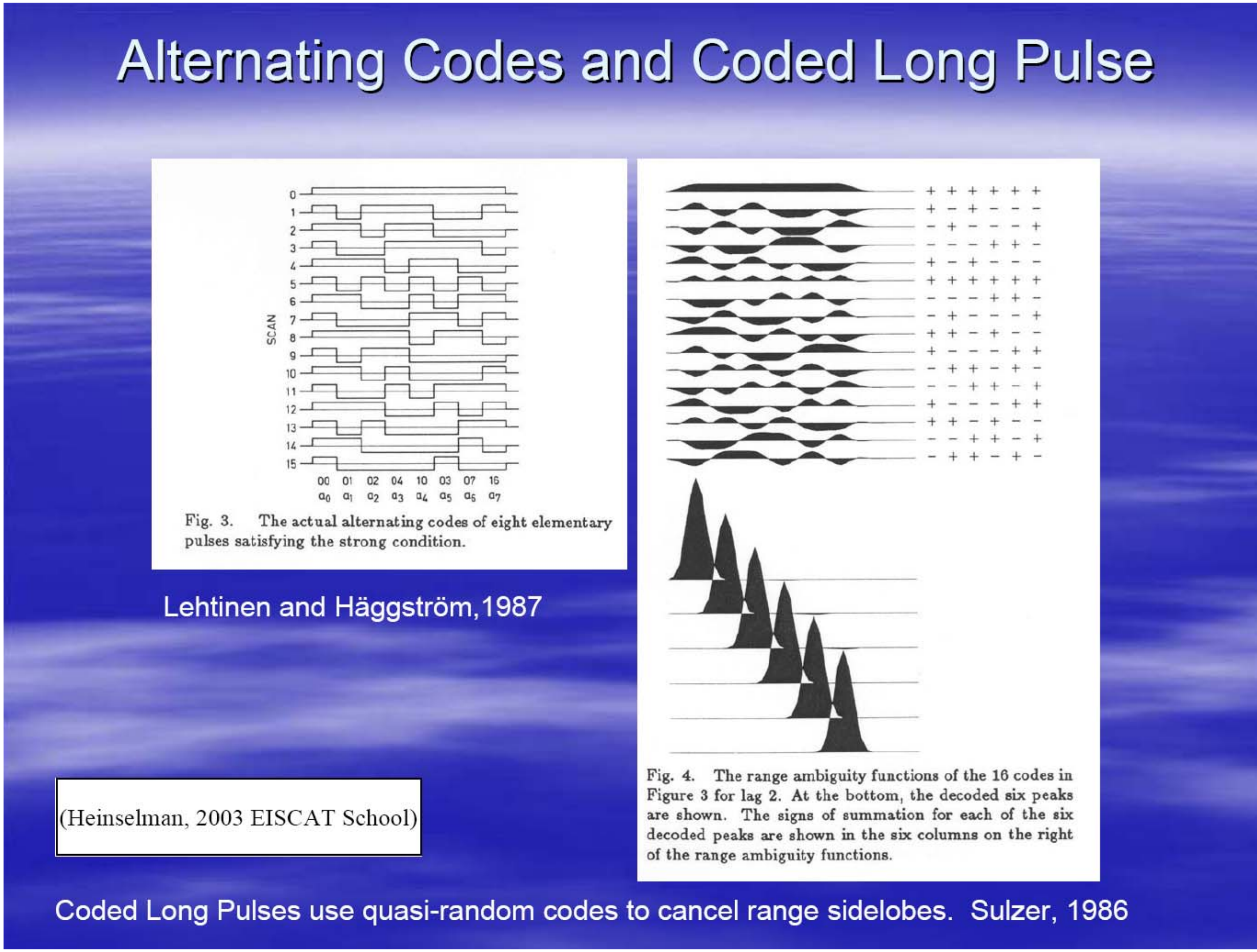
What if, further, we arranged these codes mathematically so that when we decoded them, formed their ACFs, and added the ACFs all together, we could cancel all the range sidelobes except for the central peak?

Codes which do this: alternating codes (Lehtinen and Haggstrom, 1987).

The penalty is a lot of bookkeeping: we need to match filter each individual code, save its statistical ACFs separately, and then add together all the ACF estimates at the very end. Sidelobe cancellation occurs in the second moment (power) domain – some ranges in ambiguity function give positive contribution for individual codes, some give negative contributions.

Alternating Codes

(coded long pulses use a similar idea, but cancellation happens in a statistical rather than deterministic sense.)



Poker Flat Alternating Codes

16 baud “strong” alternating code
32 codes in total set
Total time for code set transmission: about 0.25 seconds (so ionosphere must remain coherent over this time interval)

480 usec total modulation length = 64 km total range
Final range resolution = 480 / 16 = 30 usec = 4.5 km
16 points measured on ACF / power spectrum

(NB: almost the identical parameter set has been used at Millstone Hill since the mid 1990s.)