Radar Signal Processing: Part 5

Computing the ACF and Power Spectrum

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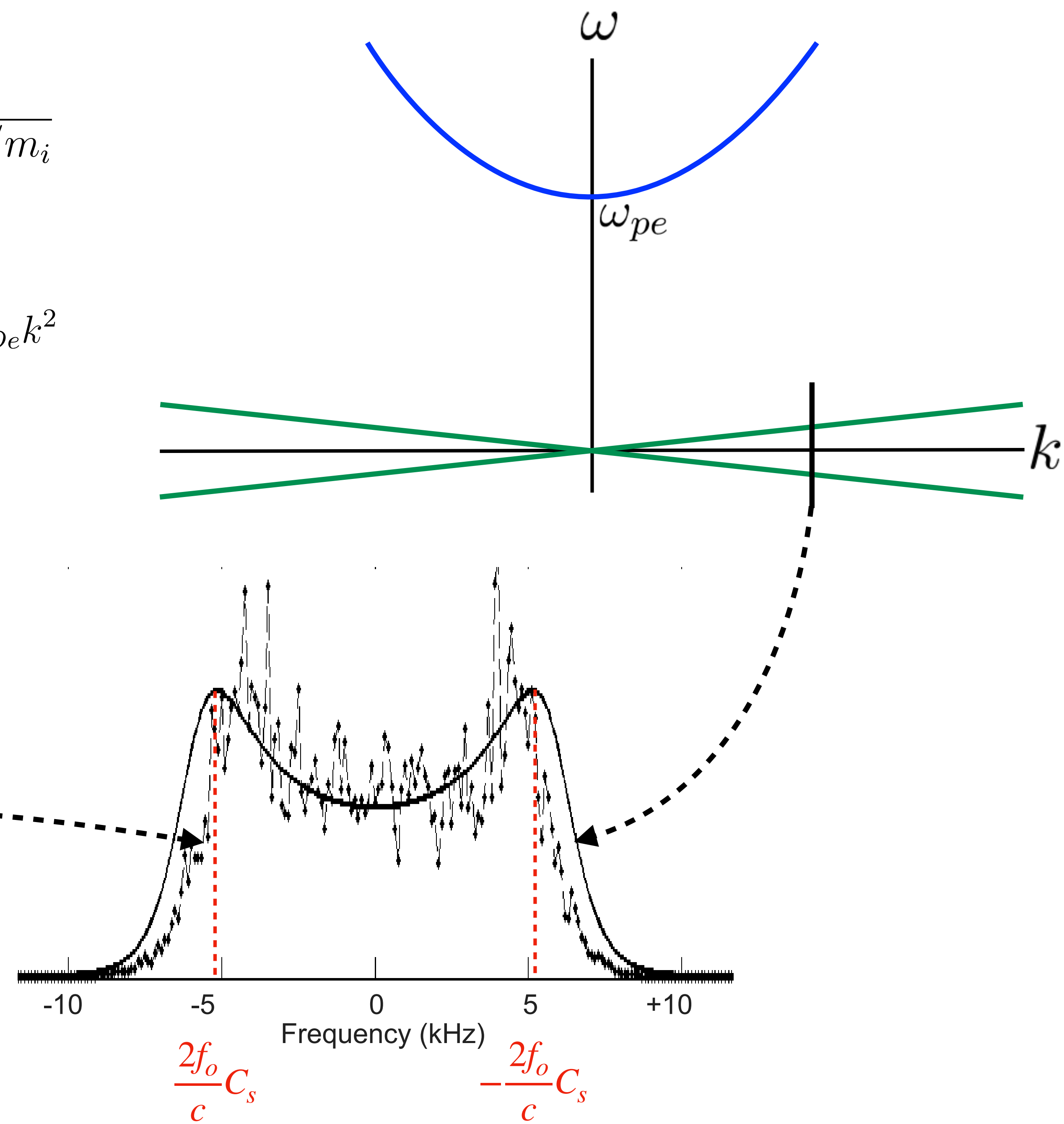
Incoherent Scatter Radar (ISR)

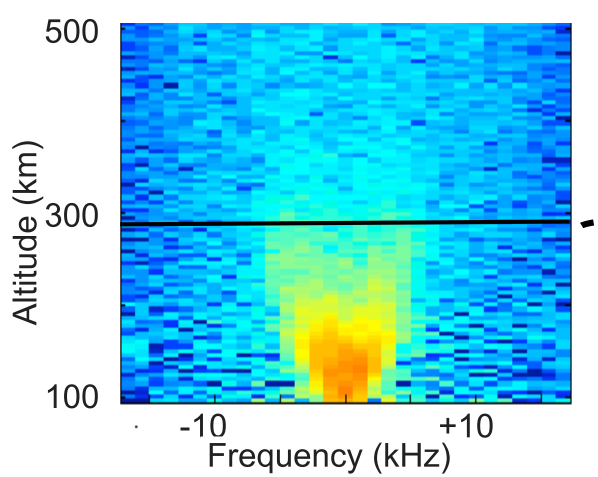
Ion-acoustic

$$\omega_s = C_s k \qquad C_s = \sqrt{k_B(T_e + 3T_i)/m_i}$$

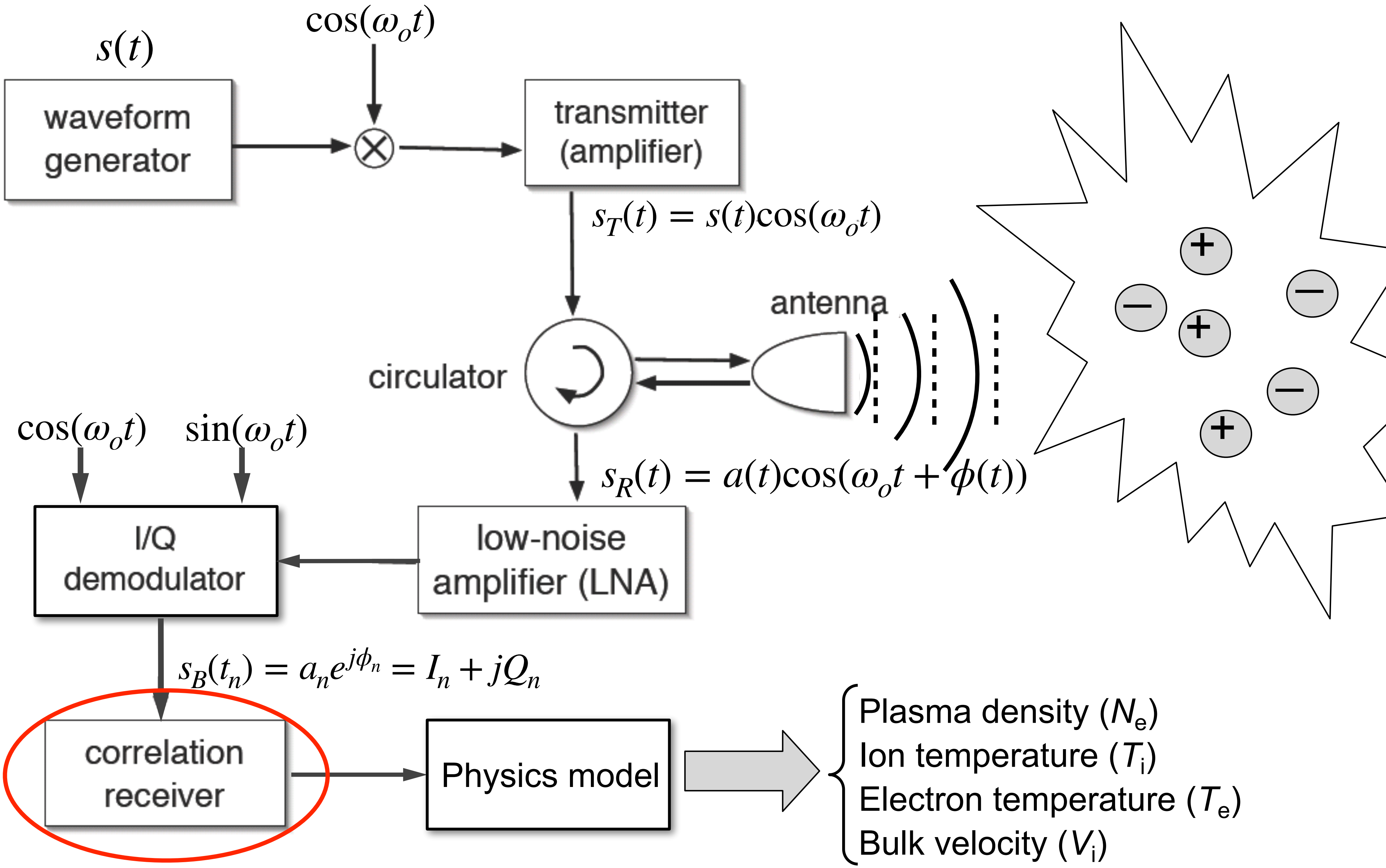
Langmuir

$$\omega_L = \sqrt{\omega_{pe}^2 + 3\,k^2\,v_{the}^2} \approx \omega_{pe} + \frac{3}{2} v_{the} \lambda_{De} k^2$$



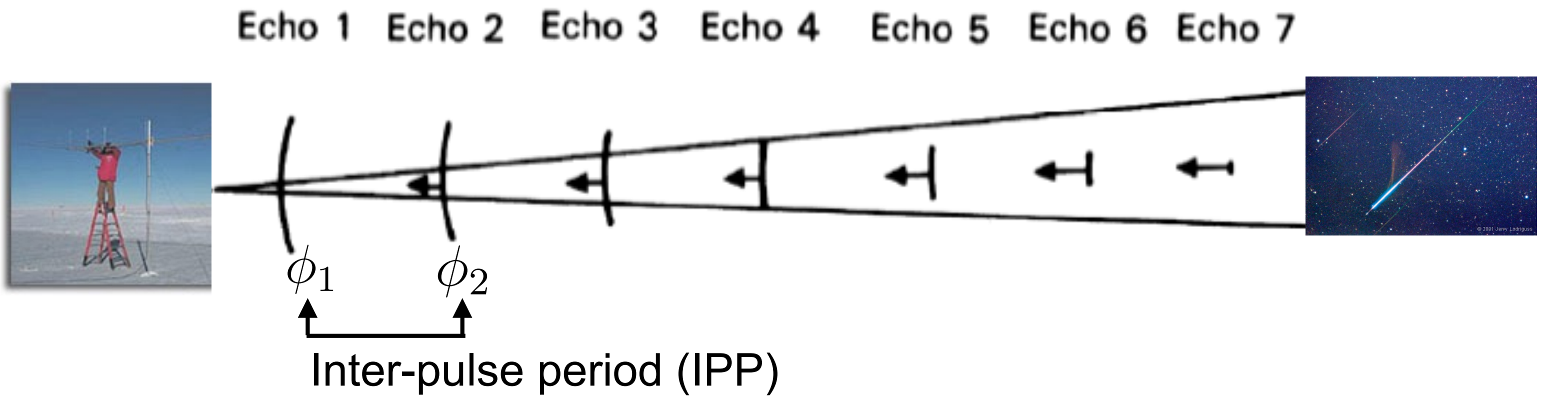


Components of a Pulsed Doppler Radar



- Plasma density (N_e)
- Ion temperature (T_i)
- Electron temperature (T_e)
- Bulk velocity (V_i)

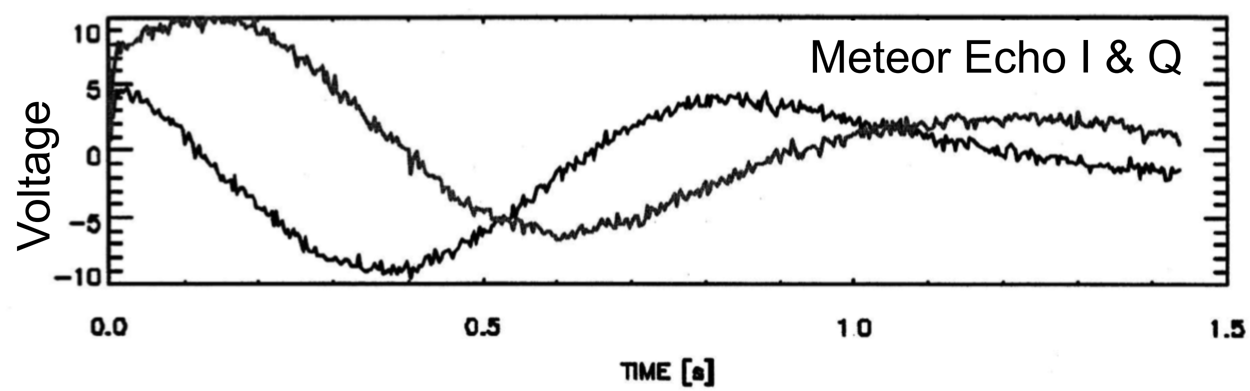
Meteor Radar Example

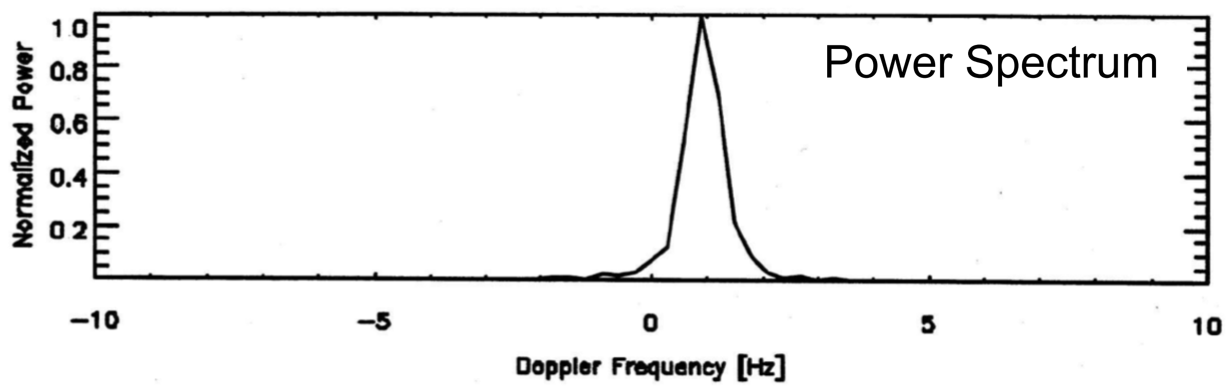


Coherent target (meteor ionization trail), with ~constant velocity.

Find velocity (hence, neutral wind velocity along radar line of sight) by sampling I and Q from many pulses, taking the Fourier Transform (FFT), and forming $|S(f)|^2$

Velocity and reflected power are found from the peak in the power spectrum.





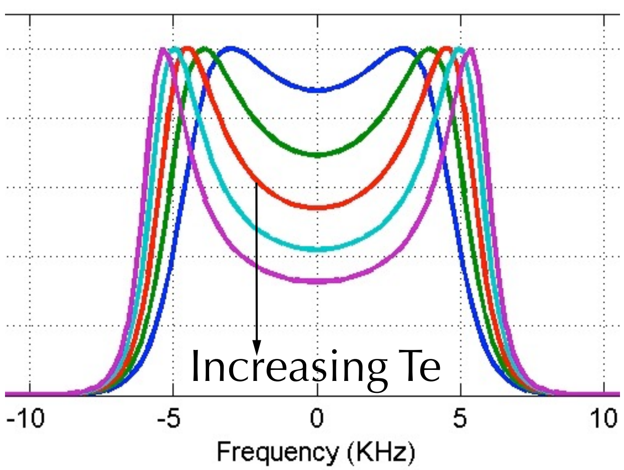
Does this strategy work for ISR?

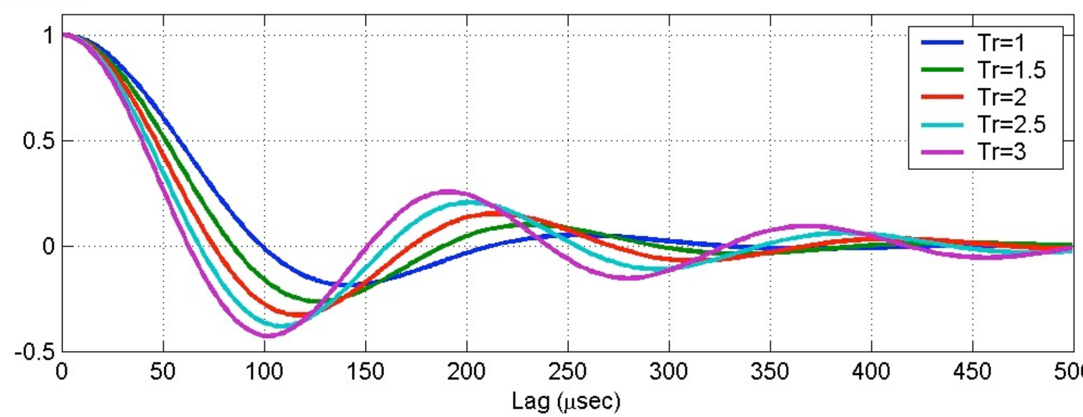
Doppler width at 450 MHz: 10 kHz
de-correlation time (zero crossing): ~1/10kHz = 0.1 ms
Inter-pulse period (IPP) to reach 500 km: $2R/c$ = 3ms

Plasma has de-correlated by the time we send the next pulse.

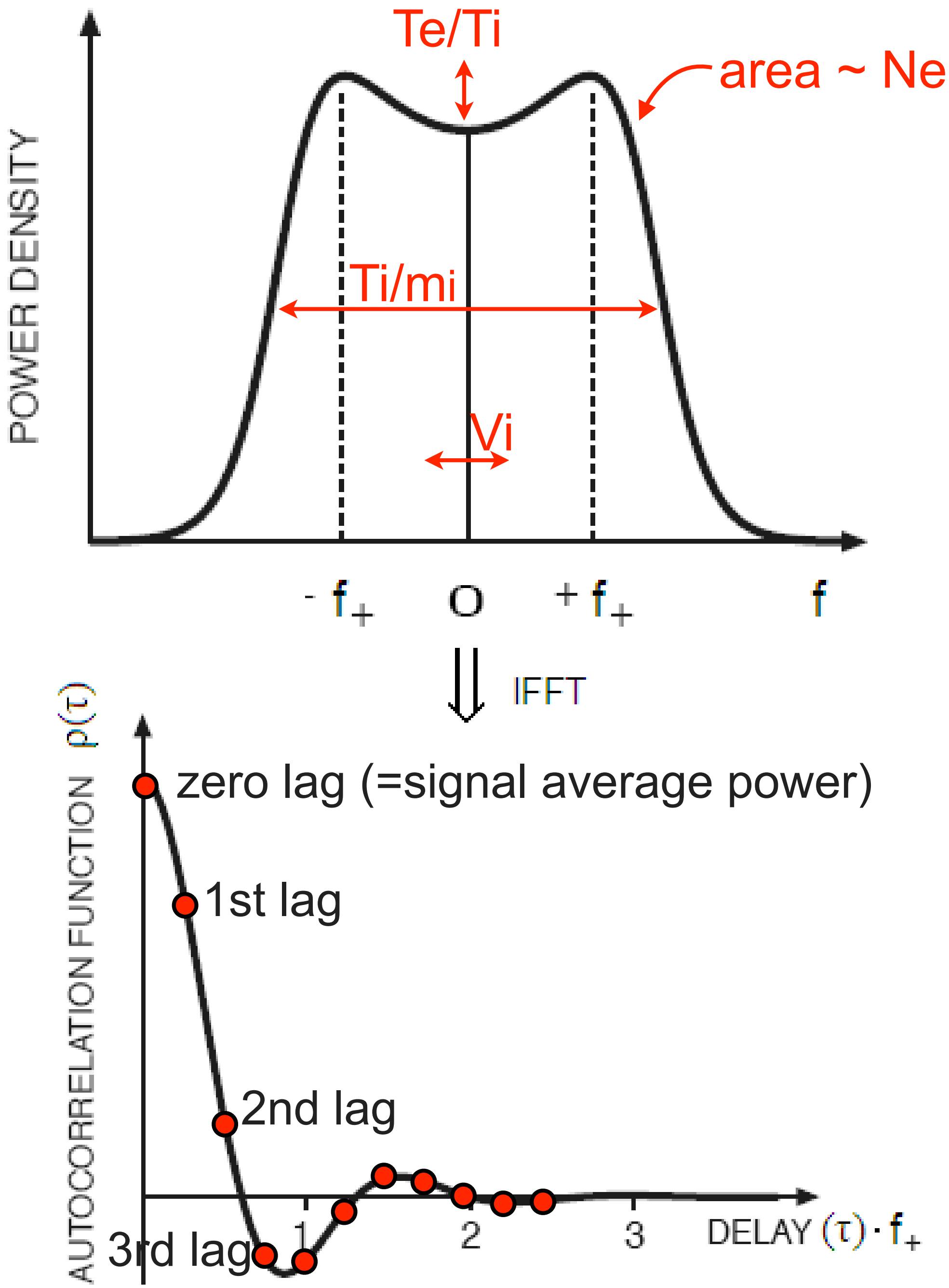
Stated alternately, the Doppler frequency shift of the plasma is much higher than the maximum unambiguous Doppler shift measurable for the pulse-repetition frequency.

ISR spectrum ⟺ Autocorrelation function (ACF)





Autocorrelation function and power spectrum



Ion temperature (Ti) to ion mass (mi) ratio from the width of the spectra

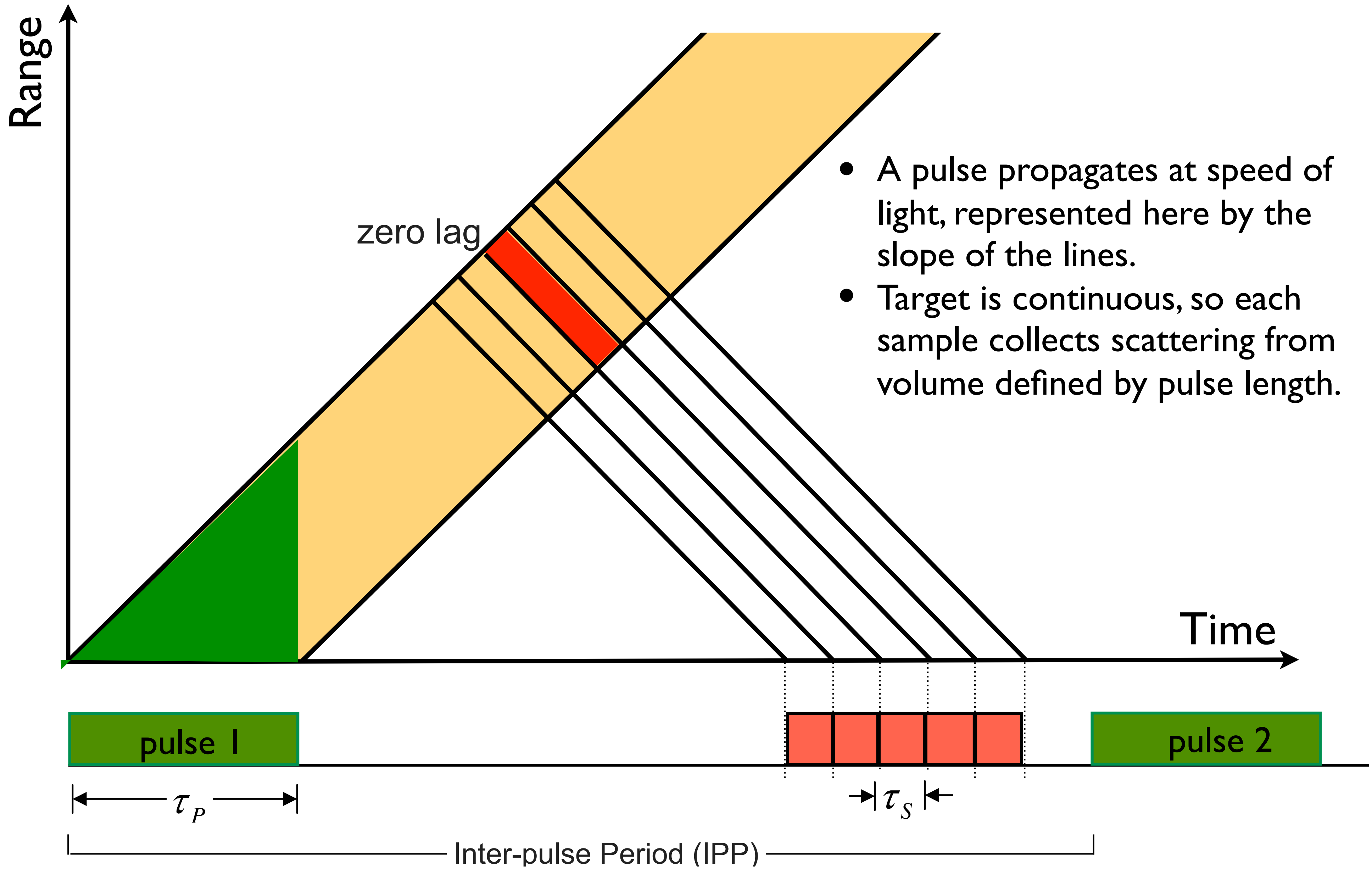
Electron to ion temperature ratio (Te/Ti) from “peak-to-valley” ratio

Electron (= ion) density from total area (corrected for temperatures)

Line-of-sight ion velocity (Vi) from bulk Doppler shift

Our goal is to sample lags with sufficient fidelity to provide meaningful estimates of plasma parameters

Computing the ACF (and, hence, spectrum)



- A pulse propagates at speed of light, represented here by the slope of the lines.
- Target is continuous, so each sample collects scattering from volume defined by pulse length.

τ_P = Length of RF pulse

τ_s = Sample Period (typically ~ 1/10 pulse length)

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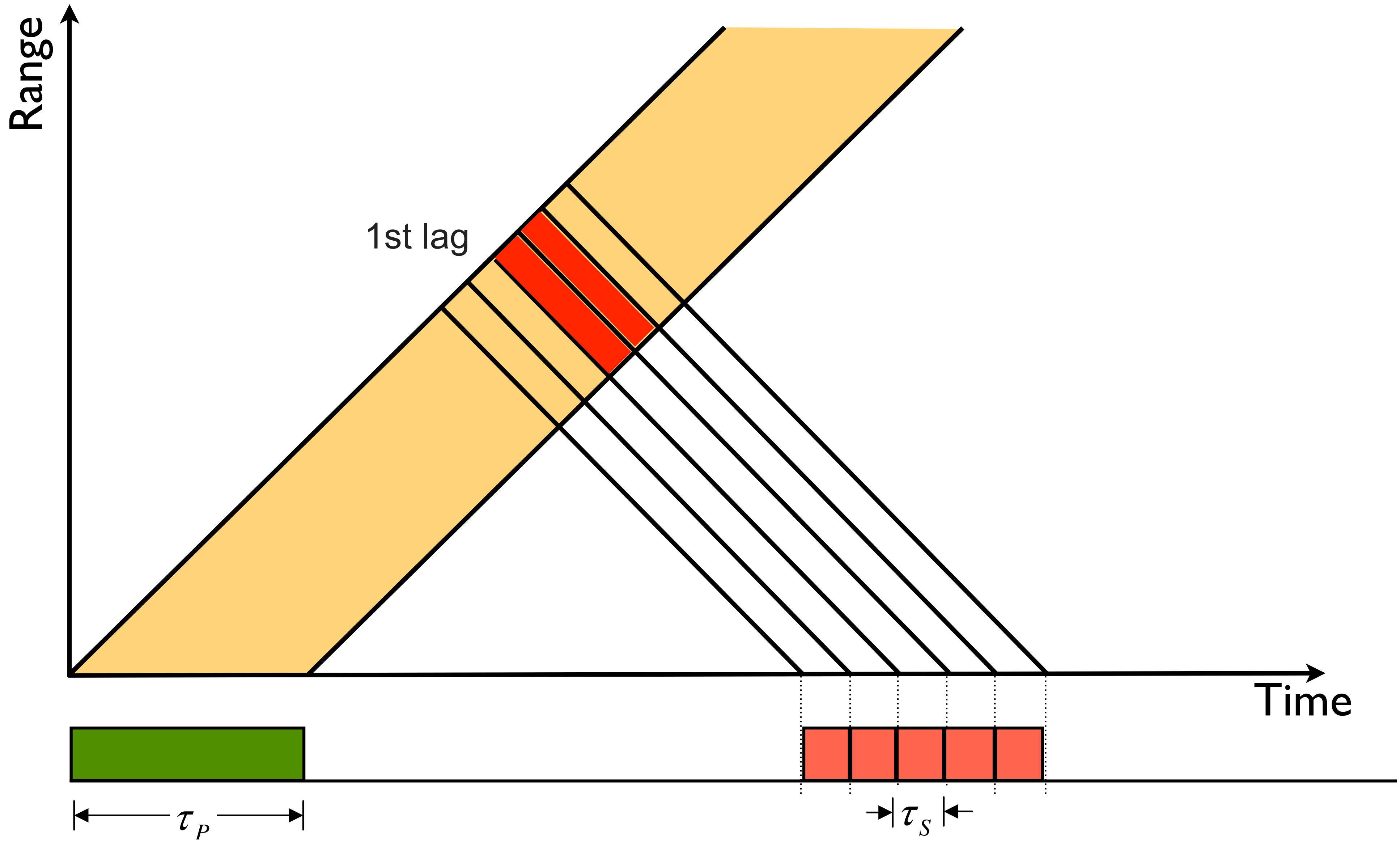

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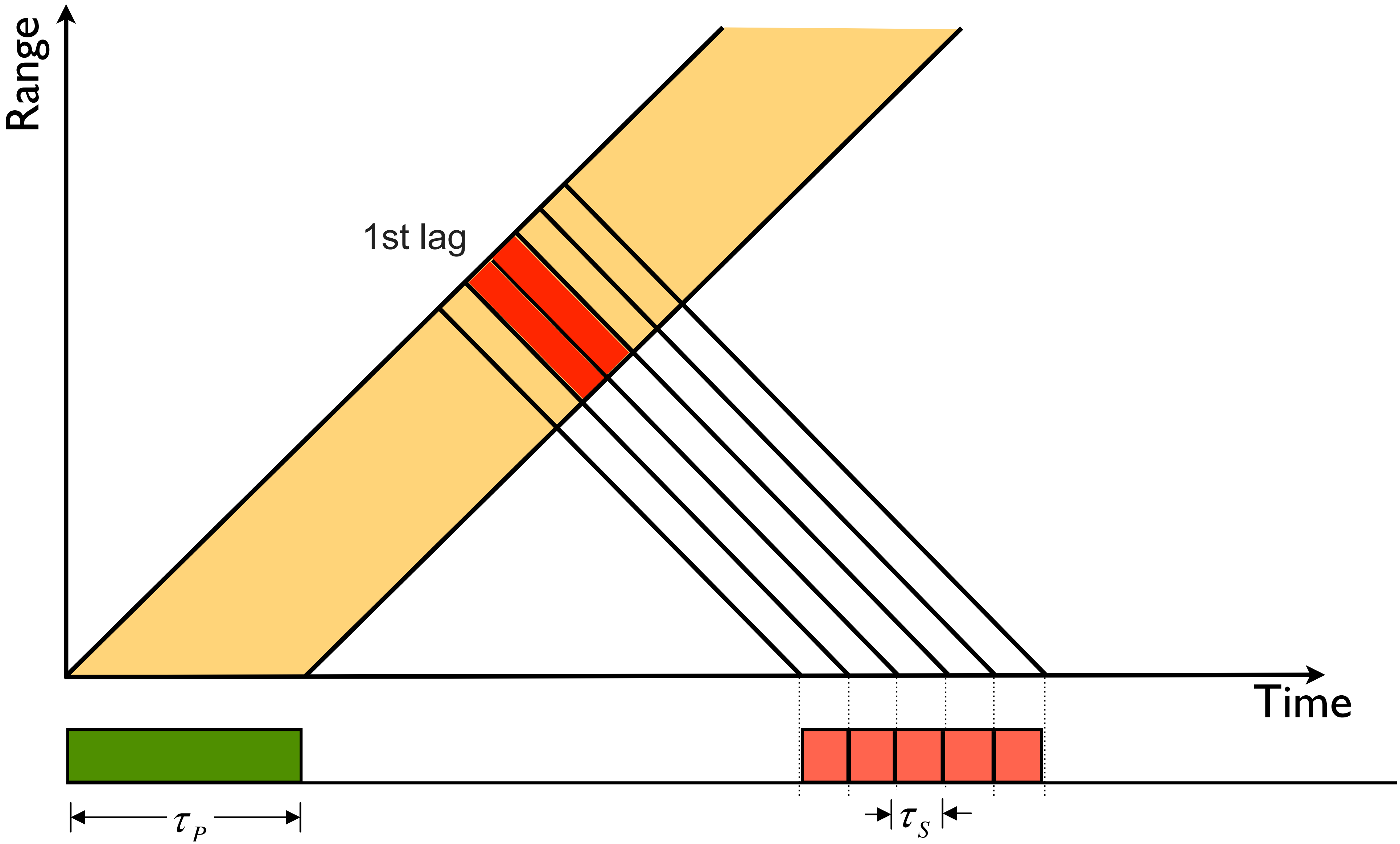

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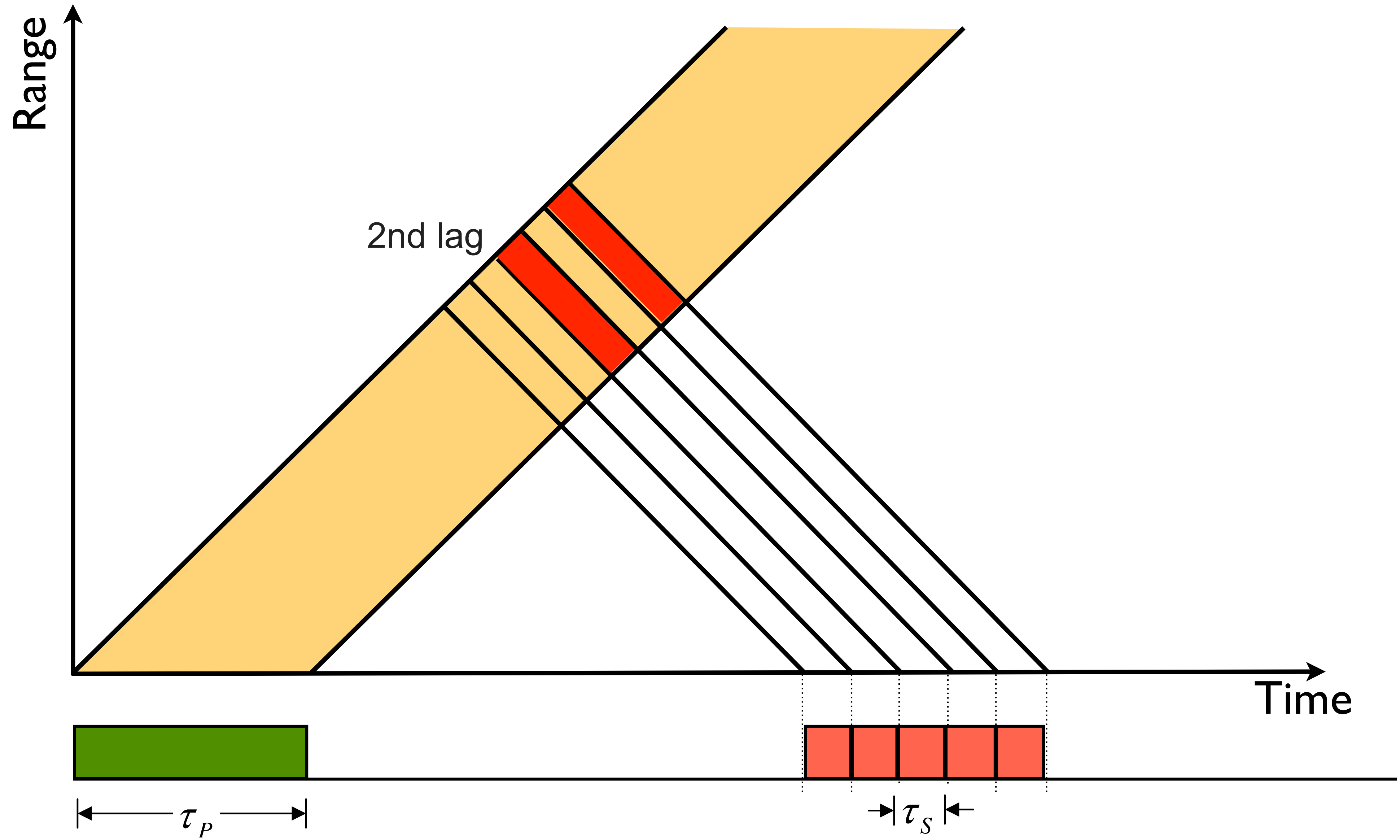

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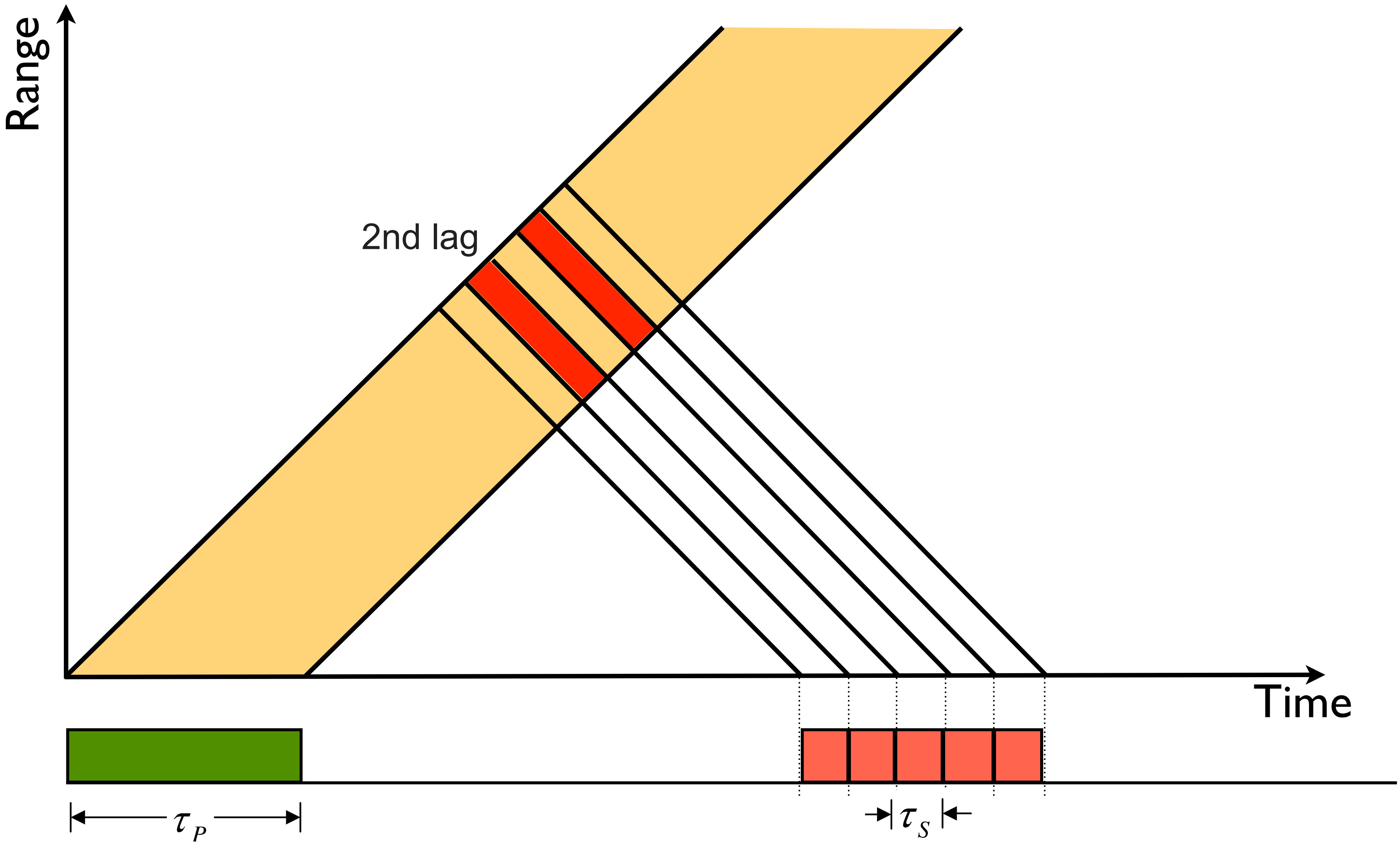

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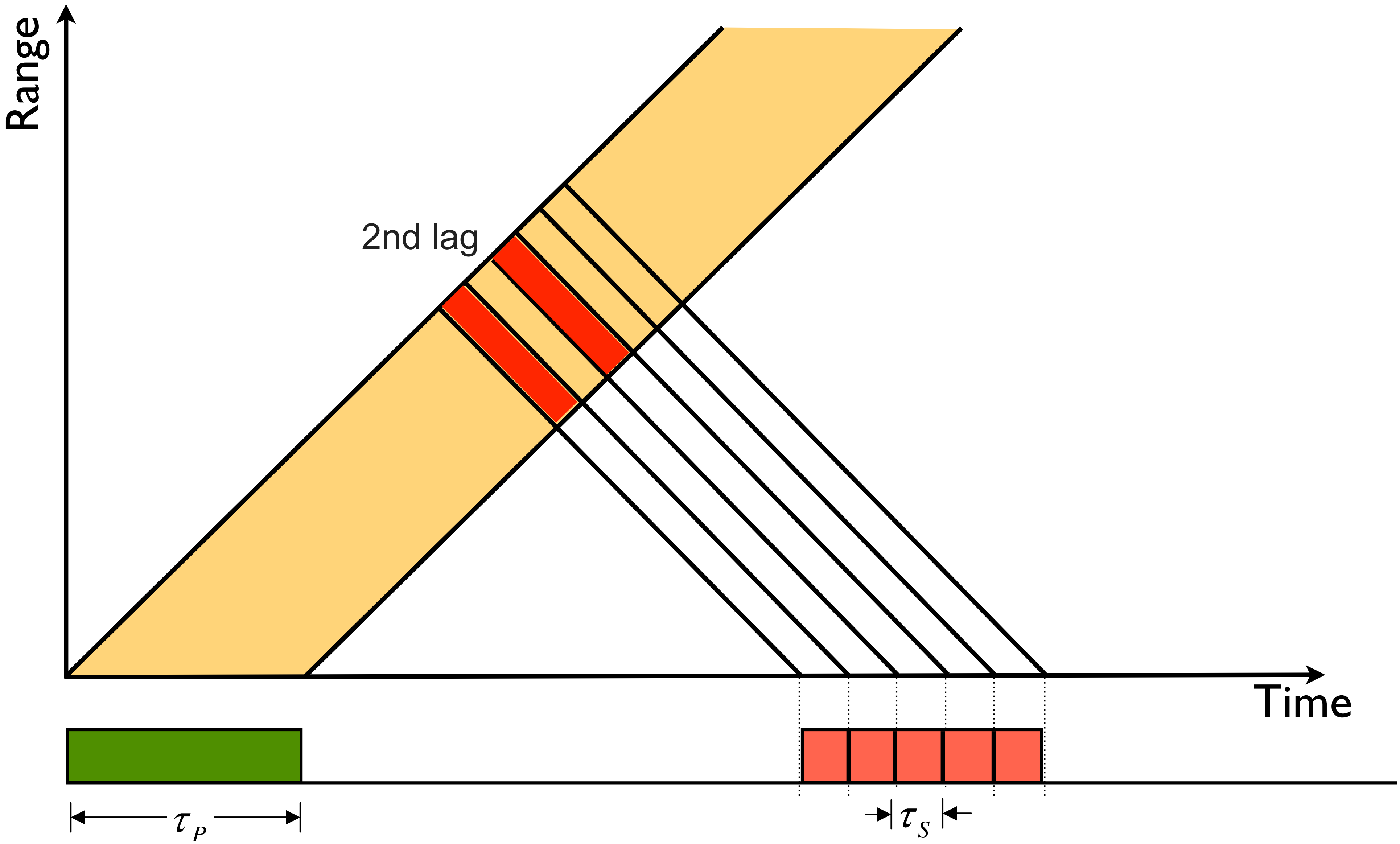

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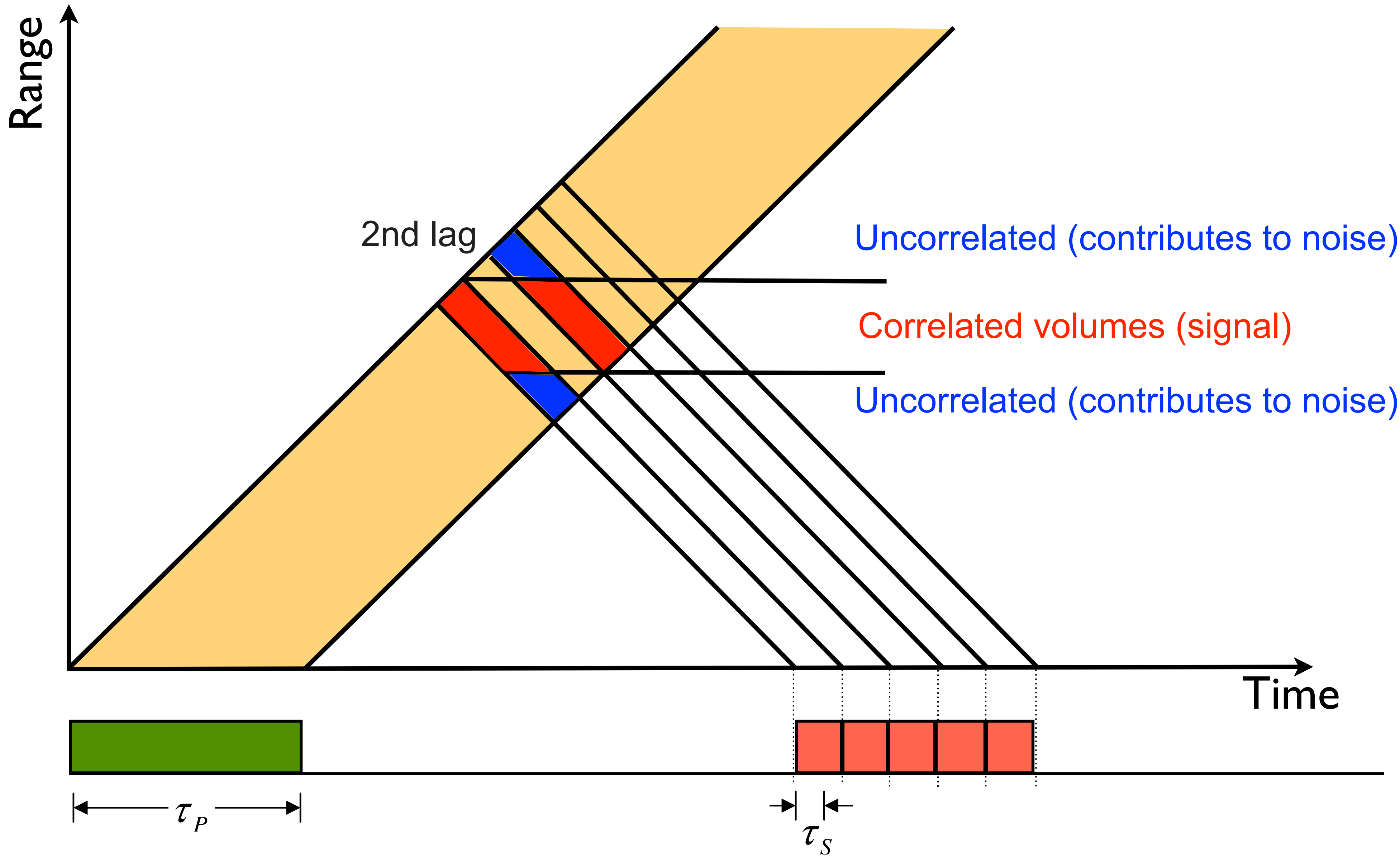

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Lag-product matrix