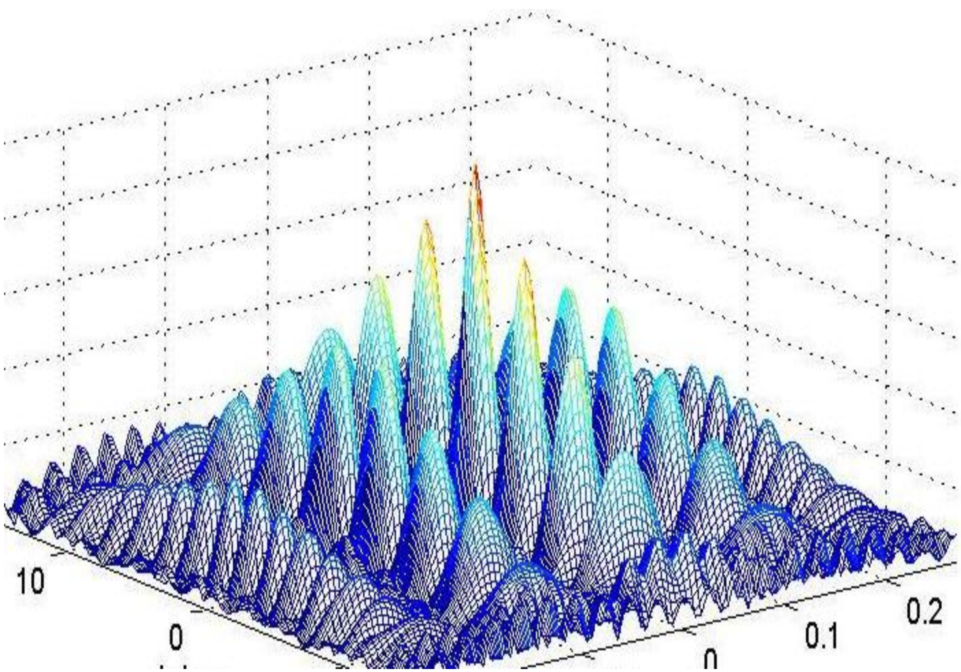
MATLAB EXPO 2019

Waveform Modeling & Option Analysis For Radar Systems Using MATLAB



Nilang Trivedi
Scientist-E,
RCI, DRDO, Hyderabad

Need of Waveform Modeling & Option Analysis

आर सी आई

RADAR SYSTEM DESIGN FLOW

OPERATIONAL SCENARIO & OPERATIONAL REQUIREMENTS

- Maximum Unambiguous Range & Doppler
- Range & Doppler Resolution
- Required Tx Power
- Required Update Rate
- LPI or LPD

Waveform Modeling & Option Analysis

WAVEFORM SELECTION & DESIGN

- ANTENNA-RADOME SUBSYSTEM DESIGN
- RF/MW TRANSCEIVER SUBSYTEM DESIGN
- DSP & POWER SUPPLY SUBSYSTEM DESIGN
- INTEGRATED SYSTEM TEST & EVALUATION

Waveform Modeling & Option Analysis

आर सी आई

Dependency of System Parameter on Waveform Design

System Parameter	Waveform Design
Maximum Unambiguous Range & Doppler Tolerance	Ambiguity Plots & Contours For Specific Type of Waveform
Blind Range	Pulse Width or Period in case of Duty Cycle < 100 %
Range Resolution	Bandwidth , Pulse Width
Doppler Resolution	PRI, Period, Integration Time
Required $P_{average}$ For Max. Range Detection & Measurement Update Time	PRI, Period , Duty Cycle Coherent & Non-coherent Integration Time
ECCM Features	Low Probability of Intercept or Low Probability of Detection

FACTORS AFFECTING CHOICE OF WAVEFORM

The choice of transmitter waveform depends on the following factors:

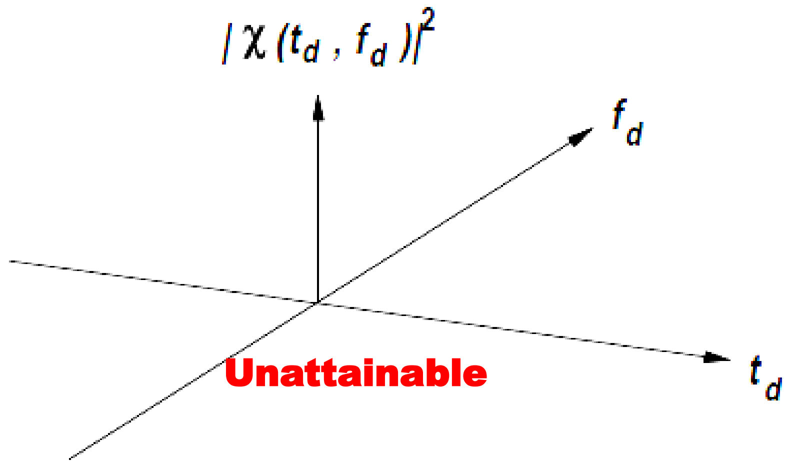
- **Ease of generation of the waveform**
- **Peak power required by the waveform**
- **Extent of compression offered by the waveform and the resultant resolution**
- **Doppler tolerance and Range–Doppler ambiguity relation.**
- **The extent to which the waveform can be detected, intercepted, jammed.**

The waveforms considered for analysis:

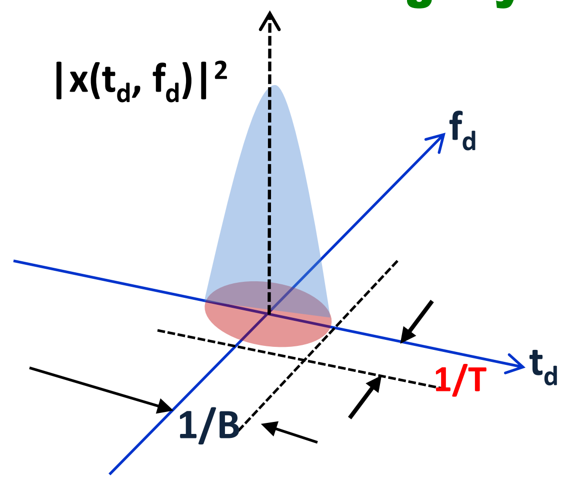
- **Pulsed RF**
- **Linear Frequency Modulated Waveform.**
- **Pseudo Randomly Bi-phase Modulated Continuous Waveform.**

Importance of Ambiguity Plots & Contours For Waveform selection

Ideal Ambiguity Diagram



An Approximation to Ideal Ambiguity Diagram



T=Signal Duration

B=Signal Bandwidth

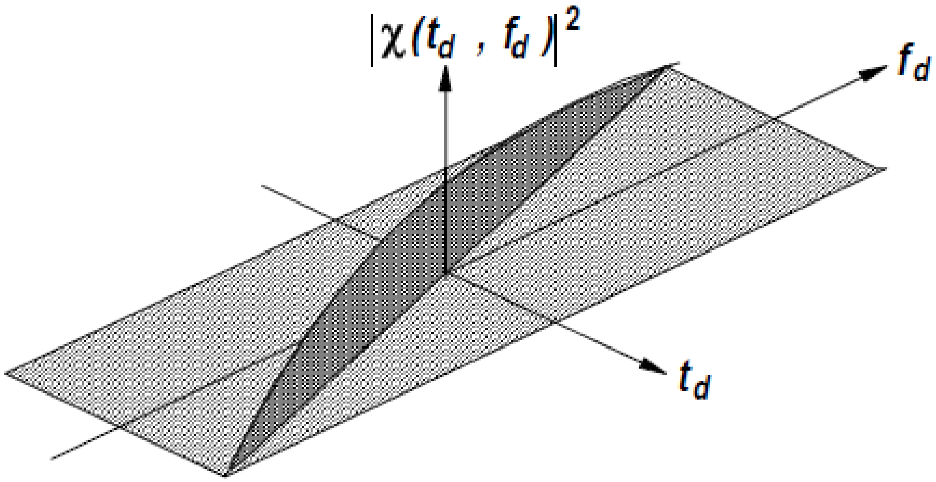
E=Energy of signal

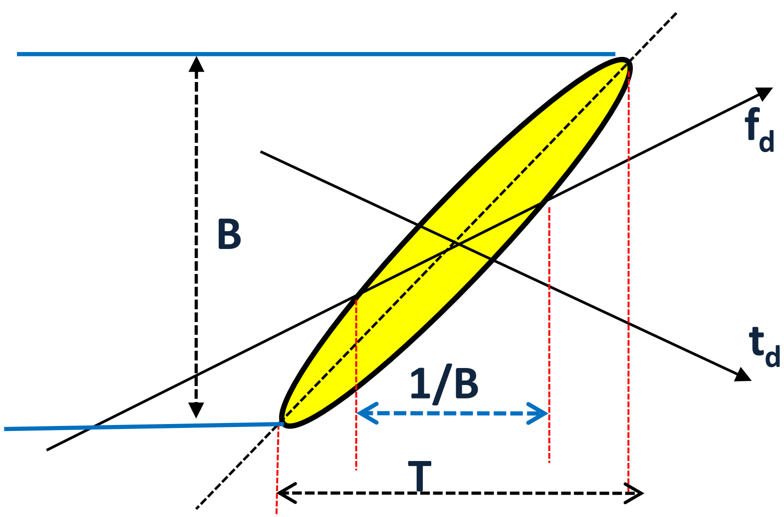
Properties :

- Max. value of $|x(t_d, f_d)| = |x(0,0)|^2 = 2E^2$
- $|x(-t_d, -f_d)|^2 = |x(t_d, f_d)|^2$
- Along td Axis $|x(t_d, f_d)|^2$ is a autocorrelation function of $u(t)$
- Along fd Axis $|x(t_d, f_d)|^2$ is a Spectrum of $u(t)$
- Total volume the ambiguity plot is constant : $v = 2E^2$

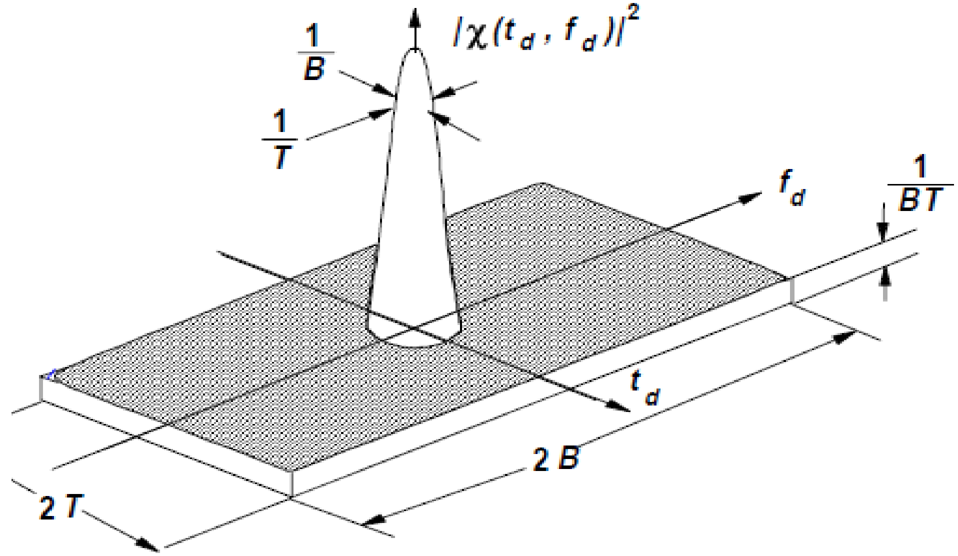
Ambiguity Plots & Contours For LFM & PN Coded Waveform

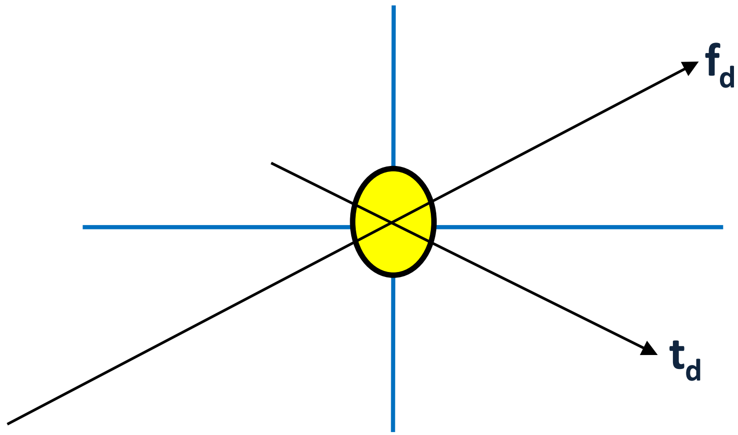
Knife Edge Ambiguity function





Thumb Tack Ambiguity function

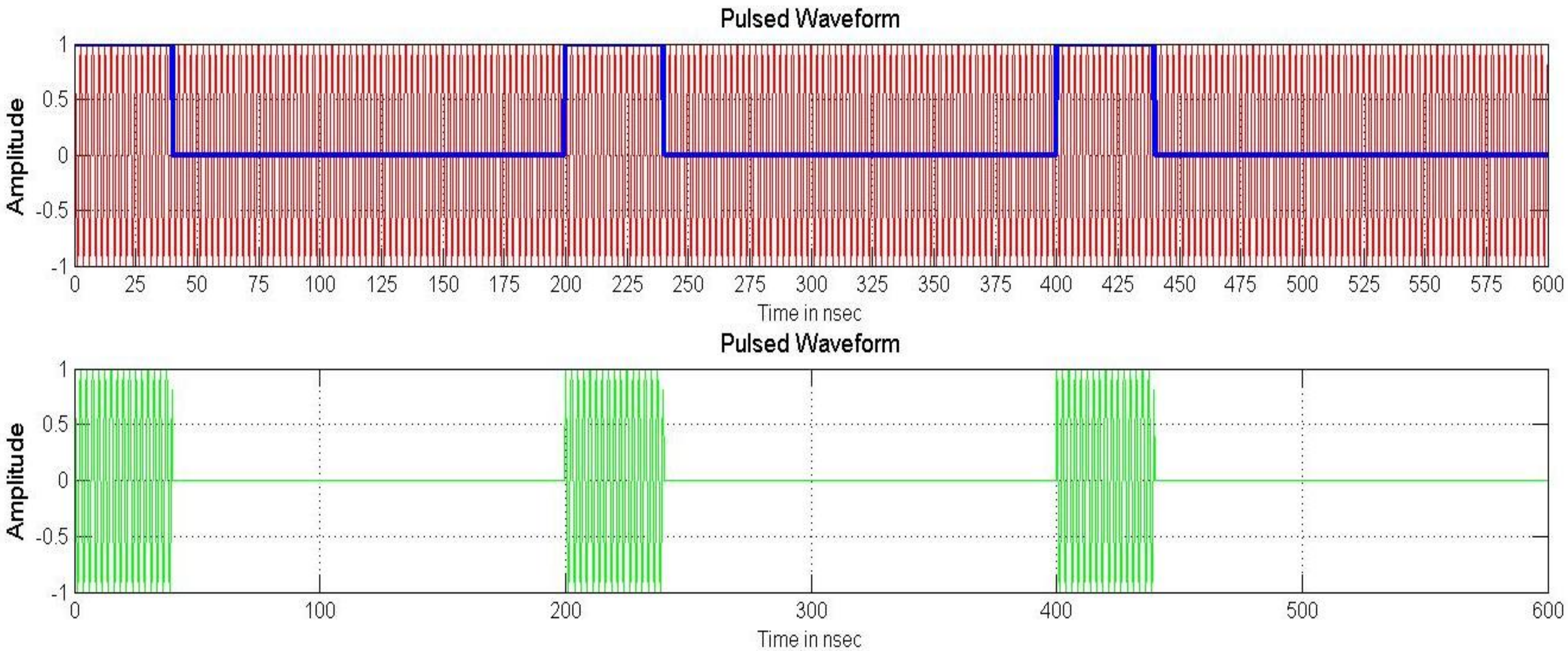




MATLAB Simulation Results For Pulsed RF Signal

Time Domain Plot: Coherent Pulse Train

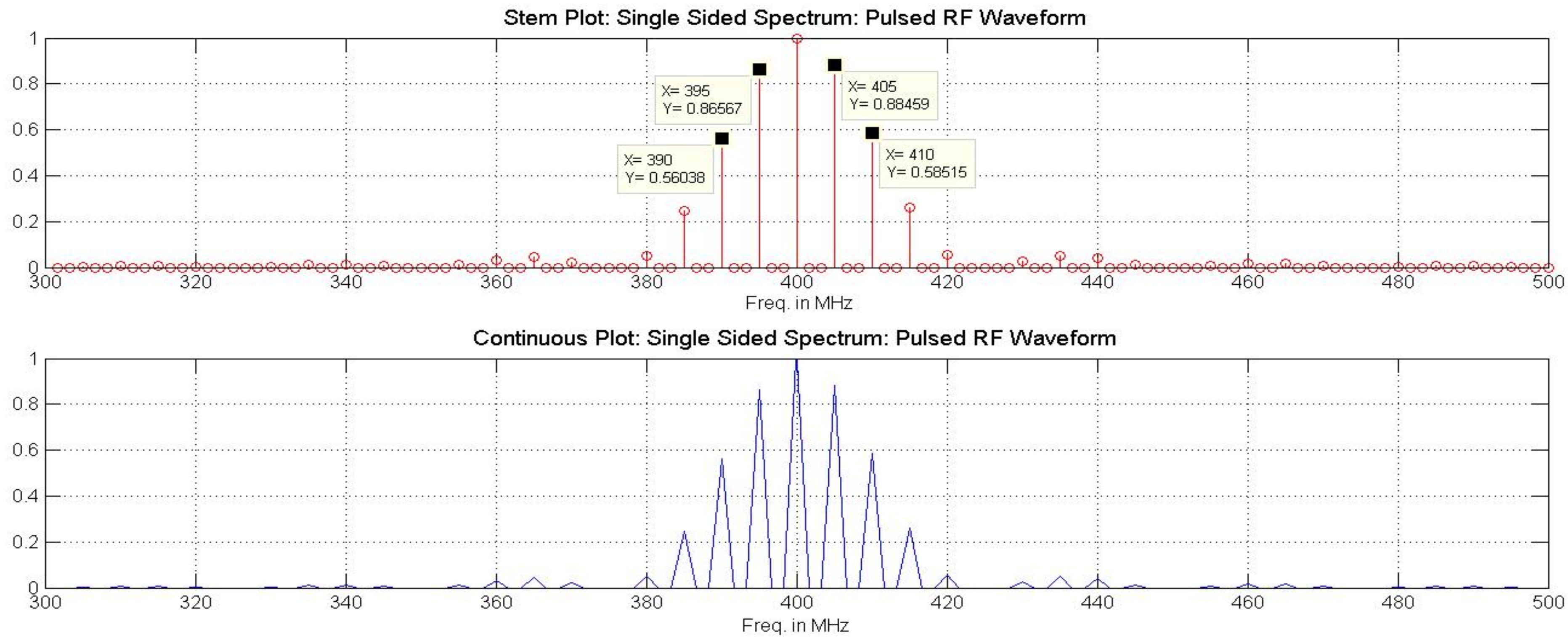
Ton= 40 nsec, PRI= 200nsec, DC=20 %



Signal Spectrum : Coherent Pulse Train

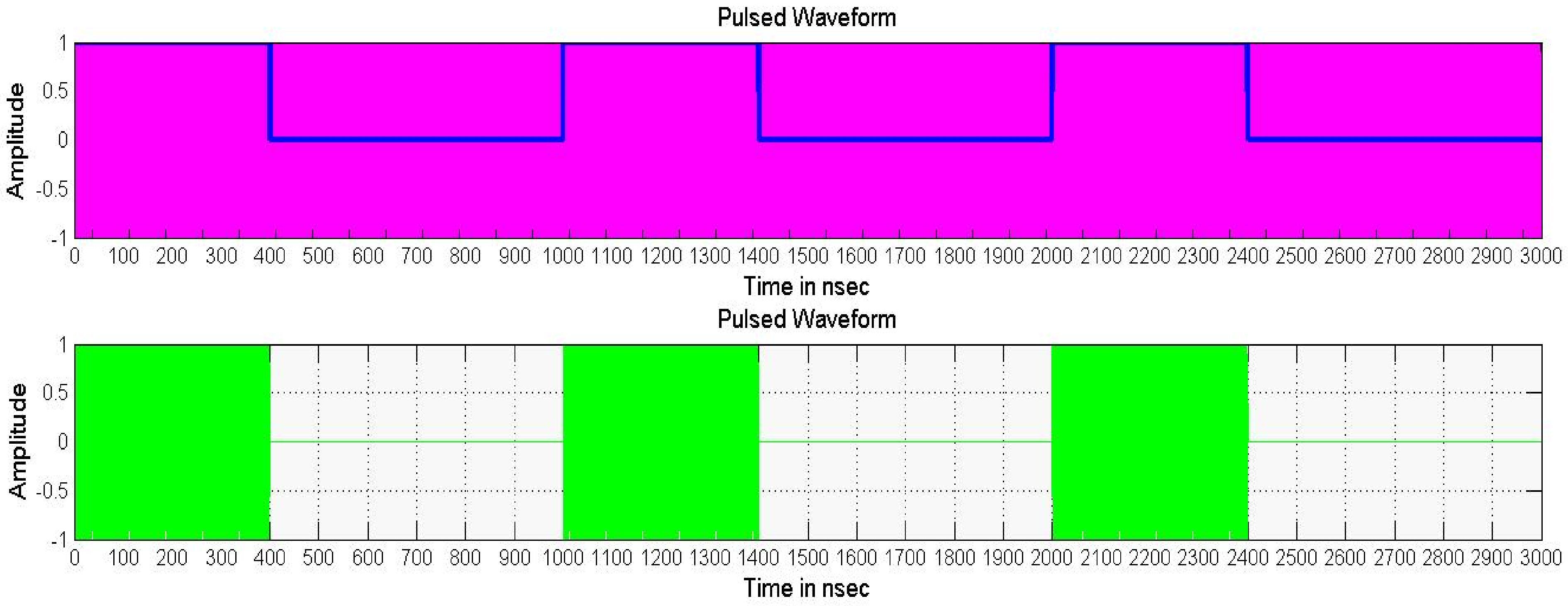
Ton= 40 nsec, PRI= 200nsec, DC=20 %

Spacing between Spectral Lines= PRF = 5 MHz



Time Domain Plot: Coherent Pulse Train

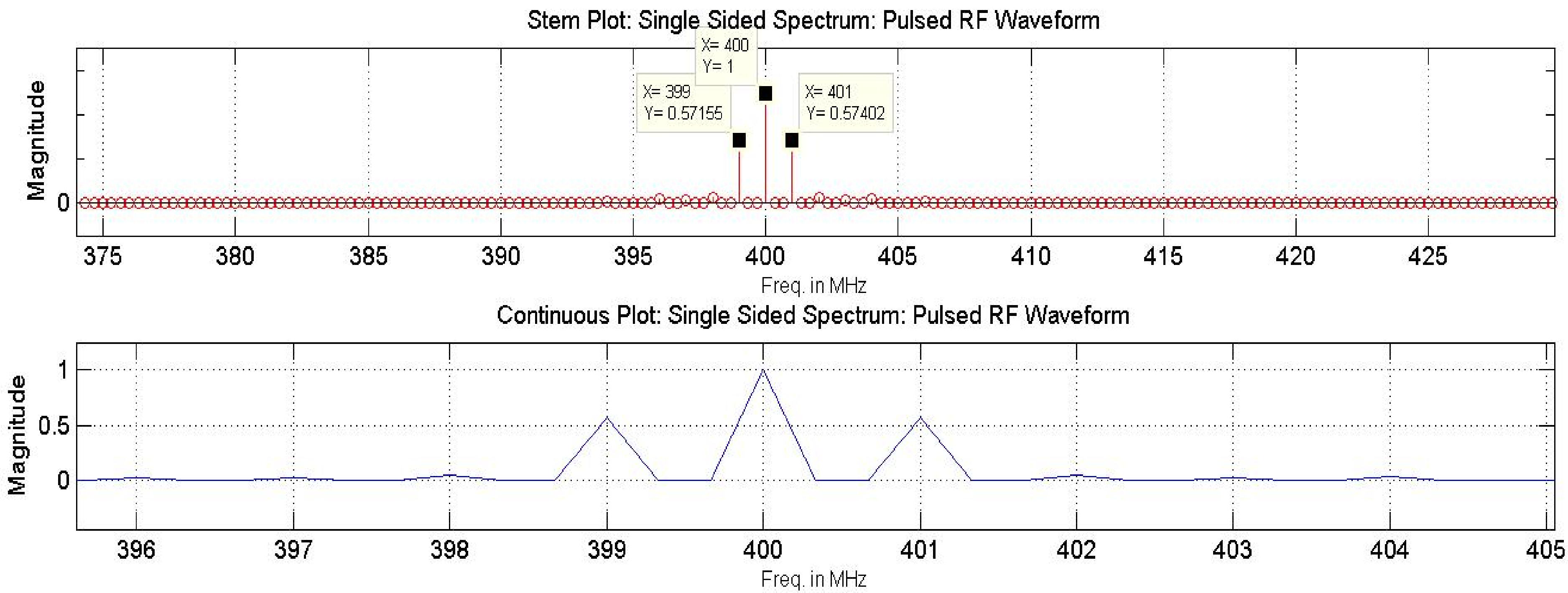
Ton= 400 nsec, PRI=1000 nsec, DC=40 %



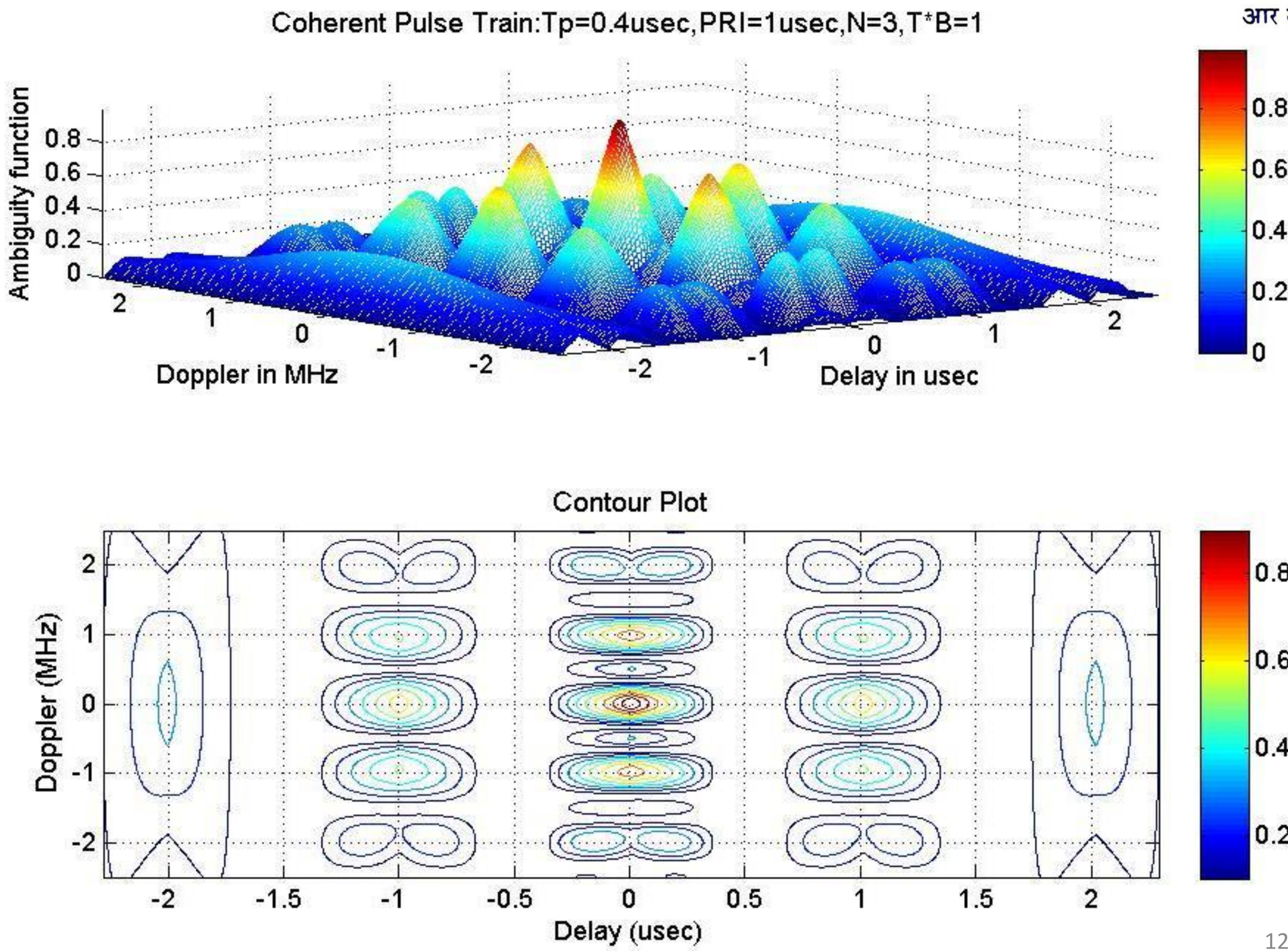
Signal Spectrum : Coherent Pulse Train

Ton= 400 nsec, PRI=1000 nsec, DC=40 %

Spacing between Spectral Lines= PRF =1 MHz

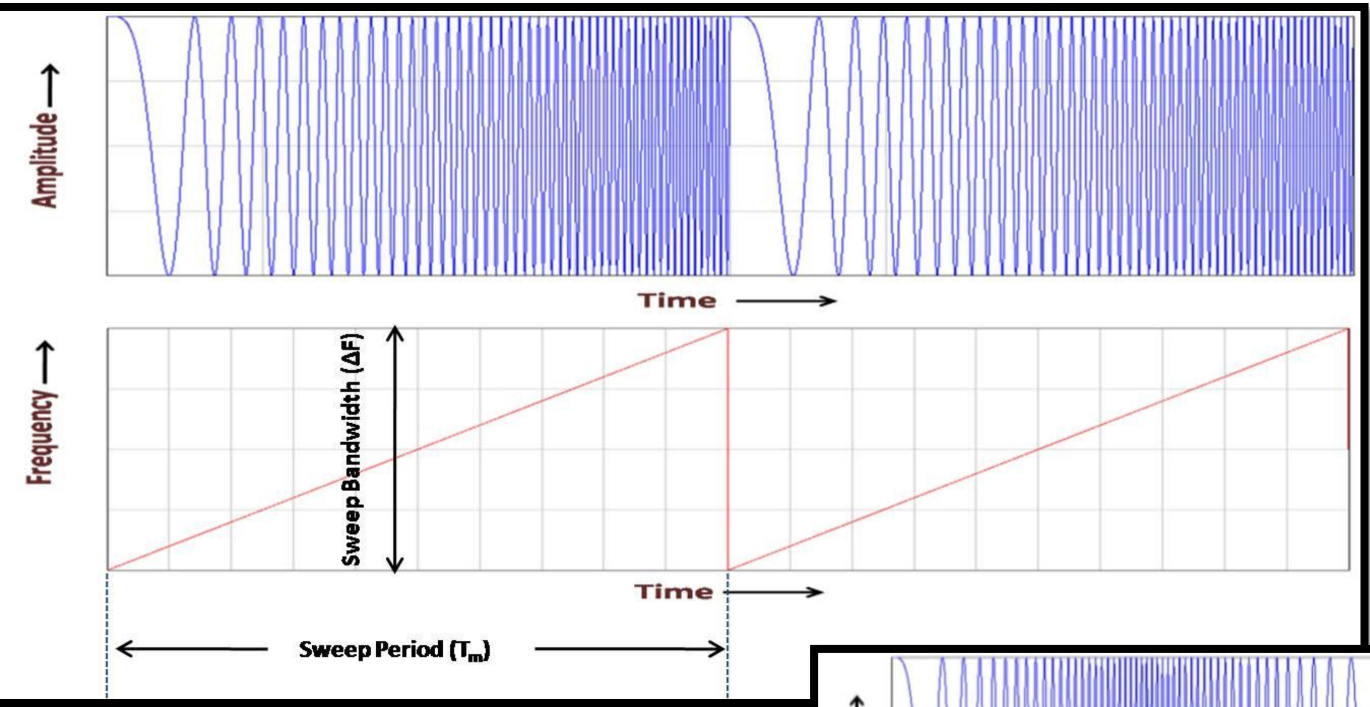


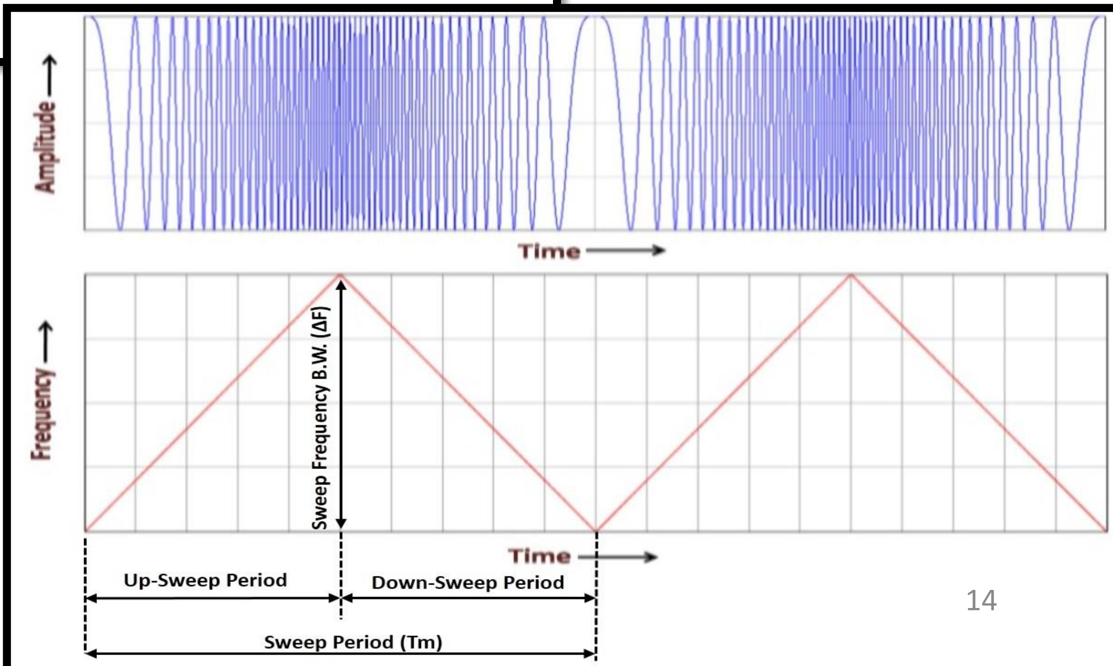
Ambiguity Plot: Coherent Pulse Train



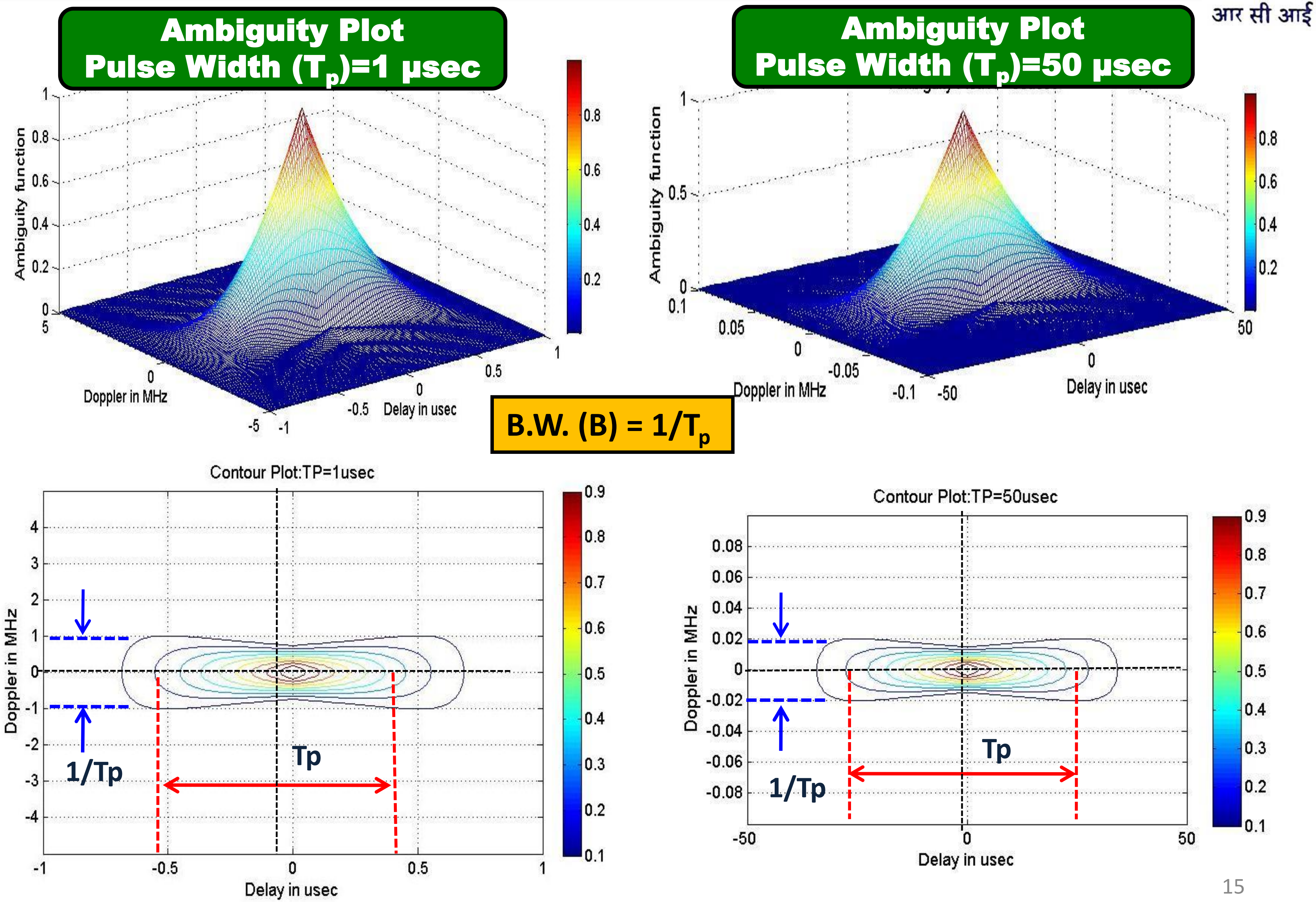
MATLAB Simulation Results
For
Linear Frequency Modulated Signal

LFM Continuous Waveform
Saw-tooth & Triangular Sweeps

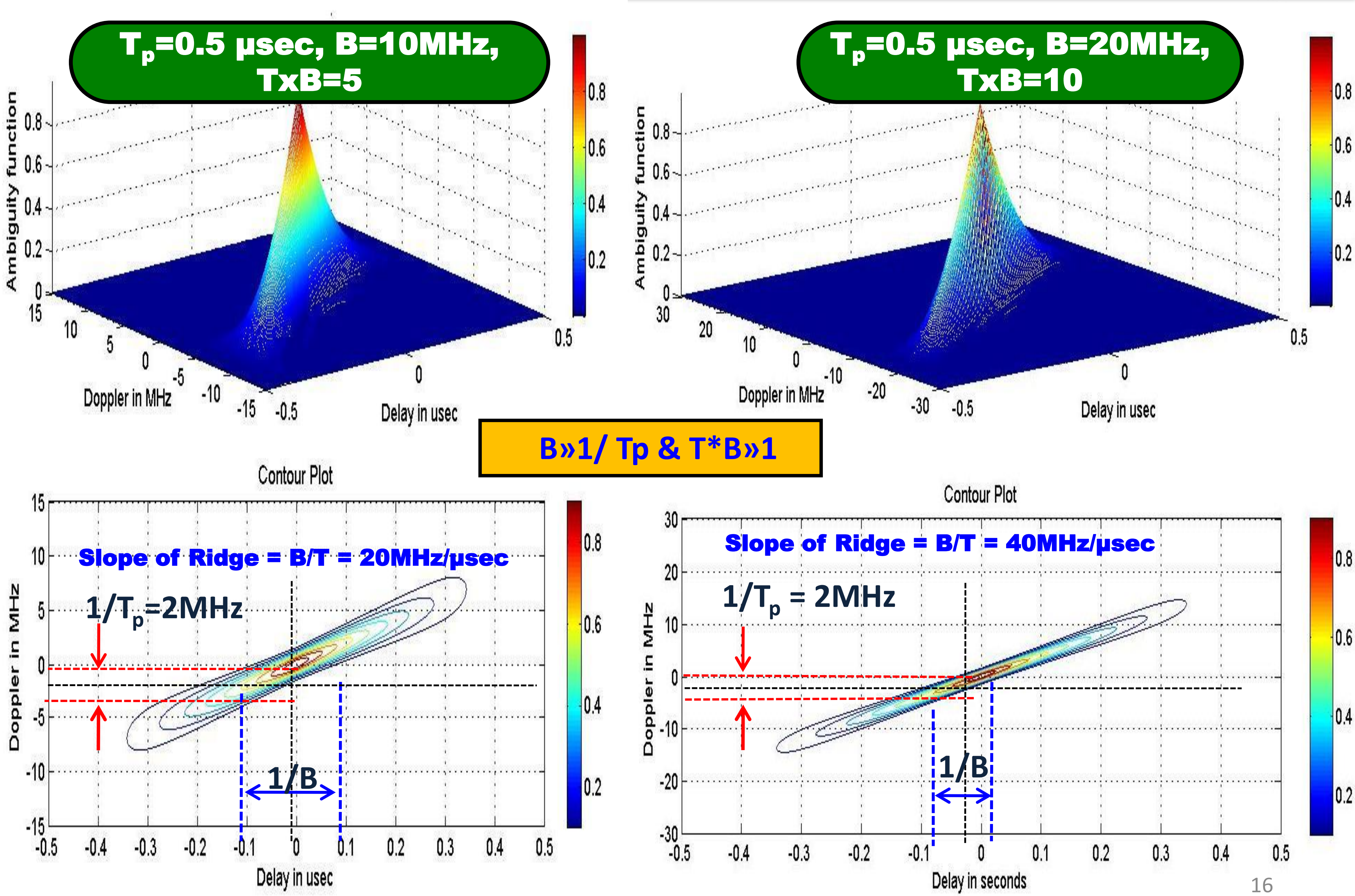




Ambiguity Plots of Single Pulse with Different Pulse Widths



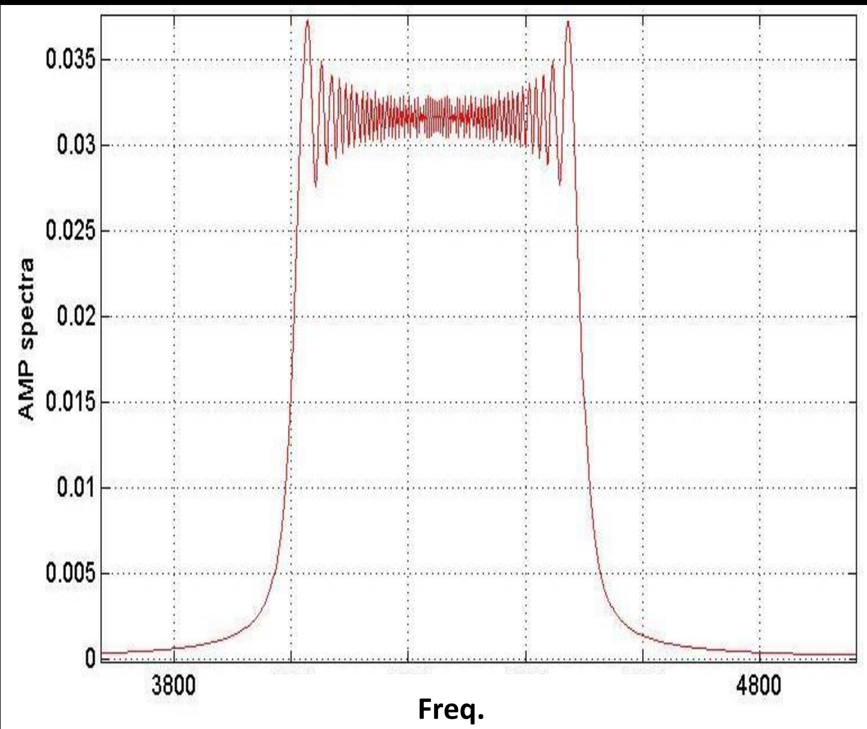
Ambiguity Plots of LFM Pulse with Different TxB Products



Amplitude Spectra: LFM Chirp
Effect of Sweep Frequency Bandwidth(B)

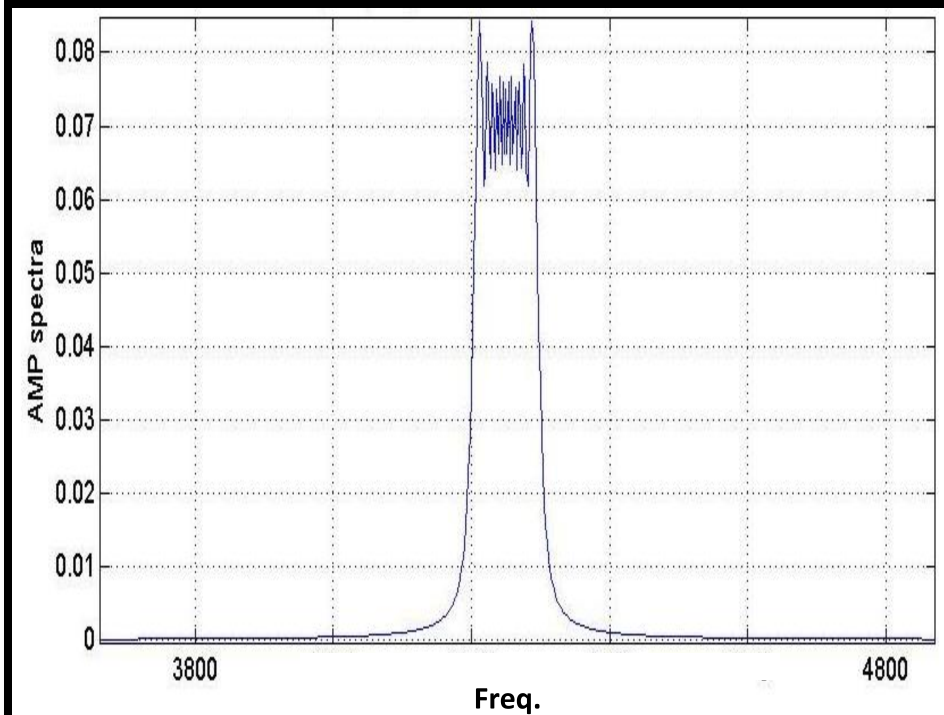
आर सी आई

LFM Up Chirp: Amplitude Spectra: Bandwidth = 500 MHz

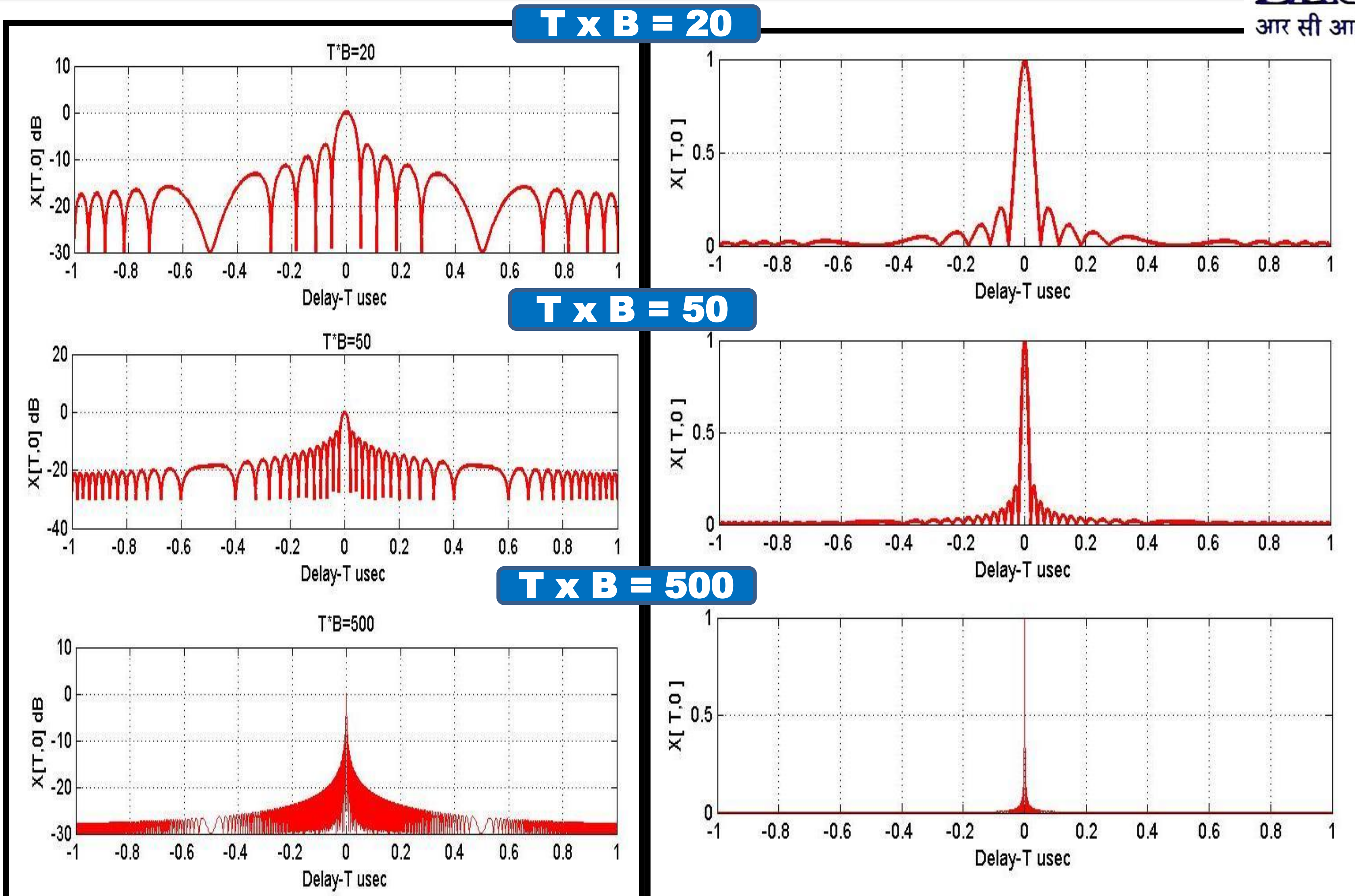


Y-Axis is in normalized scale

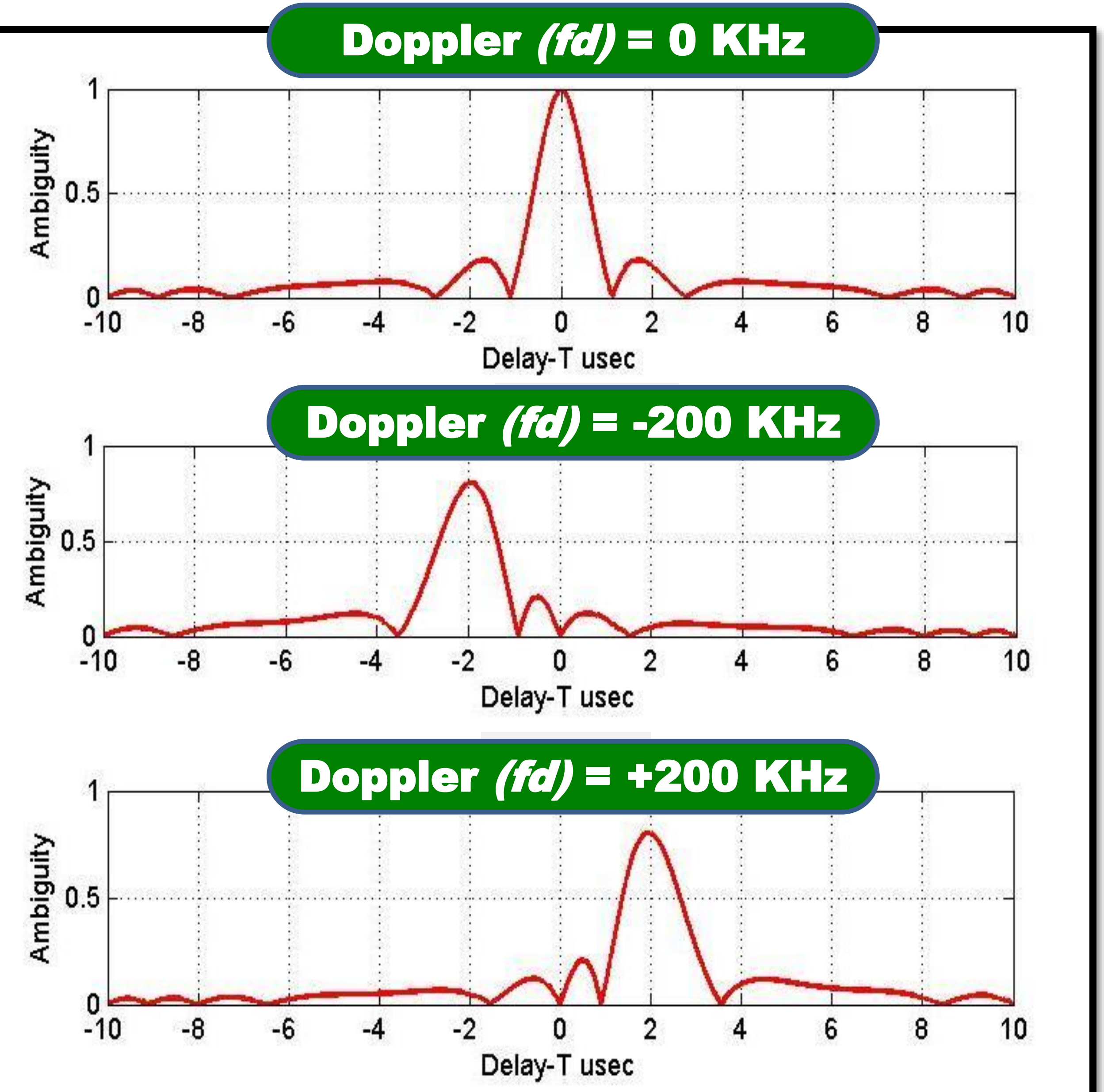
LFM Up Chirp: Amplitude Spectra: Bandwidth = 100 MHz



Effect of (Time x Bandwidth) Product on LFM Autocorrelation



Range–Doppler Coupling Effect in LFM Waveform



α = Freq. Sweep Rate

- Up Chirp: $\alpha = +B / T$

  Down Chirp: $\alpha = -B / T$

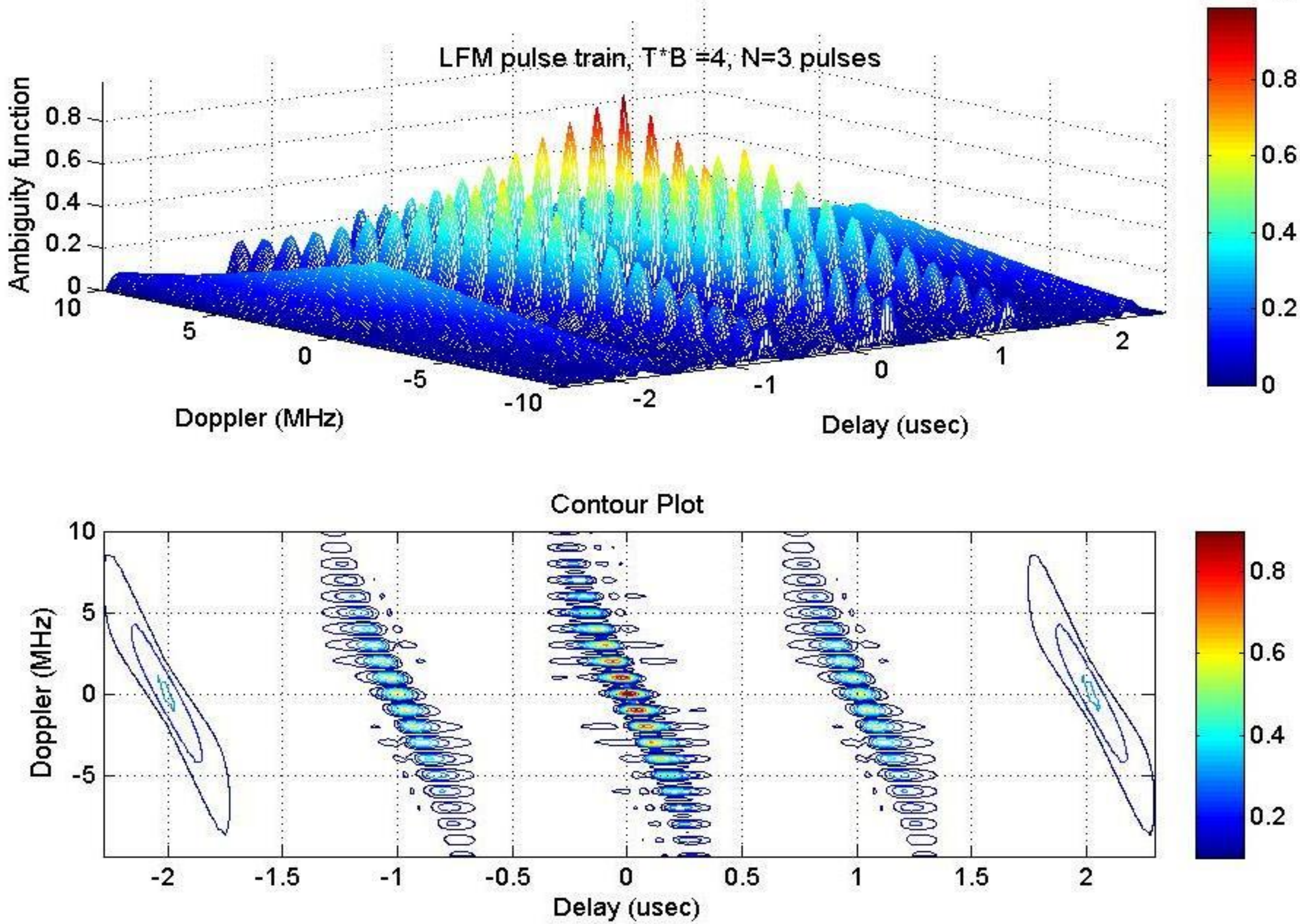
- Shift in peak of Matched Filter Output

  T = fd x T/B

  Here, α= 1 MHz/1 usec

- Compressed Pulse shape & SNR are Doppler Tolerant

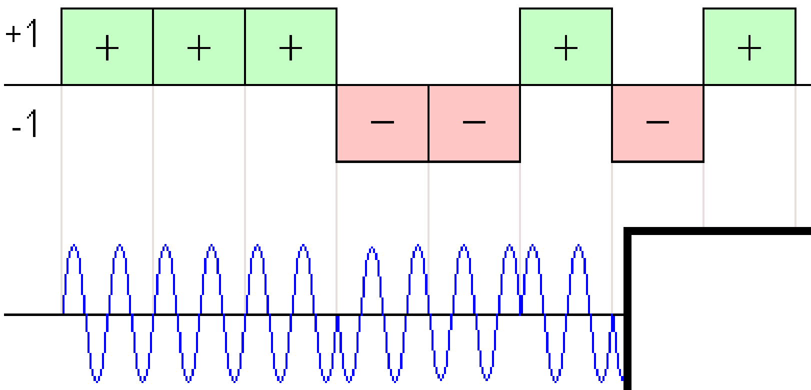
Ambiguity Plot: LFM Pulse Train

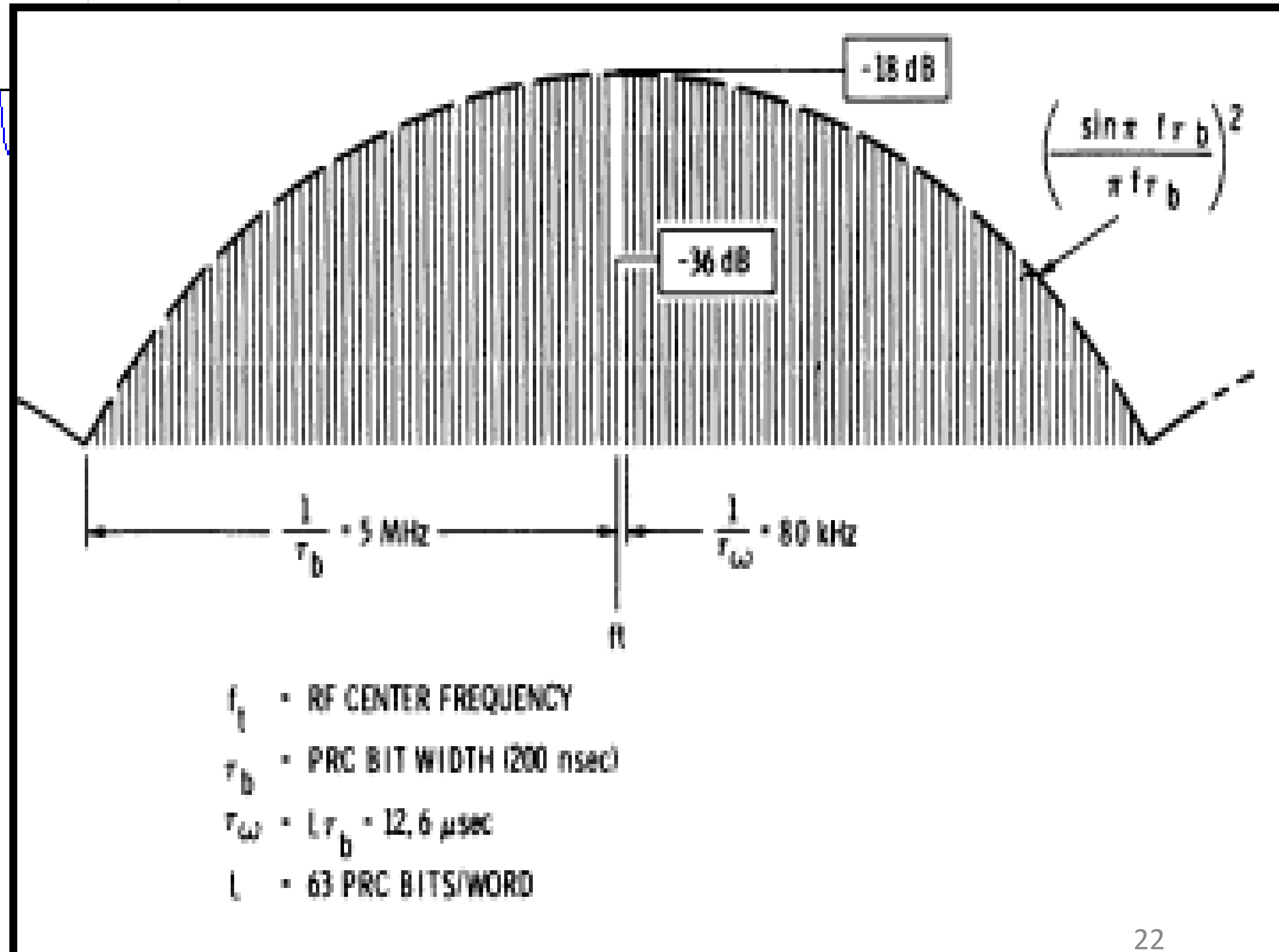


आर सी आई

MATLAB Simulation Results
For
Pseudo-Randomly Bi-phase Coded Waveform

Pseudo-Randomly Bi-phase Coded Waveform

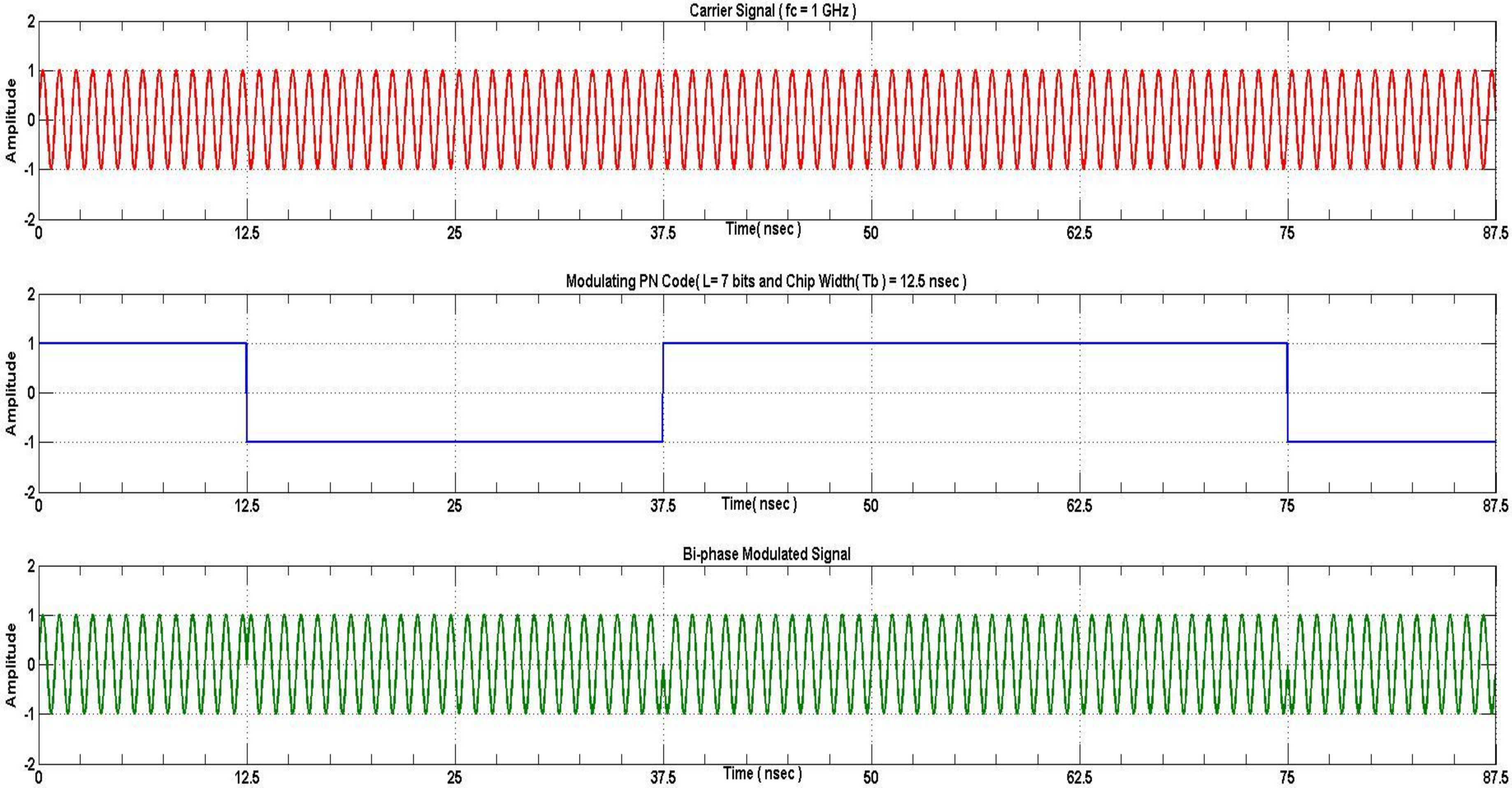




Pseudo-Randomly Bi-phase Coded Waveform

आर सी आई

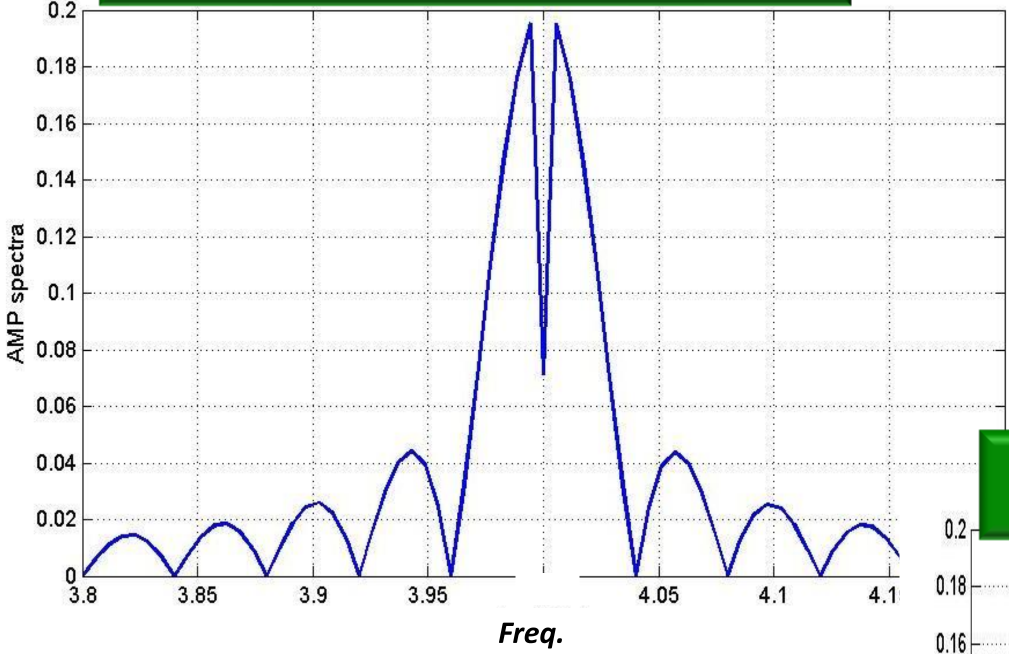
Time Domain Plot



Amplitude Spectra

Pseudo-randomly Bi-phase Coded Waveform

Single Sided Amplitude Spectra:
Chip Width = 25 nsec

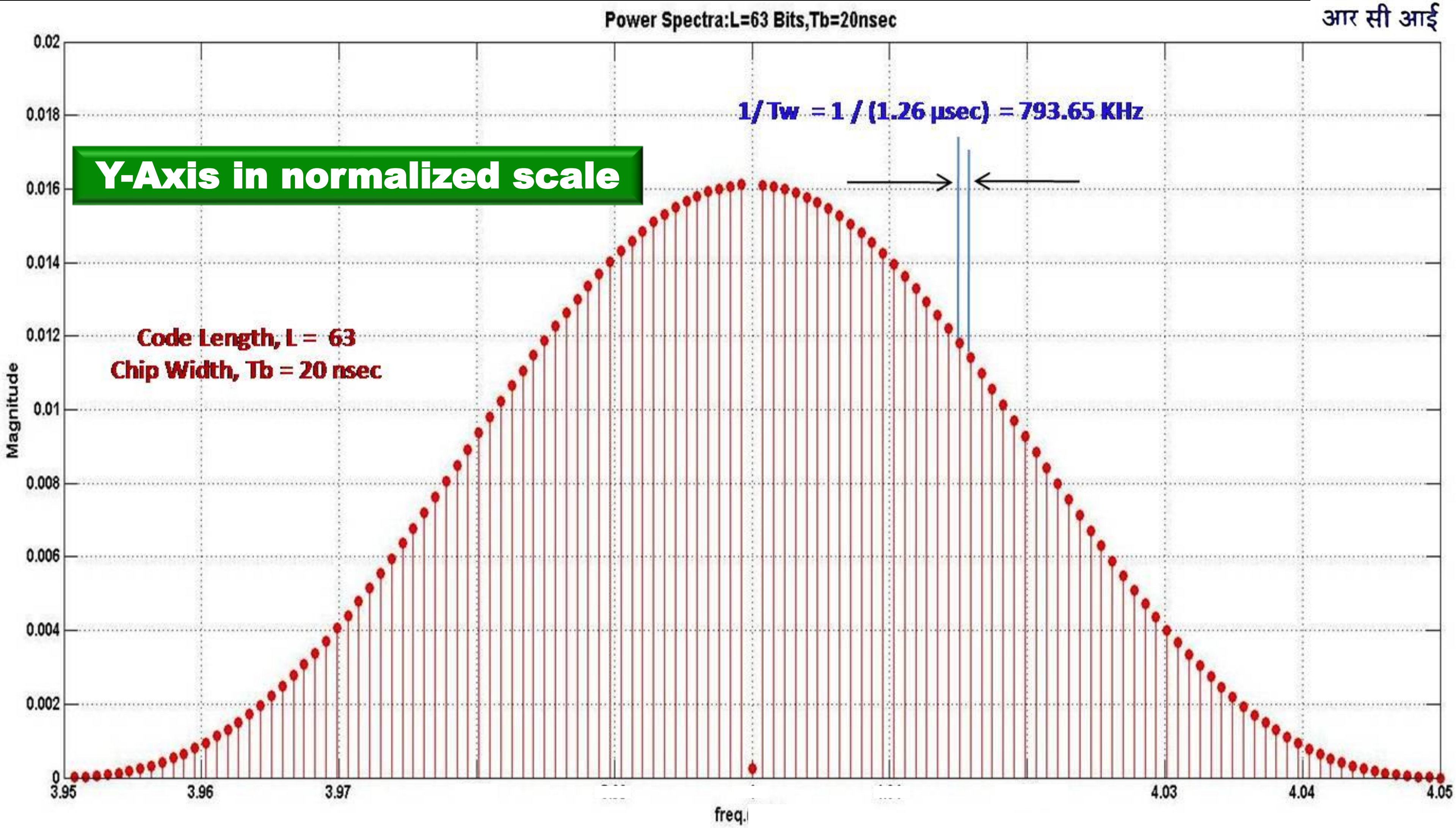


Single Sided Amplitude Spectra:
Chip Width = 10 nsec

Stem Plot

Amplitude spectra of Biphase coded waveform

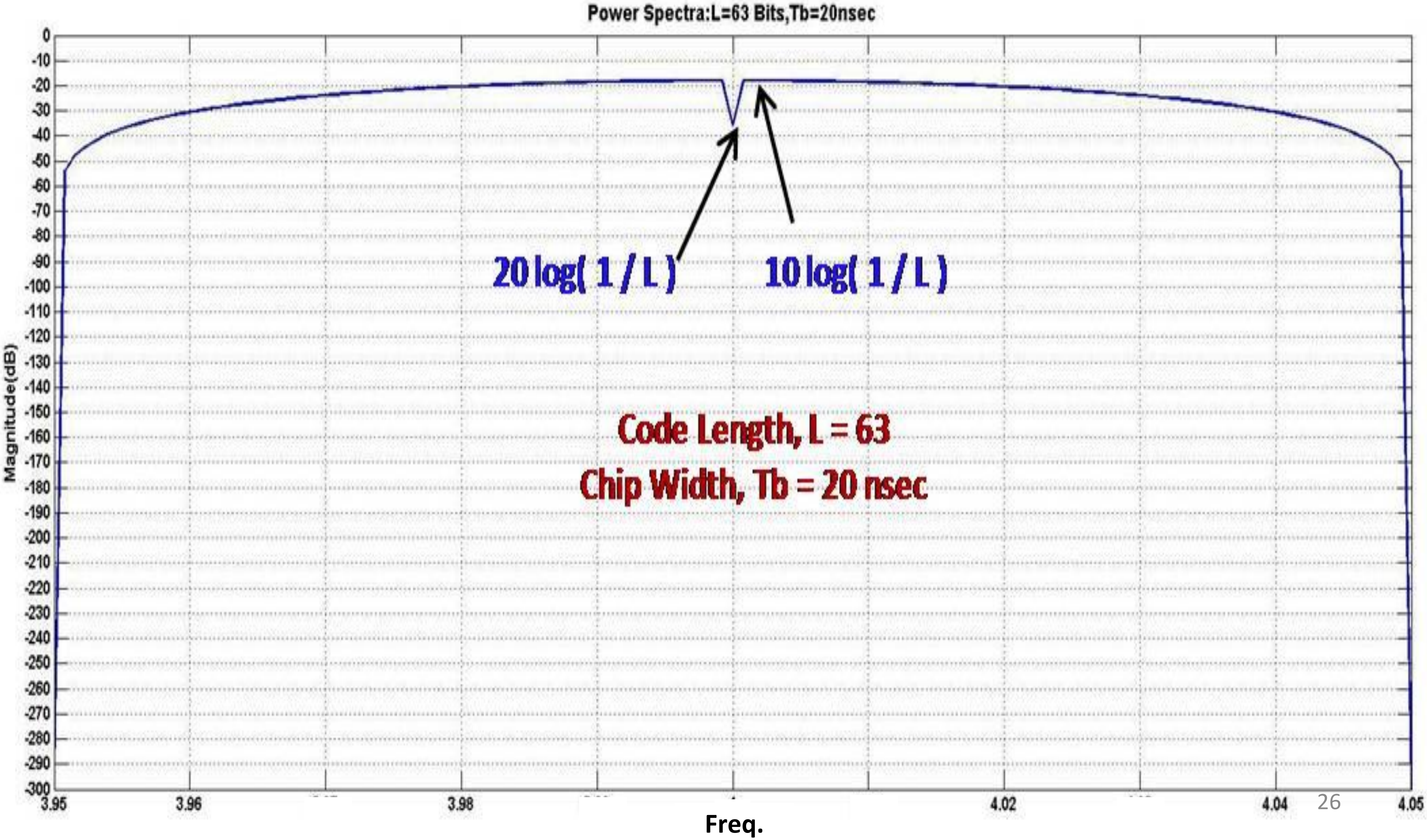
आर सी आई



Continuous Plot
Amplitude spectra of Biphase coded waveform

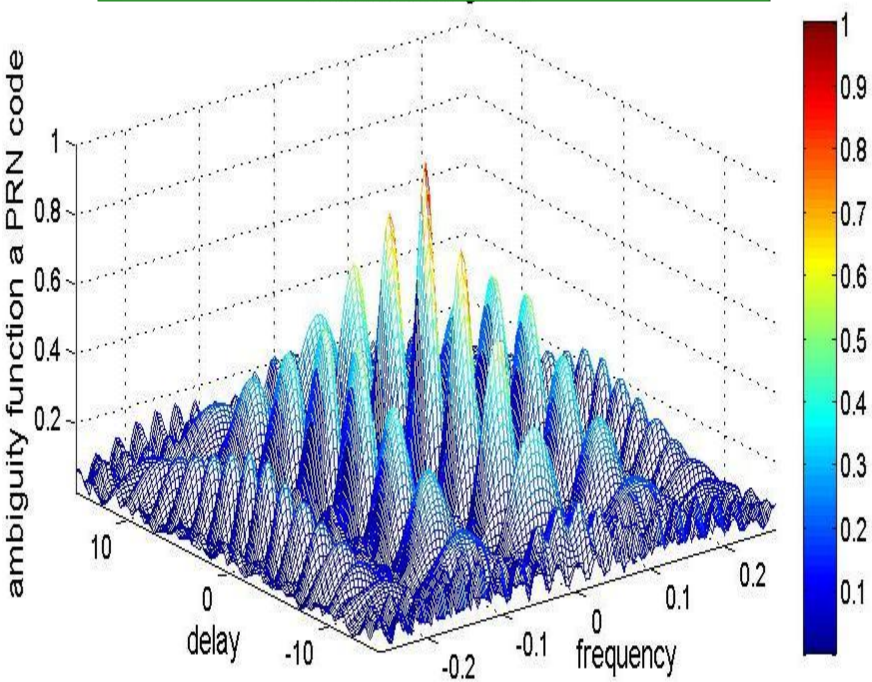
आर सी आई

Y-Axis in dB

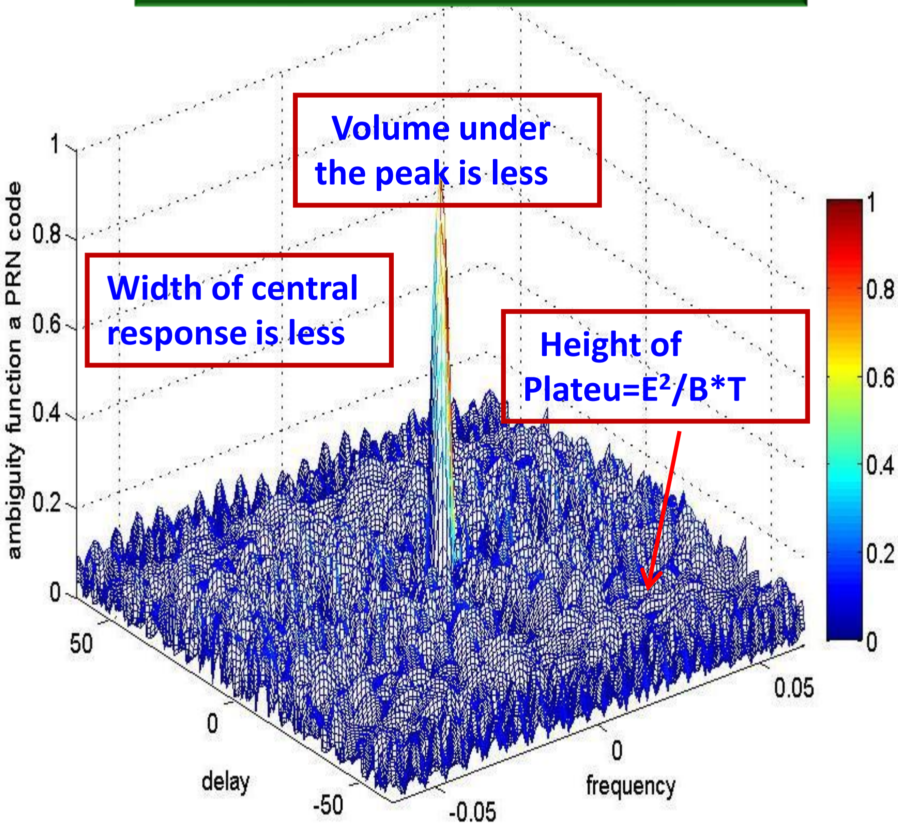


Comparison of Ambiguity Plots: PN Codes
Effect Of Code Length

PN Code: L=15, T*B=15

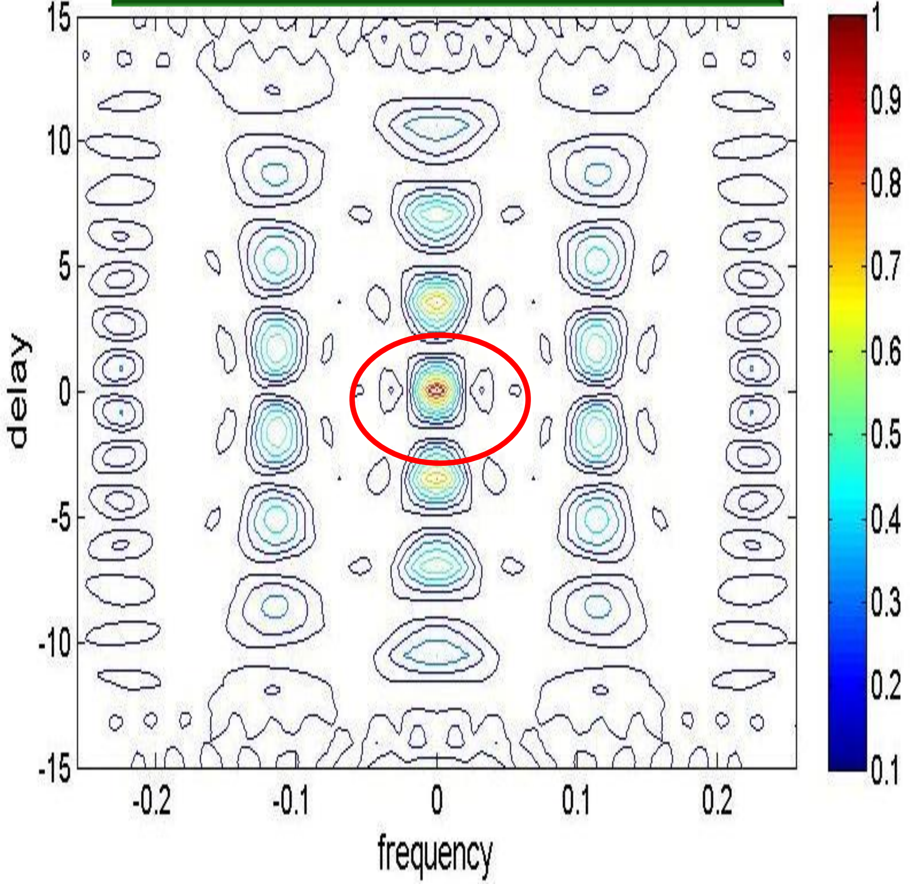


PN Code: L=63, T*B=63

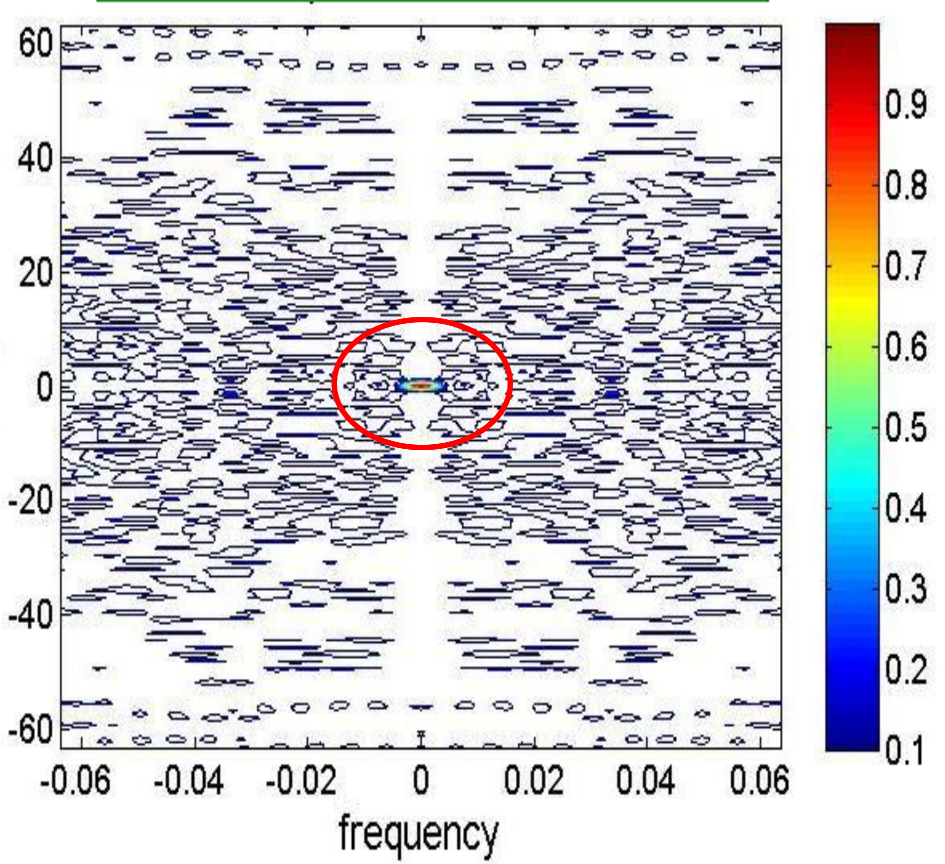


Contour Plots: PN Codes
Effect Of Code Length

PN CODE: L=15, TxB =15

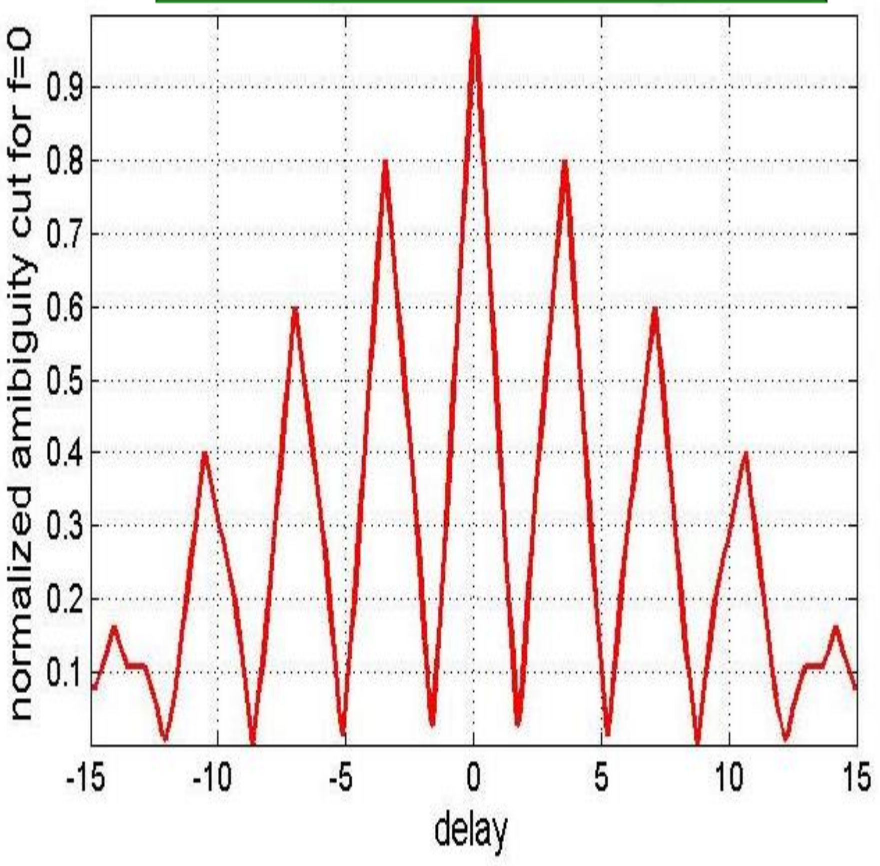


PN CODE: L=63, TxB = 63

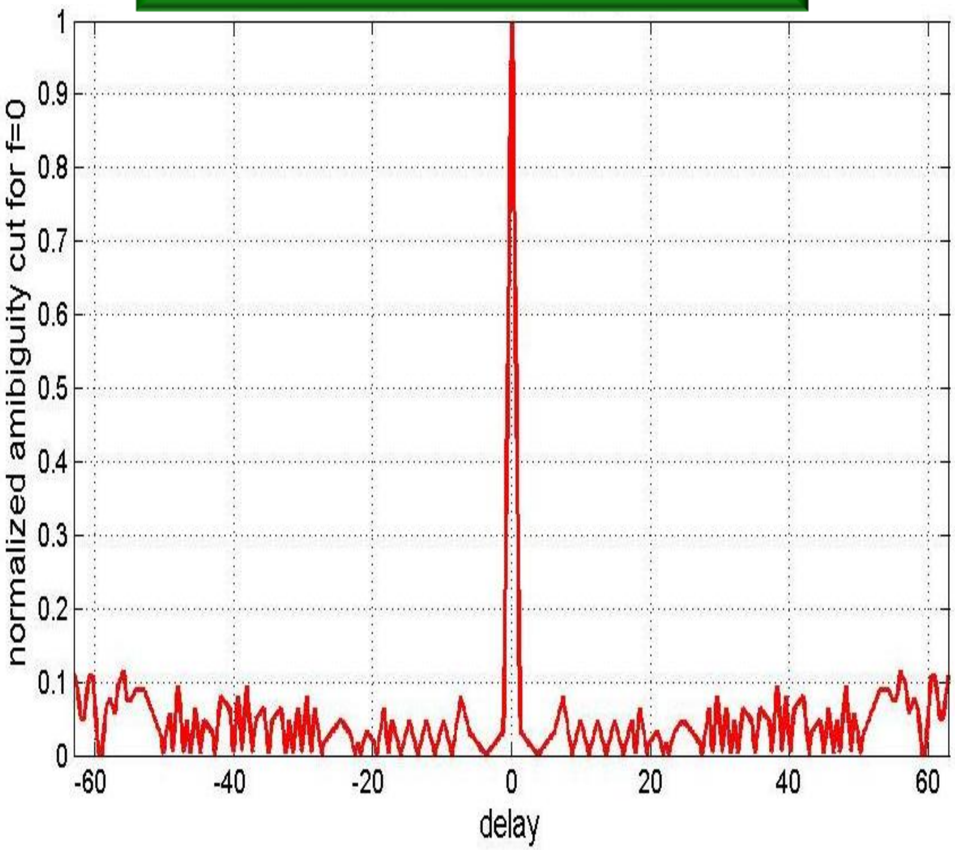


Zero Doppler cut of Ambiguity plots of PN Codes
Effect Of Code Length

PN Code: L=15, T*B=15

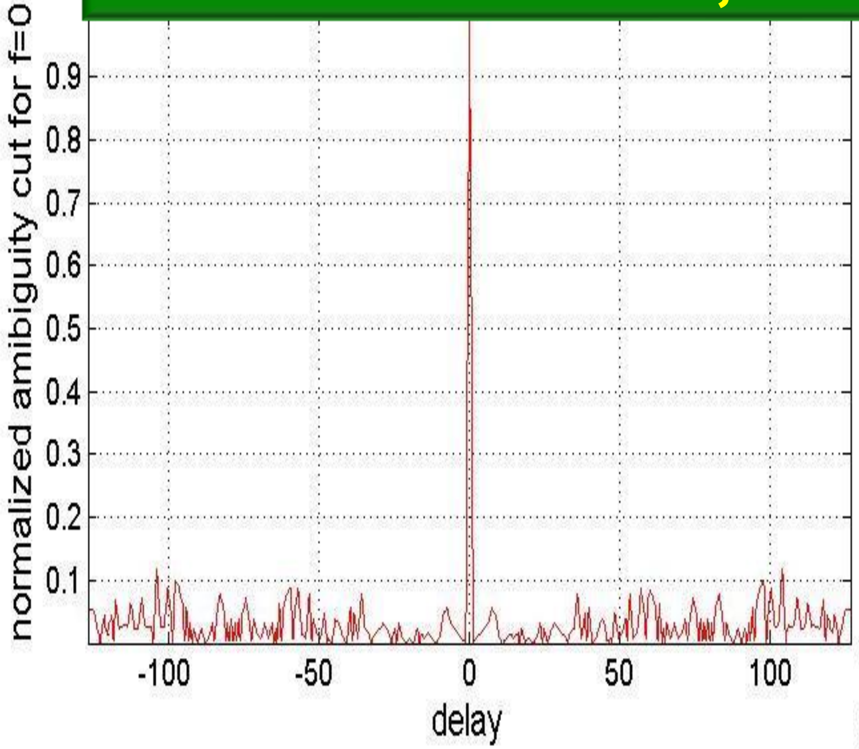


PN Code: L=63, T*B=63

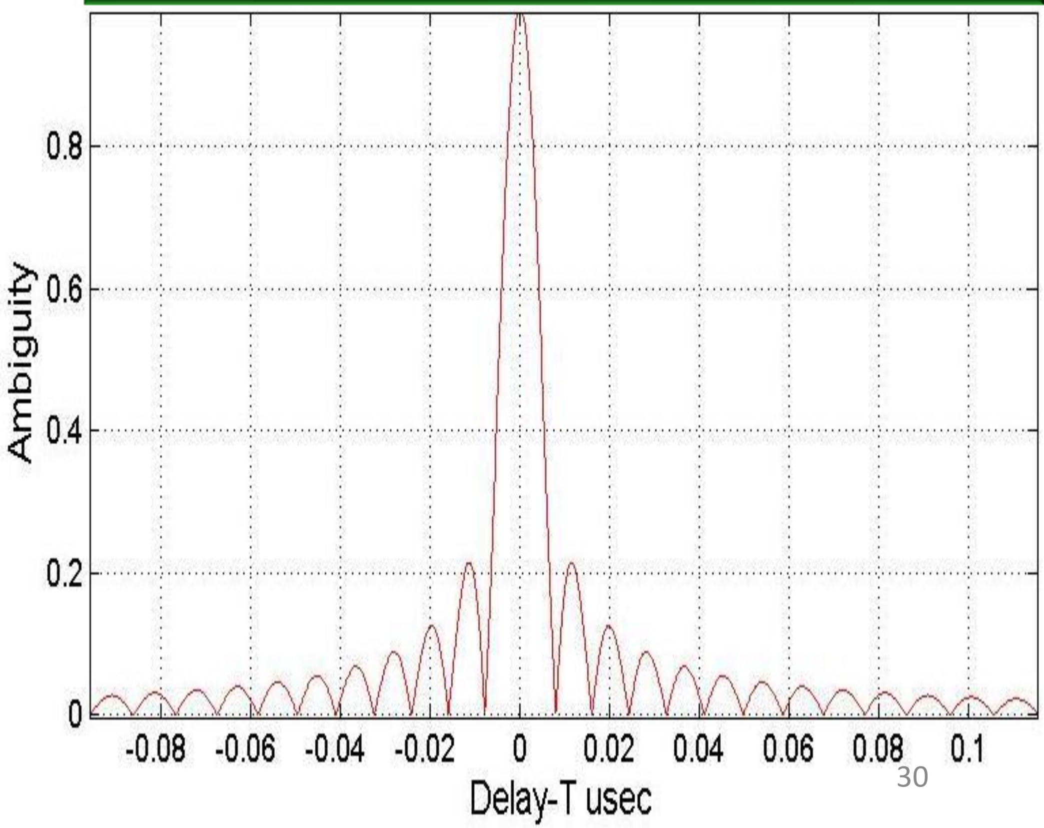


Comparison of Range Sidelobes of PN CODED & LFM Waveforms

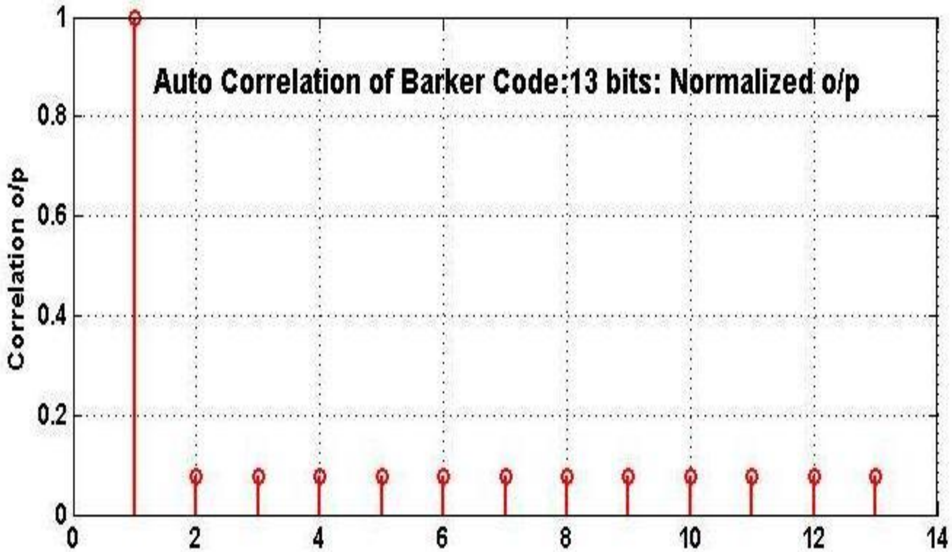
Zero Doppler Cut of PN Coded Continuous Waveform
L=127, TxB =127

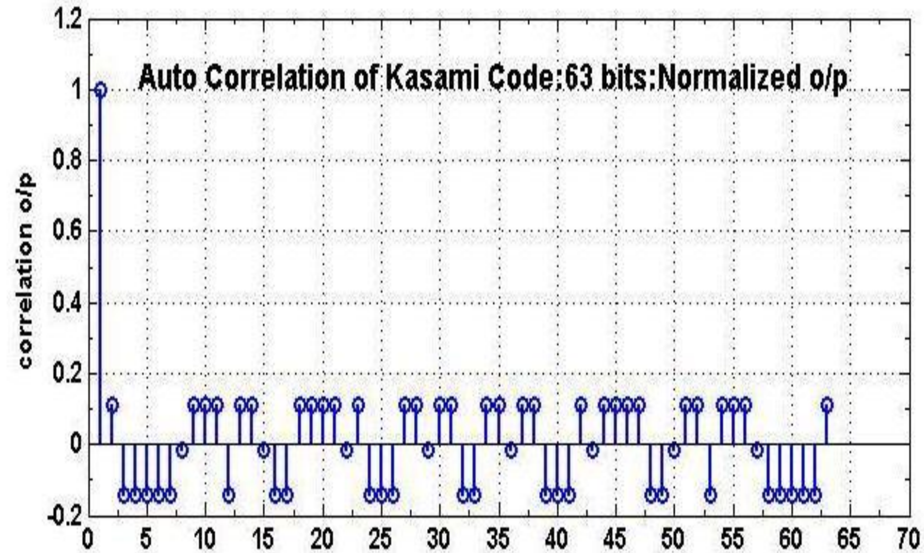


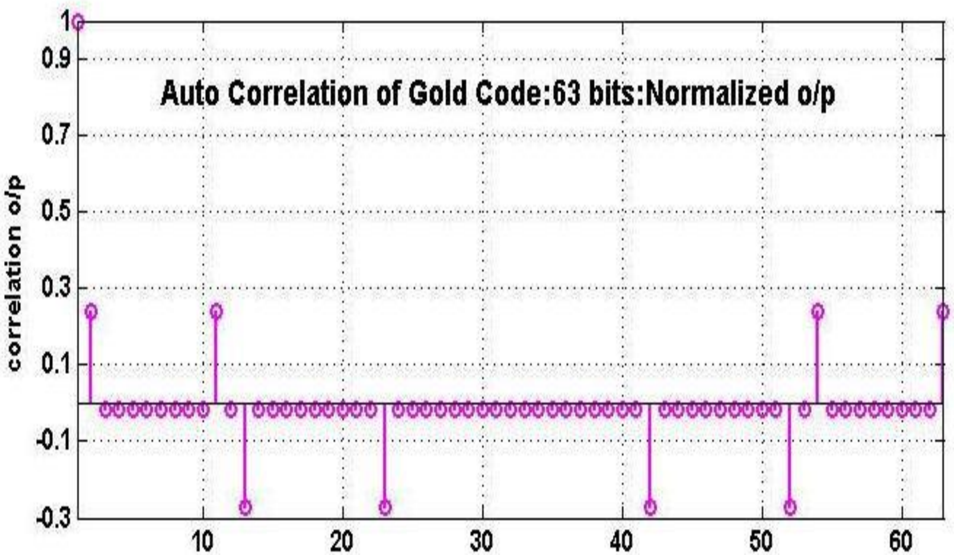
Zero Doppler Cut of LFM Waveform
Tp =1µsec, B = 127MHz , T*B=127

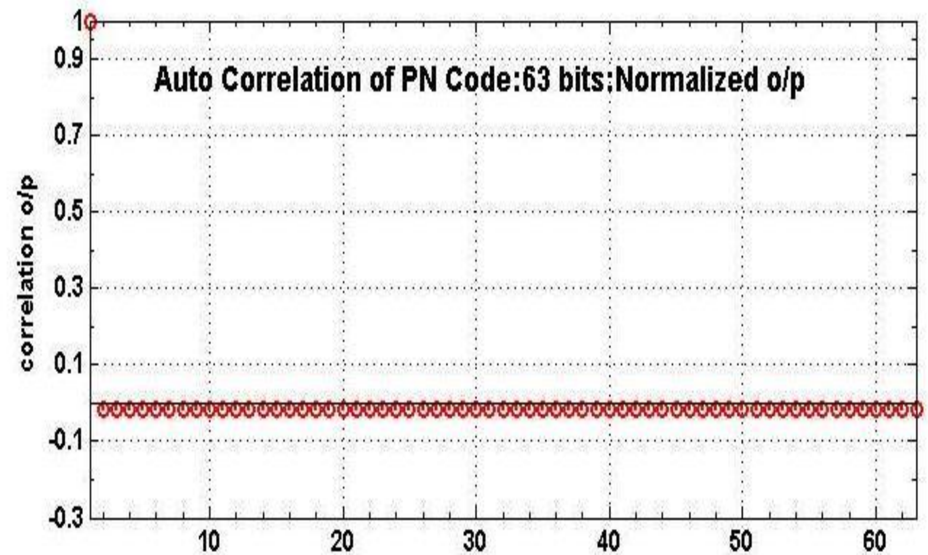


Comparison of Autocorrelation Properties
Effect of Different Type of Codes









Results: Comparative Evaluation of Radar Waveforms

Characteristic	Pulse Delay Ranging	FMCW	PN Coded CW
Tx Peak Power Requirement	High Due to absence of pulse compression.	Reduced Due to pulse compression	Reduced Due to Pulse compression. Lower than FMCW.
Range Resolution	ΔR=C x Tp/2 Tp=Pulse Width	ΔR=C /2 x Δ F Δ F=Frequency Sweep Higher range Resolution can be achieved easily. Higher T * B Product by increase in B = Δ F.	ΔR=C x Tb/2 Tb=Chip Width Limitation on low value of Tb due to ADC technology. Higher T * B Product by increase in Bandwidth = 1/Tb.
Long Range Measurement	Higher PRI. Low Duty Cycle. Req. Of High Peak Power	Longer Waveform Period(T). 100 % Duty Cycle. Lower sweep rate(Δ F/T) Higher T * B = T * Δ F Product by increase in T.	Longer Waveform Period(Tw). 100 % Duty Cycle. Higher T * B = Tw * B Product by Increase in Tw.

Results: Comparative Evaluation of Radar Waveforms

Characteristic	Pulse Delay Ranging	FMCW	PN Coded CW
T x B Product	T x B=Tp x 1/ Tp =1(Unity) Tp=Pulse Width T=Period, B=Bandwidth	T x B =T x ΔF >>1 Δ F=Frequency Sweep T=Period, ΔF =Bandwidth	T x B=Tw x 1/Tb=L*Tb/Tb=L L=Code length(no. of bits) Tb= Chip Width Lower than FMCW Radar.
Time Side lobes	Very High	Lower. Req. of Weighing filter following the Match filter. Use of Weighing filter results in reduced SNR.	Lowest. No Req. of Weighing filter following the Match filter. Higher SNR achieved. Better Correlation achieved.
Doppler Tolerance	Good.	Supports doppler shift upto +/- B/10. Time side lobes performance remains intact with large doppler shifts.	Fdmax=1/(4*Tw) Time side lobes performance & the peak of correlation deteriorates with large doppler shifts.

Results: Comparative Evaluation of Radar Waveforms

Characteristic	Pulse Delay Ranging	FMCW	PN Coded CW
Spill over & Tx Leakage	Less Due to discontinuous waveform pattern.	Poor Performance. Operation limited to short range applications	Overall performance improvement by 15-20dB compared to FMCW. Decrease in spill over by 1/L2 (i.e. 48 dB for L=127) compared to unmodulated radar signal.
Range Doppler Coupling	No.	Yes. Due to the Frequency Sweep Rate (ΔF/T).	No.
Low Probability of Intercept & ECCM	No LPI & ECCM features.	Better than Pulse delay ranging due to Pulse Compression.	Better LPI & ECCM capability compared to FMCW.

Thank You !