ECE 693 – Special Topics:
AI for Radar System Design

Radar Waveforms:

Review and Design

Dr. Sevgi Zubeyde Gurbuz
szgurbuz@ua.edu

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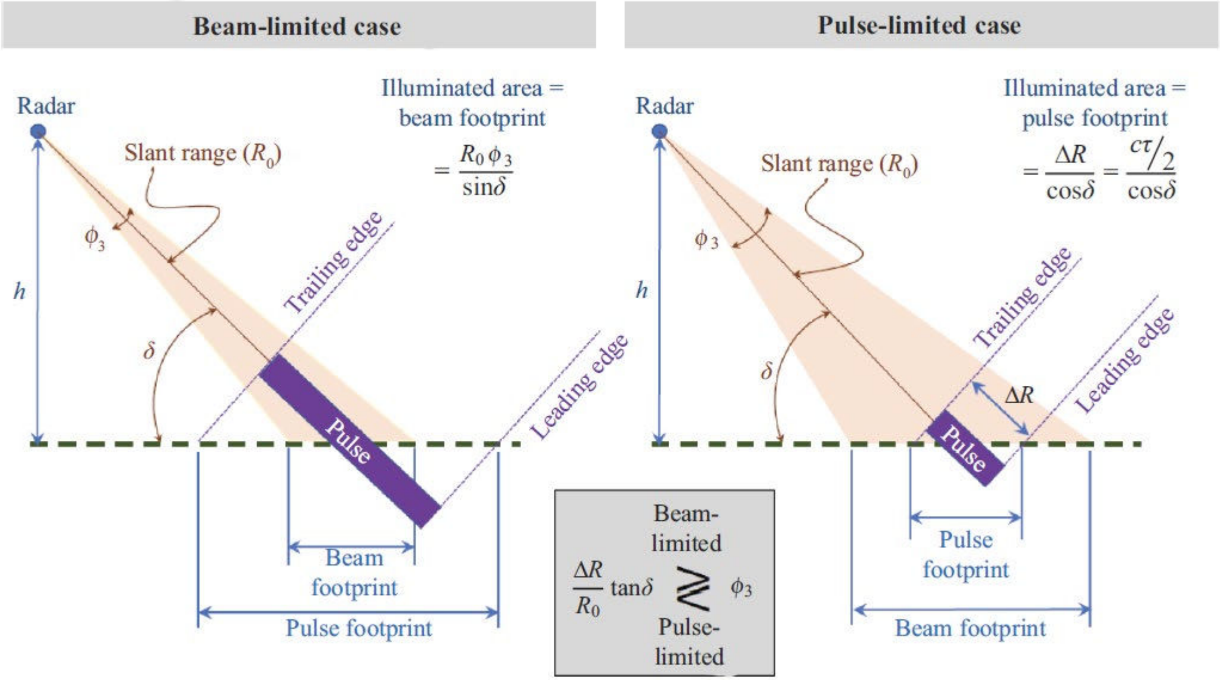
Radar Range Equation

- **Point Targets:** $$P_r = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4 L_s L_a(R)} \quad \text{W}$$
- **Distributed Targets:**



$$P_r = \frac{P_t G^2 \lambda^2 \phi_3 \theta_3 \sigma^0}{(4\pi)^3 R_0^2 L_s L_a \sin\delta}$$

$$P_r = \frac{P_t G^2 \lambda^2 \sigma^0 \Delta R \theta_3}{(4\pi)^3 R_0^2 L_s L_a \cos\delta}$$

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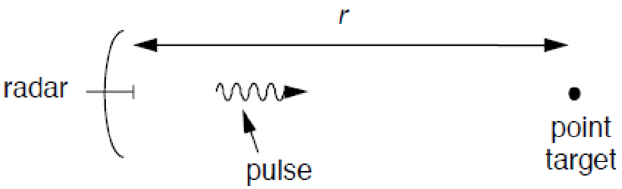
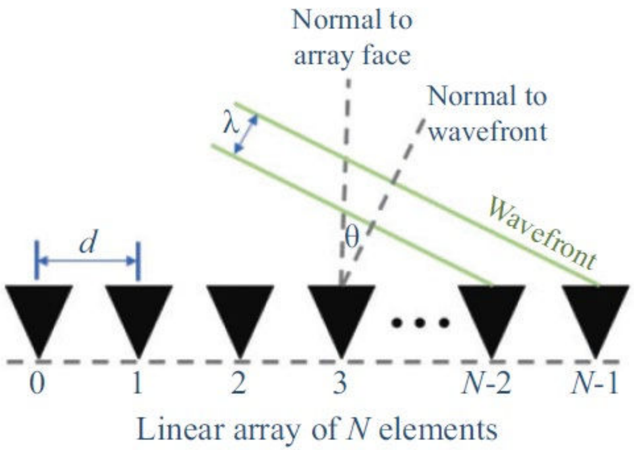
Radar Measurements

- Range: $2R = c \cdot \Delta t \rightarrow R = \dfrac{c \cdot \Delta t}{2}$



- Velocity: $\boxed{F_D = +\dfrac{2v}{c} F_t = +\dfrac{2v}{\lambda_t}}$

- Angle:



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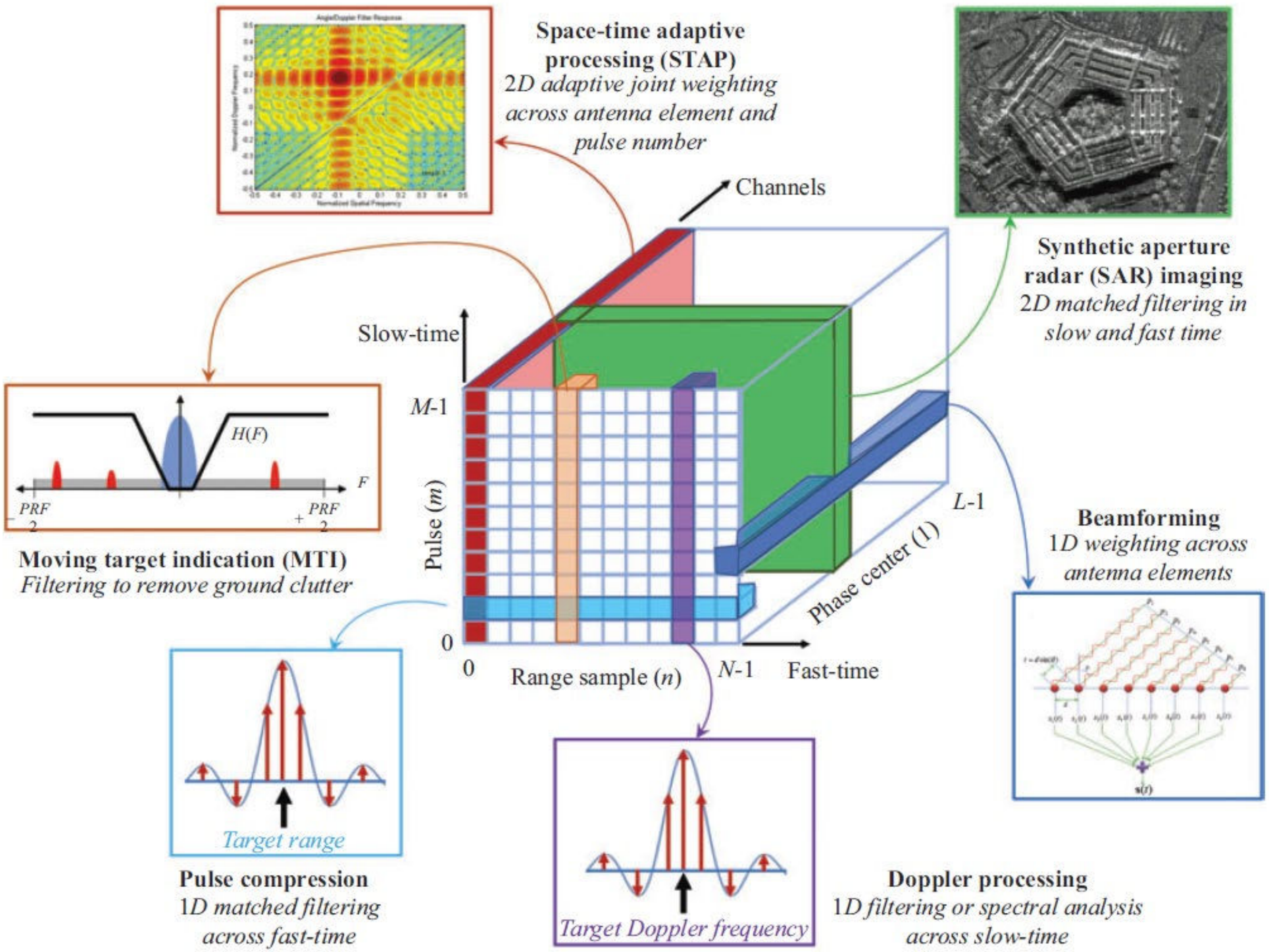
Basic Radar Signal Processing



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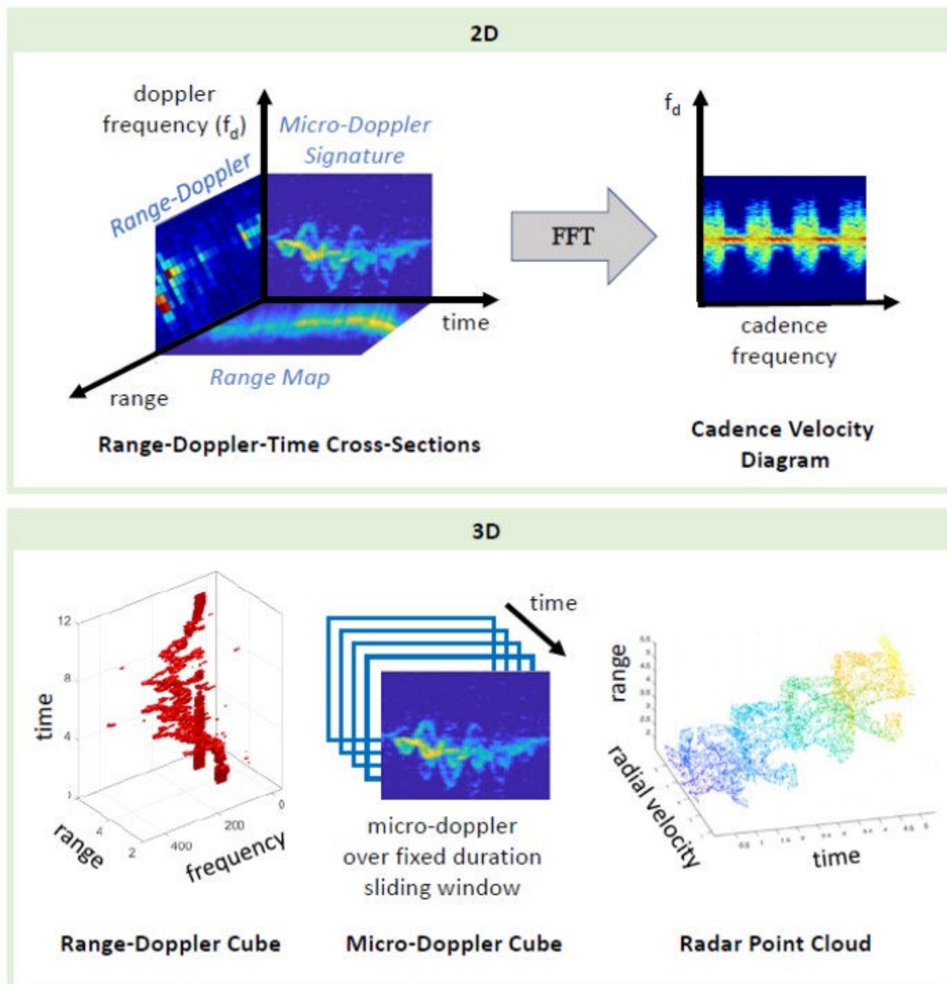
Radar Data Representations



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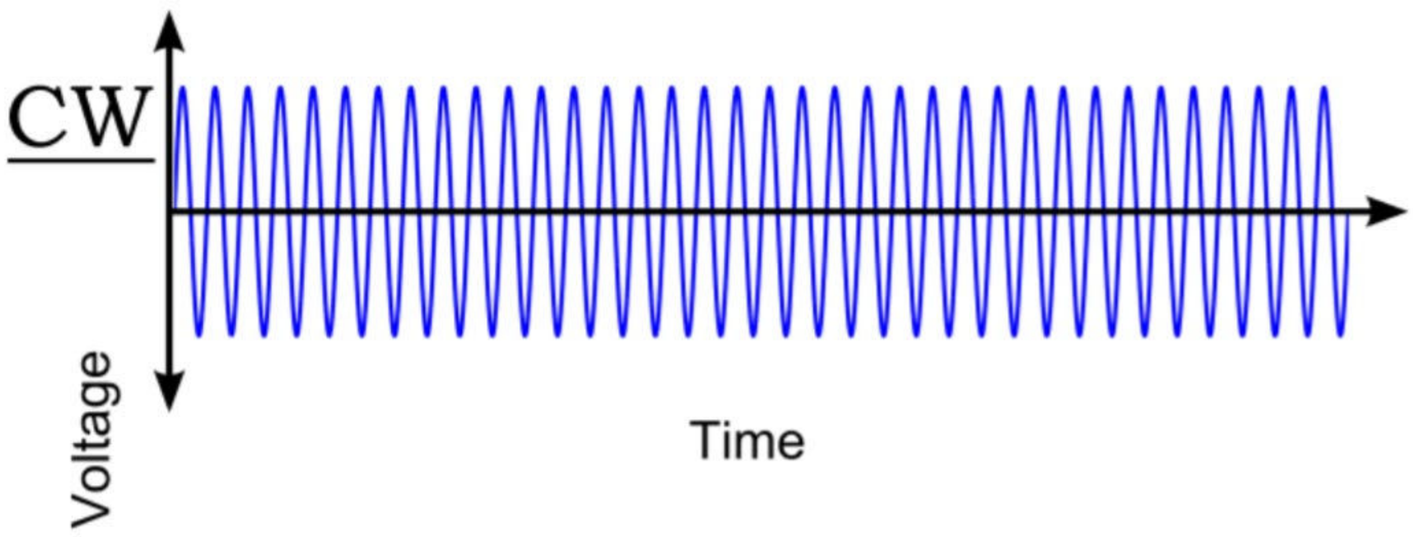
Continuous Wave (CW)

- Transmit sinusoid of constant frequency

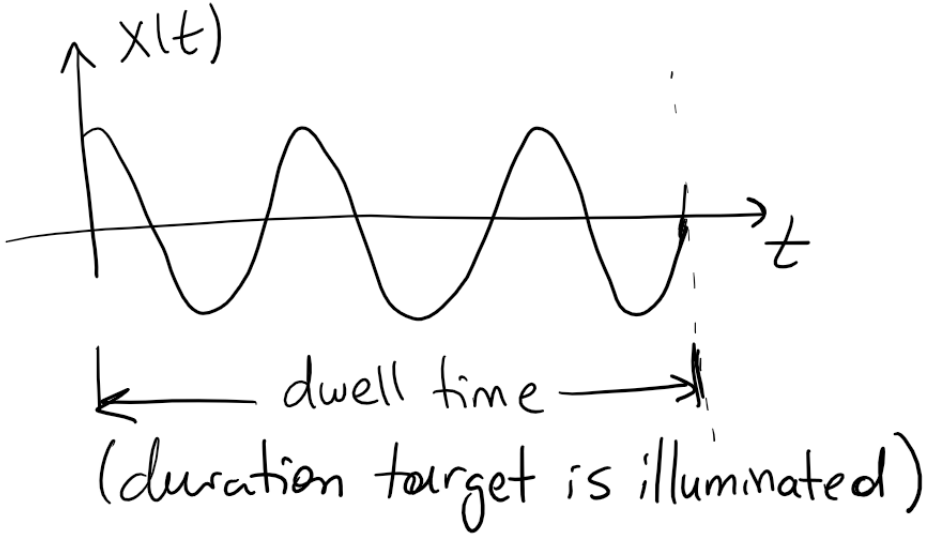


- Cannot measure range with CW waveform

CW Radar Doppler Measurement

- Can find Doppler Shift using FFT
- What about Doppler Resolution?

Finite Duration
CW Waveform



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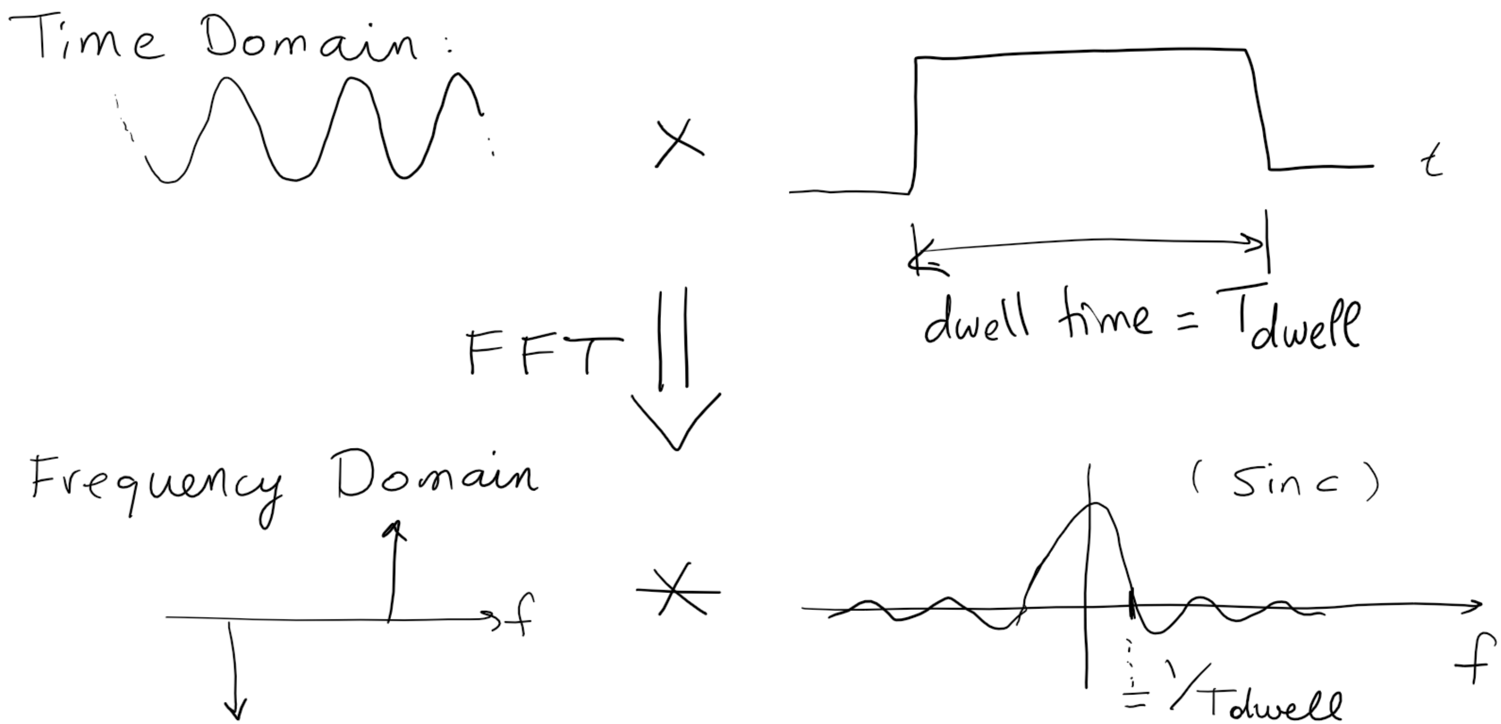
Finite Duration CW…

…is equivalent to windowing infinite duration sinusoidal signal



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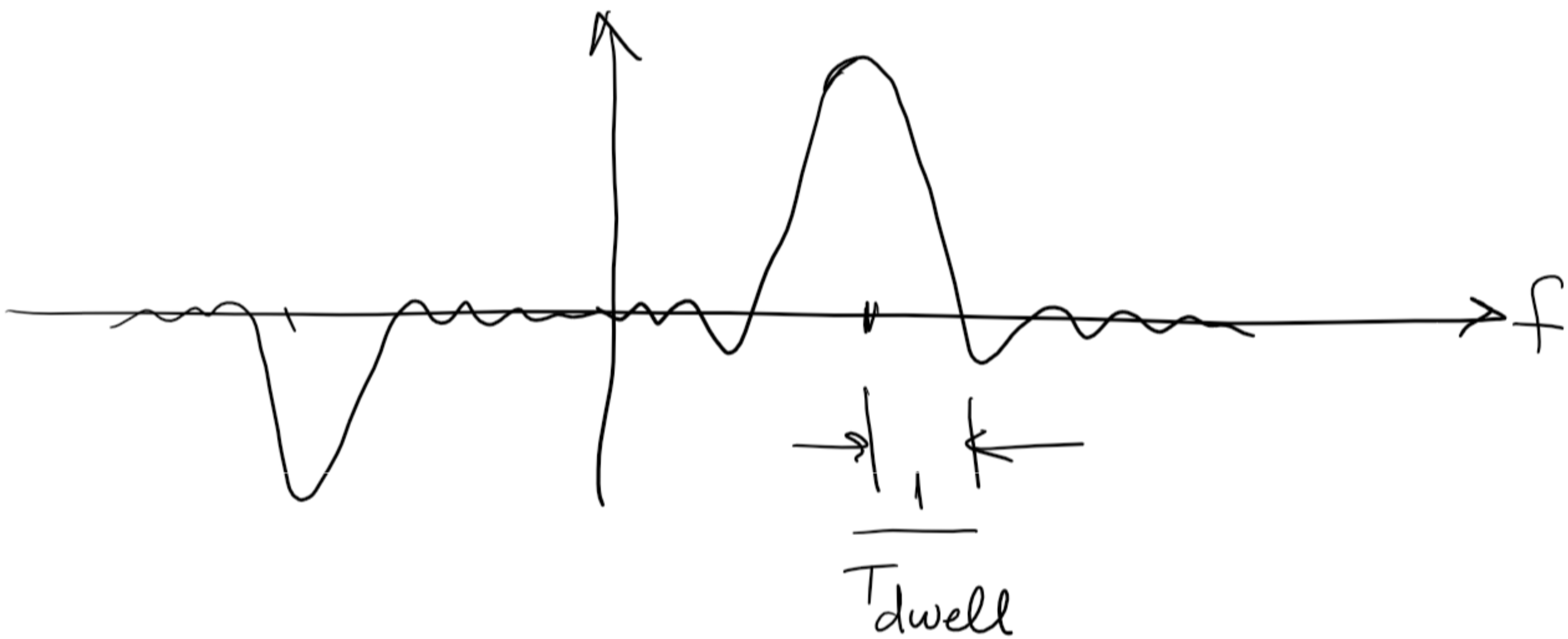
Finite Duration CW in Frequency Domain

Result of Convolution:



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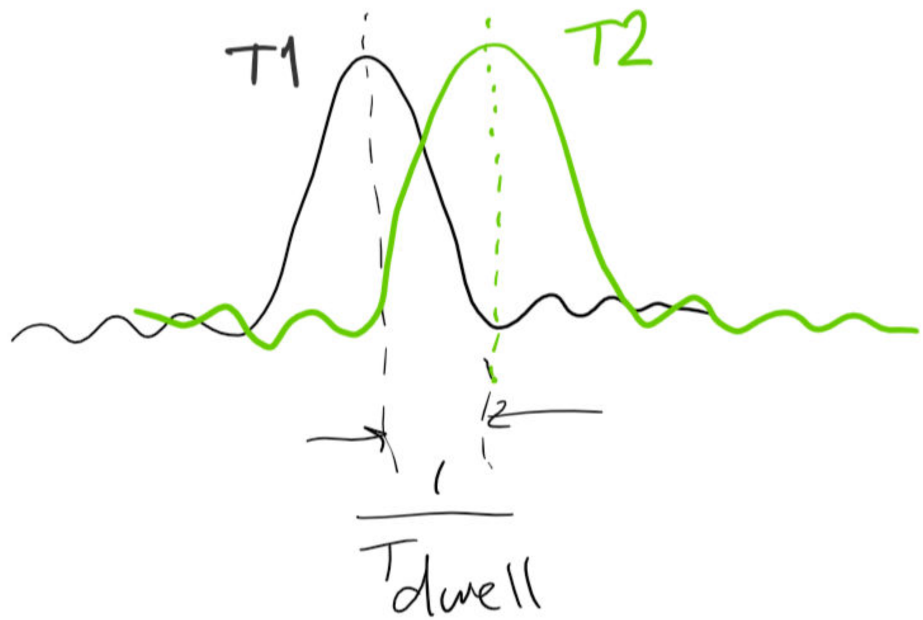
Minimum Difference in Doppler to Distinguish Two Targets in Velocity

(Draw r.h.s. sinc only)



Thus,

$$\Delta\omega_D = \frac{1}{T_{dwell}}$$

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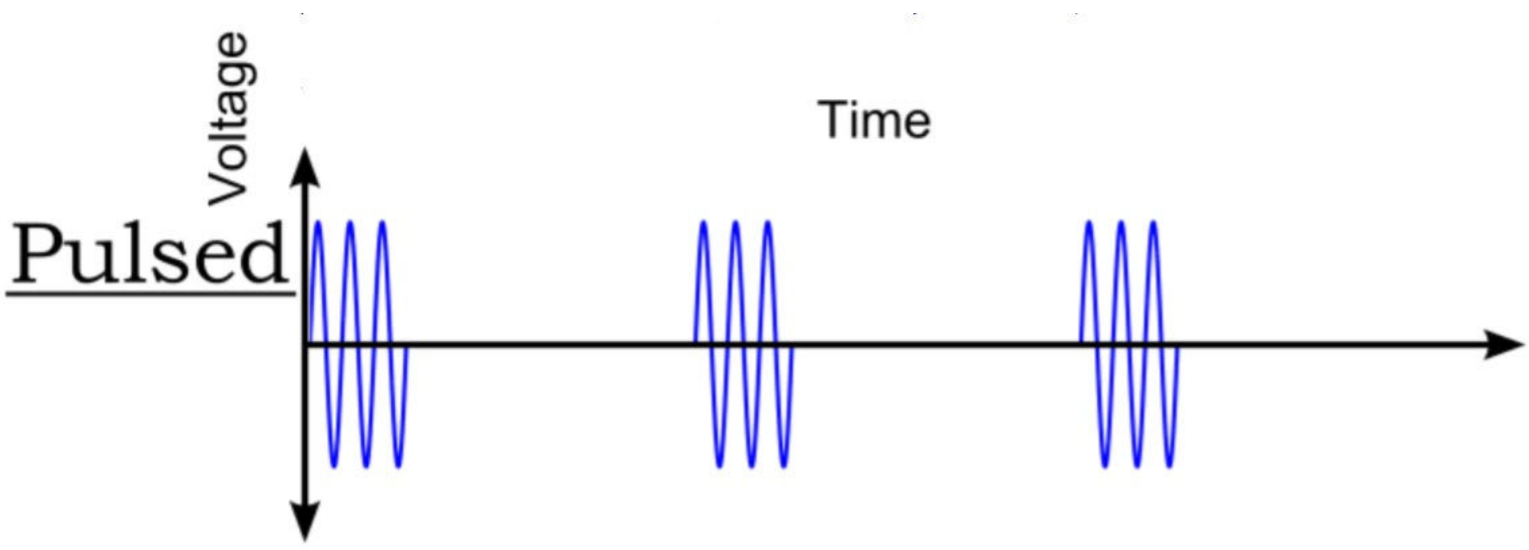
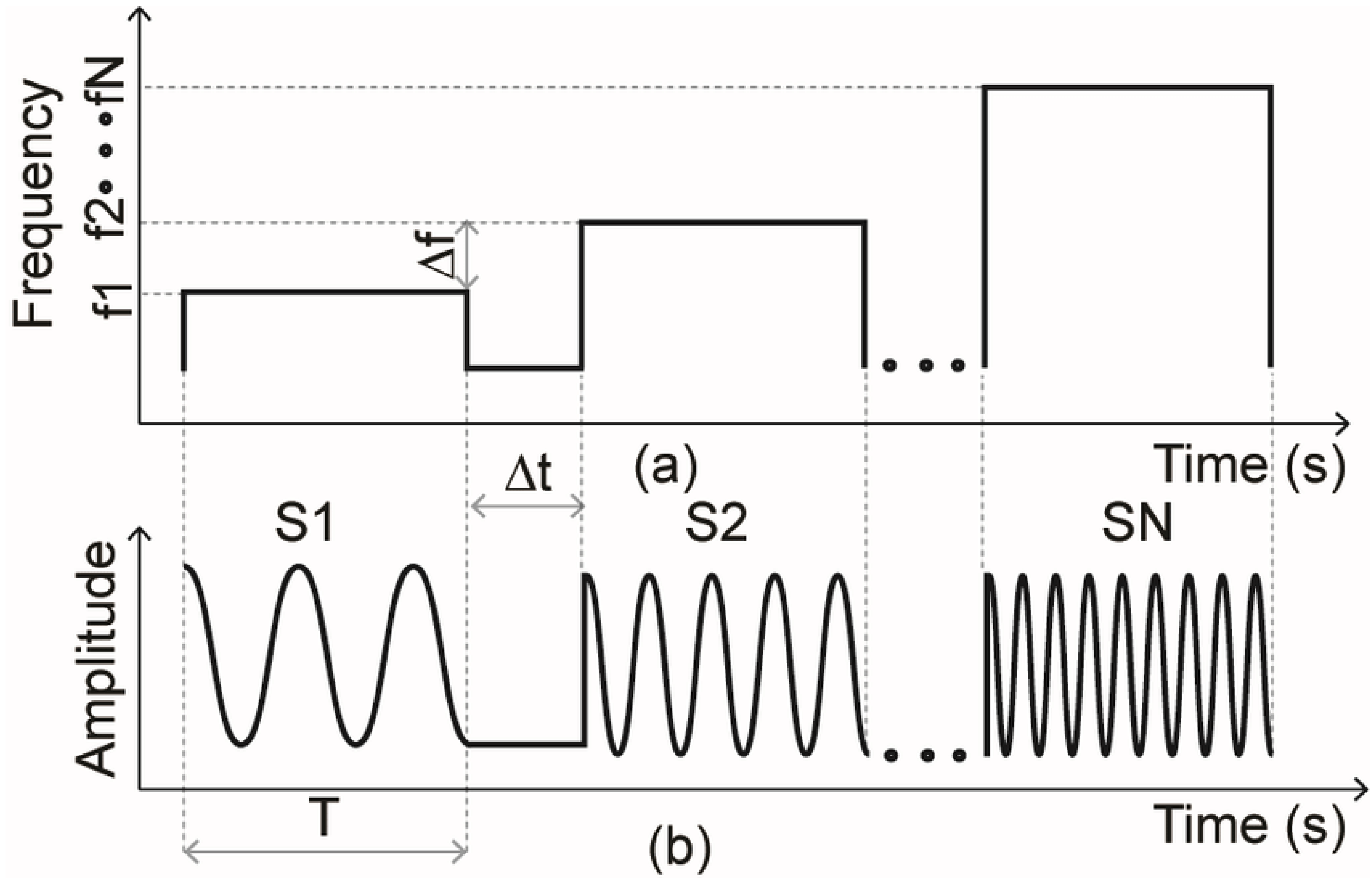
Pulsed CW Waveform

- Intermittent transmission of constant frequency sinusoid



Stepped Frequency CW



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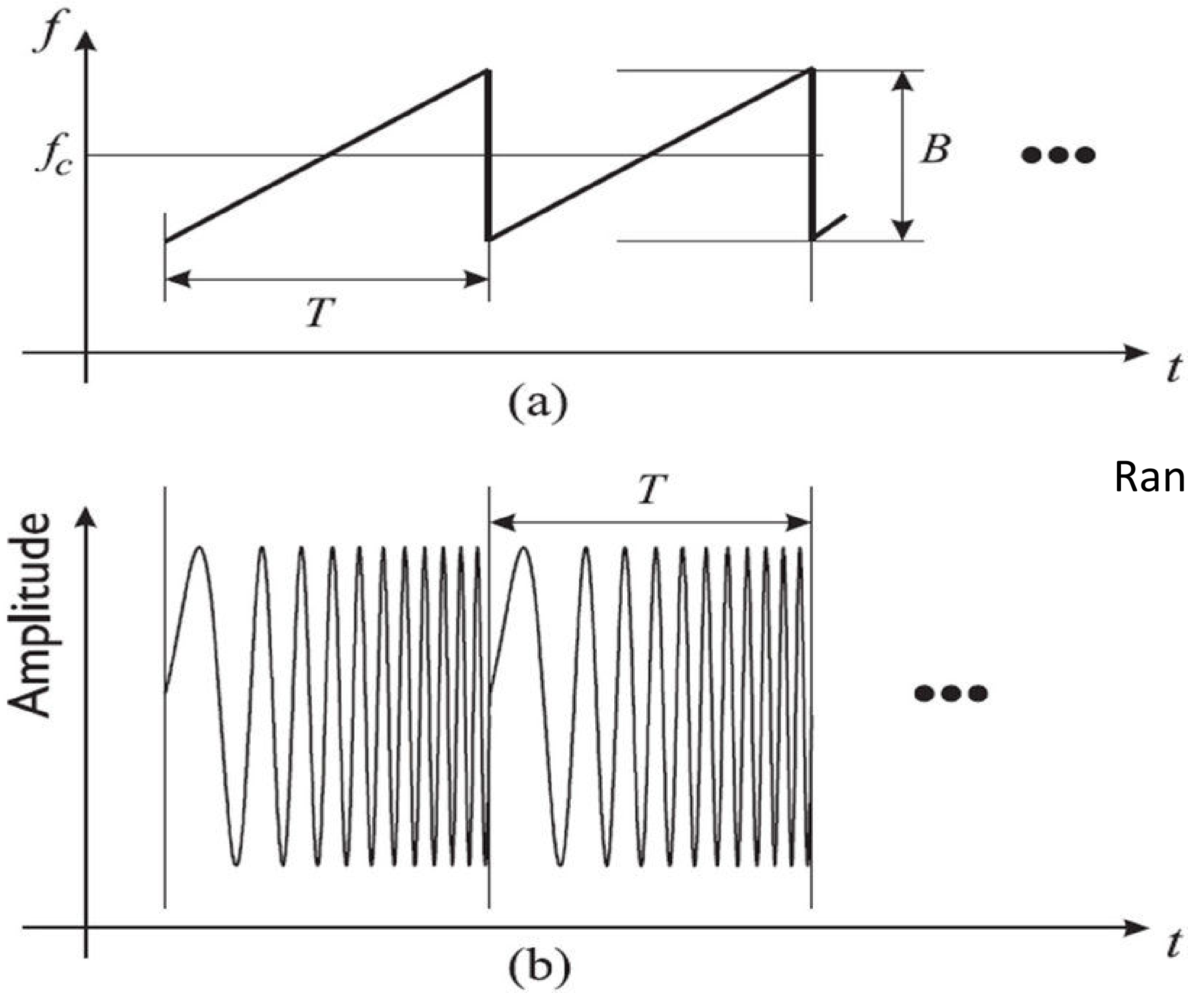
Frequency Modulated CW



Range Resolution:

$$\Delta R = \frac{c}{2\beta}$$

Range/Velocity Tradeoff

- Unambiguous width of the Doppler spectrum equals the PRF
  - Doppler shifts greater than $\pm PRF/2$ are aliased
  - this is referred to as ***velocity or Doppler ambiguity***
  - unambiguous velocity interval is $\lambda PRF/2$ m/s
- The PRF also determines unambiguous range

$$R_{ua} = \frac{cT}{2} = \frac{c\,PRI}{2} = \frac{c}{2\,PRF}$$

- Unambiguous range and velocity tradeoff:

$$R_{ua}\,v_{ua} = \lambda c/4$$

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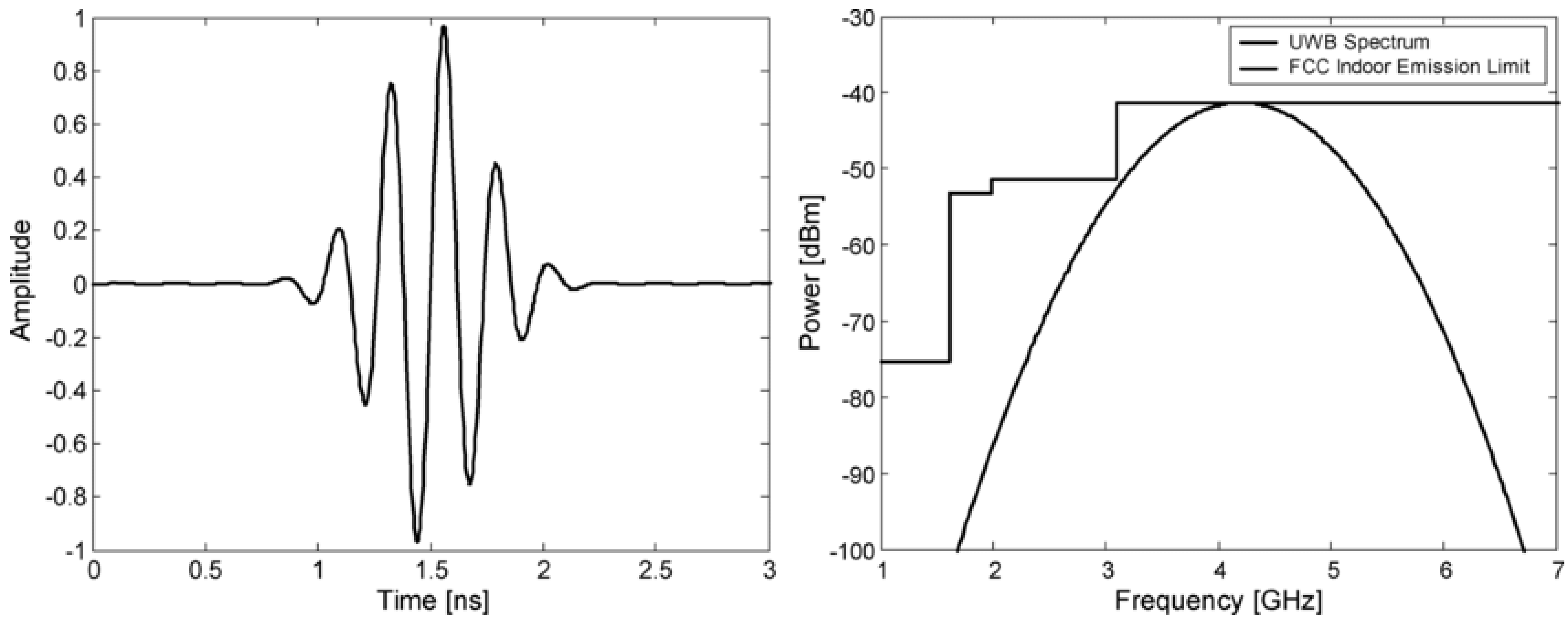
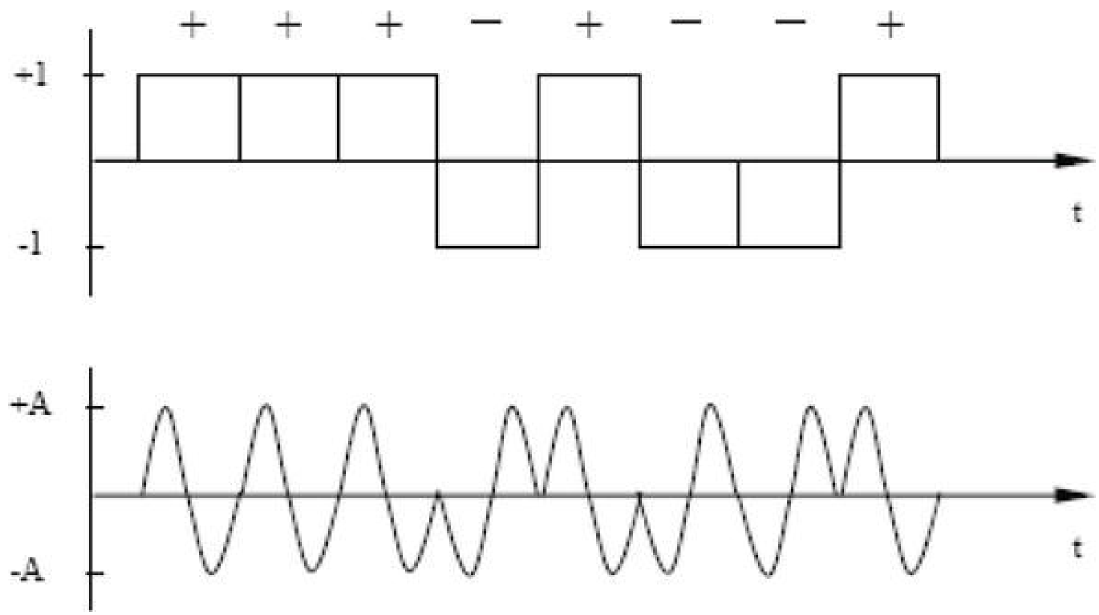
Ultra-Wide Band Impulse Radar



Phase-Coded Waveforms



Advantages:
- Low range sidelobes
- Preferred in jamming conditions

Disadvantages:
- Poor resolution in presence of distributed clutter
- More complex to implement

Radar System Design Example: Entymological Radar

Tracking the migration of insects is an important problem not only for the purposes of biological studies, but also to monitor and control the spread of diseases as well as prevent damage to agriculture. Wingbeat frequency has been noted to be an important feature in the identification of various insect species. The table below gives the body size and wingbeat frequency as measured independently using a stroboscope.

Insect Species	Body Length in mm	Wingbeat Frequency in Hz	Wing Span
Athetis Lepigone	10	37.25	20 mm
Mamestra Brassicae	18	42	34 mm
Adristyrannus	23	39	39 mm
Macroglossum corythus luteata	31	49.61	50 mm
Teretra japonica	35	36.70	70 mm
Clanis bilineata	41	25.41	102 mm

We would like to design one (or multiple) radar(s) to detect the wingbeat frequency of the insects tabulated above.

Sevgi Z. Gurbuz (szgurbuz@ua.edu)

FMCW Waveform Parameters

- Is one radar band sufficient for the detection and identification of these insects? What is/are the suitable radar band(s)?

Band	Frequency	Wavelength
HF	3–30 MHz	100–10 m
VHF	30–300 MHz	10–1 m
UHF	0.300–1 GHz	1–30 cm
L	1–2 GHz	30–15 cm
S	2–4 GHz	15–7.5 cm
C	4–8 GHz	7.5–3.75 cm
X	8–12 GHz	3.75–2.5 cm
Ku	12–18 GHz	2.5–1.67 cm
K	18–27 GHz	1.67–1.11 cm
Ka	27–40 GHz	1.11–0.75 cm
V	40–75 GHz	7.5–4 mm
W	75–110 GHz	4–2.7 mm

Range Resolution: $\Delta R = \dfrac{c}{2\beta}$

→ Should be smaller than the size of the body

- 10 mm → 15 GHz

→ If we sample 5 points on the body, we get 75 GHz

You could choose V or W band.

More Detailed Band Selection

2. Which radar bands are best suited to which species? and WHY? Please fill out the table below, but make sure to justify the choice of radar transmitter frequency for each species. Please do not give a numerical frequency but indicate using letters, such as X, C, L, Ka, and so forth. Any microwave frequency band may be indicated multiple times - i.e., you do not have to choose a separate frequency for each species, but you can if you want to :)

Insect Species	Radar Transmit Frequency Band
Athetis Lepigone	W
Mamestra Brassicae	V
Adristyrannus	Ka
Macroglossum corythus luteata	K
Teretra japonica	K
Clanis bilineata	Ku

Positioning

To enable the easiest observation of insects, should my radar be positioned

a) horizontally, looking such that the centerline is parallel to the ground?

b) 45 degrees upwards, so as to observe both low flying and high flying insects?

c) vertically, looking directly upward towards the sky?

Vertical Looking UK Radar

Believe it or not?

Super-Sensitive Radar Can Track & Identify Mosquitoes a Mile Away

April 3, 2018 | Editorial Team

China is ready to wage war on mosquitoes and is developing a **super-sensitive radar that can detect the wing-flapping of a mosquito up to 2 kilometres away.** This radar can be used to track migrating mosquitos and warn people about risks from diseases like malaria and zika. The scientist who wished to remain anonymous told the South China Morning Post that China is experimenting with its military radar technology to detect mosquitos which can eventually save millions of lives.

"*Identifying and tracking individual, mosquito-sized targets is no longer science fiction,*" researcher

Sevgi Z. Gurbuz (szgurbuz@ua.edu)

Other Waveform Parameters

6. Based upon your previous answers, please design the waveform to be transmitted, i.e. decide what the pulse duration, pulse repetition interval, and bandwidth should be. Then, based on this design, please fill out the table below. Justify all design choices.

Radar Parameter	Value or N/A
Pulse Duration	
Pulse Repetition Interval	
Bandwidth	
Doppler Resolution	
Range Resolution	
Minimum Range	
Maximum Range*	

*due to waveform, not SNR constraints

Is this reasonable?

Maximum Doppler Shift: $$f_{D,max} = \frac{PRF}{2} \rightarrow PRF = 2f_{D,max} = 2\frac{2v}{c}f_t = \frac{4v}{\lambda}$$

Max wingbeat frequency = 50 Hz

Max wing velocity : $$d = r\theta \rightarrow v = r\frac{d\theta}{dt} = r \cdot 2\pi f$$

$$PRF = \frac{4v}{\lambda} = \frac{4}{\lambda}2\pi rf = \frac{8\pi(102mm)(50)}{4mm} = 32\ kHz$$

W-Band Insect Radar

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Article | Open Access | Published: 03 May 2017

Micro-Doppler measurement of insect wing-beat frequencies with W-band coherent radar

Rui Wang, Cheng Hu, Xiaowei Fu, Teng Long & Tao Zeng

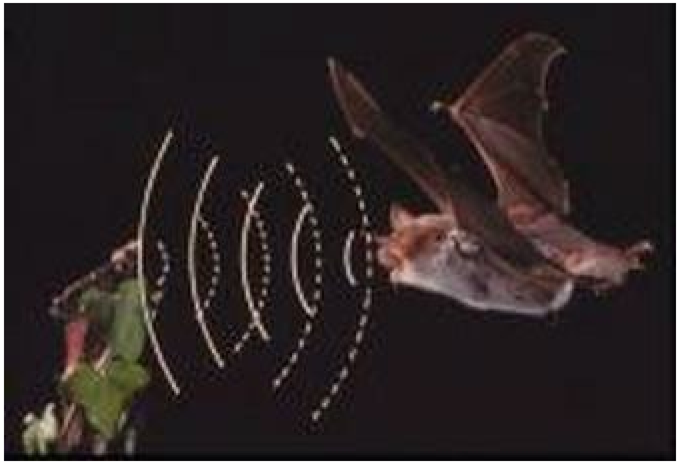
Scientific Reports **7**, Article number: 1396 (2017) | Cite this article

2899 Accesses | **28** Citations | **20** Altmetric | Metrics

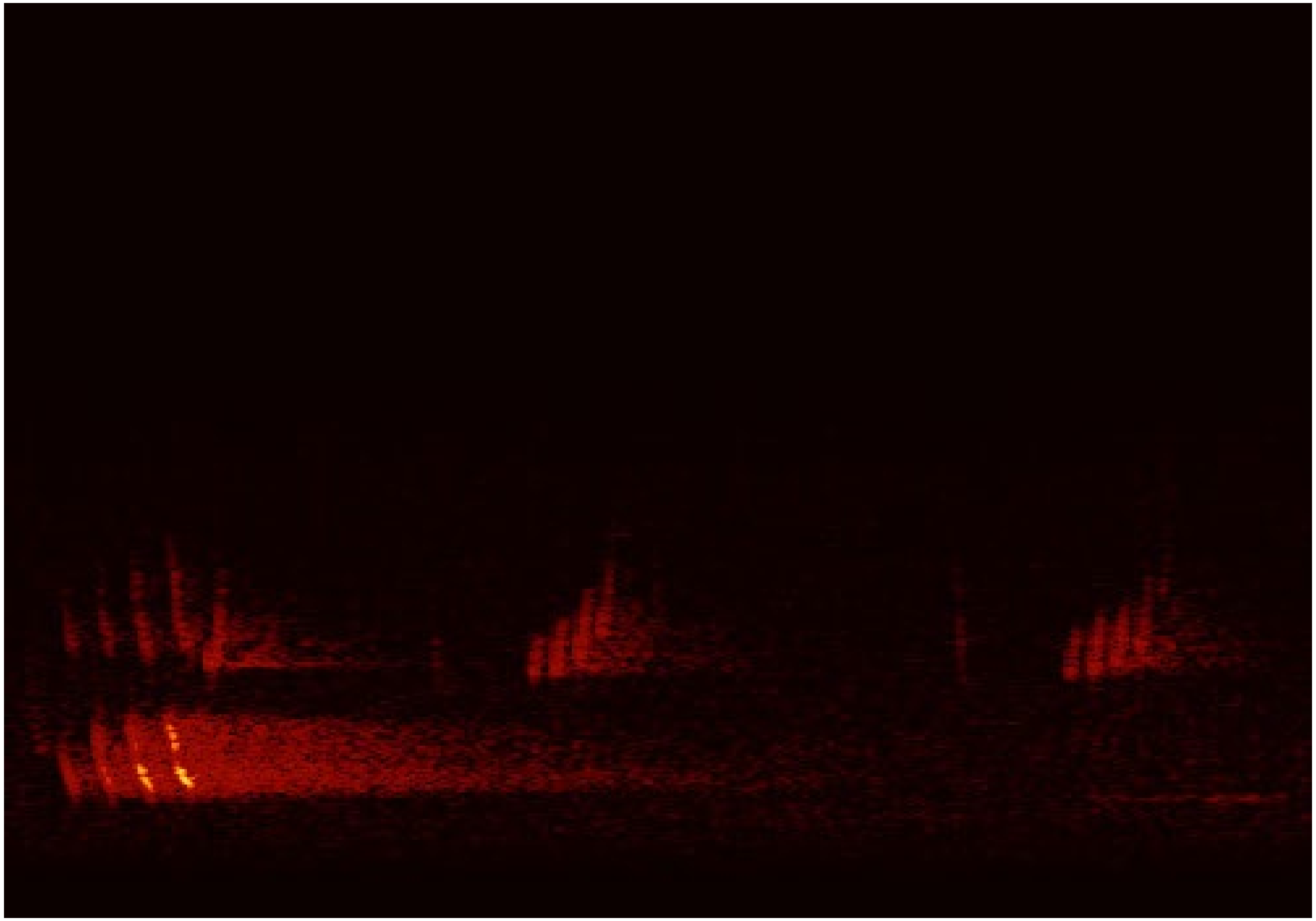
Biomimetic Radar: Using Nature for Inspiration

- Bats, dolphins, whales all use echolocation

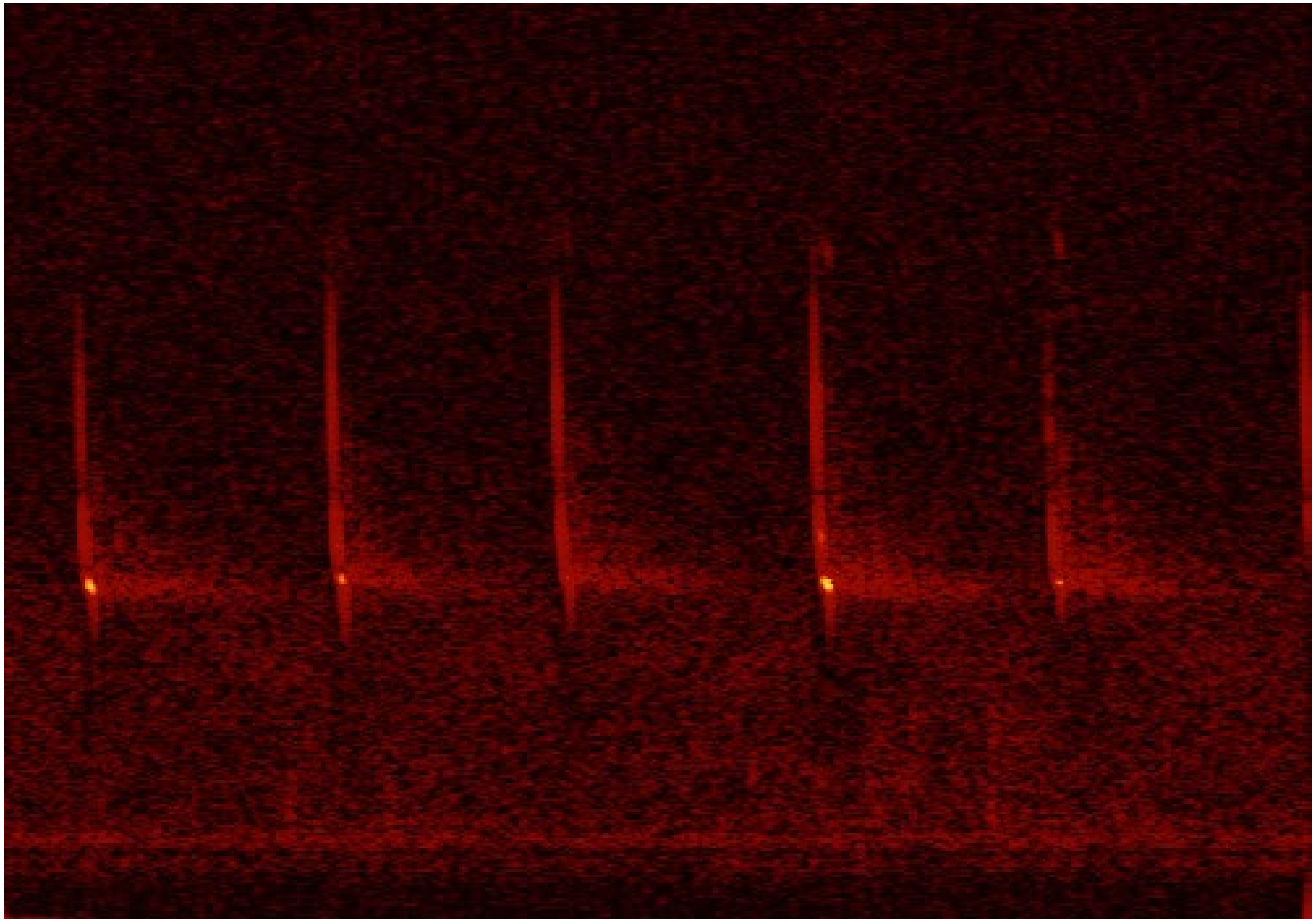
- Examples:
  - Social Communication
  - Flight Navigation
  - Hunting



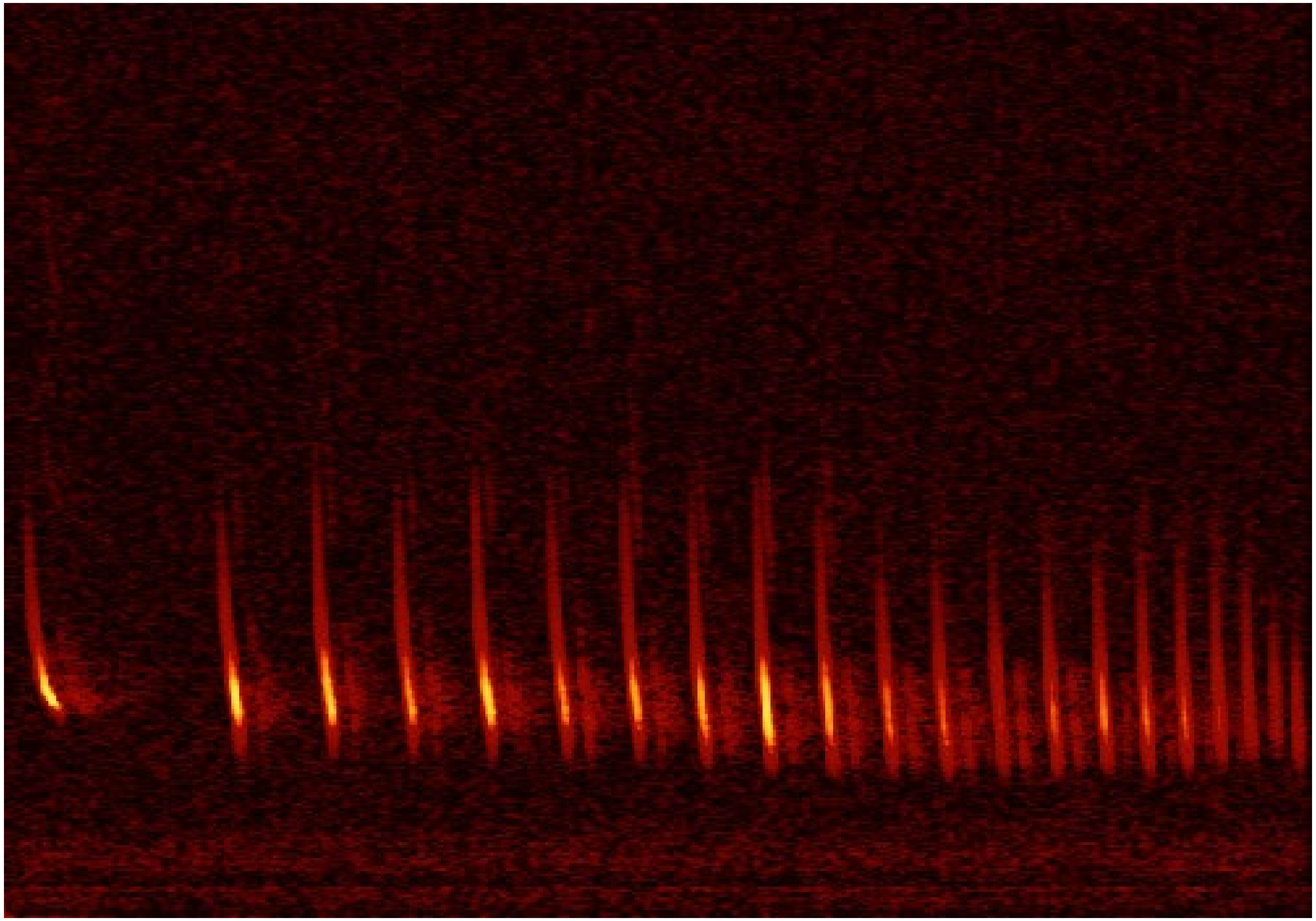
Bats: Social Communication Signal



Bats: Prey Searching Signal



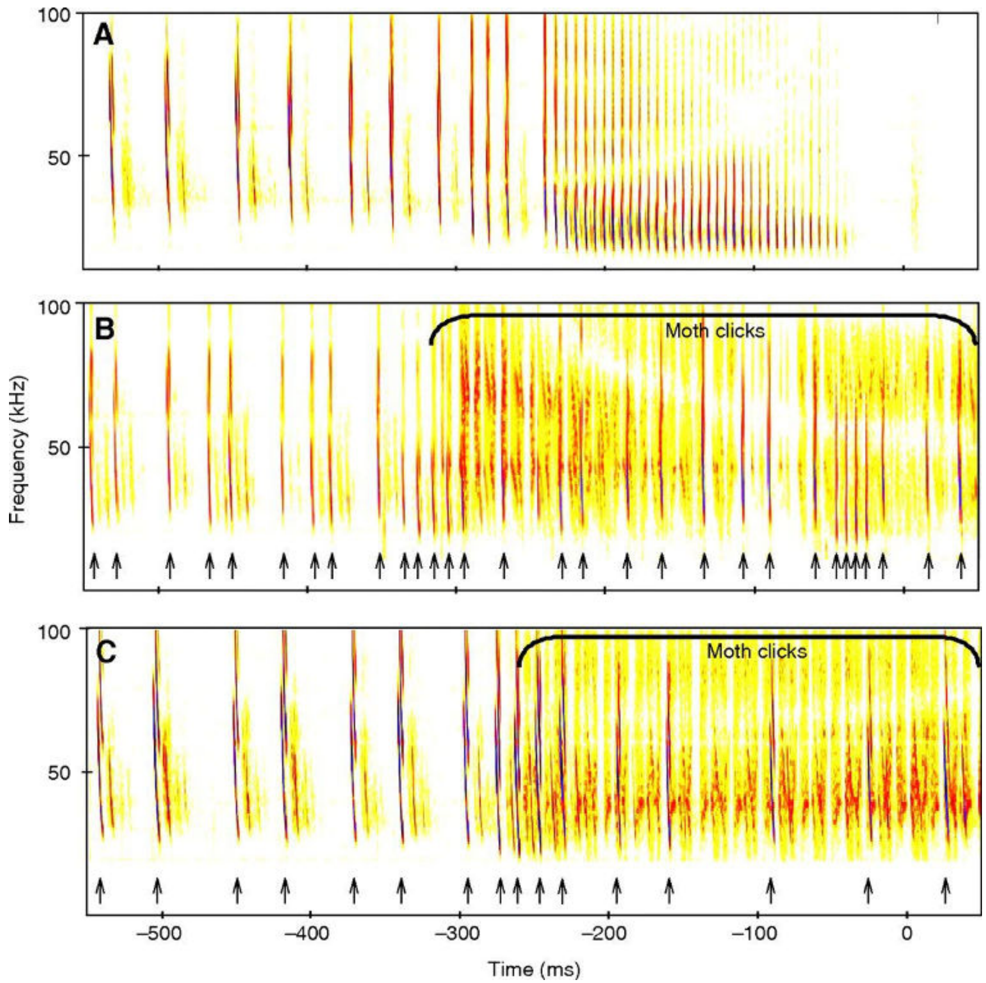
Bats: Hunting Signal



Bats and Equivalent Radar Concepts

BATS	RADAR TERMS
Changing signal based on function	Adaptive radar waveform design
Changing how frequently the chirp is vocalized	Adaptive pulse repetition interval
Object recognition based on received echo from chirp	Adaptive signal processing
Instinctive response to return from a flat surface, e.g. water/mirror	Memory
Being able to hunt using chirping of other bats	Passive multi-static radar network
Moth sounds confusing bats	Electronic Warfare (Jamming)

Visualization of Moth Sounds Jamming Bats



Sevgi Z. Gurbuz (szgurbuz@ua.edu)

Dolphins and Twin Inverted Pulse Radar (TWIPR)

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Research

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http://dx.doi.org/10.1098/rspa.2013.0512

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Accepted: 24 September 2013

Subject Areas:
electrical engineering, acoustics

Keywords:
radar, clutter, target, nonlinear, harmonic, mobile phone

Radar clutter suppression and target discrimination using twin inverted pulses

T. G. Leighton[1], G. H. Chua[1], P. R. White[1], K. F. Tong[2], H. D. Griffiths[2] and D. J. Daniels[3]

[1]Institute of Sound and Vibration Research (ISVR), Faculty of Engineering and the Environment, University of Southampton, Highfield, Southampton SO17 1BJ, UK
[2]Department of Electronic and Electrical Engineering, University College London (UCL), Gower Street, London WC1E 6BT, UK
[3]Cobham Technical Services, Cleeve Road, Leatherhead, Surrey KT22 7SA, UK

The proposition that the use of twin inverted pulses could enhance radar is tested. This twin inverted pulse radar (TWIPR) is applied to five targets. A representative target of interest (a dipole with a diode across its feedpoint) is typical of covert circuitry one might wish to detect (e.g. in devices associated with covert communications, espionage or explosives), and then distinguish from other metal ('garbage' or 'clutter'), here represented by an aluminium plate and a rusty bench clamp. In addition, two models of mobile phones are tested to see whether TWIPR can distinguish whether each is off, on or whether it contains a valid SIM card. Given that a small,

Student: Deepak Elluru

Presentation Topic: TWIPR

- Background: What was the technical problem motivating work?
- Applications
- How do dolphins use echolocation?
- How did this inspire design?
- How does TWIPR work?
- What were the results?

Supplementals:

- News articles
- Balleri, IET, Chapter 9
- What can you find?

Presentation: Next Wednesday

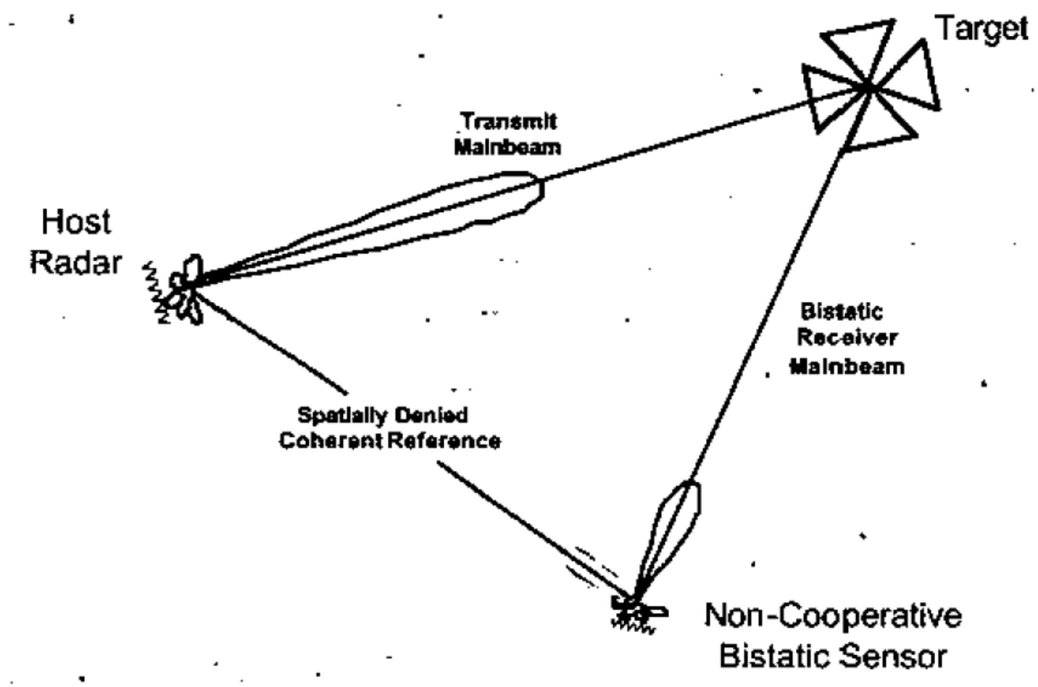
Waveform Diversity

- Definition from IEEE Standard 686-2008:

"Waveform Diversity: Optimization (possibly in a dynamically adaptive manner) of the radar waveform to maximize performance according to particular scenarios and tasks. May also jointly exploit other domains, including the antenna radiation pattern (both on transmit and receive), time domain, frequency domain, coding domain and polarization domain."

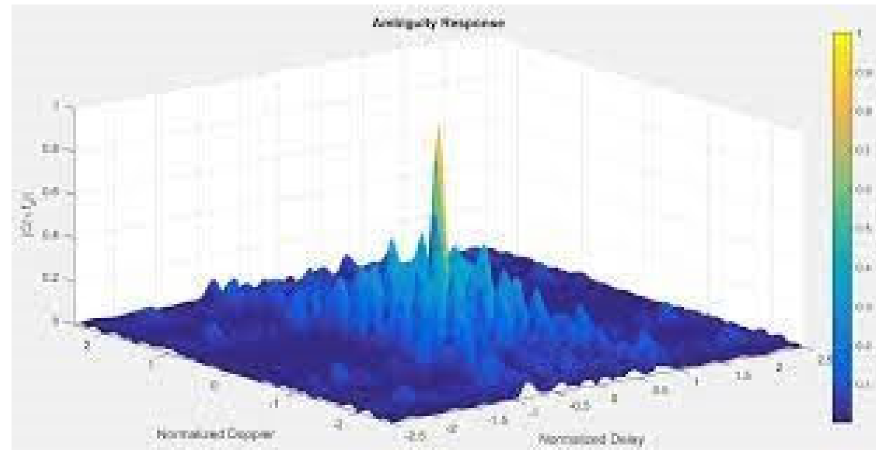
Bistatic Radar Denial by Spatial Waveform Diversity

- Scenario with Passive Bistatic Receivers



Transmission Waveform: Phase-Coded Costas Waveform

- Ambiguity function is like a thumbtack
- Relatively low pedestal



- For a fixed number of frequency hops within a radar pulse there are many different hopping patterns that result in essentially the same ambiguity function
  - Potential to confuse non-cooperative radar is great

Antenna Beam Pattern:

- Interferometric Linear Array of N elements
  - Two interferometric elements are separately driven
  - Interferometric pattern overlays host radar pattern and will serve to mask the portion emitted through the sidelobes

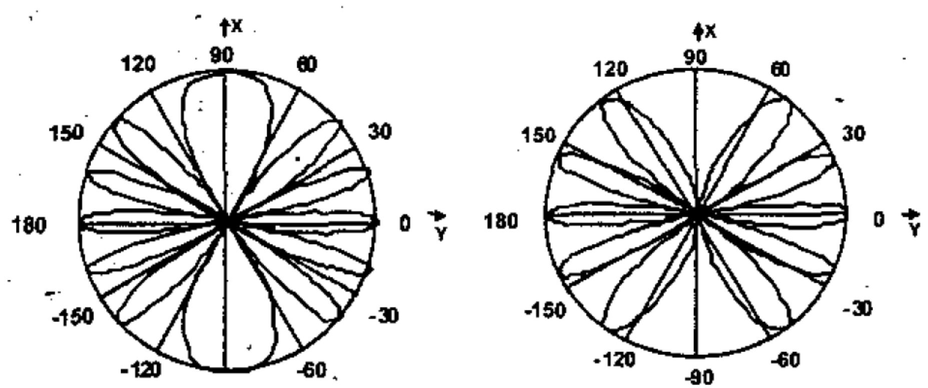


Figure 3. Azimuthal radiation patern for a) N=4 and b) N=5.

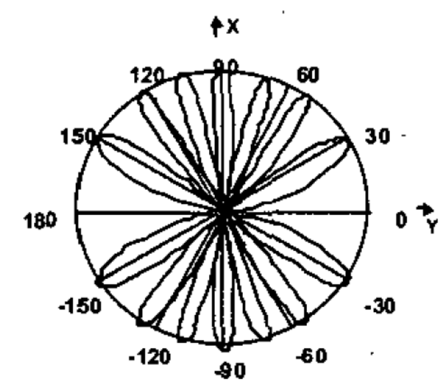


Figure 4. Azimuthal radiation patern for steered interferometer and k_s=7.

Waveform Diversity for SAR-ECCM

- Mehrdad Soumekh, “SAR-ECCM Using Phase-Perturbed LFM Chirp Signals and DRFM Repeat Jammer Penalization” IEEE Radar Conference, 2005.
- M. Soumekh, "SAR-ECCM using phase-perturbed LFM chirp signals and DRFM repeat jammer penalization," in IEEE Transactions on Aerospace and Electronic Systems, vol. 42, no. 1, pp. 191-205, Jan. 2006.
  - Student: Emre Kurtoglu
  - Specific Questions:
    - What is the new waveform proposed?
    - Why?
    - How was it designed?
    - What were the results?
    - Can you find other papers proposing new waveforms for ECCM? What other ideas are out there?