ECE 693 – Special Topics:
AI for Radar System Design

Spectrum Sharing

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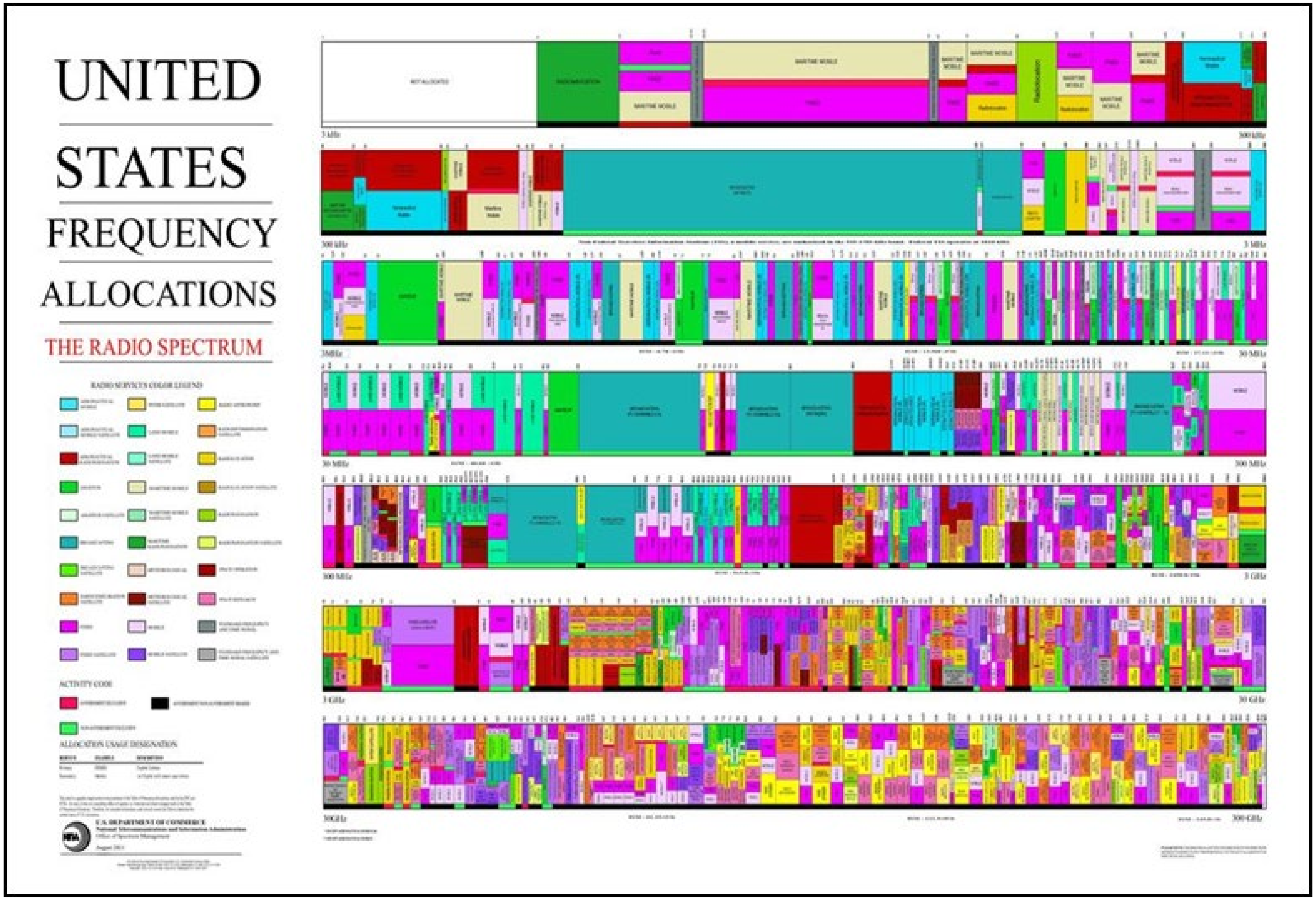
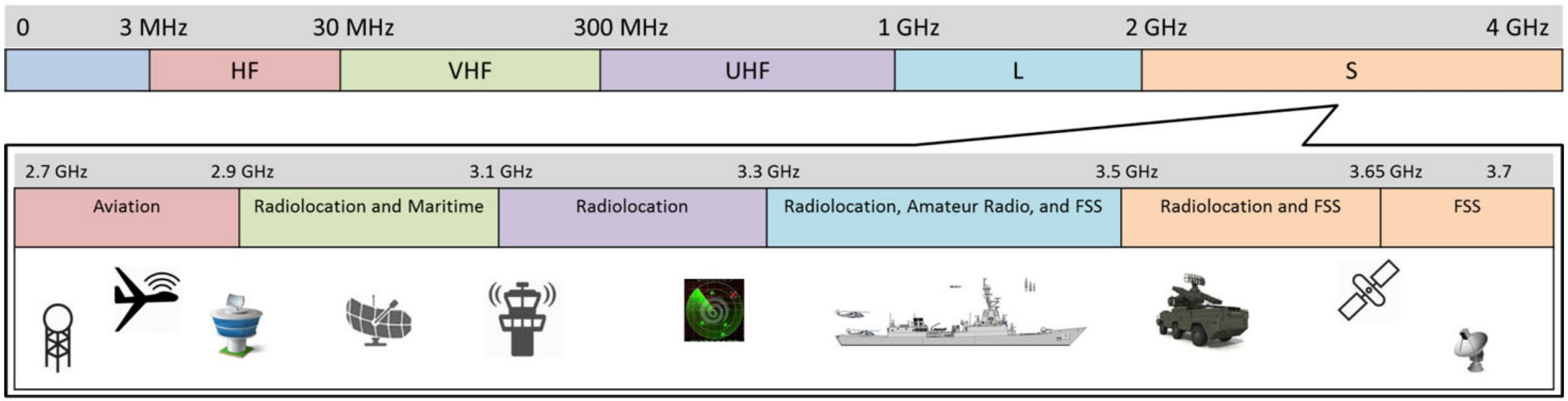
THE UNIVERSITY OF ALABAMA®

Congested Spectrum



Congested Spectrum



User	0 – 300 MHz	300 MHz – 1 GHz	1 GHz – 2 GHz	2 GHz – 4 GHz
Federal	Tactical and non-tactical mobile communications Mobile-satellite communications Air traffic control communications	Instrument Landing System (ILS) Mobile-satellite communications Space research Meteorological aids Earth exploration-satellite Meteorological-satellite Radio astronomy Enhanced Position Location Reporting System (EPLRS) Public Safety Perimeter protection radars Wind profiler radars RFID for container tracking and port security Low-capacity voice and/or data point-to-point and point-to-multipoint microwave communication Aeronautical radio navigation service (ARNS) Distance Measuring Equipment (DME) Tactical Air Navigation (TACAN) system	Distance Measuring Equipment (DME) Tactical Air Navigation (TACAN) system Air Traffic Control Radar Beacon System (ATCRBS) Identification Friend or Foe (IFF) System Global Navigation Satellite System (GNSS) Positioning, Navigation, and Timing (PNT) Joint Tactical Information Distribution System (JTIDS) Air traffic control (ATC) in the national airspace, border surveillance, early warning missile detection, and drug interdiction Ship-to-ship communication systems, nuclear burst detection system, remote sensing, and radio astronomy Passive remote sensing of ocean salinity and soil moisture content Medical telemetry devices Aeronautical mobile telemetry (AMT) Deep Space Network system	Tracking Data and Relay Satellite System (TDRSS) Military research, law enforcement video surveillance, control of robotic systems for explosive ordnance neutralization and disposal, and the testing of robotic ground vehicles Aeronautical telemetry Aeronautical mobile telemetry (AMT) Flight test missions Flight testing of aircraft, missiles, or major components Video link operations from the land mobile robot to the human control station, thus dealing with unexploded ordnance safely for explosive ordnance disposal Air-to-ground-to-air communication, flight telemetry, point-to-point data links, and ship-to-shore communication Airport surveillance radar (ASR) systems and meteorological radars such as Next Generation Weather Radar (NEXRAD) Maritime radio navigation Shipborne, land-based, and aeronautical mobile radar systems used for fleet air defense, missile and gunfire control, bomb scoring, battlefield weapon locations, air traffic control, and range safety Satellite earth stations
Non-Federal	AM and FM broadcast TV RFID Amateur Radio	ZigBee DECT/Cordless telephone GPS GSM UMTS LTE/LTE-A WLAN Bluetooth BAN/WBAN/BSN UWB Modern Cordless telephone		

[1]

Geographical Exclusion Zones

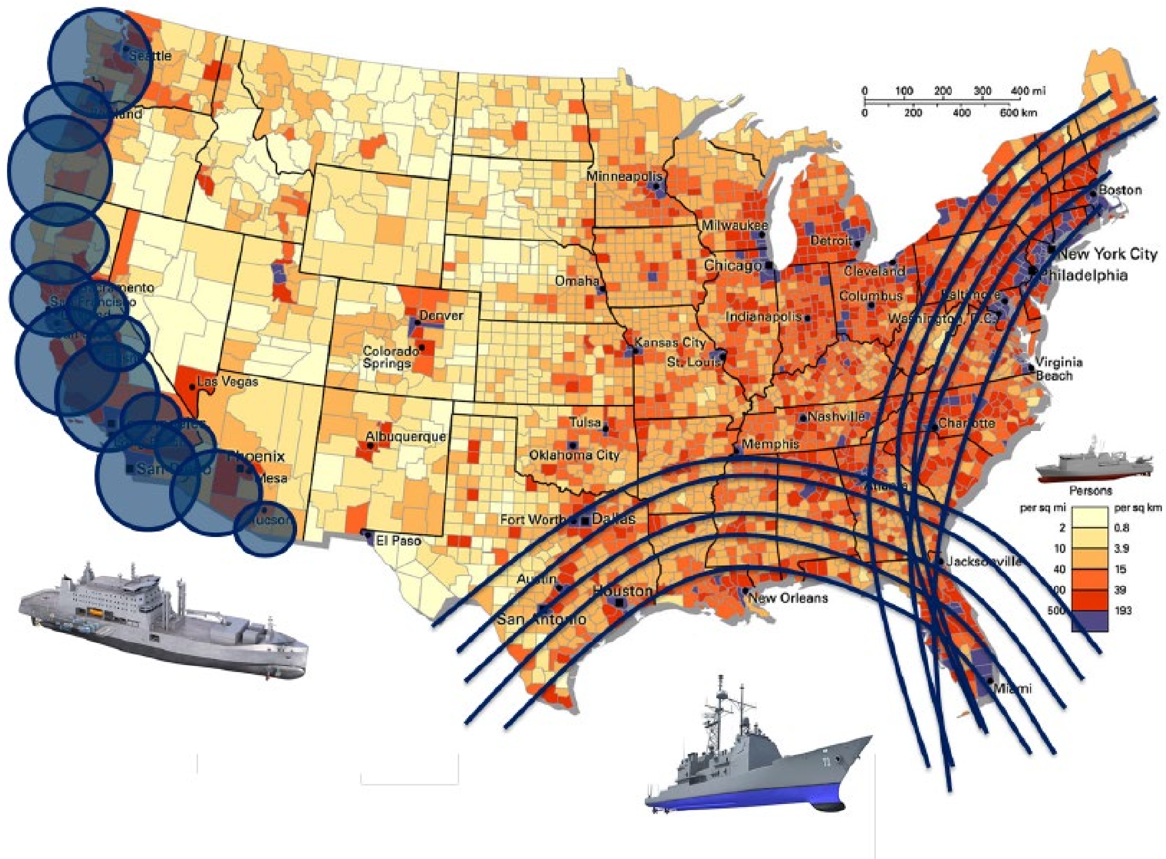


Figure 1.3: Exclusion zones required to protect radar and WiMAX systems from each other's harmful interference.

[1]

Potential Solutions (from perspective of radar)

- Do not let commercial users have some bands
  - Problem: hard to fight economics and demand!
- Find alternative radar transmit bands
  - Increasing utilization of X-band and above
  - Design tradeoffs: power, atmospheric attenuation, greater Doppler shifts, distance
  - Problem: now some comm signals are mmwave!
- Find a technical solution to allow co-existance

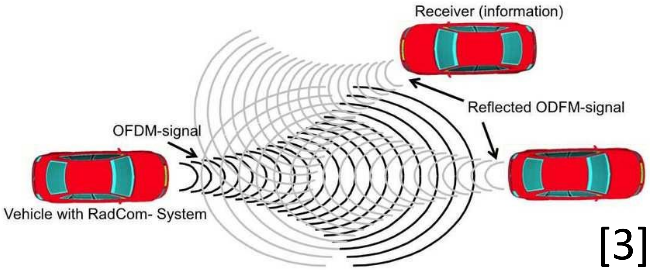
RF Convergence

- Reuse RF signals and receivers
  - Comm and radar are both RF, don't discriminate!
  - Design nodes to perform multiple tasks simultaneously

- Dual radar-communication waveform design
  - Design signals that can be used for comm and radar functions, e.g. detection, tracking, ATR

New Commercial Domains
Use Comm + RF Jointly

[2]



[3]

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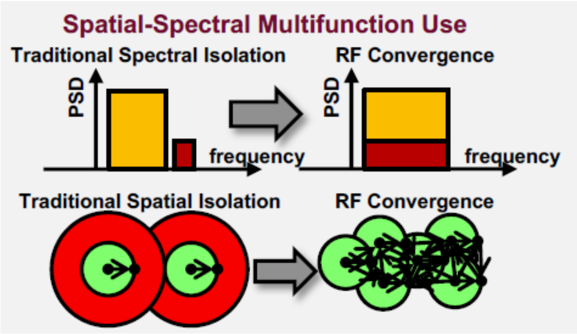
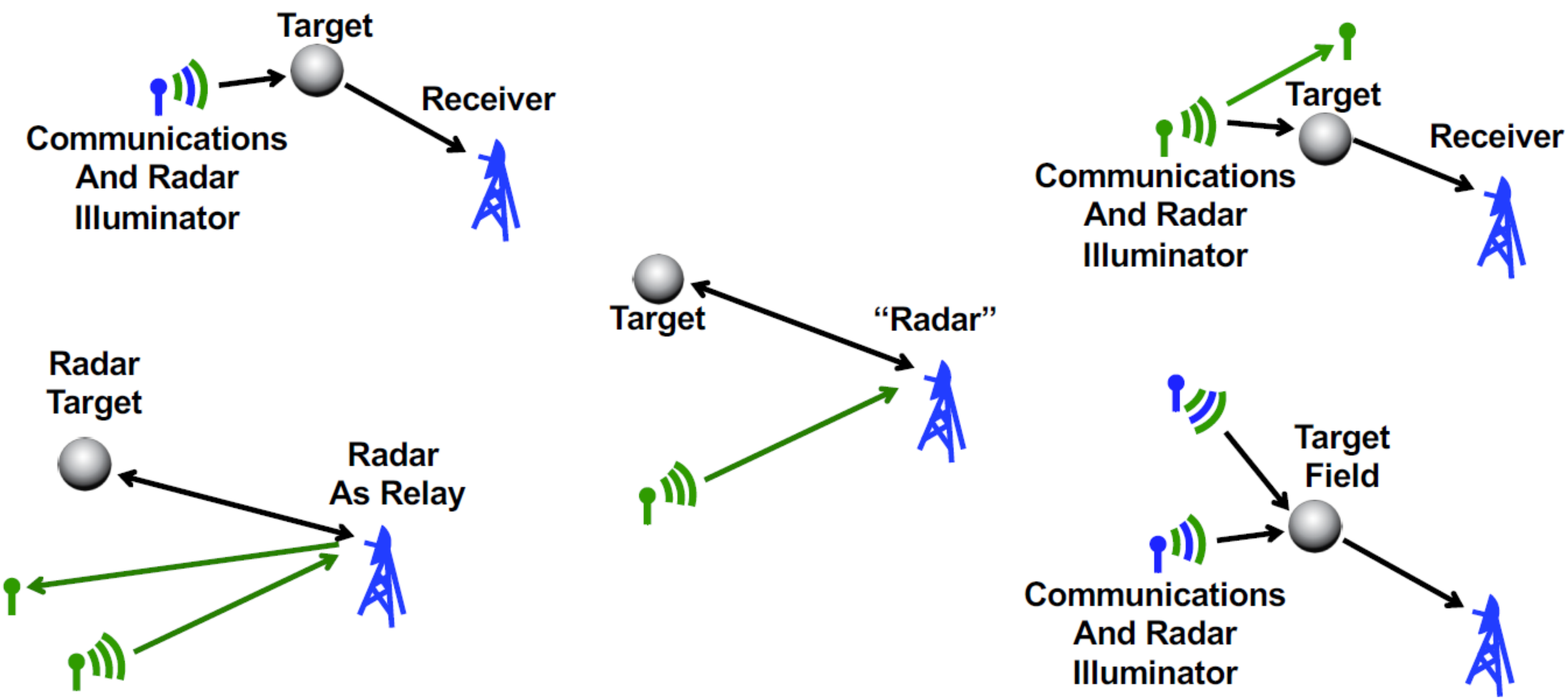
Long-Term Vision of Multi-Function Use



[4]

- Multi-functional waveforms
  - Adaptive waveform design
  - Radar + Communications
  - Anything else?
  - IoT? Human Cyber-Physical Systems?
- Sophisticated receivers that can disentangle multiple waveforms
  - Multiuser detection, adaptive antenna processing
- Optimize network performance
  - Increase multi-functional node density
  - Distributed optimization
  - Optimally using network resources and power (energy harvesting)
  - Other goals?

Topological Examples



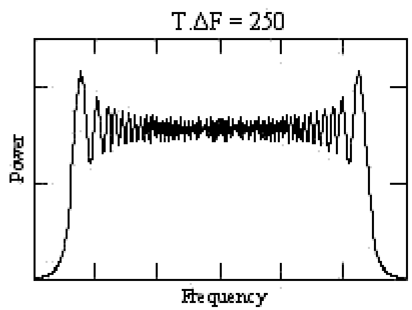
[5]

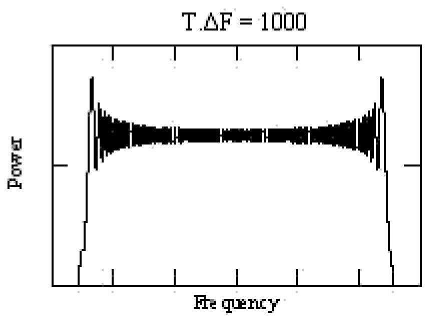
What are design considerations?

- Radar Goals:
  - Desire Constant Modulus
    - Small peak-to-average power ratio
  - Good Ambiguity Function
    - Minimize range and Doppler ambiguities
- Communications Goals:
  - Make dispersion compensation easy (e.g. OFDM)
  - Convenient modulation that matches spectral efficiency needs
  - Employ convenient coding and acknowledgement frames

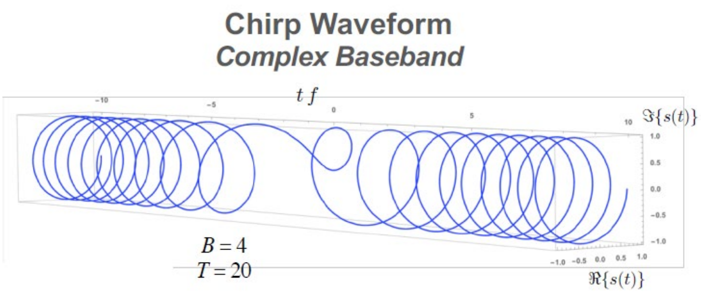
Radar Waveforms: Linear Frequency Modulation

- Linear Frequency Modulated Continuous Wave (FMCW)
  - Quite popular in low-cost, low-power commercial radars and automotive radar systems
  - It is constant modulus, with an approximately uniform spectrum





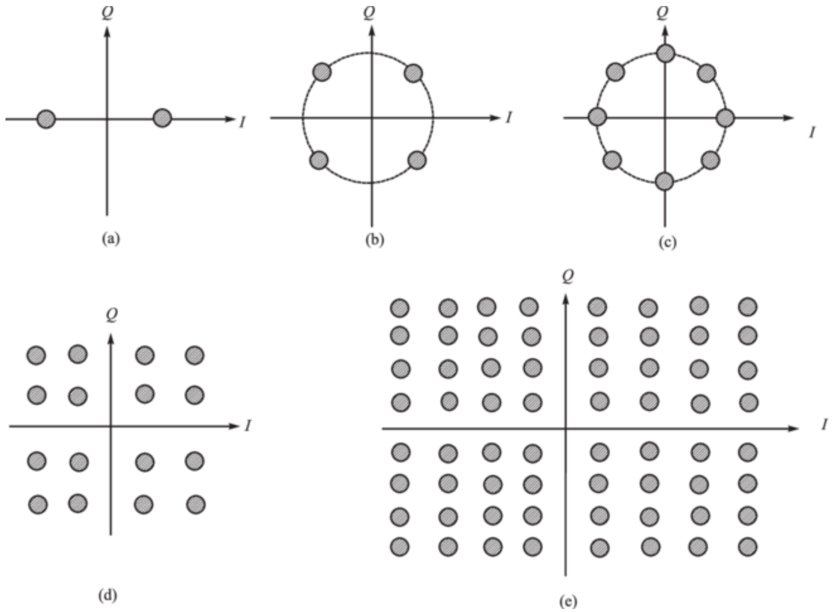
(image: wikipedia)



(image: Dan Bliss)

Communication Waveforms: Digital Modulation

- Encoded bits are converted into complex symbols
  - Number of constellation points: $2^{n_{bits}}$
- Common modulations:
  - Binary Phase Shift Keying (BPSK):
    $$\{-1, +1\}$$
  - M-Phase Shift Keying (M-PSK):
    $$\left\{e^{\frac{2\pi jn}{M}}\right\}; n \in \{0, \dots, M-1\}$$
  - Quadrature phase shift keying (QPSK):
    $$\{\frac{-1-j}{\sqrt{2}}, \frac{-1+j}{\sqrt{2}}, \frac{1+j}{\sqrt{2}}, \frac{1-j}{\sqrt{2}}\}$$
  - Quadrature amplitude modulation (QAM): $\{\pm p \pm jq\}$



(a) BPSK, (b) QPSK, (c) 8PSK, (d) 16QAM and (e) 64QAM

[6]

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Presentations

- Waveform Diversity with Noise Radar
  - S. D. Blunt et al., "Principles and Applications of Random FM Radar Waveform Design," in IEEE Aerospace and Electronic Systems Magazine, vol. 35, no. 10, pp. 20-28, 1 Oct. 2020.
  - Presenter: Eddie Hackett
- Radar-Communications Co-Existence in Automotive Case
  - G. Hakobyan and B. Yang, "High-Performance Automotive Radar: A Review of Signal Processing Algorithms and Modulation Schemes," in IEEE Signal Processing Magazine, vol. 36, no. 5, pp. 32-44, Sept. 2019.
  - Presenter: TBD
- Dual Function Radar Communication Systems:
  - A. Hassanien, M. G. Amin, E. Aboutanios and B. Himed, "Dual-Function Radar Communication Systems: A Solution to the Spectrum Congestion Problem," in IEEE Signal Processing Magazine, vol. 36, no. 5, pp. 115-126, Sept. 2019.
  - A. Hassanien, M. G. Amin, Y. D. Zhang and F. Ahmad, "Signaling strategies for dual-function radar communications: an overview," in IEEE Aerospace and Electronic Systems Magazine, vol. 31, no. 10, pp. 36-45, October 2016.
  - Presenter: Ladi Adeoluwa

Presentations (2)

- Cognitive radar for spectrum sharing
  - A. F. Martone et al., "Closing the Loop on Cognitive Radar for Spectrum Sharing," in IEEE Aerospace and Electronic Systems Magazine, vol. 36, no. 9, pp. 44-55, 1 Sept. 2021.
  - P. Stinco, M. Greco, F. Gini and B. Himed, "Cognitive radars in spectrally dense environments," in IEEE Aerospace and Electronic Systems Magazine, vol. 31, no. 10, pp. 20-27, October 2016.
  - Presenter: Sean Kearney

References

1. A. Khawar, “Spectrum Sharing Between Radar and Communication Systems,” PhD Thesis, Dept. Electrical Engineering, Virginia Polytechnic Institute and State University, 2015.
2. A. Cuthbertson, “Project Soli: Google’s Futuristic Plan to Replace Buttons and Touchscreens Gets Go-Ahead,” Independent, January 3, 2019. https://www.independent.co.uk/life-style/gadgets-and-tech/news/google-project-soli-gesture-control-minority-report-radar-chip-a8709851.html
3. Reichardt, Lars & Sturm, Christian & Grunhaupt, Frank & Zwick, Thomas. (2012). Demonstrating the use of the IEEE 802.11P Car-to-Car communication standard for automotive radar. 1576-1580. 10.1109/EuCAP.2012.6206084.
4. A. Herschfelt and D.W. Bliss, “Spectrum management and advanced receiver techniques (SMART): Joint radar-communications network performance,” IEEE Radar Conference, Oklahoma City, OK, 2018.
5. B. Paul, A. R. Chiriyath and D. W. Bliss, "Survey of RF Communications and Sensing Convergence Research," in IEEE Access, 2017.
6. Singh, Shree & Sengar, S. & Bajpai, Rochak & Iyer, Sridhar. (2014). Next-Generation Variable-Line-Rate Optical WDM Networks: Issues and Challenges. Journal of Optical Communications. 34. 331-350.