A New HF Over the Horizon Radar Architecture

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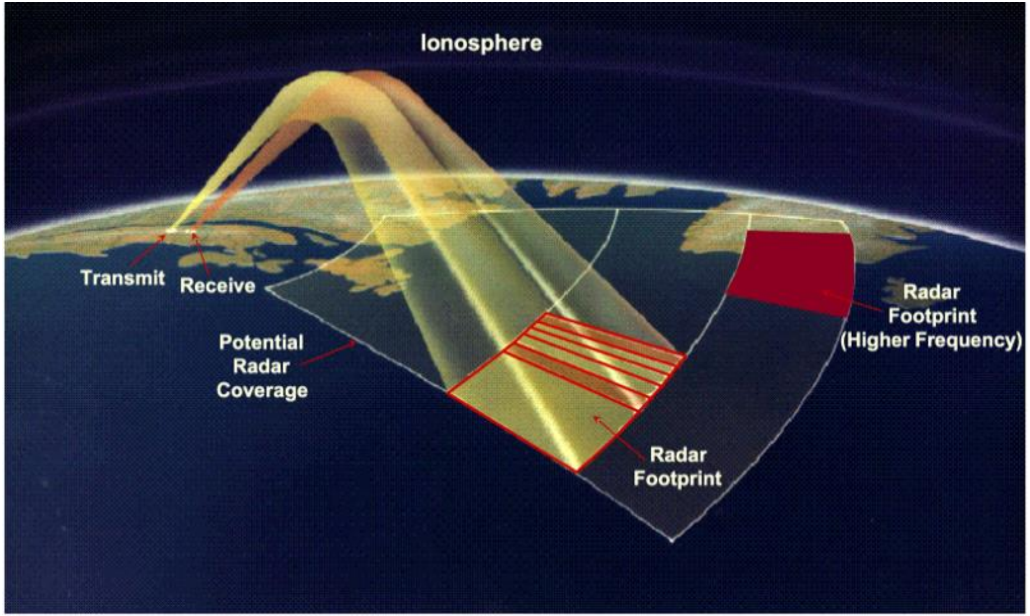
Conventional OTHR

Conventional OTHR – the basics 1

- Radar signals reflected by the ionosphere to give over the horizon operation
  - 500-3000km
- Typically
  - Tx/Rx typically separated by 50 to 100km to minimize ground wave
  - “Short” transmit array 140 m long (7 λ at 15 MHz)
  - “Long” receive array of 2 km long (100 λ at 15 MHz)
  - Power = 500 kW.
- The receive array dictates the angular/cross range resolution.
  - Angular resolution of ~0.6°
  - Cross range resolution of ~20 km at 2000 km range.



Conventional OTHR – the basics 2

- Frequency of operation is chosen via Frequency Management (FM) tool
    - Aims to maximize power on area of interest

- The radar measures the radar range (group range)
- The ground range is determined by a process known as coordinate registration (CR)
- CR Maps radar range to ground range at the operating frequency and for the propagation mode

- FM and CR requires knowledge of the ionosphere along the path.
- This could be derived from a median model
    - But the resulting accuracy would be poor
- Better a combination of model and measurement.

- The azimuthal direction of arrival (DOA) and line of sight (LOS) speed are determined by reference to the long antenna array at the receive site.

Heavy Engineering

Canadian P-OTHR array, after Riddols (2022).
On receive vertical monopoles are common.

Australian JORN transmit array – Laverton, WA.
On transmit vertical log periodic arrays are common.

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Networked Over The Horizon Radar (NOTHR)

- research in progress.

Based on patent “Over the Horizon Radar (OTH) System and Method”.

USA: US11953580 B2, 9 Apr 2024

Australia: AU2019293166B2, 13 Jun 2024

EU: EP3834007B1, 28 Aug 2024

UK: WO2020002937A1, 30 Jun 2025.

And Australian DSTG intellectual property.

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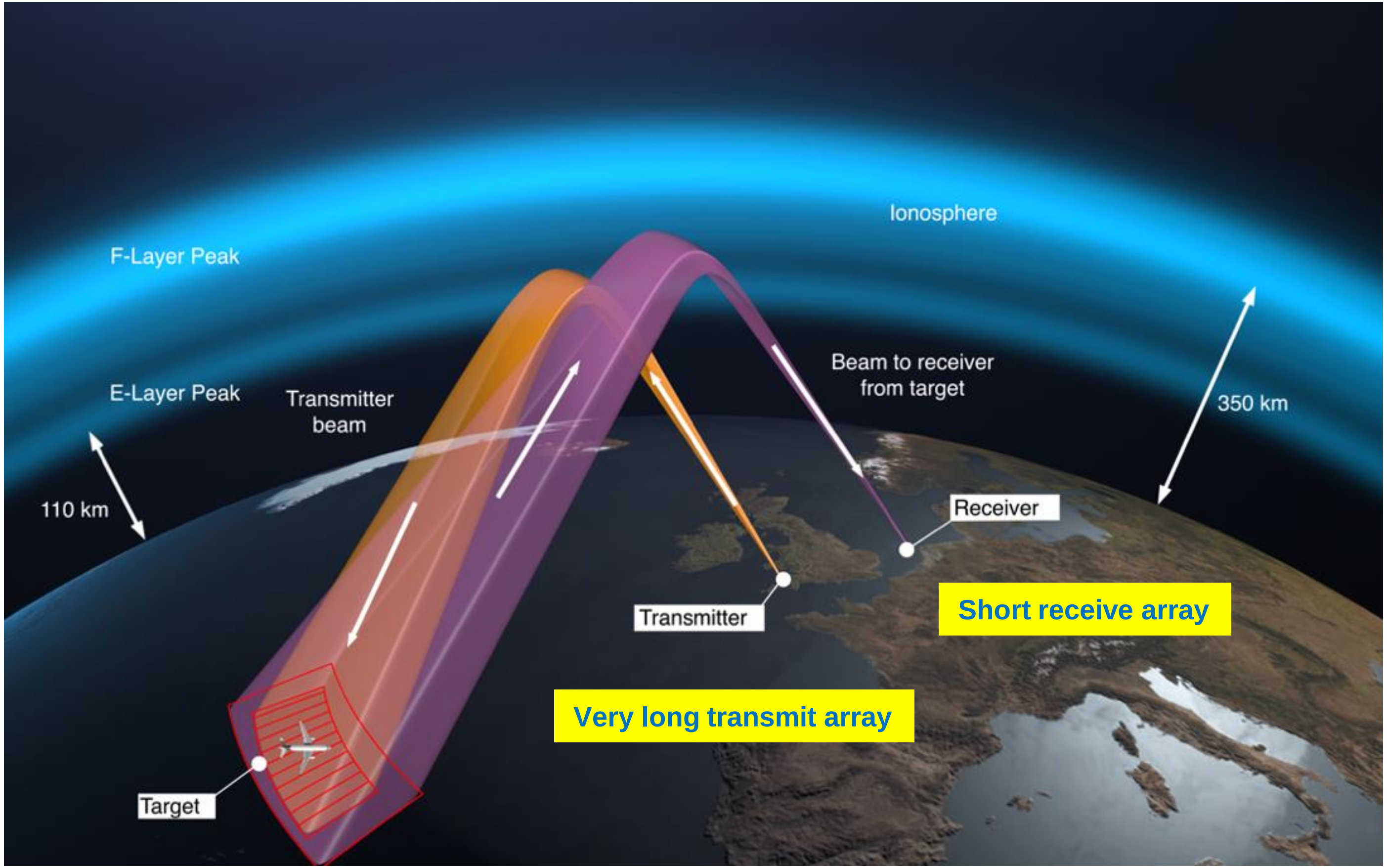
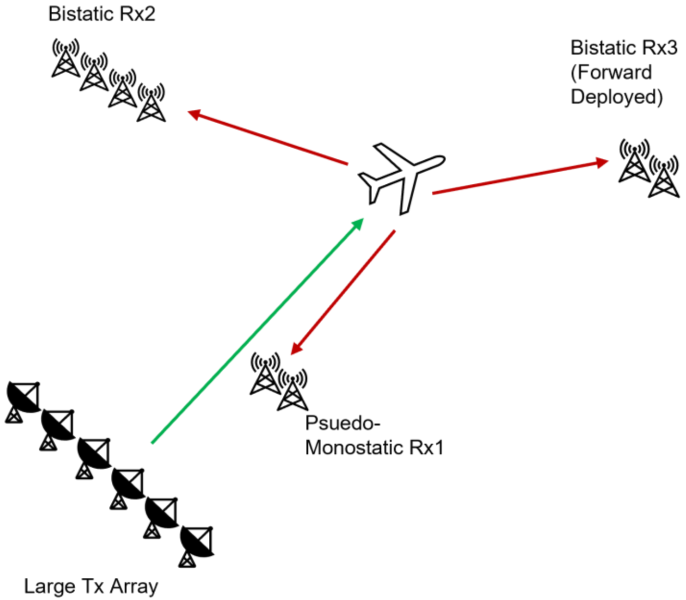
NOTHR Overview



NOTHR Attributes

- Key characteristics:
  - Large transmit array.
  - Many small receive arrays.
  - Bistatic and monostatic operation.

  - Orthogonal coded signals transmitted on each transmit array element to distinguish those signals and provide azimuthal discrimination.



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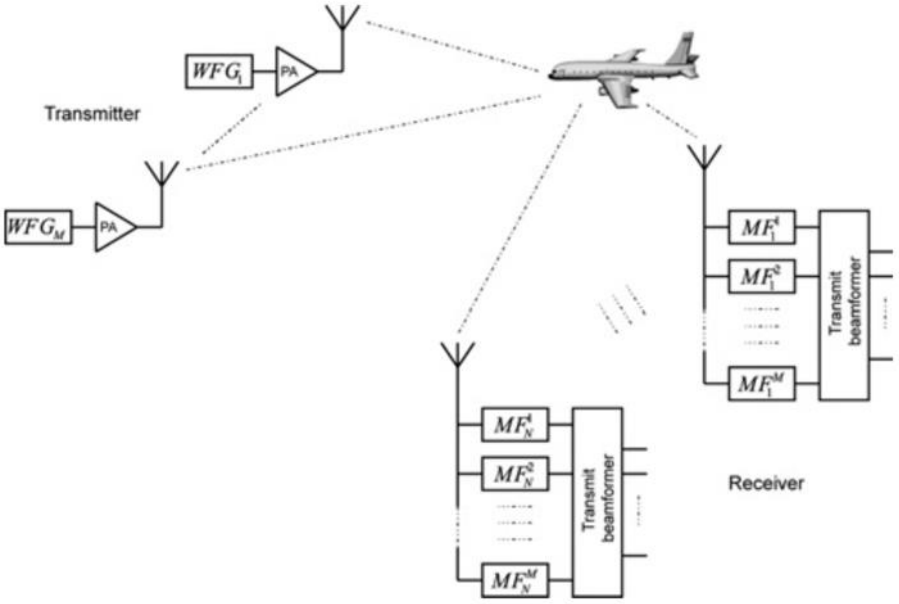
Representative MIMO radar system

- Assume a long multi-element transmit array.
- Transmit a set of orthogonal waveforms, one per array element.
- Defer the the transmit beamforming until after:
    - Propagation, scattering from the target, and propagation again.
- Then do the transmit array beam forming at the receive system knowing the transmitted coded signals and the transmit antenna geometry.
- This gives the target azimuthal direction of departure (DoD).



Benefits

- Receive systems are small and physically simple, therefore the radar receive systems are relocatable and possibly even mobile.

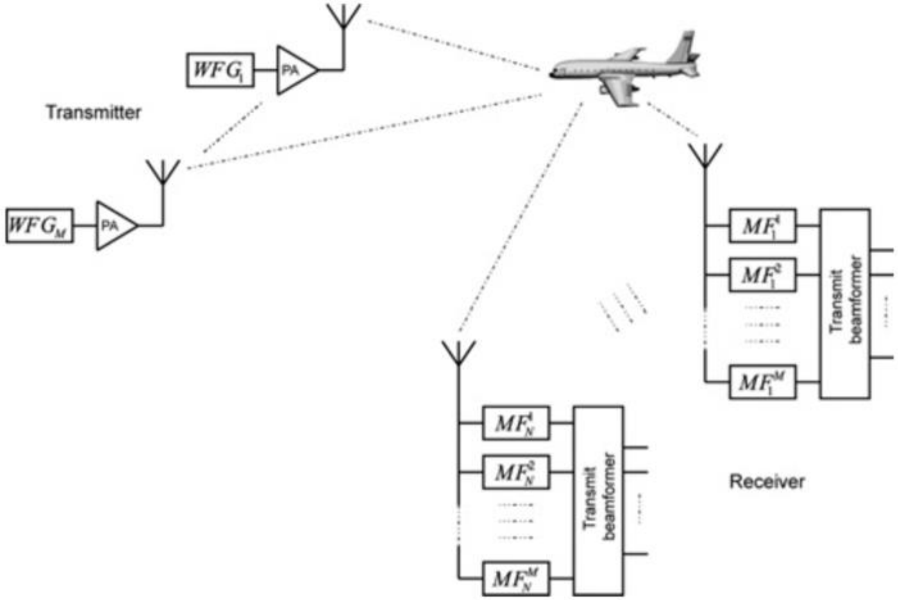
- Receive systems can be numerous: numerous receive systems can cooperatively measure velocity instead of just speed.

- Receive look angles vary for different receive systems.
  - Consequently, the radar system can detect targets hidden in monostatic sea clutter.
  - Can detect targets tracking perpendicular to monostatic lines of sight.

- If a 2D antenna is employed at either the transmit system, the receive system or both, nulls can be steered to select the propagation modes to minimize land, sea and ionospheric clutter.

Challenges – 1

- Challenges
  - For a noise limited system, aggregation of noise from M matched filters, results in a performance degradation, with respect to a conventional OTHR
    - To put this in context a system with 100 transmit array elements will be 20 dB less sensitive than a conventional system
    - Unless steps are taken to mitigate this



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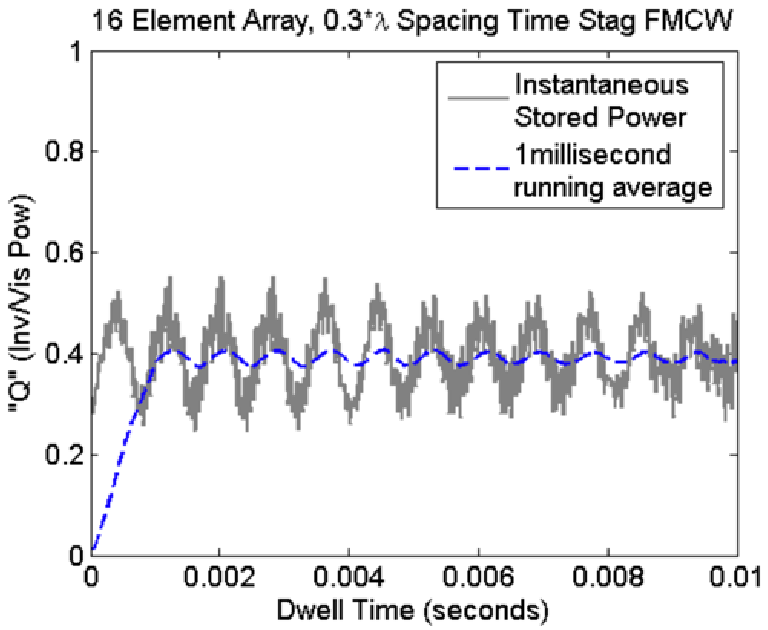
Mitigations to Challenge – 1

- A small directional receive array able to steer nulls onto atmospheric noise sources and interference will improve the SNR.
- Longer integration times will improve the SNR and are possible because the system can stare at a surveillance region continuously. This is unlike a conventional radar which must manage its resource to multiplex between different tasks. The only limitation is the level of parallelization at the receive system.
- Longer integration times may also be made possible by using a combined tracker and coordinate registration system.
- Cooperative detection and tracking between receivers can enhance the performance.

Challenges and Mitigations – 2

- Challenge
  - The out of phase orthogonal signals on the transmitter antennas can cause significant transmit antenna mismatches, due to mutual coupling (Johnson et al., 2007).

- Mitigations
  - Separate the antennas by more than half a wavelength and control the grating lobes with the receive array.



Reactive power with time-staggered FMCW orthogonal waveform set (after Johnson et al. (2007)

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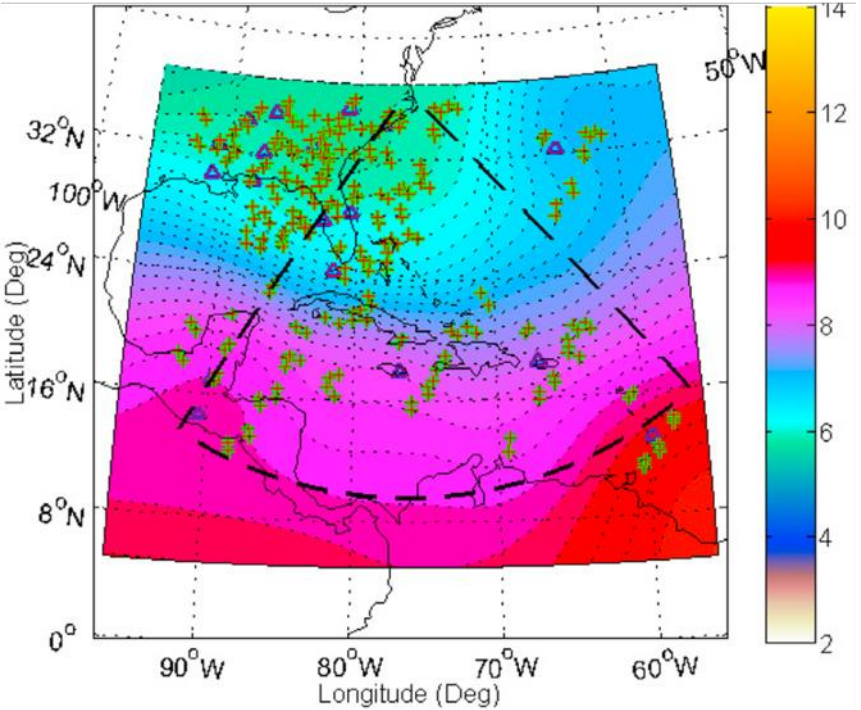
Challenges and Mitigations (3)

- Challenge
  - NOTHR coordinate registration requires knowledge of the ionosphere on bistatic paths
- Mitigation
  - Assimilative ionospheric models
  - High fidelity ray tracing
  - Regularised inversion
    - Extended SIFTER to accommodate multiple receivers
    - S. V. Fridman and L. J. Nickisch (2004) *Rad. Sci.*, 39(1)
  - Performance limited by sub-model scales variability such as TIDs



Fridman, S. V., Nickisch, L. J., & Hausman, M. (2012). Inversion of backscatter ionograms and TEC data for over-the-horizon radar, *Rad. Sci.*, *47*(4)

Conclusion

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Summary

- The NOTHR concept has a number of advantages over a conventional radar including:
  - Small, deployable receive systems
  - An inherent capability to detect slow targets which would be hidden in the clutter of a conventional radar
  - An ability to measure velocity as opposed to line-of-sight speed.

- However, it is a technical challenge to implement, requiring:
  - Mitigation of the MIMO sensitivity reduction (for a noise rather than clutter limited system)
  - Mitigation of antenna coupling effects
  - A 3D real time ionospheric model

Thank you