Aerospace & Defence Test

PASSIVE RADAR SYSTEMS

Leander Humbert
Technology Manager Radar & EW

ROHDE&SCHWARZ

Make ideas real

AGENDA

Passive Radar Systems

1.	**What is Passive Radar?** Bistatic Radars Emitters of Opportunity Bistatic vs. Forward Scattering Passive Radar vs. Emitter Location Systems Passive Radar vs. Stealth Examples of Real Live Systems
2.	**Testing Challenges for Passive Radar** “Classical” Receiver Testing Performance Testing Scenario Based Testing RF-to-the-Lab
3.	**Operational Benefits with R&S Broadband Amplifiers**
4.	**Conclusion**

AGENDA

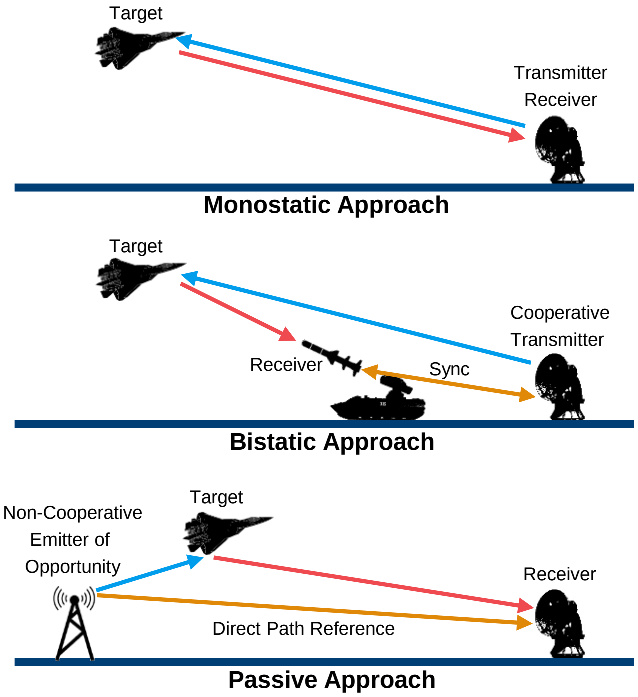
Passive Radar Systems

1. **What is Passive Radar?**
   Bistatic Radars
   Emitters of Opportunity
   Bistatic vs. Forward Scattering
   Passive Radar vs. Emitter Location Systems
   Passive Radar vs. Stealth
   Examples of Real Live Systems
2. **Testing Challenges for Passive Radar**
   “Classical” Receiver Testing
   Performance Testing
   Scenario Based Testing
   RF-to-the-Lab
3. **Operational Benefits with R&S Broadband Amplifiers**
4. **Conclusion**

WHAT IS PASSIVE RADAR?
BISTATIC RADAR 1/8

Radar Systems by Antenna Architectures

- Generally, the transmitter and receiver share a common antenna, which is called a **monostatic radar** system.
- A **bistatic radar** consists of separately transmitting and receiving sites. A bistatic radar makes use of the forward scattering of the transmitted energy. There needs to be a synchronization between both sites. Examples for bistatic radar are:
  - weather radars
  - semi-active or TVM missile control systems
  - secondary surveillance radar (SSR) systems
  - **passive coherent radar** (PCR) systems



WHAT IS PASSIVE RADAR?
BISTATIC RADAR 2/8

Why go for Passive Radar now?

Not actively transmitting

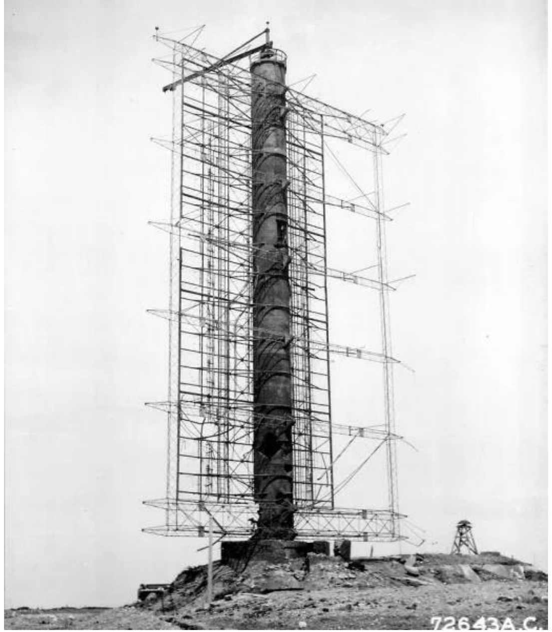
- ► Covert surveillance tasks
- ► Use in areas of electromagnetic congestion
- ► Detection beyond borders

Potential for detecting low RCS targets

Use Cases

- ► Camp and event protection
- ► Long range border/ coastal surveillance
- ► Harbor awareness & protection without interference
- ► Ship self-protection
- ► Air traffic management

Technology for
Passive Radars is not new

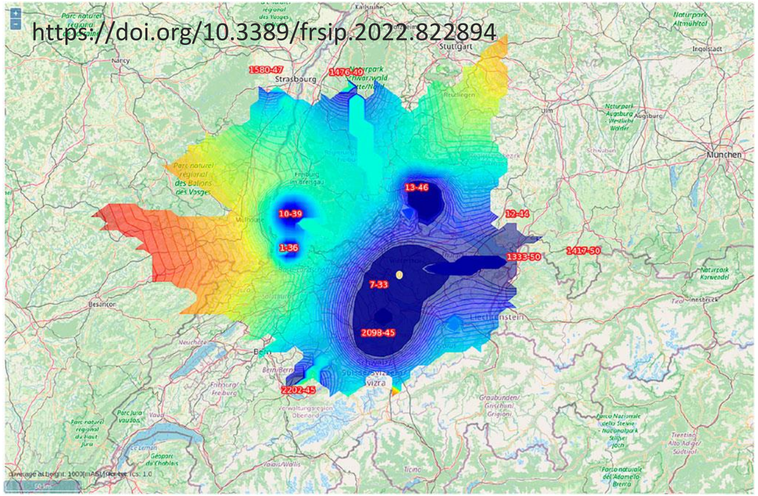


"Klein Heidelberg" (1944) passively used transmissions of the UK Chain Home Systems

WHAT IS PASSIVE RADAR?
BISTATIC RADAR 3/8

What are the challenges with PCR?

- Dependence on non-cooperative transmitters (called Emitters-of-Opportunity, Transmitters- or Illuminators-of-Opportunity)
  - time-varying characteristics of EoO (like periods of silence, power outage, leakage from adjacent channels, soil moisture)
  - pre-deployment mission planning is demanding (due to polarization, transmission coverage, shadowing etc.)
- Computational challenging in complex scenarios



Passive Radar Coverage: FM Sensor is indicated by the yellow circle and real world FM transmitters by red numbers. Coverage computation is shown as minimal detectable RCS (0.1 blue to 150 m^2 red) for altitude 3000 masl.

WHAT IS PASSIVE RADAR?
BISTATIC RADAR 4/8

Bistatic math is simple…

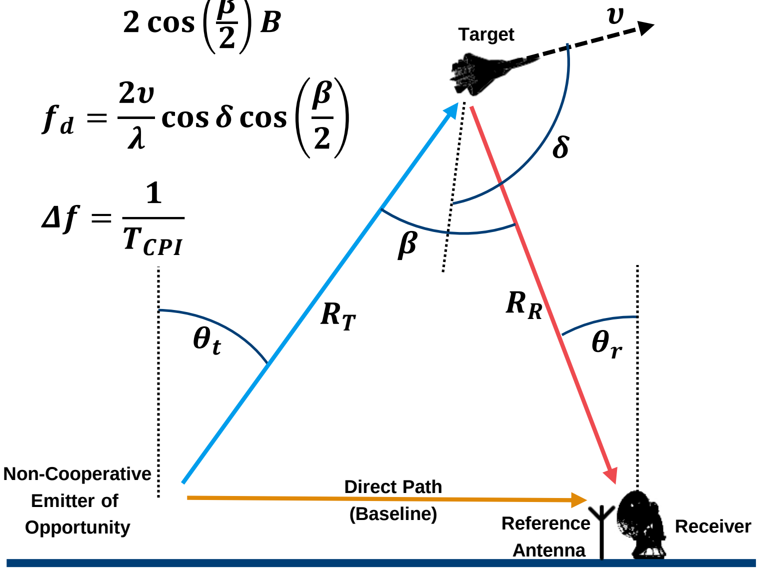
- ► Bistatic radar equation (using Oval of Cassini to solve SNR) for calculation of maximum target range
- ► Range Resolution depends on signal bandwidth reduced by bistatic geometry (with β = bi-static angle)
- ► Bistatic Doppler-Shift comprises two contributions
  - – relative radial motion between transmitter-to-target
  - – relative motion between target-to-receiver
  - – both Tx and Rx are stationary → Doppler depends on the target motion only
- ► Doppler Resolution is limited by the cross-correlation between the signals from direct to reflected path and therefore by the maximum CPI

$$R_{Rmax} = \sqrt{\frac{P_T G_T G_R \lambda^2 \sigma_B G_P}{(4\pi)^3 R_T^2 kTBF_n SNR_{min} Loss}}$$

$$\Delta r = \frac{c}{2\cos\left(\frac{\beta}{2}\right) B}$$

$$f_d = \frac{2v}{\lambda}\cos\delta\cos\left(\frac{\beta}{2}\right)$$

$$\Delta f = \frac{1}{T_{CPI}}$$



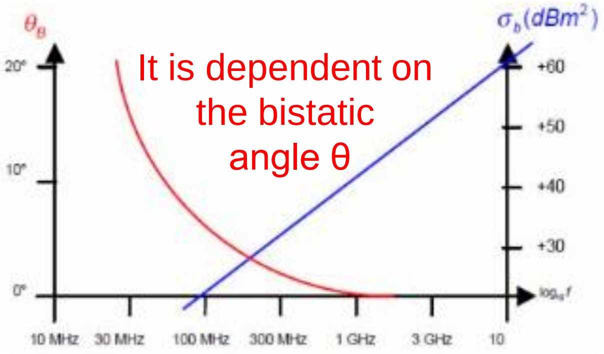
WHAT IS PASSIVE RADAR?
BISTATIC RADAR 5/8

Bistatic math is simple…

- Bistatic radar equation (using Oval of Cassini to solve SNR) for calculation of maximum target range
- Range Resolution depends on signal bandwidth reduced by bistatic geometry (with β = bi-static angle)
- Bistatic Doppler-Shift comprises two contributions
  - relative radial motion between transmitter-to-target
  - relative motion between target-to-receiver
  - both Tx and Rx are stationary → Doppler depends on the target motion only
- Doppler Resolution is limited by the cross-correlation between the signals from direct to reflected path and therefore by the maximum CPI

$$R_{Rmax} = \sqrt{\frac{P_T G_T G_R \lambda^2 \sigma_B G_P}{(4\pi)^3 R_T^2 k T B F_n SNR_{min} Loss}}$$

Note: Bistatic RCS is not Monostatic RCS!



It is dependent on the bistatic angle θ

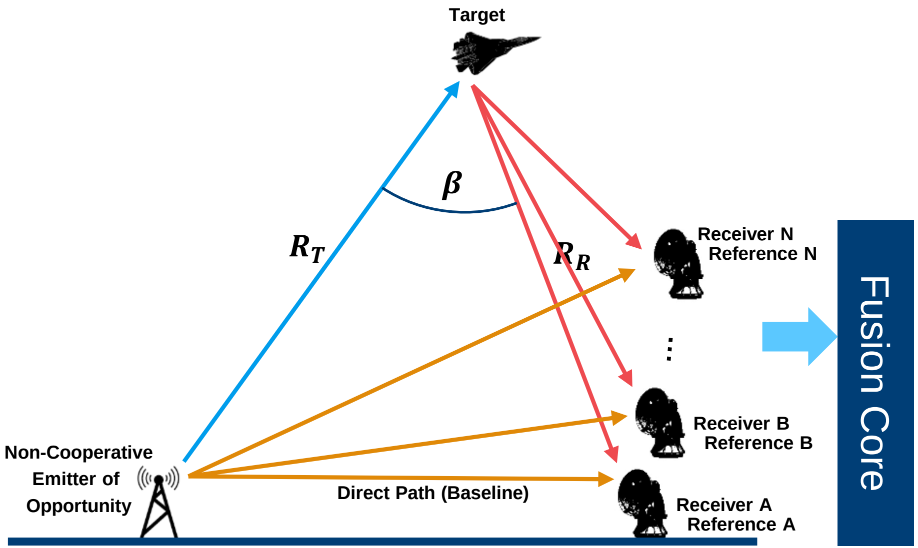
But more on that later…

WHAT IS PASSIVE RADAR?
BISTATIC RADAR 6/8

…but requires high computational effort…

- The real-time correlation processing of reference an reflected signals
- Multi-static approaches require a centralized dedicated sensor fusion
- The number of usable EoOs per PCL sensor is limited by
  - computational resources available
  - the receiver bandwidth

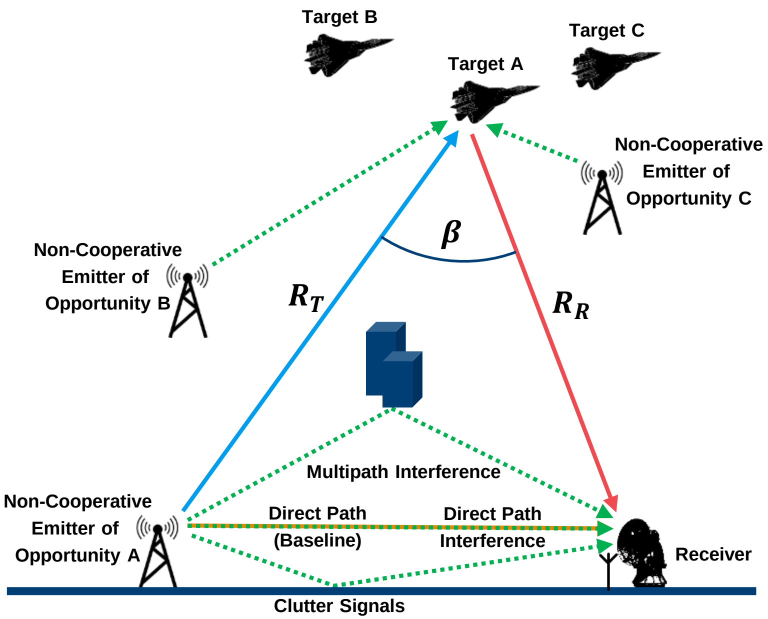
  → Available PCL systems mainly use heuristics, on site signal measurements and human expertise to chose best suited EoOs in a given area



WHAT IS PASSIVE RADAR?
BISTATIC RADAR 7/8

…especially in a dense spectral environment!

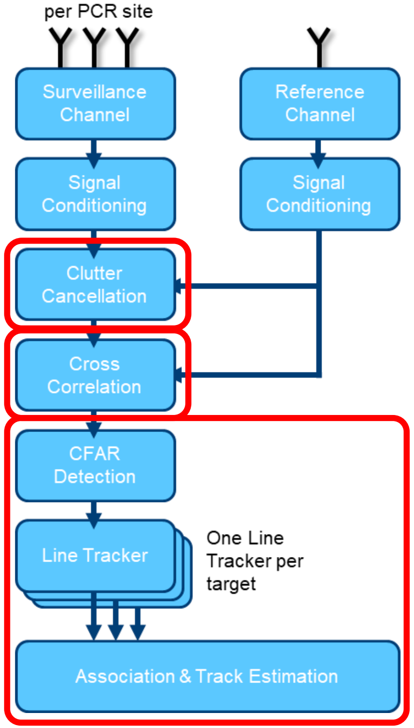
- ► Strong interference of the reflection signal due
  - – The reference signal directly ($P_{Ref} \gg P_{Target}$), called direct signal interference (DSI)
  - – Clutter Signals from Reference Signal
  - – Multipathing by other static reflectors, called Multipath Signal Interference (MSI)
- ► Other similar EoOs might have good correlation values with the reference as well
- ► Presence of multiple reflectors might have an impact on performance as well



WHAT IS PASSIVE RADAR?
BISTATIC RADAR 8/8

The main signal processing techniques for passive radars are:

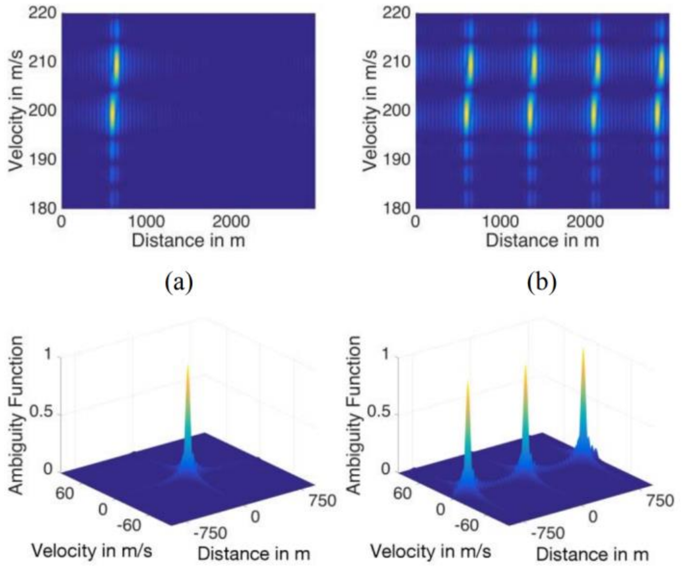
- ► The direct path and static clutter signals are to be suppressed from the surveillance signal
- ► The matched filter is used to process the "clean" surveillance signal and reference signal
- ► Time-frequency analysis to analyze the micro-Doppler of the target
- ► Processing of Beamforming for extracting Angle-of-Arrival



WHAT IS PASSIVE RADAR?
EMITTERS OF OPPORTUNITY 1/3

What makes a "good" Emitter of Opportunity?

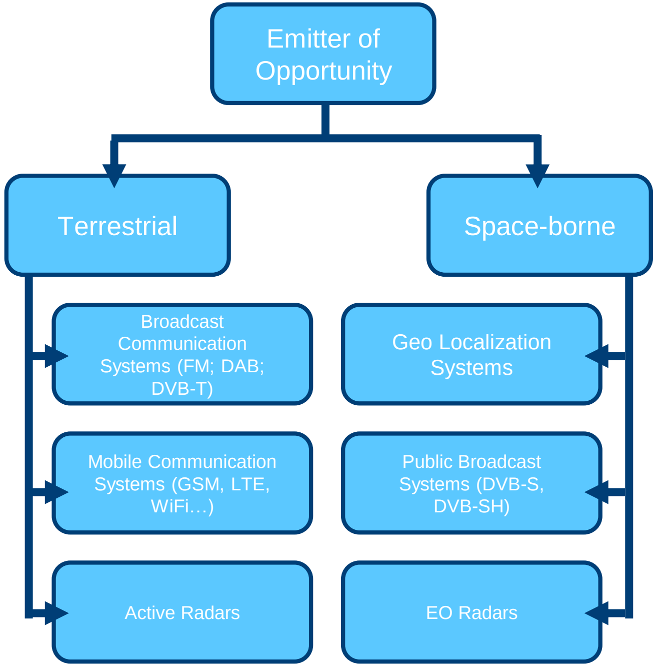
- From the previous concepts some of the signal characteristics can be derived, that are favorable for use as PCR illuminator:
  - Most obivious is the transmit power $EIRP_T = P_T G_T$ as it directly impacts the maximum detectable target range
  - The signal's bandwidth translates to the range resolution of the PCR system
  - An ambiguity function of the waveforms that ideally forms a thumbtack (2-D Autocorrelation in time and frequency)
  - The location of the transmitting antenna (LoS, Shadowing, coverage etc.)



WHAT IS PASSIVE RADAR?
EMITTERS OF OPPORTUNITY 2/3

Emitter	RF [GHz]	Modulation EIRP*	Advantages	Disadvantages
FM Radio	~0.1	FM, 50 kHz 250 kW	High power levels provided and wide coverage.	Low resolution; thus, low-RCS target are difficult
DAB	~0.2	OFDM 220 kHz 10 kW		
DVB-T	~0.6	COFDM 6 MHz 8 kW	ambiguity function independent of data transmitted	deterministic components cause peaks of ambiguity function
LTE base stations	2	CDMA 5 MHz 100 W	Excellent ambiguity function.	Limited to only low-altitude target
GNSS	1.2 1.5	BPSK ~15 MHz ~100 W	Global coverage and availability of multiple sources	No continuous signal from a single satellite
ATC Radar	Ex.1.3	NLFM, 1 MHz e.g. 60 kW	Constant and controlled coverage.	All materials do not reflect a conventional radar signal, especially low-RCS-like Drone.
DVB-S2	14	PSK 4 GHz/40 MHz ~500 kW		

*of course received field strength depends on distance

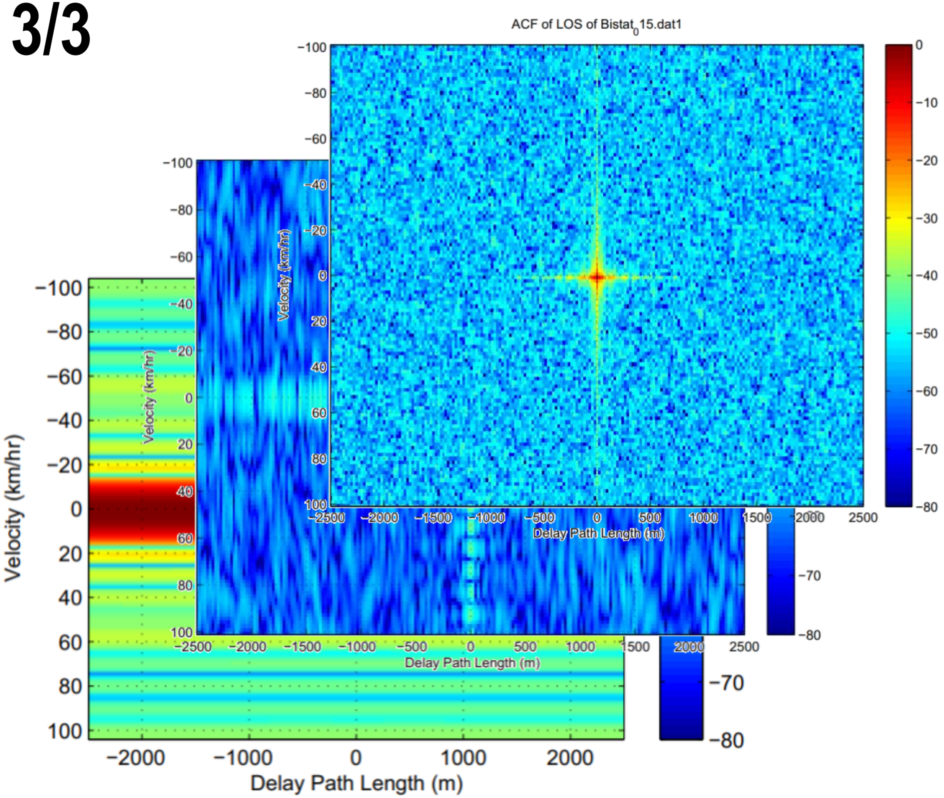


WHAT IS PASSIVE RADAR?
EMITTERS OF OPPORTUNITY 3/3

EoO Exemplary Ambiguity Functions

► Analog Terrestrial TV Broadcast
  – High power from target reflection
  – Range resolution is very poor
► DVB-T Broadcast
  – Improvement in range resolution
  – Doppler has a lot of ambiguities
► GEO Satellite
  – Very Good in both time and frequency domain

→ **Signal Bandwidth and Auto-Correlation properties rule!**



WHAT IS PASSIVE RADAR?
PASSIVE RADAR VS. EMITTER LOCATION SYSTEMS

What is the difference to Direction Finding (DF)?

- ► AoA calculation for both is in principle similar:
  - Both might be quite wideband receivers
  - Mostly interferometry-based
- ► Big difference is, that PCR uses a third-party illuminator and the targets reflection, whereas DF uses RF emissions of target directly
- ► PCR leverage Coherent Processing of Reference Signal and Reflection
  - No time-domain integration needed for position
  - This makes PCR (direct range measurement) much more capable of estimating targets elevation

What is an DF antenna?

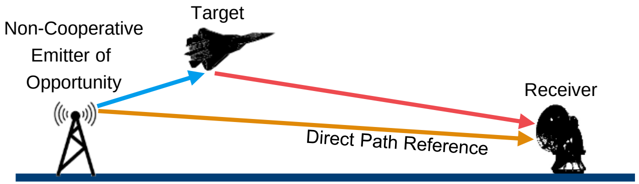
Courtesy of ELTA Systems Ltd.

And what an PCR?

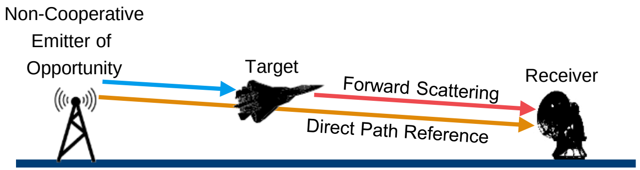
WHAT IS PASSIVE RADAR?
BISTATIC VS. FORWARD SCATTERING 1/2

What happens if the bi-static angle β approaches 180°? (target directly in LoS between Tx and Rx)

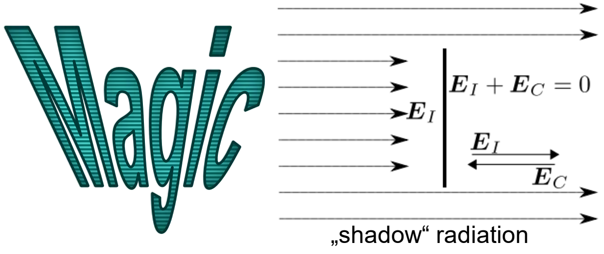
- ► In this situation
  - – Size of range resolution cell is approaching infinity
  - – Echo of the object with an arbitrary velocity has always 0 Doppler frequency shift
  - – Therefore, the radar is unable to measure the distance or speed of such targets. (Can be retrieved by processing)
- ► Forward Scatter Effect causing enlarged radar cross-section that mainly depends on the object's shadow area
  - – does not depend on a kind of material the target is made of
- ► Example: For a sphere (r=1m @ 3 GHz) FS RCS is 26 dB larger than monostatic RCS



Passive Approach using Bistatic Geometry



Passive Approach using Forward Scattering

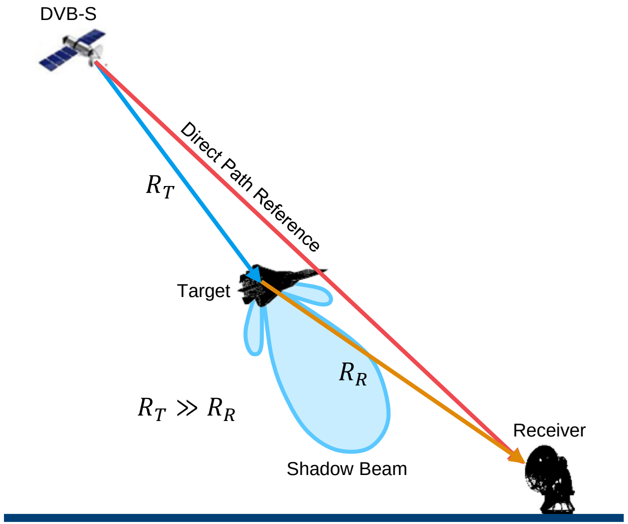


WHAT IS PASSIVE RADAR?
BISTATIC VS. FORWARD SCATTERING 2/2

Advantages of satellite transmissions as EoO

- The geometry of satellite, target and receiver are preferable for forward scattering
- Satellite signals are available in areas where terrestrial signals are poor, such as offshore
- Usually the signals have a wider bandwidth and thus a higher range resolution

Exemplary use case: The PCR can be mounted on a moving platform (e.g. a ship), with its own movement compensated for drone detection.



Satellite based Forward Scattering PCR

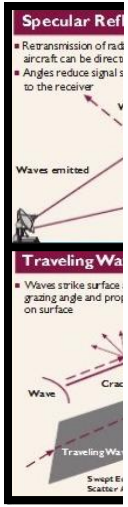
WHAT IS PASSIVE RADAR?
PASSIVE RADAR VS. STEALTH

Is PCR a "stealth killer"?

► A stealth aircraft is made up of
  – completely **flat surfaces** and very **sharp edges** to redirect reflected energy[1]
  – Avoidance of downfacing corner reflectors (engines, weapon bays etc.) [1]
  – Radar Absorbing Material (RAM)[2]

► PCR FS are bistatic and can operate at low frequencies (e.g. VHF or UHF) and therefore promise to avoid some of the stealth technologies (especially FS), but…

► …they offer limited accuracy, making further engagement very hard for FC radar or Missile Seekers!



Aerodynamics

[1]effective vs. monostatic radars
[2]frequency dependent

WHAT IS PASSIVE RADAR?
EXAMPLES OF REAL LIVE SYSTEMS 1/3

MAVERICK M-series by Silentium Systems (Australia)

- Maverick M-series man-portable system to enhance situational awareness in the Land domain
- Maverick C-series for civil applications such as commercial airspace and drone surveillance
- Maverick S-series which is designed to detect and track even small objects in Low Earth Orbit (LEO) and provide long-range air surveillance.

Courtesy of Silentium Defence

WHAT IS PASSIVE RADAR?
EXAMPLES OF REAL LIVE SYSTEMS 2/3

ELK-7080 PCL by ELTA Systems (Israel)

- Launch in 2020
- Covertly detects and tracks aerial target
- Exploits analog FM broadcasting and Digital Audio Broadcasting (DAB) for non-cooperative aerial targets detection
- Simultaneously processes multiple FM and DAB broadcast
- Immune to jamming

Courtesy of ELTA Systems Ltd.

WHAT IS PASSIVE RADAR?
EXAMPLES OF REAL LIVE SYSTEMS 3/3

Twinvis® Passive Radar by Hensoldt (Germany)

- ► Uses existing VHF and UHF transmissions from analogue and digital radio as well as television (Exploiting FM / DAB / DVB-T simultaneously)
- ► Air surveillance in urban and difficult environments
- ► Multi-angle target detection for Improved detection of targets with reduced radar cross section
- ► Interconnect sensors into a cluster

AGENDA

Passive Radar Systems

1. **What is Passive Radar?**
   Bistatic Radars
   Emitters of Opportunity
   Bistatic vs. Forward Scattering
   Passive Radar vs. Emitter Location Systems
   Passive Radar vs. Stealth
   Examples of Real Live Systems

2. **Testing Challenges for Passive Radar**
   “Classical” Receiver Testing
   Performance Testing
   Scenario Based Testing
   RF-to-the-Lab

3. **Operational Benefits with R&S Broadband Amplifiers**

4. **Conclusion**

TESTING CHALLENGES FOR PASSIVE RADAR
“CLASSICAL” RECEIVER TESTING 1/2

From Hardware perspective PCR are synchronized multi-channel receivers, so the usual measurements for component- and sub-system-level test apply:

- Spurious measurements
- Dynamic Range
- Compression point
- Gain/Frequency Response
- Noise Figure
- Input/Output Impedance
- Image rejection
- Receiver sensitivity
- IP2/IP3
- Quadrature error
- LO Phase Noise
- LO Leakage
- LO Long Term Stability
- Antenna radiation pattern
- …

TESTING CHALLENGES FOR PASSIVE RADAR
"CLASSICAL" RECEIVER TESTING 2/2

Same-same for digital and PCB side:

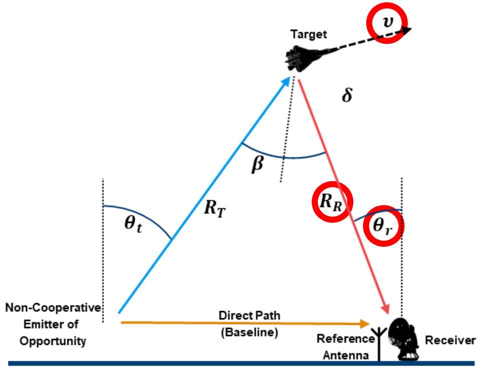
- ► Power/Signal Integrity
- ► LO/Clock Jitter
- ► Latency
- ► Timing
- ► EQ Flatness
- ► EMI debugging
- ► FPGA Tests
- ► DSP Tests
- ► ADC/DAC Tests
  - SFDR
  - EnoB
  - Speed
  - Quantization Error

TESTING CHALLENGES FOR PASSIVE RADAR
PERFORMANCE AND SYSTEM LEVEL TESTING

But was is required for validation purposes?

- ► Performance Parameters
  - – Probability of Detection
  - – Accuracy (Range, Velocity, Angle)
  - – Resolution (Range, Velocity, Angle)

- ► Reproduceable reference scenario-based testing for validation of
  - – Environmental Effects
  - – Tracking
  - – Interference mitigation



TESTING CHALLENGES FOR PASSIVE RADAR
PERFORMANCE TESTING

Wireless Communication has it!

- ► WIC outdoor scenarios have to simulate several sources of multipath:
  - scattering from rough surfaces
  - reflections from buildings
  - diffraction from walls and roofs
  - myriad of Doppler shifts relative to the motion of vehicles, low-flying aircraft
- ► Fading testing can account for the LOS signal, an interfering signal, and a wide range of channel impairments: reflection, diffraction, scattering, Doppler, shadow, refraction, and absorption

Limitations:
- 10s of km only
- No AoA
- #fader = #targets

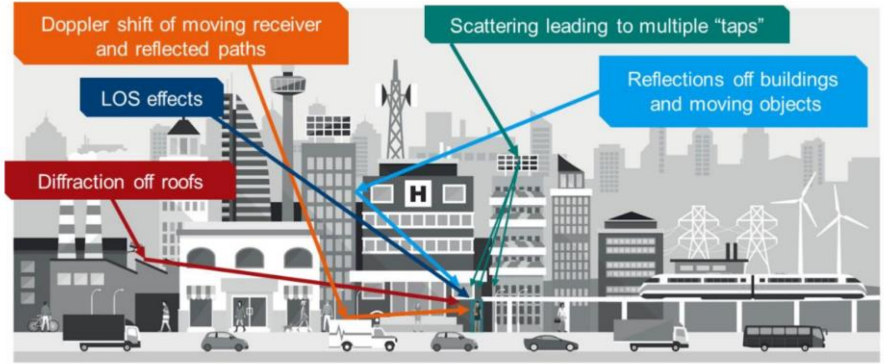
Application Note

RECEIVER TESTING: THE IMPORTANCE OF FADING

Ensuring excellent receiver performance in real-world conditions

Products:
- ► R&S®SMW200A Vector Signal Generator
- ► R&S®SMW-B15 Wideband Fading Simulator

Paul Peterson | Version 01.00 | 04.2022

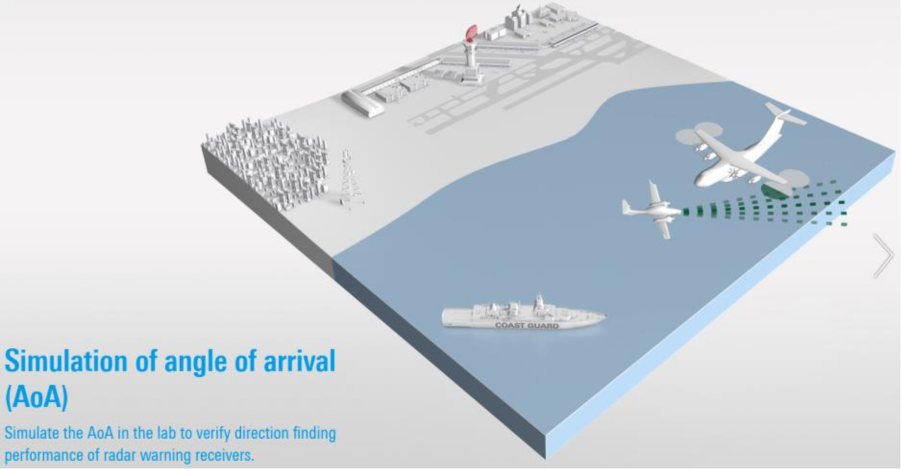


TESTING CHALLENGES FOR PASSIVE RADAR
SCENARIO BASED TESTING 1/2

Based on Pulse Sequencer (PS)

PS is a free software for simulation of a dynamic radar environment including communication signals

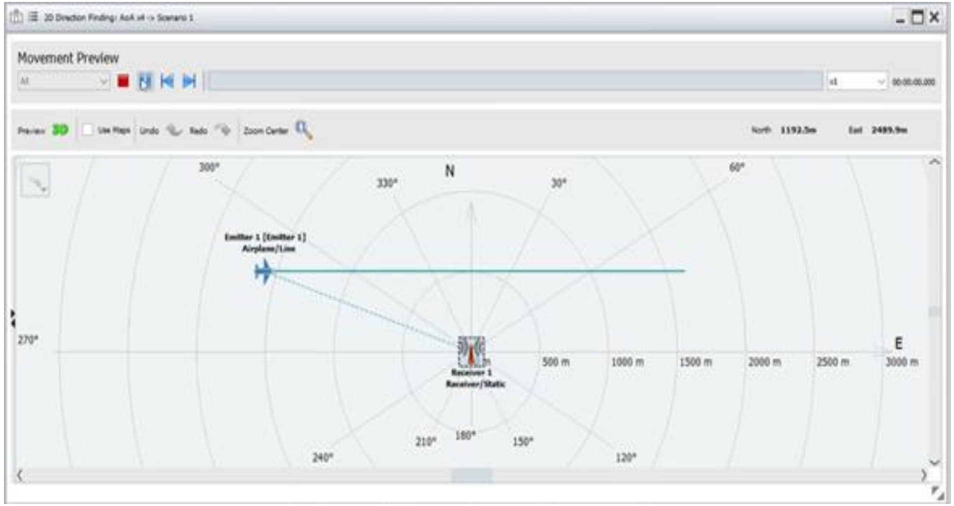
- The simulation can be used to directly control signal generators
  - SMW200A for more complex signals and classification tests
  - couple of phase coherent SGT100A for testing interferometric AoA calculation
- Another use case could be a reference scenario based acceptance testing



TESTING CHALLENGES FOR PASSIVE RADAR
SCENARIO BASED TESTING 2/2

Based on Pulse Sequencer (PS)

- ► Emitter, Receiver and platform definition is generic
- ► All entities can follow pre-defined trajectories
- ► Automatic signal generator setup to cover simulation of incidence angle (for amplitude, interferometric or time-based AoA processing)

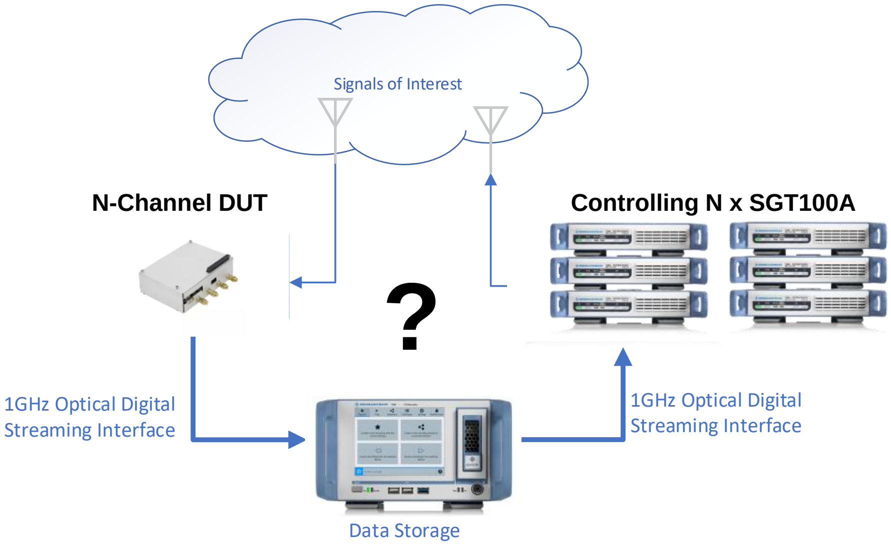


TESTING CHALLENGES FOR PASSIVE RADAR
RF-TO-THE-LAB

Realistic real-live Signals for validation

- ► Record and replay of IQ data
- ► Especially useful for providing operational data to algorithm development
- ► Trades simulation flexibility for spectral realism

- ► Open Question:
  - – Phase-Control for multiple instruments
  - – Scalability in terms of receive channels



AGENDA

Passive Radar Systems

OPERATIONAL BENEFITS USING R&S BROADBAND AMPLIFIERS 1/2

What if there are no emitters of opportunity…

- …or they are not transmitting 24/7, don't have the characteristic you like (like rock or punk music!) or make deployment of PCR hard in terms of site selection?

You build your own!

- Of course maintaining commercial spectral footprint for covert operation

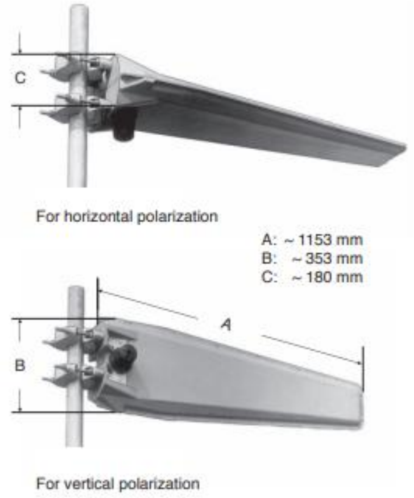
OPERATIONAL BENEFITS USING R&S BROADBAND AMPLIFIERS 2/2

R&S offers solutions from EMC or Broadcast testing that are perfectly suited!

With a suitable

- Signal Generator to provide RF
- Broadband Amplifier
- Transmit Antenna (3rd Party)

all components are available to build a EoO with a transmit power (not EIRP) of up to 3 kW



Exact configuration depends on operational requirements

AGENDA

Passive Radar Systems

1. **What is Passive Radar?**
   - Bistatic Radars
   - Emitters of Opportunity
   - Bistatic vs. Forward Scattering
   - Passive Radar vs. Emitter Location Systems
   - Passive Radar vs. Stealth
   - Examples of Real Live Systems
2. **Testing Challenges for Passive Radar**
   - “Classical” Receiver Testing
   - Performance Testing
   - Scenario Based Testing
   - RF-to-the-Lab
3. **Operational Benefits with R&S Broadband Amplifiers**
4. **Conclusion**

PASSIVE RADAR
CONCLUSION

- Anti-Stealth, C-UAV, Force Protection, Space Situational Awareness and Hypersonic Threat are giving passive Radars new momentum
- The complex RF environment makes scenario-based testing a must
  - Having repeatable scenarios increases trust in validation, optimization and acceptance testing of system performance
  - Reduces time to adapt the testing scenario
- R&S offers solutions for testing a PCR over most of the development cycle

Feel free to get into contact for a detailed discussion!