ELECTRONIC WARFARE

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ROHDE&SCHWARZ

Make ideas real

AGENDA

- EW Introduction
- Radar System
- Application in the real world

- T&M Solutions
  - RF Testing DI/OTA
  - Multiple RF channels alignement techniques
  - Radar Signals Simulation, R&S Pulse Sequencer

WHAT IS ELECTRONIC WARFARE (EW)?

ELECTRONIC WARFARE (EW)

- **EMSO – Electro-Magnetic Spectrum Operations**

  - Electronic Attack (EA) – Attacks or degrades an enemy’s electronic systems
    - Jamming, can include anti-Radiation Missiles (ARMS)

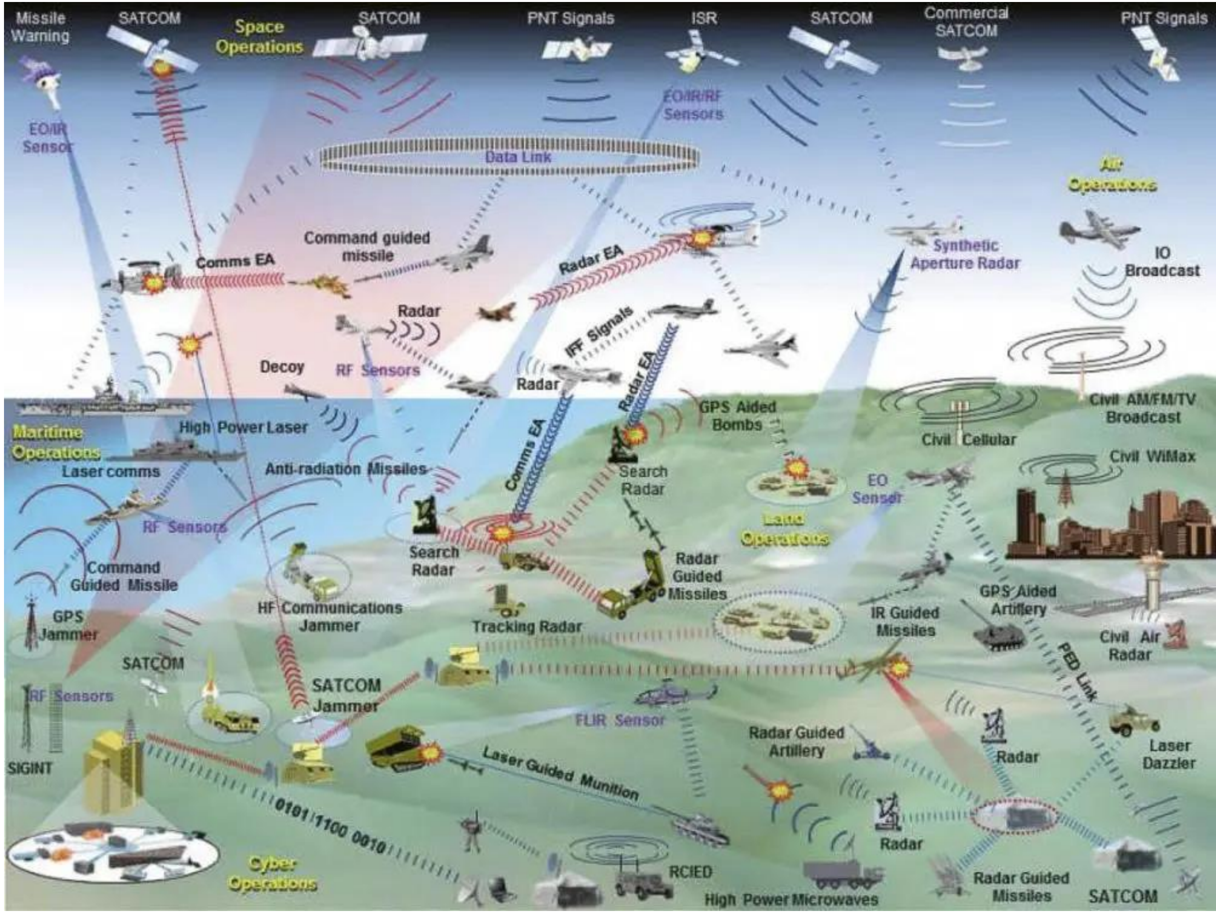
  - Electronic Support (ES) – Passive Intercept and location of an enemy’s Radar signals. ES is more commonly known as RESM

  - Electronic Protection (EP) – Protects allied systems from enemy EA
    - Techniques either built into the Radar or Operational Techniques
    - Emission Control (EMCON) (ECCM)

WHY DO WE WANT TO SIMULATE?

- ► Real world testing is:
  - – Expensive
  - – Uncontrolled
  - – Not repeatable, logistically challenging
  - – Unsecure
- ► Fly-Fix-Fly method is unaffordable

- ► Simulation is:
  - – Finite & scalable
  - – Flexible
  - – Precise
  - – Less risky (schedule, scope, cost)



https://www.japcc.org/wp-content/uploads/JAPCC_J27_screen.pdf

RADAR

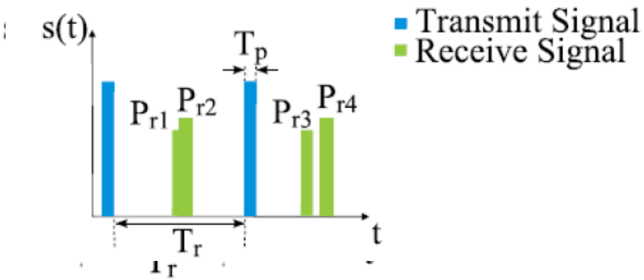
RADAR WAVEFORMS

- Pulse Radar
- CW (Continuous Wave) Radar

- FMCW (Frequency modulated continuous wave)
- Barker Code

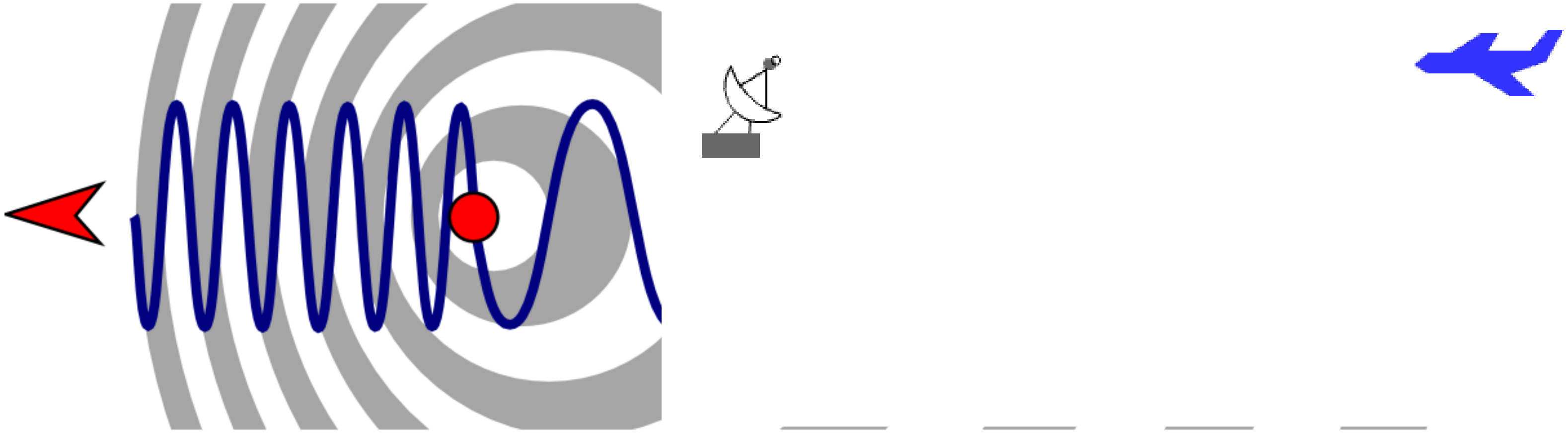
PULSE RADAR

$$Range = \frac{C\tau}{2}$$



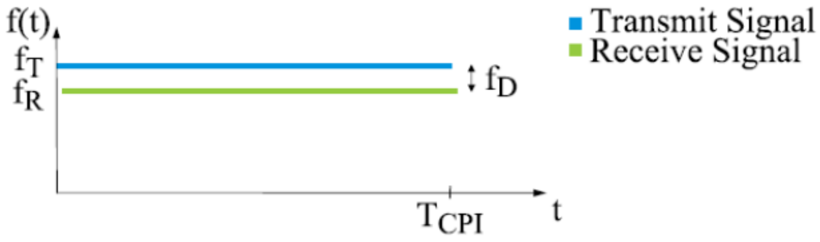
CONTINUOUS-WAVE RADAR

- Doppler effect
- Stationary not available



CONTINUOUS-WAVE RADAR

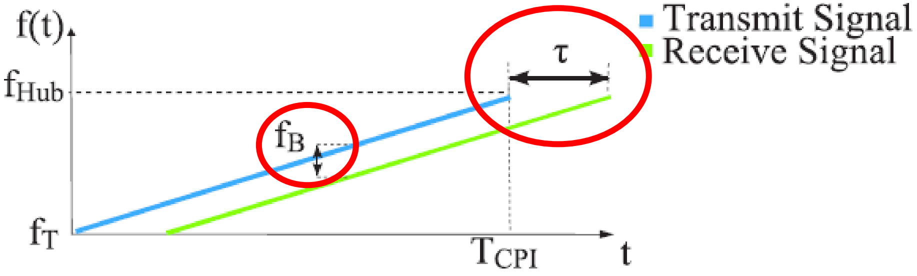
$$f = f_o\left(\frac{C \pm V_o}{C \mp V_s}\right)$$

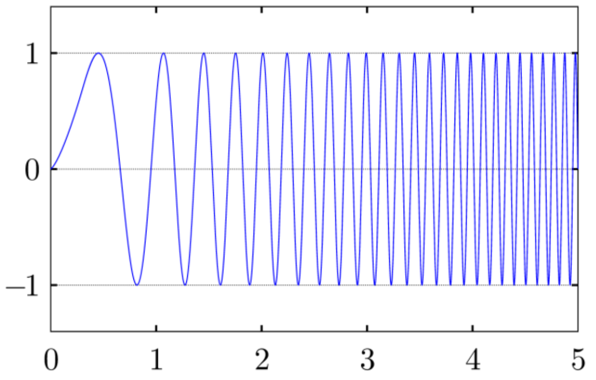


$$f_D = 2\Delta f$$
$$= 2(f - f_o)$$
$$= 2\left[f_o\left(\frac{c \pm v}{c}\right) - f_o\right]$$
$$= \pm 2\left(\frac{V_r f_o}{c}\right) = \pm 2\frac{V_r}{\lambda}$$

Range	**X**
Velocity	**V**

LINEAR FREQUENCY MODULATED CONTINUOUS WAVE RADAR (LFMCW)



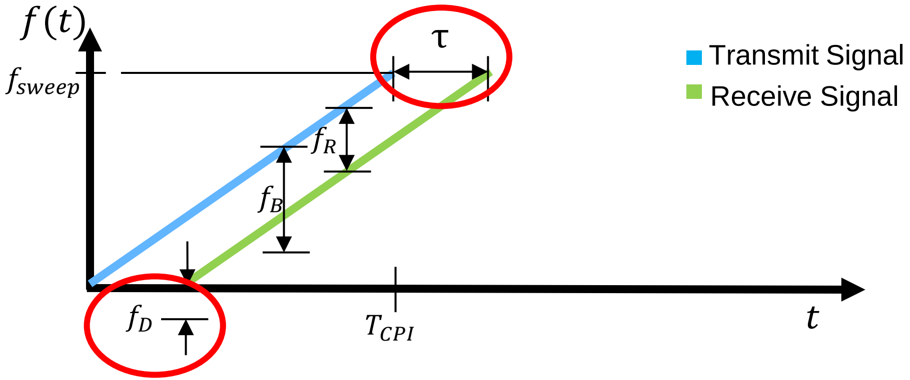


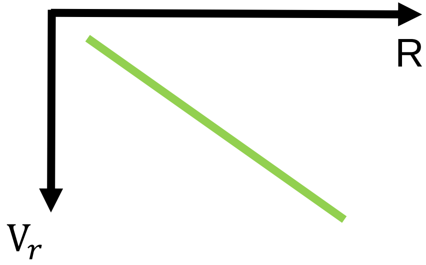
$$\frac{f_B}{f_{Hub}} = \frac{\tau}{T_{CPI}}$$

$$R = \frac{c\prime}{2} * \frac{f_B}{f_{Hub}} T_{CPI}$$

Doppler Effect?

LINEAR FREQUENCY MODULATED CONTINUOUS WAVE RADAR (LFMCW)

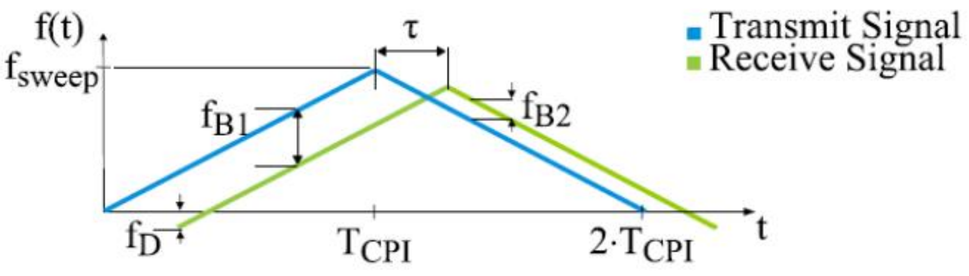


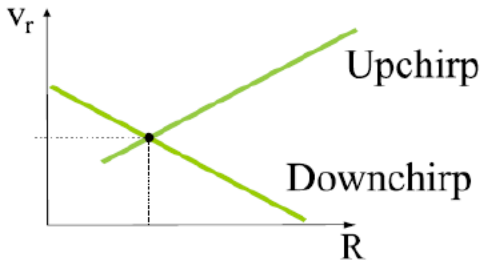


$$f_B = f_R + f_D = \frac{\tau\, f_{Sweep}}{T_{CPI}} + \frac{2}{\lambda} V_r = \frac{2 f_{Sweep}}{c\, T_{CPI}} R + \frac{2}{\lambda} V_r$$

Delta Frequency donated by range and doppler effect

LINEAR FREQUENCY MODULATED CONTINUOUS WAVE RADAR (LFMCW)



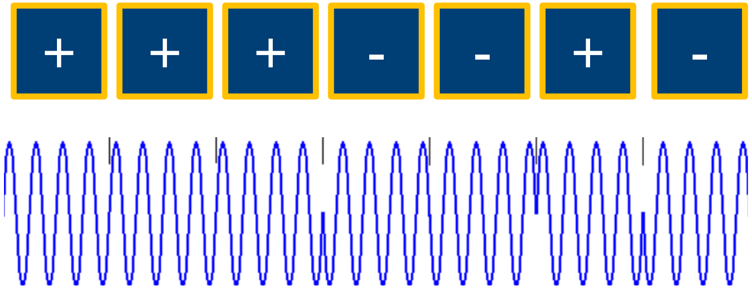


$$f_{B1} = f_\tau + f_D = \frac{\tau\, f_{Sweep}}{T_{CPI}} + \frac{2}{\lambda} V_r = \frac{2 f_{Sweep}}{C\, T_{CPI}} R + \frac{2}{\lambda} V_r$$

$$f_{B2} = f_\tau + f_D = \frac{\tau\, f_{Sweep}}{T_{CPI}} + \frac{2}{\lambda} V_r = \frac{2 f_{Sweep}}{C\, T_{CPI}} R + \frac{2}{\lambda} V_r$$

BARKER CODE

BARKER CODES



Length of codes (n)	Code Elements	Peak Sidelobe ration in dB
2	+-, ++	-6.0
3	++-	-9.5
4	++-+, +++-	-12.0
5	+++-+	-14
7	+++--+-	-16.9
11	+++---+--+-	-20.8
13	+++++--++-+-+	-22.3

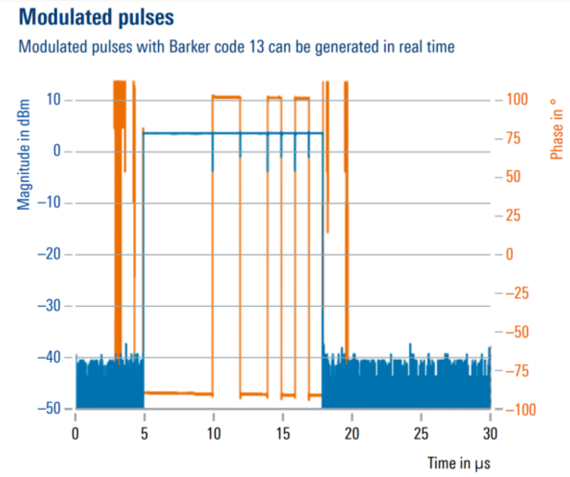
1+1+1+1+1+1+1=7

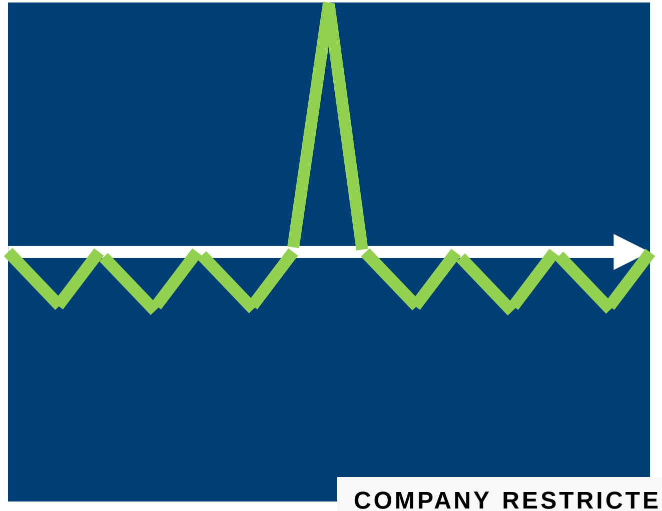
Reference :

| + | + | + | - | - | + | - |

| + | - |

Sliding Window:

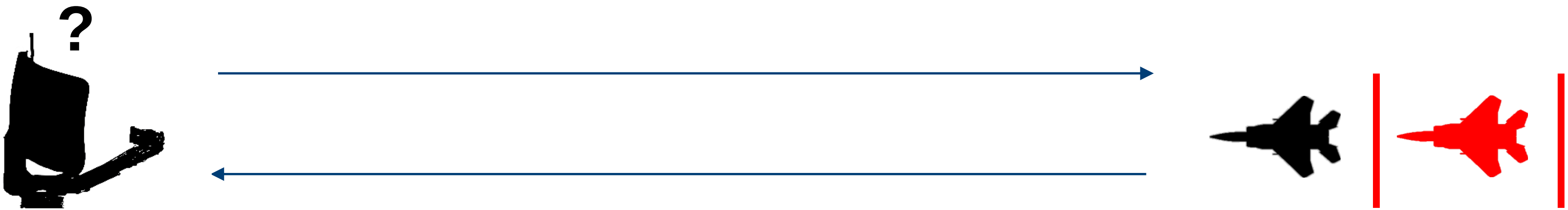




RANGE GATE PULL OFF (RGPO)
VELOCITY GATE PULL OFF (VGPO)

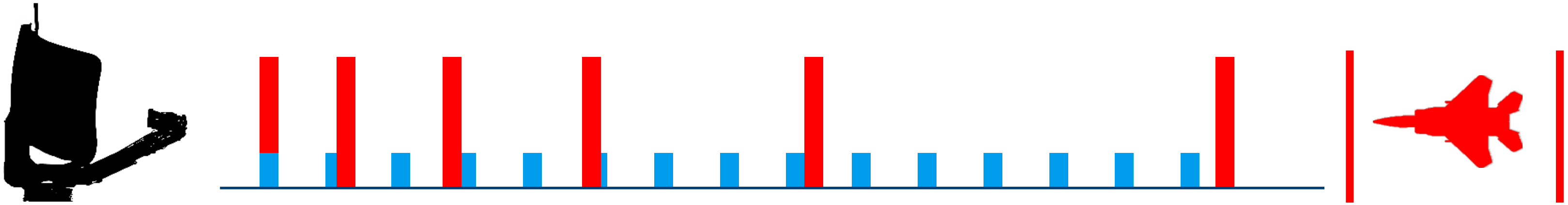
BREAK LOCK

- After false target has been moved far enough from real target, false returns are turned off
  - Causes tracking to be lost (“breaks lock”)
- Radar must restart search and acquisition
  - Increases gain / sensitivity
  - Takes time
- Target can repeat the RGPO process



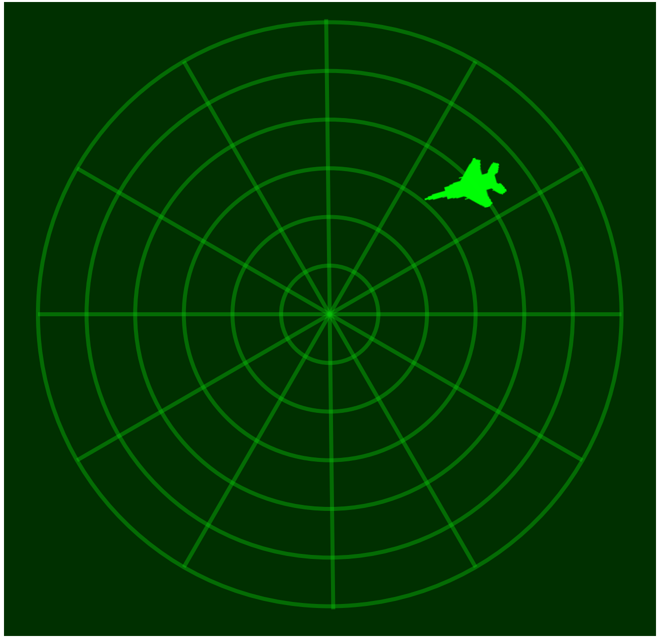
DELAY RETURNS

- False returns are progressively delayed
- High amplitude of false returns decreases radar sensitivity
  - Prevents radar from detecting real target returns
- Target appears to be moving further away
  - Moves outside of real target range gate



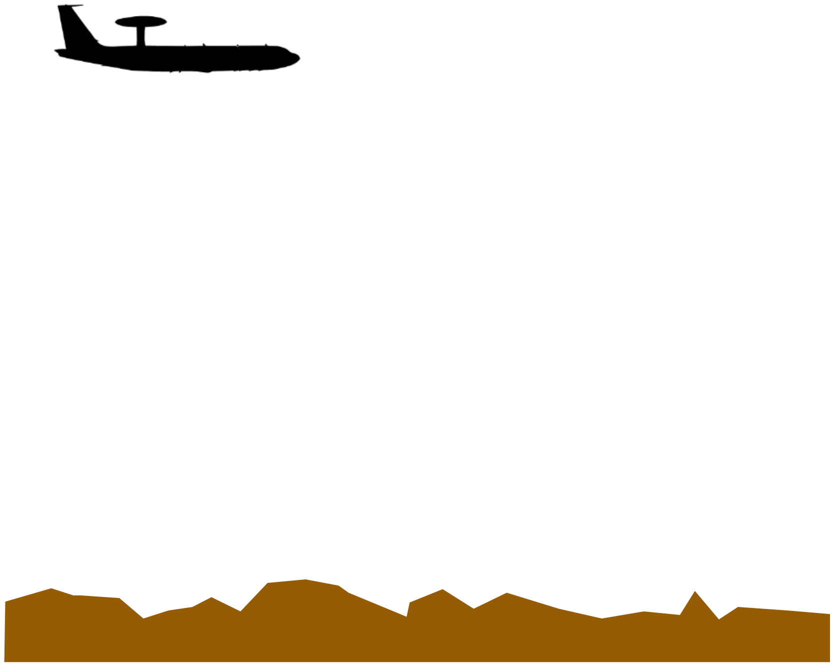
RANGE GATE PULL IN

- RGPO normally creates targets that are farther away than the real target
  - Deceptive returns are **delayed**
  - Arrive **after** real returns
- If the radar has a fixed pulse repetition interval (PRI), deceptive returns could be sent so they arrive **before** real returns
- Target appears to be moving towards radar
  - Called **range gate pull <u>in</u>**



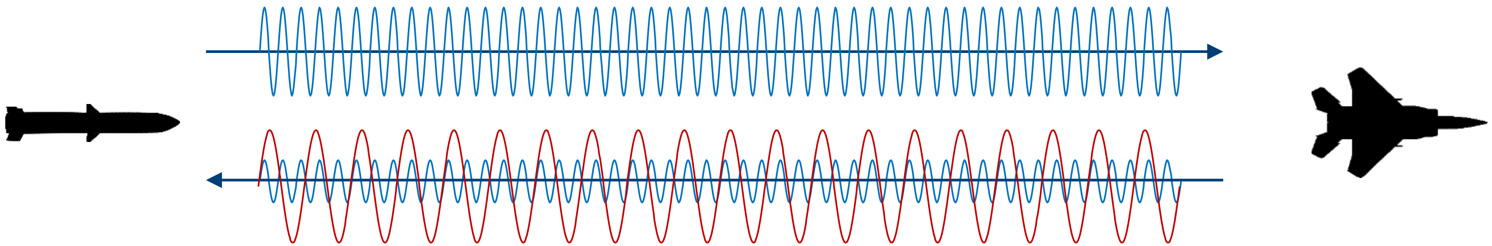
DOPPLER RADAR

- Radar returns are frequency-shifted (Doppler effect) by target movement
  - Can be used to determine target velocity
- Two types of Doppler radar:
  - Pulsed Doppler (often used to detect low altitude targets)
  - CW (often used for missile guidance)
- Doppler radars create a “velocity gate” (similar to range gates)
  - Once target is acquired, signals with velocity outside this range are filtered out

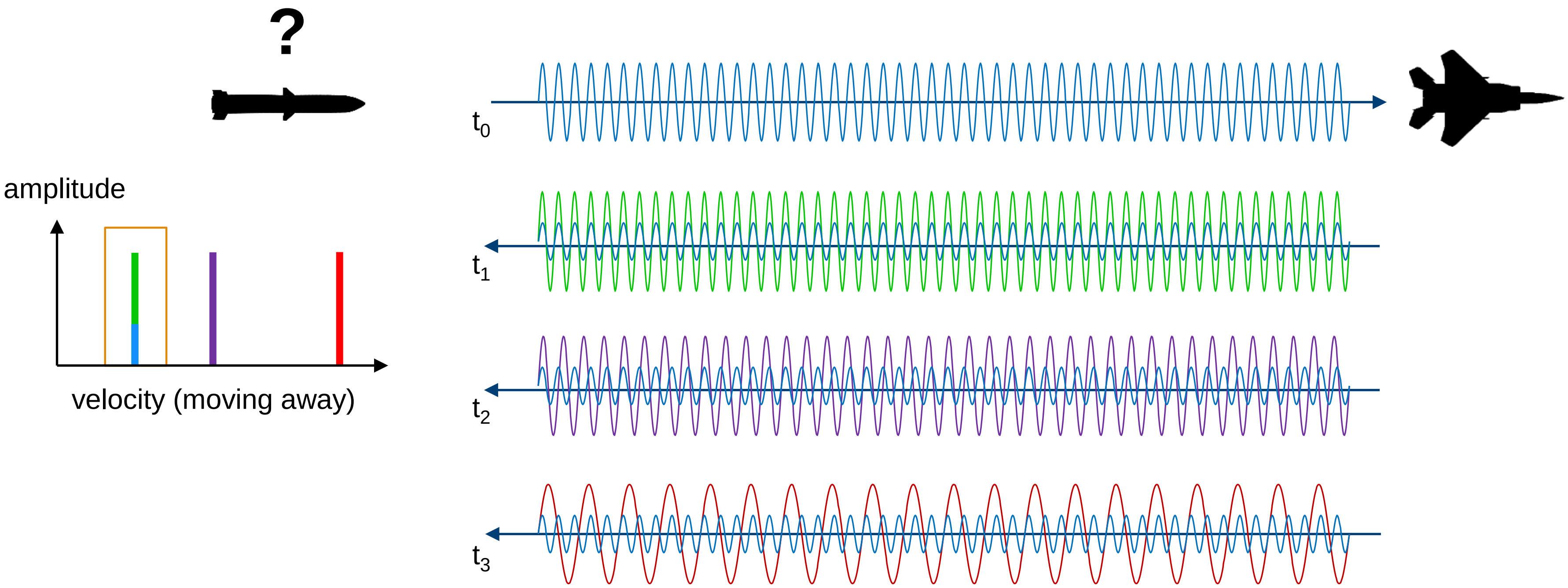


VELOCITY GATE PULL OFF (VGPO) – OVERVIEW

- Jammer sends high power signal with same frequency as (Doppler-shifted) real returns
  - Captures the velocity gate
- Slowly shifts frequency to simulate change in target velocity
  - VGPO can easily pull in either direction
- When velocity gate is far enough from the real target gate, jamming is turned off
- Target lock is lost and radar must restart the acquisition process
  - Difficult or impossible in some scenarios

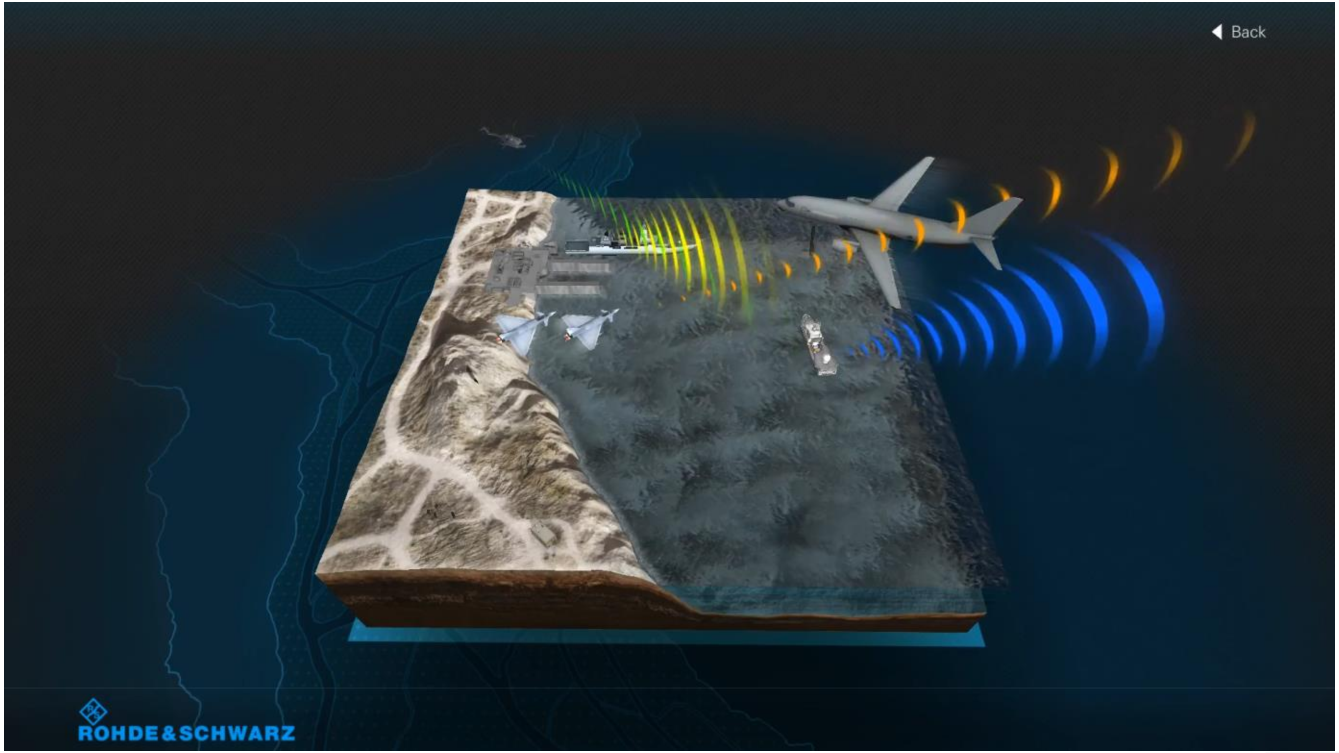


VELOCITY GATE PULL OFF (VGPO) – WALK THROUGH



TEST & MEASUREMENT SCENARIO

TEST SCENARIO



TYPICAL RWR ANTENNA INSTALLATION, AS SHOWN ON THE U-2R AIRCRAFT

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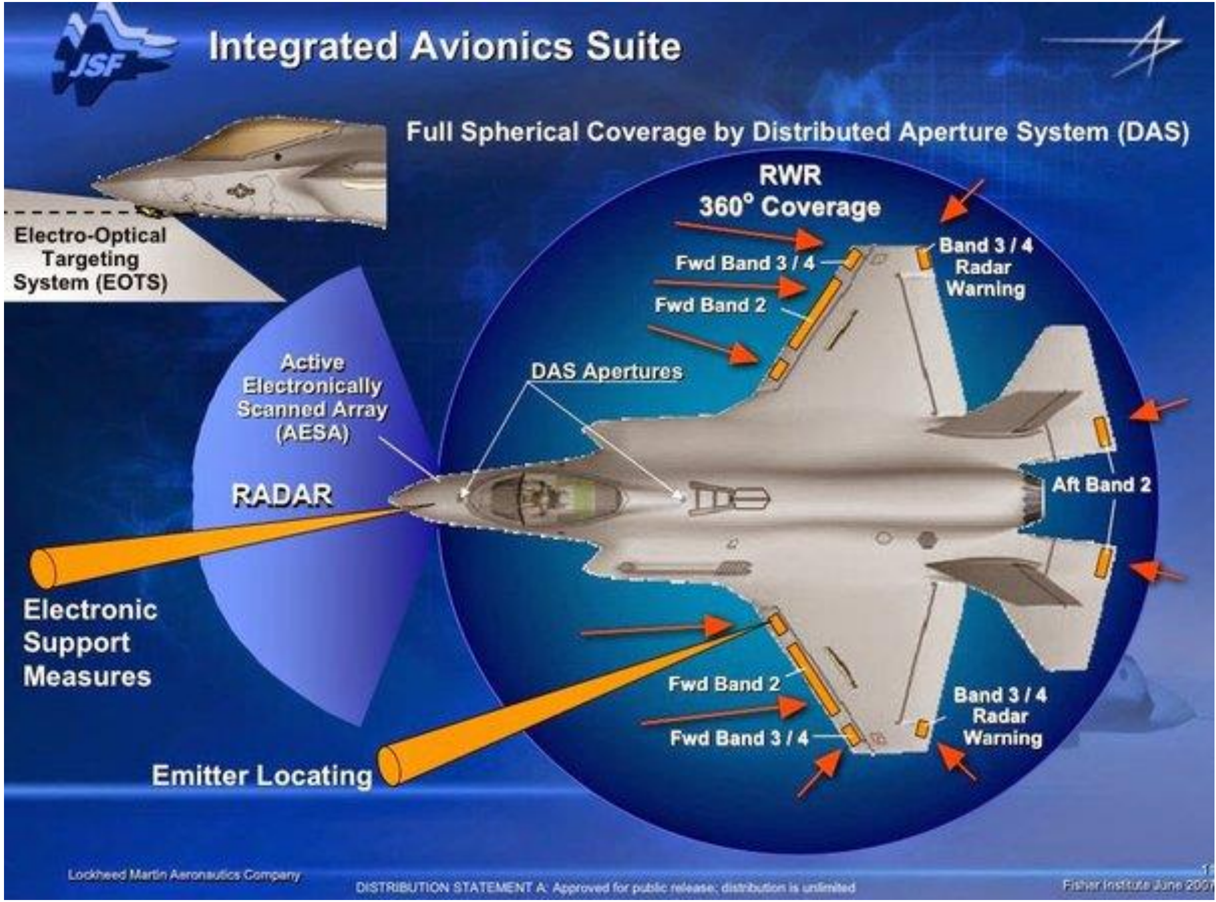
RWR APERTURES ON THE F-35



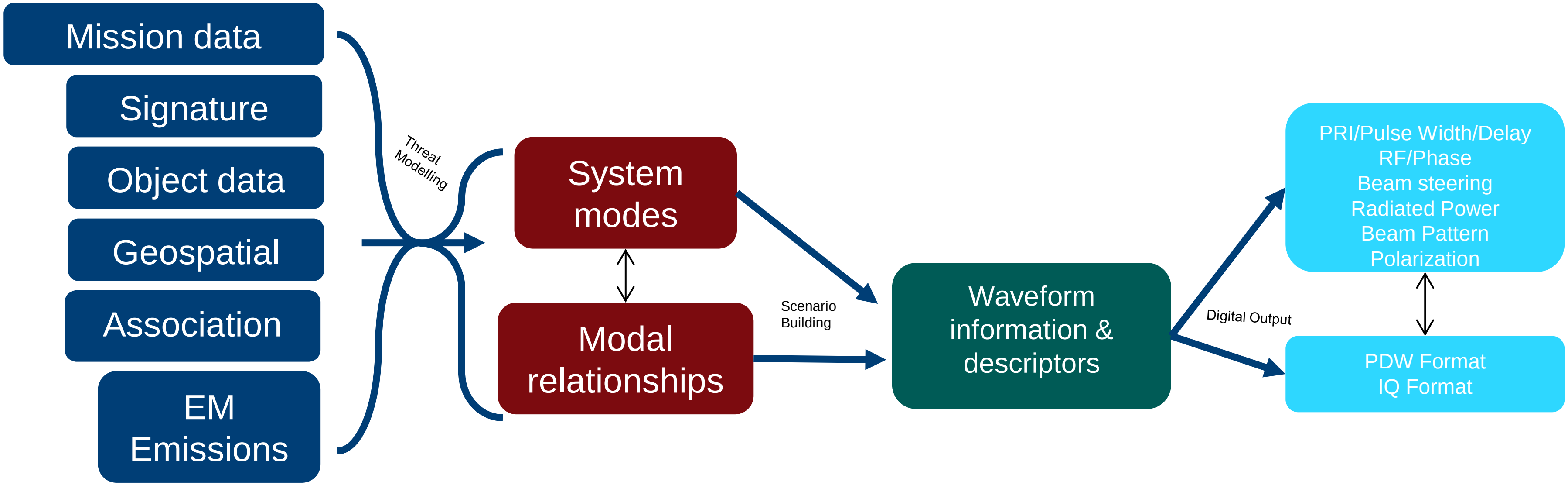
RWR
Radar Warning Receiver

Source – Lockheed Martin

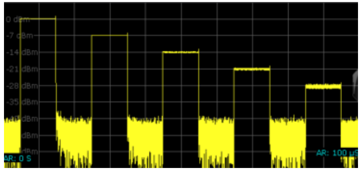
THREATS MODELLING

Threat models can be very detailed, very complex representations of real-world signals

► Some threat models include data such as:

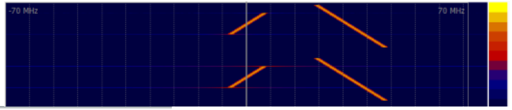


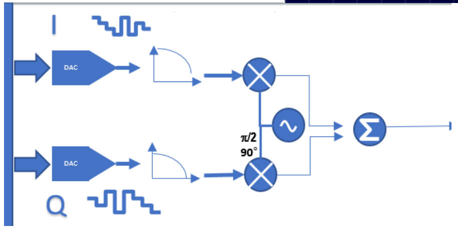
HOW DO YOU REPRESENT A WAVEFORM?



IQ

- ▶ Digital Baseband
- ▶ Exact waveform – data intensive
- ▶ Plays back *everything*
  - – *Includes off-time of signal*





PDW

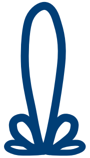
- ▶ Representative waveform (idealized)
- ▶ Great for long scenarios
  - – Avoids saving and storing "*off-time*"
  - – Data-efficient
- ▶ THE language for radar systems and components
- ▶ Allows for easy comparison to stored radar characteristics and ID and classification
- ▶ Need a PDW – RF signal generation platform

WHAT IS AN EMITTER?

An emitter is a compilation of waveform characteristics and physical characteristics that manifest as an RF characteristic

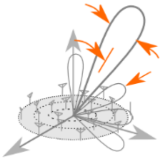
Pulses and sequences

⊕



Antenna diagram

⊕



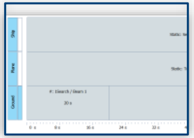
Antenna Scan(s)

⊕

- Δf
- Elevation
- Azimuth

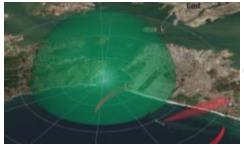
Beam specific offsets

⊕



Mode changes

⊕



Map and trajectories

⊜

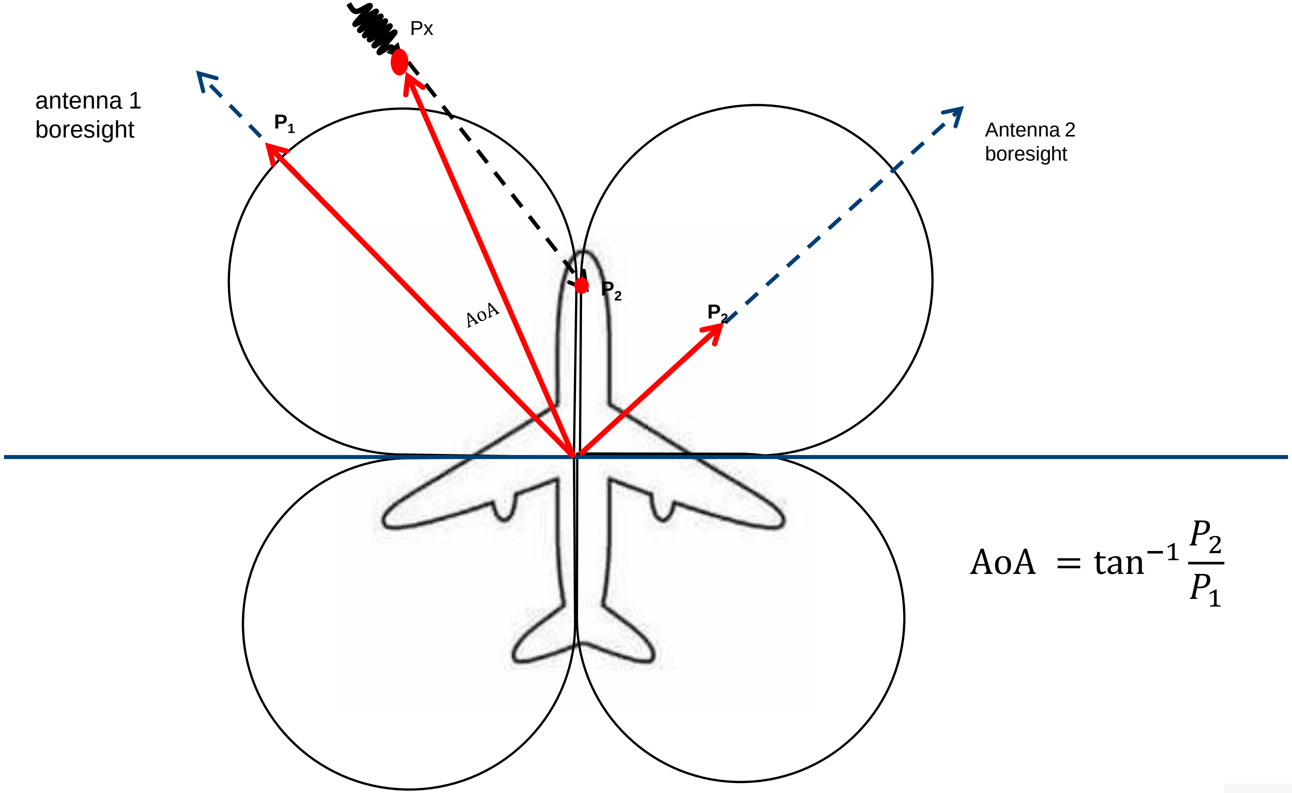
Emitter

PRI/Pulse Width/Delay
RF/Phase
Beam steering
Radiated Power
Beam Pattern
Polarization

↔

PDW Format
IQ Format

AMPLITUDE COMPARISON - MONOPULSE

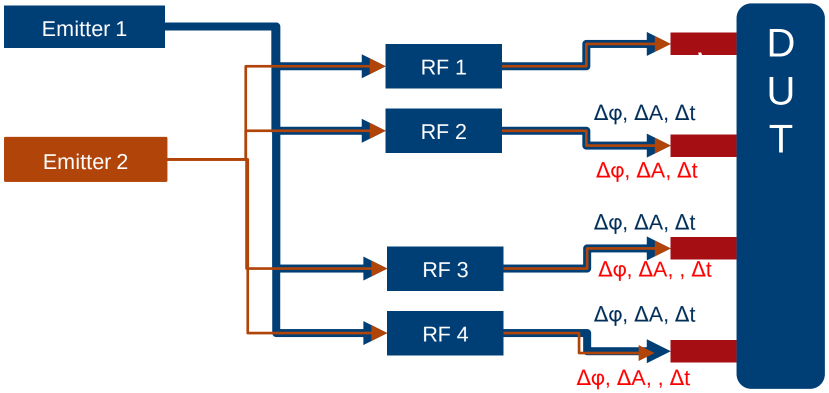


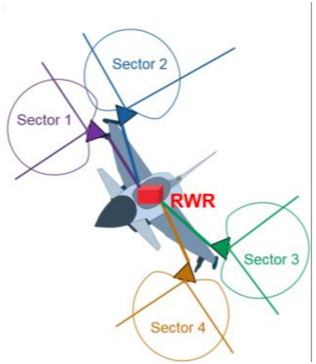
$$\text{AoA} = \tan^{-1}\frac{P_2}{P_1}$$

ADDING ANGLE OF ARRIVAL

Adding Angle of arrival to multi-channel receivers increases test complexity

- Each emitter needs to present a different phase and amplitude of the same signal to each DUT input

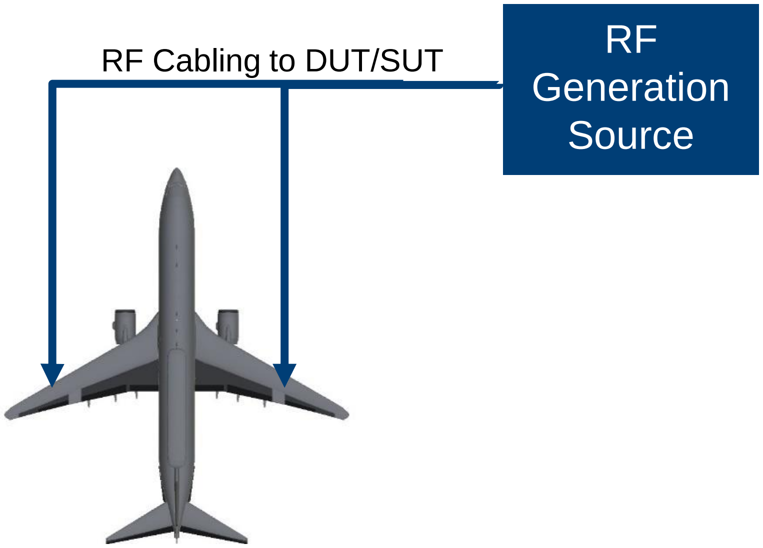


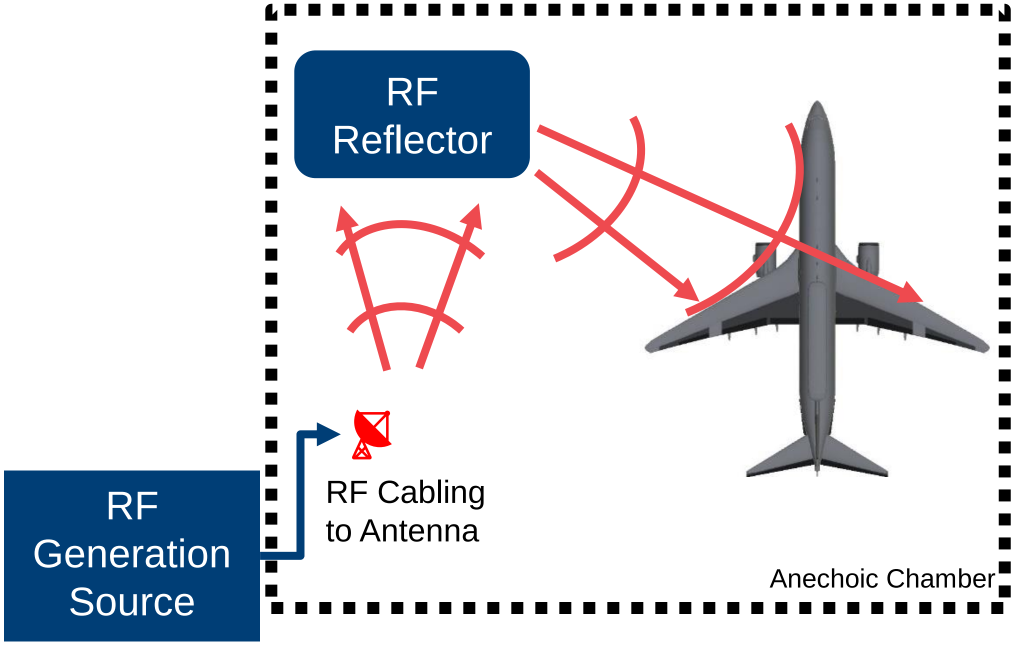


RF TEST SOLUTIONS
OTA OR DI

TEST SOLUTIONS

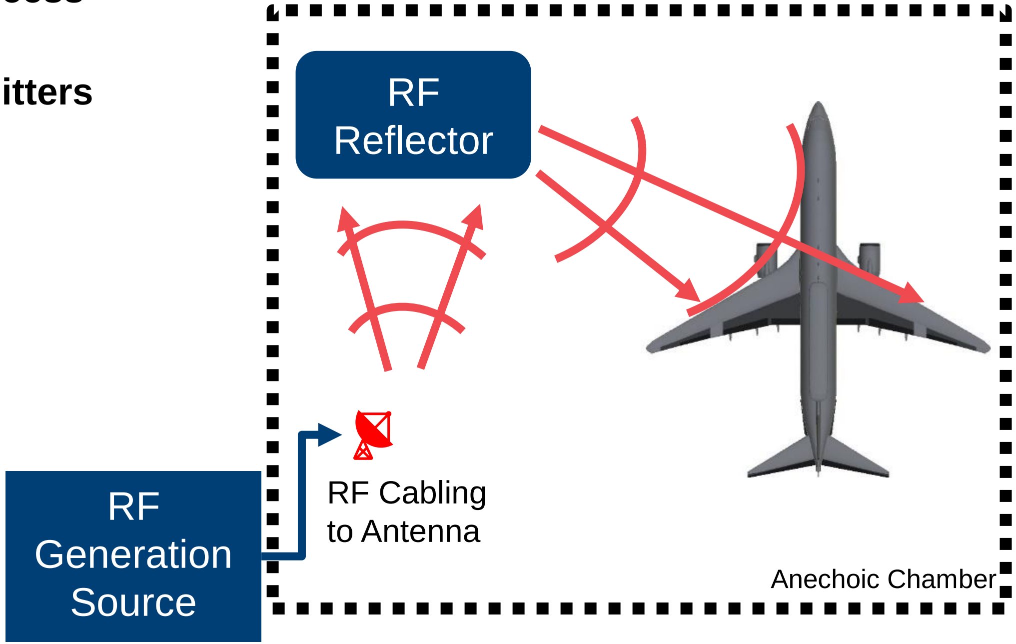
DI and Over-the-Air





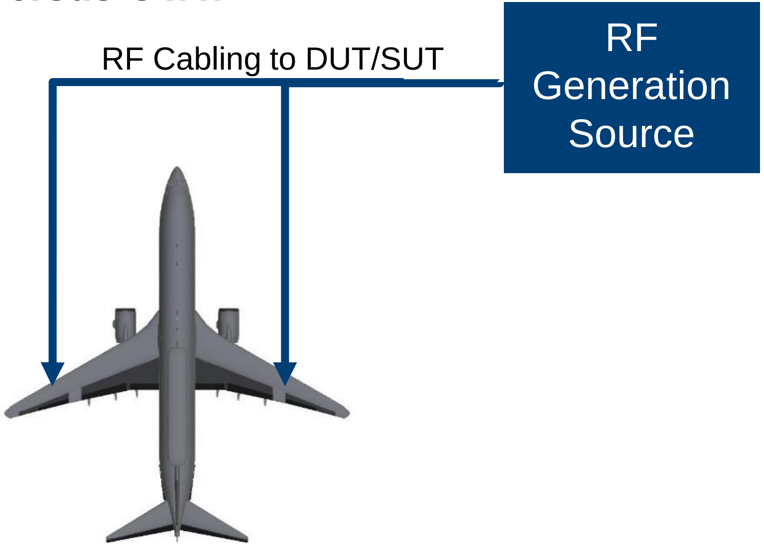
BENEFITS OF OVER THE AIR?

- **Ideal for situations with limited test port access**
- **Ideal for small functional tests with few emitters**
  - Operational testing
  - Response testing
- Reduced testing and RF complexity



BENEFITS OF DIRECT INJECTION

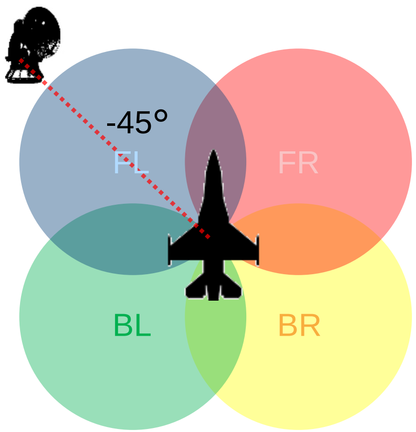
DI versus OTA?



- Scalable
  - Can simulate multi-emitter scenarios
  - More ports = more test equipment
- Flexible
  - Can operate infinite variations of environment, geometries, movement profiles
- Secure
  - Very little radiated emissions – shielding excellent
- Repeatability
  - Excellent test to test parameter accuracy
  - Can make minor changes to scenario to flesh out key SUT/DUT effectiveness parameters

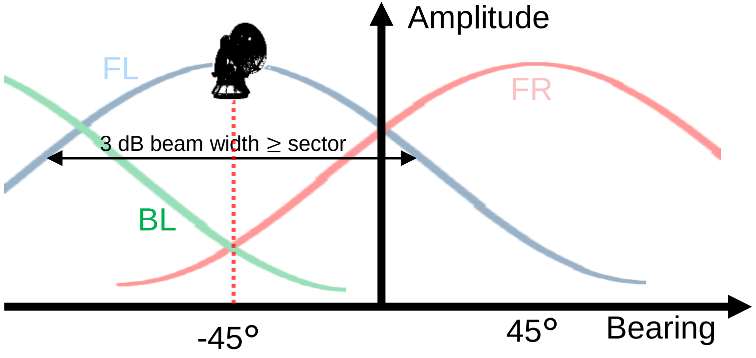
ALIGNMENT OF MULTIPLE RF CHANNELS IN AMPLITUDE, PHASE, AND TIME

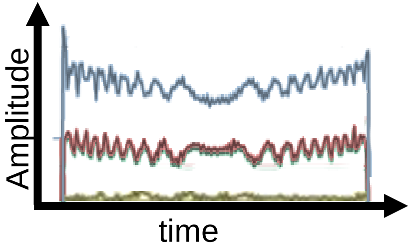
BASICS OF DIRECTION FINDING
AMPLITUDE MONOPULSE ANGLE OF ARRIVAL (AOA)



- Amplitude Monopulse DF requires 2 or more spatially separated receiver channels
- Overlapping directional antenna diagrams with gain, based on the bearing of an emitter
- From sum and difference signals of the normalized amplitudes, the bearing can be calculated

RWR Antenna Diagrams

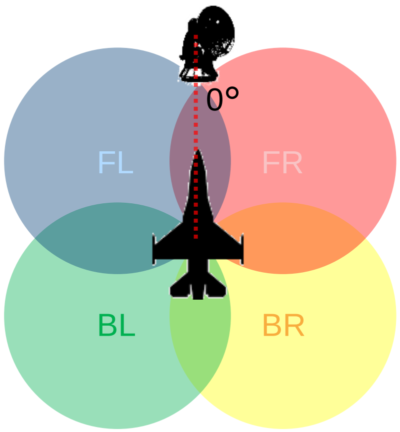




→ Σ and Δ channels AoA relative to antenna 1 boresight

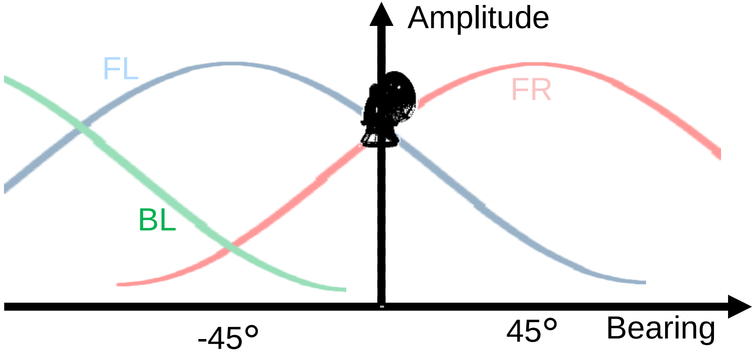
BASICS OF DIRECTION FINDING
AMPLITUDE MONOPULSE ANGLE OF ARRIVAL (AOA)

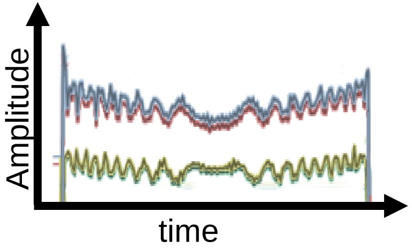
Amplitude Monopulse Angle of Arrival (AoA) – Part II



- Amplitude Monopulse DF requires 2 or more spatially separated receiver channels
- Overlapping directional antenna diagrams with gain, based on the bearing of an emitter
- From sum and difference signals of the normalized amplitudes the bearing can be calculated
- Techniques is often used in RWR due to its fast & easy implementation in DSP, but the downside is a somewhat inaccurate measurements

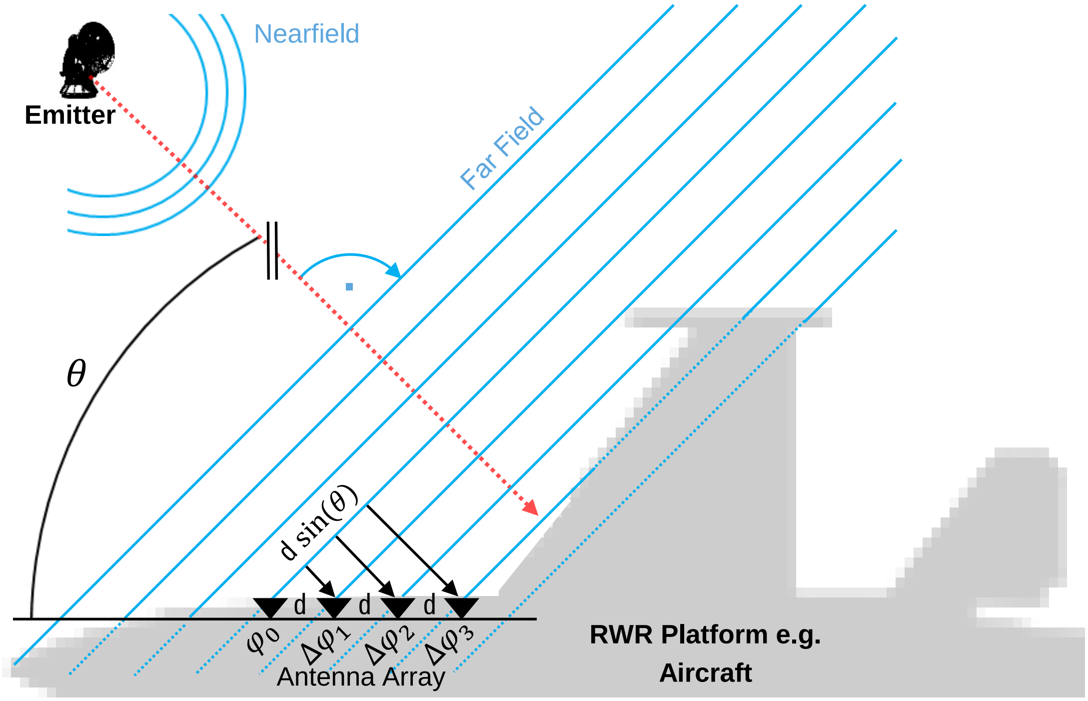
RWR Antenna Diagrams





→ Σ and Δ channels
AoA relative to antenna 1 boresight

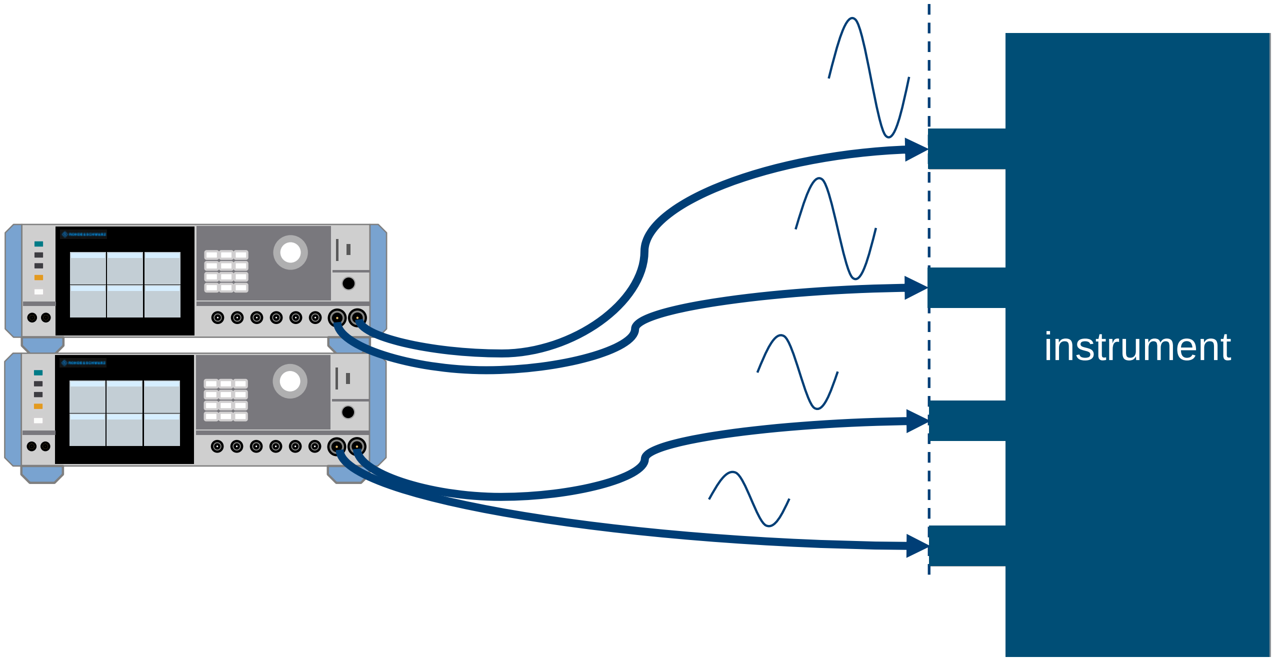
BASICS OF DIRECTION FINDING
PHASE MONOPULSE ANGLE OF ARRIVAL



$$\Delta\varphi_n = \frac{2\pi}{\lambda} d \sin\theta$$

MEASURING AND CORRECTING AOA ON SIGNAL GENERATORS

Reference plane: We need to know the simulated phase/amplitude/time difference here.



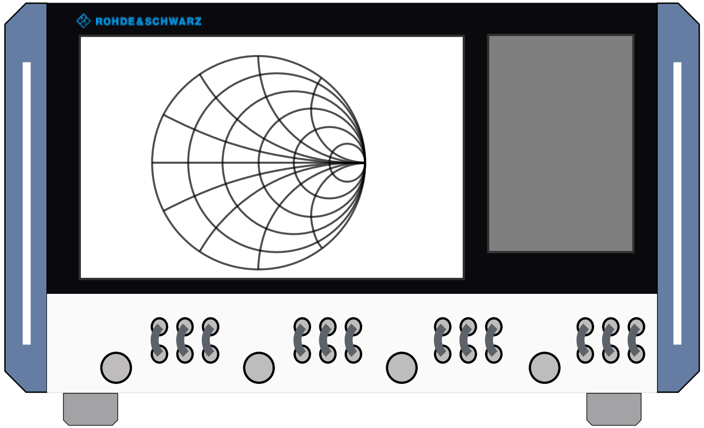
USING VECTOR NETWORK ANALYZER TO CALIBRATE AOA

Pros

- Wide frequency range
- Measure amplitude, phase and time w/group delay
- High dynamic range allows phase calibration at lower power levels
- Flexible calibration plane

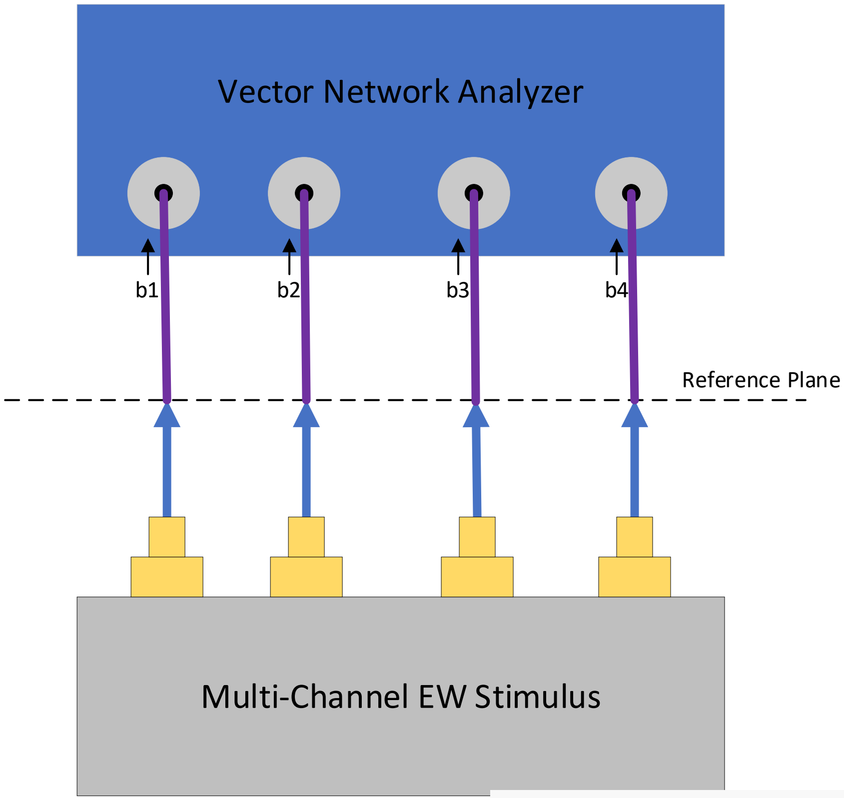
Cons

- Requires vector error correction – an added step but has many benefits



VECTOR CORRECTED WAVE RATIOS FOR MULTI-PORT STIMULUS

- The VNA is no longer used for traditional S Parameters
- The source on the VNA is de-activated
- The multi-port stimulus simultaneously drives all VNA ports
- Ratio measurements are conducted on the b receivers of the VNA



R&S PULSE SEQUENCER

WHAT IS A PULSE DESCRIPTOR WORD?

► Fully characterizes an RF Pulse.

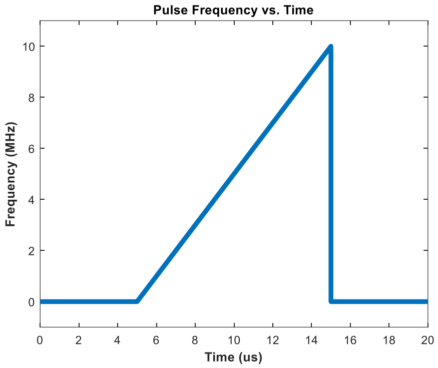
TOA

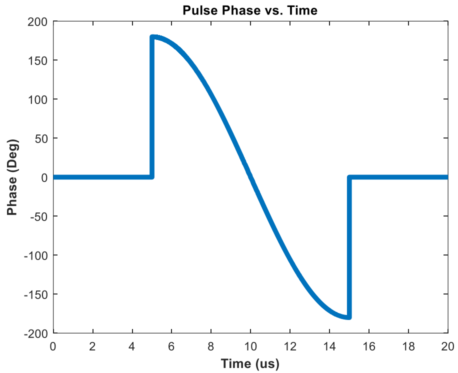
Frequency

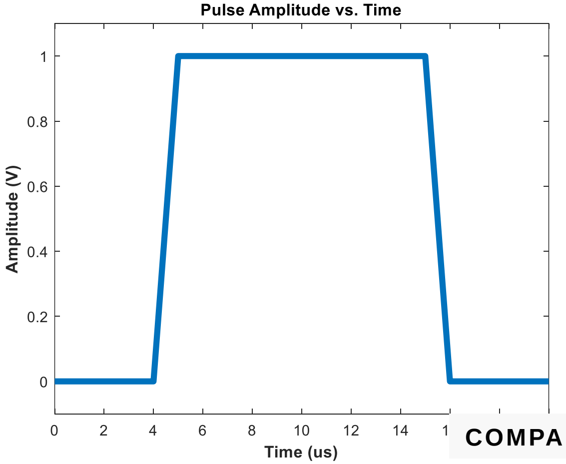
Level

Phase

Modulation







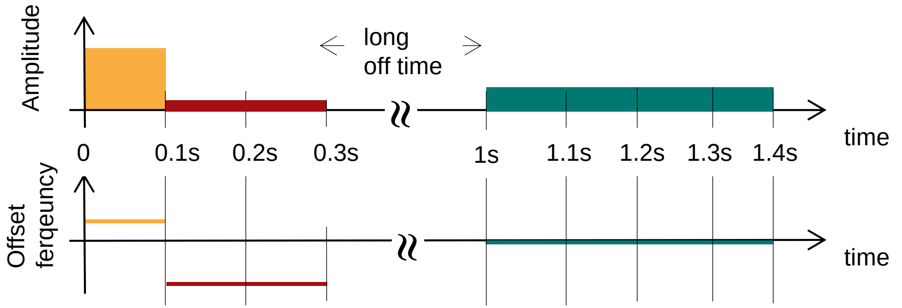
PDW CONTENT
ENABLING REALISTIC SIGNALS IN A PULSE DESCRIPTOR WORD

Signal defined by pulse parameters

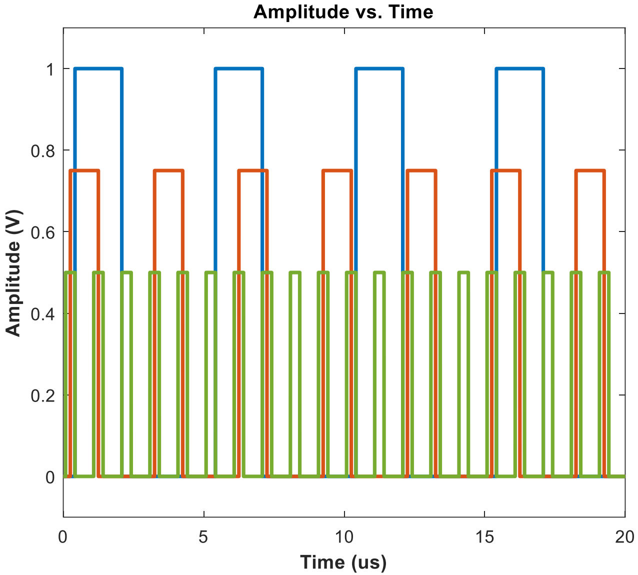
Pulse 1	Pulse 2	Pulse 3
0.1,	0.2,	0.4,
0,	10,	3,
10k	-1M,	0,
…	…	…

Sequencing list

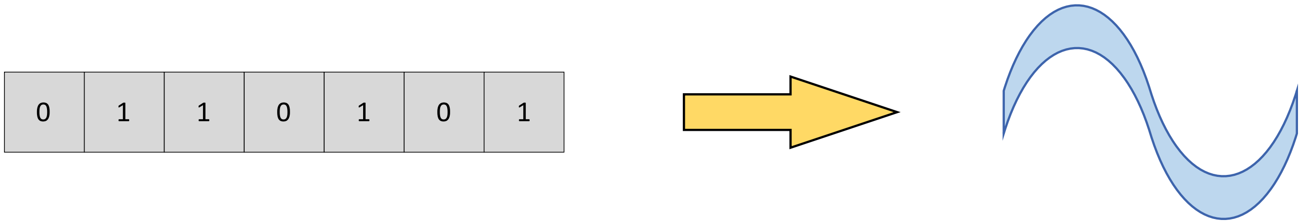
Time	Mode	PW	Attenuation	Offset frequency	Offset phase	MOP	rate
0 s	RT	0.1s	0 dB	10 kHz	0 deg	LFM	1 MHz/us
0.1 s	RT	0.2s	10 dB	-1 MHz	0 deg	LFM	1 MHz/us
1 s	RT	0.4s	3 dB	0 Hz	0 deg	LFM	1 MHz/us
…	…	…	…	…	…	…	…



ARCHITECTURAL CONSIDERATIONS



- ► Pulse-on-Pulse in the ANALOG domain
- ► Pulse-on-Pulse in the DIGITAL domain

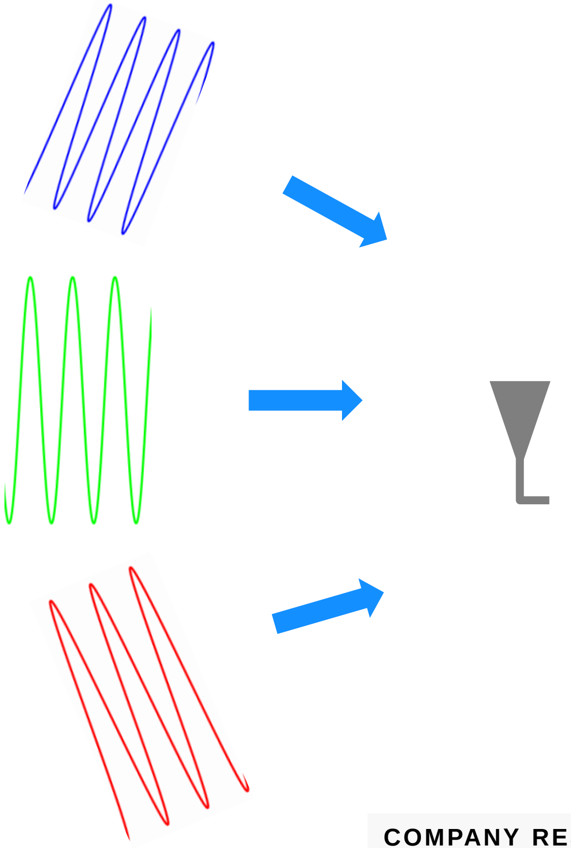


PULSE-ON-PULSE IN THE ANALOG DOMAIN

- External combination of multiple RF signal sources

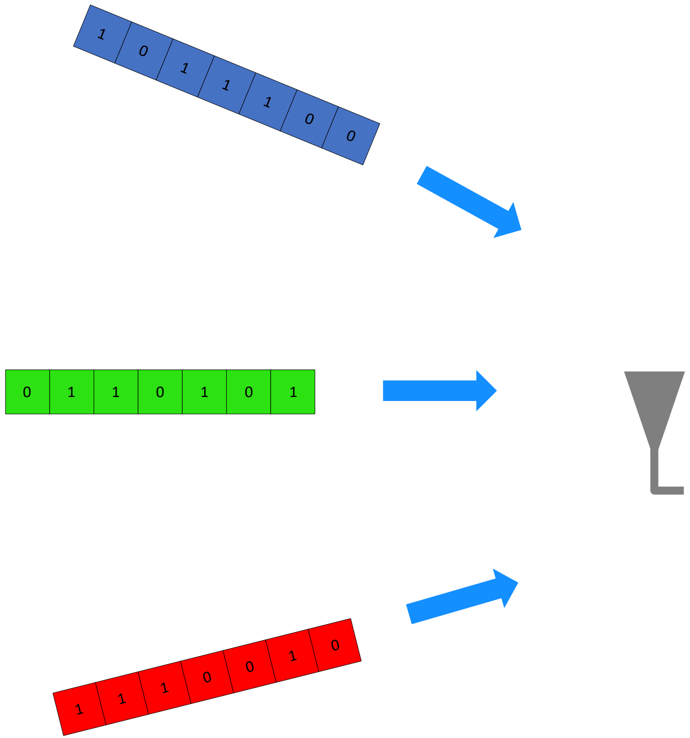
- Benefits:
  - Higher dynamic range
  - Wider bandwidth coverage

- Drawbacks:
  - SWAPC (Size Weight Power Cost)
  - Time alignment of pulses at the RF combiner output

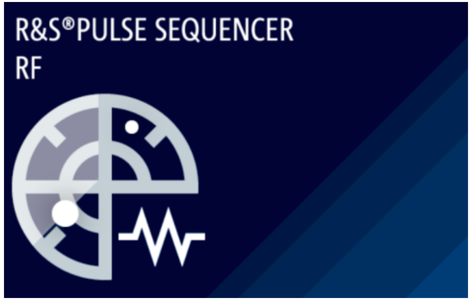


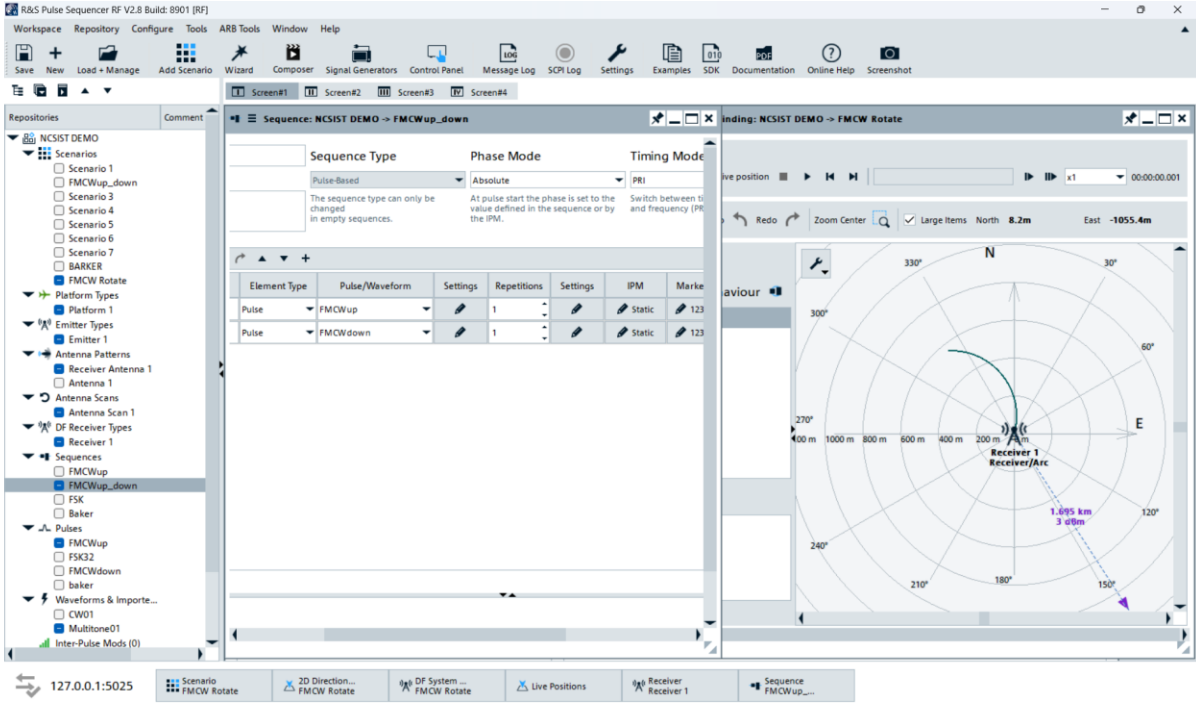
PULSE-ON-PULSE IN THE DIGITAL DOMAIN

- Digital combination of multiple baseband signals behind a single RF channel
- Benefits:
  - SWAPC
  - Time alignment of pulses at the RF combiner output
- Drawbacks:
  - Limited dynamic range
  - Narrower bandwidth coverage



R&S PULSE SEQUENCER
INTRODUCTION

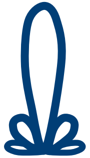




PULSE SEQUENCER

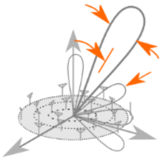
Pulses and sequences

⊕



Antenna diagram

⊕



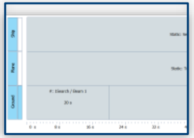
Antenna Scan(s)

⊕

- Δf
- Elevation
- Azimuth

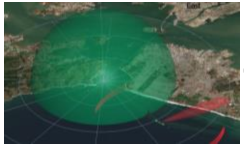
Beam specific offsets

⊕



Mode changes

⊕

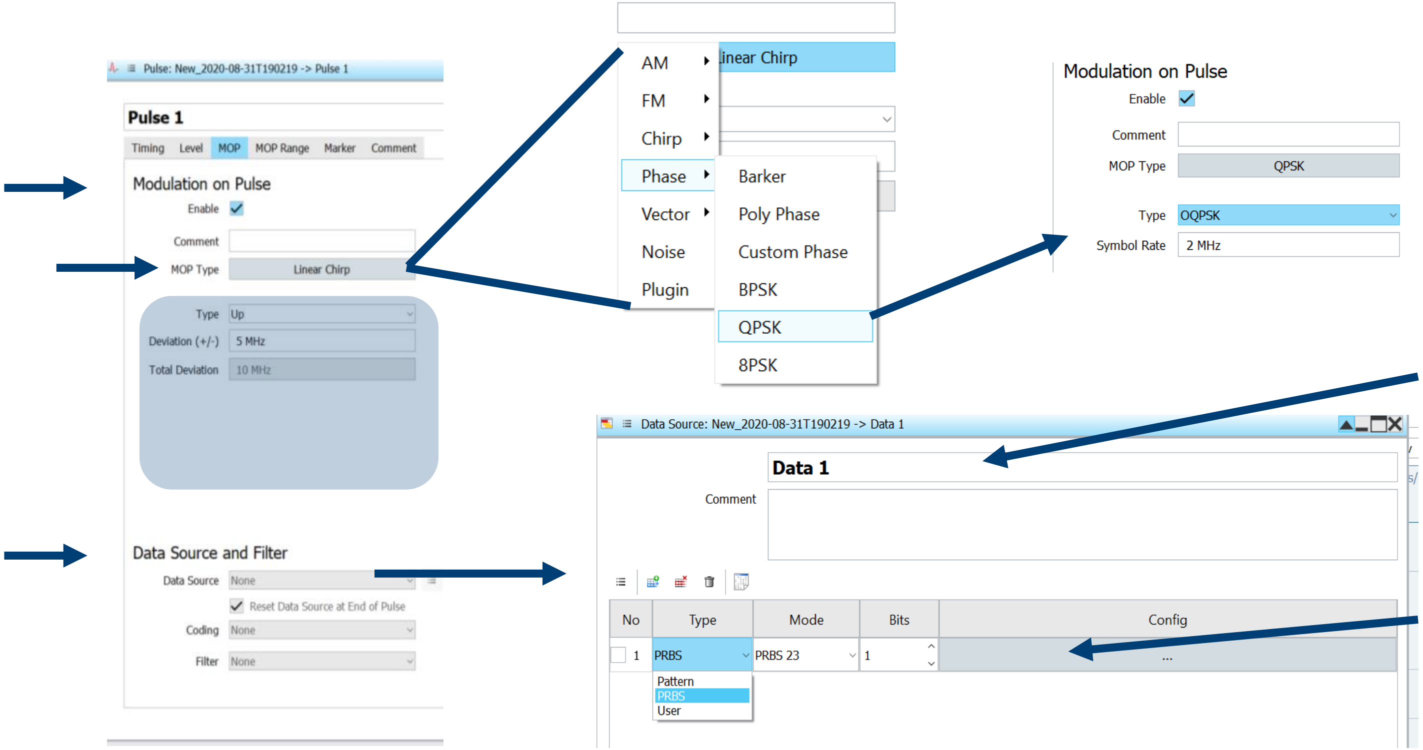


Map and trajectories

⊜

Emitter

R&S PULSE SEQUENCER
CREATING PULSES (MODULATION ON PULSE)

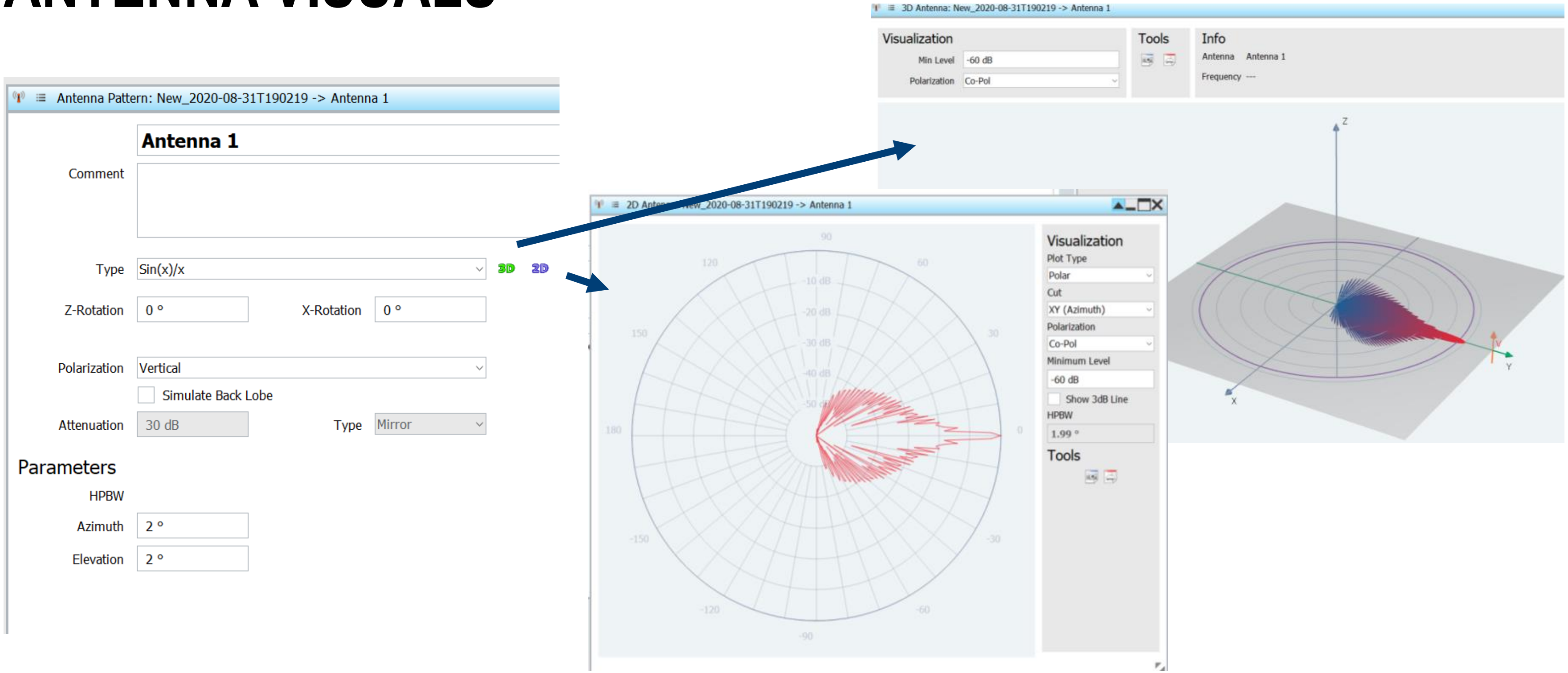


Data Sources can be assigned names and used throughout PS.

PRBS, Pattern, User Lists

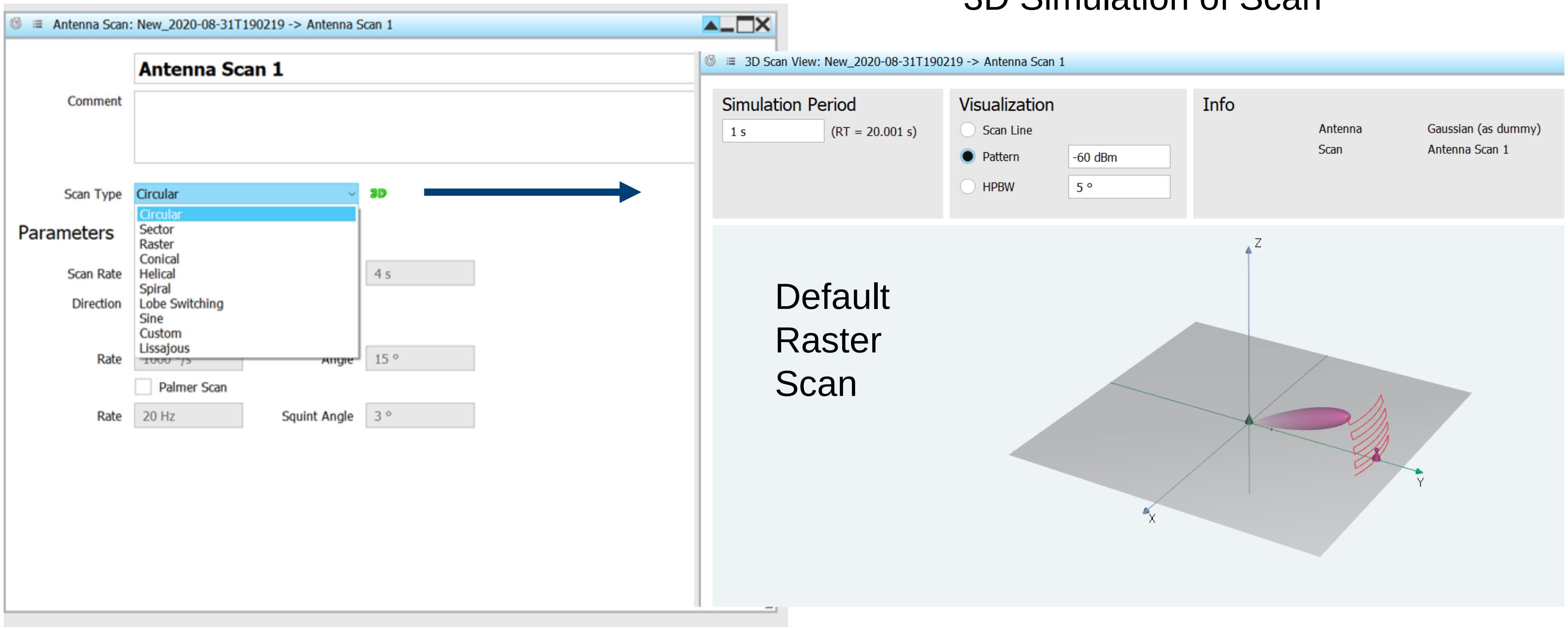
R&S PULSE SEQUENCER
ANTENNA VISUALS

2D, 3D Visuals



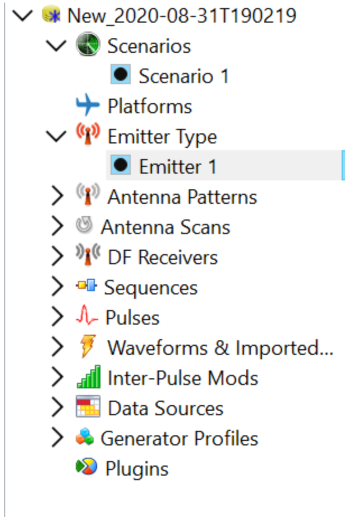
R&S PULSE SEQUENCER
ANTENNA SCAN PATTERNS

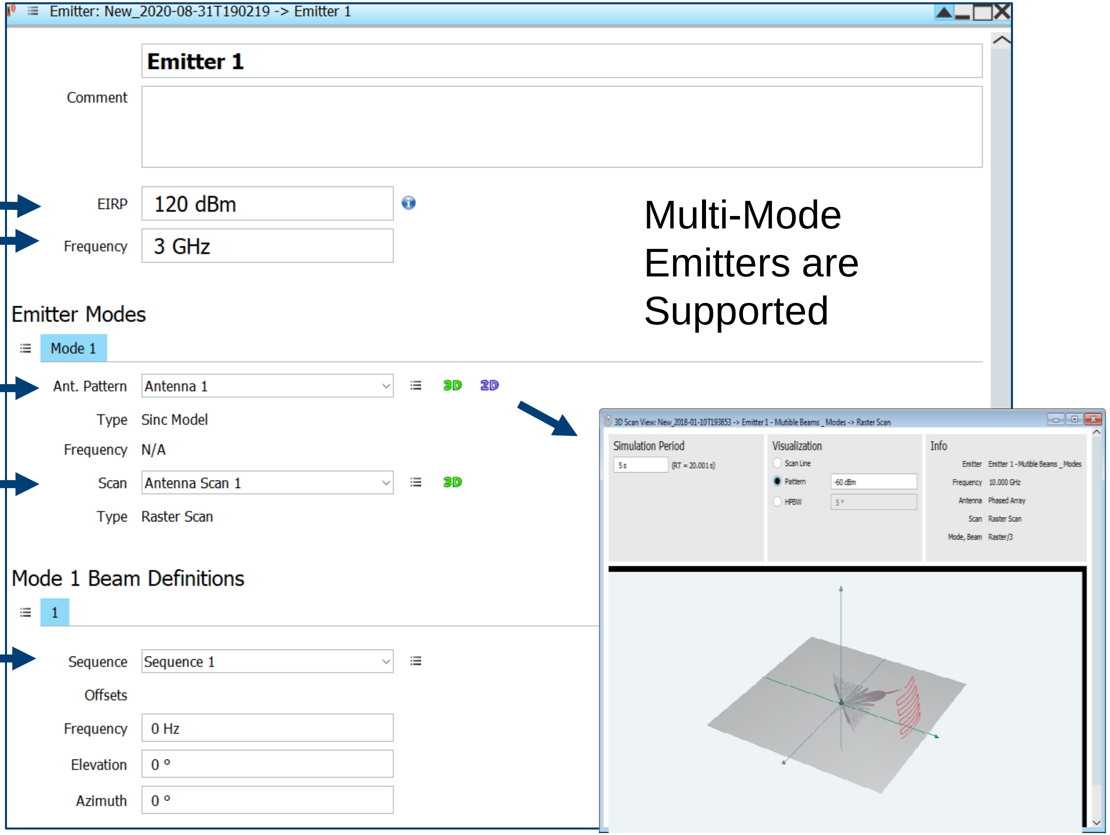
3D Simulation of Scan



R&S PULSE SEQUENCER
CREATING EMITTERS

New Emitter

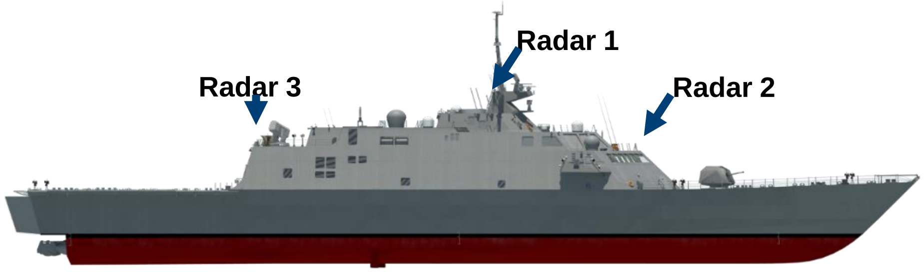




Multi-Mode Emitters are Supported

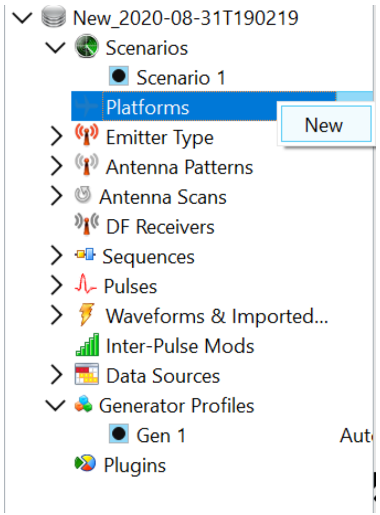
R&S PULSE SEQUENCER
CREATING EMITTERS – PLATFORMS

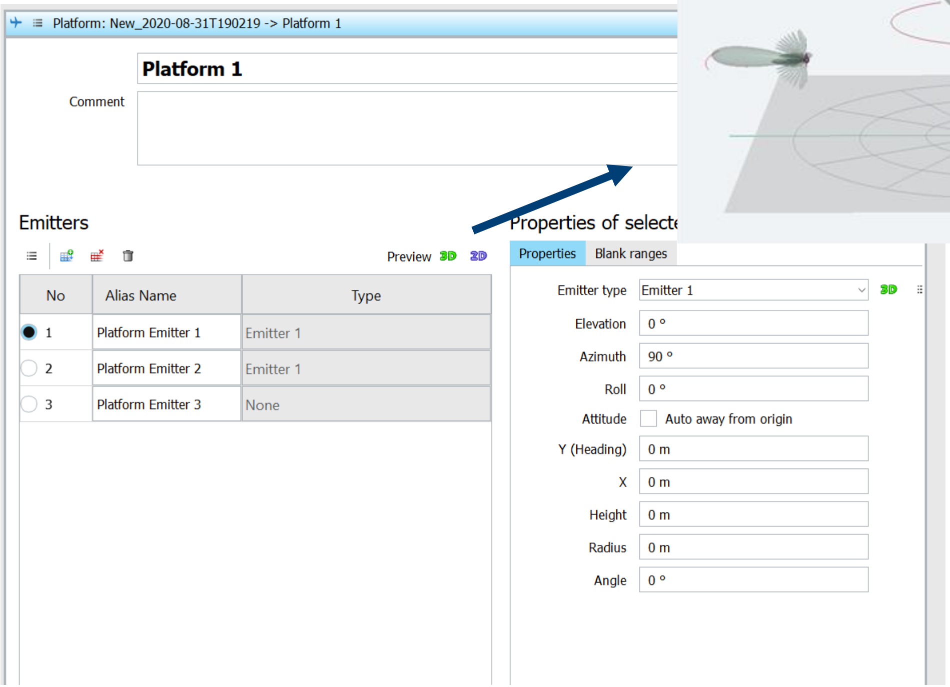
- Option K302 enables the simulation of ‘Platforms” with up to 8 Emitters on board.
- The signals from all of the emitters are precisely calculated according to their position on the platform and relative to the receiver.

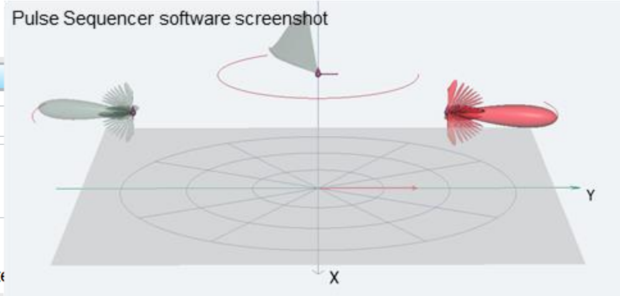


R&S PULSE SEQUENCER
CREATING EMITTERS – PLATFORMS

Platforms > New

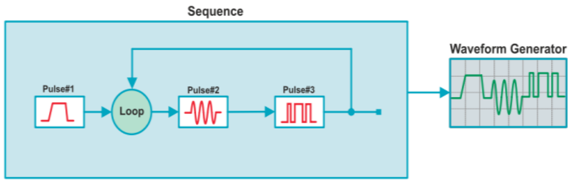




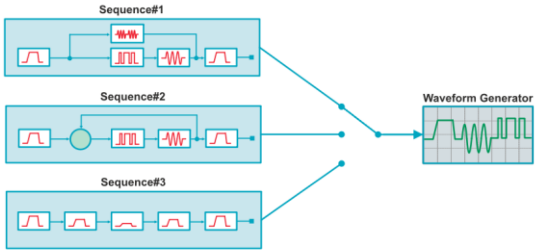


R&S PULSE SEQUENCER
SCENARIO TYPES

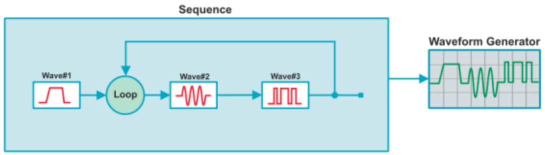
Single Sequence



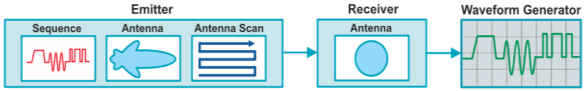
Sequence Collection



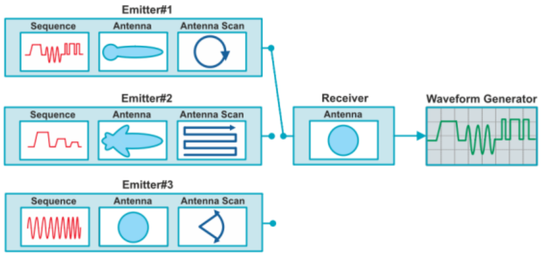
Multi Segment Waveform Sequencing



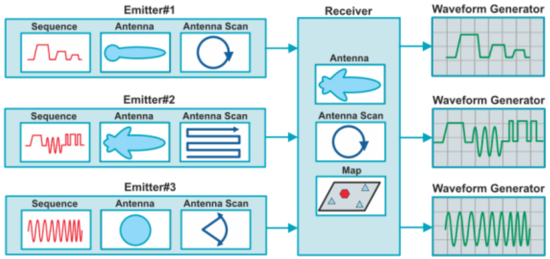
Single Emitter



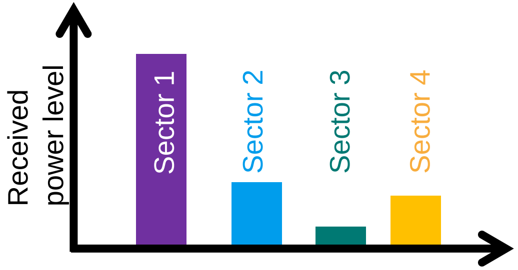
Collection of Emitters

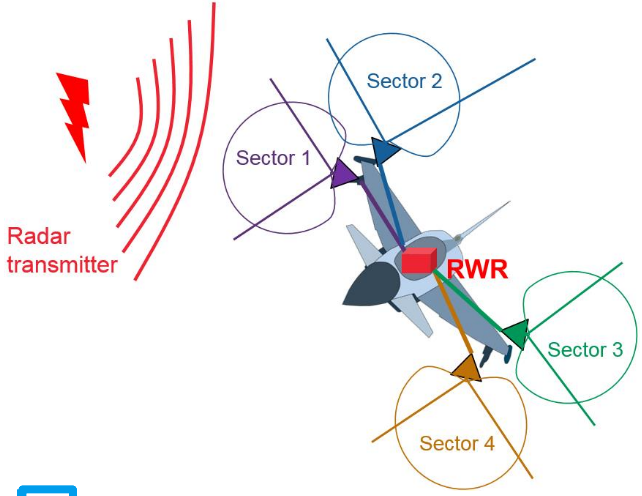


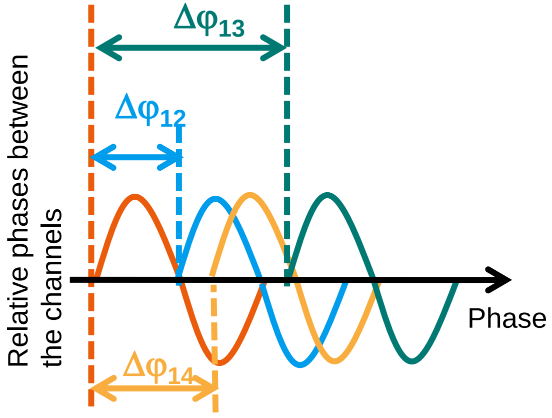
Localized Emitters – 2D Map

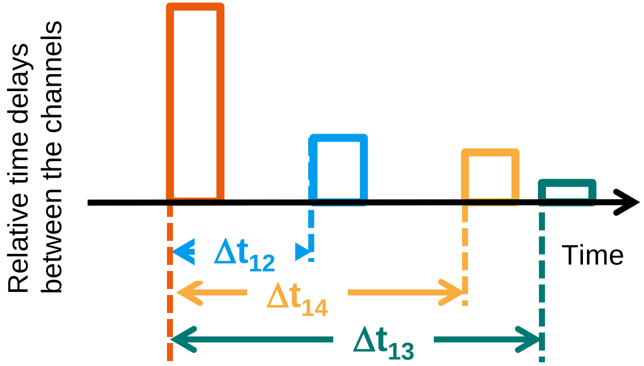


R&S PULSE SEQUENCER
SCENARIO TYPES – DF / AOA EXAMPLE

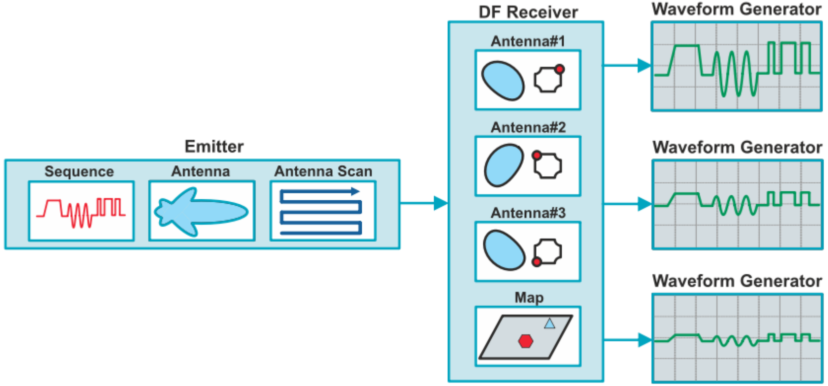


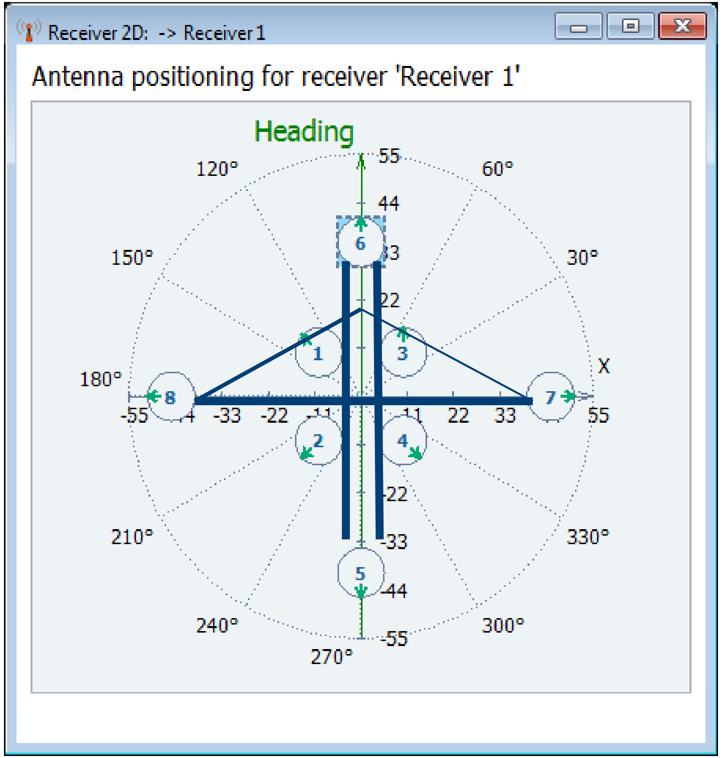






R&S PULSE SEQUENCER
SCENARIO TYPES – DF / AOA EXAMPLE

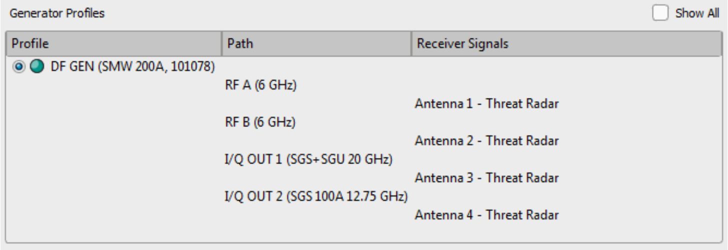




- The direction finding Scenario simulates a receiver with up to 10 antennas on a 2D map
- The individual signals of each receive antenna are simulated to enable the receiver to locate the position of the emitter.

R&S PULSE SEQUENCER
SCENARIO TYPES – DF / AOA EXAMPLE

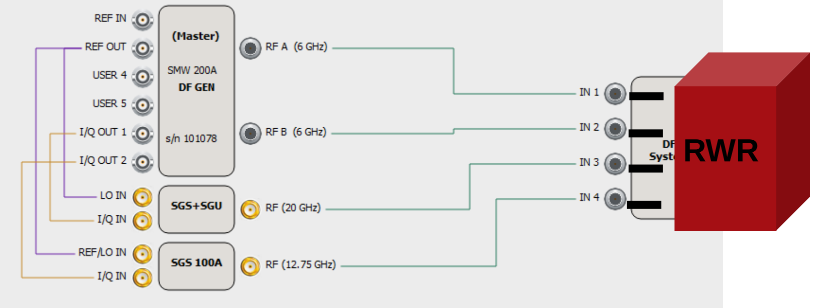
Assigned signals to respective RF output



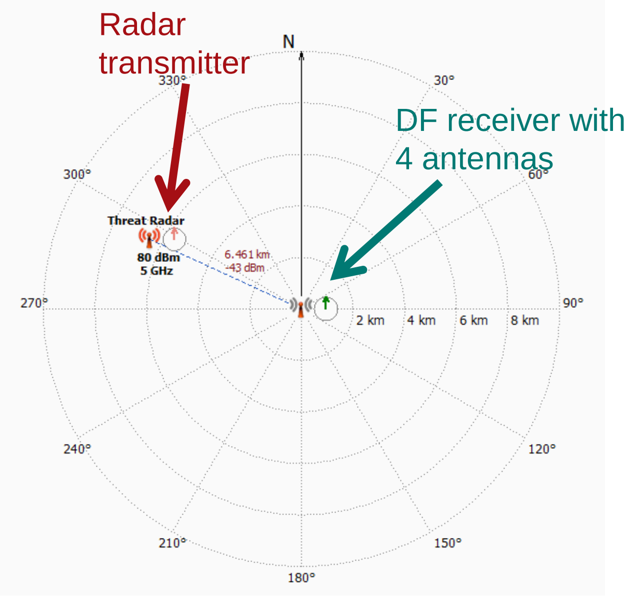
Generator Profiles — Show All

Profile	Path	Receiver Signals
DF GEN (SMW 200A, 101078)		
	RF A (6 GHz)	
		Antenna 1 - Threat Radar
	RF B (6 GHz)	
		Antenna 2 - Threat Radar
	I/Q OUT 1 (SGS+SGU 20 GHz)	
		Antenna 3 - Threat Radar
	I/Q OUT 2 (SGS 100A 12.75 GHz)	
		Antenna 4 - Threat Radar

Connection diagram

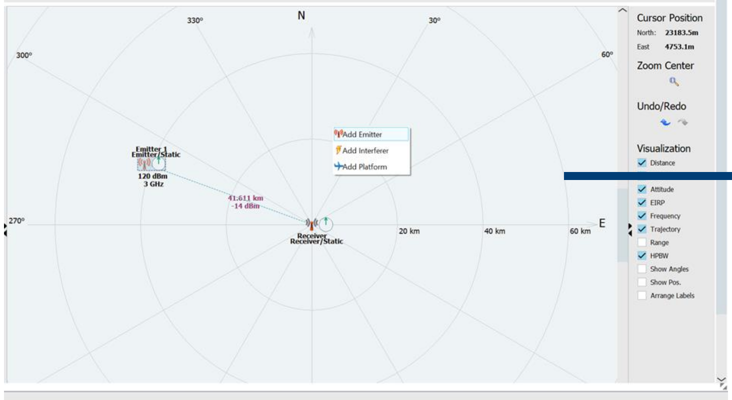


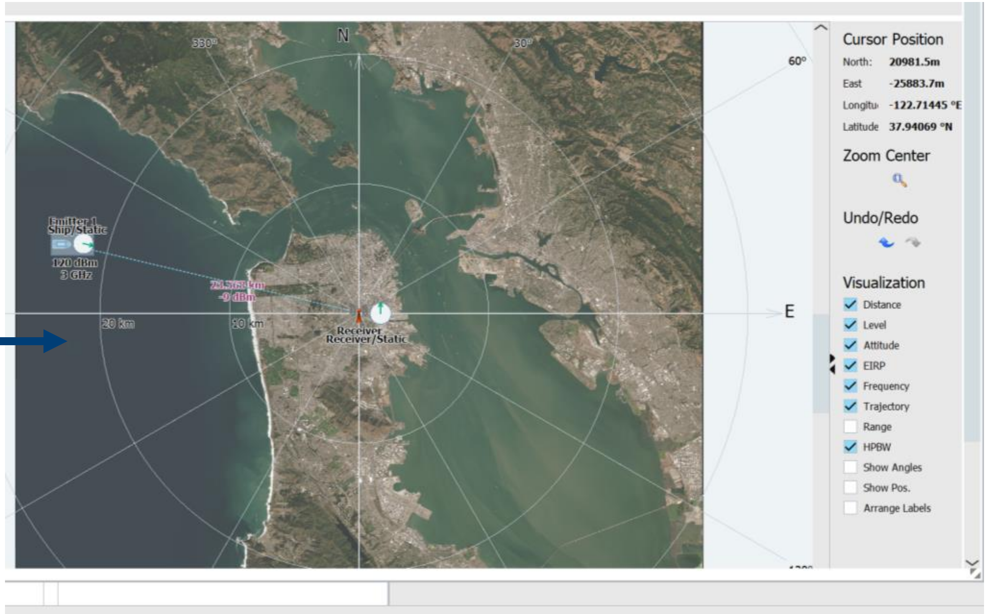
4 channel test setup



R&S PULSE SEQUENCER
SCENARIO TYPES – 2D MAPS

- Option K309 enables the ability to import 2D Maps
  - More realistic scenarios
  - Use Lat/Long coords for trajectories





CONCLUSION

EW TEST & MEASUREMENT SOLUTIONS

- In modern defense and security applications, **Electronic Warfare, Military Communications, and RADAR systems** play a crucial role in maintaining operational superiority.
- Effective **test and measurement solutions** ensure these systems perform reliably under real-world conditions.
- With the increasing complexity of threats, advanced testing methodologies—such as **real-time signal analysis, adaptive jamming techniques, and precision RF measurement tools**—are essential for mission success.

THANK YOU!