Tactical COMMS/ESM System for Submarines
–
A Front-end Perspective

Uwe Trautwein

South African AOC Chapter (Aardvark Roost) Conference
25th - 26th August 2009 at CSIR Conference Centre, Pretoria

uwe.trautwein@medav.de

Overview

- Introduction & Motivation
  - See also *Proceedings Big Crow Conference Nov 2008 : Dirk Baker – The Challenges of Developing a COMINT DF & Monitoring Antenna for … Submarine Operations*
  - ➢ COMMS/ESM – the acronym puzzle
  - ➢ The Submarine as a surveillance platform
- System Overview
- Direction Finding Capabilities
- Conclusions

Introduction

COMMS

- Radio communications reconnaissance system
- Communications Intelligence - Strategic system component

/ESM

- Electronic support measures – Tactical system component
- Identification and tracking of potential threats → EOB picture
- Integration into the Electronic Warfare System

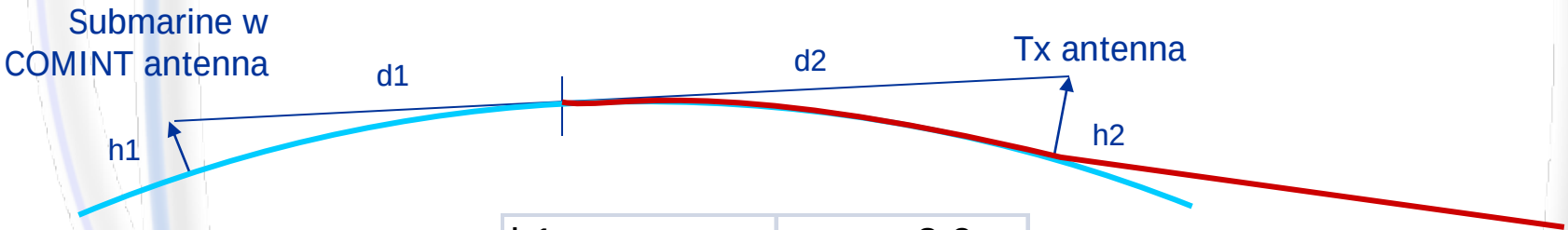
Overlap : detection and interception of signals

Covert operation

- Submarine stays submerged – only the antenna is deployed above surface
- Ideal reconnaissance platform for coastal areas and open sea

COMMS/ESM advantage

- Extended radio horizon for lower frequency COMMS signals
  - ➢ Enables the submarine to "look" behind the horizon



~2 m at periscope depth

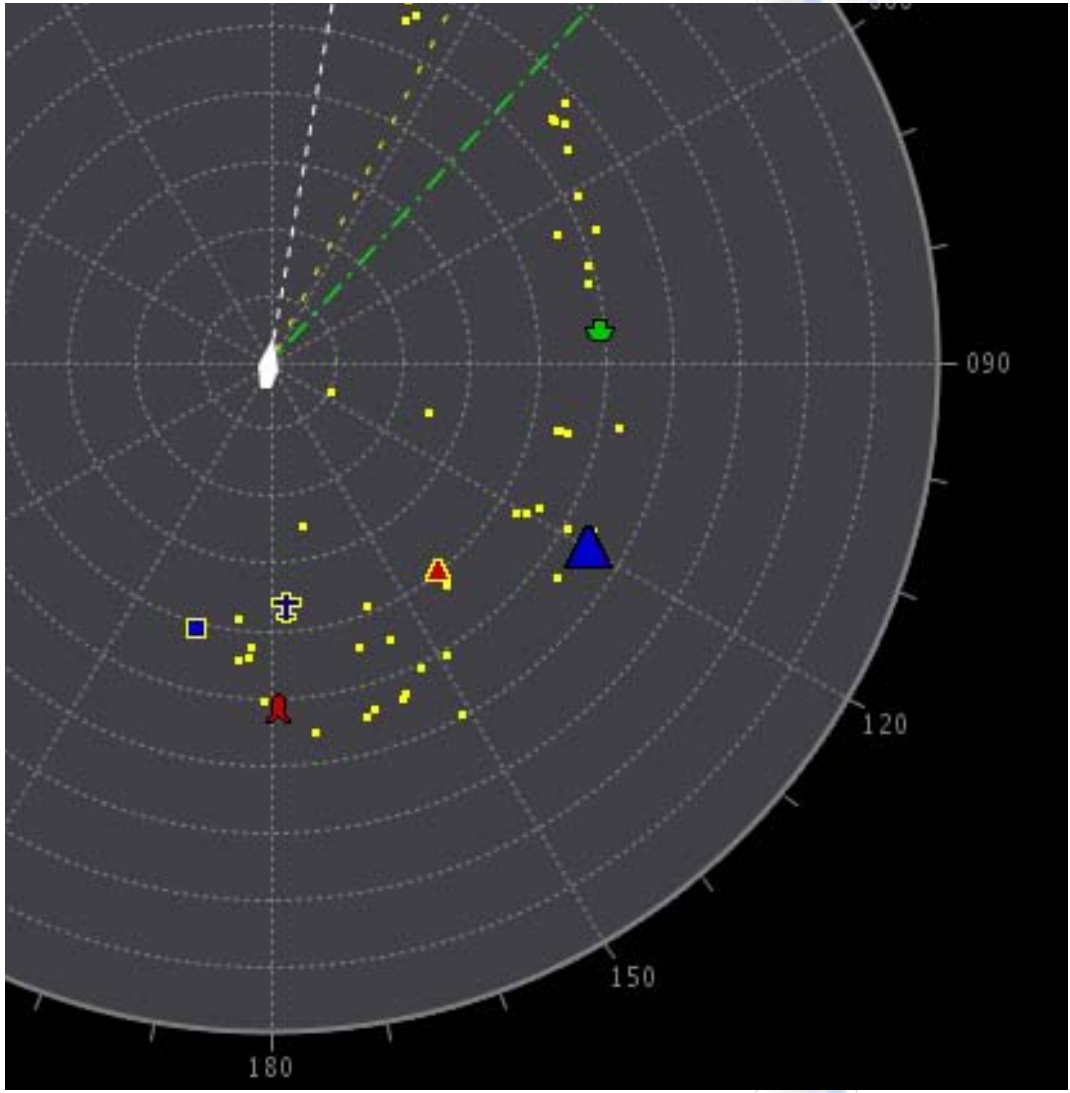
h1	2,0 m
h2	5,0 m
LOS Distance	13,0 km

No refraction

Obvious Benefits of the Direction Finding for COMMS Signals

Provide a bearing for a detected signal

- Only this enables ESM capabilities
- Allows to focus detection on a target area
- Prerequisite for locating
- Allows intelligence fusion with other sensor data



Some Less Known Benefits of the Direction Finding for COMMS Signals

Allows reliable automated emitter detection in dense scenarios

- By jointly exploiting spectrum and azimuth information

Provide SNR gain for the detection of weak signals

Separation of stations for certain signal types

- Frequency hopper networks
- Duplex communications

Separation of multiple co-channel signals

The Technical Challenges

Wideband DF antenna on very compact space (300kHz – 3GHz)

- Outer antenna diameter (radome): 510 mm
- High phase accuracy requirements for the DF system
- Antenna pattern quality impairments expected due to mutual coupling
- Pressure-tight, thick radome - Probably affecting wave propagation
- Integrated monitoring capability

Existing ESM ELINT antenna on top

- Electromagnetic coupling, space for cable feed-through

Tight specification parameters set by the customer

- Uncompromised DF accuracy up to 30 deg elevation
- DF and monitoring operation up to 70 deg elevation

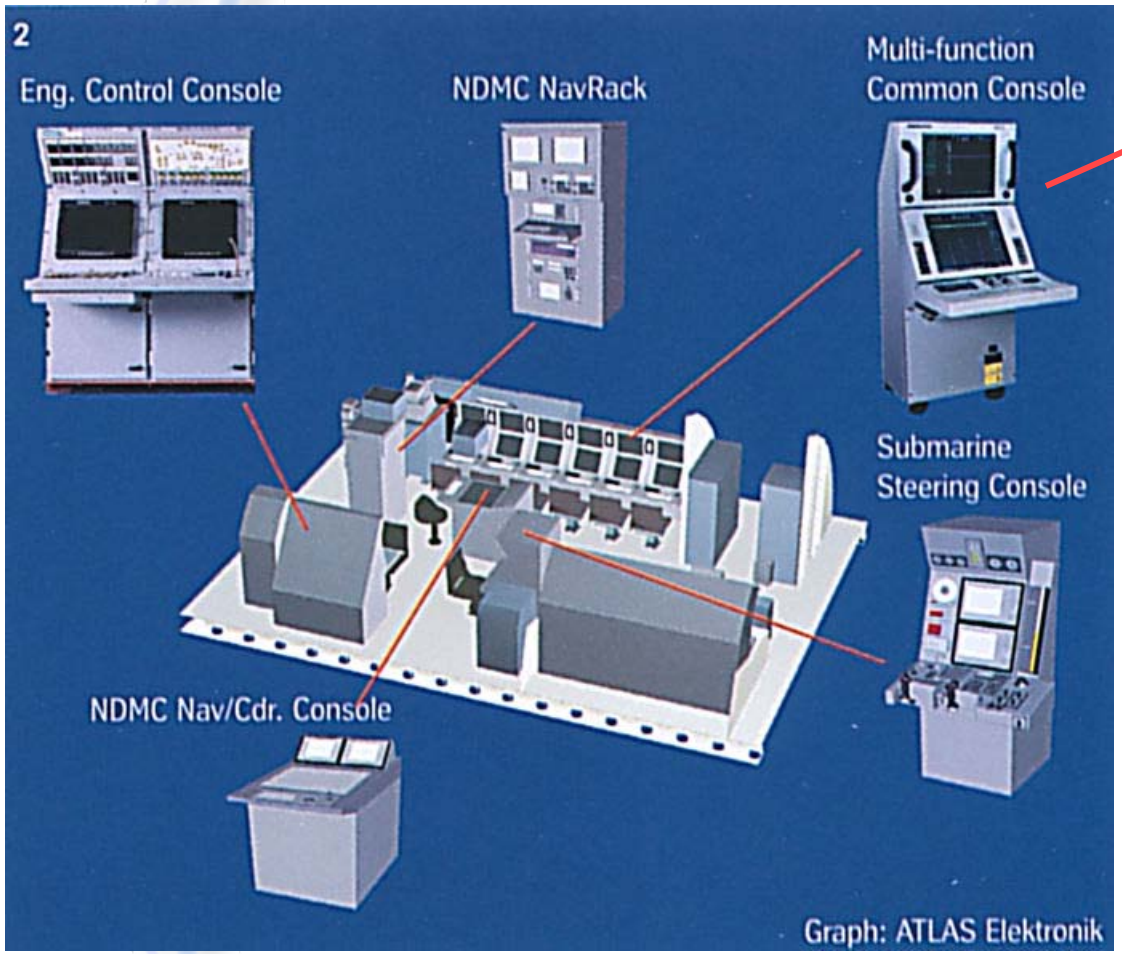
System components

- Antenna
- COMINT Rack
  - All liquid cooled
- Multifunctional Consoles

Software defined radio concept

- Medav CCT receiver with integrated FFT processor, output via Gigabit LAN interface
- General purpose computer platform for all processing tasks

Seamless Submarine Integration



MFCC for alternative systems

- COMMS/ESM (Medav)
  - Brand name: CRS-8000
    Communications
    Reconnaissance
    System
- Radar ESM (Saab Avitronics)
- Radar
- Optronics
- Etc…

COMMS/ESM with up to three simultaneous operator roles

- Supervisor
- Wideband operator
- Tracking operator
- Post-processing operator

Detail of SIGINT Antenna System

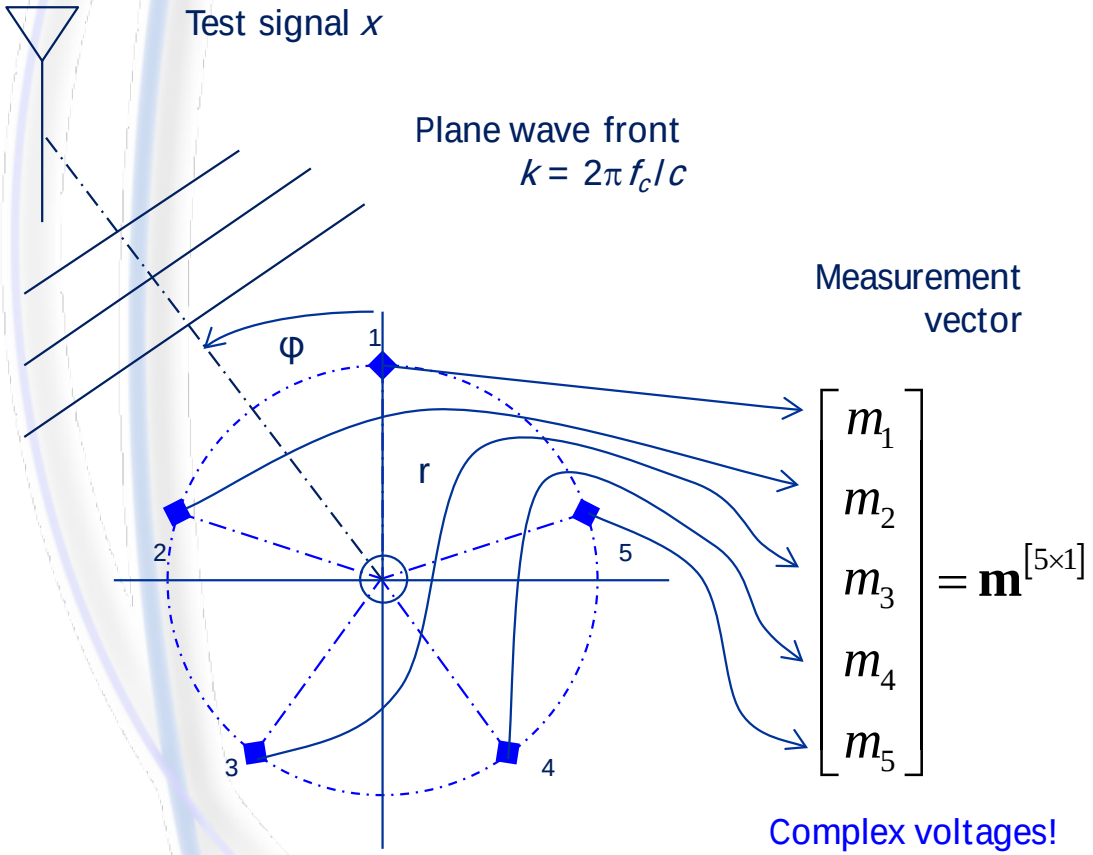
- SIGINT antenna comprises ELINT and COMINT antennas on top of **one mast**

  ELINT antenna is an existing assembly.

- COMINT antenna has several key assemblies:
  * Radome
  * UHF array
  * VHF arrays
  * HF array
  * RF assembly
  * Mast interface and clamp
  * Wet diploops

Basic Principle of the Correlative Interferometer for Direction Finding

- Vector correlation of the complex receive voltages with the array manifold
- The array manifold is obtained by antenna calibration measurements



$$c(\varphi) = \mathbf{m}^{H} \cdot \mathbf{a}(\varphi)$$

- Angular power spectrum

$$\hat{\varphi}_m = \arg\max_{\varphi}\{|c(\varphi)|\}$$

- Peak search in the angular power spectrum
- "For free": Quality criterion

Complex voltages!

→ phase synchronous receive chains

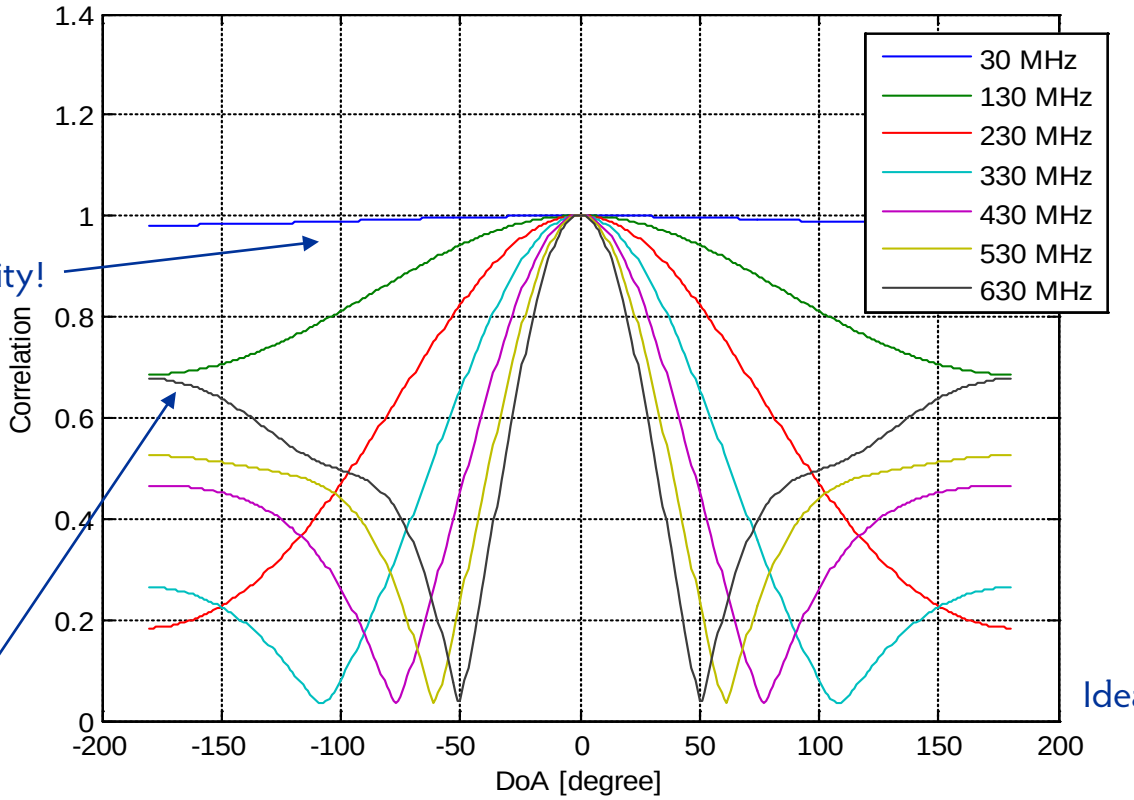
Wideband coverage

Limited array size → small phase differences → poor correlation properties + high phase measurement accuracy

Wideband use → trade-off must consider also the upper band edge

Very weak spatial selectivity!

High side lobe



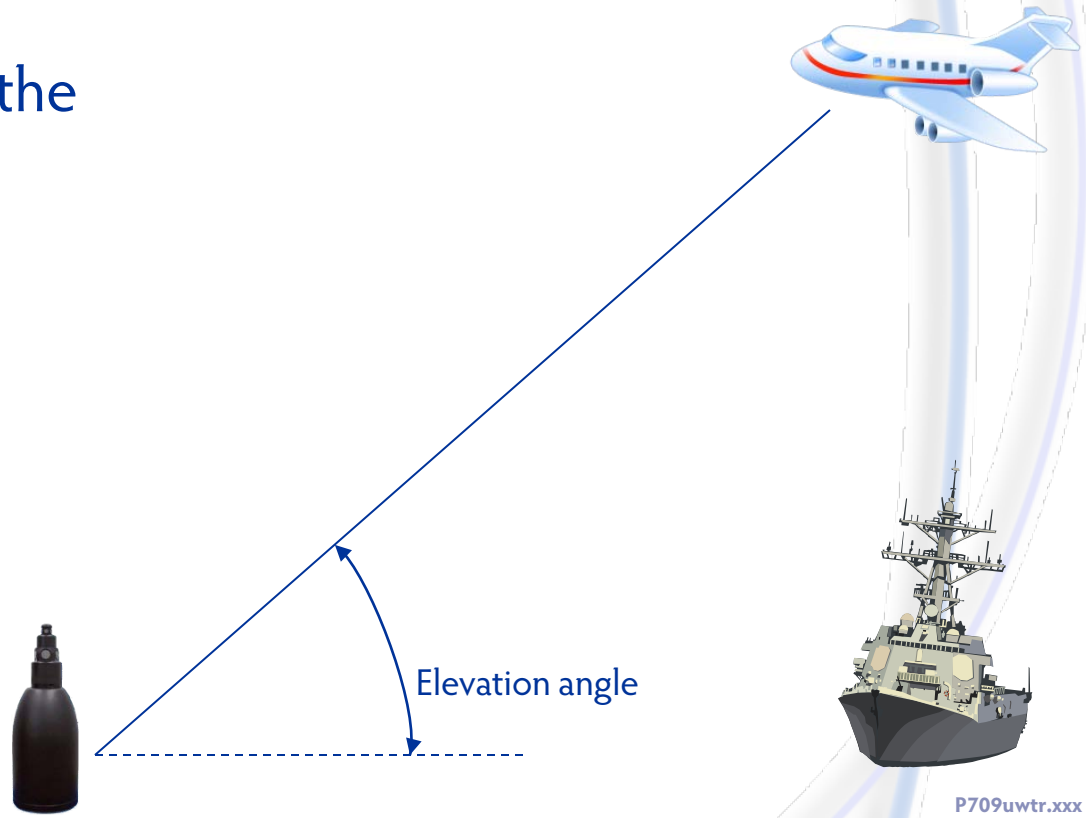
Ideal 5 element array

Elevation Coverage - Motivation

Operational aspects

- The submarine is always a "Low altitude platform"
  - Airborne emissions
- Tolerate roll & pitch of the boat
- Discriminate between airborne and shipborne emissions

- Elevation coverage vs. Elevation estimation
  - Not exactly the same

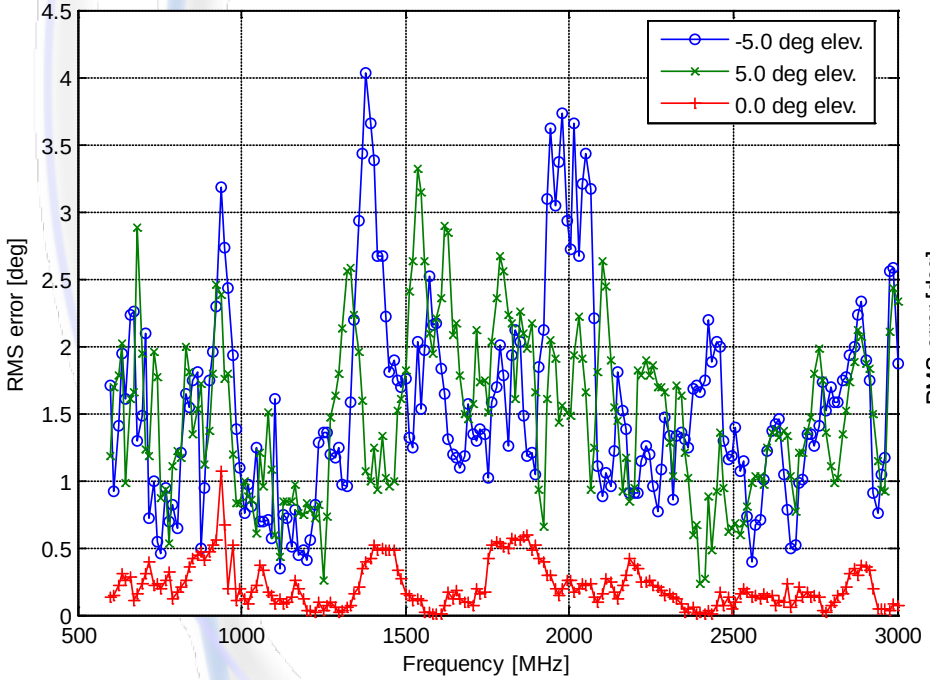


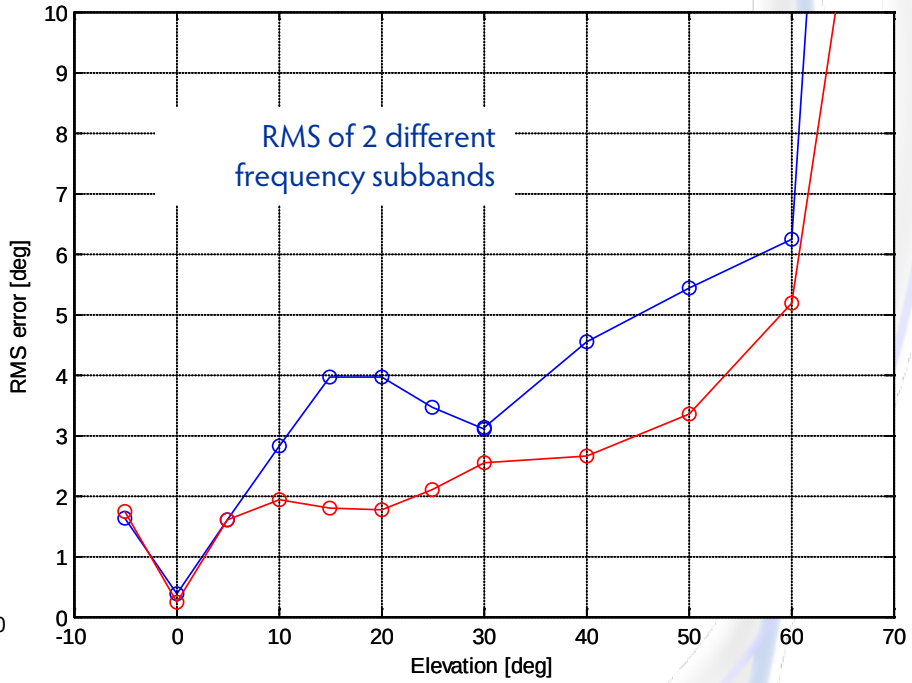
The Common Case: Degradation vs. Elevation

- Degradation is frequency-dependent visible even for modest elevation angles
- Degradation can turn into complete failure

→Full 3D calibration was found to be inevitable

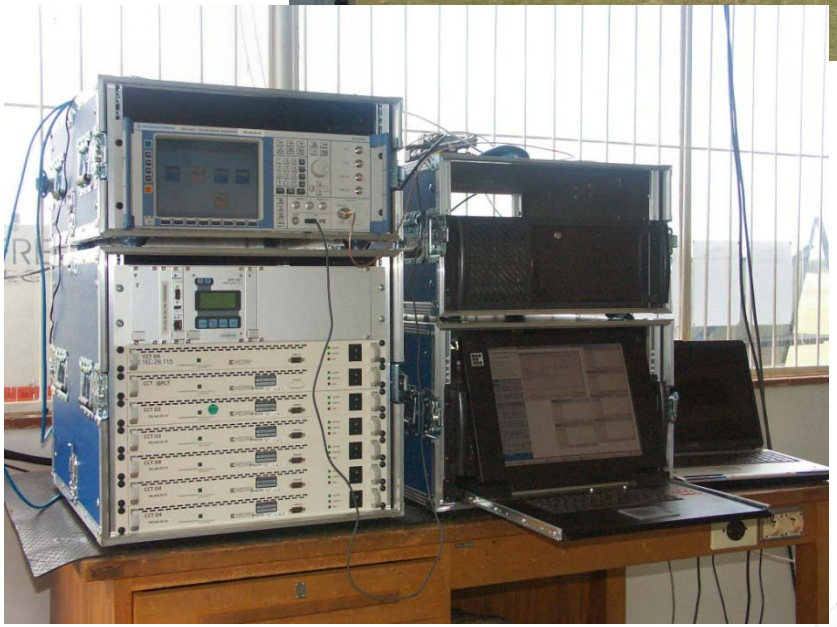
- Requires optimized calibration grid to limit measurement time
- Benefit: DF provides elevation information





Antenna Calibration and Direction Finding Test Setup

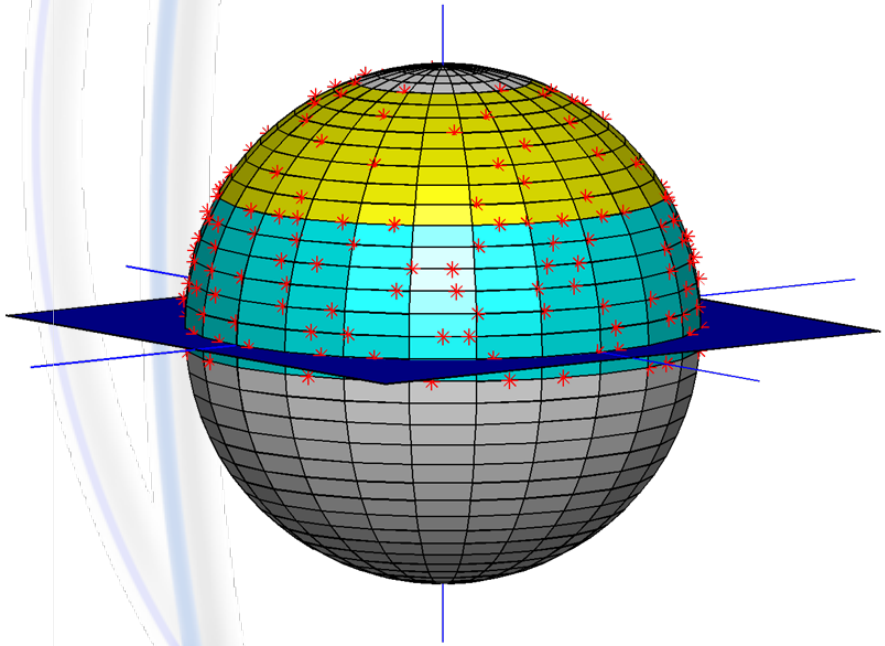
- National Antenna Test Range at Paardefontein, South Africa
- Fully automated measurements



- Prototype DF System

Factory Acceptance: Measurements over the full specified volume

- The DF accuracy (RMS azimuth error)
- The Monitoring Sensitivity (E-Field strength to achieve 10 dB SNR)



System Performance Achievements

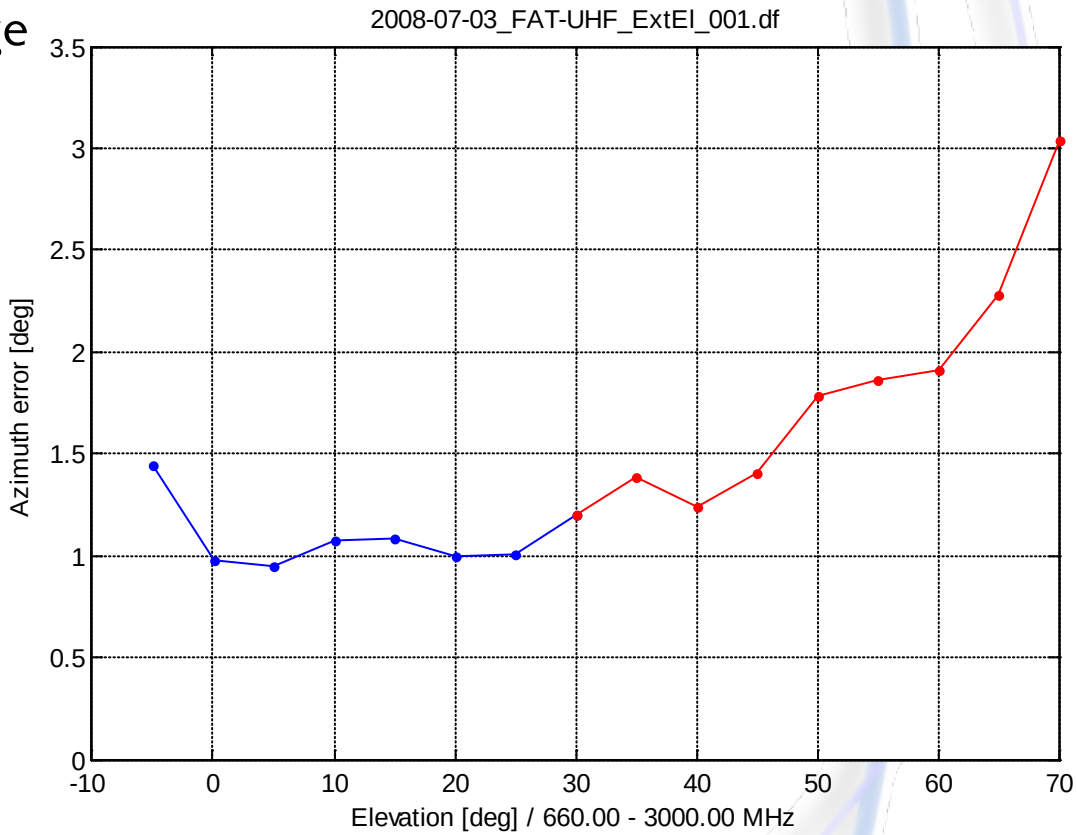
All specifications parameters are finally met

- DF accuracy typically better then 2° RMS
- Monitoring sensitivity with good margin
  - ➢ Even for full elevation range

Comprehensive verification during FAT

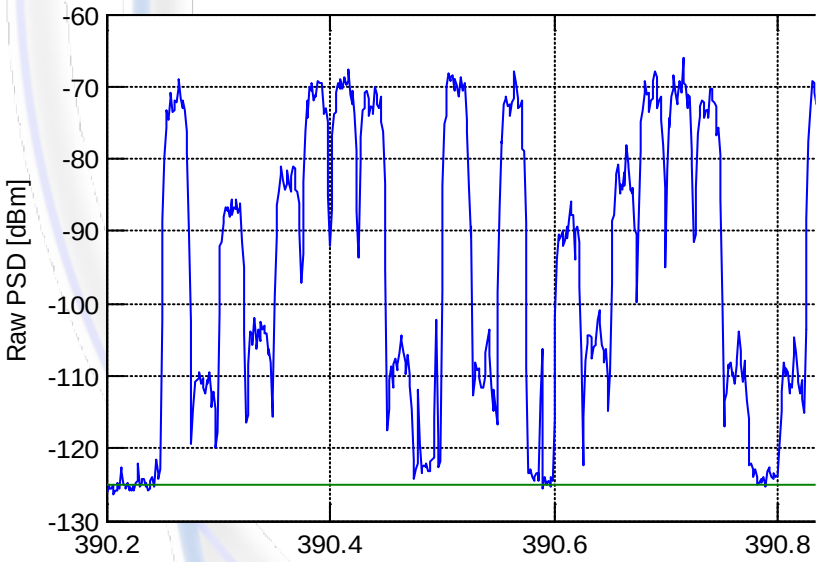
- 202,150 total samples over azimuth, elevation and frequency

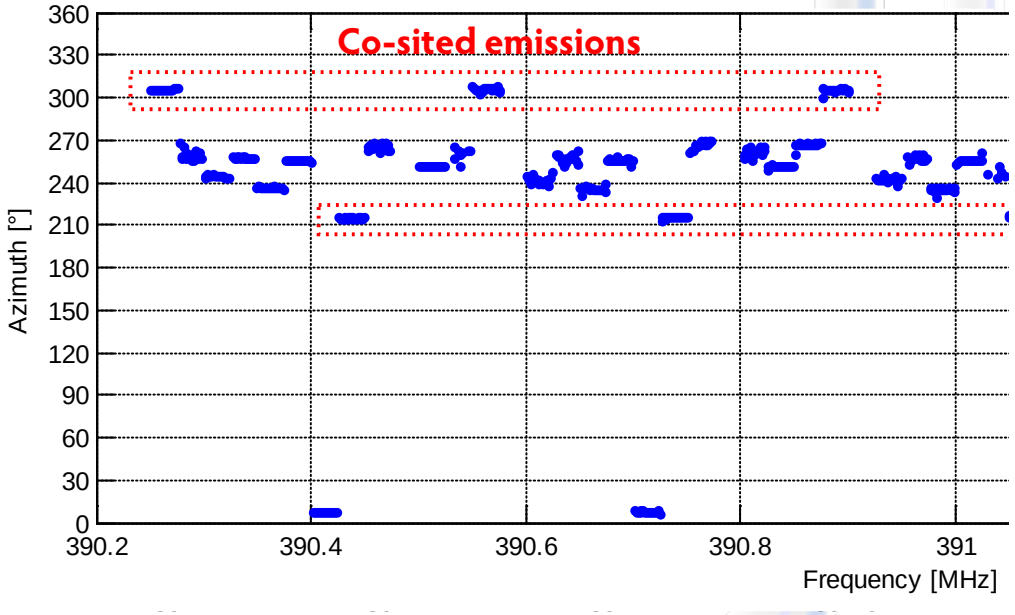
Very good reproducibility between systems



Emitter Detection in the Joint Power-Azimuth Domain

- Automated Process of identifying individual transmitters incl. base parameters: fc, B, SNR, phi
  - Used for alarm conditions, reporting, further analysis
- Exploits 3D cluster structure of FFT based DF results
  - Reliable results for many scenarios where pure power spectrum analysis must fail





Foreword on Polarization

Treatment of polarization in the COMINT DF context is rather sparse

HF space wave DF = mixed polarization

- Either monopoles (good Xpol) or combination of monopoles and loops

Common approach for VHF/UHF:

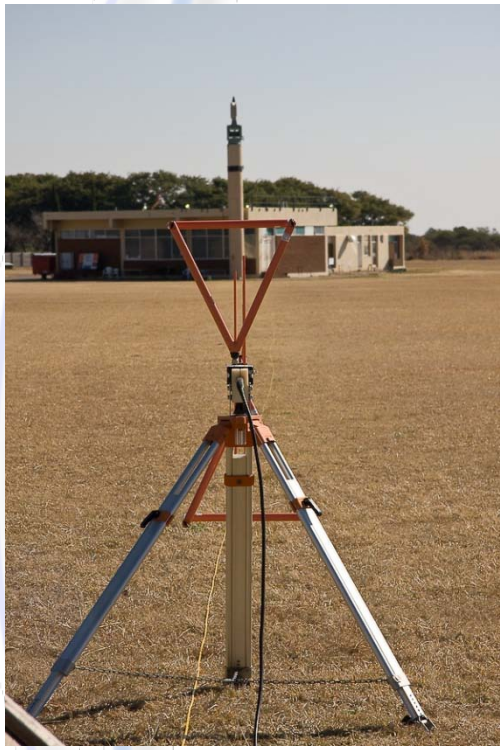
- The system is specified for vertical polarization

Important figure: Cross polarization (Xpol) attenuation (dB)

- ➢ Horizontal source → Vertical element response (HV)
- Small elements in compact configurations have typically a low Xpol
  - ➢ Good values are 15 dB and more, less is not uncommon

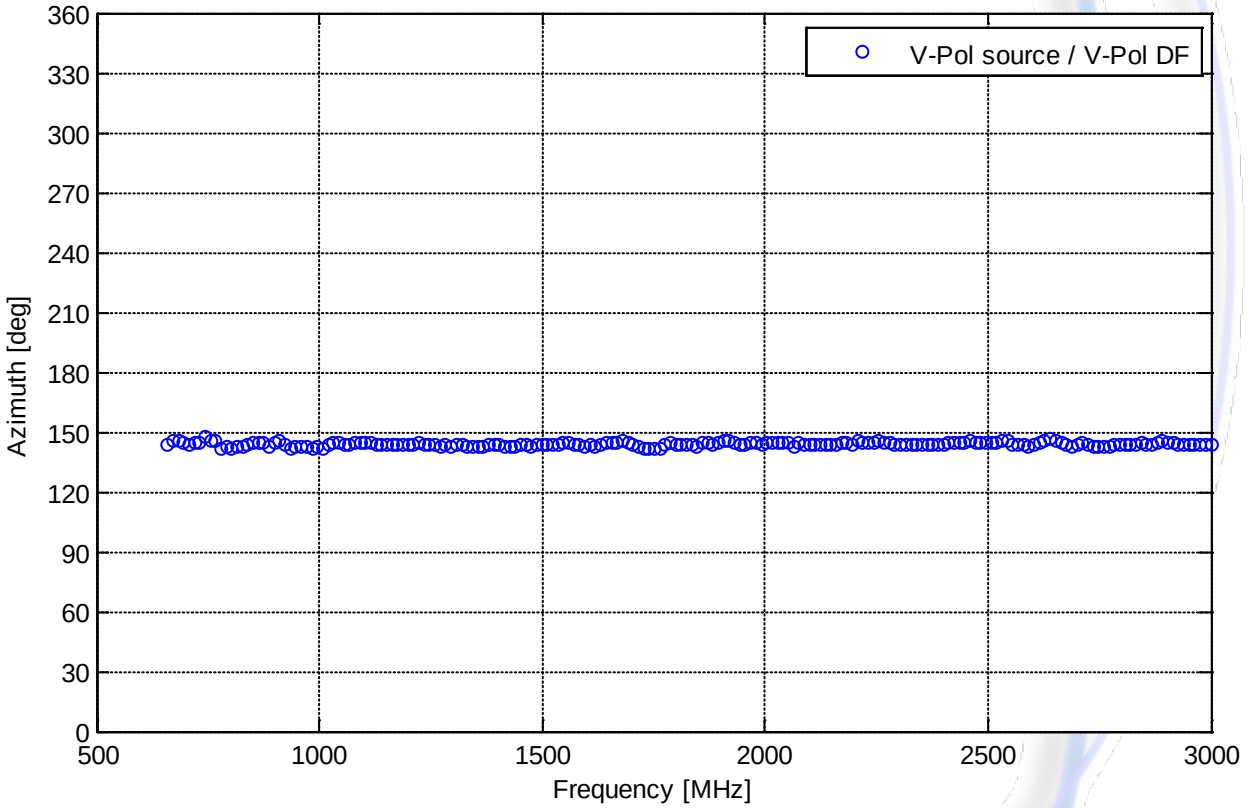
Question: What happens if a Vpol system experiences Hpol?

Vertically polarized source



■ Vertically polarized source

DF estimates for a defined DOA

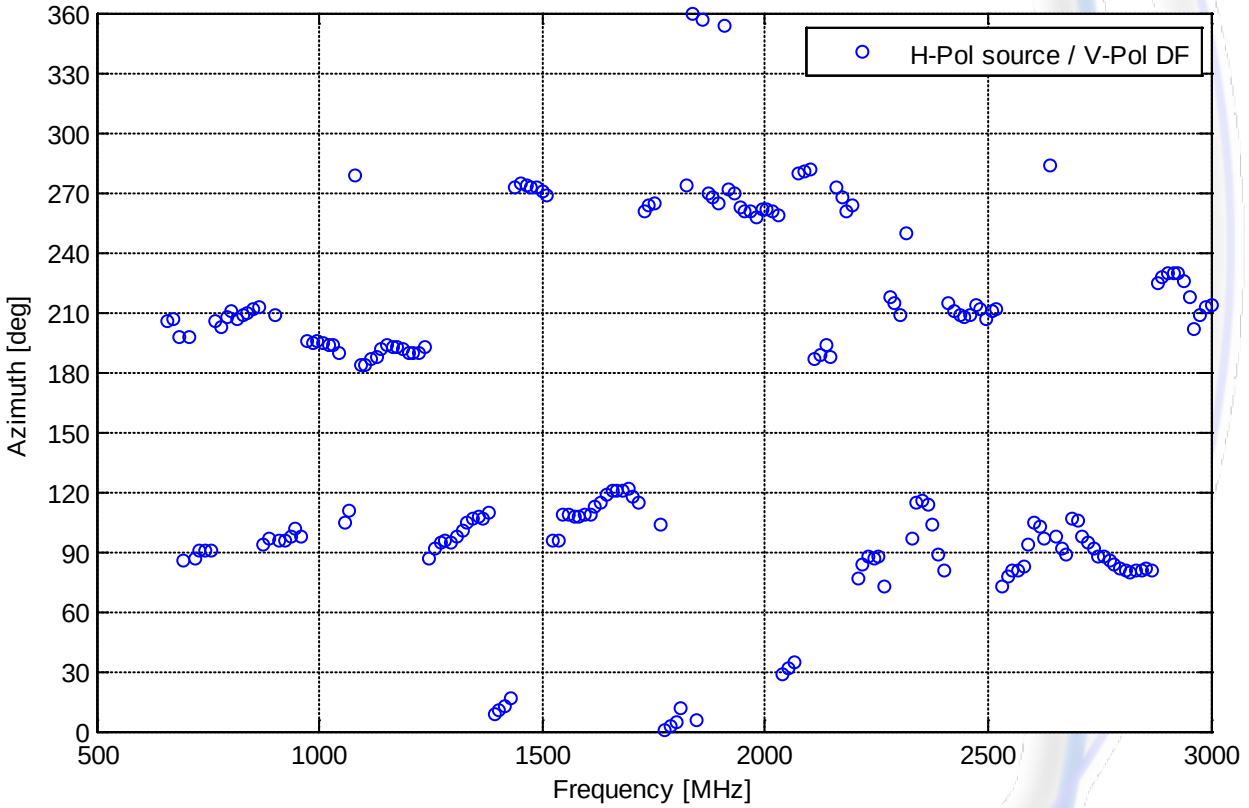


Horizontally polarized source

- Horizontally polarized source

DF estimates for the same DOA

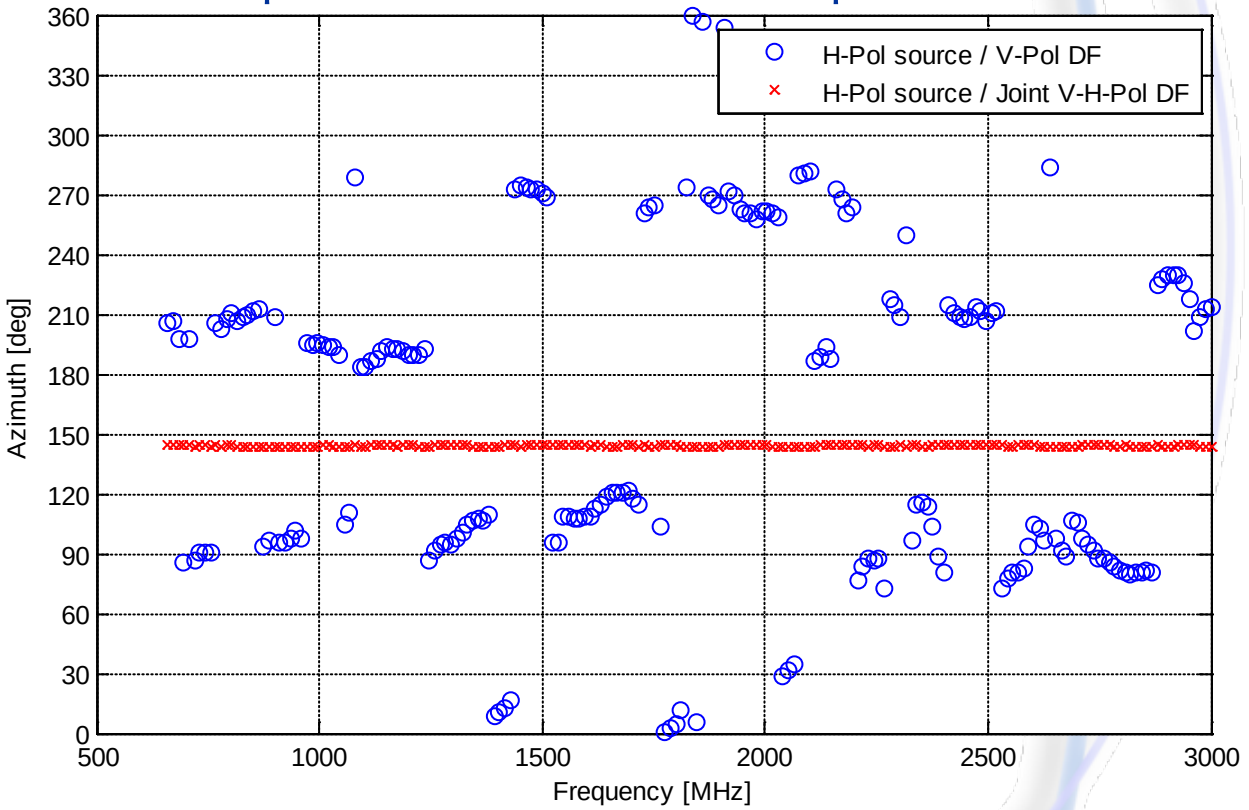
- Completely useless



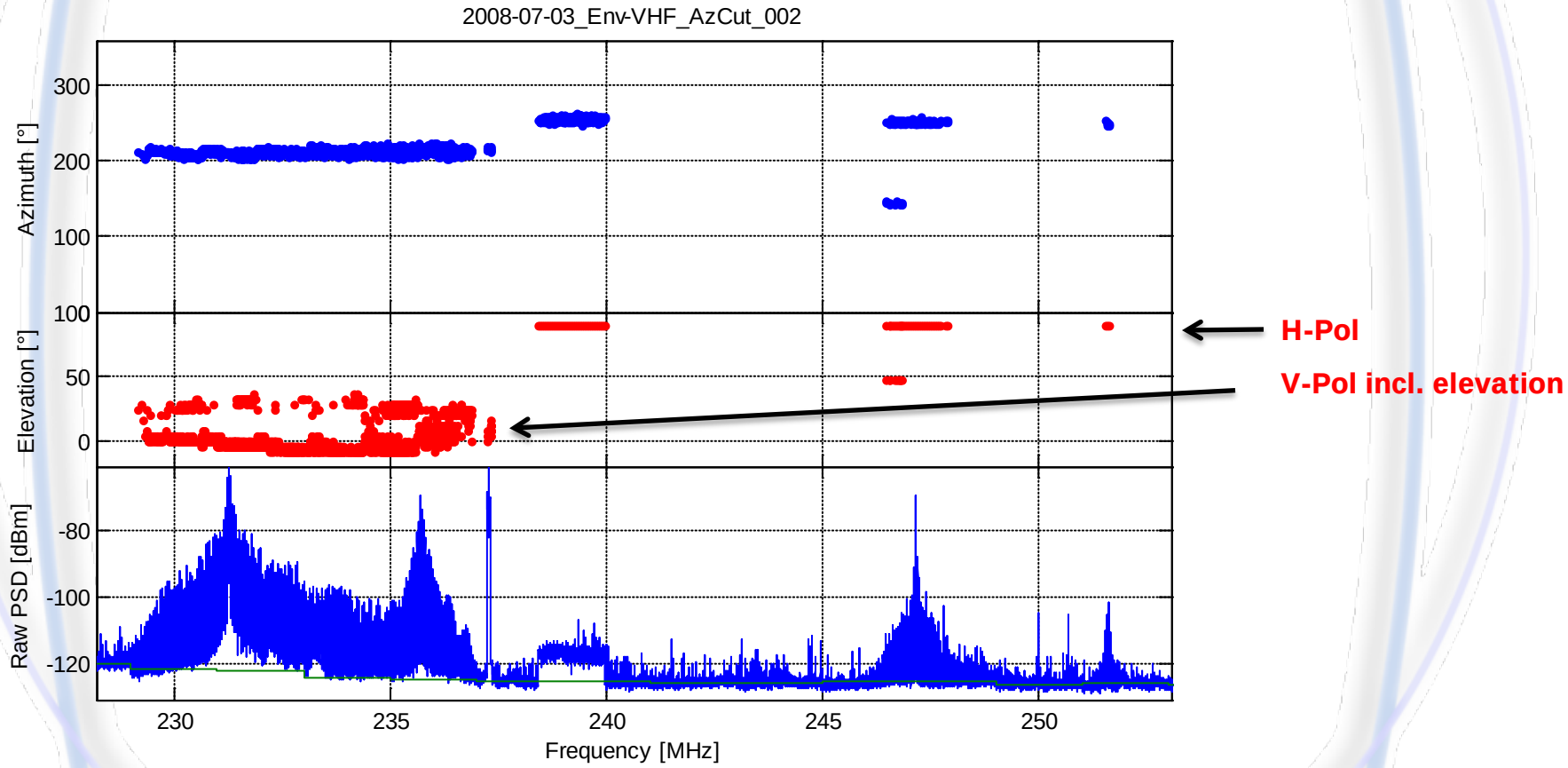
■ Horizontally polarized source

DF estimates for the same DOA

- Valid DF estimate is retained
- Source polarization information is provided



Demonstration of joint V-H-Pol DF in a broadcast band with both vertical and horizontal sources



Superresolution and the multiple sources problem

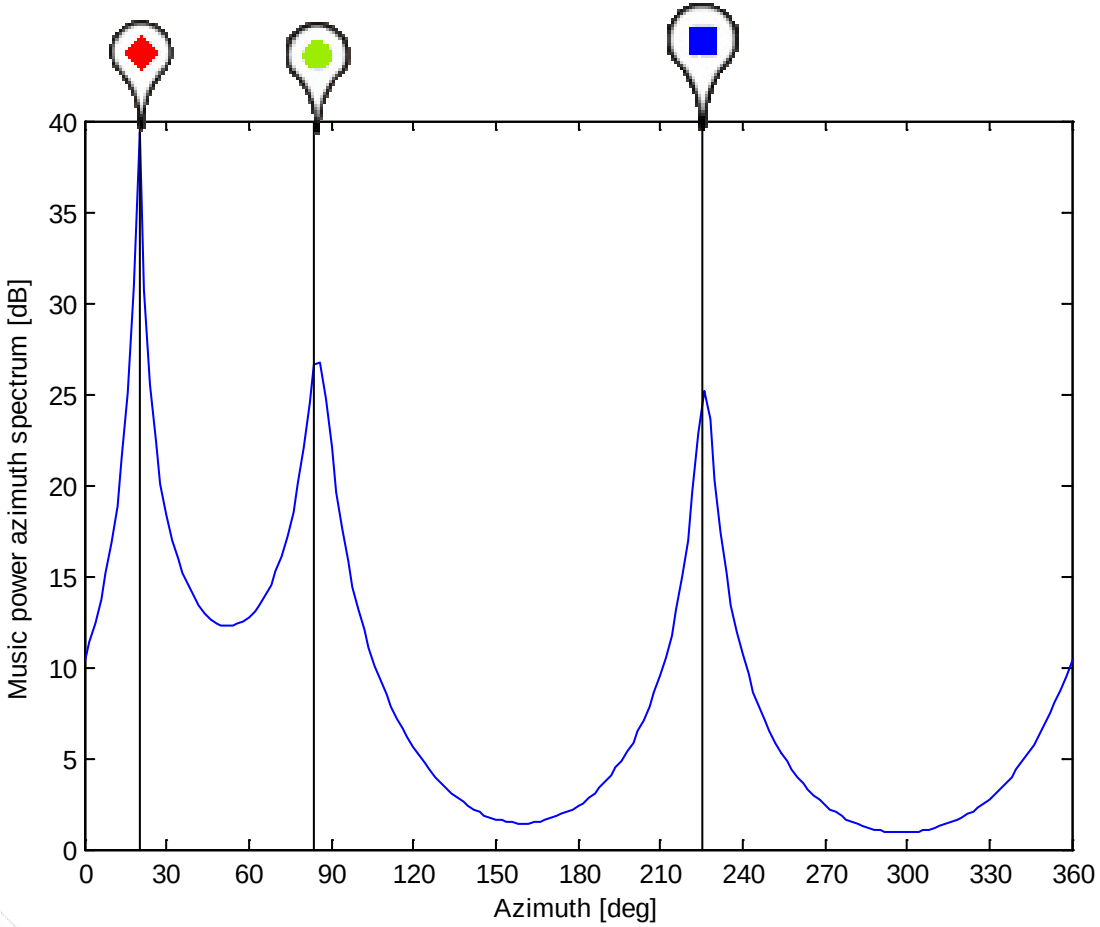
Superresolution ≠ high accuracy of the estimated angles

→ Resolution of multiple signals on the same carrier frequency (Co-channel signals)

- Conventional DF system result
  - Beam former := Peak search in the power azimuth spectrum
  - In general undefined, depends on power ratio of the sources, the azimuth spacing, the antenna properties, etc.
- Superresolution DF relies on the suppression of the co-channel signals by a weighted sum of the N antenna signals
  - Theoretical limit for the number of resolvable signals is thus N-1
  - Important distinction: Uncorrelated/Correlated sources

Superresolution DF Test Setup

The MEDAV submarine based system can resolve up to four co-channels signals by using superresolution DF



MUSIC pseudo azimuth spectrum with 3 co-channel sources

Conclusions

- An ultra compact SIGINT antenna and a completely water-cooled, ruggedized COMMS/ESM system with outstanding DF capabilities was successfully developed, qualified and produced.
- It forms an integral part of the submarine's combat management system.
- It can be used for tactical reconnaissance and radio communications intelligence gathering.
- Significant contribution to upgrade the capabilities of submarines for new tasks.

Sea Trials in Progress