Dedicated to innovation in aerospace

NLR 90 years


# Smart Antennas in Aerospace Applications
# Workshop on Smart Antennas
# April 22, NLR Amsterdam

*Jaco Verpoorte, Pieter Jorna, Adriaan Hulzinga, Harmen Schippers*

# Overview

- **Smart Antennas in Aerospace Applications**
- **Example of Smart Antenna for military naval and aerospace applications**
  - null-steering antenna for satellite navigation
- **Example of Smart Antenna for civil aerospace application**
  - beam-steering antenna for satellite communication
- **Video of SATCOM antenna demonstration**

# Overview

- **Smart Antennas in Aerospace Applications**
- **Example of Smart Antenna for military naval and aerospace applications**
  - null-steering antenna for satellite navigation
- **Example of Smart Antenna for civil aerospace application**
  - beam-steering antenna for satellite communication
- **Video of SATCOM antenna demonstration**

# Smart Antennas in Aerospace Applications

- **Smart Antennas <u>adapt</u> to environment**
  - Direction of arrival (of signal)
    - tracking/beam steering: moving platform(s)
    - beam forming: control beam shape to comply with requirements/regulations
  - Multipath
    - only multipath or multipath in addition to direct link
  - Interference
    - weaker than signal (SATCOM) or stronger than signal (SATNAV)
  - Vibrations
    - large antenna arrays (e.g. on wing of UAV)
    - compensation techniques (mechanical/electrical)

- **.. in order to maximize the signal-to-noise-plus-interference ratio**

# Smart Antennas in Aerospace Applications

- **Smart Antennas: link with hardware and algorithms:**
  - Smart Skins
    - integration in aircraft skin (fuselage)
  - Smart materials
    - meta materials for miniature multi-frequency antennas (periodic structures with "artificial permittivity or permeability)
  - Multi-frequency/Broadband antennas or Multi-function antennas
    - reduction of space
  - "Onboard" processing: intelligent antenna
    - e.g. in radar: knowledge-based aiding to reduce clutter, adaptive send and receive antenna
    - e.g. in satnav: integration of antenna and receiver

# Overview

- Smart Antennas in Aerospace Applications
- **Example of Smart Antenna for military naval and aerospace applications**
  - null-steering antenna for satellite navigation
- Example of Smart Antenna for civil aerospace application
  - beam-steering antenna for satellite communication
- Video of SATCOM antenna demonstration

# Adaptive antenna for satellite navigation

- **Signal of GNSS signals is below noise floor**
  - sensitive to interference
  - easy to jam

- **Adaptive antennas for GPS**
  - military: Controlled Radiation Pattern Antenna (CRPA)
    - null-steering antennas
    - null-steering and beam-steering
      - Space-Time Adaptive Processing (STAP)

# Controlled Radiation Pattern Antenna (CRPA)

- **Controlled Radiation Pattern Antennas (CRPAs) are array antennas, they** *optimise S / (N+I),* **two options:**
  - beam-steering
  - null-steering
  - *(or a combination)*

- **Null-steering versus beam-steering <u>in general</u>:**
  - In the case of *null-steering*:
    the ratio between the gain in the direction of the jammer and the gain in the direction of the satellite is higher (for a small array)
  - In the case of *null-steering*:
    potential loss of wanted signal if a null is directed towards the satellite
  - In the case of *beam-steering*:
    large arrays needed for low-side lobes

# Null-steering for GPS

- **Null-steering antennas have special advantages <u>in the case of GPS</u>:**
  - In the case of beam-steering:
    4 beams are needed to track 4 satellites which requires more antenna elements then needed to create nulls for one or more jammers
  - It is easier to create nulls towards the high level jammer signal than to create beams towards the low level GPS-signal (spread spectrum)

- ***State-of-the-art digital electronics enable combination of null-steering and beam-steering***

# Methods of null-steering

- **Some methods of null-steering:**
  - direct matrix inversion of the signal covariance matrix
  - method of steepest decent (LMS method): minimise output power (equals jammer power since satellite signals are below noise floor)
  - method of perturbation

- **Direct matrix inversion:**
  - + No iterations, exact solution, performance does not depend on number and power of jammers
  - - No closed control loop, practical implementation difficult (numerical instabilities, time consuming matrix inversion)

# Methods of null-steering (2)

- **Method of steepest decent:**
  - + Closed control loop, simple implementation (even analog), not sensitive to non-linearities
  - - gain control loop difficult, convergence speed depends on difference in jammer power

- **Method of perturbation:**
  - + closed control loop, simple digital implementation, not sensitive to non-linearities
  - - often many iteration steps needed, convergence speed depends on difference in jammer power

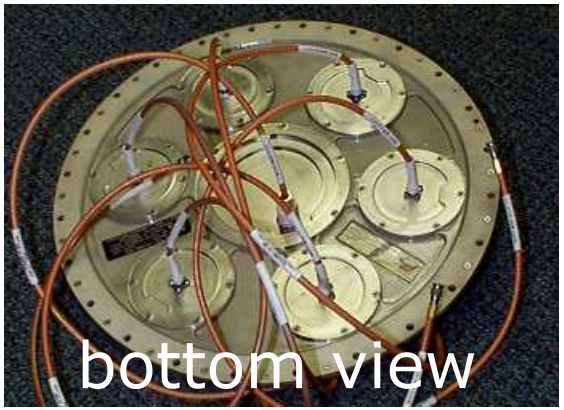
# Adaptive Nulling NAVSTAR Antenna (ANNA)

- **Prototype null-steering antenna**
  - Antenna to be used with L1/L2 PPS receivers
    - CRPA transparent for receivers (no interaction with RX needed)
  - Developed by NLR and MEOB (both NL)
  - Prototype for the Royal Netherlands Navy in the 80's
  - NLR: implementation of algorithm, electronics development, integration and test
  - MEOB: design and procurement of mounting frame and protective casing
  - Significant influence of naval environment
  - Protected against high power shipboard transmitters

# Controlled Radiation Pattern Antenna (CRPA) Raytheon GAS-1 and ADAP

AE

CRPA top view



bottom view

**Naval applications:**
**7 antenna elements**

**Aircraft applications:**
**4 antenna elements**

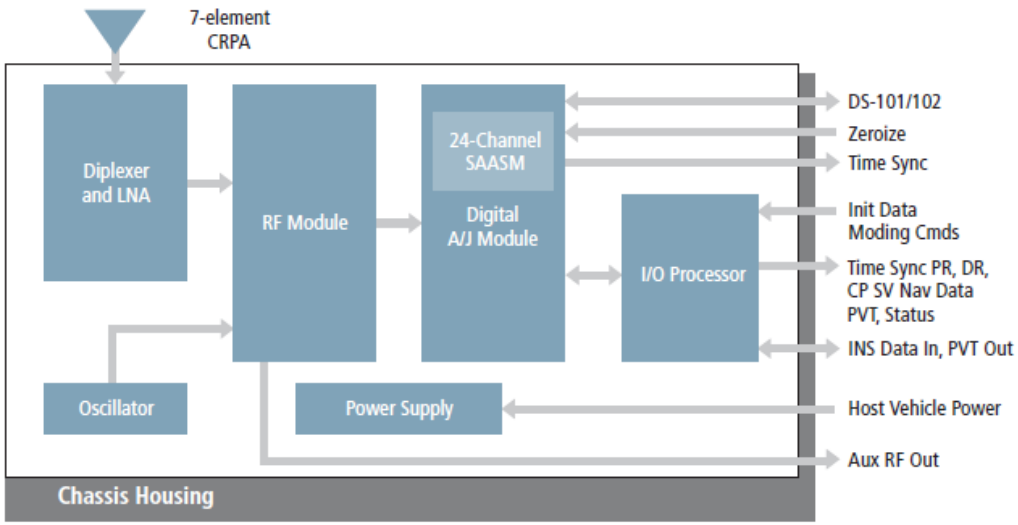
**Array antenna + antenna electronics**

- **GAS-1**
  - nulling on one frequency
- **ADAP**
  - Space/Frequency and Space/Time Adaptive Processing (SFAP/ STAP)
  - nulling on two frequencies

Composite GPE

# Current developments in CRPA antennas

- **Combination of phased array antenna and digital receiver**
- **Raytheon Digital Anti-Jam Receiver (DAR)**
  - space frequency adaptive processing (SFAP) technique
  - spatial nulls to suppress jammers,
  - multiple beams to amplify valid signals from GPS satellites.




DAR Functional Components and Interfaces

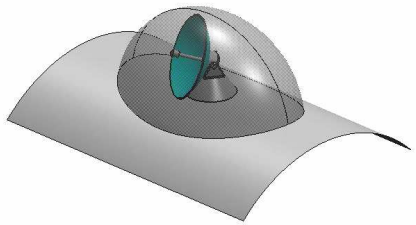
# Overview

- **Smart Antennas in Aerospace Applications**
- **Example of Smart Antenna for military naval and aerospace applications**
  - null-steering antenna for satellite navigation
- **Example of Smart Antenna for civil aerospace application**
  - beam-steering antenna for satellite communication
- **Video of SATCOM antenna demonstration**

# Smart Antenna for airborne SATCOM

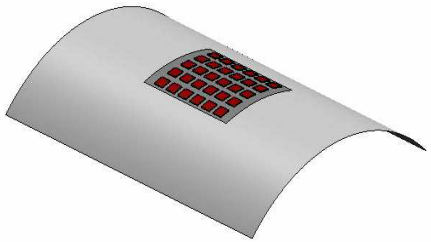
- **Passengers onboard aircraft want**
  - High-speed internet (web, multi-media) and
  - Television (Digital Video Broadcast via Satellite).

- **This can be realised by using a broadband SatCom antenna :**
  - Mechanically steered reflector/array antennas
    - -- Aerodynamic drag/Moving parts



  - Hybrid mechanically/electronically steered

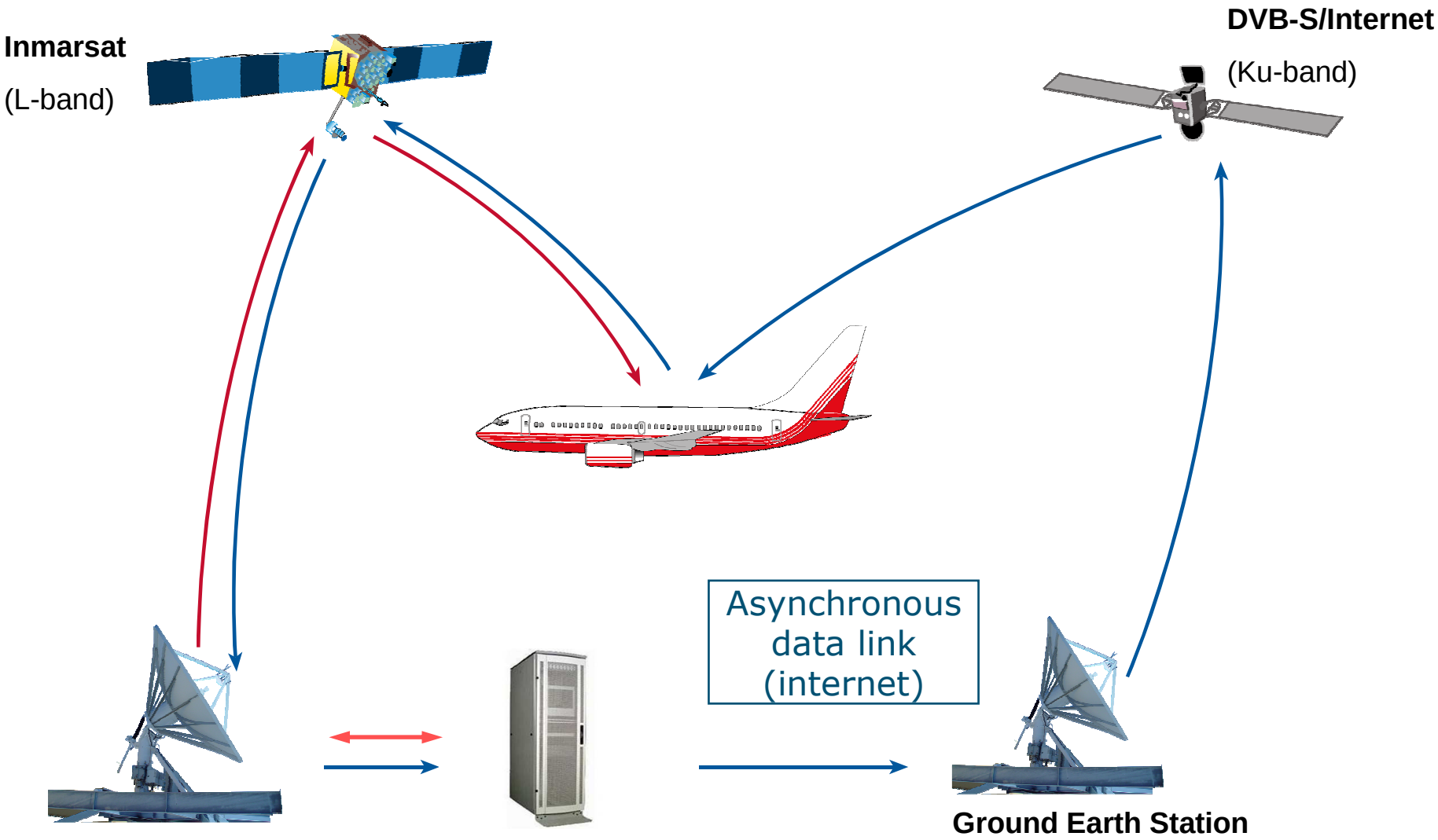
  - Electronically steered phased array antennas
    - ++ Conformal to the aircraft fuselage
    - ++ No moving parts



# FlySmart project: airborne antenna development

- **Development of an <u>antenna system for airborne use</u>,**
- **to enable <u>broadband communication via Ku-band satellite</u>:**
  - electronically scanned antenna (phased array antenna)
    - high gain, small beamwidth (2 to 3 degrees)
    - downlink frequencies: 10.7 - 12.75 GHz
      - fixed satellite service
      - broadcast satellite service
    - <u>broadband</u> antenna system (downlink up to 2 GHz)
  - antenna <u>conformal</u> to the aircraft fuselage
    - to improve aerodynamic characteristics
    - to increase antenna view
  - large scan angles (low elevation angles) to accommodate operation at high latitudes

# Design of Ku-band receive antenna array for SATCOM



# FlySmart project: 2 antennas

- **Research on <u>airborne</u> phased array antenna**
  - larger bandwidth than current designs
  - larger scan angle than current designs
  - transmit and receive
  - fully environmentally qualified
  - study only

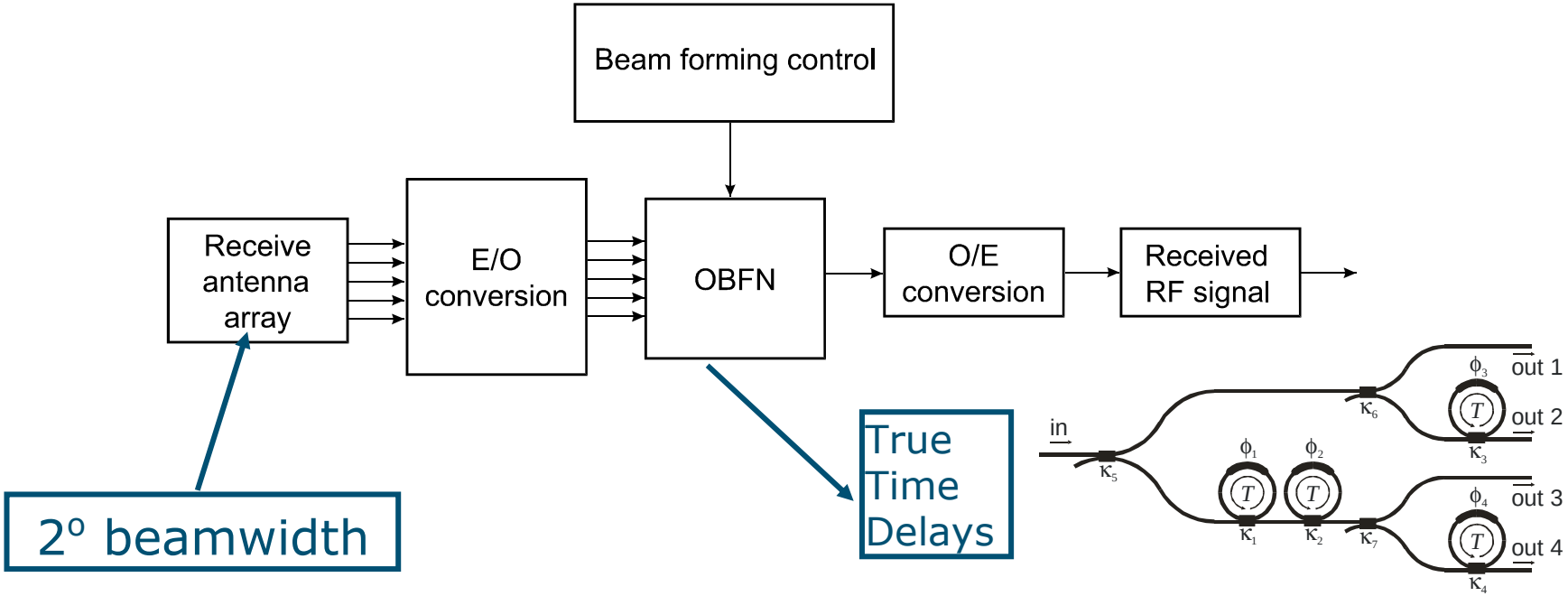
- **<u>Demonstrator</u> phased array antenna**
  - large bandwidth and scan angle
  - limited gain and beamwidth
  - receive only
  - limited environmental qualification
  - manufacturing and test

# System aspects

- Ku-band receive-only antenna system with broadband optical beam-forming network and broadband phased array antenna

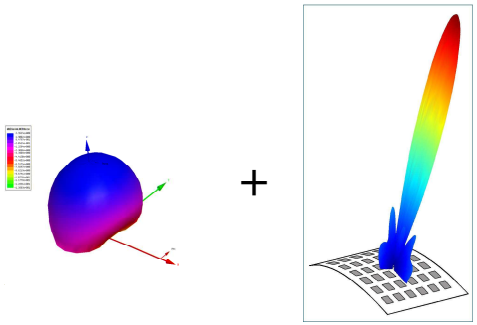
| | |
|---|---|
| AES receive band 1: | 10.70 – 11.70 GHz |
| Satellite TV: | 11.70 – 12.50 GHz |
| AES receive band 2: | 12.50 – 12.75 GHz |

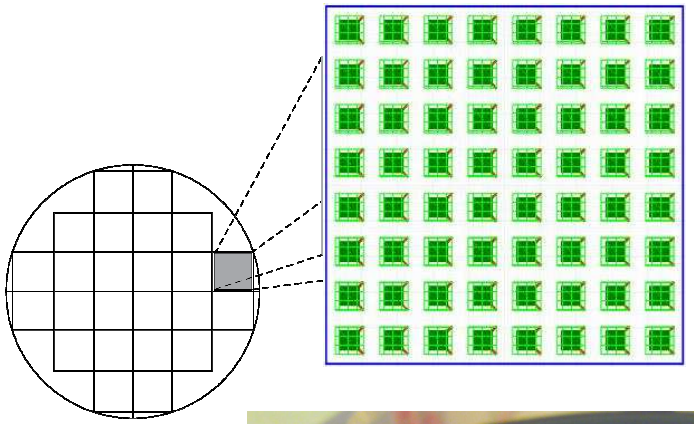
} 2 GHz bandwidth



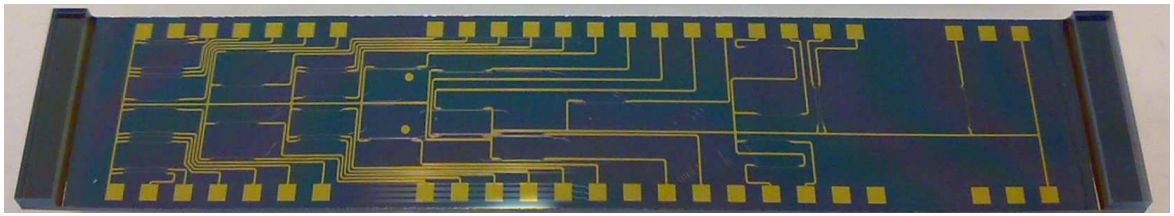
# Key technologies

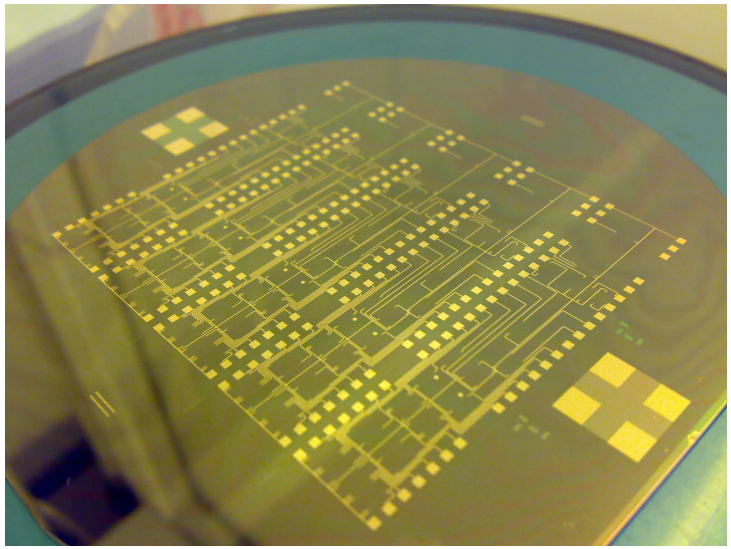
- **Development of broadband Ku-band antenna element/array**





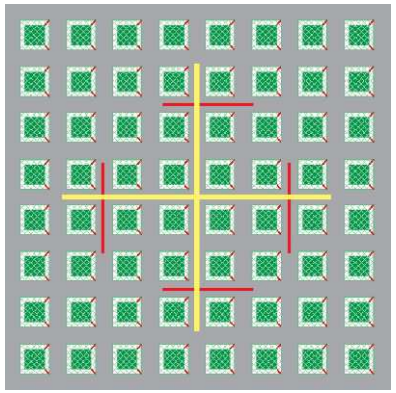
- **Development of broadband beam forming network optical chip (CMOS compatible)**

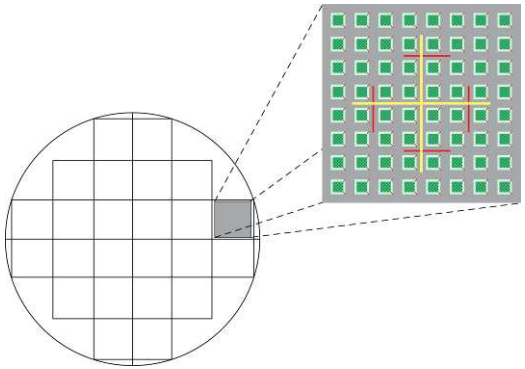




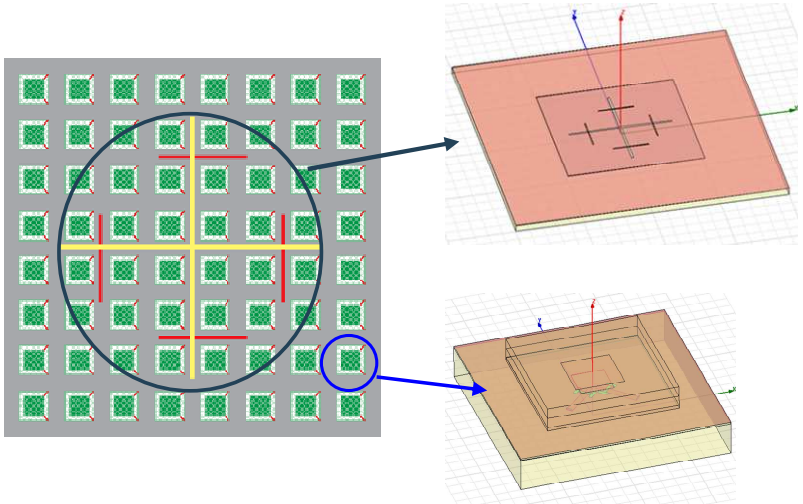
# Design of dual-frequency L/Ku-band antenna

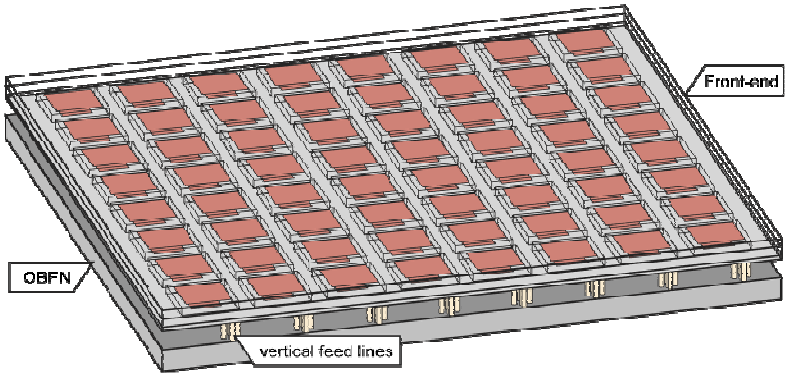
- **Size L-band antenna = 8 * size Ku-band antenna**
- **Broadband Ku-band element: Stacked patches**
- **Design of L-band element is constrained by Ku-band element**
- **L-band element: Two crossed L-band slots in ground plane with feeding slots of Ku-band array**

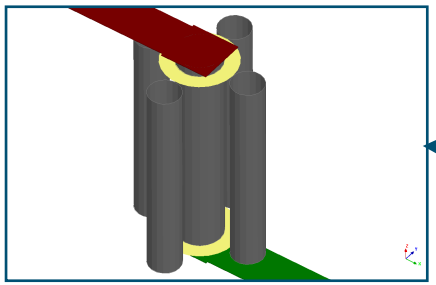


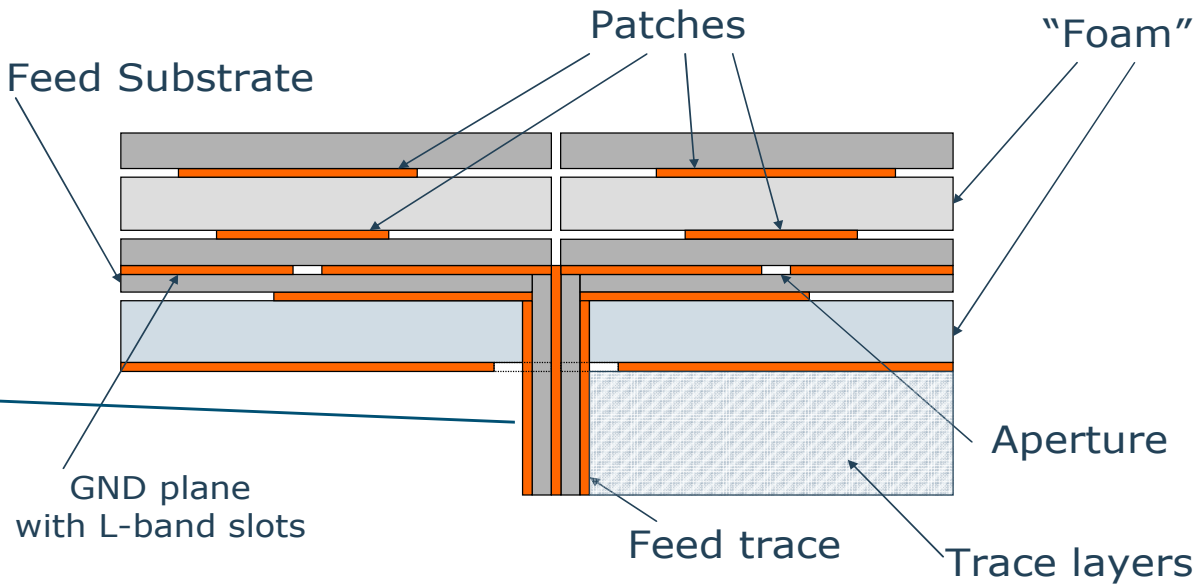


# Design for dual-frequency breadboard antenna



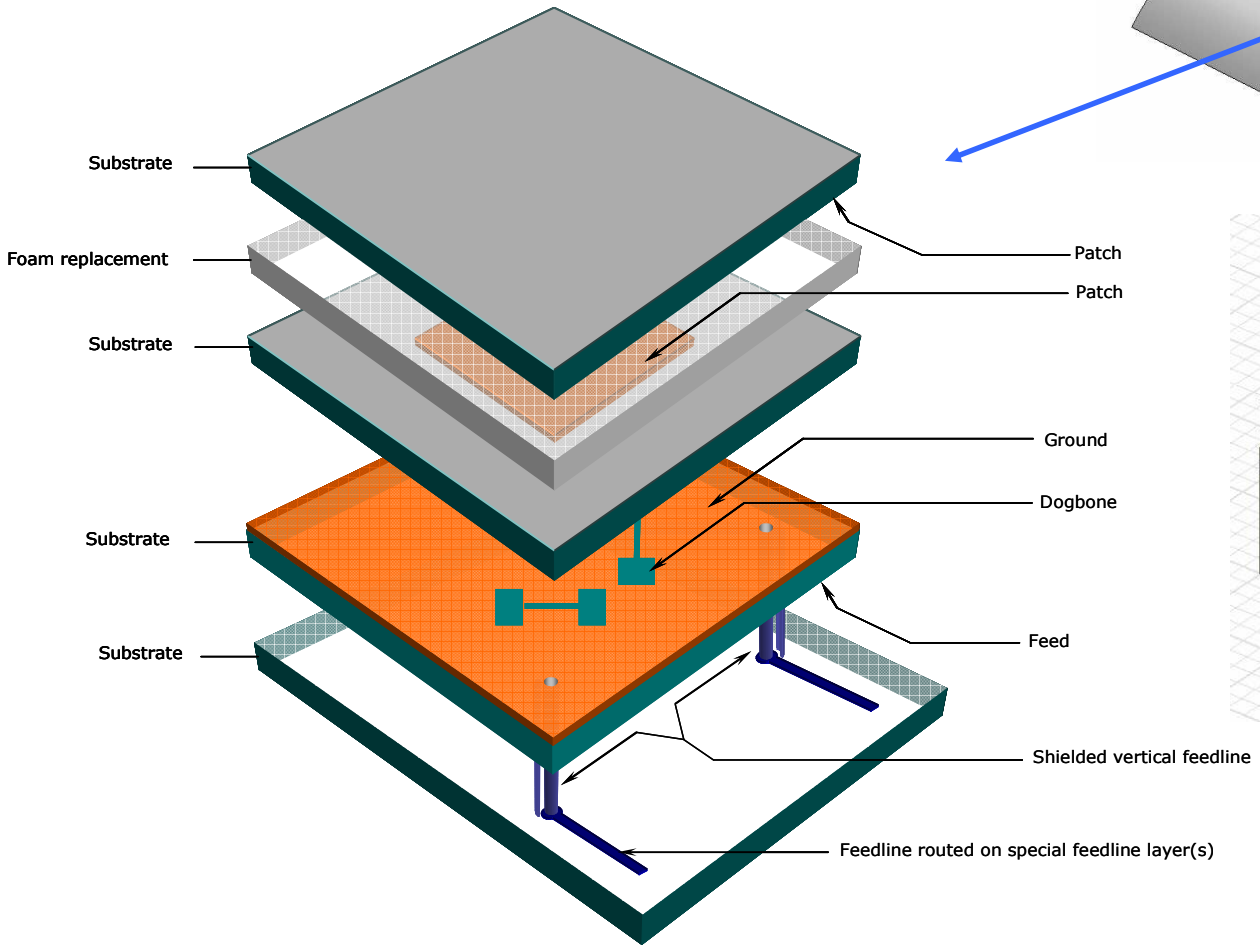


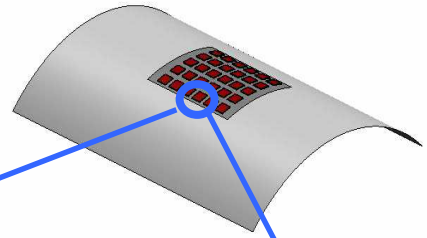



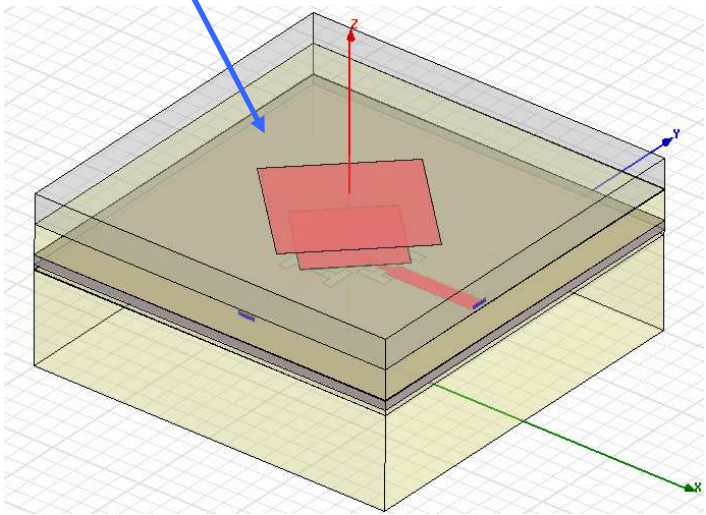


# Development of broadband Ku-band antenna

- **Stacked patch antenna element**



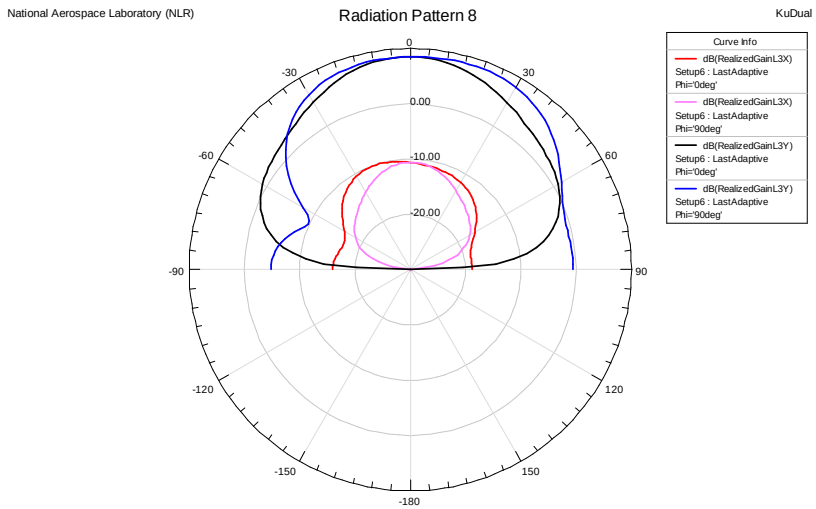



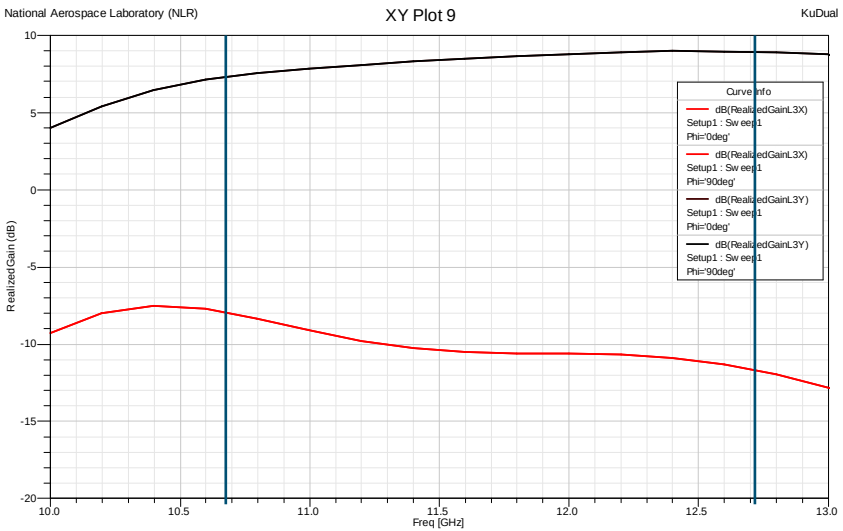


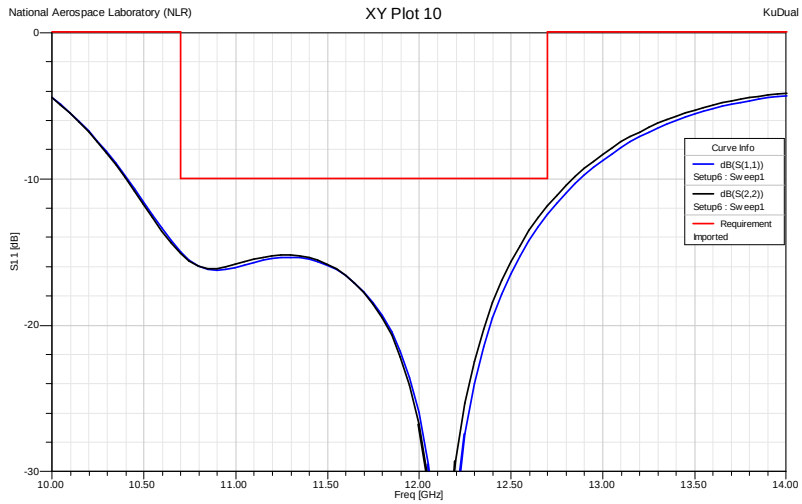
Ansoft HFSS design

# Development of broadband Ku-band antenna

- **Stacked patch antenna element with**
  - Broadband radiation pattern
  - Broadband input impedance

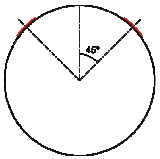


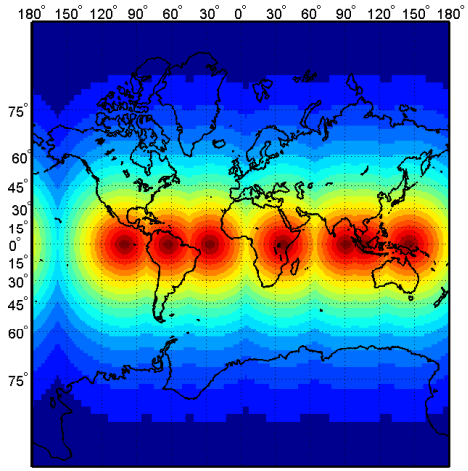



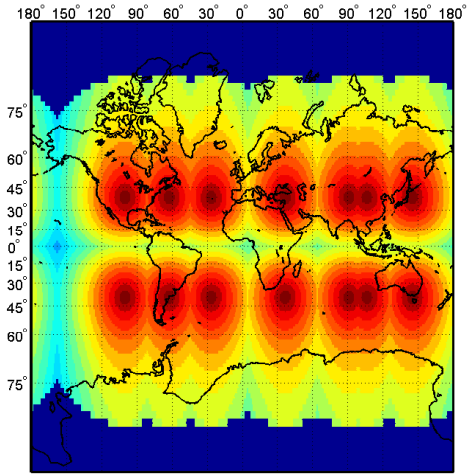



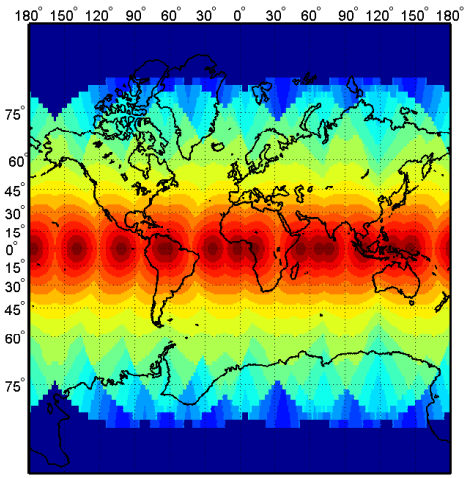
# Position of antenna on aircraft

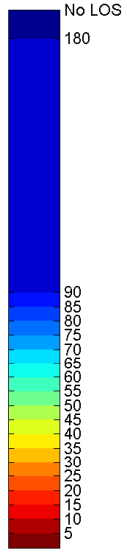
- **Required scan angles:**











- **Multiple satellites, <u>one</u> antenna on top**

- **Multiple satellites, <u>two</u> antenna (E-W)**

- **Multiple satellites, <u>two</u> antenna (S-N)**

**Beam will be steered based on aircraft position and attitude.**

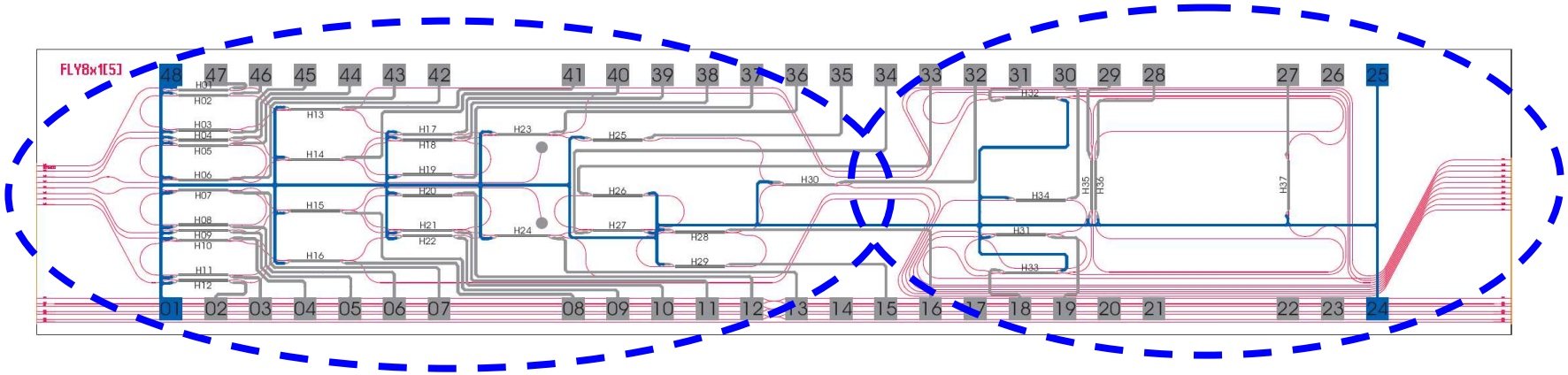
**With two antennas max. view angle +/- 45 degr.**

# Design of Ku-band receive antenna array for SATCOM

## Beam Squint in case of phase shifting ($f_{min}$=10.7 GHz, $f_{mid}$=11.7 GHz, $f_{max}$=12.75 GHz)

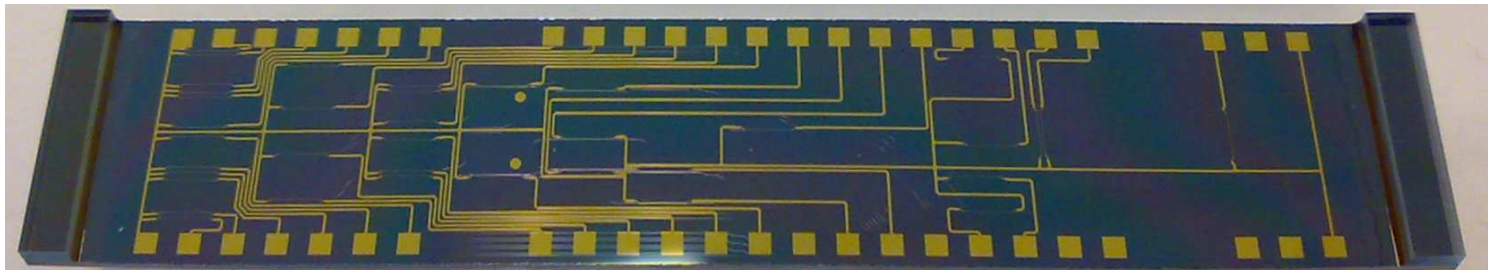
| | | | | | |
|---|---|---|---|---|---|
| $\theta$ for $f=f_{mid}$ | 0° | 15° | 30° | 45° | 60° |
| $\theta_f$ for $f=f_{min}$ | 0° | 16.4° | 33.1° | 50.6° | 71.3° |
| $\theta_f$ for $f=f_{max}$ | 0° | 13.7° | 27.3° | 40.5° | 52.6° |
| $\Delta\theta$ for $f=f_{min}$ | 0° | 1.4° | 3.1° | 5.6° | 11.3° |
| $\Delta\theta$ for $f=f_{max}$ | 0° | 1.3° | 2.7° | 4.5° | 7.4° |

# Single-Chip 1x8 OBFN
# CMOS-Compatible Waveguide Technology




**TriPleX Technology**

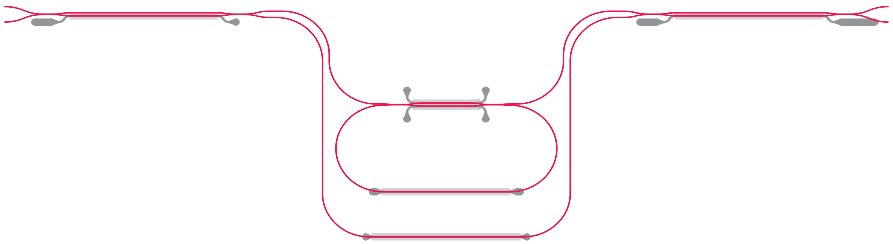
1 cm



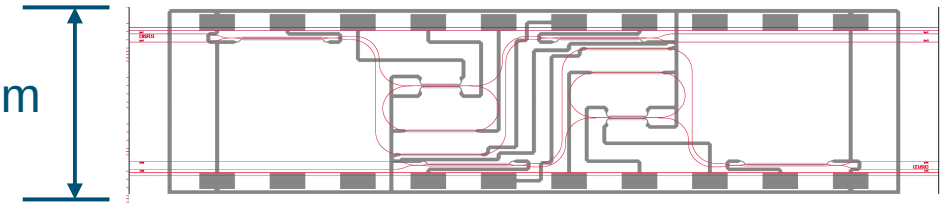
Waveguide Loss < 0.3 dB/cm 12.8 x 66 mm
Thermal Tuning Mechanism
Average Power Consumption per Heater 0.25 W

# Optical beamformer

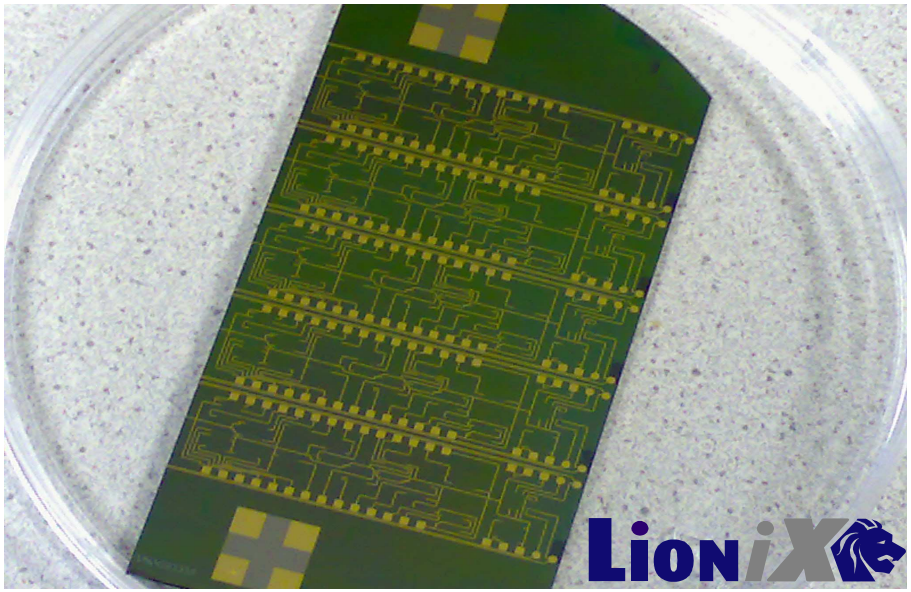
## Optical sideband filter chip in the same technology as the OBFN

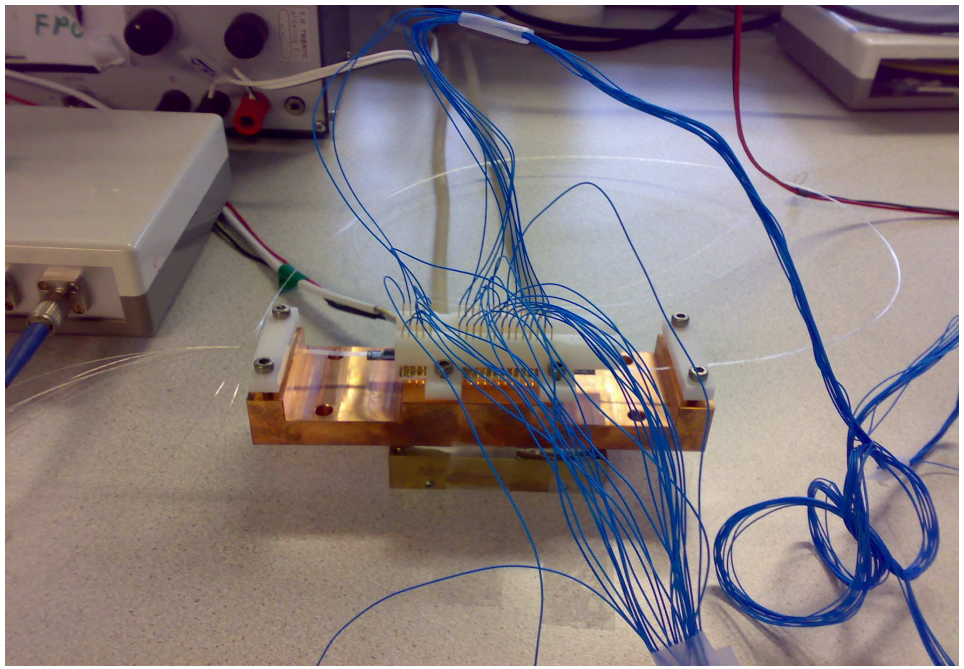


5 mm



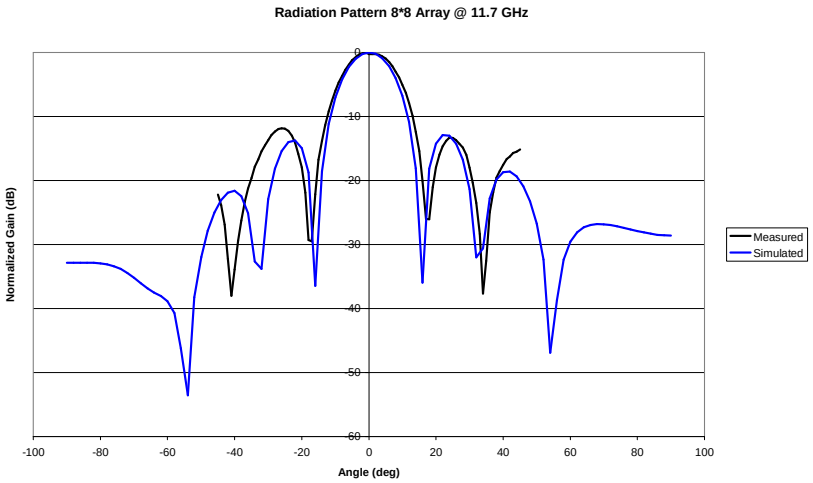
MZI + Ring

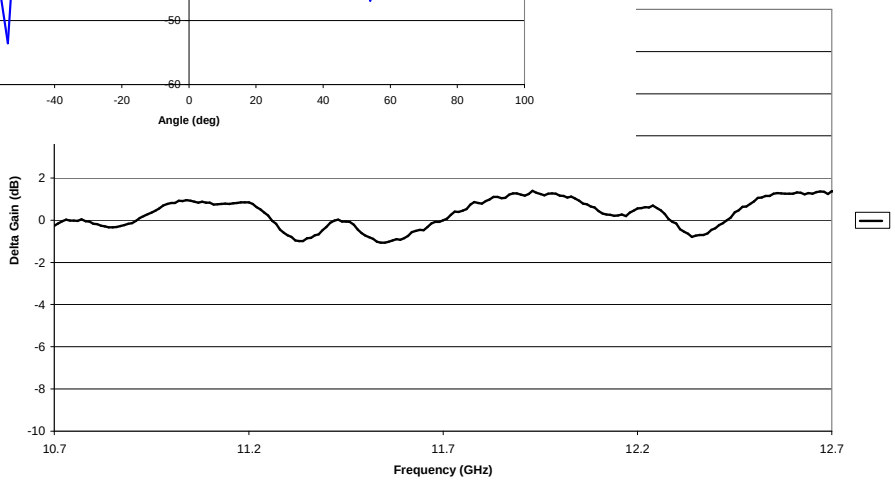


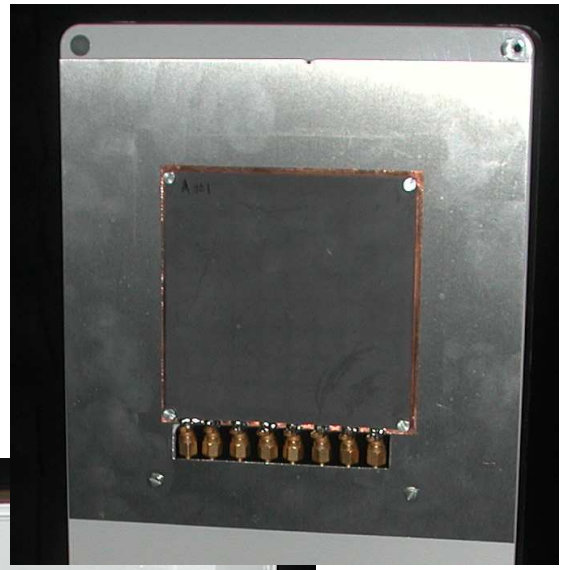



# Ku-band demonstrator array

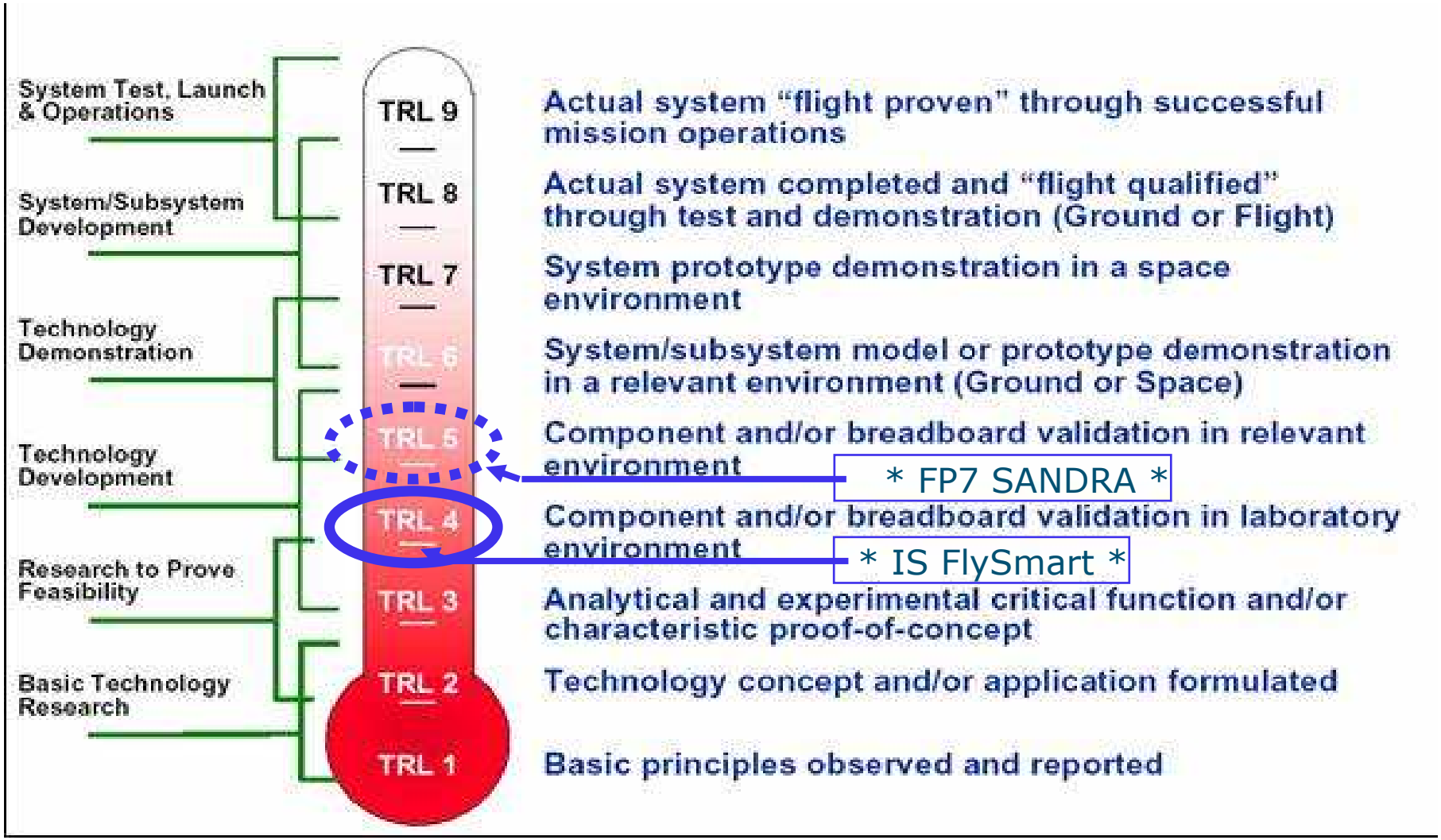
- **8x8 array preliminary measurements**
- **radiation pattern and relative gain**



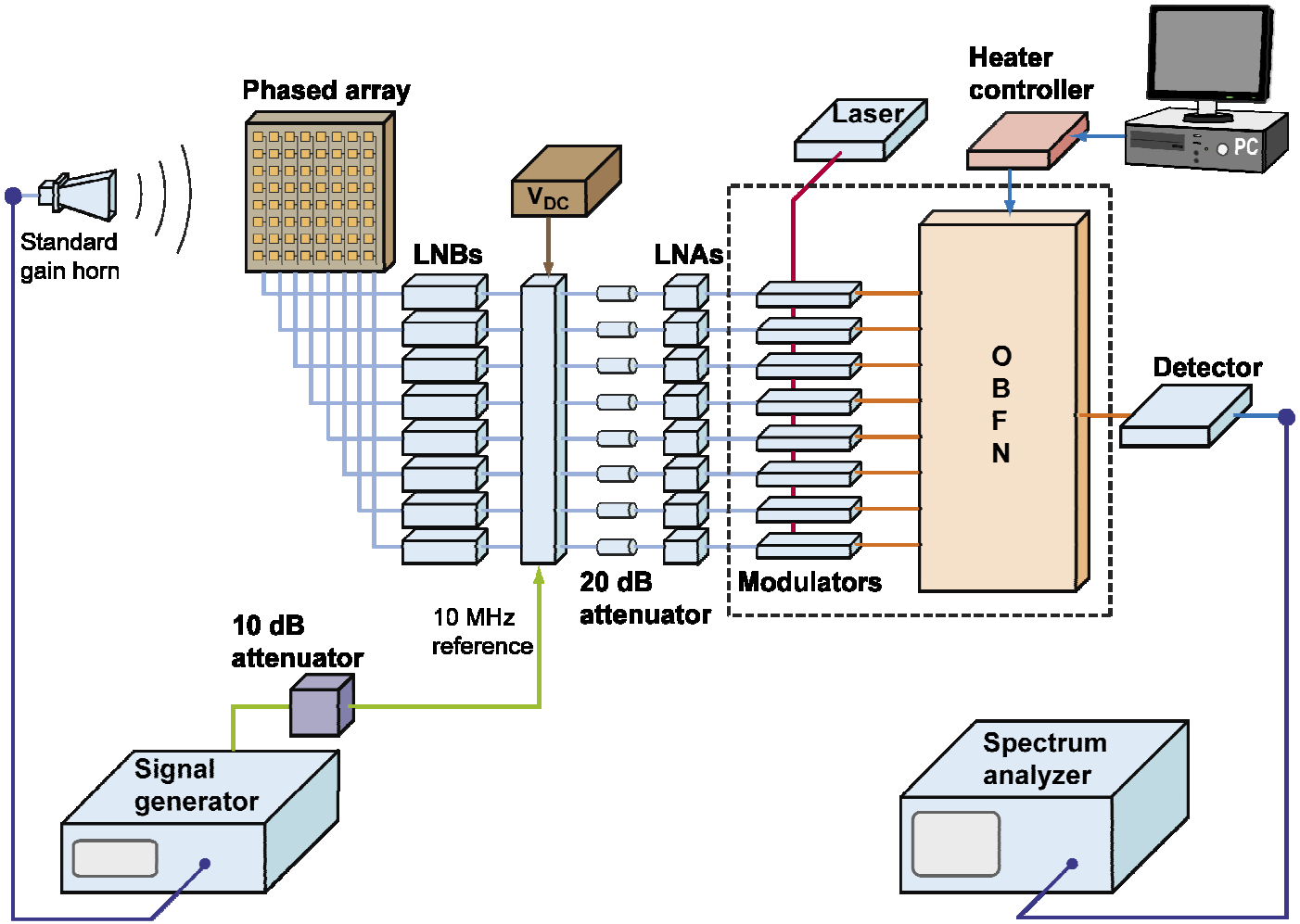
# Technology Readiness Level FlySmart



# Overview

- **Smart Antennas in Aerospace Applications**
- **Example of Smart Antenna for military naval and aerospace applications**
  - null-steering antenna for satellite navigation
- **Example of Smart Antenna for civil aerospace application**
  - beam-steering antenna for satellite communication
- **Video of SATCOM antenna demonstration**
  - FlySmart/Anastasia

# Demonstrator set-up (laboratory measurement)



# Measurement plan

- **Objectives**
  1. Verify broadband properties of antenna and OBFN
  2. Verify optical beam steering capabilities

- **Measure C/N ratio for range of frequencies (objective 1):**
  - 10.7 to 11.7 GHz (steps of 100 MHz)

- **Measure C/N ratio for the following antenna positions (objective 2):**
  - Antenna at broadside (no beam steering)
  - Antenna rotated 27 degrees to left side
  - Antenna rotated 27 degrees to right side

*Dedicated to innovation in aerospace*

NLR 90 years


www.nlr.nl - info@nlr.nl