Payloads:
Needs and Technologies

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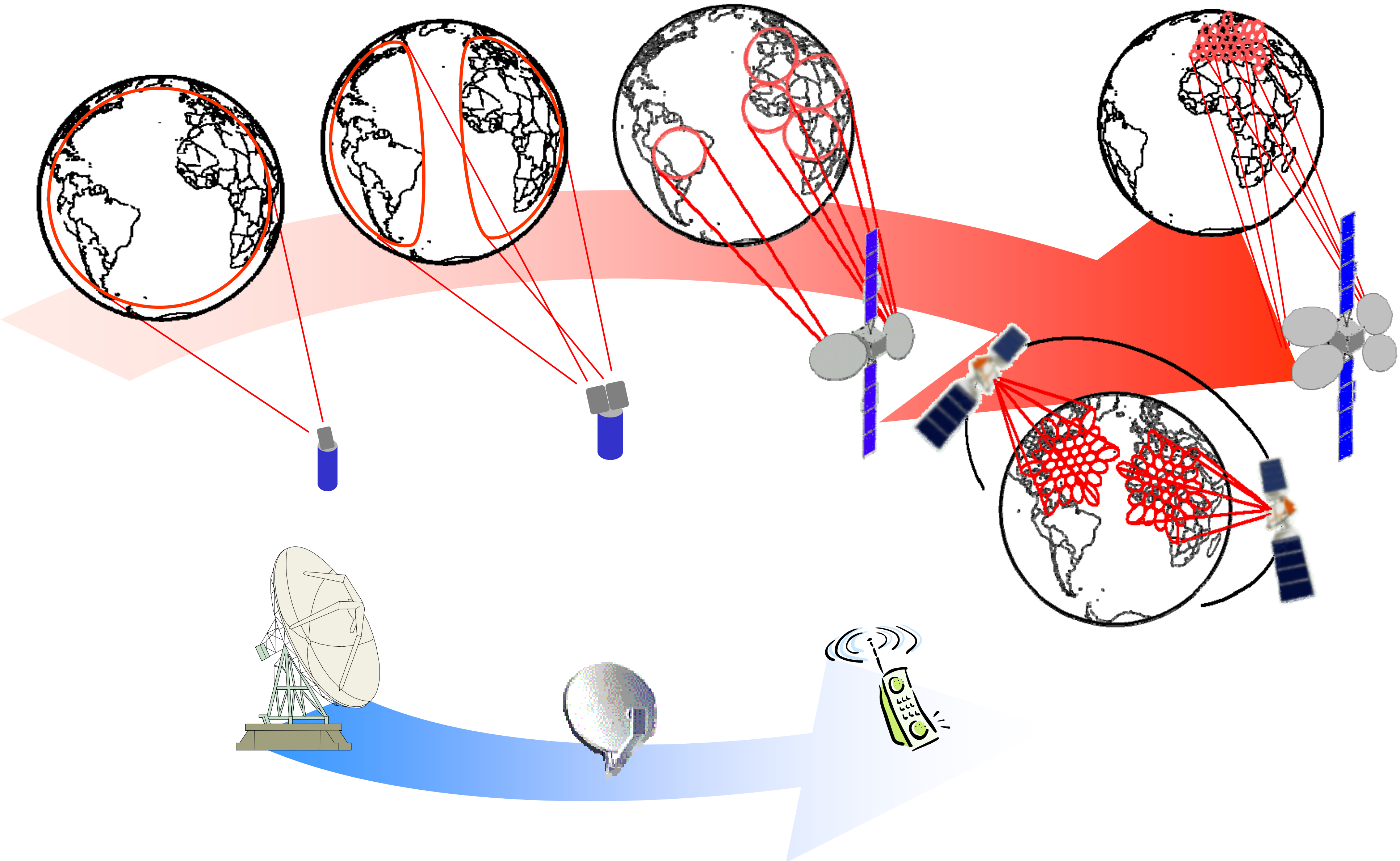
The Gold Threads of Satellite Evolution

- Success of satellite networks not only depends on the space segment but also on the user terminals.
  - Reasonable price is essential for achieving maximal market penetration and reaching a broad audience.
  - Smaller antennas (lower gain)
  - Cheaper components (lower power, higher phase noise, worst noise figures …)

- Increase of satellite payload complexity in terms of:
  - handled bandwidth,
  - offered power,
  - antenna coverage complexity,
  - processing functionalities,
  - flexibility.

The Gold Threads of Satellite Evolution



A Slow But Inexorable Shift

- Emergence of **adaptive techniques** to counteract interferences (power control, coding and modulation adaptiveness, multi-user-detection, adaptive beamforming, etc.)
- **Spread** of the user **requirements** (data rates and QoS) and terminals **performances**
- Increased need to support time and space **variable traffic**
- **Tighter** satellite **requirements** (more effective frequency reuses, finer pointing accuracies, larger spread of BOL-EOL performances of embarked devices due to longer satellite life, etc.)
- Continuous growth of the **number of** on-board generated **beams** to improve link performances (G/T and EIRP)
- Increased need of **interconnection** flexibility between beams and frequencies in a meshed topology

Multibeam Flexible Payloads and Antennas

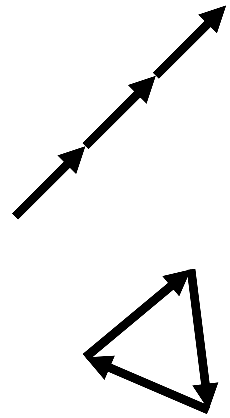
Role of Beamforming

- The development of **multibeam** and **reconfigurable antennas** has always been tightly connected to that of Beam Forming Networks (BFN's).
- The BFN is often the dominant component, the "**true hearth**" of most multiple beams antennas.
- BFN are complex networks used to precisely **control the phase and amplitude** of RF energy passing through them, which is conveyed to the radiating elements of an antenna array.
- BFN configurations vary widely from just a few basic building blocks up to tens of thousands of them depending on system performance requirements.

Beamforming

- Beamforming is the function of focusing the energy (electromagnetic, acoustic … gravitational) received (or radiated) by an array along a specified direction in space.

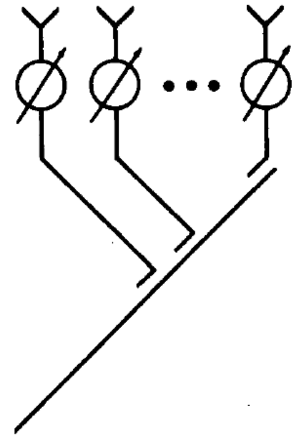
- The principle is based on the constructive/destructive interference effect of waves.
  - Energy is maximum when the signals to/from each radiating element arrives in phase.
  - Energy from an undesired direction of arrival can be minimised if the sum of each element contribution results out of phase.

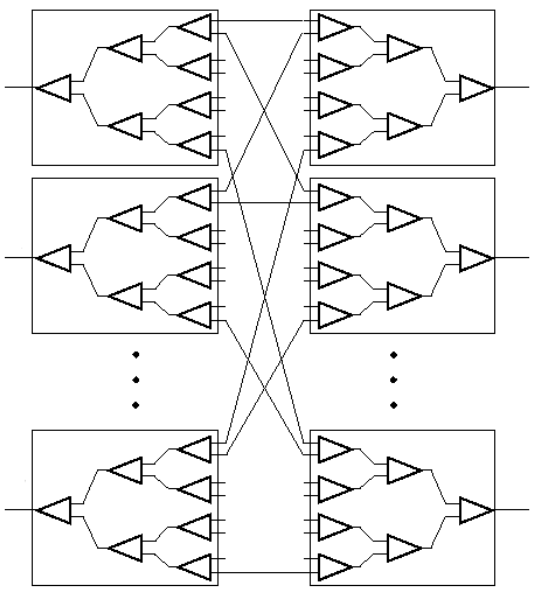


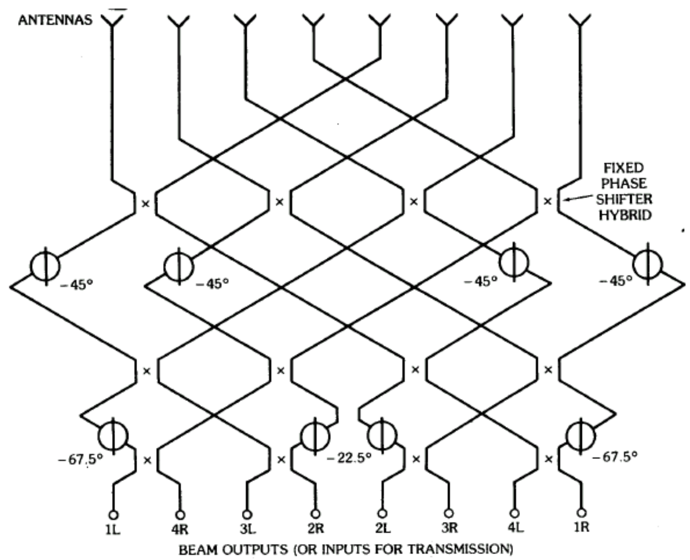
- This process is obtained opportunely phasing and weighting the signals received/transmitted by the elements of the array.

Distribution/Combination Topology

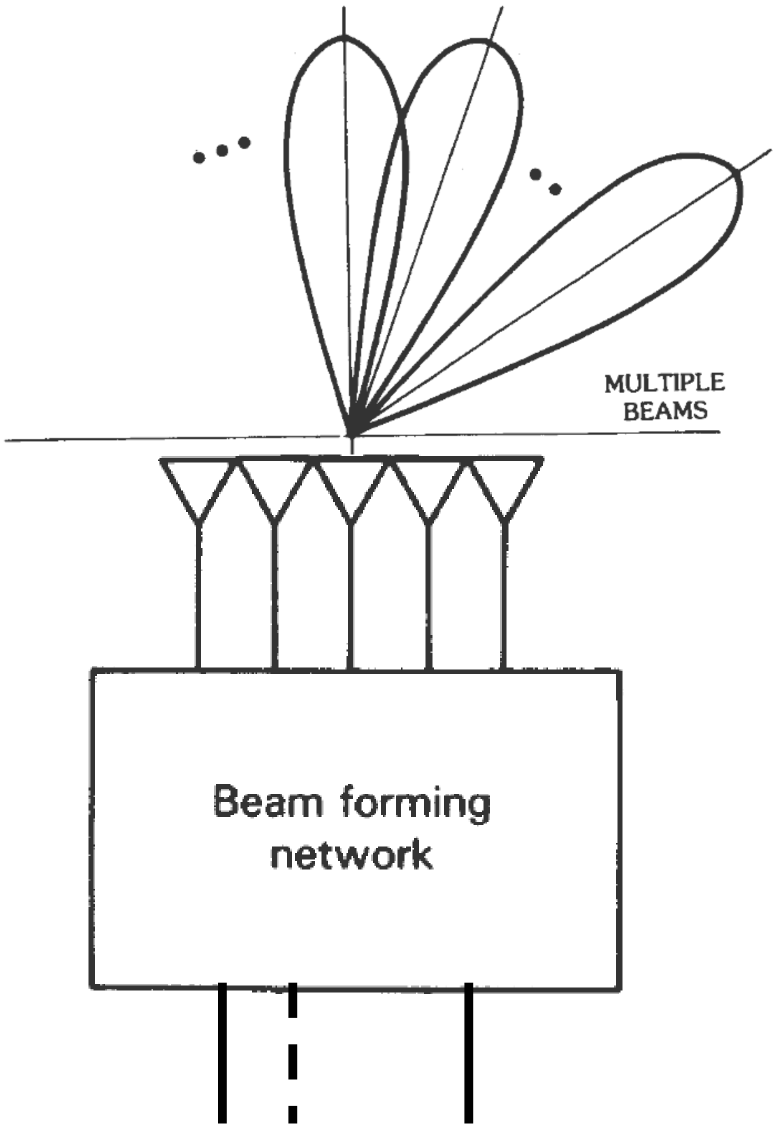
- The distribution/combination topology of a beam forming networks can be of three main types:
  - **Serial** dividers/combiners;
  - **Corporate** ("Parallel") dividers/combiners;
  - **Multimode** ("Factorised") dividers/combiners e.g Butler, Nolen/Ruggerini matrices





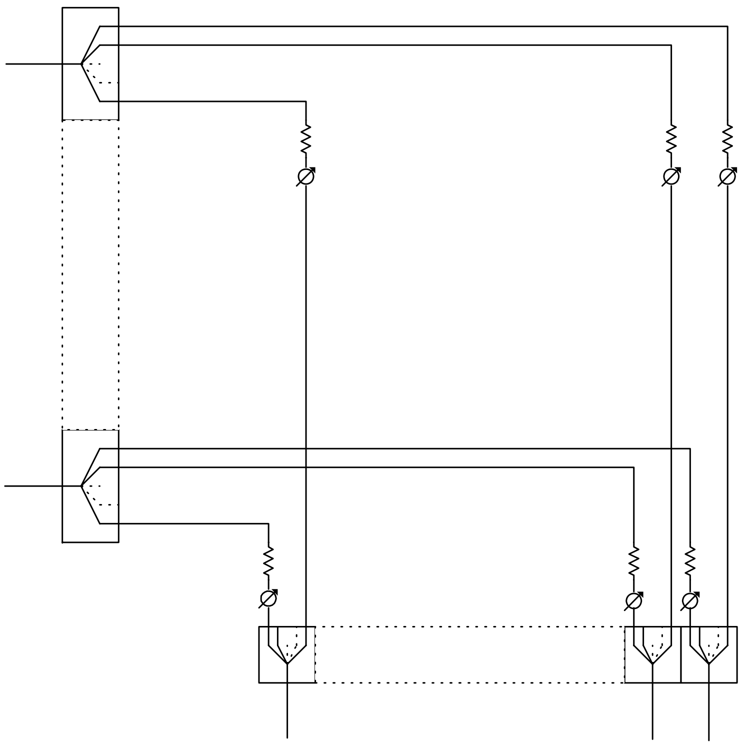


Multibeam Beamformers



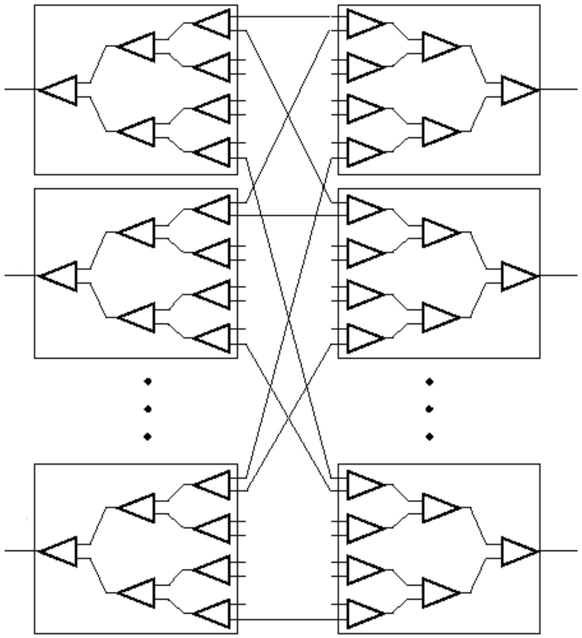
Beams

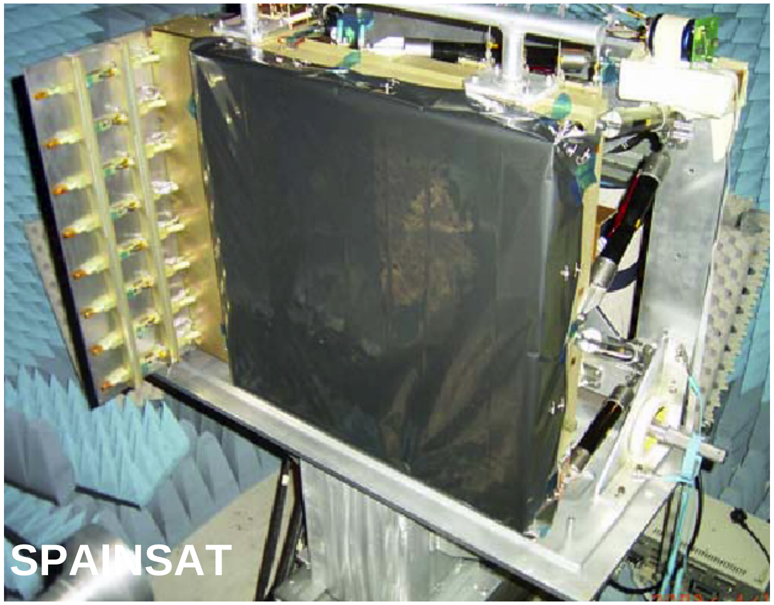
Elements



Beams

Corporate Networks in Fully Agile BFNs

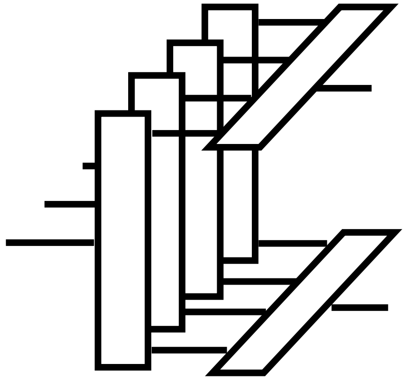




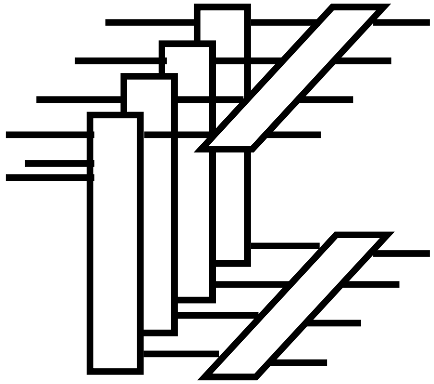
Corporate Dividers
Corporate Combiners

Factorised Beamforming

- When each beam is independently shaped the BFN complexity increases drastically with the number of Beams



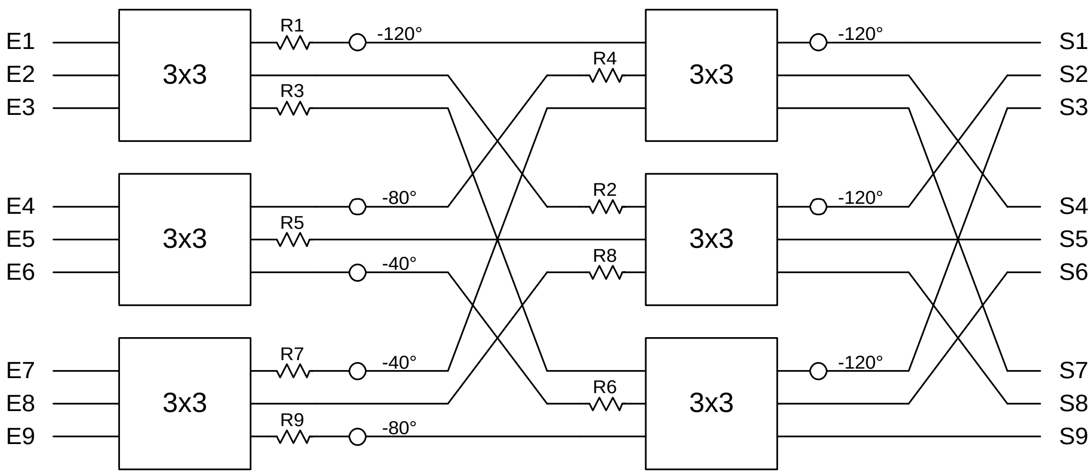
- Lower order Factorised beamforming matrices (e.g. Butler Matrices) allow to increase the number of beams or to reduce the BFN complexity
  - A constituent Radiation Pattern is chosen as prototype beam
  - Out of antenna nadir Beams are generated from the constituent beam applying the phase scanning.

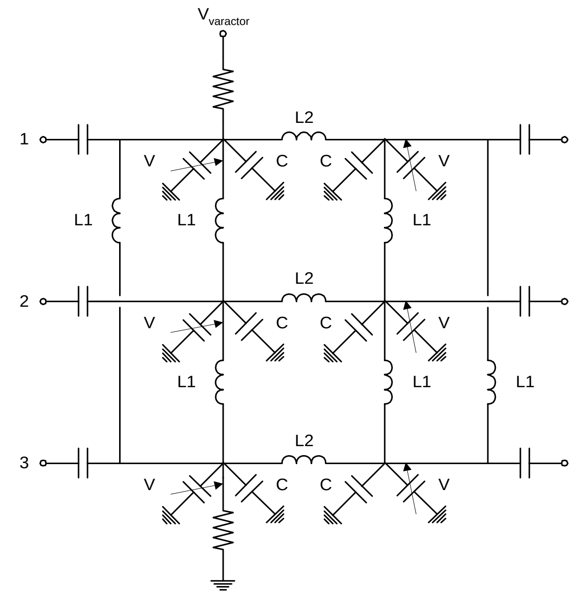


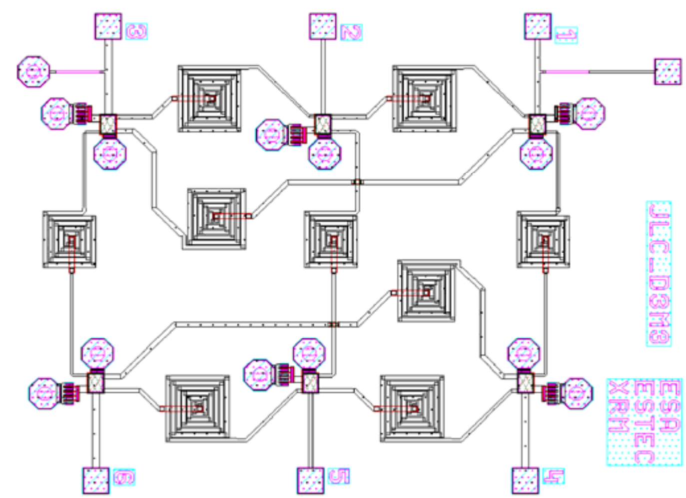
- Factorised beamforming concept is very similar to digital filter banks

FFT Based Beamforming … an 81x81 BFN (1/2)

9x9 BFN building block architecture







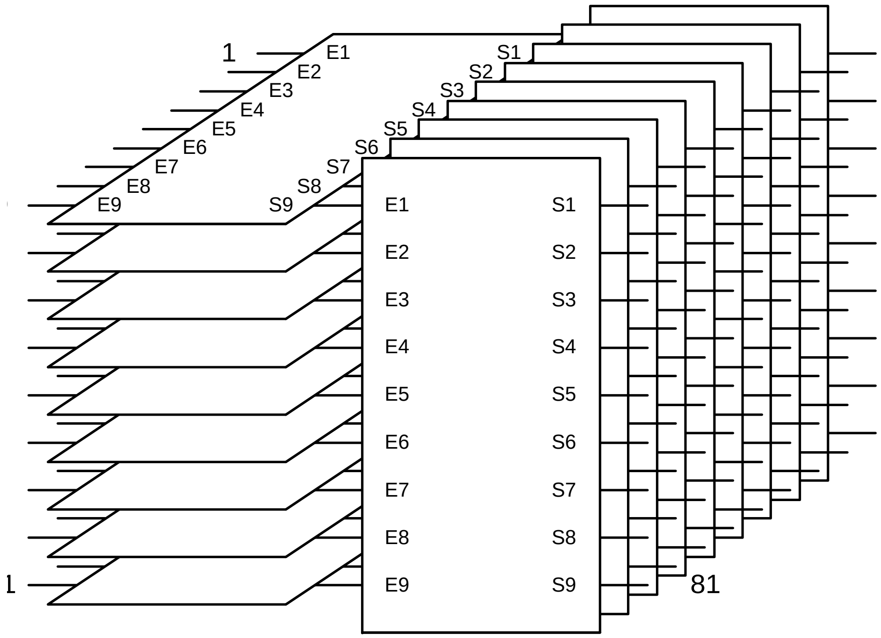
Operating @ 2.4 GHz

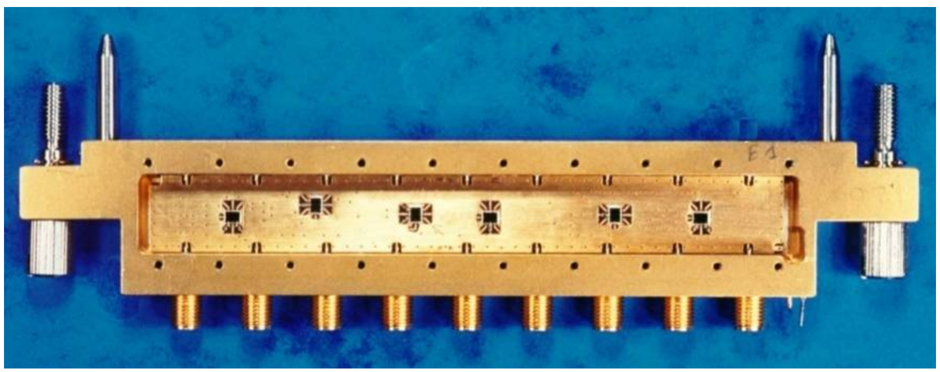
3x3 coupler using cold FETs

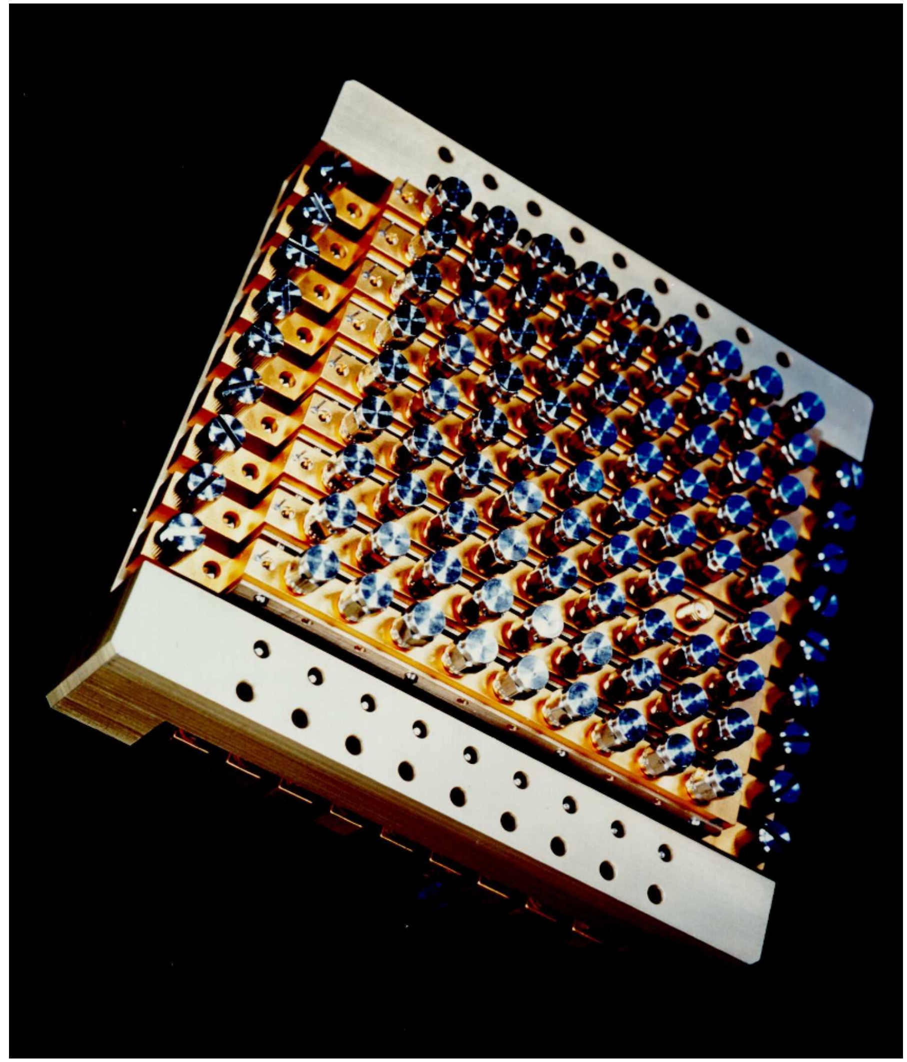
F. Coromina et al, "New multibeam beamforming networks for phased array antennas using advanced MMCM technology", IEEE MTT-S, 1996

Credits: DASSAULT ELECTRONIQUE (now THALES)

FFT Based Beamforming … an 81x81 BFN (2/2)







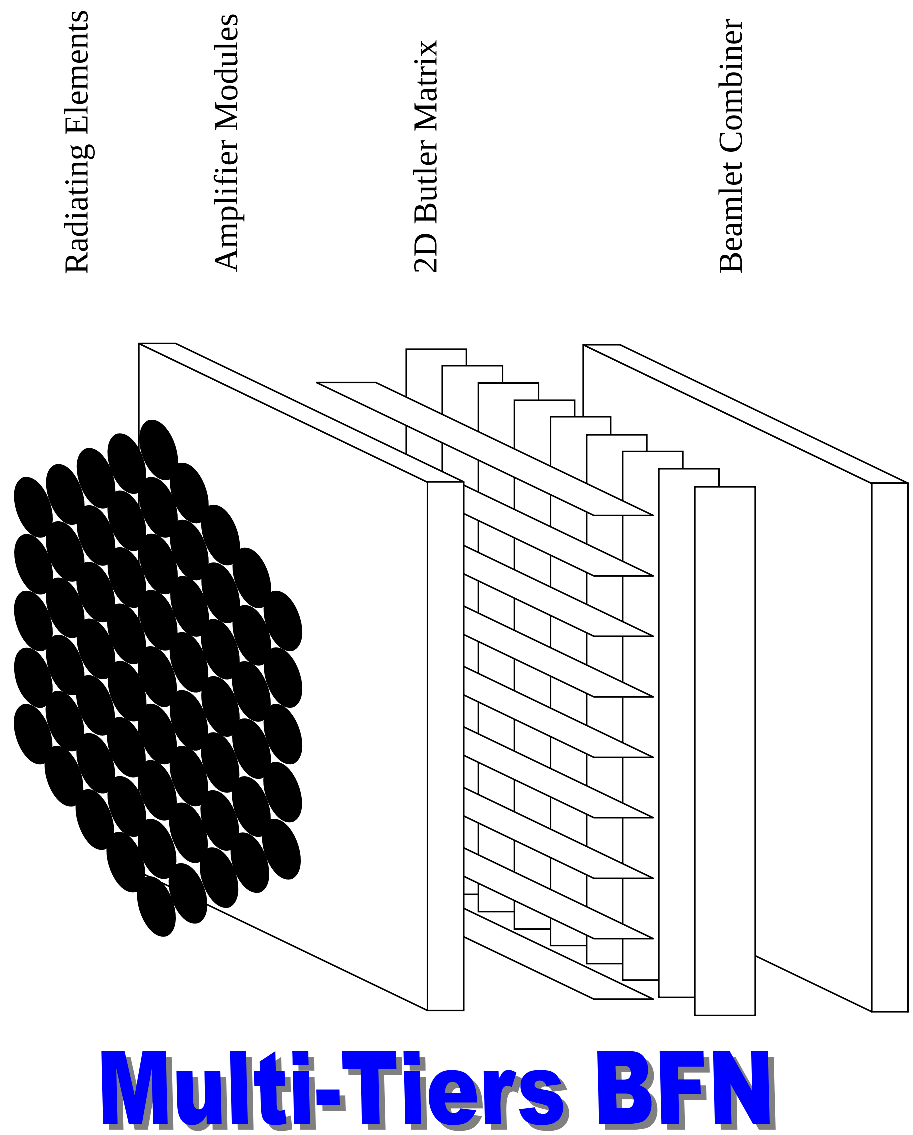
Credits: DASSAULT ELECTRONIQUE (now THALES)

Multi-Tier BFN's

- Use of factorised BFN could be unsatisfactory for the shape/number/pointing of the generated beams.

- It offer the possibility to operate a beam space beamforming (Beam Synthesis)

- The resulting architecture is a two-tier BFN based on an upper 2D Butler matrix and a lower Beam Combining Network (BCN) operating on a reduced number of beamlets.



Digital Beamforming

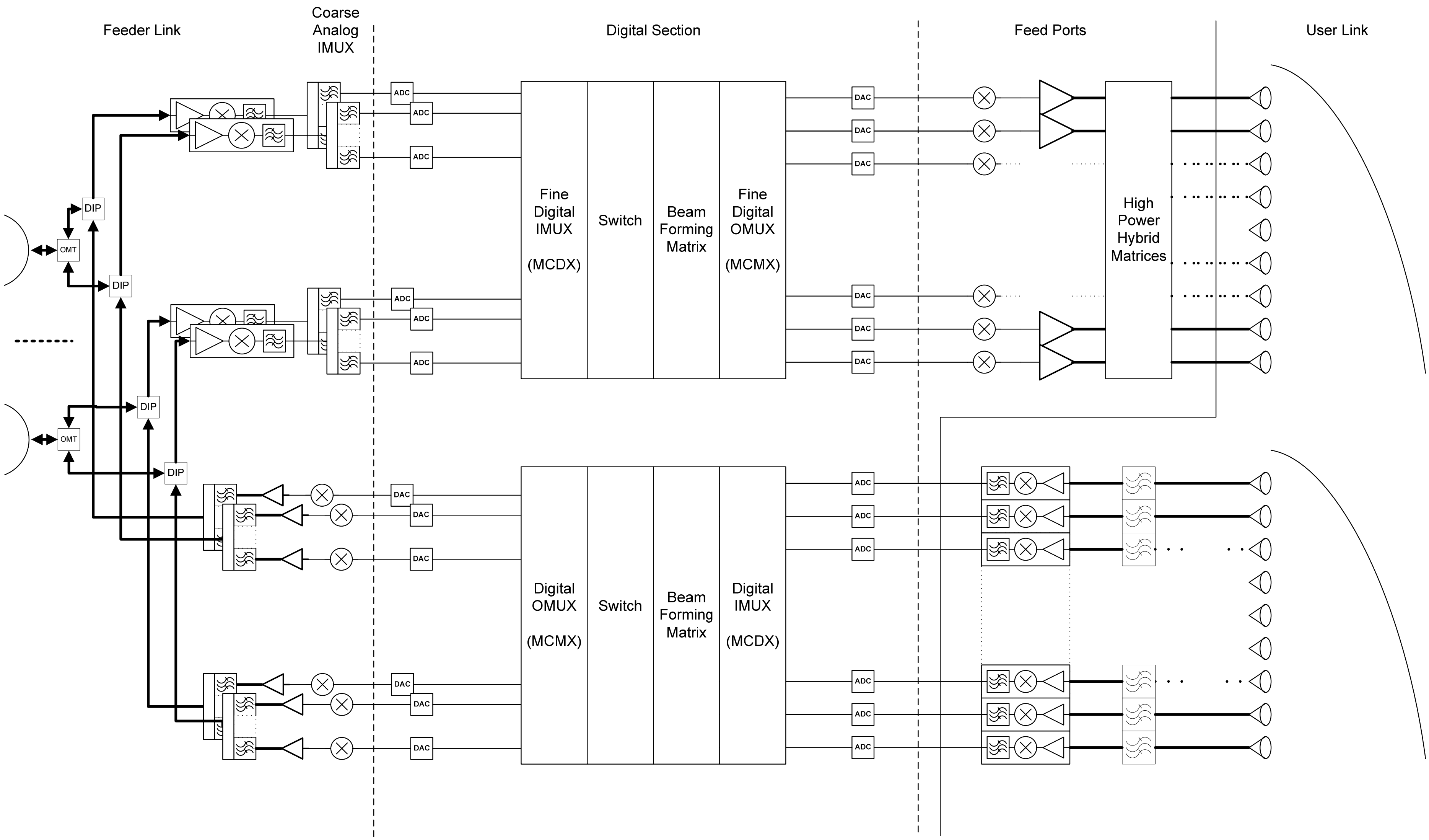
DBF can offer several advantages, non-exhaustively including:

- Beams can be individually formed, steered and shaped.
- Beamforming strategy can be software upgraded.
- Interference can be minimised implementing Adaptive Beamforming.
- Beams can be assigned to individual user.
- DSP techniques (filtering, multiplexing, despreading, demodulation, signal information extraction, performance optimisation, etc.) can be integrated.

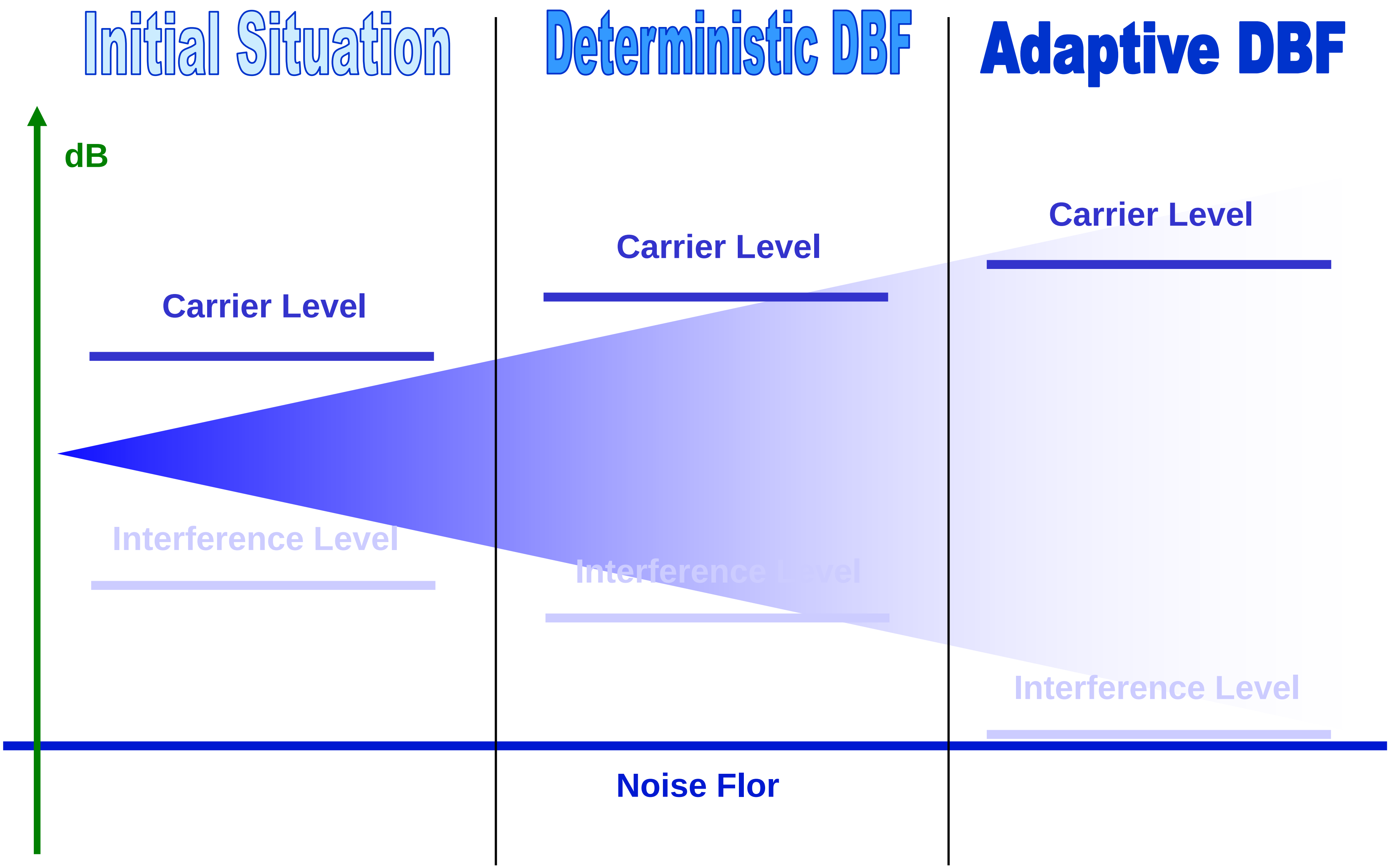
Digital Beamforming Antennas, "the Ultimate Antennas"

A.J.Viterbi

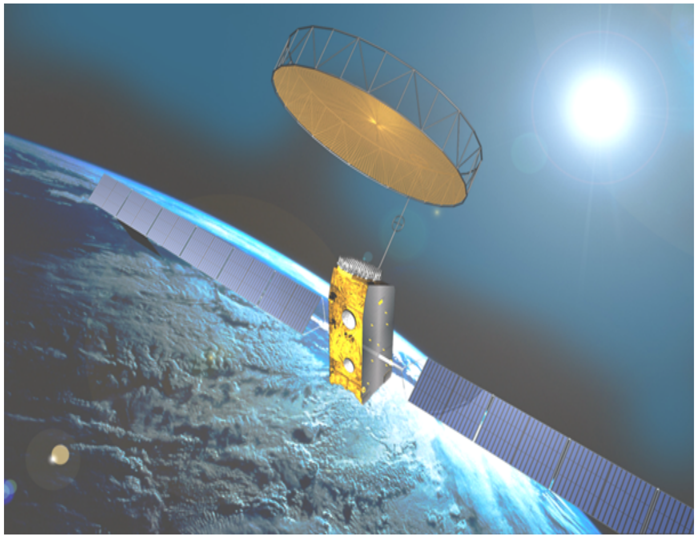
Digital-Bent-Pipe with Digital Beamforming



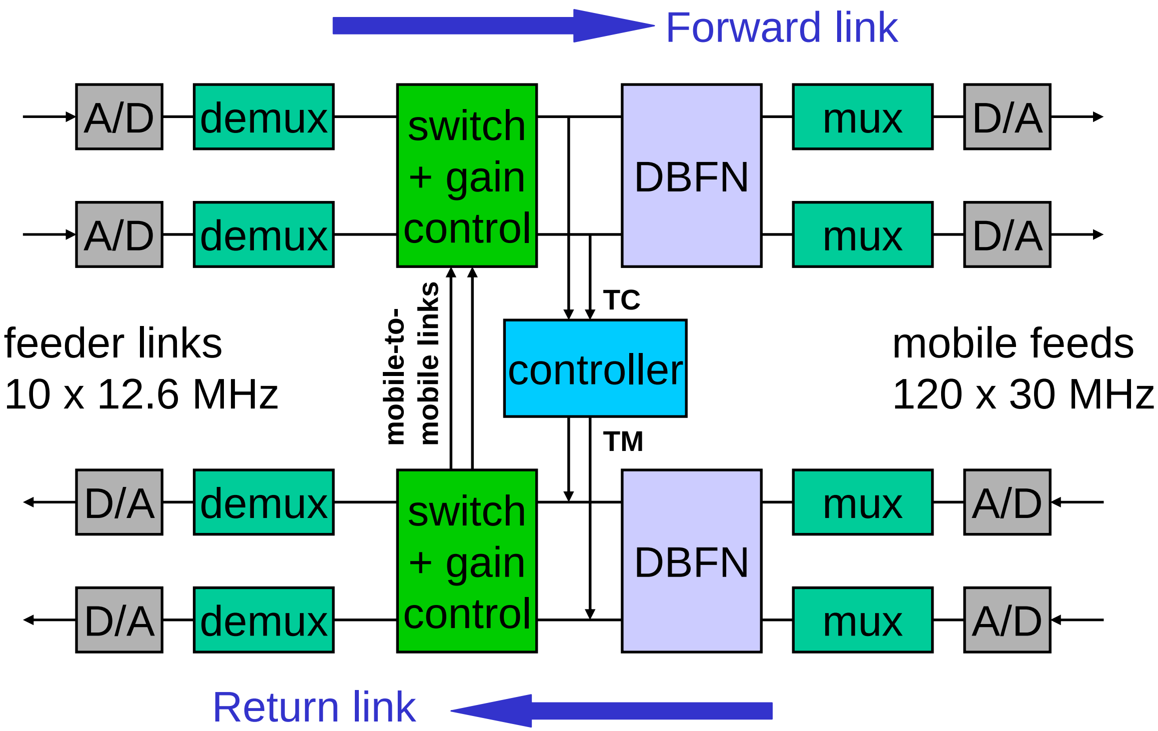
Adaptive Digital Beamforming

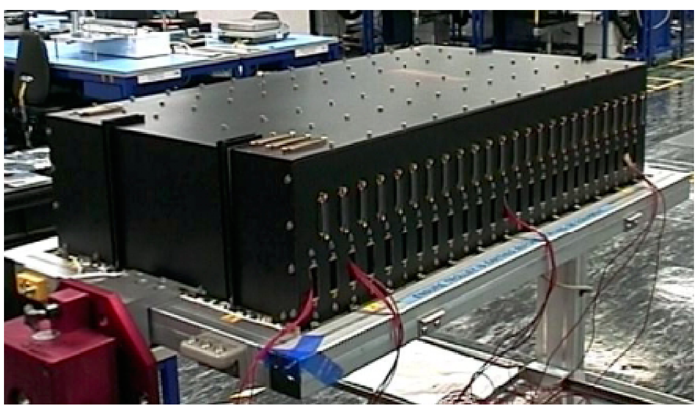


INMARSAT IV Transparent On-board processor



- 600 channels of 200 KHz
- 200 Digitally Formed Spot Beams
- Flexible frequency planning



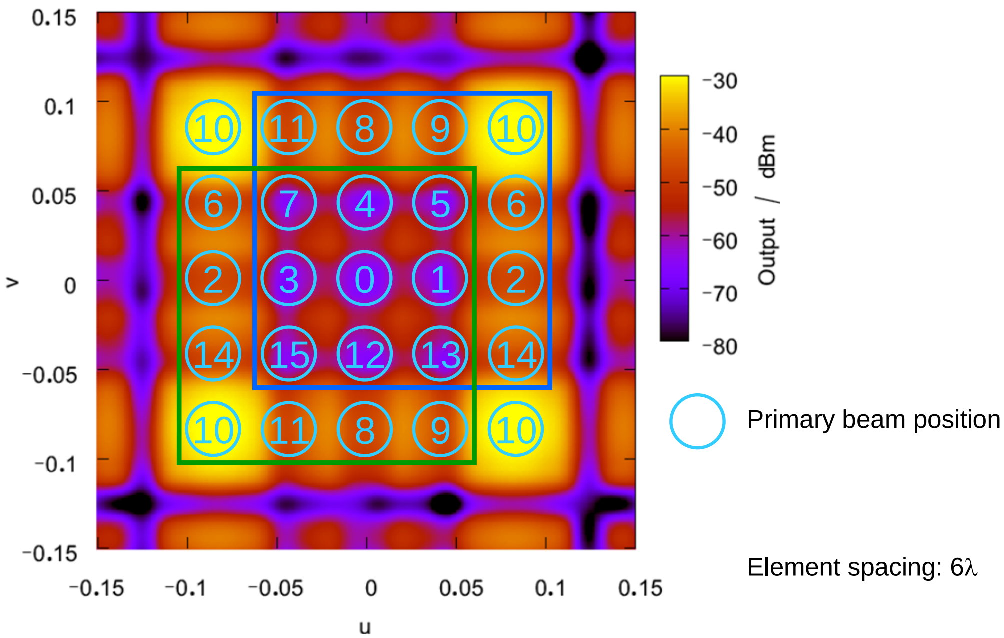


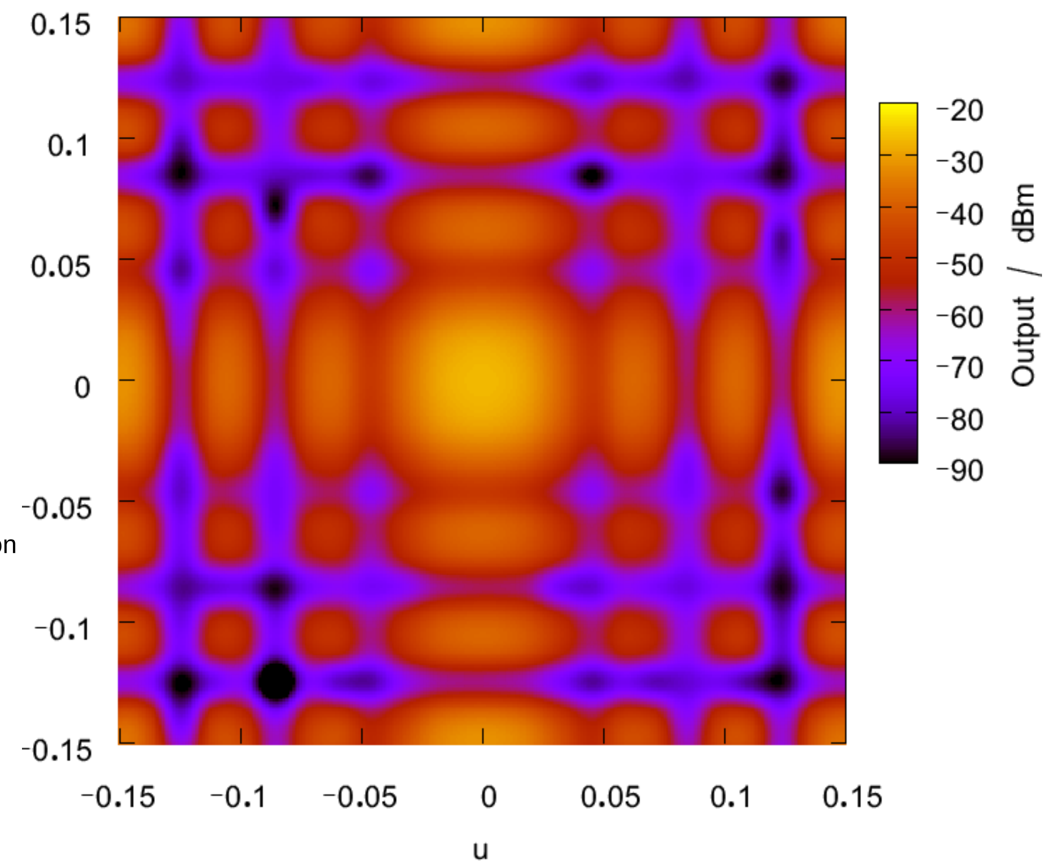
- 2 units per satellite (Forward & Return DSPs)
- 1.8 kW total power dissipation
- 160 kg total mass
- >2000 ASICs per DSP unit
  - 0.65um feature size, up to 300 kgates per ASIC
  - 8 distinct ASIC designs

Courtesy of EADS ASTRIUM

esa

Digital FFT BFN (ASTRIUM S-UMTS Processor)

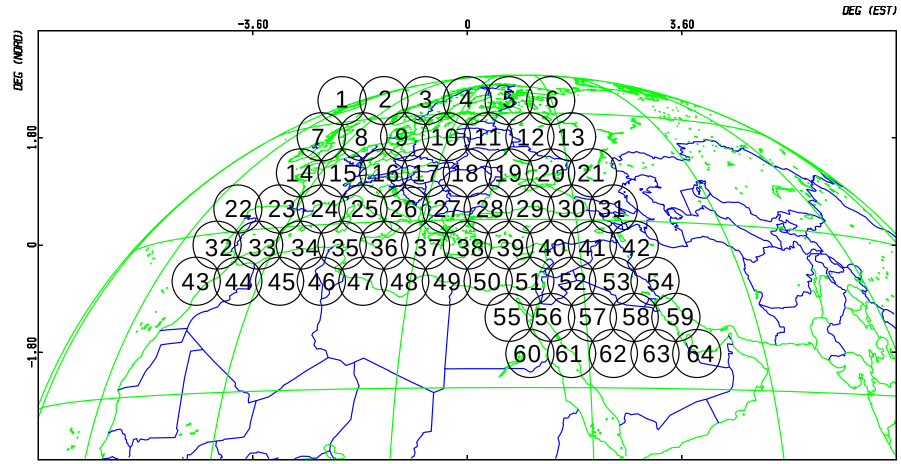




Courtesy of EADS ASTRIUM

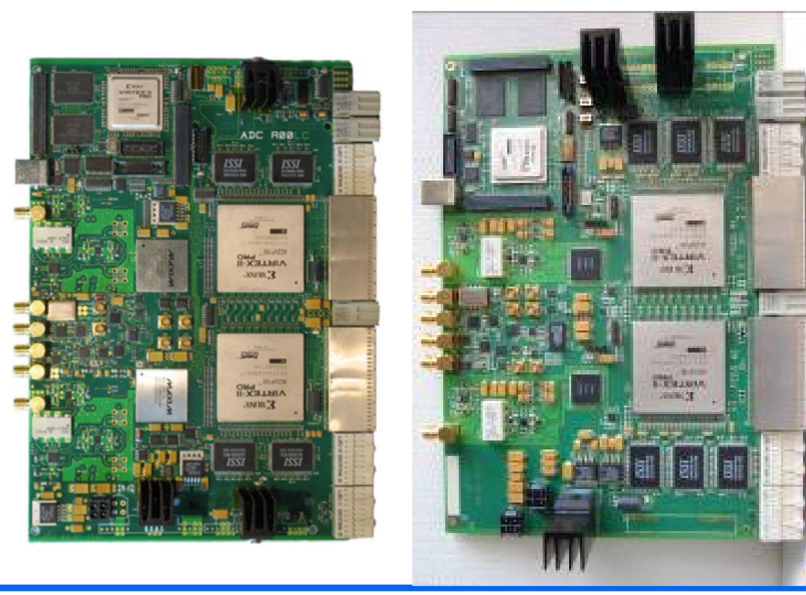
On-going ESA Activities in the field of Broadband Reconfigurable Payloads

- TRP W-DBFN (Space Engineering/TAS-F)
- 64 beams over extended Europe
- 500 MHz useful bandwidth : 29.50 GHz to 30 GHz
- 25 channels of 25 MHz each (22.5 for useful signal + 2.5 for transition bands)
- Total bandwidth to be processed : 625 MHz (25*25 MHz)
- Flexible channel to beam allocation
- Same frequency plan for TX side, with a center frequency equal to 20 GHz.
- Frequency reuse scheme with flexible number of channels per beam (no more fixed frequency reuse scheme)



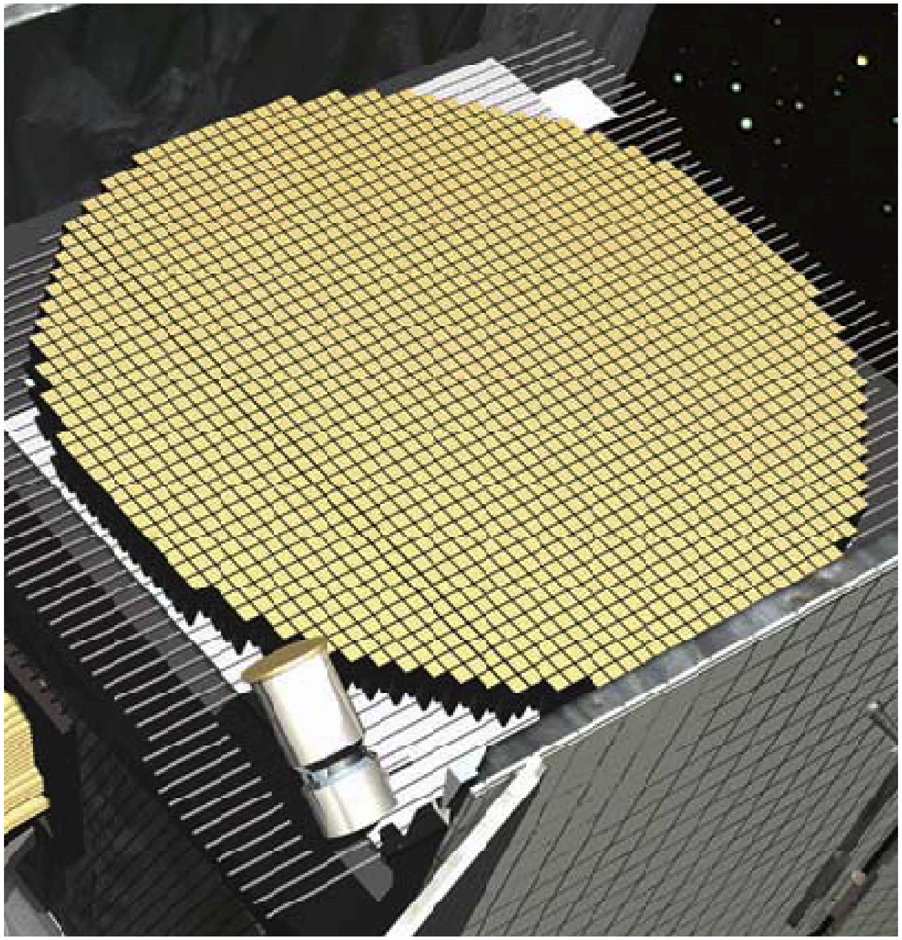
Satellite 33.00 0.00 35795.
Centre carte 26.30 36.50 0.

Custom ADCs DACs Boards



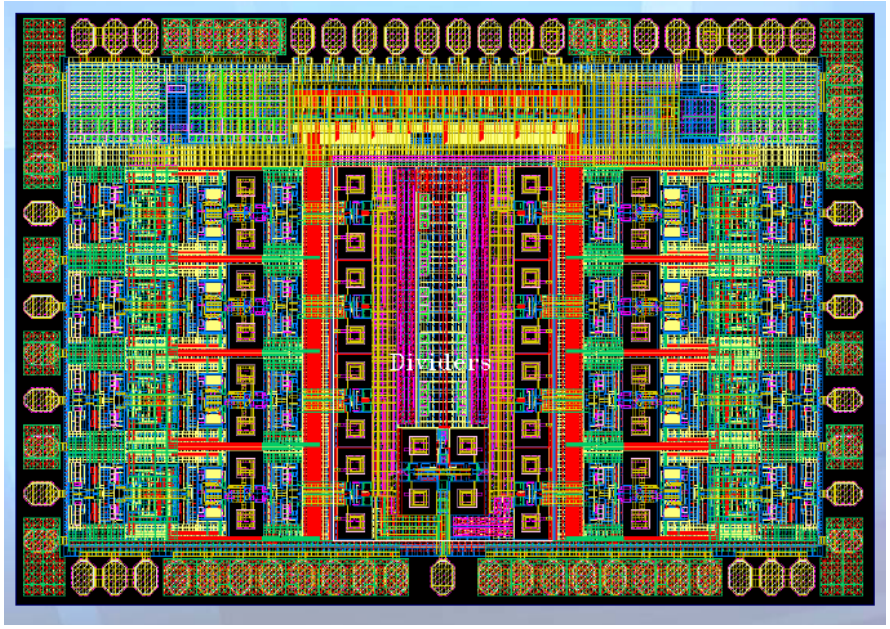
Technology Challenges

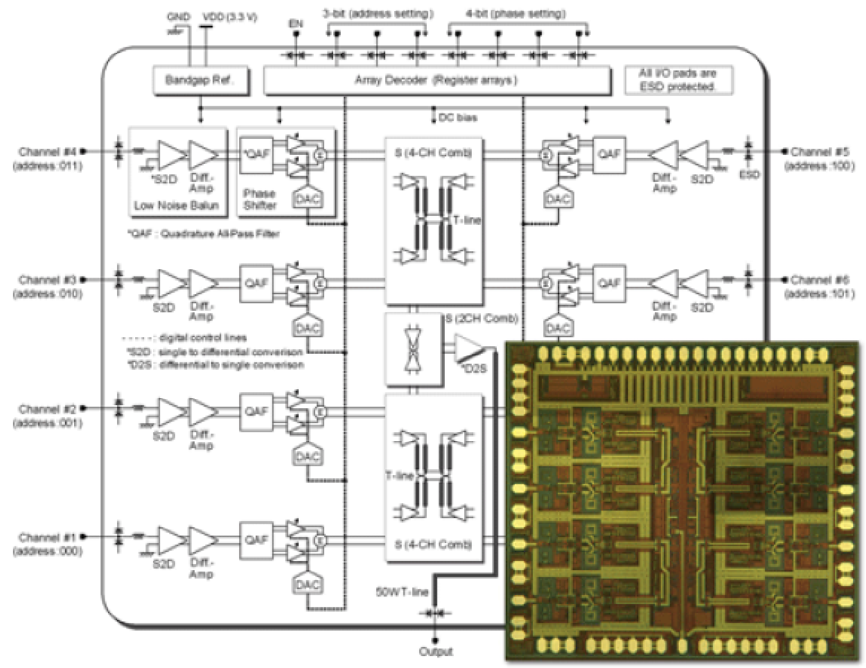
SpaceWay Tx Direct Radiating Array (Ka-band)



- 1500 Radiating Elements
- 3000 SSPAs
- Square Lattice
- Circular Shape
- Square-aperture high-efficiency dual-polarization horn radiators.
- 24 beams (12 LHCP + 12 RHCP)
- Fully-agile digitally-controlled analog BFN
- High rate reconfigurable (less than a μs)

Multi-nodes Reconfigurable BFNs

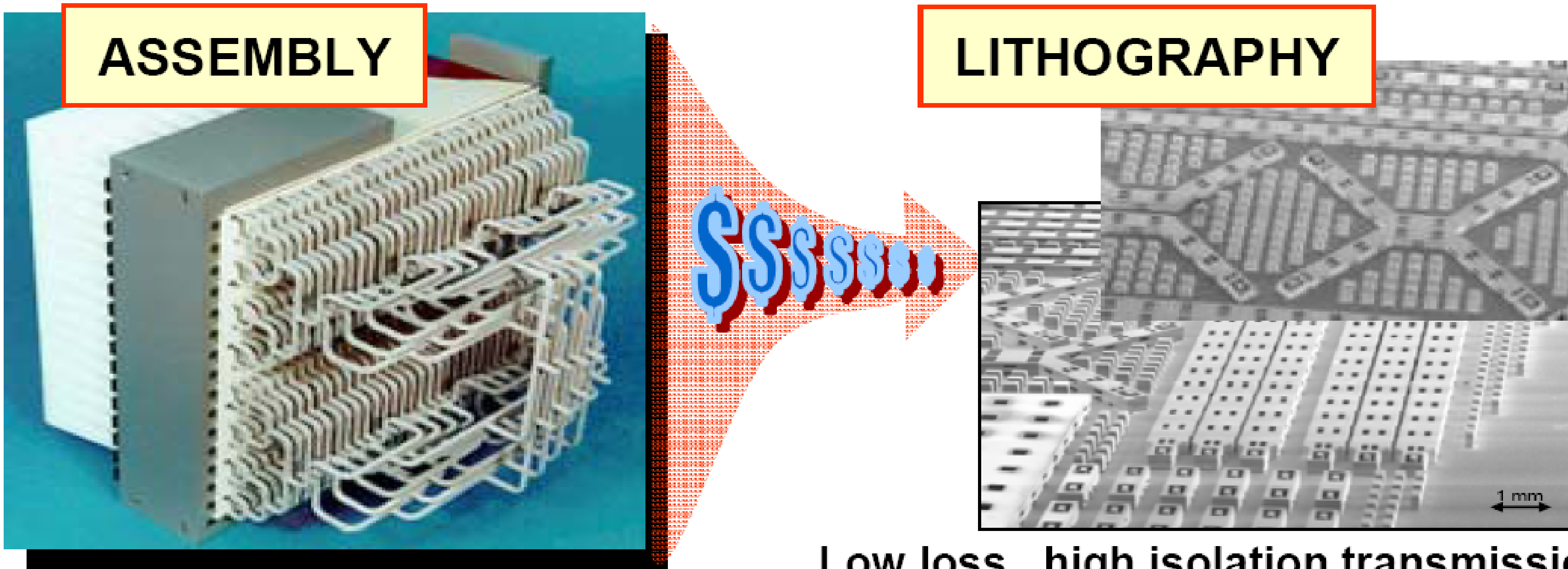




- 44GHz
- 8 channels
- All beamforming functions
  - RF amplifiers
  - 4-bit phase shifters
  - Amplitude controllers
  - Summing network
  - Power control
  - Latches for phase state
  - Address decoders
  - Digital-to-analog converters

→ 2.2x2.4 mm ←

Highly integrated RF BFNs (PolyStrata)



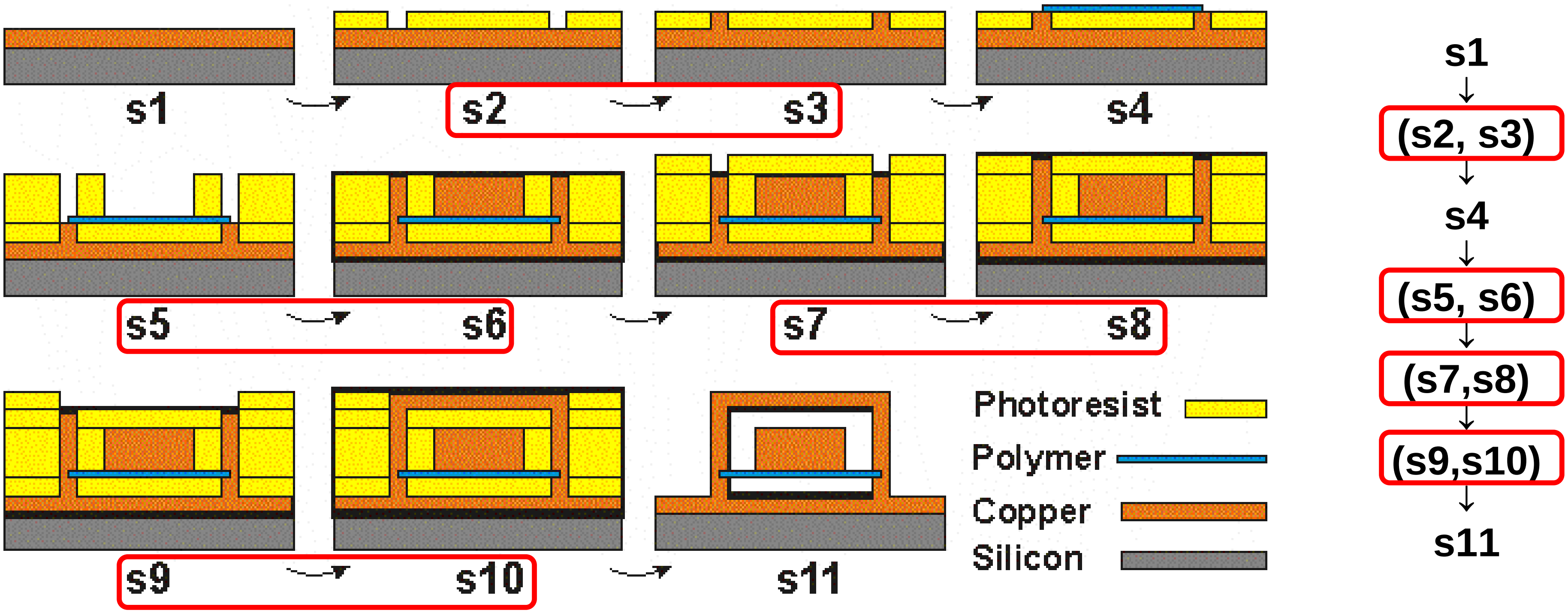
2.5 λ spacing
λ/2 NOT DOABLE

Low loss , high isolation transmission lines, couplers and resonators have been fabricated using 3D MERFS Technology.

Target:

Butler-matrix beam-forming electronically scanned arrays (ESAs) with more than 1000 elements.

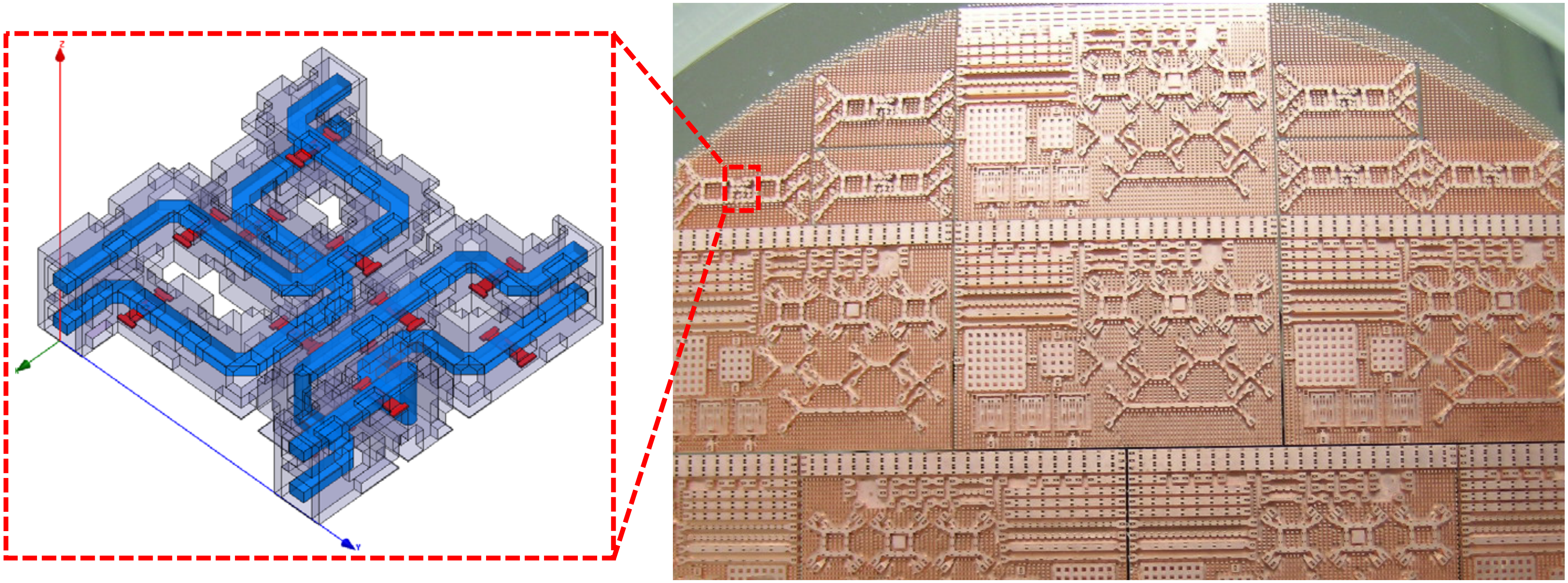
PolyStrata™ Process

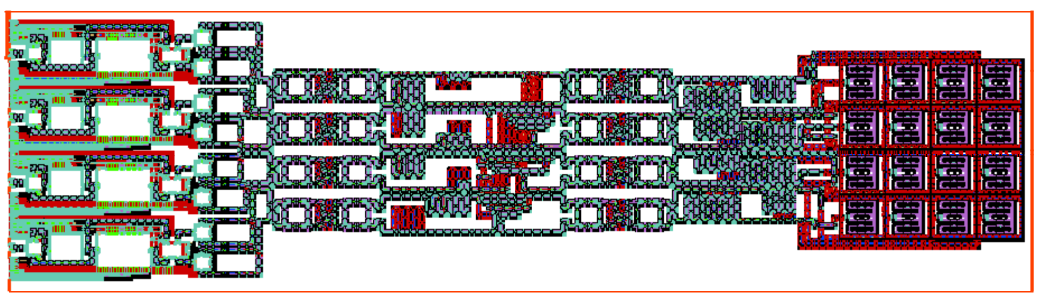


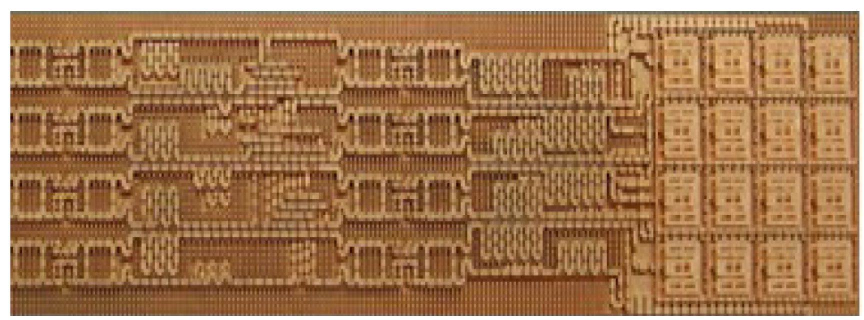
- A conductive **base layer** is formed at all locations to be plated with metal **(s1)**
- A **photoresist** pattern is formed over the base layer by coating and patterning **(s2, s5, s7, s9)**
- A **copper** structure is plated on all areas at which the base layer is exposed **(s3, s6, s8, s10)**
- Dielectric layers are deposited at a desired point in the process sequence **(e.g. s4)**
- The sacrifitial photoresist is removed from the structure **(s11)**

US Patent Application Publication No. US2004/026390A1 to Rohm & Hass Electronic Materials LLC

PolyStrata - Current US Developments







M. V. Lukic, D. S. Filipovic, Integrated cavity-backed ka-band phased array antenna, IEEE AP-S 2007

Conclusions

- Today, Europe faces important and time-critical challenges related to its independence and competitiveness in payload and beamforming technologies.

- Maintaining and expanding development and production capabilities, as well as acquiring real strategic independence will be the challenge of the European space industry for the years to come.