Satellite Payloads for Telecommunications

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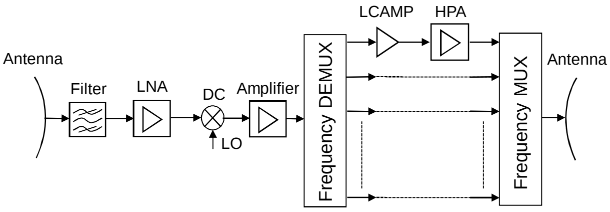
Outline

- **Transparent payload**
  - Antennas
  - Transponders
  - Redundancy management
- **Flexible payload for High Throughput Satellite (HTS)**
  - Architecture for Single-Feed-Per-Beam (SFPB)
  - Architecture for Multiple-Feed-Per-Beam (MFPB)
  - On-Board Processing (OBP)
- **Examples of HTS Payloads**
  - Transparent payload
  - Flexible payload
  - Future flexible payload

Transparent Payload

- **Input section on the global bandwidth**
  - Wideband input filter to suppress the feed-back from the satellite transmission antenna
  - Low Noise Amplifier (LNA) to minimize the repeater noise temperature
  - Down Converter (D/C) to convert to the downlink frequency using a Local Oscillator (LO)
  - Wideband linear amplifier
- **Filtering and amplification per channel bandwidth**
  - Input Demultiplexer (IMUX or DEMUX) to split the input signal in several channels
  - Amplification based on a Linearized Channel Amplifier (LCAMP) and a High Power Amplifier (HPA)
  - Output Filter (OMUX) to removes thermal noise plus out-band harmonics generated by the HPA

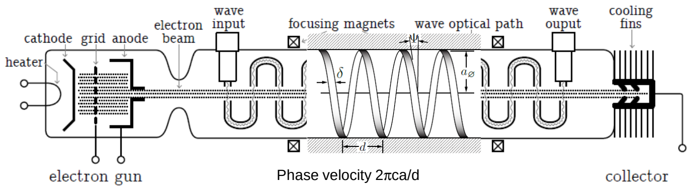


Antennas

- **Often mission-critical**
  - Risks during launch (often semi-detached)
  - Start of life (often complex deployment mechanisms)
  - Operational life (direct exposure to space environment)
- **Three complementary roles**
  - Transforming guided energy into radiation: Gain, efficiency, reflection coefficient, power handling, noise figure (antenna temperature, for reception)
  - Filtering in both frequency and space (angular) domain: Transfer characteristic (for different points in space), pattern shape (vs angle and frequency), isolation among input ports, polarization purity, group delay, out-of-band response (to help rejecting disturbances)
  - Transforming electric currents into radio waves: Circuit parameters (input impedance, S-parameters), Ohmic losses, spurious radiation (e.g. feeding lines), high-power effects (multipactor, Corona, passive inter-modulation)
- **Need of RF analysis and tests**
  - Antenna radiation highly dependent on spacecraft structure, antenna suite & mutual coupling effects

Travelling Wave Tube Amplifier (TWTA)

- **Slow wave structure to amplify wave when electron speed higher than wave phase velocity**



Phase velocity $2\pi ca/d$

Power saturation (tube end)
Nonlinear effects (>0.8 tube length)

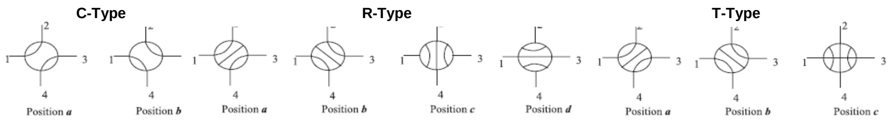
- **Recent space TWTAs manufactured by Thales Electron Devices**

Name	TL 4150	TH 4795	TH 4816	TH 4626	TH 4606C	THL40040CC
GHz	3.4-4.2	10.7-12.75	17.3-20.2	$\sim$ 26	32	37.5-42.5
P_{out}	150 W	150 W	160 W	50 W	35 W	40W
Gain	50 dB	> 50 dB	> 50 dB	> 50 dB	> 50 dB	48 dB
Eff.	73%	68%	63%	55%	54%	50%
Mass	1000 g	800 g	900 g	700 g	700 g	<890g

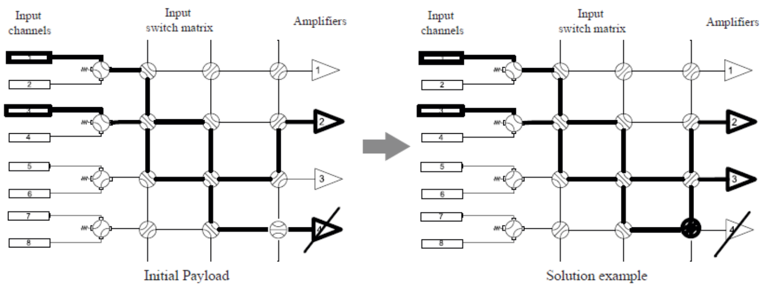
The Traveling-Wave Tube in the History of Telecommunication, D. Minenna & all, European Physical Journal, 2019

Redundancy Management

- **C-type (4-port, 2-positions), R-type (4-port, 4-position), T-type (4-port, 3-position) switches**



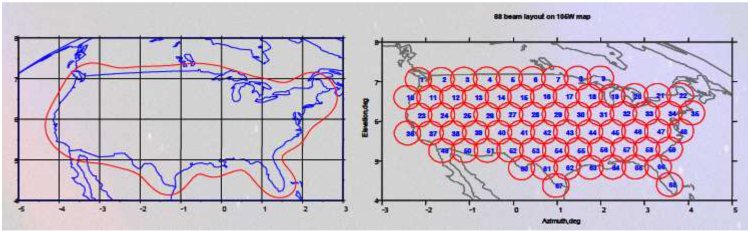
- **Example of restoration in case of failure of a TWTA**



Optimising communication satellites payload conguration with exact approaches, A. Stathakis & all, Engineering Optimization, 2015

Flexible Payload for High Throughput Satellite (HTS)

- **From contoured beam to spot beams for feeder links and multibeam for user links**



Global beam 31dBi (EOC) C/I=30dB   Multibeam with 4*17 Spots 0.6˚ 46dBi (EOC), C/I=12dB

- **From RF flexibility to on-board processing**
  - Downconverter (RF to IF or BB)
  - Analog to digital converter (sampling, quantization)
  - Switch (polyphase filters) or signal processing (demodulation, routing, modulation)
  - Digital to analog converter (sampling, quantization)
  - Upconverter (IF or BB to RF)

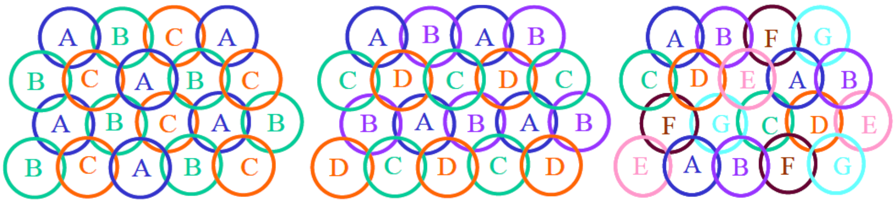
Approaches for Feeder Links

- **Large RF gateways operating at Q/V or even W-band**
  - Dedicated on-board payload
  - Tenths of large RF gateways required operating in smart diversity
  - Terrestrial interconnection costly
- **Small RF gateways sharing the Ka-band user link band**
  - Reuse of the Ka-band active antennas avoiding dedicated input section and offering full reconfigurability
  - Support of smart gateway diversity and progressive gateway deployment
  - Easier to install, lower connection cost but reusing user link precious bandwidth
- **Optical gateways with very high rate optical links**
  - 3 on-board solutions: user link regeneration (complex and inflexible), signal sampling and quantizing (bandwidth expansion of 16 or so), RF over optical transmission (simplest payload but power inefficient)
  - Heavily affected by atmospheric impairments requesting spatial diversity and pre-correction techniques
  - N+P smart GW diversity to reduce bit rate by N (e.g. 3 active with 9 extra in diversity)

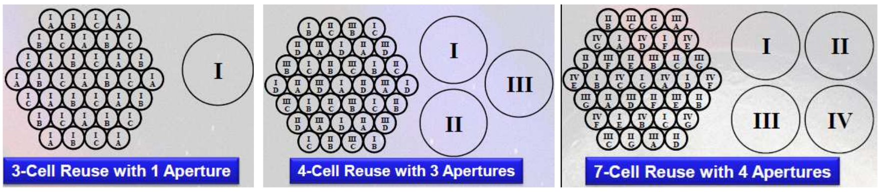
Challenges in future satellite communications, R. de Gaudenzi, IEEE Communication Theory Workshop, 2018

Single-Feed-Per-Beam (SFPB)

- **Frequency reuse schemes (3, 4, 7)**



- **Aperture reuse schemes (1, 3, 4 reflectors)**

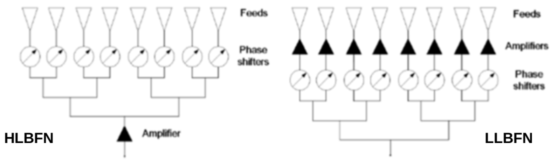


- **Inmarsat-3 (L-Band, 1995), SkyTerra-1 (L-band, 2010), Eutelsat 172B (Ku-Band, 2017)…**

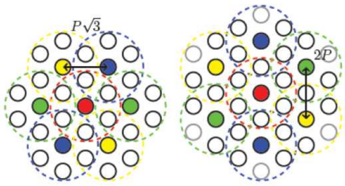
Development of a 45 GHz multiple-beam antenna for military satellite communications, IEEE TAP, S. Rao & all, 1995

Multiple-Feed-Per-Beam (MFPB)

- **Each beam produced by a cluster of radiating elements fed by an appropriate BFN**
  - Better C/I -> Reduced number of reflectors / Lower illuminating efficiency -> Lower gain
  - High Level BFN (HLBFN) between amplifiers and feeds -> More RF loss (Ka/Ku bands)
  - Low Level BFN (LLBFN) before amplifiers -> More efficient, but complex (S/L/X bands)



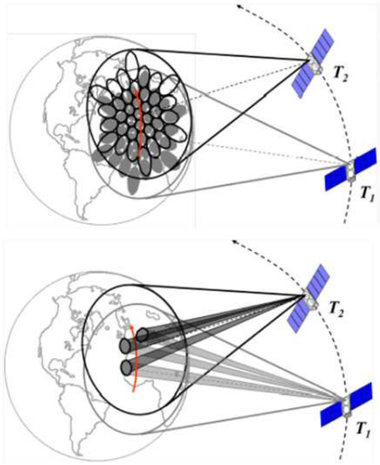
- **Examples of MFPB using 7 feed horns, 4 colors frequency and polarization reuse**

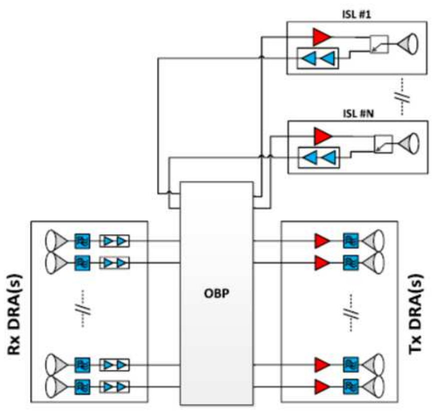


- **Iridium (S-Band, 1997), Spaceway-3 (Ka-Band, 2007)…**

Ka-Band multiple feed per beam focal array using interleaved couplers, IEEE TMTT, C. Leclerc & all, 2018

Multibeam Antenna in LEO



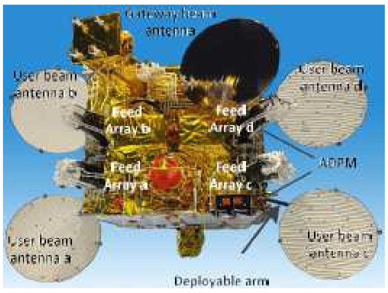


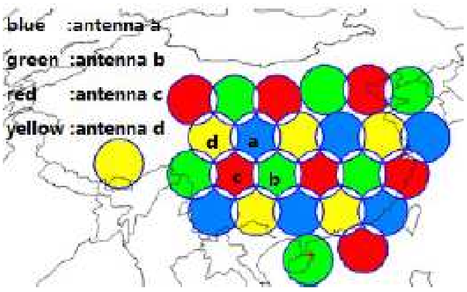
Satellite-fixed cell (LEO-MSS) vs. Earth-fixed cell (LEO-HTS) **Payload with Intersatellite Links**

Future technologies for very high throughput satellite systems, R. Gaudenzi & all, Wiley ISCN, 2019

Example of HTS Transparent Payload (Chinasat-16)

- **Antennas accommodation**
  - 1 reflector for gateway beam
  - 4 reflectors (2 on the west panel, 2 on the east panel) mounted on a deployable arm
  - RF tracking feed chain based on an RF signal transmitted from a ground beacon
  - Angular pointing errors corrected at 0.05˚





ADPM: Antenna Deployment and Pointing Mechanism

Ka-band multibeam antenna for Chinasat-16, Wei & all, IEEE, 2019

HTS Global Capacity

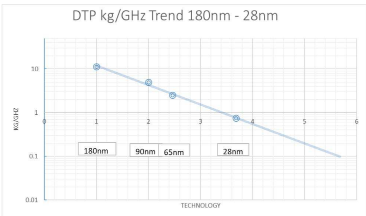
- **Total useful data rate for download and upload**

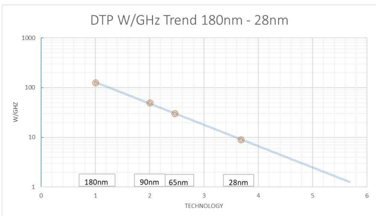
$$C = \left(\sum_i \left(\eta_{FL_i} p_{FL_i} \right) B_{FL} + \sum_j \left(\eta_{RL_j} p_{RL_j} \right) B_{RL} \right) * N * P / K * \eta_{HL}$$

  - p_{FLi}&p_{DLj}, uplink&downlink percentages of time minimizing link margins for a given link availability
  - η_{FLi}& η_{DLj}, uplink&downlink low layer efficiencies (including guard bands) for p_{FLi}&p_{DLj}
  - B_{FL}&B_{DL}, uplink&downlink bandwidths (not including double polarization)
  - N, number of beams
  - P, number of polarizations (1 or 2)
  - K, number of colors (1/K frequency reuse factor)
  - η_{HL}, high layers efficiency (throughput decrease due to overhead, signaling, latency)
- **Satellite throughput increase**
  - Use of Fade Mitigation Techniques (FMT) to limit link margins for a given link availability
  - Higher spectral efficiency (higher on-board power, better user terminal)
  - Use of higher frequency bands (Q/V or optical), especially for feeder links
  - Increase of number of beams (larger reflectors to have narrower beams)
  - Lower frequency reuse factor limiting interferences (beam hopping or non-orthogonal frequency reuse)
  - High layers protocols and on-board processing (lower overhead, signalling, latency)

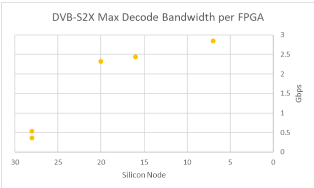
Future Digital Payloads

- **Mass and power per GHz of processed bandwidth**





- **Components**
  - ASIC RF front-end for ADC/DAC and Digital Beamforming
  - FPGA / SoC (> 250 MHz) for flexible MoDem
  - Software packet switching / router for MAC layer handling
  - High Speed Serial Link (HSSL) for interconnection
  - Laser digital signal processing for ISL



Satellite radio-frequency payloads and instruments - Overview and challenges, ESA ESTEC, 2023