5G/Satcom-on-the-move agile antenna frontends:

RF design challenges

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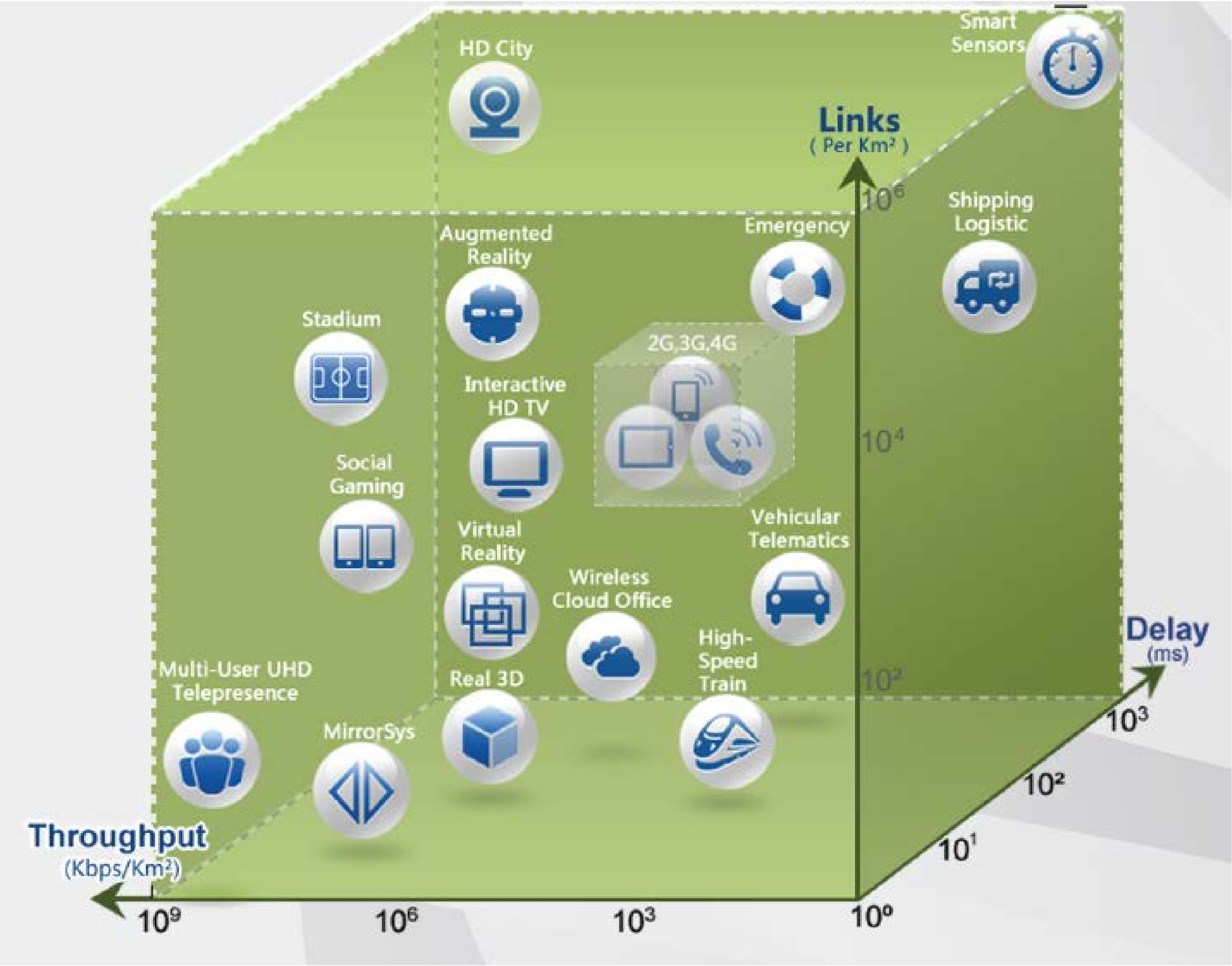
5G Eco system

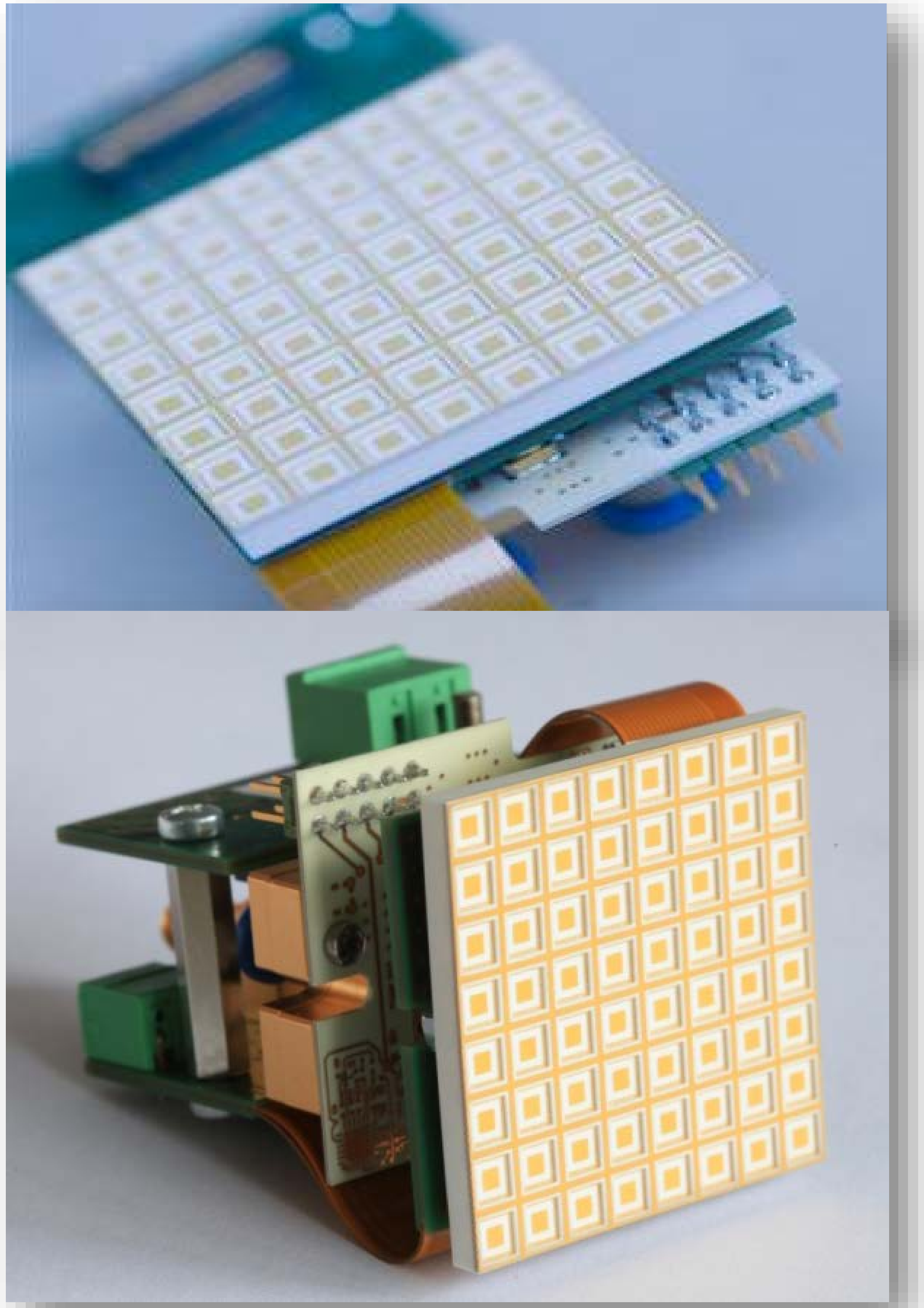
- Efficient use of radio spectrum, extension to mm-wave bands
- “One does not fit all”: flexible solutions, application driven
- Costs and sustainability: “green” communications
- Worldwide standardisation vs. user-driven applications



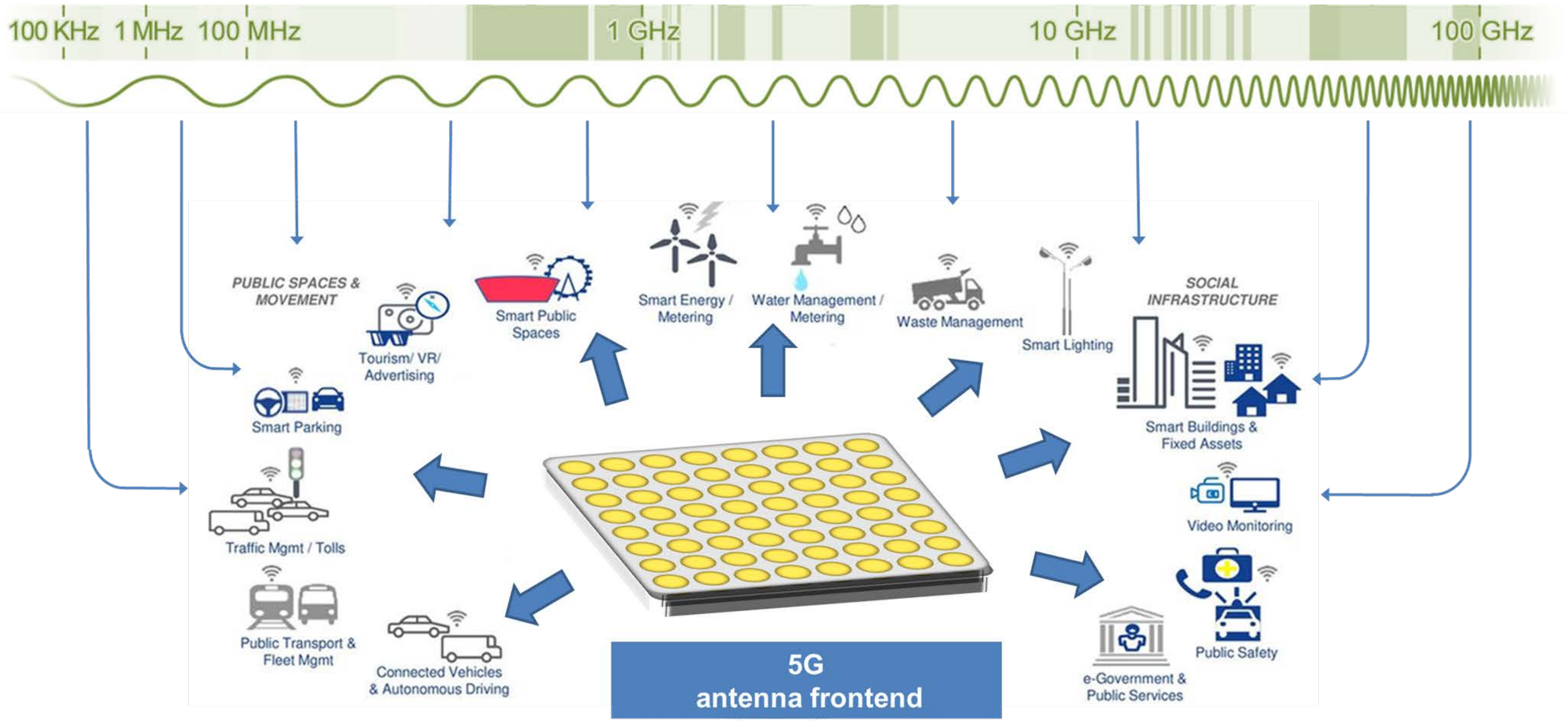
Source: Huawei

5G/IoT antenna frontends

- Large variety of user & communication platforms → multiplatform integration:
  - Wireless (WiFi, etc)
  - Cellular (operators)
  - Satellite-based, HAPS
  - D2D, M2M, IoT…
- Extremely high reconfigurability:
  - Software defined radio
  - High level cognitive radio
  - MIMO
  - Antenna beam shaping/forming
- Higher frequency spectra & large data rates:
  - Highly compact RF frontends
  - Highly integrated RF components

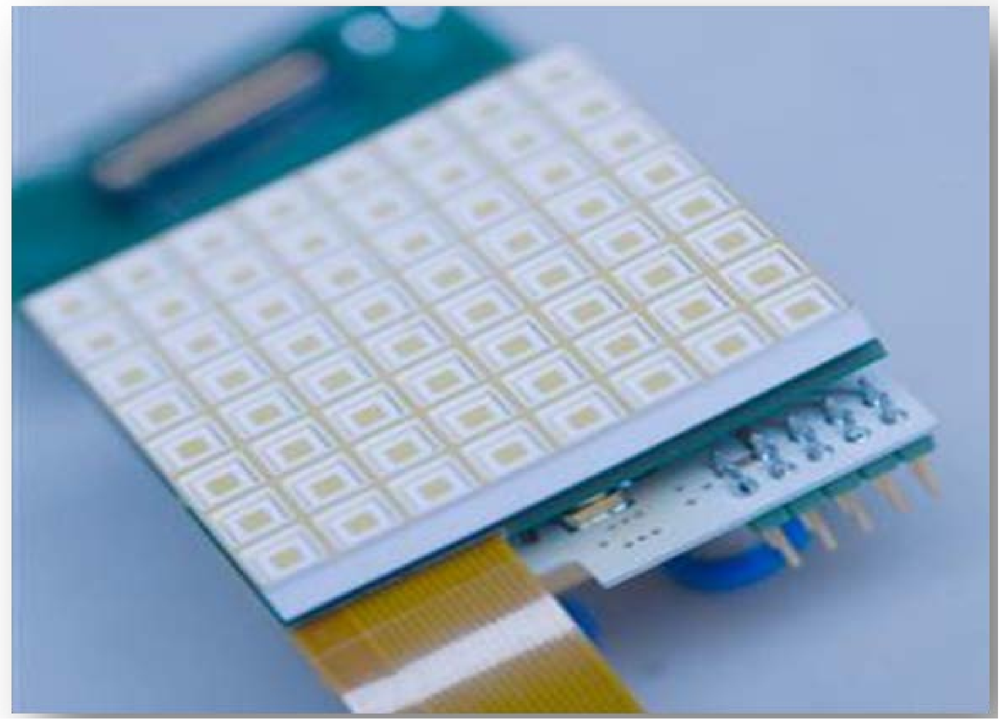


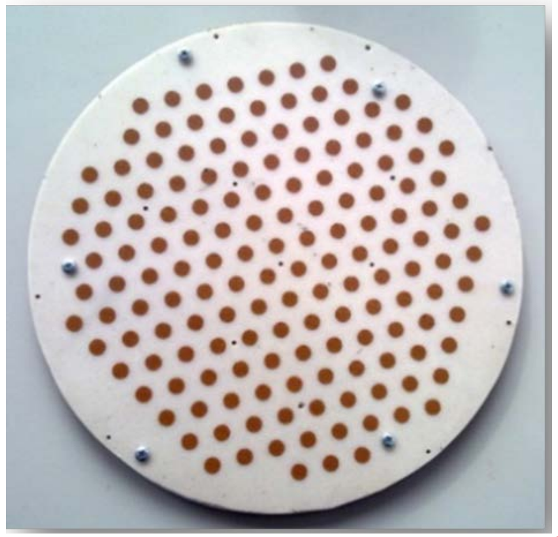
All for one & one for all… (Alexandre Dumas)



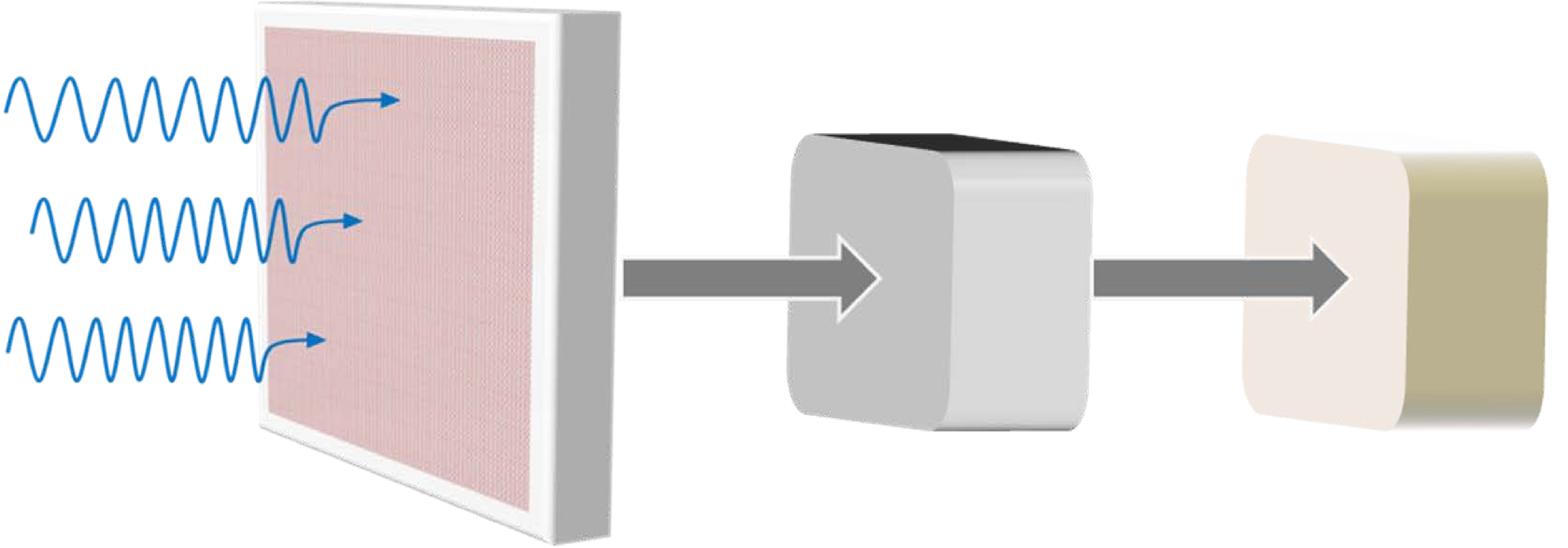
… and what about SOTM?

- Mobile satellite communication terminals have **5G-similar** requirements:
  - Reconfigurable antenna beam
  - Multibeam for LEO/MEO services
  - Large data rates (i.e.high bandwidth)
  - Compact dimensions of frontend (i.e. high integration)
  - L/Ku/K/Ka-band….V/W-band envisaged for long term
- SOTM antenna frontends have been on the market **since decades** in various forms
- First highly integrated **corechips** have been developed for SOTM (pre-2000), not 5G!
- SOTM will become / is **part** of the 5G eco system
- Extremely strong cross **pollination**





What is exactly the antenna frontend?

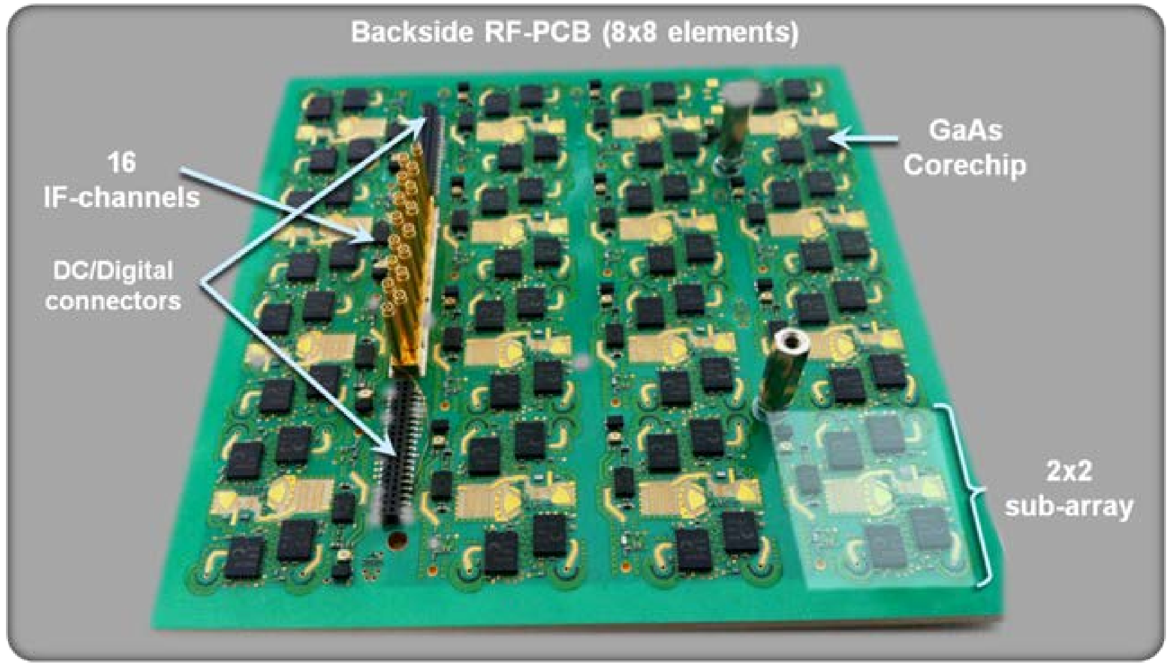


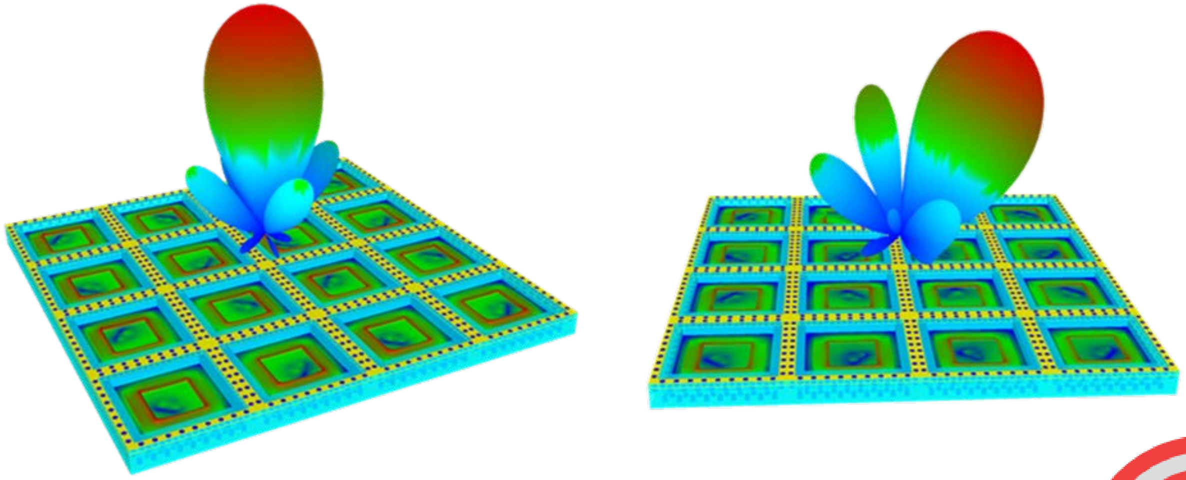
The baseband unit is often not considered part of the antenna frontend, depends on who you ask!

- **Antenna aperture**
  - Antenna elements
  - Beam forming networks
  - Filters
  - Interface to RF components
- **RF circuitry**
  - PA, LNA, mixer, AGC
  - Filters
  - Beam forming networks
  - Interfaces to antenna/baseband
- **Baseband circuitry**
  - AD/DA converters
  - FPGA/ASIC
  - Software
  - Interfaces to RF circuitry

Challenges for 5G/SOTM antenna frontends

- Extreme RF Performance over large bandwidth
  - High data rates (high RF power, low noise figures)
  - Higher order modulation schemes (high linearity)
- Extremely densely populated printed circuits boards (PCBs)
  - Efficient thermal management
  - Highly integrated building blocks (corechips)
  - Low power consumption
- Small form factor
  - Suitable for fixed, nomadic and mobile platforms
- High reconfigurability
  - Single, dual, multibeam capability
  - Linear & circular polarisation capability
- Low power consumption
- Cost effective





High performance RF components

- **High linearity/amplification** of PA and **low noise figure** of LNA at higher frequencies not trivial in design
- Most RF power **at highest efficiency** delivered by **GaN**, followed by **GaAs** → production cost are however high & on-chip integration density low (same story applies to noise figure)
- **Si**-based chips are cost effective in **bulk**, RF and digital circuitry can be combined on one single chip, and integration density of Si-circuitry is much **higher** than in case of GaN/GaAs. Amplification/Linearity and noise figure is however **less** when compared to GaN/GaAs

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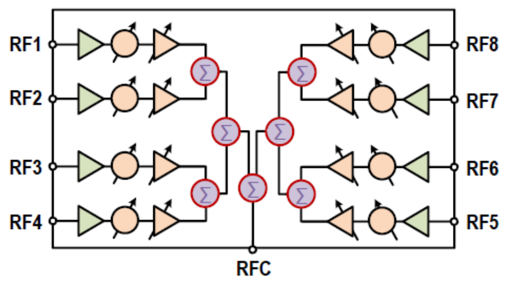
✓ *A trend can be observed that most highly integrated chips for 5G/satcom use SiGe BiCMOS or SoI CMOS technology where both RF and digital components can be realised on a single chip. In bulk, these technologies could deliver 'low' prices*

NB: In general, the cost price of a frontend is determined for 80%-90% by their active/passive RF components

5x5mm 40L
QFN Package
(LGA/BGA Package in 2018)



- 10.5-13.5 GHz operation
- 8 radiation elements
- 5 dB Noise Figure
- 6-bit phase control
- 2.5º RMS phase error
- 0.3 dB RMS gain error
- 35 dB gain control (0.2dB steps)
- Advanced SPI with 4 register memory
- 5x5mm QFN (0.4 mm pitch)
- +2.0 V operation (2.1 – 2.5V)
- 0.34 W DC (8 channels)

Source: IDT

High integration density

- The **number** of RF components/cm^2 on a PCB is becoming higher and higher with increasing functionality
- Size of antenna apertures **decreases** with frequency (assuming constant gain), chips do not: chipsize@ 30 GHz ≅ chipsize@100 GHz
- RF interconnects at higher frequencies becoming increasingly **lossy**. The more RF components, the more interconnects, the higher the losses…

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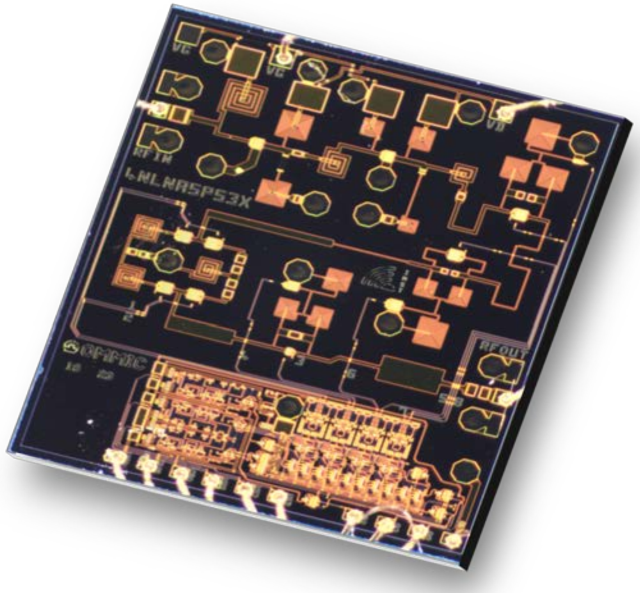
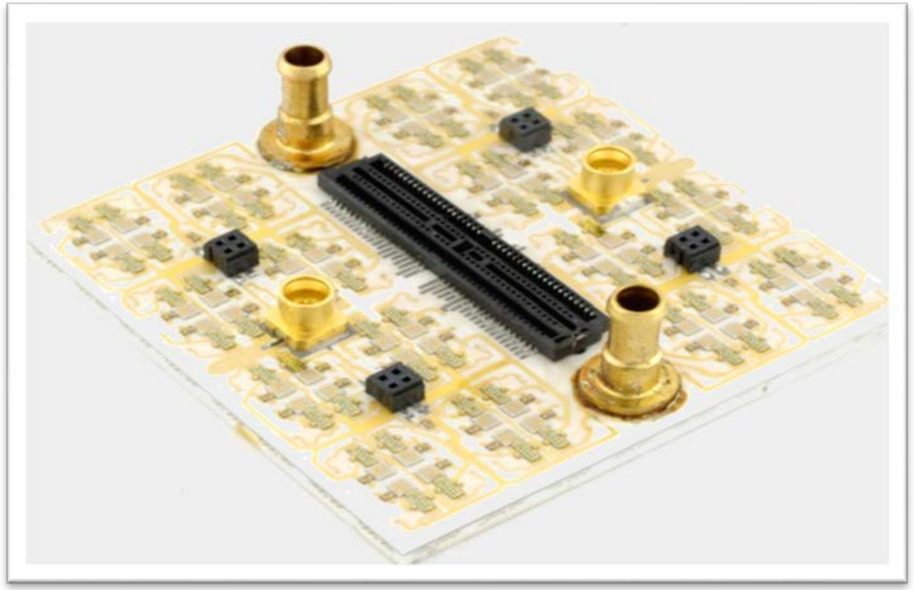
✓ *Use dies instead of packaged chips. This can however have a negative impact on the final manufacturing price*

✓ *Use corechips that combine multiple RF channels on one chip, i.e. less discrete components and less interconnects*





Thermal management & power consumption

- Number of RF-components/cm^2 is **high**, little space left for heat sinks or other cooling structures
- Cooling elements like fans, heat pipes or heatsinks are not always possible due to **space restrictions** and/or **safety requirements**
- RF-components at higher frequencies have a **power efficiency < 10%** ….. and it does not get better over frequency
- DC power is **always** required for biasing of amplifiers, modulators, etc. In addition, different technologies require different voltages hence DC/DC converters are often necessary decreasing to the overall power efficiency

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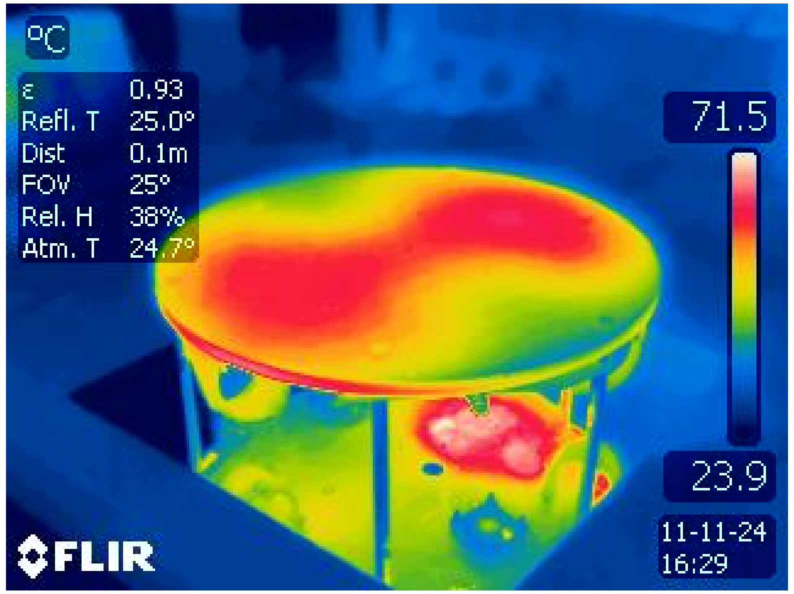
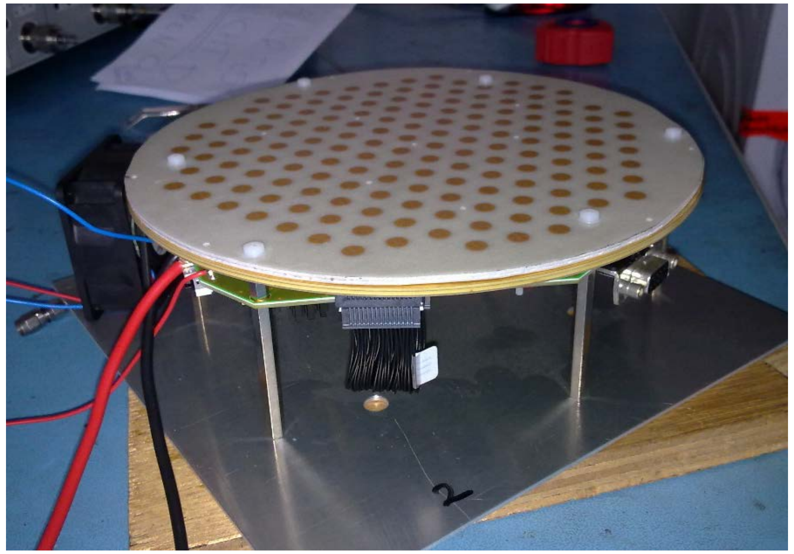
✓ *New sophisticated cooling technologies are required. Perhaps 'borrowing' some technologies from PC cooling systems is an option?*

✓ *DC power consumption is strongly linked to the chip technology applied → at the moment no real low power solution is yet visible on the horizon*





Small form factor

- The definition of ‘small’ depends extremely on the **application**:
  - Mobile devices like mobile phone or laptop
  - Basestation in a shopping mall
  - Basestation on a rooftop
  - SOTM terminal on a car
  - SOTM terminal on a plane
- Previous statement also applies to the **form factor**, sometimes quasi-quadratic shapes are preferred, sometimes slim rectangular shapes, as for example in case of planes

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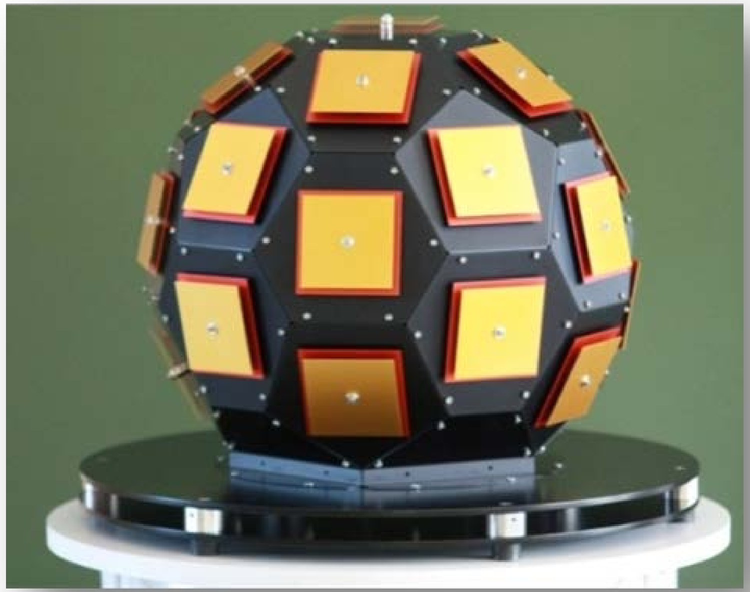
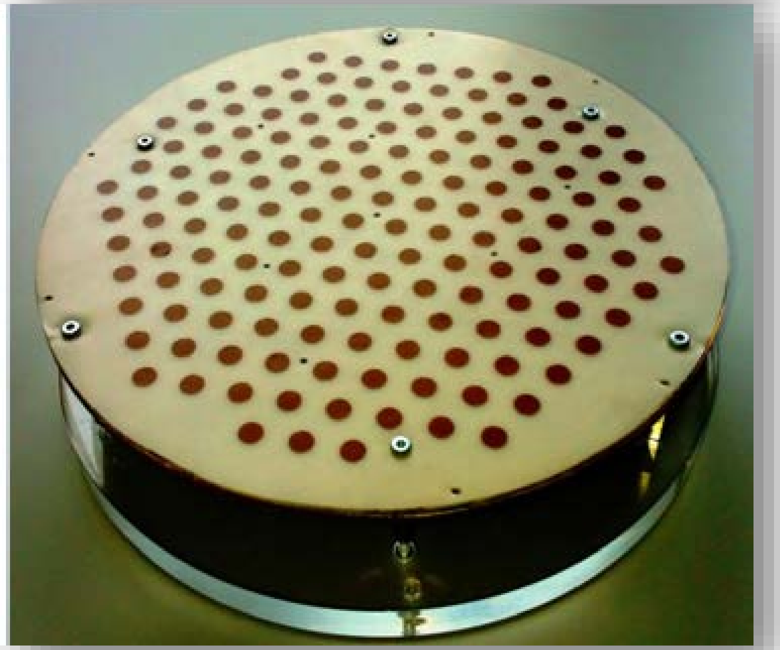
✓ *The shape of the antenna terminal has a major impact on the realisation of the antenna frontend. Unfortunately, in most cases ‘<u>something flat and very compact</u>’ is desired/required*





Good practices

RF-Interfaces lossy, costly & require a high design effort

- Keep RF-interconnections as short as possible
- Convert RF to IF at the earliest possibility

Lack of mounting space & thermal issues

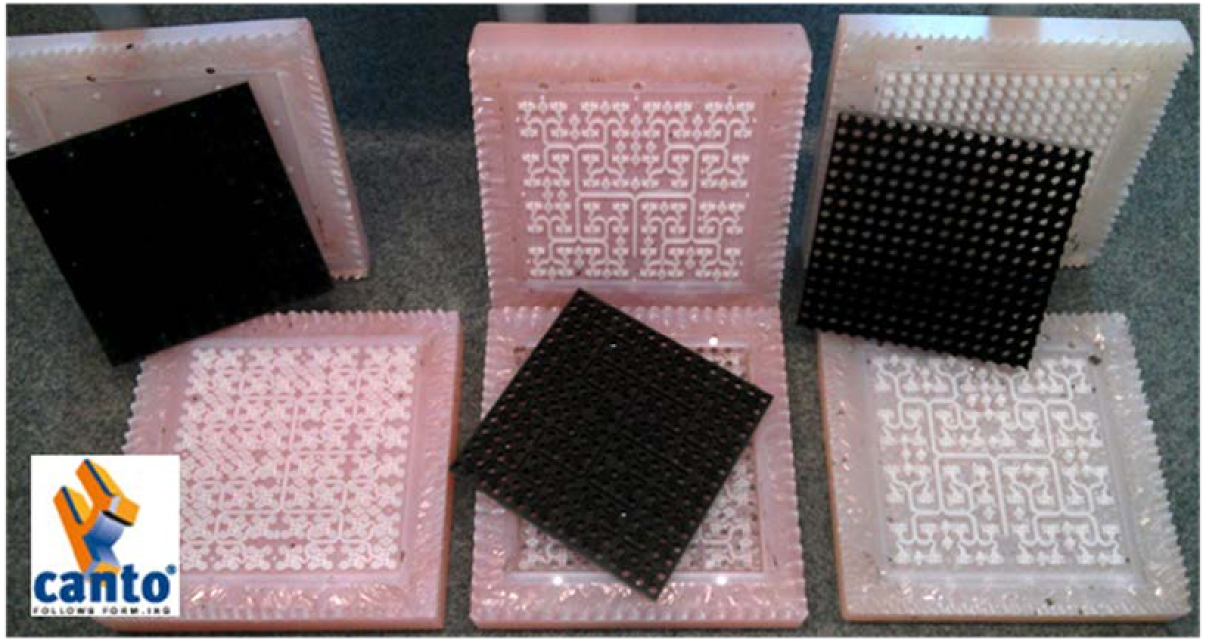
- Use MMICs in die-form, not packaged
- Include thermal management directly from the start of the RF design

Assembly and buildup suited for mass production

- Use standard PCB materials where possible
- Consider proven manufacturing technologies only

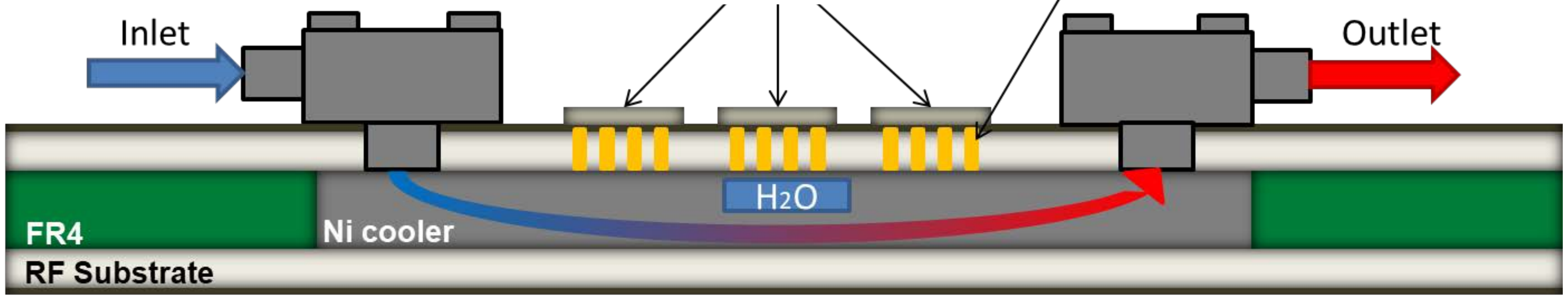
Some interesting developments: additive manufacturing

Technology		Description	Surface finish (typical)	Material examples
SL	Stereo Lithography	Laser hardened photopolymer	Additive: 0.0515 mm	ABS, PP like materials
SLS	Selective Laser Sintering	Laser sintered powder	Additive: 0.1 mm	Nylon, metal
DMLS	Direct Metal Laser Sintering	Laser sintered metal powder	Additive: 0.02 - 0.03 mm	Titan, chrome, stainless steel, aluminum
FDM	Fused Deposition Modelling	Melt-extrusion	Additive: 0.13 - 0.33 mm	ABS, PC, PPSU
3DP	3D-Printing	Liquid binder printed on powder by inkjet	Additive: 0.09 – 0.2 mm	Plaster based powder/liquid binder
PJET	PolyJet	UV cured blasted photopolymer	Additive: 0.015 - 0.03 mm	Acryl based photopolymer, elastomeric photopolymer
IP	Inkjet Printing	Direct printing of conductive ink on 2D or 3D Surfaces	Additive, lower mechanical strength	Silver based ink

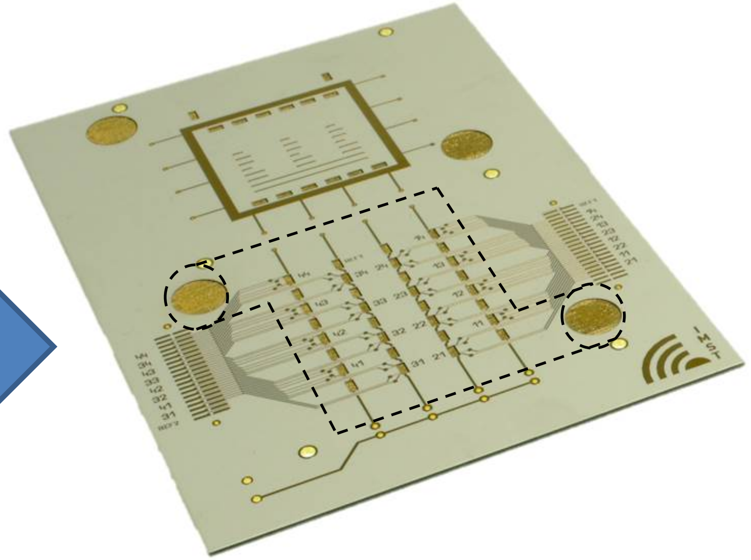


Some interesting developments: liquid cooling

- Selective Laser Melting (SLM)
- 0.8 mm thickness
- Dissipation up to 1,000 W
- Compatible with standard PCB manufacturing technologies



3D-printed Ni-cooling element, ~6 cm x 6 cm



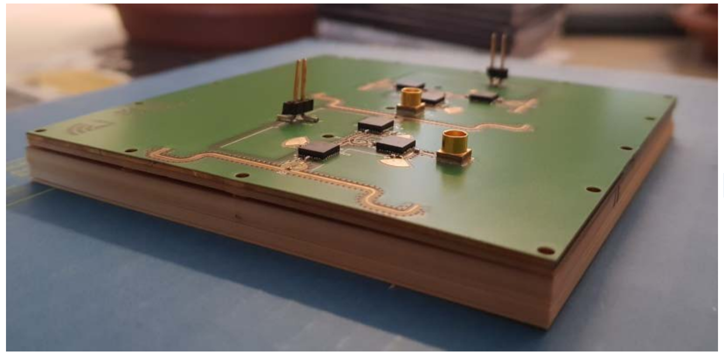
PCB with integrated cooling element

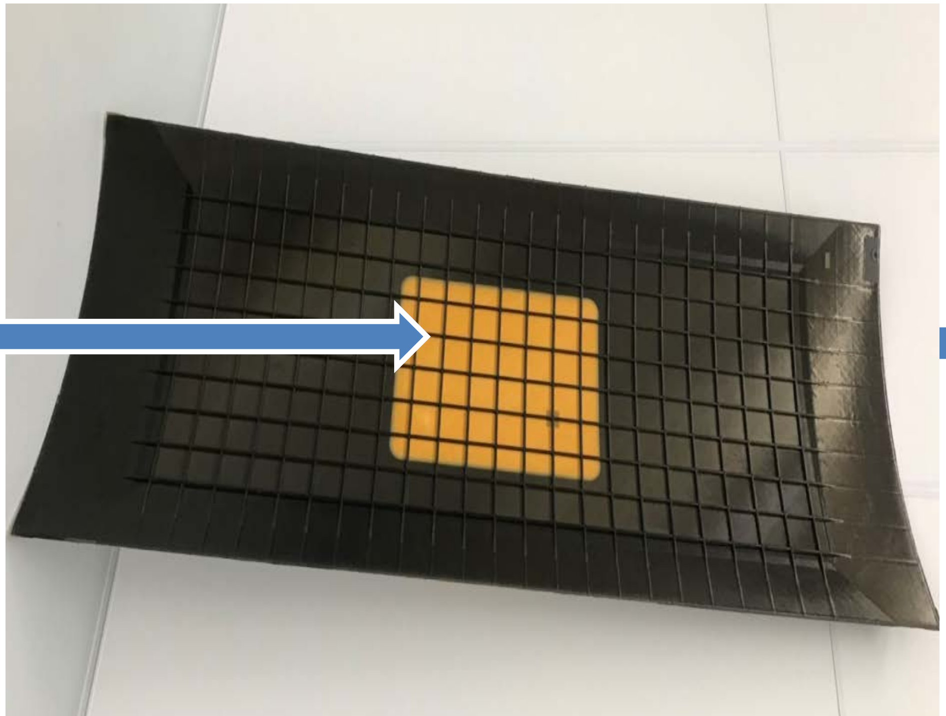
48 W power

14

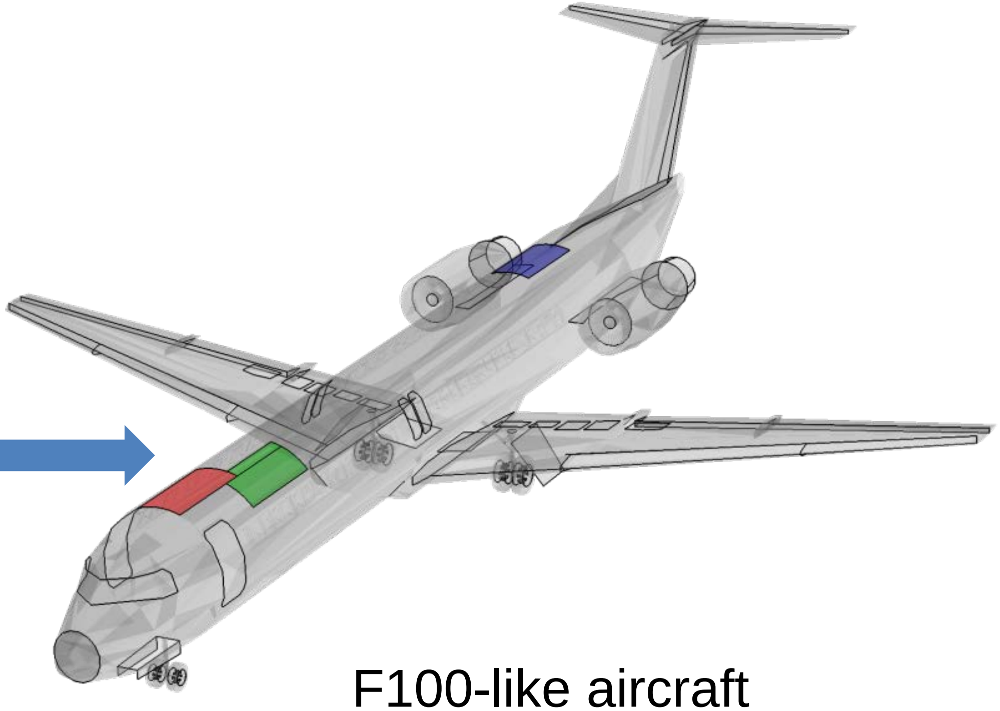
Some interesting developments: integrated antennas

- Integration of SOTM Ku-band antenna tiles in hull of plane
- Structural carbon-based hull frame is used for hosting antenna tiles
- No more drag due to antenna terminals normall mounted <u>on</u> the hull





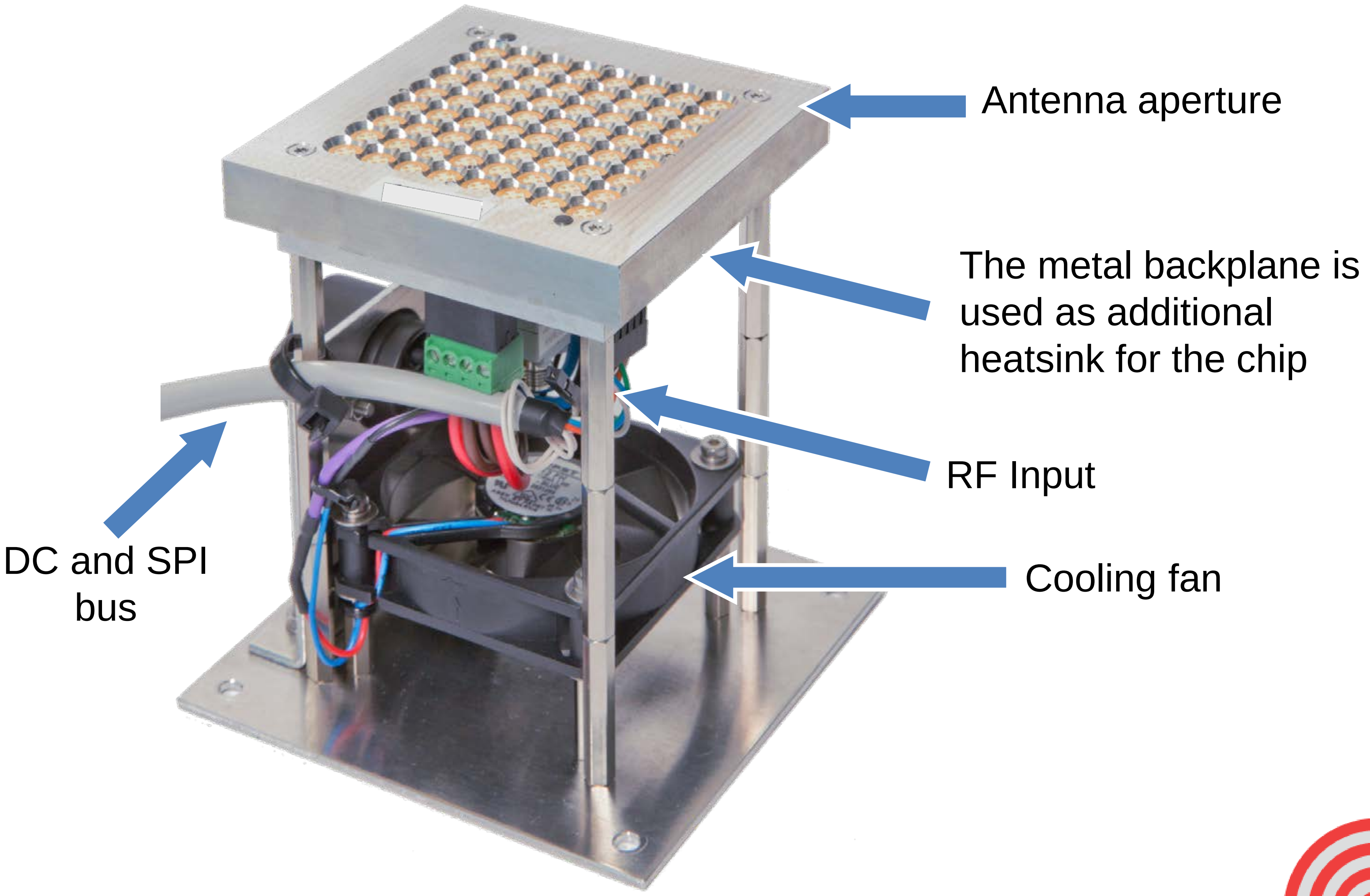
Source: NLR Netherlands



F100-like aircraft

Some interesting developments: SOTM/5G frontend I

- Highly integrated Ka-band Tx module for 5G & SOTM
- Waveguide radiators in combination with PCB technology
- Beam steering achieved via 8-channel corechips (COTS, packaged)
- Circular/linear polarisation
- 64 Antenna elements, each equipped with phase/amplitude shifter & PA



Some interesting developments: SOTM/5G frontend II

DC

Backside

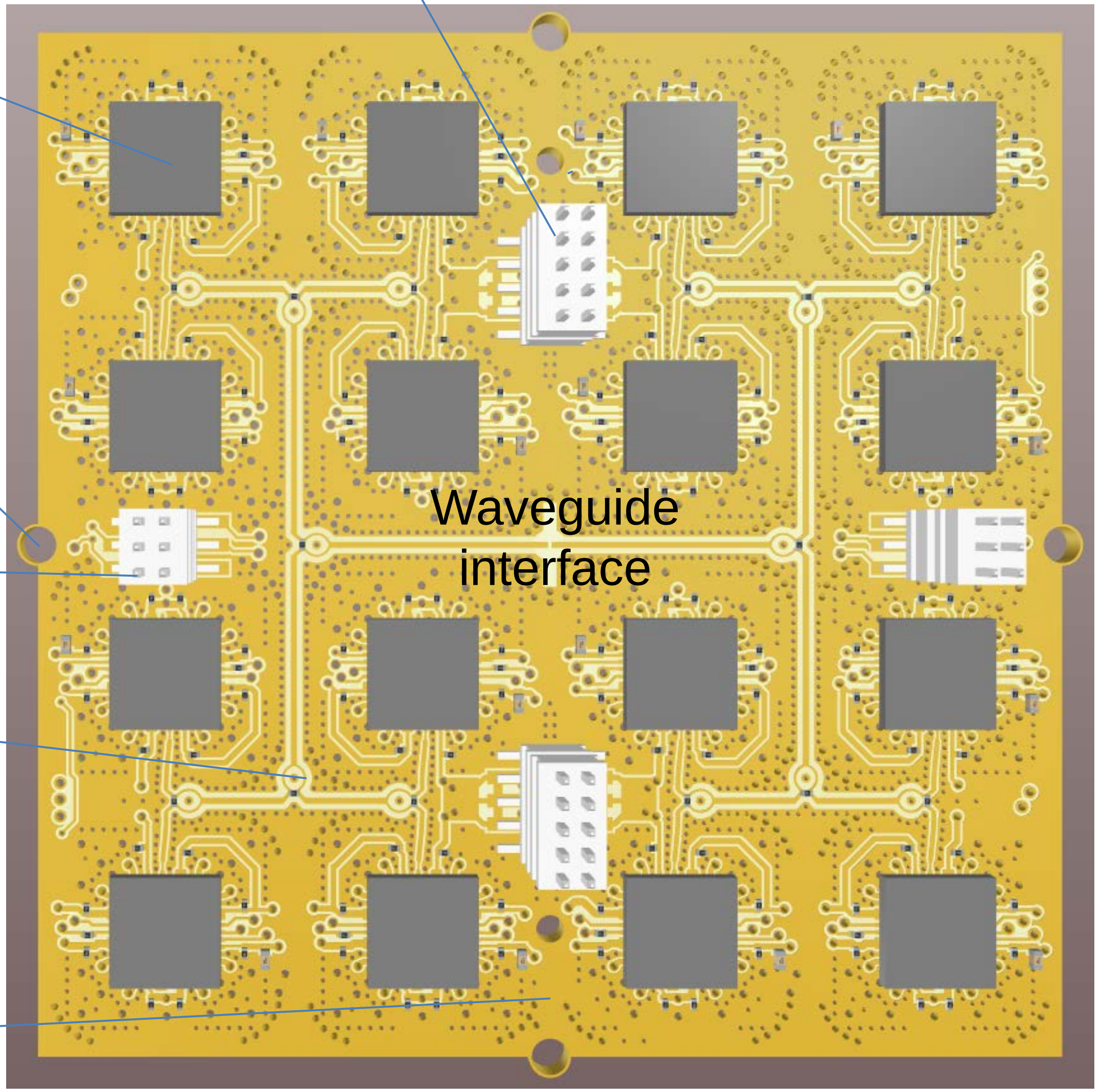
Beamformer chip
- 1:8 divider network
- Dual polarised feed of 4 antenna elements
- Amplifier
- Phase & Amplitude control

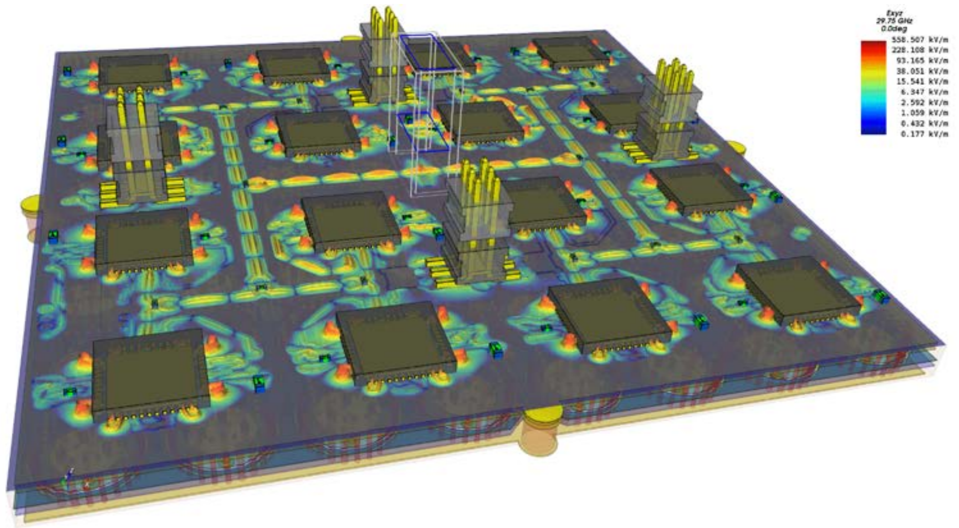
Screws

SPI Interface

Wilkinson divider network

Dowel pin for alignment of metal aperture and metal backplane





EM simulation:
Electric field @ 29.75 GHz at divider network and antenna feed

Summary

- 5G & SOTM antenna frontends have many RF topics/requirements in common. In addition, SOTM will eventually become part of the 5G ecosystem
- Antenna frontends will be capital for future communications systems
- The design of such agile frontends faces many challenges:
  - High RF performance at large bandwidths
  - Small compact terminals
  - Adequate thermal management
  - Low power consumption
  - Low prices
- Some challenges are in strong contradiction with each other and it will therefore be an immense task to find a good compromise
- New technologies and materials will be required using inter-disciplinary approaches & experience from adjacent fields so let’s get started ...

Thank you for your attention

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