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Beamforming Tradeoffs for the Different Satellite Orbits

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Agenda

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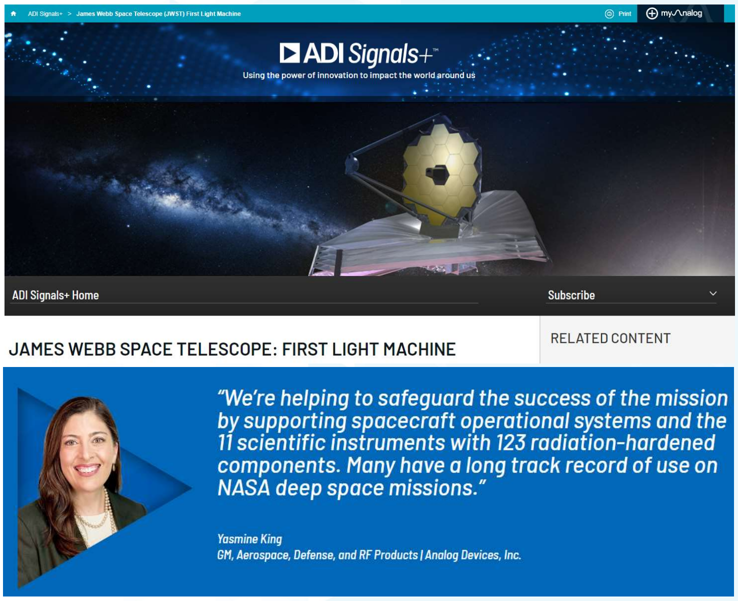
- Beamforming Overview
- Introduction to Orbits
- Marketing Trends
- ADI Signal Chain Solution



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Beamforming Overview

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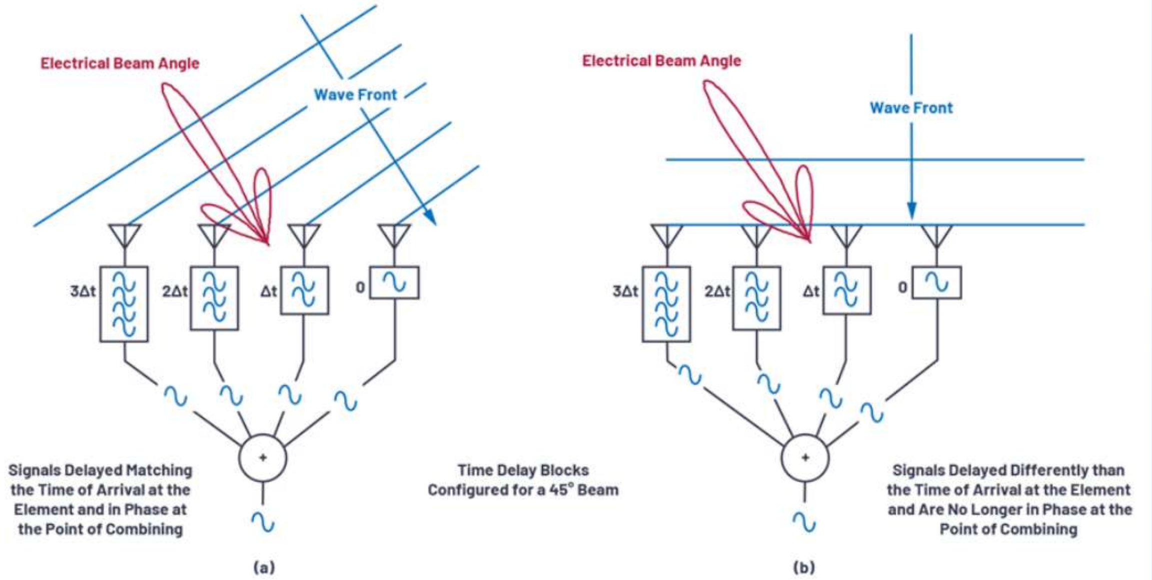
Beamforming Basics – Beam directions



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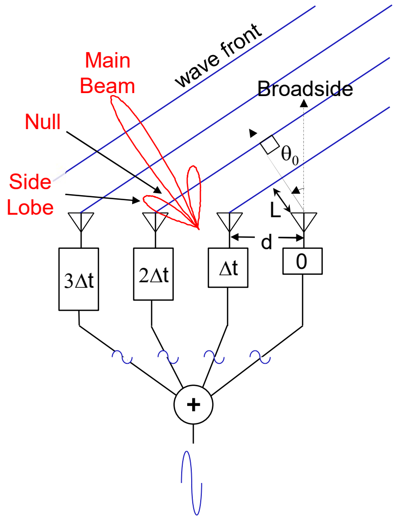
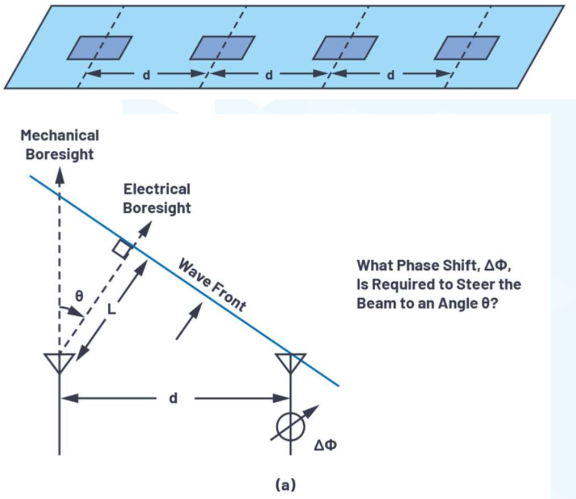
Beamforming Basics – the time delay





$$\Delta t = L / c = d \sin \theta_0 / c$$

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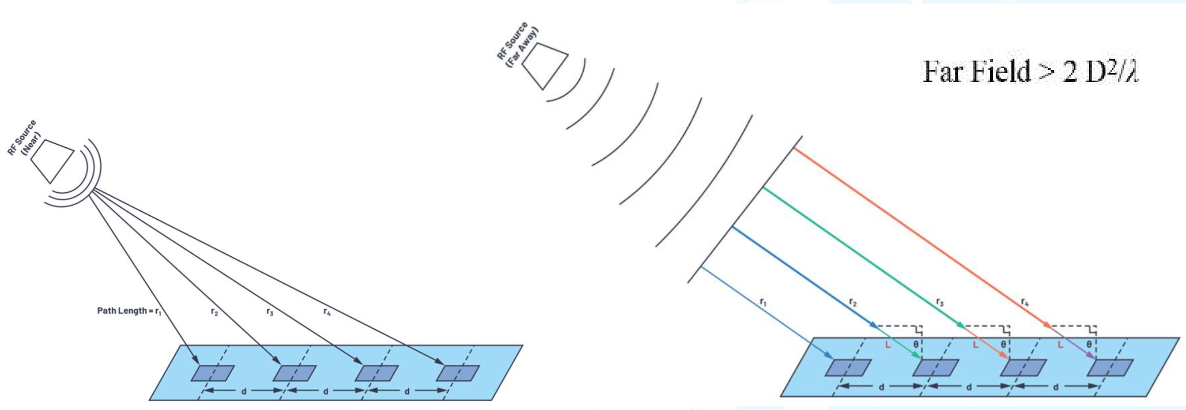
Beamforming Basics – Near/Far Field



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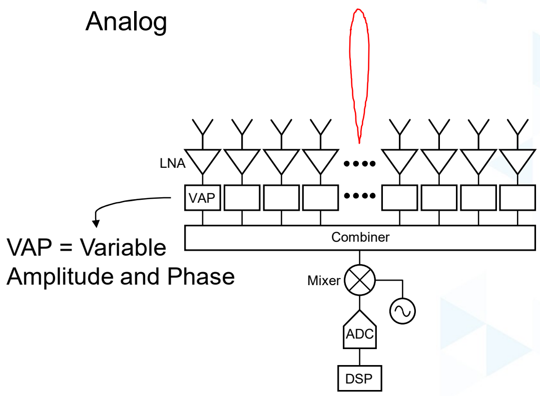
Analog Beamforming



- Lower cost
- Power efficiency
- Limited to a few beams
- Limited beam reconfigurable options

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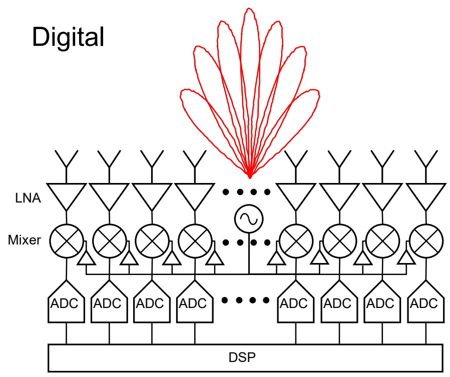
Digital Beamforming



- Beamforming operation is in digital domain
- Multiple simultaneous beams
- Reconfigurable
- Better calibration
- At the expense of cost and power consumption
- LO distribution (high frequency/phase coherent)
- Higher DSP and bigger FPGA

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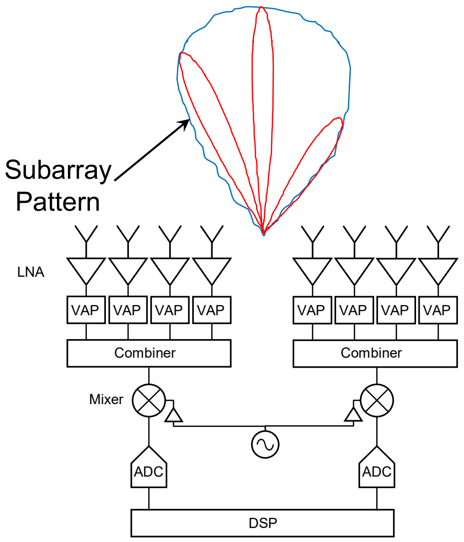
Hybrid beamforming



- Analog beamforming within sub-arrays.
- Digital beamforming using signals from the sub-arrays.
- Reduces data processing load on the DSP by the size of the subarray.
- Angle of view limited by the subarray pattern.

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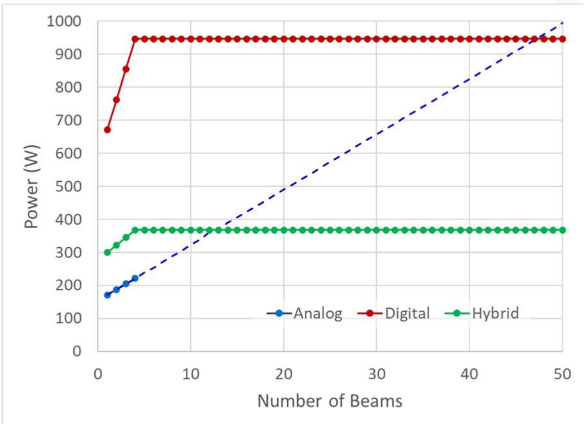
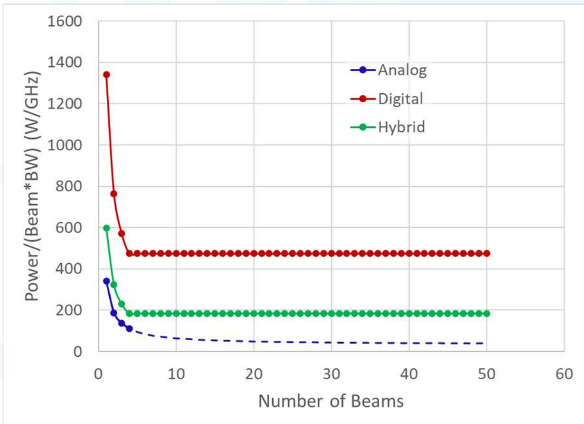
Power Efficiency





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Analog Beamforming

Beam steering in the analog domain close to the antenna

Pro	Con
Power efficient • Single frequency conversion stage and digital signal processing stage	Beam count low, < 15 beams • Increase area and complexity of combining and splitting signals make high beam count impractical • VAPS and signal combining/splitting must happen within the element spacing to minimize grating lobes.
Cost efficient • Minimal component count and PCB area	Limited beam reconfigurability options
Inherent spatial filtering	

Digital Beamforming

Beam Steering in the digital domain with an ADC or DAC at each antenna element

Pro	Con
Highest beam count	Highest cost and power consumption: • Data converter and frequency translation at each element • LO distribution and phase coherency at each element • Highest digital signal routing and processing requirements • Highest PCB area requirements
Highest flexibility in instantaneous beam count configurability, and steering	RF filtering and higher dynamic range requirements: Beamforming at baseband does not have spatial filtering benefits
Ease of calibration and adaptive nulling	

Hybrid Beamforming

Beam Steering in the analog and digital domains

Pro	Con
High beam count	Digital beams bounded by subarray analog bandwidth
Flexible beam count and reconfigurability of digital beams	Quantization side lobes
Inherent spatial filtering	
Moderate cost and power consumption: • Data converter, frequency translation, and LO distribution at subarray only • Moderate digital signal routing and processing requirements	

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Satellite Orbits

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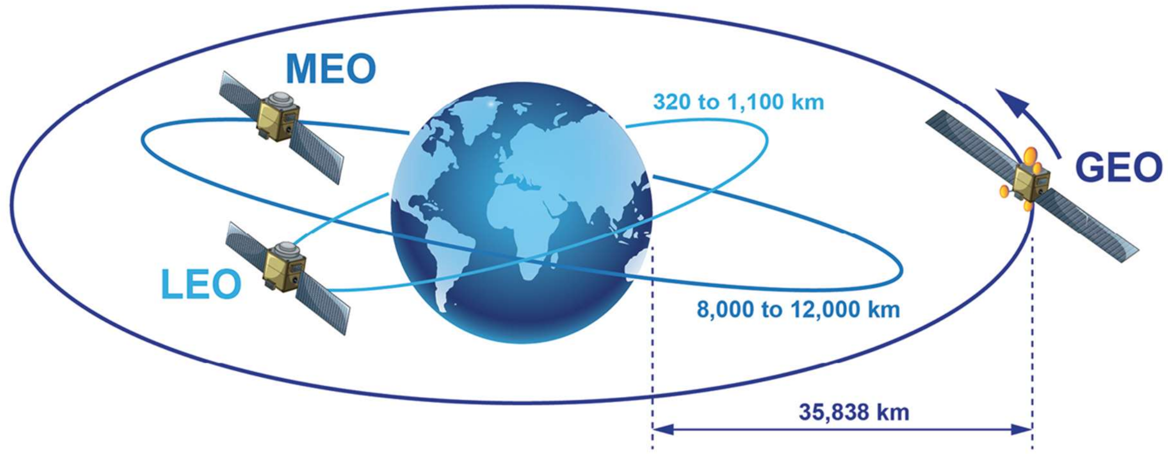
Satellite Orbits



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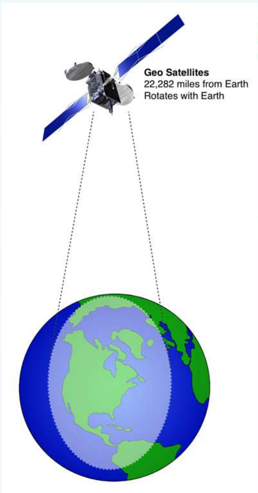
GEO Phase Array Solution

- **GEO Characteristics:**
  - GEO located furthest away from earth at 3,5786 kms. This requires very large arrays with high element counts or high gain in the signal path to compensate for the path loss.
  - Satellites in GEO cover a large range of Earth so as few as three equally-spaced satellites can provide near global coverage
  - GEO appears to be 'stationary' over a fixed position because its rotation is approximately equal to the earth's rotation
  - GEO beam coverage = 17.3°. This requires many narrow beams to cover the complete field of view



176 beams to cover earth's surface

Grating Lobe Immune in GEO
Component Count & PCB Area
Power Efficiency
Cost Efficiency
Spatial Filtering
Beam Count
Beam Count

Analog Beamforming | Hybrid Beamforming | Digital Beamforming

▶ https://www.mpoweruk.com/satellites.htm

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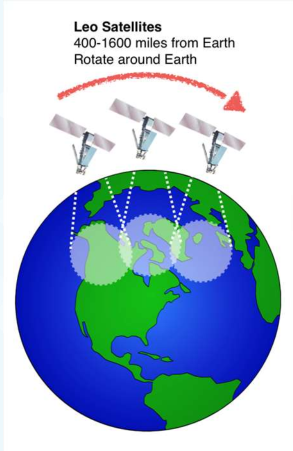
LEO Phase Array Solution

LEO Characteristics

- A low Earth orbit (LEO) is, as the name suggests, an orbit that is relatively close to Earth's surface. It is normally at an altitude of less than 1000 km but could be as low as 160 km above Earth
- More available routes for satellites in LEO
- Satellites in this orbit travel at a speed of around 7.8 km per second; at this speed, a satellite takes approximately 90 minutes to circle Earth,.
- Communications satellites in LEO often work as part of a large combination or constellation, of multiple satellites to give constant coverage.



Component Count & PCB Area
Power Efficiency
Cost Efficiency
Spatial Filtering
Beam Hop

Analog Beamforming

Beam Count

Hybrid Beamforming

Beam Count

Digital Beamforming

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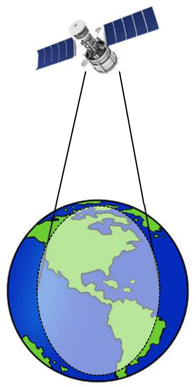
Key Differences: GEO & LEO Communications Satellites

GEO
~22,300 miles from Earth
Orbits with Earth



Geostationary (GEO)	Comms Satellites	Low Earth Orbit (LEO)
~700msec	Latency	**~50msec**
< 10	Constellation Size	**1000s**
Few; fixed	Data Gateways Required	**Numerous; local**
20+ Years	Useful Life	**3-7 Years**
10	Annual Launches	**3K to 4K**
$ Millions	SAM per Satellite	**~$100K**

LEO
~400-1,200 miles from Earth
Orbits around Earth

4X SAM Opportunity in LEO vs. GEO by FY'25

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Market Trends

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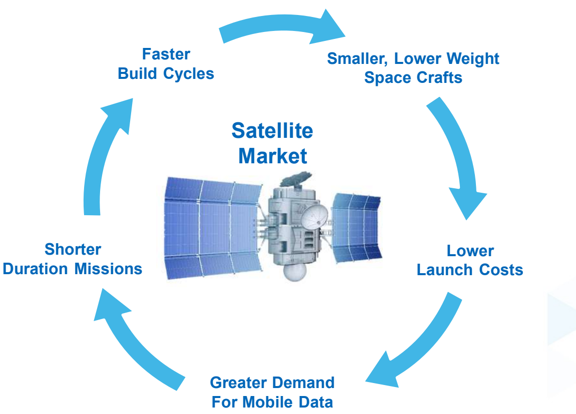
The New Space Race

Evolving Market Dynamics



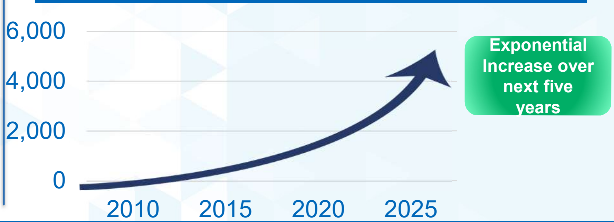
Record Investment Levels

$6B
Record
Private Investment
3Q'20 YTD[1]

5%
Space as a % of
U.S. GDP by 2040[2],
up 2x vs. 2020

$10B
U.S. Space Force
Budget in FY'20,
Growing to **$15B** in
FY'21

LEO Satellites Launch Forecasts[3]



Evolving Market Dynamics & Record Levels of Investment From Private & Public Sources

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1. Space Capital: Space Investment Quarterly Q3 2020; 2. Chamber of Commerce; 3. Internal ADI estimates, Federal Communications Commission & McKinsey.

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Major Customers Investing in New Space

Source: Wiki

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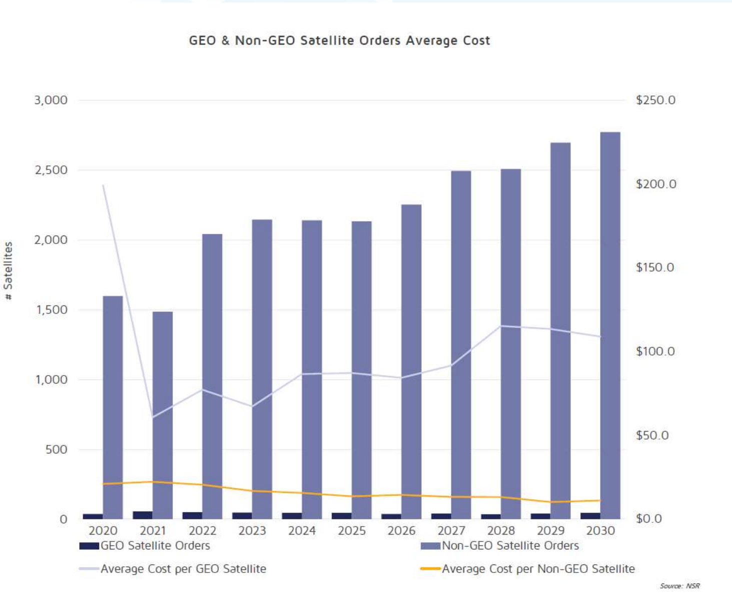
GEO Satellites – Not Going Away

- GEO Satellite Orders Constant
  - 40-50 satellites/year
- GEO Satellites will increase in price
  - More sophisticated electronics
    - Software defined radios
    - Hybrid Beamforming
  - SAM per satellite increases
    - $400M in 2025



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Significant ADI Content Opportunity in LEO Communications

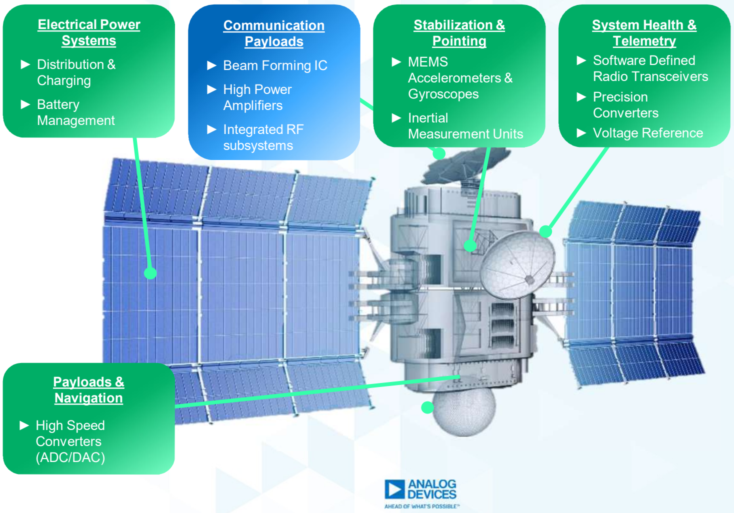
ADI's LEO Opportunity

Market Leadership
High performance precision & RF

New Content
New RF, beam forming IC & power opportunities

Complete Solutions
Acquisition leverage with the integrated transmit & receive chains (Hittite) & power (LTC)

More Volume & Faster Upgrades
Mega LEO constellations & shorter time to market



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ADI solutions

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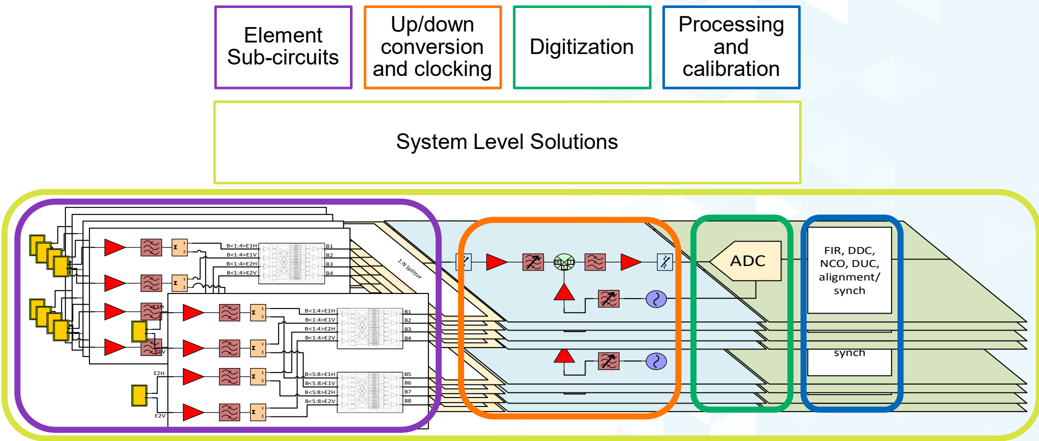
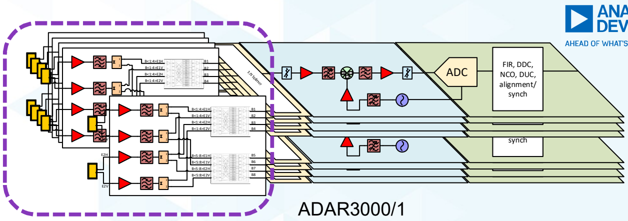
Advancing Hybrid Beamforming Technology



Element Sub-circuits

Key challenges near the antenna

- Low noise figure
- High linearity and PAE
- Wide Bandwidth
- λ/2 element spacing
- Digital control
- Very low power



ADAR3000/1

BFICs

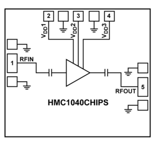
- 17-22 GHz (3001)
- 27-31 GHz (3000)
- True time delay
- <12mW/ch
- Multi-beam
- Internal memory for beam states
- L-Ka band part family

LNAs/PAs

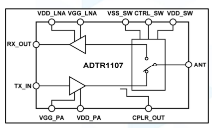
- High Linearity
- 2x2mm SMT packages
- PAE optimized
- Wideband

TRMs

- Mixed process die in single package
- Optimize transition loss
- Size reduction



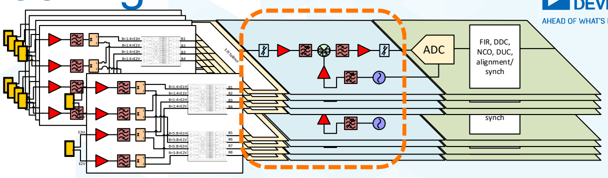
HMC1040: 20-44GHz LNA



ADTR1107: X-band Transmit/Receive Module

ADAR3000: Ka-band 4 beam BFIC

Up/down conversion and clocking

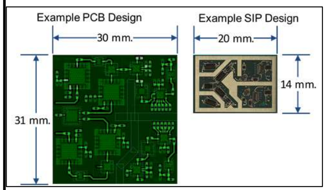


Key challenges for up/down conversion

- Frequency planning
- Managing size/power
- LO/clock Generation, distribution, and synchronization

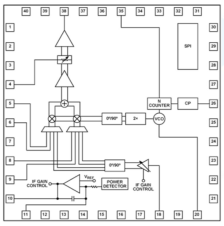
System-In-Package (SIP)

- Up to 70% size reduction
- Wideband
- Mixed processes
- Surface mount



Integrated and discrete MMIC

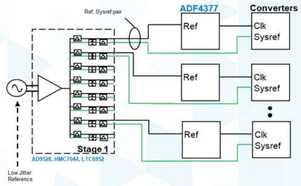
- Very small form factor
- Band specific family of products or wideband



ADMV4530: Ka band upconverter

LO & Clock Generation

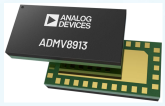
- Wideband tone generation
- Very low Phase noise solutions
- Delay adjustment
- Extreme phase stability over process, voltage, temperature



ADF4377: 12.8 GHz stable PLL

Tunable Filtering

- Decreasing size
- Increasing flexibility
- Easy to use
- Wide frequency coverage



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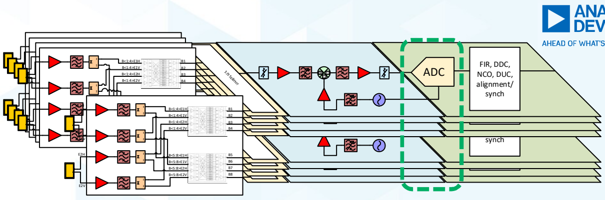
Digitization

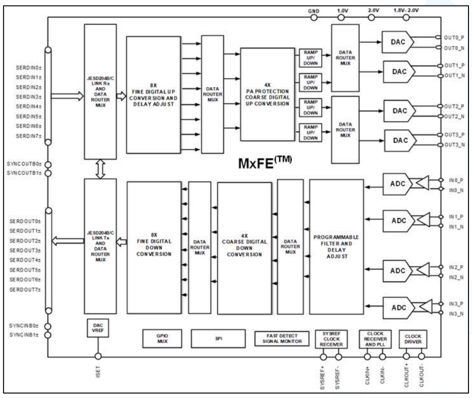


Key challenges for digitization

- Synchronization and phase alignment
- Frequency planning to avoid interferers
- Power consumption

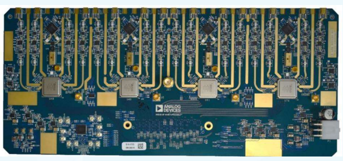
MXFE Product Family

- Highly integrated Mixed Signal Front End IC
  - 4ADC/4DAC
- ADC Fs up to 6 GSPS
- DAC Fs up to 12 GSPS
- User configurable DSP
- 15x15mm package
- On-chip PLL



Quad MXFE

- Prototyping system for L, S, and C band digital beamforming
- Demonstration of synchronization between 16R/16T
- 16 ADCs, 16 DACs, PLLs, RFFE, Power, SW



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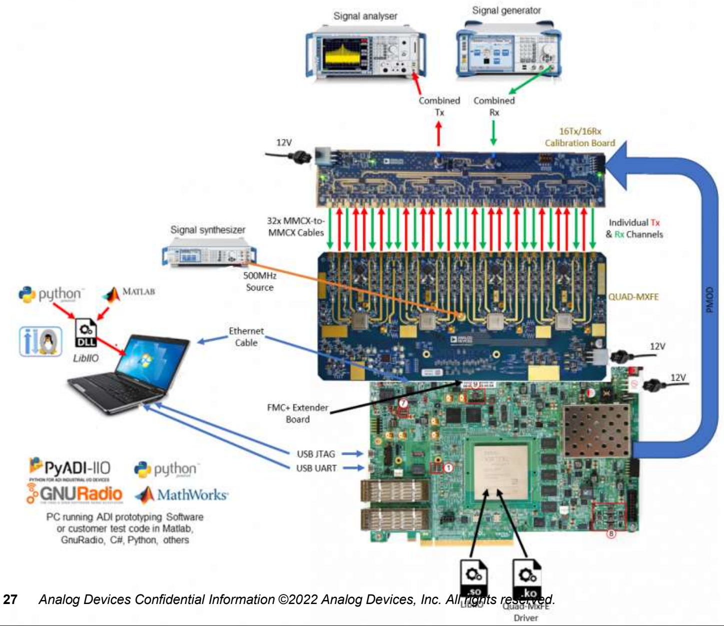
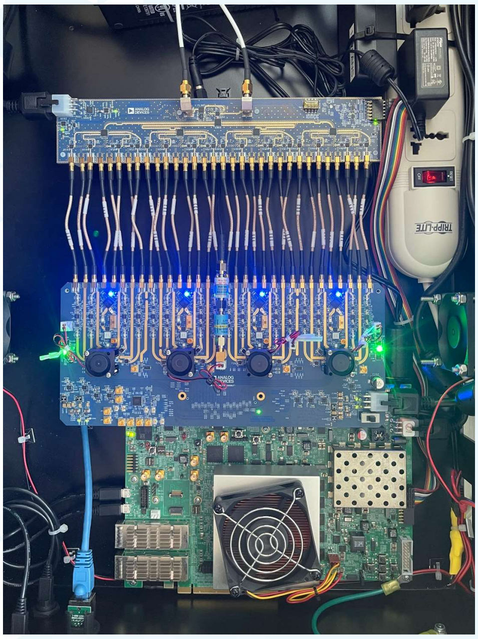
QuadMxFE platform





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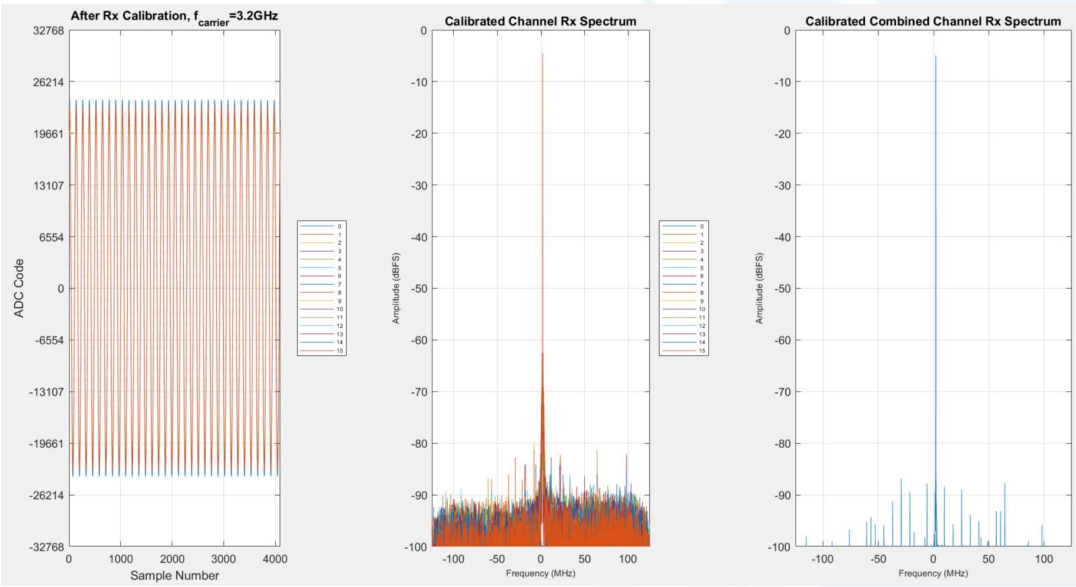
QuadMxFE_SystemAlignmentFIR.m



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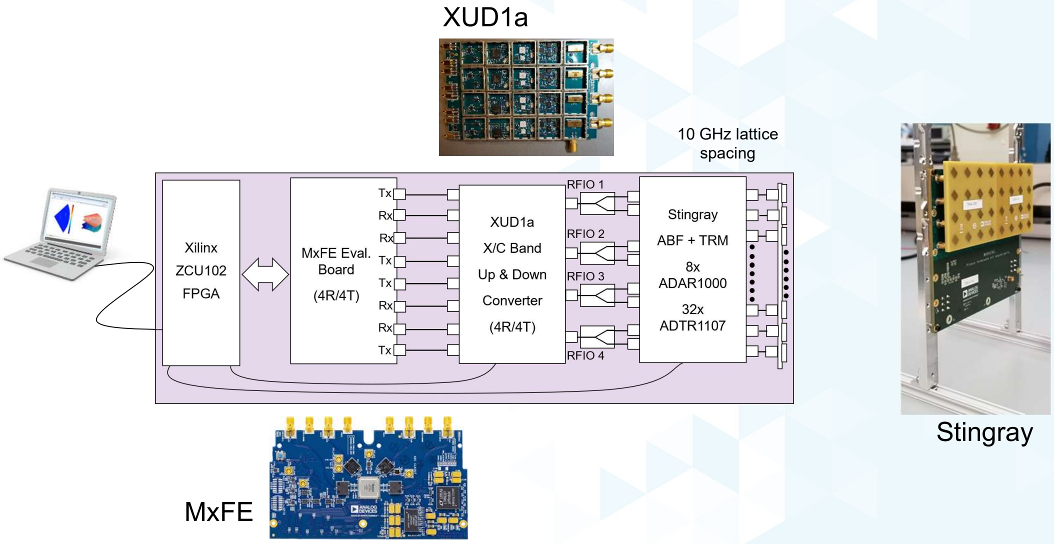
X Band (8 – 12 GHz) Phased Array Prototyping and Development System



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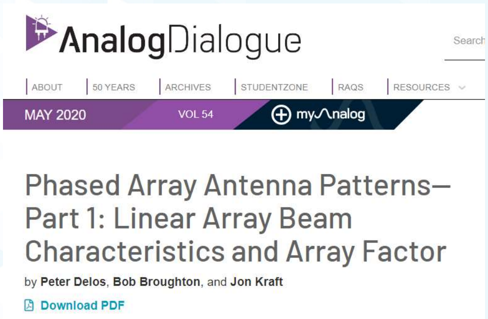
Summary and Reference

- Beamforming Theory
  - Analog
  - Digital
  - Hybrid
- Intro to Orbits
  - GEO
  - LEO
- Marketing Trends
- ADI Signal Chain Solution

https://www.analog.com/en/analog-dialogue/articles/phased-array-antenna-patterns-part1.html

https://www.analog.com/en/analog-dialogue/articles/phased-array-antenna-patterns-part2.html

https://www.analog.com/en/analog-dialogue/articles/phased-array-antenna-patterns-part3.html



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