



1

Agenda

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

JAMES WEBB SPACE TELESCOPE: FIRST LIGHT MACHINE

"We're helping to safeguard the success of the mission by supporting spacecraft operational systems and the 11 scientific instruments with 123 radiation-hardened components. Many have a long track record of use on NASA deep space missions."

Yasmine King
GM, Aerospace, Defense, and RF Products | Analog Devices, Inc.

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Beamforming Overview

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Beamforming Basics – Beam directions

Electrical Beam Angle

Wave Front

(a) Signals Delayed Matching the Time of Arrival at the Element and in Phase at the Point of Combining

(b) Time Delay Blocks Configured for a 45° Beam

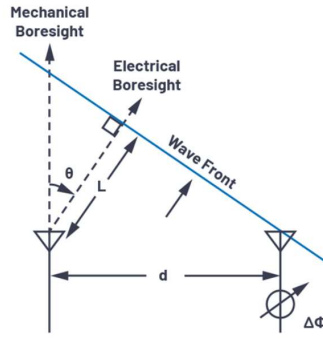
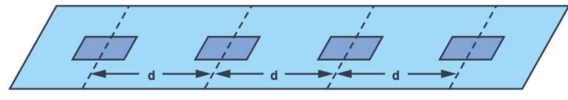
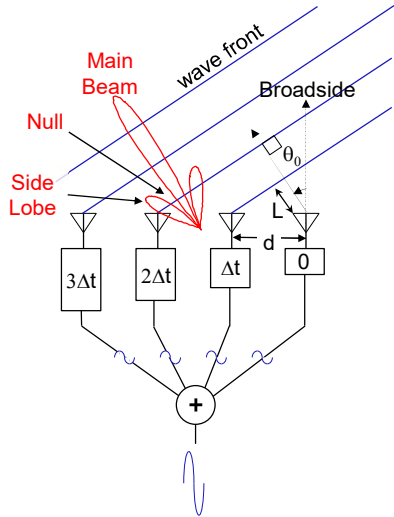
Signals Delayed Differently than the Time of Arrival at the Element and Are No Longer in Phase at the Point of Combining

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Beamforming Basics – the time delay



What Phase Shift, $\Delta\Phi$, Is Required to Steer the Beam to an Angle θ ?

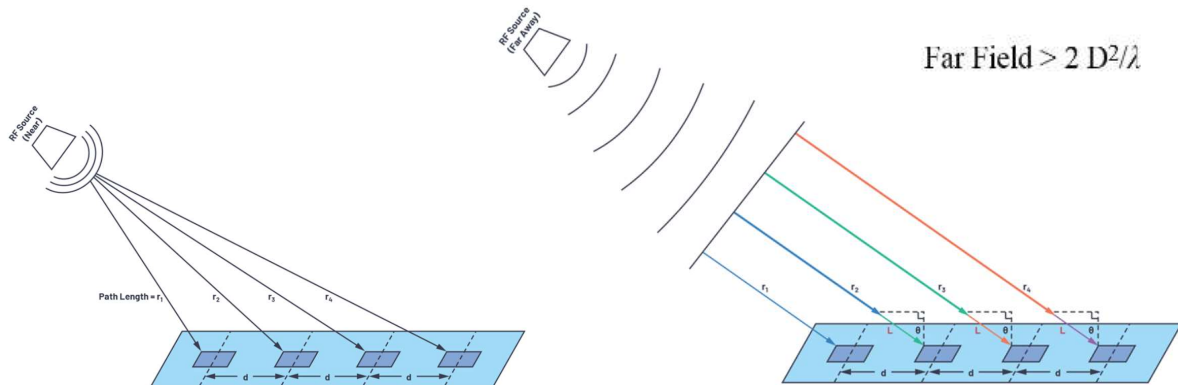
$$\Delta t = L / c = d \sin \theta_0 / c$$

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Beamforming Basics – Near/Far Field

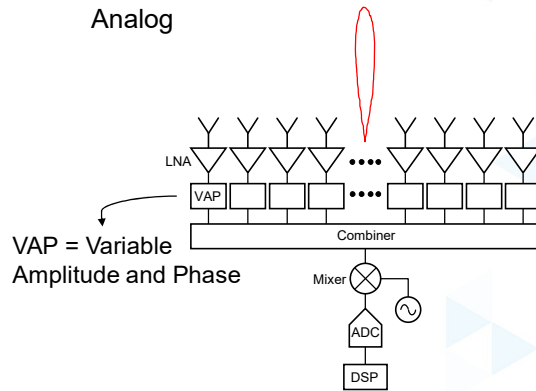


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Analog Beamforming



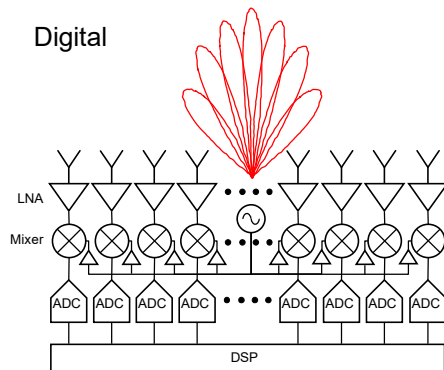
- ▶ Lower cost
- ▶ Power efficiency
- ▶ Limited to a few beams
- ▶ Limited beam reconfigurable options

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Digital Beamforming



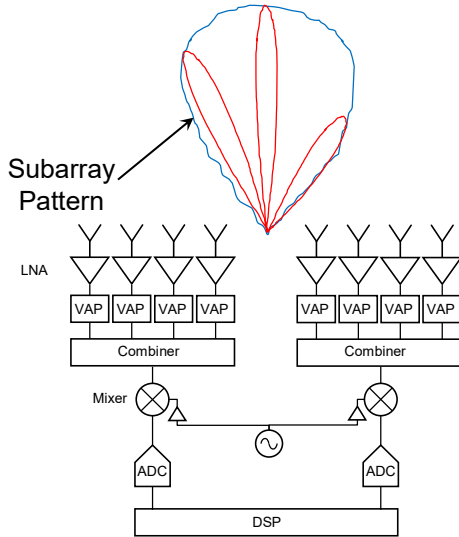
- ▶ Beamforming operation is in digital domain
- ▶ Multiple simultaneous beams
- ▶ Reconfigurable
- ▶ Better calibration
- ▶ At the expense of cost and power consumption
- ▶ LO distribution (high frequency/phase coherent)
- ▶ Higher DSP and bigger FPGA

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Hybrid beamforming



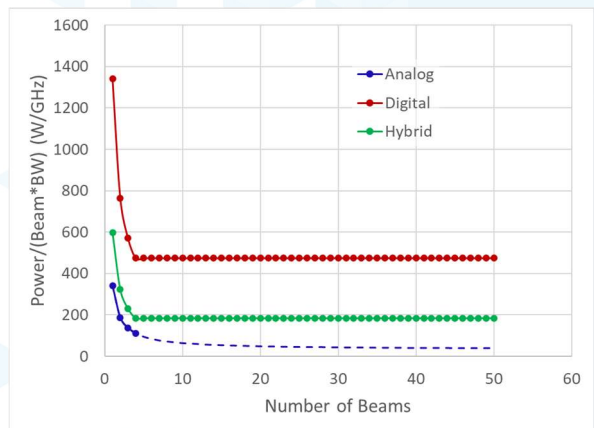
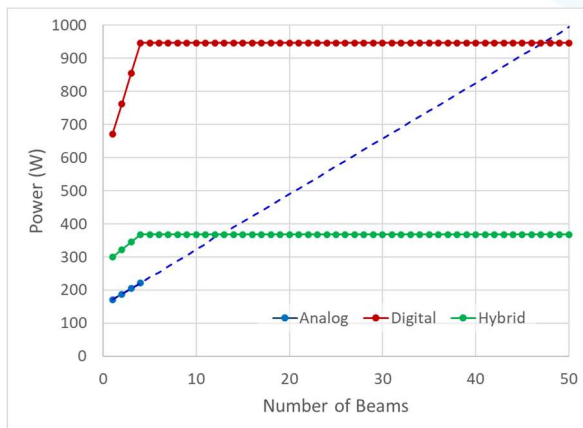
- ▶ Analog beamforming within sub-arrays.
- ▶ Digital beamforming using signals from the sub-arrays.
- ▶ Reduces data processing load on the DSP by the size of the subarray.
- ▶ Angle of view limited by the subarray pattern.

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Power Efficiency



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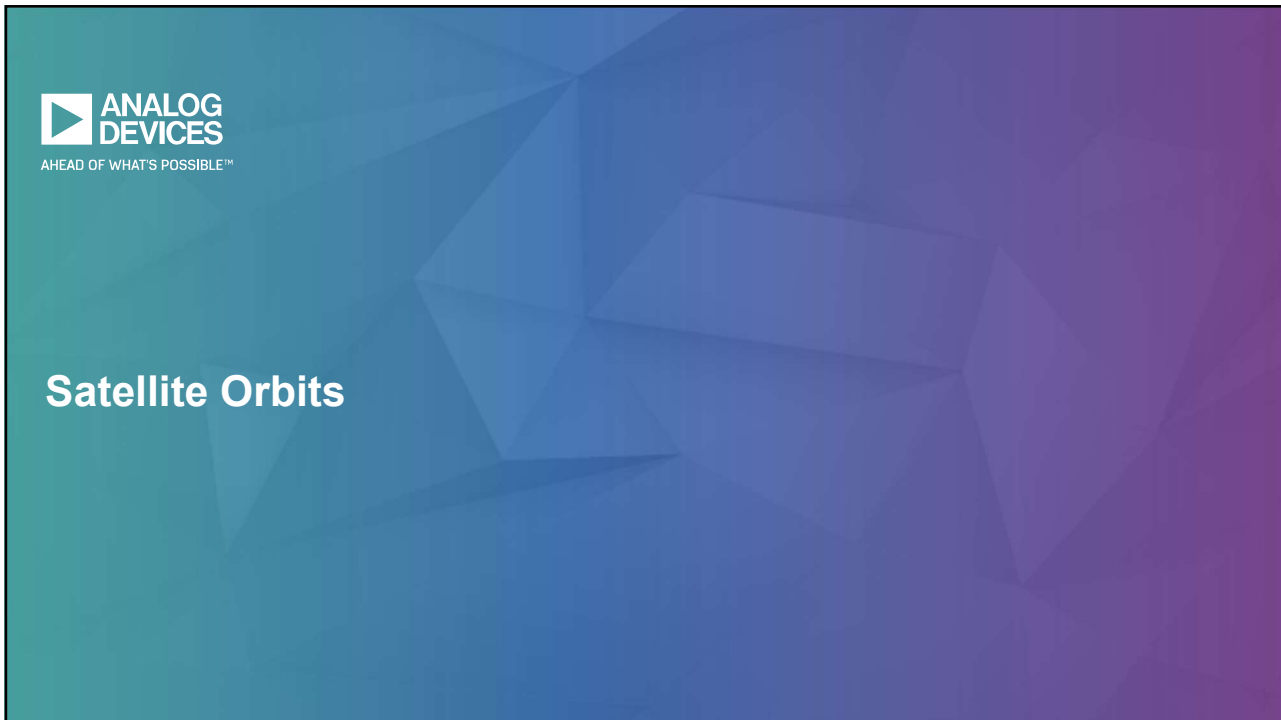
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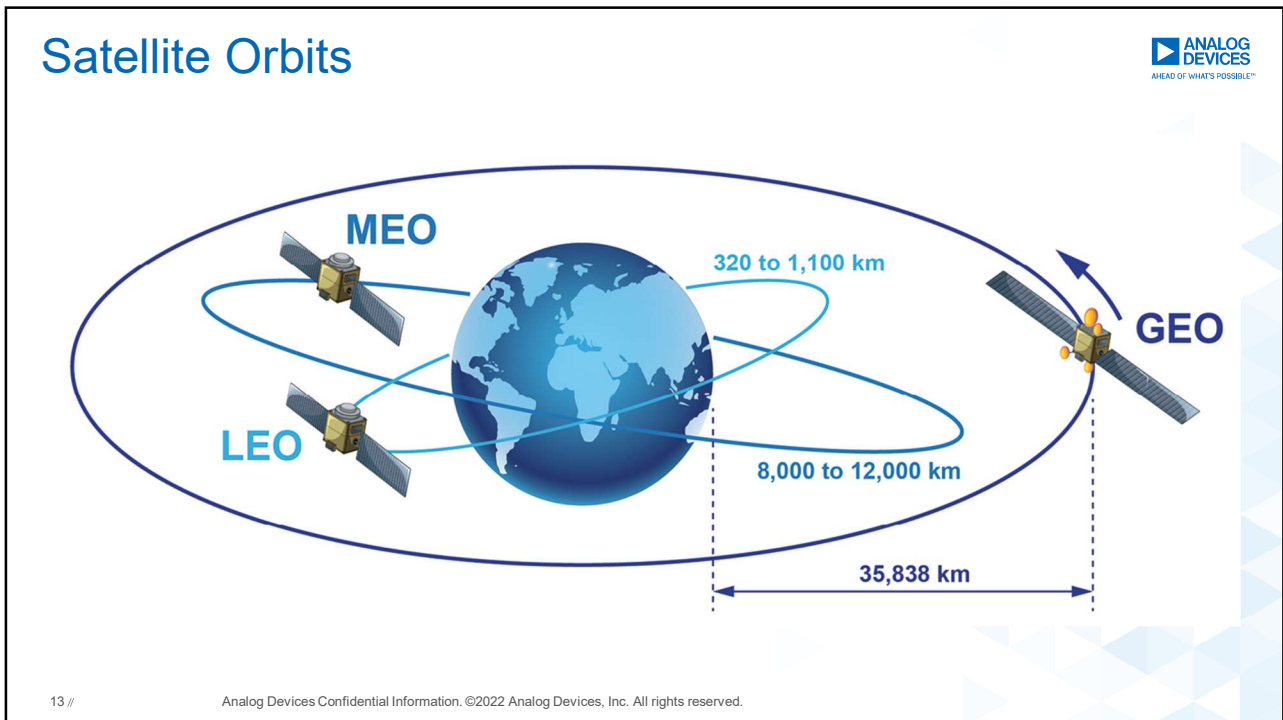
<p>▶ Analog Beamforming</p> <p>Beam steering in the analog domain close to the antenna</p>	Pro	Con
	<p>Power efficient</p> <ul style="list-style-type: none"> • Single frequency conversion stage and digital signal processing stage 	<p>Beam count low, < 15 beams</p> <ul style="list-style-type: none"> • 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.
	<p>Cost efficient</p> <ul style="list-style-type: none"> • Minimal component count and PCB area <p>Inherent spatial filtering</p>	<p>Limited beam reconfigurability options</p>
<p>▶ Digital Beamforming</p> <p>Beam Steering in the digital domain with an ADC or DAC at each antenna element</p>	Pro	Con
	<p>Highest beam count</p>	<p>Highest cost and power consumption:</p> <ul style="list-style-type: none"> • 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
	<p>Highest flexibility in instantaneous beam count configurability, and steering</p> <p>Ease of calibration and adaptive nulling</p>	<p>RF filtering and higher dynamic range requirements: Beamforming at baseband does not have spatial filtering benefits</p>
<p>▶ Hybrid Beamforming</p> <p>Beam Steering in the analog and digital domains</p>	Pro	Con
	<p>High beam count</p>	<p>Digital beams bounded by subarray analog bandwidth</p>
	<p>Flexible beam count and reconfigurability of digital beams</p> <p>Inherent spatial filtering</p> <p>Moderate cost and power consumption:</p> <ul style="list-style-type: none"> • Data converter, frequency translation, and LO distribution at subarray only • Moderate digital signal routing and processing requirements 	<p>Quantization side lobes</p>

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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

~~Analog Beamforming~~

Grating Lobe Immune in GEO

Component Count & PCB Area

Power Efficiency

Cost Efficiency

Spatial Filtering

Beam Count

Hybrid Beamforming

Beam Count

Digital Beamforming

Geo Satellites
22,252 miles from Earth
Rotates with Earth

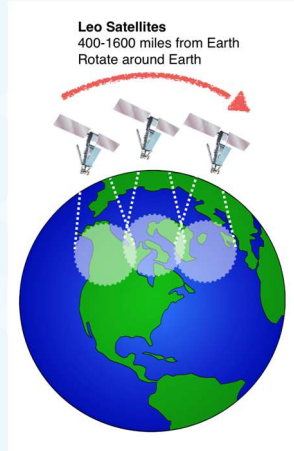
14 // Analog Devices Confidential Information. ©2022 Analog Devices, Inc. All rights reserved. <https://www.mpoweruk.com/satellites.htm>

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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

Beam Count

Beam Count

Analog Beamforming

Hybrid Beamforming

Digital Beamforming

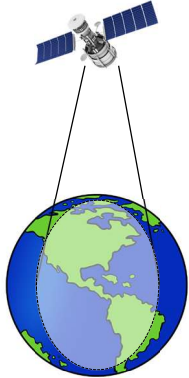
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Key Differences: GEO & LEO Communications Satellites

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

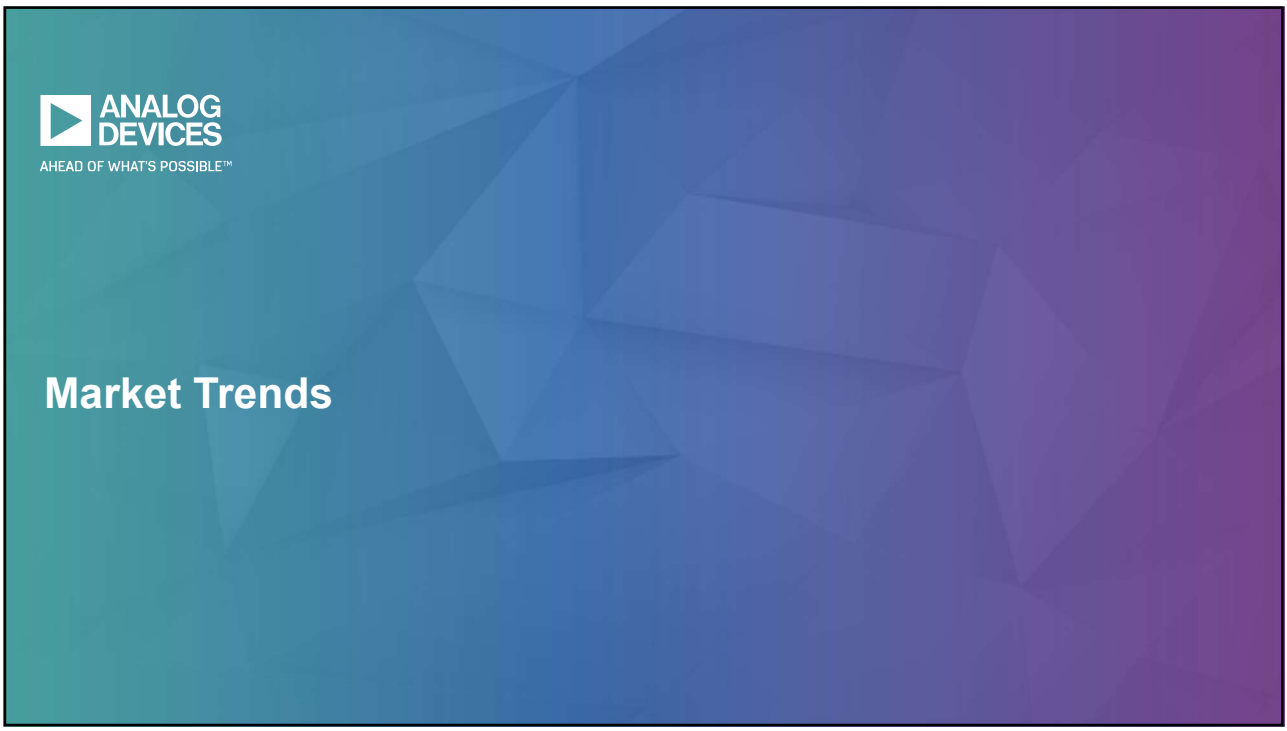
LEO
~400-1,200 miles from Earth
Orbits around Earth



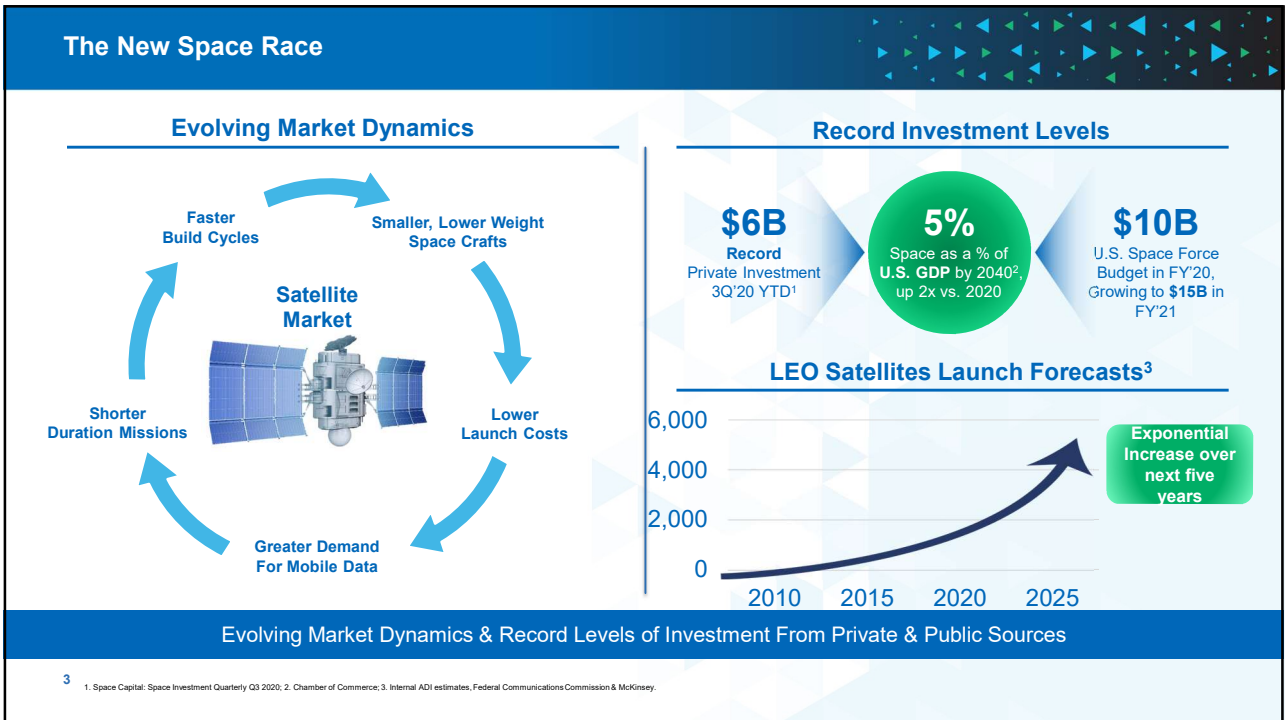
4X SAM Opportunity in LEO vs. GEO by FY'25

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Major Customers Investing in New Space



Telesat

Type Public
Traded as Nasdaq: TSAT ⓘ
Russell 2000 Component
Industry Telecommunications

SpaceX
太空探索技術公司

一網
OneWeb

公司類型 私人公司
公司前身 WorldVu Satellites
成立 2012年
創辦人 格蕾格·韋勒 [1][2][3]

Kuiper Systems LLC

Type Subsidiary
Headquarters Redmond, Washington, U.S.
Key people Rajeev Badyal (president)

國際海事衛星組織 公共有限公司
International Maritime Satellite Organization
Inmarsat plc

公司類型 上市公司
股票代號 LSE : ISAT ⓘ
ISIN GB00B09LSH68 ⓘ
成立 1979年
代表人物 Andrew Sukawaty (董事長); Rupert Pearce (CEO)

Source: Wiki

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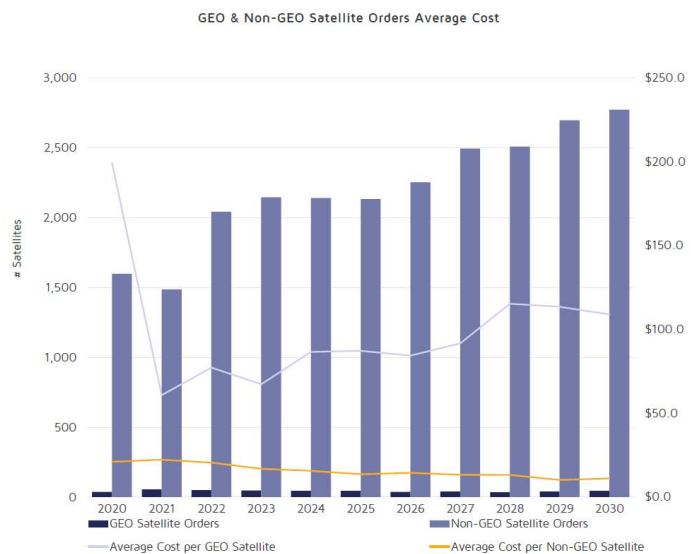
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GEO Satellites – Not Going Away



- ▶ 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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Source: NSR

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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

Electrical Power Systems

- ▶ Distribution & Charging
- ▶ Battery Management

Communication Payloads

- ▶ Beam Forming IC
- ▶ High Power Amplifiers
- ▶ Integrated RF subsystems

Stabilization & Pointing

- ▶ MEMS Accelerometers & Gyroscopes
- ▶ Inertial Measurement Units

System Health & Telemetry

- ▶ Software Defined Radio Transceivers
- ▶ Precision Converters
- ▶ Voltage Reference

Payloads & Navigation

- ▶ High Speed Converters (ADC/DAC)

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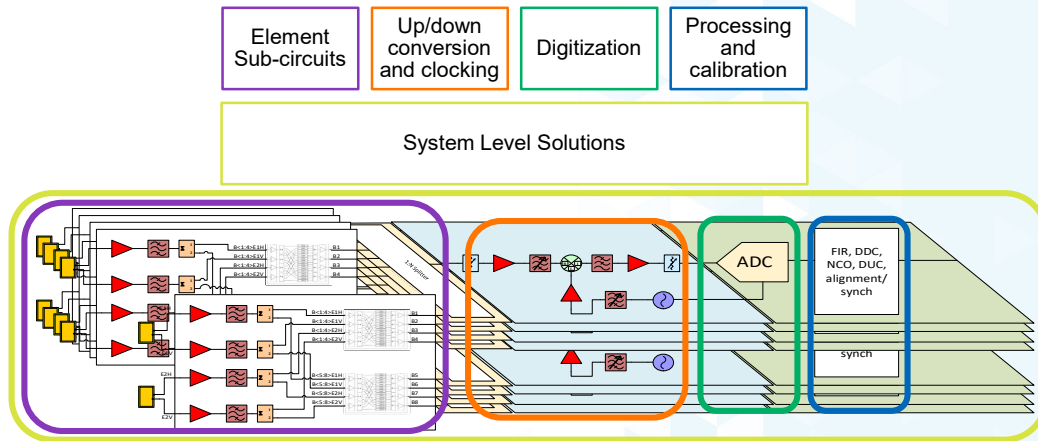
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AHEAD OF WHAT'S POSSIBLE™

ADI solutions

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Advancing Hybrid Beamforming Technology



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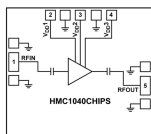
Element Sub-circuits

Key challenges near the antenna

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

LNAs/PAs

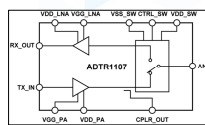
- High Linearity
- 2x2mm SMT packages
- PAE optimized
- Wideband



HMC1040: 20-44GHz LNA

TRMs

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



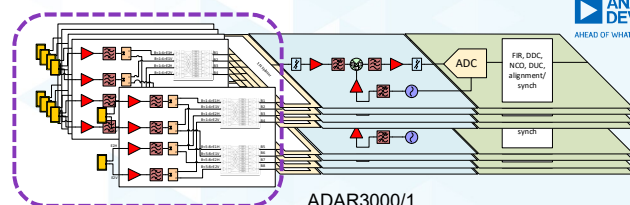
ADTR1107: X-band Transmit/Receive Module

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



ADAR3000: Ka-band 4 beam BFIC



ADAR3000/1



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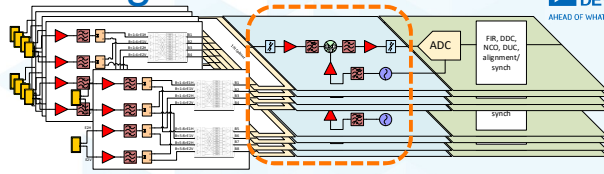
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Up/down conversion and clocking

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

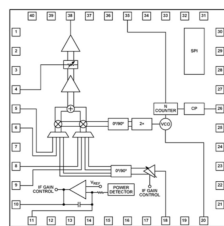
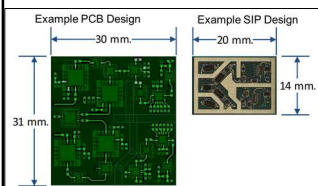
- Very small form factor
- Band specific family of products or wideband

LO & Clock Generation

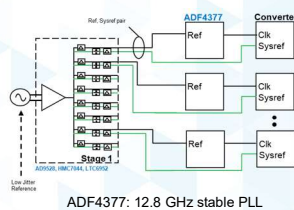
- Wideband tone generation
- Very low Phase noise solutions
- Delay adjustment
- Extreme phase stability over process, voltage, temperature

Tunable Filtering

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



ADMV4530: Ka band upconverter



ADF4377: 12.8 GHz stable PLL



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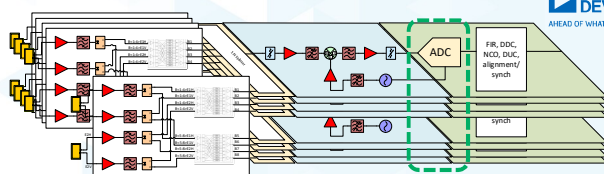
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Digitization

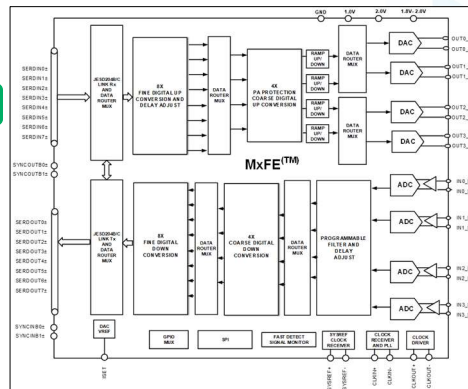
Key challenges for digitization

- 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

Signal analyser, Signal generator, Combined Tx, Combined Rx, 16Tx/16Rx Calibration Board, 12V, Signal synthesizer, 32x MMIOX-to-MMIOX Cables, Individual Tx & Rx Channels, QUAD-MXFE, 500MHz Source, Ethernet Cable, FMC+ Extender Board, USB ITAC, USB UART, Driver, 12V, 12V, PMOD

python, MATLAB, LibIIO, GNU Radio, PyADI-IIO, python, MathWorks

PC running ADI prototyping Software or customer test code in Matlab, GnuRadio, C#, Python, others

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QuadMxFE_SystemAlignmentFIR.m

After Rx Calibration, $f_{\text{carrier}} = 3.2\text{GHz}$

ADC Code

Sample Number

Calibrated Channel Rx Spectrum

Amplitude (dBFS)

Frequency (MHz)

Calibrated Combined Channel Rx Spectrum

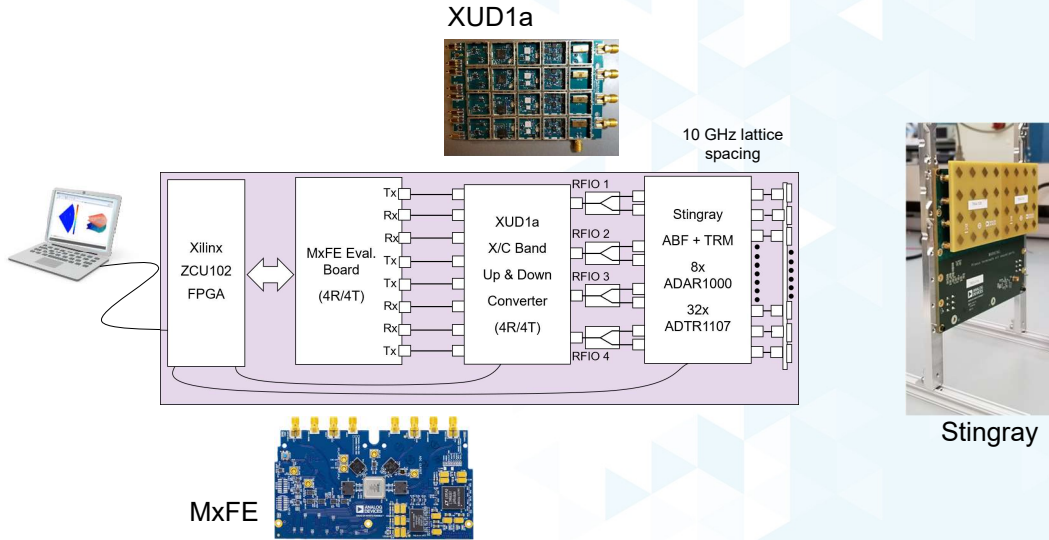
Amplitude (dBFS)

Frequency (MHz)

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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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