ANALOG DEVICES

AHEAD OF WHAT'S POSSIBLE™

Radio Frequency (RF) Advances Accelerate Moving Away From Mechanically Steered Antennas

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The Need to Focus Beams

Omni-directional

Dipole Antenna

Dipole Antenna

Horns

Parabolic Dishes

Focus Radio Frequency Energy in a Specific Direction

Mechanically Scanned Systems

- Driven By Early Radio Detection and Ranging (RADAR) System Requirements
- Basic Concept Unchanged Since World War II
- Variations
  - Spinning Bar
  - Mechanically Focused Dish
  - Fixed Parabolic
  - Multiple Antenna
  - Vertical / Horizontal
  - Multiple Small Dishes
- Bearing is Mechanically Dependent

Existing Mechanically Scanned Systems

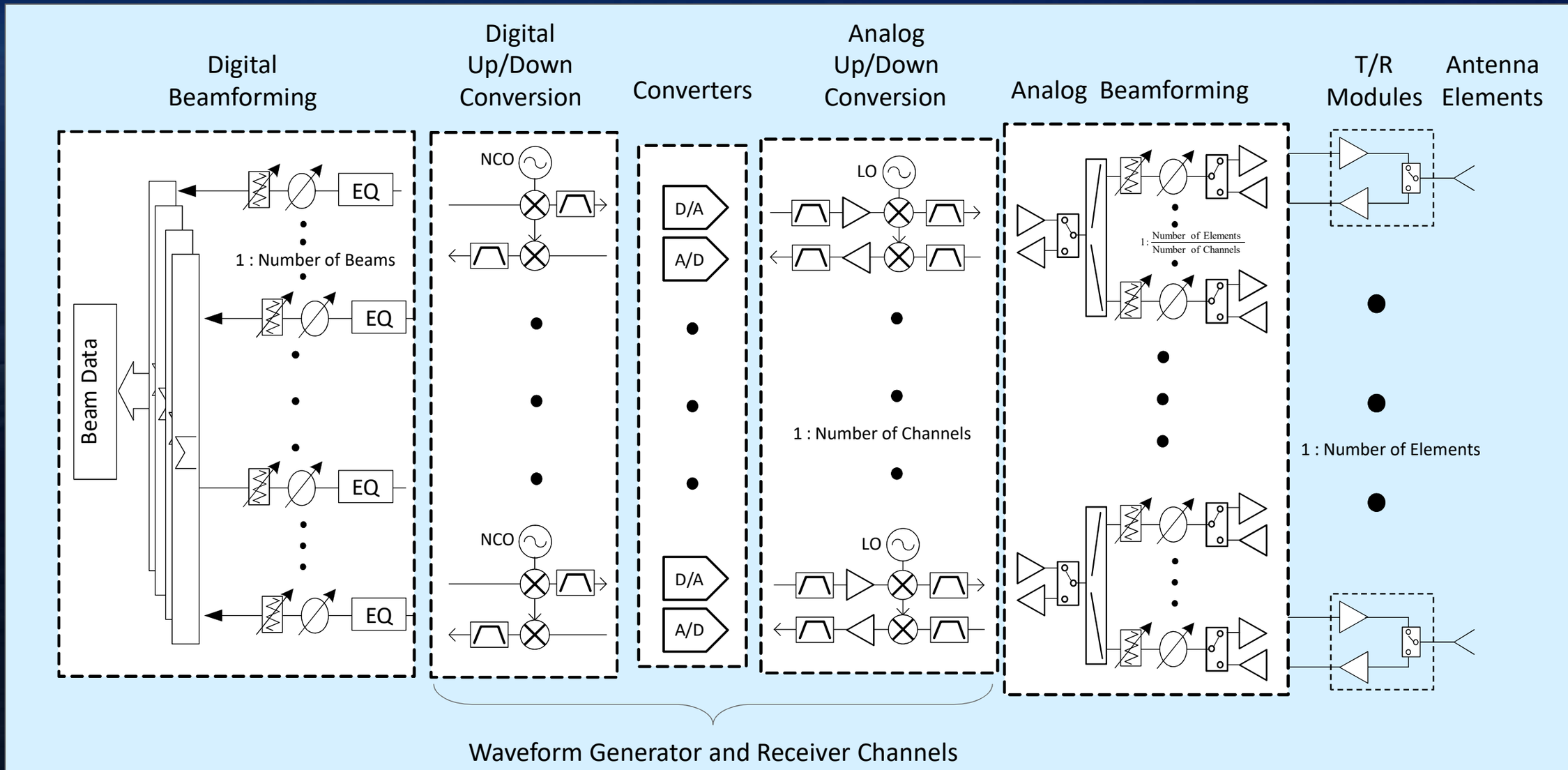
- RADAR: Air Traffic Surveillance / TRACON / Approach / Ground
- RADAR : Military Air Search / Air to Air / Air to Ground / Naval
- RADAR: Weather RADAR (Wx)
- Space: Terrestrial and On Orbit Space Vehicles
- Comms: Fixed and Variable Radio Frequency & Microwave
- Comms: Military Communications Systems

Existing Mechanical Systems – Short Comings

- Scanning Speed / Stabilization / Overshoot
- Single Function / Single Frequency / Single Beam
- Bearing Depends on Physical Alignment
- Require Space to Rotate
- Susceptible to Jamming / Blocking
- Fail in Complex Multiple Target Environments

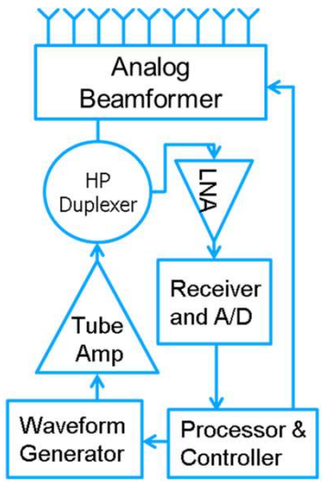
- Maintenance
  - Mechanical Breakdown
  - Environmental Constraints
  - Remote Deployments

Beam Forming Basics

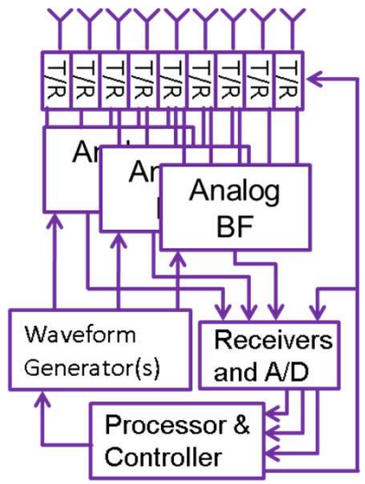


Phased Array Beam Forming

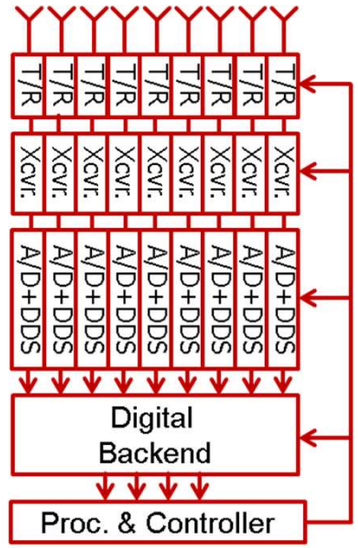
Analog



Hybrid



Digital



Ticonderoga Class Cruiser - AN/SPY-1

- First Major Deployment of Phased Array RADAR
  - Tracks 200 Unique Targets Per Array
  - Deployed Active Service in 1983
  - Key Part of Aegis System
- Multiple Upgrades Reduced Array Size
- Military Still Primary User of Phased Array

Flat Plate Antenna Systems

- Description
  - Fixed Antenna Patches On Flat or Curved Surface
  - Commonly: 1 Transmit : 2-8+ Receive
  - Basic Doppler and Time of Flight Calculations
- Functions
  - Short Range
  - Specific Purpose
  - Limited Resolutions
- Uses
  - Occupancy Detection RADAR
  - Perimeter Security
  - Altimeters
  - Automotive RADAR
  - Industrial RADAR

Analog / Hybrid Beam Forming Systems

- Description
  - Utilizes Analog Circuitry to Focus Beam via Delay, Phase and Power
  - Beam Forming is Done in the Radio Frequency Domain
  - Hybrid Design Replaces Part of Analog With Digitizers
- Advantages
  - Deployed Today in Many RADAR and Some Communications Systems
  - Proven Design and Well Understood
  - Lower Power for Given Functionality
  - Lower Cost Than Present Generation of Digital Beam Forming (DBF)
  - Significantly More Capability Than Mechanically Scanned
- Challenges
  - More Expensive Than Mechanical Scanned
  - Designed for Specific Spectrum Coverage

Digital Beam Forming Systems

- Description
  - Replaces Most of Analog Circuitry With High Speed Converters
    - Analog to Digital Converters (for receive)
    - Digital to Analog Converters (for transmit)
  - Each Element has a Digitizer – Quickly To Digital Backplane
  - Allows for Direct Digital Sampling and Digital Beam Forming
- Advantages
  - Allows for the Greatest Flexibility in Operations and Reliability
  - Large Spectrum Coverage & Common Designs
  - Multiple Targets, Multiple Beams, Multiple Frequencies
- Challenges
  - Thermal and Power Challenges
  - Most Expensive Design
  - Needs to Move Large Amounts of Digital Data

Modern Phased Array RADAR: Surveillance, Weather and Fire Control RADAR

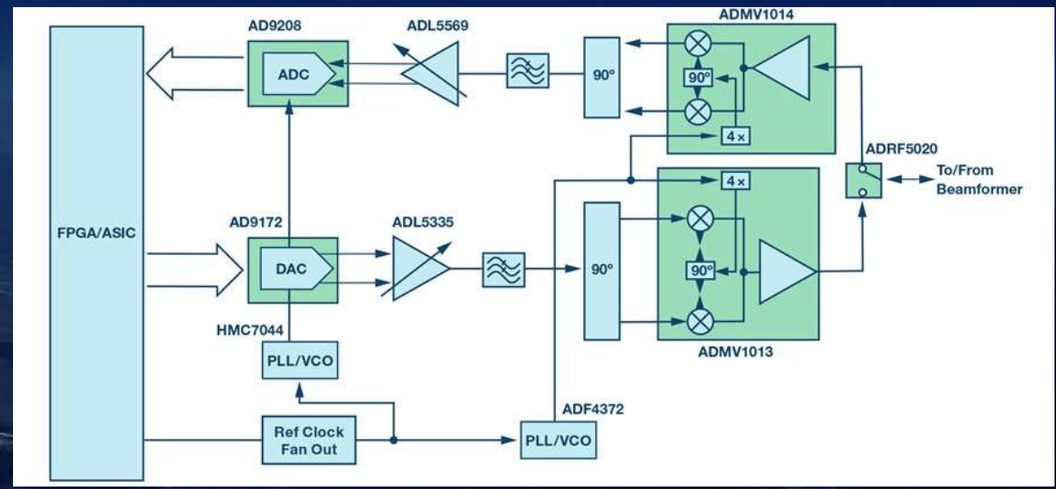
- Phased Array Combines Functions
  - Airborne Weather RADAR and Collision Avoidance Systems
  - Ground Based Surveillance and Weather RADAR Systems
  - Integration of Communications with RADAR systems
  - Multimode Military Aircraft Functions
- Reduced Cost Per Function
  - Less Systems
  - Less Weight
  - Less Power
  - Less Maintenance

Space Upgrades – Low Earth Orbit (LEO) Communications Constellations

- Proposed Low Earth Orbit (LEO) Communications To Provide Direct Space to Ground and Space to Aircraft Connectivity
- Both On Orbit Space Vehicles and Ground/Airborne Terminals Requiring Phased Array Due to Short Time of Visibility
- Driving Need For Affordable Phased Array Beam Steering Withstanding On Orbit Radiation

5G Backbone

- Phased Array and Beamforming Is Critical to Next Generation 5G
  - Frequency Agility
  - Small Area Focused Beams
  - Upgradability For Future Spectrum Allocations
  - Minimum Maintenance Once Deployed
  - High Throughput and 360 Degree Coverage
- Cost Offset By Throughput and Increase in Subscribed Devices



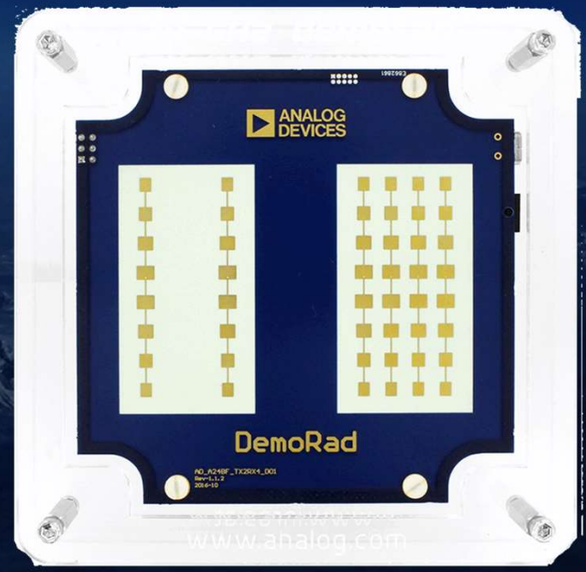
Security : Millimeter Wave Scanners

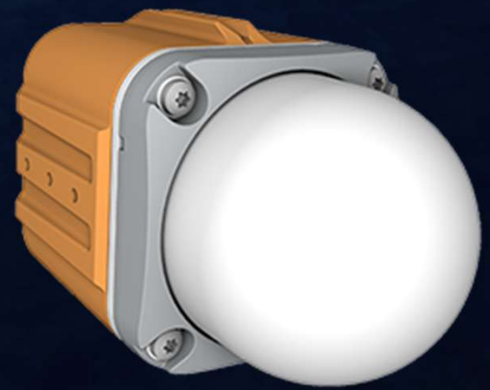
- Millimeter Wave Scanners Provide Unobtrusive yet Accurate Systems to Detect Threats at Airports, Stadiums, Hospitals, etc.
- Arrays of Antenna Allow From Rapid Scanning and Examination of Subjects
- Modern Systems Will Eliminate Moving Parts and Stationary Requirements

Safety Systems : From Cobots to Trains to Automobiles

- Small Flat Plate or Phased Array RADAR Systems Provide Safety and Contribute to Sensor Fusion
  - Cobots
  - Industrial Heavy Machinery
  - Automobiles
  - Trains
  - Aviation

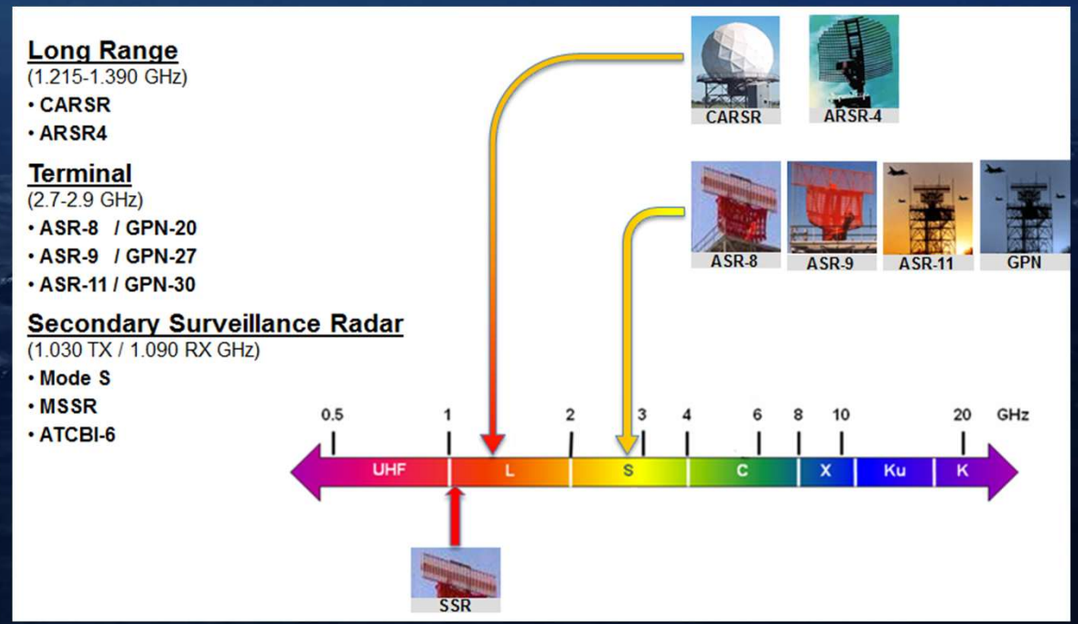
- Provide Lower Cost and Dependable Solutions For Safety Critical Applications





New Program Example: SENSR

- Spectrum Efficient National Surveillance RADAR (SENSR)
  - Proposes To Use Phased Array RADAR to Replace Hundreds of Mechanical Systems Across the USA
  - Combined FAA, DHS and DoD Functions
  - NOAA Dropped Out To Design Phased Array Weather RADAR
  - Driven by Spectrum Auction



The Concern: Complexity and Acquisition Cost vs. Full Cost of Ownership for Functionality

Mechanical Systems / Fixed System

- Single Point of Failure – Numerous Failure Points
- Complex Maintenance Costs – Difficult Upgrade Path
- Low Acquisition Cost with Low Capability
- Single Function and Single Frequency
- Compatible With Legacy Systems
- Not Forward Compatible

Low Cost Acquisition. High Life Time Cost.

Phased Array

- ✓ Limited Failure Modes – Robust
- ✓ Requires Little Maintenance – Functions with Reduced Elements
- ✓ Functionality Can Replace Multiple Single Function Systems
- ✓ Provides Multiple Beams and Multiple Frequency Capabilities
- ✓ Backwards Compatibility With Legacy
- ✓ Easy to Upgrade and Support

High Acquisition Cost. Low Lifetime Cost.

Key Technologies Accelerating the Move To Phased Array

Receivers & Transmitters

- Wideband Mixers, LNAs, Attenuators
- GaN solid state PAs
- High level of integration

Digitizers

- High speed High BW
- GSPS ADCs
- GSPS DACs

Switch Matrices

- Switches
- MEMs for High Reliability
- Splitters

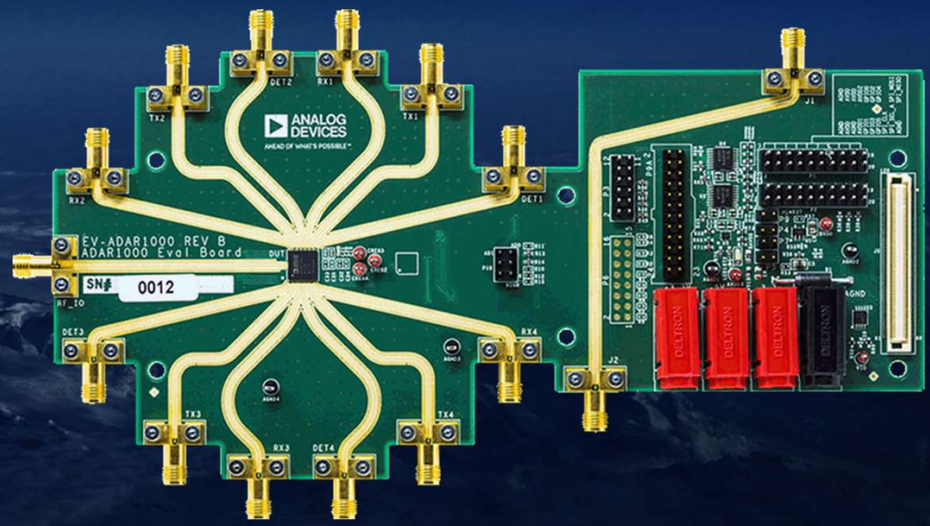
Beamforming

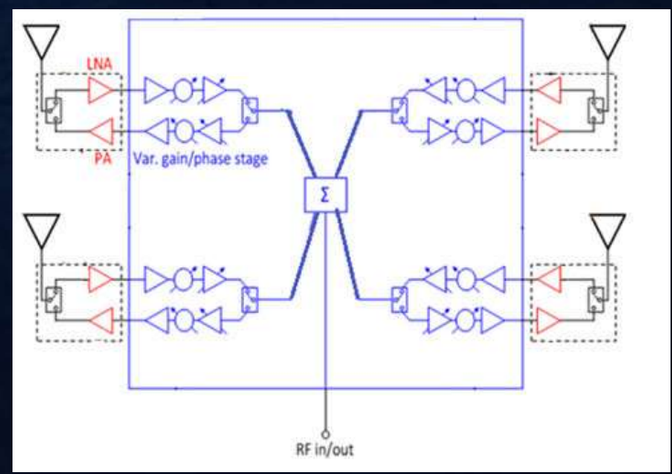
- Integrated Core chips
- Beam Former Integrated Circuits (BFIC)
- Phase shifters, Time Delay

Complete Designs Are Possible Today

Major Technology: Analog Beam Forming Integrated Circuits (BFIC)

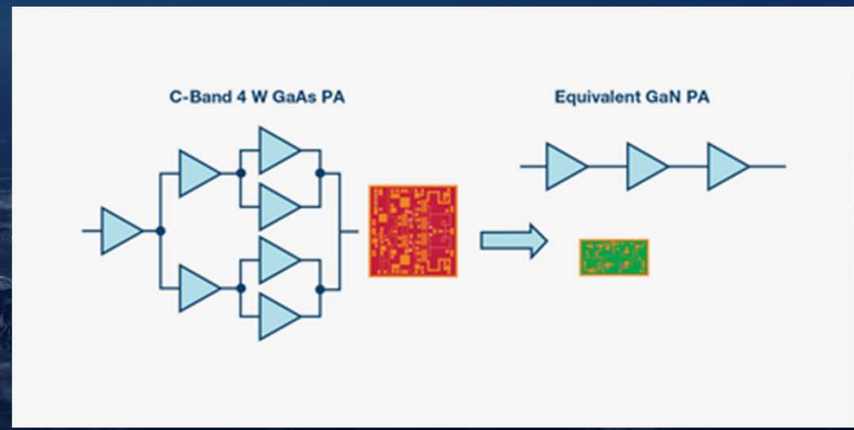
- Analog BFIC Systems Now Available
  - Expanding Coverage
- Accelerate Time to Market
- Proven Reduction in Size and Power
- Analog Design Or Incorporate Transceivers for Hybrid Design
- Excellent Cost / Performance Ratio





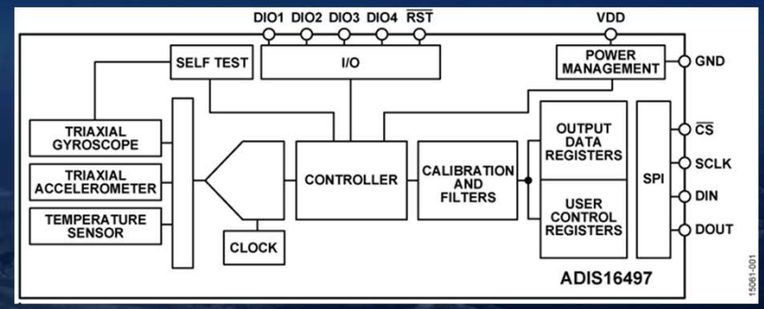
Accelerating Development: Amplifiers / RF Modules / TR Modules

- Amplifiers
  - Low Noise Amplifiers
  - Power Amplifiers
  - GaN and GaAs Advances Drive Improvements in Performance and Efficiencies
- Transmit Receive Modules (T/R Modules)
  - Integrated Systems Matched to BFIC Systems
- Radio Frequency Modules
  - Integration of Functionality
  - Reducing Component Count
  - Matched Systems



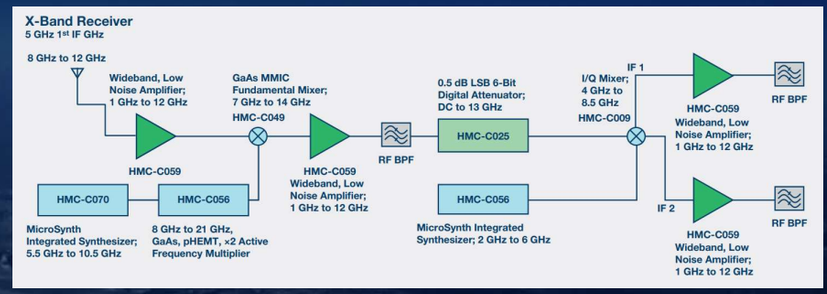
Accelerating Development: Stabilization and Pointing

- MEMS Gyroscopes
  - Augment Pointing
  - Yaw Sensors
- MEMS Accelerometers
  - Precision Motion Monitoring
  - Vibration and Movement Sensing
- MEMS Inertial Measurement Units
  - Attitude Sensing and Calibration
  - Complex Pointing and Geometries



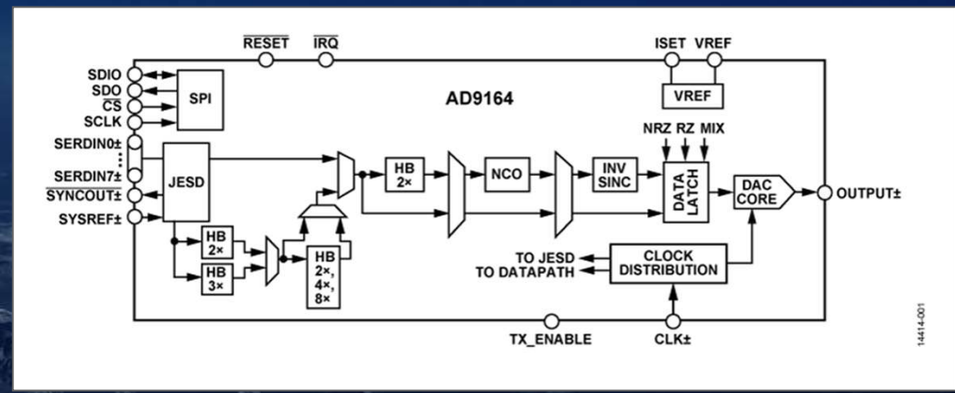
Accelerating Development: Filters / Upconverters / Downconverters

- Filters
  - Switching Filters
  - Programmable Filters
  - Complex Filters
- Upconverters
- Downconverters
- Synthesizers
- Oscillators
- Mixers



Major Technology: High Speed Converters / Transceivers

- Digital to Analog Converters (DAC)
  - Higher Giga-Sample Per Second Converters
  - Allowing for Higher GHz Direct Beam Forming
- Analog to Digital Converters (ADC)
  - Moving Higher in Sample Rates
  - Enabling Direct Sampling Architectures
- Integrated Transceivers (TRx)
  - Fast Time to Market For Design
  - Direct Digital or Hybrid Designs

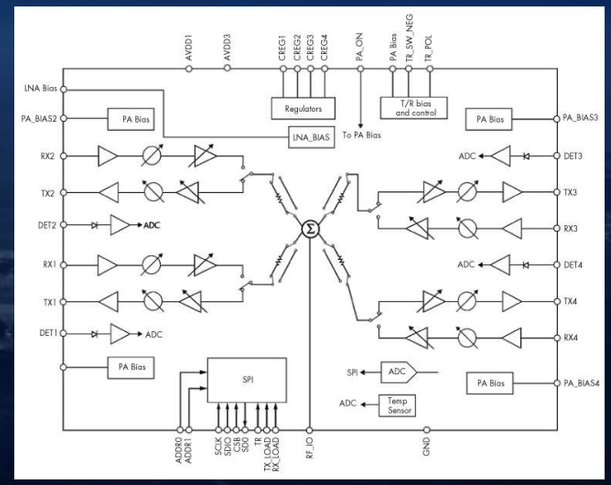


Accelerating Development: Smaller Geometries and Lower Power Densities

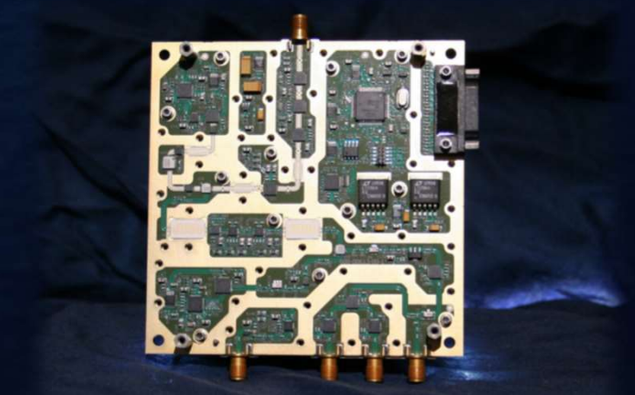
- Move Towards Smaller Geometries Drives Greater Efficiencies in Power
- Reduction in Both Die and Package Size
- Improvements in Decimation Decreasing Thermal Issues
- Analog to Digital Clocking Resolved

Accelerating Development: Packaging and Integration

- Modules and Subsystems
  - Plastic and Hermetically Sealed RF Modules and Full Encapsulated Assemblies
  - Feedback, Digital Predistortion, Gain Controls Can Be Integrated
  - High Power RF Moving Into Communications



- Systems in Package / Package on Package
  - Complete Functional Blocks Incorporated Into Single Packages
  - High Performance and Matched RF Provided By The RF/mW Experts To Allow Products To Get to Market Faster



Accelerating Development: Conclusion

- The Past Five Years Have Seen Developments That Make Phased Array Available To All Markets
- Initially the Domain of The US Military – Rapid Movement into Enabling 5G Roll Out
- When Compared To Full Cost of Ownership For Functionality, Phased Array is Becoming The Preferred Investment

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