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18th November 2009

COBHAM

AVIONICS AND SURVEILLANCE DIVISION

End to end avionics and covert surveillance solutions

DEFENCE SYSTEMS DIVISION

Critical technology for network centric operations

MISSION SYSTEMS DIVISION

Complete 'nose to tail' refuelling and 'wingtip to wingtip' mission systems capability

AVIATION SERVICES DIVISION

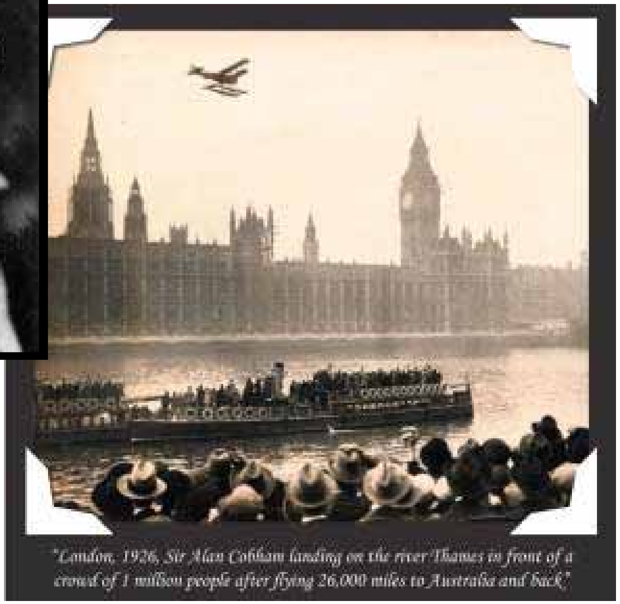
Operates, modifies and maintains more than 150 fixed and rotary wing aircraft around the world

Reducing Cost, Size and Mass of MPAR Radar Arrays

Cobham Overview
Summary

Enterprise Started in 1934 by Sir Alan Cobham

- An innovative aviation pioneer – Aug 1926 – England to Australia & back; refueling - 1933
- 1939 – Refueling aircraft from aerial tankers
- RAF & US Army Air Force began refueling trials in the last year of WWII

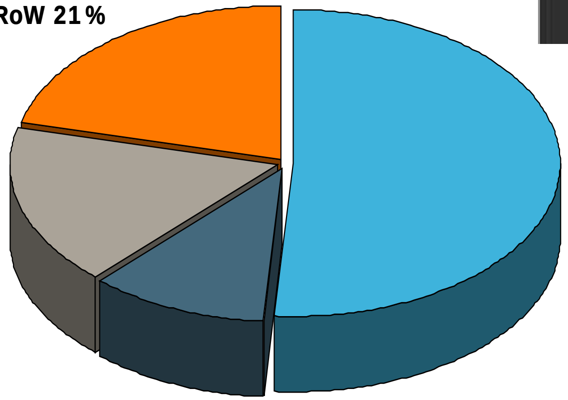


Four Divisions Operating on Five Continents with 12,000 Employees Worldwide

- **Cobham Defense Systems (CDS)**
- Cobham Avionics & Surveillance
- Cobham Mission Systems
- Cobham Aviation Services

Major Operations

- Defense Electronic Systems
- Antennas
- Avionics and Surveillance
- Communications
- Homeland Security



Alan Cobham relied on meteorological office reports in the 1920s and 30s

Cobham Overview

Cobham Sensor Systems

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Technologies / Products / Services

- Active microwave
- Passive microwave
- Electronic warfare antennas
- Communication, navigation & identification (CNI) antennas
- Radar antennas – fire control radar, weather radar, synthetic aperture radar
- Radomes and advanced composites
- High-precision positioners

Facts

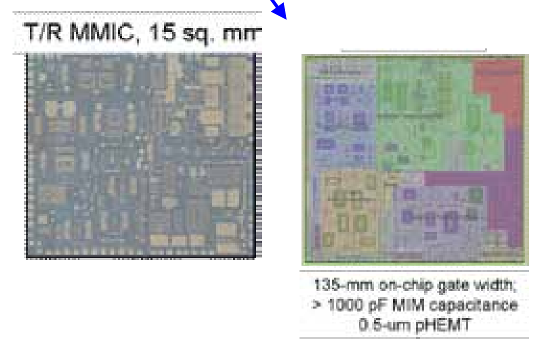
- Facilities in the USA, Mexico, Sweden
- President: Steve Schaefer

Markets

- Tactical Radar & Communication
- Satellite Communication
- Tactical Missiles
- Electronic Warfare
- Missile Defence
- Space Systems

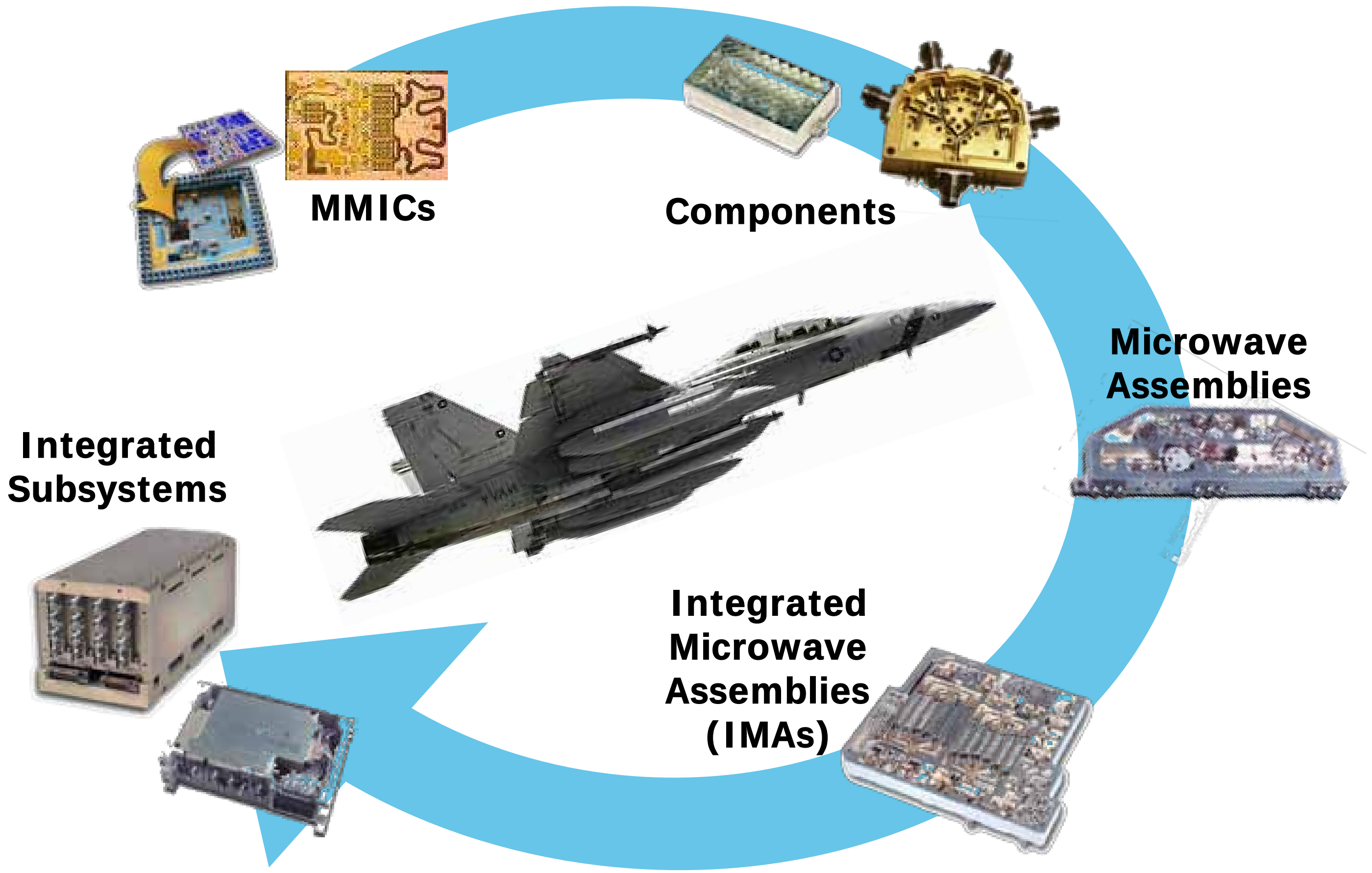
Business Units

- Sensor Electronics
- Microwave Electronics
- Microwave Components
- Advanced Programs and Technology



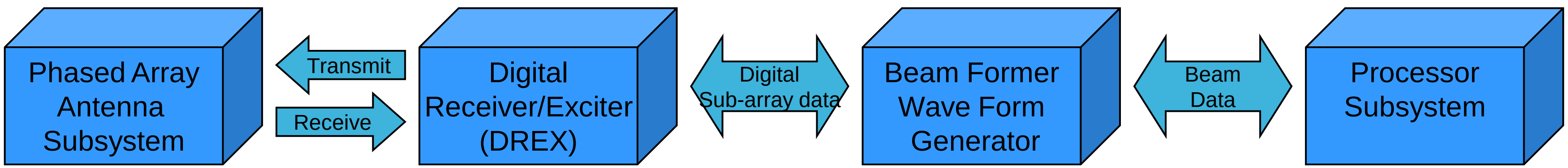
Product Integration Strategy

Strong component foundation enables the development of integrated products resulting in higher performance, smaller size, and lower cost



Radar Subsystems Roadmap

Radar architecture has four major subsystems



- L, S, X, and Ku band T/R MMIC's
- T/R module packaging
- Array architecture developed

2004

- 256 element arrays
- 1024 element array
  - X-band
- Full DREX 32 channel subsystem delivered
  - S-Band

2009

- Complete Panel building blocks for S, X, and Ku band arrays
- Partner for platform deliveries
- DREX building blocks at S and X band
  - Low cost architectures

2013

What can Cobham Contribute to MPAR?

- Architecture/implementation cost trade off studies
  - Cobham is not wedded to any particular technology; we use all types of technology
    - Technology choices based on best solution
  - We use multiple foundries for MMIC development, both within Cobham and outside
  - We manufacture hardware so we *have to* accurately estimate costs to survive in a competitive environment. *95% of the work (including development) we do is firm fixed price.*

- Demonstration hardware
  - We have similar hardware that can be adapted to MPAR needs
    - X-band phased array antenna subsystem
    - Many highly integrated custom MMICs developed for L, S, C, X and Ku-band radars, including specifically for MPAR
    - S-band Digital Receiver Exciter (DREX)
    - Large number of components developed for other radar programs

What can Cobham Contribute to MPAR?

- Strong technology in core RADAR areas
  - MSAG and HVMSAG are Cobham advantages
  - Smallest MMICs in industry, results in lower costs
  - Lowest thermal impedance MMICs -- simplifies packaging and cooling
  - Capability includes MMIC, digital, antenna, and T/R functions
- IR&D Support
  - We have internal IR&D programs for S-band and X-band development that need input from MPAR

Requirements for a LOW COST Phased Array Supplier

- Highly Integrated Custom MMICs
  - MMICs 20% or higher percentage cost of the array
  - Innovative designs required to achieve element spacing. Older approaches with “brick” T/R modules will not meet cost goals
  - Highly efficient designs required to achieve thermal performance and reliability
- Low Cost Packaging Approaches
- Innovative Antenna Technologies – Dual Polarity designs
- High Volume Manufacturing capability
  - Automation for assembly and test
- Open Architecture
  - Willingness to work with open and non-proprietary interfaces
  - Allows technology insertion, competition; not hostage to system supplier
- Scalable Design
  - Allows arrays of any number of panels to be made

X-band Phased Array Antenna Subsystem Design

Tile Design

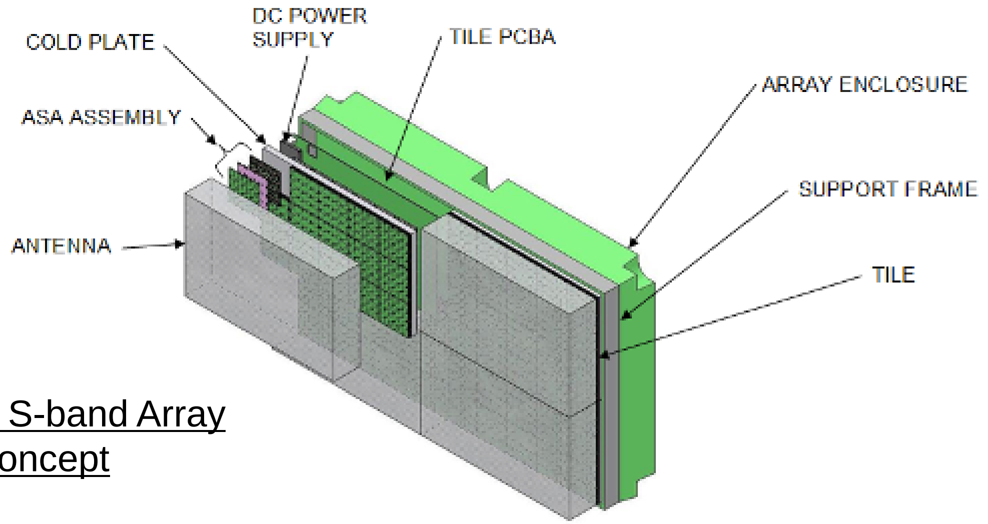
- Scalable
- 256 element building block
- Highly integrated custom MMICs for optimum performance, layout, & lowest cost
- Horizontal layout of T/R electronics instead of vertical “brick” T/R Modules
  - Allows use of single, low cost PCB (printed circuit board) for 16 elements ASA (analog subarray) building block
  - Low cost protective coatings over MMICs instead of hermetic packaging
  - Embedded passives in PCB
  - Lower cost than T/R module approach
  - Radiator assembly with various polarity
  - Air cooled
- Integrated FPGA controller and DC-DC converter

X-band Phased Array Antenna (IR&D) Subsystem Key Specification Summary

§ **DC Voltage**	**28 V – to 300 V option**
§ **DC Power Consumption**	**< 1 kW**
§ **Tile Size**	**256 elements**
§ **Tile Area**	**< 100 sq. in.**
§ **Depth**	**4.0”**
§ **Weight**	**~3.5 kg (includes all DC converters)**
§ **Transmit Polarization**	**Circular or linear options**
§ **Receive Polarization**	**Circular or linear options**
§ **Thermal**	**Air Cooled**
§ **Interface**	**Open Architecture**
§ **Calibration**	***Ability to calibrate every element individually***

Transition to S-Band

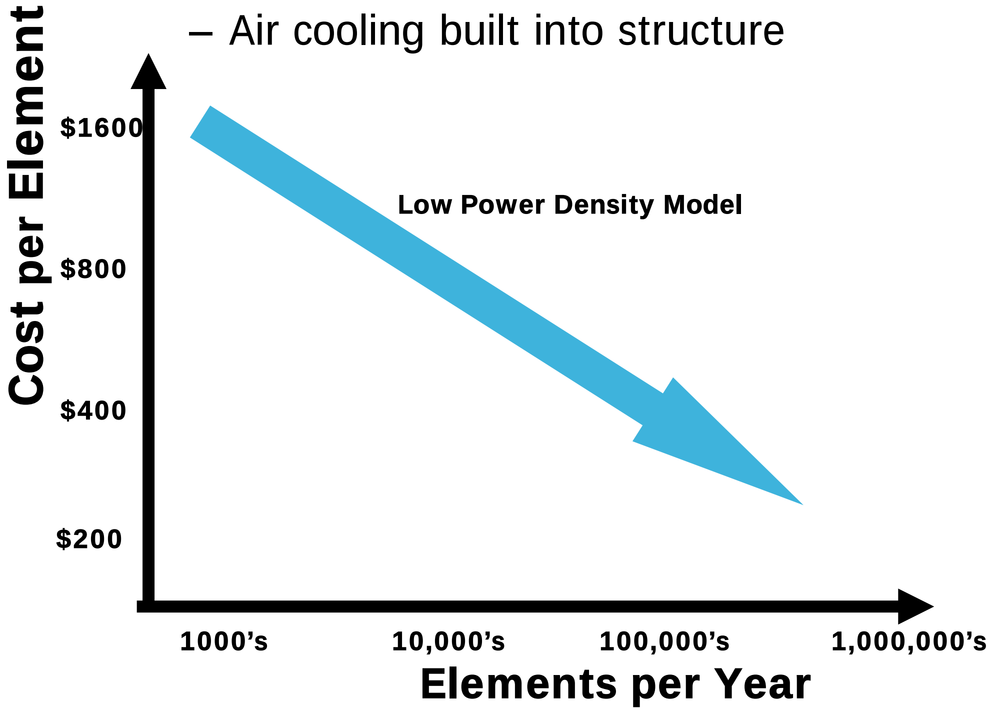
- Leverage X-band strength and benefits of the larger array spacing at S-band into a low cost building block
  - Scalable -- Dual Polarity -- Integrated MMIC chipset
  - *Air cooling to 50 W per element*; Liquid cooling to 200 W + (10% duty cycle)
  - Integrated Calibration approach -- Integrated Beam steering controller
  - Automated surface mount assembly maintaining thermal performance



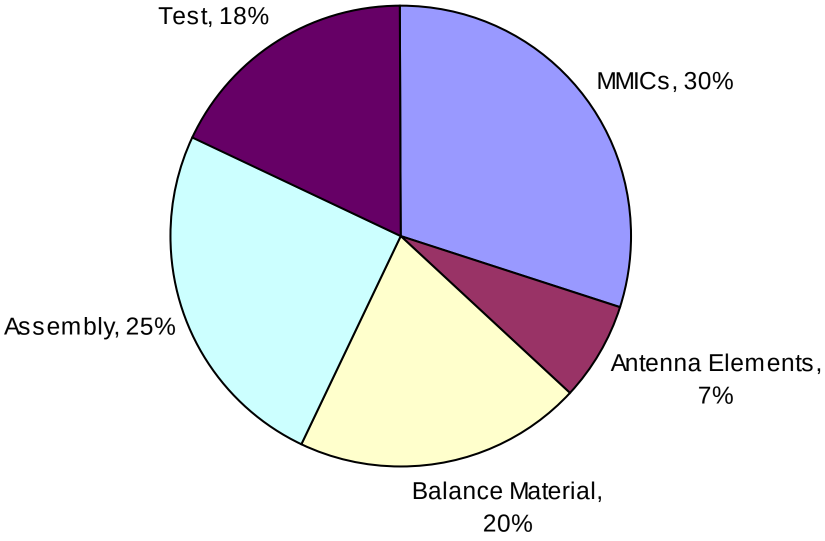
Scalable S-band Array Concept

Cost Model - Inclusive of All Array Functionality (not just T/R module cost)

- X-band model shown; S-band: lower cost packaging & lower cost MMIC processes
- Quantity required to reduce per element cost
- Must leverage building blocks across multiple programs
  - Must be considered when optimizing for one frequency band or requirement
- Innovative MMIC technologies, packaging, thermal control necessary
  - Design into 6" or larger wafers for high quantity parts
  - Air cooling built into structure



Approximate Cost Breakdown (10K element qty's)



Technology Tradeoffs

Device Type:

- GaAs - PHEMT - MSAG - HVMSAG – HBT - GaN – SiC - SiGe - LDMOS - CMOS
- Cobham has experience with all of the above

Specification Trades:

- Power per element -- Noise figure per element
- PAG/T is a one figure of merit for a radar array: **P**ower * Antenna **A**rea * antenna **G**ain / noise **T**emperature. PAG/T is proportional to the cube of the number of elements
- Polarization choices: dual linear only vs. dual linear plus dual circular, receive simultaneous polarization, etc.

Example of Trades:

- SiGe amplifiers are less expensive than GaAs but higher noise figure. Higher noise figure means more elements are required to make the same PAG/T. Conversely, pHEMT is more expensive than MESFET but lower noise figure. The trade has to be done at the system level.
- Higher power amplifiers = fewer number of elements; total DC power increases & cost per PA MMIC increases (PA is the most expensive MMIC).

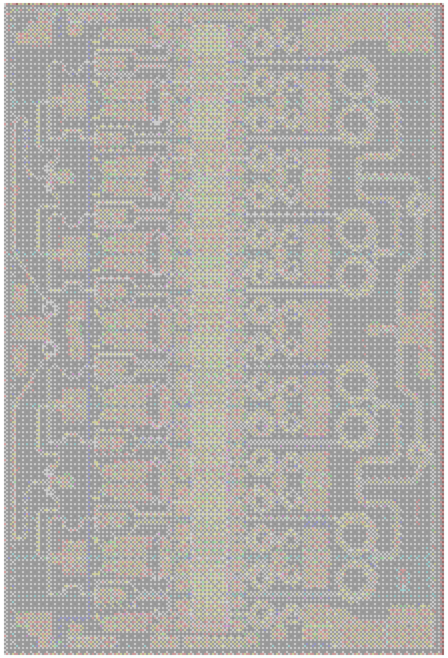
HVMSAG MMICs COST LESS Today

Material Cost Comparison	HVMSAG	GaN on SiC
Power Density (W/mm; 28 V)	1.8	6
Power Density Ratio'ed to HVMSAG	1	3.3
Starting Material Cost ($)	700	7000
Wafer Diameter (mm)	100	100
Starting Material Cost ($ / sq. mm)	$ 0.11	$ 1.10
Cost ($ / sq. mm) Ratio'ed to HVMSAG	1	10
Cost Ratio / Power Ratio	**1**	**3**

High Power L,S, and C band Radar applications

MESFET High Power Amplifier

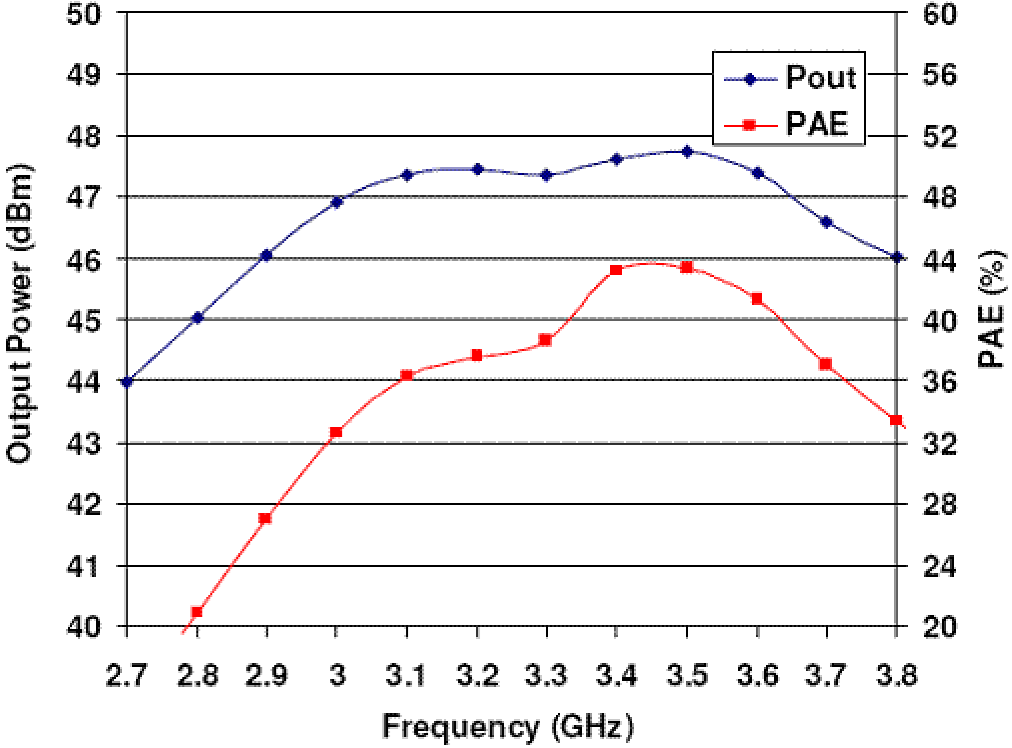
- 50W, single stage
- 3 – 3.6 GHz
- 28V Supply
- 30-44% PAE
- 2mil GaAs



Chip Size

7500 x 5000um

Fully on-chip matched PA



MPAR Pricing Targets, MMIC Constraints

Target Price: $50k / sq. meter of aperture

- Equates to $130 / element at S-Band
- Element price includes aperture structure, cooling, radiators, radome, power conditioning, logic, beamformers and T/R modules
- T/R modules will make up 50% of this budget
  - < $60-70 / module
  - MMIC Content will be largest portion of the T/R module Cost
  - PA (power amplifier) is the most expensive function
    - HVMSAG is the most cost effective technology today for S-band power MMICs in the 2 - 60 W range
    - GaN technology and cost are improving for the solution

MPAR Requirements Driving Cost

- Variable Polarization: combined linear & circular capability roughly **doubles** the MMIC area
- Power. PA MMIC area roughly proportional to power; drives heat removal techniques. Passive matching networks require more area than transistors.

MMICs Developed for S-band

- Custom S-band MMICs developed specifically for phased array radars
- Suitable for dual polarization application as needed for MPAR
- Small die area lowers cost
- MSAG (multifunction self aligned gate) and HVMSAG (high voltage MSAG) are two Cobham specific technologies
- MSAG, HVMSAG/HEMT addresses *> 80% of the Military MMIC Market*
- *3X to 5X lower MMIC cost* compared to GaN & SiC today
  - *High efficiency, gain, linearity & reliability*
  - Supports miniature*, low cost, highly integrated* T/R MMICs

Low Cost S-band T/R Module Approach

- PCB-Based Assembly
  - Surface Mount Construction, Air-Cooled
- Off-shore Assembly & Plastic Packaging of untested MMICs
  - IC Yields > 85%
- Integration of MMICs where it makes sense
  - Will not impact yield
- Total IC area < 60 sq mm
  - Tx Power to 5 W or higher at element output
  - High Voltage Process, HVMSAG or GaN

Reducing Cost, Size, and Mass

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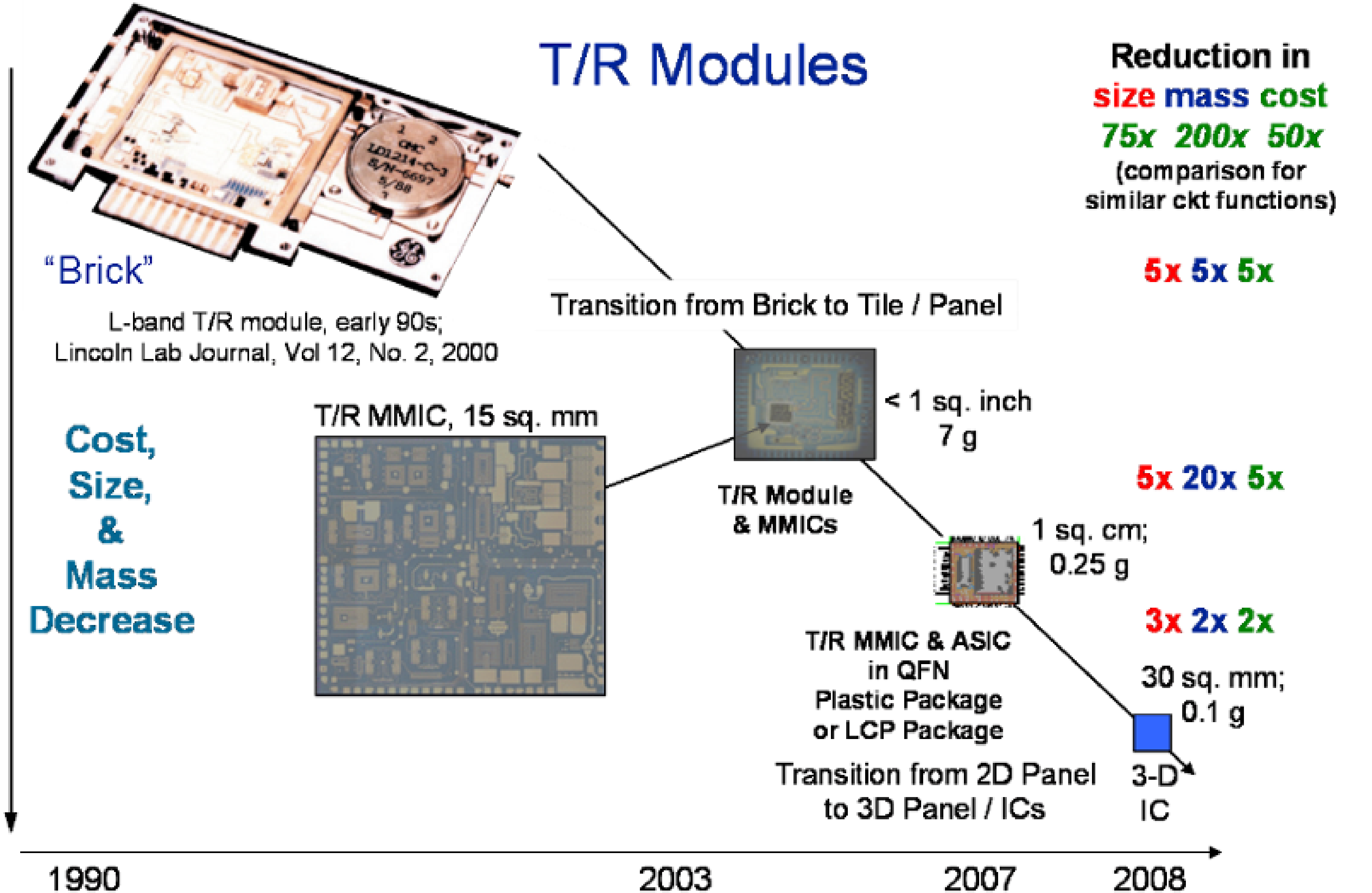
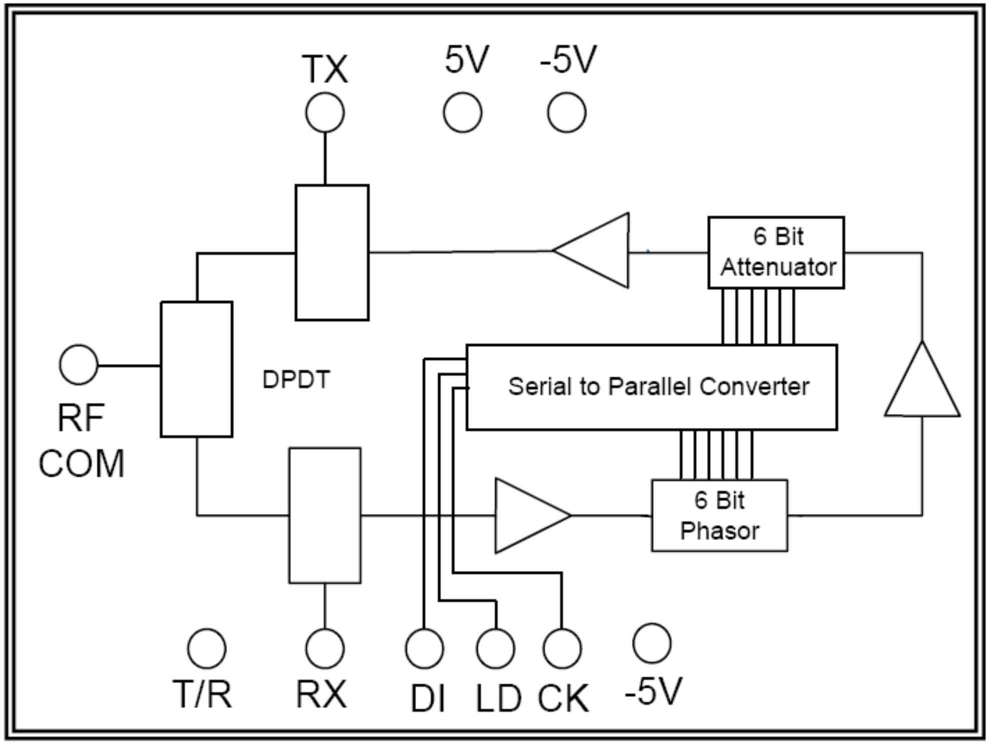
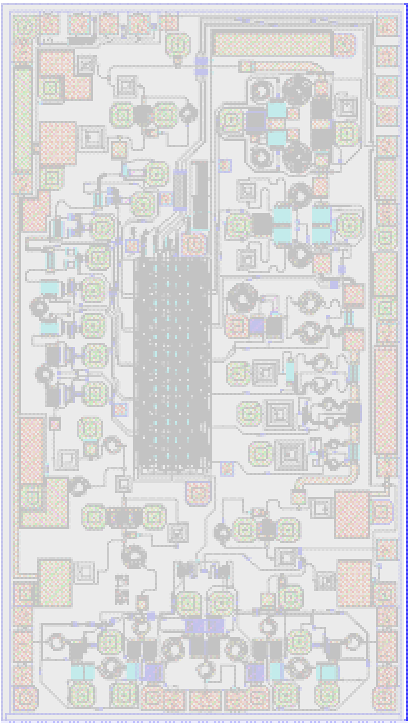


S-Band Common Leg Circuit (CLC)

Phase shifter, attenuator, amplifiers, S-to-P converter, switches

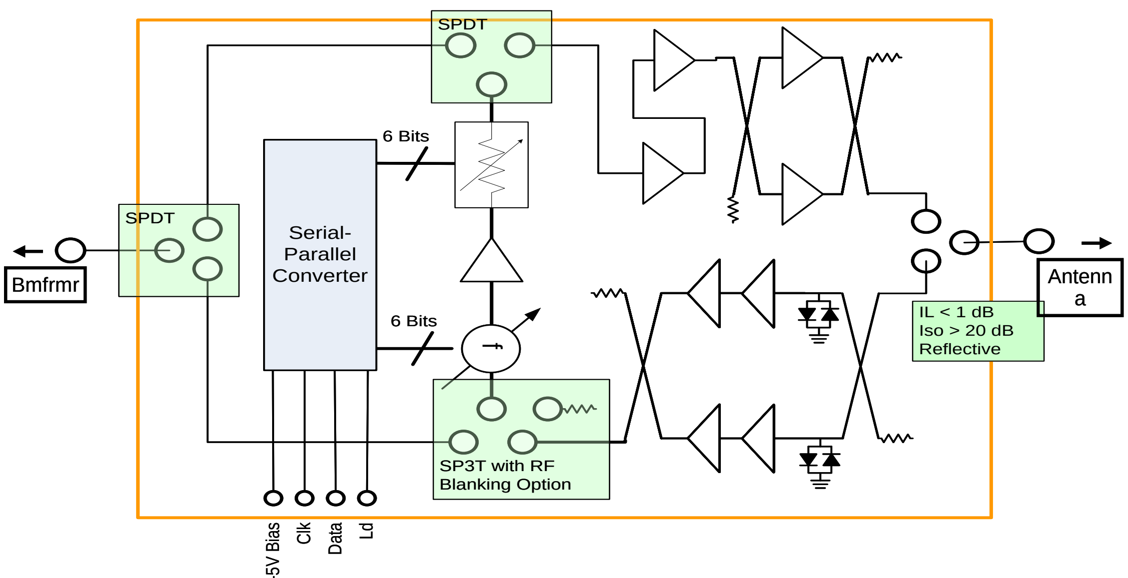


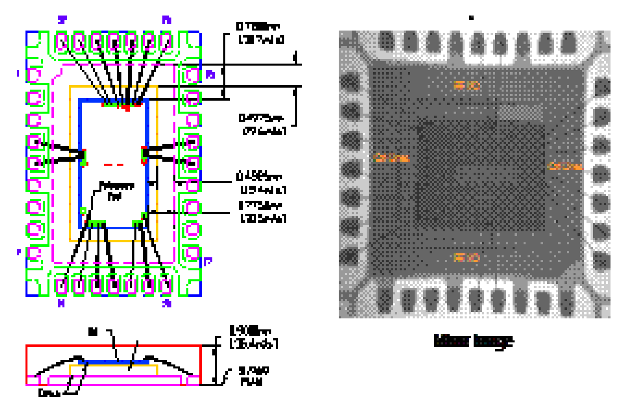


~ 10 sq. mm

S-band Radar Single Chip T/R Element

- Single chip solution
- HVMSAG process enables integration
  - Integrated control functions with RF functions
  - Competing technologies require multi-chip solutions
- Eliminates significant packaging and assembly labor costs
- Low cost solution





Simple T/R Module

S-Band DREX
(Digital Receiver-Exciter)

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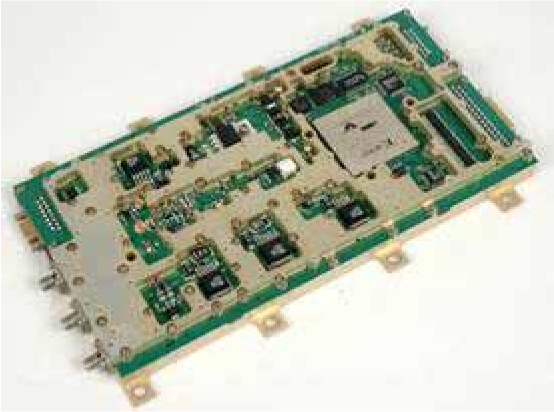
- Distributed Radar Application
- 4 synthesizers, 32 T/R channels
- Expandable to arbitrary number of channels
- Extremely low phase noise
- *Synthesizers have uncorrelated phase noise for even lower system level phase noise*



Low cost S-band DREX
Multi-channel concept

- Translates from digital signals to RF signal & vice versa
- Very good phase stability vs. time between channels

Low Cost S-Band DREX

- RF & IF bandwidth requirements significantly simplify performance requirements
- Move from modular, hermetic design approach to fully integrated single board design
- Multiple Channels per board – target 8; integrated A/D, D/A and FPGA on board

Summary

- Cobham -- has extensive phased array radar experience
- Legacy and IR&D programs are directly applicable to MPAR requirements
- Is positioned to make cost effective phased array radar hardware
- Has made significant investments in phased array radar technology
- Cobham requests MPAR inputs to influence its IR&D projects
- What can we do for you?

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