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

<table>
<thead>
<tr>
<th>Technologies/Products/Services</th>
<th>Facts</th>
<th>Business Units</th>
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<tr>
<td>• Active microwave</td>
<td>• Facilities in the USA, Mexico, Sweden</td>
<td>• Sensor Electronics</td>
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<tr>
<td>• Passive microwave</td>
<td>• President: Steve Schaefer</td>
<td>• Microwave Electronics</td>
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<td>• Electronic warfare antennas</td>
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<td>• Microwave Components</td>
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<td>• Communication, navigation &amp; identification (CNI) antennas</td>
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<td>• Advanced Programs and Technology</td>
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<tr>
<td>• Radar antennas – fire control radar, weather radar, synthetic aperture radar</td>
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<td>• Radomes and advanced composites</td>
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<td>• High-precision positioners</td>
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<table>
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<tr>
<th>Markets</th>
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<tr>
<td>• Tactical Radar &amp; Communication</td>
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<tr>
<td>• Satellite Communication</td>
<td></td>
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<tr>
<td>• Tactical Missiles</td>
<td></td>
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<tr>
<td>• Electronic Warfare</td>
<td></td>
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<tr>
<td>• Missile Defence</td>
<td></td>
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<tr>
<td>• Space Systems</td>
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*Includes the full year effect of 2008 acquisitions*
Product Integration Strategy

Strong component foundation enables the development of integrated products resulting in higher performance, smaller size, and lower cost.
Radar architecture has four major subsystems

- **Phased Array Antenna Subsystem**
- **Digital Receiver/Exciter (DREX)**
- **Beam Former Wave Form Generator**
- **Processor Subsystem**

**Radar Subsystems Roadmap**

- **2004**
  - L, S, X, and Ku band T/R MMIC’s
  - T/R module packaging
  - Array architecture developed

- **2009**
  - 256 element arrays
  - 1024 element array
    - X-band
  - Full DREX 32 channel subsystem delivered
    - S-Band

- **2013**
  - 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
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

<table>
<thead>
<tr>
<th>Elements per Year</th>
<th>Cost per Element</th>
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<tbody>
<tr>
<td>1000’s</td>
<td>$200</td>
</tr>
<tr>
<td>10,000’s</td>
<td>$400</td>
</tr>
<tr>
<td>100,000’s</td>
<td>$800</td>
</tr>
<tr>
<td>1,000,000’s</td>
<td>$1600</td>
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</tbody>
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Approximate Cost Breakdown (10K element qty’s)

- MMICs, 30%
- Antenna Elements, 7%
- Balance Material, 20%
- Assembly, 25%
- Test, 18%
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: Power * Antenna Area * antenna Gain / noise Temperature. 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

<table>
<thead>
<tr>
<th>Material Cost Comparison</th>
<th>HVMSAG</th>
<th>GaN on SiC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Density (W/mm; 28 V)</td>
<td>1.8</td>
<td>6</td>
</tr>
<tr>
<td>Power Density Ratio'ed to HVMSAG</td>
<td>1</td>
<td>3.3</td>
</tr>
<tr>
<td>Starting Material Cost ($)</td>
<td>700</td>
<td>7000</td>
</tr>
<tr>
<td>Wafer Diameter (mm)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Starting Material Cost ($ / sq. mm)</td>
<td>$0.11</td>
<td>$1.10</td>
</tr>
<tr>
<td>Cost ($ / sq. mm) Ratio'ed to HVMSAG</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td><strong>Cost Ratio / Power Ratio</strong></td>
<td><strong>1</strong></td>
<td><strong>3</strong></td>
</tr>
</tbody>
</table>

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

Fully on-chip matched PA

Chip Size
7500 x 5000um
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

T/R Modules

“Brick”
L-band T/R module, early 90s;
Lincoln Lab Journal, Vol 12, No. 2, 2000

Cost, Size, & Mass Decrease

T/R MMIC, 15 sq. mm

Transition from Brick to Tile / Panel

T/R Module & MMICs

< 1 sq. inch
7 g

5x 20x 5x

1 sq. cm;
0.25 g

3x 2x 2x

T/R MMIC & ASIC in QFN
Plastic Package or LCP Package

30 sq. mm;
0.1 g

3-D IC

T/R Module

Transition from 2D Panel to 3D Panel / ICs


Reduction in size mass cost
75x 200x 50x
(comparison for similar ckt functions)

5x 5x 5x
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

![Diagram of S-band Radar Single Chip T/R Element](image)

**Simple T/R Module**
S-Band DREX
(Digital Receiver-Exciter)

• 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*
• 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

Low cost S-band DREX Multi-channel concept
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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