

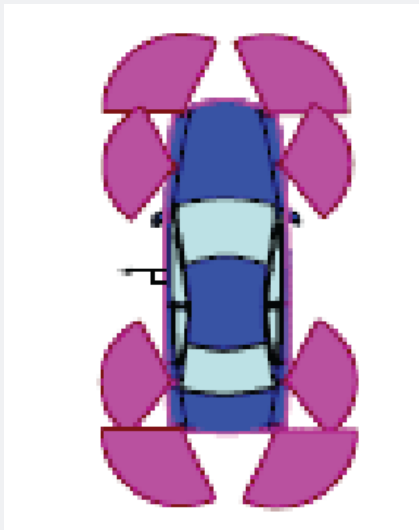
# Integrated Antenna and Package Technologies for Projectiles

MAS  
LTCC  
cgi

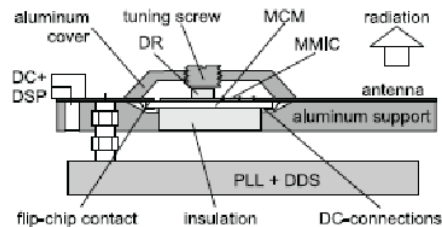
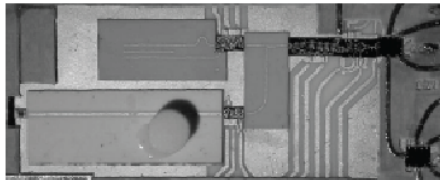
CORVID

WEMTEC

- Abstract Number: #19292
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- Automotive Radar
  - 24 and 77 GHz
  - Multiple Sensors around the vehicle
- Environment
  - Road Chemicals (months)
  - Thermal Shock and Vibration
- High Reliability
  - Typical requirement is vendor pays for recalls.
- Package c 1999 [1]
  - High Resistivity Silicon 2008

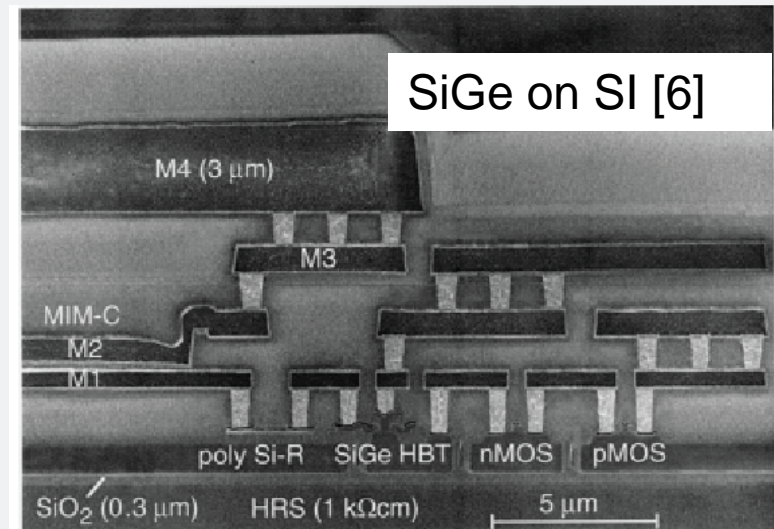




- Video games have demanded ever increasing bandwidth. Image [2]
  - Dense RF environment
    - Many gamers in close proximity
    - Drives to 60 GHz Short Range
  - Virtual Reality needs GHz of bandwidth.
- VR growing into industrial and medical applications. Image [3]
- Safety of Life Applications
  - Child proof
  - Survive sterilization



- Semiconductor developments have kept pace with the need.
  - Silicon CMOS clocked at over 200 GHz. [4]
  - Compound Semiconductors
    - SiGe on Silicon
      - Mixed signal in larger geometries
    - GaN
      - High Power
      - 1 Watt at 37 GHz [7]



- Faster chips mean more heat.
- High frequency
  - More transmission line losses.
  - More complex interconnections

- IEEE 802.11 commonly known as WiFi
  - 60 GHz extension proposed in 2009.
  - Standard 2012
    - IEEE 802.11 ad
  - 6.7 GBPS on four 2.16 GHz Wide Channels
    - Chipset introduced 2012 [5]
- High Frequency needs:
  - Integrated Packages
    - Low frequency interfaces
    - Antenna on Package
    - Package matched to semiconductor TCE
    - Good Thermal Conductivity
    - Hermetic structures.
  - Desired Characteristics
    - Clean antenna patterns
    - Isolation between radiating elements.
    - Ability to make conformal antennas

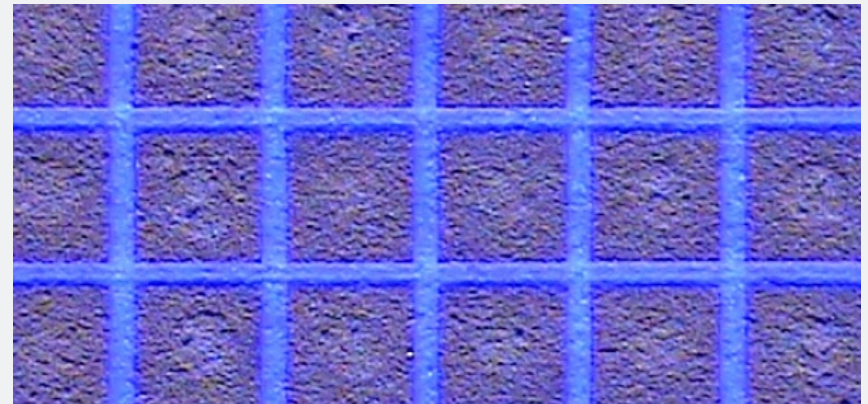
# Other Commercial Developments suited to Military Applications



- Spread Spectrum Communications [12]
  - Original patent 1924 as an anti-fading technique.
  - developed for military use during WW-II
    - Patent by actress Hedy Lamar [13]
  - Commercial Applications
    - GPS
    - Digital Cellular Radio
    - Military Radios
  - On chip IP is available
- Other Support (without references)
  - MEMS Barometric Altitude Sensors
  - GPS chips
  - Mapping Software
  - Wearable displays
  - Night vision

- In response to the needs of commercial MMW applications DuPont developed the 9K7 LTCC family
  - Gold and silver inks
    - Interior lines
    - Ground Planes
    - Solderable Conductors
    - Resistors
  - Green Tape
  - Processing Guidance

- Processing
  - Commercial Manufacturing Base
  - Laser Ablation for precision metal patterning
    - Pre and Post firing

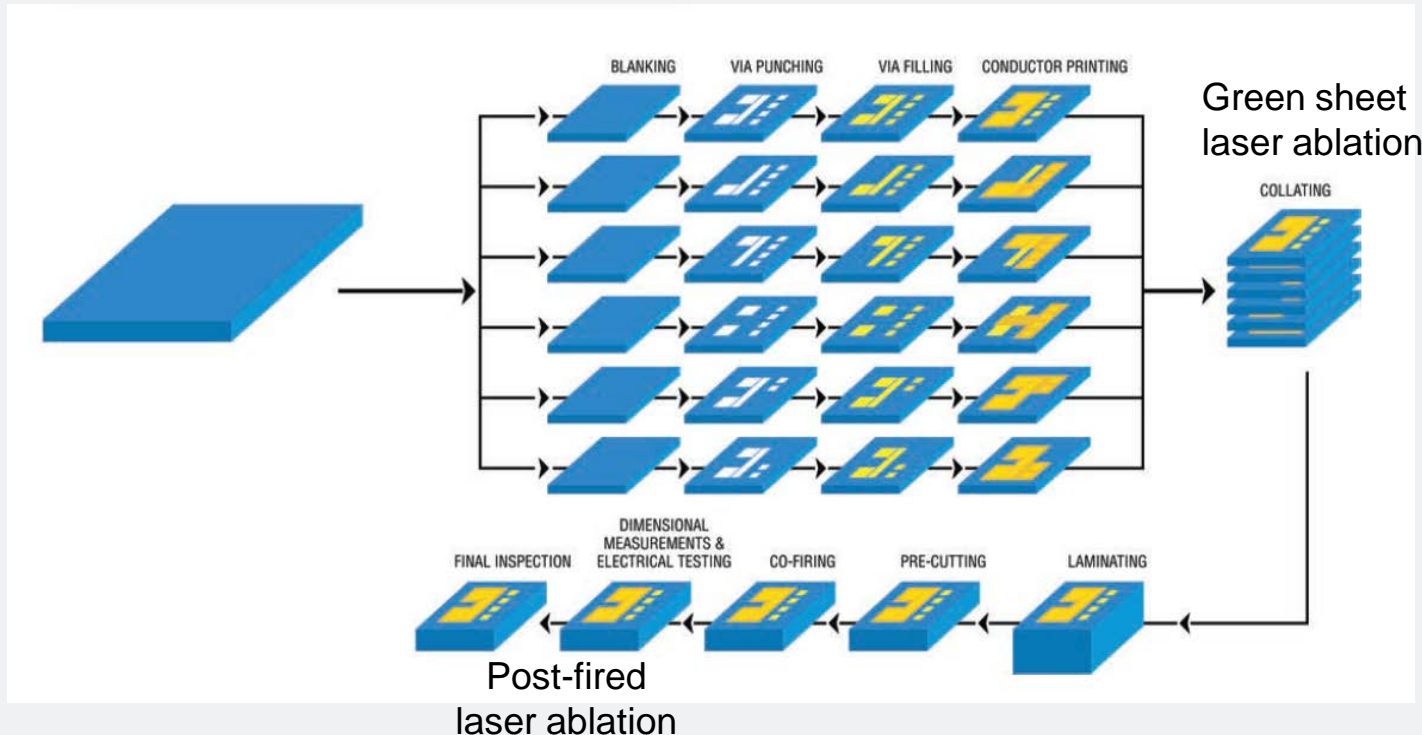


Pre-fired Laser Formed EBG Patches  
55 micron gaps

Low Temperature Cofired Ceramics (LTCC)



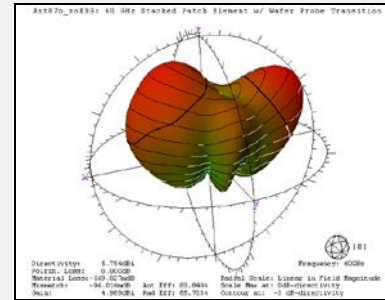
- A complete process has been developed to produce precision packages at MMW.
  - Highly repeatable
  - Controlled shrinkage



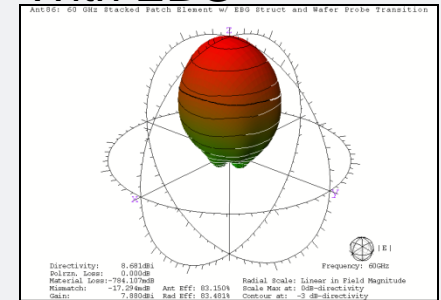
# EBG Structures for Mode Suppression

- All ceramic packages are subject to surface currents due to the dielectric constant of the materials.
  - Edge radiation
  - Cavity modes
  - Radiation from conformal structures
- EBG's [8] [10] are metamaterials that have been designed to suppress these effects.
  - LTCC processing is nearly ideal for application of EBG's

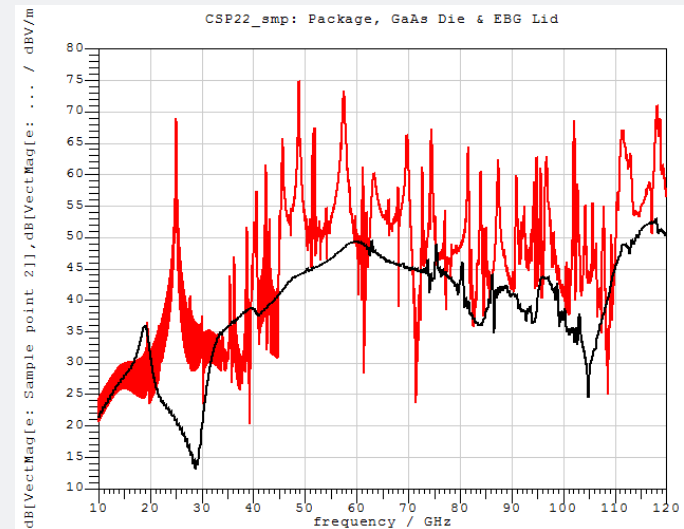
Without EBG



With EBG



EBG's Produce Clean Patterns

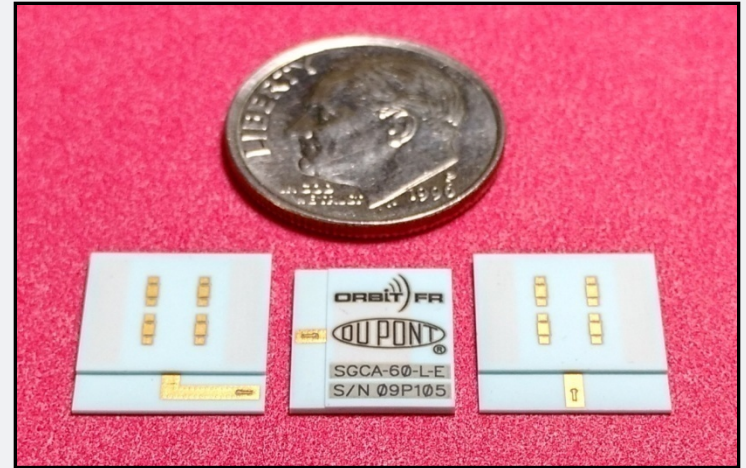


30 dB-v suppression of cavity modes  
10 to 100 GHz

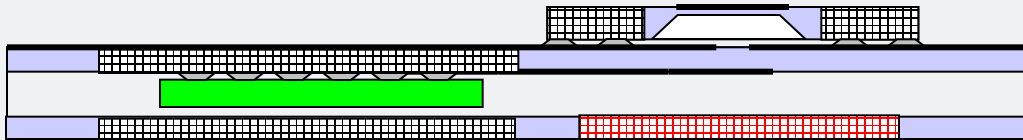
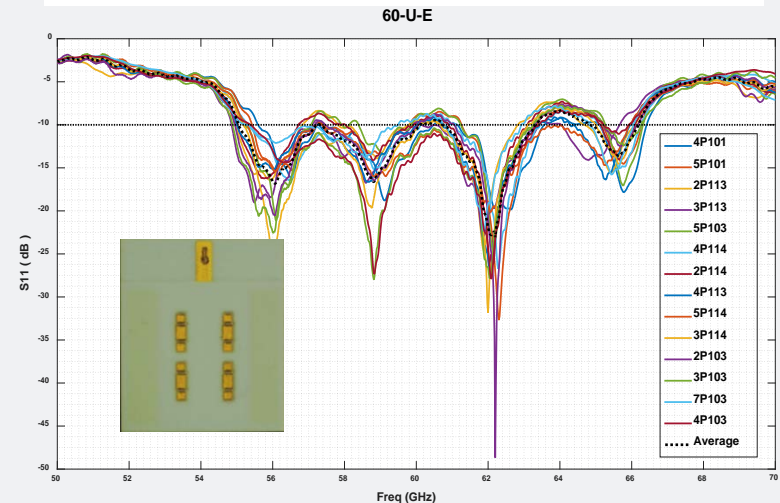
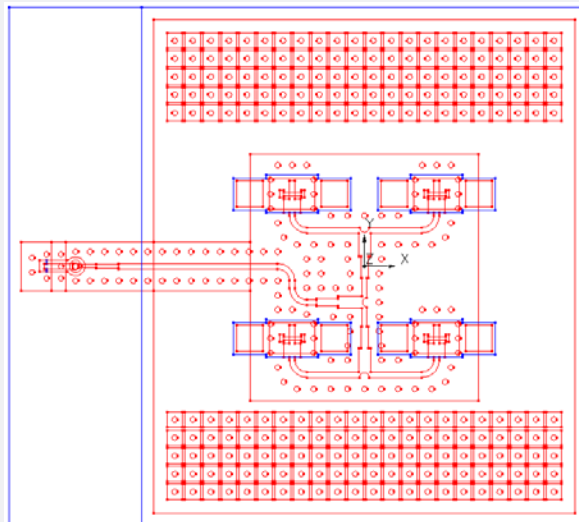
Electromagnetic Bandgap Structures (EBG)

# Commercial Antenna –Chip in Package

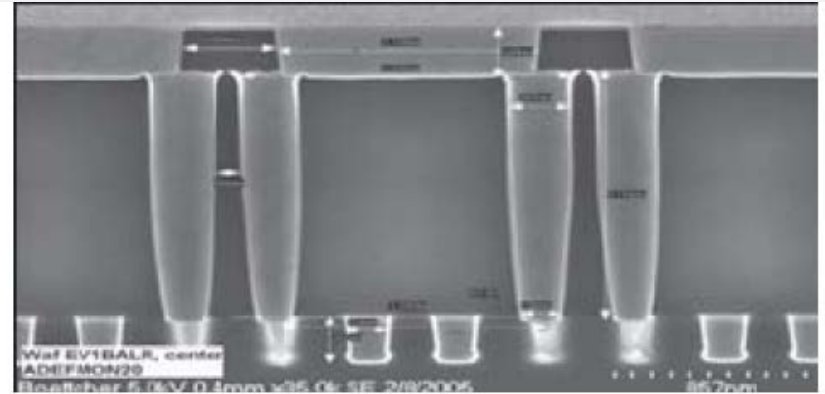
- 60 GHz commercial reference antenna announced at AMTA, October 2016 [14]
  - 9K7 is highly repeatable
  - Complete array in a hermetic package



(Data courtesy of Orbit/FR, designed by WEMTEC)



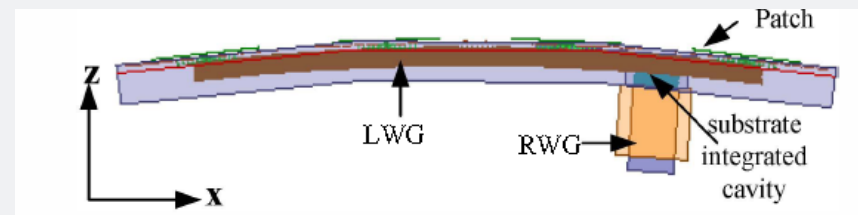
- The key to MMW military applications is to contain the MMW signals in the package.
  - Requires Analog or Mixed Signal ASIC.
  - MMW transitions require mounting close to the antenna
  - Package Survival drives toward two sided mounting.
- Concept is to include all MMW and conversion to low frequency on the RF ASIC.
  - Additional processing in FPGA's to save cost
  - Package interfaces are digital and RF Reference.
  - On chip synthesizer



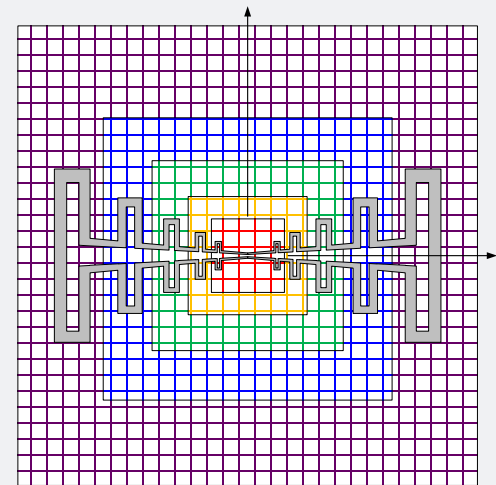
Plated TSV's [16]

- Through Silicon Vias (TSV) provide vertical interconnects above 10 GBPS in 2010 [16]
  - Simulation methods in [16] reduce risk

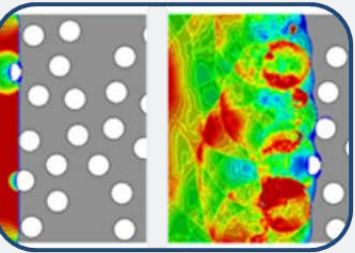
- Projectile and missile applications require conformal antennas.
  - Low Drag
  - Requires custom design for each application.
  
- Any curved antenna will radiate in undesired directions without surface wave suppression.
  - The combination of LTCC and EBG's are a widely recognized solution



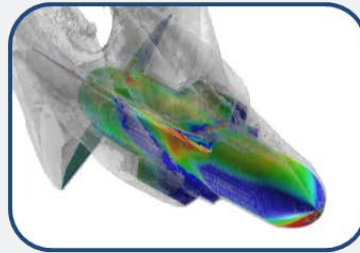
Chinese Conformal Antenna [17] at Ka Band (With AMC)



Log Periodic (LP) Conformal Antenna on AMC



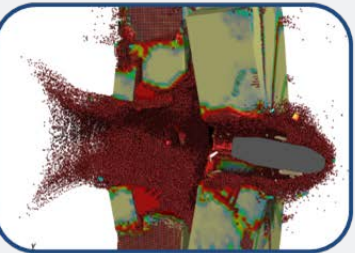
Shock Physics



Fluid Dynamics



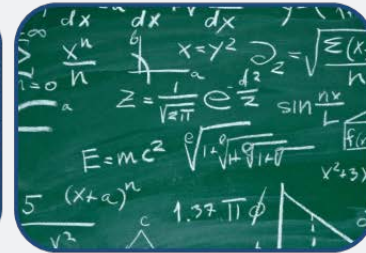
Structural Mechanics



Blast & Ballistics



Optimization



HFCP Solver Development



Warheads



Range Safety



Test & Evaluation

## CORVID

### COMPUTATIONAL RESOURCES

Corvid maintains a massively parallel super-computer system to maximize benefit from in-house, high-fidelity, physics-based tools.

### SPECIFICATIONS & HARDWARE

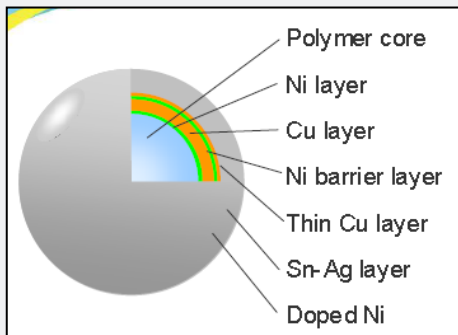
- 30,000 CPU Cores
- 56GB/s high-speed, low-latency, backplane interconnect
- 3.7PB of scalable, high-performance, high-availability data storage
- 64-core, huge-memory (500GB - 2TB), high-performance, post-processing servers
- Unclassified and classified compute partitions
- Project working directories securely segregated to groups of cleared users
- Highly-flexible queue system for accelerated scheduling of critical simulations



**Corvid utilizes proprietary multi-physics solvers to predict the behavior of complex structures when exposed to high rate or extreme loading conditions.**

# Proposed Chip Mounting

- Two sided Chip Mounting
  - Polymer Core Solder balls
  - TSV – bring low frequency out the bottom



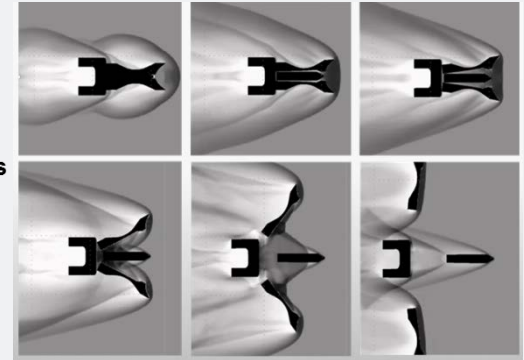
## Topology Optimization



### CORVID'S FIRST PRINCIPLE PHYSICS BASED SOLVER

#### Development Focus

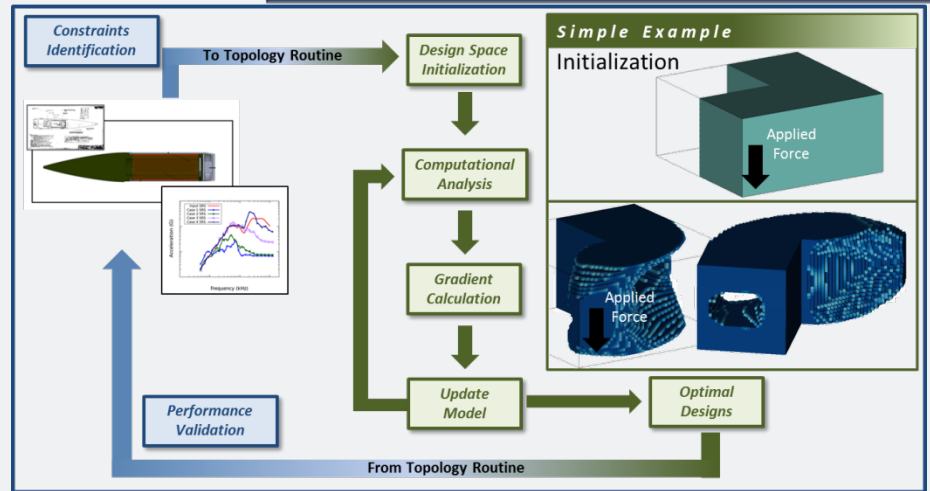
- Massively Parallel (100's of CPUs)
- Advanced Numerics:
  - Hypervelocity Regimes
  - System Level Engineering Problems
  - Predictively Solve Complex DoD Problems
- Ongoing Upgrades through In-House Support



#### Continuous Benchmarking for Validation

- Latest Reference Data in Literature
- Broad Use Across Multiple Agencies
- Anchoring Against Experimental Data

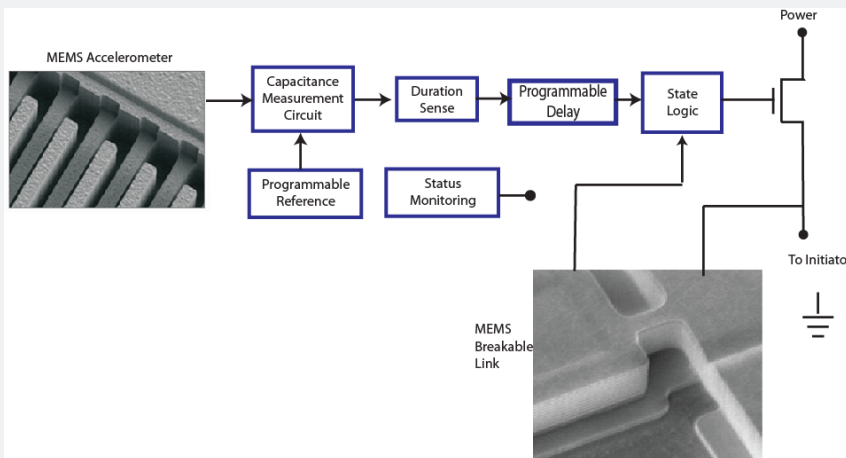
## Predictive projectile dynamics/response during launch and flight



# Safe and Arm

- Need for a safe and arm device that enables without power.
- Must not enable due to handling or abuse.
- Optionally senses spin acceleration normal to the launch direction with power.
  - Programmable spin acceleration and duration

- Automotive airbag sensors.
  - Acceleration Sense programmable device with extensive BIT.
    - Sense spin in a munition
  - Add a frangible mass to disable current prior to launch
    - Frangible mass operates without power



- Automotive sensors provide COTS solution to the ASIC IP.
- Physics based simulation of MEMS device greatly reduces risk
  - Manufacturing tolerance studies.

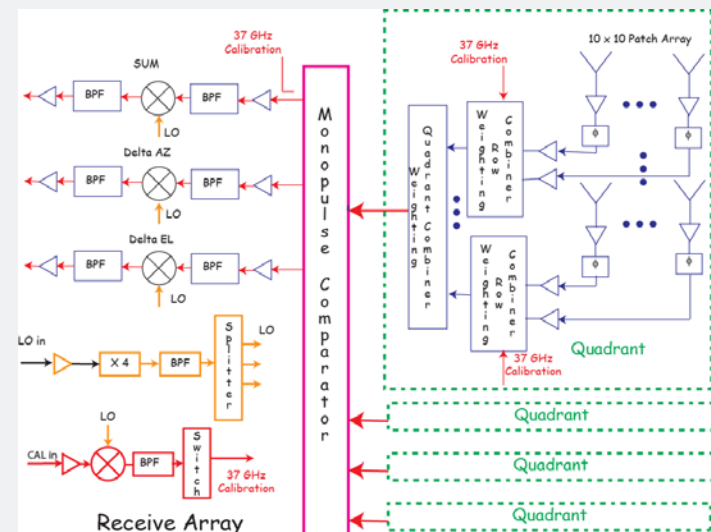


# UAS Detection

- Low cost UAS is a threat.
  - Surveillance
  - Weapon Platform
- Difficult to detect with multiple sensors
  - Low RCS
  - Slow or stationary
  - Low acoustic signature
  - Low visibility
- Krátký [15] gives mean RCS for quad and hex copters:
  - 500 to 4000 MHz
  - Quad empty: 0.08 sqm. -11 dB-sqm
  - Quad loaded: 0.14 sqm. -8.5 dB-sqm
  - Hex empty: 0.22 sqm, -6.5 dB-sqm
  - Hex loaded: 0.33 sqm, -4.8 dB-sqm
- Watt level transmit chips 2014 [7]

## ■ Solution

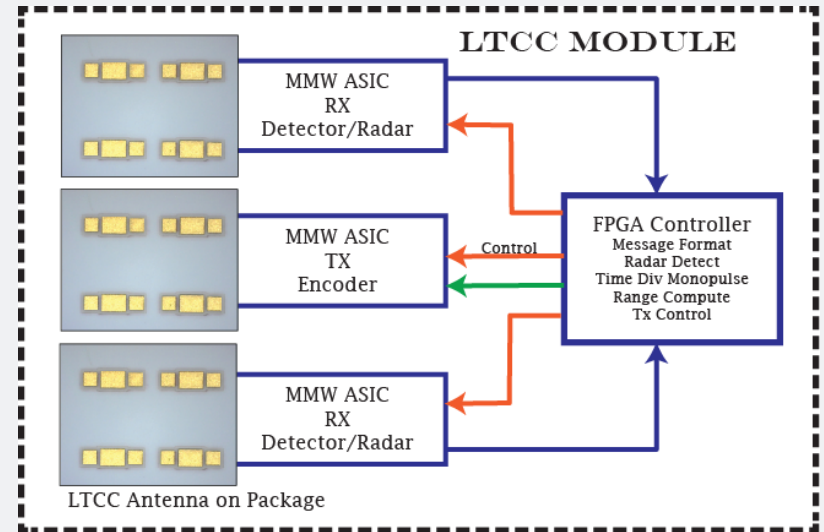
- 35 – 38 GHz FMCW Tile radar
- Search Range 3-5 km -13 dB-Sqm
- Track Range ~1.5 km
- Scalable 1 Tx Tile 1 or more Rx tile
- Rx tiles can be combined into an interferometer for precision track



# Tri-Mode Subsystem

## ■ Single Package

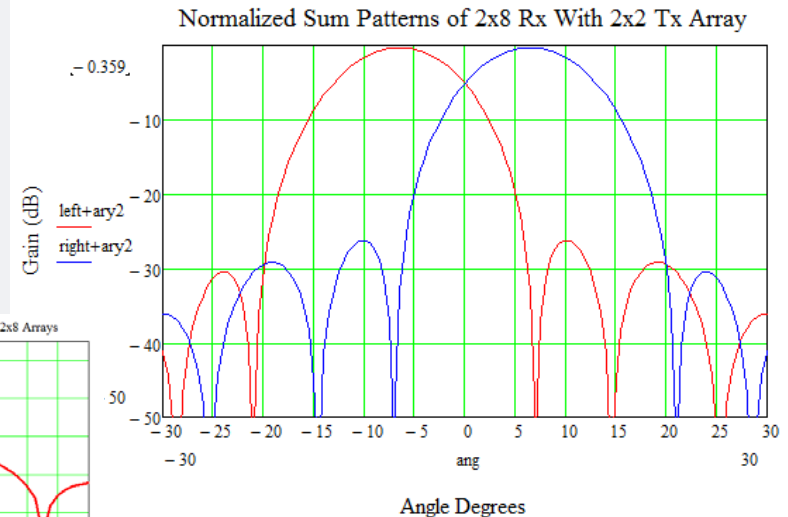
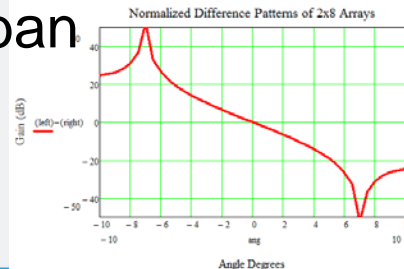
- Three offset antennas
  - Two edges receive
  - Center Transmit
- Produces vertical Sum and Difference Pattern
- Azimuth by combining around platform



## ■ Three Functions

- Transponder (I/FF)/Range Finder
- Communications
- Short Range Radar (0.3 to 1 km)

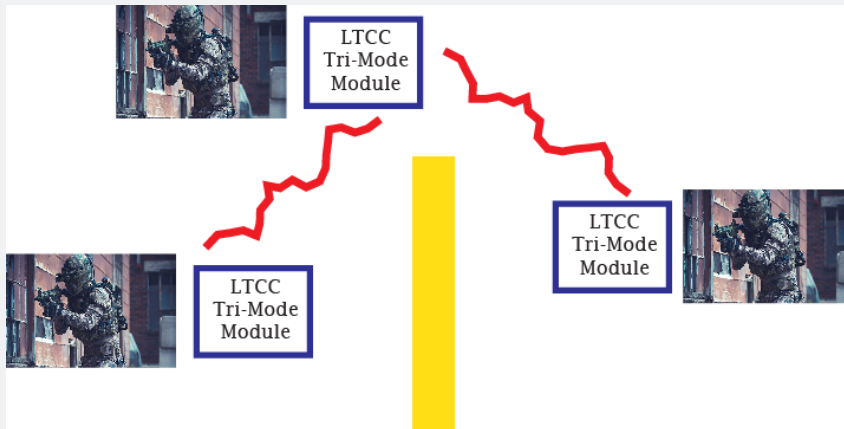
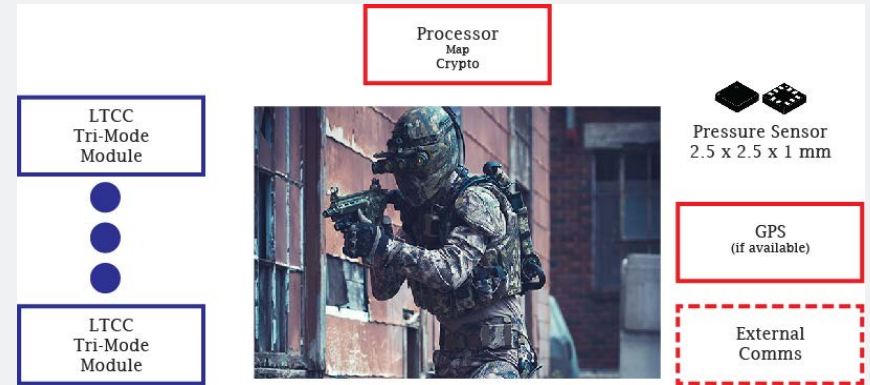
## ■ Provides Swarm and Urban Warrior Support.



- The UAS has many roles for the war fighter.
  - Small reconnaissance and relay platform
  - Various sizes to carry supplies or wounded
  
- Need the ability to swarm
  - Follow the leader.
  - Avoid obstacles.
  - Recognize friends
  
- Planned IR&D for range only mapping.



- Combat is increasingly in an urban environment.
  - Underground and in buildings
    - GPS Denied
    - Minimal visibility
  - Hostiles hidden in multiple civilians
  - Shoot – No Shoot
    - Identify team mates



- Small Soldier to Soldier Communications package.

- Leverage resources of team mates.
- Self Healing network attempts to route around blockages.
- Range and history based geolocation.

Share Resources, Self Healing Network

## ■ Chip to Package Transitions

- Frequency and chip process specific at MMW.
- May require designs for specific applications.
- Technical Risk is low
  - Risk is cost.

## ■ Shock Levels

- Shock levels need to be extended by an order of magnitude over automotive applications.
- Cannot prevent operation at MMW
- Mitigation using Advanced Physics Based Modeling

## ■ ASIC Development cost

- This is a cost associated with any program.
- Mitigate by using SiGe for larger geometries
- Mitigate by using FPGA's and off package processors.

## ■ Thermal management

- Duty factor can be reduced taking advantage of available bandwidth.
- Move processing off package.

- SEG is a traditional defense contractor that produces a range of military products including radar, radar scene simulations used as GFI for naval radar development and test, hardware radar scene simulations and other physics based models. SEG brings expertise in systems engineering, integration and test with facilities and computing cleared to the TOP SECRET level. SEG is a division of Telephonics Corporation.
- TLSI is a mixed commercial and defense contractor specializing in design and packaging of mixed signal ASIC's in the commercial, automotive and military sectors. Being foundry agnostic; the full range of chip technology is available. Services include: device design, simulation, validation and contracts with multiple sources for foundry, packaging and test of semiconductors.
- Corvid Technologies is an 8(a) certified small disadvantaged business and a leading developer of solutions for high impact/shock environments. Corvid's predictive high-fidelity computational physics solutions support the defense and motorsports industries; including post intercept debris, launch and impact modeling with a 25,000 CPU supercomputing facility.
- WEMTEC is a nontraditional defense contractor and small business that specializes in millimeter wave design and simulation using specialized techniques involving metamaterials and LTCC materials. WEMTEC owns significant intellectual property in these areas.
- MAS LTCC is a small business whose principal is one of the developers of LTCC materials and processes now retired from DuPont.

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