Digital Array Radar: MPAR Applications

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Overview of Presentation

• Introduction
  – What is a Digital Array Radar
  – Benefits/ Drawbacks
  – Comparison of Architectures
  – History

• Current DAR Effort
  – Approach
    • GaN/ SiGE
  – Current Status/ Results

• Newer DAR Effort
  – Dual Polarization
  – New SiGe Components

• The Future
What is a Digital Array Radar?

Digitization of the signal at each element. The combining of signals is done in the digital domain.

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Ethernet Output

Digital

Analog

PA/LNA

Downconverter

A/D

D/A

Digital Backend
Benefits

- Digitization takes place at each element.
  - The combining and processing of signals is done completely in the digital domain.
- This offers the ultimate in flexibility because the signals are combined digitally and can be dynamically changed as needed.
  - The connections between elements can be easily reconfigured.
- This minimizes the amount of array specific analog components.
  - Allows for massively integrated analog systems and standardized digital systems
- Advanced calibration/processing allowed at each element
  - Digital equalization allows for very good element to element consistency across a wide frequency band.
- Independent waveform synthesis capable at each element
- Memory is allowed on the panel to store information selectively

Challenges

- Synchronization
- Handling the amount of data that is generated on the panel
Overlapped Subarray Beamforming

Practical, modular approach to beamforming – scales well to large arrays and a good approach. However it is fixed and hard to reconfigure once designed.
Overlapped Subarray (OSA) Digitization

Can form on the order of $M$ simultaneous beams with purely analog beamformers

- Antenna array (N elements)
- T/R modules (N elements)
- M RF OSA beamformers
- M down-converters
- M digitizers
- Radar Signal Processor and final beamformer

Digital at Every Element with Hierarchical Digital Backend

Digitizer modules, intermediate processors, and final signal processor work together intelligently and flexibly

- Antenna array (N elements)
- T/R modules (N elements)
- M down-converters
- M digitizers
- Baseband
- Digital
- Intermediate Processor
- Intermediate Processor
- Radar Signal Processor and final beamformer
Hierarchical Digital Backend

Digital Backend with Central Processing

- Bridges the gap between traditional, multi-beam analog beamformers and the “ultimate” digital beamformer

Hierarchical Backend

- Strain is on the Central Processor to Handle the Influx of Data and Process the Entire Array
- Brings computation closer to array face and provides capabilities of beam forming and processing at different levels within the array
• Program goals:
  – Provide a generic platform for future advanced, low-cost radars
  – Push for low-cost integration of efficient, active components within radiating panel
  – Demonstrate multi-functional approach to radar system design
  – Use modern digital transceiver technology for system flexibility
  – Develop intelligent digital backend architecture

Contributions by Sierra Monolithics, Inc., CREE Semiconductor, and Lockheed Martin
At a high level, the digital radar program is trying to push technology to demonstrate where we see radar will be in years to come.

**Multifunctional** : For satisfying multiple functional requirements, the flexibility of the digital domain is exceptionally useful. (Digital at Every Element)

**Highly Integrated** : We are trying to distribute the digitization and the processing as close as possible to the apertures and have less than 1 analog IC per element. (SiGe)

**Flexibility** : This approach minimizes the analog components while pushing the difficulties into the more inherently flexible digital domain. (Hierarchical FPGA’s)

**Low Cost** : We are attempting to use commercial components and integration practices to remove the cost as much as possible. No liquid cooling or advanced packaging. (GaN)
DAR Program Concept V1
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Digital
ADC/DAC’s, FPGA’s, Memory

Analog
Antenna, GaN and SiGe

CAD Representation of Final Prototype Subarray
DAR Program Demonstrator

IDEAS Microwave Laboratory
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DAR Version I Prototype Subarray
Future Radar Needs

- Low cost per element
- High prime/RF power efficiency
- Lighter, panelized form factors
- Multiple concurrent functions
- Beamforming agility

Enabling Technologies

- Wide-bandgap semiconductors
- Silicon integration in T/R modules
  - Less than 1 IC per channel
- Commercial manufacturing
  - Surface mount integration
- Cheaper, faster ADCs & processors
- New digital architectures
History

• 2006
  – Started our effort with the antenna panel design under a contract with the ARMY (CERDEC). Loosely based on EQ36 radar specs for realistic bounds on development.
  – Cree started the development of GaN MMIC’s

• 2007
  – Sierra Monolithics identified their current MIMO WIMAX SiGe IC as a candidate for the multichannel transceiver
  – Sierra begins creation of their next generation radar specific SiGe design, direct down conversion started
  – Digital backend effort is started at Purdue with FPGA, software and GUI development

• 2008
  – First results of antenna panel presented at IEEE COMCAS conference (March 2008)
  – At the same conference, ELTA states that they have a working Digital Array Radar. Definitively states that this is their future.
  – Tracking Demo held at Lockheed Martin to show the functioning panel (Nov. 2008)

• 2009
  – Presented Air Cooling of GaN in Panel and Tracking Results (IEEE MTT IMS)
  – Dual Pole Antenna Effort Started.
Basic Assumptions for DAR

• In 5 to 10 years, one constant that will prevail is the ability to have increased processing capabilities in the digital domain.

• Common platforms and modularity will be most easily handled in the digital domain allowing for easy resolution of disputes over shared apertures.

• Power is a driving factor in radars, so creating the highest power amplifier that commercial packages can handle is a prudent approach.
  - Duty Cycle and power are continuous needs for a system that is developing, since the capabilities are developing you would ideally have power overhead.

• MIMO systems have been driven into most if not all communication specs which has lead to massive integration, for example multiple SiGe transceivers on a chip.

By 2020, you do not want to have the best in technology that 2009 has to offer. So we are pushing in the newer directions that we see on the horizon.
Low-Cost DAR Radar

"2 Chip Radar" Solution

Traditional Hybrid Radar Module

Advanced Integration

Digital Backend

Massively integrated SiGe chip transceivers

GaN MMIC

Planar “laptop-like” Integration – Simple 4 Layer Board for Analog Components

Remove Component Cost By Leveraging Commercial Integration Practices, remove T/R module

The 400 Watt Radiating Laptop

Image from Eurofighter’s radar
http://www.airpower.at/news06/0922_captor-e/index.html
1) **Antenna Panelization**  
Antenna was designed, analyzed for mutual coupling, fabricated, and tested.

2) **Plastic High Power Packaging**  
Multi-layer panel and plastic packaging designed to house efficient GaN T/R modules.

3) **Silicon Integration** Utilized integrated Sierra Monolithics 2x2 WiMAX SiGe transceiver.

4) **Digital Processing** Quadrant boards perform data conversion and element-level processing.

5) **Synchronization**  
Digital backend Control board designed, laid out, and populated in-house.

Wrote firmware for FPGAs and software for host PC interface.
High Power Organic Antenna Array

Plastic panel integration of wide band planar antennas and RF electronics board in one easily manufacturable unit.

Composite multilayer polymer antenna

Large Area Integration 8x8 antenna only array constructed

• >35 Watts per element has been demonstrated with limited cooling on RF GaN antenna panel

• Air cooling upto 50% duty cycle with 25 watts radiated

• Simulations show 80% efficiency at 7 Watts for GaN Amplifiers

• Plastic QFN packages are therefore possible
Cost is Reduced Through Simplified Packaging

- Comparison of Air Cooling Techniques
- At least 10°C cooler than without a fan
- All tested points above 22dB of Gain
- Base Plate (Solid), Input Stage (Dash) and Output Stage (Dash-Dot)

**Base Plate Temperature and Measured Efficiency**

- **Piezo Fan**
- **Fan**
- **Heatsink**
November Results – Beamforming

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Purdue DAR Digital Beamforming -- Tx.

Measured Versus Simulated Digitally Formed Patterns from Panel

Demo 1 – Generation of a pattern demonstrated for transmit and receive
Further Developments – Target Tracking

- Send out 14 MHz wide linear frequency modulated (LFM) pulse from bottom two elements
- Receive scattered wave on top two rows and demodulate waveforms in Matlab
- Perform monopulse comparison test to determine angle & strength of return
- Mutual coupling and clutter removed by recording these before introducing target
- This simulates a simple MTI (moving target indicating) radar

Demonstration of target tracking
The integrated SiGe transceiver is very useful for dual polarization.

There are two channels on one integrated circuit, so one IC handles both inputs from the antennas.
DAR Dual Polarization Work

Dual Pol Antenna Designed and Measured

Adapted to Current DAR System

Sierra SiGe board redesign for panelization of new SMI I/Q transceiver

Designed for simultaneous transmit on each polarization

Independent waveform synthesis at each antenna will allow for compensation of polarization mismatches to improve polarization metrics
Typical weather radar specifications:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half power beam width</td>
<td>&lt;1 degree</td>
</tr>
<tr>
<td>Close in side-lobe levels</td>
<td>&lt;-30 dB</td>
</tr>
<tr>
<td>Differential Reflectivity Bias Error</td>
<td>&lt;0.1 dB</td>
</tr>
<tr>
<td>Integrated Cross-Pol Ratio</td>
<td>&lt;-32 dB</td>
</tr>
</tbody>
</table>

- Cross pol isolation measured to be less than -35 dB
- Independent waveform generation at each polarization allows for compensation.
Theoretical ICPR < -55 dB for a 1 degree beam with 35 dB sidelobes (Taylor weighting assumed)

From a projection of a large array (~20,000 elements) based on the measured small array isolation (8 elements), the polarizat. compensation allows for theoretically great ICPR (<-55 dB)

Without polarization compensation, ICPR is as bad as -9 dB at certain scan angles
We believe that the DAR approach is a good candidate for the MPAR program.

DAR leverages technologies that we believe will be fully mature by the time that MPAR is activated. The main weakness (data handling and processing) should be a strength by the time of implementation.

DAR would be necessary to create a larger scale demo to show the array in operation. Only a 16 element panel created so far.

Using the University as the system planner/integrator gives both the human resource development to feed into radar programs and the novel approaches that will push technology forward.
Mutual Coupling Measurement

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Mutual Coupling Between Elements

Cross Polarization Couplings below this line (<30 dB)
Cost Analysis

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Cost of the major components of the panel:

The GaN is expected to be at a dollar per Watt by 2013 -> $20 per element

The Sierra Monolithic Transceiver IC’s are 4 to 6 dollars in bulk -> $5 per element

The quadrant FPGA’s that we are using are 15 dollars per quadrant = $3.25 per element

The controller FPGA is 40 dollar per panel = $2.5 per element