RF to Digital (RF2D™)
Data Converter Modules & RF Overview

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Agenda

- Introduction to the Data Converter Modules Business
  - Business Principles
  - Technology Introduction
  - Reference Designs

- FPGA DRFM prototyping system

- RF to Digital (RF2D)
Tek Products - Enabled by Leadership Technology

Performance Oscilloscope

20 GHz RTSA

Handheld Spectrum Analyzer

Multi-Domain Oscilloscope

Key Enabling Technology
ASIC Technology Background

Enabling Differentiation through Advanced Technology:

- **Tektronix CSO ASIC Design Team**
  - Dedicated resource of 40 engineers complimented by partnership relationship (~20 additional designers)
  - Focused on High frequency mixed signal and high speed digital design

- **IBM**
  - Technology partnership since 1996
  - 5HP/7HP/8HP SiGe BiCMOS
  - Recently entered into a deeper cooperative development around future technology nodes

- **Tektronix CSO**
  - Custom microelectronics services
  - ~65 design, assembly and test engineers

- **Certifications**
  - ISO9001:2008
  - ISO14001:2004
  - ITAR-registered
  - Secure Facility

Transistor speed evolution demonstrating advantage of switch to SiGe in 1996
Reference Design Principles

Tektronix Component Solutions data converter modules provide the performance of the Tektronix ASICs in a real-time embedded system form factor.

**DPO72004 Oscilloscope**
- Bandwidth: 20 GHz
- Sample rate: 50 GS/s

**7HP ASIC Flip Chip BGA**

**Acquisition Board**

**Data Converter Modules**
New Analog Front-end Sample & Hold

Tektronix Component Solutions data converter modules provide the performance of the Tektronix ASICs in a real-time embedded system form factor.

DPO73304D Oscilloscope
Bandwidth: 33 GHz
Sample rate: 100 GS/s

Acquisition Board

Tek 10/11 8HP ‘Deuterium’ ASIC

New data converter module
Tektronix Component Solutions
Leveraging Capabilities & IP

- RF & Microwave model:
  - MDO4000 Multiple Domain Oscilloscope
  - TSFB-900A Switched Filter Bank
  - Custom Integrated Microwave Assembly
  - Tektronix-designed & assembled element
ADC Technologies

Analog Input Frequency (Hz)

ENOB

- < 0.1 W
- 0.1 W < 0.5 W
- 0.5 W < 1 W
- 1 W < 2 W
- 2 W < 5 W
- > 5 W

ISSCC 2006
VLSI Ckts 2006

DARPA RADer ADC (Target)
Tektronix 12 GS/s Digitizer
Tektronix 50 GS/s Digitizer

"The Goal"

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Data Converter Module Reference Designs

- Provides access to Tektronix Data Converter technology:
  - Without the investment required for a custom module
  - For immediate prototyping and application tests
  - To help determine and evaluate specifications for a custom module

- Modules are:
  - Designed for use as a production solution
  - Must comply with US export requirements
Two modules are available:

- Reference Digitizer Module
  - 8 bits
  - 9 GHz Bandwidth
  - 12.5 GS/s (100 Gbps)
  - On-board FPGA-based DSP processor
  - 3.6” x 5.9”

- Reference DAC Module
  - 10 bits
  - 9 GHz Bandwidth
  - 12 GS/s (120 Gbps)
  - 4.2” x 4.5”
## Reference Digitizer-Nominal Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Bandwidth</td>
<td>9 GHz</td>
</tr>
<tr>
<td>Sample Rate</td>
<td>1-ch: 12.5 GS/s</td>
</tr>
<tr>
<td></td>
<td>2-ch: 6.25 GS/s</td>
</tr>
<tr>
<td>SFDR</td>
<td>&gt; 47 dBc up to 5 GHz</td>
</tr>
<tr>
<td>ENOB</td>
<td>7.0-7.4 bits @ 10 MHz</td>
</tr>
<tr>
<td></td>
<td>6.2-6.6 bits @ 5 GHz</td>
</tr>
<tr>
<td>Input</td>
<td>± 256 mV differential into 100 Ω</td>
</tr>
<tr>
<td></td>
<td>AC-coupled</td>
</tr>
<tr>
<td>Input VSWR</td>
<td>1.3:1 @ 2 GHz</td>
</tr>
<tr>
<td></td>
<td>1.6:1 @ 6 GHz</td>
</tr>
<tr>
<td>Length</td>
<td>3.6”</td>
</tr>
<tr>
<td>Width</td>
<td>5.9”</td>
</tr>
<tr>
<td>Height</td>
<td>1.5”</td>
</tr>
<tr>
<td>Power</td>
<td>15 W for ADC/demux; total 33-51 W dependent on user FPGA application and device variations</td>
</tr>
</tbody>
</table>
## Reference DAC Module-Nominal Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channels</td>
<td>1</td>
</tr>
<tr>
<td>Physical Bits</td>
<td>10</td>
</tr>
<tr>
<td>Sample Rate</td>
<td>10-12 GS/s</td>
</tr>
<tr>
<td>SFDR</td>
<td>&gt; 45 dBc to 2 GHz</td>
</tr>
<tr>
<td>Non-Linearity</td>
<td>0.2% of full-scale DC DNL</td>
</tr>
<tr>
<td></td>
<td>0.4% of full-scale DC IN</td>
</tr>
<tr>
<td>Analog Output</td>
<td>5 GHz 3 dB bandwidth</td>
</tr>
<tr>
<td></td>
<td>50 Ω output impedance, ±2%</td>
</tr>
<tr>
<td></td>
<td>±0.5 V per side into 50 Ω loads</td>
</tr>
<tr>
<td>Clock Input</td>
<td>10 GHz</td>
</tr>
<tr>
<td></td>
<td>50 Ω input impedance ±10 Ω</td>
</tr>
<tr>
<td></td>
<td>Differential swing ±200 mV to ±500 mV</td>
</tr>
<tr>
<td></td>
<td>Common Mode -0.5 to +0.5 V</td>
</tr>
<tr>
<td>Length</td>
<td>4.45&quot;</td>
</tr>
<tr>
<td>Width</td>
<td>4.20&quot;</td>
</tr>
<tr>
<td>Height</td>
<td>0.74&quot;</td>
</tr>
<tr>
<td>Power Dissipation</td>
<td>23 W</td>
</tr>
</tbody>
</table>
Reference DAC Characterization - SFDR

SFDR (dB) vs. Signal Freq (GHz)
Agenda

- Introduction to the DCM Business
  - Business Principles
  - Technology Introduction
  - Reference Designs

- FPGA DRFM prototyping system

- RF to Digital
High-performance ASIC Prototyping System (HAPS)
HAPS Intro

- Core FPGA hardware from Synopsys (www.synopsys.com)
- Quick & easy prototyping of complex FPGA applications
- Rich IP support
- Support for up to 4 Digitizers or DAC interposers or combinations thereof
  - System bandwidths of up to 400 Gb/s (input) & 480 Gb/s (output)
  - 4.5, 9 or 18 million gates
- Gives customer’s access to Tektronix’ digitizer and DAC technology
  - Complete packaged, validated design giving faster time to market
- Scalable architecture with high-speed FPGA to FPGA busses
  - Expandability
- Wide array of peripheral daughterboard options using HapsTrak standard to connect to industry standard busses and peripherals
- Off the shelf hardware
HAPS Digitizer & DAC Interposers

- Allows up to four high speed digitizer or DAC boards to be configured on the same system
- Precise time alignment of sampling to 2 ps, using built-in cal signals
- Up to four V5 LX330 or four V6 LX760 FPGAs available for signal processing
- Algorithm development for receivers, transmitters, or combined systems
Multi-channel Digital Receiver Test Bed
RF Capture Playback System Development

- **Challenge:**
  - Validation of processing algorithms as they are scaled to multi-GHz instantaneous bandwidth
  - Validation of required system level analog performance

- **Key business requirements**
  - Time to market: How to compress typical proof-of-concept, prototype, qualification timeline
  - Development cost: how to minimize NRE, IR&D costs

- **Proof of Concept**
  - Tektronix oscilloscopes and Arbitrary Waveform Generators used to validate proof of concept

- **Prototype**
  - Leverage commercially-available scalable FPGA emulation platform
    - Validation of FPGA code
    - Can be used for custom ASIC development
  - Interface boards developed for the DCM reference designs
  - Algorithm RTL developed in parallel
RF Capture/Playback Prototype System

- Tektronix Digitizer & DAC reference modules
- Synopsys HAPS FPGA system
DRFM Prototyping System

2 x Digitizer  HAPS board  2 x DAC
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- FPGA DRFM prototyping system

- RF to Digital (RF2D)
Traditional RF-to-Digital Approaches

Narrowband tuner

Narrowband down-conversion
RF-to-Digital Concept

- Direct digitization of ~6 GHz spectrum possible today
  - ENOB & SFDR need matching to application requirements
  - Full-rate streaming is key

- Bandwidths > 6 GHz problematic
  - Data rates exceed off-the-shelf FPGA’s
    - At 12.5Gs/s sample rate we are pumping data at 100gb/s
  - ENOB & SFDR decline below acceptable limits
  - Storage for more than a few ms requires LOTS of wide memory or expensive proprietary RAID solutions
  - Digitizer technology still evolving

- Full coverage of 20Ghz of spectrum is possible
  - Wide bandwidth filters & up/downconverter blocks
  - Wide bandwidth ADC’s
  - Size weight and power are still challenging

- Tek developing reference architectures to support 20 GHz of bandwidth at 8-bit resolution
RF to Digital Architecture

- **I/P Prot**
- **PLL**
- **Gain/Atten.**
- **Buffer**
- **LPF**
- **Cal Source**
- **ADC**
- **V6FXT FPGA**
- **3.125GHz Clock**
- **Data & Control to host via PCIe**

**0-5 GHz Block A**
- Buffer
- LPF

**5-10 GHz Block B**
- Buffer
- Preselector
- Upconverter

**10-15 GHz Block C**
- Buffer
- Preselector
- Upconverter

**15-20 GHz Block D**
- Buffer
- Preselector
- Upconverter

**Downconverter**
- PLL
Overlapping Bandwidth Characteristics
RF/Microwave Module & Sub-Assembly Experience

- **RF/μWave solutions for Tek**
  - Sampling & TDR modules (DC to 70GHz)
  - HF Broadband Probes (DC to >20GHz)
  - Spectrum Analyzer modules & sub-assemblies
  - (RTBW > 100MHz, Freq Range > 20GHz)

- **Custom Functional Blocks:**
  - Band Switches
  - Switched Filter Banks
  - Mixers, converter blocks
  - Frequency Doubleurs
  - Frequency Synthesizers
  - DROs / LOs / PLLs
  - IF Amplifiers
  - Broadband Amplifiers
  - Clock Recovery Modules
RF/Microwave Design Capabilities

Concurrent/Turnkey Design & Development:

- **Circuit Design & Simulation**
  - Trade-offs associated with physical implementation
  - Launch/connector modeling, design & characterization
  - Signal integrity optimization
  - Substrate layout & design
    - Alumina, Quartz, Duroids, other
    - Thin Film, Thick film, PCB

- **Mechanical Design & Simulation**
  - Housings & assembly design
    - Gasketing, connectors, shielding, cabling
  - Tolerance & thermal analysis
  - Assembly process & materials analysis, non-linear FEA
  - Assembly interface requirements for tooling/equipment

- **Component Engineering / Environmental Testing**
  - Connectors, custom mechanical
  - COTS active & passive
  - Accelerated life testing
  - Thermal cycling
RF/Microwave Assembly & Test Capabilities

- **Process & Assembly**
  - Physical implementation focusing on accuracy, repeatability and consistency
  - Interconnect
    - mesh, ribbon, wire bonding, beam lead, soldering
  - Component & Substrate placement
    - tight placement accuracy (5μm), gap control (50μm)
  - Component attach methods
    - solder, epoxy, RoHS compatibility
  - Precision mechanical assembly
    - housing, cables, coaxial launches

- **Test & Trim Development**
  - Design characterization and data interpretation
  - Full RF/microwave performance testing (module and sub-assembly levels)
  - Active and Passive Substrates Trim capability
  - Measurement validation and traceability
  - Troubleshooting capability

- **Procurement**
  - Risk mitigation for sole source
  - Supply chain & product life-cycle management
## RF Module Examples

<table>
<thead>
<tr>
<th>IF AMP</th>
<th>Doubler-Filter</th>
<th>LO Amp</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="IF Amp" /></td>
<td><img src="image2" alt="Doubler-Filter" /></td>
<td><img src="image3" alt="LO Amp" /></td>
</tr>
<tr>
<td>14 GHz Pre-selector</td>
<td>20 GHz Pre-selector</td>
<td>20 GHz Switch</td>
</tr>
<tr>
<td><img src="image4" alt="14 GHz Pre-selector" /></td>
<td><img src="image5" alt="20 GHz Pre-selector" /></td>
<td><img src="image6" alt="20 GHz Switch" /></td>
</tr>
<tr>
<td>14 GHz Switch</td>
<td>Mixer</td>
<td>DRO</td>
</tr>
<tr>
<td><img src="image7" alt="14 GHz Switch" /></td>
<td><img src="image8" alt="Mixer" /></td>
<td><img src="image9" alt="DRO" /></td>
</tr>
<tr>
<td>5 GHz IF Board</td>
<td>PLL Board</td>
<td>Bias Board</td>
</tr>
<tr>
<td><img src="image10" alt="5 GHz IF Board" /></td>
<td><img src="image11" alt="PLL Board" /></td>
<td><img src="image12" alt="Bias Board" /></td>
</tr>
</tbody>
</table>

Additional module details available upon request
**RF2D Module**

**Specification**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Range</td>
<td>0.5 to 18 GHz</td>
</tr>
<tr>
<td>Minimum Capture Bandwidth</td>
<td>&gt; 1 GHz per channel</td>
</tr>
<tr>
<td>A/D Converter</td>
<td>4 Channel System: ~3.125 GS/s</td>
</tr>
<tr>
<td>Channels</td>
<td>1 to 4</td>
</tr>
<tr>
<td>Size</td>
<td>3.5&quot; x 3.5&quot; x 8&quot;</td>
</tr>
<tr>
<td>Power</td>
<td>61W during cal (2 CH)</td>
</tr>
</tbody>
</table>
Typical Module Set for RF2D
Summary

- Providing a path to leverage core Tektronix technology for use in RF/μWave mil/aero applications
  - ASICs, Custom hardware development, RF design, packaging, component-level test & processing algorithms

- Equivalence between Tektronix Instruments, instrument-grade functional elements and custom assemblies provides
  - Reduction of Risk, Schedule & Costs

- Focus on C-SWaP with wide-band capability
Custom Designs
Future possible developments

- Miniaturization of RF components to address C-SWAP requirements
- Direct connect Tek-204 Digitizer to FPGA
  - Utilize SERDES on FPGA to eliminate DEMUX and reduce size/power/complexity
- Multi Chip Module (MCM)
  - Combine ADC, DEMUX & CAL FPGA on single chip
- Low-latency DEMUX
- New FPGA or XILINX ZYNQ on new ref digitizer
- Higher analog bandwidth designs utilizing Tek 10/11 ASIC
  - Interleave multiple Tek-204’s, 8 ADC’s would give 100Gs/s, 33GHz B/W
- Higher resolution through gain ranging ADC’s
  - Target is 8 ENOB (10 native) at ~3GHz of Bandwidth
  - Still in research
- Rugged modular VPX module
  - Designed for DRFM/EW/SIGINT applications
  - Flexible ADC/DAC sites – interchangeable 8, 10, 12 14+ bit designs
  - Deep memory
  - V6 FPGA
Summary

- You can have low power, high bandwidth OR high resolution
  - Unfortunately you only get to pick one attribute at a time!
  - Leading edge research focusing on 10 bits ENOB @ 10 GHz

- Capable of supplying a complete RF2D solution

- Capable of delivering full custom Integrated Microwave Assemblies (IMAs)

- Providing a path to leverage core Tektronix technology for use in embedded mil/aero applications
  - ASICs, Custom hardware development, RF design, packaging, component-level test & processing algorithms

- Equivalence between Tektronix Instruments, Reference Designs, ASICs and Test beds helps
  - Reduce Risk, Schedule & Costs

- Tek Components custom developments
  - Monolithic VME board with digitizer and larger FPGA
  - Low-latency digitizer with larger FPGA
  - Collaborated with National Instruments on PXIe digitizer
  - Single module tunable 4-channel RF front-end with digitizers
  - 17 GHz bandwidth (42 GS/s) monolithic digitizer
  - RF to digital wide-bandwidth digitizer modules