Using Digital Signal Processors in GNU Radio

Justin Ford

jrford@sandia.gov

505-284-5567

Key Team Members (SNL): Adam Goldhammer, Vince Hietala, and Kevin Malone

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Low-Power SDR: DSPs in GR

TI OMAP
(e.g. Gumstix in E100)

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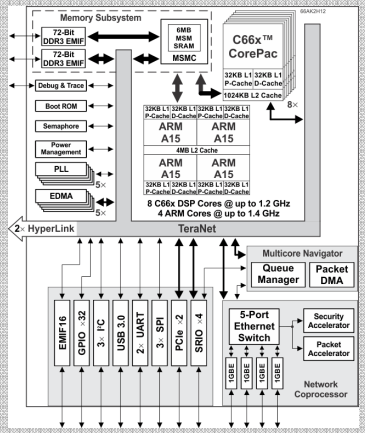
Easier Development*

Multi-Core DSP SoC

USRP image copyright Ettus Research

TI 66AK2Hx
DSP+ARM SoCs



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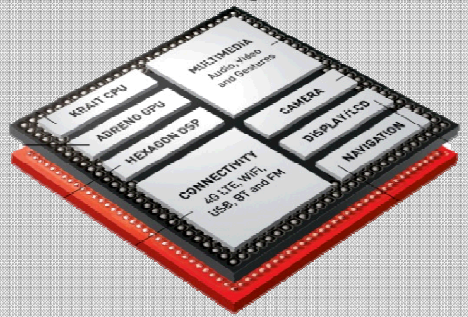
Qualcomm
Snapdragon 800



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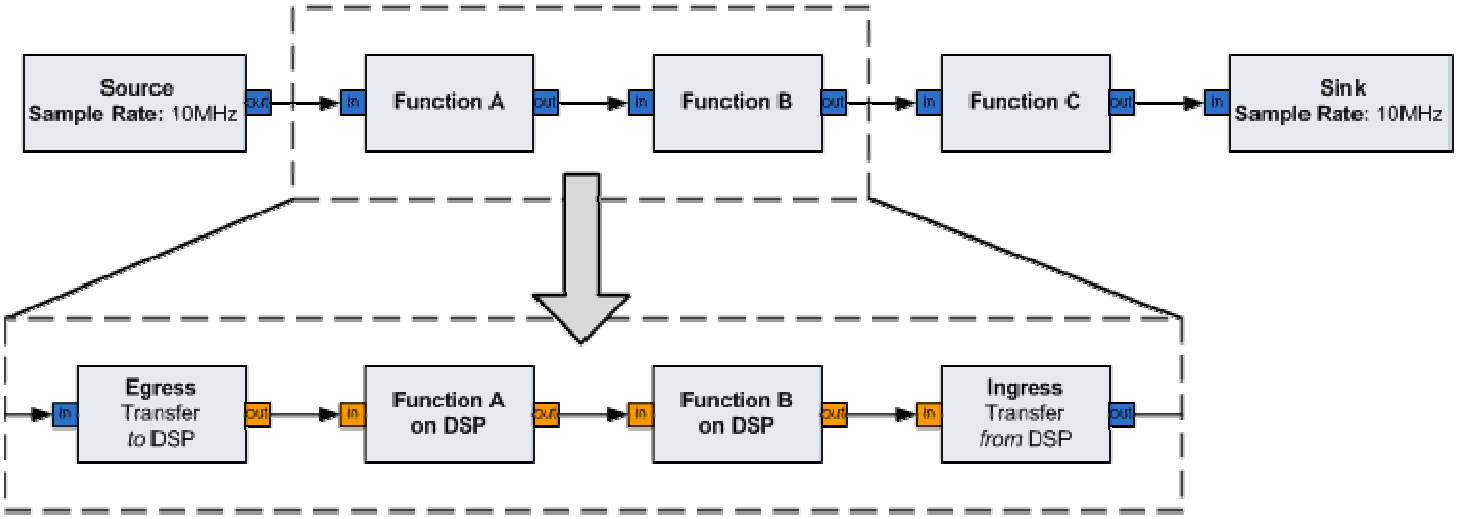
Ultimate Application

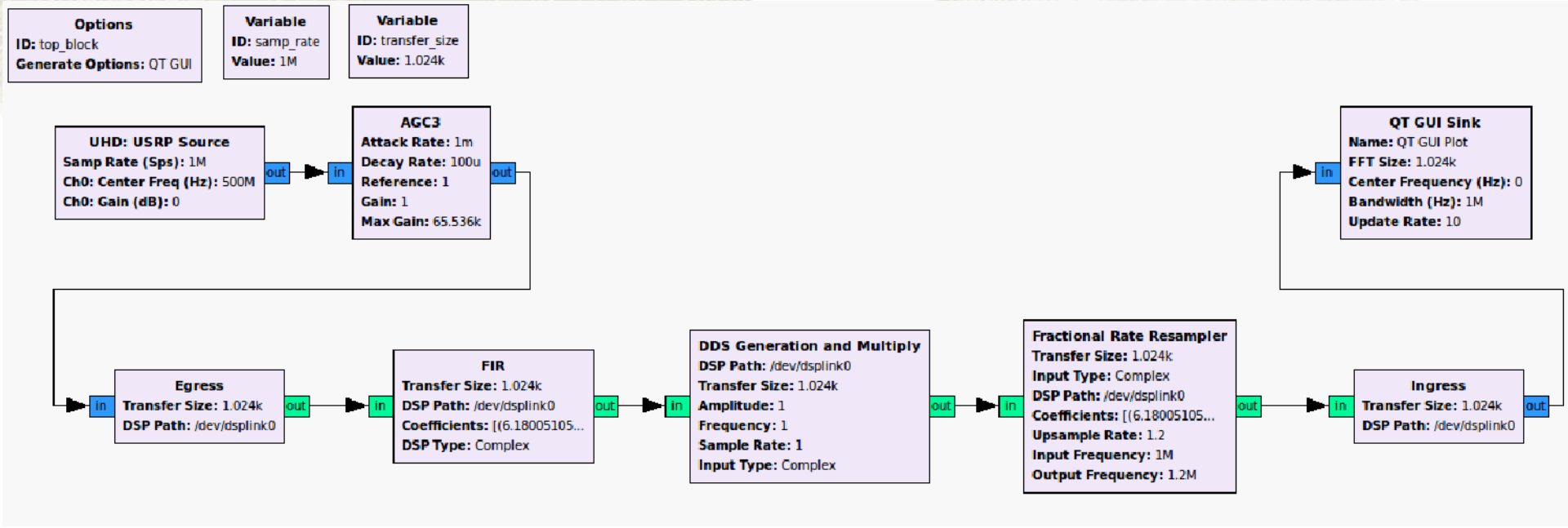
DSPs as Coprocessors in GNU Radio

- A coprocessor (DSP in this case, but similar to GRGPU*) can be inserted in a GNU Radio flowgraph by:
  1. Breaking the graph
  2. Inserting blocks to transfer data to the DSP and from the DSP
  3. Implementing the required functions in the DSP
  4. Reconnecting the graph



* Interactions with Will Plishker at UMD shaped the approach SNL has taken to using DSPs in GNU Radio

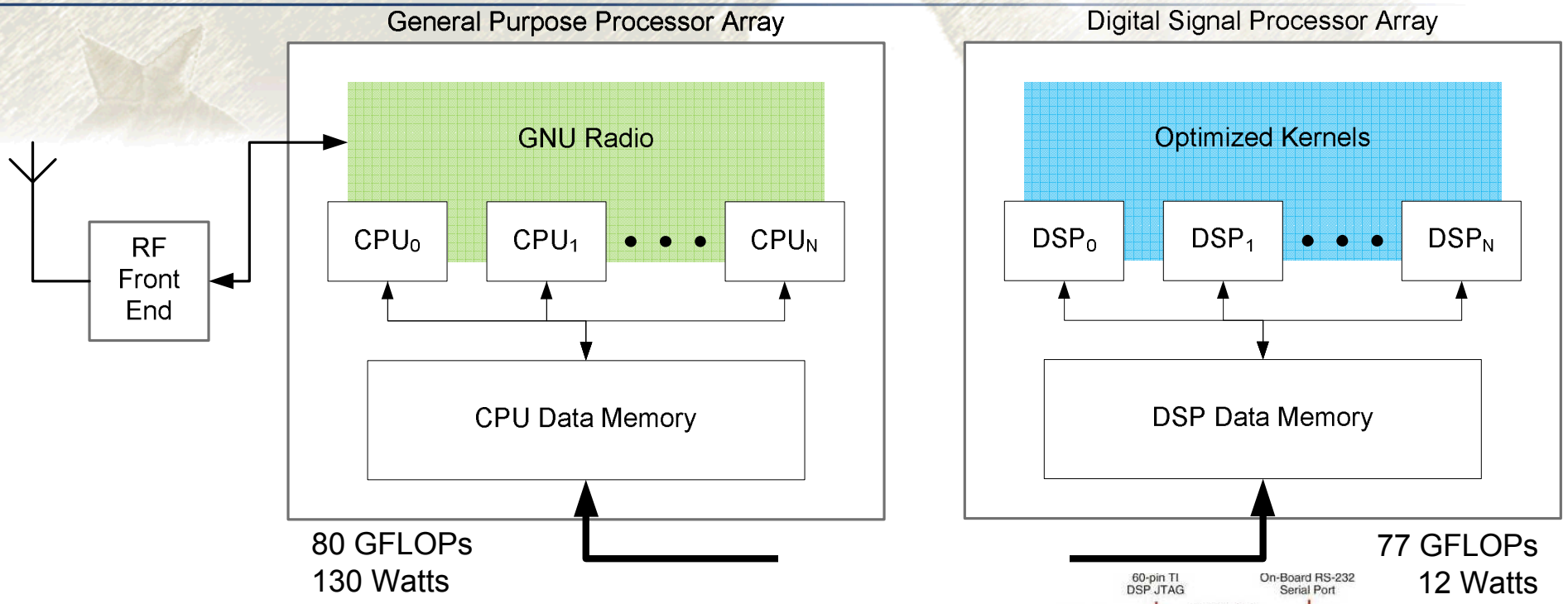
Example DSP Flowgraph



Screenshot from GNU Radio companion, a part of GNU Radio licensed under GPL

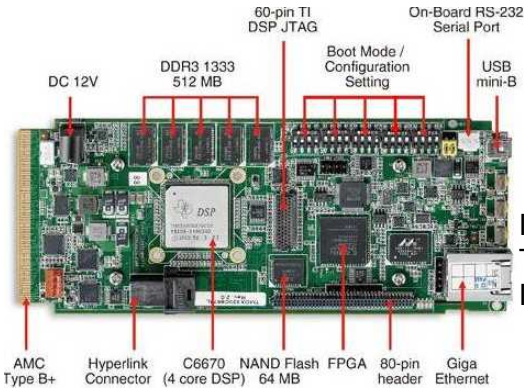
- DSP functions are performed between an egress and ingress
- Functions can be placed on host processor before and/or after DSP blocks
- DSP blocks are parameterized just like their host-side counterparts
- References to data chunks on DSP are passed as integers between DSP blocks (thus the data type change at egress/ingress)

Offloading Processing to a DSP



Texas Instruments' TMS320C6670 System-on-Chip

- Four DSP cores at 1.2GHz
  - 153.8 GMACS / 76.8 GFLOPS total (ideal)
  - Designed for SDR, radar, and broadband applications
  - Evaluation board supports PCIe interface



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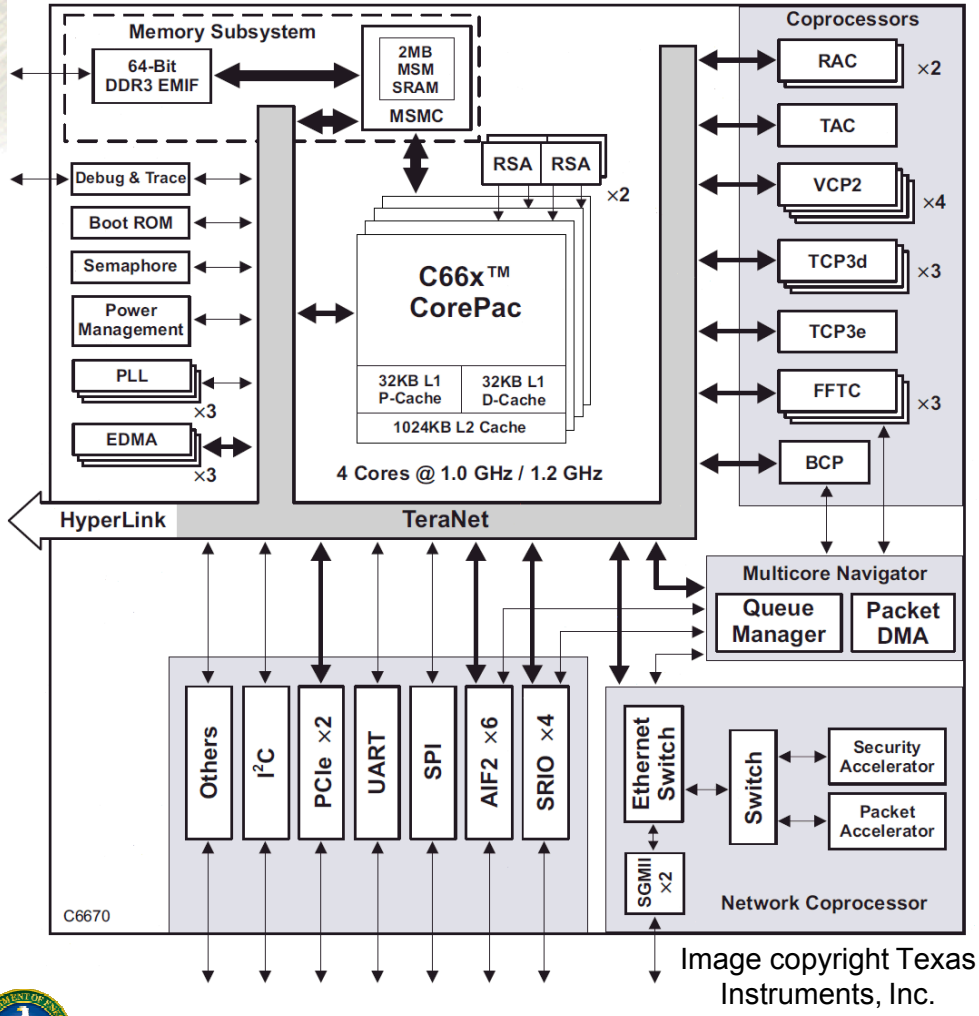
TMS320C6670 SoC Details



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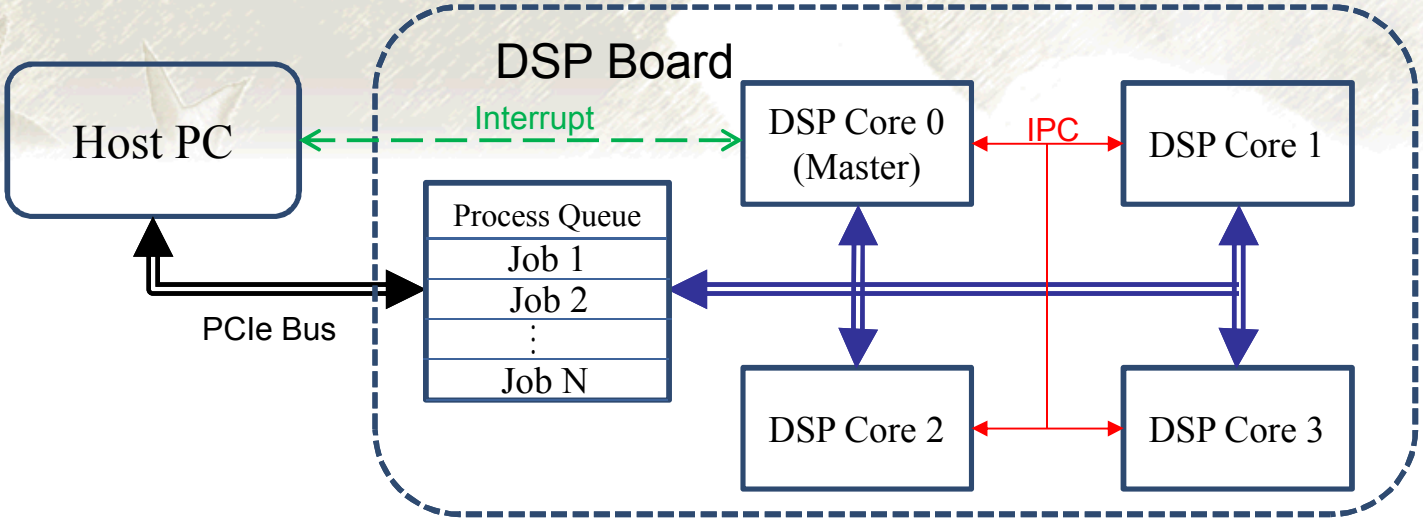
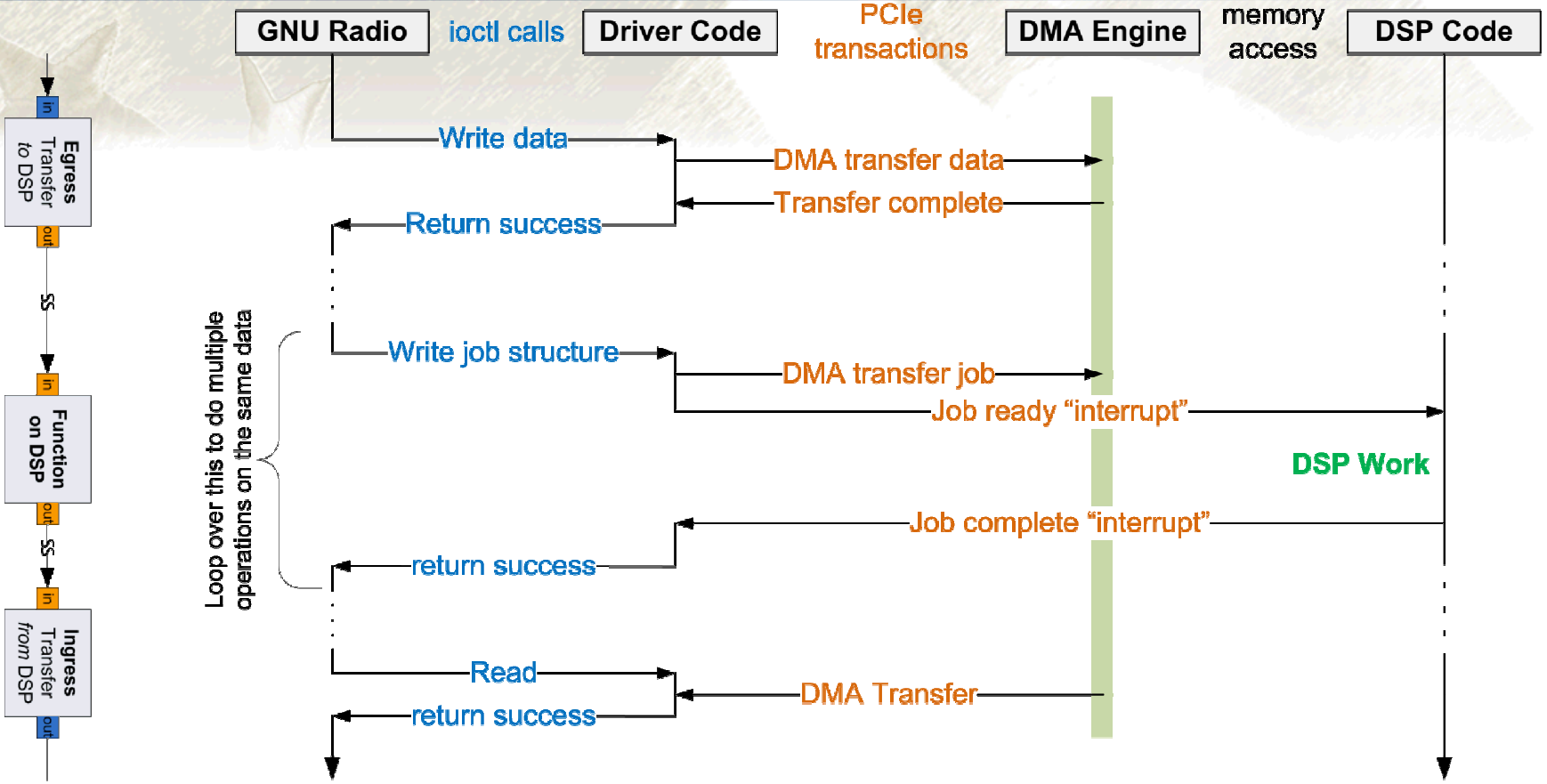
- PCIe 2.0 Interface @ 2 Lanes
  - 85% efficient ⟹ 850 MB/s theoretical
- IEEE-compliant single-precision floating point arithmetic
- Instruction set and execution unit optimized for digitally processing signals
- Fast Fourier Transform Coprocessor
  - 2048-point FFT (fixed-point) in 4.8us
- Viterbi and Turbo Decoder Coprocessors
- Future TI DSP SOCs will have multi-core A15 ARM GPPs and multi-core C6600-class DSPs

DSP Offloading Details



- Establish a DSP Process Queue (cmd, input, output) in DSP memory space
- Host driver writes command structure and input data to process queue
- Host driver sends “interrupt” to DSP
- DSP Master core searches queue for new job and assigns job to available DSP core via inter-processor communication
- Resultant data is placed in process queue and host is notified via interrupt

GNU Radio and DSP Interaction



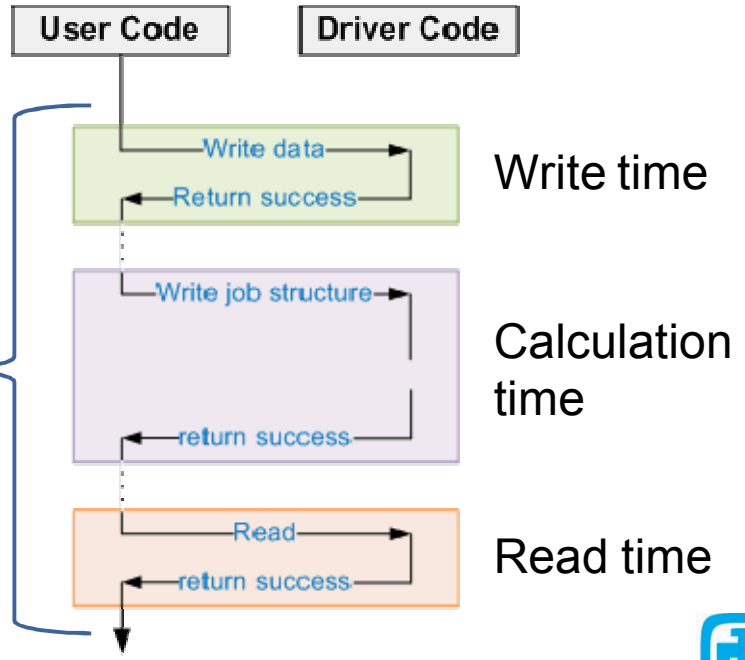
- Neither GPP or DSP are "occupied" by data transfers (DMA is used)
- The job queue allows the host to request new operations while the DSP is busy allowing for continuous utilization of the DSP

Benchmarking Performance (Linux user space)

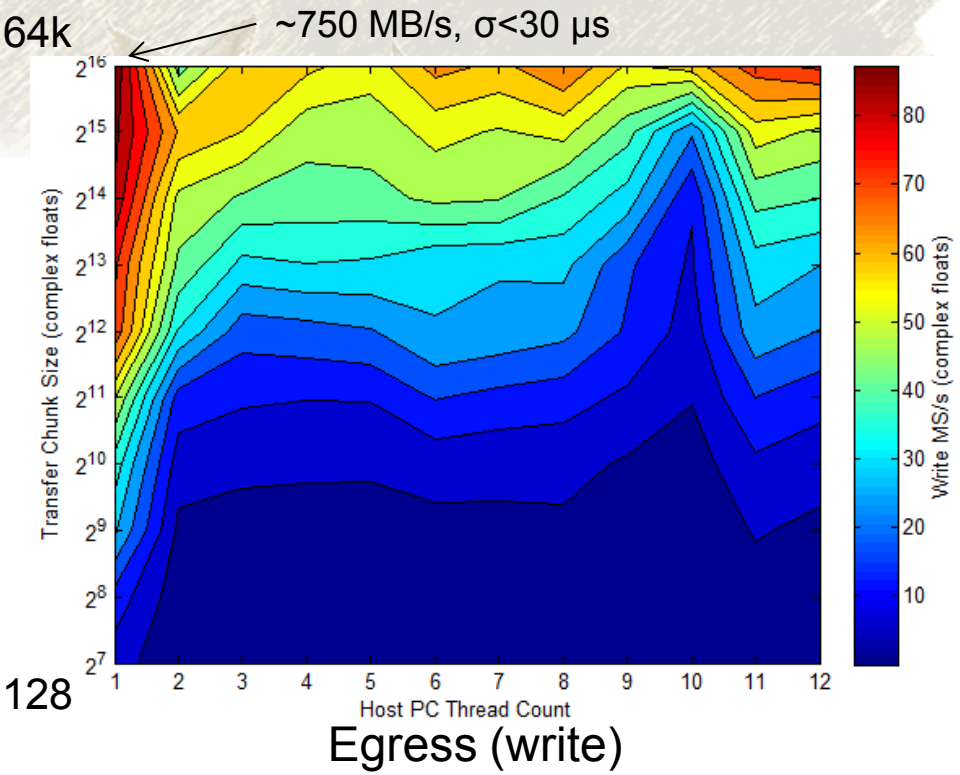
- GNU Radio 3.7 on Ubuntu 12.04 64-bit (workstation-class machine)
- Timing done using Linux system calls (~ µs accuracy)
- All operations are on complex floating point precision data
- Benchmarks are run on 1 million samples, results are averaged
- Data was collected using single DSP core

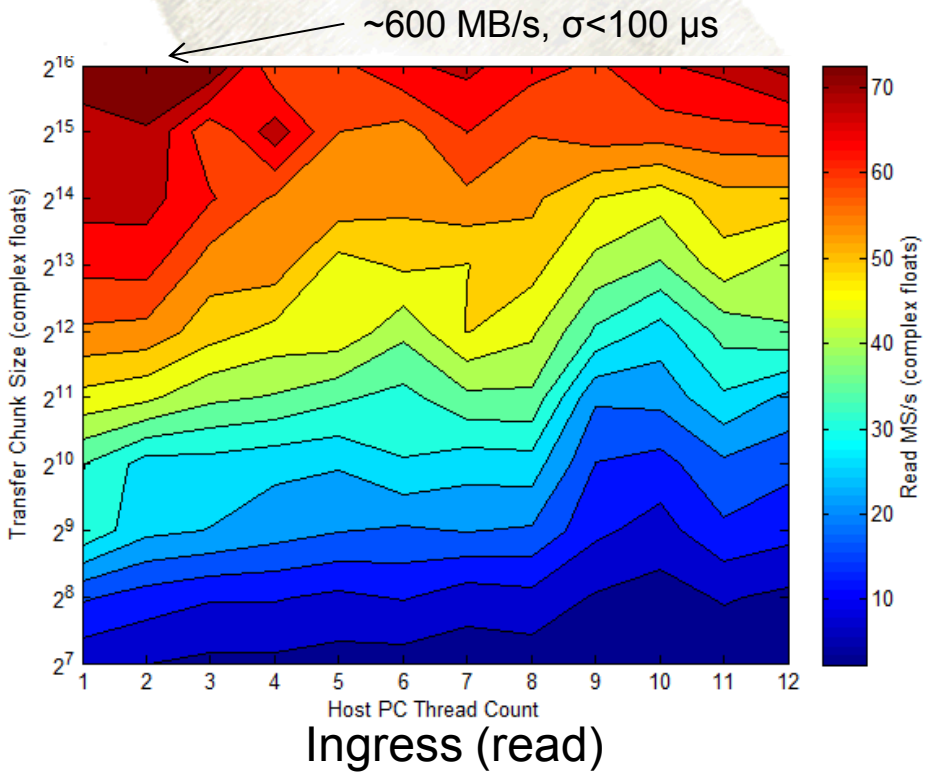
```
LOOP Thread count
  LOOP Chunk size
    LOOP Total samples
      Execute job
    ENDLOOP
  ENDLOOP
ENDLOOP
```

Overall time



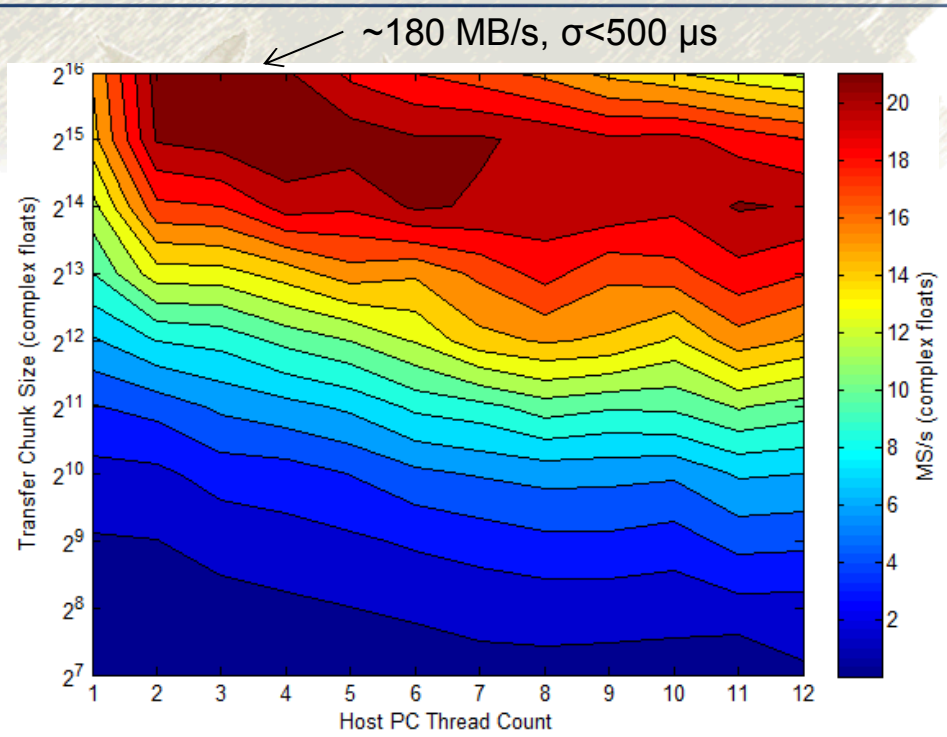
DMA over 2-lane PCIe v2.0



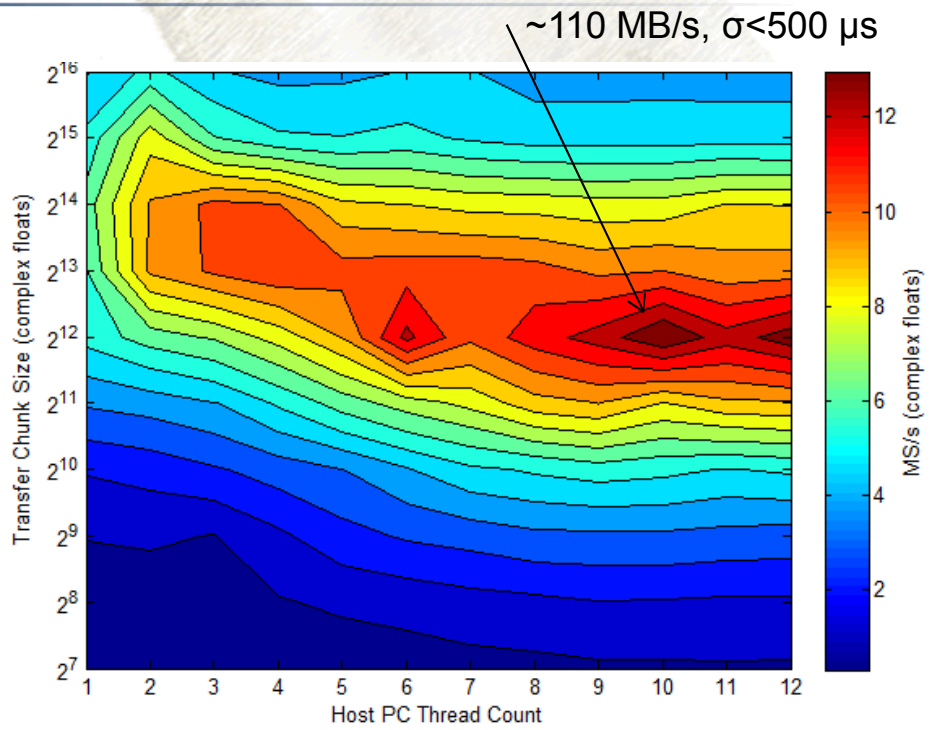


- DSP PCIe peripheral 10 GT/s or 1 GB/s max
  - TI specifies slower read rates compared to write rates
  - Slowdown with increasing host threads is mostly benchmarking artifact

Overall Throughput



Loopback (NOP)



FFT performed per chunk

- Tradeoffs are dependent on function type
  - Mostly computational intensity
  - Useful information for selecting transfer chunk size in GNU Radio

Information Systems Analysis Center

Video

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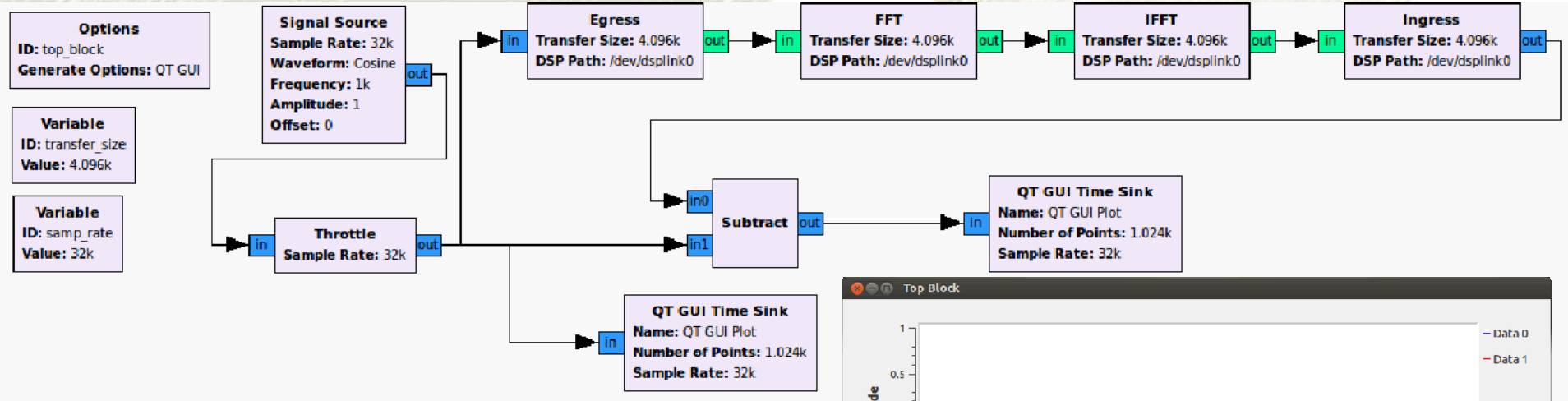
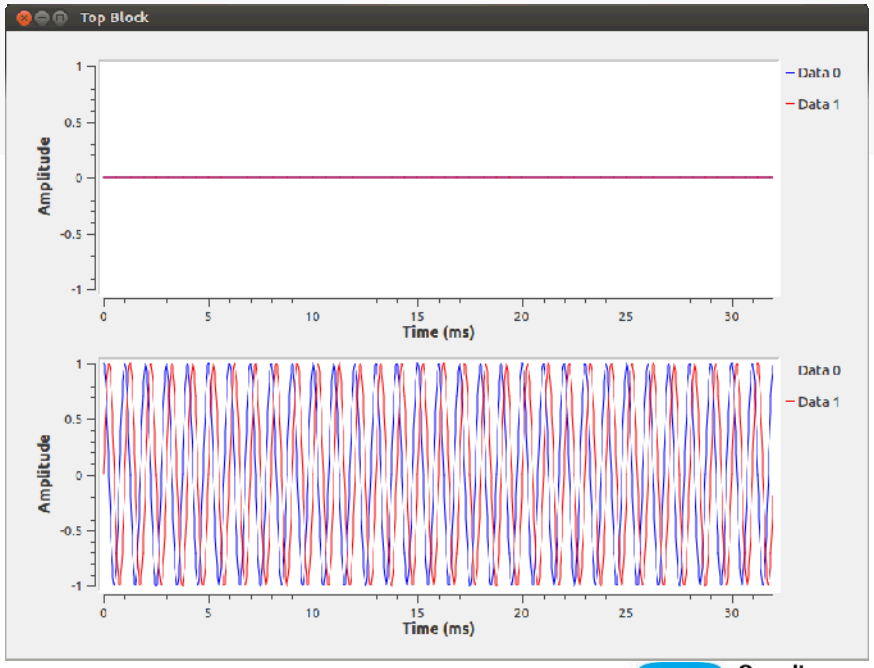
Flowgraph using DSP

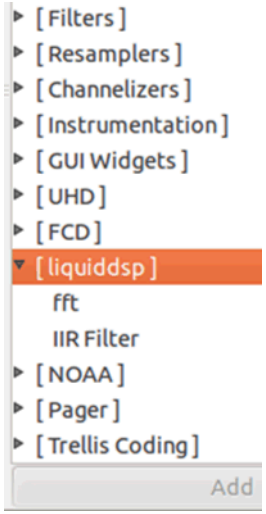




- Flowgraph to check data validity
  - Multiple operations chained together
  - Input and output data difference of zero indicates no corruption
- Admittedly not a useful operation in practice, just illustrating functionality

Aside: liquid in GR

- Hackfest in June 2013 at Virginia Tech
- Exploration of using Joe Gaeddert's C-based DSP routines
  - Available FEC and other modules might be of use
  - Apparent fixed-point support would be very attractive
- Decided to try simple cases to test integration
- Out of tree module at github.com/minimalwatts/gr-liquiddsp



Screenshots from GNU Radio companion, a part of GNU Radio licensed under GPL

Final Thoughts: Coprocessors in GR

- Digital signal processors offer unique features as a coprocessor for software-defined radio:
  - Well-suited to the task: exemplary floating point performance and instruction set/execution unit tailored to multiply/accumulate operations
  - Very power efficient with low-power variants available (applicable to embedded systems)
- There are tradeoffs between DSPs, FPGAs, and GPUs for accelerating SDR functions
  - The ultimate best choice is always going to be application-dependent
  - A general framework for using coprocessors in GNU Radio is desirable