The Use of Field Programmable Gate Arrays (FPGA) in Small Satellite Communication Systems

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Processing Needs in a SmallSat or CubeSat

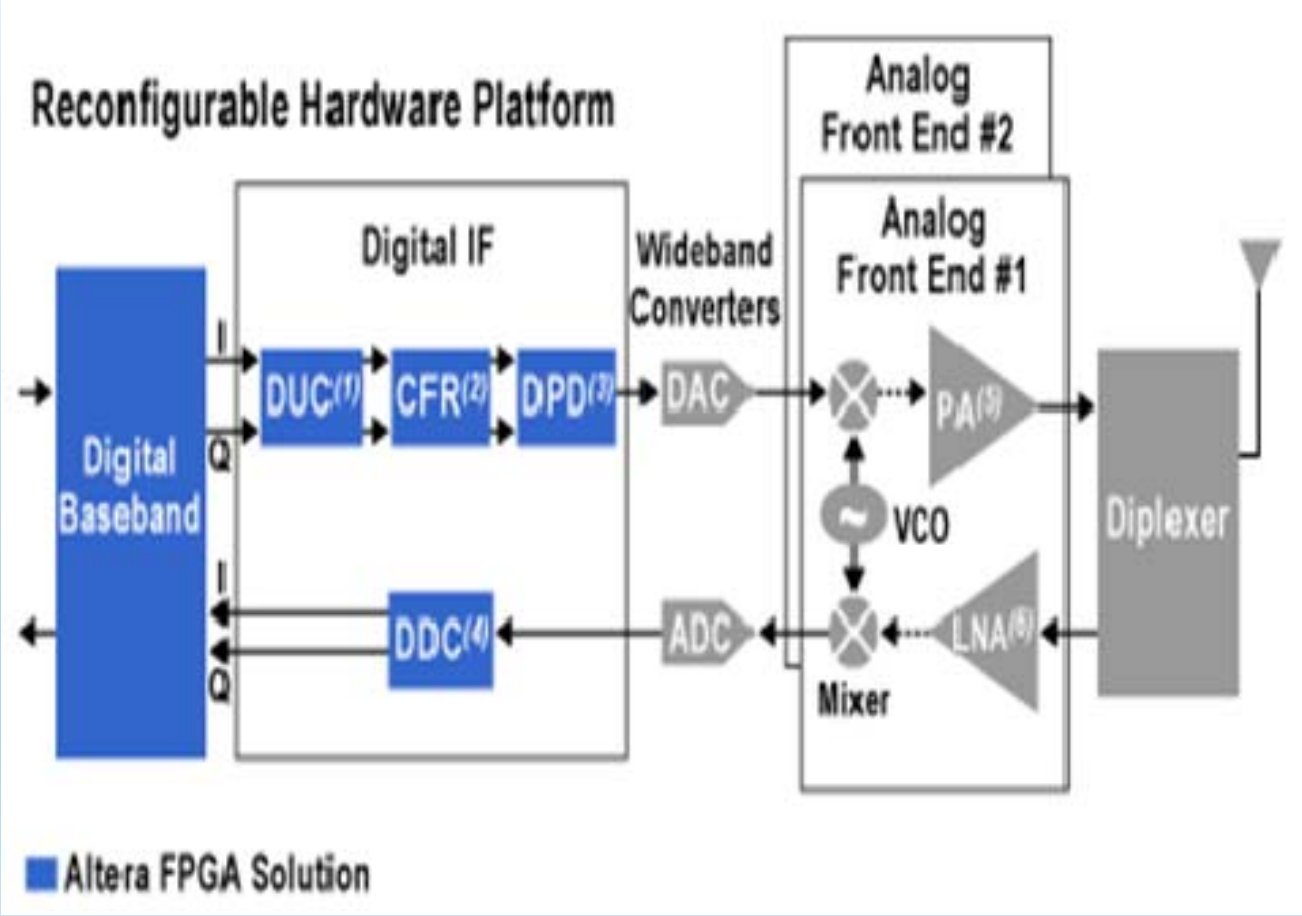
- Guidance, Navigation and Control
- Experiment Control
- Communications Control

Compute Intensive Communications

- Forward Error Correction (FEC) encoding and decoding.
- Consultative Committee for Space Data Systems (CCSDS) Packetization and de-packetization.
- Filtering and Carrier Recovery Loops
- Encryption and decryption.

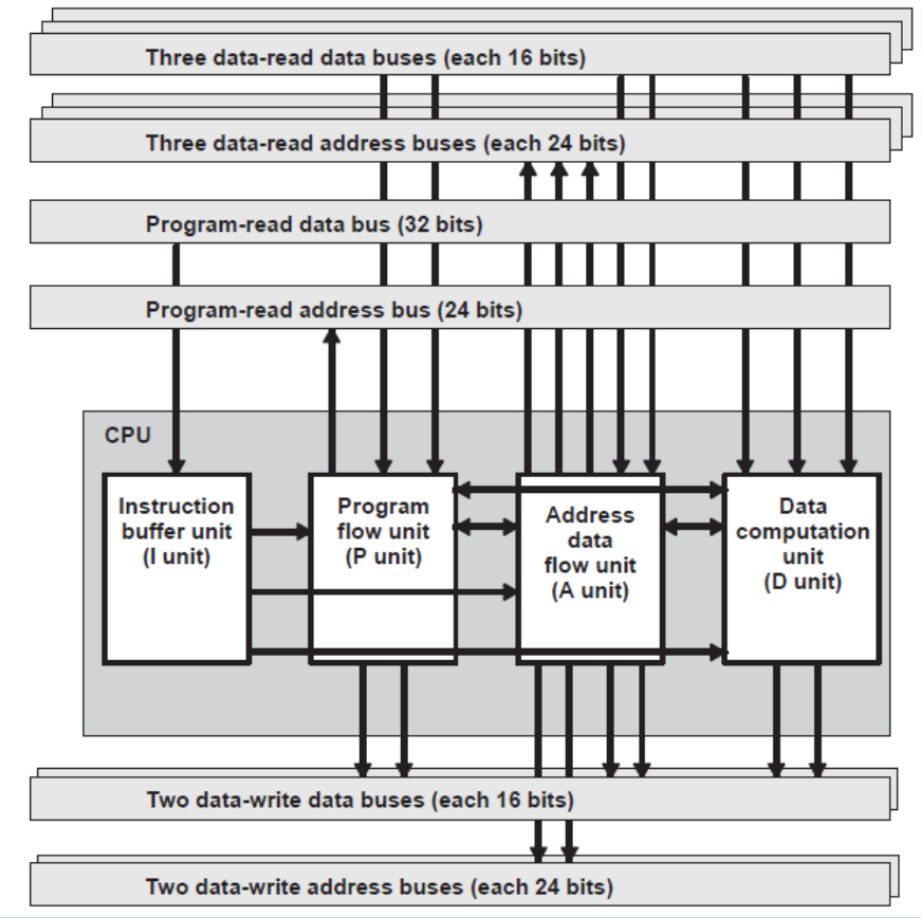
A Generic Software Defined Radio

- Minimize the analog / radio frequency (RF) components.
- Do as much as possible in the digital domain.
- Digital functions include:
  - Downconverters/ upconverters
  - Numerically controlled oscillators
  - Filtering
  - Carrier recovery
  - Forward error correction
  - Enctrypton / decryption
  - packetization
- Implement the digital functions in
  - Field Programmable Gate Arrays
  - Processor



Drawbacks to Processors

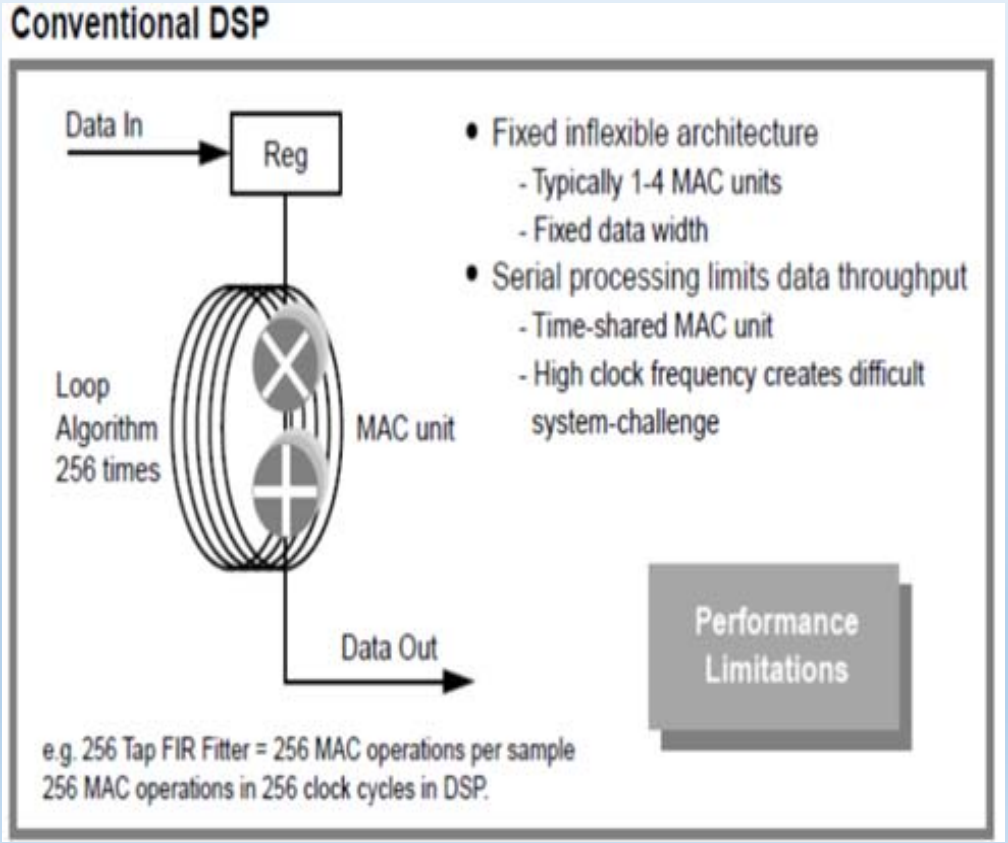
- Instructions must be fetched, decoded and executed.
- This takes numerous clock cycles.
- Special digital signal processor such as the TMS320C55x has:
  - direct memory access
  - Cache
  - embedded hardware multipliers (2)
- These processors can leverage the pipelining and parallelism to accomplish the fetch data, perform MAC, return data - process in one clock cycle.



Source: Texas Instruments Technical Overview SPRU393

Finite Impulse Response Filter (FIR) Computations

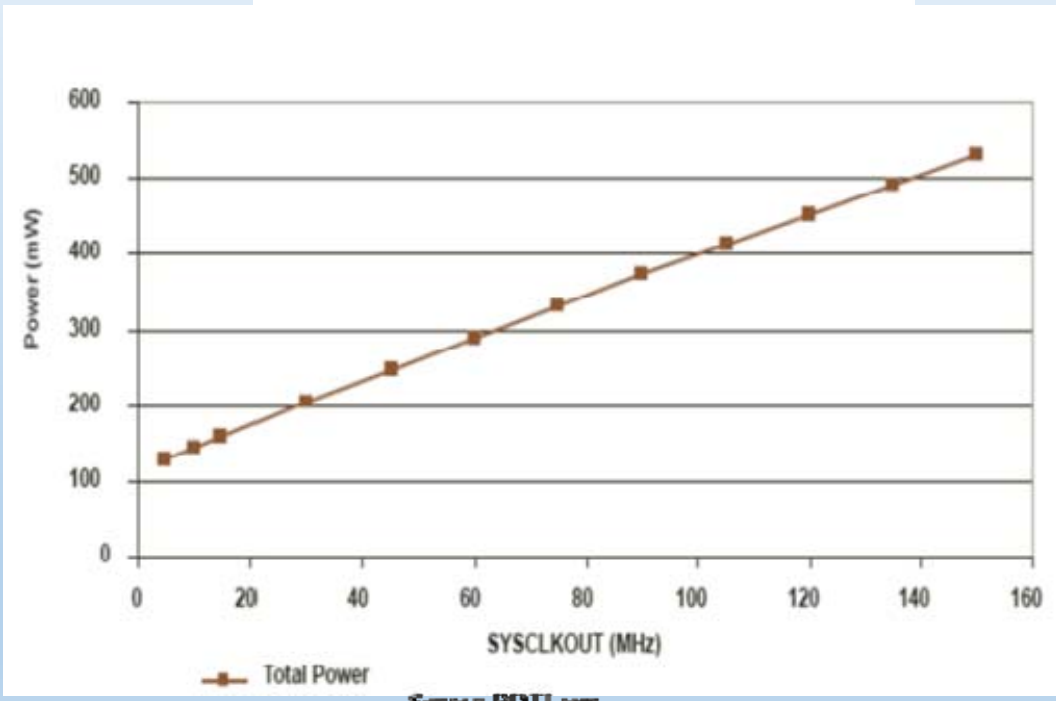
- Loop X times:
  - Move (2) input samples from memory to MAC
  - Move coefficient from memory to MAC
  - Perform MAC operation
- Higher order filters have more taps. The number of loops, X, goes up significantly.
- Using the features of the TMS320C55x , a 422 tap FIR filter could be implemented up to ~ 628 kbps.
- But this will come at a cost of ~200mW of power!



Source: Xilinx White Paper 2004 WP213

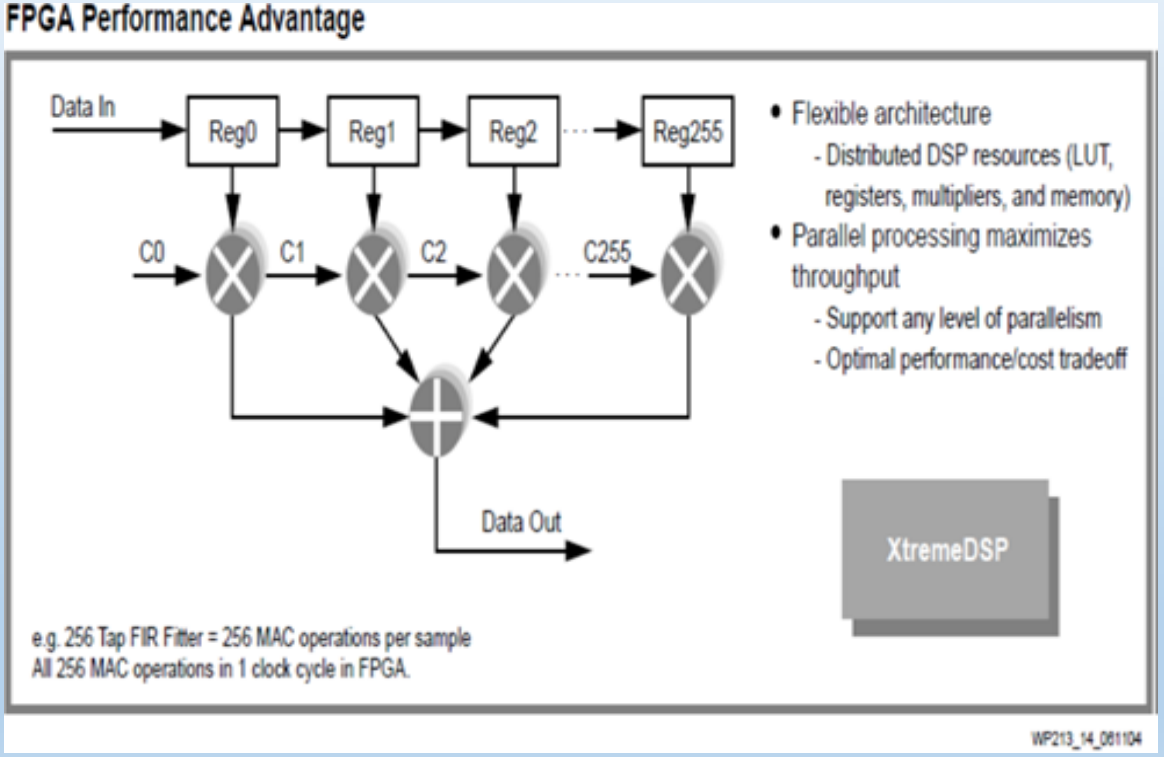
Processor Power Consumption

- Processors and clock rates are not linearly correlated.
- Higher clock rates don't necessarily mean better benchmark performance.
- Additional circuit support such as memories, phase lock loops, input / output drivers and receivers and others are necessary.
- All of this to achieve barely 1Megabit / sec with just one filter.
- Software defined radios will require numerous filters as well as other compute intensive blocks such as mixers and numerically controlled oscillators.



Advantages of Field Programmable Gate Arrays (FPGA)

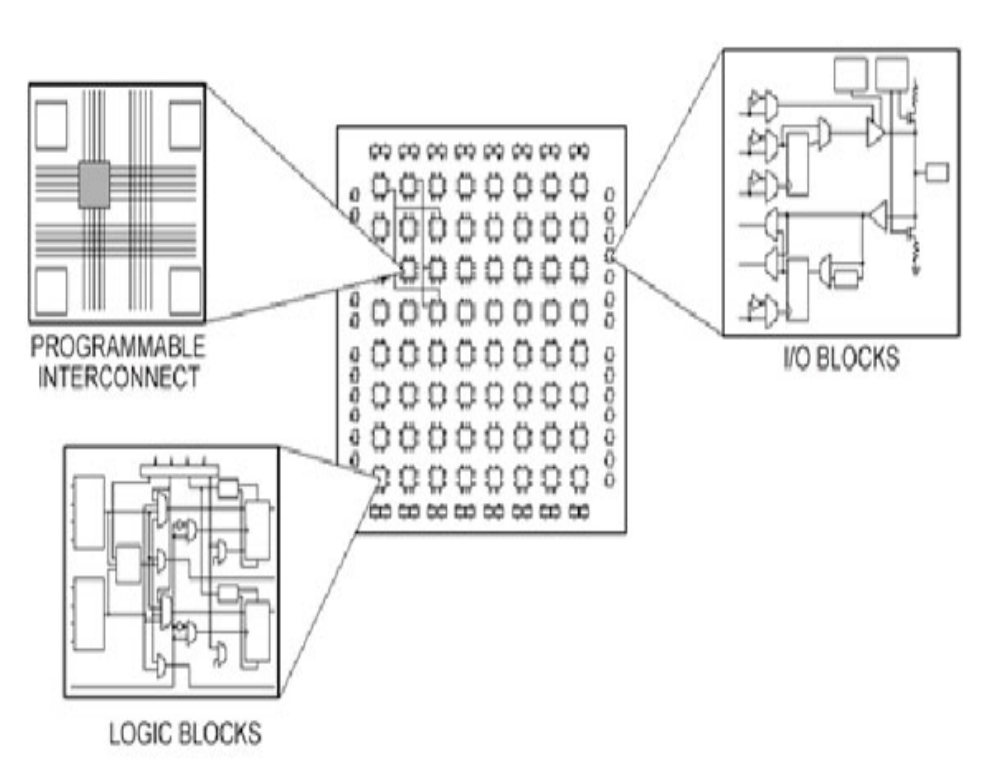
- Functions are performed in a pipeline manner.
- Each step of the pipeline has all the adders, multipliers necessary to accomplish the task.
- Numerous resources remove the need to share a few resources which requires complicated and time consuming data flow management.
- Data is presented to the next stage on every clock cycle, eliminating the need to fetch data and instructions as to what to do with the data, on every iteration.
- With a pipelined structure and some parallelism, the main clock does not have to be as high to achieve the same data rates even with numerous iterations.



Source: Xilinx White Paper 2004 WP213

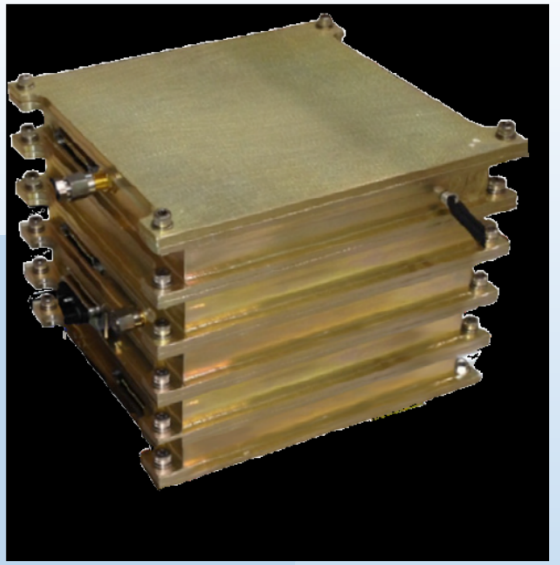
Additional Advantages of FPGAs

- FPGAs have numerous dedicated hardware multiplier / accumulators and memory blocks.
- Other signal processing functions , such as adders can be created in the fabric.
- Fabric allows for custom parallelism and pipelining specific to task at hand.
- This all creates the ability to perform the necessary function in local , dedicated hardware without having to share resources.
- More efficient use of the clock at a much lower overall clock speed.



Marshall Space Flight Center's Software Defined Radio:

Pulsar- Programmable Ultra Lightweight System Adaptable Radio



- Designed for orbital and suborbital platforms.
- Highly efficient SWaP (Size, Weight and Power).
- Downlink rates of 75Mbps per channel (2 channels with QPSK).
- Uplink rates of up to 300kbps.
- Forward Error Correction utilizing Reed-Solomon.
- Upgraded Forward Error Correction of Low Density Parity Check (LDPC) is near bench testing.
- Stackable form factor allows adding or subtracting capability.
- > 1U Cubesat dimensions currently available.
- 1U Cubesat size coming soon.
- External interfaces are Low Voltage Differential Signaling (LVDS) and RS-422.

NASA Alignment

- NASA is called to maintain an enterprise of technology that aligns with missions and contributes to the Nation's innovative economy.
- PULSAR aligns primarily with the Technology Area (TA) 5 – Communication & Navigation.
- Part of TA5 states :
  - **"avoid communications from becoming a constraint in planning and executing NASA space missions *while providing major advancements in the communication link today.*"**
- Working on the PULSAR technologies, aligns well with NASA's TA5 strategic technology investment plan and extends to other areas of Space Transportation , Space Systems and Scientific Research.