

MAMBO: A Simple Soft-core Processor used in the COPPER Mission

Steve Massey

Electrical Engineering 2013

Saint Louis University



SAINT LOUIS
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Saint Louis University

Space Systems Research Lab



Parks College of Engineering, Aviation and Technology

36 full-time faculty, 600 students

AE, ME, EE, BME, Civil, Aviation, Physics

SSRL organized in 2009

Joined AFRL's University Nanosatellite in 2009

COPPER, Nanosat-6, 2009-2010

Argus-High, Nanosat-7, 2011-2012

COPPER and Argus manifested through NASA CubeSat Launch Initiative



The COPPER Mission

Imaging Mission:

Utilize a commercially available compact uncooled microbolometer array to:

1. Capture infrared video of co-manifested satellites during separation phase
2. Capture infrared images of Earth's oceans and atmosphere

Radiation Mission:

Improve the predictive performance modeling of radiation effects on small, modern space electronics devices by collecting radiation particle collision data from electronic

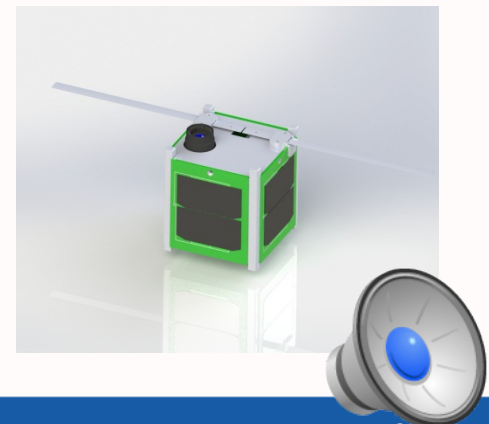
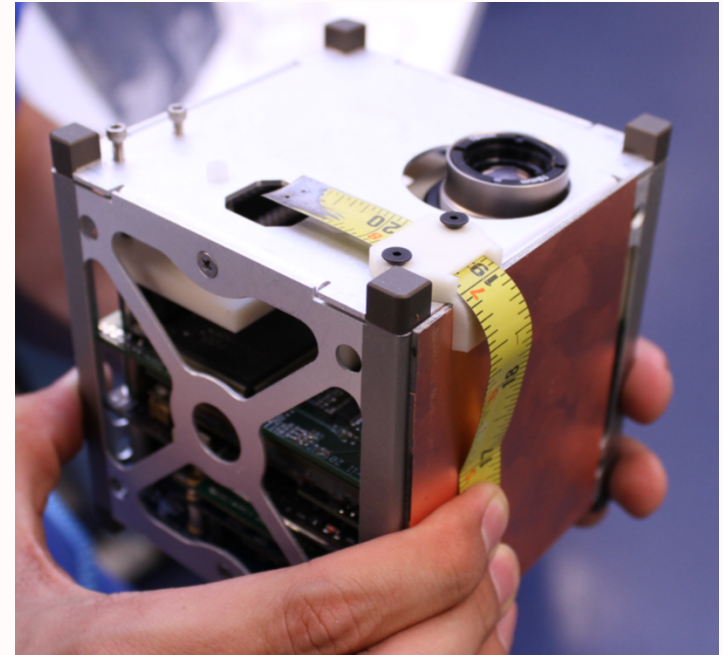
monitoring experiments and relaying the data to the ground

Project Duration: 2009-2013

Initial concept: 2009-2010 Nanosat competition

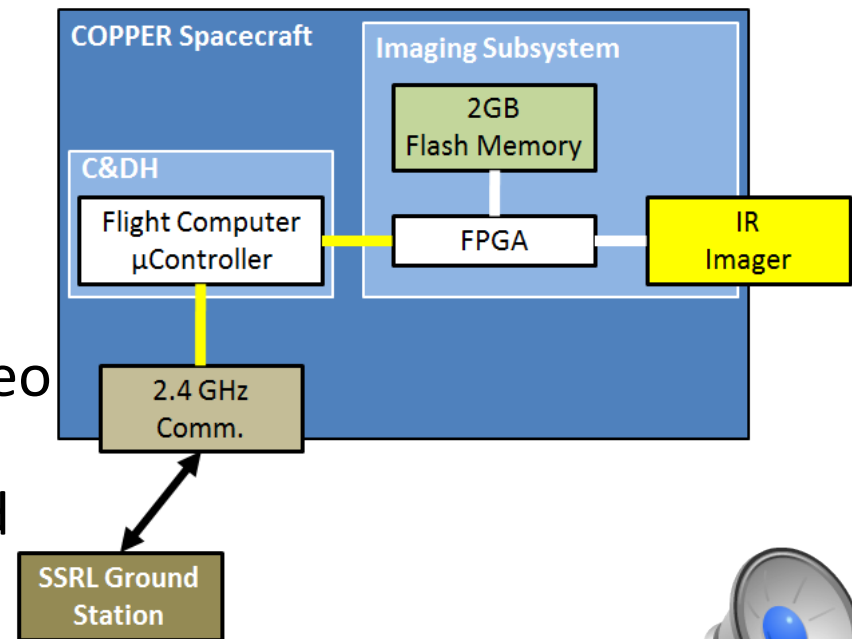
Mission Modified to Fit the CubeSat Launch Initiative

Manifested for Launch: August 2013



Solution Requirements

- Video Payload must integrate into the COPPER spacecraft
 - Communicate with flight computer; 9600 baud downlink
 - Limited power budget (generation of 2W-hr/orbit)
 - Survive Low Earth Orbit environment (~500km altitude)
- Video Payload must store required information
 - 3-5 minutes of 320x240x14 video (10FPS min, 30FPS ideal)
 - Individual stills when requested



Solutions

- Looked closely at MicroBlaze and PicoBlaze offerings from Xilinx
- Microblaze
 - Huge logic/BRAM usage requirements.
 - Offered libraries need off-chip storage (data and program RAM) for all but simplest programs
 - Bus transfers super slow, difficulty getting simulation license
- Picoblaze
 - Limited codespace, address space
- Roll-your-own state machine
 - Quickly became too-complex, difficult to manage

The logo for MicroBlaze, featuring the word "Micro" in black and "Blaze" in red, with a stylized orange and red horizontal bar behind the text.The logo for PicoBlaze, featuring the word "Pico" in black and "Blaze" in red, with a stylized orange and red horizontal bar behind the text and a small trademark symbol (TM) to the right.

Core Requirements

- Store data at sustained 25MB/s
 - FLIR's CMOS bus is 75% downtime on a 12MHz clock
- Fit in a mid-grade Spartan3E-class part
- Easily extensible using a simple bus

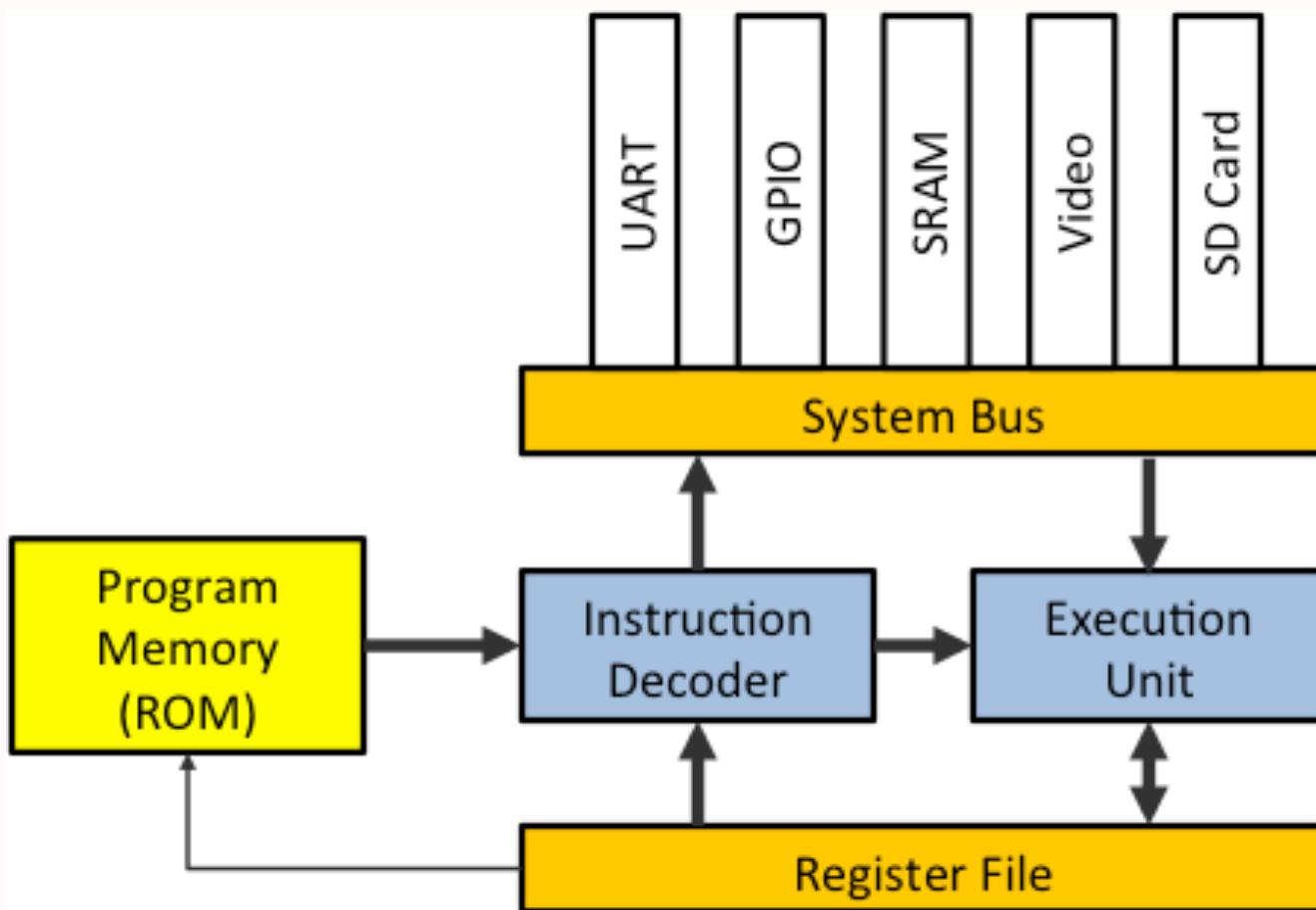


Solution: MAMBO

- MAMBO: Moving And Manipulating Bytes
 - Midpoint between Microblaze and Picoblaze
- Programmable bus arbiter
 - 32-bit instructions focused on moving data across the bus, simple bitwise operations
 - 16-bit bus with 8-bit addressing (up to 32 with 24-bit extension)
- Harvard Architecture



Dataflow



Instruction Overview

- 32-bit instruction
 - 8-bit instruction identifier
 - 24-bit instruction data
- Typical Data Usage:
 - 8-bit standard address, 16-bit immediate data
 - 24-bit extended address



Instruction Overview

- Immediate data write

xA0		xC5		x003E	
Identifier		Standard Addr		Immediate Data	
31	24	23	16	15	0

- Relative branch if rA is less than immediate value

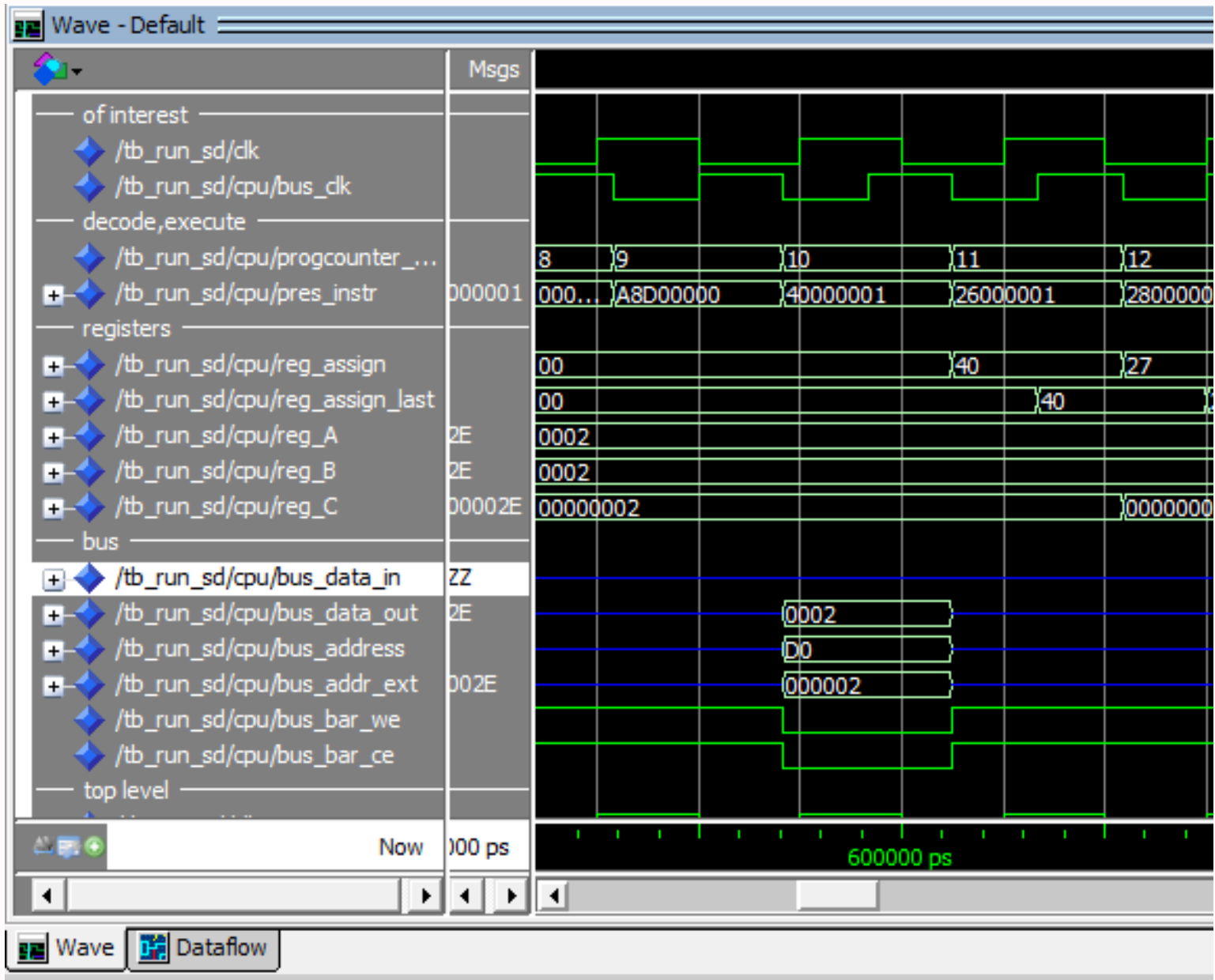
xE3		xFE		xCD14	
Identifier		Relative PC		Immediate Data	
31	24	23	16	15	0

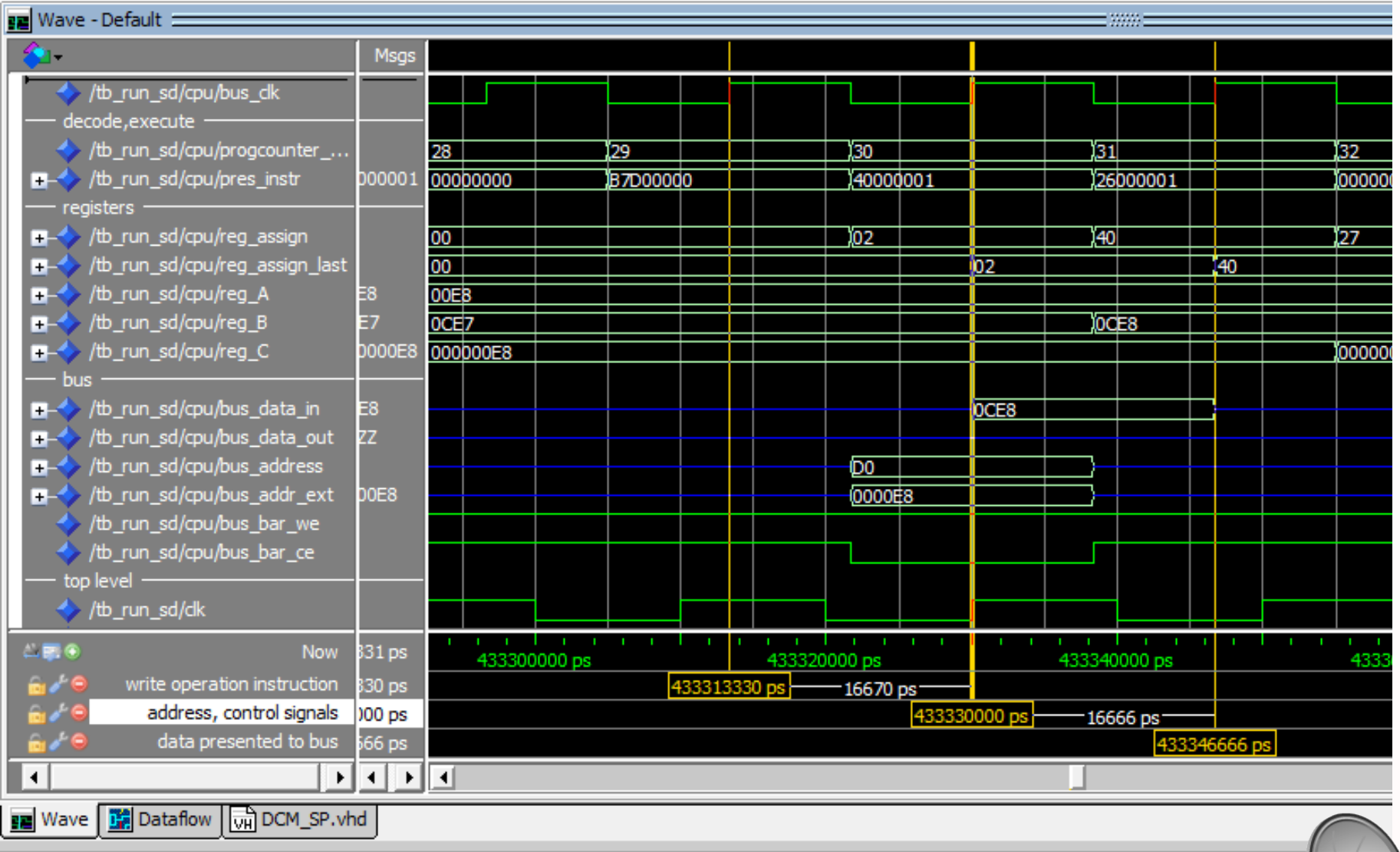


Bus Overview

- 8-bit address line
- 32-bit optional extended address line
- Two control signals:
 - Chip Enable
 - Write Enable
- 16-bit data “to-CPU” line
- 16-bit data “from-CPU” line

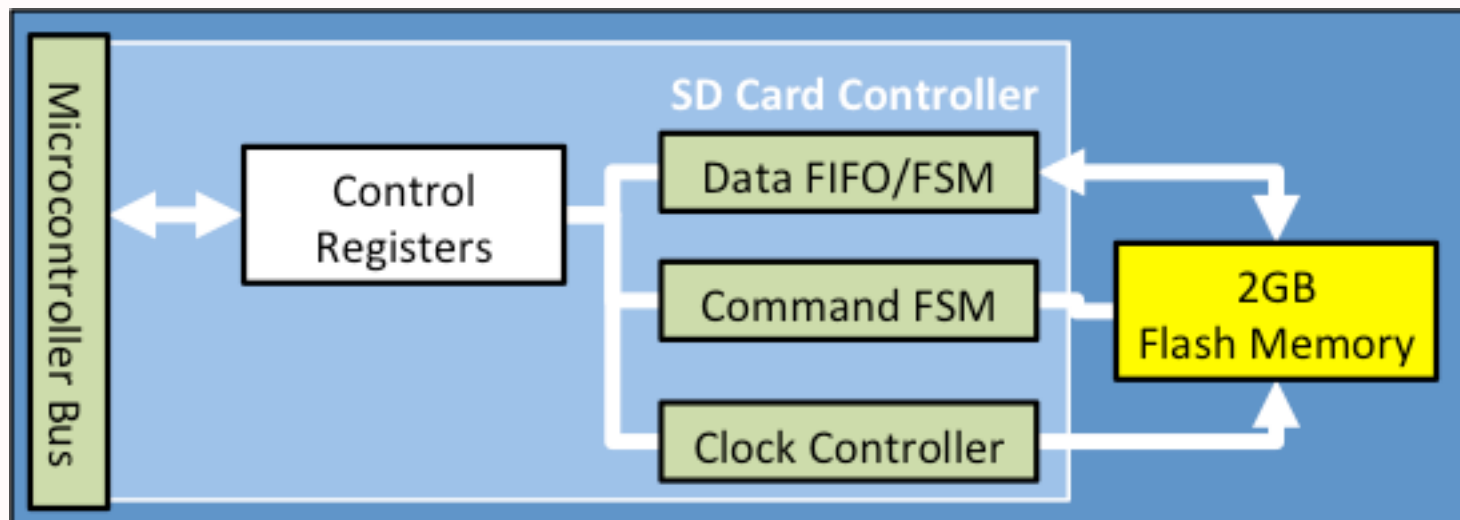






Current Peripherals

- SD Card interface
 - Standard capacity 4-bit 50MHz operation, 25MB/s
 - Single Read, Single Write, Burst Write



Current Peripherals

- UART
 - 9600bps, N81
- General Purpose I/O
 - 16-bit width, assignable
 - Separate Input and Output registers
- Cypress SRAM Controller
 - 4MB off-chip RAM



Current Peripherals

- Block RAM
 - 256 16-bit words available when using extended addressing
- Additional Registers
 - Supplement processor registers with 16x 16-bit words addressable
- FLIR Tau 320
 - 320x240x14 single-plane CMOS imager
 - Long-Wave Infrared

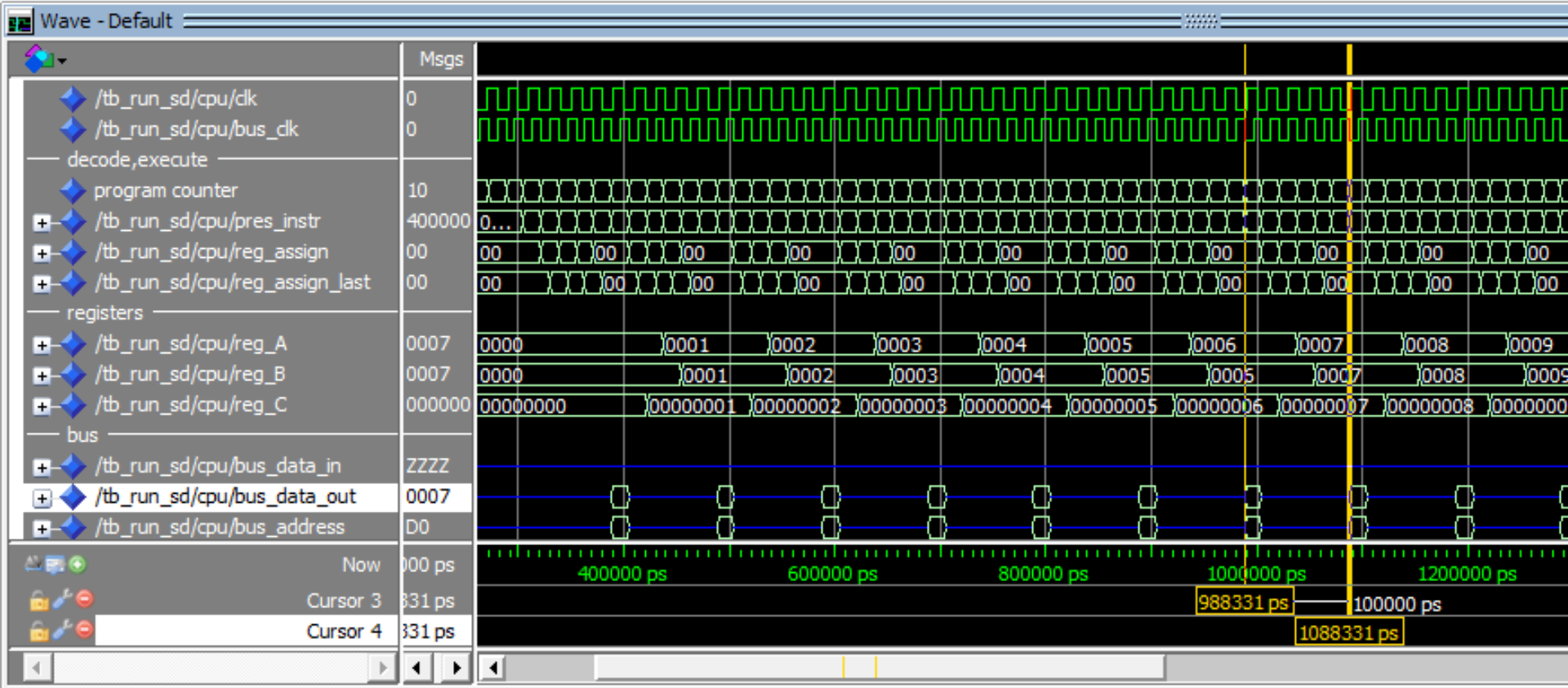


Example Code

```
65 -- program memory banks
66 type prog_mem is array ( 0 to num_instr ) of std_logic_vector(31 downto 0);
67
68 constant rom_instr : prog_mem := (
69     0 => x"FF000000", -- reset
70     1 => x"FF000000", -- reset
71
72     5 => x"10000000", -- rA = 0
73     6 => x"14000000", -- rC = 0
74     7 => x"11000000", -- rB = 0
75     9 => x"A8d00000", -- write rB to (xE2, rC)
76     10 => x"40000001", -- rC = rC + 1
77     11 => x"26000001", -- rA = rA + 1
78     12 => x"28000001", -- rB = rB + 1
79     13 => x"e3fb0fff", -- rA brlt xFF
80
81     17 => x"b0f40000", -- rA <= cache5
82     19 => x"b0f50000", -- rA <= cache6
83     21 => x"b0f60000", -- rA <= cache7
84     23 => x"b0f70000", -- rA <= cache8
85
86     25 => x"10000000", -- rA = 0
87     26 => x"14000000", -- rC = 0
88     27 => x"11000000", -- rB = 0
89     29 => x"b7d00000", -- read (xE2, rC) to rB
90     30 => x"40000001", -- rC = rC + 1
91     31 => x"26000001", -- rA = rA + 1
92     33 => x"e3fb01ff", -- rA brlt xFF
93
94     50 => x"e0000002", -- restart system
95     others => x"00000000");
96
```



Example Code



Debugging

- Simulation: ModelSim SE
- On-Chip: ChipScope Pro



Future Roadmap

- FORTH Interpreter
- Interrupts
- Testing, testing, testing!
 - Wrap up for COPPER
 - Explore additional uses

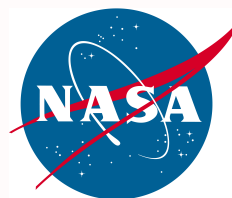


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