GreenArrays™

World Leader toward Efficiency

Secrets of Frugality in Context of an Exercise

Greg Bailey

SVFIG Forth Day

16 November 2013

Why are they Secrets?

- Frugality is unpopular (Instant Gratification)
- Most hardware doesn’t support it.
- Most programming tools don’t support it.
- Most monolithic operating systems and libraries are anything but frugal.
- Methods such as fixed point arith not taught.
- Most “programmers” are too lazy to write code.

Why is this Important then?

- Resources are *not* infinite after all.
- Available energy is actually limited
- Often energy consumption makes the difference between what is feasible, and what is not.
- This is especially true of mobile applications.
- Programming with a microammeter on your computer's power supply is *fun!*

Challenges of This Exercise

- "Always-On" in context of a mobile device
- Monitor sensor(s)
- Maintain situational awareness
- Observe events of potential interest
- Recognize Gestures

The TI® SensorTag

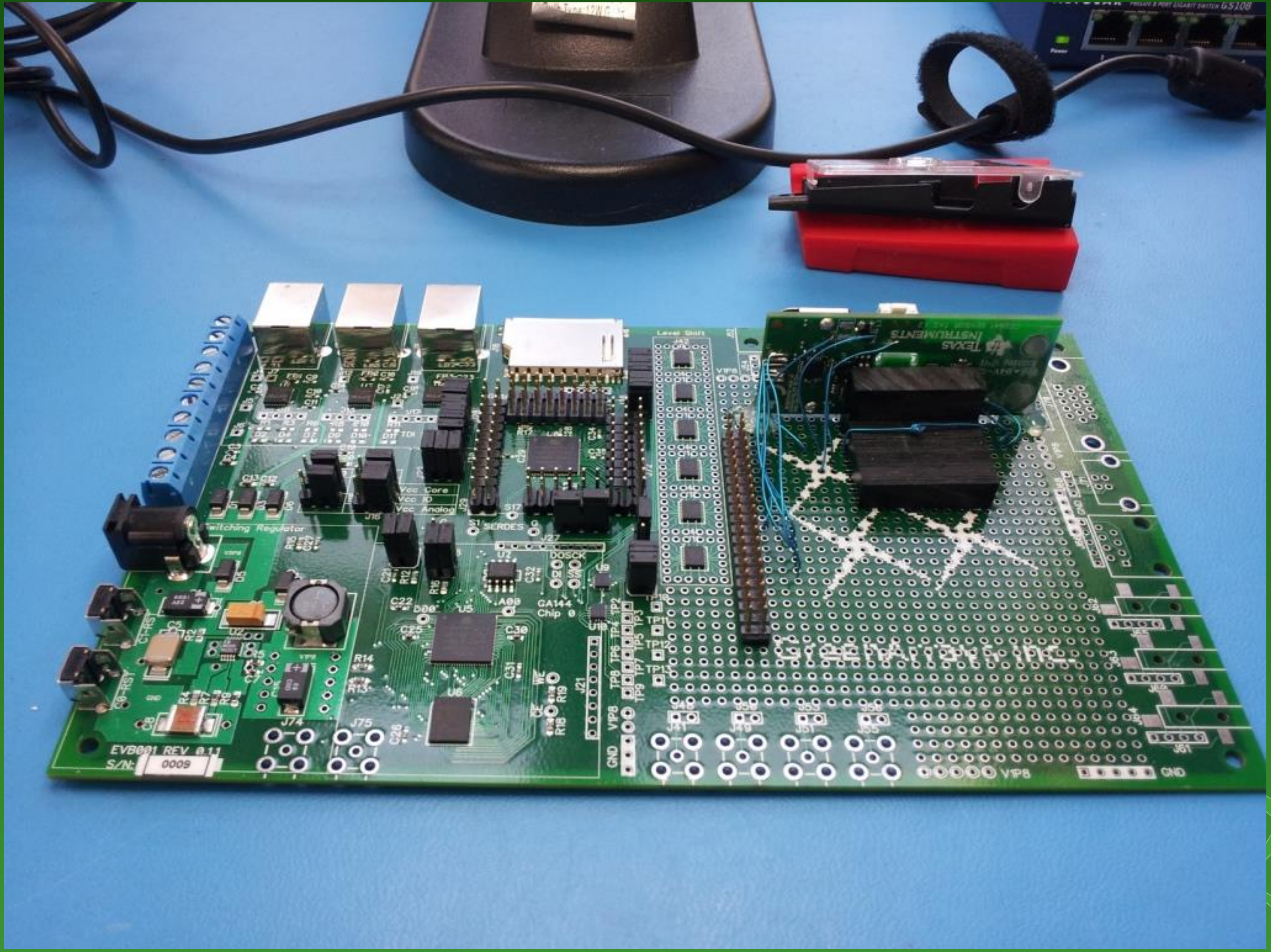
- 3V Battery regulated down to 2.1V
- Assorted sensors: 3-axis Accelerometer, magnetometer, gyro; temperature, humidity, barometric pressure
- TI CC2541 (BLE radio + 8051) chip
- CC2541 controls sensors using I^2C Bus

Our Decisions

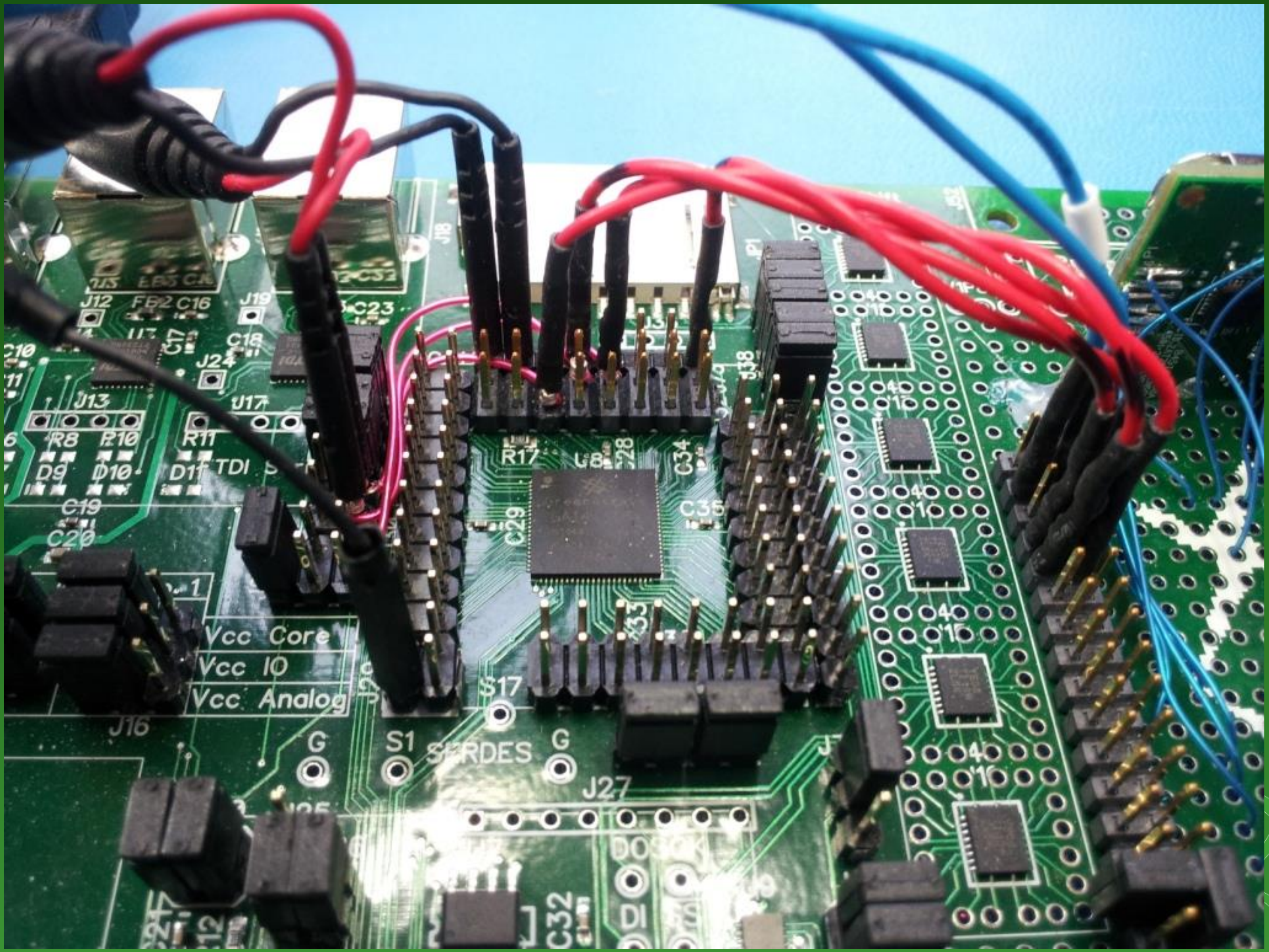
- Use Target Chip on EVB001
- Split I^2C Bus on ST, one for sensors, one for BLE chip, and control each from GA144
- Run GA144 at 2.1V to avoid level shifters
- No node may spin, therefore...
- Watch xtal (32.768 kHz) for all timing purposes (Poll/think cycles, I^2C bits)

Preparing the SensorTag

-

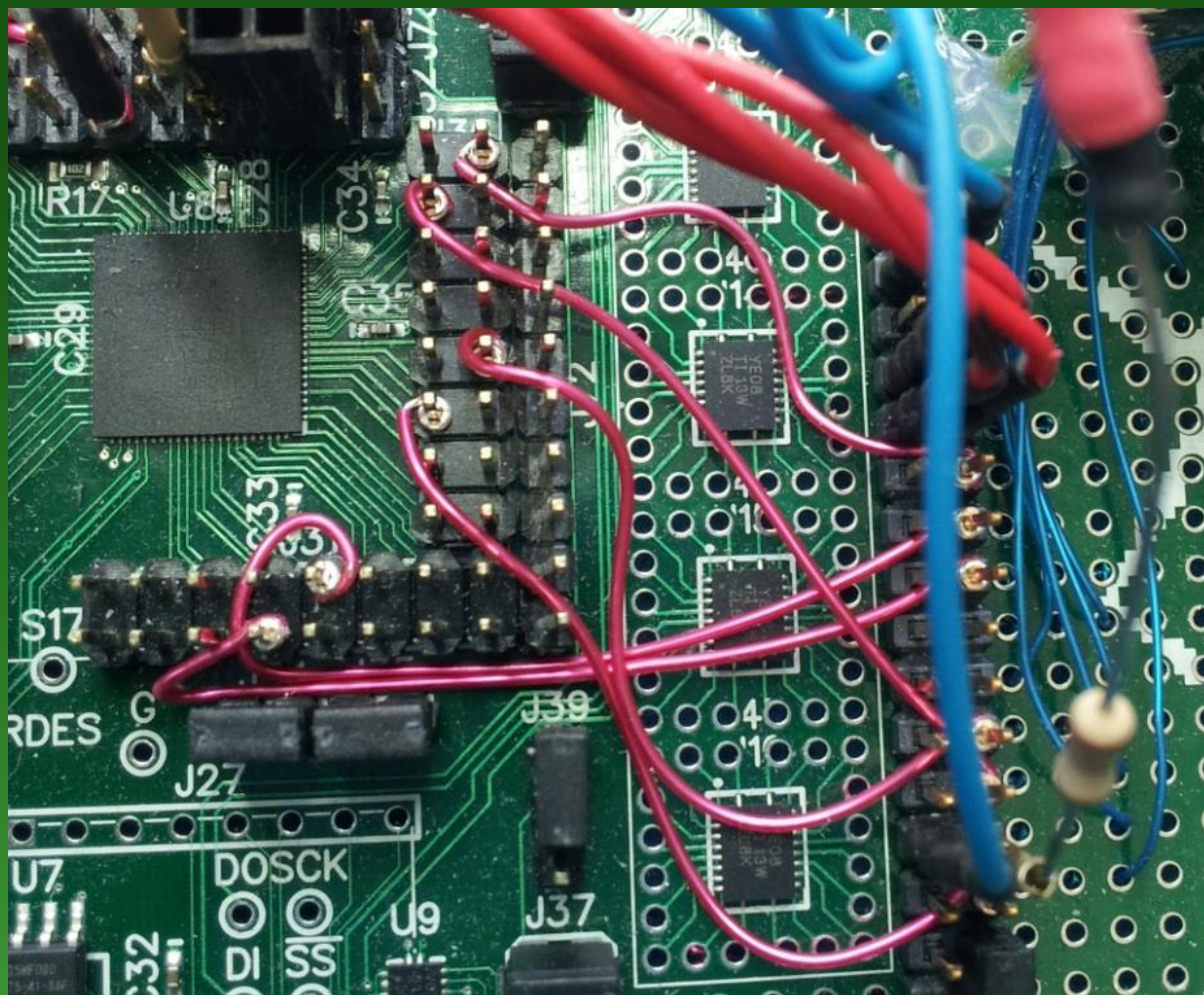


Wiring for Sensors I^{2}C Bus

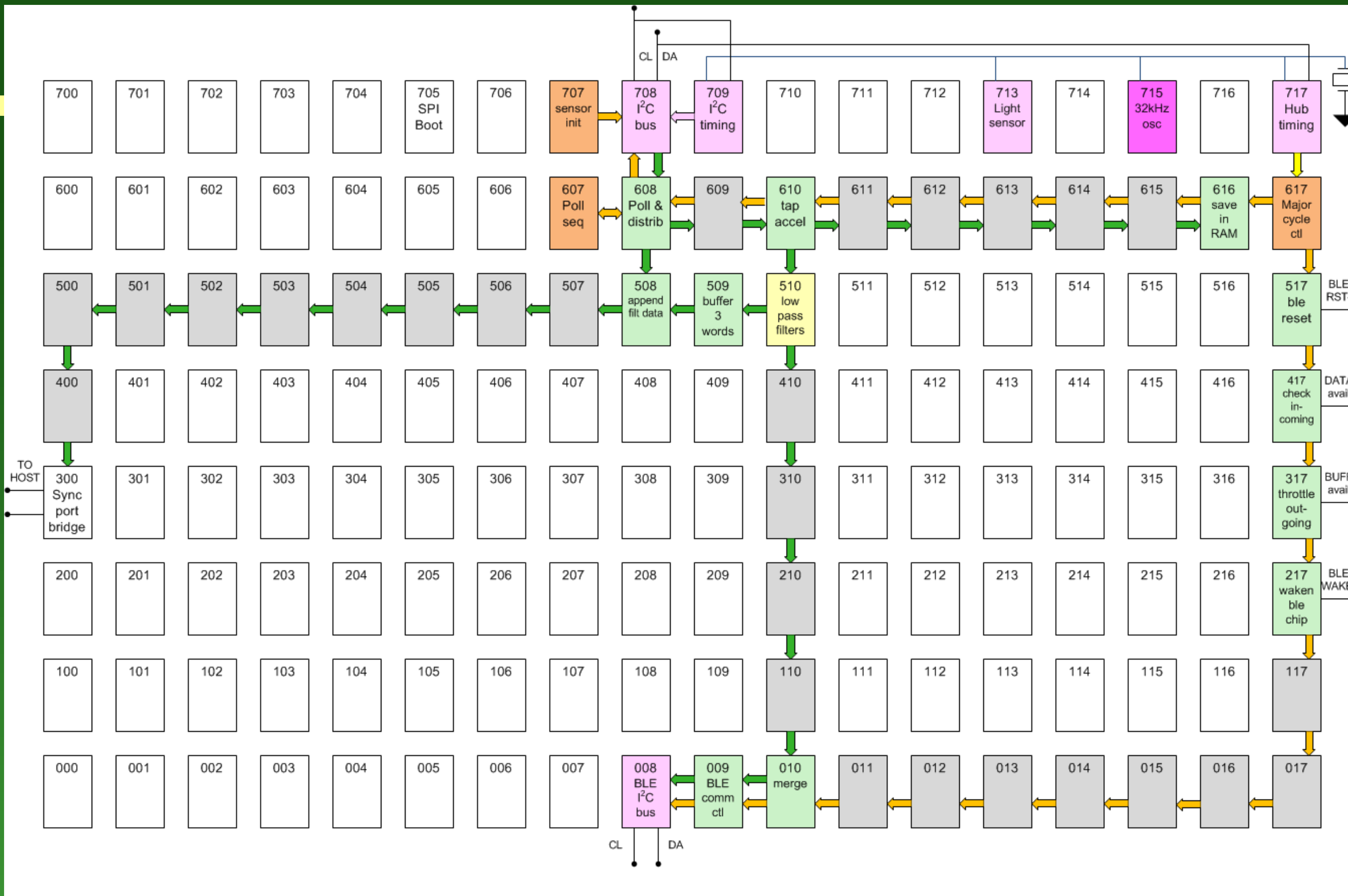


Wiring to Control the BLE Radio

▪



Target Chip Choreography



Sensor Hub Application Block Diagram

Results: 250 µW vs 15387 µW

Item	2.1v V_{DD} Usage			3V Battery Usage				
	I_{DD} µA 100% duty	I_{DD} µA in app	P_{DD} µW in app	I_{BAT} µA 100% duty	I_{BAT} µA in app	P_{BAT} µW in app	Joules per hour	Hours battery life
GA144 Fully Idle Leakage		14	29.4		10.5	31.5	0.113	21,500
+ GA144 running 12.5 pF watch xtal		27	56.7		20.2	60.7	0.218	
+ GA144 measuring 100 ms intervals		2	4.2		1.5	4.5	0.0162	
=1. GA144 total between cycles		43	90.3		32.2	96.6	0.348	6,990
+ All sensors in stby, CC2541 waiting for 3 second BLE poll					45.0	135	0.486	
=2. System between cycles					77.2	232	0.834	2,910
+ GA144 polling all sensors 14% duty and lowpass filters for accelerometer				278	38.9	117	0.420	
=3. System with GA144 awareness, all sensors & BLE in standby					116.1	348	1.250	1,940
+ GA144 reporting to Host 14% duty				15	2.1	6.30	0.0227	
=4. System with GA144 cheap report					118.2	355	1.280	1,900
+ Accelerometer lowest power mode					2.8	8.4	0.0302	
=5. System with Acceleration monitor					121.0	363	1.310	1,860
+ Magnetometer		17.2	36.1		12.9	38.6	0.139	
+ Thermopile					180.0	540	1.940	
+ Gyro					4920	14800	53.1	
=7. Sum of high-power sensors					5112	15300	55.2	
=8. System (5) w/high-power sensors					5233	15700	56.5	43
+ BLE 8051 update at 10 Hz estimated				>200	>30	>90.0	0.324	
+ BLE Radio poll at 10 Hz estimated				>2000	>20	>60.0	0.216	
=9. Sum of active BLE radio usage				>2200	>50	>150.0	0.540	
=10. System w/accel (5) and BLE					171	513	1.850	1,320
=11. System w/HP sensors (8) and BLE					5280	15800	57.1	42.6

Conclusion of Project

- GreenArrays is literally too good, so customer declined to use our wierd technology.
- Sensors use ~60 times the energy of the GA144 in this application.
- A computer using 10 times ours would only marginally decrease battery life.
- A computer using 50 times ours would still not reduce battery life by a factor of two.

Importance of Low Duty Cycle

- Average power is rate of energy consumption.
- Run only when there is work to do; get it done fast, then suspend till next stimulus.
- 700 MIPS does not cost much if you don't do much.
- In many of our applications we see duty cycles of 1/1000 to 1/10000 in nodes, thus reducing 6 mW to 6 μW or 600 nW.

About Over-Engineering

- I^2C requires heating pull-up resistors
- I^2C has published rise-time requirements
- ST delivered with 2.2kΩ pull-ups giving <66 µs rise-times
- We used DACs to source enough current for <250 ns rise-time
- Reduced current use from ~760 µA to ~280
- Other opportunities if nobody stretches clock.

Architecture for Low Duty Cycle

- Event Driven Processing. Nodes suspend until given something to do.
- Rational Data Flow (Drum Corps International)

V_{DD} 2.1V and Higher

- The ±10% Rule is for Clocked Designs
- Semiconductor Ageing
- In theory we can run safely >3V

Simple IIR Filters

- Simulate equivalent analog circuit. 8235 is just (2πf)/s ... sampling frequency is analogous to integration gain.
- Code below also maintains three integrators on the stack and filters three signals.

```
510 filter accel reclaim 10510 node 0 org
.1hz si-so 00 . + 8235 *.17 dup push,
..- 1 . + . + pop commit? dup drop ;
int s-s' 07 up a! @ 2* 2* 2/ 2/ 2/ 2/,
...1hz 2* 2* dup !b left a! ! ;,
,
run 10 x int drop y int drop z int drop,
..drop drop drop drop drop run ;,
,
16 reclaim exit
```

Software-Defined Crystal Oscillator

- Cost is negligible increase over the cost of listening to a separate oscillator.
- Easy to stop when not needed
- Provides stable time reference when needed
- Difficulty of starting increases with Q and frequency.
- Protection diodes center the swings and scavenge excess energy.

For More Information on GreenArrays and This Project

- Primary Website
  - http://www.greenarraychips.com
- App Note AN012
  - http://www.greenarraychips.com/home/documents/greg/AN012-130606-SENSORTAG.pdf
- Announcement Blogs
  - Business http://www.greenarraychips.com/blog1
  - Technical http://www.greenarraychips.com/blog2
- Tech Support on e-mail, Skype, Phone

GreenArrays™

World Leader toward Efficiency

Thank You!

For more information, please visit

http://www.greenarraychips.com