COSMICi: High Energy Particle Detector

<u>Group 25</u>

Aarmondas Walker

George Chakhtoura

Samad Nurideen

Brian Kirkland

Juan Calderin

Michael Dean

<u>Sponsor</u>

FAMU

Project Goal

Install and implement a network of Cosmic Ray detectors that will triangulate the origins of the Ultra High Energy Cosmic Ray shower events.

Component Overview

- Scintillators
- FPGA
  - Gel Ware
- Network Component Enclosure
- Cooling system
- Structural Supports

Network System Diagram

Concept Generation

- Network System operational speed
  - Use Logic Locking to optimize speed
  - Create more efficient program
- Support Structure for Detectors
  - I Beam Suspension System
  - Wall Mount Brackets
  - CLC Placement

Concept Generation Cont…

- Stratix II Cooling System
  - Simple fan heat dispersal
  - Liquid cooling system
  - Peltier method for isolated heat removal
- Network System Enclosure
  - Enclosed PC tower
  - Transparent enclosure for public aesthetics
  - Solid mounting points for all boards and power supply

Concept Selection

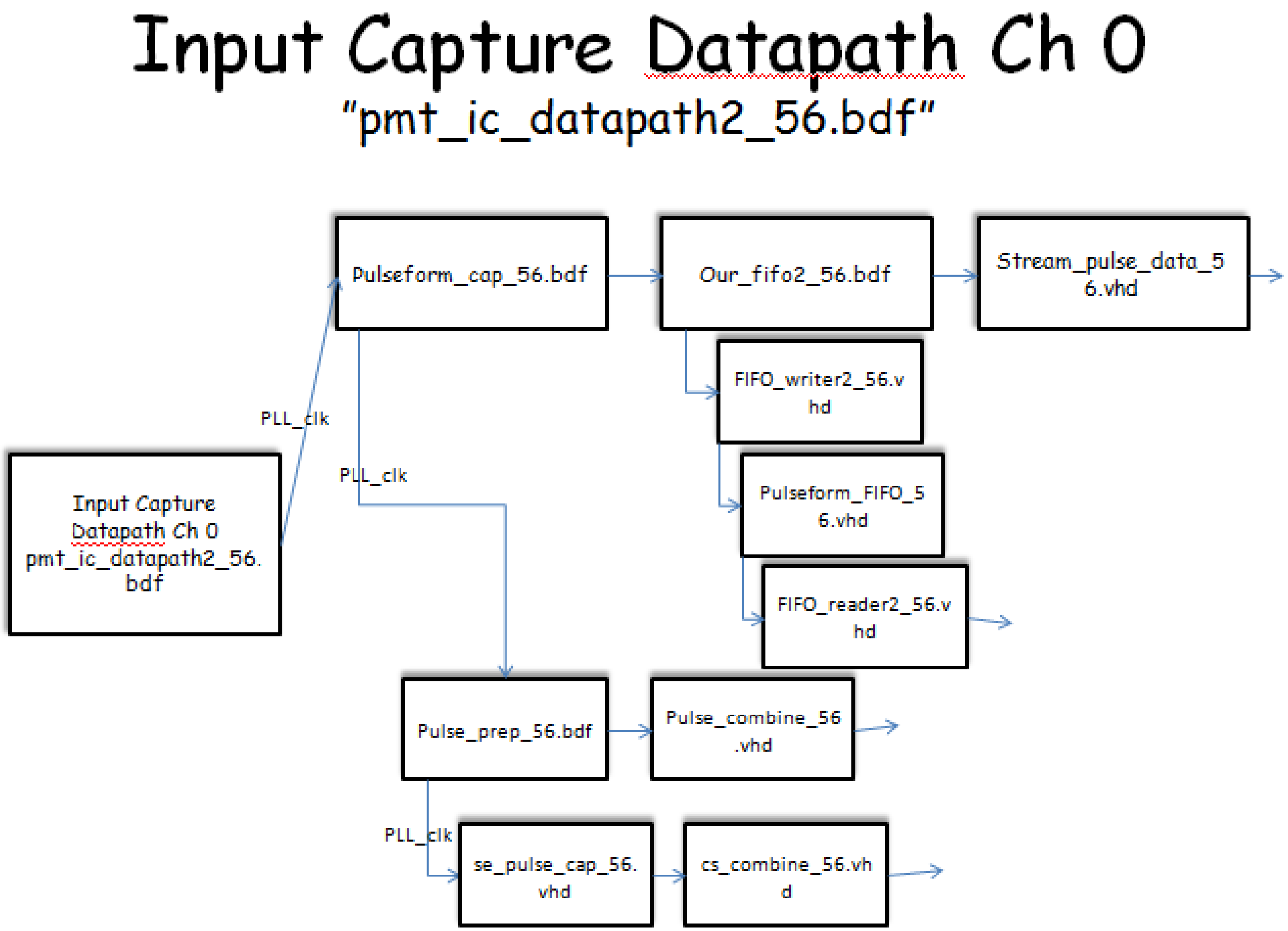
Component	Concept Selection
Network System Operational Speed	Increase current program speed
Detector Support Structure	I Beam suspension and Wall Mount Support
Cooling System	Peltier Method
Network System Enclosure	Base plate with transparent enclosure

Front End Digitizer Module

•Main board that retrieves signals from scintillators and sends to server for data processing.

•Houses Stratix II chip

Input Capture Data Path



Logic Locking of High Speed Components and Bit Width Reduction

The internal timing counter was 64-bits wide, giving over 10 years data values

This value was reduced to 56-bits and still give 4.5 years

Previous Speed 200 MHz
Desired Speed 500 MHz
Achieved Speed 323 MHz

To see the system memory improvement specifications after reduction please refer to Appendix A

Logic Locking Cont…

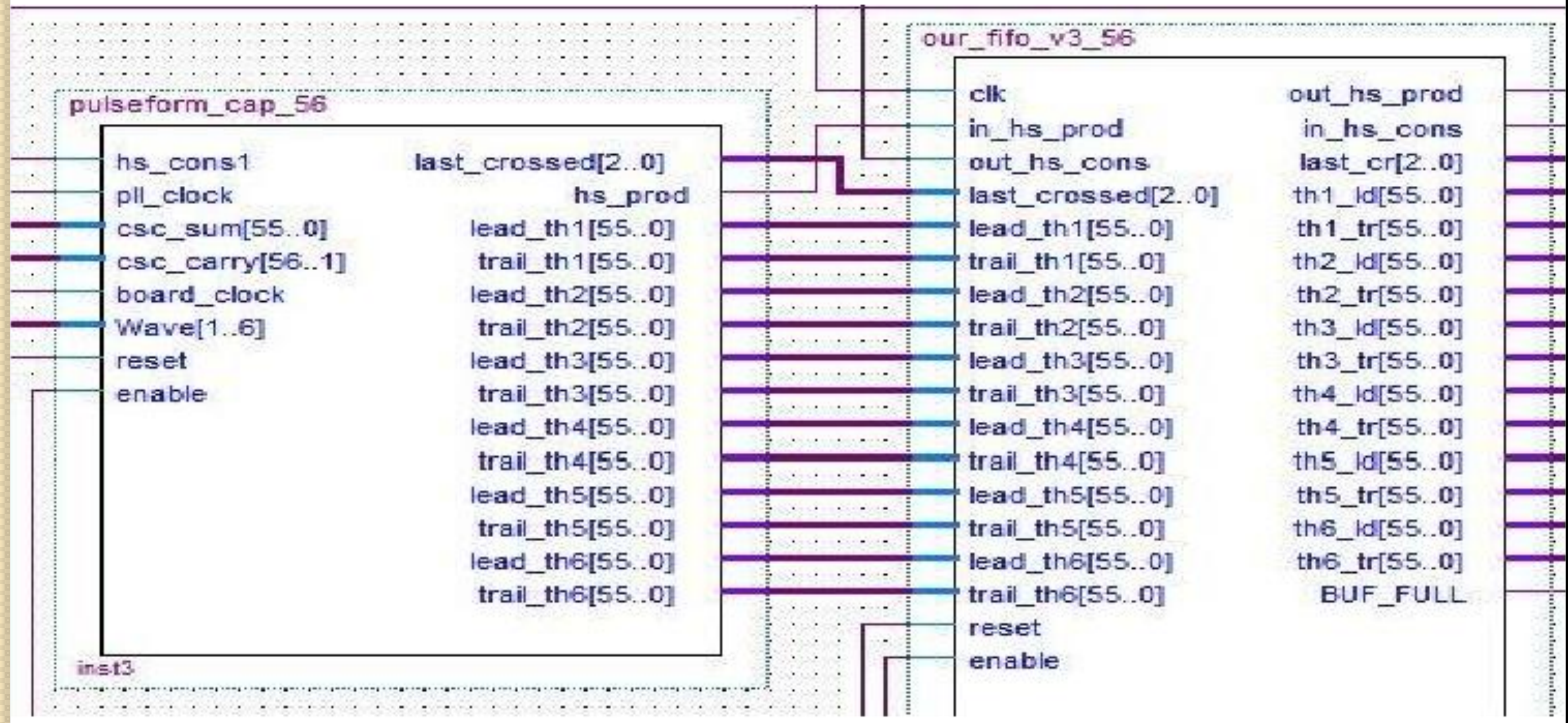
- Utilized Quartus' Logic Locking to obtain optimal operational running speed of 500 MHz
- All components utilizing the Pll_clock line will be locked
- Logic Locking settings:

  State - Floating or Locked
  Size - Auto or Fixed
  Reserved - On/Off -
  Enforcement - Hard or Soft
  Origin - Floorplan Location

  Please refer to Appendix A1 for Logic Locking methods

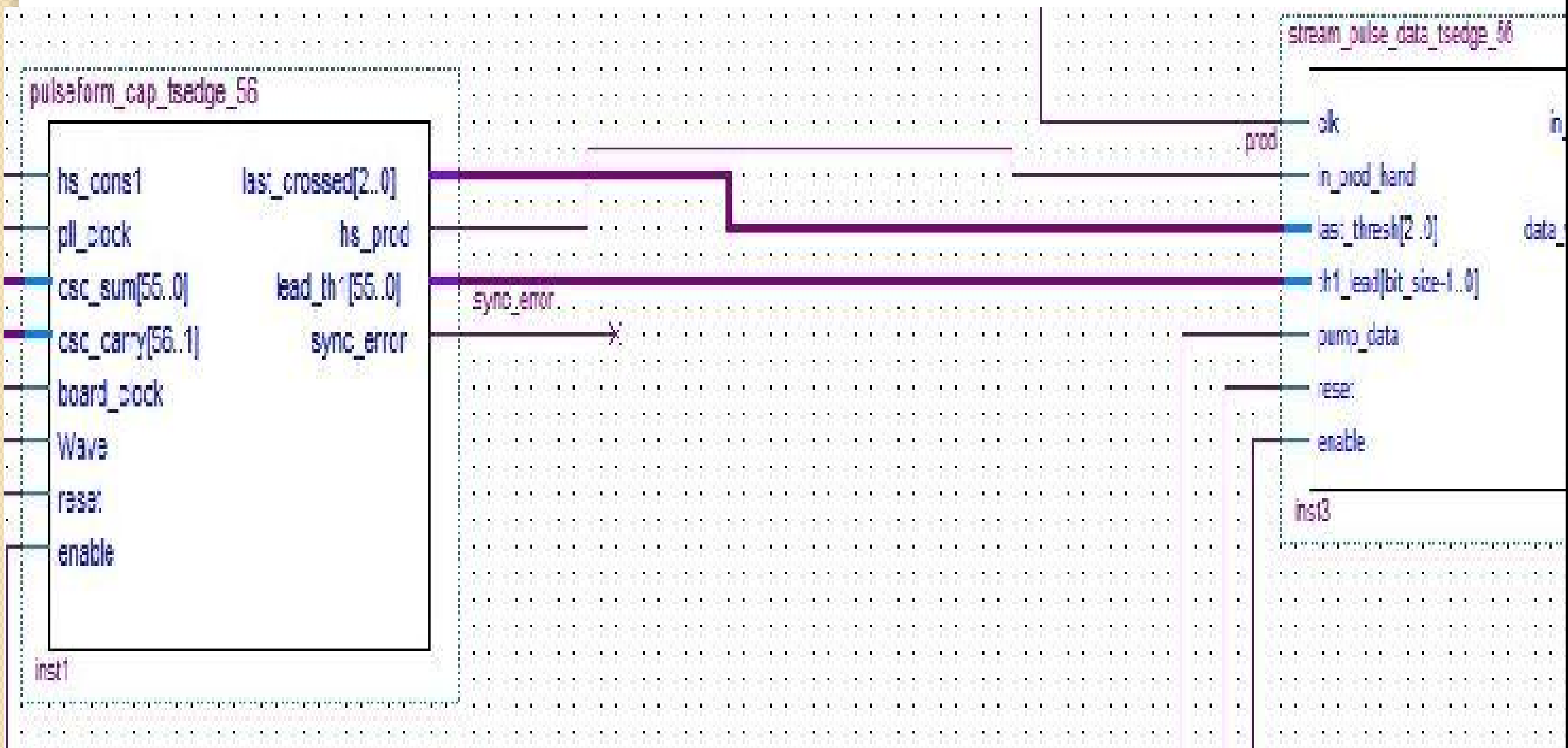
Timing Sync Data Paths

- Before Modification

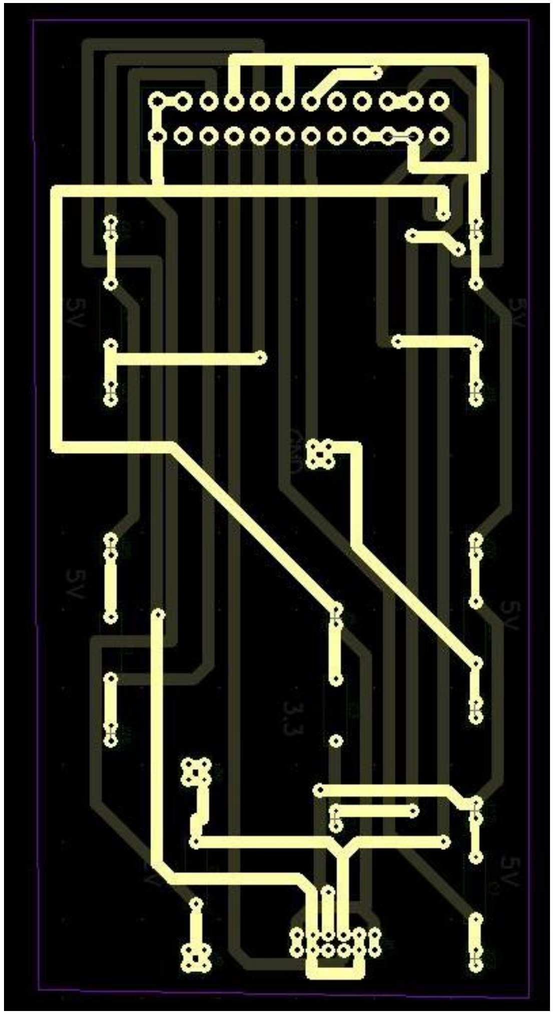


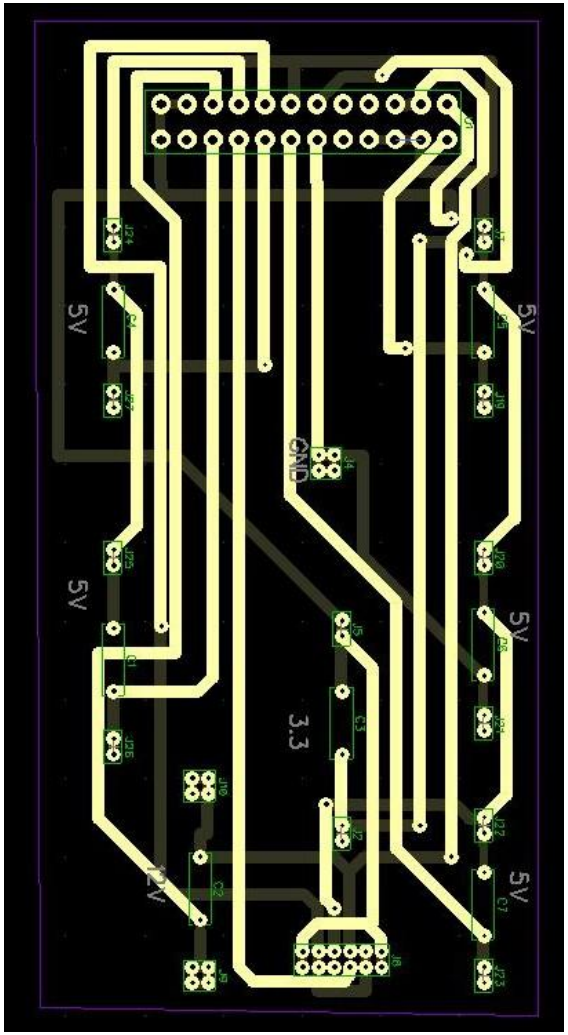
Timing Sync Data Paths Cont…

- After Modification
  - Testing Shown in Appendix C

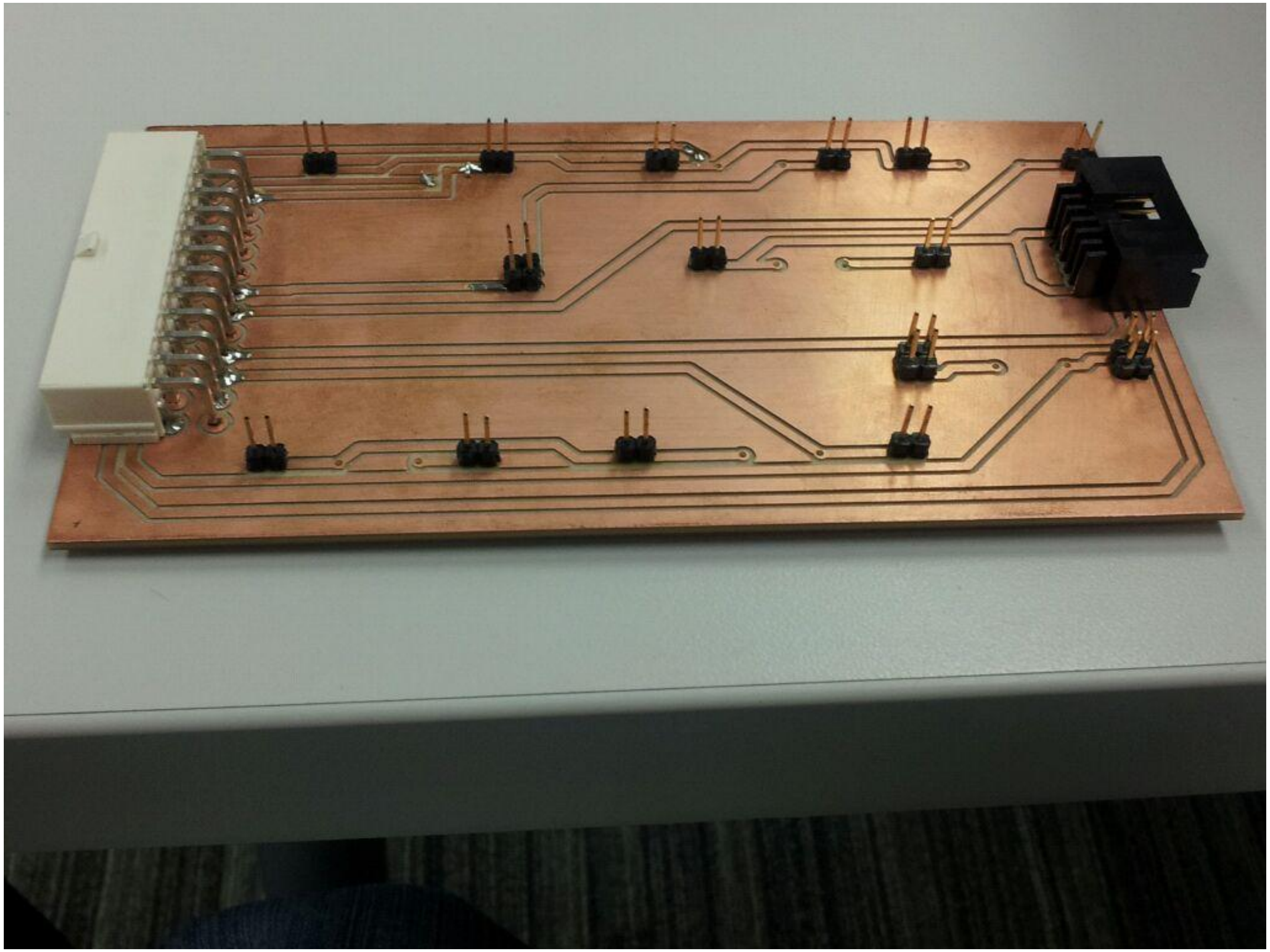


Power Distribution Board





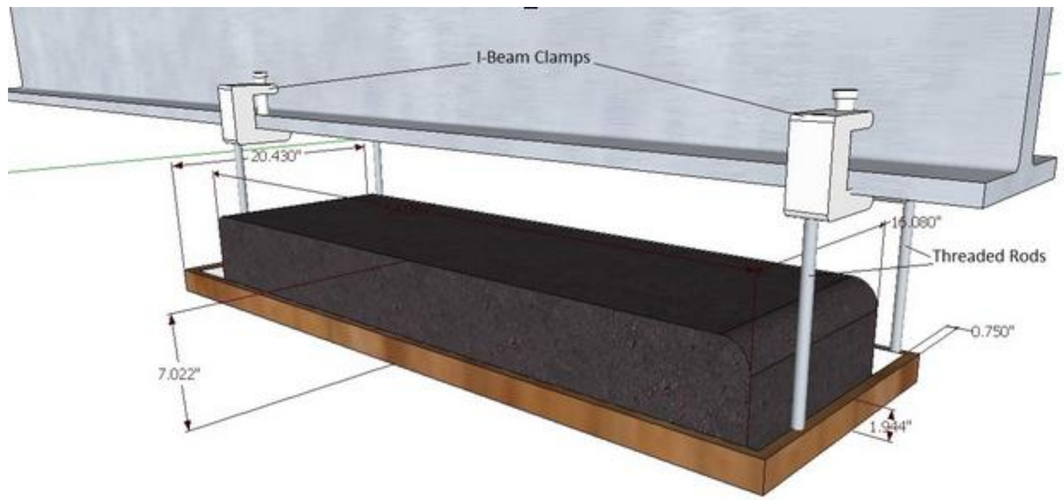
Final Power Board

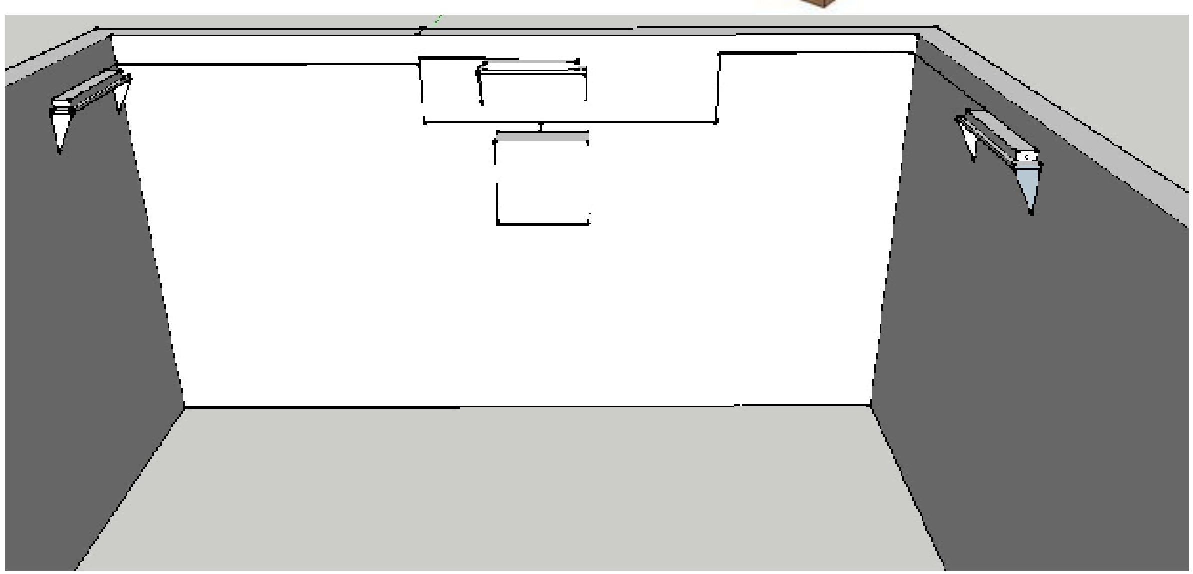


Detector Support Structure

- 3 Scintillators
  - Each 30’ apart creating equilateral triangle
  - Two shelf mounted
  - One suspended from I Beam through dropdown ceiling
- Wired to central network enclosure

Suspension & Shelving Design



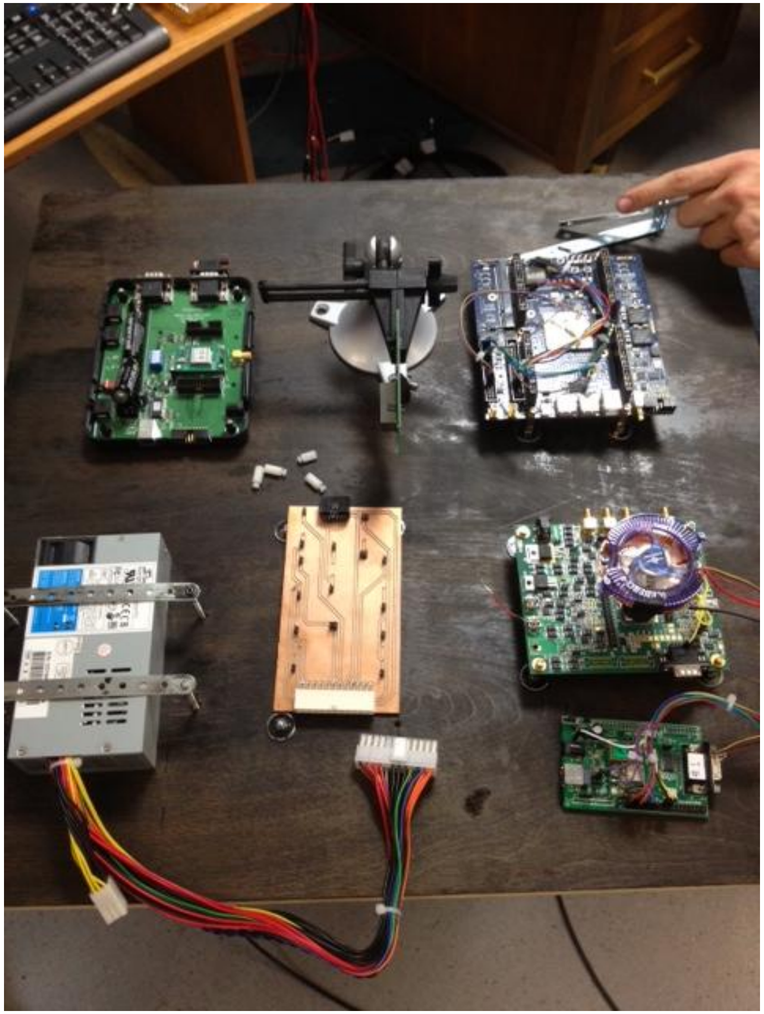


Suspension & Shelving Design Cont…

- Components of shelving units:
  - Each detector is placed in a foam insulated gun case weighing 25 lbs
  - Case is mounted and supported by 3 L brackets into the drywall
    - Single bracket weight capacity of 25 lbs
- Components of suspended units:
  - 4 I Beam Clamps
  - 4 threaded rods connected from clamp to structure
  - Structurally supports 100 lbs

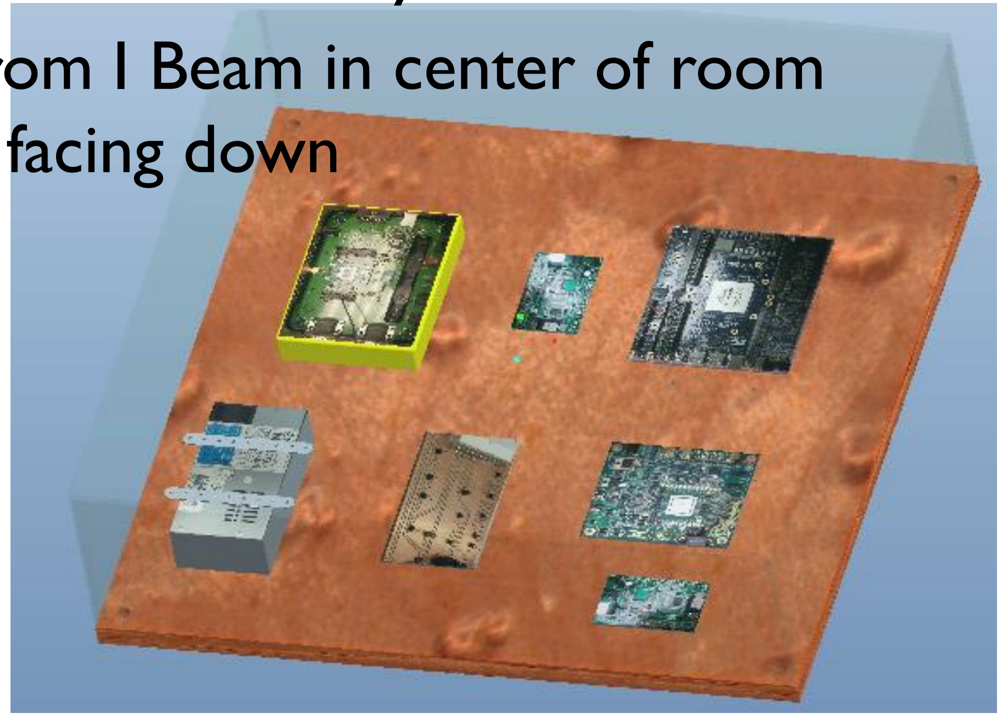
Network System Enclosure

Enclosure Houses:
FEDM Board
Power Supply
Power Distribution Board
Oscillator
GPS Board
DE3 Board
WiFi Board
Cooling System



Network System Enclosure Cont…

- All enclosure mounted on birch wood base plate.
- Enclosed in plexi-glass housing
- Latched top for accessibility
- Suspended from I Beam in center of room components facing down



Cooling System

- Used Peltier method for the Stratix II chip provides continued isolated cooling
- Mounted from base plate to fan, held in low compression against chip
- Prevents overheating and system shut down and restart which occurs at 53° C
- Maintains operational temperature at 1° C

Appendix B1

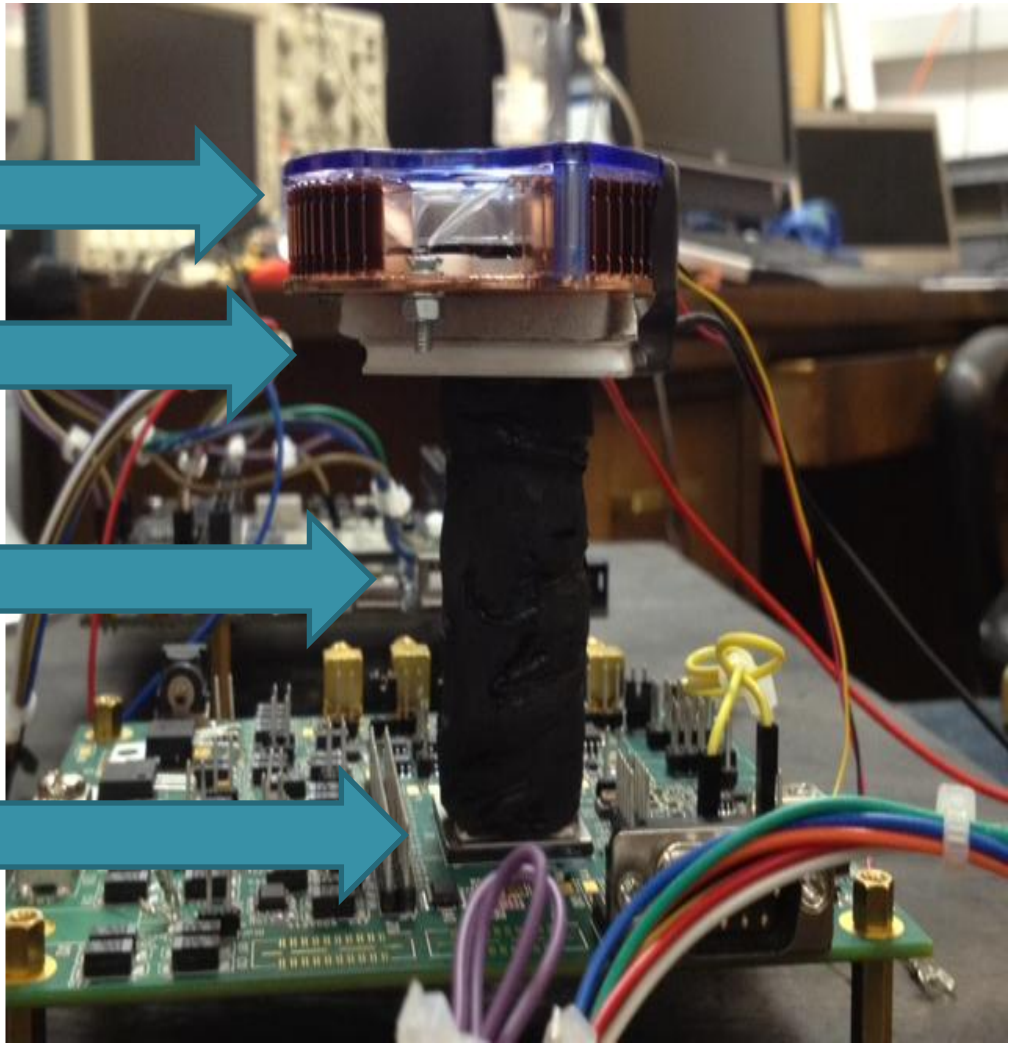
Cooling System Cont…

Copper Fin &
Fan Heat Sink

Thermoelectric
Cooler

Polyurethane
insulated Copper
rod

Stratix II chip

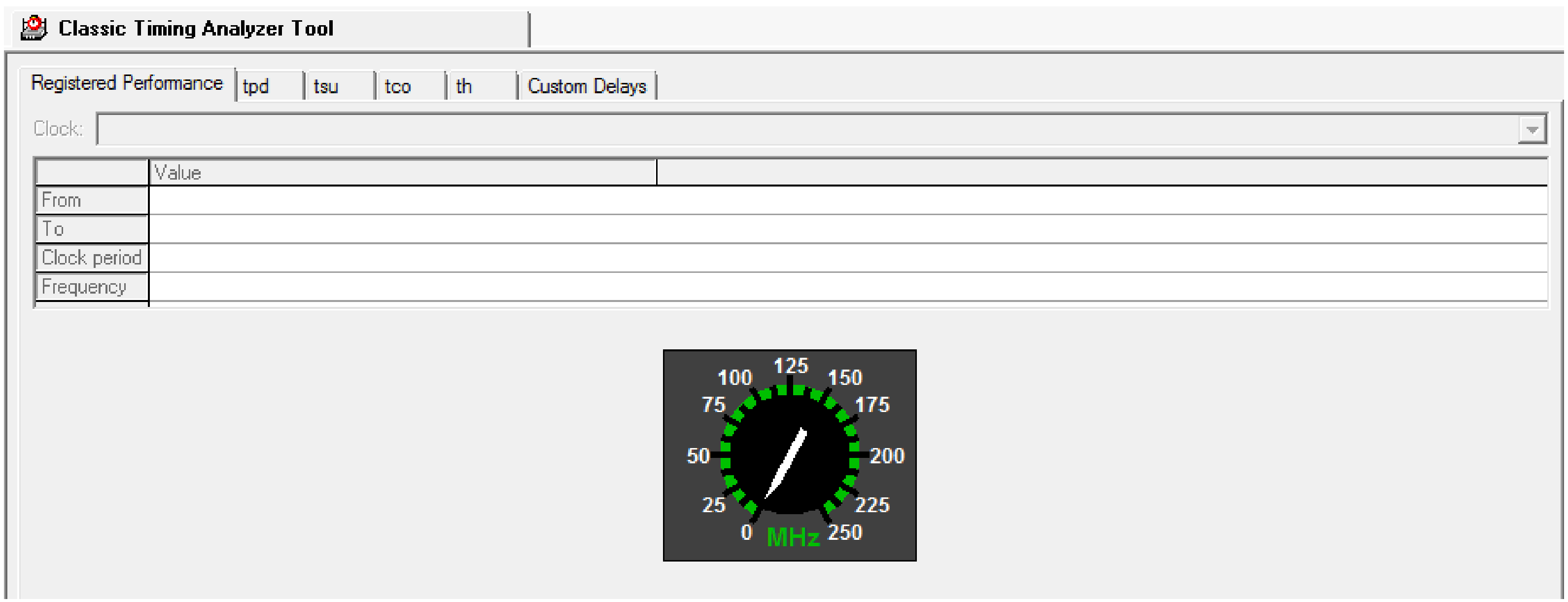


Budget

D. Expense	Quantity	Unit Price $	Total $
Equipment			
Structural Support			
Beam Clamp 3/8"	4	$2.39	$9.56
Threaded Rod 3/8"	4	8.89	35.56
Hex Nut Full 3/8" 100PK	1	6.28	6.28
Flat Washer 3/8" 100 PK	1	5.09	5.09
Cooling System			
Peltier Cooler	2	7.50	13.00
Heat Pipe	1	41.00	41.00
Fan	1	21.27	21.27
Enclosure			
Acrylic Cover	1	68.57	68.57
Birch Plywood Baseplate	1	9.99	9.99
Mounting Hardware	1	20.00	20.00
Power Supply Components			
Headers	7;1	2.50; 5.00	22.50
Power Distribution Boards		10	20
Connectors	3	n/a	15.00
Battery	2	65	130
Total Equipment Cost			210.32
Total Project Cost			**$439.09**

Circuit Speed Testing

- The Classic Timing Analyzer Tool was used to test circuit speed
- Feature gives estimate running speed from current compiled data with current FEDM design



Structural Support Testing

- Shelving Units tested in dry wall using 50lb weights
  - No failure
  - No bracket dislodgment from wall
  - Successful support testing

Enclosure Testing

- Supporting 2 lbs of hardware inverted
- Using deflection test
  - 80lb weight caused <4mm deflection

Cooling System Testing

- COMSOL rendering to support calculations.
- Successful system test of 2°C at operational speed of 353 MHz
- Slight condensation build up at thermo cooler contact point
    - Solution: Seal point of contact with small polyurethane ring

Sample Calculations Appendix B

COMSOL Rendering Appendix B2

Complete System

- Complete system test at 353 MHz
  - Have not reached 500 MHz yet
- Total system test proved successful
  - Stratix chip cooled to 2°C
  - Obtained small amount of data
    - No high cosmic activity at the time of testing

Questions?

Appendix A

- Before:
  - Slow Corner Fmax for high-speed counter: 211.28MHz
  - Logic Utilization: 24,314 / 27,104 (90%) = 2,790 remaining
  - Dedicated logic registers used: 21,878 / 27,104 (81%) = 5,226 remaining
  - M512 blocks: 193/202 (96%) = 9 remaining
  - M4K blocks: 144/144 (100%) = 0 remaining
  - M-RAM blocks: 1/1 (100%) = 0 remaining
- After:
  - Slow Corner Fmax for high-speed counter: 213.13 MHz (slightly better)
  - Logic Utilization: 22,007 / 27,104 (81%) = 5,097 remaining (almost 2x better)
  - Dedicated logic registers used: 19,463 / 27,104 (67%) = 7,641 remaining
  - M512 blocks: 188/202 (93%) = 24 remaining (more tha n 2x better)
  - M4K blocks: 144/144 (100%) = 0 remaining (same)
  - M-RAM blocks: 1/1 (100%) = 0 remaining (same)

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Appendix A1

State - Floating or Locked

Floating regions allow Quartus to determine the appropriate location of the block, while Locked uses a user defined location

Size - Auto or Fixed

Auto lets Quartus handle sizing while Fixed uses user defined sizing and shaping

Reserved - On/Off -

Enabling allows Quartus to utilize resources from this region for entities not assigned to this region

Enforcement - Hard or Soft -

Soft enforcement allows deference of the region to timing constraints, allowing entities to leave region if performance is improved. Hard enforcement does not abide by the relocation of entities

Origin - Location on Floorplan -

Defines the locations of the logic lock region

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Appendix B

- Q=k*a*(Thot-Tcold)/d
- Established Heat Rate (from current system) Q= 126.563 W
- Cross Sectional Area a= 5cm^2
- Desired Rod Length d= 8.4cm
- Thermal Conductivity of Copper k= 401 W/m*K
- Running Temperature (Thot) Thot= 53^{o}C (326K)
- Desired Running Temp(Tcold) Tcold= 0^{o}C (273K)

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Appendix B1

- Updated Specs With New Thermoelectric Cooler
- Q=40W
- =>Desired Rod Length d=3.3in

- $COP=T_C/(T_H-T_C)$
- $EFF= (T_H-T_C)/T_C$
- Eff=9.05%
- COP=11.05

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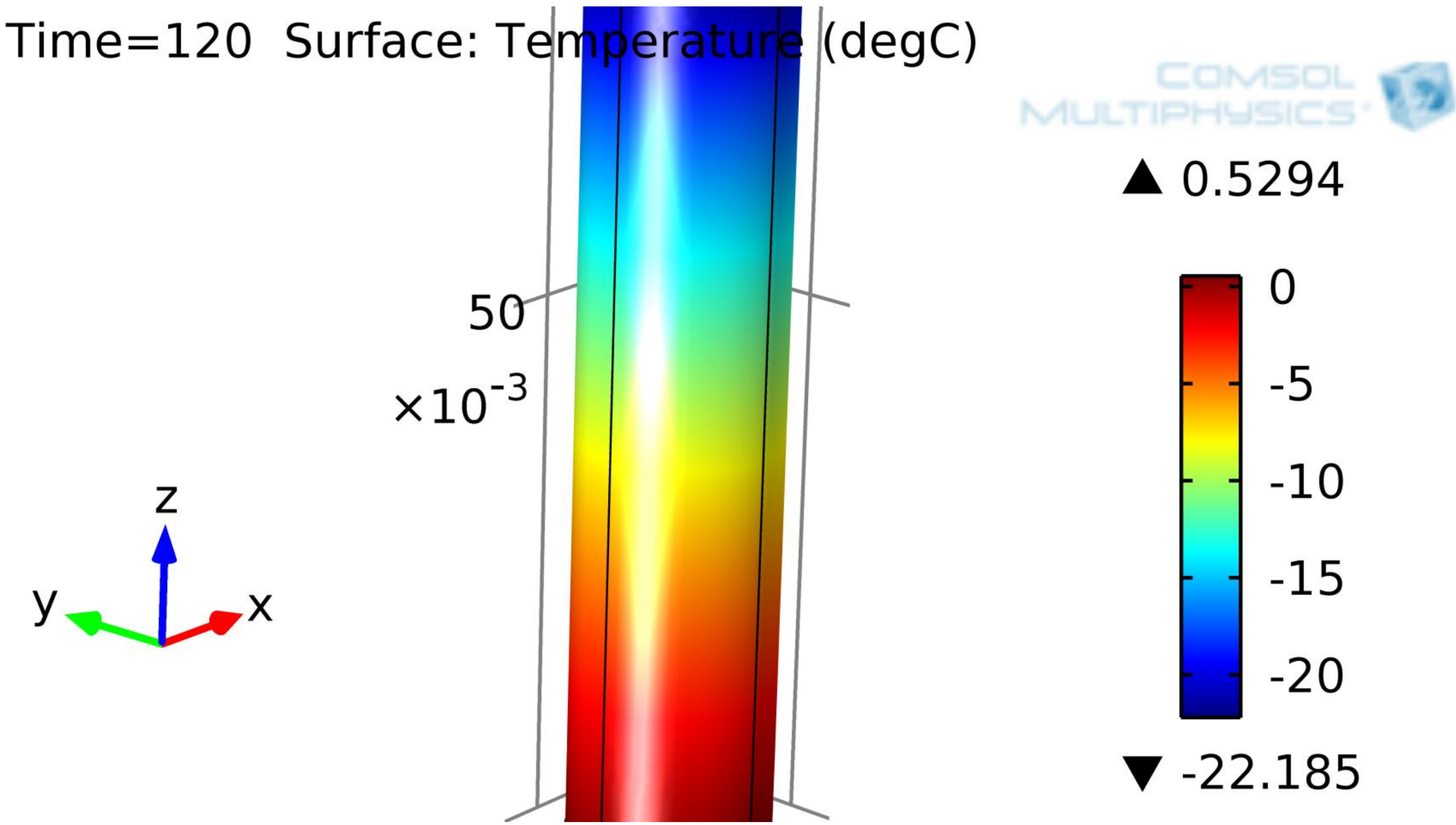
Appendix B2



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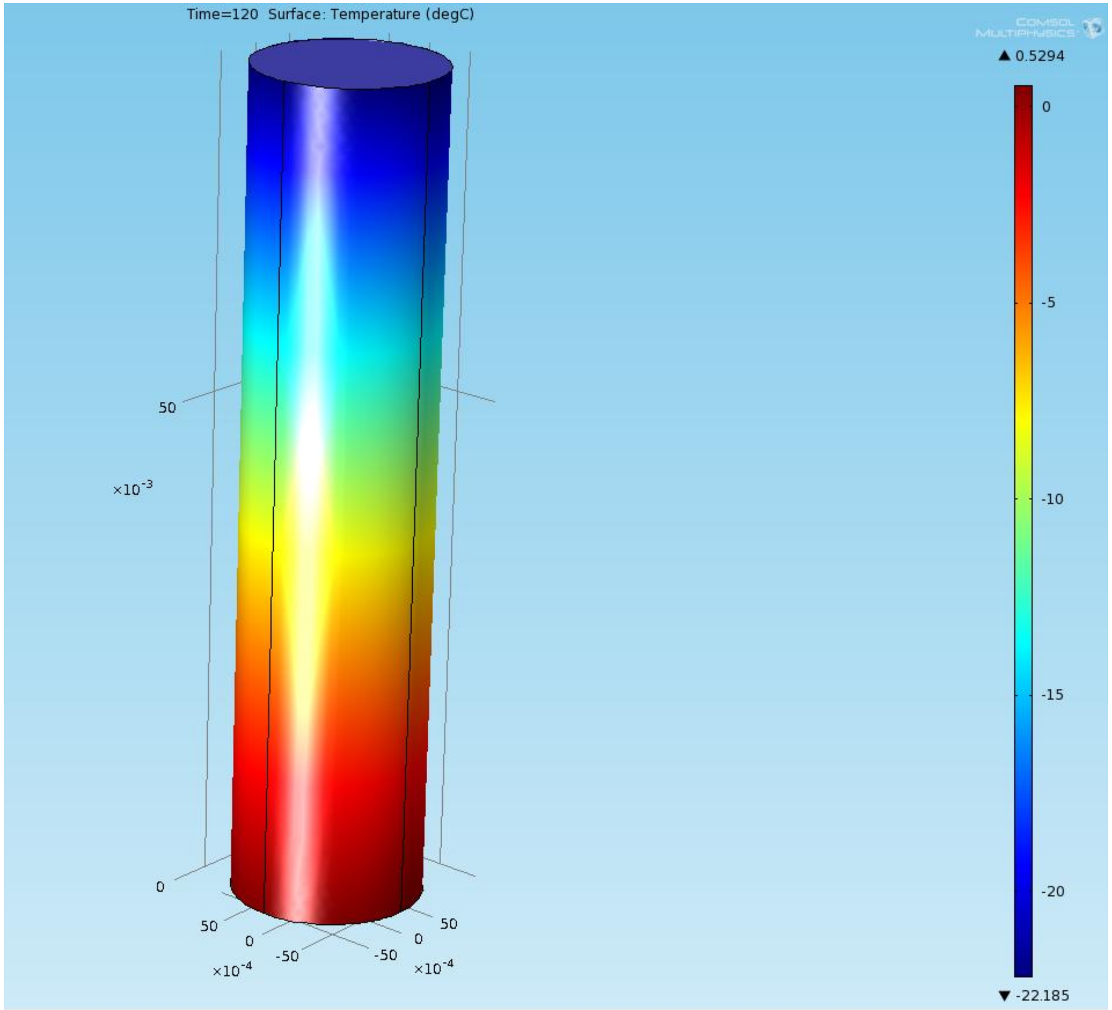
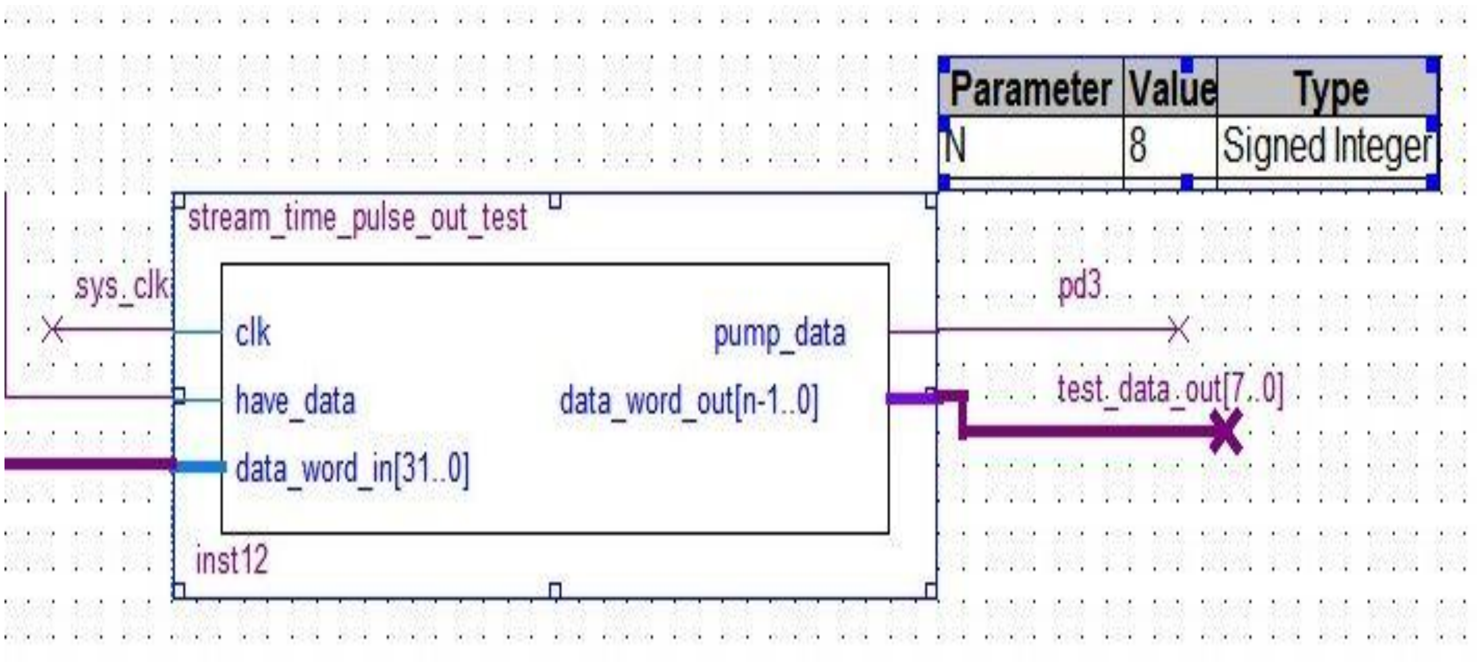
Appendix B3



Time=120 Surface: Temperature (degC)
▲ 0.5294
0
-5
-10
-15
-20
▼ -22.185
50
×10^-3
0
50
0
-50
×10^-4
50
0
-50
×10^-4

Appendix C

- Timing Sync Module Used for Testing



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Material Selection

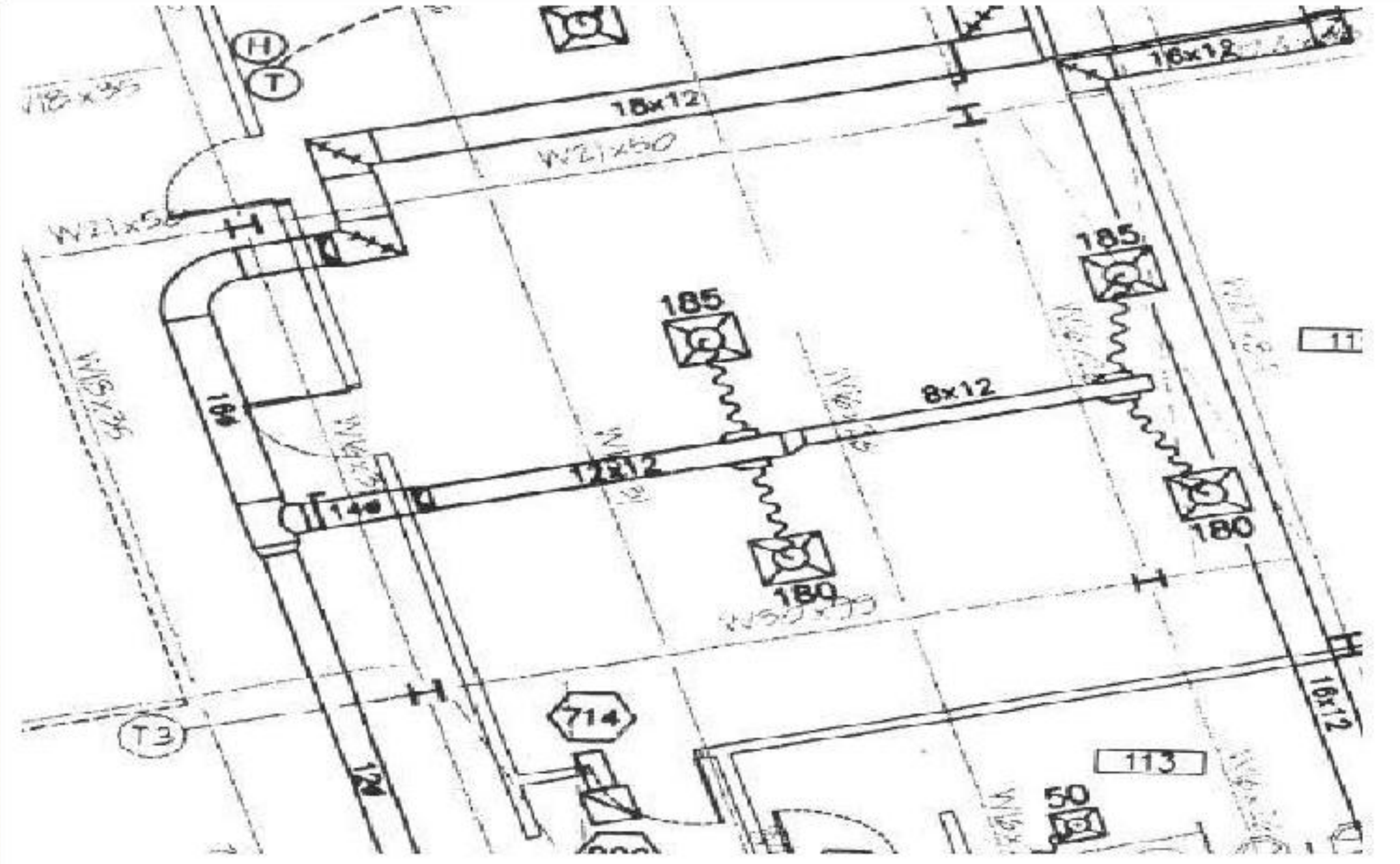
- **Need To use plots from Ashby's textbook to find the best material**
  - **Material Index**
    - **Shows which guide lines to use**
    - **Gives an idea of which plots to use**
- **Must use Modulus vs. Relative cost plot**
  - **Relative cost**
    - **Necessary to correct values and remove influence of inflation and units of currency**

$$C_{v,r} = \frac{\frac{Cost_{material\ selection}}{kg} * Density\ of\ material\ selection}{\frac{Cost_{steel}}{kg} * Density\ of\ mild\ steel\ rod}$$

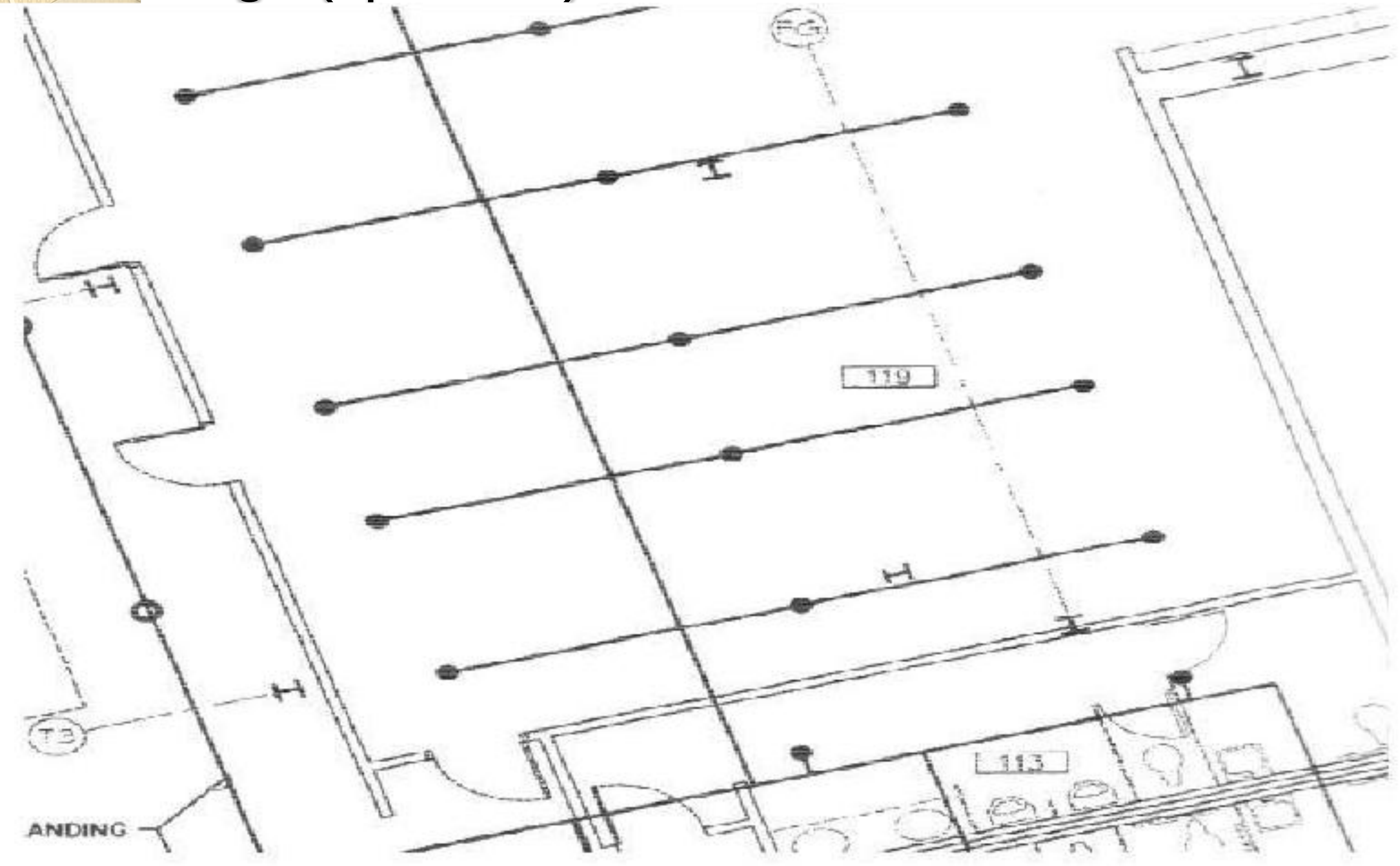
Material Choice: References

- *Aluminum Plate*. Digital image. *Made-in-china.com*. Web. 29 Nov. 2011. <http://image.made-in- china.com/2f0j00bBpEIOzJZvuV/Fireproof-Aluminum-Plate.jpg>.
- Ashby, M. F. *Materials Selection in Mechanical Design*. Burlington, MA: Butterworth- Heinemann, 2011. Print.
- *Baltic Birch Plywood*. Digital image. Web. 29 Nov. 2011. <http://images.rockler.com/rockler/images/63388-01- 200.jpg>.
- "MDF Board FAQ - Tutorial." *DIY Audio & Video - FAQs, Tutorials, and Calculators for Speaker Boxes, Crossovers, Filters, Wiring and More*. Web. 29 Nov. 2011. <http://www.diyaudioandvideo.com/FAQ/MDF/>.

Drawings (vent)



Drawings (sprinkler)



Drawings (iBeam)

Drawings (electrical)