Marx Modulator Status Report

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SLAC Power Conversion Dept.
for the Marx Team
April 24. 2008
Presentation Overview

- Marx Development Program
- P1-Prototype Development Status
- Vernier Regulator Development Status
- Cost Estimate Review
Marx Development Program

• Prototype (P1) Modulator
  – Demonstrate efficacy of Marx topology for ILC Klystron modulator application (thru FY08-Q3)
  – Power 10 MW klystron for ESB life/performance testing (start FY08-Q4)

• 2\textsuperscript{nd} Generation Prototype (P2) (FY09 & 10)
  – Modify to conform to revised tunnel design
  – Improve manufacturability
  – Improve reliability/availability
P1-Prototype Status

• Operated at Full Voltage (120 kV), Current (140 A) and Pulse Length (1.6 ms) with Coarse Flattening
  – 16 Cell at 11 kV, 11 prompt and 5 delayed
  – Load variations → >150 A
  – Vernier Regulator for 0.5% regulation under development
• Operated at Near Full Power (135 kW)
  – Maximum of ≥100 kW, limited by 11 kV source and load
• Operated at Full PRF (5 Hz)
• Operated for Several Days without Intervention
• BUT Have Not Achieved All Simultaneously
Marx Output with Coarse Flattening

Voltage: 20 kV/div
Current: 50 A/div
Energy: 4.5 kJ/div
P1-Prototype Development Challenges

• (Too) High Voltage Stress on IGBTs, Scale Back to Improve Robustness to a Suitable Level of this Application
  – $V_{OP} / V_{(BR)CES} \approx 0.67$
  – Small/No snubbers or MOVs
  – Over Voltage protection active: device turn-on delay
• Extended Operation to Evaluate “Subtle” Effects
• Fault Testing: Simulate Klystron Arc
• Prime Power/Load Limitations/Failures
• Control System Upgrades: EPICs Support
• Packaging for ESB Operation
• Vernier Regulator
Marx Water Load & Charger
Vernier Regulator

- 16-Cell “Mini-Marx”, 1.2 kV Cells
- Multiple Erections of Marx to Generate a Series of Voltage “Ramps” to Offset Droop (Sawtooth) in Coarse Pulse Flattening
- 2nd Generation Cells Successfully Operated, 5-cell Stack
- 3rd Generation Cell Design Complete
- Motherboard/Aux Board Designs Nearly Complete
5-Cell Vernier Test Set-up
5-cell Vernier Output

Voltage: 1 kV/div
Current: 20 A/div

Ch3 Min -5.76 kV
Ch4 Min -143 A

23 Apr 2008
12:29:13
Cost Estimate Revisited

• Bulk of original components, costs remain unchanged since model shown at Snowmass ’05.
  – Same architecture of cells, housing
  – Major cost drivers (IGBT’s, capacitors) ~same

• 2008 adjustments
  – Charger Supply
    • Earlier estimate assumed bulk regulator at 12 kV built onto single cell; did not included distribution or phase load balancing
    • New estimate made for 6-Pack high availability power distribution (R. Cassel) added $60K per modulator
  – Cell voltage reduction
    • Originally designed to run at 12 kV per cell, insufficient margin for protection
    • Now operating at 11 kV/cell, which means should add ~8% to cost for same level of cell redundancy
  – Results shown in next slide.
Snowmass ’05 Updated

- **Unit 1 (K$)**
- **Prod LC1 (K$)**
- **Prod LC2 (K$)**

<table>
<thead>
<tr>
<th>Component</th>
<th>Unit 1 (K$)</th>
<th>Prod LC1 (K$)</th>
<th>Prod LC2 (K$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDR BCD</td>
<td>650k</td>
<td>500k</td>
<td>200k</td>
</tr>
<tr>
<td>MARX 1 (Snowmass)</td>
<td>400k</td>
<td>300k</td>
<td>150k</td>
</tr>
<tr>
<td>MARX 2</td>
<td>500k</td>
<td>350k</td>
<td>150k</td>
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</table>
# Marx Cost Summary

Including 8-Pack Charger & AC Distribution, Extra Cell

Rev. 042408

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost Basis</th>
<th>M&amp;S</th>
<th>Labor</th>
<th>Total k$/)</th>
<th>Profit 15%</th>
<th>Total Cost</th>
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</thead>
<tbody>
<tr>
<td><strong>Main Unit</strong></td>
<td>M&amp;S Quotes, Labor Eng. Estimate</td>
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<td>(*1.08)</td>
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<td>Marx Cells</td>
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<td>131.0</td>
<td>10.0</td>
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<td>Modular Enclosures</td>
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<td>Overall Enclosure</td>
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<td>Cooling Main Unit</td>
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<td>Internal Wire/cable</td>
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<td>1.6</td>
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<td>Diagnostic Cntrlrs</td>
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<td>PLC Controls</td>
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<td>Cntrl Sys Interface</td>
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<td>Other labor</td>
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<td>15.0</td>
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<td><strong>Subtotal Main Unit</strong></td>
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<td>156.0</td>
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<td>Protection Units</td>
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<td>1.5</td>
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<td><strong>Charging Supply</strong></td>
<td>Cassel HA System w/ distribution</td>
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<td>67.2</td>
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<td>Miscellaneous</td>
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<td>10.9</td>
<td>5.0</td>
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<td><strong>Subtotal, Misc</strong></td>
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<td>79.6</td>
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<td><strong>Subtotal Prod.Unit 1</strong></td>
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<td>235.6</td>
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<td><strong>Total Cost Full Unit 1 (k$)</strong></td>
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<td>286.8</td>
<td>43.0</td>
<td>329.9</td>
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<td><strong>Avg Cost 572 Units</strong>¹</td>
<td>Conservative LC (95%M&amp;S, 95% Labor)</td>
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<td>248.8</td>
<td>37.3</td>
<td>286.1</td>
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<td><strong>Avg Cost 572 Units</strong>²</td>
<td>Aggressive LC (90% M&amp;S, 85% Labor)</td>
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<td>174.4</td>
<td>26.2</td>
<td>200.6</td>
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</table>

¹ Includes 20% ED&I in LC

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April 24, 2008

Marx Status Update

R. Larsen
Marx Program Summary

• P1-Prototype Nearing Completion (FY08-Q3)
• Integrate P1 into L-band Facility (FY08-Q4)
  Initiate Life Testing of Marx and MBK
• Complete Vernier Regulator and Integrate into P1 (FY08-Q3/4)
• Nth Unit Cost Re-examined: $200k - 290k, 
  ~30% Increase from Snowmass ’05 Estimate
• P2-Prototype Development FY09-10
The Marx Team
Past, Present, (Future?)

- D. Anderson
- P. Bellomo
- P. Blum
- C. Brooksby (LLNL)
- C. Burkhart
- R. Cassel
- R. Chestnut
- E. Cook (LLNL)

- A. de Lira
- R. Larsen
- G. Leyh
- D. Moreno
- M. Nguyen
- J. Olsen
- P. Shen
- A. Viceral