Linac Design and R&D Overview

Chris Adolphsen

- Layout and Parameters
- Modulators
- Klystrons
- RF Distribution
- Accelerator Structures and Supports
- Component and System Tests
One TeV X-Band Linear Collider

10 km of 1.8 m Long X-Band (11.424 GHz) Accelerator Structures
MAIN LINAC PARAMETERS

<table>
<thead>
<tr>
<th></th>
<th>Phase I</th>
<th>Phase II</th>
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<tbody>
<tr>
<td>Final Energy</td>
<td>250 GeV</td>
<td>500 GeV</td>
</tr>
<tr>
<td>Particles per Bunch</td>
<td>0.7 - 1.1 \times 10^{10}</td>
<td></td>
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<tr>
<td>Bunch Spacing</td>
<td>2.8 ns</td>
<td></td>
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<tr>
<td>Bunches per RF Pulse</td>
<td>95</td>
<td></td>
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<tr>
<td>Pulse Repetition Rate</td>
<td>120 Hz</td>
<td></td>
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<tr>
<td>Effective Gradient</td>
<td>55 MeV/m</td>
<td></td>
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<tr>
<td>Klystron Power</td>
<td>75 MW</td>
<td></td>
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<tr>
<td>Klystrons per Linac</td>
<td>1600</td>
<td>3200</td>
</tr>
<tr>
<td>Structures per Linac</td>
<td>2400</td>
<td>4800</td>
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</tbody>
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Changes Since Zero’th Order Design Report

- Same RF system in 0.5 TeV and 1.0 TeV designs
- Bunch spacing increased: 1.4 ns to 2.8 ns
  \rightarrow Reduced multibunch loading: 28% to 16%
  \rightarrow Reduced unloaded gradient: 85 to 74 MeV/m
- Klystron pulse width increased: 0.96 \mu s to 1.52 \mu s
  \rightarrow RF distribution changed
  \rightarrow Reduced number of klystrons by 1/3
- New accelerator structure cell design
  \rightarrow Increased RF-to-beam efficiency by 6%
Linac RF Unit

Low Level RF System
One-Four 490 kV Modulators (not shown)
Eight 2 KW TWT Klystron Drivers (not shown)
Eight 75 MW PPM Klystrons
Delay Line Distribution System (single mode)
Four Accelerator Structure Triplets

Delay = 3 \cdot 1/2 \cdot \text{Klystron Pulse Width}/4 = 168.9 \text{ m}

112.6 \text{ m}
56.3 \text{ m}

Beam Direction

Three 1.8 m Accelerator Structures (200 MW, 380 ns Each)
LINAC SECTOR - DLDS NONET

9 x 8 KLYSTRONS

9 x 12 ACCELERATOR STRUCTURES

Active / Actual Length = 9 x 12 x 1.8 / 225.2 = 86%
Relative Linac Costs

- Modulators: 25%
- Klystrons & LLRF: 20%
- RF Distribution: 15%
- Structures: 10%
- Other: 5%
Conventional Line-Type Modulator

49° KV

265 A / Klystron

1.5 μs Flattop

Thyratron

1:14 Transformer

Charging Supply

Pulse Forming Network
Conventional Modulator Test Setup at SLAC

Performance Driving a 5045 Klystron at 290 kV, 310 A

- 90% Transfer
- 79% Pulse Rise/Fall
- 92% PS (Estimated)
- 65% Overall

Efficiency

Time (μs) vs. Output Power (MW)
INDUCTION MODULATOR:
SUM MANY LOW VOLTAGE SOURCES INDUCTIVELY

\[ \Delta V = V_{kly} \div N \]

INDUCTION CIRCUIT (1 OF N)

- MetGlass Core
- Power Supply
- IGBT
- Collector Grid Emitter
- Storage Capacitor
- Driver Circuit

Isolated Gate Bipolar Transistor

Rated: 3.3 kV @ 0.8 kA (DC)
Tested: 2.0 kV @ 1.5 kA (Pulsed)
Future: 5.0 kV @ 2.0 kA (Pulsed)
500 kV, 2.1 kA INDUCTION MODULATOR DESIGN

Powers 8 Klystrons: 1:1 Turns Ratio
Predicted Efficiency ≈ 75%

Four Stacks of 25 Cores

Simulated Output

Output Voltage (kV)

Time (μs)

-200
0
200
400
600

0.5
1.5
2.5

Top View
Side View
Bottom View
Modulator Summary

- **Status**
  - Line-Type Modulator is Our Baseline Choice
    - Proven Technology + Off-the-Shelf Parts
  - Solid State Version is in Early Design Stage
    - Potential for Lower Cost, Higher Efficiency and Higher Reliability

- **Future R&D**
  - Build and Test Full Scale Prototypes of Each
  - Choose One Design and Build Enough for System Test of Eight Klystrons
KLYSTRONS

Solenoid Focused
Solenoid Power = 25 kW

Periodic Permanent
Magnet (PPM) Focused
SOLENOID FOCUSED KLYSTRONS

($\mu P = 1.2$, Multi-Cell TW Output Cavities)

KEK

- XB72K#9: BINP design - achieved 72 MW in a 400 ns pulse (modulator limited) with 31% efficiency.
- XB72K#10: KEK design - uses longer, lower $Q_{\text{ext}}$ output cavity - expect 126 MW with 49% efficiency.

SLAC

- XL4: Five built - used for beam operation in NLCTA and high power tests in ASTA.
PPM KLYSTRON LAYOUT

Axial Magnetic Field ≈ 2 kG RMS
(≈ 5 kG for Solenoid Focusing)

Collector for Spent Beam
RF Output Coupler
1.7 m
RF Input Coupler
Gun

RF Cavity
Magnetic Field
Samarium Cobalt Permanent Magnet Rings
Pole Pieces
Spacer

Beam Size (mm) and Field Profile (au)

Distance Along Axis (mm)
Klystron Summary

- **Status**
  - Have Experience with 50 MW Solenoid Focused Tubes (XL4)
  - Have Working 50 MW PPM Klystron
  - Debugging Magnetic Circuit on 75 MW Version

- **Future R&D**
  - Solicited Bids to Build 50 MW PPM Tubes
  - Design-for-Manufacture 75 MW Prototype will be Tested Next Year
  - Build Eight Klystrons for a System Test
11.424 GHz RF Reference

Fast Phase Shifters

75 MW Klystrons

Delay = 3 \cdot \frac{1}{2} \cdot \text{Klystron Pulse Width}/4 = 168.9 \text{ m}

150 MW 1520 ns

300 MW 760 ns

600 MW 380 ns

Beam Direction →

Accelerator Structures
WRAP-AROUND MODE CONVERTER

Processed to 320 MW
RF Pulse Length = 150 ns
Multi-Mode DLDS

A Different Mode is Launched During Each Quarter of the Klystron Pulse
Four Mode Launcher

Input Port Phases (e.g., + - + -)
Determines Mode Launched

Single Mode Extractor
RF Distribution Summary

- **Status**
  - Single-Moded (SM) DLDS is Our Baseline Choice
    - Have Experience with 200-300 MW Operation in TE,, ■ and TE,, • at ASTA and NLCTA
  - Multi-Moded (MM) DLDS in Conceptual Phase
    - Circular-to-Square WG Transitions Look Promising for Both MM and SM Components (Bends, Hybrids and Tapoffs)

- **Future R&D**
  - Build SM & MM Components and Test at
    - 300 MW (150 ns) in ASTA This Year
    - 600 MW (240 ns) in NLCTA Next Year
    - 600 MW (1500 ns) in System Test
Cut-Away View of the Damped and Detuned Structure (DDS)
Wakefield of the Detuned Structure (DS) and Damped Detuned Structure (DDS)
Structure
Cell Geometries

DDS $\rightarrow$ Rounded DDS (RDDS)

Shunt Impedence $\approx 12\%$ Higher

$\tau \sim 1 / v_g Q \approx 6\%$ Smaller

RF to Beam Efficiency $\approx 6\%$ Higher
Section of Linac Beamline
Structure and Support Summary

- **Status**
  - Have Built Several DS’s and DDS’s
  - Performance Tests Show Good Results for
    - Long-Range Wakefield Suppression
    - Beam Centering Based on HOM Signals
    - High Gradient (70 MeV/m, 150 ns) Operation
    - Initial and Long-Term Straightness
  - Finalizing RDDS Design and Starting Support Engineering

- **Future R&D**
  - Build Several RDDS Prototypes with KEK
  - Build Three-Structure Girder for System Test
Next Linear Collider Test Accelerator

GOALS

- To construct and reliably operate an engineered model of a section of the NLC high-gradient linac.

- To test those beam dynamics questions coupled to acceleration.
NLCTA
RF Station 1 & 2

11.424 GHz RF Reference
Station Phase Control
RF Amplitude Control
TWTs
Relative Phase Control
50 MW XL4 Klystrons

300 MW
DLDS Test Components
600 MW
240 ns
Load Tree
Linac RF Unit

Single Mode Extractor

56.3 m

4 Mode Launcher

Accelerator Structures

Beam Direction

NLCTA System Test
Component and System Testing

- **Current**
  - ASTA for High Power (300 MW, 150 ns) Processing
  - NLCTA for Beam Studies and Structure Processing

- **Future**
  - Upgrade NLCTA for DLDS Tests (600 MW, 240 ns)
  - System Test (600 MW, 1500 ns)
    - Eight 75 MW PPM Klystrons (50 khour/year Lifetime Test)
    - Multi-Mode DLDS (3 Ports to Loads, 1 to Structure Triplet)
    - Prototype Low Level RF and Interlock System
Review Focus

- Baseline Design: What is the design status, what are its risks, and what are the R&D plans.
- Other Options: What are their benefits and what R&D is needed to adopt them.
- Cost and Scheduling Model: What is our model for deriving cost estimates and construction and installation schedules in the next two years.
X-Band Klystron Production and Installation Schedule
Linac Review Schedule

Wednesday (11/4) from 1:30 to 5:30

Overview of Linac Design and R&D Program - Chris Adolphsen - 30 + 10
Overview of Costing Plans - Mike Neubauer - 20 + 10

Baseline Modulator Design and R&D - Saul Gold - 20 + 10
Break - 20
Induction Modulator Design and R&D - Dick Cassel - 20 + 10
Modulator Cost and Scheduling Model - Ray Larsen - 20 + 10

Klystron Development Program - Erik Jongewaard - 20 + 10
Klystron Cost and Scheduling Model - John Cornuelle - 20 + 10

Thursday (11/5) from 9:00 to 12:00

Baseline RF Distribution and Beamline Layout - Mike Neubauer - 30 + 10
Baseline and Multimode RF Component Development - Sami Tantawi - 30 + 10
RF Distribution Cost and Scheduling Model - Mike Neubauer - 30 + 10

Break - 20

Accelerator Structure Development - Juwen Wang - 30 + 10
Structure Cost and Scheduling Model - John Cornuelle - 20 + 10

Questions and Special Requests - 30