Working Group 2 – Introductory presentation.

Convenors –
C. Adolphsen, T. Garvey, H. Hayano
Topics covered by WG2

• Modulators / klystrons
• RF wave-guide distribution
• Low Level RF
• Beam interfaces (quadrupoles, BPM’s)
• Cryomodule
• Cryo-systems

Important interfaces with other WG’s especially WG5
Outline of presentation

• Progress in WG2 topics since last ILC meeting (will not necessarily be exhaustive!).
  – Not new R&D results; rather, “firming up” of plans for future R&D, re-orientation of Americas and Asian accelerator activities towards L-band / SC RF.
  – CARE / SRF activities in Europe
  – TTF-linac / X-FEL activities

• Overview of WG2 sessions to be held here.
• What WG2 hope to accomplish at this meeting.
FNAL-Based SMTF Proposal: “It is anticipated that, with coordination from the ILC-Americas collaboration, SLAC will lead the ILC rf power source efforts ...
SLAC plans for ILC RF Sources

- Initial SLAC program will focus on:
  - Establishing a 1.3 GHz test stand to gain experience with L-band technology. Will test NC structures and cavity power couplers.
  - Developing alternatives to the baseline modulator and klystron to reduce cost and improve efficiency and reliability.
Modulators for ILC

**Specification**

- RF Pulse Length: 1.37 ms
- Modulator Rise/Fall Time: 0.2 ms max
- Modulator Pulse Length: 1.7 ms max
- Klystron Gun Voltage: 120 kV max
- Klystron Gun Current @120kV: 140 A max
- Pulse Flatness: +/- 0.5%
- Total Energy per Pulse: 25 kJ
- Repetition Rate: 5 Hz
- Modulator Efficiency: 85%
- AC Power per RF Station: 120 kW
- Number of Modulators: ~ 600

- TESLA TDR choice is the FNAL/DESY/PPT ‘Pulse Transformer’ modulator.
- SLAC is **evaluating** three alternative designs (SNS High Voltage Converter Modulator, DTI Series Switch Modulator and SLAC Marx Generator).
SLAC Marx Generator Modulator

12 kV Marx Cell (1 of 24)

- IGBT switched
- No magnetic core
- Air cooled (no oil)
- Building prototype (2007)
Klystron Development

• DESY 10 MW Klystron Program Status
  – Three Thales tubes built, five more ordered – all 3 tubes developed gun arcing problems – two rebuilt to correct problem but not fully tested, the other has run for 18 kWhour at lower voltage (~ 95 kV).
  – One CPI tube built – achieved 10 MW at short pulse length, limited by CPI modulator - was accepted by DESY.
  – One Toshiba tube built and under test – 10 MW, 1 ms achieved – longer pulses limited by modulator, which is being upgraded.
ILC Klystron Development

GOAL
Reduce HV Requirements and Improve Efficiency (Lower Space Charge) with a Multiple Beam Klystron

Use Seven 19 A, 110 kV Beams to Produce 10 MW with a 70% Efficiency

Thales TH1801 MultiBeam Klystron

Spec's:
10 MW, 10 Hz, 1.5 ms with 4 kW Solenoid Power

First Tube Achieved 65% Efficiency at 1.5 ms, 5 Hz and Is Used in TTF
These klystrons boast a 100 khour cathode lifetime. THALES MB klystron claims 40 khour.
SLAC Klystron program

- Developing a 10 MW L-band Sheet-Beam Klystron.
- If multi-beam program falters, consider lower perveance, single beam, 5 MW tube, possibly with PPM focusing.
- Buy commercial 5 MW tubes as needed for 1.3 GHz NC structure and coupler program.
- Possibly collaborate with DESY and CPI on 10 MW tube.
SLAC Sheet-Beam Klystron

• Developing a 10 MW sheet beam klystron as an alternate to the multi-beam tubes to reduce cost

  – Uses flat beams instead of six beamlets to reduce space charge forces.
  – It is smaller with a planar geometry for easier construction.
  – No solenoid magnet (saves ~ 4 MW of power).
Gun Wiggler Type Focusing Using Permanent Magnets

Output Cavity

Collector

Wiggler Type Focusing Using Permanent Magnets

Gun

10 MW L-Band Sheet-Beam Klystron
L-Band Test Facility at NLCTA

- Recently acquired a 10 MW HVCM Modulator from SNS.
- Buying a 5 MW TH2104C tube from Thales (1 year delivery).
  - In meantime use a SDI-Legacy tube from Titan (TH2104U).
- All major LLRF and waveguide components on order.
SLAC Test Facility Program in 2006
(C. Adolphsen)

- Use 5 MW source for coupler and normal-conducting cavity tests
- Propose to add a second L-band station using ILC prototypes.
  - Depending on progress, use Marx Generator, DTI Direct Switch or buy a “baseline” modulator from PPT.
  - Buy (or borrow) a CPI or Toshiba 10 MW klystron.
SLAC ILC Linac SC Quad/BPM Evaluation

• Goal: Demonstrate Quad/BPM performance required for ILC beam-based alignment:
  – Verify < ~ 5 micron movement of Quad magnetic center with field change.
  – Show ~ 1 micron BPM resolution and < ~ 5 micron Quad-to-BPM stability with a compact RF cavity BPM.

• For this program we plan to
  – Develop linac rRF cavity BPMs and test them with beam.
  – Acquire the ILC prototype Quad built by CIEMAT (Spain) and build a test cryostat for it at SLAC.
  – Do quad center stability tests with a rotating coil at the SLAC Magnetic Measurements Lab.

• Status
  – Quad nearly finished and cryostat and coil engineering underway – expect first magnet test in 2/06.
  – BPM design complete – test with beam in 2006.
SC Quad
(~ 0.7 m long)

S-Band BPM Design
(36 mm ID, 126 mm OD)

He Vessel
SC Coils
Iron Yoke Block
Al Cylinder
SLAC WG2 Activity Summary

• Programs started in FY05
  – Assemble an L-band RF station at NLCTA
  – Build IGBT switching circuits for two SMTF modulators
  – Develop a Marx-generator style modulator
  – Develop an L-band sheet-beam klystron
  – Demonstrate linac quad and bpm performance for ILC beam-based alignment.

• Programs proposed for FY06
  – Build a second L-band station with ILC prototype modulator and klystron (collaborate with DESY).
Plans at KEK for an L-band Test Facility

Plan of Superconducting RF Test Facility (STF)

phase 1
(2005-2006)

AR-east cryogenic system
new UV Laser (ILC struc.)
200kV DC gun of ERL develop

5MW kly
2K 20W line

PNC modulator
new modulator

new 5MW kly
2K 30W line

PNC DC PS

phase 2
(2007-2009)

Operate high gradient modules with beam

new modulator
new 10MW MB klystron

new ILC Cryomodules (ILC gradient)

new 5m Cryomodule (35MV/m 4 cavity)

new 5m Cryomodule (45MV/m 4 cavity)

700 MeV
PNC beam dump

Beam Diagnostics
RFgun
STF Phase 1 RF Wave-guide Distribution

STF Phase 1 Beam Line

Plain view

Side view

Power distribution scheme
STF Modulator, klystron plan & status

1. Reuse an old TH2104A klystron, driven by an existing PNC modulator by adding a bouncer circuit and a new pulse transformer. Initial operation is scheduled in Dec. 2005 for testing the cavity input couplers. Relocate this system later for running an RF-gun.

Existing PNC modulator

Additional Pulse Trans + Bouncer circuit allows to use TH2104A.

TH2104A old klystron short pulse test.

Design of Pulse Trans is underway.

5MW, 2µs RF was confirmed.
2. Developing LLRF control based on J-PARC design.

3. Purchase a 5MW Klystron from Thales (TH2104C), and Build one more modulator for running the cavities (in 2006).
STF Phase 2 : Build ILC Main Linac RF unit

Beam: $2 \times 10^9$ bunch, 294.6 ns spacing, 2620 bunches (10.8 mA)

1:12 Pulse Trans

10MW Multi-beam Klystron

Trf = 1.38 ms, P0 = 7.6 MW, rep = 6 Hz

Bouncer Modulator

Ecm = 600 GeV
# of cavities: 14240
# of klystrons: 712
active two Linac length: 14.8 km
total two Linac length: 20.1 km

Cavity: 35 MV/m @ Q0=1 E10
20 cavities/unit
(10 cavities/cryomodule)
Low Level RF Development

Digital control systems being developed by S. Simrock and collaborators from Warsaw.

Work performed within SRF JRA of CARE (WP8).

Design of Eight Channel 81 MHz IF Down-converter Board in Digital RF Feedback System for TTF2 -

Modular & Reconfigurable Common PCB-Platform of FPGA Based LLRF Control System for TESLA Test Facility

DSP Integrated Parameterized FPGA Based Cavity Simulator & Controller

FPGA Based, Full-Duplex, Multi-Channel, Multi-Gigabit, Optical, Synchronous Data Transceiver for TESLA Technology LLRF Control System

First Generation of Optical Fiber Phase Reference Distribution System for TESLA

DOOCS Environment for FPGA Based Cavity Control System and Control Algorithms Development

FPGA and Optical Network Based LLRF Distributed Control System for TESLA-XFEL Linear Accelerator

Prototype Implementation of the Embedded PC Based Control and DAQ Module for TESLA Cavity SIMCON
New Cryomodule Test Facilities

- SMTF at FNAL
- STF at KEK
- CMTB at DESY

Existing TTF modules remain important means of test (alignment, vibration....).
Superconducting Module Test Facility (SMTF) at FNAL

Main Goal: Develop U.S. Capabilities in fabricating and operating with Beam Superconducting accelerating cavities and cryomodule in support of the International Linear Collider.

High gradient (35 MV/m or Greater) and high Q (~0.5-1e10)
Cryomodule : Cryostat Design

Valve Box

Two cryostat connection,
4 cavities in one cryostat.

Eventually 8 cavities in one cryostat
Like TTF cryomodule

Weld connection

35MV/m TESLA
design cavities (4)

45MV/m Low-loss cavities (4)
Prototype test program
CMTB (DESY)

• In general: cryomodule tests independent from linac operation
• RF cavity processing / performance
• processing of RF couplers
• cryogenic performance
• tests of vacuum systems
• tests after repairs before installation into linac
• tests of new design features (2K quad...etc.)
• dark current
• stretched wire, WPMs
• thermal cycling
• operation at different HE II bath temperatures
• ..........
TTF cryomodule – dynamic heat losses.

**2K Dynamic heat losses** of module 4 & 5 (type III): about 3 W at 25 MV/m each

(5 Hz, 500/800µ s)

0.38 W/cavity

Most cavities can be operated at higher gradients!

Very preliminary!!!!!!

corresponds to about 3 W each
Vibration measurements on quad at end of module ACC4 (H. Brueck / DESY)

**RMS average, Saturday midnight ± 1 hour**

Piezo blue and pink, Geophone red

- Good agreement between
  - the two piezos
  - piezo and geophone (20%)
- Low RMS: 34 43 45 nm for f>2Hz
- Comparable with ground motions measured by Ehrlichmann
- At low frequencies the noise signal is probably getting dominant

210804 2300 220804 0100
Vibration measurements

- Accelerometers
- Geophones / Seismic sensors
- Results
  - Experimental setups working
  - Cultural noise can be identified
  - Pumpstands for isolation vacuum identified as a noise source
    - Decoupling of mechanical vibrations tested and achieved
  - Amplitude on quadrupole 2-3 times higher than on the ground
  - Seismic sensors show larger amplitudes
- Experiments need to be continued on TTF
- Module test stand or TTF
  - Excite mechanical modes with an external vibration source
X-FEL Module Industrial Study

*Deutsches Elektronen Synchrotron (DESY)* to launch a call for tender and for contracting of the Industrial Study on behalf of the TESLA-collaboration, the X-FEL project, the EUROFEL design study and BESSY.

The present cryomodule assembly procedures and some aspects of the present design shall be analyzed and questioned with respect to the most cost effective series production.

The key aspects of the study are as follows:
1.2.1 Define the assembly procedure
1.2.1 Analyze cost-reduction and production efficiency measures
1.2.3 Analyze performance improvement measures
1.2.4 Supply a cost estimate for the module production

An important of the IS will be the presence of CONTRACTORs’ experts during the assembly of two prototype cryo-modules at DESY.
Re-entrant BPM development (Saclay)

CARE supported R&D for BPM with improved version - 1 µm, 10 ns resolution. C. Simon et. al.

Re-entrant BPM tested on ACC1 at DESY, 10 µm resolution.
TESLA Quad Magnet Package – Ciemat (Spain)

- TESLA-Magnet tested in February at DESY
Discussed Tasks of the Forum

- Create a European industrial base (esp. for the European XFEL and the future International Linear Collider)
- Provide a point of contact between
  - European industry active and interested in all aspects of SC RF accelerators
  - European accelerator laboratories, scientists and engineers
  - the European Union and its member countries
  - accelerator laboratories in Asia and the US
- Strengthen the discussion between science, industry and politics
- Develop ways of co-operation and knowledge transfer between the partners
- Provide all partners with a regular up-date of the project developments (esp. smaller ones and from other regions), e.g. through seminars
- Open information channels which single partners have no access to (like foreign administrations) and guarantee a transparent view on the competitive situation concerning the ILC in the different world regions
- Make rules transparent for administration of projects and tendering
Schedule for Linac Design Sessions (WG2)

**Tuesday Morning** : Modulators and LLRF

**Tuesday Afternoon** : Klystrons and RF Distribution

**Wednesday Morning** : Cryomodules with WG5

**Wednesday Afternoon** : Couplers with WG5

**Thursday Morning** : Beam Dynamics and Wakefields with WG1

**Thursday Afternoon** : Baseline Design Options with WG1,5

**Talks with Global Groups**

**Talks During the Second Week**
<table>
<thead>
<tr>
<th>Time</th>
<th>Duration</th>
<th>Topic</th>
<th>Presentation</th>
<th>Institution</th>
<th>Speaker / Moderator</th>
<th>Joint with</th>
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</thead>
<tbody>
<tr>
<td>8:30</td>
<td>30</td>
<td>Modulator overview</td>
<td>Modulator requirements and comparison of the various proposals in terms of functionality, serviceability and cost.</td>
<td>SLAC</td>
<td>Ray Larsen</td>
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<tr>
<td>9:00</td>
<td>15</td>
<td>TDR modulator design</td>
<td>Status of the PPT modulators at DESY and modulator plans for the XFEL</td>
<td>DESY</td>
<td>Stefan Choroba</td>
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<tr>
<td>9:15</td>
<td>15</td>
<td></td>
<td>Upgrade of the FNAL modulator for SMTF</td>
<td>FNAL</td>
<td>Howie Pfeffer</td>
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<tr>
<td>9:30</td>
<td>30</td>
<td>Coffee Break</td>
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<tr>
<td>10:00</td>
<td>20</td>
<td>Alternative modulator designs</td>
<td>Marx modulator development program</td>
<td>SLAC</td>
<td>Greg Leyh</td>
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<tr>
<td>10:20</td>
<td>20</td>
<td></td>
<td>Overview of solid state modulator options and assessments</td>
<td>DTI</td>
<td>Jeff Casey</td>
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<tr>
<td>10:40</td>
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<td>Optimized Converter-Modulator Design Topology for the ILC Application</td>
<td>LANL</td>
<td>Bill Reass</td>
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<td>10:50</td>
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<td>Long distance transmission of HV pulses</td>
<td>SLAC</td>
<td>Dick Cassel</td>
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<tr>
<td>10:00</td>
<td>10</td>
<td>LLRF</td>
<td>Phase and amplitude requirements on various length and time scales</td>
<td>SLAC</td>
<td>Peter Tenenbaum</td>
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<tr>
<td>10:10</td>
<td>20</td>
<td></td>
<td>Experience at TTF and development for the XFEL and ILC</td>
<td>DESY</td>
<td>Stefan Simrock</td>
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<tr>
<td>11:30</td>
<td>20</td>
<td>SNS LLRF design experience and its possible adoption for ILC</td>
<td></td>
<td>FNAL</td>
<td>Brian Chase</td>
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<tr>
<td>11:50</td>
<td>10</td>
<td>Summary</td>
<td>Discussion of summary slides</td>
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<td>1:30</td>
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<td>RF Sources</td>
<td>Status of the 10 MW klystron development, rf distribution schemes and rf source plans for the XFEL</td>
<td>DESY</td>
<td>Stefan Choroba</td>
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<tr>
<td>1:50</td>
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<td>Alternative klystron designs and klystron industrialization</td>
<td>SLAC</td>
<td>George Caryotakis</td>
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<td>Alternative low voltage power source</td>
<td>KEK</td>
<td>Tetsuo Shidara</td>
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<td>10 MW MBK Development at CPI</td>
<td>CPI</td>
<td>Ed Wright</td>
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<td>2:50</td>
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<td>RF Distribution</td>
<td>Overview of distribution system and cost drivers.</td>
<td>LLNL</td>
<td>Brian Rusnak</td>
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<td>Breakdown limits in waveguide and circulators and alternatives to SF6</td>
<td>FNAL</td>
<td>Al Moretti</td>
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<td>Summary</td>
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### Wednesday Morning, August 17

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<tr>
<td>10:00</td>
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<td>Cryomodule plans</td>
<td>Development of cryomodules for the XFEL</td>
<td>DESY</td>
<td>Reinhard Brinkmann</td>
<td>WG5</td>
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<td>Cryomodule plans at KEK</td>
<td>Cryomodule plans at KEK</td>
<td>KEK</td>
<td>Norihito Ohuchi</td>
<td>WG5</td>
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<td>Cryomodule Assembly and Testing Facility at Fermilab</td>
<td>Cryomodule Assembly and Testing Facility at Fermilab</td>
<td>FNAL</td>
<td>Tug Arkan</td>
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<td>11:00</td>
<td>30</td>
<td>Cryomodule issues</td>
<td>Performance of current cryomodules (including vacuum integrity, heat loss, cavity and quad straightness and quad vibrations) and changes required for ILC</td>
<td>INFN</td>
<td>Carlo Pagani</td>
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<td>11:30</td>
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<td>Layout options for quad/bpms</td>
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<td>SLAC</td>
<td>Chris Adolphsen</td>
<td>WG5</td>
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<td>Discussion</td>
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### Wednesday Afternoon, August 17

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<tr>
<td>1:30</td>
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<td>Cryomodule and coupler industrialization</td>
<td>Cryomodule cost drivers and industrialization</td>
<td>DESY</td>
<td>Dieter Proch</td>
<td>WG5</td>
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<td>Production of couplers for the XFEL</td>
<td>Production of couplers for the XFEL</td>
<td>LAL-Orsay</td>
<td>Terry Garvey</td>
<td>WG5</td>
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<td>2:10</td>
<td>15 +15</td>
<td>Coupler design and performance</td>
<td>Experience and plans to improve TTF3 performance</td>
<td>DESY</td>
<td>Wolf-Dietrich Moeller</td>
<td>WG5</td>
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<td>LAL-Orsay</td>
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<td>New design for a 1.3 GHz coupler</td>
<td>New design for a 1.3 GHz coupler</td>
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<td>Nikolay Solyak</td>
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<td>New coupler design for STF baseline cavity</td>
<td>New coupler design for STF baseline cavity</td>
<td>KEK</td>
<td>Shuichi Noguchi</td>
<td>WG5</td>
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<td>Design for a non-contacting, dielectric-loaded waveguide coupler</td>
<td>Design for a non-contacting, dielectric-loaded waveguide coupler</td>
<td>SLAC</td>
<td>Chris Nantista</td>
<td>WG5</td>
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### Thursday Morning, August 18

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<tr>
<td>8:30</td>
<td>20</td>
<td>Beam Dynamics</td>
<td>Linac Simulations</td>
<td>CERN</td>
<td>Daniel Schulte</td>
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<td>Linac Simulations</td>
<td>KEK</td>
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<td>Linac Simulations</td>
<td>FNAL</td>
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<td>Kirti Ranjan</td>
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<td>Coffee Break</td>
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<td>Beam Dynamics</td>
<td>Linac Simulations</td>
<td>Cornell</td>
<td>Jeff Smith</td>
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<td>10:20</td>
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<td>Coupled orbit motion</td>
<td>SLAC</td>
<td>SLAC</td>
<td>Roger Jones</td>
<td>WG1</td>
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<td>10:40</td>
<td>20</td>
<td>Cavity Wakefields</td>
<td>Lattice Configuration Studies</td>
<td>FNAL</td>
<td>Nikolay Solyak</td>
<td>WG1</td>
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<tr>
<td>11:00</td>
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<td>Wakefield simulation plans by the ACD group at SLAC</td>
<td>SLAC</td>
<td>Zenghai Li</td>
<td>WG1</td>
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<td>11:20</td>
<td>20</td>
<td>Equivalent circuit simulation of high frequency modes</td>
<td>SLAC</td>
<td>Roger Jones</td>
<td>WG1</td>
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<tr>
<td>11:40</td>
<td>20</td>
<td>Discussion</td>
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</table>

### Thursday Afternoon, August 18

<table>
<thead>
<tr>
<th>Time</th>
<th>Duration</th>
<th>Topic</th>
<th>Presentation</th>
<th>Institution</th>
<th>Speaker / Moderator</th>
<th>Joint with</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:30</td>
<td>120</td>
<td>Baseline Configuration</td>
<td>Joint WG2/WG2/WG1 discussion of the various linac configuration options</td>
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<td>WG1, WG5</td>
</tr>
</tbody>
</table>
Objectives of Working-group?

Make “Baseline Configuration” choices for linac components or at least identify BC “options” (criteria for doing this? – established technique, proof of principle?)

- Work to agree upon the baseline configuration choices. Use the Workshop to identify paths to decisions for unresolved issues with the expectation that these could be decided at one or two subsequent meetings during the fall of 2005.
- Start writing the BCD!
- Identify critical R&D topics and timescales necessary for alternative options to the ILC Baseline Configuration that could have a significant impact on the performance or cost of the linear collider.
ILC Cryomodule WBS

1 Level 1
This is an example of the type of information I think would be useful to concisely document.
Note that it is heavily centred on the choice of baseline.

1.1 Component

1.1.1 requirements
The basic requirements / specifications for the component. If we cannot specify them exactly because it depends on some other choices (outside the scope of this breakdown), then those dependencies should be stated.

1.1.2 baseline
the suggested baseline choice.
Note that for the Baseline Configuration Document (BCD), we want to attempt to identify a single baseline solution, even if we believe this will get superceded later by 'an option'.

1.1.3 baseline justification
The justification for why we believe this should be the (current) baseline.

1.1.4

1.1.5

1.1.6 baseline status
The current status of the baseline choice, including known limitations that required further R&D. We might consider putting information about cost here.

1.1.7 foreseen/required baseline R&D
List of on-going R&D on the baseline (including industrialisation studies). We might want to indicate R&D that’s known to be needed but is currently not happening (lack of resources?)

1.1.8 options
Options should be effectively parallel R&D paths that may possible lead reduced cost, increased performance (or both). The GDE will probably only directly support a limited number of such options.

   opt 1
   For each option some brief text about the pros and cons for the option would be useful.

   opt 2....
Cavity Shape

• **Choice based on experience**
  – TESLA design shape:
    • Achieved 35 MV/m in 5 cavities (over 200 built).
    • HOM damping / wakes / Lorentz detuning well characterized.
    • 40 cavities currently running at TTF.
    • Two industrial suppliers (1000 will be used in XFEL).

• **Choice based on potential cost savings**
  – Low loss or reentrant:
    • These designs potentially allow higher gradients, and if the iris diameter is reduced, require less stored energy and cooling (but produce higher wakes).
    • Only one cell versions have been fabricated, achieving up to 45 MV/m. Will require several year, > 10 M$ effort to qualify design – KEK is actively pursuing this approach.