EDR HLRF Plans & Issues

Draft Summary

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R. Larsen, SLAC
for
HLRF Collaboration

Outline

- EDR Assumptions
- Current Status & Readiness to Support EDR End FY09
  - *I. Modulators*
    - BCD Bouncer & ACD Marx
  - *II. Klystrons*
    - BCD MBK & ACD SBK
  - *III. RF Distribution*
    - BCD TTF-XFEL & ACD No Circulators

EDR Assumptions

- EDR to be completed in two more years, i.e. end of FY09.
- Will include detailed technical and cost plans that are considerably more mature than RDR.
- Will include a schedule and funding profile consistent with the plans.
- Will be sufficiently mature to provide a basis for international funding requests, implying
  - *technology down-selects close if not already in hand*
  - *industrialization, industrial cost estimates close if not already in hand.*

I. Modulators - BCD

- *Baseline Design: FNAL-DESY Bouncer with step-up transformer.*
  - *Status:*
    - "Mature prototypes >10 kh operation." First unit produced 1996. Lab-built and commercially built10 units total.
    - Bids in process for XFEL. Have not run sustained at ILC loads.
    - Early units designed for longer pulse and up to 10 Hz. Redesign for optimization, High Availability needed for ILC.

I. Modulators - BCD

- BCD Redesign for HA:
  - Originally assumed 3.5% extra stations for availability reasons, now removed from cost model for cost reasons (tunnel remains).
  - Current design needs to be made modular for quick replacement of failed modules, as well as N+1 design for capacitor bank, switches, charger, controls.
  - Charger needs to be optimized for power factor along lines proposed by XFEL, Cassel.
  - Pulse transformer design needs to be optimized for new ILC specs.
  - Packaging needs to be redesigned to fit into 1.3 m maximum width in service tunnel.
  - Diagnostic Interlock Layer needs to be added for HA management.

I. Modulators - BCD

- *BCD Readiness vs. EDR by end FY09*
  - With XFEL bids going out now, new industrial prototypes may be delivered by end FY09.
  - XFEL experience will provide valuable data on time, effort and cost of the industrialization phase.
  - Needs to be coupled with BCD HA design improvements for completeness, industry work packages for prototypes, cost estimate verification.

I. Modulators - ACD

- *ACD Marx Design: Stacked IGBT cells with no step-up transformer.*
  - *Status:*
    - First ILC prototype under construction and testing. Plan to complete 2000 h full load test on resistive load by end 2007. At this time will be “immature prototype.”
    - Parts still under design include vernier pulse-flattening circuit, buck regulator board for charger.
    - Enclosure built waiting for unit testing in lab cage to be completed before mounting.
    - At conclusion of 2000 h test move to L-Band test station to drive first 10 MW klystron in 2008.

I. Modulators – ACD

– *Status – Cont'd.*

- New designs with many parallel IGBTdevices take longer to de-bug.
- Problems in controlling di/dt radiated pickup and ground currents in stacked design w/ DIL circuitry near 12 kV pulsed voltages at 140 A.
- Huge benefits in operating in this regime if problems mastered and contained well below critical thresholds.
- Proof of robustness requires operation over sustained period under full load conditions.
- Our schedules assume solving several more challenges.
- Expect Marx to meet full design goals.

I. Modulators - ACD

- ACD DFM Plans:
  - *In 2007 begin work on DFM unit to be followed by construction of up to 4 units in 2008-2009, involving industry in the construction and assembly.*
  - *Tasks:*
    - New form factor, long & skinny, to fit in service tunnel
    - Improve cell design, connectors, protection
    - Improve Diagnostic Interlock Layer (DIL) design
    - Demonstrate sustained HA operation at full load (as availability of loads permits).
    - *By end 2009 plan to have several "mature prototypes" with significant running hours comparable to where BCD is today.*

Modulators - ACD

- *Summary of Marx vs. EDR End 2009:*
  - *Marx will not be in strongest position to support full level of qualification desired in the EDR by the end of 2009.*
  - *Assuming success, will be much stronger mid to late 2010, with two more industrialized DFM units running and initial industrialization pricing established.*
  - *Early success of first unit passing 2000 hr test could justify selection as a baseline*
  - *Current BCD would serve as backup solution.*
  - *If Marx misses goals, begin HA redesign of current BCD modulator.*

I. Modulators – ACD

- Industry Milestone:
  - *Stangenes Corp. recently demonstrated Marx operation at 90 kV at power level commensurate with the ILC, 125 kW.*
  - *Agile short pulse radar application*
  - *Delivered to customer, field tests starting*
  - *Performance data very interesting to ILC*

II. Klystrons - BCD

- *Baseline Design: 10 MW Multi-Beam Klystron (MBK)*
  - Status:
    - Chosen as baseline for XFEL at DESY. XFELS
    - Specified at 10 Hz vs. 5 Hz for ILC
    - Prototypes from 3 vendors, vertical, horizontal out to bid
    - Tubes operated ay < full ILC specs, problems found, addressed, repair cycles long (~6 months)
    - At least one tube passed full spec tests
    - Others have significant hours, none at ILC specs.
    - Due to limited experience at ILC specs, status is "successful first prototypes."

II. Klystrons - BCD

- *BCD MBK*
  - Evaluation Plans*:*
    - ILC R&D plan includes procuring samples of tubes for full load testing at SLAC and possibly FNAL as well.
    - SLAC-KEK ordering one tube, will order others as funds permit.
    - XFEL ordering tubes in quantity which may slow ILC samples
    - Procurement cycle > 1 yr year ARO
    - By EDR end FY09, will have small number of tubes in hand under evaluation

II. Klystrons - BCD

- BCD MBK
  - *Technical Risk:*
    - Too little data to evaluate risk and reliability.
    - MBK's with N beamlets have ~N times number of braze joints c.f. single beam tubes
    - Lifetime spec of 50,000 hours ultimately may be achieved over large sustained production run but impossible to guarantee.
    - Large production quantities needed to achieve high performance over time.
    - Cathode performance critical; failure of single beamlet will fail tube.

II. Klystrons - BCD

- BCD MBK
  - *Cost Risk:*
    - Insufficient MBK industrial experience to enable accurate yields and forecasts.
    - Prototype cost data proprietary and for early prototypes not reliable predictor of ultimate quantity cost.
    - ~30 tubes for XFEL ~ 5% ILC quantity, will not prove larger run performance, cost
    - SLAC experts developed full factory model, staged cost recovery over production stage, to steady-state replenishment level.
    - Predicts probable average cost over 650 tubes, with sustaining unit costs at somewhat higher level as quantities decrease.
    - Cost risk *high* at EDR stage because will lack manufacturing experience to verify leaning curve estimates.

II. Klystrons - BCD

- BCD MBK
  - *Summary of MBK vs. EDR in FY09:*
    - BCD MBK will be only marginally better able to support the accuracy of reliability risks, costs by EDR
    - Limited additional level of manufacturing experience
    - Limited samples to accumulate many hours operational experience at full specifications.

II. Klystrons - ACD

- *Alternate Design: 10 MW Plug-in Compatible Sheet Beam Klystron (SBK)*
  - Status:
    - Sheet beam klystrons at G-Band developed at SLAC for another government agency.
    - In view of the potentially high technical and cost uncertainties of the MBK decided to fund prototype SBK.
    - Radical new design; potentially simpler, smaller, PM focusing, potentially 2X lower cost
    - Under design, prototype expected in 18-24 months.
    - Since SBK of ILC specifications never built before, technical, schedule, cost risk all *high.*

II. Klystrons - ACD

- *ACD SBK*
  - Summary of SBK vs. EDR in FY09:
    - SBK may have conducted a first successful test in two years, but any slippage in the schedule would negate.
    - Record for maintaining schedules in new klystron development not very good.
    - Hopefully first prototype operational and DFM underway end FY09.
    - Operational reliability, manufacturing cost risks will remain *high* at end FY09

II. Klystrons: Neubauer Comments

- *BCD & ACD:*
  - Currently lack plans to:
    - *Provide industry with funds to **productize** MBKs.*
    - *Measure **lifetime** of MBK guns. Variations in each beamlet cathode may require one or more to run hotter, increasing barium evaporation and gun arcing.*
    - *Implement vendor specific **DFM** programs to minimize years to move from prototype to full production, ~3+ yrs*
    - *Implement vendor specific plans to improve performance beyond "meeting the spec". Lack of plan => **yields very low, costs very high.***
    - *Program for **qualification testing** by operating for long periods of time at full specification to find weaknesses, improve tube.*
      - *XFEL may not require since may operate for long periods at <ILC minimum power.*

III. RF Distribution - BCD

- *Baseline Design: WR650/WR770 Series Distribution.*
  - Status:
    - Similar to TTF, standard industry component models.
    - Appropriate fractions of the power extracted from main waveguide by hybrids at each cavity coupler.
    - Nine different hybrid designs needed.
    - Circulators at couplers absorb reflected power, provide isolation.
    - Dry nitrogen at 3 bar eliminates SF6 near klystron, operation being tested at SLAC
    - Systems tested at TTF, being designed for XFEL, neither tests ILC full power conditions.
    - Increased average power => more risk of breakdown, lowers machine availability.

III. RF Distribution - BCD

- *Baseline Design: TTF-XFEL*
  - Technical Risk:
    - Conservative, circulator protection & tuning for every cavity, designs modeled on existing catalog products.
    - Only manufacturing issue is industry capacity of current small manufacturers
  - Cost Risk:
    - Cost high enough to warrant alternate design.
    - Capital cost high esp. circulators
    - Assembly, installation costs high especially if installation involves connecting higher numbers of flanges and performing more leak tests in the tunnel.

III. RF Distribution - BCD

- *Baseline Design TTF-XFEL:*
  - *BCD Distribution Readiness vs. EDR end FY09:*
    - Baseline design needs further industrialization efforts and industrial cost development for full ILC requirements.
    - Requirements are similar to XFEL which will advance development.
    - Status by end FY09 should support the EDR with XFEL experience, existing work packages and industrial cost estimates.

III. RF Distribution - ACD

- *Alternate Design: Hybrid Pair Feeding with Variable Tap-Offs & No Circulator.*
  - *Status:*
    - Alternate design underway seeks to reduce expensive components and build a more integrated feed structure with fewer parts and joints.
    - Feeding the cavities in pairs through 3 dB hybrids allows the reflections, to the degree that they are identical, to be directed into a load without the use of circulators.
    - Elimination of circulators represents a large savings (25-30%) in cost and efficiency for the distribution system.
    - Overall Goal: 2X cost reduction of installed system

III. RF Distribution - ACD

- ACD No Circulator Design
  - Status cont'd:
    - Components designed, being fabricated.
    - System will be tested at SLAC FY07,delivered to Fermilab for NML test accelerator
    - Power for each pair of cavities tapped off from the main waveguide run with a variable directional coupler tap-off (VTO).
    - Common design is used for each pair, coupling set by mechanical adjustment.
    - Sections of waveguide for a complete cryomodule to be fabricated and tested at the factory, then pre-tuned and mounted on unit in staging area to streamline installation and checkout in the tunnels.

III. RF Distribution - ACD

- *ACD No Circulator Design:*
  - Technical Risk*:*
    - Power-handling capacity and function of the novel component needs to be demonstrated.
    - Full system test also required to prove that operating without circulators will not reduce the isolation between cavities to the point where the RF profile is degraded or coupled modes become a problem.
    - Possibility of imperfect cancellation of reflections back to the klystron is also a concern.
    - Once designed and proven, manufacturing poses no special problems except for the aforementioned small industry capacity.

III. RF Distribution - ACD

- Alternate:
  - *Cost Risk:*
    - Assuming successful R&D demonstration, the cost risk is reduced by less complexity and significantly fewer flanges and joints. Fabricating the structure as a larger section for easier installation and commissioning will save in-tunnel assembly and testing costs.

III. RF Distribution - ACD

- ACD:
  - *ACD RF vs. EDR Readiness end FY09:*
    - Demonstration of prototype should be well within the 2-year timeframe. However no quantity production will be accomplished.
    - As soon as prototype proven work package with industry should be a high priority in order to advance industrialization methods and costs during this period.
    - If done, the design and industrial estimates could support the EDR goals by end FY09.
    - Large scale production will not be demonstrated but fabrication poses no new technical challenges except to develop fixtures to handle larger integrated assemblies up to 12 m long.

Summary

- All three major RF subsystems require aggressive R&D up to and beyond EDR time end FY09
- High emphasis needed on industrialization through work packages released (or ready to release) for DFM designs
- Technical risks relatively low for BCD designs, higher for ACD designs.
- Cost risk remains high for all due to lack of certainty of extrapolation to industrial quantities.
- Neubauer comments on klystrons translate into need to add R&D funds, time to “productize” to achieve high yields, low costs
- XFEL, SMTF could provide some useful data to help reduce cost risk by EDR time of end FY09.