BASELINE MODULATOR

Presented by Saul L. Gold

Contributors:
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NLC Review- Baseline Modulator

- Baseline- build today
- Develop Cost Model
- Approach
  - Conventional Modulator
  - Compromise of cost, reliability, efficiency and performance
  - 1 modulator per 2 Klystrons
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- Design Overview
  - Conventional Modulator
  - 1:14 Pulse Transformer
  - Single oil tank- Depot maintenance
  - Rack mount support electronics including Charging Power Supply
  - Charge Voltage: up to 80 kV
# Baseline Modulator Requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Desired</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Klystron Voltage</td>
<td>500 kV</td>
<td>500 kV</td>
</tr>
<tr>
<td>Total Peak Current</td>
<td>530 A</td>
<td>530 A</td>
</tr>
<tr>
<td>Pulse Width (usable FT)</td>
<td>1.5 µs</td>
<td>1.5 µs</td>
</tr>
<tr>
<td>Pulse Top Flatness</td>
<td>1%</td>
<td>2%</td>
</tr>
<tr>
<td>Pulse Top Ripple</td>
<td>1%</td>
<td>2%</td>
</tr>
<tr>
<td>Pulse-pulse Ripple</td>
<td>0.1%</td>
<td>0.25%</td>
</tr>
<tr>
<td>Pulse-pulse Jitter</td>
<td>1 ns</td>
<td>10 ns</td>
</tr>
<tr>
<td>P.R.F.</td>
<td>120 Hz</td>
<td>120 Hz</td>
</tr>
</tbody>
</table>
## Baseline Modulator Requirements (cont.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Desired</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charging Voltage</td>
<td>80kV mx.</td>
<td>80kV mx.</td>
</tr>
<tr>
<td>Charging Supply Pwr.</td>
<td>65 KW</td>
<td>75 KW</td>
</tr>
<tr>
<td>Charging Supply Effic.</td>
<td>95+%</td>
<td>90%</td>
</tr>
<tr>
<td>Overall Efficiency</td>
<td>75%</td>
<td>61.5%</td>
</tr>
<tr>
<td>Reliability (MTBF)</td>
<td>15,000hr</td>
<td>8,100hr</td>
</tr>
</tbody>
</table>
Basic Modulator Block Diagram
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- Areas of Investigation
  - Energy Storage Capacitors
  - Pulse Transformers
  - Switches
  - Layout
    – Size, Maintainability, cost, etc.
  - Efficiency
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Thyratron

Pulse Transformer

PFN

Test Bed Tank
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Test Bed w/ Parallel Plate Connection
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- **Energy Storage Capacitors**
  - Studied Russian Glass Capacitors
    - Small size, high energy density
    - High dielectric constant - 1000
    - 5 nF, 80 kV (2 in series)
    - Assembled inductance ~50nH
    - Losses appeared high 5-8%
    - Good waveshape - 300+nsec risetime
    - Usable output efficiency w/PT - 83%
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- Run single glass capacitor @ 40-41 kV
  - Failed after approx. 9 hours
- Believe capacitors will run @ 75-80% rating
- Maximum history w/film Capacitors
  - Purchased film capacitors
  - Mutual inductance PFN helps overcome internal inductance of capacitor
Figure 1  PFN assembly with Sicond k15-10 capacitors

Figure 1  Two types of PFN with Maxwell capacitors
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- Studying Polypropylene Film Capacitors
  - 10 nF, 80 kV
  - Assembled inductance ~90 nH
  - Losses low 1-2%
  - Good waveshape, <400 nsec risetime
  - Usable output efficiency w/PT- 80+% 

- Preliminary specification written
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Output PFN Voltage on 4.8 Ohms Resistive Load (Sicond Cap’s)

Output PFN Voltage on 9.6 Ohms Resistive Load (Maxwell Cap’s)
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- **Pulse Transformer**
  - 1:14 ratio
  - Stangenes design
    - 2 mil core material
    - Reduced clearance margin from 5045
    - Risetime approached 300 nsec
  - North Star Research design
    - Double basket
    - Rise time slightly longer than Stangenes
- Preliminary specification written
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Stangenes Transformer Configuration

North Star Research Transformer Configuration
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**Pulse Transformer Comparison**

<table>
<thead>
<tr>
<th></th>
<th>Conventional Transformer (Stangenes)</th>
<th>Double Basket Transformer (North Star)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distributed Capacitance (air)</td>
<td>84 pF</td>
<td>110 pF</td>
</tr>
<tr>
<td>Leakage Inductance</td>
<td>100-110 µH</td>
<td>100-110 µH</td>
</tr>
</tbody>
</table>
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- Switch research
  - At these levels thyatron seems to be best present technology
  - Presently using EEV 4 gap, 100kV, cx2593
    - runs good w/double pulse trigger
  - EEV has 3 gap thyatron to try, CX1937
  - Thyatron reliability an issue
    - Spec given to vendors, need to pursue
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- Efficiency
  - Tests performed @60Hz in Test bed w/ 5045 klystron as load
    - operated TL (Temp. Limited) to simulate PPM
      - combinations of:
        - glass or film capacitor PFN’s
        - Stangenes or North Star transformer
        - 4-gap or 2-gap thyatron
  - Determine areas of loss
    - Output waveform, pulse transformer, PFN and feed, thyra tron
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- Modulator Efficiency Terms
  - Power Supply Efficiency
  - Pulse Power Transfer Efficiency
  - Waveform Efficiency
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Klystron Beam Voltage and Current

Maxwell Capacitors w/ Stangenes Transformer

Waveform Eff. \( \sim 81\% \)

Russian Capacitors w/ Stangenes Transformer

Waveform Eff. \( \sim 83\% \)
## Charge and Energy Balance

*Stangenes Transformer*

*(Second Capacitors)*

*(CX 1836 two gap thyatron)*

<table>
<thead>
<tr>
<th>Charging Process</th>
<th>Total charge delivered to PFN</th>
<th>μC</th>
<th>8578.53</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Energy to charge PFN</td>
<td>J</td>
<td>145.4407</td>
</tr>
<tr>
<td></td>
<td>Total discharge charge</td>
<td>μC</td>
<td>8578.53</td>
</tr>
<tr>
<td></td>
<td>Total PFN discharge energy on primary side</td>
<td>J (%)</td>
<td>139.3429 (95.81)</td>
</tr>
<tr>
<td></td>
<td>Total losses in the primary side:</td>
<td>J (%)</td>
<td>10.95627 (7.53)</td>
</tr>
<tr>
<td>Primary Discharge Process</td>
<td>Including:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thyratron</td>
<td>J (%)</td>
<td>4.858446 (3.34)</td>
</tr>
<tr>
<td></td>
<td>PFN + mismatch +etc.</td>
<td>J (%)</td>
<td>6.097829 (4.19)</td>
</tr>
<tr>
<td></td>
<td>The charge delivered into the beam</td>
<td>μC</td>
<td>544.9607</td>
</tr>
<tr>
<td></td>
<td>Reflected primary charge (turn ratio is 14:1)</td>
<td>μC</td>
<td>7629.45</td>
</tr>
<tr>
<td></td>
<td>Total energy delivered into klystron beam</td>
<td>J (%)</td>
<td>128.3996 (88.28)</td>
</tr>
<tr>
<td></td>
<td>Total energy losses in transformer</td>
<td>J (%)</td>
<td>6.084837 (4.37)</td>
</tr>
</tbody>
</table>
### Charge and Energy Balance

(CX 1836 two gap thyratron)
(Conventional Stangenes Transformer)
(Maxwell capacitors)

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<tr>
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<td>J (%)</td>
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<tr>
<td>Total energy losses in transformer</td>
<td>J (%)</td>
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</table>
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### Capacitor Pulse Discharge

#### Energy Loss

<table>
<thead>
<tr>
<th>Capacitor Type</th>
<th>600 Volt.</th>
<th>3 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mica</td>
<td>1.3%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Ceramic</td>
<td>4.5%</td>
<td>10.5%</td>
</tr>
<tr>
<td>Oil Filled Film</td>
<td>2.6%</td>
<td>-0.2%</td>
</tr>
<tr>
<td>Russian Glass</td>
<td>6.25%</td>
<td>6.5%</td>
</tr>
</tbody>
</table>
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**Pulse Power Transfer**

- **Eff1 = Pout/Pin**
  - (est. 90%)

- **Eff2 = Pulse Pwr out/Pin**
  - (meas. 80-91.5%)

**Total Efficiency = Eff1 x Eff2 x Eff3**

- \(0.9 \times 0.88 \times 0.8 = 0.633\) or 63.3%

**Waveform Efficiency**

- **Eff3 = Pwr Pulse Top/PwrTotal Pulse**
  - (meas. 80-83%)

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**Basic Modulator Efficiency**
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- **Layout**

  ![Diagram of a device with labeled parts: klystrons and access port with dimensions 44" and 72".](image)

  - klystrons
  - Access port

Klystron/Microwave Department
Electronic/Microwave Engineering
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- Tank Layout in process
  - Design for manufacturability
  - Design for performance
  - Design to minimize cost
- Depot Maintenance
  - Thyra tron field replacement- contingency
THYRATRON ASSEMBLY

1 - Anode Can
2 - Thyatron Mounting Base
3 - Connectors
4 - Grad. Divider (does not shown)
5 - Cap. Mntg. Basket
6 - Cathode Socket Ring
7 - Anode Socket Ring
8 - Anode Socket Ring
9 - Plate Standoffs (solid)
10 - Plate Standoffs (hollow)
11 - Ferrite Cores (do not shown)
12 - Thyatron Cathode Socket
13 - Thyatron Mntg Plate

Oil Mvr. Assy, Misc. Hardware, Assembly & Checkout
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- Developed Detailed Cost Model
  - Based upon component research and vendor interactions
  - Modulator part of High Power RF Source
  - ~$200k per unit in Qty less than 10
**NL:C Review- Baseline Modulator**

- **Risk Assessment**
  - **Basic design - low risk**
  - **Previously built 550kV, 700A**
  - **Need to demonstrate 500kV with selected components**
  - **Polypropylene capacitors should have best reliability**
  - **Thyatron Lifetime Risk**
    - Present SLC thyatrons > 20k hours
    - NLC thyatron ~1/2 RMS current
      - longer life
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**Risk Assessment (cont.)**

- Parallel klystron operation - klystron protection (fault energy)
  - NLCTA- parallel klystrons in 1/99
  - Stray capacitance @ 500kV
  - Studying klystron arc pattern and arc energy
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FY’99 & FY’00 PLANS

- Build Prototype modulator
- Continue component R&D
  - Pulse Tran former
    - Configuration/core material
  - Thyra trons
    - evaluate 1st design thyratrons from vendors
  - PFN’s
    - low level tuning optimization
    - capacitor inductance vs. cost
  - Charging Supply
    - cost & reliability
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- Work with vendors
- Watch Alternate technologies

- Other Support
  - 500kV test stand for PPM klystron testing
  - NLCTA
    - station upgrades for two klystron operation
## MODULATOR SUMMARY

### X, S&L Load Comparison

<table>
<thead>
<tr>
<th>Modulator No.</th>
<th>Klystrons</th>
<th>Klystron Voltage kV</th>
<th>Peak Current A</th>
<th>Peak Current P.Widh uSec</th>
<th>PRF-Hz</th>
<th>Avg Pwr Out-kW</th>
<th>Est. Pwr In-kW *</th>
<th>Qty for 0.5 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>X Band</td>
<td>2 @75 MW</td>
<td>60</td>
<td>490</td>
<td>510</td>
<td>1.5</td>
<td>120</td>
<td>45</td>
<td>75</td>
</tr>
<tr>
<td>S Band</td>
<td>1 @ 65 MW</td>
<td>50</td>
<td>350</td>
<td>371</td>
<td>4.0</td>
<td>120</td>
<td>62</td>
<td>104</td>
</tr>
<tr>
<td>L Band</td>
<td>1 @ 75 MW</td>
<td>50</td>
<td>388</td>
<td>387</td>
<td>6.0</td>
<td>120</td>
<td>108</td>
<td>180,</td>
</tr>
</tbody>
</table>

*Assume 60% efficiency
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- S Band & L Band
  - Conventional Modulators
  - Build on X-Band baseline design
    - larger PFN’s (possible air)
    - Commonality of components
      - capacitors
      - thyra tron
      - controls