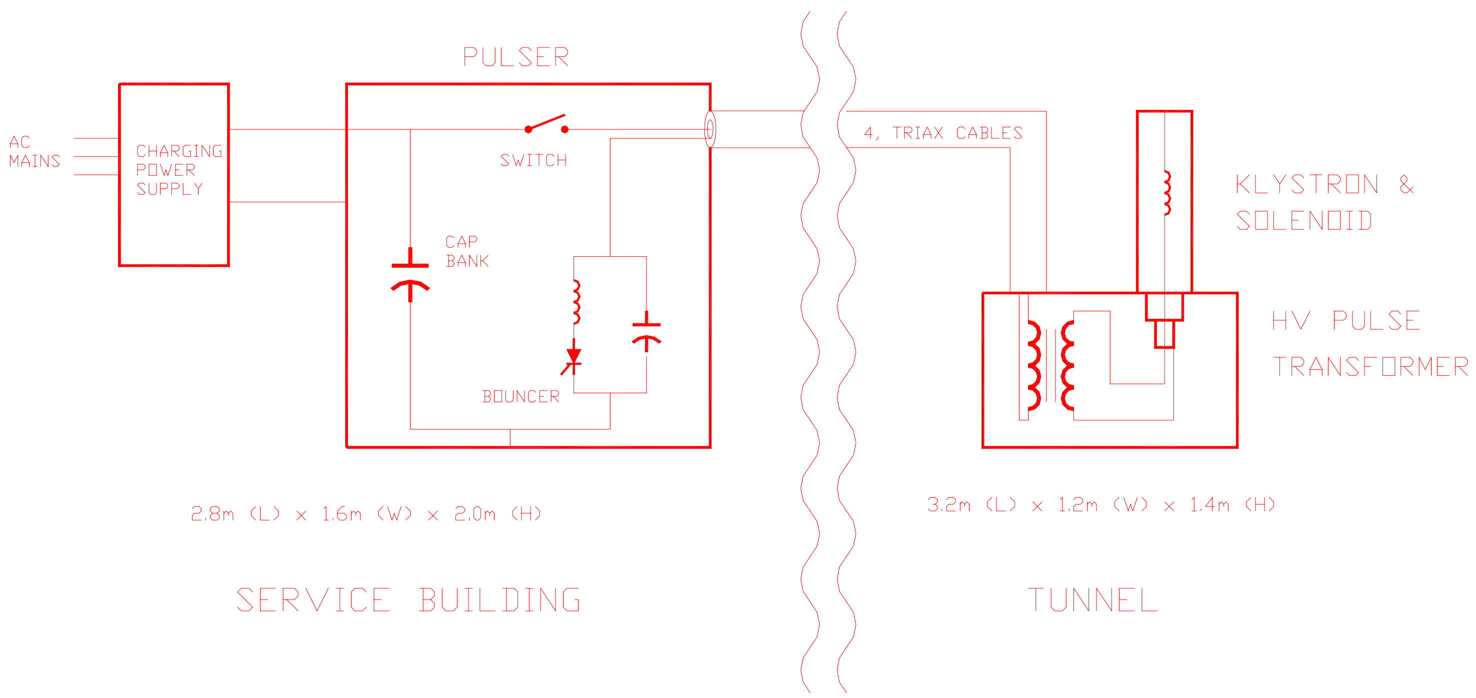
FERMILAB

# ILC MODULATORS






10/14/2004
Howie Pfeffer/Dan Wolff

# ILC MODULATOR SPECS
## (From TESLA TDR)

| | Typical | Maximum |
|---|---|---|
| Klystron Gun Voltage | 115 kV | 120 kV |
| Klystron Gun Current | 130 A | 140 A |
| High Voltage Pulse Duration (70% to 70%) | < 1.7 ms | 1.7 ms |
| High Voltage Rise and Fall Time (0 to 99%) | < 0.2 ms | 0.2 ms |
| High Voltage Flat Top (99% to 99%) | 1.37 ms | 1.5 ms |
| Pulse Flatness During Flat Top | < ±0.5% | ±0.5% |
| Pulse-to-Pulse Voltage fluctuation | < ±0.5% | ±0.5% |
| Energy Deposit in Klystron in Case of Gun Spark | < 20 J | 20 J |
| Pulse Repetition Rate for 90% of the Modulators | 5 Hz | 5 Hz |
| Pulse Repetition Rate for 10% of the Modulators | 10 Hz | 10 Hz |
| Transformer Ratio | 1 : 12 | |
| Filament Voltage | 9 V | 11 V |
| Filament Current | 50 A | 60 A |

Table 3.4.2: *Modulator requirements.*

# MODULATOR OPERATION

- IGBT switch connects cap bank to transformer during 1.7 ms pulse.
- Transformer steps up voltage to 120kV/130A (12:1)
- 1400 uF cap bank discharges by 20% during pulse
- “Bouncer” tank circuit compensates for cap bank droop.
- IGBT switch MUST open during gun spark to remove transformer stored energy and not deposit it at spark site.

# Modulator Diagram (GTO Switches)

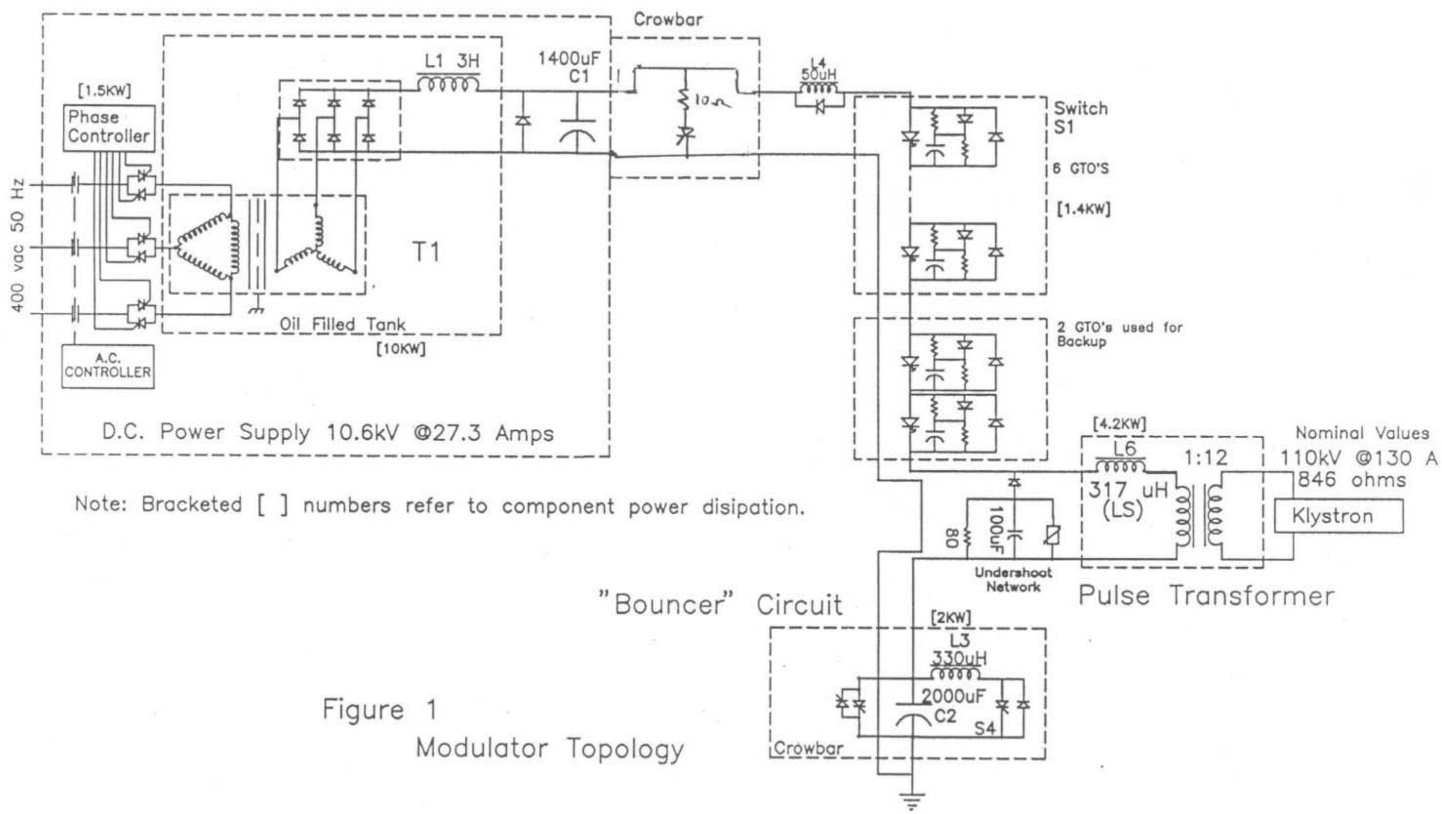
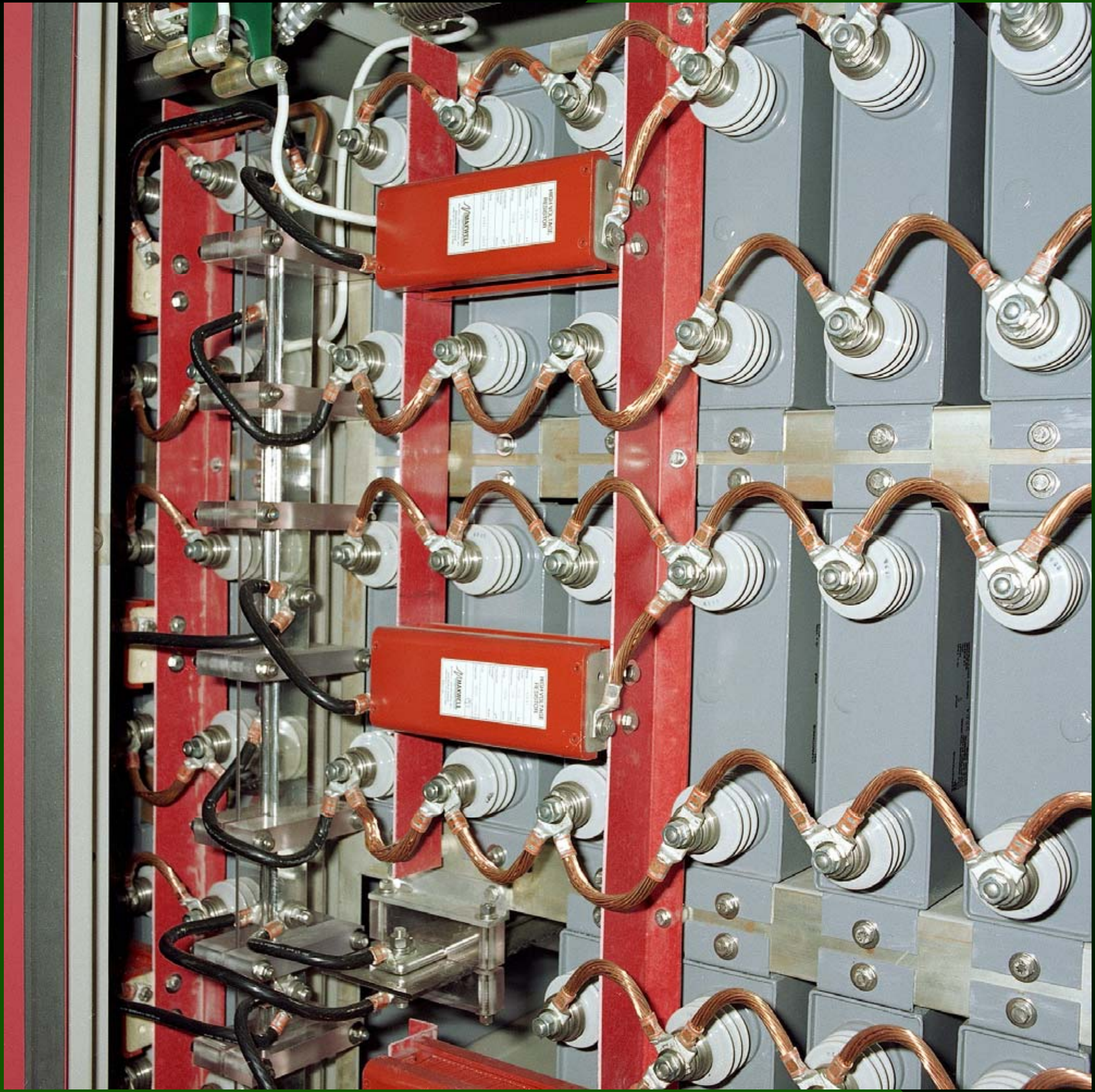
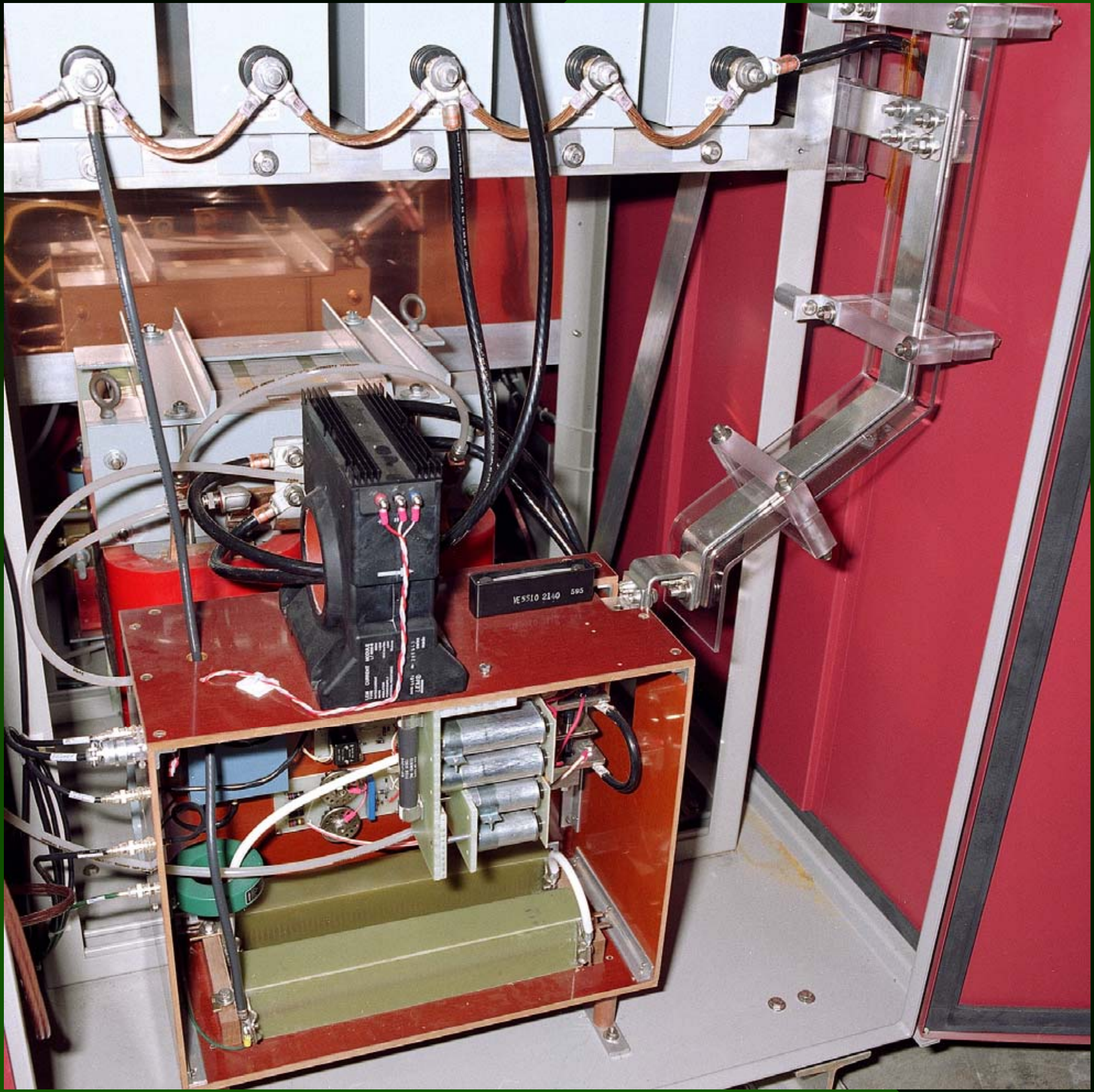


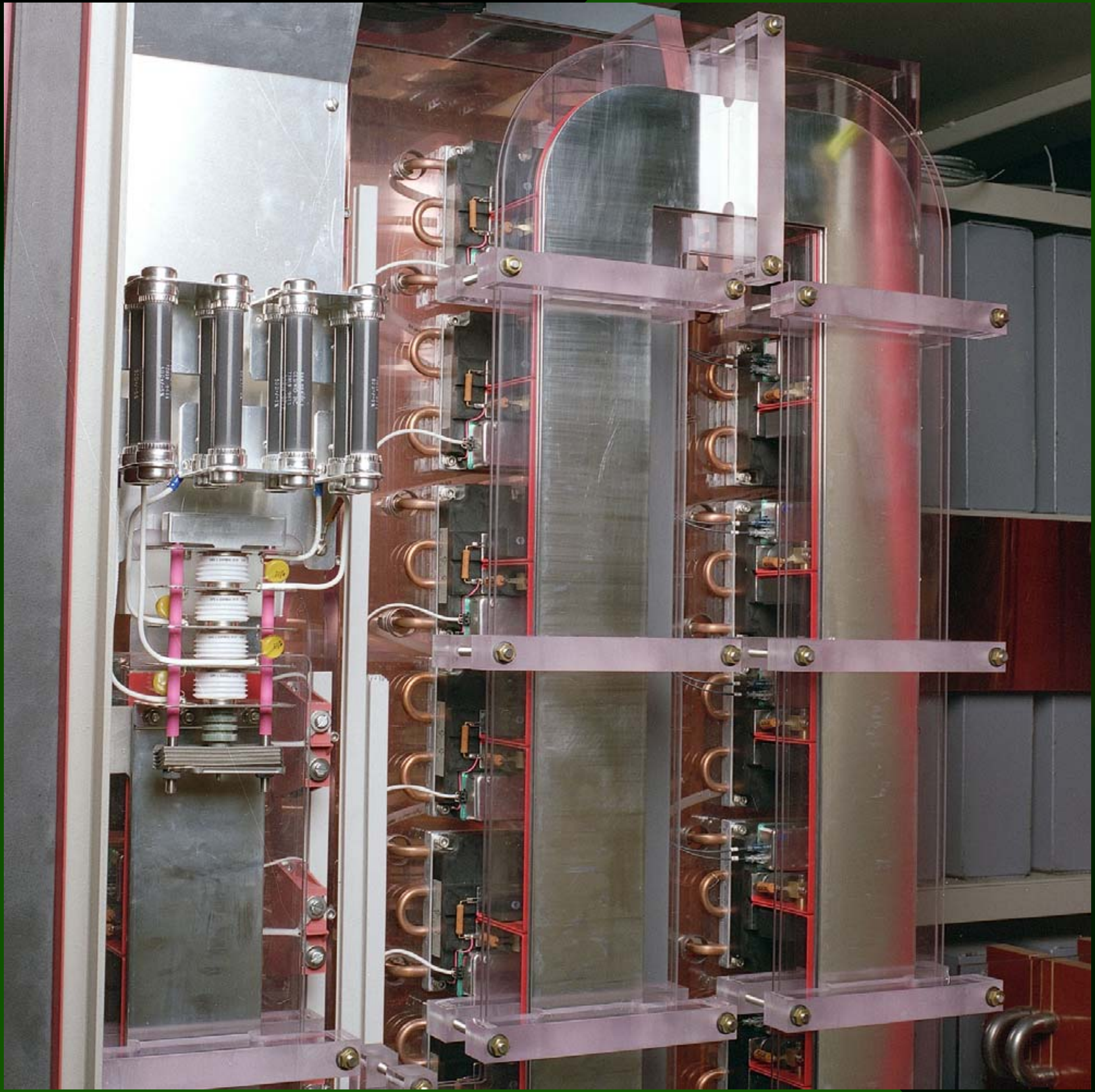

Figure 1
Modulator Topology

# Modulator pictures Fermi Cap Bank

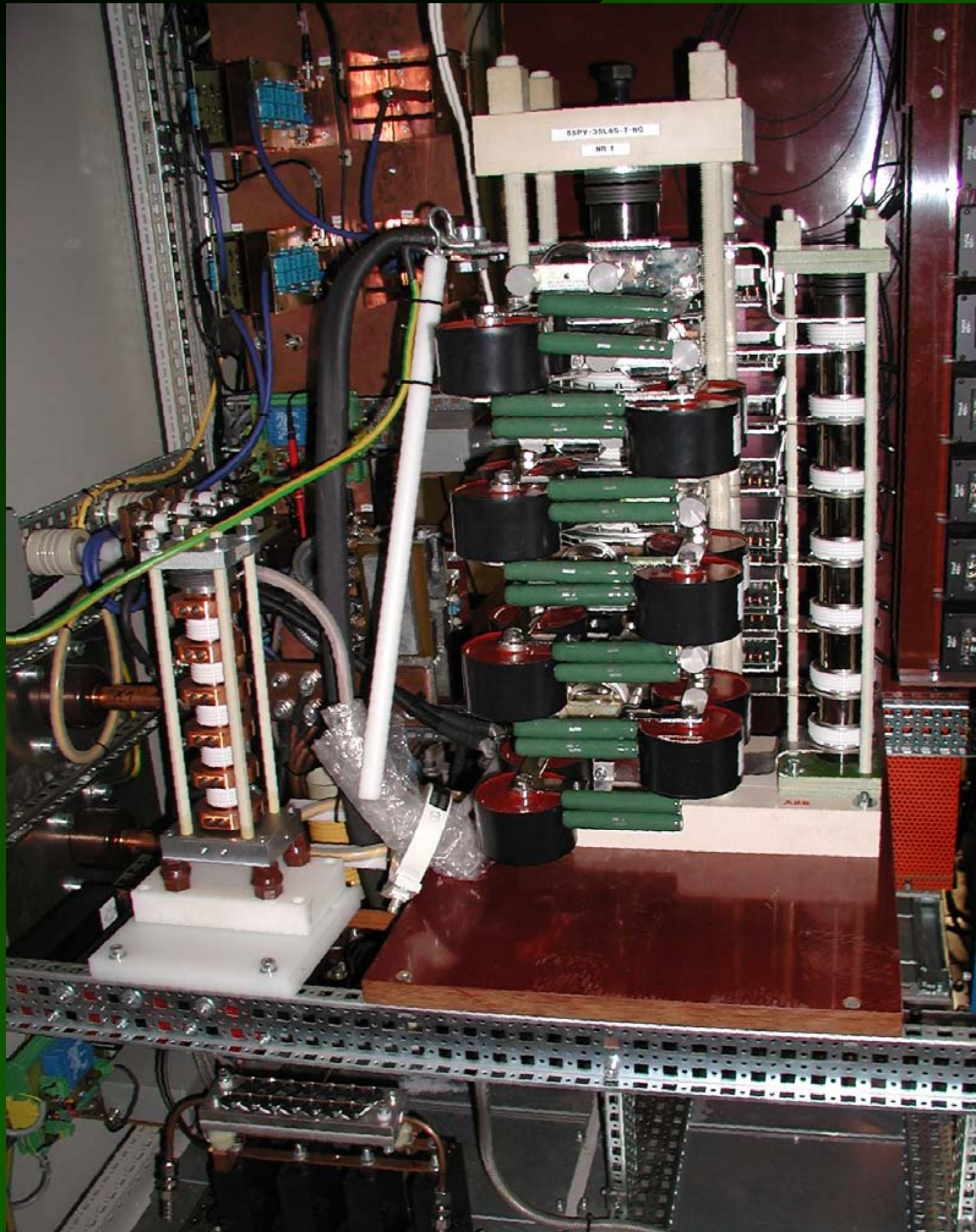


# Modulator pictures Bouncer



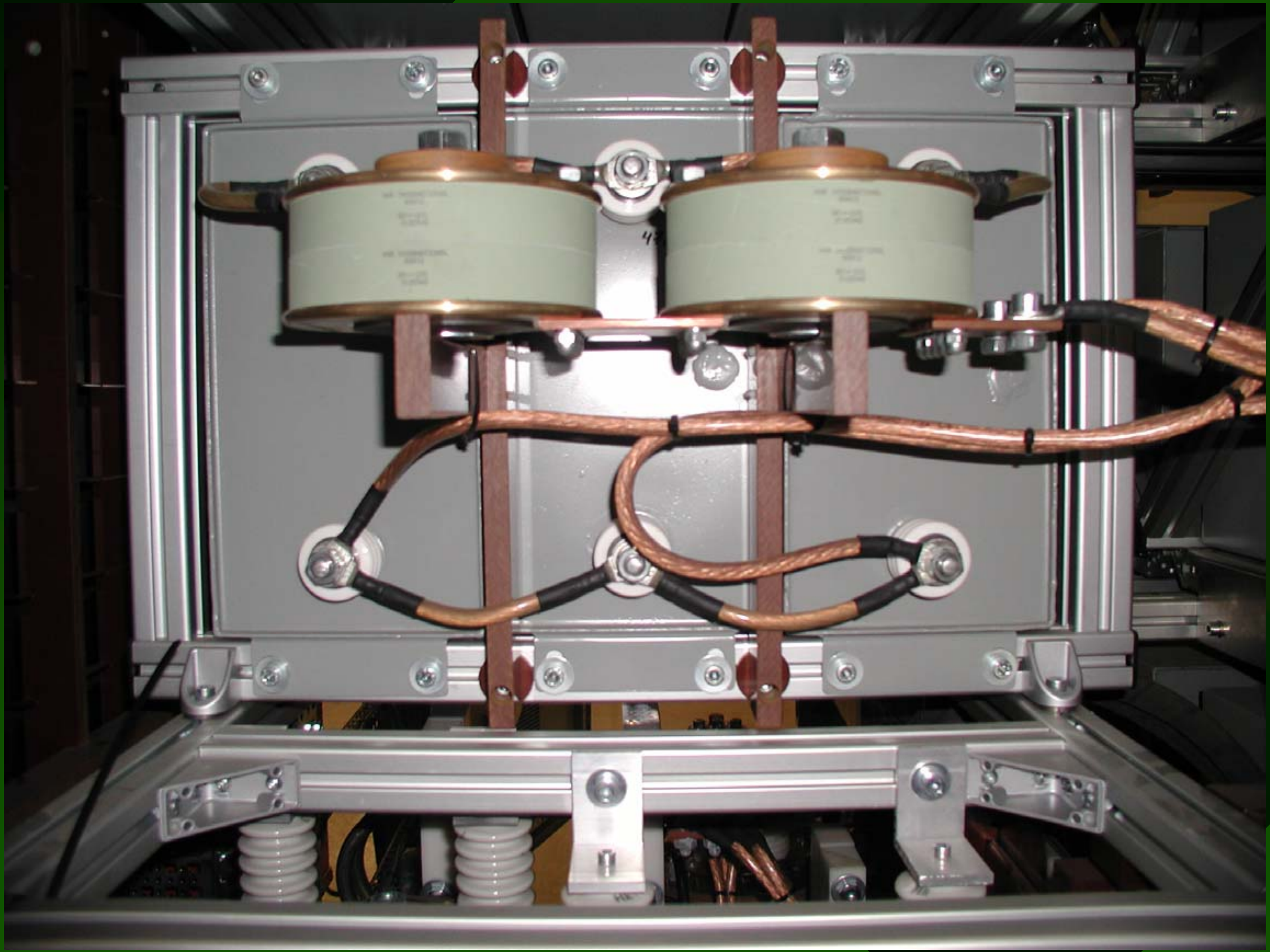


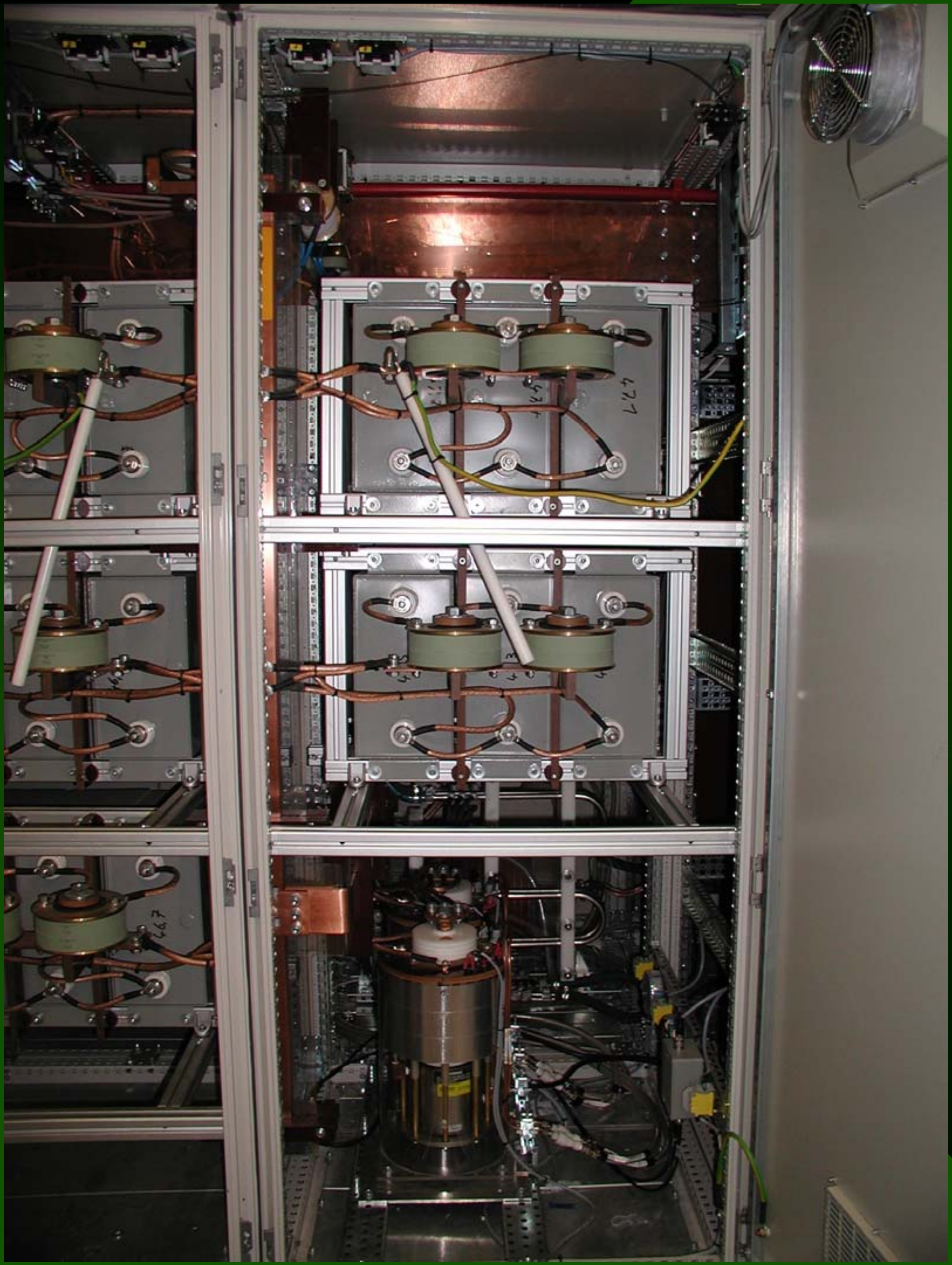
# Modulator pictures IGBT Switch



# Modulator pictures IGCT's

# Modulator pictures   DESY Capacitors





# Modulator pictures DESY Overall

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# Modulator pictures ABB Pulse Transformer

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# FERMILAB MODULATOR HISTORY AT DESY

- First modulator has run for 25,000 hours (since 1993)
- Second and third modulators have run for 18,000 hours each (since 1996)

# OLD FNAL DESIGN VS NEW FNAL DESIGN

- Back-up switch plus fast crowbar replaced with redundant, fail-safe switch.
- Standard filter caps replaced with “traction” type caps
- 1.6kV IGBTs replace with 3.3kV units
- Updated controls

# DESY COMMERCIAL UNIT

- Redundant switch and solid-state crowbar
- Traction type capacitors
- Switch built with 4.5 kV IGCTs
- Four units commissioned by PPT

# MODULATOR EFFICIENCIES

- FERMILAB:
  - Measured efficiency (Power in pulse when voltage above 95% full output/AC power) = 86%
  - Calculated efficiency from system losses = 90%.
  - Calculated loss in rise time (160us to 95% on 2.2 ms pulse) = 3%.

- DESY Commercial Modulator:
  - Stated electronic efficiency = 90%.
  - Stated loss from rise time (100us to 80% on 1.7ms pulse) = 4%
  - Stated loss from long pulse cables = 2%.
  - Stated total efficiency = 85%

# DESY "MONSTER" SOLENOID

- I assume this is a reference to the SMES (Superconducting Magnetic Energy Storage) type modulator that DESY has been pursuing.
- My impression is that this an experimental approach, and not in the main plan for the project.

# TESLA TDR COST ESTIMATE

- Price Estimates Provided by Stefan Choroba

- MODULATOR, PULSE TRANSFORMER, and CHARGING PS
  - $299.5K ea.  (572 units = $172M)
  - Price Based on Mass Production Study by PPT of the existing commercially built modulator. No mention is made of PPT's track record on similar studies.
  - One manufacturer is assumed

- HV CABLES
  - $72.2M for 1000km
  - Cost based on an estimate from Cable Manufacturer
  - Cost includes cable terminations and tunnel installation

# FERMI MODULATOR – Parts Cost

## ❑ Pulser Parts Cost

- Pulse Transformer: $108k
- Pwr Transformer: $ 50k
- Main Cap Bank: $ 31k
- Cabinet: $ 15k
- Other: $126k
- Subtotal: $330k
- IGBT Switch Subtotal: $ 50k
- Modulator Controls Subtotal: $ 40k

❑ TOTAL: $420K

# FERMI MODULATOR – Total Cost

## ❑ TOTAL COST ESTIMATE

- PULSER PARTS ESTIMATE: $420k
- RF MODULES (Spark Detection): $12k (AWAG)
- LESS Filament and Solenoid PSs: - $10k

- LABOR ESTIMATE:

  (Total parts cost) – (Pulse Transformer)

  $422k - $108k = $314k

## ❑ TOTAL: $735k

# FERMI MODULATOR – 572 Units

- COST ESTIMATE FOR 572 UNITS

- SINGLE MODULATOR COST: $735K
- "RULE OF THUMB" for mass production:

  5%/unit decrease for each 2x increase in number of units

  2**x = 580, x = 9.18

  (.95)**(9.18) = .62

  Cost per unit = $458k

- TOTAL: $262M

- NOT INCLUDING INSTALLATION





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# FERMI-BUILT MODULATOR

## ❑ Updated Technology

- IGBT Switch:
  - Using Original Devices: 25% reduction in switch cost
  - Eliminating the Backup Switch: 20% reduction
  - Using New Higher Voltage Devices:
    - 50% reduction in cost and physical size

- Main Capacitor Bank:

  Using New “HAZY” Self-Healing Polypropylene Capacitors

  50% Reduction in Cap Cost and Physical Size

- Modulator Controls:

  Using Lab G type – SM Components, fewer cable interconnects

  25% reduction in parts, 50% reduction in labor

# FERMI-BUILT MODULATOR

## ❑ Updated Modulator Cost

- IGBT Switch:

  Using New Higher Voltage Devices and eliminating the backup switch:

  - $60k savings in labor and parts

- Main Capacitor Bank:

  Using New “HAZY” Self-Healing Polypropylene Capacitors

  - $30k savings in labor and parts
  - $5k savings in Cabinet, Reduced Service Building Size!

- Controls Upgrade

  $30k Savings in parts and labor

# FERMI-BUILT MODULATOR
# - Updated Modulator costs, continued

- 5 Hz Operation

  $50k Savings in parts and labor

- TOTAL:

  $735 - $175 = $560k (24%)

  Inflation Since 1996 (5 yrs at 3%/yr) = 16%

  1.16 x $560 = **$650k**

- TOTAL – 572 Modulators

  “Rule of Thumb” for Mass Production

  .62 x $650k = **$400k**

# COMMENTS ON COST COMPARISON

- The TDR modulator cost seems low ($300k) as compared to the Fermilab modulator scaled to the TDR ($400k).

- Factors that may account for this difference:
  - The Fermilab built modulator cost estimate uses lab labor
  - The “rule of thumb (5%)” for mass production may not apply

    e.g., 8.2%/doubling would account for the difference

- THEREFORE, the accuracy of the cost estimate within 30% depends on the validity of the mass production study performed by PPT (German firm). Understanding this company’s experience (success) with similar studies would be key to placing some confidence level in the cost estimate.

# CHARGING SUPPLY DESIGN CHOICES

- Function: Recharge cap bank from 9kV to 11kV between pulses.  Power level = 150 kW at 5pps.
- Design choices:

  - Rectifier + filter choke – Fermi approach

  - Switch-mode supplies – DESY approach

  - Hybrid approaches

  - Other constant power designs.

# CHARGING SUPPLY CRITERIA

- Cost
- Noise:  For example, can 90MW of switch-mode power act as a good neighbor to other systems.
- Reactive power

Cost of remedy vs cost of heating and potential provider charges.

# CHARGING SUPPLY CTITERIA – CONT.

- For TESLA operating at 5 Hz, German standard requires less than 0.5% line voltage variations.

- 0.5% seems a severe restriction
  - FNAL Examples

    Footprint Area (Linac & Booster): 2% of 15 Hz

    Tests Done Recently With MI: 5% with 2 sec. ramp

    MI Pulsed Power: 10% with 1.5 sec. ramp

    13.8 kV Distribution Local – not shared with general public

    Sharing Level is at the 345 kV level (SC Huge)

# SINGLE VS DOUBLE TUNNELS

- Single tunnel puts modulator cap banks on the surface and transmits 10kV/1.6kamp pulses to transformers and klystrons in the tunnel.
  - Requires 1000 km of pulsed power cables.
  - Reliability of that much cable will have to be well understood.
- Double Tunnel
  - Puts entire modulator in service tunnel and distributes power via AC or DC distribution system.
  - Our bias is in this direction, there are many issues involved.

# POTENTIAL MODULATOR TECHNOLOGIES

- **FNAL** – with updated technology
- **FNAL Modified** – One built by Industry?
  IGCT's, Constant Power CPS, etc.
- **SNS** – High Frequency Switcher
  + Passive circuit on secondary to control spark energy deserves further investigation.
  - Switcher probably has to be installed in the tunnel.
  - HV/HF Transformer is tricky. Is it reliable?
- **Miss-Matched PFN** – Russian Idea, not built
  - No Bouncer Needed, combines small PFN with IGBT switch
  - Interesting, could be more reliable
  - Need to build one