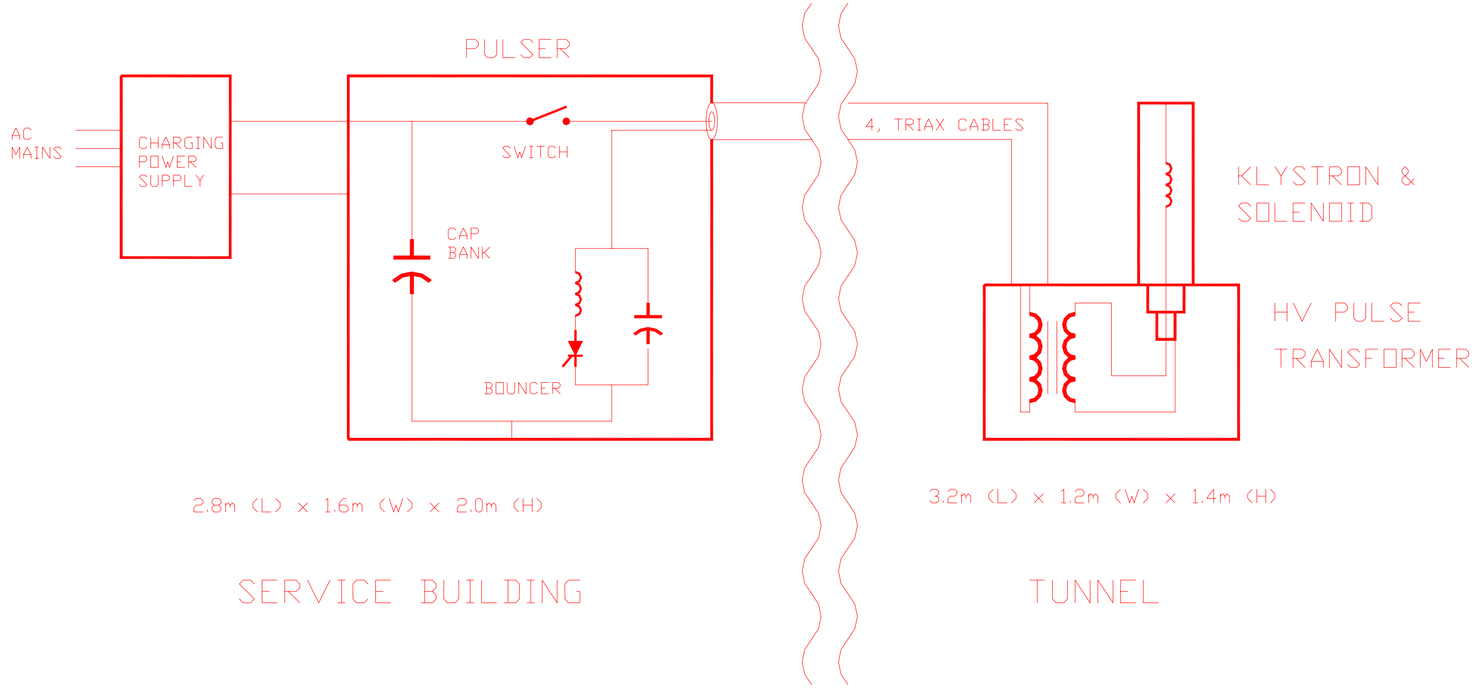
FERMILAB

TESLA TDR MODULATORS



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TESLA MODULATOR SPECS

	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	$< \pm 0.5\%$	$\pm 0.5\%$
Pulse-to-Pulse Voltage fluctuation	$< \pm 0.5\%$	$\pm 0.5\%$
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.*

POTENTIAL MODULATOR TECHNOLOGIES

- **FNAL** – with updated technology
- **FNAL Modified** – One built by Industry?
  - IGCT's, Constant Power CPS, New Caps?
  - I think this is what is in the TDR – getting more details
- **SNS** – High Frequency Switcher
  - \+ Small Size
  - \+ 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
  - Interesting, could be more reliable
  - Need to build one

TDR vs. FERMI MODULATOR

- KLYSTRON MOUNTED HORIZONTALLY – IN TUNNEL
  - Oil Leaks, Oil Containment (ES&H issue)?
- LONG CABLES: PULSER-TO-TRANSFORMER
- CAPACITOR BANK?
- SWITCH TECHNOLOGY?
- CHARGING POWER SUPPLY
  - More Complicated
  - Driven by rather severe requirements

    20 kV Source, 200 MVA Short Circuit Impedance, +/- 0.5% Reg.

MODULATOR CABLES – Xsection

The diameters of the cable are:

Inner conductor Cu bare fine strand	10 mm
Semiconductor layer	10.2 mm
Insulation VPE	19.2 mm
Semiconductor layer	19.4 mm
Outer conductor Cu bare fine strand	21.8 mm
Semiconductor layer	22.0 mm
Insulation	27.2 mm
Semiconductor layer	27.4 mm
Aluminum foil	27.8 mm
Outer sheath	33.8 mm

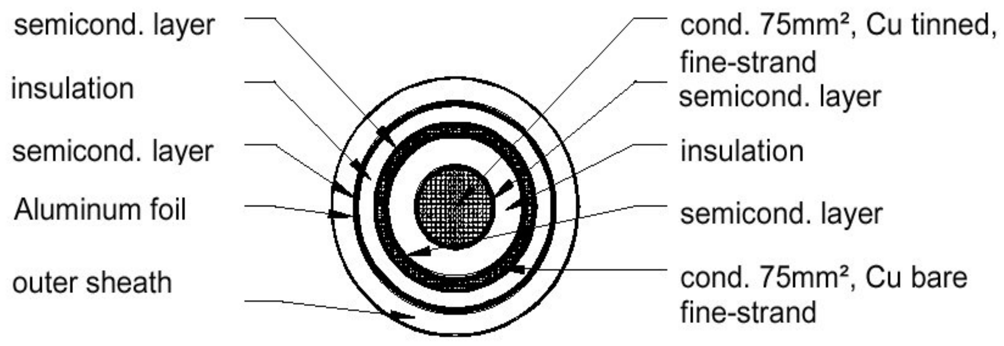

Fig .1: Cross section of the cable

MODULATOR CABLES - waveform

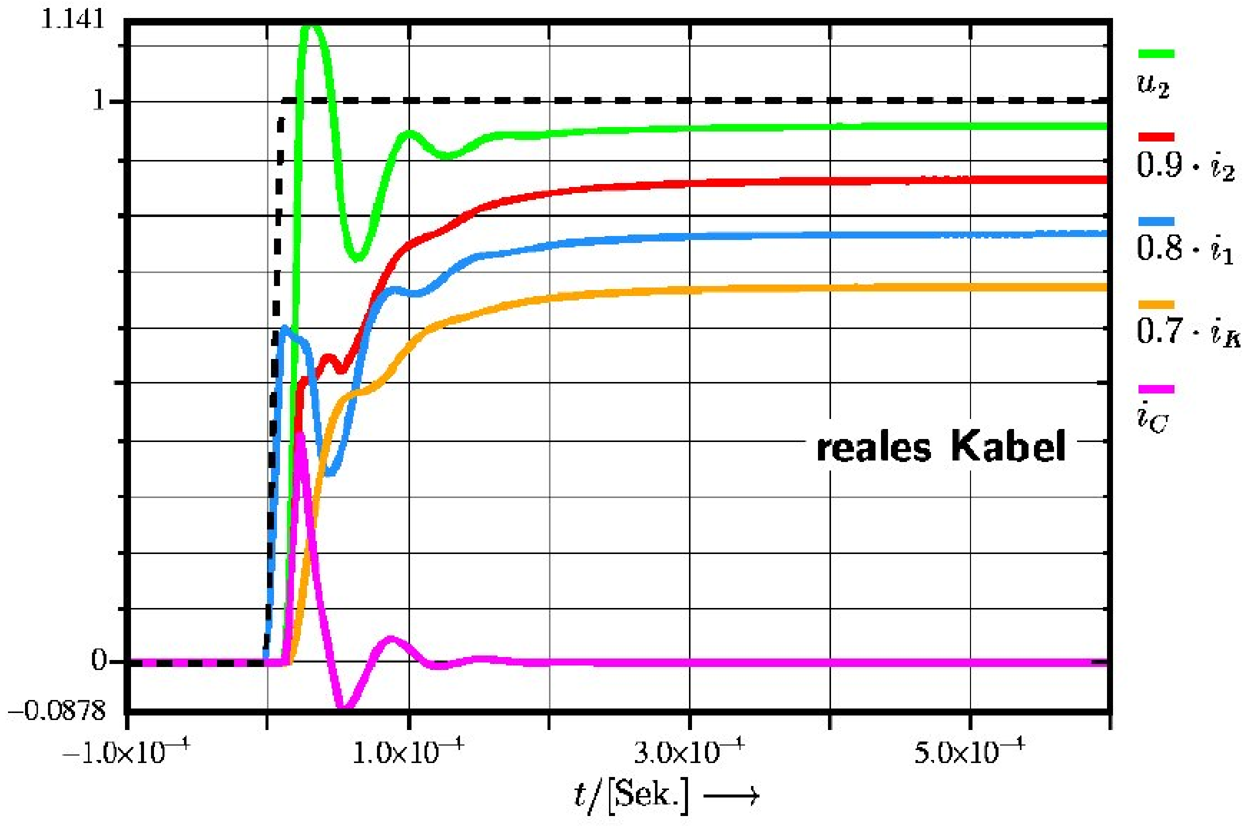

Fig.9: Simulation result of 4 cables 75 mm² in parallel 2500 m

MODULATOR CABLES – Comments

- Cable Looks Like Power Distribution Type – well known costs
- Cable Rating – checked for all enclosures and penetrations
- Matching Cable to Klystron Load – is it really necessary?

MODULATOR CPS – AC Mains

- Allowed distortions to the mains
- The German standard VDE 0838 or the equivalent European standard EN 61000 defines the amount of distortions that are allowed to be produced by a consumer of electrical energy. These distortions are defined as relative voltage changes d with

$$d = \frac{\Delta U}{U} \approx \frac{\Delta S}{S_{sc}}$$

d = allowed relative voltage changes
U = mains voltage
DU = variation of mains voltage
DS = variation of power due to the modulators
Ssc = short circuit power of the mains

- For TESLA operating at 5 Hz this value d is < 0.5%.

MODULATOR CPS - Topology

- Solution Adopted in TDR:

  - Stack up a number of industry-supplied PWM power supplies

  - Provide for Constant Power Charging by using a DESY developed self-learning regulation system.

    The capacitor charging waveform, stored in the regulator memory, is modified (learned) based on the requirement for constant power draw on the AC supply.

  - Other power supply solutions possible with the same regulation scheme.

MODULATOR CPS - Comments

- AC Mains Restriction Severe
  - FNAL

    Footprint Area: 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 System 500 MVA SC (200 MVA)

    13.8 kV Distribution Local – not shared with general public

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

- Charging Power Supply Complicated

  Floating PWM power supplies

  Number of components

  Complicated Regulation

  Reliability? (CPS is the most complicated part of mod.,)

TDR COST ESTIMATE (DT Hints)

- MODULATOR and PULSE TRANSFORMER
  - $470K ea. (572 units = $270M)
  - Price Based on Mass Production Study by PPT assuming one manufacturer.
- INTERLOCKS AND CONTROLS
  - $210K ea. (572 units = $120M)
  - Cost “ makes use of an established industrial costing procedure based on the the number of channels”
- HV CABLES
  - $60M for 1000km
  - Cost based on an estimate from Cable Manufacturer

TESLA COST ESTIMATE - Unknowns

- EDIA?
- Service Building Floor Plan
- Installation costs:
  - Rigging
  - Cable pulls and terminations
- Testing Plans:
  - Facilities
  - Lab Labor
- Installation Plans
  - Staging
  - Storage
  - Schedule

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

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FERMI MODULATOR – Total Cost

❑ TOTAL COST ESTIMATE

- PULSER PARTS ESTIMATE: $420k
- RF MODULES (Spark Detection): $12k (AWAG)
- INTERFACE Controls (SRM, VME crate, etc.): $45k (AWAG)
- LABOR ESTIMATE:

  (Total parts cost) – (Pulse Transformer)

  $477k - $108k = $370k

❑ TOTAL: $850k

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FERMI MODULATOR – 580 Units

- COST ESTIMATE FOR 580 UNITS

- SINGLE MODULATOR COST: $850K
- "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 = $527k (DT $680k: Modulator + Interlocks/Controls)

- TOTAL: $306M

- NOT INCLUDING INSTALLATION

FERMI-BUILT MODULATOR

❑ Updated Technology

- IGBT Switch:
  - Using Original Devices: 25% reduction in switch cost
  - Eliminating the Backup Switch: 30% 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:
  - $50k 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

- 5 Hz Operation

  $50k Savings in parts and labor

❑ TOTAL: $850 - $165 = $685k (20%)

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