High Power Solid State Modulator Development at SLAC

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March 5, 2010
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Inductive Adder Topology

• Modules with transformer coupled output
  – Primaries in parallel
  – Secondaries connect in series
• Array low voltage IGBTs to generate high voltage pulse
• All components at near ground potential
• Single turn (or few turn) transformers have high bandwidth
• Fault tolerant
1. **XP (8-Pack):** Driving eight PPM klystron (XP)
   500kV 2000A (500MW RF) 1.6 µsec 120 Hz for RF Program.
   (XP klystron did not get manufactured)

2. **XL4 (4-Pack):** Driving four XL4s using one half the drivers
   400kV 1260A (200MW RF) 1.6 µsec 30-60 Hz for RF Testing.
   (Operated)

3. **DFM (Design For Manufacturing) (8-Pack):**
   Design a prototype, to Drive 8 XP klystrons
   (Program change klystron reduced to 2 Klystrons per modulator)

4. **DFM1 (Hybrid 2-Pack):** Build a DFM prototype 15 stack and drive (2) XL4
   klystrons using an existing 1:10 pulse transformer
   400kV 630A 3.2 µsec.
   (Operational)

5. **DFM (Integrated 2-Pack):** Design and build a DFM Modulator using 12 turn
   secondary transformer to drive 2 XP klystrons
   (Project change to ILC, design never completed)
SLAC Induction Modulator Development

8/4-Pack

Table-top

2-Pack

Table-top

3.3 kV IGBT

6.5 kV IGBT
NLC 8-PACK (8-XP) MODULATOR

CORES AND SECONDARY
76 Primaries @ 5400 A
3 Turn Secondary
400 kV @ 1800 A,
725 Meg watts for 3.2µs,
350 kW Ave.

SOLID STATE DRIVERS
152 IGBT’s Drivers
(two per Primary)
1800 volts per IGBT
2700 Amps per Driver

Water Load
500 kV, 650 Amps

5045 Klystron
400 kV, 450 Amps

Workshop on X-Band Technology for FELs
Page 6
NLC 4-PACK (4-XL4) MODULATOR

XL4 Klystrons
400kV @ 320 A
1.6 µsec

CORES AND SECONDARY
76 Primaries @ 5400 A
3 Turn Secondary
400 kV @ 1200 A,

SOLID STATE DRIVERS
76 IGBT’s Drivers
1800 volts per IGBT
3600 Amps per Driver

(4) XL4 Klystrons
400kV 1200A
Table-top (6575 Equivalent) Modulator

- Grid
- Emitter
- GRN +15V
- Collector

**IGBT DRIVER**

- Q11
  - 0.007 V-Sec
  - 23 kV
- D11
  - 8 kv
- T11
  - 1/1

- C11
  - 100ufd 3kv

**IGBT DRIVER**

- Q21
  - 2 ea 3.3Kv 800A
- C22
  - 50ufd 400v
- D21
  - 8kv
- T21
  - 1/1

**IGBT DRIVER**

- Q31
  - 2 ea 3.3Kv 800A
- C32
  - 50ufd 400v
- D31
  - 8kv
- T31
  - 1/1

**IGBT DRIVER**

- Qn1
  - 2 ea 3.3Kv 800A
- Cn2
  - 50ufd 400v
- Dn1
  - 8kv
- Tn1
  - 1/1

10 Primaries @ 5400 A
20 IGBT drivers
2.2 kV, 2.7 kA
1 Turn Secondary
1:15 conventional X-former
330 kV, 360 A

(Note: Rise time slow due to pulse transformer leakage inductance and stray capacitance)

Workshop on X-Band Technology for FELs Page 8
NLC DFM1 Hybrid Modulator

DFM1 Hybrid modulator utilizing DFM fabricated parts; 15 Metglas cores, 30 IGBT drivers, with a single secondary turn driving a conventional 1:10 pulse transformer: 530kV, 600A, 1.6 μsec, 120 Hz

Water Load
500kV 500A

(2) XK4 Klystrons
400kV 440A
ORION 5045 Klystron Modulator

8 Primaries @ 6210 A
16 IGBT drivers: 3.0 kV, 3.1 kA
1 Turn Secondary
1:15 conventional X-former: 360 kV, 414 A

Resistive load 4 ohms 30nF
Modulator only 24kV 6000A

Workshop on X-Band Technology for FELs
Page 10
SLAC Modulator Program Conclusions

- IGBT-based solid state modulators are capable of meeting (and exceeding) the high power klystron requirements
- R&D opportunities to improve efficiency, fault tolerance, and modulator lifetime
  - Pulse power optimized IGBT
  - High voltage, high bandwidth adder design
  - Integrated HLRF design: optimize entire source including modulator