

Technical Systems Configurations -- Electrical

Subsystem: Klystron Modulators

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1. Requirements:

Klystron modulators convert AC Line power into pulsed power to drive the RF sources for both the main linac and injector linac traveling wave accelerator structures. Both linacs propose using up to 75 MW peak power klystrons with varying peak voltage and pulse width requirements. For the main linacs the peak voltage is 500 kV at 3 μ sec width, 120 Hz. Parameters for all the linacs are given below. The 3 μ sec was a recent change of the entire power system to a multi-mode DLDS, which doubled the pulse width and halved the number of klystrons and modulators in the main linac.

2. Technical Description:

The implementation is a new solid-state switch using Insulated Gate Bipolar Transistors (IGBTs), along with high efficiency low loss Metglas magnetic materials. IGBT driven cells (toroids) are stacked and threaded with a 1:3 output transformer in a configuration that drives up to eight 75 MW klystrons in parallel (8-Pack). For injection modulators, where klystrons are spread out along the linac as opposed to clustered as in the DLDS system, a two-transformer (hybrid) design is proposed in which a short stack drives a pair of klystrons (2-Pack).

2.1 Parameter Table

The table of drive requirements for the various linacs is shown in Table 1. Table 2 summarizes the main linac 8-Pack requirements. Injection 2-Pack requirements are similar except power levels and pulse widths vary as in Table 1.

Modulator (Band)	No. Klystrons per Modulator	Klyst % Eff.	Modultr % Eff	Kv Peak	Amps Peak	P.Width uSec	PRF-Hz	Avg Pwr Out-kW	Est.Pwr In-kW	Klystrons/ Modulators (Approx.)
Main (X)	8 @75 MW	60	75	490	2000	3.0	120	376	550	1656/207
Injection (L)	2@75MW	50	70	388	387	6.0	120	198	283	34/17
Injection (S)	2 @ 65 MW	50	70	350	373	5.0	120	143	204	130/65
Cmpresrs (X)	4@75 MW	60	75	490	2000	1.5	120	94	138	8/2

Table 1: Modulator Characteristics

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Output	500 kV, 2120 A, 3.05 μ sec, 1:3 step-up
Rise & Fall	200 nsec loaded
Droop/ Flatness	1% nominal
Repetition Rate	120 Hz
Load	Eight 75 MW klystrons in parallel
Power Supply	550 kW continuous for full load @ 120 Hz
Efficiency	82%
Reliability	>10,000 hrs MTBF

Table 2. Main Linac Modulator Requirements

2.2 Overall Layout

Sketches of the basic 8-Pack and 2-Pack Hybrid designs are shown in Figs. 1-2.

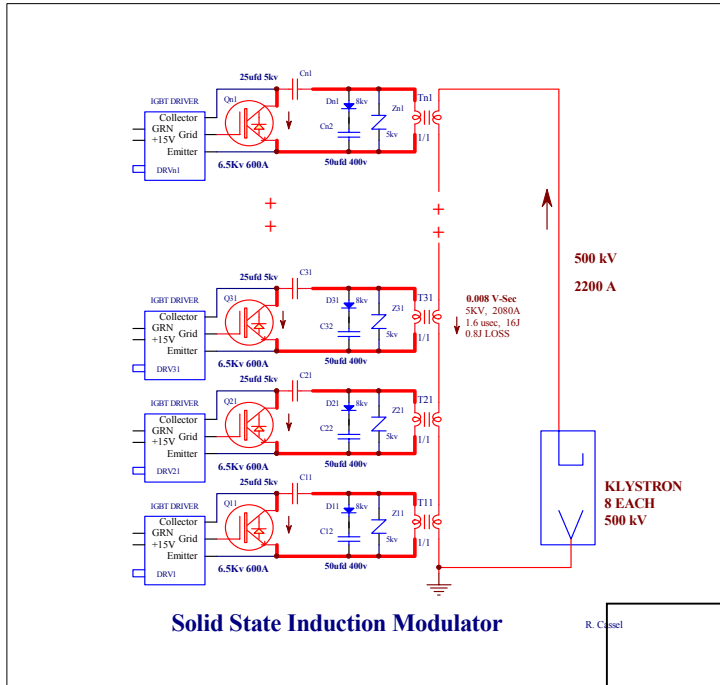


Fig. 1: 8-Pack Circuit

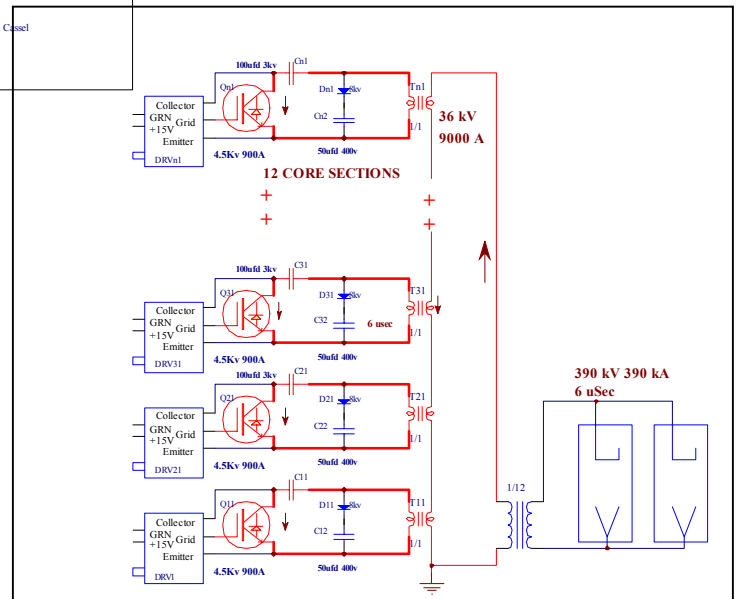


Fig. 2: 2-Pack Circuit

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3. Technical Issues:

3.1 Reliability: The prototype program is needed to prove the long-term reliability of IGBTs and Metglas cells under pulsed currents that greatly exceed the nominal AC voltage rating of the IGBTs. In low-level circuits this is not a problem because average power is extremely small compared with rating; however this may be different in the high power devices.

3.2 Voltage: Higher voltage IGBTs are appearing and the plan is to use these and decrease the required number of boards and cells in the modulators. However these units may need internal layout optimization by vendors to be usable at the higher levels without destructive voltage switching spikes.

3.3 Failure analysis: The prototype program must drive real diode and klystron loads in order to verify that occasional arcs in a single tube in a 2-Pack or 8-Pack will not grossly degrade lifetime, or cause catastrophic failure as the other connected tube or tubes dump stored energy into the arc.

3.4 Cost: Firm prices for IGBTs and Metglas have yet to be established through the Design for Manufacture (DFM) prototype program. Although prices for IGBTs are decreasing with time, Metglas is a more exotic commodity with fewer suppliers.

4. Discussion of Configuration Choices:

Traditionally klystron modulators have been a major cost driver of accelerators, with power conversion efficiencies of around 50% (wall-plug power to pulse power delivered) and high capital cost. Current designs use low MTBF thyatron switches to convert DC from a charged pulse-forming network (PFN) into a klystron drive pulse. The thyatrons wear out and are increasingly difficult to obtain. PFNs have fixed pulse width. Therefore a new Induction design was invented that modeled an Induction Linac in principle, with the induction cells driven by solid-state switches at relatively low voltage (2-4 kV). Cells are added around a linear transformer to obtain the desired output.

Key requirements for the new modulators are improved power conversion efficiency (50=>80%), lower cost (~50%), and higher reliability (~10K hrs MTBF). These goals were set as the result of proof-of-principle tests of a new solid-state switch using Insulated Gate Bipolar Transistors (IGBTs), along with high efficiency low loss Metglas magnetic materials. IGBT driven cells (toroids) are stacked and threaded with a 1:3 output transformer in a configuration that drives up to eight 75 MW klystrons in parallel (8-Pack). For injection modulators, where klystrons are spread out along the linac as opposed to clustered as in the DLDS system, a two-transformer (hybrid) design is proposed in which a short stack drives a pair of klystrons (2-Pack).]

The transformation ratios are chosen to best match the modular stack voltage and current to the load. The optimum design is the smallest number of cores at maximum current and voltage that will provide the correct drive to a pair of klystrons. The goal is a common IGBT board design for all linacs, and the smallest number of core designs, for maximum manufacturing efficiency.

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5. References

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