A Long Pulse Solid State Induction Modulator

R.L. Cassel, SLAC*
Stanford Linear Accelerator Center

Abstract

The Next Linear Collider accelerator is developing a high efficiency, highly reliable, and low cost pulsed-power modulator to drive the NLC 500KV, 230A X band klystrons. The induction of fractional turn transformer is most applicable for short pulse width of less than 1.5 microseconds due to the size of the induction cores involved. This paper will cover the techniques SLAC is developing to use the induction modulator in longer pulse operation of up to 15 microseconds. The 3 microseconds SLAC design as will, as the proposals for wider pulse application will be discussed.

1.0 Modulator Design consideration

The Next Linear Collider accelerator proposal at SLAC has selected the Solid State Induction Modulator approach for its X band klystrons because of its high efficiency, highly reliable, and low cost. The major difficulty with the conventional PFN type modulator use at SLAC for the Next Linear Collider (NLC) is the efficiency of the modulator for short pulse operation. The leakage inductance for the pulse transformer and the stray inductance of the switching circuit inherently limit the rise and fall time of the klystron voltage waveform. To reach the efficiency goals of > 75% for the modulator for the NLC it is necessary to have a rise and fall time of the klystron voltage pulse of less than 200 nsec. It is extremely difficult to obtain a fast rise time and high efficiency with a PFN modulator.

1.1 NLC Booster modulator

The NLC solid-state induction modulator program so far has been directed the main accelerator sections, which has the majority of the klystrons. In addition to the main accelerator there is the booster Accelerators. Which requires additional modulator to drive two klystrons at a time.

	Frequency MHz	Present #	Present msec	One Proposal # *	One Proposal msec
L-band	1428	30	5	15	5.5
L-band	1482			15	16.5
S-band	2856	157	4.5	50	4.5
S-band	2856			15	13.5

* Assumes two klystrons per modulator

The present proposal requires 5 μsec pulses with proposed designs up to 17 μsec. To accomplish these requirements a different approach was needed to the modulators to utilize the induction solid state approach.

1.2 The Present Induction Modulator

The present modulator topology selected for the NLC modulator is similar to an induction accelerator. It consists of a large number of single turn induction cores each driven by its own solid-state switch. Due to the inherent low inductance of such a structure the secondary will have three turns. The resulting total leakage inductance at the secondary is extremely low (<20 μhy). The major part of the leakage induction is in the multiple primary side connections and drivers. The use of three turn secondary fractional turn transformer combined with two high current IGBT allows for the driving of 8 klystrons with one modulator or approximately 1000 megawatts of power for 3 μsec see Figure 1.

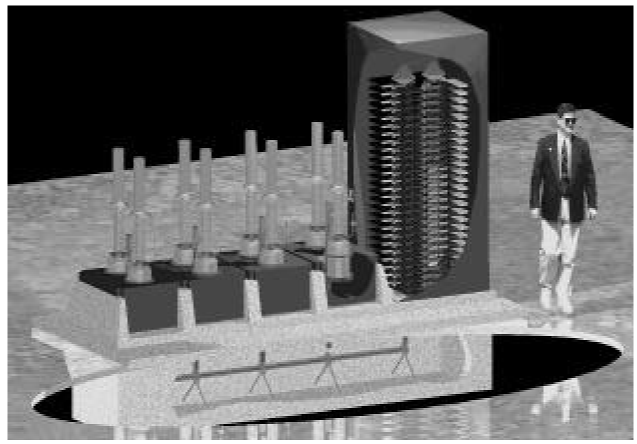
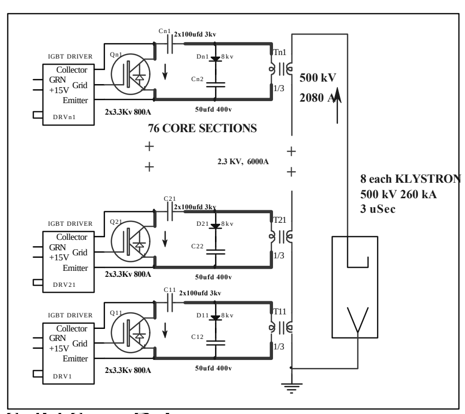


Figure 1. Induction Modulator Artistic Rendition

To obtain 500 kV for 3 μsec (1.5 volt seconds per turns) with a transformer, a three turns secondary required a large magnetic core cross sectional area. To drive the core without using a matched PFN requires a switch that can not only turn on fast at high power levels but also turn off. Switching devices now exist in the form of IGBT (Isolated Gate Bipolar Transistors). EUPEC FZ800R33KF1 was used. Figure 2.



1.3 Solid State Drive

Work supported by the Department of Energy Contract DE-AC03-76SF00515
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309
Presented at the 5th Modulator-Klystron Workshop for Future Linear Colliders (MDK-2001),
4/26/2001 - 4/27/2001, Geneva, Switzerland

The Core driver is simple consisting of an IGBT, a DC charge capacitor in series with the IGBT driving the individual magnetic core. A capacitor with fast diode is used across the core to absorb the reflected energy from stray inductance under normal and fault conditions as well as the current if the one of IGBT is turned on later or off earlier then the other IGBTs. A pulse reset of the core is used to insure that the core is totally reset before the next pulse. The energy storage capacitor is charged through the transformer core. Figure 3.

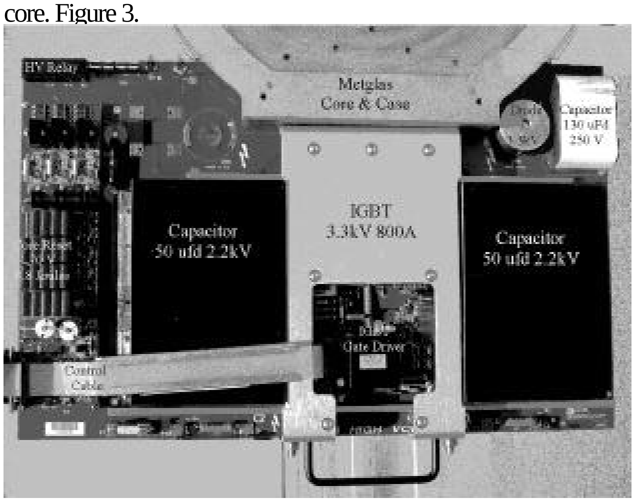


Figure 3. IGBT Drives boards

The modulator consists of two driver boards with one 3.3 kV IGBT per board. The driver boards are PC Board and arranged so that they can be plugged into the transformer core for easy replacement. Figure 4.

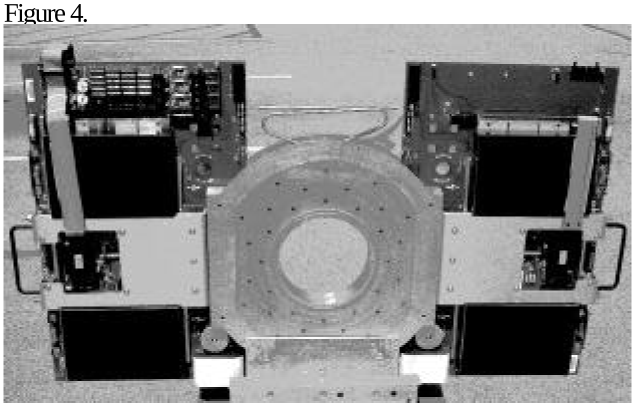


Figure 4. PC Board Core Driver circuit

The NLC solid-state induction modulator R&D program is divided into three Stages.

1) Full core stack 76 cores with three turns to drive full 500 kV into water load and then full current into 4 each 5045 klystrons at full repetition rate for a full load testing.
2) A model using 10 cores and a standard pulse transformer to drive a SLAC 5045 klystron, which is discussed in this paper.
3) A design for manufacturability prototype for 8 klystrons.

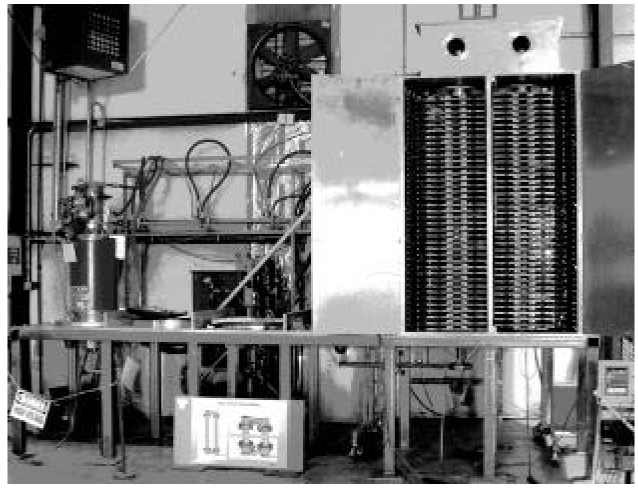


Figure 4. 4ea 5045 modulator

1.4 Model of Induction modulator

To obtain early experience with the solid state induction modulator driving a klystron load, and explore use of the induction modulator for single or two klystron operation, a model program has be developed to utilise the Induction modulator to drive one of the existing SLAC 5045 Klystrons. A stack of 10 each modulator cores driving and the existing 5045 klystron 15/1 pulse transformer would allow early testing of the induction modulator design concept. Operation the 10 core stack at 20kv and 4400 amps well drive the Klystron to 288 kV 315 A. Figure 5.

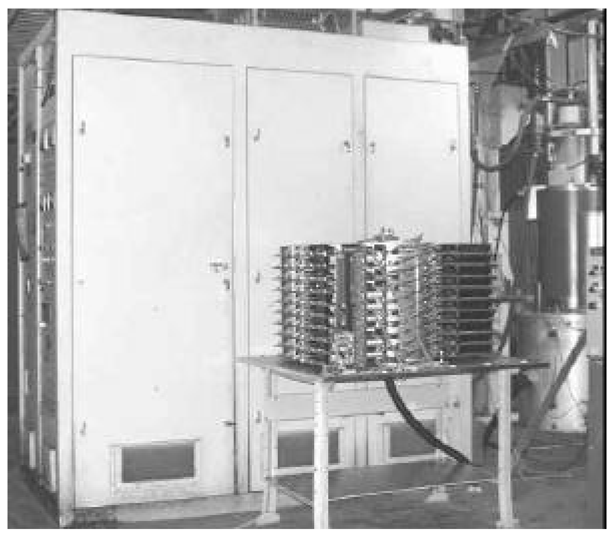


Figure 6. Table Top Induction Modulator

The model has operated to demonstrated that the concept was workable Preliminary results are shown in Figure 7. As can be seen the rise time is primarily determined by the leakage inductance of the pulse transformer and the connection inductance and therefore the induction modulator has little efficiency advantage over the thyratron modulator.

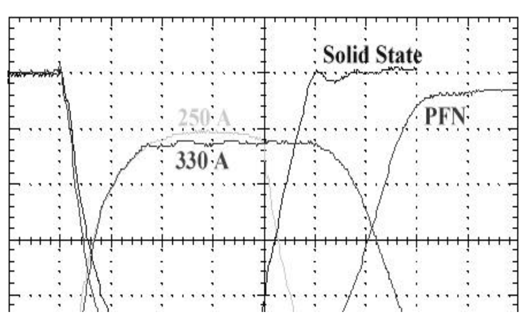


Figure 7. Model Preliminary Waveform

1.5 Wide pulse Induction modulator

For wide pulse applications the cores needed to utilize a small number of secondary turn in prohibitive expensive, so the tabletop approach is not feasible and therefore an improved concept is needed. What is needed is a low inductance connection to the primary of a conventional pulse transformer and the maximum of core area to reduce the number of turns in the secondary to reduce the secondary leakage inductance. The SNS project has had manufactured some Nanocrystalline core (29" x 16" x 3.5" thick) which could be used as the bases of an improved concept in induction modulator design. The cores have high Mu, low losses and large Volt-Second capability.

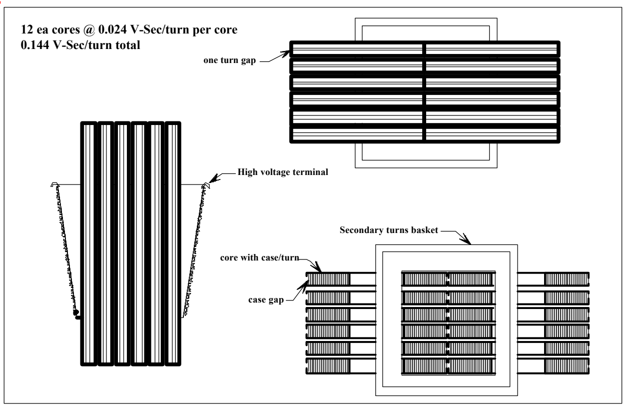
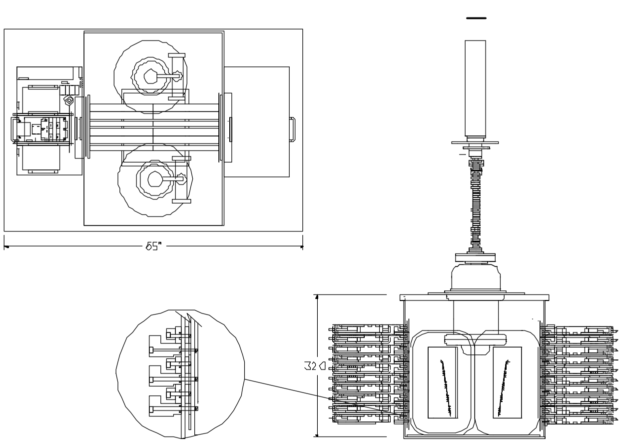


Figure 8 Pulse transformer configuration

By combining the pulse transformer with the IGBT drivers a hybrid induction modulator can be designed. The pulse transformer would consist of the standard Strangeness type secondary basket with the low leakage inductance encased single turn primary of the induction modulator. The secondary and core would be in oil for the high voltage standoff capability with the primary connections penetrated the tank walls through oil seals to a strip line to which the IGBT drivers can be connected.



1.6 specifications

1) Output 380kv 500A @ 15 μsec.
2) Cores 12 ea cores @ 0.024 V-S/Turn
3) Total Core 0.144 V-S/Turn total
4) Drive 8.4kV/turn @ 15 μsec
5) Turns 2 Series core, 60 Turn secondary
6) Drive cards 12 each 4.2kV drivers @ 3000A
7) Impedance ~700 μhy, 1000 ohms,
8) Rise time t~0.7 μsec

24 Drivers		0.144 volt-sec		380,000 volts	
Cores per driver series	**Drivers in Parallel**	**# cores in series**	**Volts/ turn**	**Pulse Length**	**# of turns secondary**
12	24	1	4,000	36	95
6	12	2	8,000	18	48
4	8	3	12,000	12	32
3	6	4	16,000	9	24
2	4	6	24,000	6	16
1	2	12	48,000	3	8

The same transformer/core configuration can be used to drive pulses from 3 μsec to 36 μsec by different number of series section.

1.9 Conclusions

The induction modulator can be made to give a high efficient, fast rise time for longer pulse by using the low inductance IGBT driver and the multiple turn conventional pulse transformer combined in a new way.

***Work supported Department of Energy contract DE-AC03-76SF515**