Novel Gigawatt Power Modulator for RF Sources*

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Abstract

A novel method for producing high voltage rectangular pulses for driving RF sources is described. The approach uses two advances in pulsed power technology: 1) The BLT switch and 2) Novel transmission line transformer techniques using switches between lines. Experimentally demonstrated is a modulator producing 80kV, 800A output pulse requiring only 22kV switch voltage. The output pulse is ~120nsec long with <40nsec rise and fall times. A modulator designed to produce 1MV , 1kA output pulse using 50kV switches is described and simulated by computer. The application of this modulator to drive RF sources for advanced accelerators is discussed.

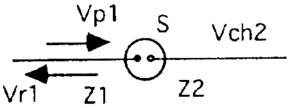
I. INTRODUCTION

There have been many attempts to use the Marx generator to get short rectangular pulses in nanosecond region of time. The stray capacitances of the lines spoiled the shape of the pulse. In this work, we describe a novel approach to obtaining a rectangular output pulse from a multistage Marx like generator. We started the investigation with a transmission line transformer scheme what was proposed by Smith[1] In a standard transmission line transformer a single switch is used at the input and the step up ratio is typically limited to about 5 or 6 thus a 1MV output requires and input switch of ~200kV. Switching at this level at high rep rates and currents is extremely difficult. In our design we use several lower voltage switches at the transition points of the transmission line transformer. This approach allows us to obtain an output of 1MV using 50kV switches.

II. SWITCHED TRANSMISSION LINE TRANSFORMER

The main idea of our approach is to locate switches between lines. In this case, the capacitance of isolation transformers and triggering transformers can be included to the capacity of lines and the switch inductance can be included to the inductivity of the lines. This means that the influence of the parasitic parameters of the switch on the output pulse can be eliminated. The charge voltage of the lines can be tripled between switches uniformly by means of charging transformer or with help of some dividers.

If we have two transmission lines and an ideal switch between them ,



the reflected wave in the first line is:

$$Vr1 = (Vch2-V1p(1-Z2/Z1))/(1+Z2/Z1) \qquad (1)$$

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The main problem in design of TLT(Transmission line transformer) to bring to 0 each reflected wave. By different law of increasing charging voltage it is very hard to get entire formula, about how the resistance of the line has to respond to this increasing. But it is very easy to write a computer program for optimization purposes.

When designing the actual device, we can use several active sections and several passive ones. Some examples at such approach are shown in Fig 2. From this figure, one can see that the closer to the beginning are pulsed the switches, the higher is the gain at the output voltage. The upper limit can be achieved when all switches are put in the very beginning of the lines. But in such case. they need to work in series which is not easy to accomplish.

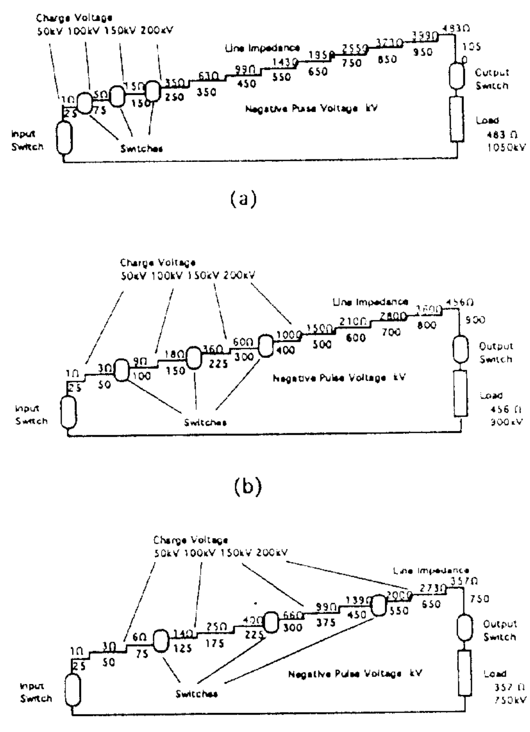

Figure 3. Three possible schemes for the switched TLT. Charge voltage is with respect to ground such that each switch is required to holdoff 50kV. a) Scheme using 3 switched sections and 9 passive sections to give 1050 kV output. b) Scheme using one impedance step between switches for 6 sections followed by 6 passive sections to give 900kV output. c) Scheme using two impedance steps between switches for 9 sections followed by 3 passive sections. For design purposes the total number of switches was limited to 4 and number of sections to 12, for computational purposes an output switch is used which will be replaced by an isolating line in the final design.

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III. EXPERIMENT

An experiment to demonstrate the switched TLT was undertaken using two BLT switches capable of operating at up to 50kV in a configuration to give an output which is four times the switch voltage. The circuit design is that of scheme b in figure 2 using a total of four sections plus an output isolating line. The block diagram of the pulse generating system is shown in Figure 3.

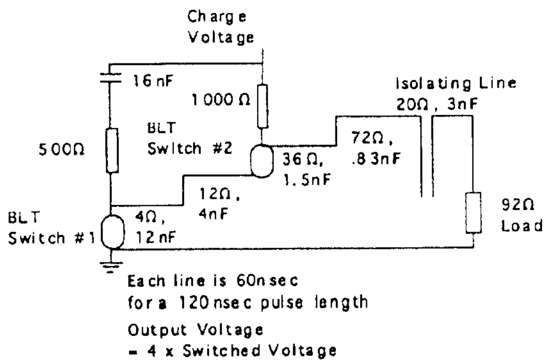

Figure 4. Experimental circuit for demonstrating the feasibility of the switched transmission line transformer using multiple BLT switches.

The test circuit was fabricated using discrete components to produce five transmission lines of different impedances. The first two lines, 4 and 12-Ω impedance, consist of ceramic capacitors and inductance formed by a rectangular coaxial housing. The third and fourth lines, 36 and 72-Ω impedance, are formed from custom capacitors fabricated by IAP using a cylindrical geometry and mylar film dielectric. Each line is twelve sections of equal capacitance the length of each line is 60nsec. The fifth line 20Ω isolates the charging voltage from the load.

The switches used in this system are the BLT-250-T which is an electrically triggered single gap BLT switch. Performance of the switch is described in another paper at this conference[2]. The switch is capable of operation at 1Ω circuit impedances at up to 50kV when pulse charged in ~10μsec. The switch uses a cold cathode to conduct the main discharge current therefore requires very low heater power. The small amount of heater power allows the switch to operate at floating voltages without large isolation transformers for the heater power.

In optimized operation using two switches an output pulse of 80kv with a 40nsec voltage risetime (10 to 90%) has been obtained at a 22kV switch voltage and is shown in the figure 4. The optimized output pulse occurs when the second switch closes precisely at the time the pulse from the first switch arrives. This is 120nsec after the first switch closes.

The BLT switch has been demonstrated to operate with timing jitter on the order of 1nsec when operating at high power. In this system two BLT switches have been synchronized to produce an output pulse with timing jitter of <1.5nsec. The jitter of the load voltage is measured statistically taking a sample of 2000pulses while operating continuously at 5Hz for 25minutes. The resulting data is presented in figure 5.

This data shows the statistical jitter of the BLT and indicates the long term stability of the system. When operating at higher power some drift of delay may occur due to thermal variations in the system however these can be compensated for with computer control. We have developed a microprocessor based system to control the drift of the BLT. The BLT uses a quickly responding gas reservoir which when combined with a computer controlled power supply the drift can be eliminated. Drift can further be reduced by varying the trigger delay time to the BLT switch.

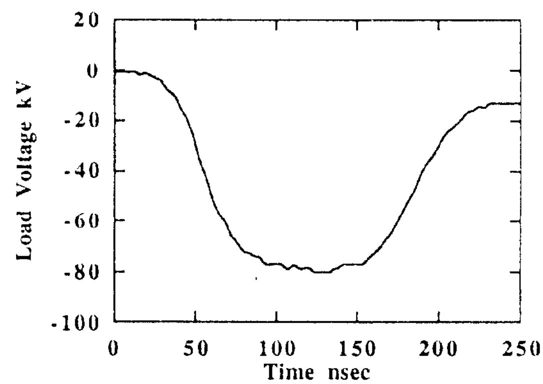

Figure 4. Output voltage obtained in experimental circuit using two BLT switches. Switch voltage was 22kV and repetition rate 5Hz, load current is 800A.

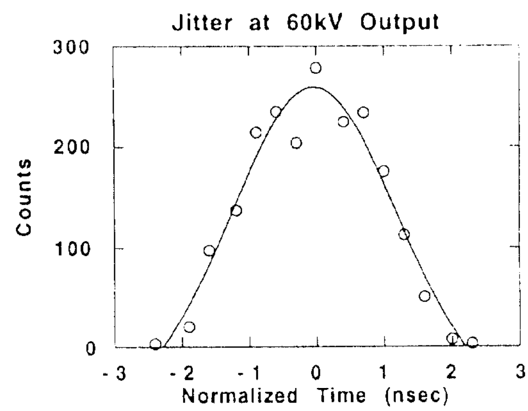

Figure 5 Statistical measurement of the jitter. Data consists of a 2000 pulse sample taken while continuously operating at 5Hz for 25 minutes. No pulses occurred outside of the data range shown.

IV. MODULATOR DESIGN FOR 1 MV

A key element in the development of higher energy and higher luminosity linear colliders is the availability and cost of the RF power required to drive the accelerator. In present designs RF power is required at 11.4GHz in 100 to 200nsec long pulses with peak powers of 1GW[3]. The present approach to obtain this output is to drive the RF source at ~100MW for ~1.4μsec then use RF pulse compression to shorten the pulse and increase the peak power. The pulse compression is innefficient therefore requires that the pulse modulator be very efficient. The pulse modulator in this approach can be a transformer based system provided that the step up ratio is not too high, however this puts severe demands on the high voltage input switch and special techniques must be used to reduce the required switch voltage[4].

Our pulse modulator techniques can be applied to directly drive an RF source at the 1GW power level with 200nsec pulse length. This approach eliminates the need for RF compression increasing the system efficiency. Additionally the modulator design operates at a maximum switch voltage of 50kV, greatly reducing the cost while improving the reliability and system lifetime.

Fig. 6 shows the system which uses twelve pulse forming lines in our novel switched transmission line modulator configuration. Each line is 1.5m long and 20cm diameter. Each BLT switch operates at 50kV holdoff voltage with the total charge voltage being 200kV. A Darlington section is used to isolate the load from the charging voltage canceling any prepulse. A passive tuning line is transformer coupled to the output for adjusting the pulse shape. The tuning line operates at ~10% of the load voltage reducing fabrication complexity.

One of the problem consists of very different wave resistances required for different lines. They start from 2 Ω for the first line and finish with 1 kΩ for the last line. The size of the lines is kept reasonable by using water dielectric for the low impedance lines, oil for the higher impedance lines and a delay structure within the lines to minimize the length.

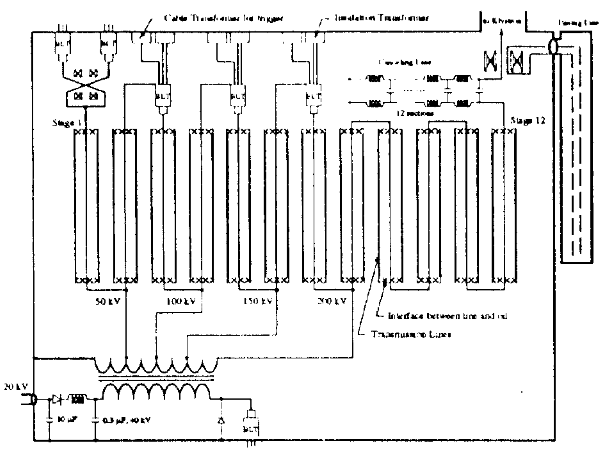

Figure 6. Modulator design to produce 1MV using 50kV switches.

Design Simulation

Computer simulation of the modulator design has been undertaken for two configurations of the pulse forming lines. Figure 7. shows the output voltage for a twelve section modulator for two cases. 1) each pulse forming line uses 12 sections, and 2) each pulse forming line uses 24 sections. In each case an optimization procedure was used to determine the inductance between lines and precise time of switching. One can see that in the case of 24 cells the rise and fall time of the pulse are shorter and the flat top longer. Since only the flat portion of the pulse is useful to RF generation the efficiency of the 24 cell system is higher. In the final design conclusion economical details must be considered.

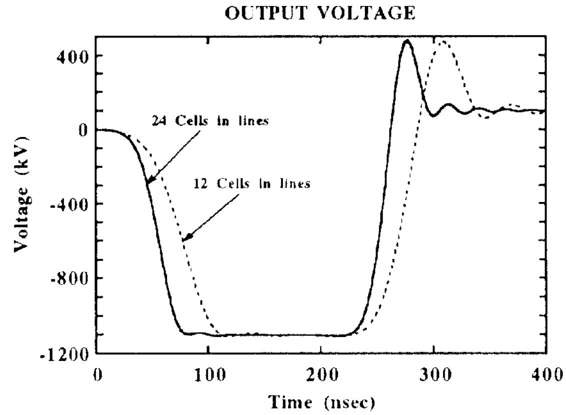

Figure 7. Computer simulated output of modulator using four 50kV switches to produce 1MV. Dashed line is for pulse forming lines consisting of 12 cells and the solid line is for lines with 24 cells.

V. CONCLUSION

In this work we have demonstrated the feasibility of producing high voltage output pulses using a transmission line transformer incorporating BLT switches between line sections. We have successfully demonstrated synchronization of two BLT switches and an output that is four times the switch voltage. Based on these results a system for producing 1MV, 1kA, 200nsec pulses has been designed and modeled by computer.

The key result is the demonstration of an innovative modulator system that could be scaled up to drive RF sources at the gigawatt power level for future accelerators. The modulator would produce high peak power with 200nsec pulse length eliminating the need for RF pulse compression. This would greatly enhance the efficiency and reduce the overall cost of RF power.

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