Max Bank: a saturating magnetic Marx generator

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Abstract: A unique method is described to make the Marx circuit usable with saturating magnetic switching. This also enables high repetition rate operation. The properties of near indestructible switching, combined with self grading voltage distribution, offer unique scalable high voltage pulser design. Additionally the leading edge is pulse compressed.

The Marx bank is one of the most elegant circuits ever devised [1]. Fig 1 shows the basic topology of a simple magnetic Marx, but the isolating resistors are replaced with inductors L, and the spark gap switchs by saturating inductors. Unfortunately this circuit is not practical, and that is why the magnetic Marx has gone un-noticed. What is the problem here? The inductors L, must be large to prevent bleed off of charge from the storage capacitors, as they shunt the C components (considering one unit cell). But the inductors L must be small to facilitate rapid charging of the transmission line formed by the LC ladder line. There is a direct contradiction here. Small L is needed to charge rapidly. Large L is needed to prevent energy wastage in bleed off , before the switches have time to saturate. Result, Fig 1 is useless. Making the charging inductor L large, intrinsically slows down the entire pulser, as there is an effective design range dictated by the charge time to rise time ratio, inherent in magnetic switching circuits.

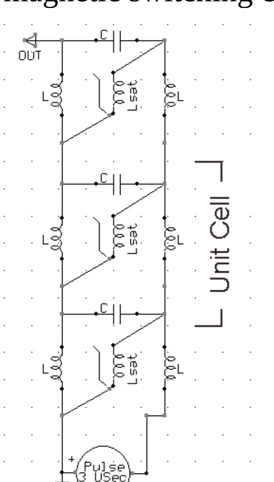

Fig1
Non-functional
Marx Bank

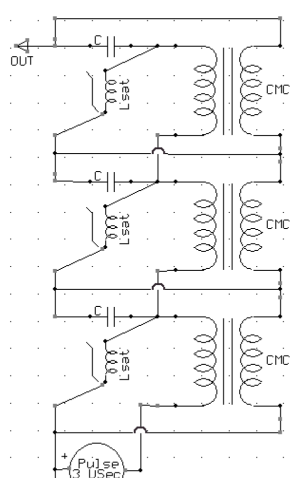

Fig 2
Max Bank
Operational

Operation of the circuit of Fig 2 is functionally quite different. Here we have combined the two charging inductors (of a unit cell) onto a single ferrite core. Additionally the wires are tightly twisted to reduce the inductance per foot, of this transmission line pair.

The pulse generator provides a 0.6 uSec pulse input to the circuit. This is produced by a thyratron trigger generator, as that was available. The pulse travels down the LC ladder line , hits the open end , and is reflected back to the pulser.
The ET product of the saturating inductors Lsat, is selected to just saturate as the reflected pulse returns to the source generator, fully charging the ladder line. That way, the entire energy of the long charging pulse is completely utilized in charging up the energy storage C array. Each inductor sees the same integrated ET of the charging pulse, and hence saturates in unison. The ET time-out triggering, greatly simplifies the circuit, compared to the regular Marx.

The transit time of the unit cell is determined by the inter-winding L of the twisted wire pair. This (CMC) common mode choke device, is a 1:1 transmission line transformer. C is of course, the energy storage capacitor as shown. This is a fast transit time, being about 0.1 uSec for the test circuit. However the shunting L which was so problematic, can be large, as it is the magnetizing inductance of the dual windings on the core. This is determined by the mu of the ferrite, wind geometry, and winding length. The shunting inductance has been separated from the design of the charge path inductance, and that is why this circuit is unique. The CMC devices serve dual roles. The simple Marx does not have this feature, and is completely unusable because of it.

Experimental results and data, are shown in Fig3. The circuit is driven by a 50 ohm, 0.6 uSec thyratron trigger driver of about 1200V amplitude. The load is 100 ohms. The oscilloscope used is a Tektronix TDS 620B of 500 MHz bandwidth. The HV probe is a Tektronix P6015A, 90 MHz bandwidth. 3X voltage gain, is shown in Fig3, as desired, for the 3 stage circuit.

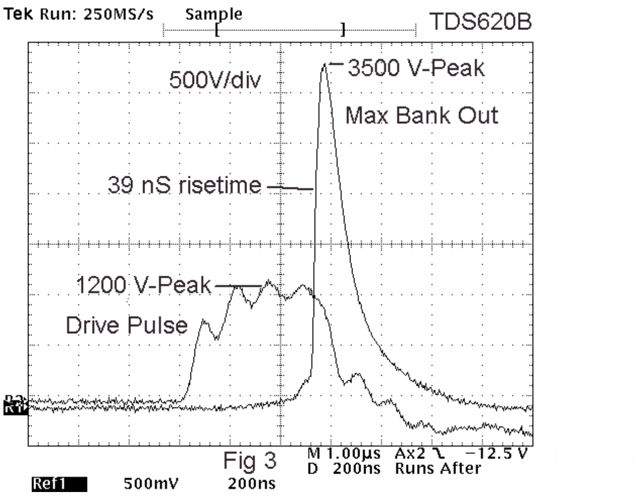

Fig 3

Risetime is 39 nSec, and is considerably pulse compressed by the saturating switches. The uniform waveform indicates the saturators are firing as desired. Material used for the saturators is CMD5005, made by Ceramic Magnetics. This is excellent compression, given the circuit simplicity. It can be improved, but it is beyond the scope of this paper.

The saturated magnetics act as a magnetic diode in the event of an arc. This helps isolate and buffer the drive generator, and reverse current flow is greatly reduced. Moreover saturated magnetic switching is the most robust, compared to all other switching methods. It is the ideal pulsed power switch.

Another key point is, no delicate silicon device is used in the HV section of the Max Bank. This makes it extremely robust intrinsically.

Rapid charging solves one of the key limitations of the Marx circuit. That is, the energy can be loaded quickly, and hence rep rate can be very high, ie many kHz.

High voltage grading, is an important feature of this device. The output voltage is uniformly distributed (graded) inside the generator. The stages can be built with much lower voltage rating parts, and wire insulation. This translates to smaller, cheaper components internally. Only the output bushing will see the total voltage, making the design much more robust.

Future use of this circuit opens a new horizon in the HV generator world. This is a simple embodiment. There are countless variants possible. One can envision bipolar designs. full bridge designs, square pulse generators, faster edge devices, 2X voltage gain stages, and so on. It is intrinsically simple and reliable. Neither will arcs harm the circuit. Triggering is simple inherently. Moreover the versatile switching is distributed and floating, not one single massive ground based switch, as is the usual practice. Jitter will be determined by the amplitude stability of the drive pulse, which can be excellent. The LV driver is best designed using ASCR technology, as it is reasonably fast, yet robust, and scalable.

As R.W. Wood once said “and thus the mystery is completely solved”.

Data Availability. The data that supports the findings of this study are available within the article.

1. Marx, Erwin (1925). "Versuche über die Prüfung von Isolatoren mit Spanningsstößen" *Elektrotechnische Zeitschrift*. 45: 652–654

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The author has no conflicts of interest.