

# SUB-NANOSECOND JITTER OPERATION OF MARX GENERATORS

J. R. Mayes, W. J. Carey, W. C. Nunnally [1], L. Altgilbers [2]

Applied Physical Electronics, L.C.  
Austin, Texas 78734

## Abstract

Low energy, high peak power Marx generators are finding applications in Ultra Wideband radar and high power microwave systems. In many cases, these systems require very precise control over the delivery of the pulse from the generator. For example, unique systems might be used for bi-static radar, and excessive temporal jitter between the generators may add ambiguity to the measurement. A 17 stage Marx generator was fabricated to study techniques for reducing the jitter in a multi-spark gap system. This paper presents the results of a jitter study.

## I. INTRODUCTION

Multi-pulse radar systems, as well as synchronization between individual pulse systems require low temporal jitter between the delivered pulses. For example, phased array systems require very low jitter for beam steering. Furthermore, if the phased array system were to be used for pulse-coding, excessive jitter might result in signal ambiguity.

Marx generators offer extremely high voltage pulses, and with proper design, may deliver extremely short duration pulses, making them excellent candidates for UWB radar and electronic warfare systems. However, if these generators are to be used in multiple generator-configurations, the temporal jitter of a delivered pulse must be reduced to a small percentage of the pulse width.

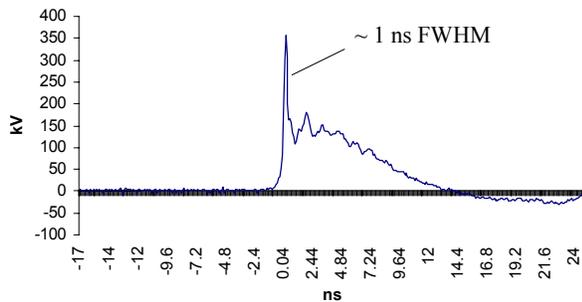


Figure 1. A typical APELC Marx generator output pulse

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Applied Physical Electronics, L.C. has successfully developed Marx generators with impulses well suited for UWB applications [3]. As shown in Figure 1, the pulse is several nanoseconds in width; however, the initial impulse has a full width-half maximum of 1 ns. This initial portion of the generator's pulse is launch by the antenna, so a temporal jitter of less than 200 ps is desired. This paper discusses the methodology and practice for achieving low jitter operation of the Marx generator [4,5].

## II. BACKGROUND

### A. The Wave Erection Marx Generator

The most efficient, compact and economical method of generating a repetitive, large magnitude, electromagnetic impulse is the wave erection of a spark gap-switched Marx circuit. Wave erection is necessary to obtain the fast voltage risetimes from the Marx circuit that generates the ultra-wideband of frequencies necessary for high resolution radar or the interdiction of flight controls and computer memories for electronic warfare.

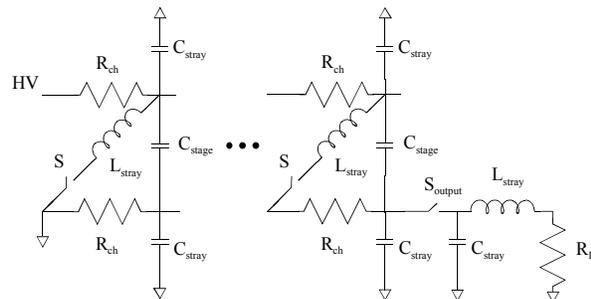


Figure 2. The Wave-Erection Marx Generator.

The conventional Marx circuit, illustrated in Figure 2, charges capacitors in parallel through resistors, and then switches the capacitors, using spark gap switches, in series to add the individual capacitor voltages at the output terminals. This approach multiplies the charge voltage by the number of stages to yield a large output voltage. Proper design of the stray capacitance and the inter-stage capacitance, in concert with coupling the spark gaps via ultra-violet energy, results in a sub-ns risetime for output voltages of several hundred kV at moderate per pulse energies.

### B. Spark Gap Triggering

There are three basic triggered spark gap types including the trigatron, the laser-triggered, and the field distortion [6]. The trigatron gap of Figure 3 (a) is a three electrode gap with the voltage held off between the anode and cathode. The third electrode, or the trigger pin, is placed within the cathode electrode such that initial closure of the spark gap begins with a breakdown between the trigger pin and the cathode. This initial breakdown generates a plasma in the high field region between the anode and cathode and ultimately leads to the breakdown of the main gap. These systems are very easily fabricated and simply require a high voltage pulse for triggering. Unfortunately, these systems result in high jitter values due to the fact that two breakdown events are required for switch closure.

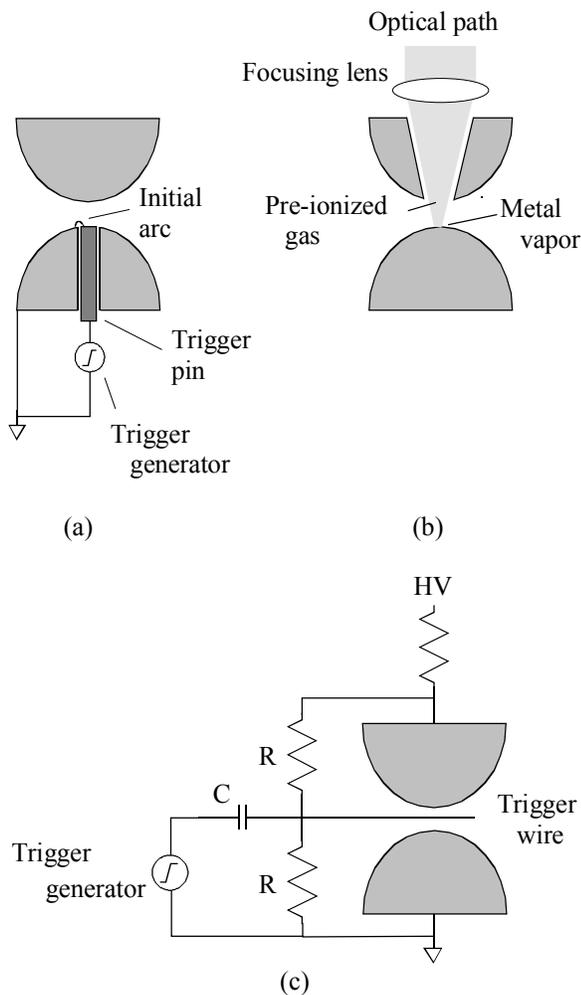


Figure 3. Trigger spark gap types, (a) the trigatron gap, (b) the laser triggered gap, and (c) the field distortion gap.

The laser-triggered spark gap of Figure 3 (b) relies on optical energy to vaporize a portion of the metal electrode. The hot metal vapor emits ultraviolet energy, which then produces free electrons at the electrode surface. Furthermore, the laser also preionizes the path back to the

opposite electrode. The electric field then heats the streamer to reduce the resistance and leads to closure of the spark gap. These systems are more difficult to fabricate and require large pulsed laser systems for triggering. However, the lowest spark gap jitter recorded came from a laser-triggered spark gap and resulted in a jitter of 50 ps.

The third spark gap triggering method, the field distortion gap, is shown in Figure 3 (c). In this configuration, a dc-biased pin is placed between the anode and cathode such that the electric field is not disturbed. Gap closure is initiated when a negative pulse is delivered to the trigger pin and results in a highly distorted electric field between the main electrodes. The field distortion spark gap is ideal for low jitter applications, since the two breakdown events occur simultaneously.

### C. Gas Breakdown

The closure of a spark gap is a statistical process. However, the breakdown process is sequential. Consider the illustration shown in Figure 4 in which the spark gap voltage is set just below the statistical breakdown level,  $V_{SB}$ . The time for breakdown process to occur is dependent on four events: (1) the statistical time delay for the appearance of a free electron,  $t_{sd}$ , which may be reduced to zero with the application of a UV source; (2) the streamer formation time,  $t_{sf}$ , which is inversely proportion to the electric field; (3) the channel heating time,  $t_{ch}$ , which is also inversely proportional to the electric field; and (4), the trigger pulse risetime,  $t_r$ .

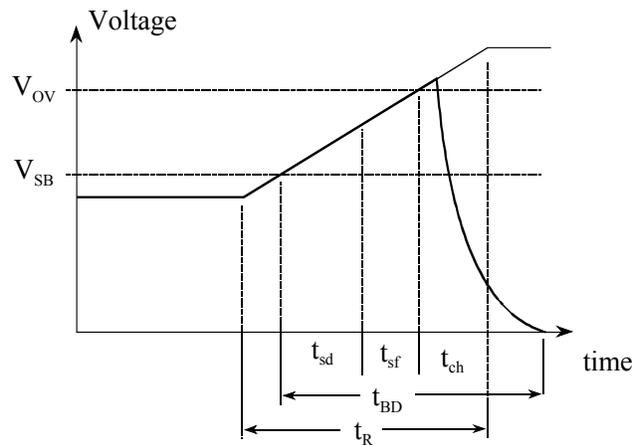


Figure 4. The gas breakdown process.

Reduction in jitter for the field distortion gap is primarily dependent on three parameters, UV illumination, a fast-rising trigger pulse (10 kV/ns), and a trigger voltage approximately equal in magnitude to the charging voltage. Achieving a spark gap jitter of less than 200 ps will require an extremely fast trigger source.

### III. TRIGGERING THE FIELD DISTORTION SPARK GAP

The proposed method for triggering the field distortion spark gap involves replacing the DC blocking capacitor shown in Figure 2 (c) with a short coaxial line, as illustrated in Figure 5. This coaxial line, referred to as the trigger line, is DC biased to  $\frac{1}{2}$  the charging voltage of the spark gap. Note that the trigger switch must hold off the DC bias voltage.

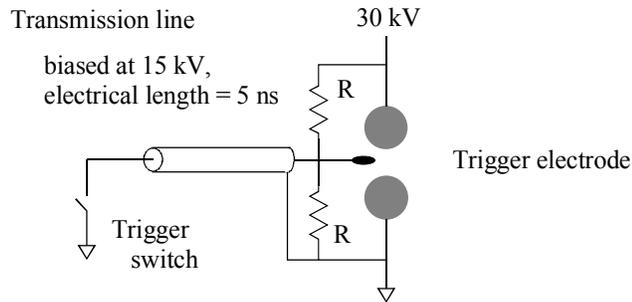


Figure 5. Initial state of the field distortion spark gap.

Upon closure of the trigger switch, a reflected pulse of  $\frac{1}{2}$  the spark gap charge voltage and of a length that is twice that of the charged transmission line propagates toward the spark gap, as shown in Figure 6. Arriving at the end of the trigger pin, the pulse doubles in magnitude, resulting in a potential of minus one-half the charge voltage. This results in a highly distorted field between the electrodes due to the presence of the small pin at the negative potential.

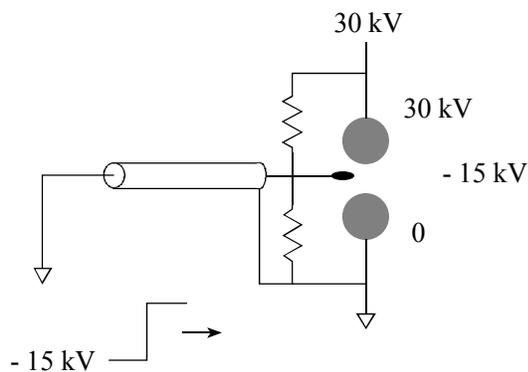


Figure 6. Triggering of the field distortion spark gap.

### IV. EXPERIMENTAL ARRANGEMENT

Gas switches, krytrons and thyatrons, offer a mature technology for triggering the Marx generator. Although these devices offer high voltage and high current capabilities, they are inherently high in jitter (several ns) and are typically slow devices, with risetimes ranging

from a few ns to 10's of ns. As shown in Figure 7, a krytron stack is used to trigger the Marx generator. This design is fabricated for extremely low inductance, resulting in a closure time of 1.5 ns.

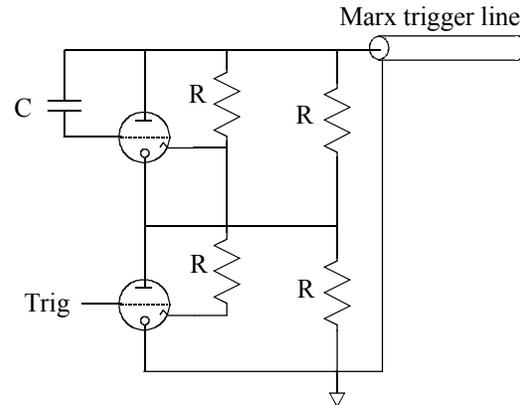


Figure 7. Marx generator trigger circuit.

A seventeen stage Marx generator was fabricated to determine the feasibility of decreasing the temporal jitter to an acceptable level required for phased array systems. The Marx was designed to deliver a voltage pulse of 360 kV. The generator was resistively charged with a 30 kV power supply, and was fitted with a field distortion trigger gap, as described in Figure 5. The output of the Marx was connected to a long section of RG-220 coaxial cable that was fitted with an uncalibrated capacitive voltage divider. A second capacitive voltage divider was placed on the trigger line, just outside the generator.

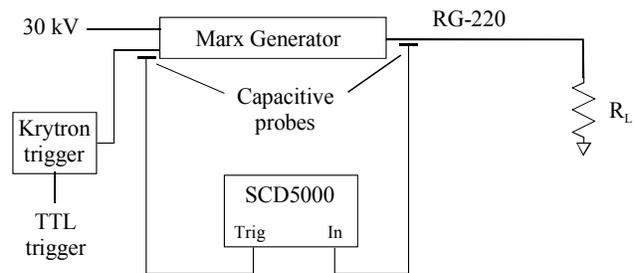


Figure 8. Experimental arrangement.

As shown in Figure 8, measurements of the Marx generator are limited the generator itself. The capacitive probe on the trigger line simply acts as a trigger signal for the SCD5000, while the output capacitive probe monitors the generator's output. In this manner, the temporal response of the generator was isolated from the trigger system.

### V. EXPERIMENTAL RESULTS

The jitter associated with the Marx generator is determined using the arrangement discussed in the

previous section. Approximately 20 random samples are taken for each measurement. Each group of waveforms is then plotted in a single Excel chart. Time crossing points are then found and the jitter is calculated as the standard deviation between these points. Three sets of measurements were made, each having a unique trigger cable length. In this manner, the effects of dispersion may be seen.

The samples of the Figure 9 result from a trigger line with a length of 5 ns. The spread of the waveforms was 540 ps, with a standard deviation of 114 ps. The trigger line between the generator and the krytron trigger circuit was increased to a 30 ns electrical length. The resulting set of waveforms, shown in Figure 10 show an increase in rms jitter, approximately 196 ps, and a spread of 620 ps. Finally, the trigger line length was increased to 60 ns. Figure 11 reveals the sample waveforms. The spread was approximately 1.18 ns, with a jitter of 285 ps. The effects of dispersion become obvious from these measurements.

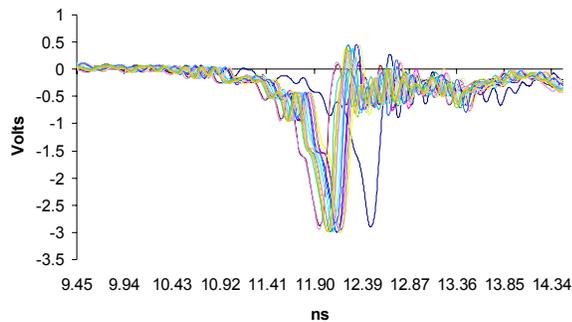


Figure 9. Output samples with a 5 ns trigger line.

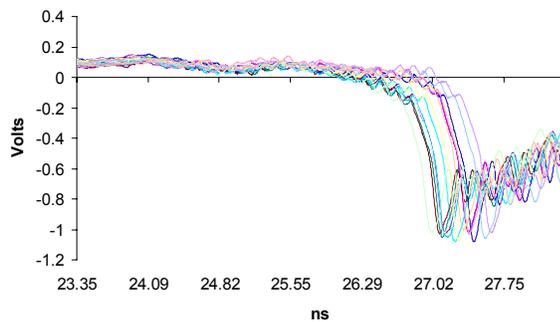


Figure 10. Output samples with a 30 ns trigger line.

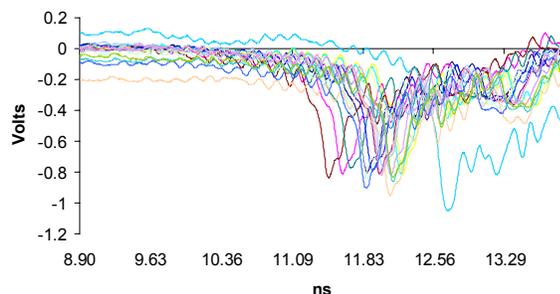


Figure 11. Output samples with a 60 ns trigger line.

## VI. CONCLUSION

This paper presented the results for the low jitter operation of a 17-stage Marx generator. Several trigger methods were explored. The field distortion method was chosen based on cost and performance. A temporal jitter of 114 ps was achieved for short trigger lines; However, as the length of the trigger line was increased, the temporal jitter increased as well, illustrating the effects of pulse dispersion.

The promise of the low temporal jitter operation of the Marx generator is offset by the fact that there is currently no trigger switch available that meets the specifications necessary to reduce the jitter of the entire system. Had the jitter results included the trigger switch, the jitter would have increased from 114 ps to several ns.

Future efforts will work toward the development of a trigger system well suited for this application.

## VII. REFERENCES

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