A COMPACT SQUARE WAVEFORM 15 kJ GENERATOR: 15 ns RISETIME, 7.5 Ω LOAD IMPEDANCE AND 100-500 ns PULSE WIDTH

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Abstract

This paper describes a compact six stage-Marx generator intended to provide the power conditioning for advanced radio frequency (RF) and high-power microwave sources.

The generator specifications, which made this system unique, called for relatively high output pulses of energy of 15 kJ across the load impedance of 7.5 Ω. The charging voltage is organized to vary from 25 to 100 kV. With the matching (dummy) load of 7.5 Ω used, the maximum output voltage should be 300 kV, the maximum output current 40 kA and the peak power 12 GW. Without application of the crowbar switch, the pulse width is 0.82 μs. A 10 to 90% rise time of about 20 ns was obtained by recording the voltage across the load with a resistive voltage divider probe. When the pulse is observed with a capacitive probe, the rise time falls closer to the value of 10 ns.

Three examples of the application of the system to achieve a powerful RF source are given.

I. INTRODUCTION

Since a large number of experiments were planned, the project was divided into the following three phases: (1) the system is exposed to atmospheric air up to the applied charging voltage of 30 kV, (2) SF6 gas is introduced to suppress the onset of the corona for the voltage range of 30-50 kV, and (3) oil will be placed in the enclosure for the voltage range 50-100 kV. The idea is to have a compact and lightweight generator that would have enhanced transportability.

The present paper deals with the first phase of the project. The current system also serves as a prototype for the next generation of the high current, square waveform Marx generators.

For the next phase of the project, it was planned to replace the existing resistive charging with an appropriate inductive charging network, to achieve the system operation in burst mode with high repetition frequency. Our goal is to find a new approach in producing an economically affordable system that would be versatile, with characteristics similar to those accomplished for use in the Army high-power test facility developed by Ramrus *et al*, 1992 of Maxwell Laboratories.

II. MODELING

The design concept is formulated using PSpice simulation, by applying the concept of the pulsed-forming networks. The goal is to achieve a low (~1 Ω) impedance per single stage. The schematic of the system is given in Figure 1. As a result of financial considerations, it was taken that the capacitance per stage should be 0.5 μF and would contain three capacitors of the S-type made by Maxwell Laboratories.

In Figure 1 the storage capacitors C_1 and C_2 are organized in such a way that the capacitor C_2 determines the leading edge of the pulse, and two added capacitors, marked by the same symbol C_1, contribute to the width of the pulse and the internal impedance of the stage. Here, C_g is the stray capacitance of the spark gap with respect to the ground.

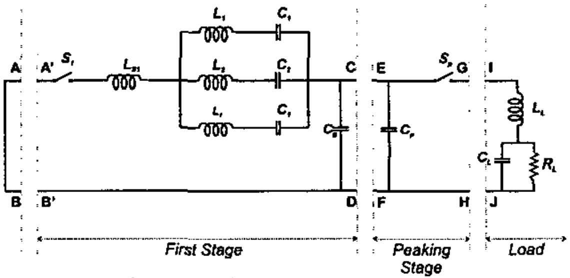

Figure 1. Schematic of the generator.

To get the desired width of the pulse, L_1 became a variable quantity. The values of L_{S1} and L_2 are predetermined by the position of the connecting leads in respect to the ground. If L_2 and L_{S1} are to be decreased, the ground plate cannot be flat, but rather segmented, to follow the contours of the leads that are joining the spark gaps with condensers.

In Figure 1 the simulation of the first stage is obtained by connecting the point A with A', B with B', C with I, and D with J. The charging voltage of 1 V is applied to each storage condenser. The result of the simulation is given in Figure 2, top. We see that the pulse has relatively smooth top with the rise-time of the order of 100 ns.

The first stage was repeated five times and introduced between the points C and E, and the points D and F to obtain the six-stage assembly. The results of PSpice analysis are shown in Figure 2, bottom. These data were sufficiently encouraging to warrant the experimental

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work. The simulation results were well confirmed by the experiments.

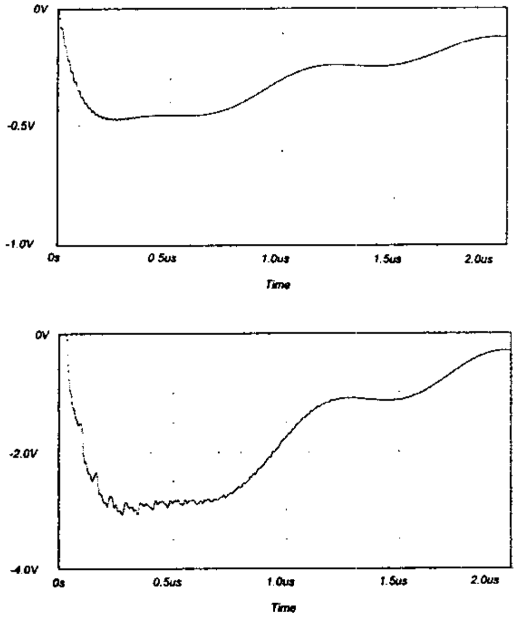

Figure 2. PSpice simulation.

Top: Characteristics of the single stage are C_1=0.15 μF, C_2=0.20 μF, C_g=100 pF, L_{S1}=150 nH, L_{C1}=150 nH, and L_{C2}=250 nH, and of the load: C_L=40 pF, L_L=100 nH and R_L=1.5 Ω.

Bottom: Characteristics of each stage in the six stage assembly remain the same. The dummy load characteristics are changed to accommodate the application of larger voltage. Load characteristics are C_L =140 pF, L_L =500 nH and R_L=7.5 Ω. The stages are initiated in a sequential manner in the time interval of 5 ns.

To improve the rise time, it is necessary to add the peaking stage. Following the methods of earlier work (Kekez, 1997) it is imperative to ensure that the inductance of the peaking spark gap S_p is as small as possible and that the value of the peaking capacitor is sufficiently large (more than 2 nF). With some effort this was achieved.

A customary way of controlling the fall time and the width of the pulse was adopted in the system by the use of the crowbar switch.

III. GENERATOR DESCRIPTION

The top view of the generator is shown in Figure 3. Triggering of the switches is done by a Mini-Marx (developed by Kekez, 1992) which produces about 200 kV trigger pulses. The Mini-Marx can be seen in Figure 1 (top left corner of the photograph) and is placed next to a large charging barrel. The system uses the rail gap plasma switches that are mid-plane triggered and are capable of handling large charge (Coulomb) transfer, without any noticeable electrode erosion after many thousands shots. The rail gaps use UV radiation in order to meet the low jitter requirements. The jitter associated with the erection of the remaining Marx stages is minimized by resistively coupling the trigger pulse to the remaining switches, as was proposed by Jaitly *et al,* 1991. The value of these trigger resistors per stage is 10 kΩ.

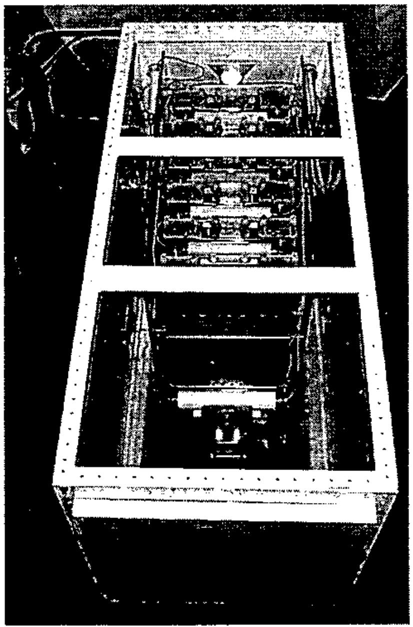

Figure 3. Photograph of the generator as seen from the top while being assembled.

IV. EXPERIMENTAL RESULTS

The development of the system according to PSpice simulation, progressed in a straightforward manner. To prevent voltage reversals in the storage capacitance, it is necessary to design an appropriate compact high-energy resistor with corona rings to avoid surface discharge across the resistor assembly. The resistor has three components (manufactured by Allen Bradley UK. Inc.), where each component is 11.4 cm in diameter, 5 cm tall and has 2.5 Ω.

The connection from the Marx generator to the resistor assembly follows the idea put forward in the design of the extended header of the Maxwell Type C model 32503-1 heavy duty capacitors to provide sufficient voltage stand-off. When the voltage exceeds 100 kV, corona discharge will take place in air leading to the tracking discharges along the surface. If the part of this header (bushing) is not sufficiently long, the surface spark discharges will cover the entire area of the surface, and in the process, crowbaring the output pulse. By varying the length of the tracking, many experiments are done. To produce the pulse of the expected width, good (air-free) adhesions amongst dielectric components are required.

The results of the measurement of the current waveform through the resistor assembly are given in Figure 4. To apply higher charging voltage to the system, the conventional crowbar switch will be added. The goal is to have the possibility of the pulses from 100 to 500 ns in width at the top level of the Marx specifications.

To broaden our knowledge in radio frequency (RF) generation, the current system was used. The results are given in Figure 5. With minor adjustments of the RF source, the radiation pulse became longer (more than 600 ns), but the radiated power was reduced. See Figures 6 and 7. It could be useful to note that encouraging data of the RF radiation emitted above 0.1 GHz were also obtained. The shape of the (RF) power was also estimated by multiplying a signal waveform by itself.

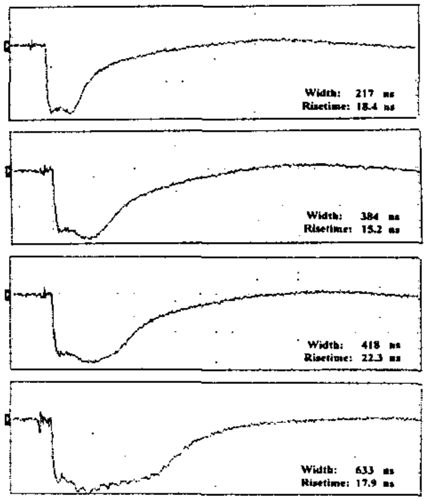

Figure 4. Experimental data of the current waveform (5 kA/div., 200 ns) obtained with a dummy load of 7.5 Ω and the charging voltage per stage of 25 kV.

V. CONCLUSIONS

A compact low (7.5 Ω) impedance generator capable of delivering high quality pulses has been successfully designed, built and tested. During the development and testing in the atmospheric air, important data related to the surface flashover across the dielectric are obtained. The flashovers are currently employed to act as the crowbar switch. When the system is oil insulated, an electronically controlled switch will be added to the system.

This generator offers the opportunity to examine new concepts in the generation of high-power radio frequency and microwaves. The experimental data should also yield information on the limits of the concept under study. The phenomena known by the generic name "pulse shortening" could be investigated.

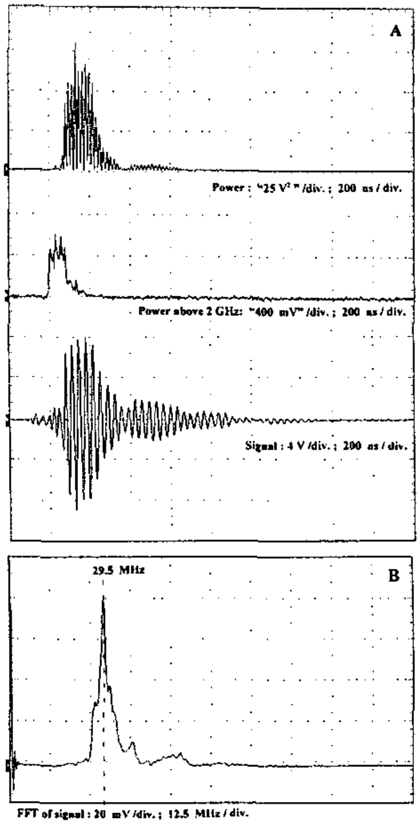

Figure 5. Application of the six stage generator to produce a RF emission.

A signal was measured with one arm of 10 GHz D-dot probe made by Prodyne Inc. The other arm of the probe was terminated by 50 Ω resistors. Theory suggests that the electric field, E_o obtained with this probe, is E_o (V/m) = (1.789 V_o (mV))/(f (GHz)). For the first 150 ns, the average amplitude of RF signal is $V_o = 7.5$ Volts. For the frequency, f of 0.0295 GHz given in frame B, we get E_o=0.454 MV/m and the power density, $E_o^2/(2*120\pi)$ of 27.34 kW/cm^2.

Limited amount of experimental data suggests that RF source has a quasi cylindrical pattern of radiation. The length of the RF source, l is 0.35 m. For the probe placed 2.10 m away from the RF source, we have that for the area of the cylinder is $2\pi*l*r=2\pi*0.35*2.10 = 4.62$ m^2. Therefore, the power of RF source is 1.26 GW. For the duration of the main portion of the pulse of 150 ns, the energy of the pulse is 189 J. Emissions above 2 GHz were recorded with 2 GHz horn, and HP detector 8474B. Horn was placed about 2 m away from a source. These microwave emissions do not contribute substantially to the energy content of the total radiation measured. (RF) power means multiplying the signal by itself. The Marx generator was charged at 32 kV/stage and had stored $6(32*10^3)^2(0.5*10^{-6})/2 =$ 1.54 kJ.

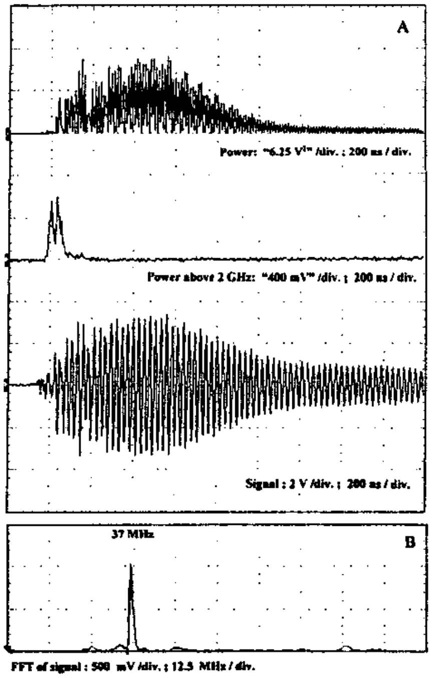

Figure 6. Conditions as in Figure 5, except that the charging voltage was reduced to 29 kV per stage. (RF) power of "4 V^2"/div. means that the oscilloscope was set to read the signal of 2 V/div. The signal was supplied by 10 GHz D-dot probe.

VI. REFERENCES

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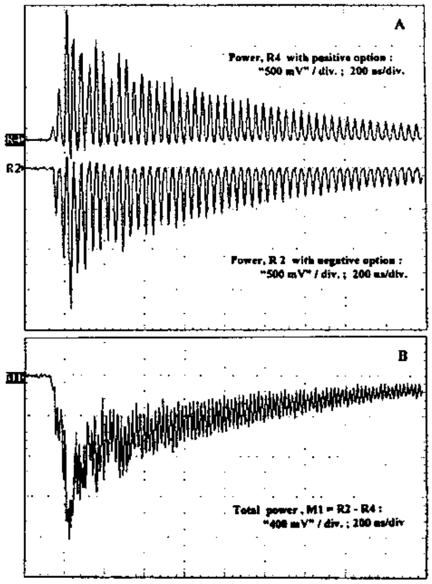

Figure 7. Experimental conditions similar to that in Figure 5 except that the charging voltage per stage was set to 25 kV. Power R_4 was recorded with one arm of 10 GHz D-dot probe which was then attached to HP detector, type 423B of positive option. Power R_2 was obtained with the other arm of the probe which was then connected to HP detector, type 423B of negative option. Total power is $M_1 = R_2 - R_4$. Power of "500 mV"/div means that the oscilloscope is set to 500 mV/div. The signals are supplied by HP detectors, type 423B with positive and negative option.