A DIRECT APPROACH TO RF/HPM GENERATION WITH REGARDS TO MCG

M. M. Kekez*

High-Energy Frequency Tesla Inc., (HEFTI), 1200 Montreal Road, NRC-Site, Building M-51, Ottawa, Ont., Canada, K1A 0R6

Abstract

Computer simulations and experimental studies were carried out. The results show that conventional Marx generators can produce powerful RF/HPM emissions. It is shown that the model herewith proposed is related to the operation of MCG as the RF/HPM device.

The RF/HPM radiation can also be produced by a simple oscillatory circuit containing a switch and operating in air. Here, the applied voltage has a Gaussian shape, as observed in our experiments on energy compression [1]. In addition to generating a wideband RF/HPM spectrum, our systems can be made to radiate mainly at discrete frequencies in this range.

I. RF/HPM EMISSIONS WITH MARX GENERATOR

The main reason for RF/HPM emissions is the consequential erection of the stages in the Marx generator. This means that, in regards to the first stage, the second stage is erected after the time interval of t_o, the third stage after the time interval of $2t_o$ and so on. For a given gas composition, pressure used, the numerical value of t_o can be obtained using a streak camera.

For simplicity, let us consider the circuit in Figure 1. The values of parameters used are typical for the family of Mini Marx generators [2] developed in the laboratory. Here, the inductance of the stage, L is 45 nH, the stray capacitance of the switch in respect to the ground, C is 10 pF and t_o = 1.053 ns. The 2 nF capacitors are charged to -50 kV. For simulation, ideal ON-OFF switches were introduced in Figure 1.

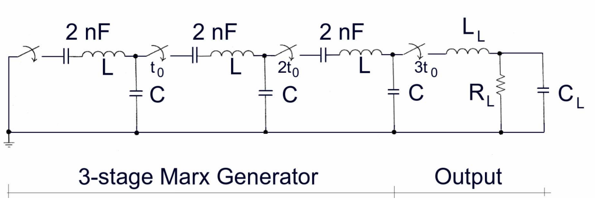

Figure 1. Equivalent circuit of a 3-stage Marx generator.

When the load of the generator is assumed to be purely resistive, with R_L of 67 , (L_L = 0 and C_L is removed from the computer simulation), the usual double exponential waveform is obtained. See Figure 2.

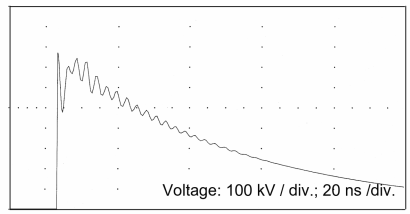

Figure 2. Output voltage waveform of 3-stage Marx generator. The load of the generator is R_L = 67 .

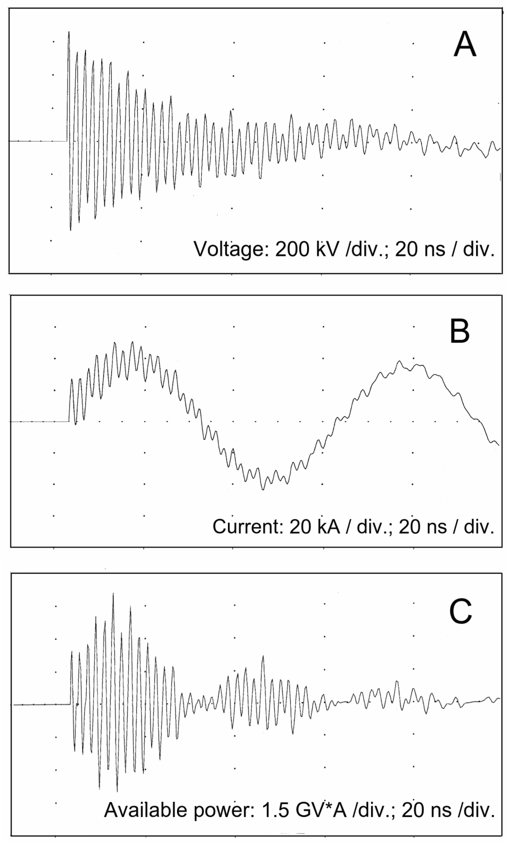

Figure 3. A: Output voltage. B: Current through L_L of Figure 2 and C is the available power, defined as the product of voltage and current. The generator is now short-circuited.

* email: mkekez@magma.ca / web: http://hefti.kekez.ca/

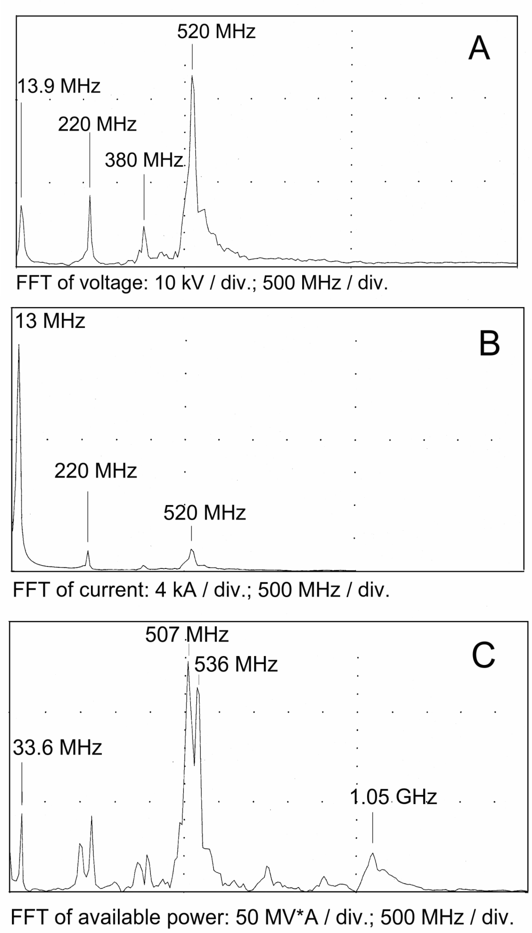

Figure 4. FFT of the waveforms given in Figure 3.

Let us now consider the Marx generator of Figure 1, when it is short-circuited by a lead. This lead can be considered as a loop antenna having $L_L = 10$ nH, $C_L = 10$ pF and $R_L = 0.4$. Under these conditions the computer results are given in Figures 3 and 4.

Using 10-stage Mini Marx generator, both the RF pulse and HPM pulse were recorded by the single turn loop of 1.89 cm in diameter. The loop is placed in the standing-wave cavity, in which a large-scale (30 × 30 cm) printed circuit boards can be placed.

In Figure 4, Frame C, the main frequency of the available power has two peaks: 520 MHz and 560 MHz. We find that the experimental data of RF emissions also shows two peaks. Both, the computer simulation and experimental data show that the amplitude of the first peek at lower frequency amplitude is higher than the amplitude of the second peak.

To get a "clean" signal, a low-pass filter of 560 MHz was used. The experimental results are given in Figure 5. The signal in Figure 5, is related to the main frequency of the available power shown in Figure 3, Frame C.

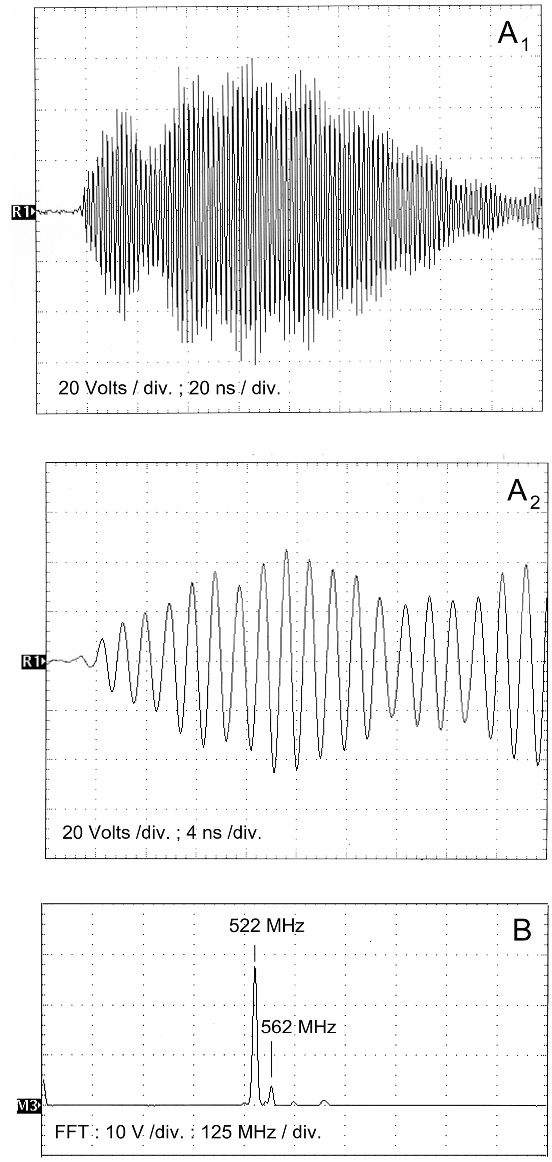

Figure 5. Experimental data of RF signal obtained with 10-stage Mini Marx generator charged at 33 kV/stage.

The signal recorded with the loop probe reaches the amplitude of 60 V. Hence, the electric field exceeds 20 kV/m at frequency of 522 MHz

If the standing wave cavity is tuned to the harmonics of available power at 1.05 GHz, fields of higher amplitude were obtained. The experimental data is given in Figure 6. The electric field reaches the value of 75 kV/m at 1.19 GHz. 10-stage-Mini-Marx generator is charged to 33 kV/stage and the energy stored in the generator is 11 joules. The power is estimated to be 1 MW, and the RF/HPM emission' pulse is able to ignite the fluorescent lamps (F4T5WW).

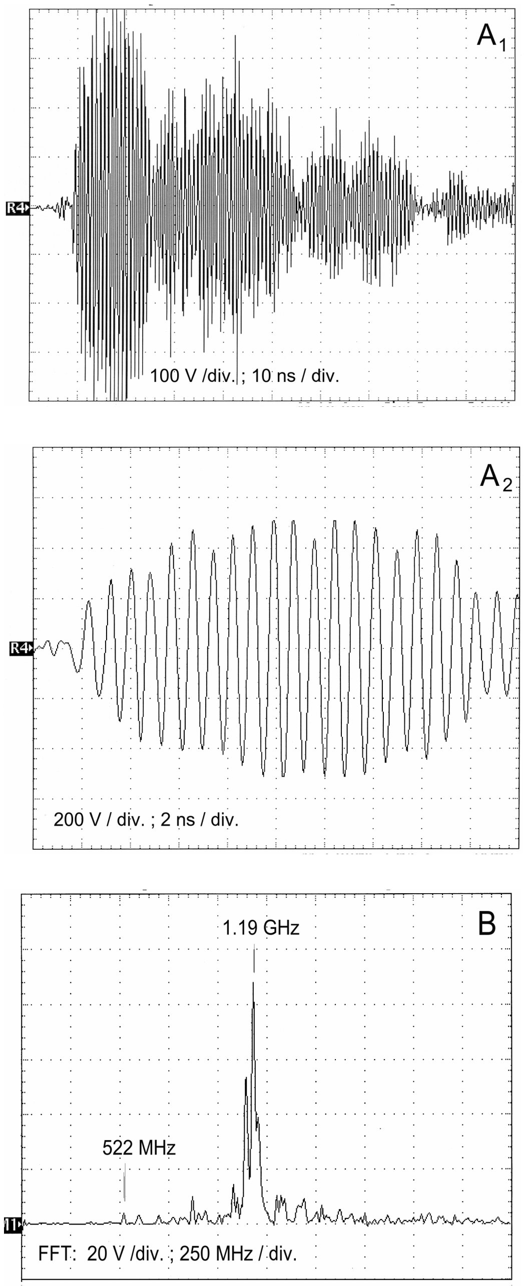

Figure 6. Conditions as in Figure 5, but the standing-wave cavity is "tuned" to the frequency towards 1 GHz.

II. RF/HPM EMISSIONS IN REGARDS TO THE OPERATION OF MCG AS THE RF/HPM DEVICE

Experimentally, it was observed that consequent breakdown also takes place between the turns of a helical coil when a large voltage impulse is applied to the coil.

To measure t_o, the coil is wound on the plexiglass tube of 76.2 mm diameter. The spacing between the turns of the coil is 3 mm. The coil is covered with fibre-epoxy coating. To facilitate the breakdown at voltages from 100 to 300 kV, the thickness of the fibre-epoxy coating was removed along a single line in the longitudinal direction of the coil. The copper tube is inserted inside the plexiglass tube, and we get the typical MCG geometry. We have short-circuited the copper tube to coil on one side, and applied the voltage impulse on the other side.

The experimental results are given in Figure 7. When t_o is plotted against the applied voltage, a smooth curve was obtained. We obtain that t_o varies from 2 ns to 0.5 ns when the voltage applied changes from 100 to 300 kV.

The streak record given in Figure 7 is indistinguishable from the streak records obtained when the erection of the stages in the Marx generator is observed. The slope in the streak record can be measured accurately in both cases. The only difference is that in Figure 7 the camera sees 48 light sources, and in the study of 10-stage Marx generator, the camera sees 10 light sources.

Figure 7 suggests that one of the mechanisms for the RF/HPM emissions in the MCG is due to the spark breakdown occurring between the turns of the coil in consequent manner.

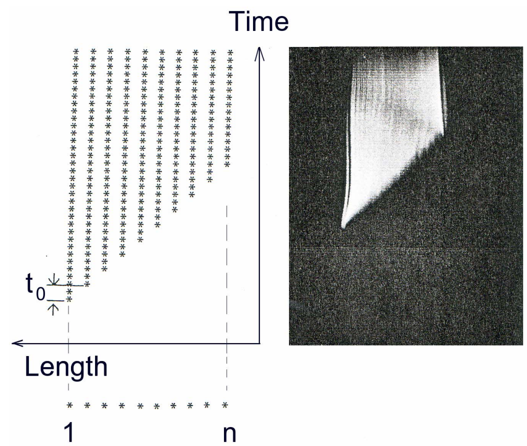

Figure 7. Right: Streak photograph of the spark breakdown between the turns of the coil. The coil used has 49 turns. As indicated in the schematic on the left, the image converter camera sees $n = 48$ light sources (i.e. spark channels) that are activated in a consequent manner with the time interval t_o.

III. RF/HPM EMISSIONS ARISING FROM THE OSCILLATORY CIRCUIT AND THE SWITCH

In the experiments on energy compression [1], it was observed that the voltage produced by an exploding wire has the shape of a Gaussian function with a rise-time of 40-50 ns, a width of about 100 ns and an amplitude up to 700 kV.

To re-examine the results of this energy compression experiment, a slow 30-stage inductively charged Marx

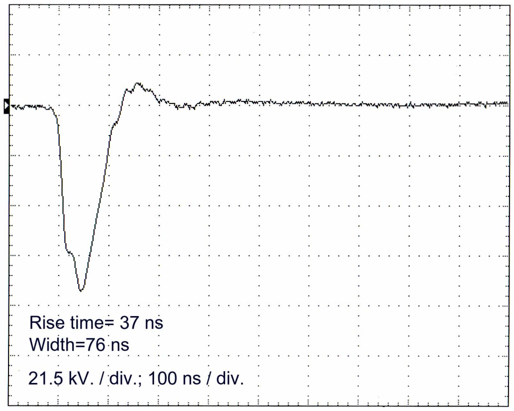

Figure 8. Experimental data of the voltage obtained with 30-stage Marx generator. The Marx generator is charged at 7.7 kV/stage. The load of the generator is 50 .

generator (without peaking stage) was used. The waveform of the output pulse is given in Figure 8.

The oscillatory circuit and the switch used in [1] are now attached to the output of the generator (i.e. the circuit with the switch are replacing the 50   resistor).

The current waveform through this circuit and its FFT is given in Figure 9. The radiation output measured with the single-turn loop of 1.89 cm in diameter is shown in Figure 10. An oscilloscope of 3 GHz bandwidth was used. The value of the charging voltage remains the same in Figures 9 and 10 as in Figure 8.

In Figure 10, the individual peak in HPM emissions can be tentatively evaluated by considering the geometry of the switch and noting the capacitance between the electrodes, C of the switch. The formation of the spark channel goes through the following phases: the glow-like phase, the developing spark channel, the return stroke, and the hydrodynamic expansion of the channel [3]. During these phases, we can estimate the average value of the inductance of the discharge, L for each phase of the channel development. From the values of L and C, the frequencies can be calculated for the range from 1.11 GHz to 2.61 GHz.

However, this simple approach may not be the whole answer. Therefore, additional experiments were done. We tuned the system to radiate mainly at lower frequencies (from 0.6 GHz to 0.9 GHz) and caused the electric field to exceed the value of 200 kV/m on the target consisting of hundreds of neon bulbs. The RF data is fairly reproducible, but the brightness arising from the neon bulbs' activation varies from shot to shot. In this experiment, the 30-stage Marx generator was charged to 18 kV/stage with the 89 J of energy stored in the system

These experiments indicate that additional powerful frequencies above 3 GHz are generated and the physical processes inside the channel have to be considered to describe the data.

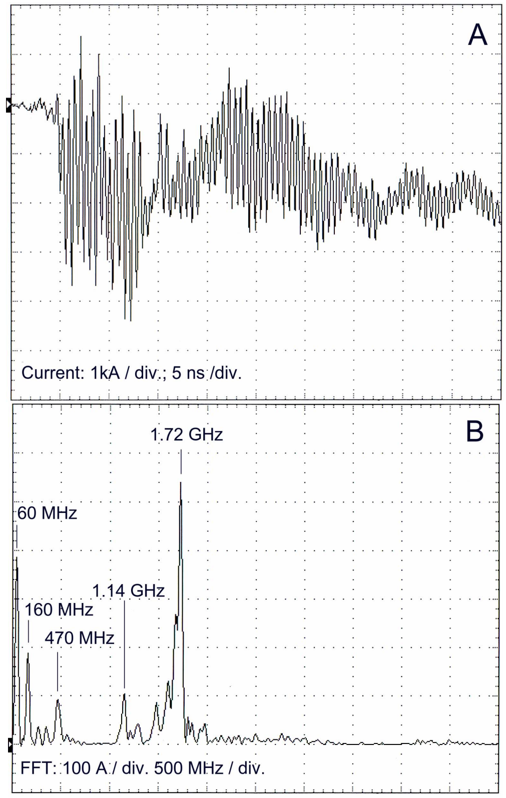

Figure 9. A: Current measured with a shunt of limited bandwidth. B: FFT of current.

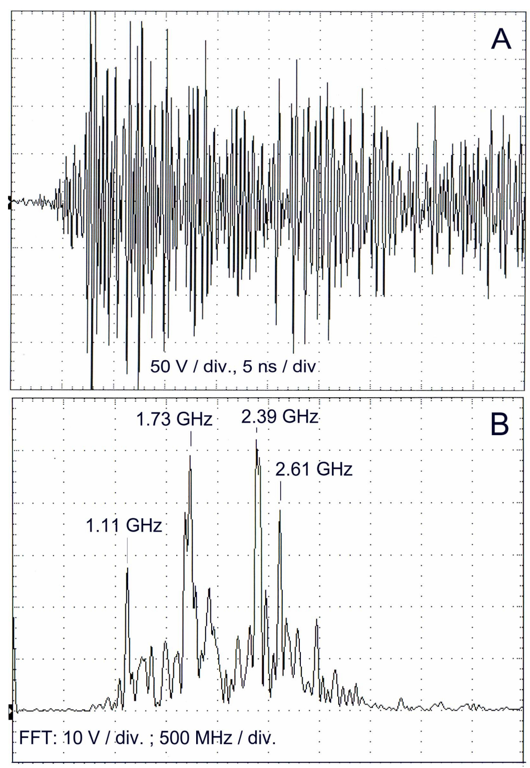

Figure 10. A: Experiment of data of signal.
B: FFT of signal.

IV. CONCLUSIONS

In this work we offer an alternative method to generate the powerful RF/HPM pulse in comparison to the idea presented by [4], where the impulse like waveform of very short (100 ps) rise time generates the frequencies from 0.02 to 2 GHz.

For the given electrically driven RF/HPM system, the RF/HPM signal rises approximately in linear fashion with the applied voltage per stage of the Marx generator and (when different generators are used) it is inversely proportional to the internal impedance of the generator.

With the method of direct energy conversion, we may suggest that the MCG with energy compression [1] is still the best candidate to obtain a powerful RF/HPM source. This is because the MCG with energy compression stage has lower impedance in comparison to any electrically driven system.

V. REFERENCES

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