The Direct Generation High Power Microwaves With Compact Marx Generators

J. R. Mayes, W. J. Carey
Applied Physical Electronics, L.C.
Austin, Texas 78734

Abstract

High Power Microwave energy may be directly generated with ultra-fast voltage pulses driving an antenna. Recent efforts with the wave erection Marx generator has seen the production of voltage pulses in excess of several hundred kV, with rise times as fast as 200 ps. This generator has been used to source Ultra Wideband antennas as well as Narrow Band antennas, each resulting in high electric field strengths. This paper describes the Marx generator and explores its use for generating UWB and NB energy. Experimental results will be presented.

I. INTRODUCTION

Recent work with compact Marx generators is moving this technology from the traditional energy storage, pulse charging supply to a direct microwave generation device. With voltage pulse risetimes decreasing down into the hundreds of picoseconds and peak powers reaching several gigawatts, these compact generators are finding their niche.

The compactness of the Marx generator, coupled with low energy, and the ability to be powered by battery technology furthers its appeal. With volumes of less than 5 x 10^{-3} m^3 for a 500 kV pulse, this impulse source becomes a viable handheld source for both commercial and military applications.

Possibly the limiting factor in making the Marx generator a man-portable system lies in the antenna. Impulse antennas, with any respectable amount of gain and directivity are typically large and cumbersome.

This paper makes a preliminary discussion of several impulse antennas as they relate to the Marx generator and its possible applications. Initial designs, including TEM horns, spirals, and monopole antennas are discussed. Test range results of each of these antennas are presented as well.

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.

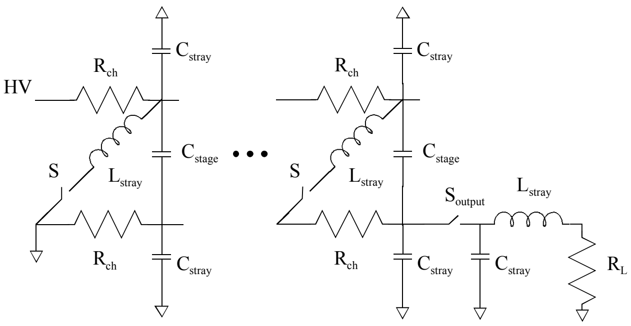

Figure 1. The Wave-Erection Marx Generator.

The conventional Marx circuit, illustrated in Figure 1, 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. Impulse Antennas

Several antenna designs are pursued including TEM horns, spirals, and rod antennas. The initial focus is on gain, as well as to establish baseline parameters from which future designs will build.

The key parameters for any antenna design are its gain, the radiation pattern and the field polarization over the frequencies of interest. The gain of an antenna is a measure of the antenna's ability to concentrate radiated power in a particular direction, with losses included.

In this section, general characteristics are presented on the geometry, radiation pattern, and field polarization of each antenna. Later sections present each antenna's dimensions, radiated waveform, and frequency response.

The TEM horn offers a simple solution for radiating the Marx generator's impulse. This antenna, shown in Figure 2 as an exponentially tapered horn offers a wideband response, about 12:1 and a gain from 2.5 to 15 dBi. The antenna is unidirectional, has a linear polarization, and is very easy to design and fabricate.

This effort was supported by BMDO under U.S. Army contract number DASG60-99-C-0079

Design of this antenna follows directly from the equation for a parallel plate transmission line.

$$w = h\left[\frac{377}{z_o\sqrt{\varepsilon_r}}\right] \tag{1}$$

Typically, the height of the output should be approximately ½ the wavelength of the lowest frequency to be transmitted.

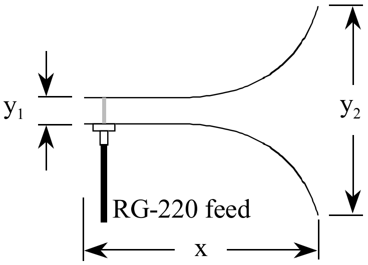

Figure 2. Exponentially tapered TEM Horn antenna.

A second TEM-styled horn antenna is illustrated in Figure 3. In this case, a single plane of the TEM horn extends over a ground plate, and linearly expands in both the **E** and **H** directions as the wave propagates toward the output. Again, the transmission line equation for a parallel plate line is used for the design; however, since the antenna is to be operated at very high voltages, the input portion of the antenna has an insulator other than air. As the wave propagates toward the output, the insulator tapers to a zero thickness. Thus, equation (1) is used for the design of the output and equation (2) defines the parameters for the input.

$$w = h\left[\frac{377}{z_o\sqrt{\varepsilon_r} - 2}\right] \tag{2}$$

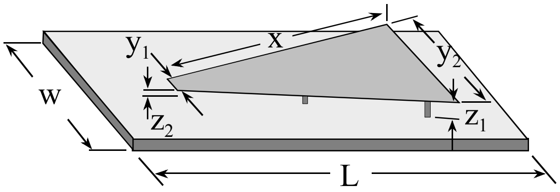

Figure 3. Half TEM ground plane antenna.

Spiral antennas offer more control over the radiated frequency. These antennas offer bandwidths of 2:1, and up to 5:1 is possible. They are unidirectional and are circularly polarized. As illustrated in Figure 4, once the center conductor parts from the ground plane, it spirals around an imaginary cylinder whose circumference is approximately one wavelength in diameter. Choosing the number of coils, which defines the gain, the length, L is derived from a coil spacing definition of $\lambda \sin \theta$, where θ is typically 12 – 14 degrees. The minimum ground plane is related by ¾ λ.

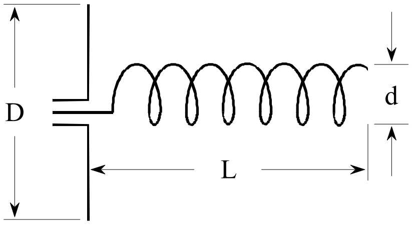

Figure 4. The spiral antenna.

The monopole antenna, as shown in Figure 5, is a rod mounted over a finite ground plane. These antennas are typically narrow-bandwidth, omni-direction and have linear polarization.

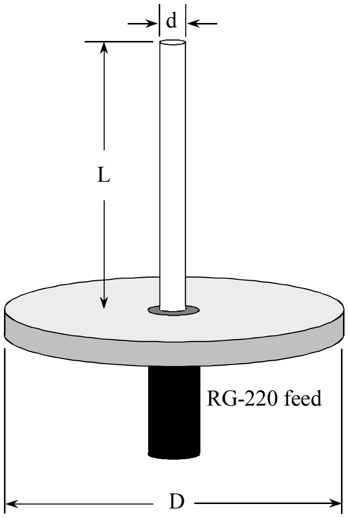

Figure 5. The monopole antenna.

III. EXPERIMENTAL ARRANGEMENT

A. Experimental Marx Generator

A 17-stage Marx generator is fabricated for the antenna testing. This particular generator offers a peak voltage of 150 kV, with a rise time of approximately 400 ps, as shown in Figure 6.

B. Antennas

The antennas described in the *Background* section of this paper are fabricated for a first-pass analysis, since only baseline parameters are sought.

The exponentially-tapered TEM horn is designed for an input plate spacing, y_1, of 12.7 mm, an output separation, y_2, of 533 mm, and a length, x, of 838 mm. The width, w, is derived to be 203 mm. The RG-220 cable is fed directly to the plates without special attention being paid toward flashover issues along the cables insulation.

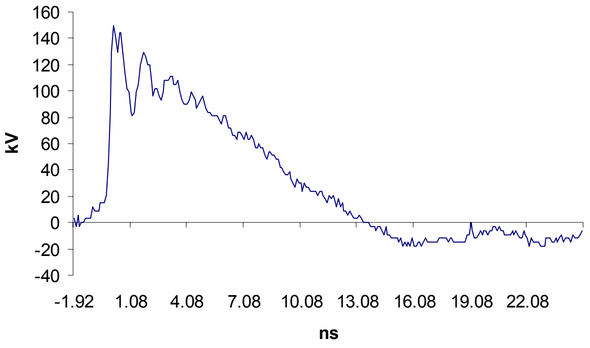

Figure 6. Output waveform of the Marx generator.

The second TEM horn, otherwise referred to as the half-TEM ground plane antenna offers a more methodical approach to its design. The input connection is designed for easy connection to the RG-220 cable, and the insulating material continues in the direction of the wave propagation, gradually tapering into the ground plane. The following dimensions, as defined by Figure 3 result.

$w = 600$ mm $L = 1220$ mm

$x = 910$ mm

$y_1 = 40$ mm $y_2 = 290$ mm

$z_1 = 13$ mm $z_2 = 290$ mm

The spiral antenna, like the half-TEM ground plane antenna, is fabricated for easy connection with the RG-220 cable. The antenna is designed for an operating frequency of 1 GHz, and 10 turns. Therefore, the coil diameter, d, is set at 95 mm, with a length, L, of 770 mm. The ground plane diameter. D, is chosen at 230 mm.

Finally, the monopole antenna has a rod length, L, of 254 mm and a ground plane diameter, D, of 230 mm. The rod diameter is arbitrarily chosen to continue the diameter of the RG-220 center conductor, which is 6.35 mm.

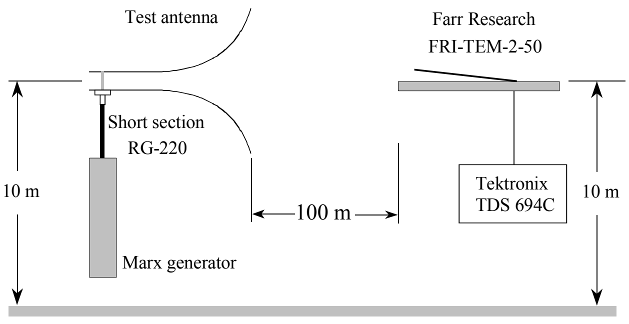

Figure 7. Test range illustration.

C. Test Range

The antennas are range tested in an open field with a configuration illustrated in Figure 7. The antennas are separated by 100 m and elevated to a height of 10 m such as to delay the effects of ground bounce for approximately 7 ns. A receiving probe was purchased from Farr Research [3] (model number FRI-TEM-2-50) and feeds a Tektronix TDS 694C oscilloscope.

IV. Experimental Results

The results of the exponentially-tapered TEM horn are shown in Figure 8. The antenna appears to radiate the rising edge of the impulse offered by the Marx generator. However, during the initial part of the pulse, the cable flashes-over, shorting the antenna. A peak electric field of 652 V/m was observed. Future work with this antenna design should incorporate insulation near the feed point to insure that the full pulse amplitude is radiated and the frequency information may be observed.

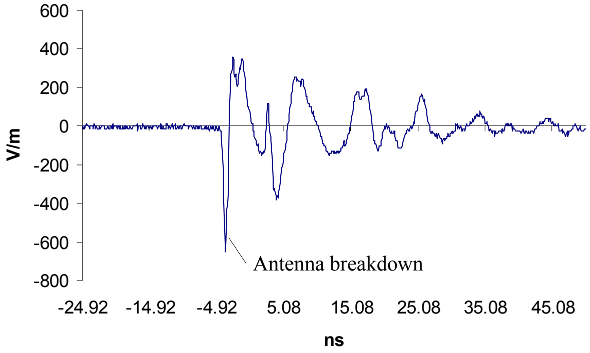

Figure 8. Range results from the exponentially tapered TEM horn.

The radiated waveform from the half-TEM ground plane antenna is shown in Figure 9. The resulting waveform is very nearly a monopulse, with an electric field of 743 V/m at 100 m. The FFT response, shown in Figure 10 shows that the signal is very broadband, with most of the energy residing in the hundreds of MHz range. The 7 ns delayed spike is probably ground bounce.

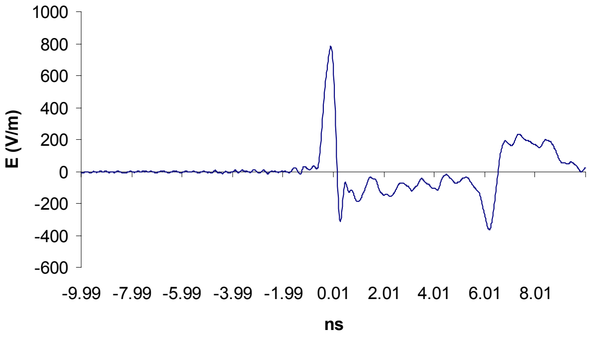

Figure 9. Range results from the half-TEM ground plane antenna.

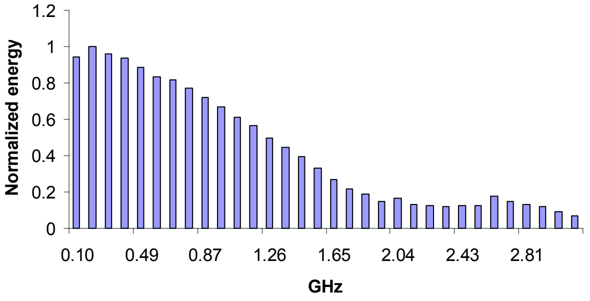

Figure 10. FFT response from the half-TEM ground plane antenna.

The range results of the coil antenna are shown in Figure 11. As predicted, this antenna produced a narrowband signal, centered around 1 GHz, as noted in the frequency response of Figure 12. The electric field strength, approximately 300 V/m, is down from previous antennas; however, the energy appears to be contained in only a few frequency components.

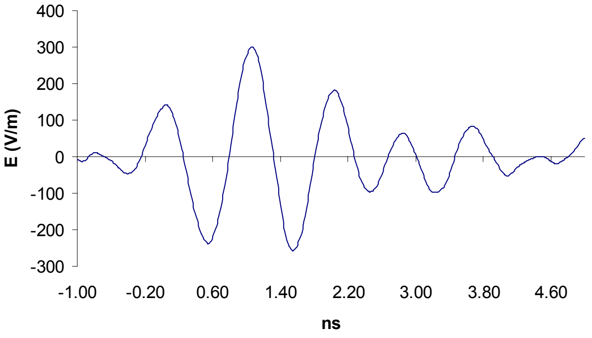

Figure 11. Range results from the coil antenna.

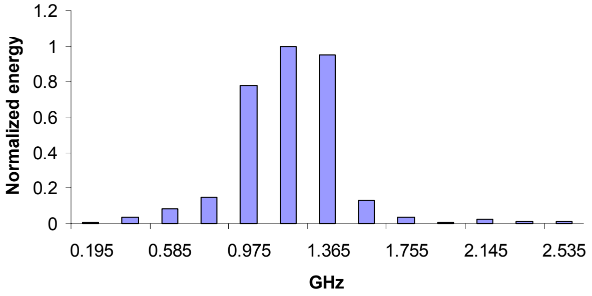

Figure 12. FFT response from the coil antenna.

Finally, the results of the monopole antenna are shown in Figure 13. A field strength of approximately 200 V/m is observed, which is omni-direction. Unfortunately, this antenna appears to be somewhat noisy, as shown in Figure 14. Most of the energy in this pulse is concentrated between the frequencies of 100 MHz to 1 GHz.

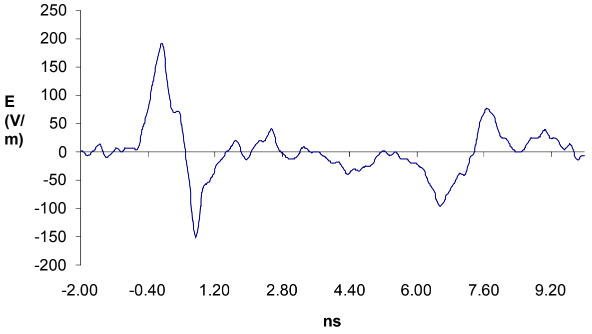

Figure 13. Radiation results from the monopole antenna.

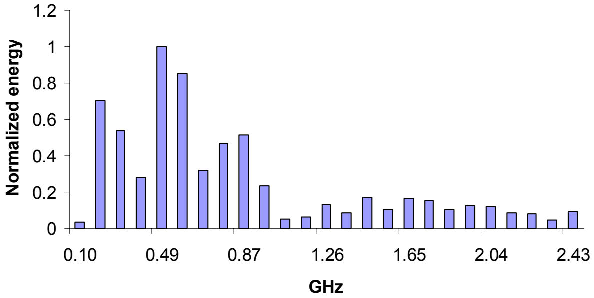

Figure 14. FFT response from the monopulse antenna.

V. Conclusion

This paper has presented preliminary results of a wave-erection Marx generator driving several impulse-type antennas. The generator's power was reduced so as to minimize breakdown problems with the antennas.

The radiation results do provide a basis for future work. The TEM horn antennas demonstrated UWB behavior. However, the results of the exponentially-tapered TEM horn were marred by flashover problems. The coil antenna demonstrated narrowband operation and the ability to focus energy into a microwave frequency.

Future work will expound on these results, increasing the generator's peak power, and ultimately, the field strength of the system.

VI. References

[1] W. C. Nunnally, The University of Missouri Columbia, Columbia, Missouri, 65211.

[2] L. Altgilbers, U.S. Army Space and Missile Defense Command, Huntsville, Alabama, 35807-3801.

[3] Farr Research, 614 Paseo Del Mar NE, Albuquerque, NM 87123.

[4] J. D. Kraus, Antennas, Second Edition, McGraw-Hill, Inc., New York, 1988.

[5] J. D. Taylor, Introduction to Ultra-Wideband Radar Systems, CRC Press, 1995.