The Direct Generation of High Power Microwaves with Compact Marx Generators

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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 have 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 are presented.

INTRODUCTION

Compact Marx generators have been employed for many years as trigger generators for larger systems. These generators are typically designed with pulse characteristics of more than 200 kV peak voltage, 3 – 4 ns rise times, 1 – 3 ns rms jitter and pulse widths of 10's of ns. Unfortunately, these characteristics make the compact Marx generator an impractical source for directly generating RF energy by driving an antenna due to the slow rise time.

However, recent efforts [1] with compact Marx generators have brought faster rise times, higher peak voltages and extremely low jitter values, making these sources viable candidates for compact Ultra Wideband (UWB) sources for both single and multiple generator systems.

While efforts continue the successful development of these generators, deployability will be limited by compact, high voltage, impulse radiating antennas. Typical impulse antennas, with any respectable amount of gain and directivity are large and cumbersome. Furthermore, high voltage antennas capable of handling voltages in excess of 100 kV are simply not available.

BACKGROUND

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 rise times 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. Wave erection is made possible through the proper design of the stray capacitance and the inter-stage capacitance, in concert with coupling the spark gaps via ultra-violet energy, resulting in a sub-ns rise time for output voltages of several hundred kV at moderate per pulse energies.

A 17-stage Marx generator is fabricated for the antenna testing. This generator provides a peak voltage of 170 kV, and a rise time of approximately 250 ps, as shown in Figure 1.

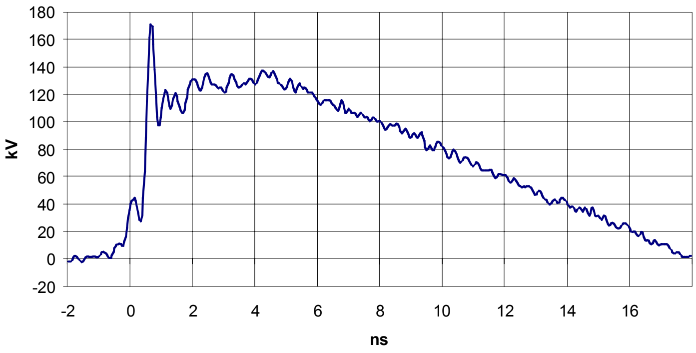


FIGURE 1. Output waveform from the Marx generator.

Several antenna designs are pursued including a linear half TEM horn and a spiral antenna. The initial focus is to gain an understanding of pulsed high voltage antenna characteristics, and to establish antenna baseline parameters for gain, radiation pattern, optimal impedance transformation requirements, and field polarization over the frequencies of interest. Future designs will build on these results.

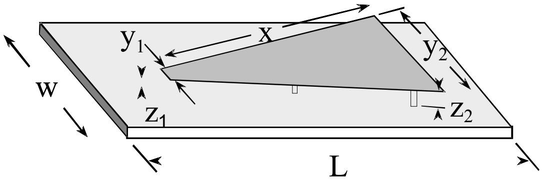


FIGURE 2. Geometry of the linear half TEM horn antenna.

The linear half TEM-styled horn antenna is illustrated in Figure 2. This antenna is characterized by a single TEM plane extending over a large ground plane. The TEM plane linearly expands in both the E and H directions as the wave propagates toward the output. The basic 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, at the input, the width of the TEM plate is defined as $w = 377\ h/(\ z_o\ \varepsilon_r^{1/2} - 2)$. Likewise, the width of the TEM plate at the output is defined as $w = 377\ h/(z_o\ \varepsilon_r^{1/2})$.

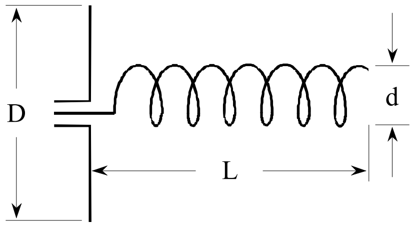


FIGURE 3. The spiral antenna.

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 3, 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 diameter is $\frac{3}{4}\ \lambda$.

EXPERIMENTAL ARRANGEMENT

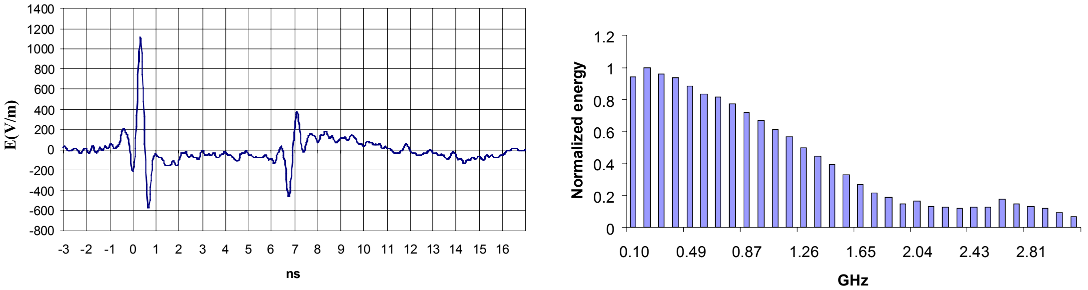
Antennas

The linear half-TEM horn antenna is designed for easy connection to RG-220 cable and is insulated at the feed point for high voltage hold-off. The insulating material continues in the direction of the wave propagation and gradually tapers into the ground plane. Matching the 50 Ω cable, the input side of the antenna has dimensions of y_1 = 40 mm and z_1 = 13 mm. The output side of the TEM has dimensions of y_2 = 290 mm and z_2 = 290 mm for a 377 Ω impedance match to free space. The length, x, of the TEM is chosen to be 910 mm for a gradual transition. Finally, the ground plane has dimensions of w = 600 mm and L = 1220 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.

EXPERIMENTAL RESULTS

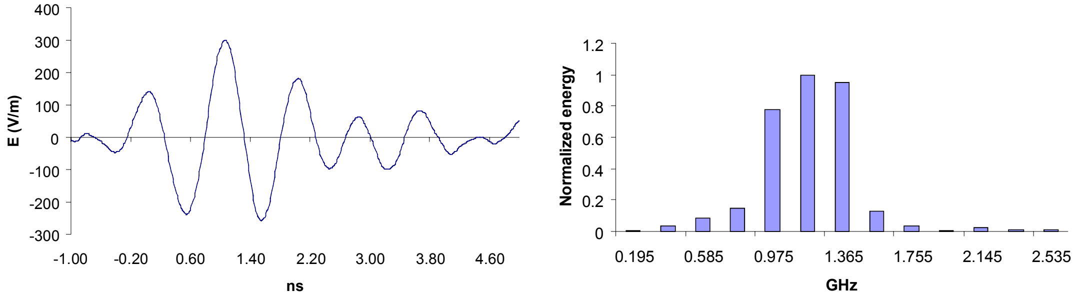
The radiated waveform from the half-TEM ground plane antenna is shown in Figure 4(a). The resulting waveform is very nearly a monopulse, with an electric field of 1100 V/m at 100 m. The FFT response, shown in Figure 4(b), shows that the signal is very broadband, with most of the energy in the hundreds of MHz range. The 7 ns delayed spike coincides with the test range's calculated first ground bounce signal.



(a) Radiated impulse (b) FFT response

FIGURE 4. TEM antenna results.

The range results of the coil antenna are shown in Figure 5. As predicted, this antenna produced a narrowband signal centered at 1 GHz, as shown in Figure 5(b). The electric field strength is approximately 300 V/m for both the horizontal and vertical polarizations. The energy is spread over several cycles in a narrow bandwidth.



(a) Radiated impulse (b) FFT response

FIGURE 5. Coil antenna results.

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. The coil antenna demonstrated narrowband operation and the ability to focus energy into microwave frequencies. Each of the antennas demonstrated the ability to successfully hold off the high voltage, with no apparent breakdown problems. However, impedance matching issues were observed and the gain and directivity measurements indicate large margins for improvement.

REFERENCES

1. Mayes, Jon R., and Carey, William J., *The Marx Generator as an Ultra Wideband Source*, 13th IEEE International Pulsed Power Conference, Las Vegas, NV, July 2001.