A COMPACT HIGH POWER WIDEBAND SYSTEM

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Abstract

A number of recent efforts have been made to develop high power wideband sources for test and evaluation and general electronic disruption. Applied Physical Electronics, L.C. has developed technology covering 100 MHz to 400 MHz, and is continually working to broaden this area of coverage. The system is based on a single compact pulse power source, capable of delivering 1.7 GW peak power with repetition rates up to 200 Hz. Interchangeable dipole antennas are connected to the pulse power source via high voltage cabling, and are capable of radiating electric field strengths of several hundred kV/m. This paper presents the basic characteristics of the system, followed by experimental data.

I. INTRODUCTION

Wideband sources are gaining in their popularity for affecting electronic systems, including vehicles, computer systems and networks, aircraft, and other general electronics. Both military and commercial assets are at risk.

Wideband sources have become an attractive alternative to Ultra Wide Band (UWB) sources and High Power Microwave (HPM) systems, due to their relative inexpensive and small packaging.

UWB sources were once viewed as the "silver-bullet" solution to stopping electronic threats, since energy could be delivered with a very wide instantaneous bandwidth, from 100 MHz to 2 GHz, and affect a very wide range of electronically-controlled targets. Unfortunately, the small amount of energy actually radiated is spread over so many frequencies that the effectiveness is small. Furthermore, these systems can become quite large, as intense peak power levels are pursued. [1]

Conversely, HPM systems can place very large amounts of energy into a very narrow spectral band, making them target specific; however, these systems are complex, relatively large, and very expensive. Furthermore, HPM sources are only practical at frequencies above 1 GHz, since operating frequencies below 1 GHz result in prohibitively large systems.

Wideband sources seem to bridge the advantages/disadvantages from the UWB and HPM approaches. Wideband sources typically operate with center frequencies from 10 MHz to 1 GHz and with an instantaneous bandwidth of approximately 50%. This spectral response is achieved by radiating a damped sinusoidal wave, where the damping coefficient determines the number of cycles, and hence the bandwidth.

Compared to UWB sources, Wideband system deliver more energy and in a smaller band of frequencies. This bandwidth limitation reduces the target set, but increases the probably of affect, since the energy is localized to fewer frequencies.

Compared with HPM, wideband source can be made very cheaply and in relatively small volumes. Since the energy per pulse is much smaller, wideband systems require much smaller capacitive energy stores, which also translates into smaller volumes and far less cost.

The volume and cost attributes of wideband sources make them a large threat to military and commercial infrastructure. The sources are being built in very small, suitcase-sized packages, and are being commercially sold around the world. As a result, there is an increased need to test assets to the wideband threat, in order to understand and mitigate the threat.

This paper describes development efforts by APELC to support the Test and Evaluation community with wideband sources. APELC has designed a base system, with several interchangeable antennas to cover a wide spectrum from 100 MHz to 400 MHz. APELC's ultimate goal is to provide a simple-to-use wideband test system to cover the spectrum from 50 MHz to 1 GHz, and with pulse repetition frequencies of up to 200 Hz. This paper describes the preliminary system development.

II. BACKGROUND

Wideband source development has been around for more than a decade, with the leading development coming from Diehl, with its development of a compact RF source. Diehl's DS-110 was a small suitcase-style source that has been demonstrated to affect a very wide range of electronic targets, with peak radiated electric field strengths of more than 100 kV/m, at 1 m.[1]

In 2002, APELC demonstrated a prototype integrated Marx generator/dipole source, illustrated in Figure 1. The

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system integrates two oppositely-charged Marx generators into a dipole geometry. By simultaneously launching their energies onto their respective cases, a cyclic behavior results, and related to the length of the Marx generator housings. The prototype system produced an electric field of 300 V/m, measured at 100 m, with a center frequency of approximately 150 MHz and five cycles, as shown in Figure 2. [2]

In 2008, APELC developed a suitcase-styled source, shown in Figure 3, to support the T&E community. This initial source produced the waveform found in Figure 4, with a peak radiated electric field of approximately 125 kV/m (at 1 m) and PRFs of up to 6 Hz. The spectral response of this source is shown in Figure 5.[3]

More recently, APELC has added more development to its compact source, bringing higher peak radiated electric fields (145 kV/m at 1 m), higher PRFs (10 Hz) and better packaging to mitigate EMI effects on the control system and power supply. A photograph of the updated system is provided in Figure 6.

Beginning in 2008, APELC began developing larger wideband sources, with the goal of radiating pulsed electric fields in excess of 300 kV/m (at 1 m), with PRFs in excess of 200 Hz. To achieve this, APELC moved to a larger Marx generator (APELC model MG15-3C-940PF) to pulse charge the dipole antenna to as much as 600 kV. Furthermore, a corner reflector was added to the dipole, and rackmount services were added to support the Marx generator for higher repetition rates. This configuration is the basis for the system to be described by this paper.

Ultimately, APELC is proposing a flexible wideband test source to better support the T&E community. As described by Figure 7, a single universal pulse power system will be developed to source several interchangeable dipole antennas connected via a high voltage coaxial cable. Each antenna will offer a unique center frequency, as well as offering a 10% frequency agility. Furthermore, since the antennas are connected via coaxial cable, they may be quickly interchanged to minimize the down-time in testing.

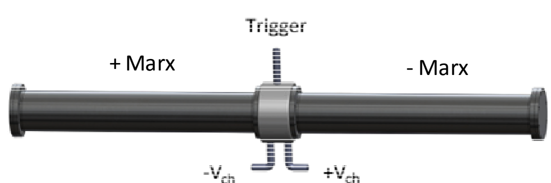

Figure 1. An illustration of the APELC's dual polarity Marx generator configured into a dipole antenna geometry.

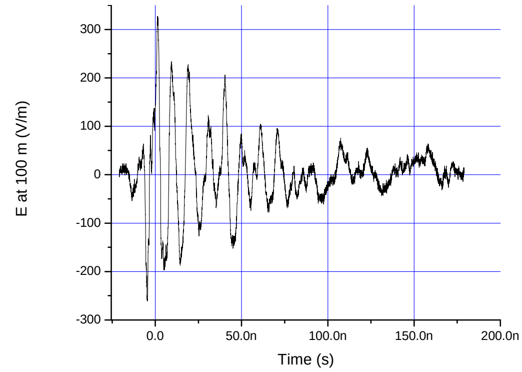

Figure 2. A sample waveform generated by APELC's integrated Marx/dipole prototype source.

Figure 3. A photograph of APELC's first compact wideband source.

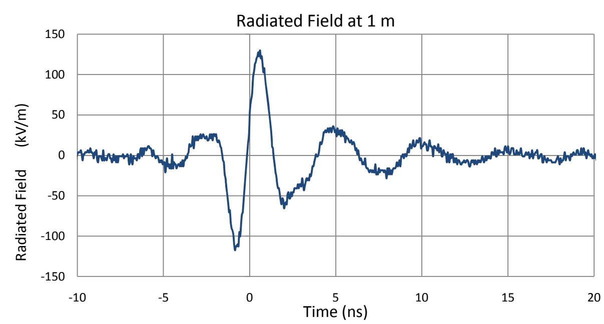

Figure 4. A sample radiated waveform from APELC's compact wideband source.

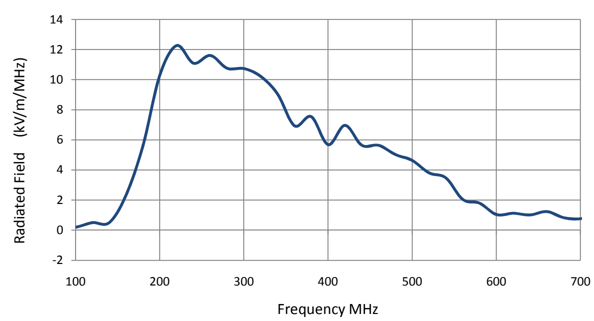

Figure 5. The spectral response from APELC's compact wideband source.

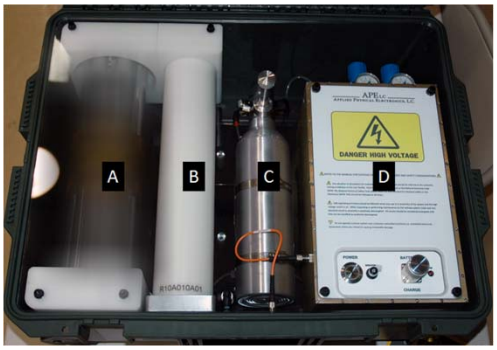

Figure 6. A photograph of APELC's updated compact wideband source. Key components include: A) dipole antenna, B) Marx generator, C) pressurized bottle of dry breathable air, and D) power and control electronics.

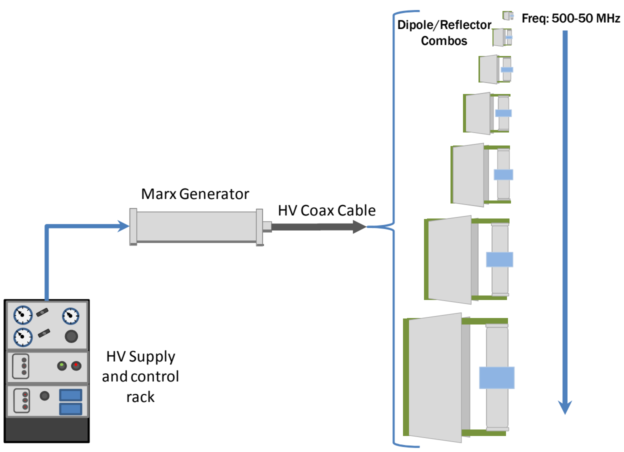

Figure 7. APELC's proposed wideband test system.

III. EXPERIMENTAL ARRANGEMENT

APELC has begun the development of the system describe in Figure 7. A great deal of effort has been dedicated toward the development of the Marx generator and the supporting rack services, including lifetime studies, failure analysis and reliable trigger development.[4] As illustrated in Figure 8, a short rack has been designed to combine most of the services required by the Marx generator and the dipole antenna, including air pressure regulation (generator and dipole), a Lambda 802 8 kJ/s high voltage power supply and an APELC-made high voltage trigger unit. Not shown is a programmable delay generator used to sequence the charge and trigger processes.

The Marx generator for this system, illustrated in Figure 9 is APELC's MG15-3C-940PF generator, designed to erect a maximum 600 kV and deliver up to 33 J per pulse. When loaded with a matched 50 Ohm cable, the generator delivers a peak power of 1.8 GW, with a maximum repetition rate of 200 Hz. The generator has a length of 31 inches, with a diameter of 6 inches, making it very portable. Table 1 provides the technical parameters for this generator.

Table 1. General Specifications of the APELC MG-15-3C-940PF High Repetition Rate System.

Symbol	Parameter	Value	units
N	Number of Marx generator stages	15	-
E_{pulse}	Maximum Marx energy per pulse	33.0	J
-	Maximum vessel pressure	150	PSI
V_{ch}	Marx peak charge voltage	40	kV
V_E	Peak Erected voltage	600	kV
C_{stage}	Capacitance per Marx stage	2.8	nF
C_E	Erected capacitance	188	pF
L_e	Erected Inductance	510	nH
Z_m	Marx Impedance	52	Ohm
L	Marx Generator Length	31	In.
D	Marx Generator Diameter	6	In.
RR_{max}	Maximum Burst-Mode Repetition Rate	200	Hz

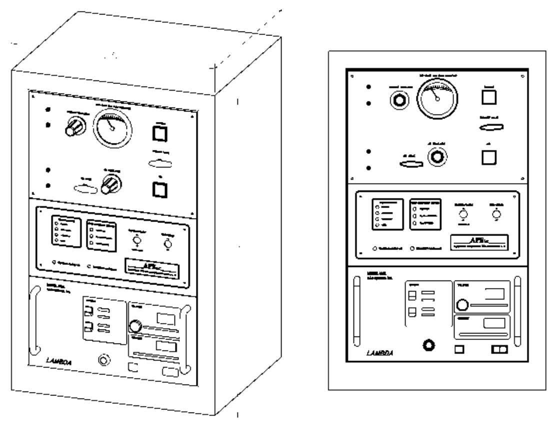

Figure 8. System support rack, including a high voltage power supply, a high voltage trigger system and pressure regulation.

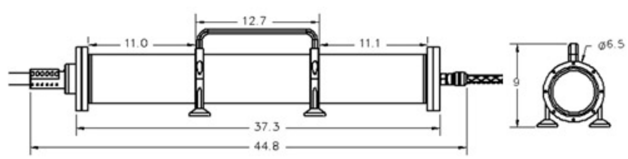

Figure 9. APELC's MG15-3C-940PF Marx generator.

The first dipole developed, for the configuration describe in Figure 7, is the 400 MHz geometry, described in Figure 10. The dipole is duplicated from the compact wideband source of Figure 3, in which a simple LC oscillator is integrated into a "fat" dipole geometry. The Marx generator connects to the dipole via high voltage coaxial cable, which is connected to the dipole by simply spanning across the length of the dipole, with the braid of the cable stopping at one end and the insulator/center conductor extended to the other end. The high voltage pulse from the Marx generator pulse charges the resonator to several hundred kV. Once charged, the resonator self-breaks, ringing at the desired frequency. The resonant filling of the dipole arms results in the propagation of surface currents along the dipole arms, which results in the radiation from the device.

The 400 MHz geometry has a designed capacitance of 16 pF and an inductance of approximately 10 nH, resulting in a resonance of 400 MHz. The design of the backing reflector follows from Kraus.[5] A simple 90 degree metal reflector, similar in height to the dipole and with panels sized to just encompass the dipole with a $\lambda/4$ spacing between the dipole and reflector, is fabricated and attached to the dipole.

The 400 MHz dipole geometry has been well optimized, with a very detailed engineering process. The basic dipole, as well as the backing reflector, was thoroughly simulated using CST Microwave Studio.

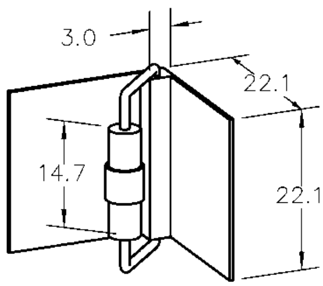

Figure 10. APELC's reflector-backed 400 MHz dipole antenna.

A 250 MHz antenna is designed and fabricated, following the design rules developed for the 400 MHz model, and described in Figure 11. An extensive engineering effort was not feasible for this geometry. This dipole has a length of 23.5 inches, a designed capacitance of 25 pF and an inductance of 15 nH. Each panel has an area of 35.4 in. by 34.5 in., with a setback distance of approximately 11.35 in.

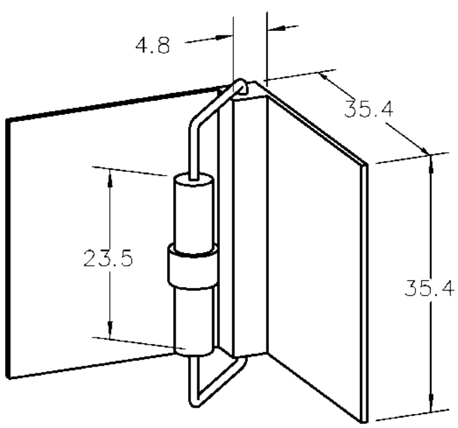

Figure 11. APELC's reflector-backed 250 MHz dipole antenna.

Finally, a 100 MHz antenna is designed and fabricated, again, following the design rules developed for the 400 MHz geometry, and described in Figure 12. Like the 250 MHz geometry, an extensive engineering was not feasible for this design. This dipole has a length of 58.9 inches, a designed capacitance of 140 pF and an inductance of 18 nH. Each panel has an area of 88 in. by 88 in., with a setback distance of approximately 27 in.

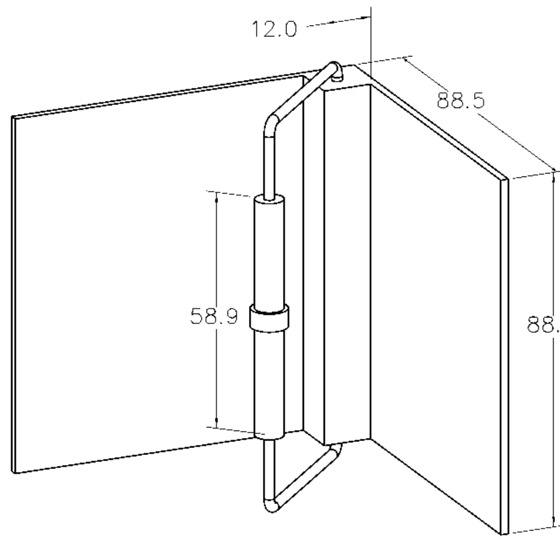

Figure 12. APELC's reflector-backed 100 MHz dipole antenna.

IV. EXPERIMENTAL RESULTS

Testing of the developed hardware begins with the Marx generator, and supporting services. The generator is tested with a cable load, which is fitted with an in-line Current Viewing Resistor (CVR). A typical waveform is provided in Figure 13. The pulse has a characteristic maximum amplitude of 300 kV, with a risetime of 4–5 ns and a FWHM pulsewidth of approximately 25 ns. Supported by the rackmount components described in Figure 8, the Marx generator can be continuously operated up to 50 Hz, or 200 Hz in 10 second bursts.

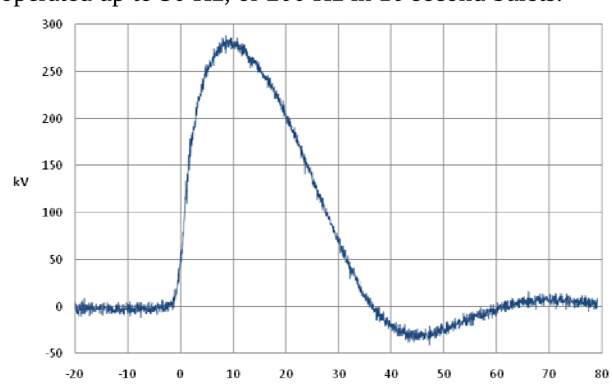

Figure 13. A typical voltage waveform measured from APELC's MG15-3C-940PF driving a 50 Ohm coaxial cable.

The 400 MHz dipole antenna was first tested. A sample waveform is provided in Figure 14, with a peak radiated electric field measured to 165 kV/m (at 1 m). It is noted the reflector has added the additional cycle of energy, from previous measurements such as shown in Figure 4. Higher electric field strengths have been measured, with this antenna, with a best measurement in excess of 300 kV/m. The antenna was also tested for high repetition rates. The source was reliably operated with the maximum capability of the Marx generator, without amplitude degradation or waveform distortion.

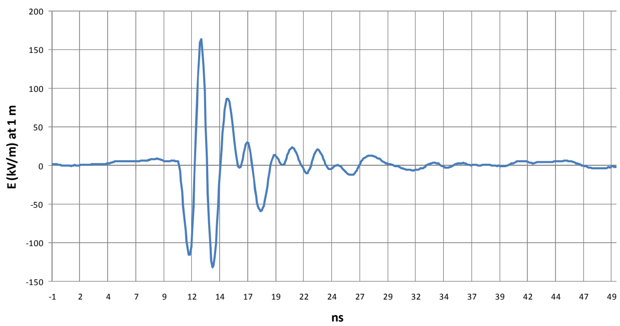

Figure 14. A sample waveform radiated from APELC's 400 MHz reflector-backed dipole antenna.

A sample waveform from the 250 MHz antenna is shown in Figure 15. A peak radiated electric field strength of 145 kV/m (at 1 m) was measured. Like the 400 MHz antenna, this antenna operated to the maximum performance of the Marx generator, without any loss in pulse fidelity.

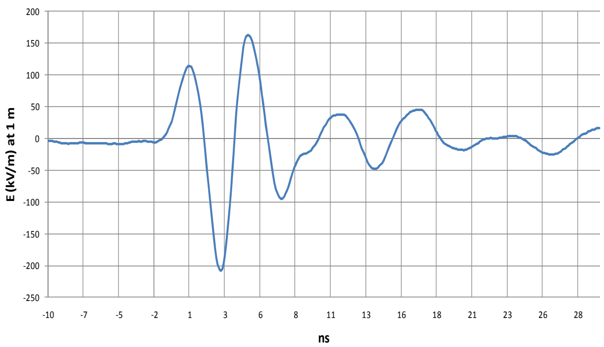

Figure 15. A sample waveform radiated from APELC's 250 MHz reflector-backed dipole antenna.

Finally, the 100 MHz dipole antenna was tested, with a sample waveform provided in Figure 16. This antenna produce a nominal peak electric field strength of 90 kV/m (at 1 m). The larger antenna capacitance has reduced the peak field dramatically from the other **a**ntennas, which might lead to the use of a larger Marx generator in the future.

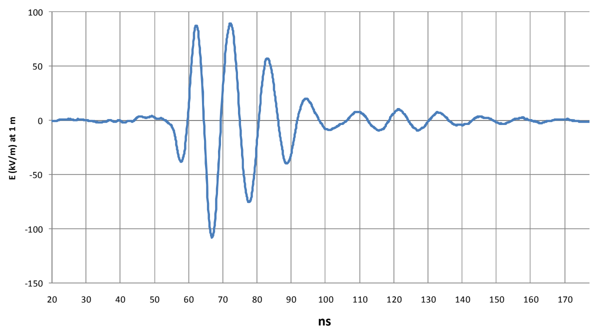

Figure 16. A sample waveform radiated from APELC's 100 MHz reflector-backed dipole antenna.

V. SUMMARY

The development of a frequency-agile wideband test solution has been proposed, consisting of a centralized pulse-power system driving interchangeable dipole antenna loads, to support the test and evaluation community. Ultimately, 5 – 7 antennas will be designed and built to cover the spectrum from 50 MHz to 1 GHz. The pulse power system has been developed and thoroughly tested for reliability and pulse-to-pulse repeatability. Three reflector-backed dipole antennas were designed and tested. Each antenna has been demonstrated to deliver peal electric fields in excess of 100 kV (at 1 m).

Future work will improve the antennas discussed in this paper, to improve their peak radiated electric fields. New efforts will expand the family of antennas to cover more of the proposed spectrum.

VI. REFERENCES

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[2] *Method and Apparatus for Generating Short Duration High Voltage Energy Pulses Using Integrated Generators and Antennae*, U.S. Patent number 7,345,382 B2.

[3] *Integrated Resonator and Dipole for Radiation of High Power RF Energy*, 12/509576, utility patent application filed July 27, 2009.

[4] T.A. Holt, et al., *Marx Generators for High-Power RF and Microwave Applications*, IEEE International Power Modulator Conference, Atlanta, GA, May 2010.

[5] John D. Kraus, Antennas 2nd Edition, McGraw-Hill, 1988.