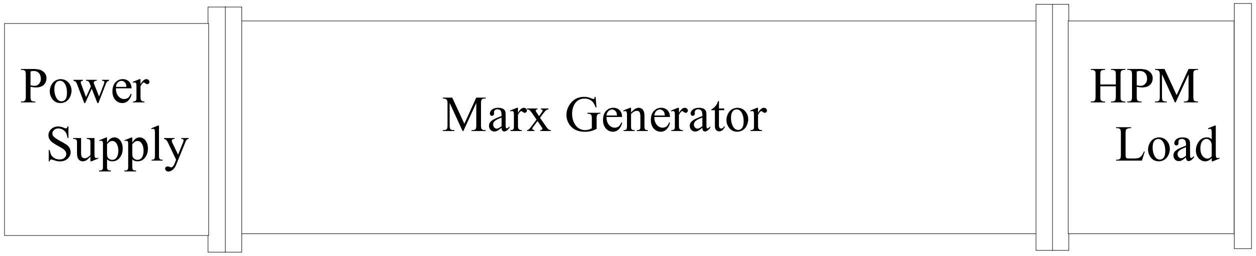
Electric Power Systems Conference
April 22, 2004
Washington DC
AIE

Compact RF and HPM Sources

Applied Physical Electronics, L.C.
Austin, Texas
www.apelc.com

APELC Summary

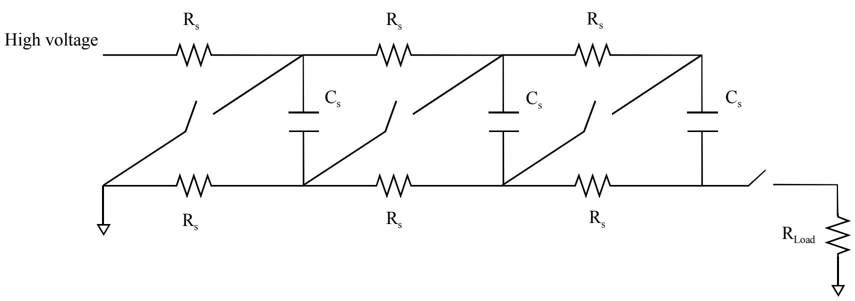
- In brief → APELC = Compact Pulsed Power Sources
  - APELC = 6 yrs
  - Primary efforts have been focused on compact Marx generators
  - Recent efforts promise integrated systems:
    - Compact power supplies
    - Novel generator designs
    - Insulating materials
    - Direct generation of RF energy (Marx/Antenna)
    - High Power Microwave sources (Marx/Vircator or MILO)



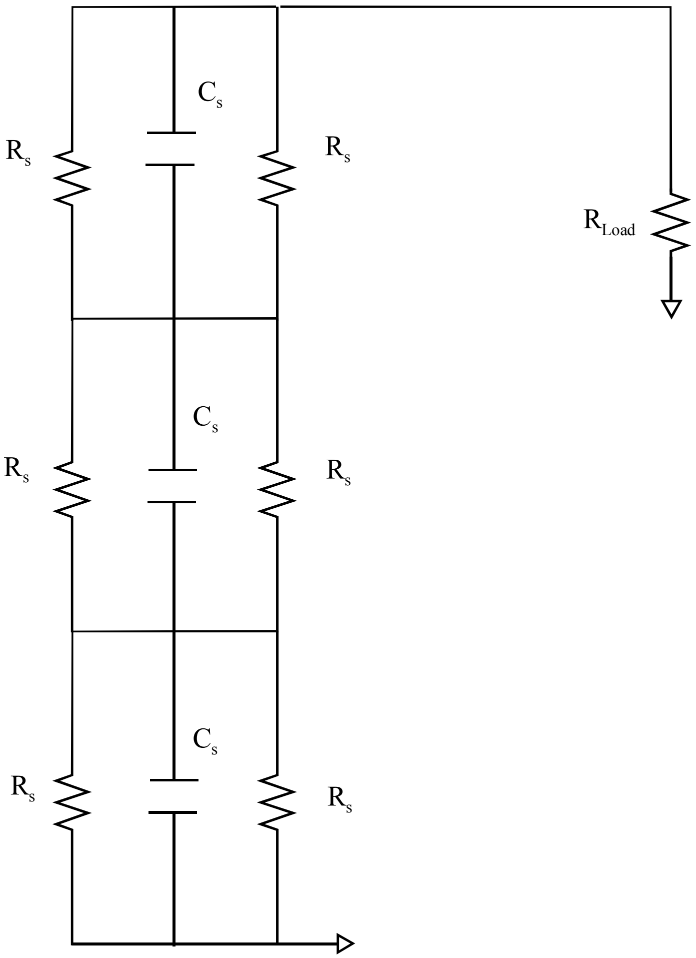
  - Presentation discusses key RF and HPM technologies under development by APELC

Marx generators – General Concept

Charge capacitors in parallel

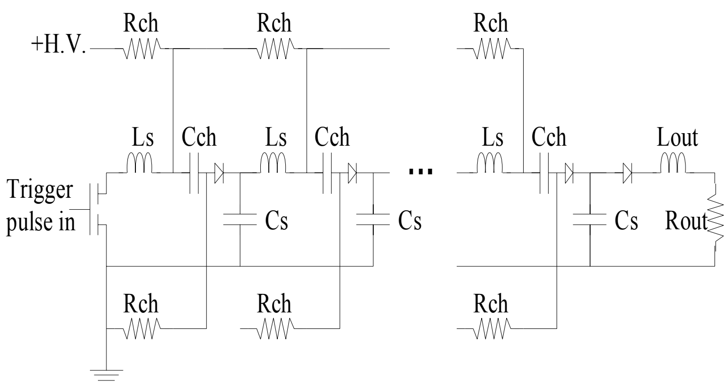


Closing the switches (preferably sequentially) “erects” the Marx generator, which adds the voltages across each capacitor → RC decay into the load



APELC Generators – “Pico-Marx”

Foundations of the TRAPATT Marx Generator

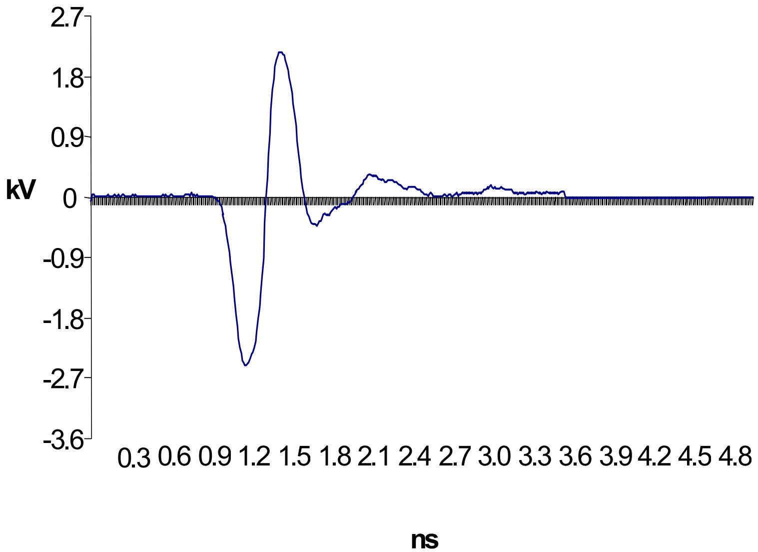


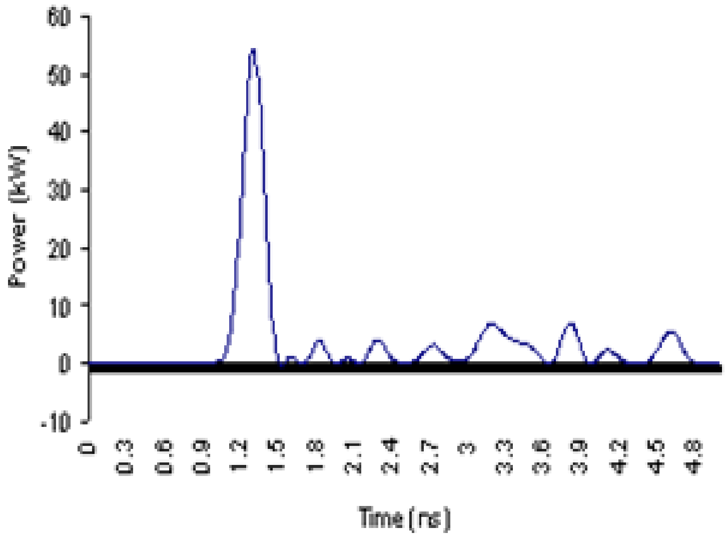
- TRAPATT (Transient Plasma Avalanche Triggered Transit) Diodes used as switches in a Marx circuit

System Advantages

- Ultra-short impulses (< 1 ns full pulse width)
- Direct derivation of range and vector information (no time-consuming FFT processing)
- Extremely compact
- High peak power = long range
- High repetition rates = high average powers (Watts)
- Low power requirements on missile power system

Pico-Marx Generator - Continued





- Early efforts resulted in a 6 stage generator (V_{ch} = 500 V)
- Preliminary results: V_p = 2 kV, 600 ps (full pulse) into 50 Ω
- Recent efforts: V_p = 6.5 kV, 500 ps (full pulse), 845 kW peak power, > 10 kHz capable
- "Credit card-sized" package

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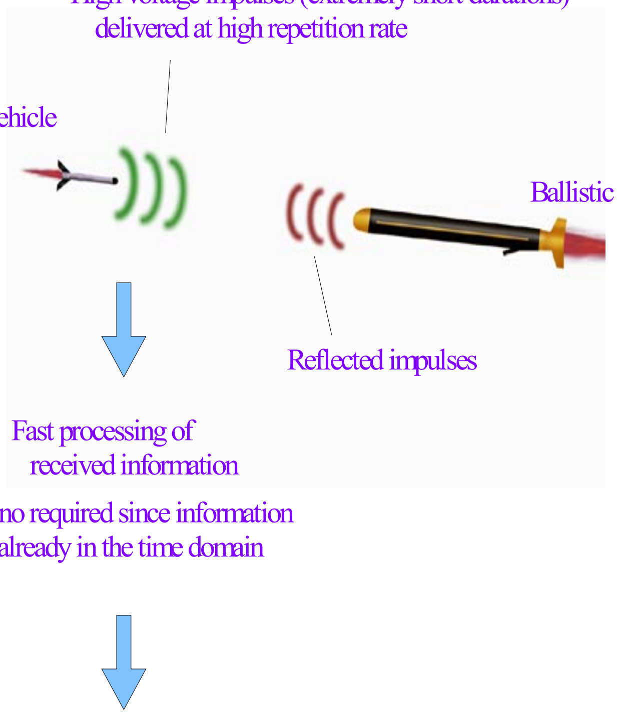
Pico-Marx Generator – Proposed Applications



Real-time impulse radar source

Munition-lauched RF disruption

APELC Generators – 10 stage

Parameter	Description	Value	Unit
V_{ch}	Charge voltage	30	kV
N	Number of Marx stages	10	
C_{st}	Capacitance per Marx stage	2.7	nF
R_{st}	Charge resistor per Marx stage	10	kΩ
Z_{load}	Load impedance (cable)	50	Ω
V_{max}	Maximum output voltage (open circuit voltage)	300	kV
V_{50}	Peak voltage into 50 Ohm load	214	kV
Z_{marx}	Marx impedance	20	Ω
C_{marx}	Erected Marx capacitance	270	pF
L_{marx}	Erected Marx inductance	108	nH
E_{stage}	Energy stored per stage	1.2	J
E_{marx}	Total energy store in Marx	12	J
P_{peak}	Peak power	916	MW
T_{RR}^{*}	Maximum repetition rate	123	Hz
P_{ave}	Average power	1500	W

Parameter	Description	Value	Unit
D	Diameter	5	in
L	Length	21	in
Vol	Total volume	412	in^2
W	Weight	15	lb

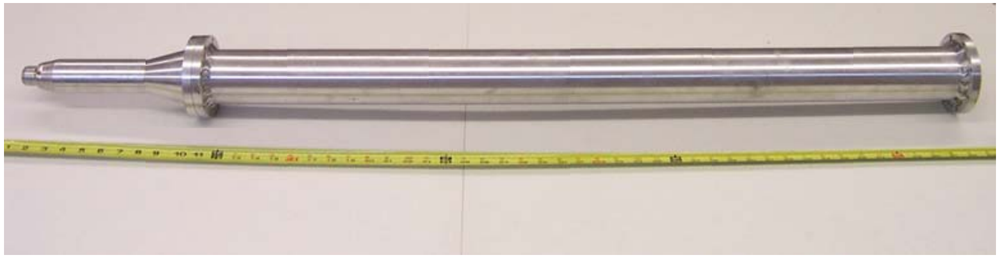
Target applications:

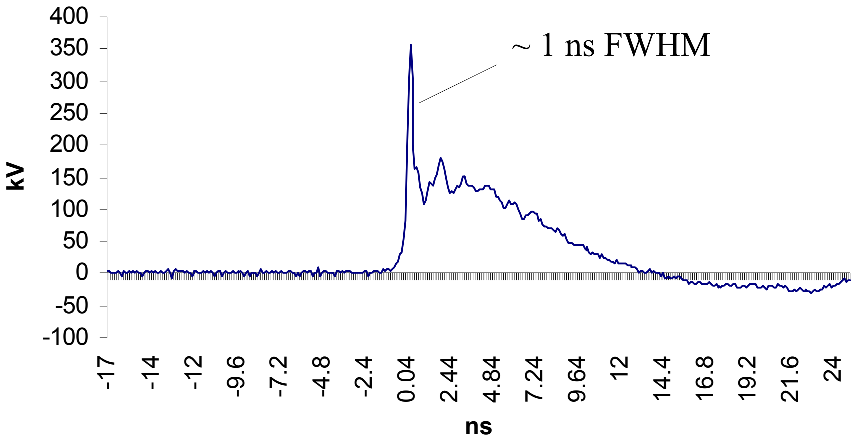
- Trigger source
- Direct RF generation

APELC Generators – 17 stage

Parameter	Description	Value	Unit
V_{ch}	Charge voltage	30	kV
N	Number of Marx stages	17	
C_{st}	Capacitance per Marx stage	940	pF
R_{st}	Charge resistor per Marx stage	10	kΩ
Z_{load}	Load impedance (cable)	50	Ω
V_{max}	Maximum output voltage (open circuit voltage)	510	kV
V_{50}	Peak voltage into 50 Ohm load	125	kV
Z_{marx}	Marx impedance	100	Ω
C_{marx}	Erected Marx capacitance	55	pF
L_{marx}	Erected Marx inductance	553	nH
E_{stage}	Energy stored per stage	0.423	J
E_{marx}	Total energy store in Marx	7	J
P_{peak}	Peak power	313	MW
T_{RR}*	Maximum repetition rate	123	Hz
P_{ave}	Average power	882	W
$V_{impulse}$	Peak impulse voltage	360	kV
P_{peak}	Peak impulse power	2.6	GW

Parameter	Description	Value	Unit
D	Diameter	3	in
L	Length	42	in
Vol	Total volume	1200	in^3
W	Weight	20	lb





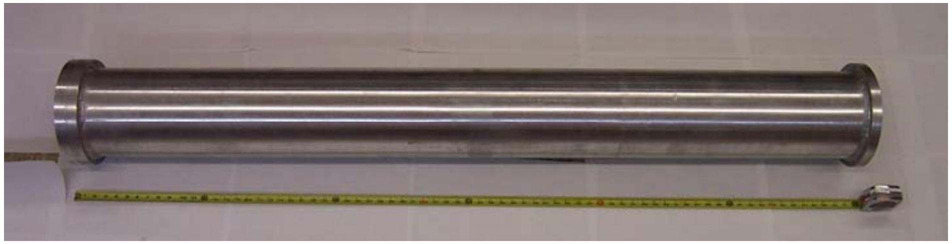
Target applications:

- Trigger generation
- Direct RF generation
- Materials testing (impulse)

APELC Generators – 40 stage

Parameter	Description	Value	Unit
V_{ch}	Charge voltage	40	kV
N	Number of Marx stages	40	
C_{st}	Capacitance per Marx stage	8.1	nF
R_{st}	Charge resistor per Marx stage	10	kΩ
Z_{load}	Load impedance (cable)	50	Ω
V_{max}	Maximum output voltage (open circuit voltage)	1600	kV
V_{50}	Peak voltage into 50 Ohm load	660	kV
Z_{marx}	Marx impedance	70	Ω
C_{marx}	Erected Marx capacitance	203	pF
L_{marx}	Erected Marx inductance	992	nH
E_{stage}	Energy stored per stage	6.5	J
E_{marx}	Total energy store in Marx	259	J
P_{peak}	Peak power	9	GW
T_{RR}^{*}	Maximum repetition rate	3	Hz
P_{ave}	Average power	667	W

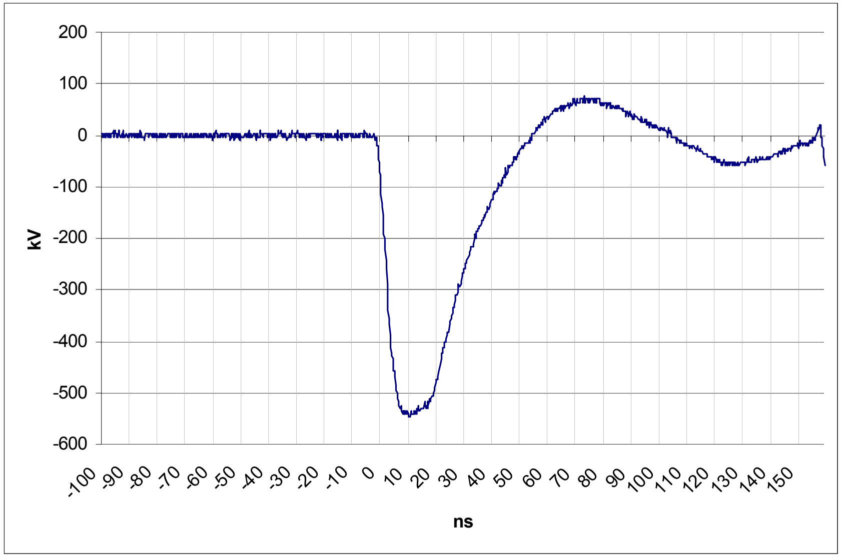
Parameter	Description	Value	Unit
D	Diameter	8	in
L	Length	72	in
Vol	Total volume	4600	in^2
W	Weight	300	lb

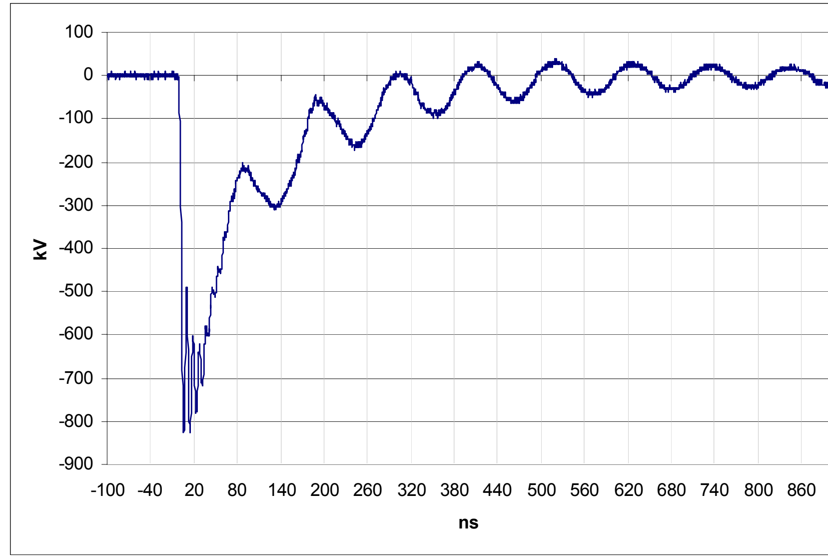


Target applications:

- Direct RF generation
- HPM driver source
- Flash x-ray driver source

40 – Stage Sample Waveforms





V_{charge} = 30 kV

V_{pulse} ~ 550 kV

T_{width} ~ 20 ns

E_{pulse} = 146 J

P_{peak} = 6 GW

V_{charge} = 45 kV

V_{pulse} ~ 800 kV

T_{width} ~ 30 ns

E_{pulse} = 330 J

P_{peak} = 12.8 GW

APELC Generators - Moderate

- Generator under development for the Air Force (PRPL & DE)
- Concept brings proprietary parallel switching concept which results in coaxial current propagation through the generator → low impedance design

- Fundamental principle:
  - Traditional HPM sources employ large capacitive energy stores used to inefficiently drive microwave diode with long pulse widths and very low repetition rates and results in large, not-so-deployable volumes.
  - APELC's concept of shorter pulse widths and higher repetition rates results in smaller capacitive energy stores with equal average power levels → compact and deployable.

The Gatling Marx Generator System

Concept: Extreme repetition rate Ultra Wide Band (UWB) RF used to detect ballistic and cruise missiles and to discriminate target from decoys, countermeasures and environmental noise.

The Gatling system:

- Multiple generators connected to a single common load (i.e. antenna)
- Each generator is completely independent of neighboring generators
- Each generator controlled for charge voltage and output timing
- A single generator is capable of 1 kHz repetition rates
- A Gatling system of "N" generators is capable of N x 1 kHz repetition rates in a continuous mode
- The minimum pulse-to-pulse spacing is 20 ns, resulting in a burst mode repetition rate of 50 MHz
- Independence of individual generators leads to a wide variety of pulsed waveforms, in real time

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Gatling Waveforms

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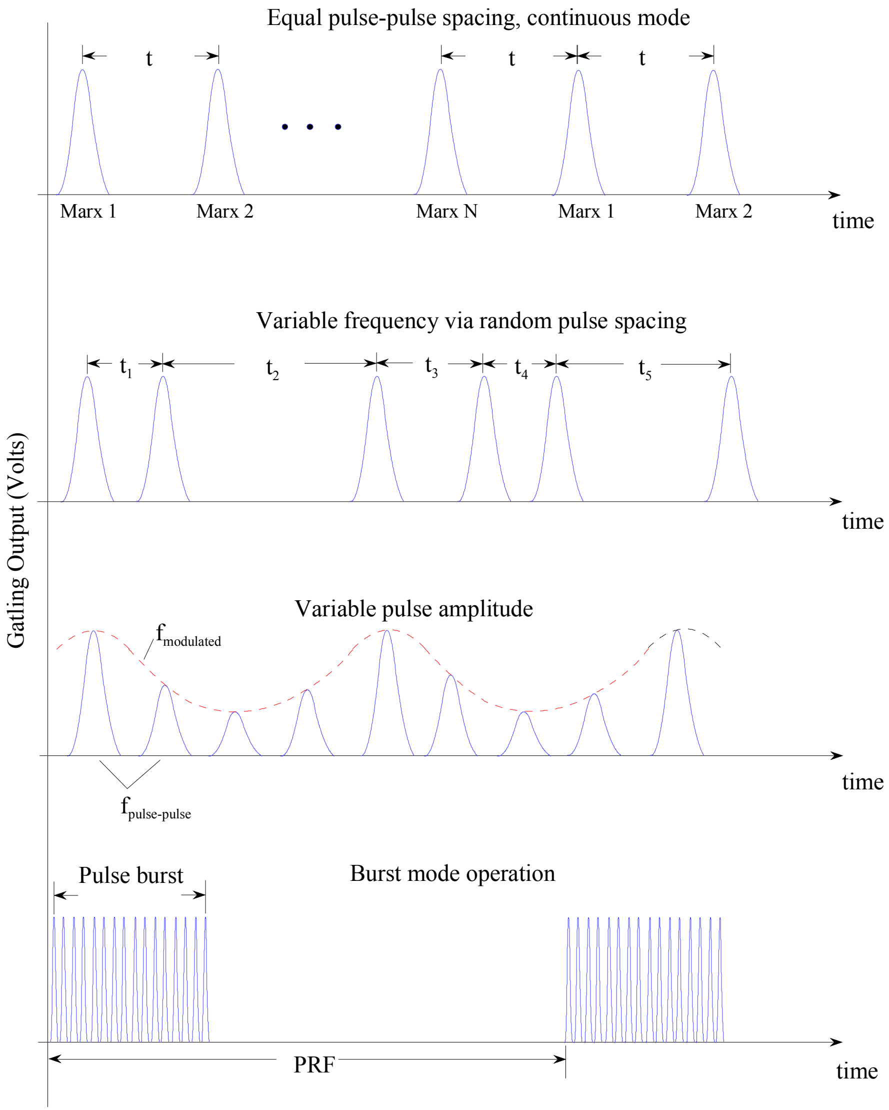
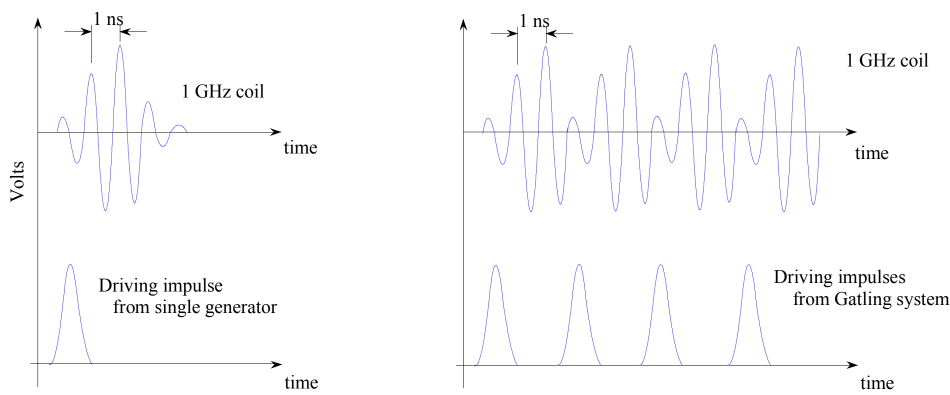
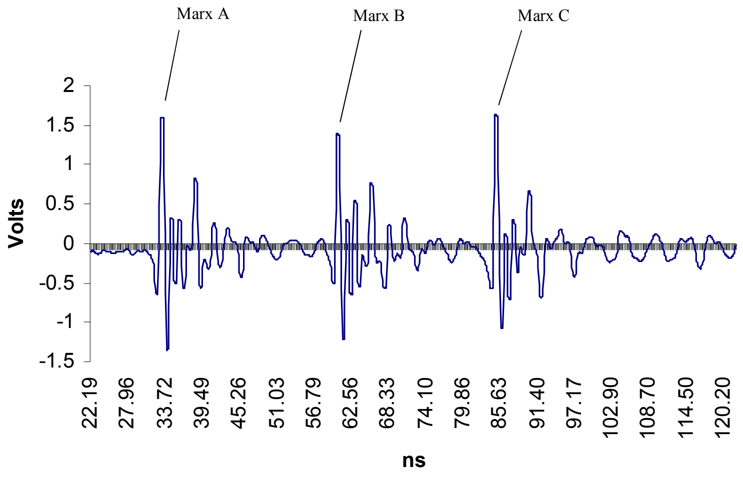
Potential modes of Operation



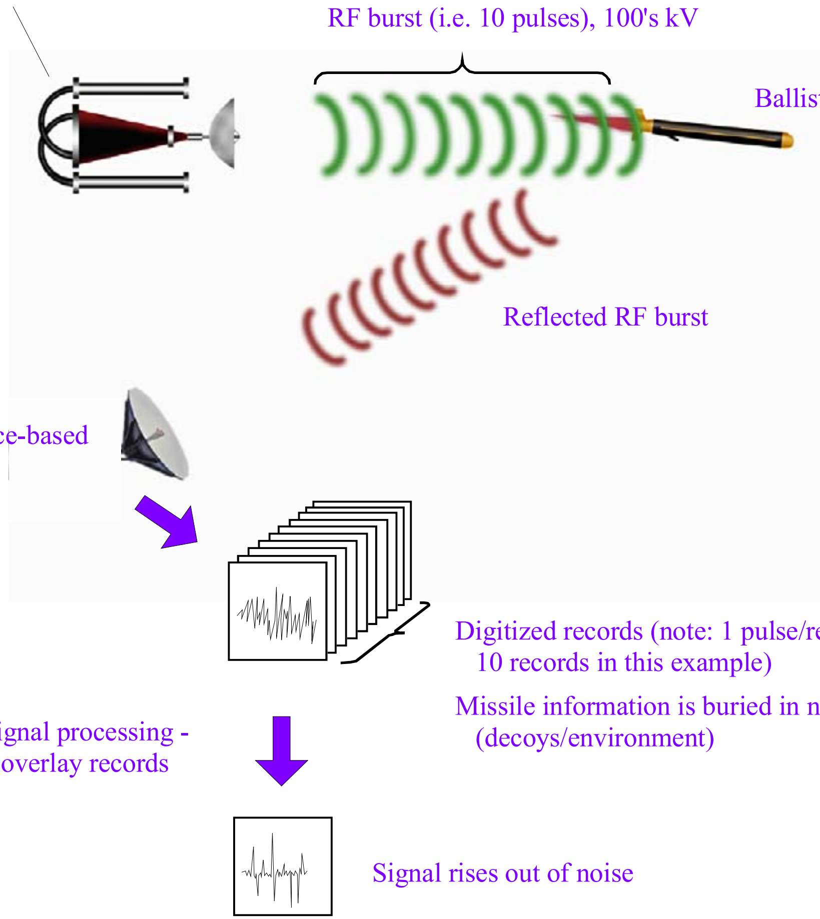
Narrow Band HPM: Gatling-Styled



A sample 3-pulse radiatiating signal



Proposed Gatling Applications



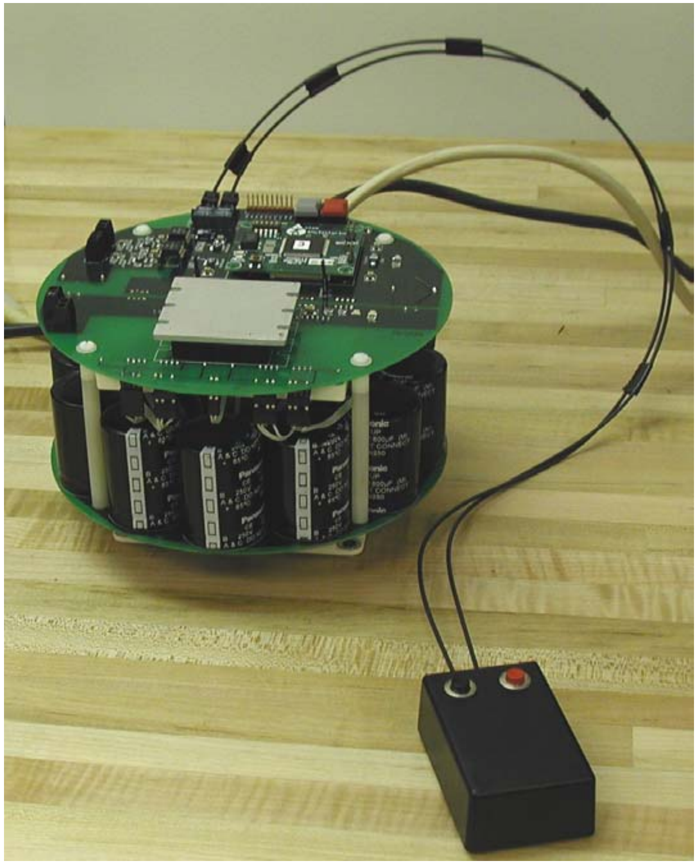
Deployment:

- Miniature vehicles
- Unmanned aerial vehicles
- Manned aircraft
- Missile based
- Ground based, mobile or static (border)

Power Supply Development

- APELC currently has Texas Tech University under contract for the development of their rapid capacitor charging power supply (Michael Giesselmann)
- APELC plans to commercialize the supply

- Power supply features
  - 50 kV peak voltage
  - 270 Vdc supply voltage
  - 10 kJ/s energy delivery
  - 1 kJ @ 10Hz repetition rate
  - Fiber optic control
  - Package diameter = 8 inches
  - Package length = 12 inches



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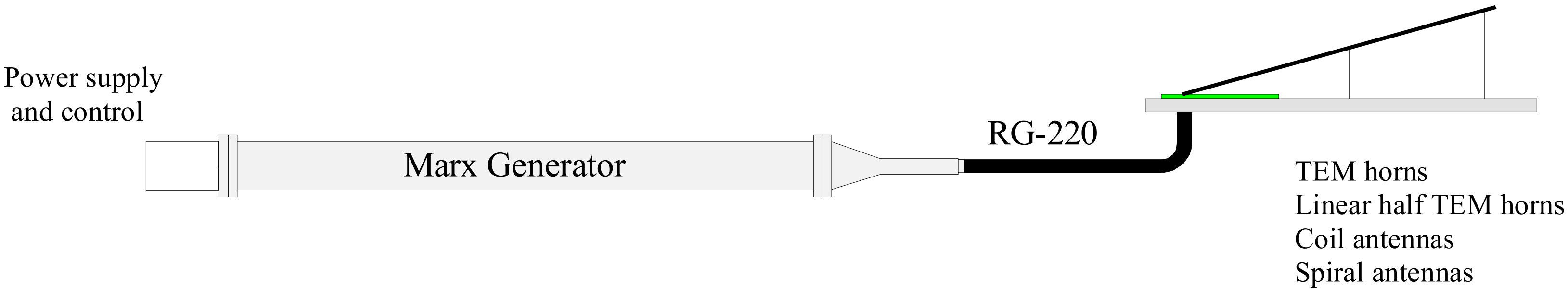
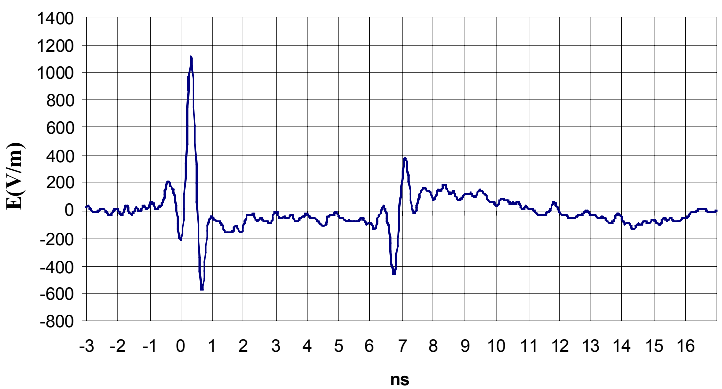
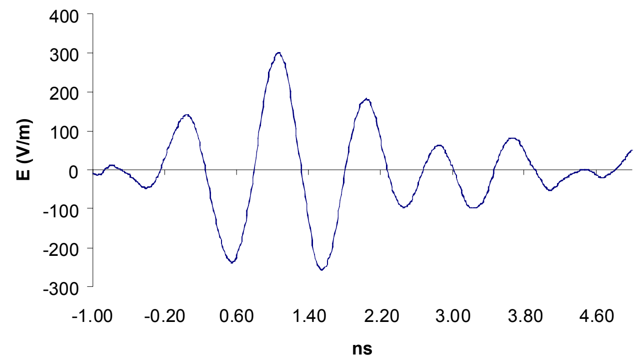
Direct Generation of RF





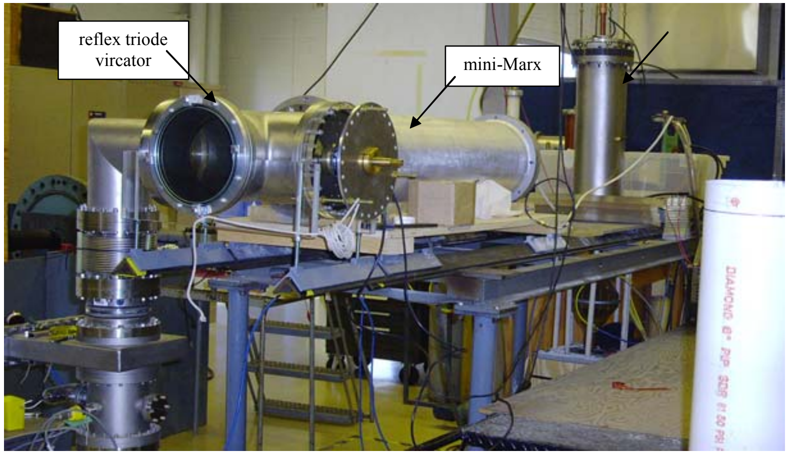


- Linear half TEM antenna
- Ultra Wide Band radiation
- E-field: 1200 V/m measured at 100 m
- Source voltage ~ 175 kV
- E-field goal of 10 kV/m at 100 m

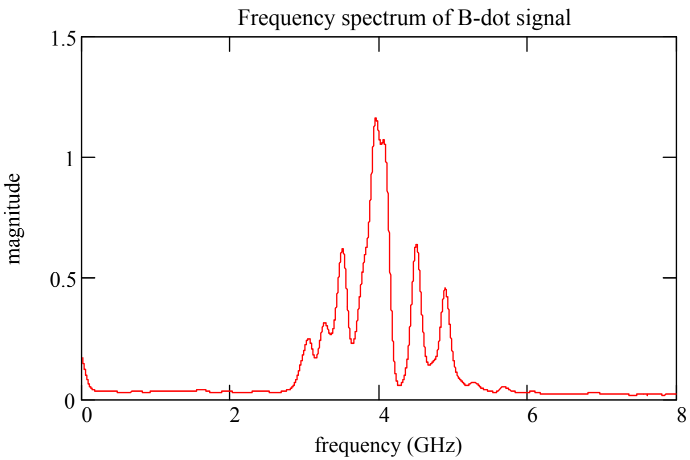
- 1 GHz coil antenna
- Narrow Band radiation
- Source voltage ~ 175 kV
- E-field: 350 V/m measured at 100 m
- E-field goal of 3 kV/m

High Power Microwave

- APELC has moved into the HPM market
- Initial effort with Texas Tech University
  - APELC's compact Marx generator
  - TTU's compact power supply
  - TTU's Vircator design
- Effort now being moved forward by APELC
  - Promise of power levels reaching several hundred MW to GWs



Experimental setup



Spectral output

High Power Microwave – Current Efforts

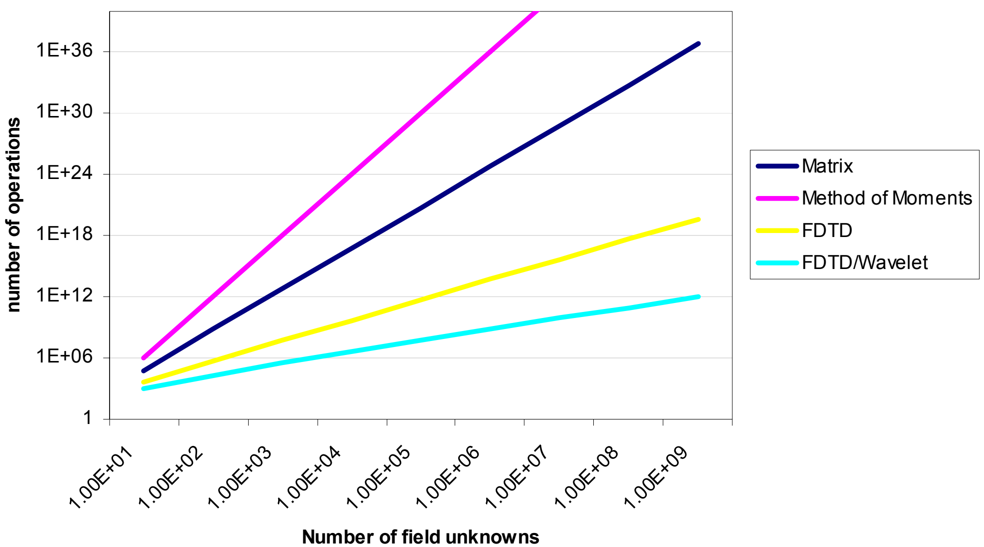
- APELC currently developing an HPM source based on the 1.6 MV Marx generator. Anticipated results include:
  - Load voltage ~ 500 kV
  - Vircator (axial design)
  - Expected efficiency of 15%
  - Radiated power of 1.2 GW
  - 40 ns pulse width

Photo of system

Computational Electromagnetics

- APELC has added computational E&M capabilities to complete staffing
- Recent efforts focused on highly-compressed FDTD field coding techniques
  - Wavelet-based image compression
  - Reduce the number of computations and required overhead
  - Wavelet image compression is a lossless compression technique
  - Make real time target prediction reality

Number of operations vs. Number of Field unknowns



Solution Method	***scaling factor***
Matrix	$6n^4$
Method of Moments	n^6
FDTD	$48n^2$
FDTD/Wavelet	$48*n*\ln(n)$

Summary

- APELC focus on compact pulsed power sources, ancillary drivers and loads
  - Marx generators directly driving high voltage impulse antennas
    - Narrow Band
    - Ultra Wide Band
  - Marx generators directly driving vacuum diode loads
    - Virtual cathodes (Vircators)
    - Magnetically Insulated Line Oscillators (MILOs)
    - Flash x-ray sources
  - Compact power supplies
  - RF and HPM load development
  - FDTD code with compression techniques (wavelet image signal processing)