

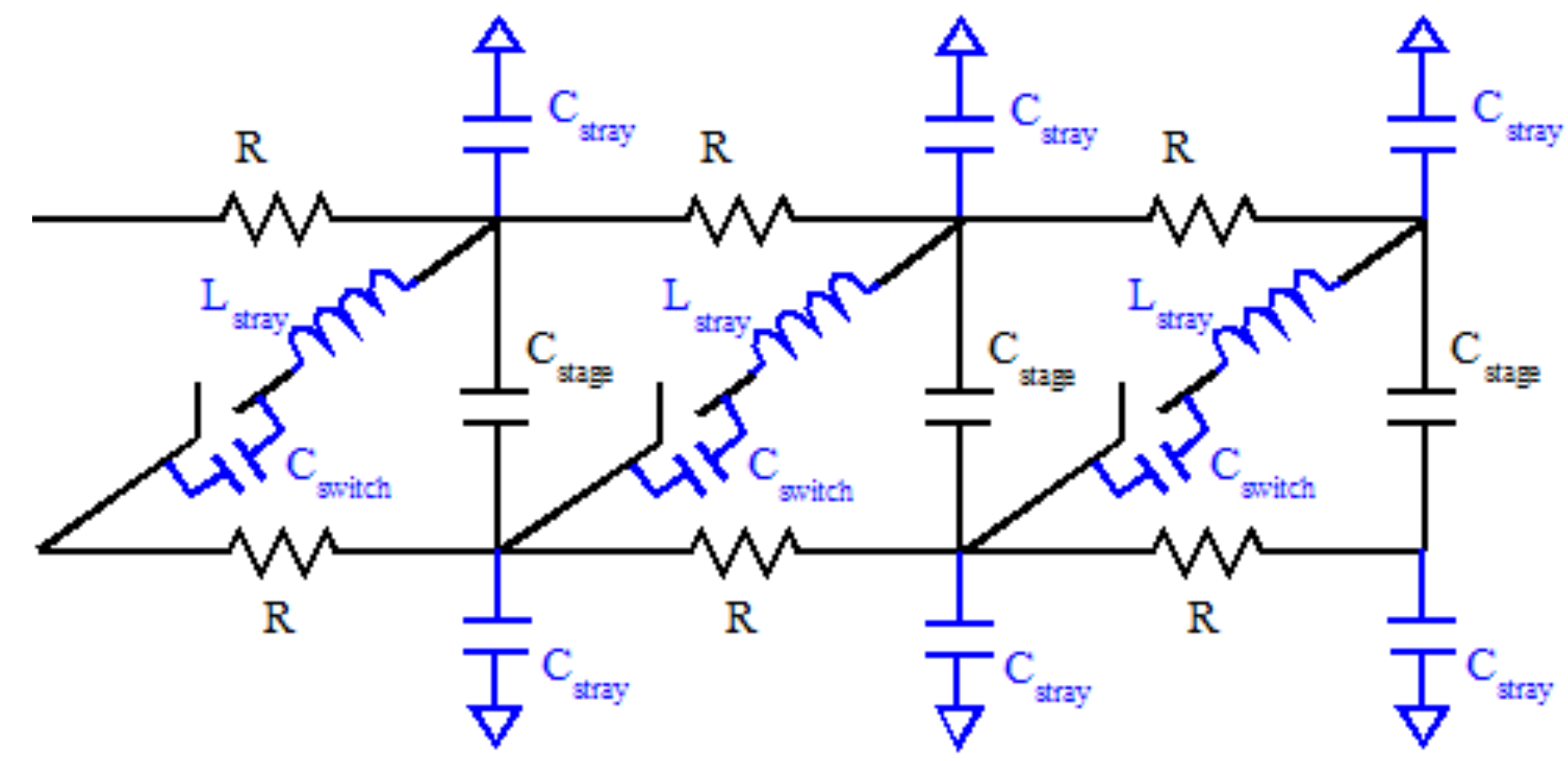
Compact Flash X-ray Systems for Radiographic Applications

Abstract

Recent developments in Marx generator technology has led to ultra compact geometries and enhanced performances, which has forge new applications for this type of generator. Applied Physical Electronics, L.C. has been a leader in the new developments of the Marx generator, making devices that are man-portable, battery operated for low average power applications and extremely fast. APELC has recently begun making strides in developing ultra compact flash x-ray loads to directly mate to their generators. This paper discusses the generators and the diode development

Background

The wave-erection Marx generator



General operation – charge capacitors in parallel.

Simultaneous closure of the switches momentarily adds voltages for short duration voltage multiplication.

Wave erection – comes with proper design of the stray components. The switches sequentially close, leading to ultra-fast voltage risetimes, increased efficiency, and ultra-compact geometries

System Characteristics

The developed compact MV Marx generator system offers many improvements over typical compact systems, including:

- a rugged and modular stage design for easy maintenance and high mechanical strength for field use
- Inductive charging elements for low charging losses and high repetition rate operation
- Modular output interfaces allowing for a multitude of load devices to be interchangeable (i.e. flash x-ray, cable, RF),
- Integrated ancillary components including power supply, voltage controlled air regulator and trigger source,
- Imbedded controller leading the way to smart (autonomous operation,
- A variety of controller interfaces including RS-232 (optical link), manual control box (fiber link), or manual front panel.

APELC Marx Generators – Designed for Flash X-ray Systems

Model MG40-3C-2700PF – Specifically designed for sourcing flash x-ray diodes, with open circuit voltages in excess of 1.6 MV, and diode conduction voltages of more than 600 kV. This generator two man-portable and can be operated from battery power. With larger power sources, this generator can be operated with repetition rates of more than 50 Hz.

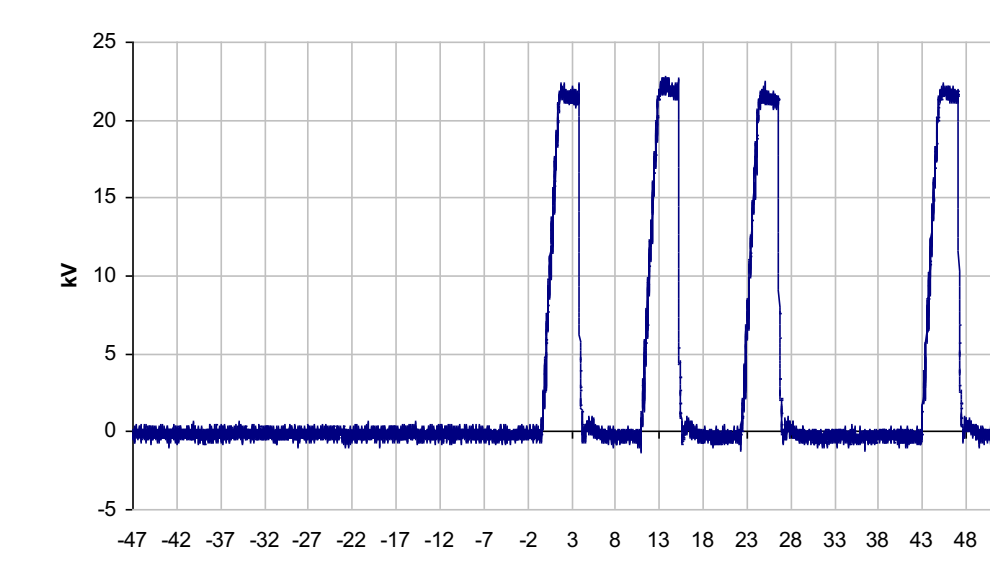
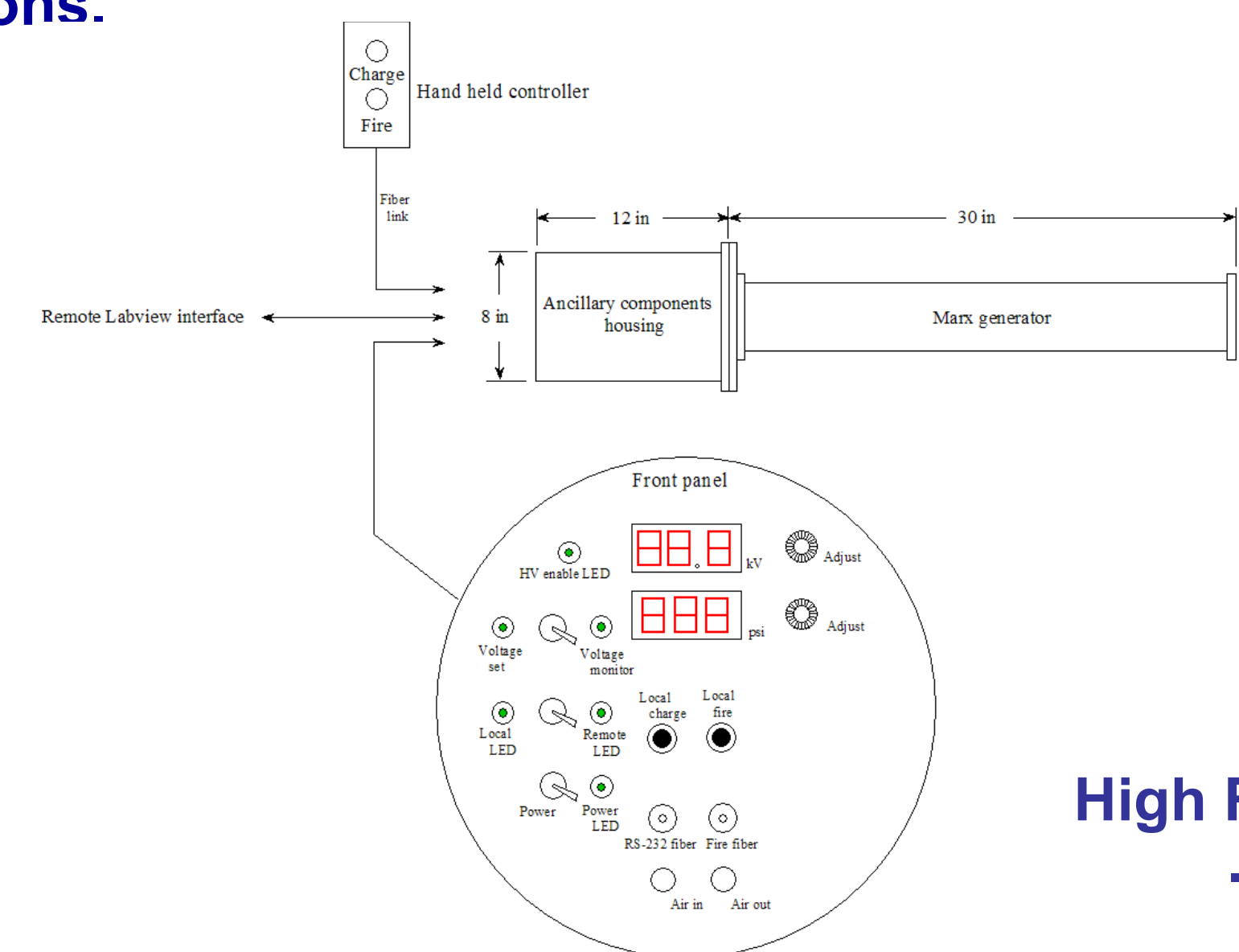
Parameter	Description	Value	Unit
V _{open}	Open circuit voltage	1600	kV
V _{ch}	Maximum charge voltage	40	kV
N	Number of stages	40	—
N _{cap}	Number of capacitors per stage	3	—
C _{stage}	Capacitance per stage	8.1	nF
C _{marx}	Erected capacitance	203	pF
L _{marx}	Erected series inductance	1	uH
Z _{marx}	Marx impedance	70	Ohm
EFF _{volt}	Voltage efficiency into 50 Ohm load	42	%
P _{power}	Peak power	15	GW
E _{marx}	Energy stored in Marx	260	J
T _{ch}	Time to charge	25	ms
T _{RR}	Maximum repetition rate	30	Hz
P _{ave}	Average power	10	kJ/s

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

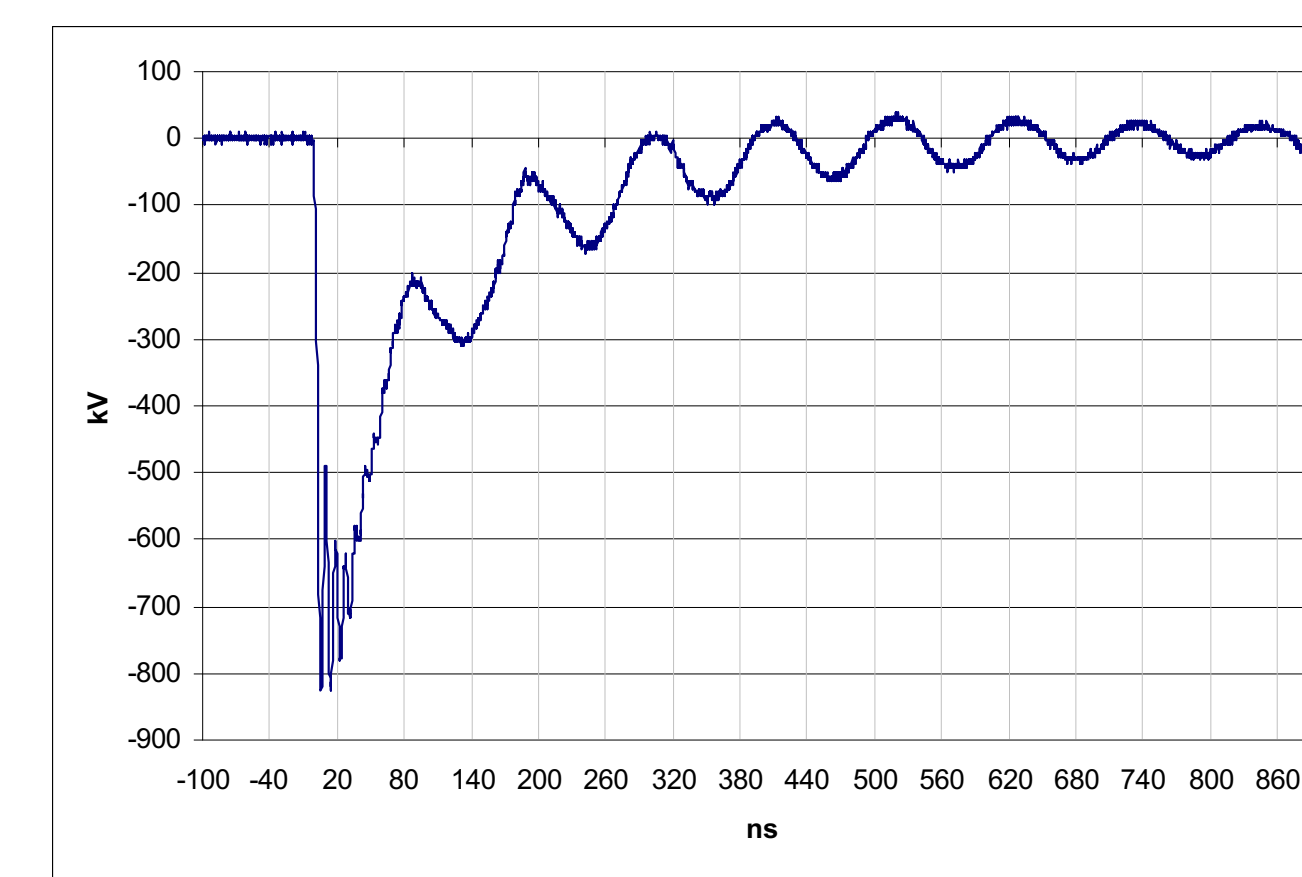
Model MG15-3C-940PF – designed as a multi-purpose generator for a wide variety of applications, from triggering, the direct generation of RF and vacuum diode applications, such as with x-ray diodes. This generator operates with high repetition rates (> 250 Hz) with a suitable power supply; but also operates under battery power for less demanding applications. This supply matches well with a 50 Ohm cable, leading to cable fed load applications.

Parameter	Description	Value	Unit
V _{open}	Open circuit voltage	600	kV
V _{ch}	Maximum charge voltage	40	kV
N	Number of stages	15	—
N _{cap}	Number of capacitors per stage	3	—
C _{stage}	Capacitance per stage	2.82	nF
C _{marx}	Erected capacitance	188	pF
L _{marx}	Erected series inductance	526	nH
Z _{marx}	Marx impedance	53	Ohm
EFF _{volt}	Voltage efficiency into 50 Ohm load	48	%
P _{power}	Peak power	950	MW
E _{marx}	Energy stored in Marx	33	J
T _{ch}	Time to charge	2	ms
T _{RR}	Maximum repetition rate	200	Hz
P _{ave}	Average power	6600	J/s

Parameter	Description	Value	Unit
L _{marx}	Marx length	30	in
D _{marx}	Marx diameter	5	in
L _{ps}	Power supply length	12	in
D _{ps}	Power supply diameter	9.5	in
Wt	System weight	30	lbs

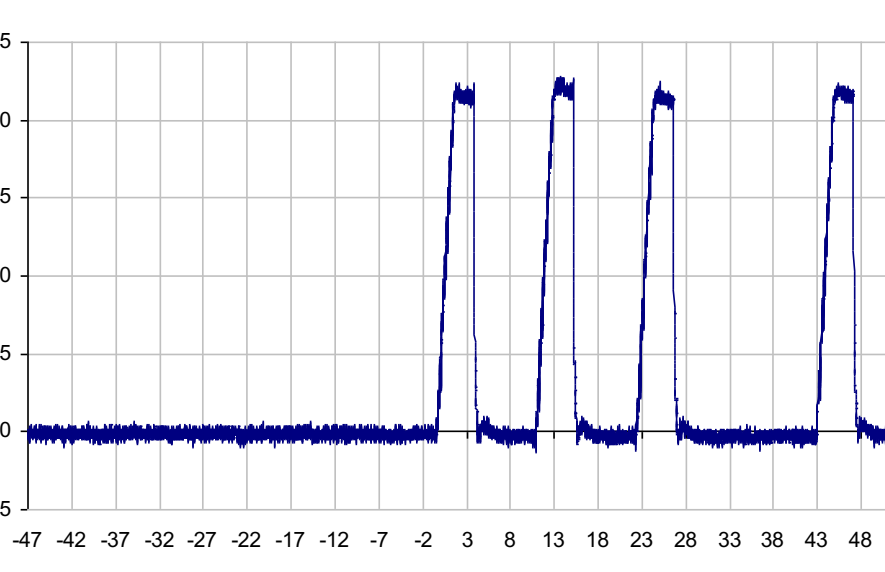


Sample voltage waveform with a 50 Ohm cable load



V_{charge} = 45 kV
 T_{width} ~ 20 ns
 P_{peak} = 12.8 GW

V_{pulse} ~ 800 kV
 E_{pulse} = 330 J

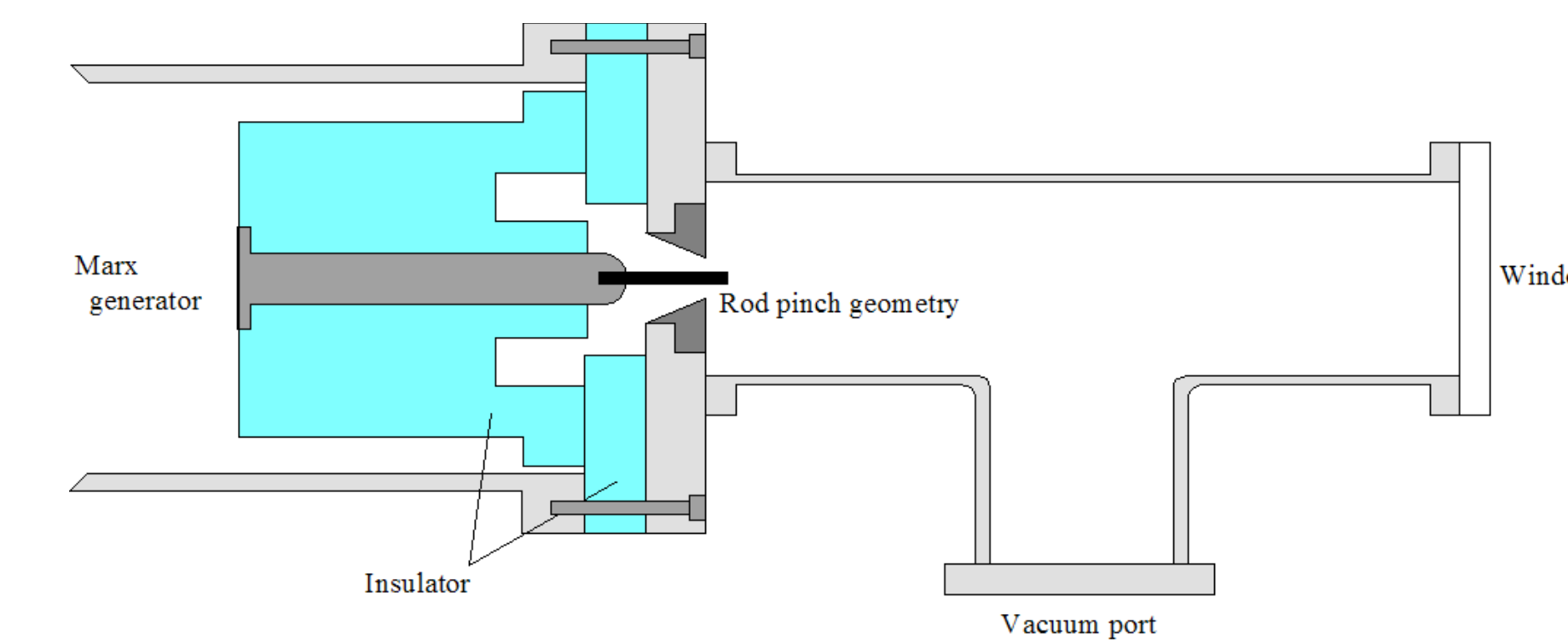


High Repetition Rate Operation

- Load = 50 Ohm (close match to generator)
- External thyatron trigger
- External 4 kJ/s power supply
- Demonstration at V_{charge} = 24 kV
- Published repetition rate of 100 Hz (continuous)
- A 200 Hz repetition rate observed

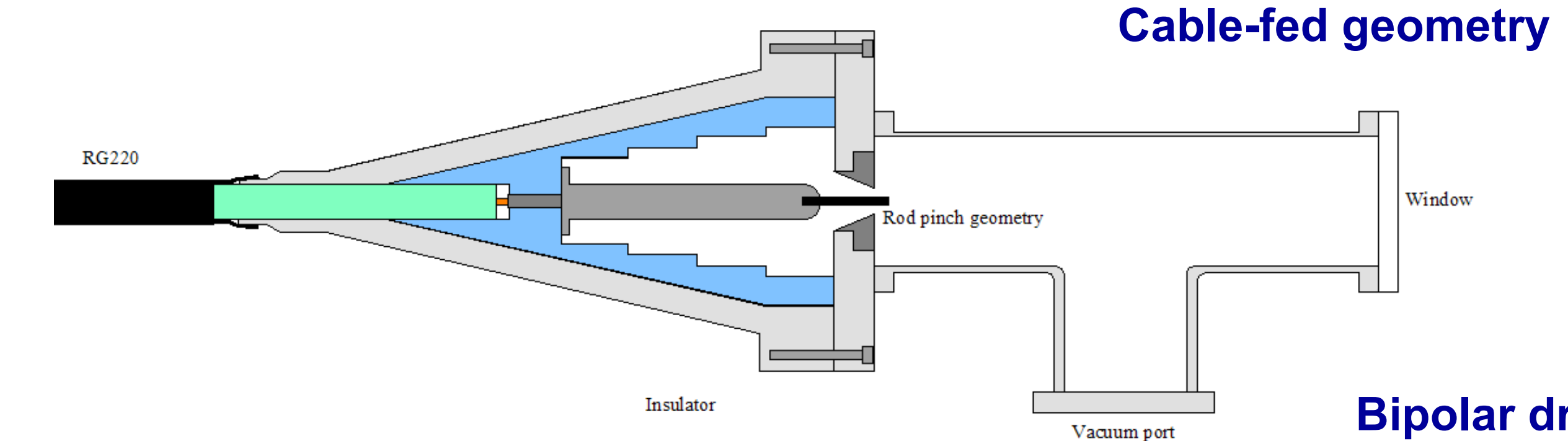
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Integrated X-ray Load

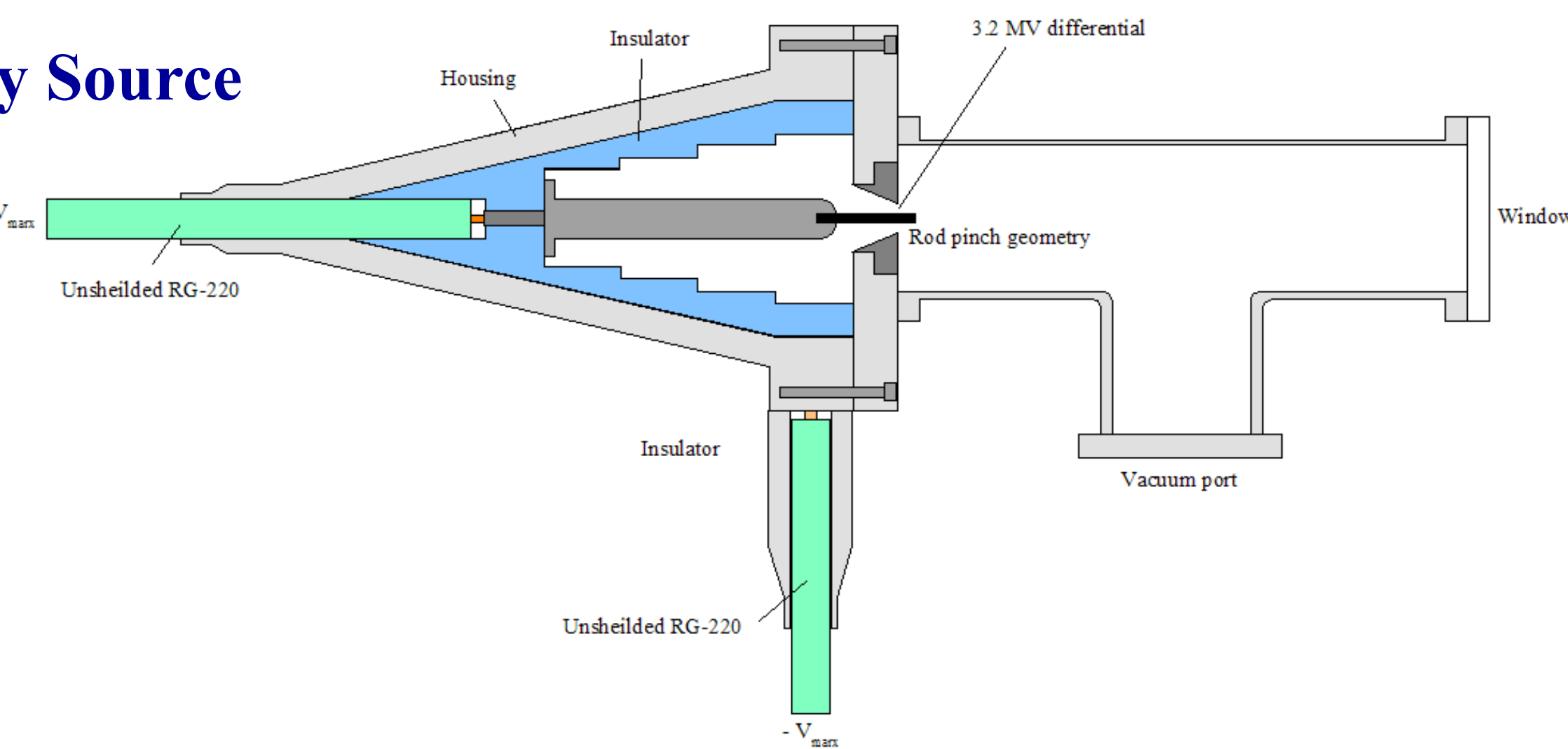


- Rod-pinch geometry
- Modular/interchangeable load
- Same “quick-change” interface for both HPM, x-ray, and cable load
- X-ray load testing underway

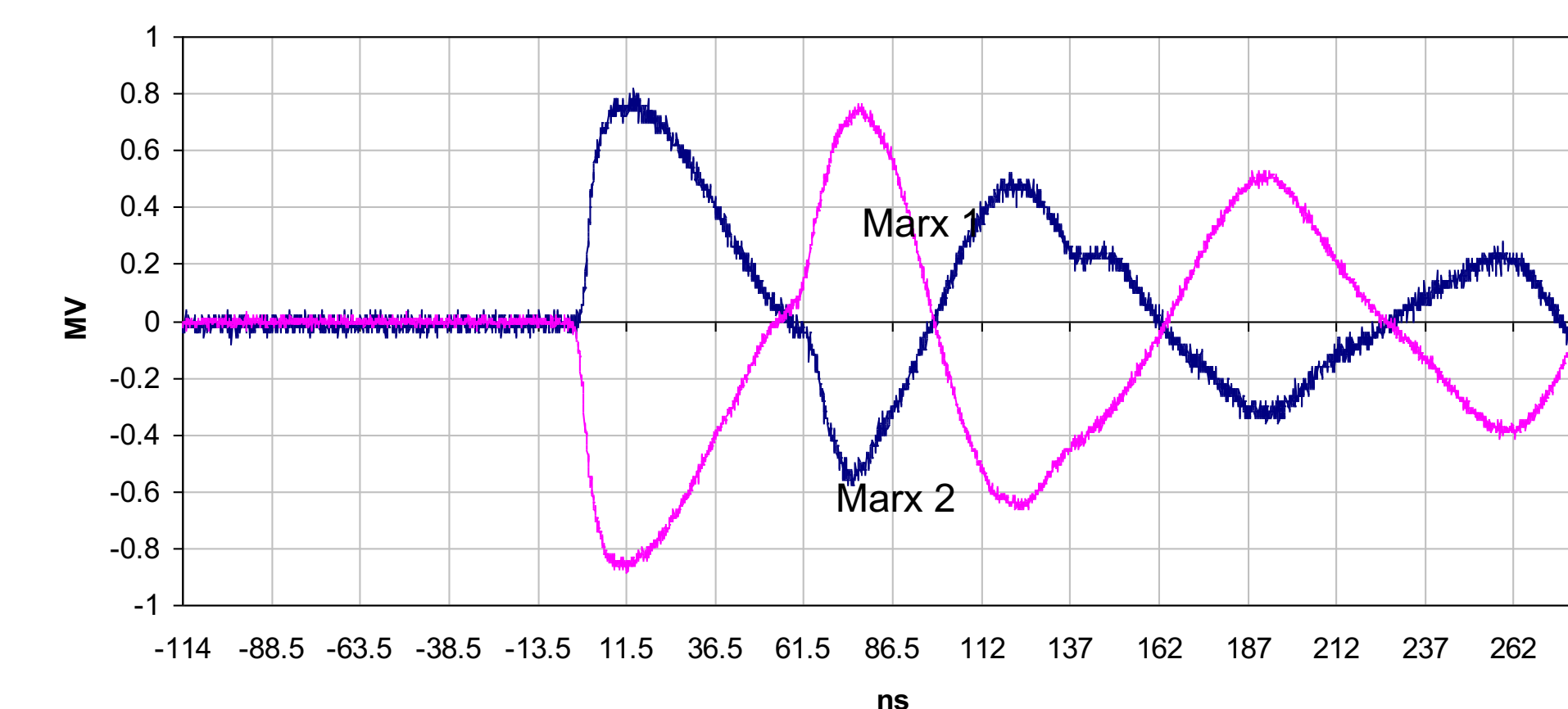
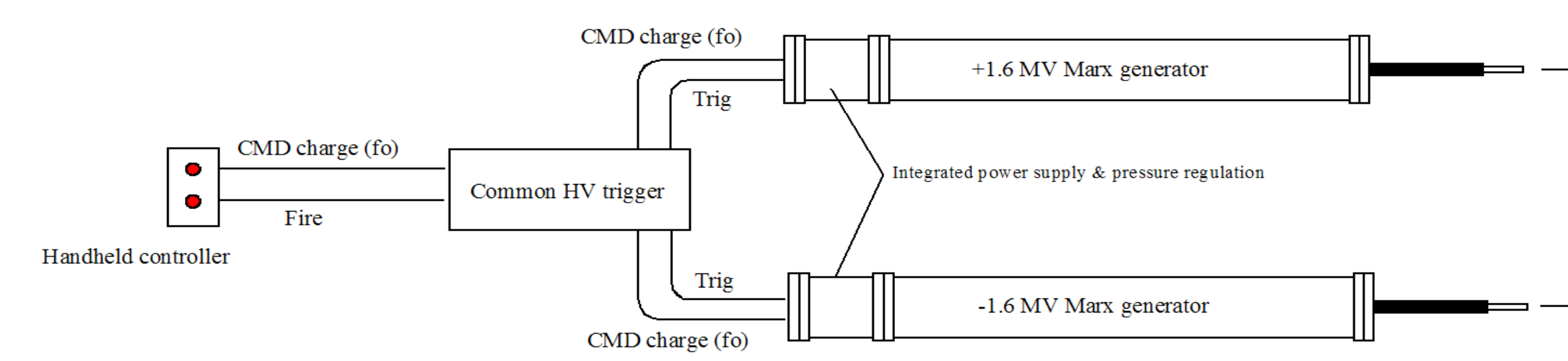
Cable-based X-ray Load



Bipolar driven 3.2 MV diode geometry



Development of a Dual Polarity X-ray Source



Un-calibrated CVR probes, mounted on coaxial cables (looking for waveshape and temporal information)

Temporal jitter < 10 ns with +/- 30 kV charge (or greater)

Load highly inductive (and produces BIG arc, hearing protection desirable)

Discussion

This paper has presented two Marx generators well suited for ultra-compact, man-portable flash x-ray applications. APELC's MG15-3C-940PF generator offers advantages in portability, weighing less than 30 lbs, this generator can easily be placed in an infinite orientations. And with its capabilities in high repetition rates, higher doses are achievable. APELC's MG40-3C-2700PF generator is unmatched in other commercially available generator, with erected voltages in excess of 3.2 MV, battery-powered and two-man portable, this generator is ideal for flash x-ray applications.

More recently, APELC has developed a dual polarity MV system, employing two MG-3C-2700PF generators charged with opposite polarity voltages. With a common trigger source, the generators deliver nearly simultaneous pulses, with less than 10 ns temporal jitter.

APELC now reports development of flash x-ray diodes based on the rod pinch concept. These diodes are being developed with compactness and interchangeability, to meet the design guidelines used in the successful development of the Marx generators. Three topologies are presented and include the direct connection diode, the cable fed geometry and the dual polarity geometry. These geometries are currently in the design process and experimental results are expected in the next year.