Design, Construction, Testing and Experiments with a new compact X/Z-pinch driver at IAC

Roman Shapovalov

Wendland Beezhold

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Outline

1. Introduction to X -Pinch / Z – Pinch

   (what and why)

2. Possible designs at IAC

   1st plan: ISIS ICD modification

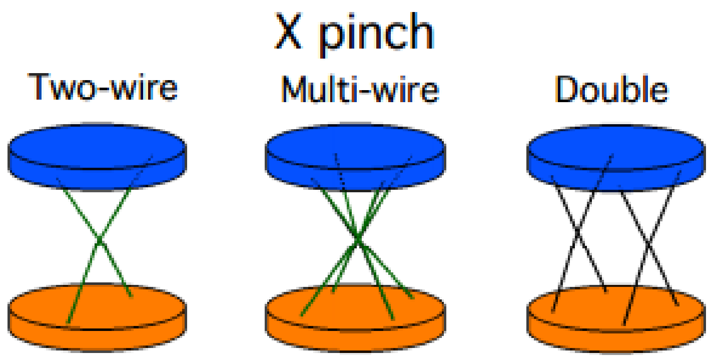
   2nd plan: separate Marx + PFL

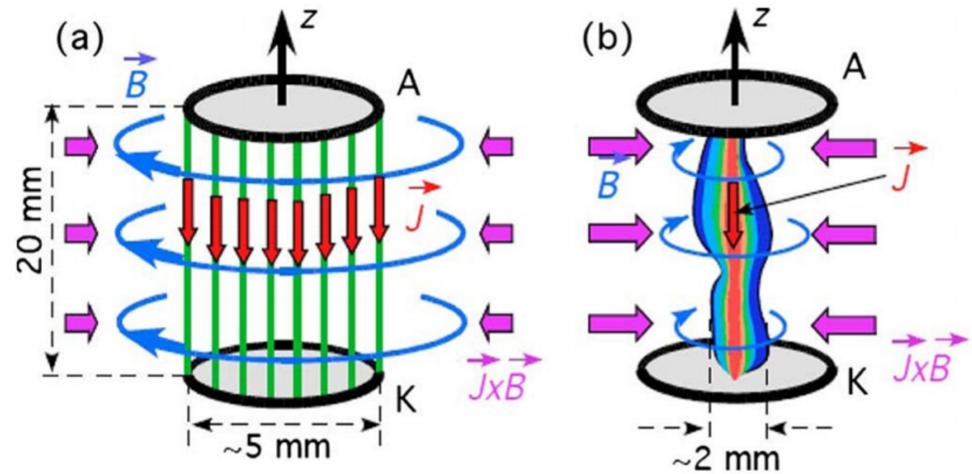
   3rd plan: new Compact PRS

   4th plan: new LTD cavity

3. Conclusion

What is X – Pinch / Z - Pinch





* two or more 5 – 100 um metal wires crossed at one point

* 100 – 300 kA, 1 kA/ns and more

* small (few um),
  bright (hundreds of mJ)
  and short (0.1-10ns) X-ray source

* cylindrical one or more metal wire array

* 1 MA and more current

* short duration, high power (hundreds of TW) radiation pulse

a)b) J. L. Giuliani and more, J.L. IEEE Transactions on Plasma Science 40, 3246 - 3264 (2012)

Why is X- Pinch / Z – Pinch (Motivation)

X – Pinch Application:

* intense, short pulse X-Ray source
* fast diagnostic tools for pulsed hot/warm plasma
* high spatial resolution imaging
* weapon effect testing to simulate X-Ray and Neutron radiation from WMD
* and more

Z – Pinch Application

* Pulsed Fusion Energy (Z-Machine)
* Z - Pinch Dynamic – Hohlraums (DH) study
* wire initiation, ablation, implosion and stagnation research

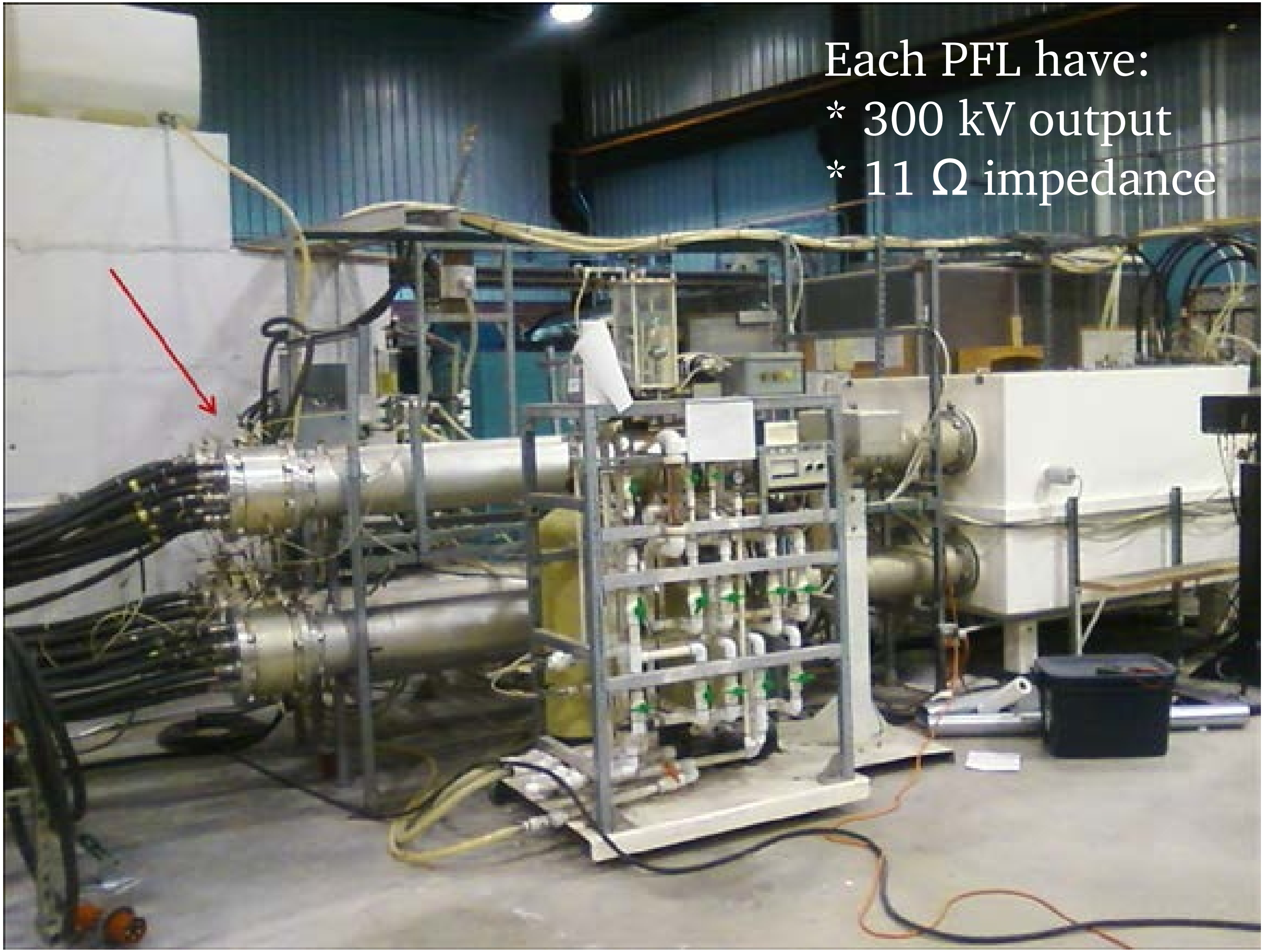
X – Pinch and Z – Pinch Application

* High Energy Density Physics (HEDP) Research
* Basic Plasma Physics Science (EOS, radiation mechanism, radiation transport, spectral properties, instabilities and more)

1st possible design for X-Pinch Driver:

Modification of ISIS Induction Cell Driver

ISIS Induction-Cell Driver: 5 Pulse Forming Lines



ISIS Induction-Cell Driver: X Pinch Radiation Source

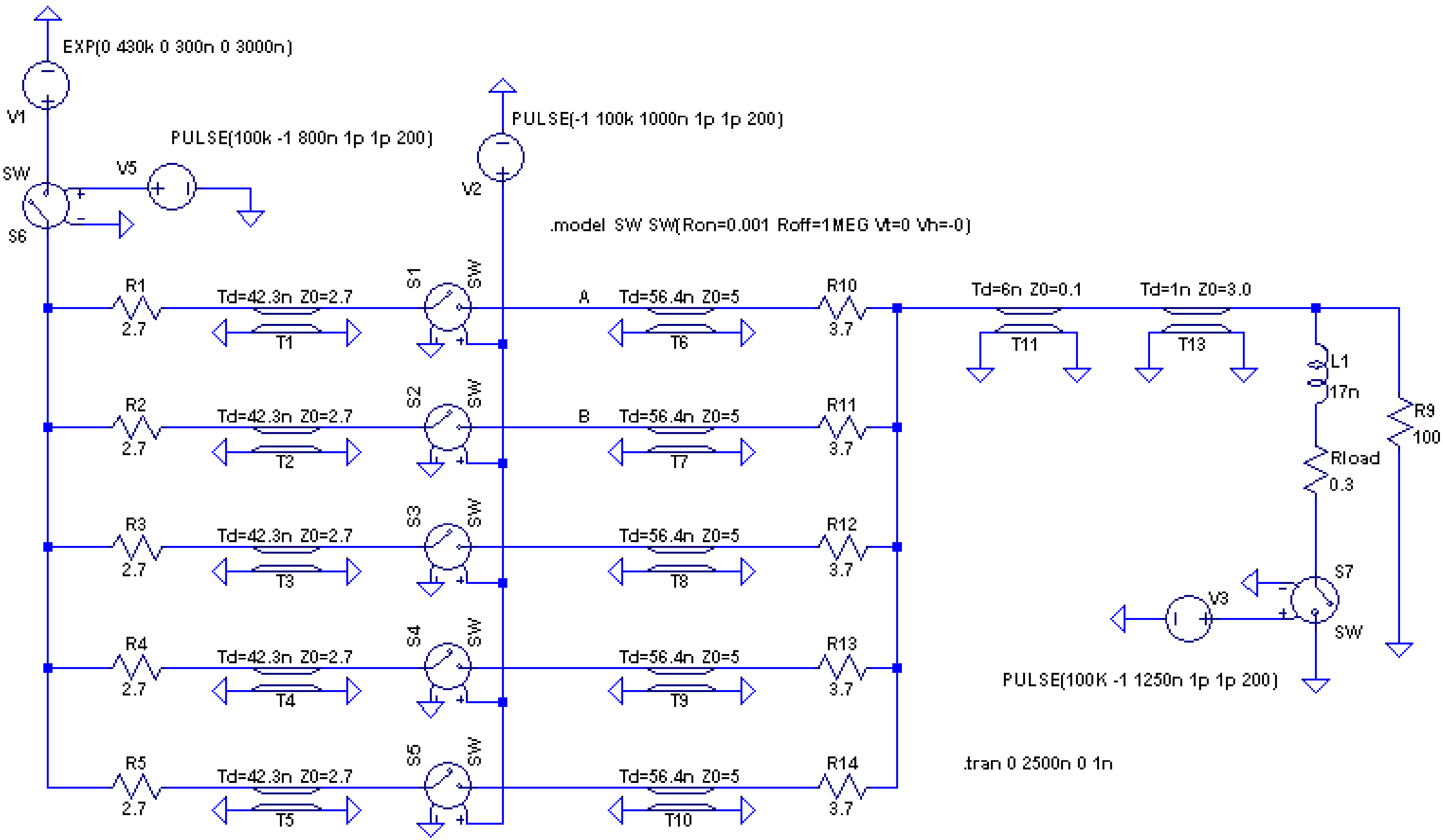
Step 1: Combine five 300 kV Pulse Forming Lines (PFLs) into one low impedance (< 1 Ohm) output (impedance transformer).

Step 2. Fed this transformer into Vacuum Chamber

Step 3. Maximize current at X – Pinch

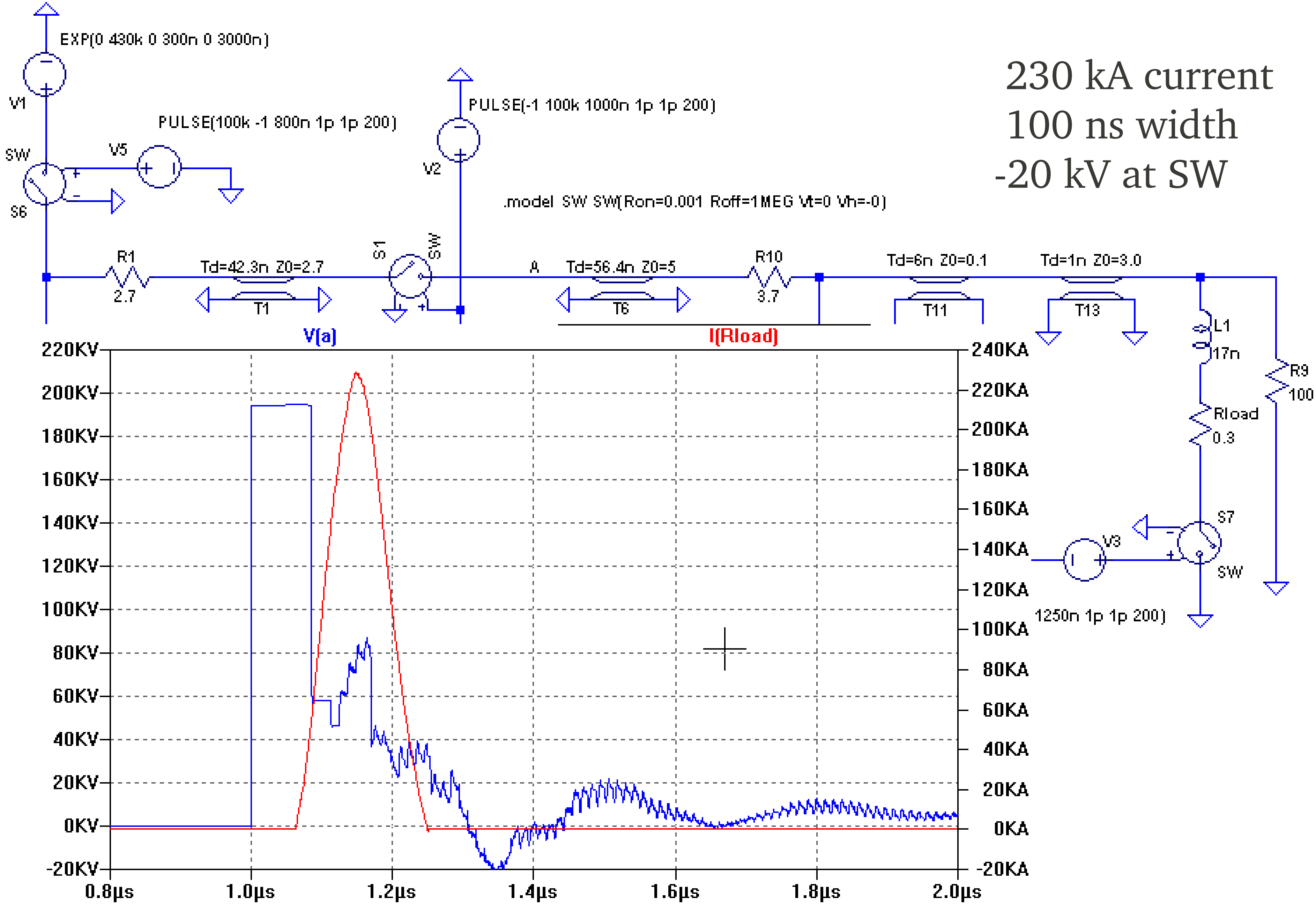
Design Criteria: simplicity, low-cost, high reliability, minimize the time to switch between the PRS mode and the normal operation mode of ISIS

LTSpice Simulation: model



LTSpice simulation: fire

230 kA current
100 ns width
-20 kV at SW



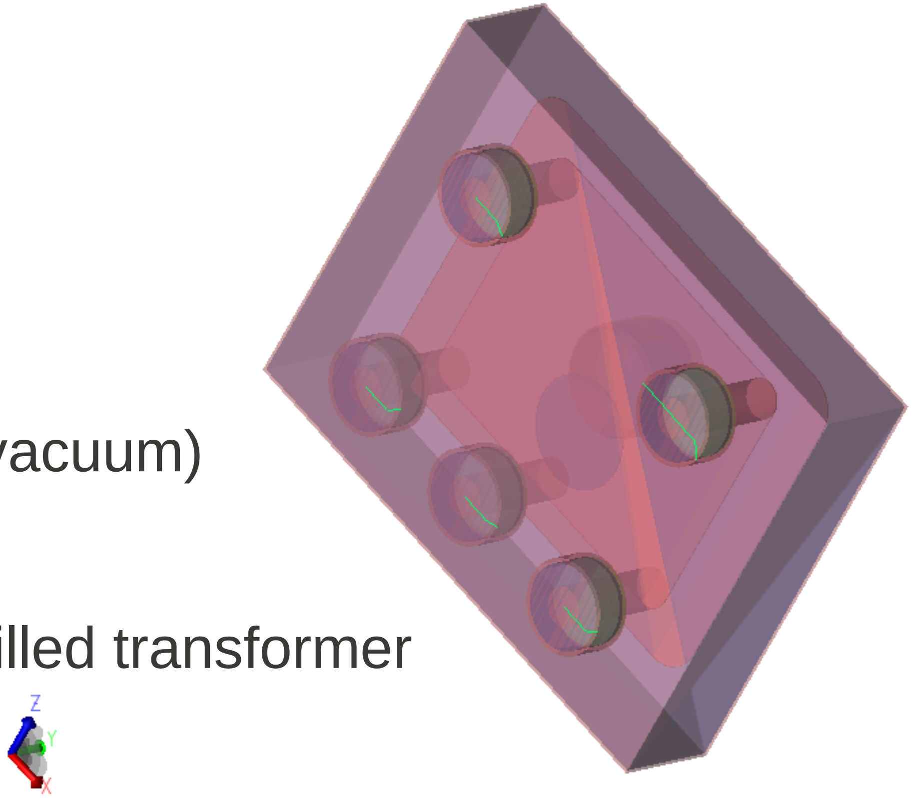
Modified ISIS Induction-Cell Driver: Transformer

$T = 6$ ns
$Z_0 = 0.1\ \Omega$

Transformer Length:

30 cm/ns * 6 ns = 180 cm (in vacuum)
180 cm / 9 = 20 cm (in water)

We can do 20 cm long water filled transformer



Transformer Impedance:

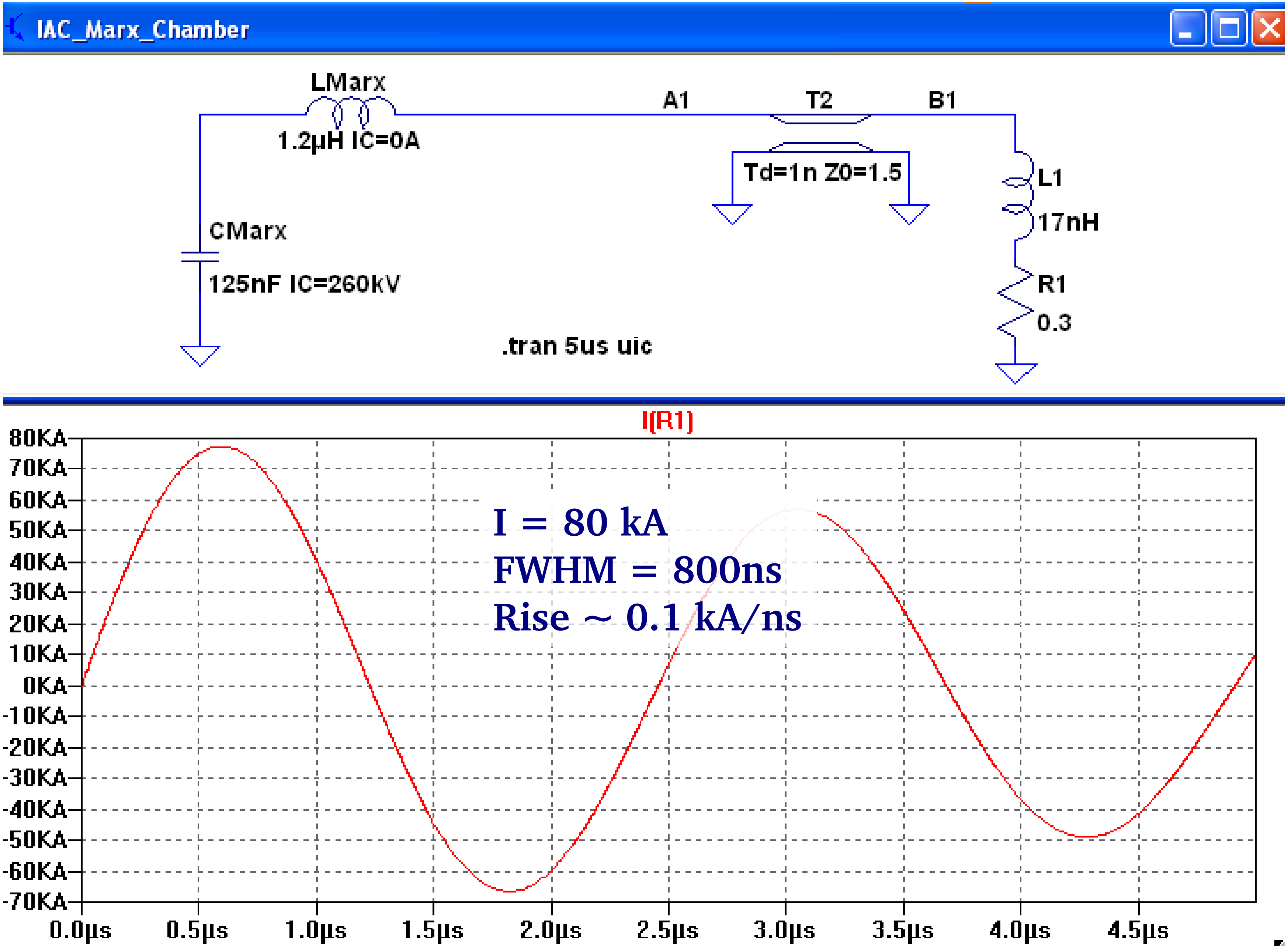
Z = L/C

Challenge to design, but can be done with XFdtd

2nd possible design of X-Pinch Driver:

Construct separate Marx generator with Pulse Forming Line

MARX + Vacuum Chamber

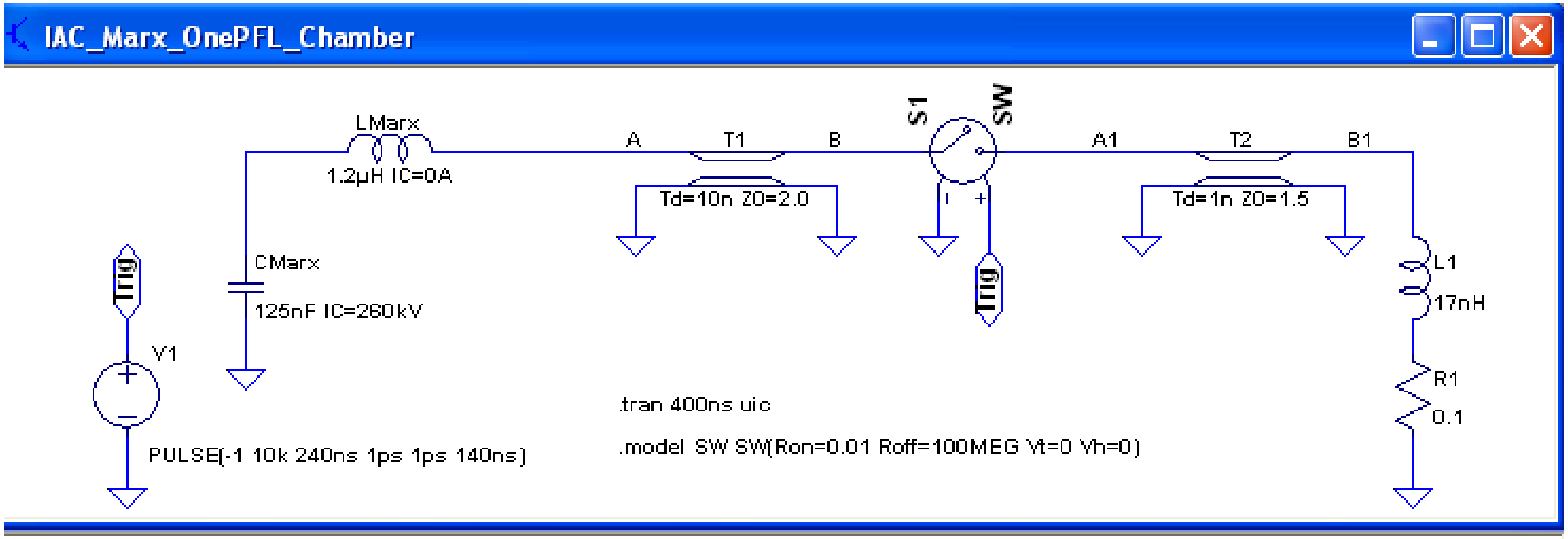


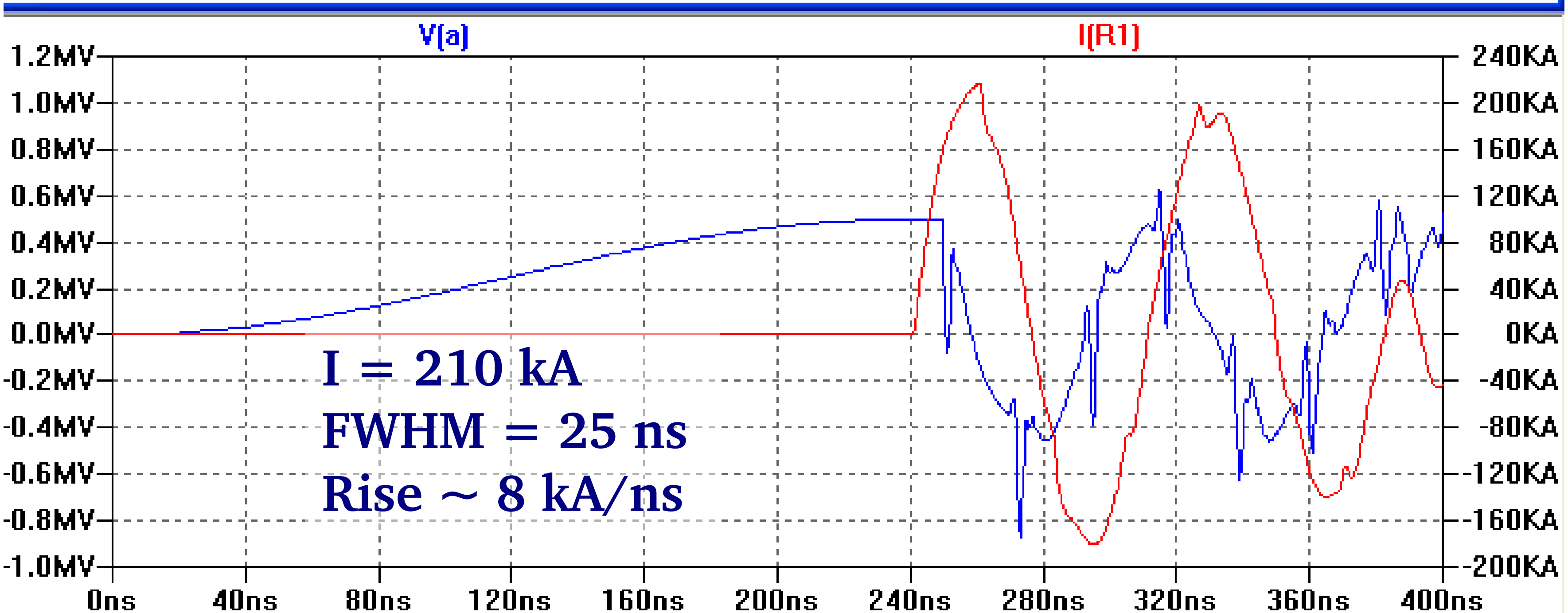
I = 80 kA

FWHM = 800ns

Rise ~ 0.1 kA/ns

MARX + one PFL + Switch + Vacuum Chamber





3rd possible design of X-Pinch Driver:

No Marx generator

No Pulse Forming Line

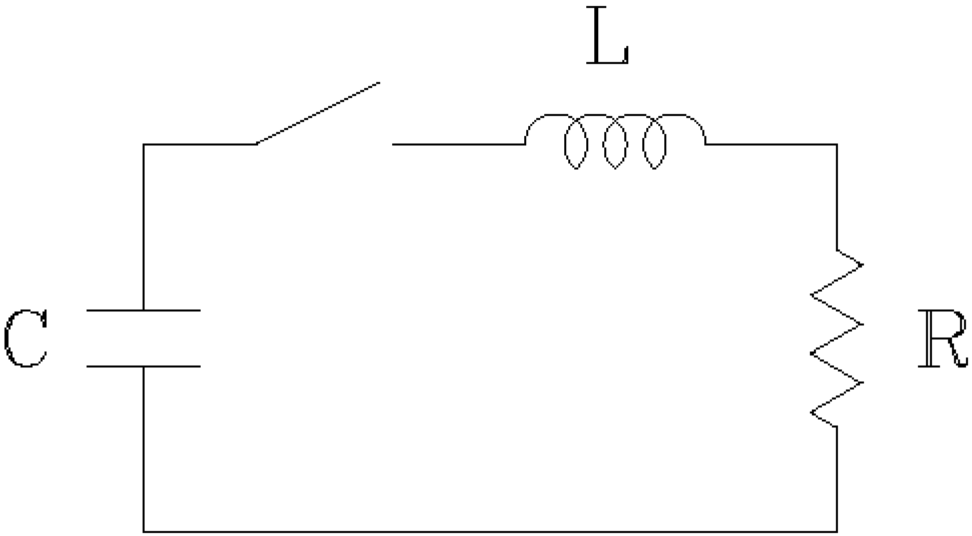
instead utilize the advantage of

a new low inductance

capacitors and switches

to build a compact PRS

LRC circuit basics*



$$L\,d^2 i/d^2 t + R\,di/dt + i/C = 0$$

"Damped"

$$R = \sqrt{L/C}$$

$$v_{peak} = 0.546293\,V_0$$

$$i_{peak} = 0.546293\,V_0/R$$

$$t_{peak} = 1.2092\sqrt{LC}$$

"Critical Damped"

$$R = 2\sqrt{L/C}$$

$$v_{peak} = 0.73576\,V_0$$

$$i_{peak} = 0.73576\,V_0/R$$

$$t_{peak} = \sqrt{LC}$$

*M.G.Mazarakis, and R.B.Spielman "A compact, high-voltage E-beam pulser" 1999 IEEE

General Atomics Electronics System: Capacitors*

Series PDS/PDSS - Fast Pulse Capacitors

Double-Ended Plastic Case Capacitors
Low Inductance, Low ESR (0.06 - 0.13 Ω)
Sub-microsecond pulse risetime to 100 kV

Part Number	Cap Rating (nF)	Voltage Rating (kV)	Rated Peak Current (kA)	Rated Voltage Reversal (%)	Design Life (at Rated VR)	Operating Temp Range (°C)	Approx. Inductance (nH)
35460	8	100	25	20	1×10^5	-10 to +40	6
35467	20	100	25	10	1×10^5	-10 to +40	6
35473	40	100	25	10	5×10^4	-10 to +40	10
35479	80	100	25	10	4×10^4	-10 to +40	8
35478	80	100	60	30	5×10^4	-10 to +40	10
35462	100	100	25	10	3.4×10^4	-10 to +40	10
35477	100	100	50	45	5×10^3	-10 to +40	10

*http://www.ga-esi.com/EP/capacitors/series-pds.php

Four capacitors 35478

Capacitor 35477: $C_c = 80\,nF,\, L_c = 10\,nH,\, V_0 = 100\,kV,\, I_c = 60\,kA$

Switch: $L_{sw} = 10\,nH$

With 4 such capacitors we can built 200 kA, 0.25 Ω generator

$I_{peak} = 200\,kA$

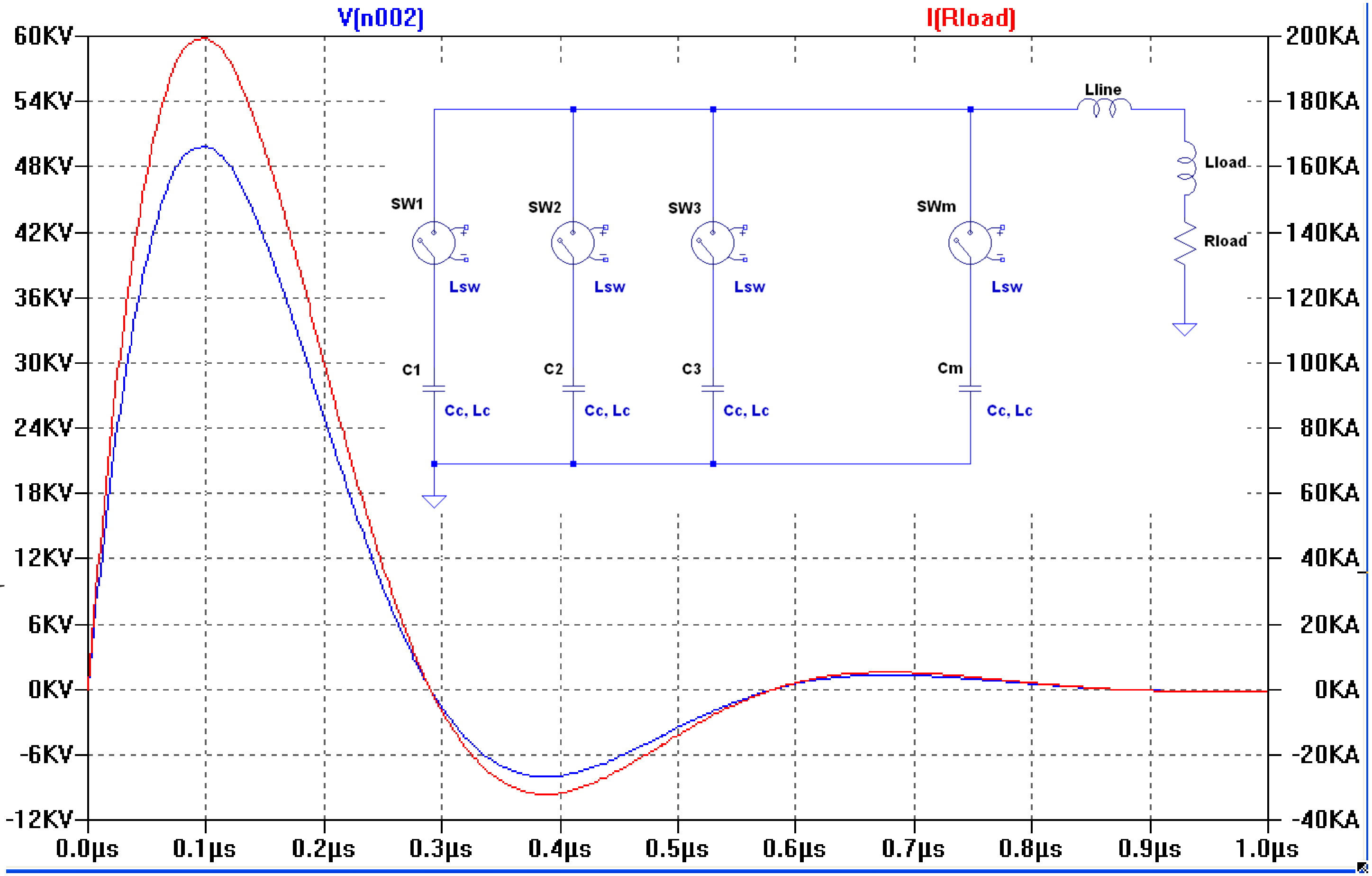
$V_{peak} = 50\,kV$

$t_{peak} = 97\,ns$

$2.06\,kA/ns$

$L_{load+line} = 15\,nH$

$R_{load} = 0.25\,\Omega$



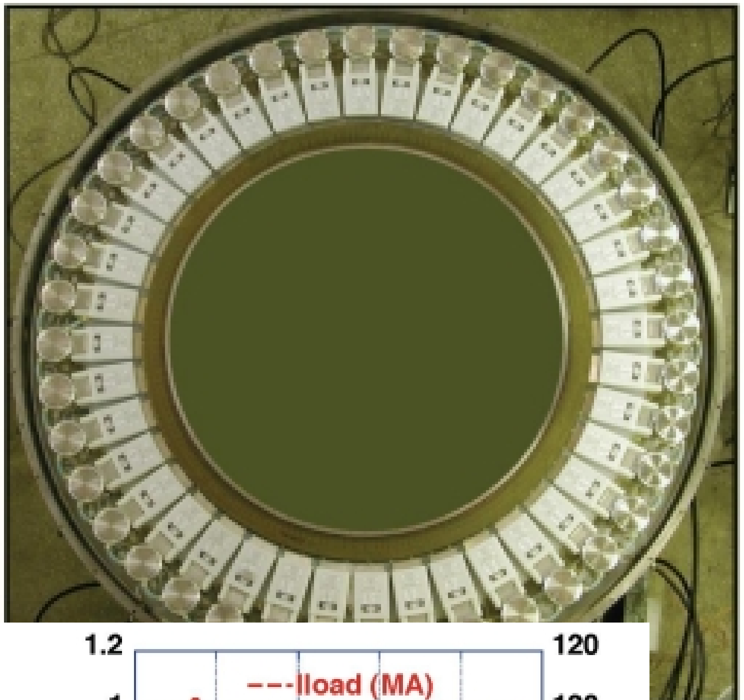
4th possible design of X-Pinch Driver:

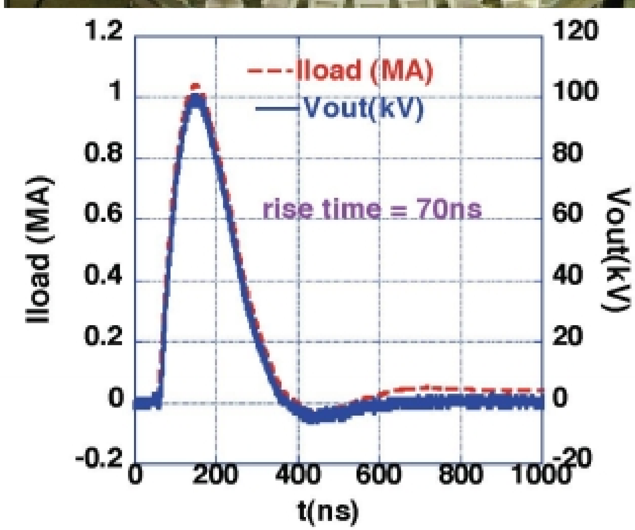
We can use a complete

Linear Transformer Driver (LTD) Cavity

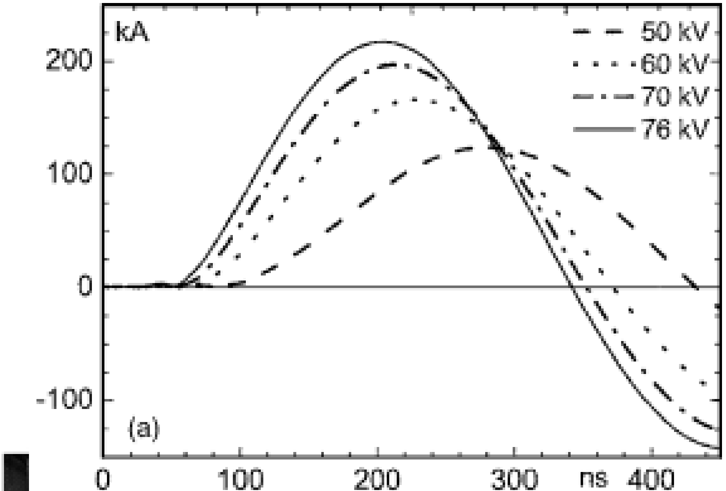
to build X/Z – Pinch Driver

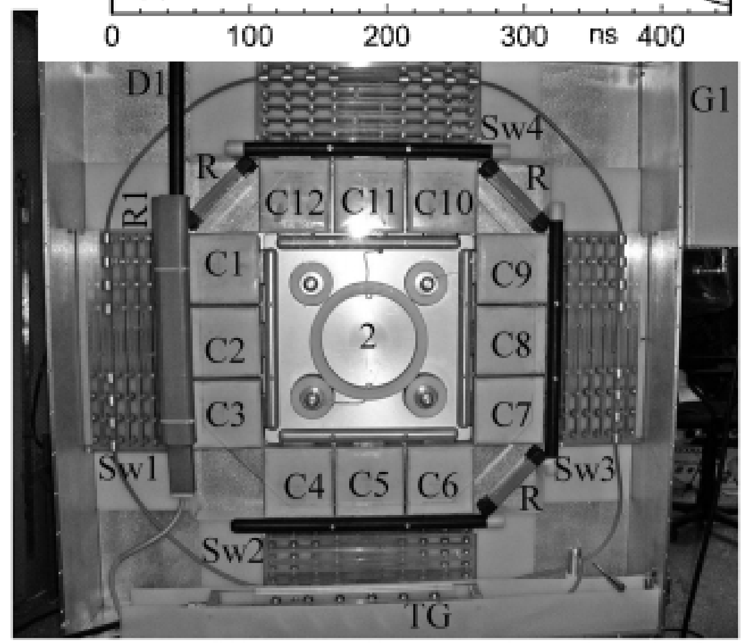
Sandia National Laboratory LTD Cavity *





Institute of High Current Electronics LTD Cavity **





* M.G. Mazarakis "High Current Fast 100-NS LTD Driver Development in Sandia Laboratory" 2005 IEEE

** A. V. Kharlov "Compact high current generator for x-ray radiography" Rev. Sci. Instrum. 77, 123501 (2006)

Conclusion

1. X /Z – Pinch Driver has many applications in different areas of research, starting from imaging, radiography and ending up with pulsed fusion energy research

2. We can actively participate in Pulsed Power Research by building one or more X/Z – Pinch Driver at IAC

3. At present moment, we can push four different plans:

* Modification of ISIS ICD
* Construction of separate Marx generator + PFL
* Utilize the new low inductance capacitor and switch technologies to build a compact PRS
* Acquire complete LTD cavity for X/Z-Pinch study

Z-Pinch/X-Pinch worldwide Installations

- Sandia National Laboratories, Z machine (1996), 18 MA 100ns [4]
- Sandia National Laboratories, ZR (Refurbished) (2006), 27 MA, 95ns
- Sandia National Laboratories, future ZN (Z Neutron), 20 and 30 MJ per short
- Sandia National Laboratories, future Z-IFE (Z-inertial fusion energy), 70 MA, 1 PetaWatt
- Sandia National Laboratories, SATURN, 8 MA
- Cornell University, USA: COBRA, 1 MA, 95-180 ns [5]
- Cornell University, USA: XP Pulser, 450 kA, 50 ns [6]
- University of Nevada, Reno: Zebra, 1MA, 100ns [7]
- University of California, San Diego: GenASIS, 210 kA, 150 ns [8]
- University of California, San Diego: X-Pinch Pulser, 80 kA, 50 ns [9]
- University of Michigan, USA: MAIZE, 1 MA, 100 ns [10]
- Florida A&M University: X Pinch system

- Pontificia Universidad Católica de Chile: Llampüdkeñ, 400 kA, 260 ns
- Pontificia Universidad Católica de Chile: GEPOPU, 180 kA, 120 ns

- Imperial College, London: MAGPIE, 1.4 MA, 240 ns [11]
- Imperial College, London: Table-top X-pinch, 40 kA, 30ns
- France?: PIAF, 250 kA, 180 ns

- Xi'an, China: QiangGuang-1, 1 MA, 50 ns
- Beijing, China: PPG-1, 400 kA, 100 ns
- CIAE, China: Light II-A, 200 kA
- Beijing, China: Table Top, 100 kA, 60 ns, 2m x 1.1m x 1.2m

- TRINITI, Russia: ANGARA-5-1, 4 MA, 100 ns [12]
- Institute of High Current Electronics, Russia: Compact Pulse Generator, 300 kA, 200 ns, 70 kg
- Institute of High Current Electronics, Russia: Compact submicrosecond, high current generator, 650 kA, 390 ns

THANK YOU