

# “The Importance of Ceramics in Pulsed Power Applications”

CDS October 2002 Meeting

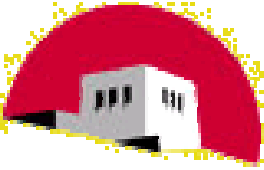
**Edl Schamiloglu, Professor and *Principal Investigator*,  
*FY'01 AFOSR/DoD MURI on Compact Portable Pulsed Power (CP<sup>3</sup>)*  
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## Report Documentation Page

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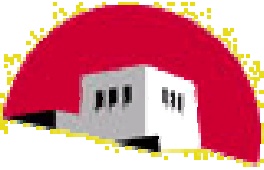
## CONCLUSIONS



**A revolution in pulsed power requires:‡**

- 1) High strength, high dielectric constant, high frequency components**
- 2) Architectures that reduce the number of compression stages**
- 3) Better switching**
- 4) Diagnostics: nondestructive testing and active prognostics**
- 5) Modularity**

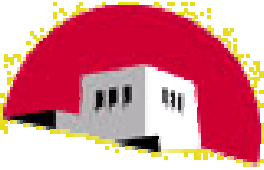
‡ Comments of Dr. Malcolm Buttram (Sandia National Laboratories) during the first annual review of the Compact Pulsed Power MURI program (portions of his talk are posted at: <http://www.eece.unm.edu/cp3/HlywdReview0702/Presentations/PMC%20MURI%20talk.ppt>)



## OUTLINE



- **Introduction to the Compact, Portable Pulsed Power MURI Program**
- **Quick tutorial on pulsed power, our interest in it, and its academic foundation**
- **Our particular interest in pulsed power: compact drivers for HPM**
- **Where ceramics can provide important advances in compact pulsed power for HPM**
- **Conclusions - How can we work together?**



## Compact Pulsed Power MURI (UNM-Led Consortium)



**Consortium Lead: Professor Edl Schamiloglu, UNM**

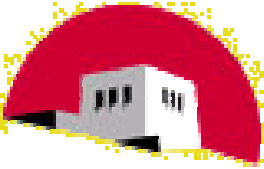
**Consortium Partner: Professor Karl Schoenbach, Old Dominion University**

**Consortium Partner: Dr. Robert Vidmar, University of Nevada, Reno**

***Consortium Affiliates: Sandia National Laboratories (Gerold Yonas), Los Alamos National Laboratory (Mike Fazio), Air Force Research Laboratory (DE Directorate), Lockheed Martin Aeronautics Company (Steve Calico), and Diversified Technologies, Inc. (Marcel Gaudreau).***

**Program Began 1 June 2001, \$1 M/year for up to 5 years.**

**<http://www.eece.unm.edu/cp3/index.htm#>  
(our CP<sup>3</sup> web site)**



# Pulsed Power Needs for DoD



- High power microwave
- (Ultrawideband HPM systems)
- (Particle beam self-protect)
- Electro-thermal chemical gun
- Dynamic armor
- Electromagnetic gun (rail and coil)
- Electromagnetic launch and recovery

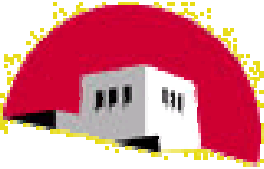
electrical energy    pulse length    peak pulse power    burst avg. power

10 kJ	100 ns	100 GW	100 kW
10 J	1 ns	10 GW	10 kW
100 J	1 us	1 GW	10 kW

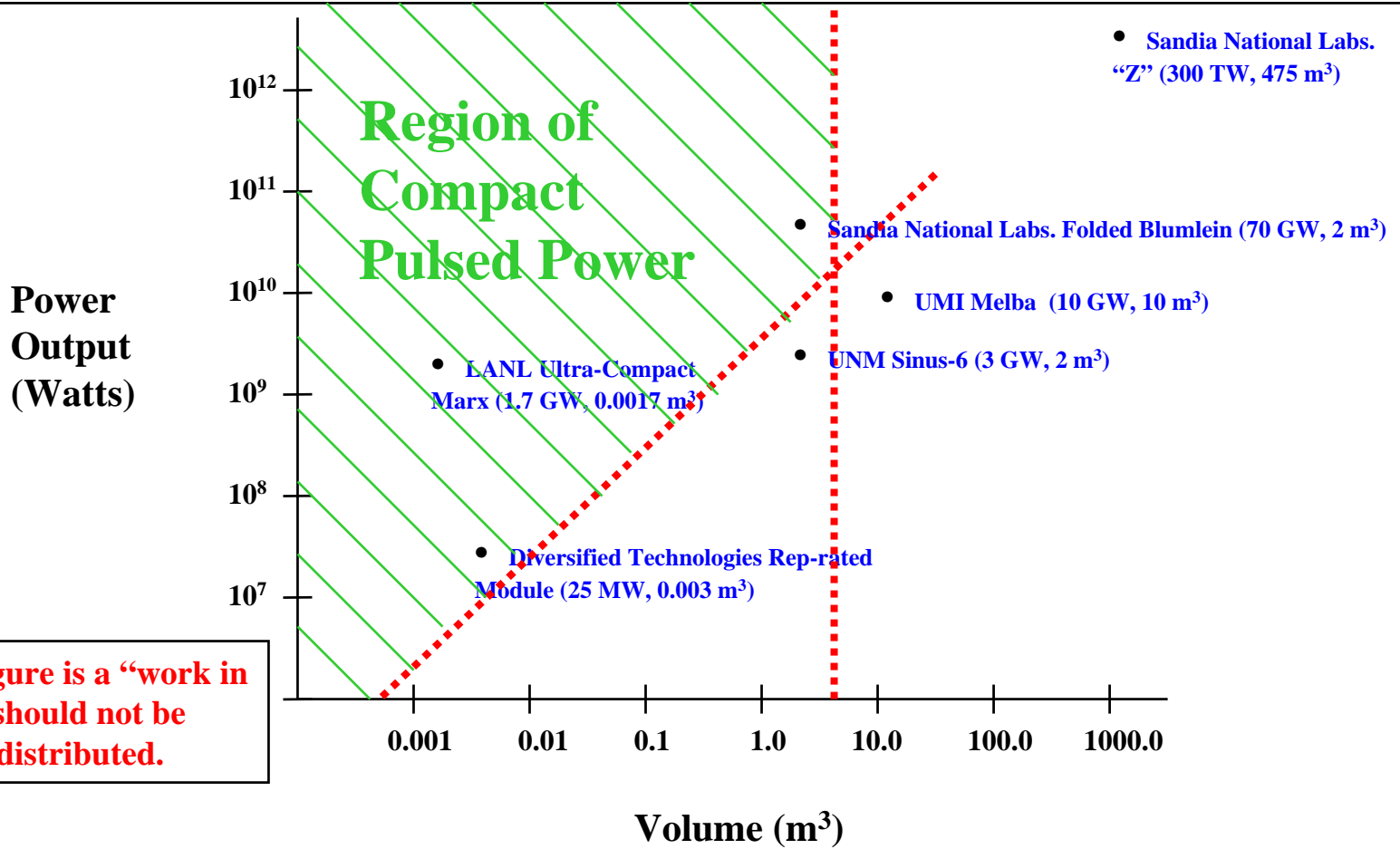
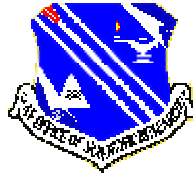
1 MJ	10 ms	0.1 GW	1 MW
1 MJ	1 ms	1 GW	1 MW
100 MJ	10 ms	10 GW	100 MW
100 MJ	1 s	100 MW	1 MW

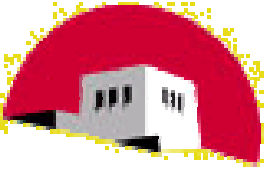
In general, there will be commonalities among the pulsed power needs for each of these two groups

*Slide courtesy of Dr. Malcolm Buttram (Sandia National Laboratories).*

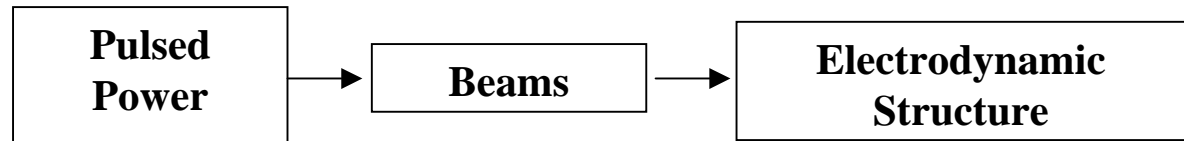
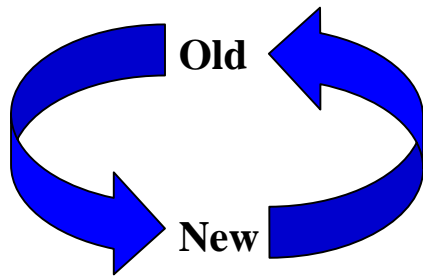


# What is Compact Pulsed Power?



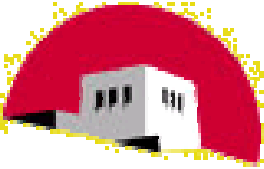


# What is the UNM Consortium's Interest in Compact Pulsed Power?



**Our present focus – new materials, sophisticated diagnostics, better modeling**

**Compact Pulsed Power for High Power Microwave Source Drivers**



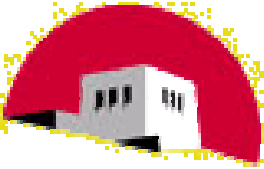
## Definitions



**Pulsed Power** - imprecise term, typically denotes the combination of a capacitive energy storage system that is charged over a long period of time (time scale seconds), and that is rapidly switched to yield a high power pulse that is tailored and better matched to a load using a pulse forming line (final pulse width in nanosecond to microsecond range).

**High Power Microwaves** – imprecise term, usually denotes sources of coherent radiation spanning 1 GHz - >100 GHz at power levels scaling as  $Pf^2$  driven by high-perveance, relativistic electron beams.

***Pulsed Power is the technology used to generate the high-perveance beams to drive HPM sources.***

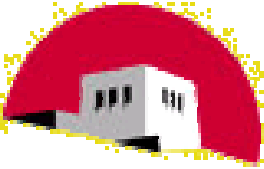


## Alternate Meanings



**Pulsed Power** - a) can mean rapidly switched solid state components, typically used to drive ultra-wideband sources. b) can include chemical explosive-generated voltage pulses (explosive flux compression generators).

**High Power Microwaves** – a) can mean high average power sources. A 10 kW average power tube is considered high power. A 100 kW pulsed power-driven tube is not very high power. b) can mean high power ultra-wideband microwave sources (not coherent, but broadband).



## History of HPM Linked to History of Pulsed Power

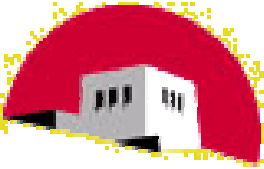


**High Power Microwaves** “born” in late 1960’s and early 1970’s – Prof. John Nation (Cornell University) and Drs. Petelin, Kovalev\* (Institute of Applied Physics, Gorky - Nizhny Novgorod, USSR, in collaboration with group in Moscow).

**Pulsed Power** – “modern pulsed power” attributed to Charlie Martin and colleagues at AWRE, Aldermaston in England in 1960’s. Group interested in radiography had to use pulsed power to increase doses.

***Some initial HPM sources revisited traditional microwave tubes, except used intense beams to drive them. Some HPM sources (e.g., the gyrotron) exist because of intense, relativistic beams.***

*\*Professor Kovalev was Distinguished Visiting Professor of UNM-EECE, June-July, 2002*



## How Do We Place HPM & Pulsed Power in an Academic Context?

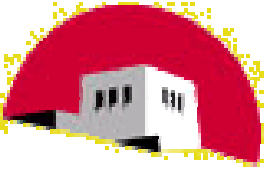


As an academic discipline, our research falls within the field of High Energy Density Plasma Physics Research (see National Academy of Sciences study, led by Ron Davidson, in progress: <http://www7.nationalacademies.org/bpa/1rd.pdf>)

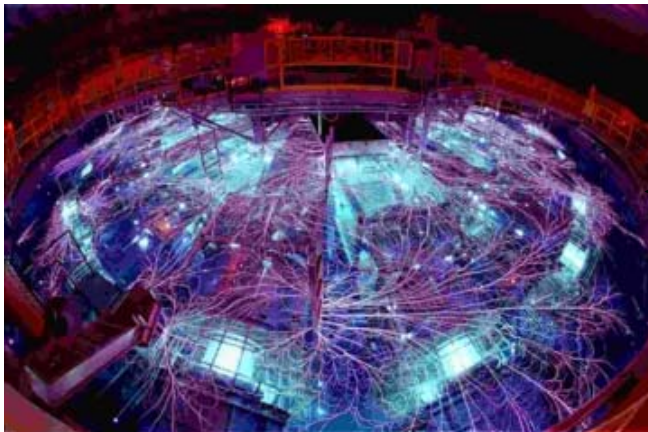
- Inertial Confinement Fusion
- X-Ray and Gamma-Ray Radiation Sources
- Plasma Accelerators
- High Power Microwaves

Why is there Interest in High Energy Density Research?

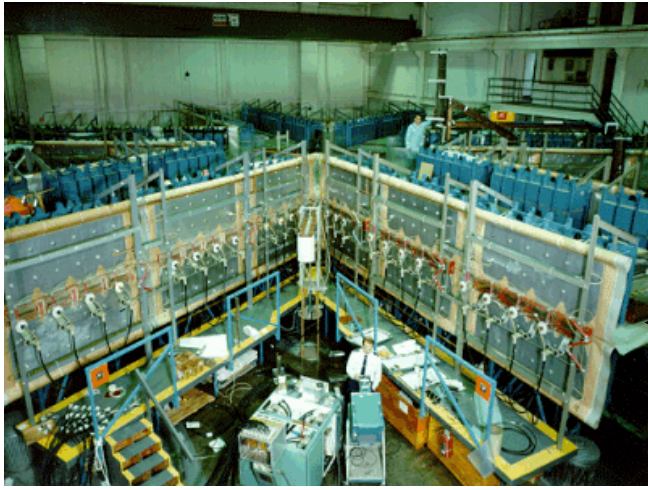
- Stockpile Stewardship (DoE – radiation sources and ICF)
- Threats to the Infrastructure (General – “e-bomb”)
- Fusion Energy Research (DoE – alternate energy source, HPM as ECR/LHD)
- Directed Energy Weapons (DoD – chemical lasers, HPM)



Pulsed Power is the Enabling Technology for High Energy Density Plasma Physics Studies



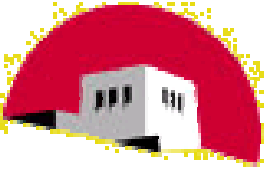
← The "Z" Pulsed Power Accelerator at Sandia National Laboratories



Explosive Pulsed Power Experiment at Los Alamos National Laboratory →

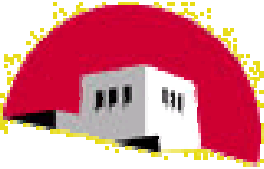
← The Shiva-Star Pulsed Power Experiment at the Air Force Research Laboratory





# UNM is Located at the Hub of Pulsed Power Research in the United States

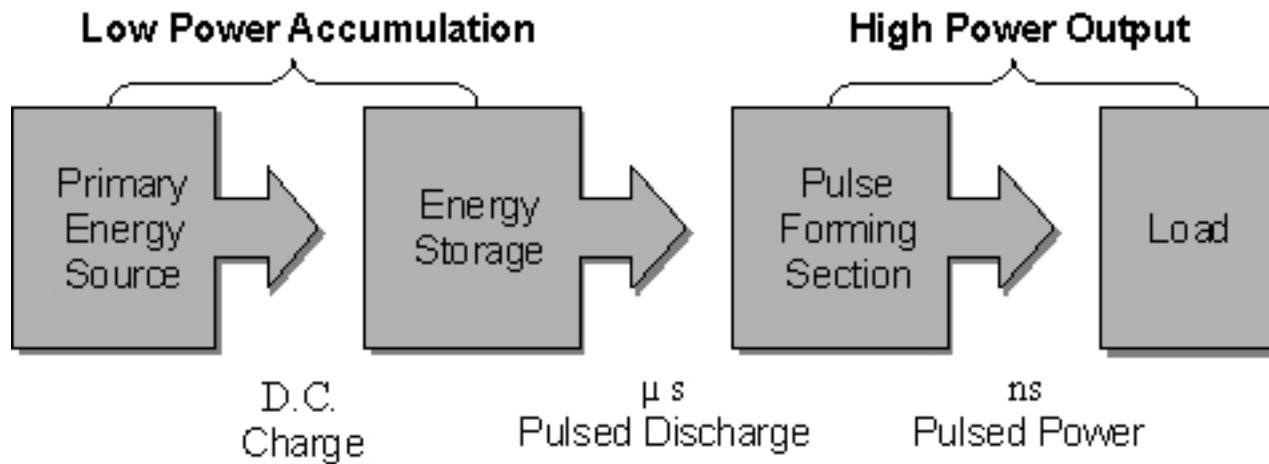


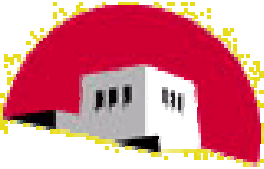


# Pulsed Power for HPM

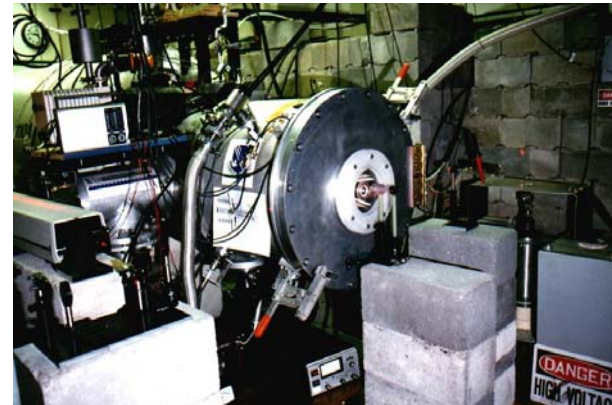
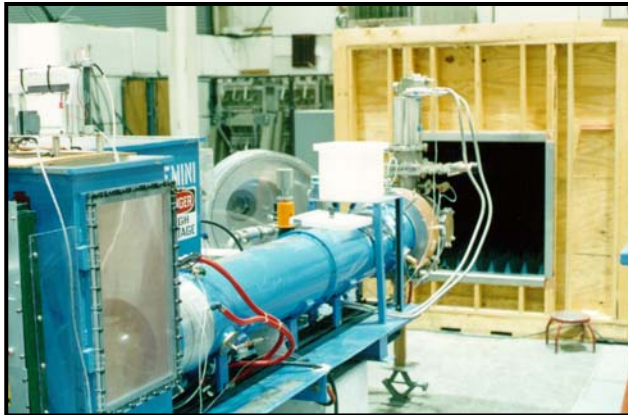
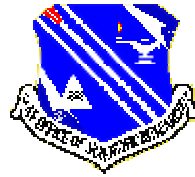


## Capacitive Energy Storage-Based Pulsed Power Systems, Which Are ...



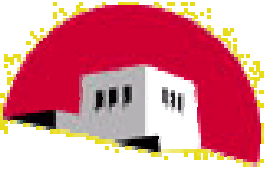


... Typically Large and Massive (as can be seen in the HPM sources below! ),



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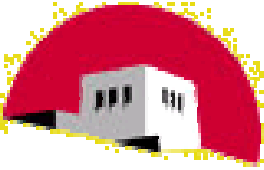


**But Could Be Designed  
To Be More Compact!**

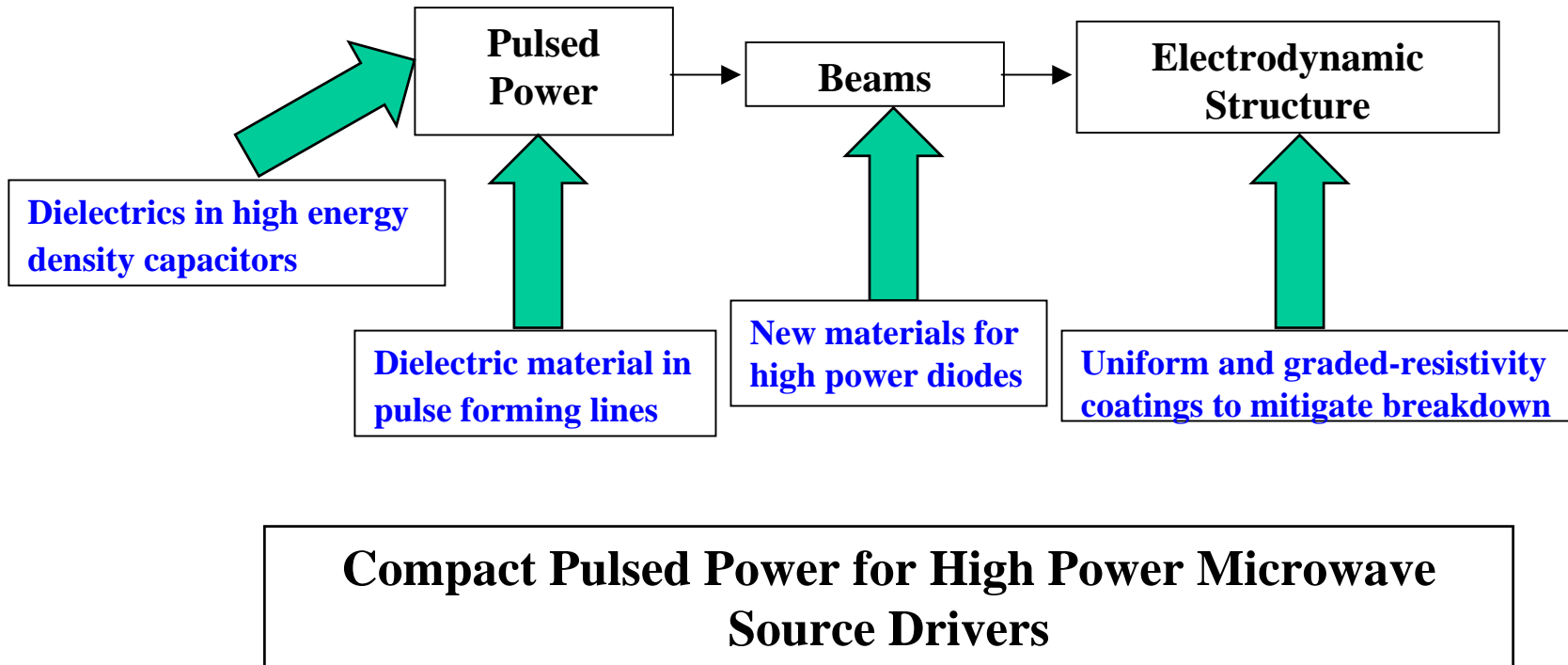


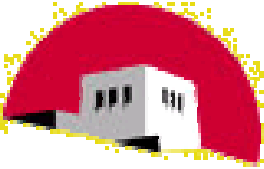
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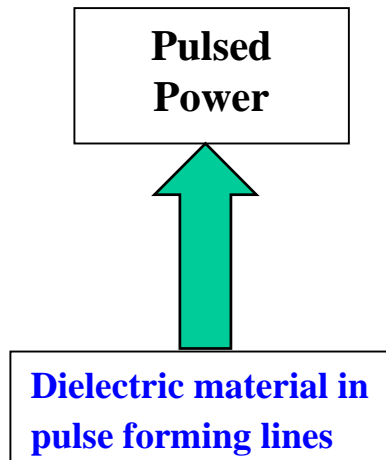


Where can ceramics advance the state-of-the-art in pulsed power?

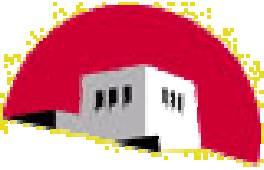




**Our immediate focus:**



**Compact Pulsed Power for High Power Microwave Source Drivers**

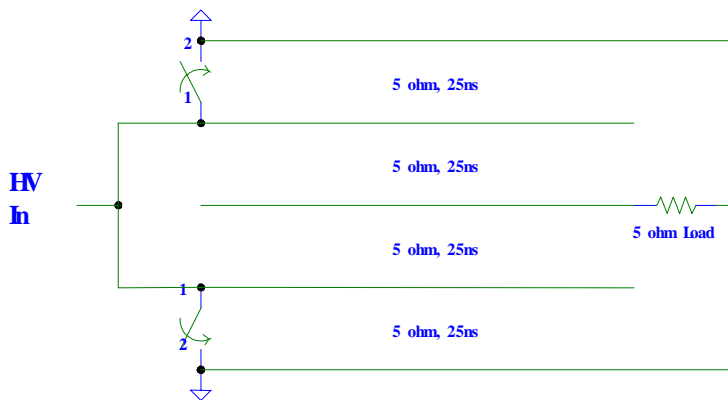


## What Is Required To Achieve This?

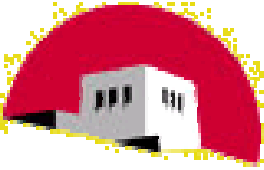


### Basic Research In:

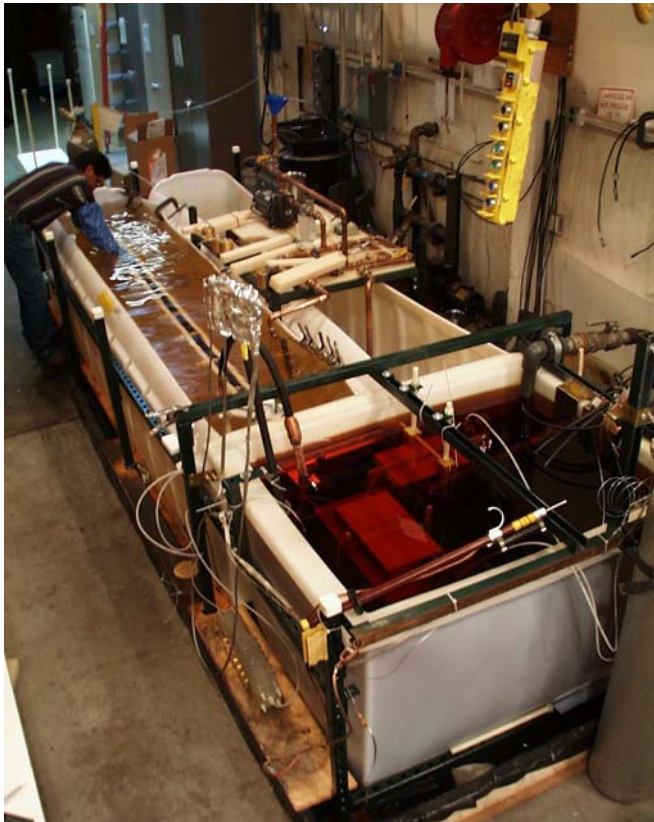
✓ Compact Pulsed Power Topologies (Folded Blumlein Pulsers Attractive – Research Ceramics and Liquids – Support AFRL/SNL Research)



$$Z \approx \frac{377d}{w\sqrt{\epsilon_r}} \Omega$$



## WHY IS AFRL INTERESTED IN COMPACT BLUMLEIN TECHNOLOGY?

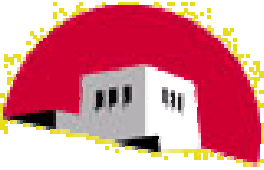


**Compact folded Blumlein pulse-shaping driver being developed as a module to power an HPM source on an air frame.**

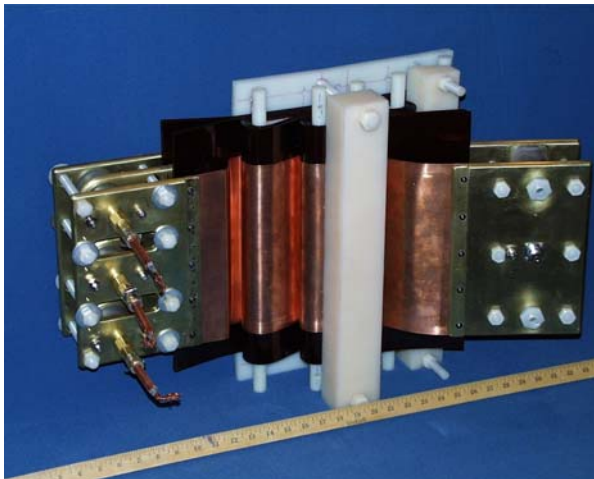
**Four technical problems being addressed by this MURI:**

- 1) Electrical breakdown at edges**
- 2) Better switch required**
- 3) Prebreakdown in propylene carbonate (w/ODU)**
- 4) Research directed towards liquid free (ceramics) dielectric**

*(Dr. Ron Pate, SNL and Dr. Tom Hussey, AFRL)*



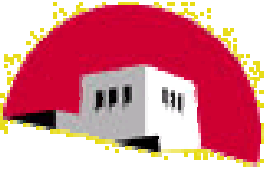
## Present Approach: Folded Blumlein



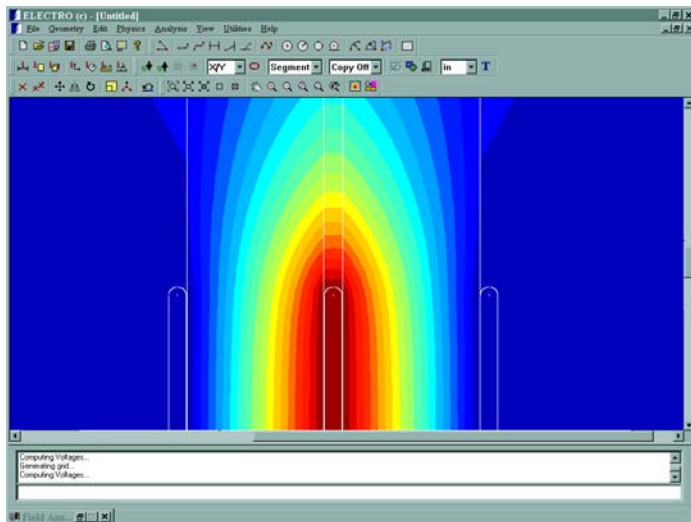
**Problem: Electrical breakdown at edges**

**(48-inch Blumlein folded into a 15" assembly)**

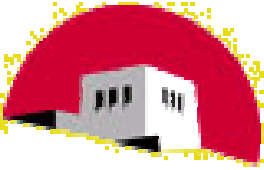
*Courtesy Ron Pate*



## Extreme Electric Field at Edges



**Electrostatic calculation of voltage contours at edge of Blumlein. Breakdown at the edge a problem.**

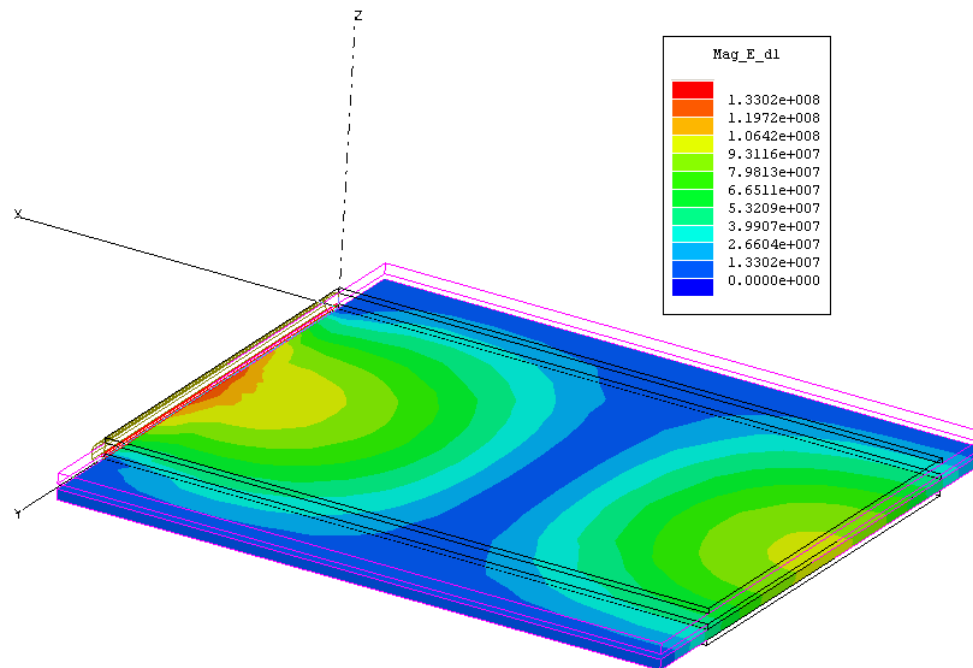


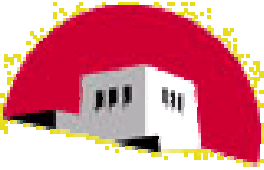
## A Steady-State Calculation



# Dielectric Breakdown at the Edges of the Line

Results of HFSS™  
(Agilent/Ansoft)  
calculation at UNM





**A More Desirable, Longer Term Approach Would Require High Energy-Store Dielectrics**



$$Z \approx \frac{377d}{w\sqrt{\epsilon_r}} \Omega$$



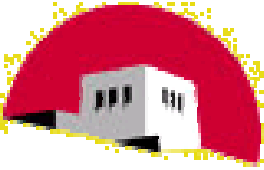
**Increasing dielectric constant leads to more compact system with increased energy storage (no folding necessary)**

$$W_E = \frac{1}{2} \epsilon_0 \epsilon_r E^2$$



$$t_{pulse} = L / v_{ph}, v_{ph} = c / \sqrt{\epsilon_r}$$

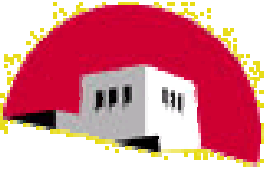
**Challenge: To identify such a material that has a high breakdown strength and can survive > 10<sup>4</sup> discharges.**



## Our Proposed Approach



- 1) use electromagnetic modeling tools to design resistively graded structure for use in Blumlein (UNM) (presently working on time-domain simulations to study single pulses on Blumlein)
- 2) work with ceramists to develop sample matrices
- 3) use pulsed high voltage tester to assess breakdown strengths (presently building such a pulser)
- 4) iterate with ceramists

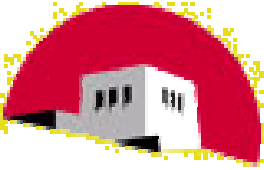


## Some of our Earlier Work with Ceramic Coatings



- 1) C.S. Mayberry, B. Wroblewski, E. Schamiloglu, C.B. Fleddermann, “Suppression of vacuum breakdown using thin-film coatings,” *J. Appl. Phys.*, vol. 76, 4448, 1994.
- 2) C. Grabowki, J.M. Gahl, E. Schamiloglu, and C.B. Fleddermann, “Pulse shortening in high-power backward wave oscillators,” *Proceedings SPIE , Intense Microwave Pulses IV*, vol. 2843, 251, 1996.

**NOTE:** The idea of using a graded resistivity is not new. This has been used in the pulsed power community and is commonly used in the manufacture of capacitors. Peter and Zucker recently proposed applying a graded resistivity coating to high gradient rf structures in accelerators (W. Peter and O. Zucker, “Resistive-gradient coatings and high-voltage rf breakdown,” submitted to *J. Appl. Phys.*).

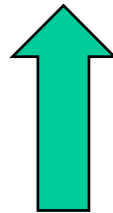


## CONCLUSIONS

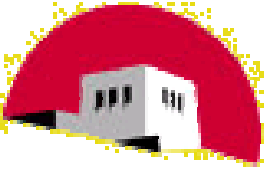


**A revolution in pulsed power requires:**

- 1) High strength, high dielectric constant, high frequency components**



**This is why I am attending this workshop.**



## ACKNOWLEDGEMENT



My UNM collaborators on this project are Marvin Roybal (EECE undergraduate), Miroslav Joler (Ph.D. student), Professor Christos Christodoulou and Research Professor John Gaudet. Our collaborators at Sandia National Laboratories include Mr. Jeff Alexander, Dr. Ron Pate, and Dr. Malcolm Buttram. Our supporters at the Air Force Research Laboratory (Directed Energy Directorate) include Dr. Peter Turchi and Dr. Tom Hussey.