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RPPR Final Report
as of 24-Jul-2023

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PARTICIPANTS:

Participant Type: PD/PI

Participant: Jane Lehr

Person Months Worked: 1.00

Funding Support:

Project Contribution:

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RPPR Final Report
as of 24-Jul-2023

Participant Type: Other Professional

Participant: Ender Savrun

Person Months Worked: 1.00

Project Contribution:

National Academy Member: N

Funding Support:

Participant Type: Graduate Student (research assistant)

Participant: Leonardo Rossetti

Person Months Worked: 1.00

Project Contribution:

National Academy Member: N

Funding Support:

Participant Type: Staff Scientist (doctoral level)

Participant: Andrew Fierro

Person Months Worked: 1.00

Project Contribution:

National Academy Member: N

Funding Support:

Partners

,

I certify that the information in the report is complete and accurate:

Signature: Jane Lehr

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Final Report

“Enabling Technologies for Deployable, High Repetition Rate Directed Energy and Pulsed Power Systems”

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Introduction

Pulsed power technology was initially developed to provide a low cost method for x-ray imaging of nuclear detonations. The United Kingdom's Atomic Weapons Research Establishment used the time dependence of electrical breakdown to produce pulsed, energetic x-rays instead of the particle accelerator which it could not afford. Over the next decades, the techniques and components were developed largely by groups in the UK, USA and USSR and predominantly used for the simulators for nuclear testing. These simulators were physically large and operated in single pulse mode. In the late 1990s, applications began to emerge for both mobile and repetitively operated systems. The component developed for single pulse systems were co-opted and used in repetitive systems with varying degrees of success. Compact, portable and high pulse repetition rate (PRR) systems were proposed typically for an emerging class of nonlethal military weapons now known as Directed Energy Weapons (DEW). Simultaneously, new commercial applications were investigated where repetition rates were important. Industrial and commercial applications include material modification, laser ablation, protection of the environment, decontamination technologies, and biological and medical developments. These applications tend to be a modest voltage (10kV) and current (10A) levels. New wide-bandgap semiconductor switches are fueling the developments because of their compact size, light-weight, high repetition-rate, low-cost, and high efficiency. A number of companies exist to provide pulsers for these commercial applications. Military applications tend to have specialized requirements such as very high voltages (~1 MV) and/or high currents (~25kA).

As the technology developed from applied science to system development, a host of issues have emerged regarding the operation of high PRR pulsed power yet the bulk of the development funding focused on the applications and not on technology development for repetitive systems. High pulse rate operation with simultaneous high peak powers is not well understood. Many, even experienced pulsed power practitioners, assume high repetition rates are simply an extension of the single pulse regime and are shocked to find it not to be the case. Some aspects, such as the limitations in dielectric recovery of spark gaps, are not especially surprising. Others, such as the rate of energy extraction from batteries are easily overlooked during the design phase. Still other aspects, such as the loss of switch trigger range with increasing PRR, continue to be both unexplored and baffling. These surprises typically become apparent during one of the two most critical phases of a technology demonstration: the prototype and the field test. Moreover, since auxiliary equipment is not commercially available, systems are fixed "on the fly" which is not good systems engineering practice.

Applications such as force protection area are more subtle. While a technology can be demonstrated in the laboratory, for a working demonstration, the technology must be used in a realistic scenario. This means that, say an IED locator has to move with the vehicle. The vehicle speed is determined by the PRR. Higher PRR, means higher speed but also more prime power. Deployable systems require robust technology which can operate in a wide variety of environments. As nonlethal weapons using directed energy moves toward inclusion in the arsenal, it is becoming clear that a suitable pulsed power technology not generally available for repetitive systems.

The UNM team investigated the commercialization potential of repetitively operated pulsed power components developed under DoD funding. Initial product offerings will center on two

key components of high PRR systems: the capacitor charging power supply and repetitive trigger generator.

A key element of these compact repetitive pulsed power systems is the high voltage power supply that typically charges a capacitive storage element. As pulsed power applications require increased repetition rates, the corresponding power requirements of the power supplies must also increase. With inductive isolation of the capacitor bank, the pulse repetition frequency (PRF) is primarily limited by the charge rate of the power supplies. The design provides for low-loss charging of capacitors by providing a constant current to allow for repetitive operation. Based on the range of likely applications it is envisioned that the output of this design will be scalable between 100 and 1000 J/s with a maximum charge voltage between 10 and 50 kV. Note that, for a constant current capacitor charger, the peak output power is twice the average charge rate – a 200 to 2000 Watt peak output design. The base design targets a nominal 24 Vdc input power source to provide compatibility with a vast number of energy storage components. The control interfaces will be kept to the simplest implementation required to enable the device to accomplish its function. The control interfaces will incorporate ruggedized optical interfaces, thus eliminating the EMI coupling issue inherent in using low-voltage electrical interfaces.

Presently, only one US based company offers a ruggedized DC to HVDC converter. UNM is developing a power supply specifically to charge capacitors in response to a field test of a force protection technology that failed twice due to the electromagnetic susceptibility of the COTS power supply. The company encapsulates the units - meaning the units are unrepairable – and replacement units take 6 weeks after receipt of order for delivery. The field test was canceled after the power supply unit – and the 3 replacement units – all failed for unknown reasons. Competition to this company would benefit the high voltage community in general and the DoD in particular. UNM developed a compact power supply specifically for charging capacitive loads. Future products could include ruggedized test capability.

The DoD in particular has stringent field testing requirements. Component failure results in not only a failed field test, but other waste as the entire technology effort is put at risk. Components developed for high voltage field testing should be engineered to be impervious to electromagnetic interference.

Proposed Offerings:

The UNM proposes to investigate the commercialization potential of repetitively operated pulsed power components. Initial product offerings will center on two key components of high PRR systems: the capacitor charging power supply and repetitive trigger generator.

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The topology and components of the power conversion circuitry of the proposed converter have been selected based on the requirements for ruggedness, reliability, simplicity, and efficiency – in that order. While efficiency is often the first priority of power conversion design, at the power levels under consideration an improvement in efficiency of only a few percent results in a trivial absolute power savings.¹ However, a design that maximizes efficiency often does so at the cost of increased complexity and the use of less robust components which can easily lead to failure in harsh testing environments.

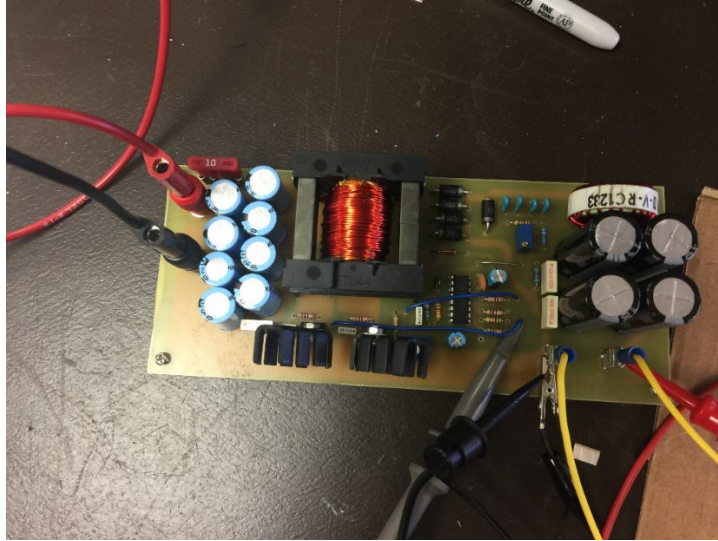


Figure 1 The prototype high voltage capacitor charging power supply during initial testing.

The other item developed in this program is a high voltage, high pulse repetition rate trigger generator. It is largely unrecognized that high performance trigger generators are difficult to produce as well as purchase. In the past, almost all trigger generators were provided in initial, low jitter pulse, known as a trigger amplifier - to a high voltage unit. The trigger amplifier provided a low jitter, high current signal of a few kilovolts to trigger the HV unit that was produced by a krytron switch which are no longer made.

In general, trigger generators may be considered as comprised of three parts: a control unit, a trigger amplifier and a high voltage assembly. The control unit is typically a TTL signal and several high performance commercial units with variable delays between signals are available. The trigger amplifier, initiated by the control unit, produces a high voltage pulse suitable for triggering the HV Assembly. The HV assembly may be a transformer or a capacitive discharge of any level of complexity. For a high performance, predictable trigger generator each of these subsystems must have low jitter.

Until recently, many systems used a robust commercial generator by a long defunct company, Pacific Atlantic, known as a PT-55, which is a krytron-based trigger amplifier. The operation of the PT-55 was described in Augsburger² as “*A commercial spiral generator was used to generate the trigger pulse for the field distortion gaps. This spiral generator is made by Pacific Atlantic Electronics, model PT-55. The output pulse of the PT-55 has an amplitude of 50 kV and a pulse width of 75 ns. The PT-55 is charged to 7 kV and then triggered with a 300 V D.C. pulse. Isolation of the PT-55 from the Marx generator was achieved with resistors at each switch.*” Now, however, the lack of availability of small, fast, high current switches such as krytrons (such as the once ubiquitous KN6B) makes the design of high voltage spark gap trigger units problematic.³ The importance of the trigger amplifier illustrated by the Naval Air Station Patuxent River simulator: as recently as 2011 where Pacific Atlantic PT-55 pulse amplifiers were used. Fortunately, advances in power electronics yield commercial solid-state switches with low jitter.

The timing sequence is initiated with a control panel/delay generator that starts a trigger amplifier applied to a HV switch that initiates the HV multiplying sequence. The HV multiplier may be a 1) simple capacitor discharge, 2) Marx generator, 3) LC generator, 4) stacked transmission lines, or 5) pulsed transformers. Of all these types, the pulse transformer is the most widely used but suffers from a slow risetime. The stacked transmission line can be large but may be configured in a self-matching configuration and does not have a large capacitance. Generating the high voltage/fast risetime pulse after the pulse amplifier is relatively straightforward and low risk. The challenge really is to generate a low jitter trigger for the start switch in the trigger amplifier. With a 500 ps jitter or below, a higher voltage spark gap switch can be configured in multiple stages so that only one portion of the switch needs to be triggered. This requires a lower trigger voltage on the high voltage generating stage than switching the whole operating voltage and can still yield nanosecond jitter.

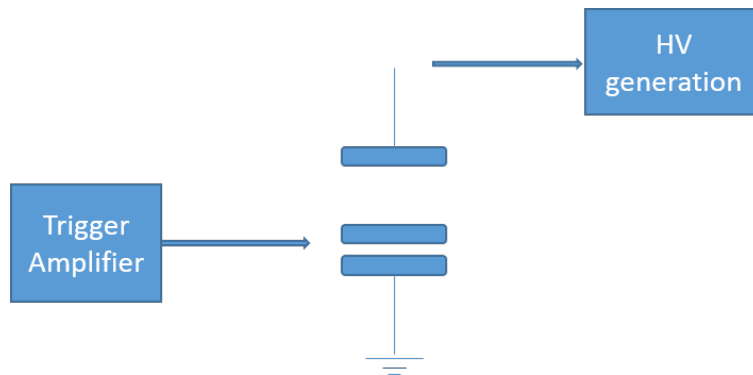


Figure 2 A trigger amplifier can reliably trigger a multigap switch with triggering only a fraction of a switch. In the cartoon above, the trigger amplifier triggers a gap that is notionally 30 percent of the total gap distance. Several architectures may be used to generate the high voltage output.

Triggered switches are once again becoming a subject of intense scrutiny as systems become more compact and modularized and as new high-power spark gap switch topologies are introduced. Moreover, the requirements on triggered switch performance are increasingly severe with jitter in the single nanoseconds needed over the entire triggered switch range. Implementation in compact Marx generators, with the critical role that stray capacitance plays in their erection, makes triggered switch performance even more critical.⁴ Repetitive operation exacerbates these issues.

Trigger generators may be used in numerous ways in high voltage applications. When used as a start switch, where the purpose is to simply initiate a sequence, significant jitter can be tolerated. However, when the relative timing initiation of multiple units or coupled generators/diagnostics is important, the operation of the trigger generator from the initiating signal is critical.

The trigger generator developed in this program uses power electronics to generate a 4 kV, low jitter pulse as an input signal into an approximately 1:10 transformer in approximately 100 ns. The specific output waveform will be determined by the parasitic reactance of the final transformer.

Weight estimate:	HV trigger amplifier	1 kg
	Custom transformer	2 kg

12 VDC Battery 2 kg?

For an overall suspended weight on the order of 5 kg. This, of course, assumes that the trigger has sufficient energy to trigger the final design.

The trigger generator layout is shown in the figure below. As the trigger timing requirements for the system are not yet determined, this proposed unit is sufficiently flexible to be used in a variety of ways, including the direct triggering of spark gaps or triggering another high voltage assembly. The system components are described below. The description is grouped into location: the TTL and LED light source which initiates the trigger generator is located in the control shack while the rest of the unit is located with the Marx generators. The two locations are connected with fiber optic cable.

Trigger Amplifier The trigger amplifier is designed to produce a 4 kV, fast rising pulse with jitter less than a nanosecond. The high voltage is supplied by an EMCO DC to HVDC Converter (EMCO G60) to produce voltage to 6kV. The unit has a weight 43g. Switching is achieved with a power MOSFET.

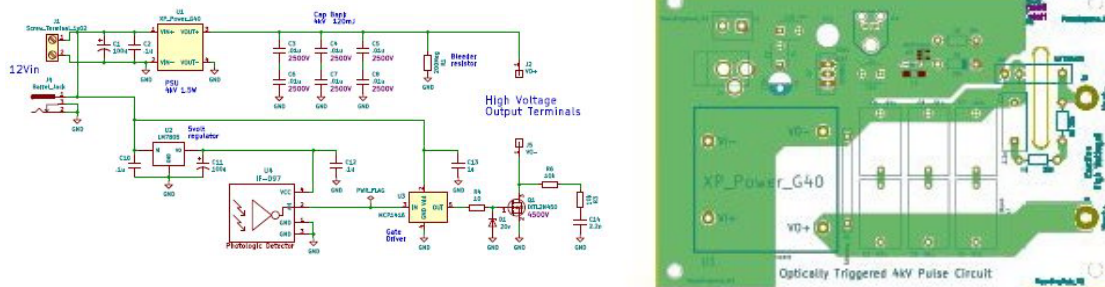


Figure 3 Circuit schematic

Composition and Capabilities of the Team

The proposed team was as follows:

Technical Lead: Professor Jane Lehr, UNM Dept of Electrical & Computer Engineering

Entrepreneurial Lead (EL): Leonardo Rossetti, UNM Electrical Engineering Master's student

Mentor: Dr. Ender Savrun, President & Founder, Sienna Technologies, Washington

However, there was a significant delay between the initial award and our scheduled cohort. Originally, **Entrepreneurial Lead (EL):** Leonardo Rossetti:

When proposed and the team interviewed, Leonardo Rossetti was midway through his MSEE program doing research with Dr Lehr in the Applied Electromagnetics track with plans to continue for a PhD. We applied for the program with Mr. Rossetti's interests in mind: he had long been interested in entrepreneurship and was enrolled in the dual engineering/business program offered at UNM as an undergraduate. Mr. Rossetti has been performing research in the modeling of High Gradient Insulators (HGI) as well as unusual phenomena related to high voltage triple points. Dr Ender Savrun is a manufacturer of aluminum nitride substrates and was our partner on the high gradient insulator work, which started as a SBIR.


Professor Lehr is a strong collaborator who actively seeks out commercial partners. She currently has funding from both the SBIR (with Sienna Technologies) and STTR (ASR Corporation) programs and is on a Phase II SBIR proposal submitted with another company, Verus Technologies. In the Fall 2017 semester, Dr. Lehr served as the faculty mentor for the BioDesign class. The class was divided into groups to investigate technological solutions for medical applications. That semester, the medical application was Trauma care and Dr. Lehr's team was given the specific issue of pressure ulcers. Her team did the market research and developed a multi-technology pressure ulcer detection and prevention device which has been submitted to STC.UNM under an invention disclosure. As such, she has some similarities with the fundamentals of commercializing technology.

Dr. Ender Savrun is the President of Sienna Technologies, a manufacturer of ceramic components and space systems. The Company offers aluminum nitride, microwave ceramics, metallization, catalyst, thrust chamber component, and pressure sensors. Sienna Technologies serves electronics, energy, chemical processing, defense, and space propulsion applications. Sienna Technologies, Inc.® is a vertically integrated U.S. based manufacturer of Advanced Ceramic Materials with extensive R&D facilities for product development from design to prototyping to full capacity manufacturing. Sienna Technologies, Inc.'s advanced materials technologies provide innovative solutions to today's diverse and demanding industrial and scientific applications. Sienna Technologies offerings range from high thermal conductivity aluminum nitride based ceramic products for high power electronics, to aluminum nitride based microwave absorbers for particle accelerators and high power microwave tubes; to ultrahigh temperature catalysts and FGM thruster components for chemical propulsion, to complex high performance insulators for electric propulsion systems in space exploration markets.

Sienna's capabilities include shape forming by dry pressing, isopressing, extrusion, tape casting, and hot pressing; machining; metallization, and brazing operations. Sienna provides full metallization and brazing for AlN ceramics to give you one-stop shopping. Through our strategic alliances with precision machining facilities, we can deliver the exact component you need. We

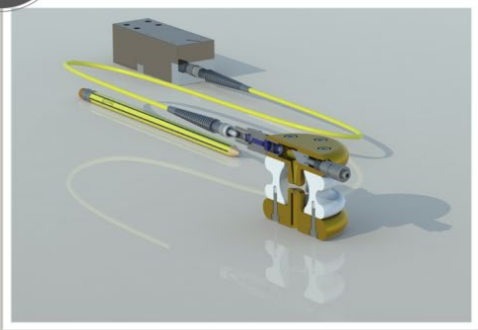
manufacture and stock many standard sizes and shapes including rods, plates, tubes, tiles, heat sinks TO-insulators, crucibles, evaporation boats, thermocouple insulators, and grinding media. Sienna Technologies, Inc. is at the forefront of electronic package development for harsh environments, low and high temperature electronics. Sienna has developed a leadless robust packaging technology for use at high temperatures over 300°C up to 800°C and low temperatures down to – 180°C in harsh environments utilizing its unique materials expertise to metallize and seal aluminum nitride, alumina, and silicon nitride.

Mr. Rossetti decided not to continue to a PhD degree. Between the submission of the proposal and the notice of award, Mr. Rossetti decided to get a technical position and was offered one at the Naval Research Laboratory. It appeared like the timing was going to work out so that the program would be completed before he started his new position. It did not work out that way, but Mr. Rossetti wanted to complete the program. To assist, a Research Professor Dr. Andrew Fierro was added to the team as co-Entrepreneurial Lead to help with the interviews. Mr. Rossetti, however, remained the primary EL.







Summanus

TECHNOLOGIES




Compact and deployable high-power/high current switches for directed energy weapon systems


	Interview Count			
NEW	5	4		1
TOTAL	5	4		1




Leonardo Rossetti
Co - Entrepreneurial Lead



Dr. Andrew Fierro
Co - Entrepreneurial Lead



Dr. Jane Lehr
Principle Investigator



Dr. Ender Savrun
Industry Mentor

Team 1681

The Firm:

The company was named Summanus Technologies. Although Leo grew up in a small town in New Mexico, his parents immigrated from Europe. Leo grew up speaking Italian at home and spent most summers in Italy with his extended family. Ender suggested having a tie to the name as he did with Sienna. In last position he worked for someone, he would often go to visit the plant in Siena, Italy where there was clay. His employer had helped him tremendously in starting his business, so Sienna reminded him of a very pleasant time in his life and helped him remember how much his success was predicated on others. He pointed out that his logo was the color of that clay from Siena. Leo ed that advice to all the company Summanus which was the god of nocturnal thunder for the ancient Romans. Thunder (and lightning) are also reminiscent of pulsed power.



Summanus
TECHNOLOGIES

Customers

The field of pulsed power is growing exponentially as the interested in EMP has started to return. The EMP community requires fast high voltage pulses.

Who will buy it?

Researchers in pulsed power (i.e. SNL, AFRL)

Growth into larger customers (i.e.. Prime contractors, Raytheon, Booz Allen)

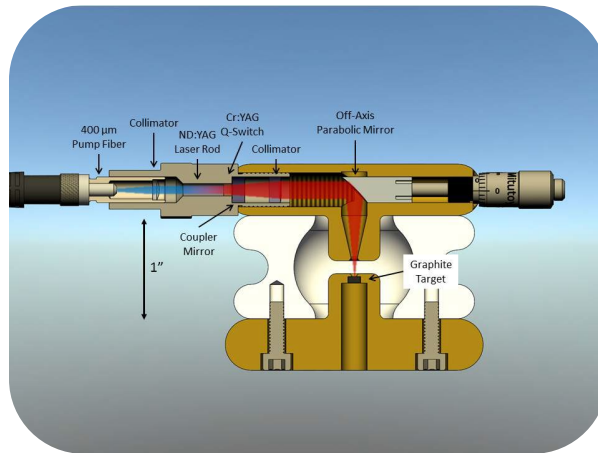


Figure 4: an example of the Laser Triggered Switch. The research effort proposed to become a product

Competing products



Price: ~\$2K per unit

2~4x in size

Not a Sealed Solution

Figure 5: The L3 Maxwell Rail Gap Switch a possible competing product

Pre-Planning

Customer Discovery

Pre-Planning

- Find 100 Names
- Use Social Media
- Business to Business Sales
- Start in the middle of the company
- Face to face data
- Read their expression, do their pupils dilate?
- Last question, what should I have asked?
- Set up pass/fail tests to validate hypothesis

Interviews

- Introduce yourself, mention you not selling
- You have come to listen
- Convince them they are important
- Keep it to a conversation not a script
- Record the interviews, and maybe take a picture
- Its not about pitching your idea

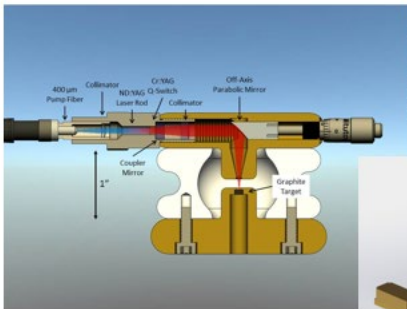
Post Interview

Interview Visual Aids of Sample Technologies

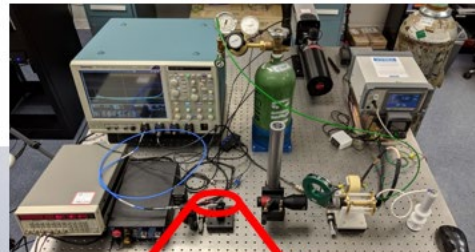
After a few rounds of interviews, we changed tactics to aid discussion by bringing some sample technologies that we developed during our DoD research activities. We found this to be a good conversation starter, particularly with the highly technical engineers who were responsible for system development. The technique was effective in that it gave a specific item to speak to. We found that UNM and the principals are highly regarded. Intense interest was shown in the technology but it mainly highlighted that system development-intensive engineers would rather purchase items such as trigger generators than make them because it was generally difficult. However, the vast majority of bench-level research engineers would rather develop their own devices because it is “fun”.

To aid discussion during interviews, we brought this deck of three slides in hardcopy as a conversation starter. This was surprisingly effective because we could pull it out if we needed to but we did not necessarily need to. With certain interviews – particularly ones with whom we were not familiar – it gave an indication of the high quality and unique perspective on pulsed power that we could bring. Three was also a nice compromise where it could not become a lecture, was quickly scanned and left an impression.

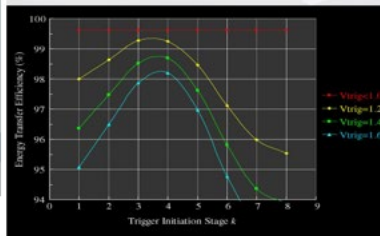
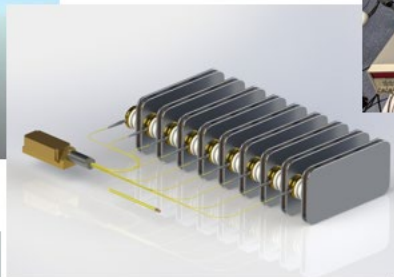
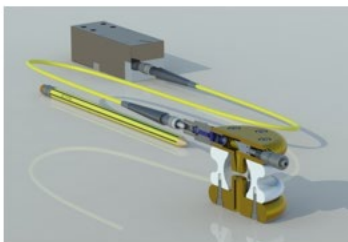
The Micro Integrated Laser Switch



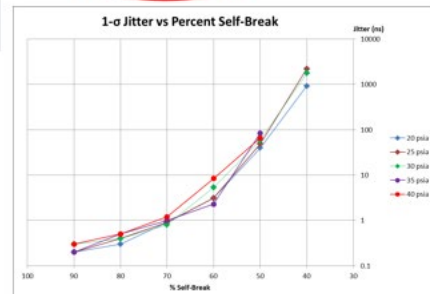
- Galvanic isolation of trigger electronics
- Increased trigger range
- Reduced trigger power consumption
- Increased modulator efficiency
- Improved SWAP



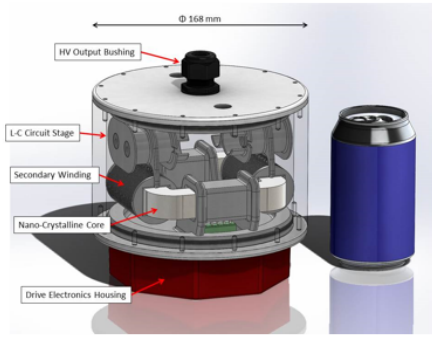
- 1535 nm – Class 1
- 250 μ J, 4 ns
- 9 x 28 mm



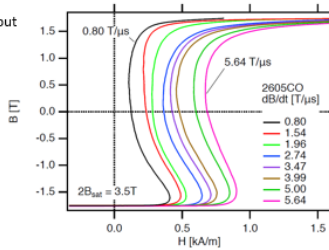
Energy transfer efficiency versus trigger initiation location for an eight-stage Marx network with sequential switching charging an external capacitor.¹



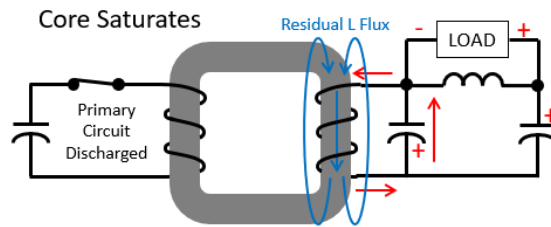
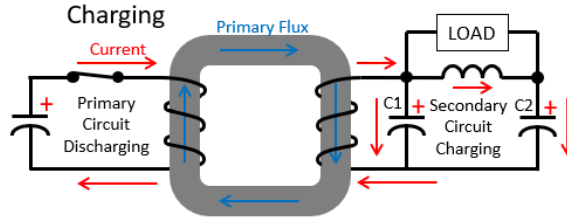
Saturating Pulse Transformer Trigger



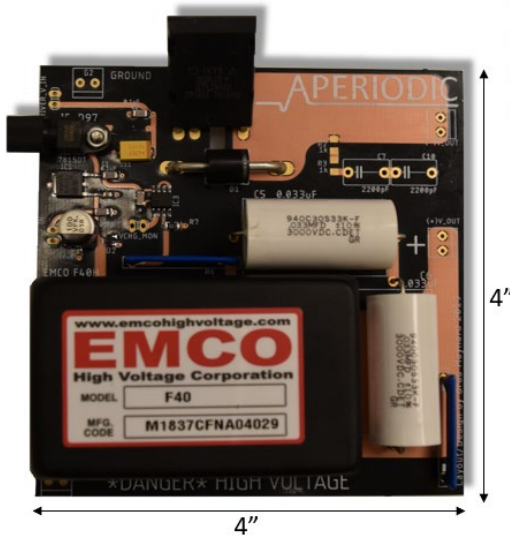
- All solid state
- 50 to 100 kV output
- 10's ns risetime
- ~ns jitter
- 100+ Hz rep rate
- DC powered
- Self-contained



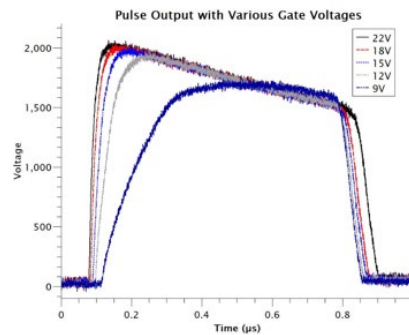
- Traditional "series" magnetic compression limited – cannot provide voltage multiplication at high efficiency
- Saturating pulse transformers permit voltage multiplication and high efficiency
- SPTs not widely exploited in the past for two reasons:
 - Very complex multi-variable design problem – needs simulation
 - Low-loss high-frequency magnetic materials not widely available



Optically Triggered Pulser



- Variable output voltage (~4.5kV max)
- Multiple kHz rep-rate
- ~1ns jitter
- Fast risetime (load dependent; 20-90 ns)



ICORPs Questionnaire

Sample questions, there is no need to follow the questions exactly but be sure to test hypothesis with every interview. When an interviewee says something like “lifetime is a big problem” make sure to follow up and get a quantity “What number of shots do you need?”. We need quantifiable data to put in the canvas and show progress. “Big, small, important”, all need values assigned to them or they are impossible to compare.

Opening Questions

How do you use pulsed power?

When working with pulsed power systems what are your biggest pains/complaints?

What are usually the circumstances/deciding factors that lead to you needing/wanting a new pulsed power system?

More Specific to Marx Banks/ Switches

Where do you find trouble in Marx Banks/Switches?

What happens when there is an issue, what steps must happen to get what you need?

What would be the benefits of purchasing a system/switch versus making your own?

Customer Segment Questions

What is the process of purchasing?

Who is the driving force to purchasing products for a system?

Specific Hypothesis to Test (Value Propositions

(SF6 Questions)

What insulating material do you use and why?

(Reliability and cost/time consequences questions)

What happens when a system goes down or has a problem? What are the consequences for you?

Specific Hypothesis to Test (Channels)

What methods do you use to decide which vendor you want to purchase something from?

For maintenance of pulsed power drivers, is it done in house or do you contract that work out with the people you bought it from?

Sample ICORP Email

Hello,

My name is Leonardo Rossetti, I am a recent graduate student and current employee of the Naval Research Labs in DC. Currently, I am involved in a grant from the NSF/DoD in an effort to learn about the futures of Pulsed Power Systems and High-Powered Microwaves. The grant involves conducting 100 in person interview to gain better insights, I would greatly appreciate your willingness to be interviewed. The interview process requires only a moment of your time. If it would be possible to schedule an interview with you, please let me know. I can be reached anytime by email at lrossetti7@gmail.com, or by phones at _____.

Thank you for your time.

Final Business Model Canvas

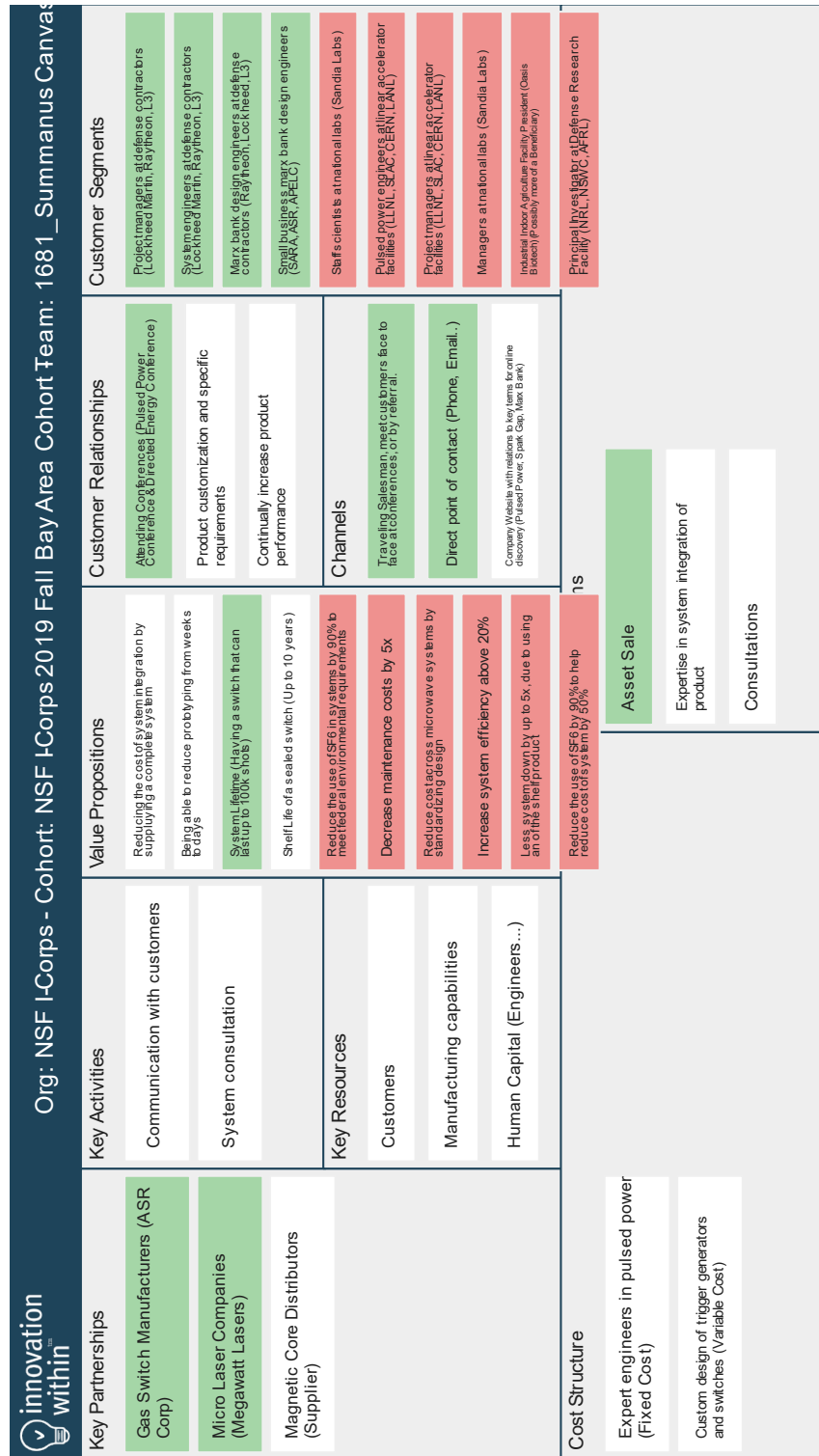
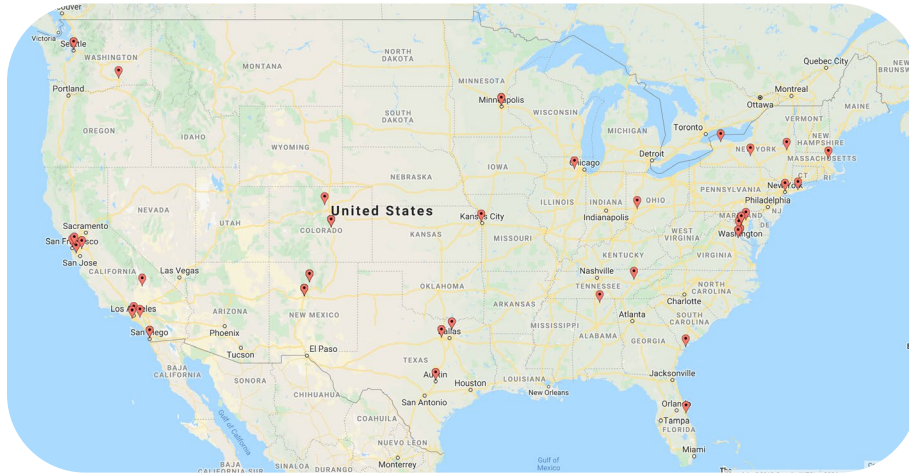


Figure 6: The final business model canvas that was completed by the end of THE PROGRAM

Interviews



Interview List

A total of 126 interviews were conducted and recorded. The interviews were conducted mostly in person but some by telephone. Since Albuquerque is a hub for pulsed power, many interviews could be conducted in person without travel. Interviews were conducted by pulsed power developers as well as users and auxiliary users.

In addition to traditional pulsed power users, some innovative power companies were contacted since that sector also uses spark gap technologies.

Company Name	Contact Name	Contact Title	City	State	Phone (Office)	Phone (Cell)	Email	Interview Date	Comments	Complete
Typhoon HIL	Matt Baker	Director: Microgrids and Critical Power	Somerville	Massachusetts		760-401-2575	matt.baker@typhoon-hil.com	10/2/2019		
Max Power, Inc	Benjamin Meyer	R&D Manager					maxpowerdc@aol.com	10/10/2019		

Company Name	Contact Name	Contact Title	City	State	Phone (Office)	Phone (Cell)	Email	Interview Date	Comments	Complete
AFRL	Bob Torres		Albuquerque	New Mexico			robert.torres.10@us.af.mil	10/8/2019		x
AFRL	Brad Hoff		Albuquerque	New Mexico			brad.hoff@us.af.mil			x
AFRL	Sterling Beeson		Albuquerque	New Mexico			sterling.beeson@us.af.mil	10/2/2019		x
AFRL	Don Shiffer		Albuquerque	New Mexico						
AFRL	Commacho	Senior, Electrical Technology	Albuquerque	New Mexico						
AFRL OH	Joseph Weimer		Wright-Patterson AFB	Ohio	937-255-6235		joseph.weimer@wpafb.af.mil			
Alpha-Omega Power-Technologies	W. Ray Cravey	President	Albuquerque	New Mexico	505-341-4828		wrcravey@aol.com			
APE LC	John Mayes	CEO	Austin	Texas			mlara@apelc.com	10/9/2019		x
APE LC	Matt Lara	Senior Test Engineer	Austin	Texas	512-264-1804			10/9/2019		x
Applied Pulsed Power		Manager	Batavia	Illinois	630-313-2378		hds@appliedpulsedpower.com			
Applied Pulsed Power	Craig Dunham	CEO	Freeville	New York	607-844-3426		ctd@appliedpulsedpower.com			
Applied Technology Associates	Anthony Tenorio	CEO	Albuquerque	New Mexico	505-767-1203	505-269-7756	anthony.tenorio@atacorp.com			
Applied Technology Associates	Darren Laughlin	Chief inventor	Albuquerque	New Mexico	505-767-1224		darren.laughlin@atacorp.com			
Army Research Lab	Marc Litz	Physicist	Adelphi	Maryland	301-394-5556		litz@arl.mil			
Army Research Lab	Bruce Guile		Adelphi	Maryland			bruce.r.guile.civ@mail.mil			
Army Research Lab	Miguel Hinojosa		Adelphi	Maryland						
ASR Corporation	The Milkes		Albuquerque	New Mexico						
BAE	Tyler Winecoop?		Minneapolis	Minnesota						
BAE	Luis Hernandez		Minneapolis	Minnesota					Jane contacted this person	
BAE	Steve Zelenak		Minneapolis	Minnesota			Steve.Zelenak@baesystems.com			
Ball Aerospace	Daniel Gibson	Vice President and General	Boulder	Colorado	303-939-5507		wgibson@ball.com			
Ball Aerospace			Colorado Springs	Colorado						
Ball Aerospace	Kenneth Travis	Senior Manager	Albuquerque	New Mexico	505-242-2227		kttravis@ball.com			
Berkley National Labs			Berkley	California					Charlie Anderson will give contacts suggested by Dejan	
Blue Origin			Seattle	Washington						
Boeing	Dejan Nikic	Physicist	Seattle	Washington	2206-544-0369		dejan.nikic@boeing.com			
Booz Allen Hamilton	Jim Potter	Director	Linthicum	Maryland	410-865-3824		potter_patrick@bah.com			
Booz Allen Hamilton	Andrey Adnreev	Associate	Albuquerque	New Mexico	505-563-5802		andreev@andrey@bah.com			
Booz Allen Hamilton	Gerald Wood	Associate Electrical Engineer	Albuquerque	New Mexico	505-563-5807		wood_gerald@bah.com			
Booz Allen Hamilton	Kevin Lawson		King George	Virginia			lawson_kevin@bah.com			
Booz Allen Hamilton	Joe Shepherd	Principal	King George	Virginia	540-644-6903		shepherd_joe@bah.com			

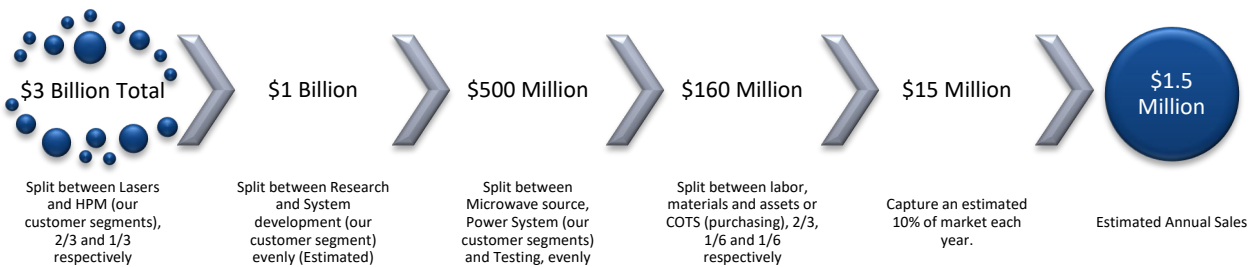
Consolidated Edison Company	John Fantl	New York	New York	System Engineer	212-606-2780			fantj@coned.com		
Defense Threat Reduction Agency	Jacob Calkins	Virginia	Fort Belvoir	Physical Scientist	571-616-5946			jacob.a.calkins.civ@mail.mil		
DE-JTO	Diana Loree	New Mexico	Albuquerque	AF Rep	505-248-8211	505-350-3337		diana.loree@jto.hpc.mil		
Eagle Harbor Technologies	Dr. James Prager	Washington	Seattle	Senior Research Scientist	206-582-1244	206-276-1570		prager@eagleharbortech.com		
Electric Power Research Institute	Steve Willard	California	Palo Alto	Sr Project Manager	505-366-7230			swillard@epri.com		Research Gate
GE	Timothy Summer	New York	Niskayuna							
General Atomics (Pulsed Power) Harris		California	San Diego							
Intelligent Optical Systems	Marvin Klein	California	Long Island	Laser Ultrasonics Products	424-263-6361			mklein@intospsys.com		
ITHPP Alcen	Saad El Amari	France		R&D Engineer Project				selamari@ihpp-alcen.fr		
ITHPP Alcen	Beatrice Laile	France		Manager				blaille@ihpp-alcen.fr		
IXI Technology		California	Yorba Linda							Tim and Joe both know him
Joint Non-lethal	David Law		D.C.							
LANL	Gregory Dale	New Mexico	Los Alamos	R&D Engineer	505-664-0795			gedale@lanl.gov		
LANL	Martin Taccetti	New Mexico	Los Alamos					Taccetti@lanl.gov		
LANL	Tom Tierney	New Mexico	Los Alamos	Senior Project Leader	505-667-6944	505-699-4639		tierney@lanl.gov		
LANL	Robert Wheat	New Mexico	Los Alamos	R&D Engineer	505-665-3564	505-699-0222		rwheat@lanl.gov		
Lidos	Haynes	New Mexico	Albuquerque							x
Lidos	Josh Gilbert	New Mexico	Albuquerque							x
LLNL	Brent McHale	California	Livermore	Pulsed power and Electronic Systems Associate Program Leader	925-422-8730	925-293-6585		mchale@llnl.gov		
LLNL	Adam Conway	California	Livermore		925-422-2412	925-337-2180		conway8@llnl.gov		
Lockheed Martin	Braxton Bragg	Texas	Forth Worth					braxton.bragg@lmco.com		x
Lockheed Martin	Eric Taylor	Texas	Forth Worth		703-416-6298	571-867-6053		Eric.LTaylor@lmco.com		
Lockheed Martin	Patrick Kelly	Texas	Forth Worth			cell: 432.413.6111, office: 972.603.0706		patrick.m1.kelly@lmco.com		x
Main Stream Engineering		Florida	Rockledge		321-631-3550					
Megawatt Lasers		South Carolina	Hilton Head							

Lockheed Martin	Patrick Kelly					cell: 432.413.6111, office: 972.603.0706	patrick.m1.kelly@lmco.com		x
Main Stream Engineering									
Megawatt Lasers									
Metglass	Vadym Pysmennyi						vadym.pysmennyi@nrl.navy.mil		
MK Magnetics									
Naval Research Labs	John Guilian	Head, Dense plasma dynamics section					giul@ppdmail.nrl.navy.mil		
Naval Research Labs	David Abe		D.C.						
Naval Research Labs	Zach Drikas		D.C.						x
Naval Research Labs	Tony Carusso		D.C.						Will be visiting UNM Monday Oct. 14
Naval Research Labs	Joe Croman		D.C.						Will be visiting UNM Monday Oct. 14
Naval Research Labs	Frank Hegeler	Head, Pulsed Power Energy Technology Section	D.C.			202-404-4440	frank.hegeler@nrl.navy.mil		
Ness Engineering	Richard Ness		San Diego	California					
Northrop Grumman	Mike (Jane knows last name)		Albuquerque	New Mexico					
Northrop Grumman	Mike Chin		Albuquerque	New Mexico					
Northrop Grumman	Andy Kwas		Albuquerque	New Mexico					
NSWC China Lake	Shawn Higgins		China Lake	California			shawn.higgins1@navy.mil		
NSWC Dahlgren	Brian Hankla	Directed Energy Chief Engineer	Dahlgren	Virginia		540-653-2625	brian.hankla@navy.mil		
NSWC Dahlgren	Mike Jones		Dahlgren	Virginia		540-653-9340			
NSWC Dahlgren	Matt McQuage		Dahlgren	Virginia			matthew.mcquage@navy.mil		x
NSWC Dahlgren	Jake Walker		Dahlgren	Virginia			jacob.w.walker@navy.mil		
NSWC Dahlgren	Jordan Chapparo		Dahlgren	Virginia			jordan.chapparo@navy.mil		x
NSWC Dahlgren	Ben Grady		Dahlgren	Virginia			benjamin.grady@navy.mil		x
NSWC Dahlgren	Chris Reichart		Dahlgren	Virginia			christopher.reichart@navy.mil		
NSWC Dahlgren	Kimberly Morales		Dahlgren	Virginia					x

SNL NM	Jeff Alexander	Albuquerque	New Mexico						
SNL NM	George Laity	R&D Manager Albuquerque	New Mexico					9/27/2019	x
SNL NM	Mike Cuneo	Senior R&D Manager Albuquerque	New Mexico						
SNL NM	Keith Cartwright	DMTS Albuquerque	New Mexico					9/27/2019	x
SNL NM	Kevin Howard	Albuquerque	New Mexico						
SNL NM	Steve Glover	Albuquerque	New Mexico						
SNL NM	Ben Yee	SMTS Albuquerque	New Mexico					9/27/2019	x
SNL NM	Brian Huttsel	SMTS Albuquerque	New Mexico					10/7/2019	x
SNL NM	Jason Neely	Albuquerque	New Mexico						Contact from Charlie
SNL NM / Consulting	David Reisman	Albuquerque	New Mexico	505-844-6974					
TD	Harry Barnes	Albuquerque	New Mexico						
Tetra	Steve Pronko	Albuquerque	New Mexico						
Tetra	Bill Money	Albuquerque	New Mexico						
The Aerospace Corporation	Mark Johnson	Senior Project Engineer Albuquerque	New Mexico						mark.a.johnson@aero.org
TPL, Inc.	Lew Bragg	Albuquerque	New Mexico	505-342-4440					lbragg@tplinc.com
Trek, Inc.	Chris Lemke	Sales Engineer Medina	New York	585-798-3140					chris.lemke@trekinc.com
Verus	Mike Butcher	Albuquerque	New Mexico						willmatt@verusvetustestatic.com
Verus	Will White	Albuquerque	New Mexico						
Voss Scientific	Don Voss	Albuquerque	New Mexico					9/30/2019	x
White River Tech	Jack Foley	Vice President of Operations Albuquerque	New Mexico	301-342-3378 (TPC)					
	Peter Duselis	Albuquerque	New Mexico						
	Dr. Darin Khaus	Engineer	New Mexico	603-640-2355					dak@creare.com

Decision NO Go

While the fundamental premise was correct – for certain pulsed power components, there is a need for commercial products – there is simply not enough need to sustain a business. In fact, several small businesses told us that a basic commercially available product line is essential to level the financial fluctuations to maintain even a small business. In the time since we have completed this ICORPS, I see substantially increased purchase of core components – including switches – but the diversity of technical needs is large and the market segment small.



Final Presentation

**TEAM 1681
SUMMANUS**

ESTIMATED MARKET \$40 MILLION 

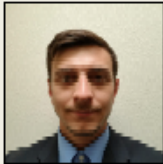
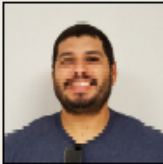


INTERVIEWS 100 TOTAL 95 IN PERSON 

SELLING COMPONENTS FOR HIGH POWER MICROWAVE SYSTEMS. BEING THE FIRST TO MARKET SHOULD MAKE IT EASY

RAYTHEON HIGH POWER MICROWAVE SYSTEM - 2013

1


Who are we?

	Leonardo Rossetti - EL		Dr. Andrew Fierro - Co EL
	Dr. Jane Lehr - TL <small>A subject matter expert in gas discharge switches and fundamental of electrical breakdown phenomena.</small>		Dr. Ender Savrun - IM <small>Business owner and entrepreneur. Bringing the much-needed business experience to the team.</small>

2



3

 Org: NSF I-Corps - Cohort: NSF I-Corps 2019 Fall Bay Area Cohort - Team: 1681_Summanus Canvas				
Key Partnerships	Key Activities	Value Propositions	Customer Relationships	Customer Segments
Gas Switch Manufactures	Communications with customers	Purchasable Solution	Product customization and specific requirements	High Power Microwave Engineers
Micro Laser Companies	System consultation	Small Package Usable in any system	Continually increase product performance	Compact Pulsed Power Systems
Magnetic Core Distributors	Key Resources Customers Manufacturing capabilities Human Capital (Engineers...)	Fast deployment and utilization	Channels Direct point of contact (phone, email, ...etc) References from previous customers Web based Sales	SLAC
		Expertise in the operation, inclusion, and design of triggered gas switches		Prime Defense Contractors (Lockheed, Raytheon...)
		Switch Performance (Rise time, Jitter, Voltage, Power)	National Labs/ Linear Accelerators	
		Cost		
Cost Structure		Being able to prototype faster		
Expert engineers in pulsed power (Fixed Cost)		Reliability and Lifetime	Direct Sales of product	
Design of trigger generators and switches (Variable Cost)			Expertise in system integration	
			Consultations	

4

innovation within

Org: NSF I-Corps - Cohort: NSF I-Corps 2019 Fall Bay Area Cohort - Team: 1681_Summanus Canvas

Key Partnerships	Key Activities	Value Propositions	Customer Relationships	Customer Segments
Gas Switch Manufacturers	Communications with customers	Purchasable Solution	Product customization and specific requirements	High Power Microwave Engineers
Micro Laser Companies	System consultation	Small Package Usable in any system	Continually increase product performance	Compact Pulsed Power System
Magnetic Core Distributors		Fast deployment and utilization		SLAC
	Key Resources	Expertise in the operation, inclusion, and design of triggered gas switches	Channels	Prime Defense Contractors (Lockheed, Raytheon)
	Customers	Switch Performance (Rise time, Jitter, Voltage, power)	Direct-point of contact (phone, email, website)	National Labs/ Linear Accelerators
	Manufacturing capabilities	Cost	References from previous customers	
	Human Capital (Engineers...)	Being able to prototype faster	Web based Sales	
		Reliability and Lifetime		
Cost Structure				
Expert engineers in pulsed power (Fixed Cost)			Direct Sales of product	
Design of trigger generators and switches (Variable Cost)			Expertise in system integration	
			Consultations	

No idea where to start on this side

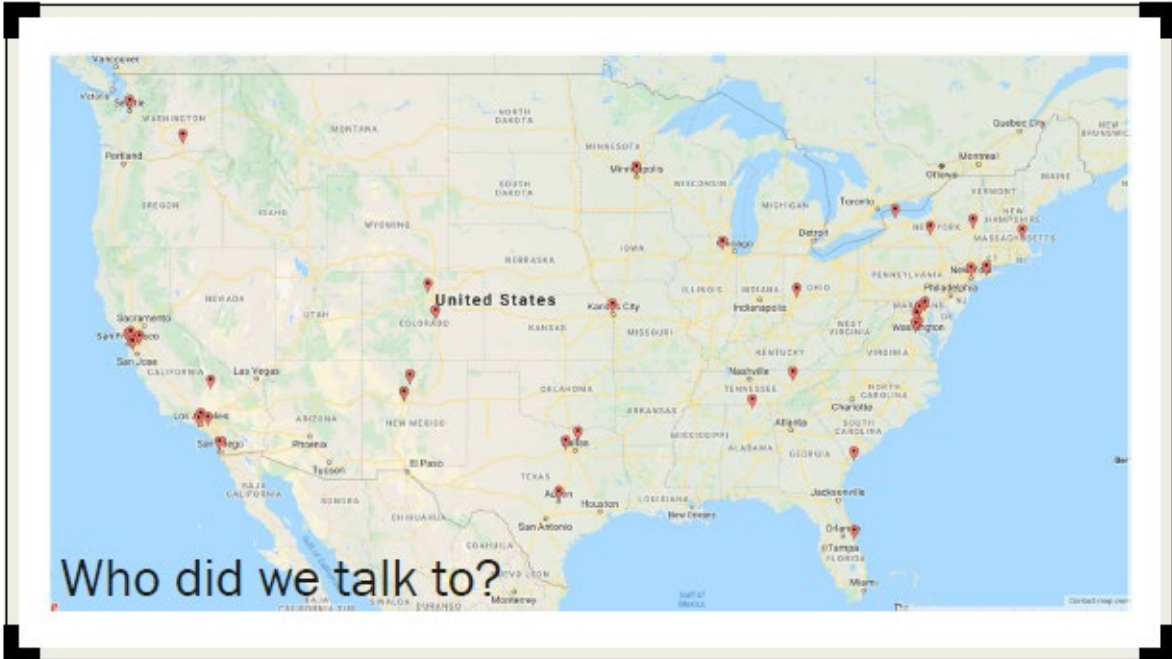
How do you measure these?

Who? Vague! companies? What about people?

5



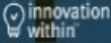
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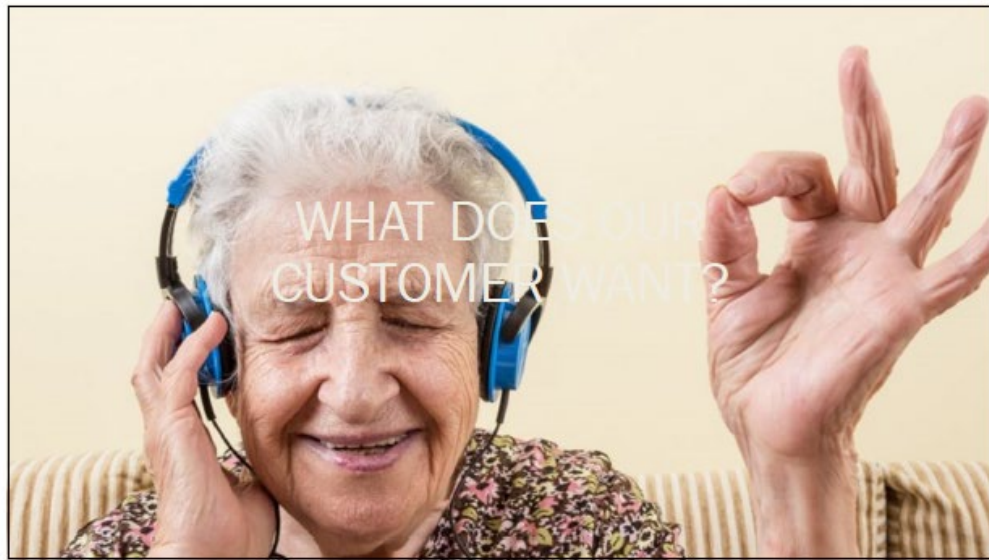
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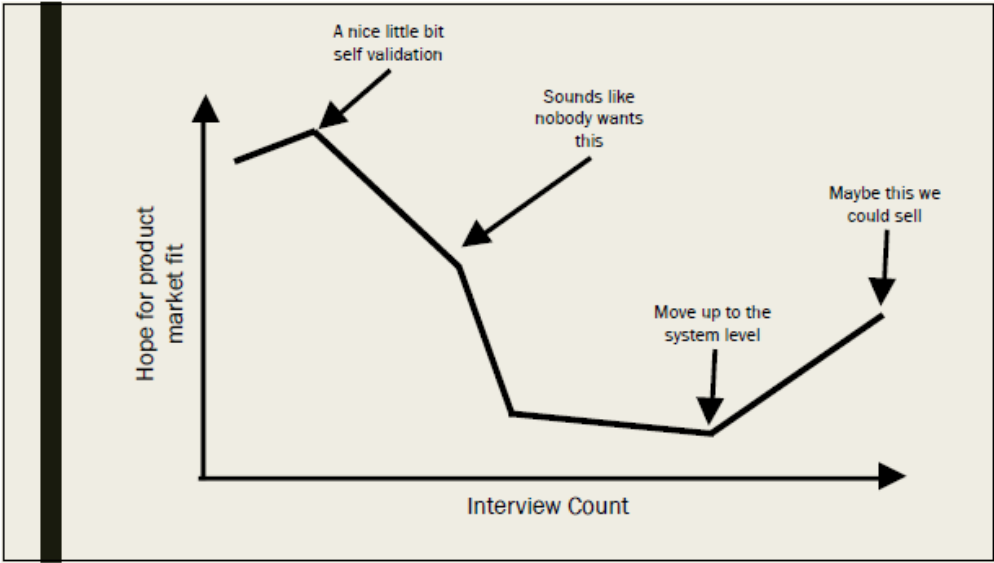
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 Org: NSF I-Corps - Cohort: NSF I-Corps 2019 Fall Bay Area Cohort - Team: 1681_Summanus Canvas				
Key Partnerships Gas Switch Manufactures Micro Laser Companies Magnetic Core Distributors	Key Activities Communications with customers System consultation Key Resources Customers Manufacturing capabilities Human Capital (Engineers...)	Value Propositions Being able to prototype faster Reduce the use of SPB in systems by 90% to meet federal environmental requirements Increase time between device failures Reduce cost across 5 different microwave systems by standardizing design Increase system efficiency above 20% Reduce the use of SPB	Customer Relationships Product customization and specific requirements Continually increase product performance Channels Direct-point of contact (phone, email, ...etc) References from previous customers Web based Sales	Customer Segments Project managers at defense contractors (Lockheed Martin, Raytheon, L3) System engineers at defense contractors (Lockheed Martin, Raytheon, L3) Main bank design engineers at defense contractors (Raytheon, Lockheed, L3) Small business system engineers (SARA, ASR) Staff scientists at national labs (Sandia Labs) Pulsed power engineers at linear accelerator facilities (LLNL, SLAC, CERN, LANL) Project managers at linear accelerator facilities (LLNL, SLAC, CERN, LANL) Managers at national labs (Sandia Labs) Industrial Indoor Agriculture Facility President (Crescent Bio Tech)
Cost Structure Expert engineers in pulsed power (Fixed Cost) Design of trigger generators and switches (Variable Cost)		Revenue Streams Direct Sales of product Expertise in system integration Consultations		

9



10



11

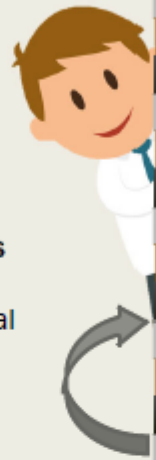
Pivotal Interviews

The slide features the title "Pivotal Interviews" in the top left. Below the title is the logo for the Office of Naval Research Science & Technology, which includes an anchor, the letters "OR", and a Marine emblem. On the right side of the slide is a portrait of an older man with white hair, looking directly at the camera with a serious, slightly frowning expression.

12

Market Size – Too Small

- Our hypothesized market size was much bigger than the actual market.
- Need to move up the value chain (from Component Space to Pulsar/Modulator)
- Moving Forward: Determine Serviceable Obtainable Market (SOM) for Pulsar/Modulators
- Moving Forward: Calculated estimated additional costs, partners, and key resources.

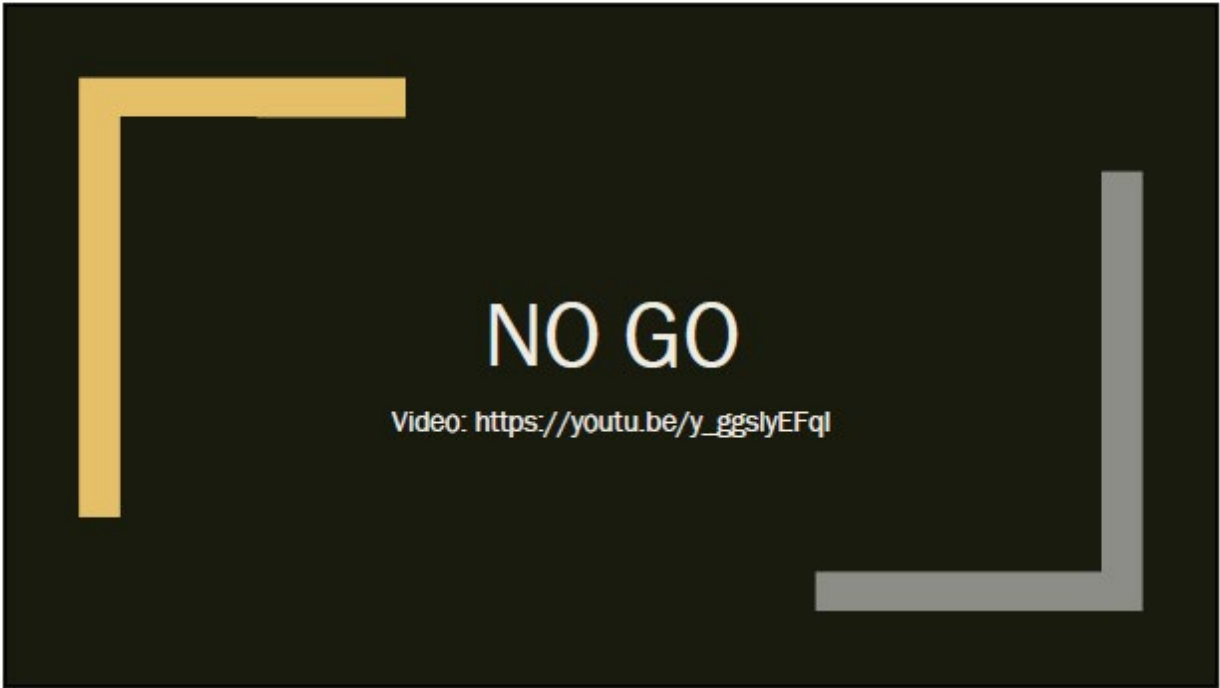


Org: NSF I-Corps - Cohort: NSF I-Corps 2019 Fall Bay Area Cohort - Team: 1681_Summanus Canvas

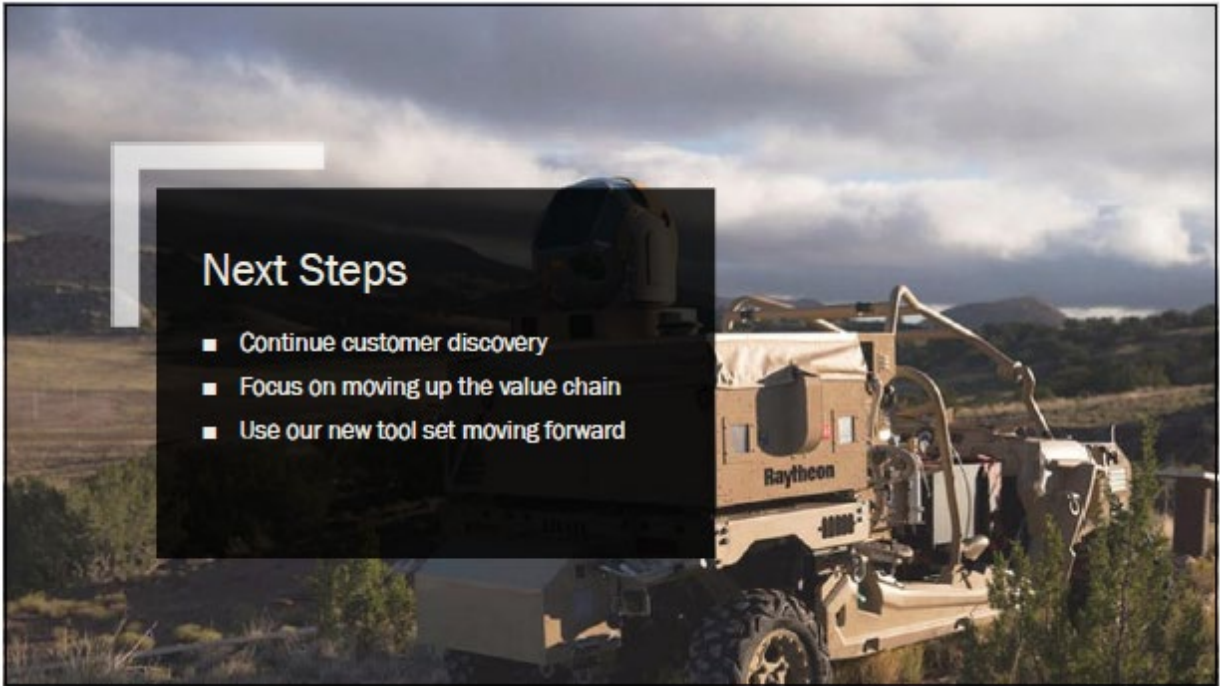
Key Partnerships	Key Activities	Value Propositions	Customer Relationships	Customer Segments
Gas Switch Manufacturers (ASR Corp)	Communication with customers	Reducing the cost of system integrations by supplying a complete system	Attending Conferences (Pulsed Power Conference & Directed Energy Conference)	Project managers at defense contractors (Lockheed Martin, Raytheon, L3)
Micro Laser Companies (Megawatt Lasers)	System consultation	Being able to reduce prototyping weeks to days	Product customization and specific requirements	System engineers at defense contractors (Lockheed Martin, Raytheon, L3)
Magnetic Core Distributors (Supplier)		System Lifetime (Having a product that can last up to 100k shots)	Continually increase product performance	Marx bank design engineers at defense contractors (Raytheon, Lockheed, L3)
	Key Resources	Shelf Life of a sealed system (up to 10 years)	Channels	Small business marx bank design engineers (SARA, ASR, AFELC)
	Customers	Reduce the use of off the shelf systems by 90% to meet federal environmental requirements	Traveling Salesman, meet customers face to face at conferences, or by referral.	Staff scientists at national labs (Sandia Labs)
	Manufacturing capabilities	Decrease maintenance costs by 5x	Direct point of contact (Phone, Email...)	Pulsed power engineers at linear accelerator facilities (LLNL, SLAC, OSR, LANL)
	Human Capital (Engineers...)	Reduce cost across microwaves systems by optimizing design	Company Website with relations to key terms for online discovery (Pulsed Power, Spark Gap, Marx Bank)	Project managers at linear accelerator facilities (LLNL, SLAC, CERF, LANL)
		Increase system efficiency above 20%		Managers at national labs (Sandia Labs)
		Use system down by up to 5x, due to using an off the shelf product		Industrial In-door Agriculture Facility President (Dana Storch) (Possibly more of a beneficiary)
		Reduce the use of SPS by 90% to help reduce cost of system by 50%		Principal Investigator at Defense Research Facility (NRL, NDWC, AFRL)
Cost Structure			Asset Sale	
Expert engineers in pulsed power (Fixed Cost)			Expertise in system integration of product	
Custom design of trigger generators and switches (Variable Cost)			Consultations	

Customer Driver Values

Focused



15



16

Conclusions

During the ICORPs experience the team Summanus Technologies focused on customer discovery in the area of pulsed power technology. The program involved the minimum requirement of speaking with 100 potential customers, partners, and industry influencers. Through the process, the team spoke with 102 different members of the pulsed power, directed energy, linear accelerator and other related communities with potential interests in this technology. The interviews gave insight into the potential market space. As the program progresses, the team narrowed down the potential customer segment and determined measurable value propositions.

The Customer segment is defined as the direct customer or the driving force in a purchase. For team Summanus the narrowed down customer segments were Marx bank design engineers and high-power microwave systems engineers. These were determined as the most suited customers for the technology with corresponding value propositions. The value propositions are used to determine how valuable the technology is to the customer and defines where the problem-solution fit occurs with the technology. The most valuable propositions were determined to be the lifetime and reliability of the switches. This is defined by how many times a switch can be used without the need for maintenance or replacement. Later through the interview process, it was determined that the sale of the component (a gas discharge switch) was less desirable than the sale of a system (a full Marx generator) with the switches integrated. This led the team to pivot the technology to hit a larger market. The ending results of the program have determined that the current state of the market is not large enough to sustain a business. The next steps for the team are to continue customer discovery and improve the development of the technology to meet customers' needs.

Sample Data Collection of ICORP Questionnaires

ICORP Questionnaire (John Krile)

Sample questions, there is no need to follow the questions exactly but be sure to test hypothesis with every interview. When an interviewee says something like “lifetime is a big problem” make sure to follow up and get a quantity “What number of shots do you need?”. We need quantifiable data to put in the canvas and show progress. “Big, small, important”, all need values assigned to them or they are impossible to compare.

Opening Questions

How do you use pulsed power?

Applied Physics division, use pulsed power for rapid prototyping and quick turn development. “Jack of all trades”, innovative solutions delivered very quickly. 60 units in 3 months, design to production. Pulser from concept to deliver 6-8 months.

When working with pulsed power systems what is the single most important problem that comes up (or ask for top 3 problems)?

High energy storage capacitors, high energy density, Joules per cubic centimeter. 1kA or less, when looking 20-30kA for a pulse. Capacitors 0.1 joules per CC. Lower current high capacitance, mF’s Ka or less. Snubbers for solid state switches. Lower voltages larger values, mF’s. Switching is a big pulsed power problem, opening switches is something they are interested in. High current opening switches, high rep rate high current opening switch. Inductive energy storage is high than a capacitive energy store. Current on the inductor, mechanical stress. Capacitor dielectric holdoff and constant. Current sources and opening switches. Solid state is a possible opening switch solution. High current discharge, High current diodes, thermal management, for CW.

What are usually the circumstances/deciding factors that lead to you needing/wanting a new pulsed power system?

Spark gaps: electrode erosion, triggered spark gaps are impossible to find a commercial high rep rate high energy trigger generator. Beverly, low energy low rep-rate. L-3 dual output, for 50ohm load. Spark gap triggering is a big issue. High voltage feed through from oil to vacuum. This is done through trial and error. Reducing the size of the feedthrough of a 500kV - 1MV holdoff, for compact systems.

More Specific to Marx Banks/ Switches

(If Marx Bank/Switches are not mentioned)

(If Marx Bank/Switches are mentioned)

Where do you find trouble in Marx Banks/Switches?

Lack and cost of commercial spark gap switches, very expensive, \$2k-\$10k. Is a rough value \$1k for a reasonable cost.

What happens when there is an issue, what steps must happen to get what you need?

(Follow up if the customer mentions switches as a problem)

What would be the benefits of purchasing a system/switch versus making your own?

Customer Segment Questions

What is the process of purchasing?

Most projects are rapid turnaround, so there is very little difference between manager and engineer. COTS is always the choice if available, in the time frame. COTS is the choice always, because the timelines are short, and time is 10x more important than cost. 2-8 months are an average time range, custom products are too long. If components can be purchased in those timelines, and if internal costs and time are same as COTS, if COTS is anything less it is chosen.

Who is the driving force to purchasing products for a system?

Specific Hypothesis to Test (Value Propositions)

(SF6 Questions)

What insulating material do you use and why?

(Reliability and cost/time consequences questions)

What happens when a system goes down or has a problem? What are the consequences for you?

Specific Hypothesis to Test (Channels)

What methods do you use to decide which vendor you want to purchase your components from? SARA does it through reputation & word of mouth referrals. Website is not the main force. The SBIR program is where a lot of business grows from. Applied Physics, 4 main customers that they deliver too. Of being able to meet timeline needs. Capacitor development, and HPM side. Hiring people with industry connections. Pulsed Power Conference.

ICORP Questionnaire (Steve Calico)

Sample questions, there is no need to follow the questions exactly but be sure to test hypothesis with every interview. When an interviewee says something like “lifetime is a big problem” make sure to follow up and get a quantity “What number of shots do you need?”. We need quantifiable data to put in the canvas and show progress. “Big, small, important”, all need values assigned to them or they are impossible to compare.

Opening Questions

How do you use pulsed power?

To make money, commercializing pulsed power.

When working with pulsed power systems what is the single most important problem that comes up (or ask for top 3 problems)?

Biggest problem is the customer, the government. They are bad at telling you what they want, indecisive. This results in “Requirements Creep”.

- Moving away from oil insulation, not SF6. They do not have the time or resources to research to find alternatives to SF6 for gas insulation.
- Energy density, piezo electric effect of capacitors. 50kV. 50 ohm. Sub-100ps solid state switches.
- Capacitors: Minimum factor for 2x or 30% improvement of energy density.

What are usually the circumstances/deciding factors that lead to you needing/wanting a new pulsed power system?

Differences in fast versus slow,

- Fast, small impedance mismatches cause problems in the capacitors.
- Slow, compact pulsed power Marx generator acts like a transmission line.
- High power RF problems
- Plastic cannot be used at ultra high vacuum.
- Transitions from traditional RF tubes moving from plastic to ceramic.
- Conflict between mechanical vs electrical.
-

More Specific to Marx Banks/ Switches

(If Marx Bank/Switches are not mentioned)

Why do you not consider Marx Banks/Switches a problem?

The switch should be considered the weakest component. The wear on the stwitch, the balance between reliability and the voltage holdoff. The ability to mitigate prefires.

Lifetime is an issue for the pulse discharge capacitors. For instance, at 500Hz, 30,000 shots is not long enough. As size goes down so does the amount of shots, 1k shots is a good amount for a munition. There has to be a base for the industry.

What happens when there is an issue, what steps must happen to get what you need?

(Follow up if the customer mentions switches as a problem)

What would be the benefits of purchasing a system/switch versus making your own?

A 1 year warranty, the cost comes in after that!

Customer Segment Questions

What is the process of purchasing?

Who is the driving force to purchasing products for a system?

Specific Hypothesis to Test (Value Propositions)

(SF6 Questions)

What insulating material do you use and why?

(Reliability and cost/time consequences questions)

What happens when a system goes down or has a problem? What are the consequences for you?

Specific Hypothesis to Test (Channels)

What methods do you use to decide which vendor you want to purchase your components from?

Pulsed Power Conferences, industry connections/networking.

For maintenance of pulsed power drivers, is it done in house or do you contract that work out with the people you bought it from?

References: Mike Fazzio (SLAC)

Dr. Randy Curry (Texas Tech/ Missouri Columbia)

Gerg Engel

Dave Hemmert (Texas Tech) HEM Technologies

Dr. Dickens (Expert Witness)

Dr. Neubar (Texas Tech)

Maxwell CCDS (Ellis Lorie)

Ingwerson (Fixes power supply)

ICORP Questionnaire (Charlie Anderson)

Department Head of EMP Survivability and Effects

SARA – Scientific Applications and Research Associates

EMP and EMP simulators, HPM and solid-state switching. Power modulating lots of energy up to 800 kJ.

Size and weight do matter – specifically for EMP work they want different assets tested and aren't as mobile as you would like. Would like EMP testing capability testing that is capable of being moved to a different site. Do testing with a small of device as possible and be able to travel to different test sites. Needs to be deployable and mobile. Pulsed power technology that must be fielded by small teams. Internal R&D focused high energy density components. Typically, don't want to use gas switches unless they are operating at an energy level that requires gas switching.

Sealed gas switches would be a nice solution, don't want to drag around gas bottles

Lifetimes of components does not always matter

In general, cost is generally of not concern. More interested in fielding a technology and having it deployable – government understands it comes as a certain cost for this specialized testing. Interested in flexible technology – things that could be used for multiple applications. I.E. Ring-down pulser that could operate at 1 MHz to 10 MHz, and government could be willing to pay more if it covers multiple applications areas.

How much is done in-house? Machining or custom built things are done in house – cut raw materials. 95% of this is done in house. Do solid-state switching where they buy build bulk materials and make own switches. Build own capacitors. Build high-energy resistors. **Out of necessity for timelines because of problems with supply chains (note: this is pre-COVID19).** outsource PCB, SMD components. **Manufacture most stuff in house from raw materials, 40% done externally, 60% internally. Mostly for custom applications. A little more expensive but permits rapid prototyping – a needed capability in-house for customers so that we control the timeline.**

Think that laser triggered switch is a big need right now in the pulsed power community. Control timing and jitter is a huge advantage. want mobile systems that are deployable in a few days – size control is done with capacitors and switches.

Rise-times are big in the EMP community – the 10 to 90 is less than 10 ns and the **dI/dt is huge!** lots of frequency content and energy.

Control jitter and rise-time for distributed systems for constructive interference applications.

Size/weight vs. power – this is the key trade off

Very little testing done in Colorado Springs. qualifying and small testing. and prototyping (proof of concept). Want it mobile so they can take it places. Hang their hat on that they come to you. Deploying and big testing done where their final customer is.

competitive environment - not always going to be the cheapest, but they are looking for the best value.

References: J

Jonathon Parson, specialized pulsed power.

Dave Reisamn, Consulting Business, could introduce to potential customers

Berkeley National Labs (CA will introduce me to some people)

Stanford Linear Accelerator

Lisa Bonetti

Why does slac design own modulators for LINAC?

They wanted to write a very good specification. Most of design was done at SLAC but used Ling (company probably not around anymore) to build for the sheer manpower.

Higher and higher pulse repetition rates can be important for CJ and ultrafast electron deflection. The faster you can make the pulse train the more information you will be collecting.

Even for Radar there used to be constant rep rate, but now there are chirps and fancy signal processing.

Low-cost medical accelerator work – higher peak power. Using mini-klystron. Shorter pulse, higher repetition rate.

Jeff

Store bought or things they have made? Moving towards super-conducting and getting rid of modulators, moving to solid-state amplifiers. Modulators for driving large Klystrons, RF for linear accelerating beam. Built in the 1960's and they keep them going. Have a total of 250 modulators, and even a thousand dollar change is a quarter of a million dollar change.

Late 80's, changed the experiment that they were doing and wanted a different pulsed width and changed the PFN. PFN is all thyatron driven, and has been traditionally the cheapest way. 50 kV, 10 kA type of switches. Even in medical device industry, driving a magnetron.. still used thyatrons and very simple PFN's. Couple of reasons: (1) cheap to build (2) easy to design (3) ??? making most of your money in service contracts for these microwave devices.

One problem with solid-state is that they are changing all the time. Degradation starts from day 1

Klystrons operate at 350 kV. Pulse transformer between modulator and microwave source.

A lot cheaper to come in with a drop in replacement for solid-state. Repair a lot of modulators, and replace the modulators. Thyatrons last about 2 years and constantly have to be tweaked.

Varian was testing a solid-state replacement for their Thyatron switch.

Solid-state switches work for small average powers, but haven't been applied here to the LINAC.

Switch-tubes (vacuum tube, guitar amplifier tube), but they have solid-state solutions for this. 30 kV but only 10 A, manageable with solid-state (Behlke). Lots of applications with 10's of kV and 10's of nanoseconds operation time. Use a lot of induction modulators that are IGBT driven.

Now doing solid-state amplifiers instead of doing klystrons.

Still using pulsed power, "kicker". Make modulators

Haven't though about spark gaps in a long time.

The challenge is that everybody's requirements are always different.

Synchrotron light. Accelerator builder for a light source requirement.

Guys who want to scan cargo, accelerators for that stuff. Scan pipes in refineries that are looking for cracks. **SMALL XRAY DEVICES**

Tony

Incredibly hard with solid-state switches is to get a design that works really well for high power, high voltage. Not an off the shelf solution for their current modulators. So many pieces that quality control matters. Buy modulators from scandinova. Thyatron replacement switch there are a few companies that you can buy them from. Haven't had any success for Thyatron replacement –

Solid-state switches in theory have an “infinite” lifetime, but have not had experience that one has lasted that long. At lower rates and voltages, labs have (Oak ridge) have had lots of success with solid-state switches.

Have very many difficult parameters. 150 kV, 6 kA, 500 Hz, solid-state is not currently the solution.

Advantage of solid-state switches is the jitter goes down to less than a nanosecond, but dI/dt may not be that great.

New linac is super-conducting. Walls of RF cavity that accelerate the beam are lossless. You can keep putting energy in and it just adds up, no longer needs to be pulsed. Only doing that with a 1/3 portion of the machine. 2/3 of machine is power modulator, not sure if transition will happen to entire machine.

“Kicker” modulators are often smaller than Klystron modulator. The “kicker” steers particle bunches to different places. Bunch frequency could be from 120 Hz up to 10^6 Hz. However, only a few of them are operating on LINAC.

For pulse generators, he has seen more and more stuff that he can buy companies. Often you are driving 50 ohms with some tens of kV, and you want the pulse to be nanoseconds to microseconds. There are companies that make pulsers that meet these specifications.

Saving grace for pulsed power for a long time was you generate high current, high voltage devices but it was a single shot type of device. Now, people are making these same pulses that operate at MHz or faster.

Timing resolution that could be tolerates is about a couple nanoseconds, but it does depend on application. That's the nice thing about solid state, in theory it has less jitter than Thyatrons. Jitter for solid-state might be 250 ps, and a Thyatron may operate like that for a couple minutes and then change. Had to change Thyatron's for a specific system every 6 months to 1 year.

Use RF MOSFETS – SiC at reasonable currents are about 2 kV range.

Number of magnetic transformers in the world is pretty limited and don't think that this is going away.

Maybe shape the pulse?

Sometimes, its not clear who to ask for a modulator that meets a certain requirement. 5 kV low current things. He spends a lot of time building these things because he is not sure who to go to. 1 kV to 10 kV, 10 to hundreds of Hz, hundreds of Amps.

Build to a particular code because more and more they are looking for a product that meets safety standards. Pulsed power devices that have built-in safety features.

Technical Video Script

1-Minute Technical Video

Intro

Scene (Camera): Close shot of Leo speaking directly into the camera

Hello, my name is Leonardo Rossetti I am the entrepreneurial lead for Summanus Technologies. I am currently a graduate student working in the Aperiodic laboratories at the university of New Mexico focusing on pulsed power.

Summanus technologies focuses on advanced all-purpose component solutions for pulsed power systems. Our compact, high reliability trigger generators can be utilized in research grade pulsed power systems and deployable High-Power Microwave systems.

Body/Technical Details

We are currently focusing on two separate designs to add increased reliability and improved SWaP to current triggering systems.

Scene (Slide): Example of how the system works, graphics show separation of laser switch and laser trigger

First, laser triggered gas switches, using a switch and low energy laser combination we can create a compact reliable solution to triggering gas switches. This design allows switch triggering with only an optical connection.

Scene (Slide): Example of how the system works, graphics show sample design

Second, Saturated Pulse Transformer triggers or SPT's. Our design of SPT's utilize a magnetic core to quickly and reliably generate high voltage pulses. The SPT's allow fast rises times up to 10ns and sub Nano-second jitters. Alongside high performance the SPT is also designed in a compact solid-state solution with optimized SWaP in mind. 707

Conclusion

Scene (Camera): Close shot of Leo speaking directly into the camera

We hope through the ICORP program Summanus Technologies will be able to better understand the feasibility and customer needs related to pulsed power trigger generation. Thank you.