2015 Pacific Symposium on Pulsed Power and Applications Program

August 5th – 7th, 2015

Royal Lahaina Resort, Ka'anapali Beach, Maui, Hawaii, USA

Technical Topics

High-Power Microwave and RF Sources

Compact Pulsed Power Sources

Repetitive Pulsed Power

Industrial, Commercial, and Medical Applications

Advisory Committee

Prof. Weihua Jiang
Extreme Energy-Density Research Institute, Nagaoka University of Technology, Japan

Prof. John Mankowski
Center for Pulsed Power and Power Electronics, Department of Electrical and Computer Engineering, USA

Prof. Jianjun Deng
Institute of Fluid Physics, China Academy of Engineering Physics, China

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Center for Pulsed Power and Power Electronics, Department of Electrical and Computer Engineering, USA

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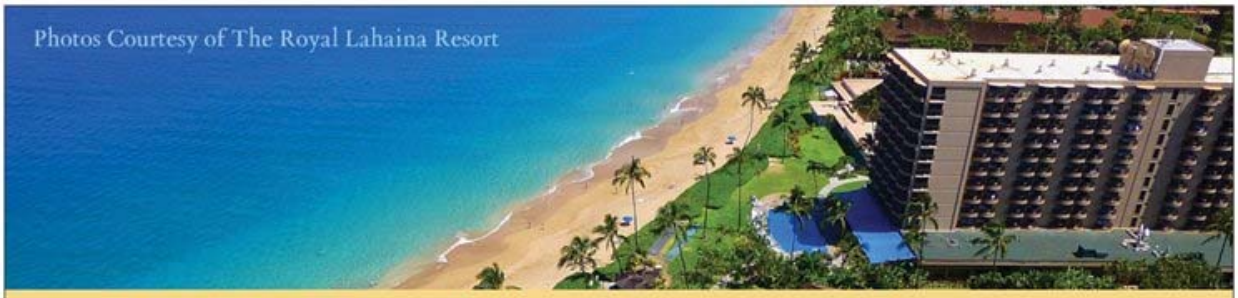

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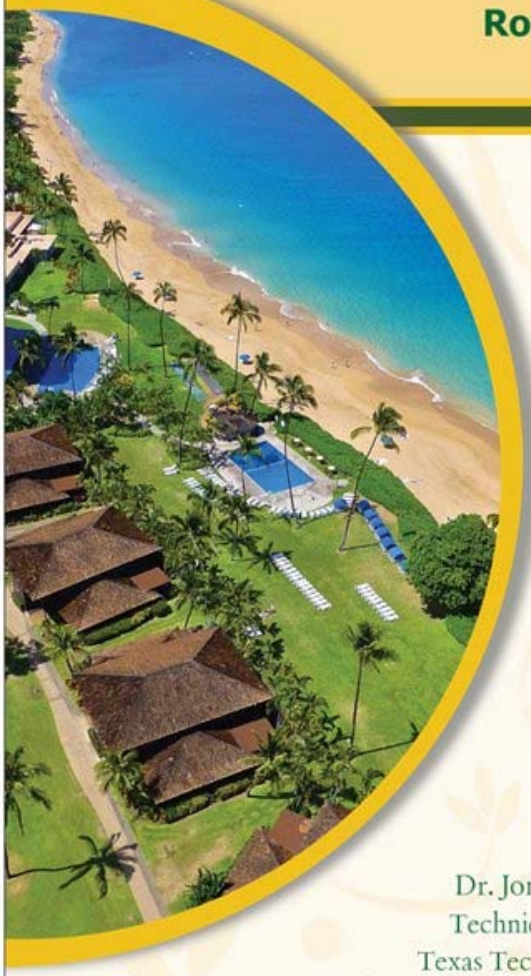

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Abstract Deadline: April 15, 2015
Paper Deadline: July 1, 2015

Abstract Submission to: symp.p3e@ttu.edu
Website http://p3e.ttu.edu/symp2015

Schedule

Wednesday, August 5th

Check-in / Registration	2:00 PM – 5:00 PM
Welcome Reception	6:00 PM – 9:00 PM

Thursday, August 6th

Breakfast	7:30 AM – 8:30 AM
Session C1: Compact Pulsed Power	8:30 AM – 10:00 AM
Coffee Break	10:00 AM – 10:30 AM
Session C1: Compact Pulsed Power cont.	10:30 AM – 12:00 PM
Lunch Break	12:00 PM – 2:00 PM
Session C2: Compact Pulsed Power	2:00 PM – 4:00 PM
Session S1: High Power Microwave and RF Sources	2:00 PM – 4:30 PM
Lu'au at The Westin	5:30 PM – 8:30 PM

Friday, August 7th

Breakfast	7:30 AM – 8:45 AM
Session A1: Industrial, Commercial, and Medical Applications	8:45 AM – 10:00 AM
Session R1: Repetitive Pulsed Power	9:30 AM AM – 10:00 AM
Coffee Break	10:00 AM – 10:30 AM
Session A1: Industrial, Commercial, and Medical Applications	10:00 AM – 12:00 PM
Session R1: Repetitive Pulsed Power	10:00 AM – 12:00 PM
Lunch Break	12:00 PM –
Catamaran Dinner Cruise	5:30 AM – 8:30 PM

Registration Desk

Wednesday, August 5th	12:00 PM – 4:30 PM
Thursday, August 6th	8:00 AM – 4:00 PM
Friday, August 7th	8:00 AM – 12:00 PM

Social Events

Welcome Reception 5:00 PM – 8:00 PM	Wednesday, August 5th Beach Front Lawn
Lu'au 5:00 PM – 8:00 PM	Thursday, August 6th The Westin Hotel
Catamaran Dinner Cruise 5:00 PM – 8:00 PM	Friday, August 7th Alli Nui

Exhibitors

ScandiNova

douglas.eaton@sc-nova.com
http://www.scandinovasystems.com/

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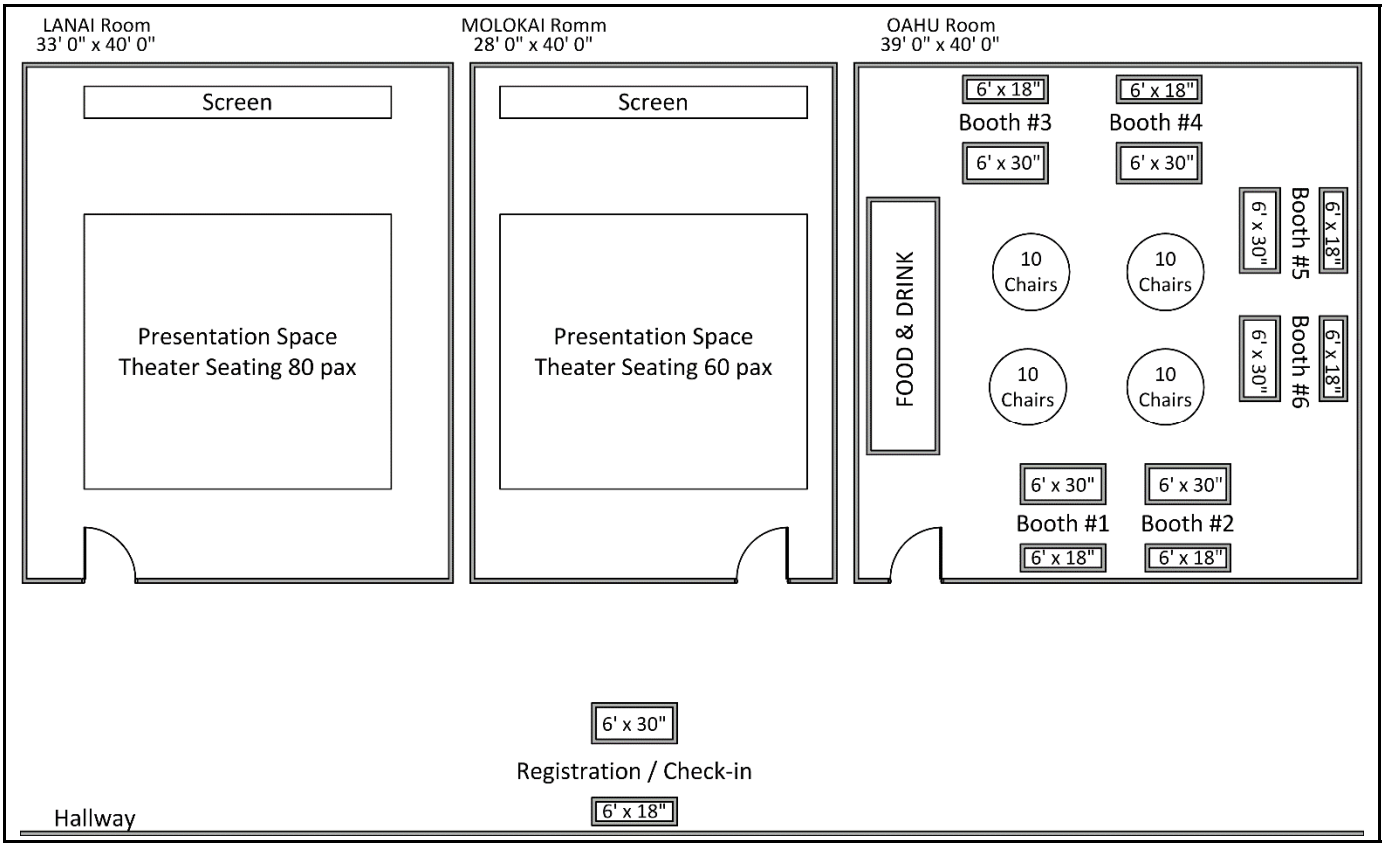

Exhibitor Booths — Oahu Room

ScandiNova	Booth #1
Stangenes Industries, Inc.	Booth #2
Pulse Power Solutions, LLC	Booth #3
Orbital ATK	Booth #4
Diversified Technologies, Inc.	Booth #5
Pearson Electronics	Booth #6

Transportation

Lu'au at The Westin Resort & Spa — August 6th

Departure: buses will pick up at 4:30 PM in front of the Royal Lahaina Resort

Return: buses will pick up at 8:30 PM in front of the Westin Resort & Spa

The Catamaran Dinner Cruise — August 7th

Departure: buses will pick up at 4:30 PM in front of the Royal Lahaina Resort

Load at slip #56 in the Ma'alaea Harbor

Return: buses will pick up at 8:30 PM at the Ma'alaea Harbor

NOTE: SCHEDULE IS SUBJECT TO CHANGE.

Session C1: Compact Pulsed Power

Thursday, August 6th — Lanai Room
8:30 AM – 12:00 AM

Chair: **Prof. James Dickens** – Center for Pulsed Power and Power Electronics Texas Tech University, Lubbock, TX, USA

8:30 AM

C1-1 PRELIMINARY EXPERIMENTS OF MAGNETIC FLUX COMPRESSION WITH PLASMA ON A LINEAR TRANSFORMER DRIVER

Lin Chen, Fan Guo, Wenkang Zou, Jie Wang, Yuanjun Zhang and Ye Li
Key Laboratory of Pulsed Power, Institute of Fluid Physics, CAEP, P. O. Box 919-108, Mianyang 621999, China

A plasma magnetic flux compression generator (MFCG) was designed and tested to investigate the possibility of current amplification on the 1 MA linear transformer driver (LTD) test stand. In this kind of MFCG, a seed azimuthal magnetic field was not preliminary injected, but switched and then trapped in the compression region during current switching stage. The influence of geometric parameters of MFCG and the initial plasma density on load current has been investigated in the preliminary experiments. Experimental results indicate that the process of plasma liner acceleration, current switching, and flux compression stages can be determined according to the current waveforms. It shows that, due to lower current transfer efficiency during the current switching stage, only 90% of generator current can be observed on the inductive load after current switching and amplification. The lower efficiency might be the results of low opening resistance between the plasma liner and the cathode.

1. J. F. Leon, R. B. Spielman, and J. R. Asay, "Flux compression experiments on the Z accelerator", Proceedings of the 12th IEEE International Pulsed Power Conference, 1999, pp. 275-278.
2. S. A. Sorokin, "Current amplification by magnetic flux compression", Proceedings of the 16th International Symposium on High Current Electronics, 2010, pp. 227-229.
3. Xiang Xu, Lin Chen, Chengzheng Qian and Younian Wang, "Theoretical analyses of current amplification in a new kind of plasma magnetic flux compression generator", J. Plasma Physics, 2014, 80(3), pp. 329-339.

8:45 AM

C1-2 PULSED HIGH POWER AMPLIFIERS*

Chris Chipman, Raul Ramos-Schulze, Dr. Marcel P. J. Gaudreau, and Rebecca Simpson
Diversified Technologies, Inc., Boston, MA 01730, USA

Diversified Technologies, Inc. (DTI) has delivered two solid-state pulsed klystron transmitters. Though not identical, the units are similar in design, and will be provided to Lawrence Berkeley National Laboratory (LBNL) and Daresbury Laboratory in England. DTI's goal across these two projects was to develop a complete package which can subsequently be marketed in the high peak power laboratory transmitter market. The modulator is a pulse transformer-coupled hybrid system, including ancillary klystron components (i.e., focus coil, socket) but not the actual klystron tube. The RF includes a drive amplifier, simplified protection circuitry and two pieces of waveguide. A simple PLC-based controller is incorporated into the transmitters. Water manifolds are included as is a secondary oil containment basin. Both systems employ a relatively simple modulator, which consists of an energy storage capacitor, a high voltage series switch, a step-up pulse transformer, and a passive pulse-flattening circuit. This arrangement gives an extremely flat pulse and allows the use of a moderate value storage capacitor. The DTI switch can open or close as commanded, so the pulse width is adjusted by the gate pulse to the system. Each system employs a 35 kV primary voltage supplied by a DTI high performance high voltage switching power supply. The high primary voltage allows optimization of all components to give a simple, reliable, and high stability system.

*Work supported by Lawrence Berkeley National Laboratory and Daresbury Laboratory.

9:00 AM

C1-3 DEVELOPMENT OF SOLID STATE PULSED POWER TECHNOLOGY FOR DWA

DENG Jianjun, XIA Liansheng, SHI Jinshui, ZHANG Linwen, CHEN Yi, WANG Wei
Key Laboratory of Pulsed Power, Institute of Fluid Physics, CAEP, P. O. Box 919-150, Mianyang, Sichuan, 621900, China

Solid state pulsed power technology has been developed for many years at IFP for different applications. The most recent progress of solid state pulsed power technology for die-electric wall accelerator(DWA) with high accelerating gradient is presented in this paper.1MV test stand consisted of 3 identical modules has been built and tested for DWA, initial results will be presented.

9:15 AM

C1-4 VERIFICATION OF KLYSTRON VOLTAGE PULSE-TO-PULSE STABILITY AT THE PARTS-PER-MILLION LEVEL

Klas Elmquist and Roger Karlsson
ScandiNova Systems AB, Ultunaallen 2A Uppsala 756 51 Sweden

Stability in the range of 20 ppm has been achieved on high power pulses used to power klystrons in the 40-60MW RF power range. The modulator used is pulsed up to 400 kV and is designed with the latest solid state technology developed by Scandinova Systems AB. Measurement techniques used to measure the stability level are using an offset amplification of the voltage pulses.

9:30 AM

C1-5 A REVIEW OF EXPLOSIVELY DRIVEN FERROELECTRIC GENERATOR TECHNOLOGY

David J Hemmert
HEM Technologies, 2306 FM 1585, Lubbock, TX 79423 USA

Ferrolectric generators have been shown to be unique sources of ultra-compact high voltage pulsed power. The ability of ferroelectric material to store electric charge within a small volume provides a compact material power source for certain pulsed power applications. The released power can achieve voltages greater than 100 kV and be designed as a high current power source as well. This presentation will discuss the engineering development of explosively driven ferroelectric generator worldwide with a review of its history and unique configurations for delivery of pulsed power.

9:45 AM – Coffee Break

10:15 AM

C1-6 INVESTIGATION OF A COMBINED PCSS AND MAGNETIC SWITCH TRIGGERED BY LASER DIODE

Liu Hongwei, Yuan Jianqiang, Ma Xun, Jiang Ping, Wang Lingyun, Wang Meng and Xie Weiping
Key Laboratory of Pulsed Power, Institute of Fluid Physics, CAEP, P.O. Box 919-108, Mianyang, Sichuan 621900 China

Based on the characteristics of the Si photoconductive semiconductor switch (PCSS) and the magnetic switch (MS), a new combined switch is developed. The combined switch integrates a traditional Si PCSS and a normal magnetic switch. Compared with normal magnetic switch, the combined switch can withstand a charge time of several tens microsecond and give an output voltage with several tens nanosecond rise time which means the gain is more than 1000. The combined switch also can reduce the power of the laser for triggering the traditional single Si PCSS and then laser diode can be used. In this paper, the traditional singles Si PCSS and the combined switch were triggered by laser diode with different power and pulse width. Test results also been discussed based on the drift-diffusion model of the PCSS and the hysteresis behavior of magnetic core.

10:30 AM

C1-7 FUNDAMENTAL RESEARCH OF THE BREAKDOWN PERFORMANCE OF COLLOIDAL SUSPENSIONS IN PC

Yanpan Hou, Zicheng Zhang, Jiande Zhang, Zhen Wang, Zuyin Song
College of Opto-electronic Science and Engineering, National University of Defense Technology, Changsha, 410073, People's Republic of China

Propylene carbonate (PC) has potential to be used in compact pulsed power technology for its high permittivity and high resistivity. In this study, a series of nano-particles with different dielectric properties have been suspended into PC and the dielectric breakdown of PC and PC-based nano-fluids (NFs) subjected to high amplitude electric fields with microsecond duration has been investigated. Breakdown voltage and the time lag to breakdown have been determined by suiting a calibrated voltage divider on the source side of the test gap. Results show that the breakdown voltage increases and the time lag to breakdown decreases with increasing high-voltage increasing rate and the dielectric properties of NFs are strongly influenced by the type of the nano-particles suspended. In general, the addition of nano-particles to PC is favorable for the overall dielectric strength. For a high volume percent of nano-particles, the breakdown voltage of the base liquid is much increased and for a low volume percent, the scatter of breakdown data is improved. Changes in dielectric strength of NFs compared with that of PC are illuminated in light of the physical properties of the suspended nano-particles.

10:45 AM

C1-8 DEVELOPMENT OF PULSE POWER TECHNOLOGY IN NUDT

Zhang Jun, Zhang Jiande, Zhong Huihuang, Yang Jianhua, Yang Hanwu, Zhang Zicheng, Gao Jingming and Cheng Xinbing
College of Opto-electric Science and Engineering, National University of Defense Technology, Changsha 410073, People's Republic of China

For driving high power microwave sources, two typical pulse power drivers are developed in National University of Defense Technology. One is based on pulse transformers, pulse forming lines and spark gap switches. The feature is that high energy storage density liquids were used to prolong the output pulse duration while keeping the driver compact. Typical parameters of such drivers is pulse power of 1-10's GW, pulse duration of 30-200ns and, and the repetition rates is as high as 30Hz. The other is magnetic pulse compression generator without any spark switches, which can be run with very high stability. The generator accomplishes the power compression and the pulse forming by two-stage magnetic compressions, a low impedance PFN and a magnetic main switch. The output pulse power is about 5GW and the pulse width is about 170ns. In this report, research activities and their recent advancements of the drivers are reviewed, the descriptions of designing, some key technologies and their applications are also included.

11:00 AM

C1-9 AFFORDABLE SHORT PULSE MARX MODULATOR*

Michael Kempkes, Robert Phillips, and Dr. Marcel P. J. Gaudreau
Diversified Technologies, Inc., Boston, MA 01730, USA

Dr. Jeffrey Casey
Rockfield Research, Las Vegas, NV, USA

High energy, short-pulse modulators are being re-examined for the Compact Linear Collider (CLIC) and numerous X-Band accelerator designs. At the very high voltages required for these systems, all of the existing designs are based on pulse transformers, which significantly limit their performance and efficiency. There

is not a fully optimized, transformer-less modulator design capable of meeting the demanding requirements of very high voltage pulses at short pulse widths. Under a U.S. Department of Energy grant, Diversified Technologies, Inc. (DTI) is developing a short pulse, solid-state Marx modulator. The modulator is designed for high efficiency in the 100 kV to 500 kV range, for currents up to 250 A, pulse lengths of 0.2 to 5.0 µs, and risetimes <300 ns. Key objectives of the development effort are modularity and scalability, combined with low cost and ease of manufacture. For short-pulse modulators, this Marx topology provides a means to achieve fast risetimes and flattop control that are not available with hard switch or transformer-coupled topologies.

*Work supported by U.S. Department of Energy SBIR Award DESC0004251

11:15 AM

C1-10 PULSED POWER SYSTEMS FOR ESS KLYSTRONS

Michael A. Kempkes, Dr. Ian Roth, and Dr. Marcel P. J. Gaudreau
Diversified Technologies, Inc., 35 Wiggins Ave., Boston, MA 01730, USA

Diversified Technologies, Inc. (DTI) has designed and built several advanced, high-voltage solid-state modulators for the testing and conditioning of European Spallation Source (ESS) klystron tubes. The modulator uses a proven series-switch design that DTI has delivered to hundreds of clients over the last 19 years. The heart of the ESS modulator is a high-voltage solid-state switch, based on DTI's patented technology. The switch is made of seven series-connected IGBT modules, and operates at 6.7 kV. The IGBTs in the switch give redundancy: two of the devices can fail without affecting the ability of the switch to operate at full rated voltage. This is possible because the devices always fail as a short circuit. The DTI power supplies are rated for 250 kW, and are high reliability, with a demonstrated MTBF of over 90,000 hours; highly efficient (96.9%); and regulate to much better than 0.02%, with ripple of 1.5×10-3%. A capacitor bank capable of directly meeting the ESS pulse requirements would be unrealistically large and expensive. DTI's modulator has a much smaller capacitor, which will droop by 15% during a pulse. This droop is eliminated by the switching regulator. The regulator supplies only the droop voltage (~7.5% of the output) rather than the full voltage. This means that the regulator can be small and efficient. The regulator operates in opposition to the variation in capacitor voltage, and produces both a flat output pulse and a constant load voltage to the DC power supply. As a result, the power supply can operate at constant current and constant power – and so does not produce flicker, regardless of the switching frequency. Because the regulator sinks and sources the same energy during each pulse / charge cycle, the regulator itself is non-dissipative – it uses no net power over a cycle. DTI, working in partnership with SigmaPhi Electronics has delivered one modulator to a US National Lab and will deliver two more in late 2015 to European facilities.

11:30 AM

C1-11 EXTENDED SOLIDS UNDER EXTREME PRESSURE AND ELECTROMAGNETIC CONDITIONS*

James Y. B. Kim and Eric N. Enig
Enig Associates, Inc., 4600 East West Hwy Suite 620 Bethesda, MD 20814

Enig Associates, Inc. ("ENIG") will introduce scalable devices to compact sample solids of up to 100 grams to ultrahigh pressure ranges, from 30GPa to 1 TPa. ENIG is performing on-going explosive pulsed-power research, studying compact flux compression generators (FCG) for hyper-velocity launch of metallic jets, and enhancement of explosive performance under extreme pressures (up to 1 TPa) and magnetic pressure (100GPa). The device is composed of an ENIG-designed and validated small form-factor FCG and imploding cylindrical liner to compact various solid targets up to 1 TeraPascal dynamical impact. ENIG and its team partners are identifying and characterizing extended solids, using fundamental computational techniques to characterize stability. The team will test and diagnose the device and samples under dynamic and static conditions. Computational results from ALEGRA-MHD will be presented.

*Work supported by Army Research Laboratory (ARL) and DARPA.

11:45 AM

C1-12 DESIGN AND CHARACTERIZATION OF A COMPACT LONG PULSE MARX GENERATOR FOR LOW IMPEDANCE HPM AND RADIOGRAPHIC LOADS

Artem Kuskov, Ahmed Elshafiey, Sydney Horne, and Salvador Portillo
Department of Electrical and Computer Engineering, MSC01 1100, University of New Mexico Albuquerque, NM 87131-0001, USA

The Electrical and Computer Engineering Department at the University of New Mexico is conducting basic physics research on charged particle beam driven High Power Microwave (HPM) sources, high brightness, narrow beam Bremsstrahlung sources and pulsed power drivers. As part of these efforts we have developed a high energy modular Marx generator designed to drive low impedance loads. The Marx generator was designed to provide a fast rise time, a long pulse width, in excess of 300 ns, efficiency greater than 60%. And deliver in excess of 40 kA at 500 kV. This presentation details the electrical and mechanical design decisions made as well as numerical SPICE and electrostatic models validating these decisions. This paper also presents initial characterization of the output at various voltages and various loads of different impedances as well as short test results verifying the inductance and capacitance of the erected Marx.

12:00 PM – Lunch Break

Session C2: Compact Pulsed Power

Thursday, August 6th — Lanai Room
2:00 PM – 4:00 PM

Chair: **Prof. Jianjun Deng** – Key Laboratory of Pulsed Power, Institute of Fluid Physics, CAEP, Mianyang, China

2:00 PM

C2-1 INVESTIGATION ON THE HEAT FLUX ON ELECTRODE SURFACE AND ITS EFFECT ON ELECTRODE EROSION IN GAS SPARK SWITCHES

Xiaoang Li, Xuandong Liu, Lei Feng, Baofeng Nan, Shanhong Liu, Qiaogen Zhang
State Key Laboratory of Electrical Insulation and Power Equipment, Xi'an Jiaotong University, 710049, Xi'an, China

Gas spark switches are widely used in pulsed power system for their high current capability, stability and low costs while electrode erosion is a serious problem restricting the performance and shortening the life time of gas spark switch [1-2]. During the discharge, the electron, ion and neutral molecule can accumulate energy from the electrical field and impact the electrode surface, which brings heat flux to electrode surface and causes temperature increasment or even melting and evaporating of electrode materials[3]. In this paper, the heat flux caused by each kind of particle is analysis and its effects on electrode erosion property are investigated. The results show that the heat flux includes three parts, the heat fluxes from electron, ion and neutral molecule respectively, and the heat flux on cathode surface is severer than the one on anode. Besides, with the increase of current ampitude, the density of heat flux acted on electrode surface increases rapidly and as a result, the electrode mass loss increases exponentially.

1. J. R. Woodworth, J. A. Alexander, F. R. Gruner, et al. "Low-inductance gas switches for linear transformer drivers." Phys. Rev., vol. 12, no. 6, pp. 1-17, June 2009.
2. X. Li, X. Liu, X. Gou, et al. "Degradation of performance due to electrode erosion in field distortion gas switch in long-term repetetive operation." IEEE Trans. Plasma Sci., vol. 42, no. 10, pp. 3064-3069, Oct 2014.
3. H. Wang, Q. Zhang, X. Tong, et al. "Study on heat fluxes and theirs effect on electrode material removal on the copper electrode of a field-distortion gas switch." Euro. Phys. Lett., vol. 96, no. 4, pp. 45001-1-45001-3, Nov. 2011.

2:15 PM

C2-2 BREAKDOWN CHARACTERISTICS OF A GAS SWITCH TRIGGERED BY SPARK-DISCHARGE EJECTED PLASMA

Shan H. Liu, Xuan D. Liu, Bao F. Nan and Qiao G. Zhang
State Key Laboratory of Electrical Insulation and Power Equipment, Xi'an Jiaotong University, Xi'an 710049, China

Zhi B. Li and Xiang L. Yan,
China Electric Power Research Institute, Beijing 100192, China

In this paper, the breakdown characteristics of a gas switch ignited by spark-discharge ejected plasma are studied with different gas pressures, gap distances, triggering pulse amplitude and switching coefficients. The switch has the configuration of two-electrodes, in one of which a micro-incentive chamber is embedded to develop ejected plasma into the switch gap, leading to the closing of the switch. The switch is filled with SF6. The results indicate that the gas switch ignited by spark-discharge ejected plasma can be triggered reliably under extremely wide switching coefficient of 10%~90%, and the delay time significantly reduces from dozens of μs to hundreds of ns with the switching coefficient increasing. The switch gap distance has a great influence on the triggering breakdown characteristics of the switch. As the gap becomes longer, the delay time increases rapidly. With the decrease of gas pressure and the increase of triggering pulse amplitude, the delay time of the switch reduces.

1. A. Larsson. Gas-discharge closing switches and their time jitter[J]. IEEE Transactions on Plasma Science, 2012, 40(10): 2431-2442.
2. Woodworth J R, Stygar W A, Bennett L F, et al. New low inductance gas switches for linear transformer drivers[J]. Physical Review Special Topics-Accelerators and Beams, 2010, 13(8): 080401.
3. W. H. Tie, X. D. Liu, Q. G. Zhang, et al. Note: Design and investigation of a multichannel plasma-jet triggered gas switch[J]. Review of Scientific Instruments, 2014, 85(7): 076105.
4. W. H. Tie, S. H. Liu, X. D. Liu, et al. A novel low-jitter plasma-jet triggered gas switch operated at a low working coefficient[J]. Review of Scientific Instruments, 2014, 85(2): 023504.
5. W. H. Tie, X. D. Liu, S. H. Liu, et al. Low-jitter discharge of a plasma-jet triggered gas switch at low working coefficients[J]. IEEE Transactions on Plasma Science, 2014, 42(6): 1729-1735.

2:30 PM – C1:15

C2-3 FOURIER SERIES ANALYSIS AND SYNTHESIS OF TYPE-E PFNS FOR TIME-VARYING LOADS

C. R. Rose
Los Alamos National Laboratory, PO Box 1663, Los Alamos, NM 87544, USA

The synthesis of type A, B, and C pulse forming networks (PFNs) is relatively straightforward with Cauer and partial-fraction (Foster) expansion methods of the driving-point impedance or admittance functions. Analytical derivations of type D and E PFNs are much more difficult due to the necessity of calculating the negative inductances of the type D network. Type E networks are preferred in practice due to their ease of construction. Normally, these networks are designed for constant loads. However, non-linear or time-varying loads are common. When accurate voltage flat-tops are required, matching a PFN to the load is critical. Other authors have examined PFN designs for time-varying loads based on type-C topologies. This paper builds on the theory and synthesis methods developed by E. A. Guillemin and shows how for a time-varying load to analytically derive the negative inductances of Type D and then coupled inductors in Type-E PFNs. Analysis techniques are applied to empirical data to compute the Fourier coefficients necessary for PFN synthesis. The

validity of the synthesized PFNs is demonstrated through comparisons to measured data and circuit simulations.

2:45 PM – C1:16

C2-4 THYRATRON REPLACEMENT*

Ian Roth, Dr. Marcel P. J. Gaudreau, and Michael. A Kempkes
Diversified Technologies, Inc., 35 Wiggins Ave., Boston, MA 01730, USA

Semiconductor thyristors have long been used as a replacement for thyratrons, at least in low power or long pulse RF systems,. To date, however, such thyristor assemblies have not demonstrated the reliability needed for installation in short pulse, high peak power RF stations used with many pulsed electron accelerators. The difficulty is that a fast rising current in a thyristor tends to be carried in a small region, rather than across the whole device, and this localized current concentration can cause a short circuit failure. It is not clear that this failure mode can be overcome with currently available device designs. An alternate solid-state device, the insulated-gate bipolar transistor (IGBT), can readily operate at the speed needed for the accelerator, but commercial IGBTs cannot handle the voltage and current required. It is, however, possible to assemble these devices in arrays to reach the required performance levels without sacrificing their inherent speed. Diversified Technologies, Inc. (DTI) has patented and refined the technology required to build these arrays of series-parallel connected switches. Under a DOE contract, DTI is currently developing an affordable, reliable, form-fit-function replacement for the klystron modulator thyratrons at SLAC capable of pulsing at 360 kV, 420 A, 6 µs, and 120 Hz.

* Work supported by DOE under contract DE-SC0011292

3:00 PM – C1:17

C2-5 INVESTIGATION OF MONOLITHIC RADIAL TRANSMISSION LINE FOR FUTURE Z-PINCH*

Chongyang Mao, Xinxin Wang and Xiaobing Zou
Department of Electrical Engineering, Tsinghua University, Beijing 100084, China

Recently, a number of architectures have been proposed for the design of future pulsed power Z-pinch drivers. In these architectures monolithic transmission lines (MRTLs) are used to combine the outputs of several-hundred terawatt-level pulse generators to produce a petawatt-level pulse. In this paper, MRTL was investigated by analytical solution, 3-D electromagnetic simulation (EMS) and scale-down experiment. As a nonuniform transmission line, MRTL was considered as a cascaded multiple-section lines that are equal in length and short enough to be treated as uniform lines with step impedance varying in accordance with impedance profile of MRTL. An analytical expression of the output voltage from the nonuniform line was derived. The correctness of the expression was verified by comparing the result from the expression with that from circuit simulation using PSpice code. The high-pass and pulse-compression characteristics of a nonuniform line were further clarified by the theoretical analysis of the analytical expression. The 3-D EMS of MRTL was performed. Focusing on the difference in the maximum transmitted power efficiency between the 3-D EMS and the circuit simulation, MRTLs with different impedance profile (exponential, Gaussian, hyperbolic) were compared. All the power efficiencies obtained with the 3-D EMS are about 15% lower than those obtained with the circuit simulation, indicating the existence of considerable non-TEM modes and a non-ignorable error in the circuit simulation based on the quasi-TEM mode approximation. In consideration of several MRTLs being stacked together, the hyperbolic line with flat electrodes was recommended as the best choice since it is much easier in fabrication although it has a little bit lower transmitted power efficiency than that of the exponential line. The experiments were performed on a scaled-down MRTL to test the validity of 3-D EMS. Having a hyperbolic impedance profile, the scaled-down MRTL is composed of two flat aluminum plates that are 1m in diameter and separated by 1-cm gap of deionized water. The MRTL was simultaneously powered by 20 identical voltage pulses that were uniformly distributed along the outer circumference of the MRTL. The measured waveform of the output voltage from the MRTL shows a good agreement with that from 3-D EMS, which indicates that the 3-D EMS of MRTL is correct.

* Work supported by the National Natural Science Foundation of China under Contact No. 51277109 and the Key Laboratory of Pulsed Power of China Academy of Engineering Physics (CAEP) under Contact No. PPLF2014PZ02.

3:15 PM – C1:18

C2-6 COMPACT PULSED POWER SYSTEMS BASED ON MARX GENERATOR

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Compact pulsed power systems based on compact Marx generator have found wide ranging applications for driving resistive and capacitive loads. It incorporates high-performance components including high energy density capacitors and compact gas switches that are integrated into a compact assembly. This paper outlines the research and development of compact Marx generators in recent years. Energy density and power density of the whole set which are two key parameters to characterize the capability of compact Marx generator systems will be discussed in this paper. In addition, design elements for two types of compact PFN-Marx generator based on the voltage-fed PFNs and Guillemin type “C” PFN which can output rectangular pulse profile also will be discussed.

3:30 PM – C1:19

C2-7 APPLICATION OF A CERAMIC VACUUM INTERFACE FOR A REPETITIVE OPERATED PULSED POWER SOURCE*

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Research on the surface flashover of the vacuum insulation under pulsed voltage is significant for the design and manufacture of pulsed power devices. The interface problem is difficult because the electrical, mechanical and vacuum issues that must be satisfied simultaneously. In this paper, an improved coaxial high-voltage ceramic vacuum interface applied in a water pulse-forming line generator, has been designed and tested. Results from electro-static calculation by ANSYS and transient simulation by Vorpal show that the electric field (E-field) distribution within the improved interface is uniform. Key structures such as the anode and the cathode shielding rings of the ceramic insulator have been optimized to significantly reduce E-field stresses. The Weibull statistical weighted method was applied to estimate the surface breakdown field. Aging experiments with this interface were conducted in the condition of ~500 kV, ~50 ns and 1~5 Hz pulses. The preliminary test show that the ceramic vacuum interface can work stably with the hold-off field of more than 40 kV/cm. The experimental results agree with the theoretical and simulated results.

* Work supported by the National High-Tech Research and Development Program of China. It was also supported by the National Natural Science Foundation of China under Grant No.11305263.

3:45 PM – C1:20

C2-8 ALL SOLID STATE PULSED POWER SOURCE BASED ON PHOTOCONDUCTIVE SWITCHES: FROM MODULE TO GENERATOR*

Jianqiang Yuan, Weiping Xie, Hongwei Liu, Xun Ma, Ping Jiang, Lingyun Wang, Jinfeng Liu and Hongtao Li
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High power photoconductive semiconductor switches (PCSSs) are considered a promising device for compact, repetitive pulsed power generation due to their advantages over other switches, such as fast response time, negligible time jitter, precise synchronization, high repetition rate and optical electrical isolation. In the past several years, high power PCSSs have been investigated at Institute of Fluid Physics, CAEP. Photoconductivity tests have been performed at different bias voltages, laser wavelengths and energies. Several packaging methods for lateral and bulk PCSSs were investigated and peculiar photoconductivity of high power GaAs PCSSs was observed. By using laser spots to trigger the opposite side of electrodes for lateral PCSS, the damages to ohmic contact were alleviated. Current filaments image of GaAs PCSSs when triggered by laser spots with different patterns were obtained by ICCD camera and analyzed. As a key unit of stack Blumlein lines (SBL), ferroelectric ceramic solid state pulse forming lines (PFL) and glass-ceramic PELs were developed for both energy storage and pulse forming. Combining the ceramic PFLs and PCSSs, a SBL module with an output voltage of 20.2 kV and a current of 8.1 kA were developed. Based on developments of SBL modules, an all solid state pulsed power generator with twelve modules was constructed to drive the industrial cold cathode diodes with different cathode configurations for generating intense x-rays. The diode voltage of 220 kV and electron beam current of 1 kA were achieved, and x-ray with full-width-at-half-maximum (FWHM) of 40 ns was generated. This all solid state x-ray machine can be operated in the repetition rate of 1 kHz.

* Work supported by the National Natural Science Foundation of China under Grant 51007085

Session S1: High Power Microwave and RF Sources

Thursday, August 6th — Molokai Room

2:00 PM – 4:30 PM

Chair: **Prof. Weihua Jiang** – Extreme Energy-Density Research Institute, Nagaoka University of Technology, Nagaoka, Niigata 940-2188, Japan

2:00 PM

S1-1 HIGH POWER SOURCES FOR THE PHYSICS OF IONOSPHERIC MODIFICATION*

B.L. Beaudoin, T.M. Antonsen Jr., N. Goyal, I. Haber, T.W. Koeth, A.H. Narayan, G. Nusinovich, K. Ruisard
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The performance of critical civilian and Department of Defense systems including the Extremely Low Frequency-Ultra Low Frequency (ELF-ULF) communication, radar and navigation systems such as the Global Positioning System (GPS) is in part determined by the ionosphere. Traditional research, typically known as Space Weather (SW), emphasizes passive observations and measurements of natural phenomena that result in physics based specifications/forecast models. Ionospheric Modification (IM) is a complementary approach to passively studying the ionosphere that has been developed over the last 30 years and intensified with the construction of the High-Frequency Active Auroral Research Program (HAARP) in Alaska. The objective of IM is to control and exploit triggered ionospheric and magnetospheric processes to improve the performance of trans-ionospheric C3I systems and to develop new applications that take advantage of the ionosphere as an active plasma medium. A key

instrument in IM is the Ionospheric Heater (IH), a powerful High Frequency (HF) transmitter that modifies the properties of the ionospheric plasma by modulating the electron temperature at preselected altitudes. A major reason for the development of a Mobile IH source (MIHs) is that it would allow investigators to conduct the needed research at different latitudes without building permanent installations. As part of a multi-university research initiative (MURI), UMD is developing a powerful RF source utilizing Inductive Output Tube (IOT) technology running in class-D amplifier mode. This technology was chosen because it has the potential to operate at very high efficiencies. This paper reviews progress on: two electron guns (a novel IOT source design that minimizes intercepted current and an off-the-shelf gridded gun), a compact tunable hybrid cavity operating in the 1-10MHz range and an efficient modulator system capable of modulating a high power beam.

* Work supported by the Air Force Office of Scientific Research under grant FA95501410019.

2:15 PM

S1-2 POWER COMBINER/DIVIDER FOR HIGH POWER MICROWAVE APPLICATIONS

Ahmed Elfrgani

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Microwave power combining is an attractive technique for enhancing the output capacities of high power microwave (HPM) devices. Unfortunately, standard RF systems that have been in use for decades, such as waveguide power combiners/divides, directional couplers, and hybrids, cannot be used directly because of peak field considerations. Indeed, we need to reinvent most of these components, taking into account the constraints imposed by HPM operation. The proposed HPM combiner components are all overmoded circular waveguides to allow high power handling capability while maintaining a compact, inexpensive system. This passive power combiner not only combines the microwave power, but also outputs a different mode pattern. An efficient serpentine mode1 converter has been used as the basis of the power combiner design where the field sums up at the common section of the mode converters. The power combiner combined the microwaves from several HPM devices (i.e. Cherenkov devices). In fact, the microwave sources should be driven by the same high voltage pulser to prevent phase difference at the output of the power combiner. That can be achieved by using nonlinear transmission lines (NLTLs) with a saturated ferrite in an axial magnetic field2 to electronically control the delay of the voltage pulse. In this work, four-way microwave power combiner for HPM applications is designed and simulated. N-way power combiner basic concept is proposed as well.

1. D.V. Vinogradov, and G.G. Denisov, “Waveguide mode converter” USSR Patent 1566424, January 29 1988.

2. V.V. Rostov, A.A. El’chaninov, I.V. Romanchenko, and M.I. Yalandin, “A Coherent Two-Channel Source of Cherenkov Superradiance Pulses,” Appl. Phys. Lett. Vol. 100, pp. 224102-1, 2012.

2:30 PM

S1-3 CLAMP KLYSTON

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We propose a new design for a klystron that allows this microwave source to be driven by multiple electron beams in a novel configuration. This device can operate either as an amplifier or as an oscillator. This klystron is made from a single mode rectangular waveguide that is bent into the form of a clamp. An electron beam intersects the waveguide in the two shorter lengths of the clamp, parallel to upper longer part of the waveguide through ports in the waveguide’s side walls. Parameters of this device are chosen to be similar to those in conventional klystrons. Electrons in the first gap (that is the first entrance to the side wall of the waveguide) experience velocity modulation and then, after propagating through a narrow channel in which the operating electromagnetic (EM) field cannot propagate, the electrons are gradually bunched; the electron bunches then give their energy to the EM field in the second gap (that is the second interception of the waveguide side wall on the other side of the clamp). This EM energy propagates in opposite directions: to the output and to the waveguide input, providing positive feedback. Therefore, this device can operate as an oscillator when the input port is covered by a metal plate. The proposed design permits the use of many parallel electron beams. For example, when operating as an oscillator, the first electron beam enters the waveguide at a distance equal to an odd number of half-wavelengths of the operating EM wave. When the second electron beam enters at a distance from the first beam that is a multiple of the wavelength, then these beams are co-phased and result in increased output power. When the second beam enters the waveguide (parallel to the first electron beam) at a distance that is equal to a multiple of an odd number of half-wavelengths, then one beam operates in the first half of the microwave period, whereas the second beam operates in the second half of the period, which results in an output with double the operating frequency. With increasing number of electron beams these effects continue to add, resulting in even further increase in the output power. Examples of the operation of such a klystron with two electron beams are demonstrated in particle-in-cell computer simulations.

* Work supported by AFOSR Grant FA9550-15-1-0094

2:45 PM

S1-4 THE MECHANISM AND REALIZATION OF AN S-BAND LONG-PULSE HIGH POWER MICROWAVE SOURCE

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Recently, many efforts have been made to lengthen the pulse duration to increase the average output power and the pulse energy. However, the pulse duration of high power microwave (HPM) sources usually does not exceed 20-30 ns owing to the "pulse shortening" phenomenon. Various reasons may lead to this phenomenon, among which the appearance of "unexpected" plasma is most common. The mechanism and realization of an S-band long-pulse HPM source are presented in this paper. Two measurements can be taken to prolong the pulse duration. One is to increase the smoothness and cleanness of the slow-wave structures (SWSs) surfaces and improve the vacuum level to elevate the breakdown threshold. The other is to optimize the electrodynamics structures to decrease the electric field on the surface of SWSs while maintaining relative high power conversion efficiency. In the initial experiment, a microwave with a frequency of 3.76 GHz, power of 2 GW, pulse duration above 140 ns, and repetition rate of 20 Hz is generated, which proves this technical route to be feasible. Undoubtedly, the technical route can provide a guide in designing other types of HPM sources and will benefit the practical application of the long-pulse HPM systems.

3:00 PM

S1-5 MEASUREMENT OF ELECTRON BEAM PULSE ON COLD CATHODE WITH DIELECTRIC GUIDE TUBE

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In the fields of plasma heating, communication systems, radar, biotechnology, food, agriculture, and medical care, the development of compact and variable frequency high-power microwave sources such as back wave oscillators1,2 are desired. For generating microwaves, it is essential to use the reliable cathodes producing a high current electron beam with uniform cross sectional shape. R.B.Milleres3 used a cold cathode fitted with velvet. The cold cathode arranged a cylindrical ceramic to outside of a copper disc was used. The purpose of this study is to apply the broadband pulse surface wave oscillator, so that the electron emission characteristics of the beam diode with a disk-type cold cathode are measured. In this experiment, the cold cathode equipped with a dielectric guide was used. The electron beam emitted from metal parts of triple junctions hits the dielectric surface, the electron density is increased by producing a secondary electron emission. The burn patterns of electron beams were observed with a thermal paper on the beam collector. From the measured current and voltage waveforms, it was found that the electron emission took place at the parts of plasma generated at the cathode. Moreover, the cold cathode with dielectric guide tube could obtain more uniform circular burn patterns than cold cathodes of conical and circular plate shape.

1. H. Yoshimura, K. Ogura, K. Bansho, H. Iiduka, M. Takahashi and A. Sugawara: "Experimental Study of Over¬sized Backward Wave Oscillator with Coaxial Slow-Wave Structure", Journal of Plasma and Fusion Research, Vol.5, pp.S2093-1-S2093-4, 2010.
2. M. Takahashi, K. Ogura, H. Yoshimura, H. Iiduka, A. Sugawara, K. Yambe and W. S. Kim "Experimental Study on Weakly Relativistic Oversized Backward Wave Oscillator with Coaxial Rectangular Corrugations" Journal of the Korean Physical Society, Vol.59, pp.3573-3577, 2011.
3. R. B. Miller "Mechanism of explosive electron emission for dielectric fiber (velvet) cathodes" J Appl. Phys, Vol. 84, No. 7, 1 October, 1998.

3:15 PM

S1-6 DESIGN AND SIMULATION OF A GIGA-WATT CLASS RELATIVISTIC INVERTED MAGNETRON*

Michael R. Lambrecht, Timothy P. Fleming, and Peter J. Mardahl
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Two Inverted Relativistic Magnetron (IRM) configurations consisting of a twelve vane and sixteen vane slow wave structure are investigated using the three-dimensional electromagnetic particle in cell code ICEPIC. IRMs offer several performance advantages over the standard relativistic magnetron; among these are larger cathode surface area for higher input current at lower voltages, low magnetic field, and the elimination of downstream loss current. The desired resonant RF phase velocity requires the slow wave structure to possess an unusually large vane count for a relativistic magnetron. The large vane count supports many more possible modes, leading to mode competition and mode lock-in problems which significantly impede output power and efficiency. Moreover, the method by which electromagnetic energy is extracted from the magnetron may also influence what modes are favored. Our ICEPIC simulations show that these performance problems may be mitigated by the introduction of small perturbations in the cathode surface. These perturbations prime the diode electric field such that a DC azimuthal electric field component, Eθ, is introduced within the electron hub region. This azimuthal field component in turn hastens the capture of electrons into spokes and initiates oscillations, as well as reducing mode competition. Our results show that the twelve vane IRM is capable of generating over a Giga-watt of RF power at 500 kV diode voltage.

* Work supported by a Government Agency

3:30 PM

S1-7 REPETITIVE OPERATION OF A MEGAWATT-CLASS VIRCATOR*

Jonathan M. Parson, Curtis F. Lynn, Shad L. Holt, David H. Barnett, Patrick M. Kelly, James C. Dickens, Andreas A. Neuber and John J. Mankowski

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Steve E. Calico and Michael C. Scott
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Repetitive operation of high-power microwave (HPM) sources is primarily restricted by thermal properties of anode and cathode materials. This study presents a hard-tube reflex-triode virtual cathode oscillator (vircator) capable of burst-mode operation at pulse repetition frequencies (PRFs) of 100-500 Hz in the L, S, and C-band frequency regimes. Note that even in single shot operation, vircators generally inject undesired plasma from the anode/cathode surfaces under high current densities, yielding to excessive heating of electrode materials, vacuum degradation and impedance collapse that may ultimately lead to cut-off of microwave power. Heating of the anode and cathode materials during repetitive operation intensifies these problems and will cause accelerated erosion, especially when metallic electrodes are used. Hence, the vircator herein utilizes a carbon fiber cathode and a pyrolytic graphite anode that permits the vircator to operate at PRFs in the 500 Hz to 1 kHz regime for up to 2 sec burst-mode durations.

* Distribution Statement A: Approved for Public Release – Distribution is Unlimited

3:45 PM

S1-8 DESIGN OF AUXILIARY POWER SUPPLIES FOR 30 KW, 95 GHZ GYROTRON

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This paper describes the design of auxiliary power supplies, including body power supply (BPS) and heater power supply (HPS) for the operation of 30 kW, 95 GHz gyrotron with the following specification: -BPS: 25 kVmax, 10mAmax, output voltage ripple less than 1%-HPS: 12 Vmax, 5 Amax, 50kV Isolation For designing BPS, single-phase resonant converter with MHz switching frequency is adapted to takes advantages of the low output voltage ripple, high-efficiency, and highpower density. Eight separate transformers, which are coupled with primary winding, are designed for BPS to solve difficulty boosting voltage from 310 V to 25 kV by using a single core. In addition, by applying tertiary windings to two cores in each group, balancing voltage can be achieved. For designing HPS, we propose an isolated voltage-sensing circuit that uses an additional sensing transformer to detect the primary voltage of the main transformer instead of detecting voltage on high potential. Based on high frequency resonant converter topology to achieve the goal of highpower density, the design and the implementation of two power supplies are presented.

1. Claesen, R.; Bonicelli, T.; Coletti, A.; Rinaldi, L.; Santinelli, M.; Sitta, L.; Taddia, G., "Gyrotron body power supply, validation of design with test results," European Conference on Power Electronics and Applications, 2005.
* This research was supported by the KERI Primary research program of MSIP/NST

4:00 PM

S1-9 DEPENDENCE OF SPACE-CHARGE-LIMITED FLOW ON CONDUCTING CURRENT IN THREE RELATIVISTIC CONFIGURATIONS

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Institute of Fluid Physics, China Academy of Engineering Physics (CAEP), P.O.Box 919-108, Mianyang 621999, China

In the paper a generalized Poisson's equation for three relativistic configuration, including plane and coaxial cylinder and common-vertex-coaxial-cones conductors, has been deduced under assumption of space-charge-limited (SCL) flow. The equation governs the dependence of space charge current flow on conducting current when these configurations are used as vacuum magnetically insulated transmission lines (MITLs) of high powered pulse machines. For a given extremely high voltage applied to the MITL's metallic electrode, there is always a maximum SCL flow striking on its anode surface that is called as loss current when no conducting current is carried on it. But with the increase of the conducting current, the loss will decease gradually to zero and finally the MITL will reach a state of magnetic insulation. We used the generalized Poisson's equation to calculate the maximum loss current and establish a quantitative relationship between the loss current and conducting current and then form a database about this relationship for various voltages and different geometrical impedance of the three configurations. The database has been already utilized to develop the circuit model of PTS's MITL in CAEP.

4:15 PM

S1-10 A COMPACT HARD TUBE VIRCATOR HIGH REP-RATE SYSTEM FOR IN-CHAMBER TESTING*

John J. Mankowski, Jonathan M. Parson, Curtis F. Lynn, Shad L. Holt, Patrick M. Kelly, Mark Taylor, David H. Barnett, Eric Cordero, Andreas A. Neuber, James C. Dickens
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We report upon the development of a Compact Hard Tube Vircator (CHTV) system featuring an L, S, and C-band High Power Microwave (HPM) source intended for in-chamber testing. CHTV has several unique operational features for end-user requirements. The prime power

source is a Lithium Ion Polymer battery stack eliminating the need for 3-phase wall power. The 600 V battery stack output voltage is converted to high voltage via a compact Rapid Capacitor Charger (RCC). The RCC features IGBT H-bridge switching and an amorphous silicon transformer core in a hard-switch topology. A nominal 35 nF capacitor can be repeatedly charged up to 50 kV in 1.5 msec. A 10-stage Marx-PFN hybrid generator converts the 50 kV charge from the RCC to a 300 kV, 70 nsec wide pulse to an HPM source. High speed air flow across the individual spark gaps within the Marx-PFN generator enables repetition rates of 500 Hz. The HPM source is a reflex triode Vircator. Fabrication features of the Vircator include sealed tube technology, a carbon fiber cathode and pyrolitic graphite anode, and an externally adjustable AK gap. A baseline pressure of 1×10^{-9} Torr and operational pressures < 1×10^{-5} Torr are achieved via 4400 cm^2 of ST707 non-evaporable getter material and a 20 l/s ion pump. Typical peak input and rf output powers are 700 and 40 MW, respectively. HPM frequencies between 1 and 5.9 GHz have been demonstrated. Repetition rates up to 500 Hz for 1000 shots have been attained.

*Distribution Statement A: Approved for Public Release – Distribution is Unlimited

Session A1: Industrial, Commercial and Medical Applications

Friday, August 7th — Lanai Room
8:45 AM – 12:00 PM

Chair: **Dr. David Hemmert** – HEM Technologies, 2306 FM 1585, Lubbock, TX 79423 USA

8:45 AM

A1-1 PROBABILITY OF UNDERWATER STREAMER DISCHARGES BY WATER FLOW RATES*

Masahiro Akiyama and Koichi Takaki
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Akinori Yamamoto, Hamid Hosseini and Hidenori Akiyama
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Underwater streamer discharges produced by pulsed power have potential applications for water treatment [1]. The underwater streamer discharges in a fast water flow become unstable, and do not occur frequently at a water flow speed near 1 m/s. In this paper, a moving rod electrode in water is used to simulate flowing water. The behavior of high repetition streamer discharges is investigated using the movable rod electrode up to 1 m/s. Discharge ratio decreases with increasing the electrode speed (i.e., flow rate), and increases with increasing the applied voltage to the moving rod electrode. Bubble behavior near the electrode tip has an important role in producing a large streamer discharge.

1. S. Gnapowski, H. Akiyama, T. Sagakuwa and M. Akiyama, "Effects of Pulse Power Discharges in Water on Algae Treatment", IEEJ Transactions on Fundamentals and Materials, Vol.133, No.4, pp.198-204, 2013.

9:00 AM

A1-2 APPLICATION OF POWERFUL LASERS FOR RESEARCH IN LABORATORY ASTROPHYSICS*

Vadim S. Belyaev, Boris V. Zagreev, Anatoliy P. Matafonov
Central Research Institute for Machine Building, Korolev, 141070 Russia

Vladimir P. Krainov
Moscow Institute of Physics and Technology (State University), Dolgoprudny, Russia

Results of the work on selection and justification of the perspective directions of research in laboratory astrophysics using powerful lasers are presented. These directions are determined by the possibility of modeling the following problem processes of modern astrophysics in laboratory conditions: 1) Generation and evolution of magnetic fields in space. The role of magnetic fields in space at different spatial scales; 2) Cosmic gamma ray bursts and relativistic jets, mechanisms of their formation and evolution; 3) Plasma instability in space and astrophysical objects, plasma jets, shock waves; 4) Explosions of supernovae. Mechanisms of the explosion of supernovae with collapsing core; 5) Nuclear processes in astrophysical objects; 6) Cosmic rays, mechanisms of generation and acceleration to high energy; 7) Astrophysical sources of X-ray radiation. Database of X-ray spectra of astrophysical objects. It is shown that the use of existing high-power lasers with intensity of 1018–1022 W/cm2 and pulse duration of 0.1–1 ps and high-energy lasers with the energy of more than 1 kJ and pulse duration of 1 to 10 ns allows carrying out experiments in laboratory astrophysics in all selected perspective directions. Presented experimental results in laser plasma research, obtained with the help of created in TsNIIMash laser facility of 10-TWpower level; show the possibilities and the potential of these facilities to carry out a number of experiments in the field of laboratory astrophysics.

* Work supported by the Russian Foundation for Basic Research, grants 14-29-06045, 13-02-00878.

9:15 AM

A1-3 CLASS D AMPLIFIER DESIGN FOR PULSING APPLICATIONS

Abdullah Eroglu
Indiana University-Purdue University Fort Wayne US 46805

Class D amplifiers has two pole switching operation of transistors either in voltage mode configuration that uses series resonator or current mode configuration which uses parallel resonator circuit. In the operation of the Class D amplifier, transistors act as switches and they turn on and off alternately. The series resonator circuit comprised of L and C resonates at the operational frequency and tunes amplifier output circuit to provide sinusoidal output current waveform. Class D amplifiers

are widely used in RF applications including semiconductor wafer processing, medical resonance imaging (MRI) and radar applications due to their several benefits including capability of delivering significant level RF power per die in comparison to other existing RF amplifier topologies. In plasma applications, pulsed RF power is used to improve the quality of the process results in semiconductor fabrication by enhancing notch effect and selectivity in the etch-process. Plasma processes during pulsing may require high pulsing frequencies with small duty cycles. Hence, RF amplifiers that give the ability to provide high pulsing frequencies with adjustable duty cycles become very important. In this paper, the design, simulation and implementation of Class D RF amplifier that can operate between medium frequency (MF) to high frequency (HF) ranges for pulsed plasma applications are given. The characteristics of Class D amplifiers under various load conditions for RF continuous wave (CW) and pulsed waves have been studied extensively. The analytical, simulation, and experimental results are compared and agreement has been observed.

1. A. Eroglu, Introduction to RF Power Amplifiers Design and Simulation, ISBN : 978-1-4822-3164-9 1st Edition, CRC Press - Taylor and Francis, July, 2015.

9:30 AM

A1-4 RF GENERATOR DESIGN FOR PULSED PLASMA SYSTEMS

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RF generators in plasma systems for semiconductor wafer processing provide required power level to sustain plasma as show in Fig. 1. Plasma system impedance may vary quickly and drastically depending on the process steps. RF generators under such impedance changes need to still deliver the adequate power level without any harmonics and spurious signal to sustain the plasma. RF generators consist of several components such as impedance matching networks, V/I probes, combiners, inductors, filters, directional couplers, etc [1-3]. Hence, the design and implementation of all the components carry great importance for RF generator design to meet the specifications for nay plasma system. In this paper, the analysis and design techniques for linear and switch-mode RF generators for plasma systems have been discussed. Simulation and implementation methods for RF generators and components are given for different configurations. The performance of RF generators operating in linear mode and switch-mode are also compared. The agile rail systems versus fixed rail generators for pulsed plasma systems are studies.

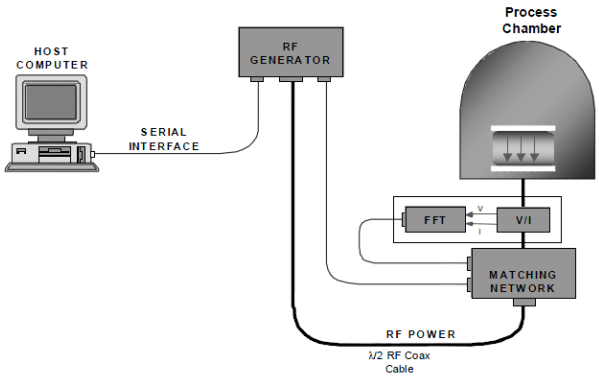

Fig. 1. RF Generator for Plasma System

1. A. Eroglu, *Introduction to RF Power Amplifiers Design and Simulation*, ISBN : , 978-1-4822-3164-9 1st Edition, CRC Press - Taylor and Francis, July, 2015
2. A. Eroglu, *RF Circuit Design Techniques for MF-UHF Applications*, ISBN : 978-1-4398-6165-3, 1st Edition, CRC Press - Taylor and Francis, April 8, 2013.
3. A. Eroglu, " RF technology in semiconductor wafer processing," Microwave Journal, vol. 56, no. 12, pp. 24-34, December 2013.

9:45 AM

A1-5 RAILGUN RECOIL AND THE ELECTROMAGNETIC FORCES IN HIGH CURRENT SLIDING CONTACTS

Neal Graneau
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Railguns are an area of intense research effort in the field of high current pulsed power where they are being developed for both military and civilian applications. These devices contain the most extreme case of high current sliding contacts. The force and acceleration of the railgun armature as a function of electric current is easily and accurately predicted by several calculating techniques ranging from the geometrical self inductance gradient to the more complete Lorentz force which can also take into account the force augmentation due to externally located pulsed current coils. Despite the well documented success in predicting the armature force and consequent motion, there remains an ambiguity in discerning the seat of the electromagnetic (EM) recoil force which is ultimately transferred to the earth or a heavy vehicle. The normal assumption is that the EM recoil force is felt only on the conductors in the circuit which have a current component perpendicular to the armature acceleration force. This assumption excludes any possibility of the EM recoil force being generated anywhere in the railgun rails in which the current is precisely aligned with the direction of armature acceleration. Consequently it is assumed that the EM recoil force is completely generated in circuit components at the breech end of the rails or in any force augmentation components. Both new and referenced experiments are described in this paper, which reveal strong evidence that there are longitudinal EM recoil forces acting on the rails, aligned with the current flow direction and acting just behind the armature. Despite their contravention of the conventional Lorentz EM force

law, the existence of these longitudinal EM recoil forces is precisely predicted by Ampère's force law, originally proposed in 1822 and not to be confused with the Maxwell field equation often called Ampère's Circuital Law. Ampère's force law describes all of the correct transverse EM forces on the armature, rails and breech components, but in addition predicts a tension between all current carrying elements in a conductor. This tension normally does not reveal itself due to the strength of a metallic lattice. However, one of the ramifications of this tension is that railgun rails just behind the armature are pushed backwards and this force can be experimentally revealed as a result of the sliding contact inherent in the railgun geometry. A thought experiment based on an unexpected circuit design will also be described which makes it inevitable that the seat of the recoil force must reside in the rails. It is argued that a better understanding of the seat of EM railgun recoil forces will eventually help to improve rail design and lead to improved gun performance and efficiency. Similarly, this knowledge will benefit any other existing or future technology that involves high current sliding electrical contacts. These railgun recoil experiments will also prove to be crucial to the future development of EM theory.

10:00 AM – Coffee Break

10:30 AM

A1-6 EFFECT OF CURRENT RISE TIME ON LASER-TRIGGERED DISCHARGE PLASMA FOR EUV RADIATION

Soowon Lim, Seiya Kitajima, Takashi Kamohara, S. Hamid R. Hosseini and Sunao Katsuki
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Powerful and stable extreme ultraviolet (EUV) source is the most important component for the EUV lithography and EUV mask inspection1,2. We have investigated characteristics of laser-triggered discharge (LTD) plasma by changing current rise time. A height adjustable coaxial birdcage is used to hold a tin anode. The rise time was changed from 66 ns to 124 ns with peak current of 10 kA. A pulsed laser was focused on the high-voltage tin cathode surface to form tin vapor jet across a 3 mm long anode-cathode gap, which leads to the electrical breakdown. The LTD technology enables us to compress the plasma quickly and efficiently in comparison with conventional gas-fed Z-pinches3. The extreme ultraviolet (EUV) emission intensity was monitored by a EUV photodiode (IRD AXUV5) after passing through a spectrum band pass filter (2% at 13.5 nm). The EUV intensity was stronger in case of faster current rise rather than slower rise time. The plasma dynamics were observed using both of a high-speed camera and the Mach-zehnder interferometer. The plasma dynamics such as positions of pinch region and the number of pinch during a Z-pinch were compared and discussed.

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3. S. Lim, S. Kitajima, P. Lu, T. Sakugawa, H. Akiyama and S. Katsuki, "Optical observations of post-discharge phenomena of laser-triggered discharge produced plasma for EUV lithography", Japanese Journal of Applied Physics, 54(1S), 01AA01.

10:45 AM

A1-7 USING THE HIGDON OPERATOR FOR WB MATCHING OF EM-PIC SIMULATIONS*

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The Higdon [1] operator provides the basis for a multi-phase velocity absorbing boundary condition. In its higher order implementation it can provide for the injection of extremely low reflection incident wave into the interior of a simulation environment as well as near perfect absorption of scattered outgoing waves. The method has been applied with great success in a number of wave equation environments. These include the shallow water equation and acoustic phenomena as well as in dispersive electromagnetic modelling. In Cartesian coordinates the Higdon operator of order J may be described as follows for wave propagation of the transverse electric field, E_T, along the z axis:

$$\left[\prod_{j=1}^{J}\left(\partial_t + \nu_j\,\partial_z\right)\right] E_T = 0$$

Here, the parameters ν_j, can be seen to represent phase velocities of the wave. For J=1, this reduces to the familiar 1 dimensional wave equation in which the sign of the phase velocity may be used to indicate a forward or backward traveling wave. Use of this expression directly for values of J=2, leads to the 2nd order phase velocity model previously reported by the authors [2]. While the authors have also looked at the 3rd order Higdon operator the implementation begins to get very cumbersome once the differential operators are recast into Finite Difference Operator form. As J increases it becomes necessary to capture information that is more remote spatially and temporally from the boundary edge. This runs into the issue of geometry variation as the information capture is carried further into the simulation and performance as well as simplicity may be degraded by the presence of evanescent waves from structural discontinuities. Givoli and Neta [3] have suggested a method of recasting the solution in terms of auxiliary functions of arbitrarily high order and localized at the boundary cell by converting the longitudinal spatial derivatives into only 2nd order derivatives in the transverse spatial coordinates confined to the boundary cell. We will report on our implementation of this method.

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2. L.D. Ludeking and A.J. Woods, "A Dual Phase Velocity Boundary Method for Simulation of Broadband Microwave and Millimeter Applications ", presented at ICEAA Conference in Turin, Italy, Sept 2013.
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* Work supported by Orbital ATK

11:00 AM

A1-8 APPLICATION OF PULSED ATMOSPHERIC PLASMA FOR INDUSTRIAL WASTEWATER TREATMENT BY CONAP TECHNOLOGY

Anatoly N. Maltsev, Maxim V. Martynov, Viktor G. Podkovyrov, and Zhongqing Jia
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Application of pulse-periodic action of atmospheric plasma on various pollution in sewage of the industrial plants is one of the basic constituents of the CONAP (COagulation, Nanoparticles, Atmospheric Plasma) technology, developed recently by the "Laser Technologies & Systems", LLC (Tomsk, Russia). Besides, the electro-erosive generation of metal nano-particles (on which surface are adhering many products of reaction between pollution and atmospheric plasma in water) is used. In the pollutant sorption and adhering processes a nano-particle dimension is growing and their coagulation in complexes with micron sizes have been obtained (which afterwards are easily filtered off by standard filters). Several types of atmospheric plasma, including the newest atmospheric plasma with runaway electrons[1-2], are used in CONAP technology for affecting on pollution in water. Several types of high-voltage periodic nanosecond and microsecond pulse "PROTEUS" (II and V)[3] generators are using in the generators of atmospheric plasma. The "PROTEUS-II" generators have the output voltage pulse amplitude up to 100 kV at duration of leading front less than 20 ns, and pulse repetition frequency up to 2 kHz. One channel of atmospheric plasma treatment module can contain up to three different types of high-voltage generators and/or reactors. Testing results for the pilot sample of sewage water treatment station "APHRODITE-1000" are shown in the present publication. This station has been developed for sewage treatment of 100 tons per a day, and allows (unlike standard chemical reagent or biochemical technologies) decrease concentration of the industrial sewage basic pollutants (heavy metal ions, organics, bacteria) to the maximum permissible concentrations defined by the most rigid ecological standards, at economically expedient cost of treated water. So the Cr^{6+} ions concentration 0.05 mg/l in treated water was obtained at initial concentration about 50 mg/l by one circle treatment. The treatment effectiveness more than 99.9% was obtained for many heavy metal ions like Cu^{2+}, Ni^{2+}, Zn^{2+}, etc, as well as for As^{3+}, and other toxic pollutant.

1. A. N. Maltsev. Patent of RF № 2274923. Bulletin of inventions, № 11, 2006.
2. V. S. Korolev, A. N. Maltsev. Izvestiya VUZov. Physika, № 2, 1992, p.p. 7-10.
3. A. N. Maltsev, A. Yu. Ivanov, M. V. Martynov, A. V. Mikov, V. G. Podkovyrov, L. L. Zhukov. High Voltage Engineering Journal, V. 39, 2013, # 10. p.p. 30695-30702.

11:15 AM

A1-9 DESIGN AND DEVELOPMENT OF 20 KW, 45 KV, 30 KHZ POWER SUPPLY FOR PULSED DIELECTRIC BARRIER DISCHARGES

Surender Kumar Sharma and Anurag Shyam
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Dielectric barrier discharges are frequently used for industrial [1], environmental [2] and biomedical application [3] such as for UV sources, ozone production, toxic gas treatment, water treatment surface treatment and plasma medicine applications. These discharges are generated inside the insulated chamber placed between parallel plated by applying the pulsed high voltage at a frequency ranging from few 100's Hz to 1 MHz, the high voltage pulse ionizes the gas in the chamber and produces radiations for various applications. The voltage ranges from 1 kV to 100 kV depending on the gas, dielectric material, geometry and the dimension of the discharge chamber. A high voltage power supply is designed to generate and study dielectric barrier discharges at atmospheric, higher and lower pressures. A 20 kW, 45 kV power supply with the pulse frequency ranging from 1 kHz to 30 kHz is designed. The power supply consists of dc rectifier, high frequency inverter using MOSFET switches switching up to 30 kHz, high voltage transformer and feedback control circuit. The voltage of the power supply can be adjusted from 2 kV to 45 kV. The frequency of the high voltage pulse can also be varied from 1 kHz to 30 kHz with the pulse duration of 1 µs. The rise time and fall time of the high voltage pulse is < 200 ns. The power supply is short circuit proof and can withstand variable load condition from overloads to arcs. The discharge chamber is made of evacuated quartz tube of 50 mm diameter with SS mesh electrodes on the external surface. The design details and the performance of the power will be discussed in the paper.

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2. Daniel S.L, "On the inonization of air for removal of noxious effluvia", IEEE Trans. on Plasma Science, 30 (4), 1471 – 1481 (2002)
3. Weltmann K D, Von Woedtke T"Campus PlasmaMed – From basic research to clinical proof", IEEE Trans on Plasma Science, 39 (4), 1015-1025 (2011)
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11:30 AM

A1-10 PHOTORESISTS STRIPING USING A RADIO FREQUENCY PLASMA BRUSH

Shouguo Wang
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A plasma brush was developed using a 13.56 MHz radio-frequency discharge for stripping photoresists. Its working gases are oxygen and argon and its electrical and optical characterizations were measured. It was verified that photoresists can be cleaned easily by the plasma brush, but there are still some residue in the etched groove due to the glow discharge characteristics at atmospheric pressure. Therefore, to make the photoresists removal thoroughly, we must combine the hybrid process including a follow-up wet cleaning process.

11:45 PM

A1-11 SEPARATION OF METAL FROM MATERIAL COMPOSITES BY USING PULSED POWER

Tomohiko Yamashita, Mickael Martin Sully, Hamid Hosseini, Takashi Sakugawa and Hidenori Akiyama
Kumamoto University, 2-39-1 Kurokami, Chuo-ku, Kumamoto, 860-8555, Japan

Nowadays, portable devices like smart phones, tablets and personal computers using electrical parts coated in a plastic base with metal are deeply rooted in our society. For now, most of companies are disposing of these parts with detrimental effects on the environment. However, because of the rise of environmental concerns and the fact that metal is a very rare and unsustainable resource, we need to find new alternative ways to recycle these elements more efficiently. That is the reason why we want to divide the coated parts of some devices by using pulsed power. We are currently studying the effect of pulsed power, which was produced by a magnetic pulse compression generator with 40 J/pulse on the separation of an aluminum foil from an insulator for CD-ROM. Almost all metal covering the polyethylene basis was removed gradually when applying the 20 shots' pulsed power. To study thoroughly the separation mechanism in order to separate the metal part more efficiently, each of our experiments is carried out by using a high speed camera.

Session R1: Repetitive Pulsed Power

Friday, August 7th — Mokolai Room
9:30 AM – 12:00 PM

Chair: **Prof. Zhang Jun**– National University of Defense Technology, China

9:30 AM

R1-1 A STRIPLINE KICKER DRIVER FOR THE NEXT GENERATION LIGHT SOURCE*

Dr. Neal Butler, Fred Niell, Dr. Marcel P. J. Gaudreau, and Michael Kempkes
Diversified Technologies, Inc., Boston, MA 01730, USA

Diversified Technologies, Inc. (DTI), under an SBIR grant from the U.S. Department of Energy, assembled a prototype pulse generator capable of meeting the original specifications for the Next Generation Light Source (NGLS) fast deflector. The ultimate NGLS kicker driver must drive a 50 Ω load (a 50 Ω terminated Transverse Electromagnetic (TEM) deflector blade) at 10 kV, with flat-topped pulses according to the NGLS pulsing protocol and a sustained repetition rate of 100 kHz. Additional requirements of the specification include a 2 ns rise time (10 – 90%), a highly repeatable flattop with pulse width from 5 – 40 ns, and a fall time (90% to .01%) less than 1 μs. The driver must also effectively absorb high-order mode signals emerging from the deflector itself. It is envisioned that a scintilla of deflection will be imparted by a symmetric pair of shaped parallel deflection blades, pulsed in opposition at 10 kV. Within the guide, comprised of the two deflector blades and their environment, each TEM wave produced by the two pulse generators traverses the guide synchronously with the selected (relativistic) charge packet. The DTI team has designed and demonstrated the key elements of a solid state kicker driver capable of meeting the NGLS requirements, with possible extension to a wide range of fast-pulse applications. The MOSFET array switch itself is suitable for many accelerator systems with < 10 ns kicker requirements. Full scale development and testing of this design are anticipated in the latter half of this Phase II DOE SBIR effort.

*Work supported by the US Department of Energy under contract DE-SC00004255

9:45 AM

R1-2 BURST MODE OPERATION OF A HIGH PEAK POWER HIGH PULSE REPETITION RATE CAPACITOR CHARGING POWER SUPPLY*

Shad L. Holt, Eric S. Cordero, Curtis F. Lynn, Jonathan M. Parson, James C. Dickens, Andreas A. Neuber and John J. Mankowski
Center for Pulsed Power and Power Electronics, Texas Tech University, Lubbock, TX 79409, USA

Steve E. Calico and Mike C. Scott
Lockheed Martin Corporation Missles and Fire Control, Grand Prairie, TX 75051, USA

Fast capacitor charging is a power electronics application with unique challenges requiring both low voltage, high current operation and high voltage, low current operation from the same system at different points in the charge cycle. Such dynamically differing operating points create distinct challenges in obtaining high efficiency throughout a charge cycle. In addition, the power supply must be protected from negative voltage swings when attached to a high rep-rate power modulator. This paper presents the design and testing of a battery powered rapid capacitor charger designed for high rep-rate command charging of a Marx generator. The capacitor charger is comprised of a hard-switch IGBT H-bridge

topology that utilizes peak-current mode control, and is powered from a Lithium-Ion Polymer (LiPo) battery pack. The battery pack consists of multiple cells which store multi-MJ, corresponding to thousands of charge cycles. The output stage uses a large inductor to delay discontinuous conduction during the early portion of the charge cycle and greatly improve efficiency. The design goals and tradeoffs will be discussed and simulation results will be compared to experimental data.

*Distribution Statement A: Approved for Public Release – Distribution is Unlimited

10:00 AM – Coffee Break

10:30 AM

R1-3 DESIGN OF 50KW HIGH VOLTAGE CAPACITOR CHARGER FOR SOLID-STATE PULSED POWER MODULATOR*

Sung-Roc Jang, Hong-Je Ryoo, Chan-Hun Yu, and Jung-Ho Seo

Korea Electrotechnology Research Institute, University of Science & Technology, 34 Boolmosanro, Changwon, 641-120, Korea

This paper describes the design of a 50 kW high-voltage capacitor charger for the solid-state pulsed power modulator (SSPPM) which has following specifications for radar application: pulse voltage 40 kV_{max}; pulse current 20 A_{max}, pulse width 300 μs; pulse repetition rates 200 Hz. Depending on the circuit of SSPPM which consists of 48 pieces of Marx cell, the resonant inverter is designed with multiple transformers and rectifiers for simultaneous charging of a number of the storage capacitors. Soft-switching operation of the proposed resonant inverter provides high-efficiency with the reduced switching loss and high-power density by reducing the size of transformer as well as by using leakage inductance as a resonant inductor. In addition, a novel structure of transformer and rectifier is proposed based on power stage module which includes one transformer with 4 secondary windings and 4 voltage doubled rectifiers, and 6 power stages are implemented for charging 48 pieces of separated capacitors. By using high-voltage insulation cable, the power loop which represents the primary winding of transformer for all the stages is designed to transfer the power from the resonant inverter to each stage, simultaneously. Furthermore, additional tertiary winding is especially proposed for compensating the charging voltage difference between each stage. The proposed high-voltage capacitor charger facilitates effective charging of a number of capacitors without additional semiconductor switches and allows high-reliability against high-voltage breakdown. The experiment results verified that the proposed circuit and structure can be used effectively for Marx based SSPPM.

1. Seung-Bok Ok; Hong-Je Ryoo; Sung-Roc Jang; Suk-Ho Ahn; Goussev, G.; , "Design of a High-Efficiency 40-kV, 150-A, 3-kHz Solid-State Pulsed Power Modulator," Plasma Science, IEEE Transactions on , vol.40, no.10, pp.2569-2577, Oct. 2012.

* This research was supported by the KERI Primary research program of MSIP/NST

10:45 AM

R1-4 REPETITIVE PULSED POWER GENERATOR BASED ON HYBRID LTD

Weihua Jiang, Mohammad R. Ghurbanali, Taichi Sugai, and Akira Tokuchi

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Solid-state linear transformer driver (LTD) has been proved to be a promising approach to compact and repetitive pulsed power generation for industrial applications. Power MOSFETs have been used as switches in the LTD systems developed so far in order to demonstrate short-pulse output with fast pulse front. However, the output current is limited by the relatively low current capacity of the MOSFET devices even a large number of them are used in each LTD module. A hybrid LTD system has been developed by using both power MOSFETs and IGBTs. It is developed for applications to gas discharge where a fast high-voltage pulse is required for initiating electric breakdown and a high current pulse is required for delivering pulsed energy. Since the high-voltage and high-current phases are not synchronized, LTD modules using MOSFETs and IGBTs are switched at different timings so that both a fast and short high-voltage pulse and a relatively long high-current pulse can be generated by the hybrid LTD system. The test system consists of 30 modules switched by MOSFETs and 10 modules switched by IGBTs. The output voltage pulse reaches 40 kV in about 40 ns which is followed by a current pulse of about 2 kA with pulse width of more than 300 ns. This system is used to demonstrate the performance of hybrid LTD switched by different types of semiconductor devices.

1. W. Jiang, H. Sugiyama, and A. Tokuchi, "Pulsed Power Generation by Solid-State LTD", *IEEE Transactions on Plasma Science*, **42**(11), 3603-3608 (2014).

11:00 AM

R1-5 A PULSED POWER GENERATOR WITH 20 SYNCHRONIZED NANOSECOND HIGH-VOLTAGE OUTPUTS

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This paper presents a pulsed power generator with 20 nanosecond synchronous high-voltage outputs. It is developed by using a TLT (Transmission Line Transformer) based multiple-switch technique. It consists of a 20-stage TLT and 20 spark-gap switches. Each stage of TLT is constructed of five RG218 coaxial cables with micro-gap ferrite magnetic cores placed around them. All the switches are interconnected via the TLT, in such a way that all switches can be synchronized automatically like Marx generator within tens of nanosecondsIn order to minimize the stray inductance,

all the spark gap switches, the capacitor banks and the input sides of stage TLT are integrated in one compact unit. Experimental results show that when the TLT is connected to a resistive load, the setup produces 20 independent and simultaneous high-voltage pusles with a rise-time of about 15 ns, a width of about 70 ns, a peak voltage up to 200 kV. The time interval between two pulses is less than 2 ns.

11:15 AM

R1-6 HIGH POWER MULTICHANNEL SYSTEM OF PULSE REPETRTIVE HIGH-VOLTAGE "PROTEUS" GENERATORS

Anatoly N. Maltsev, and Zhongqing Jia
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Alexander Yu. Ivanov
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Anastasiya A. Maltseva
Siberian State Medical University, Tomsk, 634050, Russia

The multichannel system of high-voltage pulse generators of PROTEUS[1] type for industrial applications is presented in the publication. This system is intended for increasing the total average power of the atmospheric plasma[2-4] with runaway electrons used at an industrial plant, at the expense of simultaneously operating plasma generators number magnification (in our case - to 24 generators) with one system of their control. For the solution of the specified problem the "PROTEUS" (I, II, II, IV, V) 1 line generators of high-voltage periodic nanosecond and microsecond pulses with a digital control and an optical interface, and also system of automated communication OFS-24 for 24 channels has been developed. The "PROTEUS" I-IV generators can consume to 2 kW of average power from the single-phase electrical power line and at repetition frequency to 2 kHz have following amplitudes and duration of leading front of output voltage pulses on the resistive load 600 Ohm (I - 30 kV, 150 ns; II - 100 kV, 20 ns; III - 150 kV, 4 ns; IV - 150 kV, 1 ns). The "PROTEUS-V" generator has 2 kV, 5 mks at 1 kHz pulses with 5J of energy (up to 5 kW of electric power consumption). Management system OFS-24 consists of 4 PCB's for switching of 24 input and 24 output optical signals using RS-232 communication port by means of the industrial programmable logic controller DVP20EX200T connected with HMI (operator panel Weintek MT8070iH) through port RS-485. The communication protocol matches to standard industrial MODBUS that allows to build the OFS-24 control system into technological processes control system of higher level. The testing results for "PROTEUS-5" generators six-channel system loaded on atmospheric plasma electro-erosive reactors of an industrial sewage water treatment plant are shown in the present publication.

1. A. N. Maltsev, A. Yu. Ivanov, M. V. Martynov, A. V. Mikov, V. G. Podkovyrov, L. L. Zhukov. High Voltage Engineering Journal, V. 39, 2013, # 10. p.p. 30695-30702.
2. A. N. Maltsev. Patent of RF № 2274923. Bulletin of inventions, № 11, 2006.
3. V. S. Korolev, A. N. Maltsev. Izvestiya VUZov. Physika, № 2, 1992, p.p. 7-10.
4. V. S. Korolev, A. N. Maltsev. Izvestiya VUZov. Physika, № 3, 1993, p.p. 67-70.

11:30 AM

R1-7 ANALYSIS AND SIMULATION OF FAST-CHARGE, OIL SWITCH JITTER

William Nunnally
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The requirements for very high voltage (MV), low inductance (nH's) and low resistive phase time (ns) switches leads to investigation of dielectric oils as a switching medium, Dielectric oil has been used in very high voltage switches to generate pulse risetime of less than 1 ns for impulse source applications. The opoortunity ot employ multi-channel oil switches in ns pulse devices also requires quantifying the jitter of the switches and investigation of the resistive phase duration. This paper documents the results of a fast charged (10's ns) transfoermier oil switch experiment to determine the temporal jitter and resistive phase duration as well as the effective dielectric strength. In addition, the switch performance parameters are compared to the emphirical formulas for slower charged oil switches.

11:45 AM

R1-8 COMPACT PULSED POWER MODULATOR USING FAST RECOVERY DIODE

Takashi Sakugawa, Hidenori Akiyama
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Tatsuya Hatanaka, Koichiro Yamashita
Graduate School of Science & Technology, Kumamoto University

There are various methods of pulsed power generation using semiconductor switch. Semiconductor switching device is indispensable to realize a high repetitive operation of the pulsed power modulator. High repetitive operation of the modulator have contributed to industrial application. However, the semiconductor switching device is impossible to generate fast rising high voltage pulse directly. In this study, we have employed a fast recovery diode (FRD) for pulse compression circuit of the compact pulsed power modulator. Primary switching devices were use Silicon-Carbide based Metal Oxide Semiconductor Field Effect Transistor (SiC-MOSFET), the pulse compression circuit was using a saturable transformer (ST) and FRD. We have investigated the effective saturation timing of the ST for applied reverse current to FRD. We have realized generating a fast rising high voltage pulse using fast recovery characteristics of

the FRD. The developed modulator can be obtained over 50 kV output voltage with several ns rise time.

12:00 PM

R1-9 IMPLEMENTATION OF SOLID STATE PULSED POWER MODULATOR WITH HIGH PERFORMANCE PULSE DRIVING CIRCUIT*

Chan-Hun Yu, Hong-Je Ryoo, Jung-Ho Seo, and Sung-Roc Jang

Korea Electrotechnology Research Institute, University of Science & Technology, 34 Boolmosanro, Changwon, 641-120, Korea

In this paper, a novel solid-state pulsed power modulator (SSPPM) with high performance pulse driving circuit in order to realize a long life span, a fast falling time, and a fast rising time is proposed. The specifications of the developed pulsed-power modulator are the pulsed output voltage, the output current, the pulse repetition rate (PPR), the pulse width, and an average output power of $40kV_{max}$, $20A_{max}$, 200, 300μs, and 48kW, respectively. Proposed pulse driving circuit cell consists of two IGBTs for generating output pulse and pulse transformer generates on-off signals of IGBT gating with gate power simultaneously. It can be used for various kinds of pulse power application. Especially, in capacitive load application such as gas treatment system, it is very useful because of good discharging characteristic with bypass IGBT. The operational principle and analysis of proposed circuit are presented in this paper. The validity of this study is confirmed by the experimental results.

1. Seung-Bok Ok; Hong-Je Ryoo; Sung-Roc Jang; Suk-Ho Ahn; Goussev, G.; , "Design of a High-Efficiency 40-kV, 150-A, 3-kHz Solid-State Pulsed Power Modulator," Plasma Science, IEEE Transactions on , vol.40, no.10, pp.2569-2577, Oct. 2012.

* This research was supported by the KERI Primary research program of MSIP/NST

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