A novel injection-locked amplitude-modulated magnetron at 1497 MHz

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Outline

• Muons, Inc.
• SBIR Program Status Year 1 including Year 2 plans
• Phase III Framework.

Muons, Inc.
• Rolland Johnson, President
  – Founded in 2002
    • From 2002-2010 --- focused on Muon Collider Technology
    • 2010-Present --- focused on product development and ADSR (Accelerator Driven Sub-critical Reactor) Technology

• Individuals within Muons have created exciting teams and networks for doing research and developing products.
Muons, Inc: a few of the projects

- Simulation programs: MuSim and G4beamline (TR)
  - From Muon Collider to ADSR applications
- Gas Filled Cavities (RJ)
  - Muon Cooling Channels to beam monitors in high radiation environments
- ADSR (RJ MAC BA)
- Ion Sources (VD)
  - H- ion sources for SNS and PIP-II Proton Driver
- Magnet R&D (SK)
  - Muon Collider to ADSR applications and magnetrons
- Microtrons for Gamma Ray and Neutron Sources (GK)
- Magnetrons and RF Components (MN)
- www.muonsinc.com
SBIR Program Status

• Program Overview
  – How we got here

• The Magnetron System
  – Injection Locking and Phase Stability
  – Amplitude Modulation of the magnetron
    • Magnetics Design Optimization
  – Magnetron Prototype
    • Commercialization
  – Year 2 Plans

• Phase III Framework
Muons, Inc. and JLab have been working on this problem for a number of years. We had a Phase I study that did not go to Phase II in 2013.

The study evaluated various options for sources: Klystron, IOT, CFA, magnetron(s) and produced a table showing a “scoring” for the best options.
JLab R&D on magnetron RF source

Comparison of Klystrons to Magnetrons with Wavelength in cm

- Klystron from different vendors
- Reciprocal fit for klystron data 
  $\%=100/(1+0.828*\mu P)$
- L3-L4031 917MHz magnetron, 20-80kW CW
- Reciprocal fit for magnetron data 
  $\%=100/(1+0.067*\mu P)$
- National cooker magnetron, 
  2.45GHz, 1.2kW CW

* L3 20-80kW magnetron
* L3 13 kW klystron
* National 1.2kW oven magnetron
Magnetron RF source, the potential impact

Capital and operation cost saving for CEBAF in RF power
- Low cost of magnetron device
- DC-to-RF efficiency from klystron to magnetron improves from ~35% to ~90%
- 2.22MW of DC power saving
- $2.8 million saving in power bill, if 41 weeks/year of CEBAF in 6-12GeV operation

Technology demonstration for all SRF accelerators in the DOE complex

References:
Phase II Magnetron System

• There are three critical areas for building a prototype System
  – 1. Injection-locking: a prototype system has been built for a 2.45 Ghz magnetron and tested by JLAB
  – 2. Amplitude Modulation by adjusting the magnetic field of the magnetron at low audio frequencies requires a coil design with a matching impedance to a programmable AC power supply
  – 3. Magnetron anode needs a design and a manufacturing process to minimize eddy currents
Phase Locked Magnetron (JLAB)

- Using FM from SG384 signal generator with low noise 1W RF amplifier as the LO and a clean RF injection seeding source
- Magnetron output power up to 1.2kW
- Noise level -40dB down from peak power
- ~30 dB gain
Injection Locking

• JLAB has performed locking tests on a 1kw 2.54 GHz “cooker” magnetron. The 1497 MHz magnetron is planned for completion by Dec 2017 and testing will begin.

• Digital controller algorithms that were designed for “cooker” magnetron will be tested on the 1497 MHz magnetron and modified as required.

• On schedule
Magnetic Field Variation

• Coil Design and placement in the prototype configuration

• The trim coil design is being evaluated for optimum inductance to match a programmable power supply. (It maybe similar to California Instruments CS Series (3kVA-18kVA) programmable AC supply)

• We will be doing more experiments this year to evaluate power supply options and trim coil design

• On Schedule
Magnetron Production of the 13 kW tube

• All parts are on order and being delivered for assembly at Altair Technologies in Fremont, CA.

• Plan to build a standard 1497 MHz magnetron so that injection locking system can be evaluated first.
  – This will include the optimization of the $Q_{\text{ext}}$ which controls the bandwidth of injection-locking and the gain of the system.

• A second magnetron will be built to have a special anode for minimizing eddy currents also by Dec 2017.
Eddy Current

- A varying the magnetic field in a conductor (copper) creates opposing magnetic fields

- Changing the material to stainless steel reduces the effect, but does not eliminate it.

- Manufacturing a magnetron anode with stainless steel has never been done before because of the obvious heating problems

- We have studied the problem extensively and have a solution.
Anode design

• Several Comsol runs to evaluate the thermal issues.

• We will be using a manufacturing process to create a bi-metallic anode.

• The tips of the vanes receiving most of the intercepted power will be copper.

• The method for manufacturing the anode is being worked out and will be incorporation in the second magnetron we will be building in December of this year.

• On Schedule
Phase III Framework
(Sequential Phase IIA)

• The Magnetron will need to be licensed by Muons, Inc. to be manufactured by an established tube facility
  – (The least likely option is for Muons, Inc to build a manufacturing plant.)
  – Two US options for tube facilities: L3 Electron Devices and CPI Econco Division

• Manufacturability needs to be established during a Sequential Phase IIA
  – Do processes match a tube manufacturing plant?
  – Life-testing the prototype system with additional design changes as required.
    • For example: Permanent magnet biasing field with a trim coil for AM

• Some Initial investigations and actions have already been taken to establish the parameters for Phase III.
Phase III- background

• CTL (California Tube Lab) was bought by L3 and commercial magnetrons transferred to Williamsport, PA (2012)
  – Two senior magnetron engineers stayed in California and were hired by Muons, Inc as consultants (350 MHz magnetron for Niowave).
    • Knowledge of transfer issues from prototype to manufacturing
    • Knowledge of tube facilities and best practices.
      – CPI Econco Division and Williamsport (L3)

• Consultants will play an important role in establishing the manufacturability of the unique magnetron prototype being designed and built by Muons, Inc.
Phase III --- Summary

1. A network is in place
2. Potential for commercialization has some hurdles to overcome
3. Sequential Phase IIA has a place in the mix
Summary

• The program is on schedule to construct a prototype system.
• No new technical hurdles to overcome.
• Additional funding will be required to ensure a commercially viable product.