An Energy-Efficient RF Power Source for the Jefferson Laboratory CEBAF Linac*

* Work supported by DOE
Office of Nuclear Physics
Outline

Company intro/capabilities

JLAB Power Amplifier Progress

Plan for Final Test

Commercialization

Conclusion

People:
N. Barov, X. Chang, and D. Newsham, FAR-TECH, Inc.

Thanks to:
R. Nelson, JLAB
FAR-TECH, Inc. Management and Facility

• Located in San Diego, CA

• Founded in 1994, formerly known as Fusion and Accelerator Research (FAR), to pursue fusion and accelerator related research, technology and development.

• Core staff of 16 (14 PhDs)

• Facility:
  – Linux cluster (88 processors) with 96GB of memory via Infiniband connection; 15 TB redundant storage
  – RF, UHV, laboratory and assembly
RF Test and Fabrication

Capabilities:
- CAD, HFSS, ACE3P modeling
- RF test equipment
- Class 1000 clean room
- Vacuum station, RGA
- Relationship with machine shops
- Consultants (mech. eng.; braze)
- Access to CNC equipment

Soft-wall cleanroom

RF Test Area

Vacuum equipment
JLAB Solid State Amplifier

Motivation:
- Present klystrons are inefficient (<33% efficiency).
- Some nearing end-of-life.
- Replacements are becoming more costly.

Features:
- >55% efficiency
- Graceful degradation
- MTBF can be high; simple repair

Specifications:
- 1497 MHz CW Operation
- 6.5 kW, Linear Mode
Transistor Board and 500W Module

125W Board and Circulator Based on GaN Transistor

1:4 divider

4:1 combiner

125 W board
125 W board
125 W board
125 W board

500 W Module Diagram

RF3934
Circulator & terminator

Input
Output
System Layout

Preamplifier 1 of 4 Sections

125 W board

4:1 splitter

Pre-amp

16:1 combiner

500W Module

500W Module

x16

Controller
4:1 Combiner Test Results

Meets JLAB spec for linearity/compression at 400W
Efficiency at 400W per operating point in excess of 60% (drain efficiency)

*to account for cable losses
500W Module Recently Tested

Results:
The unit was operated at the nominal 400W operating point, 6 hours. Testing and optimization continues.

Physical:
- 14” x 15” x 1”
- Approx 8 lbs.
- 16 units per amp
16:1 Power Combiner

Results:
- Two combiners built, including pressure window
- Tested to better than 20 MHz bandwidth (below -30 dB return loss)
- Less than +/-1% imbalance of individual inputs
Preparation for Final Test

Tasks:

1) Ramp up module production
2) Build pre-amplifier
3) Module 24 hr. burn-in
4) Assemble amplifiers; conduct several 24 hr. burn-in tests
5) Deliver to JLAB
Economics: Klystron vs. Solid-State

Assuming a device (solid-state amp or klystron) must be purchased, how to choose in favor of more expensive solid-state amp?

<table>
<thead>
<tr>
<th></th>
<th>Efficiency</th>
<th>Cost of device</th>
<th>Cost of electricity/yr*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Klystron</td>
<td>28%</td>
<td>$32k</td>
<td>$11.3k</td>
</tr>
<tr>
<td>Solid-state amp</td>
<td>58%</td>
<td>$55k</td>
<td>$5.4k</td>
</tr>
</tbody>
</table>

*Assumptions:
6.5 kW, 4300hr/yr, 0.01$/kw, 90% efficiency of power supply (mains to 48V or 12 kV)

Rate of return:
Excess cost of $23k is paid back at a rate of $5.8k/yr due to energy savings, therefore achieving payback in 4 years.
Re-Tune for 1300 MHz Operation?

1) Redesign 16:1 combiner

2) Slight change to 4:1 combiner

3) Retune transistor matching circuits.

Use scenario: Project X Linac (Included in 2013 SBIR Solicitation, for our design is ready to commercialize).
On-track to deliver first amplifier in early 2013

Many commercialization opportunities