PROTOTYPE TO PRODUCTION FABRICATION OF A NEW RF POWER AMPLIFIER FOR LANSCE

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BACKGROUND

- The Los Alamos Neutron Science Center (LANSCE) RCA 738 triodes, used to drive it’s 201.25 MHz LINAC, were underperforming, resulting in reduced headroom in average power capability and necessitating operation at half of its original duty factor.
- In addition: CEC IGBT power supplies, designed for klystron operation, were unable to withstand tuning excursions due to a combination of VSWR effects and reduced tube margins.
- Beginning in 2006 LANCE began the process of replacing their legacy RF Final Power Amplifiers (FPAs).
- As a result: A LANSCE Risk Mitigation (LRM) project was tasked to replace the triode amplifiers with modern circuits having higher average power capability, improved operational efficiency, reduced beam losses and to allow for the modernization of low level RF controls.
- Extensive investigations were conducted to identify a suitable replacement amplifier including reviews of both tube and solid-state based devices.

BACKGROUND

- Those investigations resulted in the selection of the Thales TH628L Diacrode, a high DF (CW) device that could utilize the existing (modified) HV power supplies, capacitor banks and water cooling systems as the older triode FPA.
- Fabrication and manufacturing of key components for the prototype was accomplished by the Prototype Fabrication Division shop at LANL.
- Construction of the LANL designed prototype was completed in September of 2010.
- Extensive power testing in 2011-2012 suggested minor modifications to the design
- Mechanical design, manufacturing and assembly steps were finalized and became part of the process for identifying an industrial partner for the production of seven more FPAs.
- In 2012 Continental Electronics Corporation (CEC) was awarded the contract for two large HV decoupling / blocking capacitors (Upper Anode assemblies).

BACKGROUND

- **CEC was then awarded a contract for the first production FPA in 2012, which was delivered in FY2013.**
- **A subsequent order was received for two more units delivered in early FY2014.**
- **An order for units #4 and #5 has also been received for delivery in 2015.**

- **Three primary components and one optional component of the LANCE FPA will be discussed:**
  - Output Cavity
  - Input Cavity
  - Blocking Capacitors
  - Anode Power Supplies

FPA

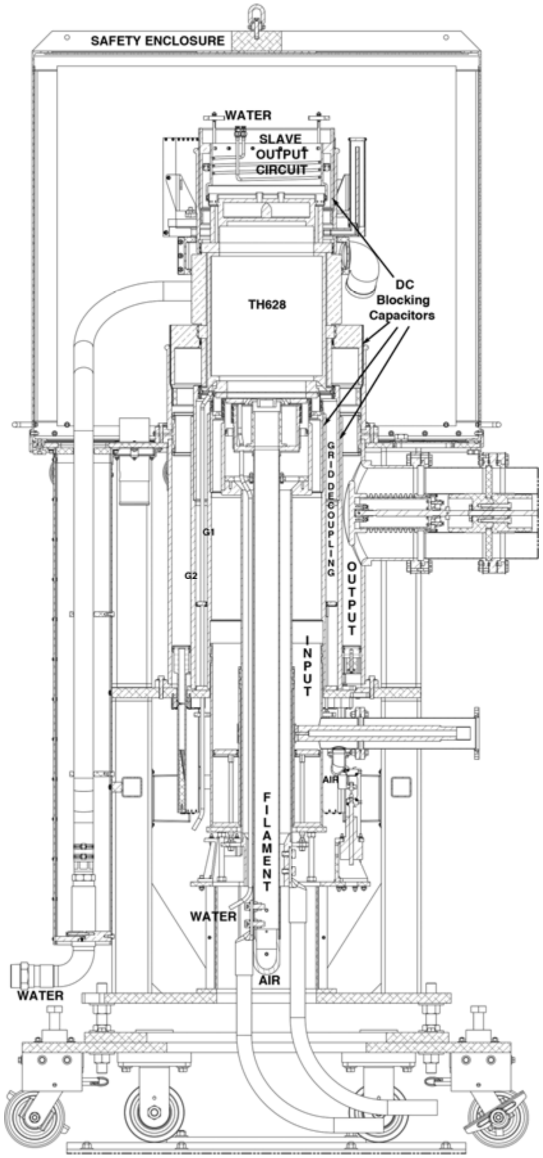


Figure 1.
FPA Cross section diagram

CWRF2014

OUTPUT CAVITY

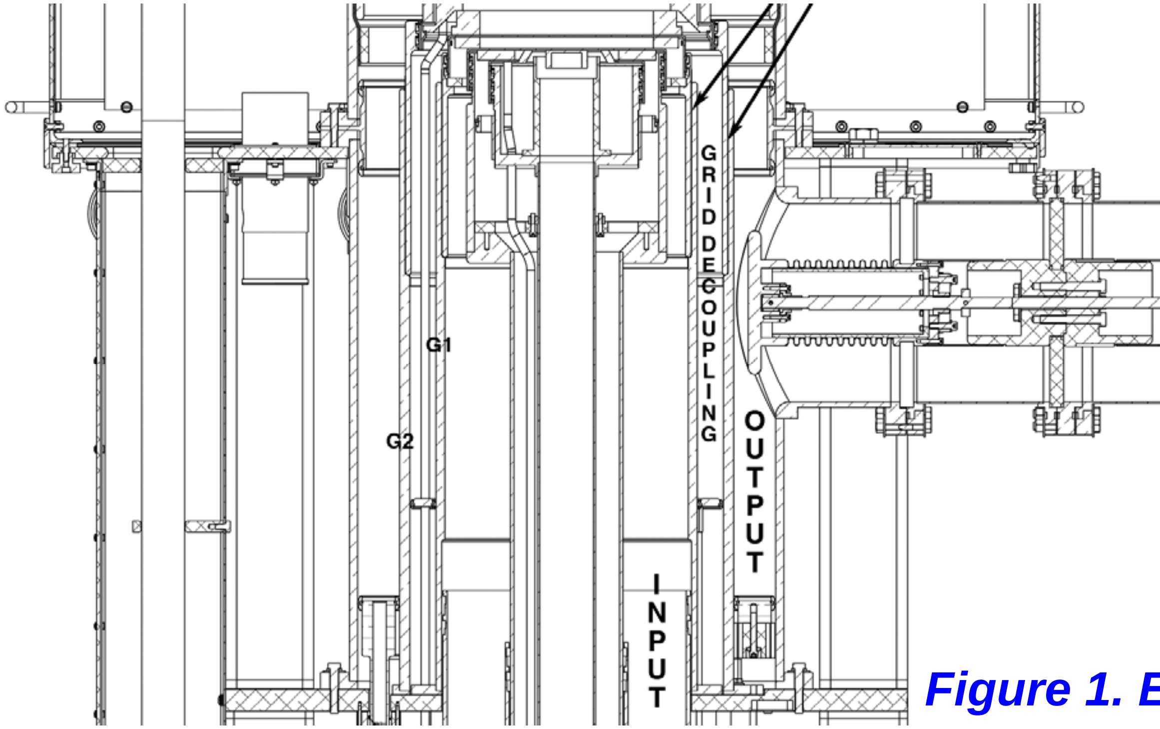


Figure 1. Expanded view

The screen grid (g_2) line is the inner conductor for the lower output resonator. DC bias of 1500 volts is applied to g_2, isolated with a 7.6 nF blocking capacitor constructed by pressing fluorinated ethylene propylene (FEP) film dielectric between two concentric cylindrical copper cylinders.

OUTPUT CAVITY

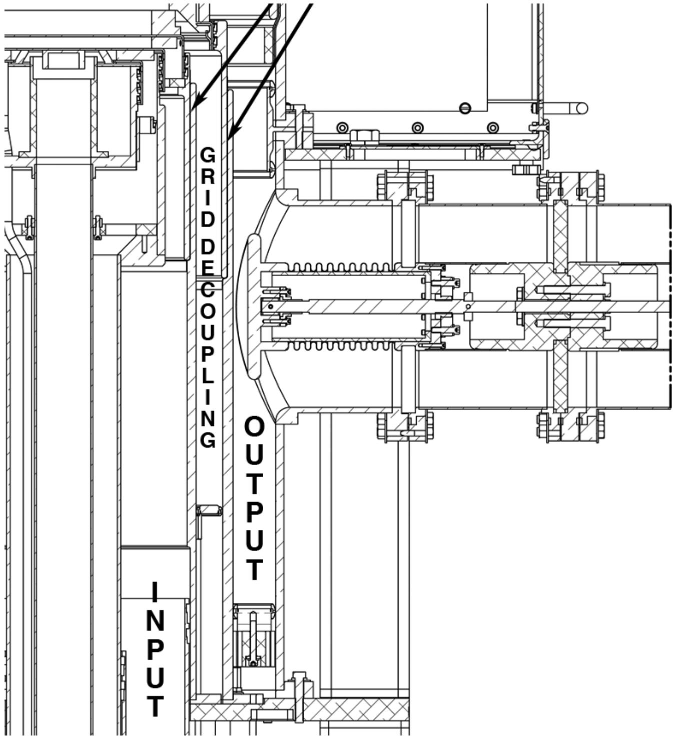


Figure 1. Expanded view

- An outer cylinder with 48.2 cm ID forms a line impedance of 13.4Ω with the OD of the g_2 cylinder.
- A movable tuning plane at the lower end is driven by linear actuators to tune the resonator.
- The output power coupler is adjacent to a high electric field region in the resonator.
- A copper capacitor plate is attached through a copper-plated bellows to the center conductor of the 22.8 cm diameter 50Ω coaxial output feeder. Slight extension of the bellows allows adjustment of coupling to the output circuit without requiring sliding contacts.

OUTPUT CAVITY

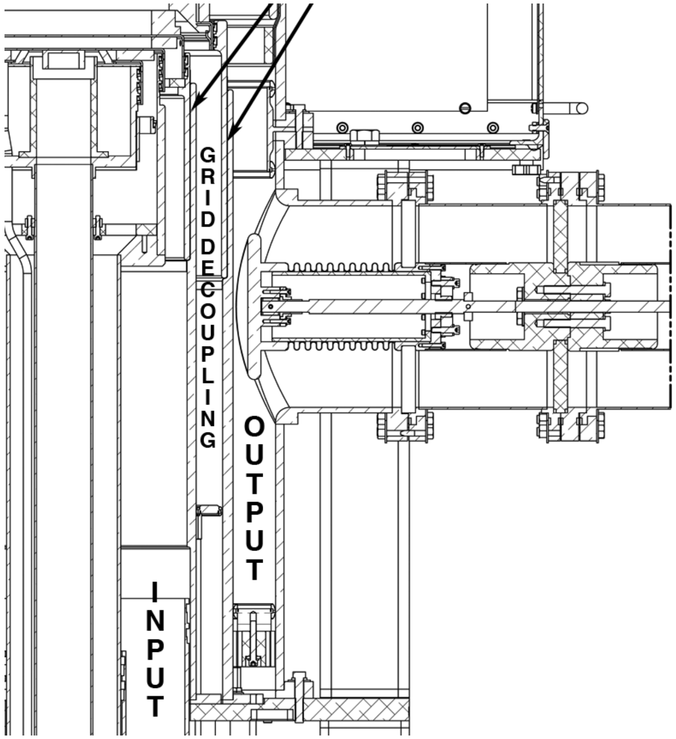


Figure 1. Expanded view

- **The mechanism can be adjusted under power, as it is introduced through a grounded λ/4 stub (not shown). The stub also provides excellent second harmonic attenuation, typically measuring -50 dBc or better.**

OUTPUT CAVITY

- The primary manufacturing challenge of the output cavity was the large size of components and the need to hold tight tolerances, especially around the output feeder port and tuning surfaces.
- A copper forging was machined, to minimize material waste.
- To attach flanges and the output feeder port, hydrogen furnace brazing was used to insure that current-carrying joints were free of voids.
- Careful and continuous quality reviews and inspections were performed to confirm the final dimensions of all assembled parts.
- Care was required to avoid scrapping of forged billets due to fabrication error or handling accidents.
- As a result material costs were minimized, including the cost of multiple silver plating processes. It is estimated that the fabrication cost savings are in the range of 25%.

INPUT CAVITY

Figure 6.

Movable (Motorized) Output Tuner

OUTPUT CAVITY

Figure 3.
Installing Output Cavity

INPUT CAVITY

- **The Input Cavity circuit is configured as a ¾λ coaxial resonator and consists of silver plated concentric copper cylinders and a movable tuning plane to place a RF voltage node between the grid cylinders (g_1 and g_2) inside the tube.**
- **The outer cathode conductor is grounded at the bottom while an isolated inner pipe carries both 1000 amperes DC for filament power and cooling air for the tube base.**
- **RF filament bypass capacitance is provided by a FEP film dielectric captured between concentric filament conductors near the base of the tube.**
- **The ID of the g_1 cylinder carries the RF current of the input circuit, which coaxially surrounds the outer diameter (OD) of the cathode conductor, with a line impedance of 46.1Ω.**

Figure 2.
Nested Assemblies
for Filament, g1 and g2

INPUT CAVITY

Figure 4.
g_1 Line Assembly

Figure 5.
g_2 Line Assembly

- **The upper end of the g_1 cylinder is constructed from two parts pressed together with FEP film between them which forms a high quality 5.5 nF DC blocking capacitor.**
- **The most critical aspect of assembling the g_1 and g_2 lines is the requirement to maintain concentricity the entire height of the amplifier assembly. Small air gaps, irregularities in the FEP film or too tight of a FEP fit could have disastrous operational consequences.**

BLOCKING CAPACITORS

- A separate collar (Upper Anode Blocker) is fastened to the upper edge of the output cavity shell containing an integral 1.2 nF DC blocking/decoupling capacitor, made from multiple layers of FEP captured between 2 cylinders.
- The upper cylinder of this part has ~23 kV DC applied, and connects to the anode through contact fingers; it is perforated to allow air to exhaust from the cavity across the lower ceramic seal of the tube.
- An upper slave output circuit contains a similar blocking capacitor with a second movable annular tuning plane above the Diacrode.
- All of these capacitors are formed by applying a cylindrical layers of FEP film to the inner cylinder, shrinking the film with heat, and then sliding the outer cylinder over that assembly.
- This sounds easy, but it actually is not.

BLOCKING CAPACITORS

Figure 7. Blocking Capacitor/Line Assembly in Kiln

- **The quality of the FEP film, distortion caused during the assembly process and the presence of any trapped air or foreign particles between the cylinders and the FEP will result in catastrophic failures. CEC uses a special kiln and a proprietary process in an environmentally controlled room to perform the application of the FEP film and assembly of the cylinders.**

PROTOTYPE POWER SUPPLY

- **The charging power supply for the LANCE prototype began with an existing Continental 95 kV @ 20 Amp IGBT power supply, previously used in a klystron project.**
- **CEC provided a conversion kit to reverse the polarity, reduce the voltage and double the current. The modified supply passed operational tests with up to 12% duty factor with 1 mS pulses.**
- **Approximately 220 uF of capacitance was used to keep the pulse droop as small as tolerable.**
- **Due to the design of the power supply and large capacitance required a mercury ignitron crowbar was employed for amplifier protection.**
- **The pulsed current was on the order of 120 - 130 peak amps for a nominal 1.6 - 1.8 MW pulsed RF output. Voltage was set at 23 kV, requiring from 8-12 Amps of DC current from the IGBT power supply for charging current to the capacitor bank. Prototype testing never got close to the 40 amp rating of the modified power supply.**

CEC ANODE POWER SUPPLIES

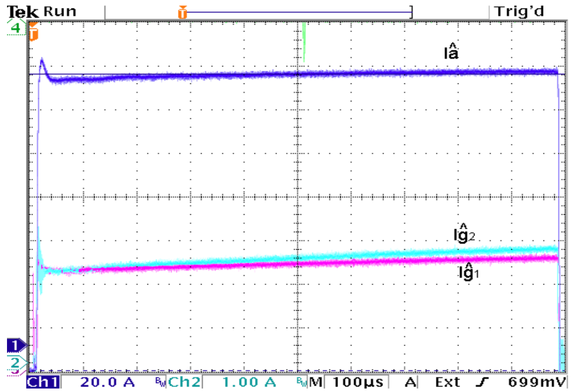
- Should a power supply be required for a new installation Continental would deliver a variation of its *IGBT production modulator power supply*, the capabilities of which can be modified to meet nearly all critical requirements.
- An important difference between a production CEC modulator and a more complex waveform power supply is the peak-to-average power ratio. The production CEC solid-state modulator is designed to provide a peak-to-average power ratio in the vicinity of 4:1. This is the ratio of the Peak Envelope Power (PEP) to carrier power of a 100% sine wave modulated AM transmitter. In contrast, the peak to average power ratio of more complex waveforms could be in excess of 350:1.
- Like all current CEC solid-state modulators, the power supply is disconnected from the load by high speed semiconductors eliminating the need for crowbar protection.

LANL INSTALLATION

- Units #2 and #3 were delivered at year-end of 2013 and tested at full power at LANL in January and February of 2014.
- The prototype and unit #1 were installed at the LANSCE DTL in April, to be power combined to produce 3.5 MW at 12% duty factor, equivalent to 420 kW of average RF power.
- High power testing of the two FPAs into a water load begins on the week of May 19 to be followed by integrated system testing in June of this year.

Figure 8.
Two FPAs Installed, Diacrodes in Center, Cooling Hoses for Water (Blue) and Air (White). Upper Blocking Capacitor/Slave Tuner on Top.

LANL INSTALLATION



Test Parameters April 11, 2014

TH628L s/n 741734, running into water load

Ea(kV)	Ia(A)	Eg_2(kV)	Ig_2(A)	Eg_1(V)	Ig_1(A)	Pin(kW)	Pout(MW)	n(%)	Pg(dB)
22.6	116	1.5	1.34	-380	1.78	56	1.5	56	14.3
22.9	136	1.5	2.54	-380	2.4	75.8	2.0	62.7	14.2
25.4	154	1.5	3.98	-380	3.16	97	2.5	62.4	14.1

"All currents measured at middle of pulse. There is no droop, in fact there is increase in power and currents at the end of pulses (an "inverse" droop). This is due to design of the pulsed control grid power supply, a negative voltage that droops towards positive during conduction pulses. This increases gain in the tubes and counteracts the droop of the IPA power and the anode HV capacitor bank."

SUMMARY

- Manufacturing of the new LANCE FPA's have been relatively problem free and all systems were delivered within budget.
- Units #4 and #5 are forecast to be delivered for installation in 2015 with units #7 and #8 to be delivered as needed.
- It is expected that this new generation of commercially-made high power FPA's will perform well in new scientific 200 MHz applications needing high peak and average RF power.
- The FPA design is copyrighted by Los Alamos National Labs.
- CEC is currently negotiating to become exclusive manufacturer of the LANCE design.

SITE PHOTOS

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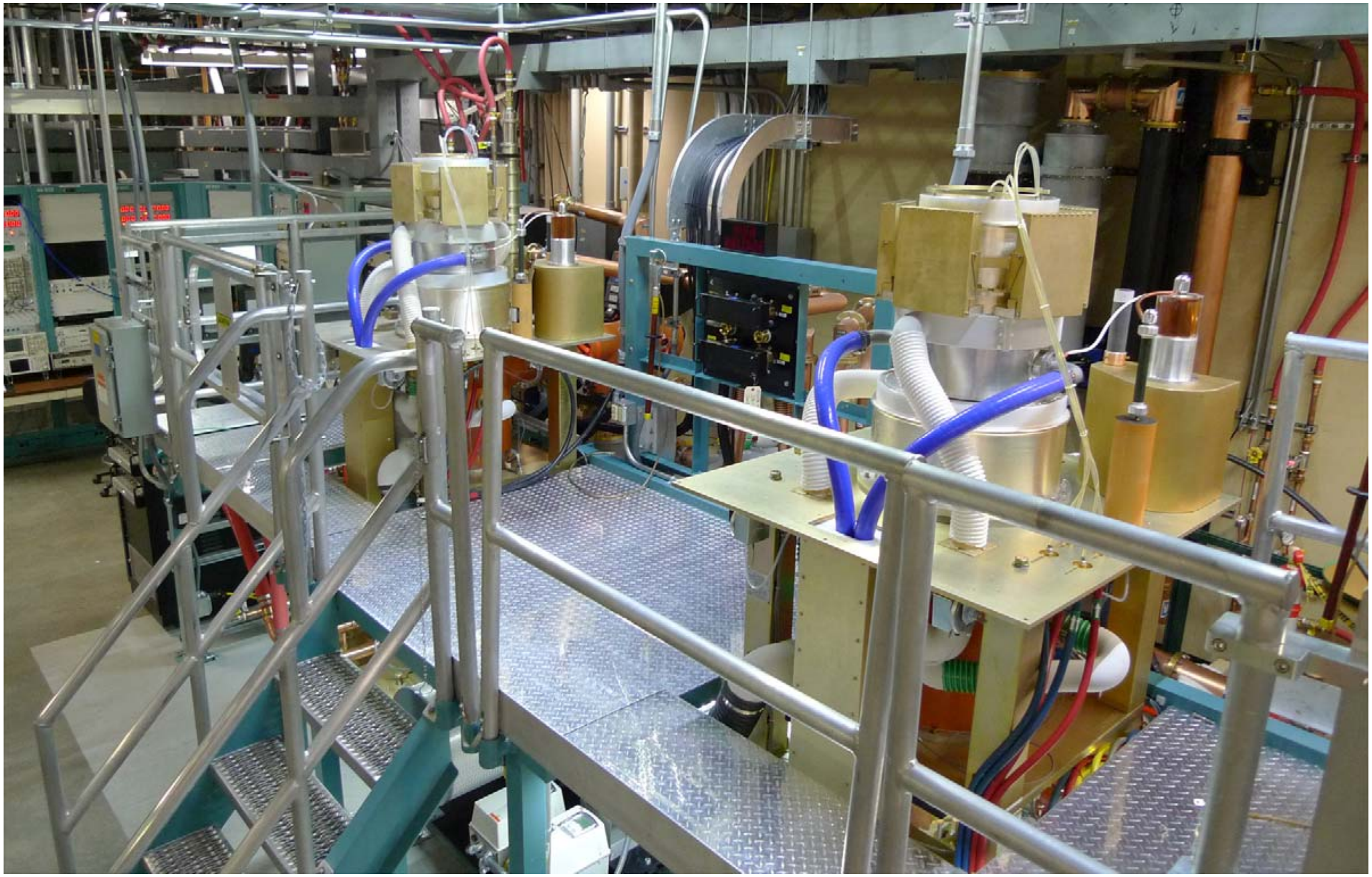

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Thank You!

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