# Multiple Beam Power Grid Tubes for High Frequency and High Power Operation

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**Abstract:** *High power, high efficiency RF sources are required at frequencies below 700 MHz for ion and proton accelerators. These sources are also used for high energy accelerators, such as the Advanced Photon Source, which is seeking 350 MHz RF sources producing more than 200 kW of continuous power. The program is developing multiple beam triodes capable of providing this RF power at efficiencies exceeding 80%. The sources would be extremely compact and low cost. Both the triodes and the associated RF cavities are being developed.*

**Keywords:** triodes, RF source, accelerator, power grid tube

## INTRODUCTION

The U.S. Department of Energy (DOE) is funding research to develop high power, high efficiency, RF sources for scientific and industrial applications [1]. Calabazas Creek Research, Inc, (CCR), in collaboration with Communications & Power Industries, LLC (CPI) and JP Accelerator Works, is developing multiple beam triodes to produce RF power from 350 – 700 MHz with an average power exceeding 100 kW. During the first phase of the development, the team is designing and building a 200 kW CW, 350 MHz source.

Triodes are extremely compact sources of electron beams for RF power generation. Operating in Class C, triode-based RF sources can achieve efficiencies approaching 90%. In addition, the cost is extremely low compared to other sources in this frequency range. Estimated cost is approximately $0.50/W, which is ¼ the cost of klystrons or solid-state sources. Design and available test results will be presented.

## MULTIPLE BEAM TRIODE

Figure 1 shows the current solid model for the multiple beam (MB) triode. The MB triode uses the existing grid-cathode assemblies produced by CPI. These use barium oxide cathodes, which are low cost and capable of high peak power. These cathodes, however, are limited to low duty, short pulse operation. Dispenser cathodes, capable of high peak and average power, will be used for high duty operation. Twenty dispenser cathodes are currently in stock. The barium cathode version of the multiple beam triode is nearing completion, and testing should begin in October.

## RF CIRCUIT

Triode based RF sources consist of a triode that provides the pulsed RF beam, an input cavity that drives the gun grid in Class C, and an output cavity that converts electron beam power into RF power. Consequently, these sources only consist of two coaxial cavities. While efficiencies of 90% can be achieved, these sources are relatively low gain, with 14 dB being typical. This program is tasked with producing approximately 200 kW of RF power. Consequently, approximately 6 kW of drive power will be required.

CCR will use a multiple beam triode to produce the 200 kW of delivered power and a single beam triode for the driver. Despite this complexity, the total cost of driver and output tube is estimated at $100K, or $0.50 per watt. In addition to being more efficient and significantly lower cost than alternative sources, the triode-based sources are considerably more compact. Fig. 2 shows a photograph of a 25 kW, 425 MHz RF source using a single beam triode. A modified version will provide the drive power for the 200 kW, 350 MHz RF source.

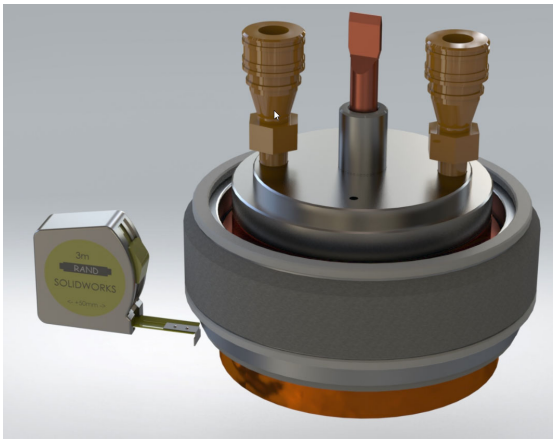

**Fig. 1:** Multiple Beam Triode

Fig. 3 shows a solid model of the multiple beam RF source. These sources do not require a magnetic field, providing an additional cost savings over klystrons.

The multiple beam RF source incorporates an input cavity below the cathodes and an output cavity that extends above and below the anode-collector. These upper and lower output cavity sections incorporate sliding shorts which determine the inductance of the coaxial sections. The tuners can be adjusted to achieve resonance at the operating frequency using the tube's internal capacitance and circuit stray capacitance.

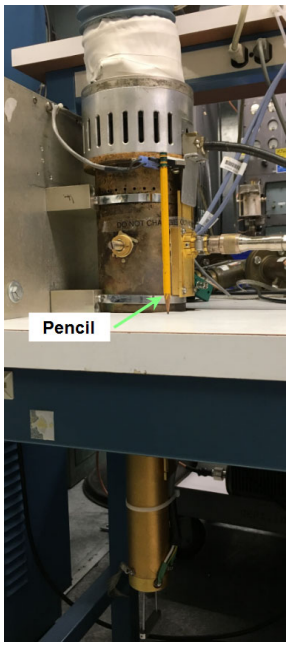


**Fig. 2:** 425 MHz RF Source

The single beam source shown in Fig. 2 can be tuned from 500 MHz to less than 400 MHz. Consequently, a single design can be used for a multiplicity of applications.

## SCHEDULE

Design of the multiple beam triode is complete, all parts are fabricated, and final assembly is in progress. Fig. 4 shows the 8-beam, grid-cathode assembly and the coolant side of the anode. RF design of the cavities for the 200 kW, 350 MHz tube are nearing completion, and many parts are fabricated. The program is finalizing details of the output cavity.

The program is upgrading test facilities at CPI for both the short pulse devices and the high average power devices. These facilities are nearing completion. Testing of the pulsed, low duty sources is scheduled for November – December 2020. The purpose of the short pulse testing is to confirm the electrical and RF design. Operation at high average power only requires replacing the barium-cathode version of the triode with one using dispenser cathodes. The rest of the RF source is unchanged. High average power testing is scheduled for January – February 2021.

## SUMMARY

This program is developing highly efficient, extremely compact, and low cost RF sources between 350 and 700 MHz. The triodes are designed to operate at approximately 8 kV, and the multiple beam device is anticipated to produce more than 200 kW at an efficiency approaching 90%. Coupled with a single beam driver, the total package would provide 200 kW of

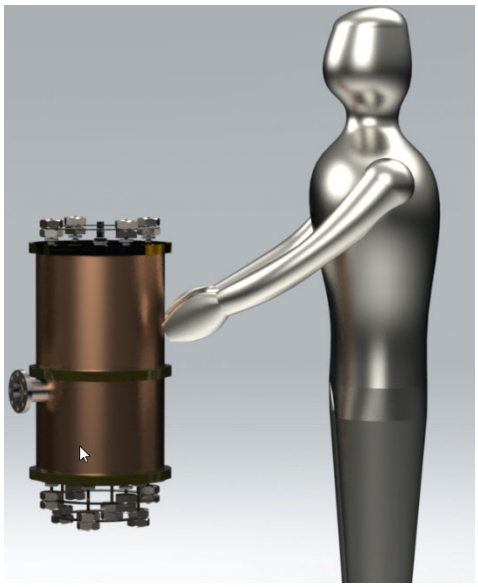

**Fig. 3:** Image of the current 200 kW, 350 MHz multiple beam triode RF source model with human figure

RF power at a total efficiency of approximately 80% and total gain estimated at 28 dB. Design of the triodes and RF sources

**Fig. 4.** Multiple beam gird-cathode assembly and coolant side of the anode.

will be presented, as well as available test results.

## ACKNOWLEDEMENT

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## REFERENCES

[1] "Workshop on Energy and Environmental Applications of Accelerators", U.S. Department of Energy, Office of Science, page 53, June 2015, https://science.energy.gov/~/media/hep/pdf/accelerator-rd-stewardship/Energy_Environment_Report_Final.pdf.