ADJUSTABLE HIGH POWER COAX RF COUPLER WITH NO MOVING PARTS*

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Abstract

An extremely low emittance RF gun is being designed for the X-ray Free Electron Laser Oscillator (XFEL-O), which is now being proposed by ANL. An adjustable coupling factor for this gun is very desirable for providing operational flexibility. What is required is a fundamental RF power coupler (FPC), adjustable in situ, that can operate at 100 MHz and 200 kW CW. If rotational motion is used to adjust the coupling, it is usually necessary to break the vacuum between the coupler and the RF cavity, thereby risking prolonged down-times and the introduction of contaminants into the vacuum system. Rather, we propose a novel system for adjusting the coupling coefficient of coaxial couplers to allow for individual control and adjustments to the RF fields under different beam loading scenarios. The RF coupler has no movable parts and relies on a ferrite tuner assembly, coax TEE, and double windows to provide a VSWR of better than 1.05:1 and a bandwidth of at least 8 MHz at 1.15:1. The ferrite tuner assembly on the stub end of the coax TEE uses an applied DC magnetic field to change the Q_{ext} and the RF coupling coefficient, β, between the RF input and the cavity.

INTRODUCTION

A fundamental RF power coupler (FPC) at 100 MHz and 200 kW CW with an adjustable in situ coupling factor would be highly desirable to provide flexibility in operation of an extremely low emittance RF gun for ANL proposed X-ray Free Electron Laser Oscillator (XFEL-O).

In current designs of adjustable coax couplers, the adjustment is provided either by the longitudinal movement of an antenna feed into the RF cavity or by the rotational movement of a coupling loop. Both types of coaxial couplers are complex mechanically and can create mean-time-between-failure (MTBF) problems for complex accelerator systems [1]. The process of adjusting coupling by rotational movement usually requires breaking the vacuum between the coupler and the RF cavity resulting in prolonged down-times and the risk of introducing contaminants.

While the maximum power capabilities of coaxial RF couplers have peaked at fairly high values during testing, operating power levels tend to only be about half of the maximum level achieved during test. Figure 1 is a summary of the maximum power capabilities of coaxial RF couplers, during testing, for various systems. This indicates that a coaxial RF Coupler operating at 200kW CW at 100 MHz is a very aggressive proposition and will be pushing the state of the art. .

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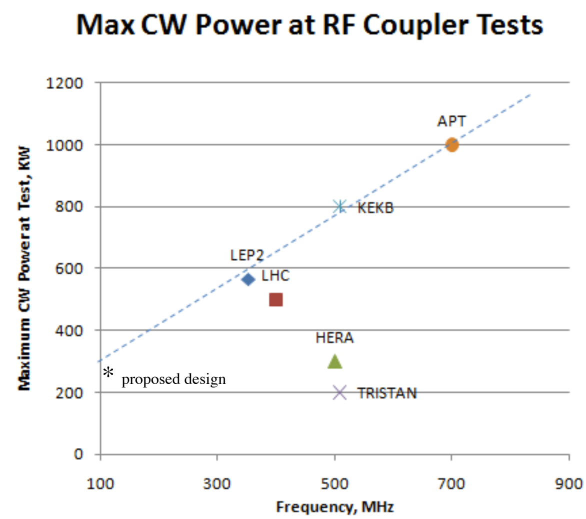

Figure 1: Maximum CW power of coaxial couplers achieved during tests. Most couplers operate at levels that are about half the maximum power achieved during tests. [2].

BACKGROUND

We first consider rotational motion as one standard design approach for adjustable RF couplers. In order to cope with the large electrical currents found with rotational adjustment, quarter wave chokes would most likely be required. At 100 MHz, a quarter-wave choke is about 29.5 inches long. Mechanically, this may be a problem. The use of a ceramic bushing would shorten the length by about one-third, which is more manageable. However, the metal to ceramic joint may be problematic, because it can create metal particles that get into the system. Finger stock has been used successfully for creating a high current short for movable components, but its use requires precise positioning along the length of the coax [3] and introduces the problems of fretting corrosion.

A second standard design approach is to use longitudinal motion. In that case, bellows would have to be employed. At these frequencies, large bellows would be required, and heating problems are likely to be serious. In the APT high power tests, the bellows failures were critical and helium gas cooling was required to reduce the operating temperature by 400°C [4].

To avoid these problems at 100 MHz and 200 kW CW, we propose an RF coupler in which coupling adjustments can be made without moving parts. There are also no matching elements that complicate the coaxial line and that tend to provide ample opportunities for multipacting.
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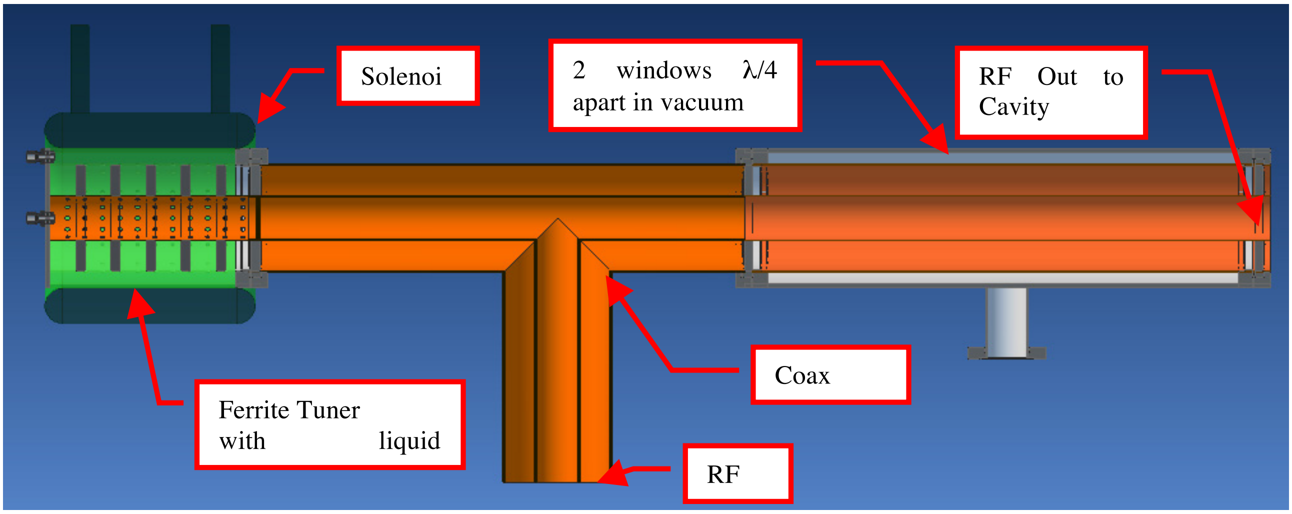

Figure 2: Cutaway view of the proposed RF coupler. Total length is 70 inches. The coax is standard EIA 6-1/8 inch.

TECHNICAL APPROACH

The variable coupler is composed of three fundamental elements:

1. A variable ferrite or garnet tuner.
2. Double coax windows, $\lambda_g/4$ center to center.
3. EIA 6-1/8 Standard Coax Tee and components.

Variable Ferrite or Garnet Tuner

The Tuner is a cavity with NiZn ferrite or yttrium garnet disks surrounded by a liquid dielectric. This dielectric removes the heat in a closed system with a heat exchanger, as describe in Dr. Popovic's invention [5]. This section of coax is surrounded by a solenoid to provide the magnetic field orthogonal to the TEM fields in the coax. The change in magnetic field changes the characteristics of the cavity, the Q_{ext}, and therefore the β of the system. At critical coupling the losses in this coax section are in the hundreds of watts depending on the characteristics of the ferrites or garnets, and the closed heat exchanger system will be designed to remove the heat and maintain a stable operating temperature.

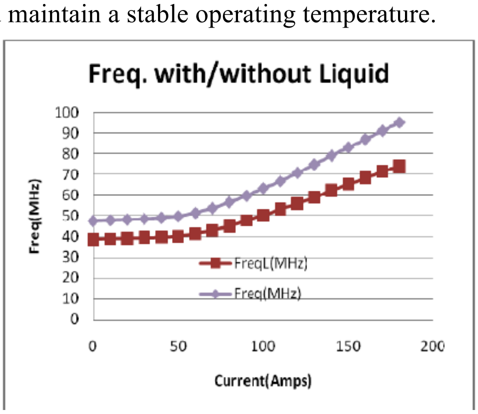

Figure 3: Resonant frequency of a cavity with ferrites and liquid dielectric as a function of solenoid current [5] Red is with and blue is without the dielectric liquid.

The losses in the ferrite and garnet system in a coax line have been studied as a function of frequency and magnetic field orthogonal to the TEM fields as shown in Figure 4.

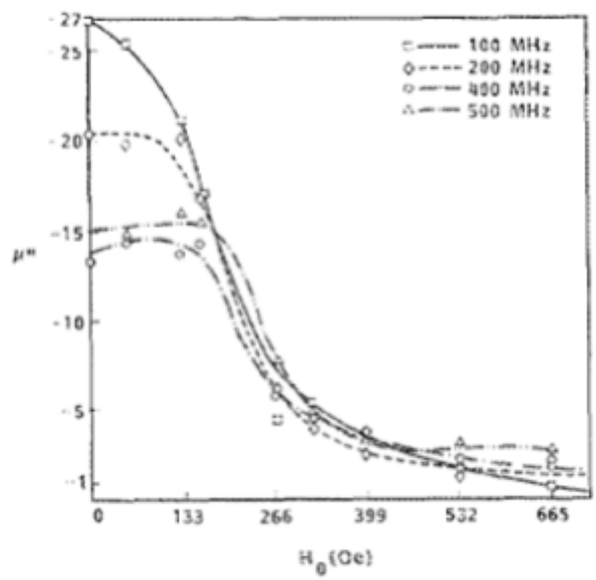

Figure 4: Im (μ) for $Mg_{.35}Zn_{.65}Fe_2O_4$ magnesium-zinc spinel ferrite as a function of solenoid field wrapped around a coax line with a ferrite plug[6].

Double Coax Windowsλ_g/4 Center to Center

Muons, Inc. is currently working on a funded STTR grant to develop high-power coax windows using compression rings, in order to pre-stress the windows and to allow for higher operating temperatures. This technology will also be employed in this SBIR/STTR grant proposal. In addition, it is proposed that two windows be used and spaced a quarter-wavelength apart to provide a cancelation of the reflection due to the impedance step [7]. The windows are designed to have the same inside and outside diameters as the 6-1/8" 50Ω coax line proposed for this RF system. At critical coupling to the RF Cavity, the bulk ceramic of half-inch thick windows dissipate about 20 watts each, while the metalizing on the inner and outer edges produces a similar amount of loss. Thus, the total loss per window will be about 40 watts at 200 kW input

EIA 6-1/8 Standard Coax Tee and Components

This coax has a 250kW rating at 100 MHz.

MICROWAVE MODEL

The microwave model for this system was done in Comsol [8].

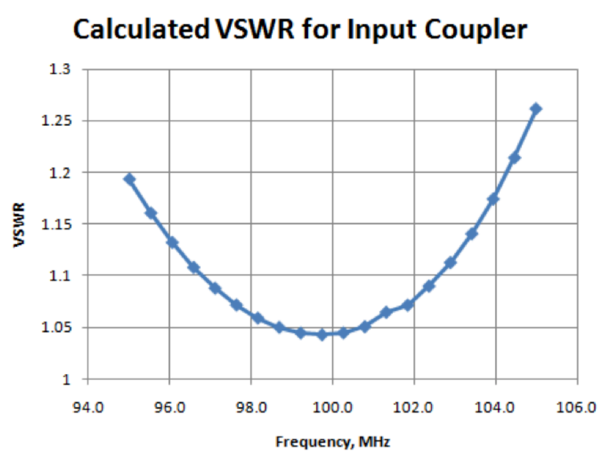

Figure 5: The calculated VSWR of the complete RF coupler shown in Figure 2.

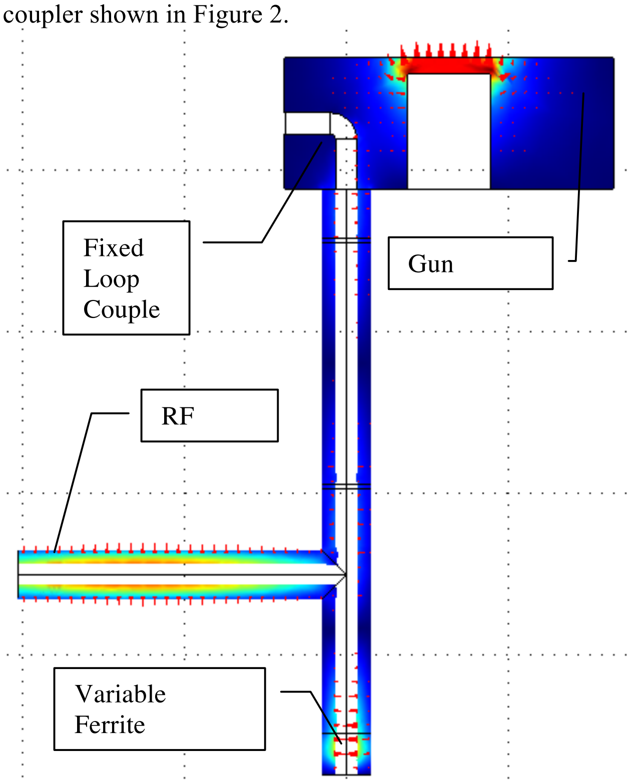

Figure 6: A model of the coupler with fixed coupling into the gun cavity.

CONCLUSION

A concept is presented with calculations of the performance of a variable input coupler without moving parts. Tuning of the coupler is accomplished by changing the current in a solenoid whose magnetic field, oriented orthogonal to the TEM fields in the coax line, changes the permeability of a ferrite or garnet material. The heat generated by the losses in these materials is removed from the tuner with a liquid dielectric in a closed cooling loop.

The vacuum system to the RF gun is maintained by a double window configuration for maximum reliability. The distance between the centers of the two windows is $\lambda_g/4$ apart, providing a perfect match without enhanced fields which could lead to multipactor.

The entire system is proposed to be built with EIA 6-1/8 coax which has a standard rating of 250kW at 100 MHz.

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