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RF DELIVERY SYSTEM FOR FETS

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Abstract

The Front End Test Stand (FETS) is an experiment based at the Rutherford Appleton Laboratory (RAL) in the UK. In this experiment, the first stages necessary to produce a very high quality, chopped H- ion beam as required for the next generation of high power proton accelerators (HPPAs) are designed, built and tested. HPPAs with beam powers in the megawatt range have many possible applications including drivers for spallation neutron sources, neutrino factories, accelerator driven sub-critical systems, waste transmuters and tritium production facilities.

An RF system outline, RF circulator installation, RFQ frequency test, and Buncher RF amplifiers test are presented and discussed. Experimental measurements of the RFQ frequency for the first metre of the 4-metre RFQ and chopping cavities' RF power amplifiers operating will be presented as part of the system testing results.

INTRODUCTION

The Main acceleration section of the FETS project is the 4-metre long 4-vane RFQ. It is designed to have a resonant frequency of 324 MHz; The FETS ion beam will transient the 500kW powered RFQ pulsed at 50 Hz, with pulse lengths of 2ms and leaves with 60 mA current and energy of 3 MeV [1]. The task of FETS RF system is to power up the RFQ by delivering the RF power from the system's Klystron to the RFQ input couplers. TOSHIBA E3740A is a high power pulsed amplifier klystron used in FETS, it's designed to work as an RF source in particle accelerators applications. The E3740A delivers 3MW at 324MHz with 55% of efficiency and more than 50dB of a power gain.

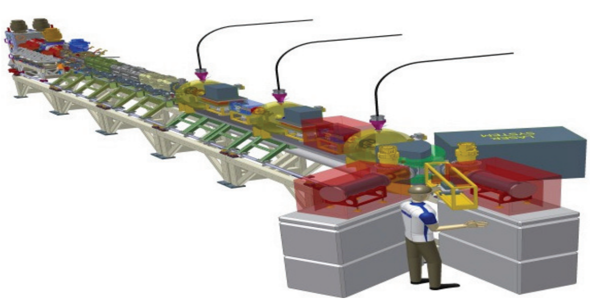

Figure 1: FETS Project Model.

The output window of the klystron is a WR2300 waveguide flange. Therefore, our system is made of a WR2300 waveguides designed to go up to the nearest point of the RFQ couplers where we transform our RF waveguide to 6-1/8" coaxial line to match the RFQ power couplers inputs considering the capability of power levels through the link.

THE RF SYSTEM

The shown FETS RF system design, figure 2, is the top view of final layout which planned to minimise the power loss and considering shielding and space limitations. The FETS RF system is mainly constructed from primary RF power devices and secondary RF assembly sections. The main elements of our RF system is the klystron, then the three ports RF circulator, which will be connected to the klystron by a WR2300 waveguide directional coupler mounted at the output window of the klystron to monitor and protect the klystron from any reflections in the case of system breakdown. The output port of the circulator will be feeding the RF power toward the RFQ while the third port would be connected to a dummy load to absorb any reflected power from the RFQ line. All system's waveguide and coaxial line pieces, load, directional couplers and T splitter were manufactured and delivered by MEGA Ind. [2].

To optimise the system capability of delivering the RF power with minimal loss and temperature rise all through the line, we have confirmed the loss figures with manufacturer to come out with numbers reflecting the loss per foot/metre in order to get an estimate rates of the loss difference in case of considering different layout options of the system. We found that the loss in total is not bad even with having a longer coaxial line, but the differences were still considerable.

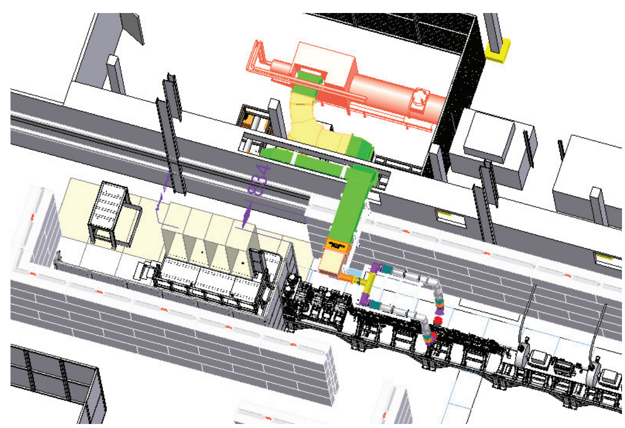

Figure 2: RF distribution layout.

For our power rate of 500kW, 50Hz pulsed, 2ms pulse width at 324MHz, the average power would be around 50kW. Generally speaking, relating the WR2300 waveguide and the 6-1/8" coaxial lines, the coaxial line loss per metre were about 3 times the loss in the WR2300 waveguide according to the manufacturer guidance. Moreover, the loss in the flexible coaxial cable (if we had

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to use any) would be around 2 times the loss in the fixed coaxial line (6x the waveguide loss rates). Furthermore, considering our power rates in the system in particular, the loss in the waveguide for our system would be around 1.43Watts/foot (**4.7**Watts/Metre), which is equivalent to the manufacturer loss guidance of (0.03dB/100 feet) and expecting few degrees temperature increment in the waveguide line. On the other hand, The loss in the coaxial line in the case of our system power rate would be around 3.22Watts/foot (**10.6**Watts/Metre), which is equivalent to the manufacturer loss guidance of (0.112 dB/100 feet) and the line should equalise at approximately +10C° above the ambient temperature. These figures were reasonable and useful details to consider in our system design which shows what we would expect running the system in different layouts.

The second main RF device inline is the MEGA matched coaxial T splitter; this splitter has low VSWR performance and 50 Ohms impedance in all arms. The splitter would be preceded by another main part of the system which is the WR2300 waveguide to 6-1/8" coaxial transition section. From the splitter arms, the 50kW power would be divided into two 25kW parallel power coaxial lines each directed to one of the two RFQ couplers. These two lines would have diagnostics coaxial directional coupler in each arm as well as a flexible coaxial assembly to make it possible to fine matching the phase of the two power's fraction fed into the RFQ.

THE CIRCULATOR INSTALLATION

The system circulator is a custom designed 3 ports Ferrite Tee shaped 324MHz CPR2300 circulator by AFT microwave GmbH [5]. The orientation of power rotation is set to counter clockwise for our system design need. The circulator can handle a forward peak power of 1MW and 10% duty factor, and can handle 100% reflection power. The typical insertion loss is <0.1dB with typical return loss and isolation of ≥ 30dB at the centre frequency. The cooling system of the circulator is demineralised water with operating temperature of 10°C to 40°C.

Figure 3: Klystron and Circulator setup of FETS.

RFQ FREQUENCY TEST

The first section of the 4-metre RFQ was manufactured and completer early this year, figure 3. Alignment inspection of the RFQ vanes showed that the modulation shape is correct but offset from the correct position. The offset is ~1.4mm longitudinally, ~0.2mm transversally. Simulations of the case were used to predict the influence of the problem on the frequency [3]. Then after, a low level RF test was performed to compare with simulation results.

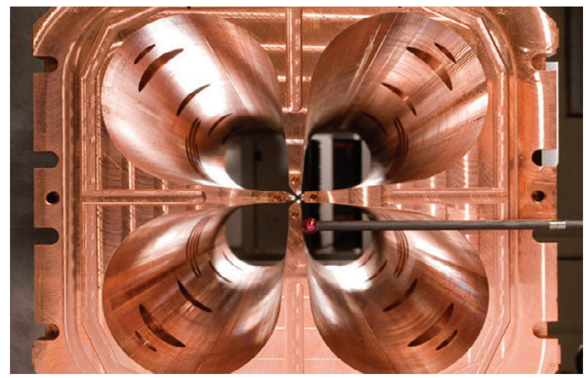

Figure 4: The vanes alignment of first metre FETS RFQ.

In order to compensate for the lack of vane cutbacks and to restore the frequency of an individual RFQ section to 324MHz, special end flange assemblies have been produced. The end flange has been equipped with an adjustable central protrusion to allow for fine frequency tuning. Moreover, special power couplers were designed and made for the purpose of frequency testing.

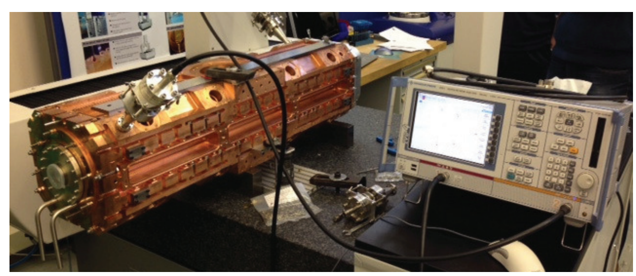

Figure 5: RFQ frequency test setup.

Experimental frequency test by the vector network analyser and simulation results were both matched and confirmed a frequency shift of ~6MHz to 329.4MHz. Figure 6, showing the S parameters, S_{11}, and S_{21} readings from the VNA. The upper frequency poles are the quadrupoles while the lower poles were the dipole frequency of the RFQ. The quadrupole frequency of 329.4MHz is well outside the tuneable range of the section which makes the frequency shift due to the vane offsets is not tolerable. Correction action is been considered with the manufacturer to moderate this offset. The second section of the RFQ is in manufacturing. Similar testing would be performed on each section prior assembly to confirm individual frequency and field flatness performance using the VNA and bead pull test.

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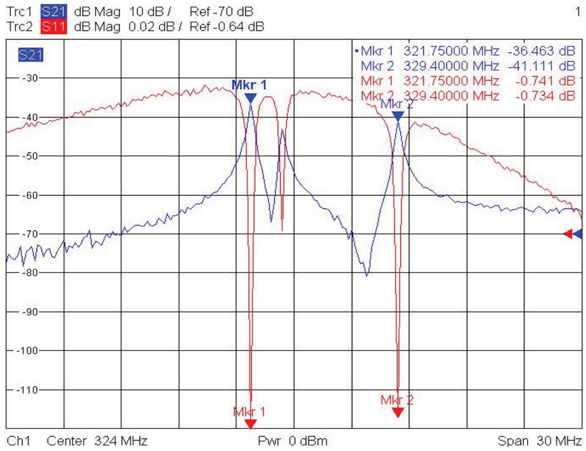

Figure 6: RFQ frequency test showing quadrupole and dipole frequency S-parameters.

BUNCHER RF AMPLIFIERS

FETS beam bunchers will have three bunching cavities. These cavities would be powered by three independent RF amplifiers. 8kW, KDP 8000, analogue solid state air cooled, single phase powered amplifiers, Figure 6, have been custom built and supplied by DB science, Italy [4]. Each amplifier can supply an 8kW at 324MHz pulsed power with maximum pulse width of 2.5ms at 50Hz. each amplifiers are built from two combined KDP 4000 amplifiers, a control logic unit and power driver combined in a 19”-31U Racks.

Figure 7: Setup for 8kW FETS amplifier tests.

RF AMPLIFIERS TEST

To confirm performance and power delivery of the amplifiers, a set up to test the amplifiers, one at a time to a dummy load to power up and confirm operation and power been performed. Signal generator to produce an RF signal at 324MHz, a pulse generator to provide the pulse width window and amplifier trigger been used to perform the test. Different RF pulse widths been applied during the test rated between 300µs to 20ms in steps. Amplifier’s output RF power been derived from few watts up to 8kW in ascending scale by increasing the RF input signal of the RF drive. Results confirm the stability of the amplifiers over the time of the test as well as the linearity of the output gain, forward and reflection performance. Figure 8, shows the input triggering pulses to the amplifier and the signal generator modulation. 50µs delay interval is required prior and after the RF signal to the amplifier for best RF amplification performance is required according to the manufacturer.

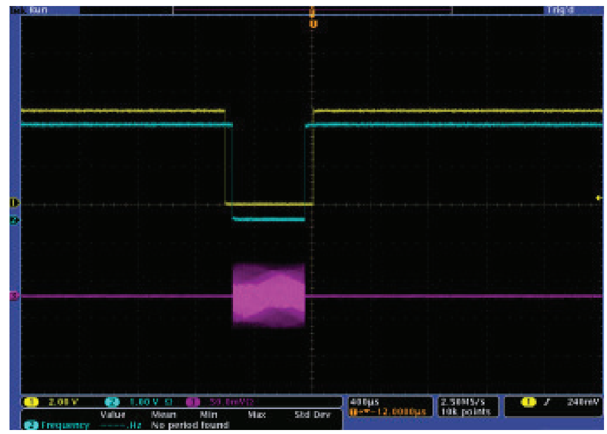

Figure 8: FETS Amplifiers Trigger pulse and RF input.

Figure 9, shows the RF input signal and triggering pulse with the forward output RF signal (Meganda) and the reflected RF power (Green) at the load dirceticonal coupler. Primary testing showed a good agreement of the results with the required specifications of the project.

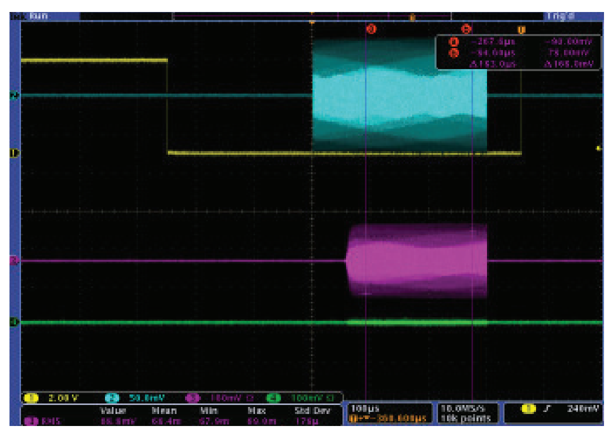

Figure 9: Amplifiers forward and reflected RF output.

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