FETS RF SYSTEM DESIGN AND CIRCULATOR TESTING

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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 and design options of the waveguide and coaxial parts with shielding are presented and discussed in this paper. Experimental measurements of the system's circulator low power test 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][2]. 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 [3].

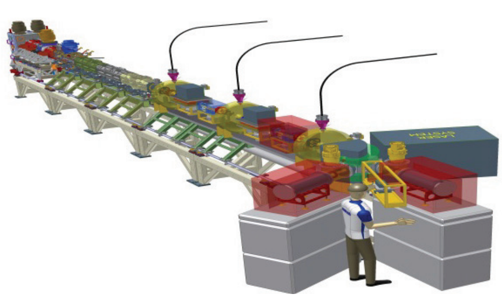

Figure 1: FETS Project Model.

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 design in figure 2 is the suggested layout to consider in order 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 dump load to absorb any reflected power from the RFQ line. All the system's waveguide and coaxial line pieces, load, directional couplers and T splitter were manufactured and delivered by MEGA Ind. [4].

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.

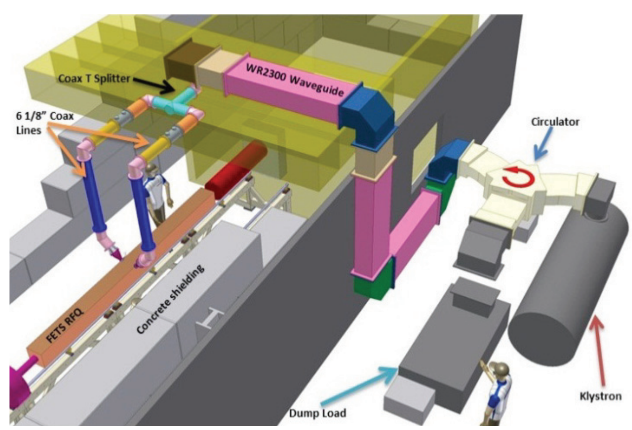

Figure 2: The FETS RF system layout.

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 to use any) would be around 2 times the loss in the fixed

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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

The system circulator is a custom designed 3 ports Ferrite Tee shaped 324MHz CPR2300 circulator by AFT microwave GmbH. 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.

LOW POWER CIRCULATOR TEST

The purpose of performing this test was to duplicate, verify and approve manufacturer low power test results of performance and confirm the specifications of rotating direction, insulation and reflection parameters. The low power test of the circulator been performed using a vector network analyser, RF cables with N-Type connector terminations, a well matched WR2300 waveguide transmissions to coaxial connectors designed and modelled by our team then externally built. Figure 3 shows the simulation and actual waveguide transmission termination boxes with the transceiver antennas which built by our engineering team.

Common waveguide calibration standards were used to perform the system calibration. The circulator measurements with the thermal compensation system TCU connected were performed at the optimum water inlet temperatures as well as within the specified water temperature range, at and ambient temperature of 22°C ±3°C. The data were collected in thermal equilibrium after about 2 hours of settle time. The manufacturer test results were considered to confirm performance and provide evaluation comparison.

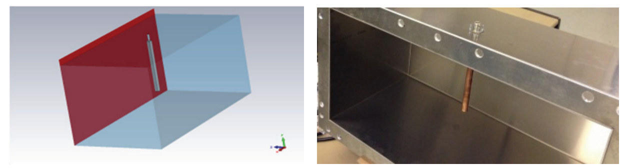

Figure 3: Circulator test waveguide termination boxes.

THE RESULTS

After satisfying all the settings and procedures of performing the test, we were able to start collecting the transmission, isolation and the reflection S parameters of the circulator. Considering the 3 circulator's ports are alike, there were 6 different sets of combinations of Port(in)Port(out) readings of the S parameters. These combinations are; port1Port2, Port1Port3, Port2Port1, Port2Port3, Port3Port1, and Port3Port2. We have checked all possible combinations and selected port1Port2 as our main test configuration with having Port3 as the dump load termination port for reflections as this configuration is the one would be used in our high power RF system.

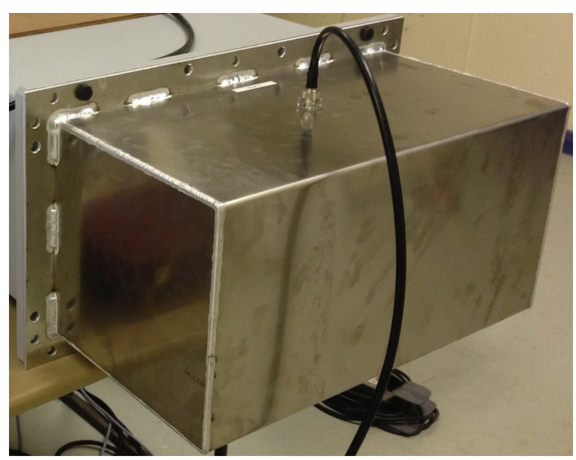

Figure 4: Waveguide termination box connection.

With some antenna's positioning and optimisation, we have managed to achieve a very good match of the manufacturer results. Moreover, we have done some work to optimise the 50 Ohms matching load as the manufacturer results was showing a sort of drifted, wider band lower performance S parameters considering our system desired centre frequency of 324MHz. in this term

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we have managed to exceed the manufacturer results and achieve a sort of narrower band frequency response centralised at the desired frequency of 324MHz. from the figures 6 and 8 we can clearly see that we have matched and exceeded the manufacturer results of -31dB in the S11.

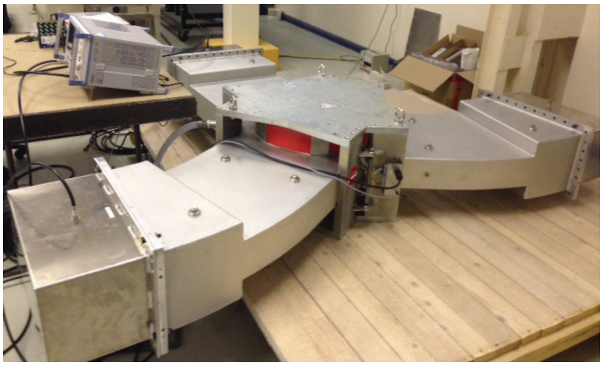

Figure 5: Circulator test setup.

Moreover, we have recorded all the S parameters of the test to guarantee simultaneous performance of all ports together. Figure 6 shows our test results of the circulator showing only S11 and S21 parameters connecting Port1 as input and Port2 as output and Port3 matched to a 50 Ohms dumping load.

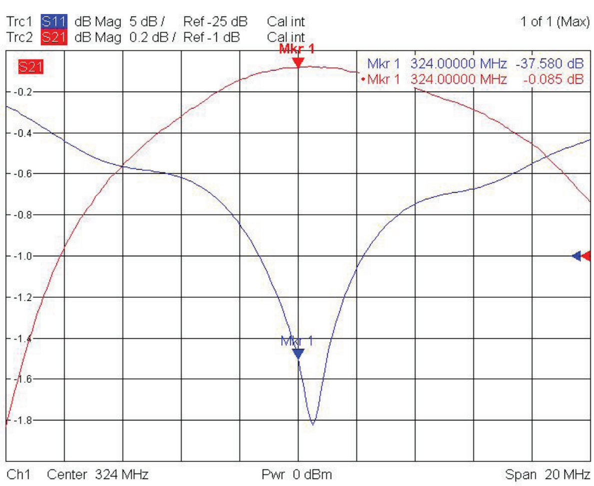

Figure 6: FETS circulator test results S11 and S21as Port1 input and port2 output.

The manufacturer test results were showing -31dB at the frequency of interest point of 324MHz with a less pointed wider band results for the same ports setup, figure 7, while with our test we have managed to get a narrow band and closer frequency response to the central frequency of the system at 324MHz. the S11 figure of our test was lower than -37dB compared to the results of around -31dB in the manufacturer test results. Moreover, the circulator's isolation performance parameter S21was around -0.085dB in our test compared to -4.186mdB in the manufacturer test case.

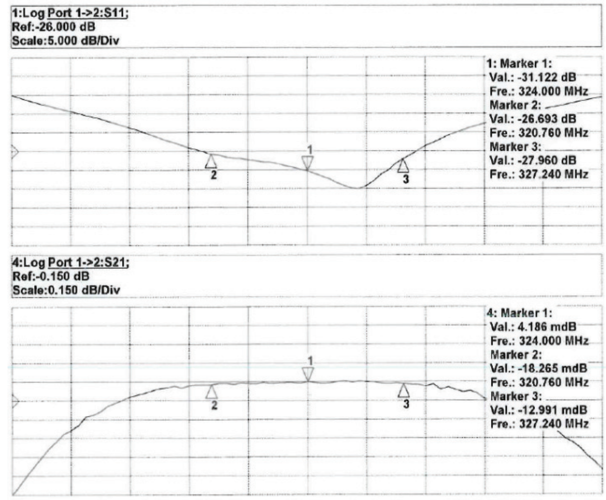

Figure 7: AFT FETS's circulator test Results.

Figure 8 below shows the S11, S12, S21 and S22 parameters in one go, it can clearly say that optimising one of the parameters with the reflection antennas will affect the other parameters in both value and frequency. Therefore, we have concluded our test to a best value and frequency results with no big compromising in total with an optimum system central frequency at 324MHz.

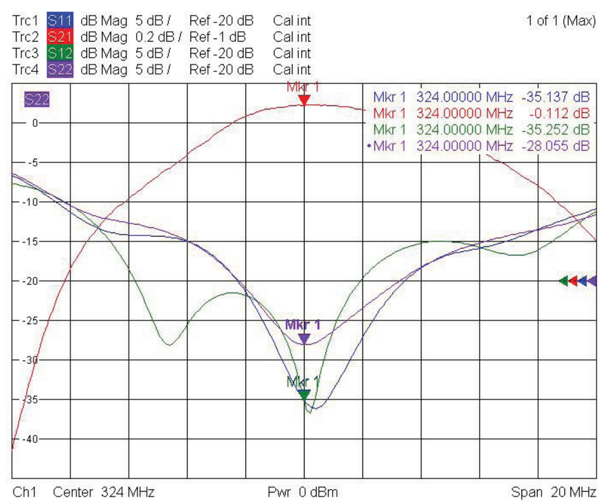

Figure 8: FETS circulator test results of Port1 input and Port 2 output considering all the S parameters.

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