# THE FEEDBACK CONTROL FUNCTIONS OF THE LLRF SYSTEM FOF PEFP RFQ

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*Abstract*

The RFQ (Radio frequency quadrupole) for PEFP (Proton Engineering Frontier Project) has been built, which is a low energy accelerator for 3MeV proton beam. The required peak power of the cavity is 535 kW, and pulse width, repetition rate for initial operation are 100 us, 10 Hz respectively. To accelerate proton beam in the RFQ linear accelerator, the Low-Level RF System should have feedback control functions of cavity field (amplitude, phase), cavity resonant frequency and high power protection. Field stability of ±1% in amplitude and ±1°in phase are required, but the current LLRF System with analog feedback control system has field control function of 1dB/step in amplitude and 1.4°/step in phase. Because the temperature regulation of cooling system is presently poor, the shift of the cavity's resonant frequency due to RF heating and beam loading is controlled by the frequency modulation function of the RF signal generator. In this paper, the test details and results are described.

## INTRODUCTION

The RFQ linear accelerator for PEFP (Proton Engineering Frontier Project) has been built [1], which is a low energy accelerator for 3MeV proton beam. To accelerate proton beam in the RFQ linear accelerator, it is necessary that the RFQ linear accelerator should maintain continuously 350MHz resonance frequency. Resonance control is required in order to control the shift of the cavity's resonant frequency due to RF heating, beam loading, cryogen pressure change, and variation in klystron high voltage[2]. The shift of the cavity's resonant frequency causes the variation of the cavity field (amplitude, phase). Thus, resonance control is an essential function for beam acceleration together with field control function. In addition to resonance control, the low-level RF System provides cavity field control function, and incorporates the personnel and machine protection functions [3].

Field stability of ±1% in amplitude and ±1°in phase are required, but the current LLRF System with analog feedback control system has field control function of 1dB/step in amplitude and 1.4°/step in phase. Because the temperature regulation of cooling system is poor, the shift of the cavity's resonant frequency is controlled by the frequency modulation function of the RF signal generator. This system has interlock functions for high power RF system protection.

## LLRF SYSTEM

In the present LLRF system with analog feedback control system, the reference RF signal is generated by a master oscillator, which consists of OCXO and PLL. The power level of the master oscillator is 10 dBm and monitored. The design of the system is based on the CW operation, but it can be operated in pulsed mode for the initial RFQ conditioning. RF switch (On-Off Keying) is used for pulse modulation. This System is comprised of three control loops and an interlock system. The schematic diagram and description of LLRF system is shown in Fig. 1, table 1 respectively.

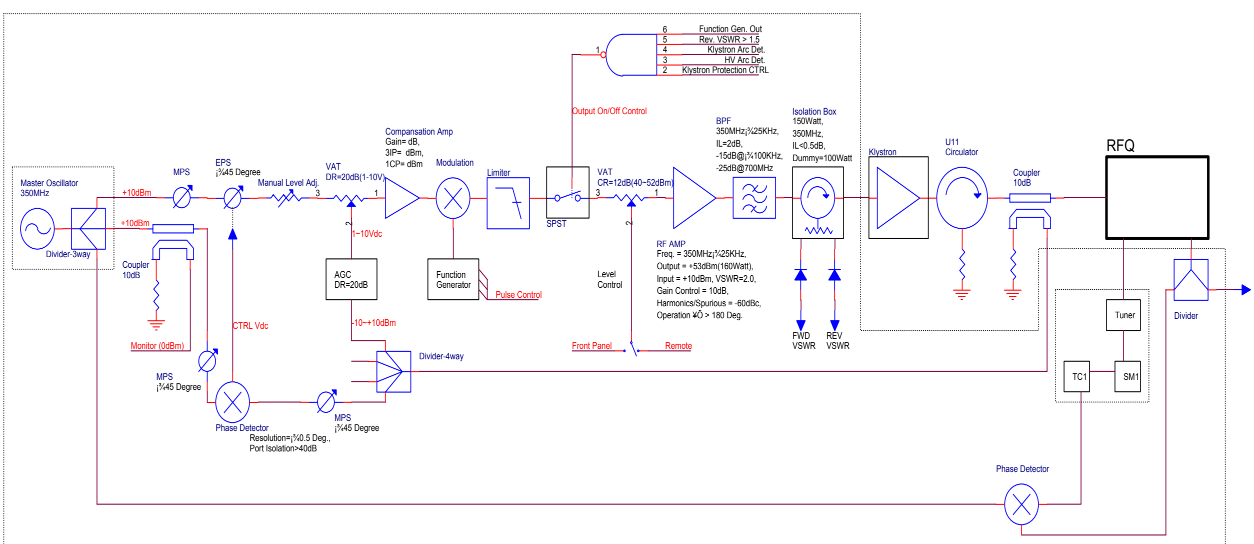


Figure 1: LLRF System Block Diagram for RFQ

Table 1: LLRF system description

| | |
|---|---|
| Center frequency | 350 MHz |
| Output RF power | 52 dBm (160 Watt) |
| VSWR | 2.0 max. |
| Operation mode | CW, pulse |
| Pulse modulation | OOK (on-off keying) |
| Harmonics/spurious | < 60 dB |
| Field control | 1dB/step in amplitude<br>1.4deg./step in phase |
| Resonance control | Movable tuners<br>Water temp. control |

## FEEDBACK CONTROL

The low-level RF system is comprised of three loops, which control cavity's field and resonant frequency. The Amplitude loop keeps the gap voltage constant by measuring the magnitude of the cavity field, comparing it to a reference voltage, and adjusting the electronic variable attenuator in the main signal circuit. The phase loop is to keep the phase of the field in the cavity locked with the master signal generator and will also compensate the phase change with the RF power variance, due to the power amplifier, the klystron, the circulator, the driving electronics and so on.

Field stability of ±1% in amplitude and ±1° in phase is required, but the present LLRF System with analog feedback control system has field control function of 1dB/step in amplitude and 1.4°/step in phase.

In order to control the shift of the resonant frequency due to RF heating, beam loading, cryogen pressure change, variation in klystron high voltage, cavity resonance control loop is required. Cavity's resonant frequency is controlled by the variation of phase difference between the RF input coupler and the RF pickup loop, and is maintained by cooling water temperature. In this resonance control test, because the temperature regulation of cooling system is poor, the shift of the cavity's resonant frequency is controlled by the frequency modulation function of the RF signal generator. Figure 2 shows the picture for RFQ resonance control test using frequency modulation function of RF signal generator. The tuning scheme is as follows. First, make the loop open and search for operation frequency to correspond to the minimum reflection. Secondly, adjust the output of the phase detector to zero by adjusting the mechanical phase shifter. And at last, close the loop for actual operation and connect the output of phase detector to FM function of RF signal generator. The loop measures the phase between the cavity voltage and the input RF voltage. Then, input RF frequency is shifted due to the variation of cavity's resonant frequency.

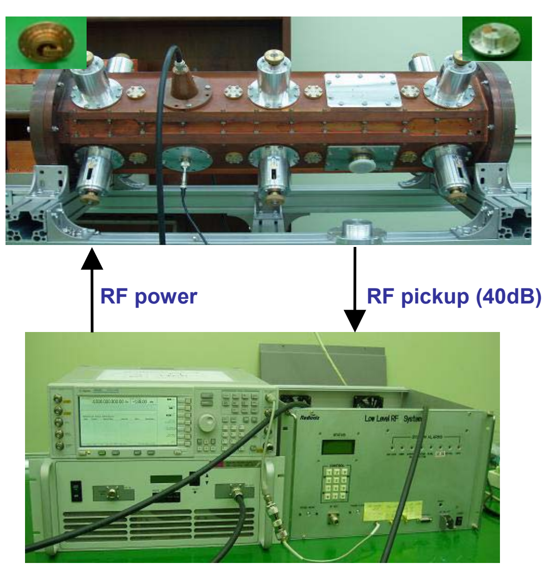


Figure 2: Resonance control test using FM

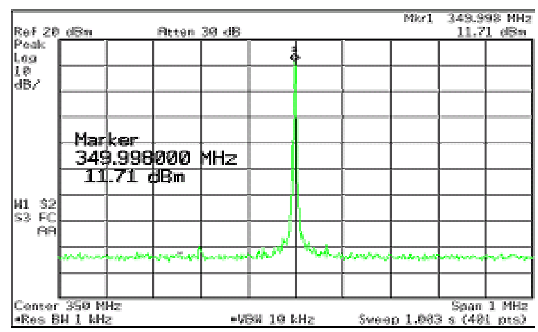


Figure 3: Input RF power

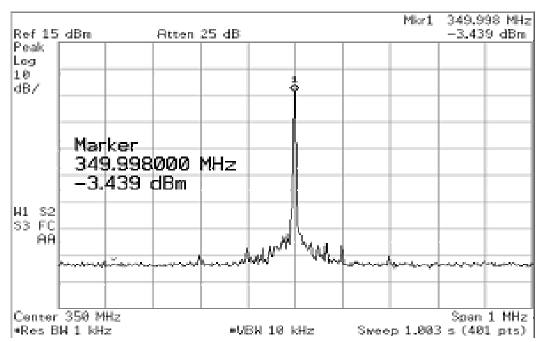


Figure 4: Reflected RF power

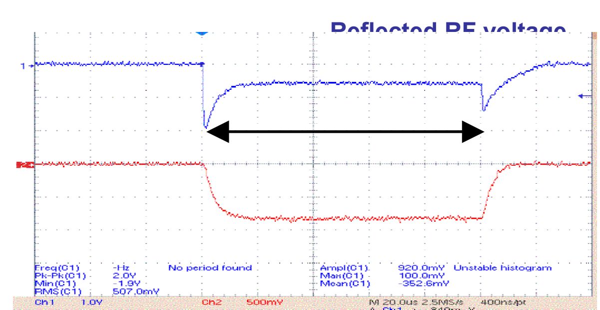

Figure 5: pulse operation

Figure 3 and Figure 4 show RF input RF power and reflected RF power measured in resonance control test respectively. In this test, 20dB Attenuator and 20dB directional coupler were used, so input RF power and reflected RF power level are 51.71 dBm (148.252 Watt), 36.561 dBm (4.53 Watt) respectively. Figure 5 shows reflected RF voltage and cavity RF voltage in pulse operation. Pulse width and repetition rate for initial operation are 100 us, 10 Hz respectively.

## INTERLOCK SYSTEM

This system is required to turn off the RF driver in the event of arcing in the RF windows, the klystron window, or the circulator, which are very essential and expensive. The photo and description of the interlock system is shown in Fig. 6, table 2 respectively. The response time is about 2us.

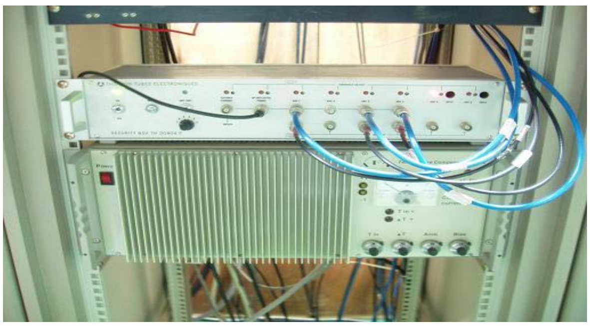

Figure 6: interlock system

Table 2: The specifications of interlock system

| Signal source | Type | Action |
|---|---|---|
| Klystron window arc | On | RF off |
| Circulator arc | On | RF off |
| RF window arc | On | RF off |
| Reflected RF power | Max. | RF off |

## HIGH POWER TEST

The required peak RF power of the cavity is 535kW at 350MHz. It's operating scheme is pulse mode with 120Hz repetition rate and 0.1-2ms pulse width. But, the tuning results of the PEFP RFQ showed that its resonant frequency was 352.1MHz [4]. Therefore it was determined to drive the RFQ at 352.1MHz in advance and then new RFQ was re-built [5].

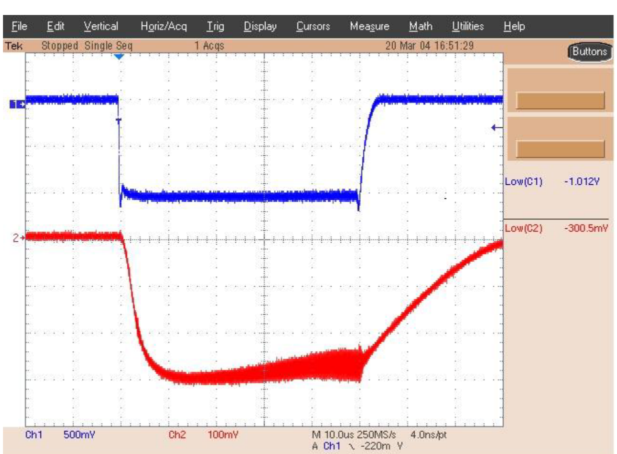


Figure 7: Pulse shape in high power test at 352.1MHz

Figure 7 shows pulse shape in high power RF test. The klystron delivered RF power up to 260kW at 352.1MHz, and the pulse width and repetition rate were reduced to 50μs, 0.1Hz respectively during conditioning. The relatively long tail of the cavity pickup pulse came from the crystal detector characteristics.

## SUMMARY

The LLRF system with analog feedback control system has been tested. This system has the field control function of 1dB/step in amplitude and 1.4°/step in phase. Because the temperature regulation of cooling system is presently poor, the shift of the cavity's resonant frequency is controlled by the frequency modulation function of the RF signal generator. This system has a protection function to turn off the RF driver in the event of arcing in the RF windows, the klystron window, or the circulator. Because of the tuning problem of the RFQ, the operating frequency was 352.1MHz. Until now, the klystron was operated up to 260kW at 352.1MHz.

## ACKNOWLEDGEMENT

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