THE DESIGN, FABRICATION AND PERFORMANCE TESTING OF THE ANALOG I/Q RF CONTROL SYSTEM AT NSRRC

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Abstract

An analog low-level RF system, based on an I/Q modulator and demodulator, has been tested at NSRRC. The I/Q RF control system has the same function blocks as the digital low-level RF system, which we plan to develop for our proposed 3-GeV light source machine. This analog I/Q RF system provides a real function structure to verify the working principle, block functions and performance evaluation of the developing digital low-level RF system. This work presents the designed function diagrams, the measured results for the characteristics of the main RF components, and the performance testing of the analog I/Q RF control system with a dummy cavity.

INTRODUCTION

The existing low-level RF control system for the superconducting cavity of CESR-B type in NSRRC is based on analog feedback loops. It comprises four independent feedback loops, to control the gap voltage, the cavity phase, the klystron phase and the cavity frequency (tuner). These control loops ensure the required conditions of stability for operation of the superconducting cavity. Figure 1 shows a simplified block diagram of the analog low-level RF control system.

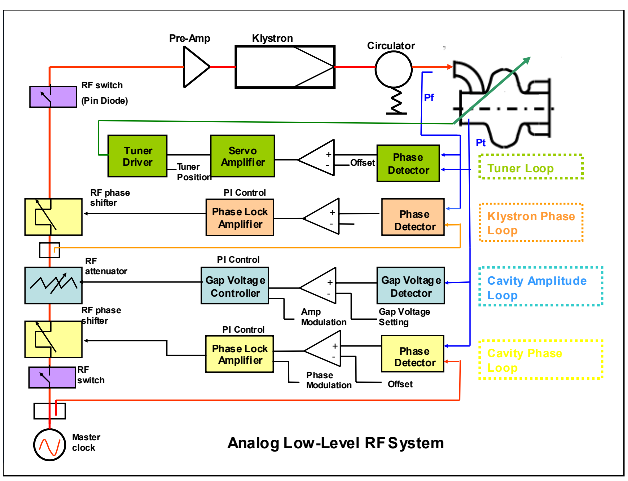

Figure 1: Functional block diagram of the analog low-level RF control system.

The fluctuations of amplitude and phase are controllable within ±1 % and ±2° respectively in routine operation with the current analog low-level RF system.

The present RF feedback control system is based on analog feedback loops for amplitude and phase. The I/Q (in-phase, quadrature) demodulation and modulator techniques are currently favoured in modern accelerating structures. A translation of the amplitude and phase information into IQ is advantageous because of the symmetry of the IQ signal paths. This analog I/Q RF system also provides a real function structure to verify the working principle, block functions and the performance evaluation for the developing digital low-level RF system. A new, FPGA-based, digital, low-level RF system is proposed for development of the new Taiwan Photon Source [1]. The analog I/Q and digital FPGA LLRF systems are conceptually similar, both being based on the IQ method and PID regulation.

This paper presents the designed function diagrams, measured results for the characteristics of the main RF vector components and the integration test of the analog I/Q RF control system

ANALOG I/Q CONTROL SYSTEM

The analog I/Q feedback control circuits are based on NIM modules and use in-phase (I) and quadrature (Q) signal components, commonly called an I/Q detection system [2-4]. Figure 2 shows a schematic of the analog I/Q RF control system.

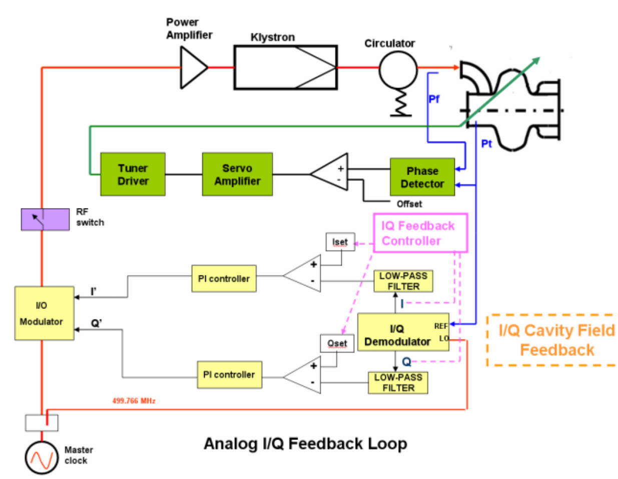

Figure 2: Function blocks of an analog I/Q control system.

The cavity field is directly down-converted to base-band signals, for which a vector demodulator performs I/Q detection. The resulting I/Q base-band signals that describe the cavity field are fed to a pair of Proportional & Integral (PI) controllers, one for the I signal and another for the Q signal. The set points for the I/Q channels are also fed to the PI controllers in which the cavity-field error signals are generated and processed. The outputs from the I/Q PI controllers are fed to an RF vector modulator, which modifies the I and Q components of the carrier frequency from the master reference clock

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to produce the specified RF for the klystron based on I/Q vector inputs from the analog I/Q feedback.

I/Q demodulator module

The AD8348 is a broad-band quadrature demodulator with an integrated intermediate frequency (IF), variable-gain, amplifier (VGA), and integrated base-band amplifiers [5]. It is responsible for converting the RF signal down to base-band differential I and Q components. To generate signal in-phase and quadrature data, the AD8348 requires an external LO signal of frequency twice the desired carrier frequency.

The I/Q demodulator module integrates the AD8348, manual phase shifter, manual attenuator and signal-adjustment circuit. Figure 3a shows a block diagram of the I/Q demodulator module. The 360-degree manual phase shifter is used to zero the initial loop phase for operation of the I/Q feedback control.

In Figure 3b, the performance measurement of the I/Q demodulator that covers 0 to 360 deg as shown with varied amplitude. The display mode of the oscilloscope is an XY mode.

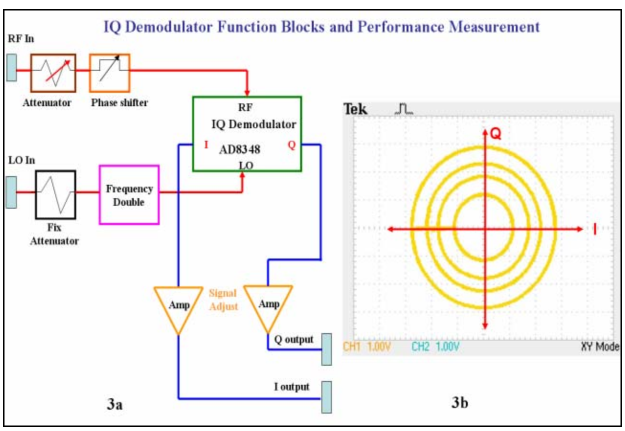

Figure 3: IQ demodulator function diagrams and performance measurement.

PI Controller module

The PI Controller module comprises an integrator with a proportional gain. The controller design consists of a front-end differential amplifier, followed by an integrator. The differential amplifier (or "error amplifier") amplifies the differences of the two single-ended inputs, the set point and measure, and multiplies the result by the proportional gain. An electronic switch is finally provided that opens the loop and switches a preset voltage at the I/Q modulator input; this mode of operation, called a "Tune Mode", allows a few kilowatts of RF into the cavity and is set by screw adjustment at the front panel of the module.

The frequency response of the PI controller was measured and the unit-gain point should be near 7 kHz.

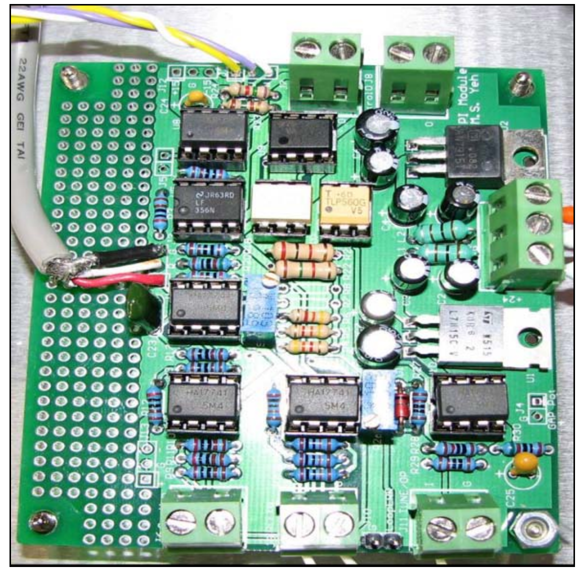

Figure 4: Circuit board of the PI controller.

I/Q modulator module

The vector modulator module modifies the I&Q components to produce the desired RF drive signal for the klystron according to the PI controller signal.

The AD8345 is used to perform I/Q up-conversion [5]. The component provides excellent specifications of amplitude and phase balance and sideband suppression.

I/Q Feedback-control module

The I/Q feedback-control module is the central controller of the feedback system, providing the following controls.

1. Two potentiometers adjust the operational set levels of I and Q for the cavity accelerating voltage; two panel meters display separately the I set and Q set values.
2. In the tune mode, the Tune/Operation mode manual switch turns the drive power on at a decreased level at which the cavity frequency-tuning loop can tune the cavity frequency to a resonant frequency. In the operation mode, the cavity-accelerating voltage becomes controlled by the set values of I and Q.

INTEGRATION TESTING

After development and construction of hardware for the analog I/Q control system, the integration bench testing of the I/Q control system is currently in progress. Figure 5 shows the configuration of system integration testing in operation with the NIM I/Q control module, rf signal source and oscilloscope.

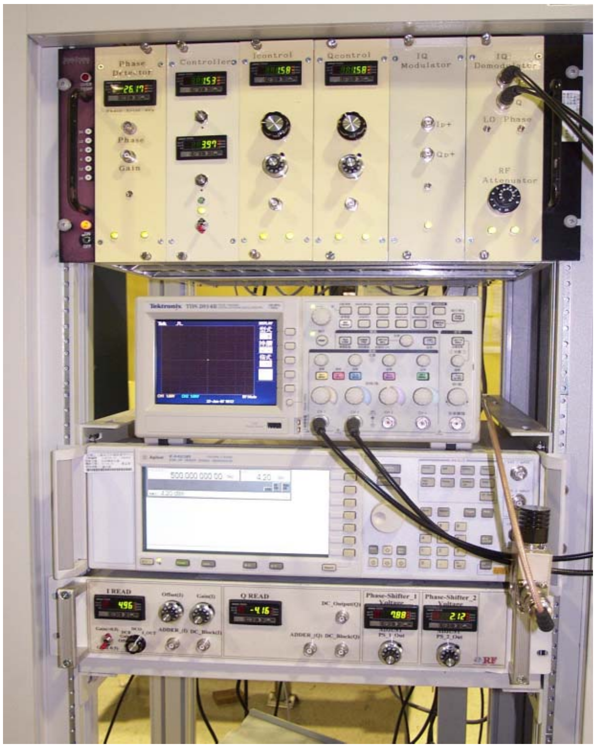

Figure 5: Photograph of analog I/Q control system.

To test the closed-loop response of the I/Q components to the set value, the I/Q components are recorded on the horizontal/vertical axes of the oscilloscope in persistence mode, shown in figure 6, as we vary the I component set value at a fixed Q set value, and vary the Q set value at a fixed I set value. Figure 6 shows that the RF I/Q components of the cavity field can be satisfactorily controlled independently.

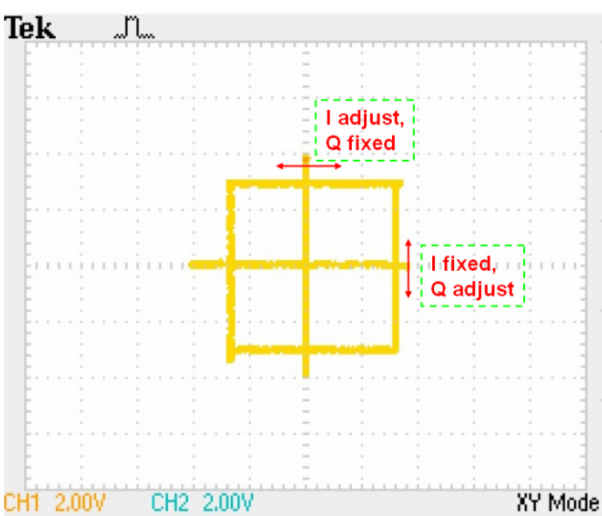

Figure 6: Measurement of I and Q components of the dummy cavity field in closed-loop bench testing.

CONCLUSIONS

Integration testing of the overall I/Q feedback system with a dummy cavity has been demonstrated to be successful. We expect to test the analog I/Q control system with the conventional Doris cavity in our booster. A campaign of tests will follow to assess finally the performances.

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