LOW LEVEL RF SYSTEM FOR JEFFERSON LAB CRYOMODULE TEST FACILITY*

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Abstract

The Jefferson Lab Cryomodule Test Facility (CMTF) has been upgraded to test and commission SNS and CEBAF Energy Upgrade cryomodules. Part of the upgrade was to modernize the superconducting cavity instrumentation and control. We have designed a VXI based RF control system exclusively for the production testing of superconducting cavities. The RF system can be configured to work either in Phase Locked Loop (PLL) or Self Excited Loop (SEL) mode. It can be used to drive either SNS 805 MHz or CEBAF Energy Upgrade 1497 MHz superconducting cavities and can be operated in pulsed or continuous wave (CW) mode. The base design consists of RF-analog and digital sections. The RF-analog section includes a Voltage Control Oscillator (VCO), phase detector, I&Q modulator and "low phase shift" limiter. The digital section controls the analog section and includes ADC, FPGA, and DAC. We will discuss the design of the RF system and how it relates to the support of cavity testing.

INTRODUCTION

The present RF system was designed to control RF signals driving two types of cavities: SNS and CEBAF upgrade in pulsed or CW mode. Table 1 contains the main parameters of these cavities.

Table 1: Cavity Parameters

Parameters	SNS	CEBAF upgrade
Frequency[MHz]	805	1497
Gradient[MV/m]	10.5/12.5	12.5
Mode	pulse/CW for test only	CW/pulse for test only
Loaded Q	7.3E5/7E5	2.2E7
Cavity bandwidth(Hz)	1000	70
Number of cavities /per cryomodule	3/4	8
Number of cells	6	7
Repetition rate/duration	60Hz/1.2ms	cw

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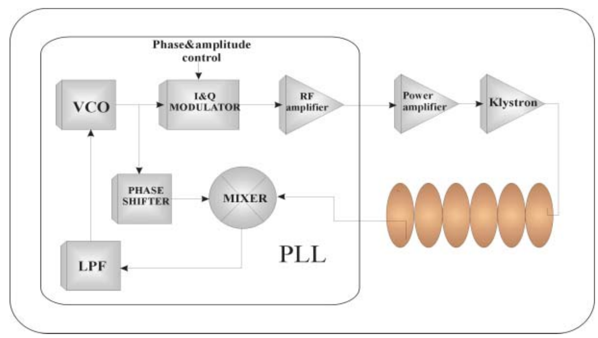
\# Coplanar Waveguide consists of two slots on a dielectric substrate with the same width

The initial goal of the system was to build a generic, VXI based, remotely and locally controlled card for both 805 and 1497 MHz frequencies. Later, due to problems with finding an appropriate VCO and phase shifter, two separate boards were designed and built. To reduce noise on the board, the analog section is separated from the digital (separated grounds). For all RF paths 50 ohm CPW[#] lines are used.

CONCEPTUAL DESIGN



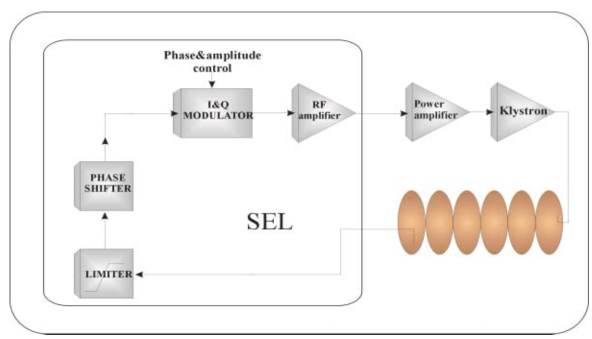


Figure 1: PLL vs. SEL

Unlike a typical RF system where requirements are defined in terms of amplitude and phase stability, the CMTF RF control system has to follow the cavity resonance frequency, which due to high Q_{ext} is particularly susceptible to microphonics and Lorentz forces causing its fluctuations. Two modes can be chosen: Phase Locked Loop (PLL) or Self Exciting Loop (SEL). Fig. 1 shows these two setups. The PLL system requires a frequency source (VCO) and phase detector. The SEL, where loop gain>1 and phase shift is equal $2*\pi*n$, will oscillate by itself at the cavity resonance frequency. In addition, we have implemented a "low phase shift" limiter to protect the system against saturation and undesired phase shift.

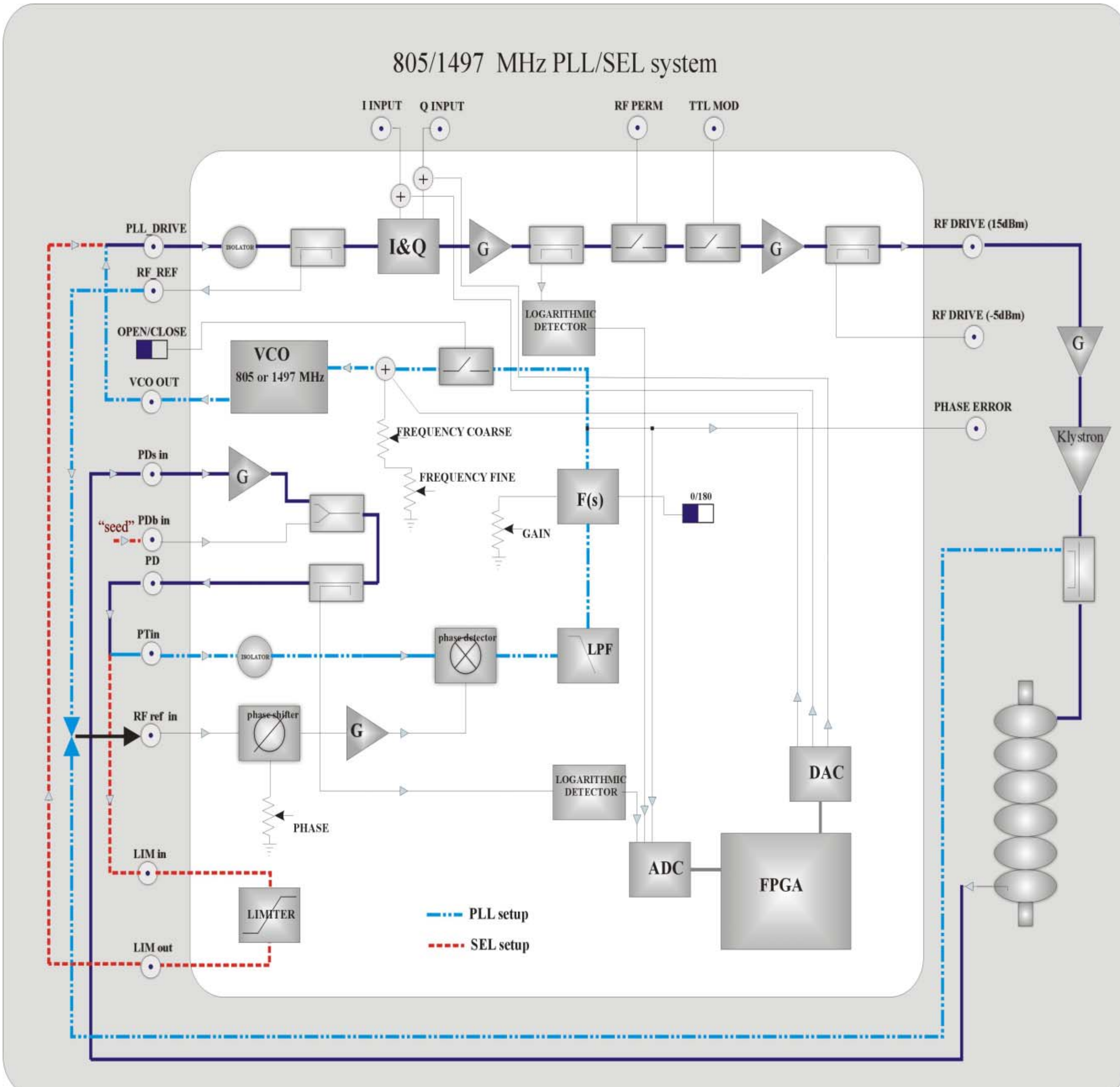


Figure 2: Block diagram of the RF system

RF SYSTEM

A block diagram of the RF system is shown in Fig. 2. Depending on connection “dot-dash or dash line” the two configurations (PLL and SEL) can be established. Amplitude and phase are controlled using I and Q modulation. To lock the system in PLL mode, initial tuning of the VCO frequency, phase, and gain is required. After the system is locked, it can operate in pulse or CW mode. For SEL configuration, the start-up process is statistical in nature and the system can be locked to modes other than π mode. In addition a seed signal can be injected to accelerate the tuning process. The Phase Locked Loop consists of a voltage-controlled oscillator, a phase detector and a low pass filter. For our application we have chosen two types of VCOs from EMHISER MICRO-TECH:

790-820 MHz/Phase noise @ 10kHz -95dBc

1420-1540 MHz/Phase noise @ 10kHz –80dBc

A passive, double balanced, level 7 mixer was implemented as a phase detector. An active, 1-pole low pass filter reduces loop bandwidth to 30 kHz. The dynamic range and the stability of the PLL setup were improved by implementation of the additional limiter (see Fig. 2). Initials problems with stability and EMI noise observed on the first version of the board were reduced by improved grounding and by replacing microstrip line with CPW. To reduce the cost of production, regular 6-layer FR-4 board was used. The effective dielectric constant of the FR-4 substrate was measured and supplied by the manufacturer. Figure 3 shows measured, forward, reflected and gradient signals for PLL setup and pulse operation. The system can be switched between pulse and cw, while the lock remains undisturbed. Figure 4 shows measured, forward, reflected and gradient signals for SEL setup and pulse operation. The system can follow changes in resonance frequency even when the cavity is detuned several hundred kHz from the operational frequency. The start-up process is fast enough (~10us) for a 1.2 ms RF pulse.

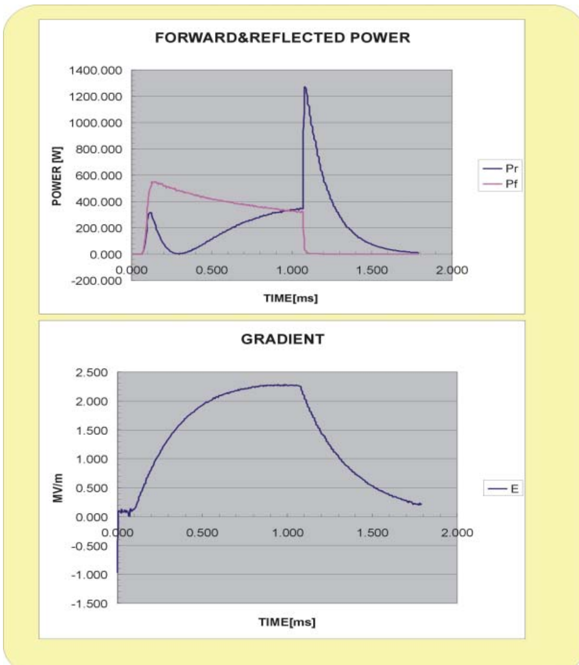


Figure 3. Results from PLL Setup

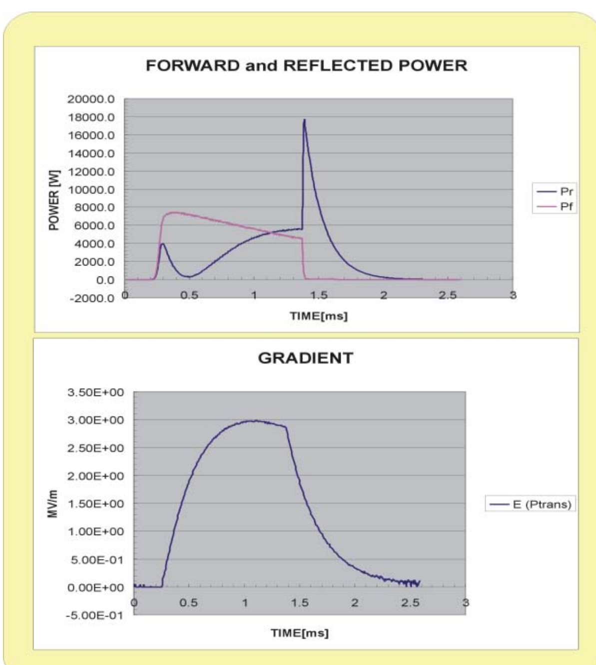


Figure 4: Results from SEL Setup

CONCLUSION

The presented system was successfully tested and commissioned in the CMTF and currently is used in the cryomodule testing process were cavities are tested under strong coupling conditions and for high power pulses. For static and dynamic Lorentz forces measurements different type of AM modulation were used. It is planned to use different RF parts (phase detector, limiter) according to market evaluation to achieve larger dynamic range and better stability of the system.

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