TRIUMF e-LINAC RF CONTROL SYSTEM DESIGN*

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Abstract

The rf control system for the 1.3 GHz TRIUMF e-linac elliptical superconducting cavities is a hybrid analogue/digital design. It is based in part on an earlier design developed for the 1/4 wave superconducting cavities of the ISACII linac. This design has undergone several iterations in the course of its development. In the current design, down-conversion to an intermediate frequency of 138MHz is employed. The cavity operates in a self-excited feedback loop, while phase locked loops are used to achieve frequency and phase stability. Digital signal processors are used to provide amplitude and phase regulation, as well as mechanical cavity tuning control. This version also allows for the rapid implementation of operating firmware and software changes, which can be done remotely, if the need arises. This paper describes the RF control system and some early test results.

INTRODUCTION

This paper briefly reviews the development and outlines the design of the TRIUMF e-linac superconducting rf control system. Since this design draws heavily on work done for the existing ISACII linac and the high-Beta extension currently being constructed, some of this design history is outlined. Some preliminary test results obtained with the prototype system are presented. Finally, a few conclusions are offered.

THE ISACII SYSTEM

This was the first superconducting linac application at TRIUMF. It consists of five four cavity cryomodules operating at 4K. The cavities are quarter wave resonators mechanically tuned via a servomotor system. The control system for these cavities has been documented elsewhere [1], but is reviewed briefly here. A block diagram of this system is shown in Fig. 1. A commercial low phase noise crystal-based synthesizer provides the reference frequency for the system via phase-stable coaxial cable.

The RF module includes two phase detectors implemented in a single FPGA. One is used to control the RF phase while the second controls the tuner. The FPGA also includes two counters – one for the reference and the second for the cavity frequency. These are used for initial tuning of the self-excited cavity prior to closing the phase loop. A single DSP provides amplitude and phase control while a second DSP is used to regulate the tuner. Considerable design effort went into optimizing the system for low noise, as the noise floor of the controls has a direct impact on the phase and amplitude noise of the cavities. It may be noted that the control system is currently divided into two VXI C-size modules. Under test at the moment is a single module which incorporates both the RF and DSP functions. Besides the obvious advantages of space and cost savings, it is hoped that this step will further reduce the noise floor of the system by eliminating module interconnects which are currently routed via the VXI analog bus.

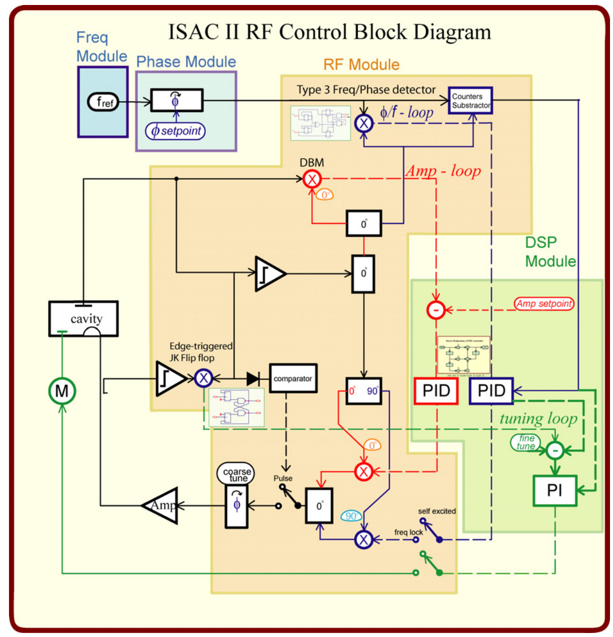

Figure 1: Superconducting Control.

THE e-LINAC SYSTEM

System Requirements

As a starting point, we would like to achieve performance at least equal to that of the existing ISACII RF control system. This means amplitude regulation of about 0.2% and phase regulation of less than one degree. To minimize the development of new hardware, we would like to utilize as much of the above system as possible.

One obvious obstacle to that goal is that the e-linac requires an RF frequency of 1.3GHz. The upper limit of the FPGA phase detector used in the current system is about 250MHz, with performance which diminishes as that limit is approached. To circumvent this limit a frequency up/down converter will be employed, with an IF frequency close to that of the existing system.

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Frequency Converter

A schematic of the frequency converter currently being tested is shown in Fig. 2. The cavity frequency of 1.3 GHz is mixed with a local oscillator operating at 1168 MHz to produce an intermediate frequency of 138MHz, which is well within the operating range of the RF control system. Since phase information is converted as well, and VHF phase shifters are somewhat easier to come, the RF and tuner loop phase adjustment is done at the IF frequency.

All of the components used in this converter are either off-the-shelf or semi-custom parts from commercial vendors. The bandpass filters were supplied by Lorch, while the mixers were from Mini-Circuits.

There are two input signals which require down-conversion. The first of these is the RF input feedback signal from the cavity pick-up. This signal is split three ways – to provide amplitude and phase information to the respective control loops, as well as being combined with the remaining down-converted signal to provide phase information for the tuner loop.

The signal which requires up-conversion is the drive signal to the solid-state amplifier. To accomplish these conversions, the 1168MHz reference is split three ways.

Frequency Converter Test Results

The frequency converter has been subjected to a variety of tests to determine its operating range, performance characteristics, and its suitability for the intended application. Of particular interest for the up and down converters was the range over which a relatively linear response could be expected. Also of concern were the conversion losses and resulting signal levels. Also verified was the phase response of the 1.3GHz bandpass filter to ensure that there were no significant non-linearities.

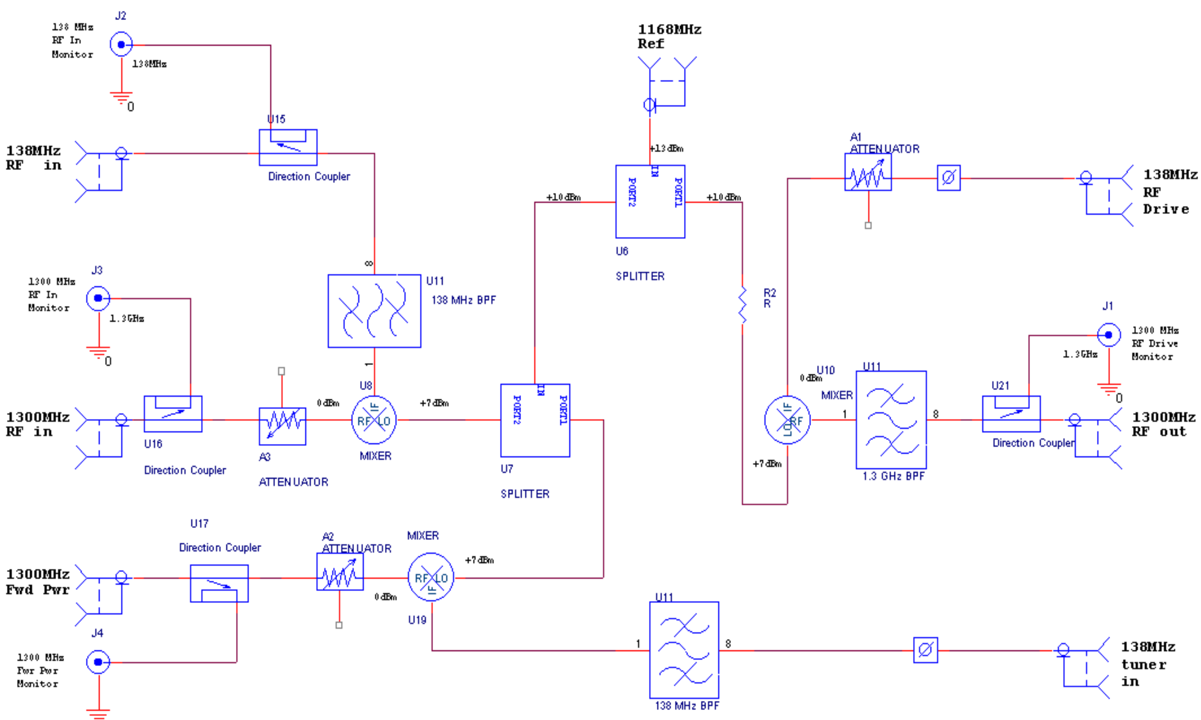

Figure 2: 1.3GHz Up/Down Frequency Converter.

Figure 3 shows a plot of the amplitude response curves for the two frequency down-converters. They both display the sharp knee and saturation characteristics typical of diode mixers. In the region of interest (below the knee) the response is relatively linear or at least monotonic. Obviously the saturation region must be avoided for all normal operating conditions.

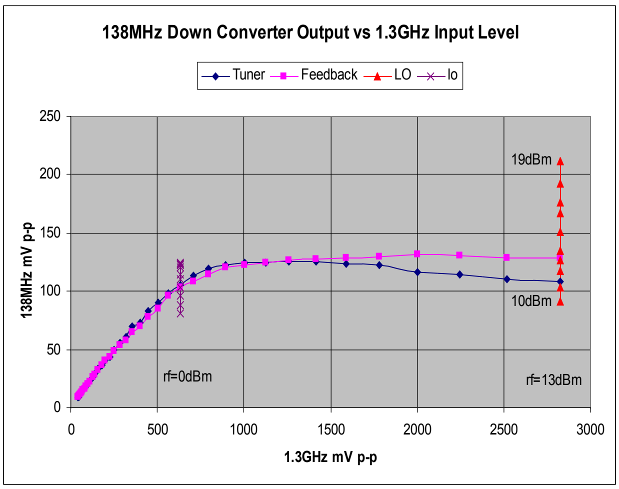

Figure 3: 138 MHz Down-converter Response.

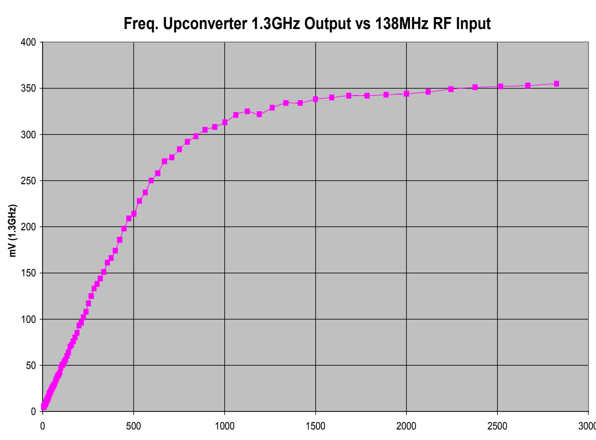

Figure 4: 1.3 GHz Up-converter Response.

Figure 3 also shows the shift in output level obtained for two fixed 1.3 GHz levels when the local oscillator level is varied over the operating range. The total signal loss through the converter is about 16dB, which is in the expected range, from the manufacturers specifications.

Figure 4 shows the amplitude response of the frequency up-converter. Of note is that the loss in this direction is significantly less, mainly due to the lower loss in the bandpass filter.

Figure 5 shows the phase response of the 1.3 GHz bandpass filter. It was checked to ensure that there were no significant non-linearities in the region of interest.

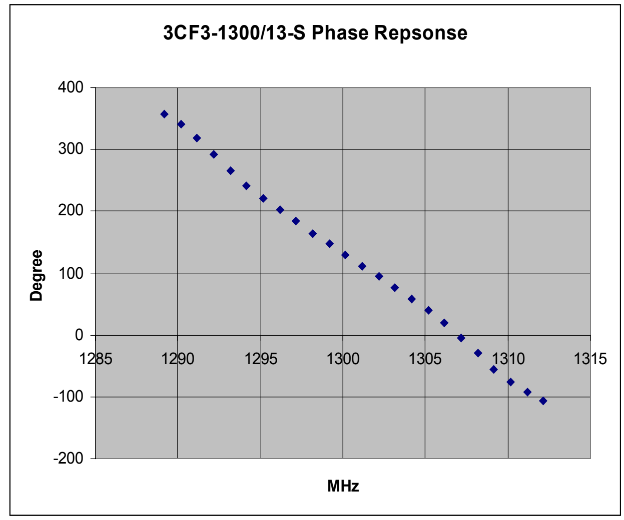

Figure5: 1.3GHz Bandpass Filter Phase Response.

CONCLUSIONS

For an overview of the e-linac project of which this control system forms a small part, refer to [2].

The system, as tested, should meet the design requirements.

It had been hoped to have an operating single 1.3 GHz cavity cryo-module to test prior to this conference, but such was not the case.

In the interim, work proceeds on the single module RF control system which forms the core of the e-linac RF controls. It is anticipated that most, if not all of these will be operational by the end of this year.

REFERENCES

[1] M. Laverty, K. Fong, S. Fang, Q. Zheng, "ISAC II RF Controls - Status and Commissioning," EPAC'06, Edinburgh, June 2006, THPCH106, http://cern.ch/AccelConf/PAPERS/THPCH106.PDF .

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