ERLP/4GLS LOW LEVEL RADIO FREQUENCY SYSTEM

A. J. Moss, J. F. Orrett, P. A. Corlett, J. H. P. Rogers, CCLRC Daresbury Laboratory, Warrington, WA4 4AD, UK

Abstract

The Energy Recovery Linac Prototype (ERLP) being constructed at Daresbury Laboratory will use an analog-based low level RF (LLRF) control system designed and built at FZR Rossendorf. Once the machine is operating, the testing and development of a digital LLRF feedback system will take place using the ERLP as a test bed.

INTRODUCTION

Daresbury laboratory is constructing ERLP to develop the skills required for building a larger 4th Generation Light Source (4GLS) as currently there is little experience of Energy Recovery Linacs (ERLs) and superconducting RF (SRF) at the site. This paper deals with the low level RF (LLRF) system that will be critical to the operation of the ERLP. The ERLP is being constructed with a conservative budget both in terms of time and cost. To this end the low level RF control system was purchased from FZ Rossendorf [1] where it has proved itself on the ELBE machine running the same type of SRF cavity and cryomodules, with similar parameters to the ERLP.

The ERLP will be commissioned in October 2006 and will initially start operation for only 8 hrs per day. Once a stable running regime has been found, the machine will be used to develop new systems for the 4GLS project, an important part of this will be digital based LLRF systems. Initially the ERLP will be used with pulsed RF mode. This is necessary as the maximum operating power of the fundamental input couplers to the SRF modules is limited to ~10 kW CW. For low energy particle acceleration, > 30 kW is required and so a pulsed regime of 20 Hz and 1ms has been chosen to reduce the average power to within the operational limits of the couplers. Later in the project CW RF will be used when the cryomodule input coupler's have been improved to allow higher average power throughput. A layout of the ERLP RF system is shown in Fig. 1.

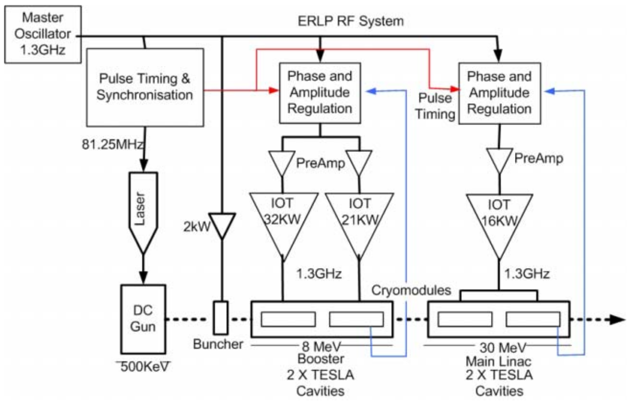

Figure 1: ERLP RF System.

ERLP low level RF system

The source of the ERLP RF system is an ultra stable low noise oscillator constructed using a 10MHz rubidium class oscillator (Vectron OC-050-BJB). This is phase locked and multiplied to 1.3 GHz for the RF system and 81.25 MHz for the photocathode gun laser. The frequency multiplier module has been produced using Wenzel Associates low noise multipliers (see Fig. 2).

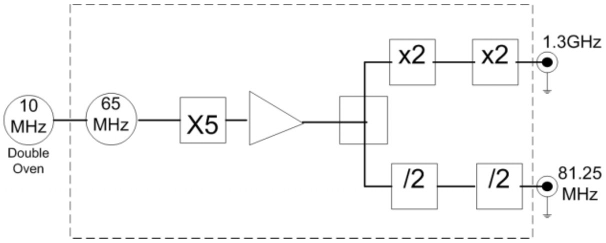

Figure 2: Multiplied Wenzel Oscillator.

The oscillator system will be located within the RF rack in the main accelerator hall. Low noise amplifiers (1.5dB noise figure) (Minicircuits ZHL1217MLN) are used to boost the signal amplitude and phase stable/low loss cable from ATM (CFR135 and CFR500) is used to transmit the 1.3 GHz to locations around the RF system (see Fig. 3).

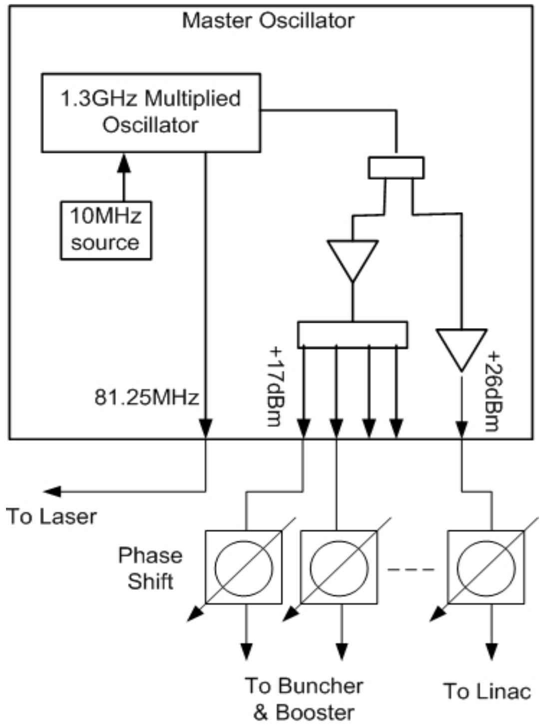

Figure 3: Master Oscillator Distribution System.

Laser RF

The laser for the photocathode free-runs at a frequency of 81.25 MHz. The photocathode gun needs to be synchronised with the RF system, therefore the laser electronics will be locked to the main RF frequency using the 81.25 MHz referenece signal from the mulitplied oscillator. The timing signal to generate the RF pulse scheme (1 mS 20 Hz) is taken from a mechanical rotating shutter that esentially chops the laser beam. The timing signal generated occurs 13 mS before the electron beam leaves the photocathode gun. Although the timing jitter of this signal is poor, it allows sufficent time for the LLRF control electronics to drive the SRF cavities to the required gradient (12 mS). The phase and amplitude control loops are then closed to provide stable conditions for 2 mS ready for when beam arrives in the cavities.

ERLP Low Level Control System

The analog LLRF card was designed and built at FZ Rossendorf (see Fig. 4) where it has been used and developed successfully for a number of years. Purchasing a working/well proven system was an important factor in delivering the ERLP LLRF systems to tight timescales. We can now build on the ERLP experience and try out new developments for 4GLS while retaining a known working solution for the machine. Both pulsed and CW operation is supported, and the LLRF card is able to control phase to 0.1°. Control to a level of 0.02° has been proven on the ELBE facility with amplitude stability of 2×10^{-4}.

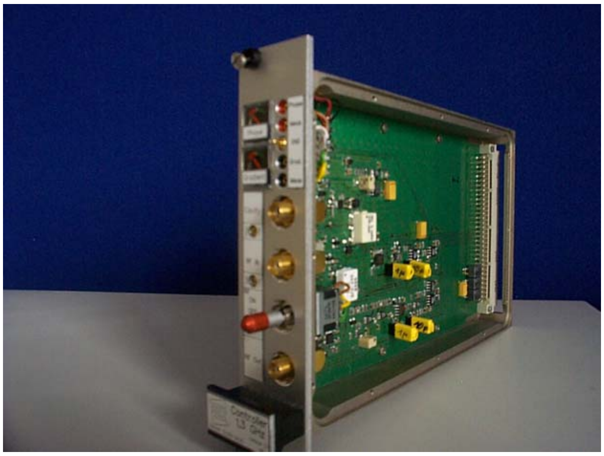

Figure 4: FZ Rossendorf LLRF control card.

RF Amplitude Detection

For detection of RF signal levels, the AD8361 chip will be used. This provides a 30dB range and is usable from DC to 2.5 G Hz providing an output of 700 mV for 10 dBm input. The electronic circuits have been designed to handle both pulsed and CW signals automatically.

4GLS LLRF REQUIREMENTS

The 4GLS project will demand new levels of stability from its RF system to achieve electron bunch timing to 10's of pS resolution. Critical to this is the RF reference and distribution system. The RF reference signal will be required to be distributed to equipment and RF structures around the entire machine, some of which could be separated by 100 m or more [2]

4GLS Oscillator System

4GLS is likely to utilise a mode locked laser based system to transmit the RF reference around the machine. This has the advantage of lower phase noise whilst preserving phase timing relationship over long distances [3]. Temperature stabilisation of the fibre takes place using optical line stretchers. The only environmental problem with a fibre-based system is the intolerance to radiation. Therefore the laser fibre system cannot be used in areas such as the accelerator hall. However this is not seen as a major problem since the RF signal can be demodulated from the fibre at any point along its length and converted to traditional coaxial transmission line preserving high stability over short distances.

4GLS LLRF Control

The demands placed on the RF system, particularly the LLRF control system, will be substantially higher for the 4GLS project (see Fig. 5). The complex nature of simultaneously accelerating and decelerating high peak current beams inside the main Linac will push feedback control system technology to its limits, demanding more speed, flexibility and accuracy than ever achieved before.

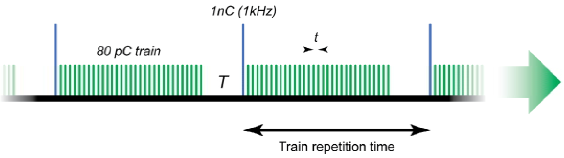

Figure 5: 4GLS bunch structure in main Linac.

Currently the 4GLS (see Fig. 6) design has individual amplifiers and LLRF control loops for each accelerating cavity. This would provide the best engineering solution, allowing independent control of each cavity and minimise inter cavity disturbances. Investigations into the use of one amplifier and multiple cavities will be undertaken in the near future. Using this approach the LLRF control system would receive and process information from a number of cavities. The control algorithm would then be required to act on only one amplifier.

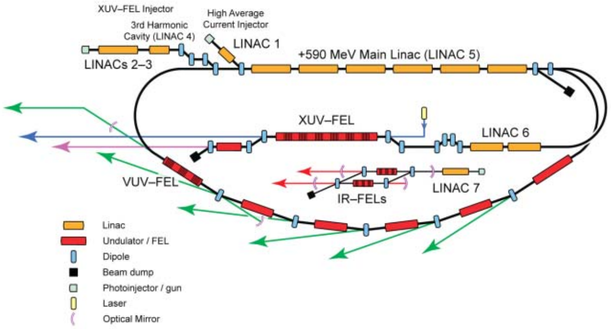

Figure 6: 4GLS Layout.

For the photoinjector and low energy linac sections, Linacs 1 to 4, the phase stability of the RF fields will need to be kept to 0.01° (~ 21 fs at 1.3 GHz) and to 10^{-4} for amplitude stability due to electron bunch acceleration being off-crest. Errors in phase and amplitude at this point will result in energy modulation and hence timing jitter of the pulse-to-pulse structure of the beam. This level of phase stability control has been demonstrated at TJNAF using the Cornell LLRF control system [4]. In the main linac (Linac5) and the additional XUV FEL linac (Linac6) the beam will be accelerated almost on-crest, reducing the required phase stability to 0.1° (or ~ 0.1 ps at 1.3 GHz) and 10^{-3} for amplitude. The 4GLS feedback system will comprise a phase comparator and regulation loop to maintain a phase error of < 0.01° with reference to the desired working point for each RF station. The amplitude loop will consist of a proportional integral controller taking inputs from the cavity probe and amplitude set point for that accelerating structure. The drive level to the RF amplifier will be controlled using vector modulation techniques.

For 4GLS the dynamic range of the controller will need to be greater with increased immunity to noise and environmental effects than an analog based system, such as that being used on ERLP. These criteria point towards a digital-based feedback system. The current state of the art, Field Programmable Gate Array (FPGA) digital feedback systems can stabilise the RF to enable 10 mA to circulate in an ERL [4]. The same LLRF system will enable mechanical tuning of the SRF module, thus enabling slow field changes to allow setting and control of the required accelerating field.

CONCLUSION AND OUTLOOK

Given the short timescale and limited funds for ERLP, the decision to use a proven LLRF control system solution appears to be the best solution. The control electronics has undergone steady evolution and is currently being used on the ELBE accelerator in CW control mode. However, investigations into its use in pulse mode are continuing with favourable results.

The ERLP will be operational from October 2006. Once the operation of the machine is characterised and understood, experimental development of LLRF systems required for 4GLS can be undertaken. It is hoped that commercial and laboratory based development LLRF control systems can be tested on the accelerator to assess the best way forward for the 4GLS machine

ACKNOWLEDGEMENTS

The ERLP LLRF control card was designed and manufactured at FZ Rossendorf, Dresden, Germany.

REFERENCES

[1] A.Buchner, F.Gabriel, FZR, Dresden, Germany.

[2] 4GLS Conceptual Design Report, April 2006, found at: http://www.4gls.ac.uk/documents.htm#CDR

[3] A. Winter et al, ‘High-precison optical synchronization systems for x-ray free electron lasers’, presented at FEL 05, FROA002.

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