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WAKEFIELD MONITOR SYSTEM FOR X-BAND LINEARISER LINAC ON CLARA *

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Abstract

CLARA linear accelerator in phase-2 will utilise an X-band fourth harmonic linac to linearise bunch phase space. Beam induced transverse higher order modes (HOMs) between 15.3 to 16.2 GHz will be coupled out through HOM ports, which can be used to correct both position offset and angle misalignment to minimise beam degradation due to HOMs. In this paper we present design of a wakefield monitor system under development, with capability to use either baseband broadband signal for basic alignment, and also carry a detailed narrow-band spectrum analysis on all four (X and Y transverse modes from two couplers) signals. Initial laboratory testing of its subsystem is also presented.

INTRODUCTION

The CLARA linear accelerator is being developed in phases to serve as a test platform for new concepts and technologies for future large scale XFEL facilities, such as proposed UK-XFEL. It is undergoing a planned upgrade to phase-II which will accelerate electron bunches up to its nominal energy of 250 MeV [1,2], using normal conducting linac RF systems operating at ~3 GHz. It will also utilise a fourth harmonic X-band linac to linearise the bunch phase space. The X-band linac will be installed on a five axis precision mover. The linac was designed by PSI in collaboration with CERN. The relevant parameters of the X-band linac are summarised in Table 1 [3,4].

Table 1: Relevant specifications of the X-band linac cavity.

Parameter	Value	Unit
Fundamental frequency	11.994	GHz
Length	96.5	cm
Number of cells	73	
HOM coupling cells	2	
HOM frequency range	15.3 - 16.2	GHz
HOM impedance	~ 100	$k\Omega/(mm \times m)$

An electron bunch passing through the linac induces electromagnetic (EM) field, known as wakefield, which can be expressed as sum of the field induced in fundamental and various higher order modes (HOMs). The induced HOM field interacts back with the bunch and degrades beam quality, hence it is desirable to minimise HOM excitation in the linac. The amplitude of the induced dipole HOMs depends on the bunch charge and transverse bunch offset from the cylindrical axis of the linac [4]. The phase of the HOM field flips by 180° depending on the direction of offset from the centre. By coupling out and analysing the HOM field signals, bunch trajectory offset and angle can be determined and used to minimise HOM excitation. The linac cell iris and radius are varied along the linac length to achieve the desired gradient profile of the fundamental accelerating field, which also results in variation of the dipole HOM frequencies of the cells. As the HOM frequency varies along the cavity length, cell misalignment within the cavity can be studied in detail by analysing narrow band sections of the HOM spectrum.

The X band linac has two HOM couplers, the first is located in the mid section of the linac and couples to the HOMs from upstream cells. The second is at the end of the linac and couples to the HOMs from the downstream cells situated after the first HOM coupler. The HOMs are coupled out through the side coupled waveguides with cutoff frequency above the fundamental accelerating frequency to prevent the large accelerating field at 12 GHz. Each HOM cell has four ports, two each for X and Y bunch offset measurements, which can be combined to increase measurement sensitivity. The cavity misalignment can be minimised by measuring only the amplitude of the wideband HOM signals, but the ability to study the spectrum in detail and extracting the phase allows us to utilise it as a beam position monitor (BPM) system by knowing the direction of the offset. Hence the minimum requirement from the wakefield monitor system is to have four channels that can measure the amplitude of the wideband HOM signals, but additional functionality of spectrum analysis and phase measurement is highly desirable.

WAKEFIELD MONITOR SYSTEM

A wakefield monitor system is under development to facilitate HOM measurement and alignment of the cavity with 10 μm resolution for 200 pC bunch charge. A simplified block diagram of the system is shown in Fig. 1. It is designed as a modular system with signal processing in two stages. To minimise the cable losses at the higher HOM signal frequencies, the front-end box will be placed in the accelerator tunnel next to the linac and can either measure the baseband amplitude, or down convert the signal to less than 1.5 GHz and send it to the back-end box in an RF room through the long coaxial cables. The back-end box in the RF room can further process the amplitude, or scan the HOM spectrum for detailed narrowband analysis.

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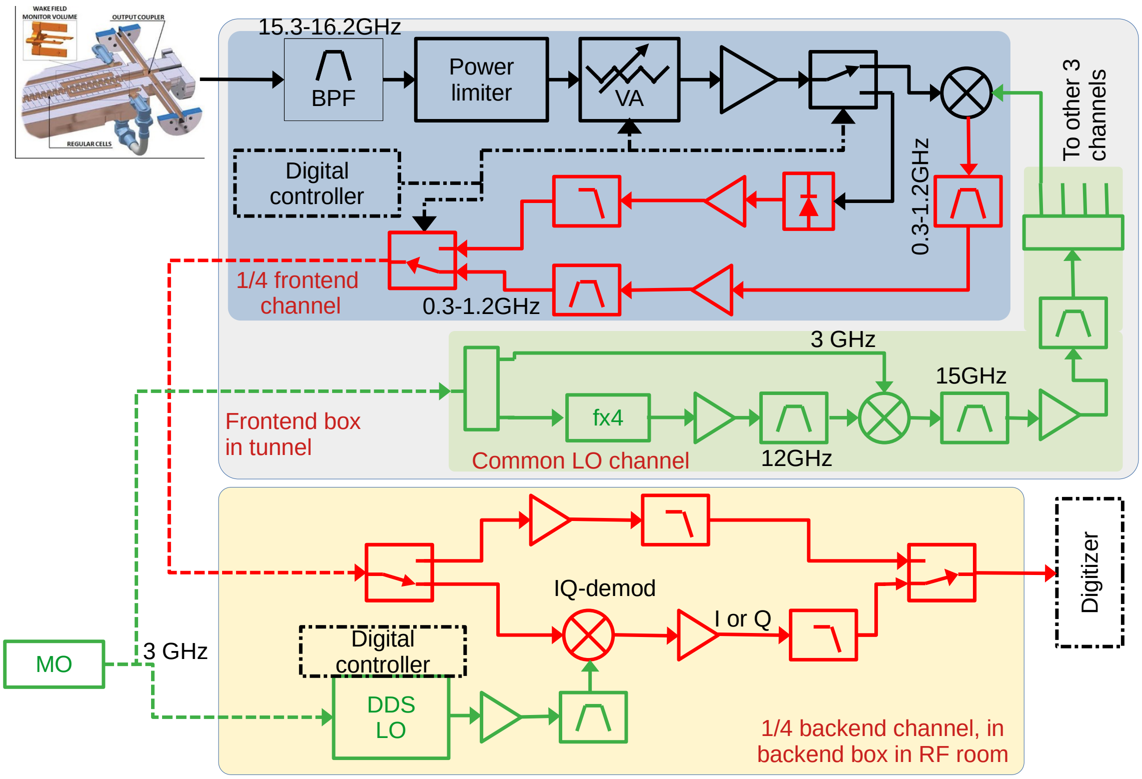

Figure 1: Simplified block diagram showing one of the four wakefield monitor system channels.

Front-end box

The front-end box will host four RF channels and one common local oscillator (LO) channel generating four signals. At higher HOM RF frequencies, availability of the components poses constraints on the system design. Each of the four front-end RF channels will accept only wideband HOM signals using cavity band pass filter (BPF), followed by power limiter to protect the circuit from the high signals induced by large misalignment. To achieve higher measurement resolution at small beam offsets, while availing larger dynamic range, a combination of a digitally controlled variable attenuator (RF5740-EVALZ-292, up to -22 dB) and low noise amplifier (HMC963LC4) is used. A digitally controlled RF switch directs the amplified signal to either a log-detector for baseband amplitude measurement, or to a mixer which down converts the signal to 0.3 to 1.2 GHz. The log detector (ZV47-K44+) further increases dynamic range of the measurement. The down converted signal is amplified before the second switch, which transmits them through approximately 20 m long RF cable to the back-end box in the RF room. Even with only 22 dB front-end gain and 50 MHz bandwidth, the log detector should receive -15 dBm input power generating more than 50 mV output voltage, sufficient to achieve 10 μm resolution.

The front-end box also has a common local oscillator (LO) channel which generates four stable ~15 GHz LO signals providing 15 dBm power for each RF channel. LO signals are generated by multiplying and mixing the 3 GHz master oscillator (MO) signal to preserve the phase coherence during the down conversion.

Back-end box

The processed signal arriving at the back-end box will again be multiplex depending on the mode of operation and the digitiser chosen by our controls group. In the spectrum analysis mode, individual mode peak will be analysed by scanning the frequency of a direct digital synthesis (DDS) LO board. The AD9914 DDS-LO board uses ~3 GHz MO signal as a clock and can generate coherent, ultra stable LO signal up to 750 MHz. A frequency doubler will be used to cover the higher frequency range of 750 to 1500 MHz for the HOM signals from the downstream coupler. Amplitude and phase will be retrieved using IQ demodulator (LTC5584) feeding two digitiser channels.

Digital controls

The system can operate in two measurement modes with a large dynamic range by utilising digitally controlled switches, attenuators and DDS-LO source. Each front-end channel needs total of eight digital controls, four for the attenuator and two each for the SPDT switches. A Red Pitaya board [5] comes with sixteen digital GPIO channels, FPGA and processor with embedded Linux which can run EPICS IOC [6] to integrate in to the overall machine control system. One card will control two front-end channels. In the

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back-end box, Raspberry-Pi board will be used to control the DDS-LO board and switches. DDS-LO frequency, attenuation and mode of measurement will be available as process variable (PV) to set and read remotely through the control system.

PHASE PRESERVATION AND INITIAL COMPONENT TEST

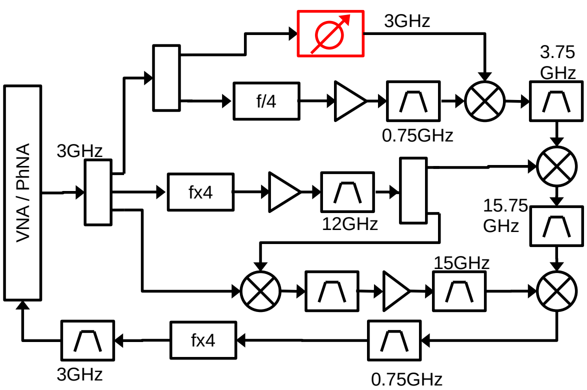

Figure 2: Simplified block diagram of circuit to test phase determination accuracy.

To utilise the HOM signals as a BPM, it is essential to know the direction of the bunch offset, and hence the phase of the HOM signals. A phase preservation viability test was carried out in laboratory to test component performance and phase jitter. As described in a simplified block diagram of the test circuit in Fig. 2, 3 GHz from a vector network analyser (VNA) or a phase noise analyser (PhNA) was divided, multiplied and mixed to generate the coherent signals of 15 and 15.75 GHz to act as the LO and RF signals respectively, with a variable phase shifter in the RF path. The difference frequency of 0.75 GHz was multiplied to regenerate 3 GHz which was fed back to the VNA/PhNA to measure the phase error.

The VNA (Agilent PNA-E8363C) was operated in zero span mode at 3 GHz. The phase shifter was used to change the mean phase delay in the RF path and phase stability was recorded at each phase delay. The maximum observed phase jitter was 0.39°, which is sufficiently accurate as the phase changes by 180° step when the direction of the offset flips. This measurement was verified by measuring the phase noise using PhNA (R&S-FSWP8), which showed phase jitter of 0.32° over a frequency offset range of 10 Hz to 1 GHz, as shown in Fig. 3.

SUMMARY

A Ku-band HOM wakefield monitor system is under development to measure bunch offset in X-band lineariser linac. It is designed to facilitate not only the baseband amplitude measurement, but also detailed spectrum analysis. Coherent LO signal generation is implemented to preserve the phase to derive the direction of the offset, to use it as a BPM. Testing

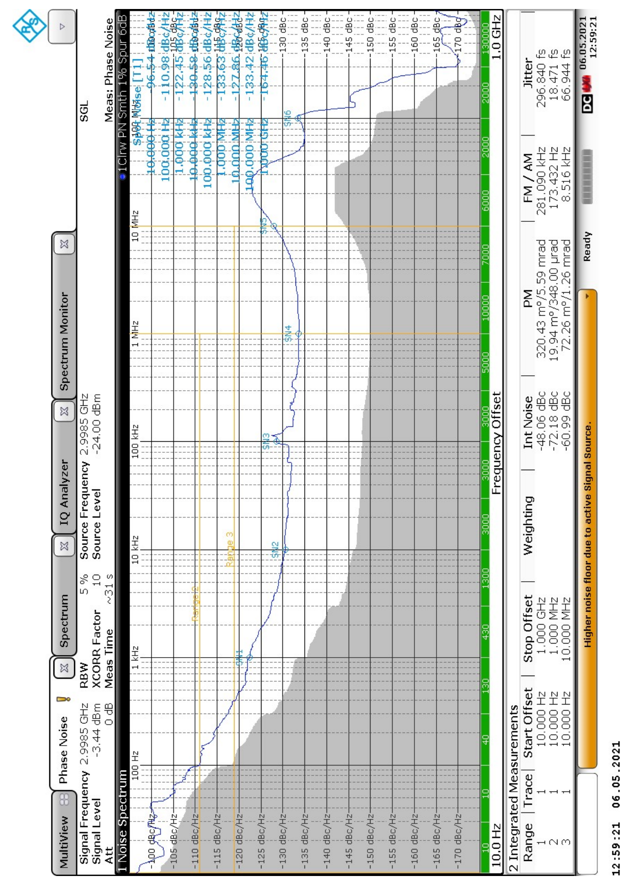

Figure 3: Phase noise measurement of test circuit using PhNA.

of high frequency component performance in laboratory verified phase jitter of better than 0.39° and sufficient amplitude sensitivity to provide 10 μm bunch position offset resolution. A digital control setup is developed for the variable attenuators, switches and DDS board to achieve higher dynamic range and operation mode selection remotely through central control.

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