LOW LEVEL RF INCLUDING A SOPHISTICATED PHASE CONTROL SYSTEM FOR CTF3

J. Mourier, R. Bossart, J.-M. Nonglaton, I. Syratchev and L.Tanner
CERN, Geneva, Switzerland

Abstract

CTF3 (CLIC Test Facility 3), currently under construction at CERN, is a test facility designed to demonstrate the key feasibility issues of the CLIC (Compact LInear Collider) two-beam scheme. When completed, this facility will consist of a 150 MeV linac followed by two rings for bunch-interleaving, and a test stand where 30 GHz power will be generated. In this paper, the work that has been carried out on the linac's low power RF system is described. This includes, in particular, a sophisticated phase control system for the RF pulse compressor to produce a flat-top rectangular pulse over 1.4 μs.

INTRODUCTION

An international collaboration is currently building CTF3 (CLIC Test Facility 3) at CERN. When completed, this facility will consist of a 150 MeV 3 GHz linac followed by two rings for bunch-interleaving and a test stand where 30 GHz power will be generated [1]. Its aim is to demonstrate the key feasibility issues of the CLIC (Compact LInear Collider) two-beam scheme [2]. At present, the linac is being constructed and commissioned in stages and well over half is completed. Six 35 MW to 45 MW 3 GHz klystrons are operational. One powers two standing-wave pre-buncher cavities and a travelling-wave buncher. The others each power two damped travelling-wave accelerating structures with a loaded gradient of 6.5 MV/m. Commissioning results in 2003 demonstrated full beam loading operation of these structures with the nominal beam current of 3.5 A [3].

CTF3 uses a large part of the infrastructure of LPI, the now decommissioned LEP pre-injector linac. This includes re-use of modulators, klystrons and LIPS pulse compressor cavities at the klystron output [4]. RF pulse compression is mandatory in order to reach the required power level of over 30 MW for the 1.5 μs pulses at each structure's input. In LPI, the phase function for compression consisted of a straightforward 180^{O} phase inversion at the klystron driver's output. However in CTF3, with much longer bunch trains of 1.4 μs, a much more sophisticated phase function was required and this was one of the principal reasons why the low level RF system needed a complete re-design. In this paper, an overview of the current status of the CTF3 low level RF system is presented, concentrating on the pulse compression phase control scheme.

AMPLITUDE AND PHASE CONTROL

The layout of the low power system for one klystron is shown in Figure 1. The 3 GHz is distributed from a master synthesizer to the low level equipment of each klystron over low-loss phase-stable 7/8-inch coaxial cable. To minimize differential phase variations with temperature, equal lengths of cable are used (100 m ±1 cm). The 360^{O} "digital" phase shifter (analogue with integrated DAC) is slow and is used for adjusting the

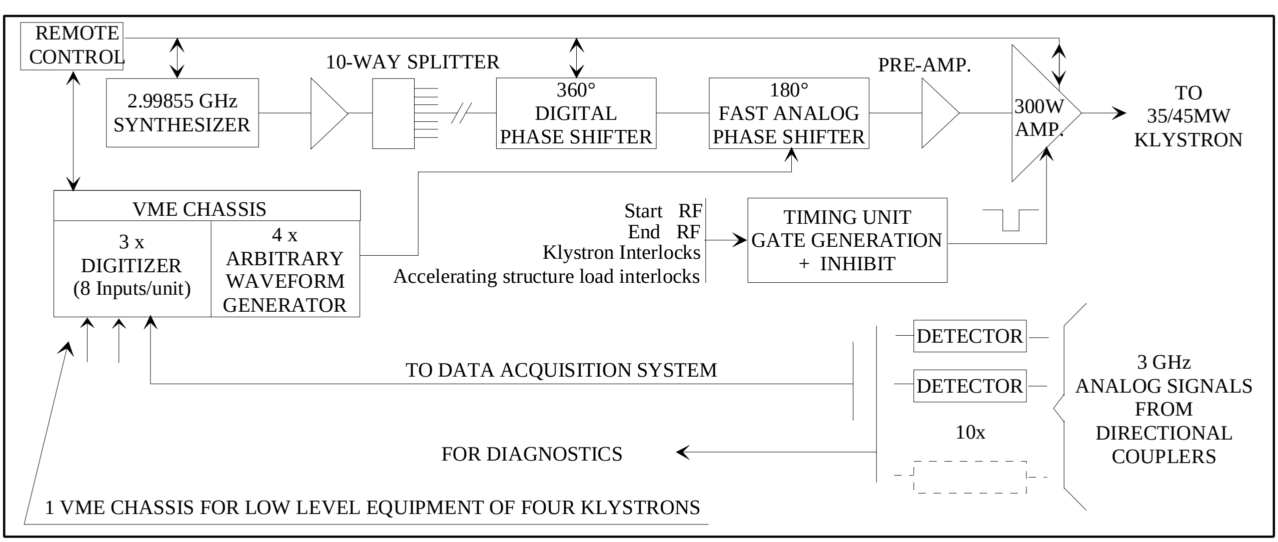

Figure 1: Simplified block diagram of low level system.

klystron phase relative to the beam. The 180^{O} analogue phase shifter has a step response of 10 ns. It is controlled by a VME-based 100 MS/s arbitrary waveform generator that produces the phase function for pulse compression. Both phase shifters have a temperature coefficient specification of less than $0.15^{O}/^{O}C$.

The continuous wave RF signal is fed to a 300 W power amplifier that incorporates an input PIN diode switch producing the pulse. Key specifications of the amplifier are the stability of amplitude and phase during the pulse of less than 0.2 dB and less than 3^{O} respectively. The first five of these amplifiers were purchased in industry. However, for reasons of economy, it was decided to fabricate the remaining amplifiers at CERN. The development work is now completed. They consist of a chain of cascaded NPN silicon class C power transistor stages on a low-loss substrate. The end of the chain is split and terminates in two 190 W stages that are combined in a hybrid. The amplifier output feeds the klystron via a circulator.

The timing unit has two functions. Firstly, it interfaces the amplifier to the machine timing system's start and end RF production events. These permit remote setting of the klystron RF pulse length. Secondly, it is part of the interlock system and, under certain conditions, will inhibit the driver output pulse. This is the case for certain modulator or klystron problems or, for example, if the power limit of the accelerating structure output loads is exceeded. This can occur with beam if the klystron phase is incorrect.

SIGNAL ACQUISITION AND DIAGNOSTICS

The low level RF system includes a data acquisition system permitting real-time display of a variety of signals such as the phase and amplitude of the klystron output, pulse compressor output and accelerating structure input and output. It consists of 3 GHz phase and amplitude detectors followed by 100 MS/s VME-based ADC cards. The system has proven indispensable during both RF conditioning and machine operation. During conditioning it facilitates the localisation of breakdowns and other anomalies. During operation the system permits real time observation of detected RF waveforms in the CTF3 control room. This is particularly important when setting

Figure 2: LIPS pulse compressor.

Figure 3: BOC pulse compressor.

up the RF pulse compression. At present there are 56 detectors, 29 of which have digitized outputs. These numbers will increase to 110 and 59 respectively when CTF3 is completed.

RF PULSE COMPRESSION SYSTEM

CTF3 requires nine RF pulse compression systems that will give a power gain of about two in klystron peak power. Since only a limited number of LIPS systems (Figure 2) was available from LPI, additional systems were built based on the Barrel Open Cavity (BOC, Figure 3). Such a system (VPM) was developed for the VLEPP linear collider [5] and an X-band version was successfully tested at KEK at an RF power level of 150 MW [6]. Unlike the LIPS system that uses two standing-wave cavities coupled via a 3 dB hybrid, BOC consists of a single cavity [7].

In order to achieve a compressed pulse with a flat top in amplitude, the RF input to the compressor follows a pre-defined phase modulation function. An example of the compressed pulses for two different klystron pulse lengths is shown in Figure 4. The typical shape of the phase modulation function and the resulting compressor output phase is shown in Figure 5. CTF3 has a stringent specification on the stability of the compressed RF pulse of ±1% in amplitude and 5^{O} in phase. To compensate the phase ramp $\Delta\phi$ introduced by the modulation, a detuning of 130 kHz is added [8]. The residual phase variation is compensated by operating alternate klystrons with an inverse phase function. To make best use of the total modulator pulse length, the RF is switched on during the rising edge of the modulator pulse.

Fine frequency tuning of both the LIPS and BOC is achieved by precise temperature control of the cavities. To keep within the required flatness of the compressed

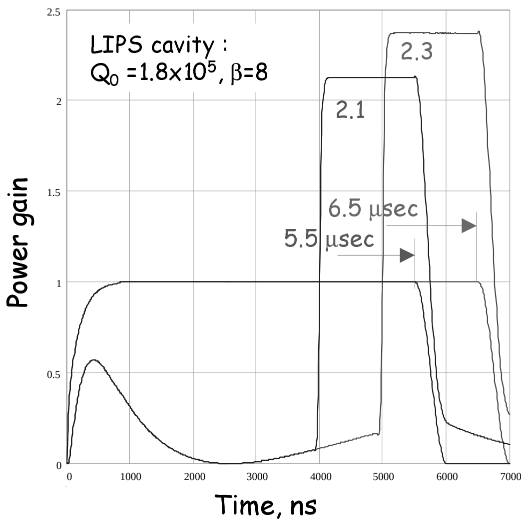

Figure 4: Compressed pulses for two different klystron pulse lengths.

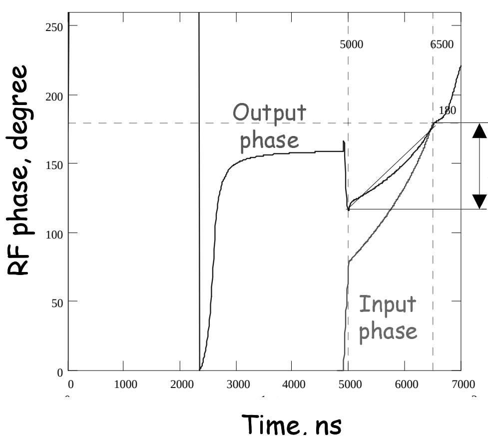

Figure 5: Input and output RF phases.

pulse, their resonant frequencies must be stabilised to ±1.5 kHz (Figure 6). This corresponds to ±0.03^{O}C of maximum permitted temperature variation. Each compressor is connected to an independent remote controlled cooling station. For the BOC cavities, this is the sole tuning method and they require a ±5^{O}C temperature range. The LIPS cavities incorporate tuners for coarse frequency control.

The phase function is generated by the VME arbitrary waveform generator modules referred to in the previous section. The 500 data points that cover the 5 μs pulse are downloaded into local memory via high-level application software. A programme has been developed that analyses the compressed RF pulse and, in an iterative process, optimises its phase and amplitude characteristics by varying the input phase function. It also compensates the parasitic phase modulation introduced by the klystron. A software check on the slew-rate of the phase function is made so as to avoid dangerous peaks of RF power at the output of the compressor cavity.

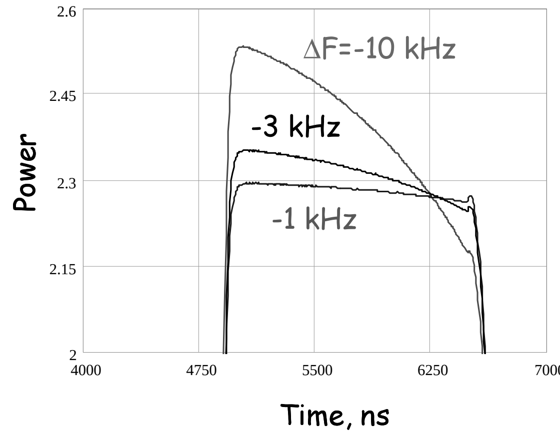

Figure 6: Sensitivity to detuning.

CONCLUSIONS

Staged commissioning of the CTF3 linac in 2003 and 2004 has already demonstrated the proper functioning of the low level RF system. The remaining 3 GHz klystrons will be equipped with the same hardware. Additional work on the CTF3 RF low level will include systems for the 1.5 GHz sub-harmonic bunchers and RF deflector. These will be required for bunch-interleaving when the two rings are constructed [1].

REFERENCES

[1] G. Geschonke and A. Ghigo (editors), "CTF3 design report", CERN/PS 2002-008 (RF).

[2] G. Guignard (editor), "A 3 TeV $e^+ e^-$ linear collider based on CLIC technology" CERN 2000-008.

[3] R. Corsini *et al.*, "First full beam loading operation with the CTF3 linac", 9th European particle accelerator conference EPAC2004, 5 to 9 July 2004, Lucerne.

[4] A. Fiebig and R. Hohbach, "Study of peak power doublers with spherical resonators", Proc. 1983 particle accelerator conference, Santa Fe, 21-23 March 1983, pp.3563-5.

[5] V. E. Balakin and I. V. Syrachev, "Status of VLEPP RF Power Multiplier", Proc. 3rd European Particle Accelerator Conference EPAC92, Berlin, 24-28 March 1992, pp.1173-5.

[6] I.V. Syrachev, V.F. Vogel, H. Mizuno, J. Odajiri, Y. Otake, S. Tokumoto. "The Results of RF High Power Tests of X-Band Open Cavity RF Pulse Compression System", Proc. int. conference Linac-94, Tsukuba, pp. 475-477, 1994.

[7] I. V. Syratchev, "RF pulse compressor systems for CTF3", Proc. 5-th MDK Workshop, Geneva, June 2001.

[8] R. Bossart, P. Brown, J. Mourier, I. V. Syratchev, L. Tanner "High-Power Microwave Pulse Compression of Klystrons by Phase-Modulation of High-Q Storage Cavities", CERN-OPEN-2004-015; CLIC Note 592.