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THE LEP RADIO-FREQUENCY LOW POWER SYSTEM

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Summary

A brief description of the low power and controls electronics for running the 128 cavity assemblies in the initial phase of LEP is given. Virtually identical hardware will be used for the future extension of LEP with superconducting niobium cavities. One complete RF unit consisting of 16 cavities and all associated drive and controls electronics has been successfully tested.[1]

Introduction

For Phase 1 of LEP a total of 128 coupled-cavity assemblies operating at 352 MHz will be installed, providing a maximum of 400 MV circumferential voltage.

The large bunch spacing in LEP allows the exchange of energy between the five cell slot coupled accelerating cavity and a low loss storage cavity during the interval between each bunch passage. The total power dissipation is thus reduced by a factor q.

$$q = \frac{Q_a + Q_s}{2 \cdot Q_s}$$

Q_a = Q value of accelerating cavity

Q_s = Q value of storage cavity.

The coupling between the two cavities determines the two resonant frequencies of the system f_1 and f_2. The cavity assembly is driven by both resonant frequencies where

$f_1 = f_{RF}$ (nominal LEP RF frequency)

$f_2 = f_{RF} + \Delta f$

$\Delta f = k \cdot f_{RF} = 8 \cdot f_{revolution}$

k = coupling factor ($2.55 \cdot 10^{-4}$).

The cavity input signal is then the modulated waveform shown in Fig. 2.

Sixteen of these assemblies driven by two 1 MW CW klystrons and the associated controls electronics form one RF unit. The low power and controls electronics for each of the eight RF units are identical and each unit can be operated independently.

The eight units will be installed in two RF stations around intersection points 2 and 6 of LEP.

The RF frequency and phase reference are transmitted from a "Master Clock Generator" situated in the LEP control centre (near the SPS) to each RF station over monomode optical-fibre cables laid in surface ducts over a maximum distance of ~ 8 km corresponding to about 10 000 RF wavelengths in free space.

Within each RF unit, several feedback loops around the klystrons and the cavities keep the phase variations down to a few degrees under all operation conditions of the RF system.

Out of the 31 320 RF buckets only eight will be filled with particles, four with electrons and four with positrons. A high-precision timing system has been developed to allow injection and accumulation into preselected RF buckets situated symmetrically around the circumference to allow simultaneous collisions in the four intersection points where experiments are installed.

The control of each major component inside one RF unit is done via a microprocessor-operated "Equipment Controller". All the Equipment Controllers (for one RF unit) are connected via a bus system to an "RF Data Manager" which coordinates all control functions inside one unit and also provides the interface to the general control system for LEP.

RF Generation and Distribution

The RF master generator which is located in the LEP control centre generates a reference frequency (f_{REF}) for the whole RF system. From this signal the frequency $\Delta f/2$ = 44.982 kHz is derived and synchronization pulses for the injectors are generated. Both f_{REF} and $\Delta f/2$ are distributed to all the RF units. The signals are transmitted over optical fibre cables using laser diodes working at 1.3 µm. Laboratory tests on 4 km of monomode fibre have shown that the spectral purity of the RF signal is not noticeably affected by the optical transmission. However, phase changes of 1.8° per km/°C were measured at 176 MHz. A feedback system as proposed in Fig. 1 is expected to keep these phase changes down to a few degrees over a temperature variation of 30°C on the cable.

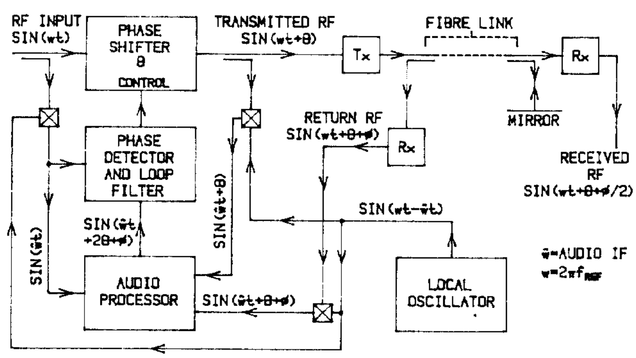

Figure 1: Phase feedback system for fibre optic link

The reference frequency (f_{REF}) passes through a voltage variable phase shifter giving a phase shift θ. This signal is transmitted to the RF unit over the fibre optic link. With a mirror, a sample of the received modulated light is returned to the transmitting end on the same fibre where it is separated from the transmitted light in an optical directional coupler and passed to a receiver. Samples of the reference signal, the transmitted signal and the return signal are converted down to an intermediate audio-frequency. After mixing and filtering the signal $\sin(\hat{\omega}t + 2\theta + \phi)$ is obtained. This signal is compared in phase to the reference signal $\sin \hat{\omega}t$ and the error signal used to drive the phase-shifter. The closed loop therefore maintains $\theta = -\phi/2$ and hence keeps the received phase constant. This scheme suffers from an ambiguity of 180° in the received phase. Therefore the frequency of the reference signal is chosen to be $(f_{RF} + 0.5\Delta f)/2$. In the RF units frequency doublers are added and the klystron frequencies f_1 and f_2 are generated in single sideband mixers.

Local Phase and Voltage Control

The phase of the klystron output voltage is kept independent of power level and high-voltage fluctuation with a phase feedback system. The phase detector in this loop is a double balanced mixer which works with constant amplitude input signals. In order to damp the 600 Hz phase ripple caused by the klystron power supply the bandwidth of the loop is high - about 50 kHz.

In normal operation the klystrons work with saturated drive power. The output power is adjusted by modulation of the klystron current by means of the modulation anode.[1] With a voltage feedback loop which acts on the modulator (Fig. 2) the cavity sum voltage is adjusted by comparing the detected sum voltage with an adjustable reference voltage. The error signal is, after amplification, fed to the grid of the modulator tube. Each of the two klystrons in one RF unit has its own loop. The correct waveform is obtained with a differential loop which detects the two klystron output voltages and adds to the main loops a correction signal in such a way that the output voltage is the same for both klystrons. The closed-loop bandwidth of the voltage loops is limited by the high-voltage power supply to about 20 Hz.

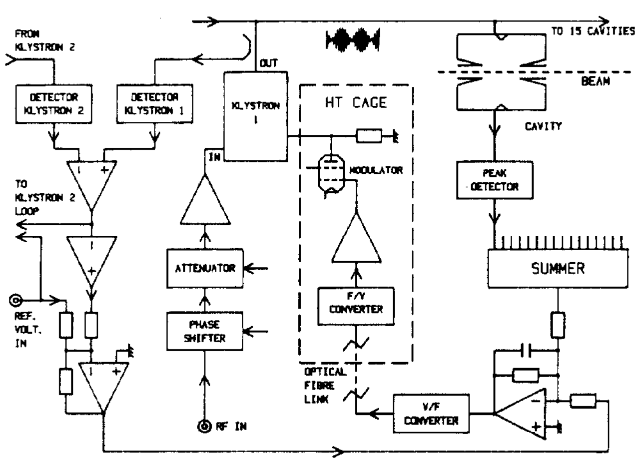

Figure 2: The voltage control system

Cavity Tuning

Each accelerating-storage cavity unit is tuned by 3 piston tuners, an identical pair of short tuners in cells 2 and 4 of the accelerating cavity and a single long polarizer-tuner in the storage cavity.[2] Samples of the RF fields are taken from the storage cavity and each cell of the accelerating cavity via inductively coupled field probes. The forward and reflected drive signals are sampled with directional couplers placed in the wave-guide straight section just before the cavity input power coupler.

These sample signals are transmitted to the equipment racks in the klystron gallery via low loss coaxial cables. Here double balanced mixers are used to convert the sampled 352 MHz RF signals down to an intermediate frequency of 20 kHz whilst still retaining the same relative phases and amplitudes but where the increased fractional separation makes it possible to isolate one frequency with a relatively simple bandpass filter. For tuning control it is the filtered signals corresponding to the lower RF frequency that are fed to the phase and amplitude detectors of the control loop.

For closed loop control a phase detector senses the incremental phase change between the forward drive and the driven cavity, whilst an amplitude ratio detector senses the relative changes in amplitude between the driven and coupled cavities. An additional amplitude ratio detector compares the fields in cells 2 and 4 of the accelerating cavity. After processing and amplification these error signals are used to tune the cavities by moving their respective tuners. The accelerating cavity is tuned by parallel movement of its tuners and balanced by moving them differentially.

To avoid undue wear of the tuner, a window detector is used to inhibit tuning until the error signal exceeds a pre-set threshold level. Loop operation is similarly inhibited in the absence of RF drive.

The tuning system is interfaced to the Equipment Controller such that the error signals, closed loop set points and window thresholds can be read and set remotely. An additional set of amplitude detectors allows both frequencies of each accelerating cavity cell to be read and summed to give a measure of the total cavity voltage. These and similarly processed signals from the storage cavity and wave guide will be used for remote optimization of the set points. The Equipment Controller can also override the closed loop system and directly move the tuners to a detuned parking position.

Fast Timing

At the heart of the fast timing system is a delay generator capable of delaying a trigger signal at the LEP revolution frequency over the full range of 31320 buckets, programmable in steps of one RF period (2.8 ns). Its application is in triggering events requiring initiation a programmable number of buckets after the reference bucket. A simplified block diagram is given in Fig. 3. The reference trigger input occurs every 31320 RF periods. In order to delay this over the full range of 31320 buckets, two counter chains are employed, termed master and slave, each consisting of a ÷10/11 prescaler clocked at 352 MHz and five decades of fully programmable counters. Counting in the master is initiated every second reference input, alternate reference triggers being ignored.

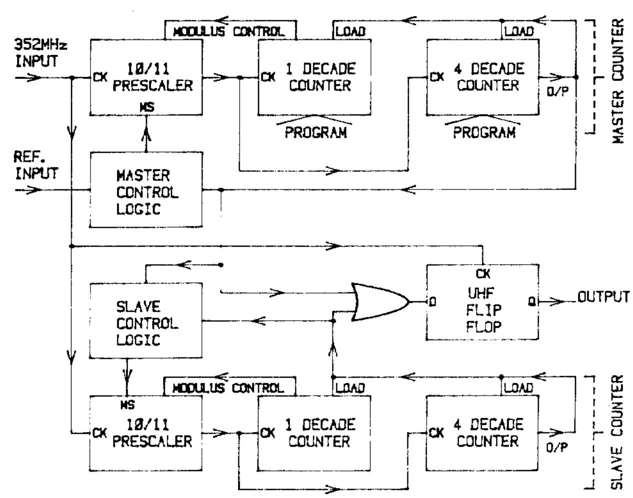

Figure 3: Beam synchronized digital delay

The master counter is programmed to produce an output after 31320 ± 15660 RF periods. As the master output occurs at half the rate of the reference trigger, the slave counter is required to supply the missing outputs. The master counter output itself initiates counting in the slave which produces an output a fixed 31320 RF periods later. Finally, the master and slave outputs are combined in an OR gate and re-synchronized in a flip-flop clocked at 352 MHz in order to remove the jitter between alternate outputs.

A laboratory prototype of this system demonstrated satisfactory performance. Output jitter is less than 15 ps and temperature stability better than 5 ps/°C.

Digital control

The control layout of the LEP RF system reflects the organization of the RF system as 8 identical RF units. The layout inside each RF unit is the same and is such that each unit may be run independently, either remotely or locally. Overall control of the RF system is by the general control system, the RF units being linked by process control assemblies to the controls network.

A diagram of the control layout within the RF unit is shown in Fig. 4. Each major piece of equipment, cavities, klystrons, high voltage, cavity vacuum equipment and low level has associated with it a device called an "Equipment Controller". The Equipment Controller provides the interface to the hardware associated with the piece of equipment. It also provides facilities for surveillance, logging and local display of equipment parameters. The Equipment Controllers (21 per RF unit) are interconnected by a bus system to a device called a "Data Manager". The Data Manager coordinates the control of the RF unit and carries out actions requiring access to one or several Equipment Controllers. It provides the interface to the main control system, carries out diagnostic and surveillance procedures and provides full local control of the RF unit. Communication between the Data Manager and the Equipment Controllers is on a simple command/reply basis. Commands are

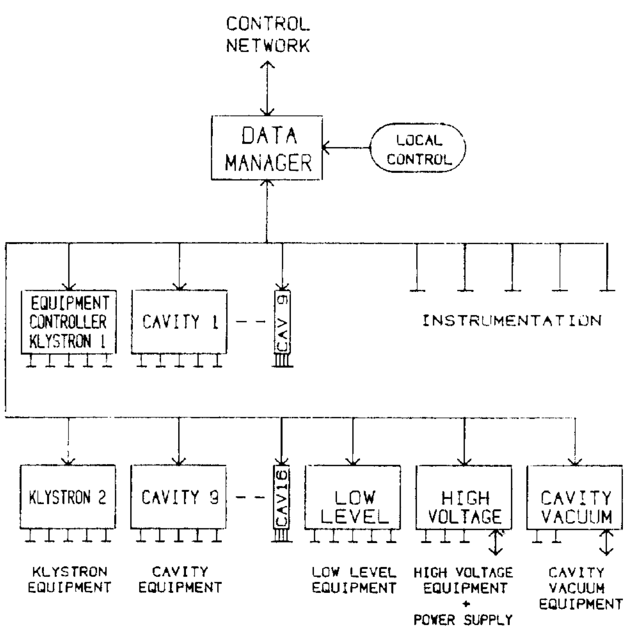

Figure 4: Digital control of one RF unit

initiated only by the Data Manager. The bus system used is the IEEE 488 standard (GPIB). This allows direct connection of standard commercial RF instrumentation.

The Equipment Controller is contained in a 6U Eurocrate. It contains a 20 slot G64 bus driven by a Z80 micro-processor. The software is written mainly in Pascal and is resident in PROM. The Equipment Controllers interface a diverse range of equipment hardware, e.g. interlocks, temperature measurements, voltage and current readings and various tuning, phase and amplitude control loops. In some cases the equipment hardware is interfaced directly using a specially designed 6U Eurocard. In the case of more complicated hardware the interface is to a separate crate, using standard 6 unit interface cards in the Equipment Controller as far as possible. The standard interface cards are: 16 bit parallel input output with isolation, 16 channel 12 bit ADC with input protection and 4 channel DAC. There are direct connections between the HV Equipment Controller and the HV power supply in the surface building and also between the vacuum Equipment Controller and the separate vacuum equipment racks.

The Data Manager will be a multi-tasking VME based system handling control procedures, communications, surveillance and local control and will incorporate a touch panel and colour display facilities.

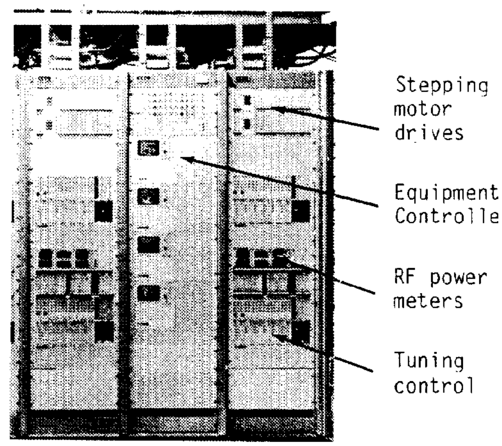

Figure 5: Low power and controls electronics for a group of four cavities

Running the test string

One complete RF unit has recently been built in one of the experimental halls at CERN. Most of the low power and controls electronics used as well as all other major components are final LEP designs.

The Data Manager used in this test string is a CAMAC based SPS intelligent touch terminal computer which provides full touch panel control with colour graphics.

At the time of writing, 80% of full power has been reached with all essential parts of the low-power system working correctly.

Acknowledgements

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References

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