HIGH SENSITIVTY ELECTRONIC SYSTEM FOR THE PHASE PROBES OF THE LNS/MILANO SUPERCONDUCTING CYCLOTRON

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ABSTRACT

A computer controlled electronics has been developed to process the signals induced by the beam on the phase probes installed in the LNS/Milano K800 Cyclotron. The system works in the frequency range 30 to 96 MHz, corresponding to the 2^{nd} harmonic of the RF voltage. Circuits schemes together with layout solutions and system performances are reported in this paper.

1. SYSTEM DESCRIPTION

The LNS/Milano Superconducting Cyclotron[1] is equipped with 14 non intercepting probes to measure the phase of the beam bunches with respect to the accelerating voltage. This phase detection would assure a precise adjustment of the magnetic field topology for all particles and energy. The required phase reproducibility is ± 0.3°, for an absolute error below ± 1°. The probes are placed inside proper groves carved over two adjacent liner hills.

A photograph of a phase probe is shown in Fig. 1.

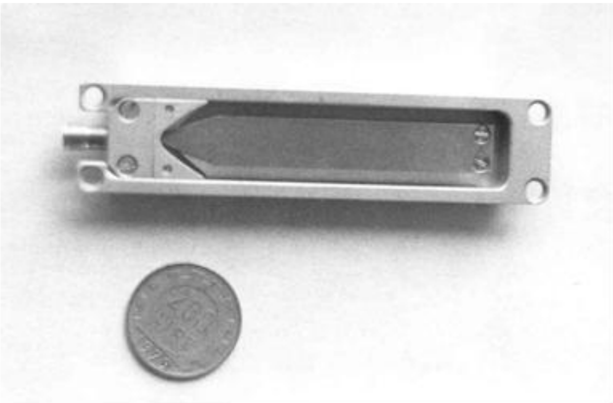

Fig. l. Photograph of a phase probe.

Each probe converts the beam charge into a pulse, whose repetition frequency is that of the accelerating voltage (15- 48 MHz)[2].

A high sensitivity electronic system converts the signal picked up by the probe into a phase information, via the extraction of its 2^{nd} harmonic. The electronic system block diagram is shown in Fig. 2.

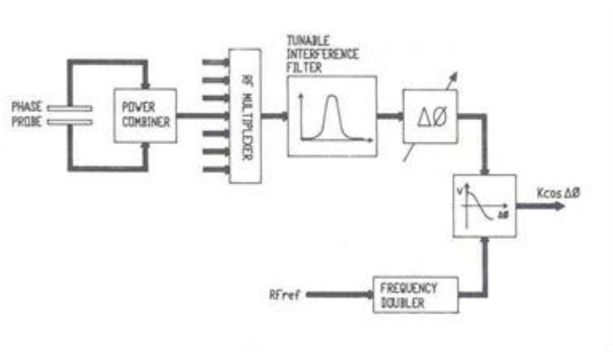

Fig.2 Control Electronics block diagram.

The high spectral density RF signal induced on each probe is fed to a power combiner to increase the signa1 to noise ratio[3]. In this way the 1^{st} harmonic noise, due to stray coupling with the accelerating voltage is expected to be reduced. A sixteen channels RF multiplexer is used to select the desired probe signal and to connect it to the control electronics, which is one for all the probes.

A tunable filter is used to extract 2^{nd} harmonic of the signal. The filtered signal is then amplified and compared with a reference one to detect the beam phase.
The phase detector working point (i.e. its bias) has to be chosen in such a way that the detected phase difference of all isochronous beams, with respect to the phase reference, is independent from the probe position and the signal frequency. A frequency doubled sample of the accelerating voltage is used as phase reference.

A DC voltage, proportional to the cosine of the ion beam phase, is the output of the phase detector. This signal is interfaced to the computer control via a INTEL 4410 microcomputer board.

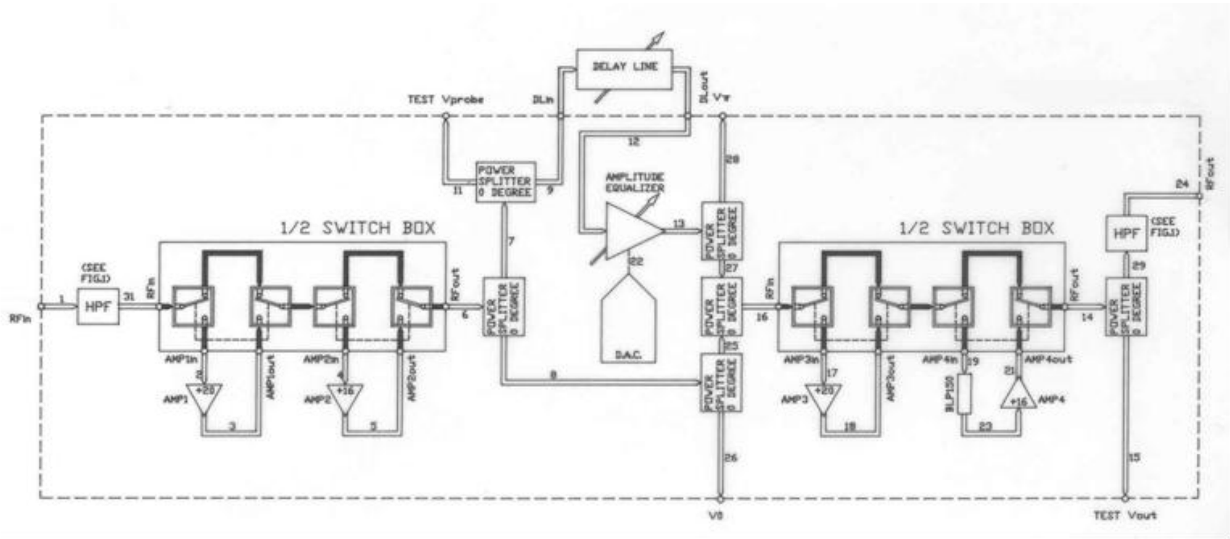

Fig.4. Filtering section scheme

1.1. Probe selection system

The probe selection system block diagram is shown in Fig. 3.

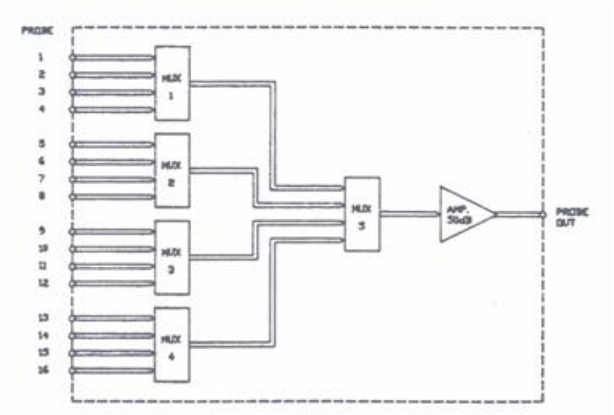

Fig.3. Probe selection system. The 50 dB RF amplifier is also shown.

The RF multiplexer is a microstrip based device. RF relays shunt the transmission lines to perform channel selection, while the non selected channels are loaded with 50 ohm resistors. The multiplexer main characteristics are: VSWR < 1.5 ($Z_o = 50\ \Omega$) and insertion loss < 2 dB.

The desired channel is selected by the computer control through a digital interface board.

A 50 dB RF amplifier is used after the multiplexer to provide amplitude gain before the signal enters into the interference filter, to improve the signal to noise ratio.

The problems of noise and electromagnetic interference has been a crucial aspect in the multiplexer-amplifier system design and construction. In fact the amplitude of the signal can be so low to be comparable with the stray TTL noise from digital boards and with RF picked up signals from radio waves. Special assembling techniques have been used to reduce these dangerous stray signal interferences. These techniques involve a combination of: filtration of input and output lines, careful layout and grounding, extensive electrostatic and magnetic shielding. High frequency circuits are enclosed in metallic boxes to shield them from logic circuits and the rack itself is fully enclosed in metallic walls to avoid RF pick up from the environment. Noise power level has been reduced below -90 dBm with these improvements.

1.2. Filtering section

The filtering section scheme is shown in Fig. 4.

The interference filter is the most crucial part of the phase probe control electronics system. The extraction of the bunch pulse 2nd harmonic from a high spectral density RF signal is in fact performed by this device. The principle of operation is the following.

The phase probe signal is split by a 0° two ways power divider and one of the two lines is than tuned in such a way that, at the recombination point, the odd harmonics differ by $k\pi$ and cancels while the even ones differ by $2k\pi$ and add. A low pass filter after the "odd harmonic rejection filter" cancel the even harmonics higher than the second. A variable length delay line performs the required phase delay all over the operating range (15-48 MHz). This device is a modular six bits computer controlled stepping line (1 ns step for 63 ns maximum delay) together with a continuously variable length line used for fine adjustment in between two adjacent steps.

The delay line has been assembled using six pieces of RG58 coaxial cable of different length, shunted by six RF relays. The continuously variable length line is a microstrip trombone line with a motorized sliding short.

An amplitude equalizer is inserted after the delay line to ensure high degree of rejection in spite of signal amplitude variations .

Four RF amplifiers are also included in the filter rack. These amplifiers are optionally inserted via a system of pin diode switches to cover the required 80 dB working range; in fact the probe detected signals span from some µV (heavy ions injected from the Tandem) to some mV (axially injected light ions).

1.3. Phase detection system

The phase detection system, shown in Fig. 5, is designed around the Mini Circuits RPD 1 frequency mixer.

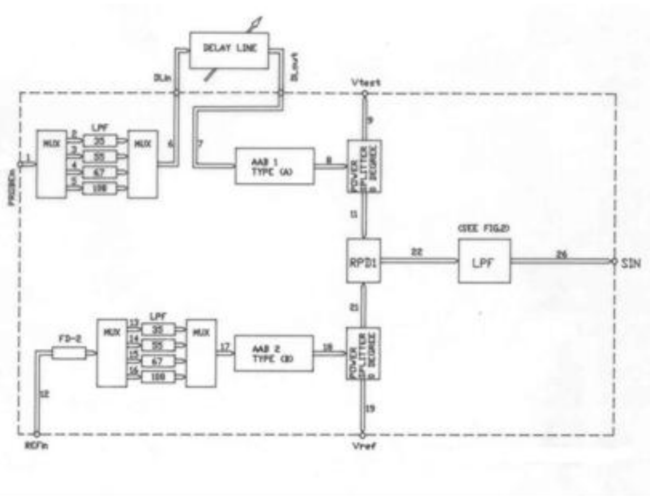

Fig.5 Phase detection system. The frequency doubling system is also shown.

The phase detector sensitivity must be independent of signal frequency and amplitude and this is not the case of a mixer output signal that is strongly influenced by input signal levels. One applied solution is to overdrive the input ports (Pin> +7 dBm) and to use the device saturated[4]. Unfortunately this solution can not be applied in our case because of the device linearity reduction.

So that we have chosen to control the level of input signals, obtaining the curve presented in Fig. 6, where a linear output characteristic is confronted to a saturated one. The former curve has been obtained with +3dBm and +1dBm input power on the LO and RF ports respectively, the actual phase detector working point.

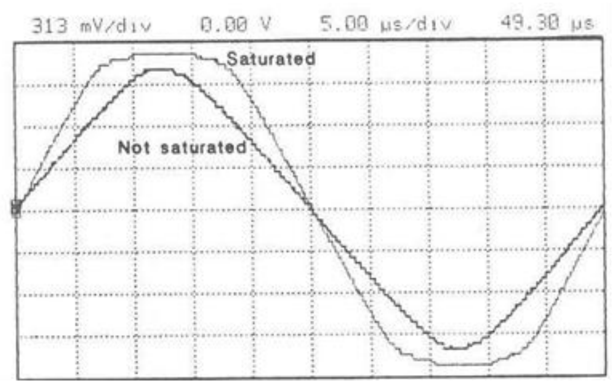

Fig.6 Phase detector output characteristics, taken from a HP 5420lA/D digitizing oscilloscope.

A vector analyzer is used to control the input signa1 levels, which are set to the right value by two computer controlled attenuation/amplification boxes[5]. A stepping delay line before the mixer RF port sets the proper phase detector working point, independently from the working frequency.

The frequency doubling system (based on a Mini Circuits FD2 RF doubler) is also inserted in the phase detector rack. A low pass filter, after the frequency doubler, cancels the stray high harmonic signals generated by the frequency doubling.

2. SYSTEM PERFORMANCE

Probe sensitivity calculations have been carried out before performing system testing. Particles are supposed to be packed in short bunches (less than 100 RF long) in which the electric charge is uniformly distributed. We have to consider the case of radial injection separately from the case of the axial one.

Axially injected particles follow the same trajectories and the probes always see the same number of orbits. So that the sensitivity does not depend on the kind of accelerated particle and its computed value is:

$$V_{s2}/I_{dc} = 540\ \mu V / \mu A$$

where: V_{s2} is the amplitude of the 2^{nd} harmonic signal and I_{dc} is the DC current intensity.

Conversely, for radial injection, different particle beams follow different trajectories, and consequently the probes detect different numbers of orbits, being the accelerated voltage amplitude fixed at 100 kV. The probe sensitivity varies from a minimum of 270 µV/µA for the heaviest ions, to a maximum of 540 µV/µA for the lightest particles.

Typical probe detected RF signal have been generated to test the electronic system (Table 1). Radial injection only has been considered.

Table 1. Typical beams

Ion	MeV/n	Z/A	V_{S2}[mV]	f[MHz]
C	100	0.5	79	48
C	60	0.5	47	38
O	100	0.5	105	48
O	60	0.5	62	38
Cu	30	0.34	92	28
Cu	60	0.34	181	38
I	10	0.22	21	16
I	30	0.22	63	28
U	16	0.143	50	21
Cu	40	0.34	123	32

The probe induced voltages are simulated synthesizing a short pulse whose repetition frequency and 2^{nd} harmonic signal amplitude are chosen from Table 1 for the desired particle beam. Signal expected spectrum when accelerating copper ions is shown in Fig. 7 Accelerating voltage frequency is 38 MHz and the beam final energy is 60 MeV /nucleon[6)].

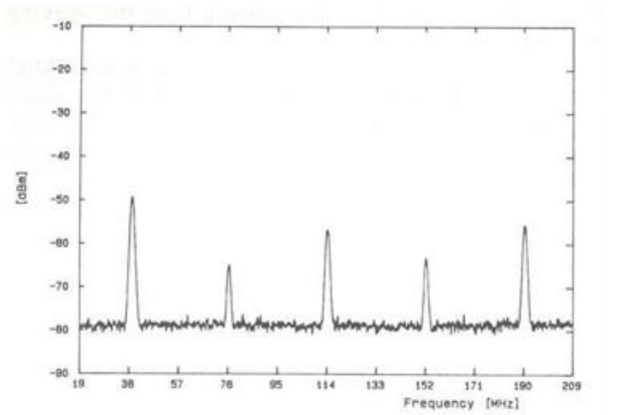

Fig. 7. Filter input signal spectrum. This signal is a simulation of a probe detected voltage when accelerating copper ions.

Signal after the interference filter is shown in Fig.8. Note that a nearly 50 dB first harmonic rejection has been reached.

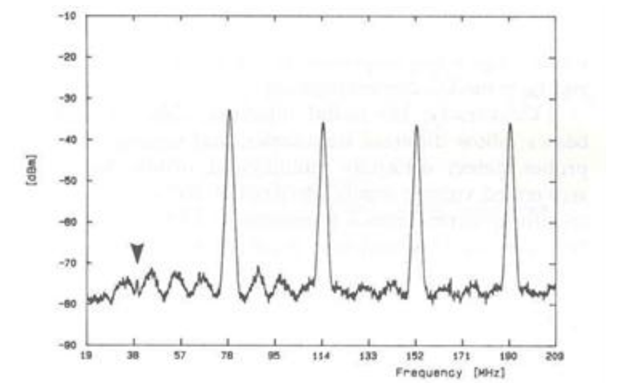

Fig.8. Signal after interference filter. The arrow show 1st harmonic power level.

Phase detection system output is shown in Fig. 9. This curve was taken varying the "beam phase" in the full operating range, i.e. ±90° RF, with respect to the reference signal.

A wide linear range, covering nearly the full working region, is shown in Fig. 9, the phase detector sensitivity being- 14 mV /°RF.

The analog signal coming from the phase detector is converted in a digital signal via a SBX 311 12 bit A/D converter, mounted upon a Intel 4410 board. The A/D converts phase information with 494μV resolution, corresponding to about 0.05°.

At the same time the phase is read, with a lower phase resolution, by the vector analyzer connected at the phase detector input.

As an example a picture of the phase detector rack. showing the internal layout, is shown in Fig. 10.

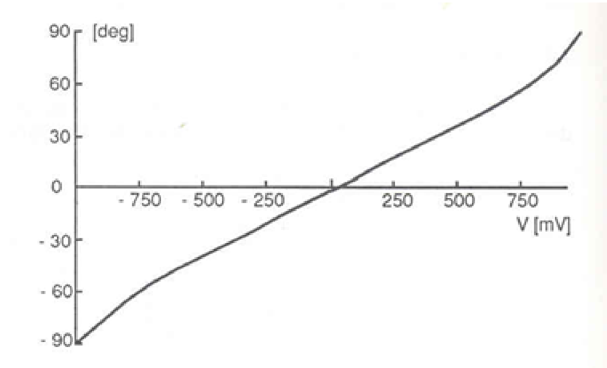

Fig.9 Phase detection system output .This graph is obtained after phase detector output signal processing.

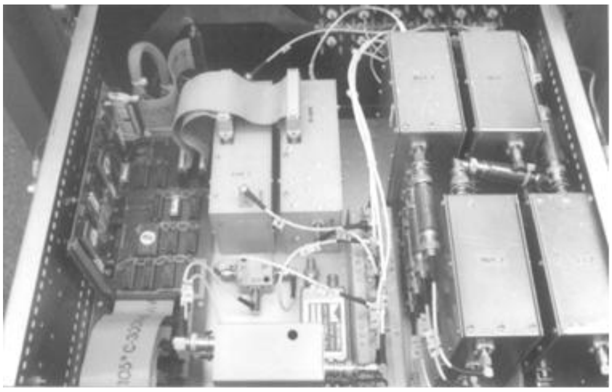

Fig.l0. Internal layout of the phase detection section. Assembling techniques to reduce electromagnetic interference are shown.

3. REFERENCES

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