RF-SYSTEM FOR STOCHASTIC COOLING IN THE FAIR COLLECTOR RING

C. Peschke, R. Böhm, C. Dimopoulou, F. Nolden, P. Petri, GSI, Darmstadt, Germany

Abstract

The collector ring (CR) of the FAIR project is designed for fast stochastic cooling of rare isotope and antiproton beams injected at different velocities. A flexible RF signal processing scheme for the stochastic cooling system will be presented. It includes cooling with time of flight (TOF), notch filter and Palmer methods. A Palmer pick-up with Faltin electrodes is foreseen for pre-cooling of hot rare isotope beams. For TOF and notch filter methods, a horizontal and a vertical pick-up tank with movable cryogenic slotline electrodes for ions with two different velocities is under development. The layout of this slotline pick-up tank will also be presented.

INTRODUCTION

The signal processing for the stochastic cooling has to be very flexible. The rare isotope beams (RIBs) or stable heavy ions will have a relativistic β=0.83 and the antiprotons ($\bar{p}$) will have β =0.97. The stored beam current varies from 21 nA (10^5 $\bar{p}$) to 17 mA (10^9 U^{92+}ions). The stochastic cooling system should achieve a 6D phase space volume reduction of $9 * 10^3$ in 9 s for $1 * 10^8$ $\bar{p}$ and $1 * 10^6$ in 1 s for $1 * 10^8$ U^{92+}ions. The beam diameter at the pick-up will be up to 160 mm at injection and will shrink to $\leq$20 mm after cooling.

For cooling of $\bar{p}$ and RIBs there will be two cryogenic pick-up tanks with movable slotline electrodes located at zero dispersion. For hot RIBs, the unwanted mixing from this position to the kicker is too large. Therefore, there will be an additional pick-up with Faltin type electrodes at a high dispersion position nearer to the kicker for Palmer pre-cooling of RIBs. The Faltin type pick-up is discussed in another paper at this workshop [1]. The frequency band of the system is 1-2 GHz in the start version. For an upgrade to a frequency band of 2-4 GHz, space for one additional pick-up tank and one additional kicker tank for $\bar{p}$ cooling is reserved in the ring.

SLOTLINE PICK-UP TANK

The slotline pick-up tanks will be used for cooling in all three planes of $\bar{p}$ and RIBs. The notch filter or the TOF method will be applied for longitudinal cooling. A group of eight coupling slots in a row with 25 mm spacing will be integrated together with the first Wilkinson combiner on a common alumina printed circuit board (PCB) [2]. The eight signals from this PCB will be combined to a single vacuum feedthrough. The seven Wilkinson combiners and the delay lines are integrated on a second PCB. The delay lines are dimensioned for $\bar{p}$. The RIBs deliver much stronger signals compared to the antiprotons. The slight performance degradation due to the fixed delay lines is acceptable. Two of these modules will be mounted together on a linear motor- driven support. So, the modules can follow the decreasing beam envelope from $\pm$80 mm to $\pm$10 mm during the cooling process [3].

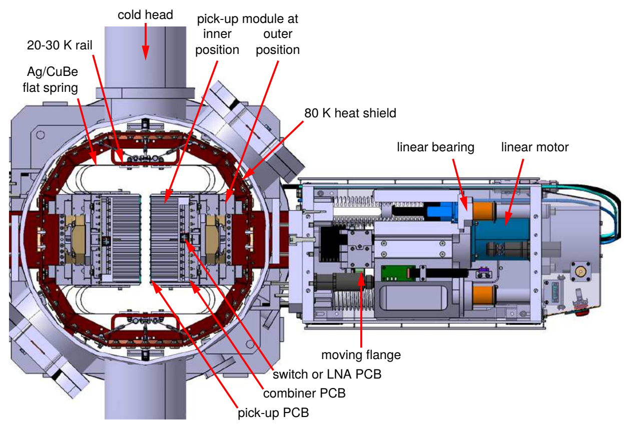

Figure 1: Sectional view of the prototype cryogenic slotline pick-up tank.

Fig. 1 shows a sectional view of the tank. The modules are thermally coupled by silver plated BeCu flat springs to the second stage of two cold heads. These cryogenic coolers will bring down the temperature to 20-30 K. The first stages of the cold heads will cool down a heat shield and the support rods to 80 K. In the start version, one low noise amplifier (LNA) per module, directly behind the vacuum feedthrough at the movable flange is foreseen. As an ugrade, a cryogenic LNA can be installed inside the module between the pick-up and the combiner PCB. A LNA at this point would not see the losses of the internal combiners and RF lines. The slotline coupler with the first Wilkinson combiner has an high reflection factor. Therefore, this LNA would see its own electrically cold input as terminator. These two benefits can significantly increase the signal to noise ratio. Additionally, each module will have a test signal input, which can be switched to each slot individually or phase correct to all slots in order to simulate a $\bar{p}$ beam. This input can be used for commissioning and self test without beam.

The signals from eight modules per side will be combined to one signal. The combiner will have integrated switchable delay lines (β switch). A 180° hybrid combines the signal from the two sides to a sum signal (longitudinal) and a difference signal (transversal). There will be one tank for horizontal and one for vertical cooling. Behind the hybrids, the signals go to the pick-up signal processing inside the radiation shielded inner part of the building. The longitudinal signals from the two tanks will be combined through a β switch to a common sum signal.

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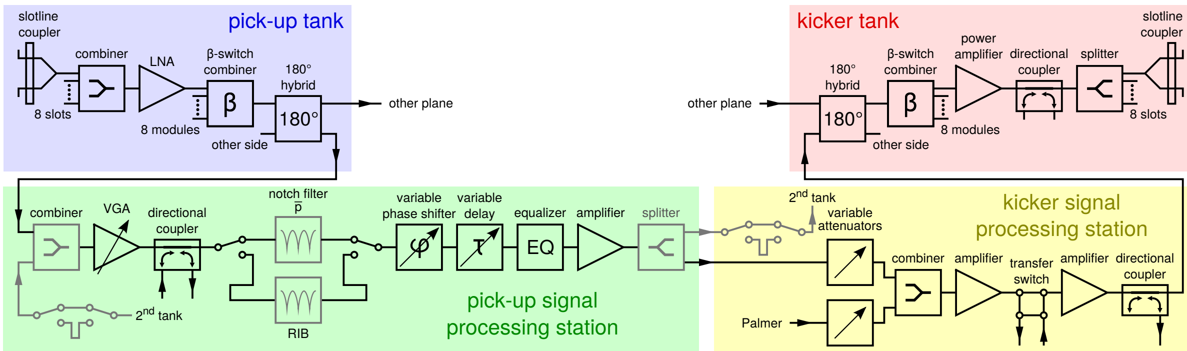

Figure 2: Block diagram of one RF signal processing path. The grayed components are present only in the longitudinal path. Some intermediate amplifiers and attenuators are not shown.

SIGNAL PROCESSING

All components of the intermediate power RF signal processing will be mounted on aluminum boards with a large thermal capacity and conductivity. Additionally, they will be thermally stabilized by water cooling to keep the thermal drift of the RF components low. The boards will be mounted vertically in the inner part of the building nearby the pick-up and kicker positions. The RF paths for longitudinal, horizontal and vertical signal processing are very similar, except the notch filters and the combiners for both longitudinal tanks. Fig. 2 shows one RF signal path.

The signal processing must handle a very high dynamic range. For example, the calculated power of the combined longitudinal signal is -103 dBm for 10^5 $\bar{p}$ with -76 dBm thermal noise on it and -20 dBm for 10^9 U^{92+} ions. Therefore, the first stage of each signal path will be a variable gain amplifier (VGA) with four amplifications from -4.6 dB to +40.6 dB. Behind this VGA, there will be a test circuit, which can measure the power and couple out signals to a spectrum analyzer during operation. The power meter can be used to automatically select the optimum amplification of the VGA. The test circuit can also couple in signals from a network analyzer for setup and test.

The next component will be a switch between $\bar{p}$ and RIB operation. In the transversal paths it switches between different delays from pick-up to kicker for $\bar{p}$ and RIBs. In the longitudinal path it additionally switches between notch filters for the two different revolution frequencies. A similar notch filter with optical fiber delay and controls has already been built up and tested at the existing experimental storage ring (ESR) [4]. The only difference in the CR notch filter, besides the length of the delay line, is a 180° power combiner (Minicircuits ZAPDJ-2) used instead of the 180° hybrid in the ESR notch filter. This device has lower amplitude and phase errors over the frequency band but is not available for the ESR frequency band. To apply TOF cooling, the long signal path of the notch filter can be switched off. There is a second switch for recombination of the $\bar{p}$ and RIB paths.

The next device will be a variable phase shifter with constant electrical length and attenuation. It can shift the phase of the signal between 0° and 360° for all operating modes and is rampable to compensate position-dependent phase errors of the movable pick-ups. Behind the phase shifter, there will be a variable delay line with constant phase and attenuation. It will have an virtually stepless delay from 0 to 1.28 ns. An equalizer is foreseen to compensate the negative amplitude slope over frequency, which is caused by the frequency dependent attenuation of all components and cables, and other systematic errors. The following device is an amplifier which drives the air filled coaxial cables to the aluminum boards nearby the kicker position (kicker signal processing station).

Up to here, all components are dedicated to the slotline pick-ups. Fig. 3 shows the preliminary block diagram of the Palmer pick-up tank. The difference between the inner and the outer Faltin rails gives a combination of horizontal and longitudinal signals. For the subtraction, the same type of 180° power combiner as in the notch filter will be used. The signal processing for the Palmer pick-ups also will have the same or similar VGAs, phase shifters, variable delays, equalizers, and amplifiers as on the slotline pick-up signal processing station. To save propagation time, the air filled coaxial cables and most of the components will be mounted on a straight line 15 cm below the beam height. The signals from the Palmer pick-ups will go to the same kicker signal processing stations as the signals from the slotline pick-ups.

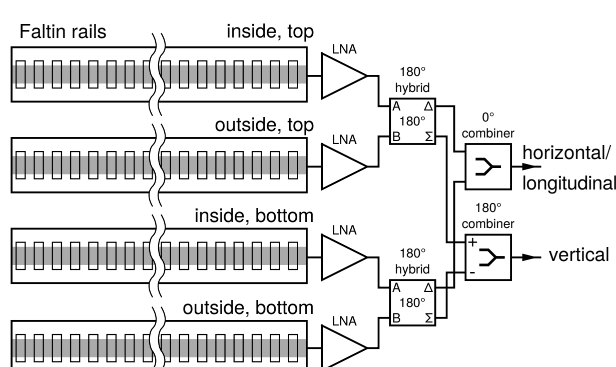

Figure 3: Block diagram of the Palmer pick-up tank.

The first component at each kicker signal processing station will be a rampable variable attenuator with constant

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delay and phase. It can be set or ramped to any attenuation from -6 dB to -36 dB. Such attenuators are foreseen separately for Palmer and slotline signals. These two signals per plane are combined behind the variable attenuator. Behind an intermediate amplifier there will be a transfer switch for beam transfer function measurements and offline tests. A second medium power amplifier will drive the air filled coaxial cable to the kicker tanks. Between this amplifier and the cable, a coupler with a power meter is foreseen for test purposes and to avoid overdrive of the power amplifiers.

SLOTLINE KICKER TANK

The slotline kicker tanks will be used for all cooling methods and both particle species. One tank is foreseen for horizontal and longitudinal cooling and one tank for vertical and longitudinal cooling. The signal processing at the kicker tank is very similar to the slotline pick-up tank. The first RF component at each kicker tank is a 180° hybrid, which distributes the longitudinal and the transversal signals to the two sides of the tank. The signals will be splitted through the same type of β switches used on the pick-up tank to eight signals per side.

The fixed delay lines will be followed by water cooled power amplifiers. Each power amplifier will have a CW output power of 250 W at 1 dB compression point, resulting in 8 kW RF power for the whole system. Each amplifier will have an integrated directional coupler to monitor the forward and reflected signals. Each power amplifier will drive a kicker module which consists of a splitter board and a slotline electrode board with eight slots with 25 mm spacing. The major part of the RF power will be reflected from the slotlines through the last Wilkinson splitter. Due to the different lengths of the delay lines on the splitter board, the power is dissipated in the splitters. Therefore, 180° hybrids will be used as splitters. In this case, the reflected power comes out of the difference ports and can be dissipated in water cooled power terminators inside the tank.

For high reliability, all components in the RF signal path and the test circuits are solid state devices. No mechanical relays or delay trombones are foreseen. Most of the RF components will be connected to the control system trough the same type of power supply and control units. Each of these units will have an Ethernet uplink to the control system and eight connectors for devices. Each such connector provides two positive and one negative programmable supply voltage with current monitoring, two analog inputs, two digital inputs or outputs, and one asynchronous serial interface (RS-232, RS-422, or RS-485).

All RF test and measurement signals from the different nodes in the RF signal processing will be switched through solid state relays to a central network analyzer and a central spectrum analyzer at the kicker signal processing station. The connection to the main control room is primarily done by Ethernet. For commissioning, some single mode optical fibers and some low frequency cables are foreseen.

SUMMARY AND OUTLOOK

The presented RF signal processing can be used for Palmer, TOF, and notch filter cooling in all three planes for particles with two different velocities and a wide range of beam currents. Calculations of power levels and delay time in the whole circuit are currently in progress. Some of the standard components are already chosen and characterized. For the β-switches with integrated combiner, a prototype exists. For the variable attenuators, variable delays, and variable phase shifters the development has begun. Most of the other components are pending but commercially available. The power amplifiers are specified and will be developed and built by an external company. A call for tender is in progress. A first prototype of the pick-up module has been built up and measured without tank and beam [2]. A second prototype with some minor modifications is underway. The major parts of a first prototype slotline pick-up tank with motor drives and cryogenics is designed and constructed and will be tested later this year. The design of the Faltin pick-ups is in progress [1]. The design of the kicker tank has not yet started.

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