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New Control Structure of the 200 MHz RF System in the CERN PS

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Abstract

The 200 MHz RF system is an essential tool for the preparation of high-intensity beams in the CERN PS. Presently, six RF cavities are operated to control the longitudinal bunch emittance and rebunching of the beam before the transfer to the SPS. Cavities are selected for the various processes with a dedicated hardware matrix, switching the individual timing pulses and voltage programs per cavity. However, the electronics used for the matrix hardware is obsolete and its reliability cannot be guaranteed due to a lack of spare modules and components. Instead of replacing the old hardware matrix by modern hardware, this note describes a new control structure for the 200 MHz RF system so that no dedicated hardware will be required anymore. The implementation of the new control structure is based on two main concepts. Firstly, linked timing trees per blow-up or rebunching are used to handle all related timings and to store one row of the matrix. Secondly, as a reflection of the RF signal generation for the 200 MHz system, where all units always receive the same RF signal, the new implementation features a single global voltage program function. Internal stops in the voltage program function are restarted by timings in the linked trees and assure inherent coherence between timings and voltage programs for the cavities. After a description of the requirements of the present hardware in terms of timing signals and functions, a functional specification of the new application program is given.

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1 Introduction

The 200 MHz RF system is an essential tool for the preparation of high-intensity beams in the CERN PS. Presently, six RF cavities, each capable of delivering some 25 kV of peak RF voltage to the beam are operated to control the longitudinal bunch emittance and rebunching of the beam before the transfer to the SPS. The parameters of four longitudinal emittance blow-ups and two functions to rebunch the beam are controlled from a matrix application, selecting cavities for the different functionalities in pulse-to-pulse (PPM) mode.

For each blow-up or rebunching, each of the 200 MHz cavities needs a number of timing pulses and a voltage program. Dedicated matrix hardware, programmed by the matrix application, transforms the timing pulses per blow-up or rebunching into timing pulses and programs per cavity. This special hardware has been designed and built more than twenty years ago [1, 2]. However, the electronics used for the matrix hardware is obsolete and its reliability cannot be guaranteed due to a lack of spare modules and components. A possible replacement had already been considered some time ago [3], but was not implemented.

Instead of replacing the old hardware matrix by modern hardware, this note describes a new control structure for the 200 MHz RF system so that no dedicated hardware will be required anymore. Standard controls hardware and a new application program will provide the same functionalities as the old hardware matrix. The implementation of the new control structure is based on two main concepts. Firstly, linked timing trees per blow-up or rebunching are used to handle all related timings and to store one row of the matrix. Secondly, as a reflection of the RF signal generation for the 200 MHz system, where all units always receive the same RF signal, the new implementation features a single global voltage program function. This voltage function contains a sequence of voltage programs for all blow-ups and rebunchings. Internal stops in the voltage program function are restarted by timings in the linked trees and assure inherent coherence between timings and voltage programs for the cavities. Furthermore, overlapping of voltage program functions is excluded due to the unique sequence.

It must be emphasized that the new implementation, as presented in this note, will be fully backwards compatible with the old control structure. Therefore, during the 2008 run, the new implementation can be commissioned with the old hardware matrix as back-up.

After a description of the requirements of the present hardware in terms of timing signals and functions, a functional specification of the new application program is given.

2 Functions of the 200 MHz RF system

Three functionalities are presently available with the 200 MHz RF system in the PS, each of which uses a different signal chain for the generation of the RF signal sent to the cavities: Test-pulse (without beam), longitudinal blow-up and rebunching. These functions must be controlled with the new application program. In the present configuration, the voltage program and switchings for the test pulse are implemented in hardware, which should also be covered by the new application. As the rebunching RF manipulation is only needed shortly before extraction, the different functions are always executed in the sequential order as summarized in Table 1.

1. A few milliseconds after the start of the cycle and long before injection, a test pulse must be generated. This test pulse not only allows the behavior of the cavities to be analyzed, but also keeps the cavities and amplifiers in thermal equilibrium in case a cavity is not selected for any blow-up or rebunching.
2. At various times throughout the cycle, three operational and a spare blow-up must be programmable. The RF signal is generated as a harmonic of the revolution frequency of the beam, modulated in phase according to a set of given modulation parameters.
3. For the rebunching, the RF signal is normally switched to the one from the SPS.

	Function	RF signal source	Remarks
1.	Test pulse	RF generator	Before injection
2.	Blow-up 1	Modulated harmonic of beam signal	Radial steering
3.	Blow-up 2	Modulated harmonic of beam signal	Retuning of C202/C203
4.	Blow-up 3	Modulated harmonic of beam signal	
5.	Blow-up 4	Modulated harmonic of beam signal	Spare blow-up
6.	Rebunching 1	RF signal from SPS	
7.	Rebunching 2	RF signal from SPS	Spare rebunching
8.	Spare	to be defined	Spare function

Table 1: Functions of the new 200 MHz system implementation in sequential order.

4. A spare function should be implemented to program any further functionality that might be required during machine experiments.

3 New control structure replacing the 200 MHz matrix

For each functionality, the 200 MHz cavities have to receive the appropriate RF signal, including modulation for the blow-ups, and a voltage program. In the present configuration, the voltage programs for the longitudinal blow-ups and rebunching are generated by one analog function generator (GFAS) channel per function, resulting in six GFAS channels for the complete voltage program. The matrix switches the component voltage programs and the corresponding timings to the selected cavities. In the new implementation, the number of GFAS channels for the voltage program will be reduced significantly from six to one. The phase modulation functions for the four blow-ups are generated by one GFAS channel per blow-up as before. As the phase modulation is part of the RF generation chain and is not related to the matrix, their number and functionality remains unchanged in the new implementation.

The new control structure replacing the matrix has been developed under the following assumptions:

- The voltage program is always the same for all cavities (similar to the global voltage program function for the 10 MHz RF system).
- All cavities receive the same RF signal as a reference for the voltage control loop (AVC). The driving frequency and phase modulation is always identical for all cavities.
- It is sufficient to inhibit only warning and start timing pulse to disable a cavity. Measurements have shown that it makes no difference to disable the voltage program together with the timings or the timings alone.

Therefore, a single voltage program distributed all the time to all cavities will replace the various voltage program components, distributed by the matrix hardware. The cavities are selected or unselected by enabling or disabling their corresponding start timing pulses. Start timing pulses per cavity are thus required, replacing the global timing pulses distributed per blow-up or rebunching.

The number of timing pulses needed increases with the new implementation of the 200 MHz matrix in software. The effective arrangement of such timings in the control system of the PS Complex are linked timing trees of the LKTIM type. Editing these timing trees directly, should be reserved to the expert user and is not part of the normal operation of the 200 MHz system in the PS. New application software, replacing the 200 MHz matrix application that is presently used to control the matrix hardware, will allow a comfortable selection of cavities and the adjustment of all parameters relevant to the operation of the system.

4 Control of the cavities and hardware implementation

Besides the sinusoidal RF signal around 200 MHz at constant amplitude, each of the 200 MHz cavities needs three timing signals and an analog signal for the voltage program. The timing signals are warning, start and stop.

- The warning pulse serves to reset the high-power interlock surveillance and is presently also used for retuning of the cavities C202 and C203 during the blow-up at intermediate energy. The warning pulse is normally generated some 50 ms before the start pulse.
- The start pulse switches the PIN diodes to virtually open the cavity gap and enables the AVC loop so that voltage is produced in the cavities.
- The stop pulse switches the PIN diodes back to the position of reduced cavity impedance and cuts the voltage program by disabling the AVC loop.

In between start and stop pulses, the voltage program must be sent to the cavities as an analog voltage from a GFAS. It is important to point out that a cavity cannot deliver any voltage until a start pulse enables the AVC loop. Therefore, the global voltage program can be sent to all cavities in parallel by a single GFAS channel. Inactive cavities are disabled by inhibiting their corresponding start pulses. The timing sequence is shown in Fig. 1. Normally, the cavity voltage is cut by the stop pulse at the end of the blow-ups. The voltage program returns back to zero later. Decreasing the voltage program to zero protects the hardware against too long pulses: If the length of a blow-up, adjusted by the stop timing pulse gets beyond the end of the voltage program function, the cavity voltage is automatically reduced. The length of the voltage program thus defines the maximum possible length of the blow-up.

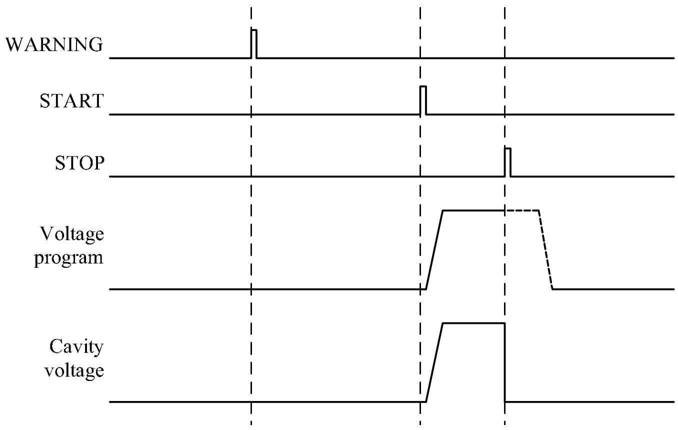

Fig. 1: Controls signals needed to control the voltage of one 200 MHz cavity.

4.1 Hardware modifications of the AVC module

Two modifications will be implemented to the voltage control loop (AVC) module to upgrade it for the new control structure:

- Besides regulating the cavity voltage, the AVC modules of the 200 MHz RF system switch the PIN diodes to virtually open or close the cavity gap, respectively increase and decrease the cavity impedance visible to the beam. The old matrix hardware is equipped with an input, detecting if the amplifier of a cavity is in the so-called level2 status (from the RF shut off & cavity status crate), meaning that the amplifier is switched on and operational. The matrix hardware normally disables the timing pulses to the AVC modules so that the PIN diodes stop pulsing, if the power amplifier is not ready. This level2 interlock function will be implemented in the AVC modules by adding an additional level2 enable input to modules. Thus, consequently the AVC loop will not be closed and the PIN diodes will not pulse until the level2 ready signal is received.

- Presently, the old matrix hardware assures a direct correspondence between voltage program and detected voltage signals per cavity sent to the OASIS observation system. Since such a correspondence is extremely important for fault diagnostics by directly comparing analog signals of program and cavity gap voltage, it must be implemented elsewhere. The AVC modules will be equipped with an additional electronic switch to combine voltage program function and start/stop timing pulses to deliver an analog signal of the voltage program per cavity that will replace the signal acquired in OASIS today. It will be a direct representation of the voltage program that should be played by the cavity.

Both modifications have already been tested successfully on a prototype AVC loop module.

4.2 Voltage program generation

The RF signal generation of the 200 MHz system is designed in such a way that only one signal can be applied to all cavities simultaneously. The voltage program is thus identical for all cavities, except for disabled cavities delivering no voltage at all. Moreover, the various blow-ups and rebunchings performed by the system are always in a sequential order and must never overlap in time. Therefore, the global voltage program for all functions of the 200 MHz system within a cycle can be generated by a single GFAS channel. So-called internals stops of the GFAS function separate the voltage program for test pulse, blow-ups and rebunchings, as well as the rising and falling edge in each case. The internal stops assure coherence between the timing trees generating the timings for the cavities and the global voltage program.

According to tests with the existing hardware of the AVC loops of the 200 MHz cavities, there is no measurable difference between a cavity being disabled by cutting its timing pulses and the voltage program, or disabling only its warning and start timings. Hence, the analog voltage program can be distributed to all cavities in parallel, even in case a blow-up has been disabled completely. A sequence of restart timings for the voltage program GFAS that are always enabled make sure that the correct fraction of the voltage program is played with the corresponding restart event. The restart events also serve as root timings for the timing trees of the corresponding blow-up or rebunching.

As an illustration, an example for such a combined voltage program function is shown in Fig. 2. The voltage function has two internal stops for each blow-up or rebunching (see Table 1), as rising and

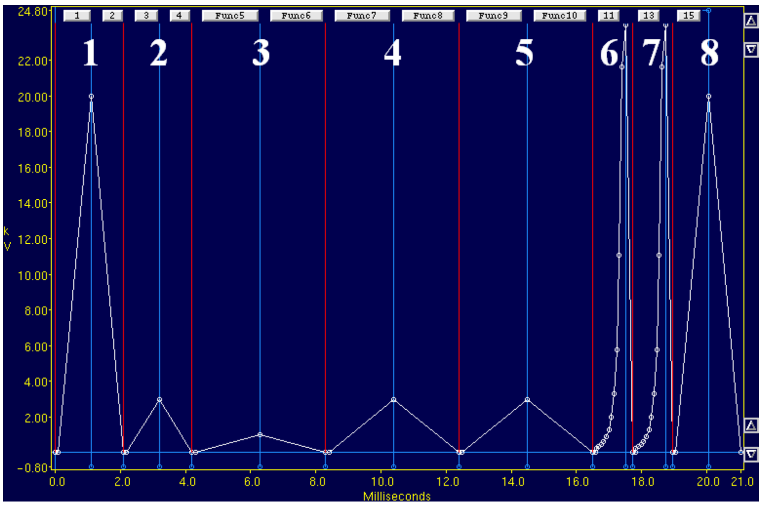

Fig. 2: Combined voltage function containing voltage programs for test pulse, four blow-ups, two rebunchings and a spare program (see Table 1 for function numbers).

falling edge of the voltage program are restarted by different timings. After the start of the cycle, the GFAS is directly halted by an internal stop, waiting for the first restart pulse. The following procedure describes how a voltage function for a blow-up or rebunching is then generated:

1. The voltage program is at zero; the system is waiting for restart pulse PAX.SnV200 (red lines, Fig. 2).

2. When PAX.SnV200 is received, the rising part of the voltage program for a blow-up or rebunching is played (see Fig. 1, voltage program curve). The voltage program halts at the next internal stop, which is at maximum voltage (blue lines, Fig. 2).
3. The blow-up takes place or the beam is kept at constant voltage after a rebunching. The system is waiting for the next restart pulses PAX.EnV200.
4. When PAX.EnV200 is received, the falling part of the voltage program is played (see Fig. 1) until the voltage program returns to zero and is again halted by the subsequent internal stop. The system is now back to the first state, ready for the new blow-up or rebunching (red lines, Fig. 2).

Depending on the time of the stop pulse to the cavities relative to the restart time and length of the falling edge voltage program, the cavity will be cut by the stop pulse in the normal case. If the length of the blow-up has been set beyond the maximum permissible length, the cavity will be stopped by the voltage program function (see Fig. 1). The limitation of the number of vectors in a GFAS to 510 does not restrict the flexibility of the voltage program, as normally only 5 points for a blow-up with constant RF voltage and some 15 points for a rebunching are needed.

4.3 Phase modulation

The $200\,$MHz cavities are driven with a phase modulated signal for the longitudinal blow-ups. This modulation is generated with a fast phase shifter module that can be controlled by a digital phase word. The sinusoidal phase curve needed for the phase shifter is generated directly by a GFAS in recurrent mode, storing several periods of the modulation function. The modulation function for each blow-up is generated by a dedicated GFAS channel, namely PA.GSPMBU1 to PA.GSPMBU4. The starts and stops for the phase modulations are directly wired to the start and stop timings of the blow-ups. All this is unchanged in the new implementation.

5 Timing tree structure for the control of the 200 MHz system

Presently, the information about which cavity is to be operated for which function is kept in the application program and transferred to the matrix hardware. In the new control structure of the $200\,$MHz RF system, each row of the old matrix will be stored by enabling or disabling timings in linked timing trees of the type LKTIM. Additionally, the new timing structure allows the specialist to control start time and length of the blow-up by changing a single parameter in the timing tree, even without an application program. Global enable and disable of the blow-up is also possible.

The proposed new structure of such a timing tree for a blow-up is shown in Table 2. The timing

Event	Description	Remarks
PAX.S2V200	Start voltage program blow-up 1	Root, always enabled
- PAX.SBU1	Start blow-up 1	Global enable/disable
- PAX.WBU1	Warning blow-up 1 (all cavities)	
- PAX.S2C201	Start 2, C201	En-/disable by application
⋮	⋮	⋮
- PAX.S2C206	Start 2, C206	En-/disable by application
- PAX.EBU1	Stop all cavities	
- PAX.E2V200	Start voltage program blow-up 1	Always enabled

Table 2: Example for a timing tree for blow-up 1 according to the new control structure for the $200\,$MHz RF system.

trees for the test pulse and rebunching are very similar. The more detailed timing trees for all functions can be found in the appendix. The root of the tree is the restart pulse to the voltage program GFAS for the rising part of the corresponding voltage component. This timing pulse must be protected from being disabled. In case it would be disabled, rising and falling edges of the voltage program function can be mixed, leading to an undefined state of the system. To globally enable or disable everything related to the blow-up, the existing timing PAX.SBU1 remains in the new tree structure.

At the end of the blow-up, all cavities are stopped by the PAX.EBU1 timing which opens the AVC loop. Independently from this stop pulse for the cavities, the voltage program is reduced to zero with a separate pulse, PAX.E2V200 (always enabled). This assures that the voltage in the cavities is either cut by the end pulse of the blow-up or, if this stop timing is set too late, by the voltage program.

6 Requirements for the new 200 MHz matrix application

Since the control of the 200 MHz RF system via the LKTIM timing trees is rather cumbersome, a new application software is needed for the new control structure. It will essentially provide the same user interface and functionality as the existing application program. As with the old software, the new application must comprise the functionality to comfortably edit the modulation parameters, the duration and the voltage amplitude for the blow-ups. A multiplicative scaling to the voltage program used for the rebunching should also be implemented, as well as directly adjusting the start and end times of a rebunching.

A screen-shot of the old 200 MHz matrix application illustrates its main features (Fig. 3). The

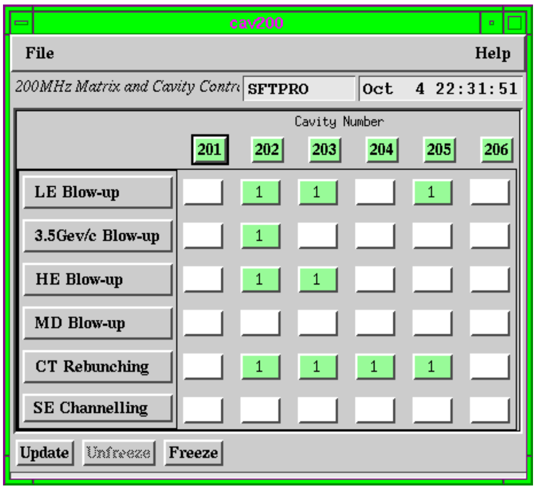

Fig. 3: Screen-shot of the old matrix application. Cavities are selected by directly clicking on the elements of the matrix.

new matrix application should be very similar to this old application, but acting on the linked timing structures instead of a dedicated matrix hardware.

6.1 Status, enabling and disabling of cavities

The user interface of the new matrix application can be very similar to the existing application. The first row indicating the numbers of the cavities from C201 to C206 serves as a status indicator for the cavity, where different colors show if the cavity is on, off, in local or in fault status. Clicking on the cavity numbers must open the corresponding cavity control knob PR.C201 to PR.C206 that allows to switch on and off the cavity, to put it in stand-by and to perform a reset of the high-power amplifier interlock. These cavity control buttons are not PPM.

Clicking on the matrix elements selects or unselects a cavity for the corresponding blow-up or rebunching. The following actions must be executed when a cavity is selected or unselected:

- To select a cavity, the corresponding timing pulse start pulse PAX.Sn20x is set from disabled to enabled, where n is the function number according to Table 1 and x is the number of the cavity.

Additionally, a “1” is displayed in the matrix element button of the matrix application to indicate that the cavity is now selected. The color of the matrix element button should indicate if the selection is compatible with the general status of the cavity (first row).

- To unselect a cavity, the corresponding start timing pulse PAX.Sn20x is disabled. The cavity selection button is cleared and its color becomes gray.

As an example, cavity C203 should be selected for blow-up 3. As blow-up 3 corresponds to the fourth function (see Table 1), the corresponding timing to be enabled is PAX.S4C203. Clicking on the same matrix element again disables this timing event and the cavity is unselected for blow-up 3.

6.2 Adjusting the blow-up and rebunching parameters

The blow-up and rebunching parameters should be editable in a way that mimics the old application software. Clicking on the function column on the left of the matrix, a sub-menu to select RF voltage, timing and modulation parameters (only blow-ups) should open. For the blow-ups these editable parameters are RF voltage, length of the blow-up, modulation depth and modulation frequency. For the rebunchings, the test and spare pulses, it is the RF voltage, the start and end time that should be adjustable from the application software.

6.2.1 Voltage program

To adjust the voltage of a blow-up or rebunching the application program must scale the corresponding part of the vector table of the voltage program GFAS. It can be easily identified by counting internal stops of vector table. Changing the blow-up voltage of, e.g., blow-up 3 must execute the following actions (see Fig. 4):

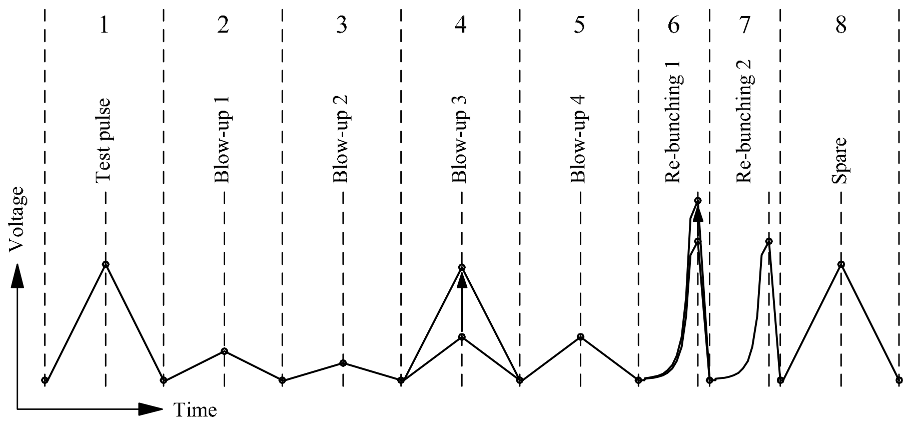

Fig. 4: The voltage function in-between internal stops (dashed lines) according to the function number has to be scaled by the new matrix application with respect to its maximum value (function numbers according to Table 1).

Firstly, the positions of the 8th (as blow-up 3 corresponds to function 4, see Table 1) and 10th internal stop vectors are extracted from the vector table and the vectors in-between are read by the application. Secondly, the largest voltage within the fraction of the voltage program vector table corresponding to blow-up 3 is extracted and displayed as an initial value for the voltage button. Ths maximum value should be at the internal stop separating rising and falling voltage program. Thirdly, when the voltage is changed, the extracted vector table fraction is scaled by the ratio of new to old voltage. The scaled vector table fraction is finally inserted back between 8th internal stop and the first vector after the 10th internal stop into the global voltage program function.

Therefore, the application must be capable of identifying internal stops, extracting a fraction of a vector table, computing the maximum value, scaling the vector table and inserting it back into the voltage program function. More sophisticated changes of the voltage function should not be performed by the application. When, e.g. the voltage program of the rebunching should modified or the voltage rise at the beginning of a blow-up needs to be changed, the global voltage program function can still be opened and edited manually with the conventional GFAS function editor.

6.2.2 Timing parameters

Clicking on the timing parameters sub-menu item should open a knob to adjust the duration of the selected blow-up. In case of a rebunching, there will be two knobs for start and stop time. The knob for the adjustment of the length of the blow-up acts on the end timings PAX.EBU1 to PAX.EBU4. For the adjustment, the application reads the difference between PAX.EBUn and PAX.S$(n+1)$V200. When the length is edited by the user, the application adds again PAX.S$(n+1)$V200 and, after timing verification, writes the resulting value back to PAX.EBUn. The implementation of a general timing check in the application, which verifies if all restart pulses of the global voltage program GFAS are in the correct order, is an important feature to assure that the preceding blow-up or rebunching must end properly before the subsequent operation can be started. Changing the start time of the blow-up can be done via timing tree and is not required to be modified from the application, since the observation of various hardware signals is required to adjust the start-time properly. Except for small time shifts, this is presently only possible from the central building.

For the rebunchings, the test and the spare pulse, the application should just open knobs for the start (PAX.SREB1, PAX.SREB2, PAX.SC200TEST, PAX.SC200SPARE) and stop timings (PAX.EREB1, PAX.EREB2, PAX.EC200TEST, PAX.EC200SPARE).

6.2.3 Modulation parameters

No changes will be made in the implementation of the buttons for the modulation parameters with respect to the old application program. The application must simply open a knob for the modulation frequency and the phase modulation depth. Additionally, the new application should display the blow-up voltages on the main window of the user interface (Fig. 3).

6.3 Reference settings

The old matrix application did not allow any reference settings to be saved. Due to the new structure using linked timing trees, the saving and recalling of reference settings is automatically possible with the LinkTg8 editor for LKTIM devices. However, the application program should also contain a button to send back the reference values of all matrix, timing, voltage and modulation parameter settings associated with a blow-up or a rebunching.

7 Conclusions

A new control structure for the 200 MHz RF system in the PS is proposed to replace the 200 MHz matrix hardware. This new structure does not rely on any dedicated hardware but maps the matrix functionality to standard controls hardware. The new control structure is based on two main features already existing in the present control system of the PS Complex. Firstly, all timings related to one blow-up or rebunching of the 200 MHz system together with the information stored in one row of the matrix are placed in a linked timing tree structure. Secondly, to reflect the hardware structure of the system, where only one RF signal can be delivered to all cavities at a time, the new structure foresees a single global voltage program function for all cavities. This voltage function contains a sequence of all blow-ups and rebunchings throughout the cycle. Overlaps between functions are thus excluded automatically. The logical connection between the timing trees and the global voltage program to form a coherent structure are internal stops. These internal stops assure that the voltage program is automatically moved in time coherently with the timings. Finally, the new structure is fully compatible with the old hardware matrix-based implementation. That means the new control structure can be gradually implemented and that the old matrix hardware remains available as back-up during the 2008 run.

A new application is required to provide a convenient user interface, allowing an easy selection of cavities for the various blow-ups and rebunchings. This application will enable and disable cavities in the related timing trees in a transparent way. As implemented in the present application, the user can also open knobs for all parameters relevant to a blow-up or rebunching. The timing trees themselves allow much more adjustments for tests and setting-up, but should only be used by experts.

It should be pointed out that analog signals of voltage program and detected voltage per cavity will be provided for OASIS in the new implementation. This will allow direct comparison in case a cavity is suspected not to work correctly.

The experience gained with the new 200 MHz matrix in software will be of importance for a potential replacement of the hardware matrix controlling the voltage programs of the 10 MHz RF system in the PS. The hardware of this matrix can still be deployed for some time. However, removing the need for special, dedicated electronics will improve the reliability of the system.

The authors are grateful to Andrew Butterworth, Ioan Kozcar and Claude-Henri Sicard for stimulating discussions on the control system of the PS Complex and the implications of the new control structure.

References

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A Timing trees

Remarks:

- The adjustable time length of a blow-up or rebunching is considered to be the time length between start (PAX.SnC20x) and end (PAX.EBU1 to PAX.EBU4, PAX.EREB1, PAX.EREB2, PAX.EC200TEST, PAX.EC200SPARE) pulse, including the rising edge of the voltage program.
- Multiple timings follow the general naming convention PAX.WnNAME, PAX.SnNAME and PAX.EnNAME.

A.1 Test pulse

PAX.TREEC200TEST				
Name	Predecessor	Description	Interval [ms]	Remark
PAX.S1V200	PX.SCY	Start test voltage program	**Start time test pulse**	Root, always enabled
- PAX.SC200TEST	PAX.S1V200	Start test pulse (virtual)	0	**Global enable/disable**
- PAX.WC200TEST	PAX.SC200TEST	Warning test pulse (all cavities)	-50	
- PAX.S1C201	PAX.SC200TEST	Start 1 (test) for C201	0	En-/disable by application
- PAX.S1C202	PAX.SC200TEST	Start 1 (test) for C202	0	En-/disable by application
- PAX.S1C203	PAX.SC200TEST	Start 1 (test) for C203	0	En-/disable by application
- PAX.S1C204	PAX.SC200TEST	Start 1 (test) for C204	0	En-/disable by application
- PAX.S1C205	PAX.SC200TEST	Start 1 (test) for C205	0	En-/disable by application
- PAX.S1C206	PAX.SC200TEST	Start 1 (test) for C206	0	En-/disable by application
- PAX.EC200TEST	PAX.SC200TEST	Stop all cavities	**Test pulse length**	
- PAX.E1V200	PAX.S1V200	End test voltage program	Maximum length	Always enabled

A.2 Blow-up 1

PAX.TREEBU1				
Name	Predecessor	Description	Interval [ms]	Remark
PAX.S2V200	PX.SCY	Start voltage program blow-up 1	**Start time blow-up 1**	Root, always enabled
- PAX.SBU1	PAX.S2V200	Start blow-up 1	0	**Global enable/disable**
- PAX.WBU1	PAX.SBU1	Warning blow-up 1 (all cavities)	-50	
- PAX.S2C201	PAX.SBU1	Start 2 (blow-up 1) for C201	0	En-/disable by application
- PAX.S2C202	PAX.SBU1	Start 2 (blow-up 1) for C202	0	En-/disable by application
- PAX.S2C203	PAX.SBU1	Start 2 (blow-up 1) for C203	0	En-/disable by application
- PAX.S2C204	PAX.SBU1	Start 2 (blow-up 1) for C204	0	En-/disable by application
- PAX.S2C205	PAX.SBU1	Start 2 (blow-up 1) for C205	0	En-/disable by application
- PAX.S2C206	PAX.SBU1	Start 2 (blow-up 1) for C206	0	En-/disable by application
- PAX.EBU1	PAX.SBU1	Stop all cavities	**Length of blow-up**	
- PAX.E2V200	PAX.S2V200	End voltage program blow-up 1	Maximum length	Always enabled

A.3 Blow-up 2

PAX.TREEBU2				
Name	Predecessor	Description	Interval [ms]	Remark
PAX.S3V200	PX.SCY	Start voltage program blow-up 2	**Start time blow-up 2**	Root, always enabled
- PAX.SBU2	PAX.S3V200	Start blow-up 2	0	**Global enable/disable**
- PAX.WBU2	PAX.SBU2	Warning blow-up 2 (all cavities)	-50	
- PAX.S3C201	PAX.SBU2	Start 3 (blow-up 2) for C201	0	En-/disable by application
- PAX.S3C202	PAX.SBU2	Start 3 (blow-up 2) for C202	0	En-/disable by application
- PAX.S3C203	PAX.SBU2	Start 3 (blow-up 2) for C203	0	En-/disable by application
- PAX.S3C204	PAX.SBU2	Start 3 (blow-up 2) for C204	0	En-/disable by application
- PAX.S3C205	PAX.SBU2	Start 3 (blow-up 2) for C205	0	En-/disable by application
- PAX.S3C206	PAX.SBU2	Start 3 (blow-up 2) for C206	0	En-/disable by application
- PAX.EBU2	PAX.SBU2	Stop all cavities	**Length of blow-up**	
- PAX.E3V200	PAX.S3V200	End voltage program blow-up 2	Maximum length	Always enabled

A.4 Blow-up 3

PAX.TREEBU3				
Name	Predecessor	Description	Interval [ms]	Remark
PAX.S4V200	PX.SCY	Start voltage program blow-up 3	**Start time blow-up 3**	Root, always enabled
- PAX.SBU3	PAX.S4V200	Start blow-up 3	0	**Global enable/disable**
- PAX.WBU3	PAX.SBU3	Warning blow-up 3 (all cavities)	-50	
- PAX.S4C201	PAX.SBU3	Start 4 (blow-up 3) for C201	0	En-/disable by application
- PAX.S4C202	PAX.SBU3	Start 4 (blow-up 3) for C202	0	En-/disable by application
- PAX.S4C203	PAX.SBU3	Start 4 (blow-up 3) for C203	0	En-/disable by application
- PAX.S4C204	PAX.SBU3	Start 4 (blow-up 3) for C204	0	En-/disable by application
- PAX.S4C205	PAX.SBU3	Start 4 (blow-up 3) for C205	0	En-/disable by application
- PAX.S4C206	PAX.SBU3	Start 4 (blow-up 3) for C206	0	En-/disable by application
- PAX.EBU3	PAX.SBU3	Stop all cavities	**Length of blow-up**	
- PAX.E4V200	PAX.S4V200	End voltage program blow-up 2	Maximum length	Always enabled

A.5 Blow-up 4

PAX.TREEBU4				
Name	Predecessor	Description	Interval [ms]	Remark
PAX.S5V200	PX.SCY	Start voltage program blow-up 4	**Start time blow-up 4**	Root, always enabled
- PAX.SBU4	PAX.S5V200	Start blow-up 4	0	**Global enable/disable**
- PAX.WBU4	PAX.SBU4	Warning blow-up 4 (all cavities)	-50	
- PAX.S5C201	PAX.SBU4	Start 5 (blow-up 4) for C201	0	En-/disable by application
- PAX.S5C202	PAX.SBU4	Start 5 (blow-up 4) for C202	0	En-/disable by application
- PAX.S5C204	PAX.SBU4	Start 5 (blow-up 4) for C203	0	En-/disable by application
- PAX.S5C204	PAX.SBU4	Start 5 (blow-up 4) for C204	0	En-/disable by application
- PAX.S5C205	PAX.SBU4	Start 5 (blow-up 4) for C205	0	En-/disable by application
- PAX.S5C206	PAX.SBU4	Start 5 (blow-up 4) for C206	0	En-/disable by application
- PAX.EBU4	PAX.SBU4	Stop all cavities	**Length of blow-up**	
- PAX.E5V200	PAX.S5V200	End voltage program blow-up 2	Maximum length	Always enabled

A.6 Rebunching 1

PAX.TREEREB1				
Name	Predecessor	Description	Interval [ms]	Remark
PAX.S6V200	PX.SCY	Start voltage program rebunching 1	**Start time rebunching 1**	Root, always enabled
- PAX.SREB1	PAX.S6V200	Start rebunching 1	0	**Global enable/disable**
- PAX.WREB1	PAX.SREB1	Warning blow-up 4 (all cavities)	-50	
- PAX.S6C201	PAX.SREB1	Start 6 (rebunching 1) for C201	0	En-/disable by application
- PAX.S6C202	PAX.SREB1	Start 6 (rebunching 1) for C202	0	En-/disable by application
- PAX.S6C203	PAX.SREB1	Start 6 (rebunching 1) for C203	0	En-/disable by application
- PAX.S6C204	PAX.SREB1	Start 6 (rebunching 1) for C204	0	En-/disable by application
- PAX.S6C205	PAX.SREB1	Start 6 (rebunching 1) for C205	0	En-/disable by application
- PAX.S6C206	PAX.SREB1	Start 6 (rebunching 1) for C206	0	En-/disable by application
- PAX.EREB1	PAX.SREB1	Stop all cavities	**Rebunching 1 length**	
- PAX.E6V200	PAX.S6V200	End voltage program rebunching 1	Maximum length	Always enabled

A.7 Rebunching 2

PAX.TREEREB1				
Name	Predecessor	Description	Interval [ms]	Remark
PAX.S7V200	PX.SCY	Start voltage program rebunching 2	**Start time rebunching 2**	Root, always enabled
- PAX.SREB2	PAX.S7V200	Start rebunching 2	0	**Global enable/disable**
- PAX.WREB2	PAX.SREB2	Warning blow-up 4 (all cavities)	-50	
- PAX.S7C201	PAX.SREB2	Start 7 (rebunching 2) for C201	0	En-/disable by application
- PAX.S7C202	PAX.SREB2	Start 7 (rebunching 2) for C202	0	En-/disable by application
- PAX.S7C203	PAX.SREB2	Start 7 (rebunching 2) for C203	0	En-/disable by application
- PAX.S7C204	PAX.SREB2	Start 7 (rebunching 2) for C204	0	En-/disable by application
- PAX.S7C205	PAX.SREB2	Start 7 (rebunching 2) for C205	0	En-/disable by application
- PAX.S7C206	PAX.SREB2	Start 7 (rebunching 2) for C206	0	En-/disable by application
- PAX.EREB2	PAX.SREB2	Stop all cavities	**Rebunching 2 length**	
- PAX.E7V200	PAX.S7V200	End voltage program rebunching 2	Maximum length	Always enabled

A.8 Spare

PAX.TREEC200SPARE				
Name	Predecessor	Description	Interval [ms]	Remark
PAX.S8V200	PX.SCY	Start spare voltage program	**Start time spare**	Root, always enabled
- PAX.SC200SPARE	PAX.S8V200	Start spare	0	**Global enable/disable**
- PAX.WC200SPARE	PAX.SSPARE	Warning test pulse (all cavities)	-50	En-/disable by application
- PAX.S8C201	PAX.SC200SPARE	Start 8 (spare) for C201	0	En-/disable by application
- PAX.S8C202	PAX.SC200SPARE	Start 8 (spare) for C202	0	En-/disable by application
- PAX.S8C203	PAX.SC200SPARE	Start 8 (spare) for C203	0	En-/disable by application
- PAX.S8C204	PAX.SC200SPARE	Start 8 (spare) for C204	0	En-/disable by application
- PAX.S8C205	PAX.SC200SPARE	Start 8 (spare) for C205	0	En-/disable by application
- PAX.S8C206	PAX.SC200SPARE	Start 8 (spare) for C206	0	En-/disable by application
- PAX.EC200SPARE	PAX.SC200SPARE	Stop all cavities	**Spare length**	
- PAX.E8V200	PAX.S8V200	End spare voltage program	Maximum length	Always enabled

B List of control system equipment

B.1 Function generators GFAS

	Equipment name	Description
	PA.GSV200	Global voltage program send to all cavities
	PA.GSPMBU1	Phase modulation function blow-up 1
	PA.GSPMBU2	Phase modulation function blow-up 2
	PA.GSPMBU3	Phase modulation function blow-up 3
	PA.GSPMBU4	Phase modulation function blow-up 4
Total:	→ 5 function generators GFAS	

B.2 Simple timings

	Equipment name	Description
Test pulse	PAX.WC200TEST	Warning test pulse
	PAX.SC200TEST	Start test pulse
	PAX.EC200TEST	End test pulse
Blow-up 1	PAX.WBU1	Warning blow-up 1
	PAX.SBU1	Start blow-up 1
	PAX.EBU1	End blow-up 1
Blow-up 2	PAX.WBU2	Warning blow-up 2
	PAX.SBU2	Start blow-up 2
	PAX.EBU2	End blow-up 2
Blow-up 3	PAX.WBU3	Warning blow-up 3
	PAX.SBU3	Start blow-up 3
	PAX.EBU3	End blow-up 3
Blow-up 4	PAX.WBU4	Warning blow-up 4
	PAX.SBU4	Start blow-up 4
	PAX.EBU4	End blow-up 4
Rebunching 1	PAX.WREB1	Warning rebunching 1
	PAX.SREB1	Start rebunching 1
	PAX.EREB1	End rebunching 1
Rebunching 2	PAX.WREB2	Warning rebunching 2
	PAX.SREB2	Start rebunching 2
	PAX.EREB2	End rebunching 2
Spare pulse	PAX.WC200SPARE	Warning spare pulse
	PAX.SC200SPARE	Start spare pulse
	PAX.EC200SPARE	End spare pulse
Total:	→ 24 simple timings	

B.3 Multiple timings

	Equipment name			Description
	PAX.S1C201	to	PAX.S8C201	Start for cavity C201
	PAX.S1C202	to	PAX.S8C202	Start for cavity C202
	PAX.S1C203	to	PAX.S8C203	Start for cavity C203
	PAX.S1C204	to	PAX.S8C204	Start for cavity C204
	PAX.S1C205	to	PAX.S8C205	Start for cavity C205
	PAX.S1C206	to	PAX.S8C206	Start for cavity C206
Common	PAX.S1V200	to	PAX.S8V200	Start voltage program
	PAX.E1V200	to	PAX.E8V200	End voltage program
Total:	→ 8 timings with 8 possible events each			

B.4 Timing trees

Function	Timing tree
Test pulse	PAX.TREEC200TEST
Blow-up 1	PAX.TREEBU1
Blow-up 2	PAX.TREEBU2
Blow-up 3	PAX.TREEBU3
Blow-up 4	PAX.TREEBU4
Rebunching 1	PAX.TREEREB1
Rebunching 2	PAX.TREEREB2
Spare	PAX.TREEC200SPARE
Total:	8 timing trees

B.5 Working sets

Function	Working set
Test pulse	LL_C200TEST
Blow-up 1	LL_BLOW-UP1
Blow-up 2	LL_BLOW-UP2
Blow-up 3	LL_BLOW-UP3
Blow-up 4	LL_BLOW-UP4
Rebunching 1	LL_REBUNCH1
Rebunching 2	LL_REBUNCH2
Spare	LL_C200SPARE
Total:	8 working sets