

## Linac4-to-PSB injection scheme and Linac4 Feed-forward algorithm

Discussion 01/06/2018 with Simon Albright, Fanouria Antoniou, Hannes Bartosik, Philippe Baudrenghien, Bartosz Bielawski, Robert Borner, Gian Piero Di Giovanni, Bettina Mikulec

### **Preamble:**

General effort is ongoing between TE-ABT, TE-EPC, BE-ABP, BE-RF and BE-OP to define the details of the synchronisation of the future PSB injection, see <https://indico.cern.ch/event/732085/>

The default starting assumption is that the Linac4 pulse will be treated as the current Linac2 pulse. The PSB operator will define the number of turns for each ring and the pulse will adapt in length accordingly. As a consequence, the related start timings for each ring will shift. See Fig. 1 as an example.

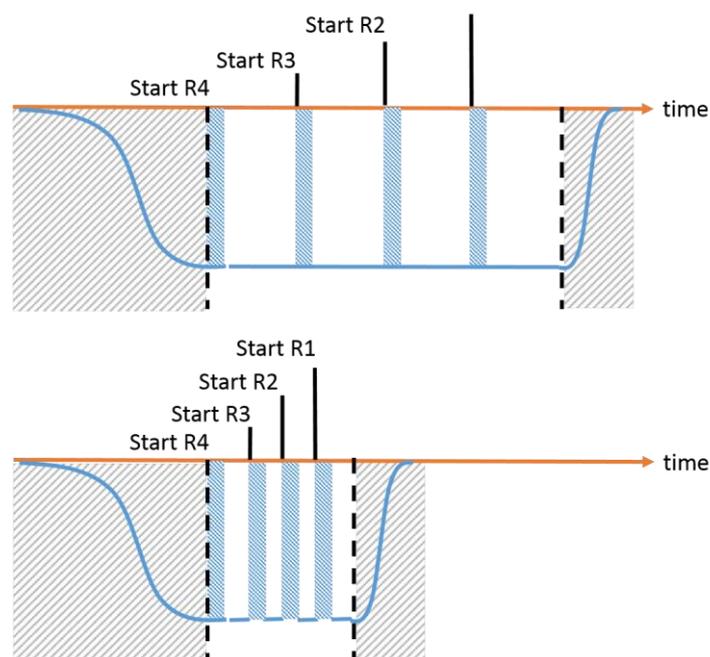


Figure 1: Schematic sketch to illustrate the original assumption for the treatment of the Linac4 pulse. Depending on the number of turns per ring the Linac4 pulse will adapt as well as the related start time for each ring. The head of the pulse is cut with the pre-chopper in combination with the chopper. The tail of the pulse is cut with the chopper. Between each ring a slice of  $\sim 2 \mu\text{s}$  is cut to accommodate for the rise time of the distributor (shaded blue area). Top: longer number of turns per ring (e.g. ISOLDE-type beam). Bottom: shorter number of turns per ring (e.g. LHC-type beam).

During the discussion about the PSB injection synchronisation, it became clear that implementing the new H<sup>-</sup>-injection scheme from Linac4 based on similar principles as for the Linac2 would require a high level of precision in the control of the timings of each equipment involved in the injection process, namely the KSW, BSW, Bd1 and QSTRIP circuits. Moreover, a new challenge for the Bd1 manifested itself, as for this specific correction circuit the start time is also directly connected with a change of current amplitude and it is not only a time shift, which has to be taken into account.

At the time of the meeting, an alternative scheme was very briefly discussed. The idea would be to always produce the maximum pulse length from Linac4, while keeping the ring start times fixed and cutting the remaining portion of the pulse with the chopper to adjust for the required intensity. A sketch is presented in Figure 2.

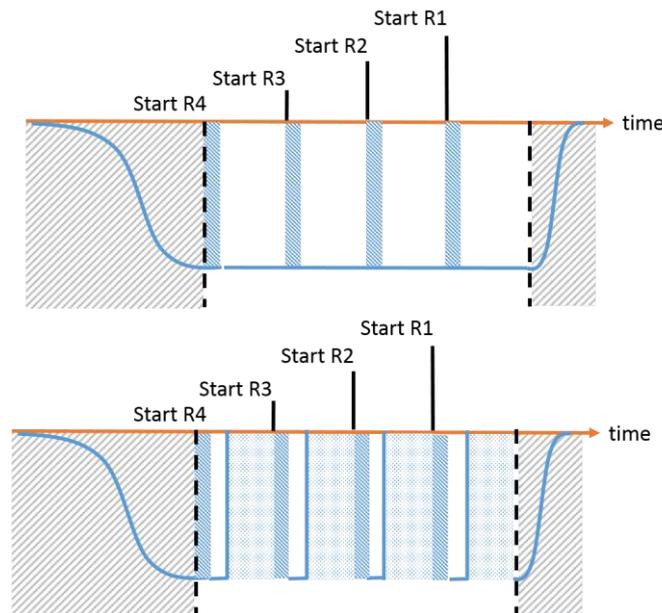


Figure 2: Schematic sketch to illustrate the newly proposed the treatment of the Linac4 pulse. Independently from the number of turns per ring the start times for each ring are kept in the same position in time along the pulse. This implies that the Linac4 pulse will always be produced at its maximal length and the slice not needed will be cut by the chopper. The head of the pulse is cut with the pre-chopper in combination with the chopper as well as the tail of the pulse. Top: longer number of turns per ring (e.g. ISOLDE-type beam). Bottom: shorter number of turns per ring (e.g. LHC-type beam).

This new scheme should simplify the synchronisation of the new PSB injection process, as the injection time for each ring will be fixed and predictable, improving the magnetic repeatability of the injection process. This scheme was proposed as **a back-up solution** for the commissioning of the future PSB injection, to possibly reduce the inherent complexity of the H<sup>-</sup>-injection scheme if issues arise with the baseline scheme. As a matter of fact, the implementation of the baseline scheme does not exclude the possibility to employ the back-up scheme, but not the other way around. Therefore, the idea is to keep the baseline scheme as default and, only if needed, fall back to the alternative scheme. The back-up scheme will also have several implications on different equipment, which still have to be evaluated. Some initial observation and investigations are reported below.

The option to always produce a Linac4 pulse with the maximum length was in fact discussed with Linac4 RF experts and it seems to be the favourable option to keep the stability of the pulse under control, important for reaching the LIU parameters. The initial discussion also led to the understanding that there are no major showstoppers, even with this new scheme, but the details have to be clarified with the relevant experts.

One of the issues that were raised in adopting this new scheme was its possible incompatibility with the space-charge compensation and feed-forward algorithm for Linac4, in particular considering as well ring interlocks. Therefore we launched a

discussion with RF experts to understand these potential limits and evaluate the feasibility of this possible new injection scheme.

## **Discussion:**

- Bartosz explained the changes that are currently being implemented; most FESA2 classes will be eradicated; could partly be tested with crab cavity run in the SPS; CCDTL5+6 now single modulator, single klystron, single LL-RF, double tuner (CCDTLs 1-4 still different).
- Philippe explained that Linac4 has an **RF feedback** that **compensates** variations in the RF voltage due to **transient beam loading induced by abrupt changes of intensity along the pulse**, e.g. at the start of the pulse or at the gap between the pulses for the different PSB rings. **In case the beam quality achieved with this feedback is not sufficient** due to its limited bandwidth (time constant of a few hundred ns), a **feedforward** algorithm would be implemented at a later stage which would "learn" the best correction for the upcoming pulse **based on the previous cycle (PPM)**.
- **How would the Linac4 RF react to ring interlocks (holes in the beam pulse)?**
  - **Beam loading would be different**; the feedforward correction pre-computed from the previous cycle would not be correct; however, this would only concern the part of the pulse with the hole (i.e. the part without beam): The gap in the pulse for the distributor to the different PSB rings (about 1 us) is large enough so that the remaining part of the pulse is not affected (the RF feedback has a time constant of few hundreds of ns for the cavity field regulation). In other words, there is no cross talk between the different parts of the pulse for the different PSB rings.
  - In case of a ring interlock, the feedforward "learning" would need to be inhibited, otherwise the correction would be wrong when the request for that ring is back (this would also affect only the respective ring). Similarly, the feedforward "learning" needs to be paused if there is no intensity requested by the PSB (e.g. "0 turns"). This would need to be implemented on the LLRF side (based on SIS and EC by-ring interlocks). Otherwise, a few cycles would be needed to re-establish a stable situation (how many?) and this should be avoided.
  - **With the reduced Linac4 current it might even not be necessary to use the feed-forward - this should be measured in autumn.**
- **The new proposed treatment of the Linac4 pulse seems possible**; we have to check that the information is received before the end of the cycle to ignore the feed-forward learning for the following cycle(s) in the case of EC or SIS by-ring interlocks. **The RF team will send some expected performance data to Alessandra Lombardi who should check that the beam performance at the end of the linac would be acceptable.**
- BE-OP should write a **specification document** for this proposed implementation and possibly organise a **review in summer** with everybody involved to discuss all potential related issues or mitigations. This will also define partly the measurement program in autumn concerning the RF.

Few items to consider for the alternative scenario (also including some input from a discussion with Jose-Luis Sanchez Alvarez):

- The chopper should be able to provide a changing pattern for instance to be able to cut the variable-in-length end of the pulse per ring. This choice may have impact on the reliability, cooling, performance of the chopper as it will have to pulse at its maximum voltage more often than originally anticipated.
- The distributor will always have to produce 150  $\mu\text{s}$  pulse per ring, with probable impact on the reliability of the equipment.
- The chopper dump will receive much more integrated intensity than for the baseline scheme.
- We will have to make sure that the RF could accept the modified timing layout and receive the input of the external conditions, the SIS and the number of turns set to be able to adapt.
- Longer pulses implies longer integration time for the BCT watchdog so they will also integrate more noise. Not a major setback, but still to keep in mind.
- Higher exposure to different chopper failure scenarios. Even for low intensity beam the full pulse will be produced and will be injected into the corresponding ring in case the chopper fails to cut out the unwanted slice of beam.