Upgrade of the Beam-synchronous RF Source System in the CERN PS

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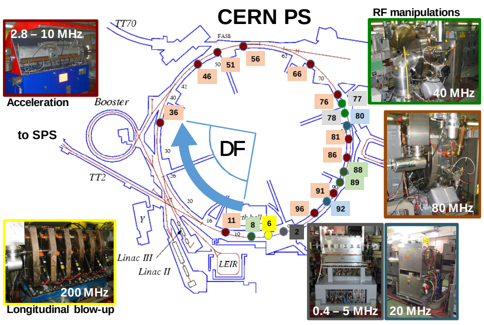
LLRF 2017
Barcelona

Abstract

For acceleration and RF manipulations the CERN Proton Synchrotron is equipped with in total 26 RF cavities in the frequency range of 0.4 MHz to 200 MHz. Eleven ferrite-loaded RF cavities cover a frequency range large enough to accelerate beams at harmonic numbers from 6 to 24. To drive the cavities and to distribute signals like the beam synchronous revolution frequency from the low-level RF system, a new master-slave RF source system has been developed and commissioned. The slave multi-harmonic sources are clocked at the 256th harmonic of the revolution frequency and are fully configurable in harmonic, azimuth and phase. Their phase accumulator always runs at the revolution frequency and is resynchronized once at fixed frequency before injection. This guarantees a well-defined phase relationship at any harmonic number for all sources, even at different physical locations. The flexible sweeping clock and synchronization scheme allows operating parts of the beam control system at different clock frequencies such that future extensions like additional feedbacks can be easily integrated.

Introduction and requirements

Circumference, 2pR:	2p · 100 m = 628.3 m
Injection energy (kinetic), E_{kin}:	1.4 GeV ® 2 GeV
Ejection energy (total), E:	14 GeV/26 GeV
Rel. mass factor at transition, g_{tr}:	6.1
Revolution frequency range, f_{rev} • Protons: • Pb^{54+} ions:	436.5…476.8 kHz 178.0…472.6 kHz
Peak RF voltage for acceleration, V_{RF}:	10 (+1) · 20 kV = 200 kV
Stable phase, f_s:	Up to ~35°



- 10 (+1) tuneable ferrite-loaded cavities, 2.8…10 MHz for acceleration
- Fixed frequency cavities at 20 MHz, 40 MHz, 80 MHz and 200 MHz for manipulations
- Finemet cavity as wide-band longitudinal kicker for coupled-bunch feedback
- **Acceleration possible at any RF harmonic from *h* = 6 to *h* = 24**

Requirements for RF sources replacing the 1st generated tagged-clock MHS [1-3]

- Generate beam synchronous RF signals at an **arbitrary harmonic number**
- Automatically **compensate time of flight** between RF stations
- **Change harmonic number** multiple times during acceleration cycle
- **Configure harmonic number, azimuth position, phase offset and delay**
- Fast, programmable **phase jumps triggered by timings**
- Generation of **integer and non-integer harmonics**

Implementation

- Modular building block in VHDL to be used as:

® **Separate RF source** driving DAC

® Numerical oscillator as **part of signal processing**, e.g., coupled-bunch feedback [4]

® **Simple, hardware-independent resynchronization scheme:**

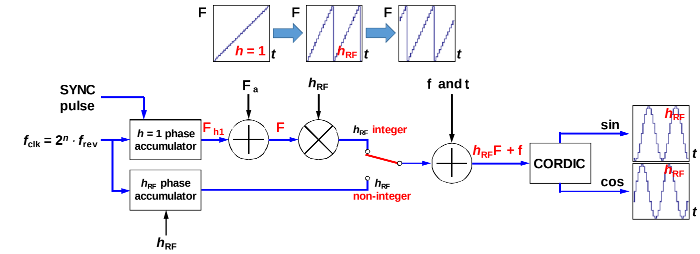
® Sweeping, **beam synchronous clock at $2^n \cdot f_{rev}$**, no clock tagging

® **Synchronization** pulse well **before injection** and **at fixed frequency**

Basic building block: multi-harmonic source

Signal processing for multi-harmonic sources (MHS)

1. Azimuth, F, accumulator **always at *h* = 1**, counting clock at $2^n \cdot f_{rev}$
2. Add **offsets**, $F = F_{a,position} + F_{a,offset}$, as azimuthal position of cavity or pick-up
3. Multiplication with integer harmonic number to **calculate RF phase, *h*F**
4. Add **phase offset, f_{offset}**, which may also contain **virtual delay, $2pf_{rev}t$**
5. Classical phase accumulator counting RF phase for non-integer harmonics
6. Logic to **handover from integer to non-integer harmonic without phase jump**
7. Standard CORDIC to translate phase in sinusoidal signals



® **All configuration parameters are programmed asynchronously:**

$F_a = F_{a,position} + F_{a,offset}$	$F_{a,position}$: **azimuth position**,	$F_{a,offset}$: **global offset**,
$f = 2ph f_{rev} t + f_{offset}$	t : **delay**,	f_{offset} : **phase offset**

® Azimuth phase accumulator **reset once at fixed frequency** before injection

® Changing harmonic number and other parameters without resynchronization

® Not necessarily a physical source: **firmware block in VHDL**

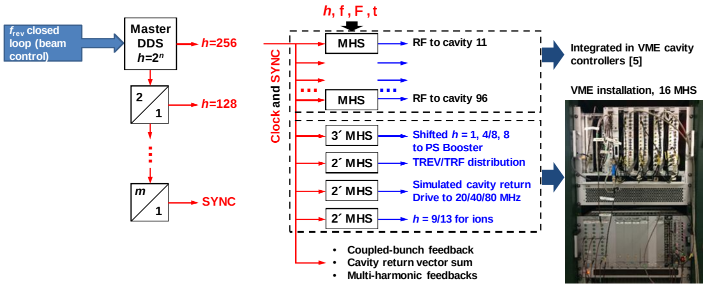
Master clock and synchronization

Master clock and resynchronization pulse infrastructure

® Each multi-harmonic source needs **sweeping, beam synchronous clock at $2^n \cdot f_{rev}$**

® **Resynchronization pulse common to all multi-harmonic sources**

® **Sources may run at different clock frequencies without loss of synchronism**



Cavity return de-phasing

Inverse multi-harmonic source system

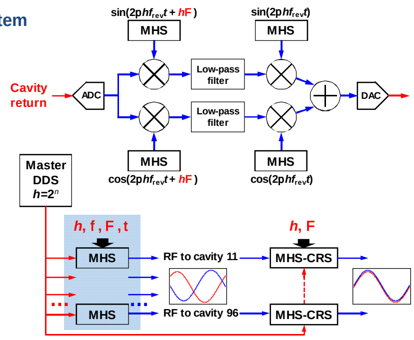
- **MHS as digital local oscillators** to down- and up-convert cavity return signals

® Programmable **sweeping phase shifter filter**

® De-phasing of cavity return signals shifts them **back in phase**

® **Automatic phase compensation according to cavity azimuth, F**

® **Simple cavity return vector sum (MHS-CRS)**



® **Successful proof-of-principle acceleration test using MHS-based cavity return**

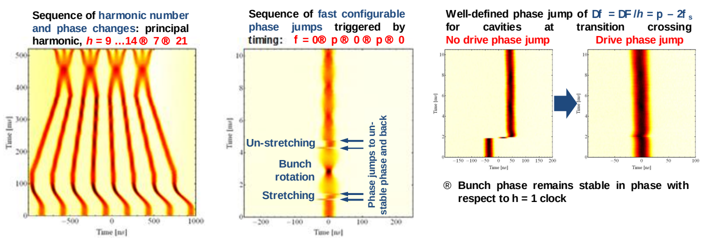
Commissioning results with beam

New multi-harmonic source system commissioned in 2017

® **Drives main accelerating cavities** with RF from integrated MHS in cavity controllers

® Temporarily **drives 20 MHz, 40 MHz and 80 MHz cavities via frequency multipliers**

® Generates all beam synchronous **signals for injection, bucket selection, etc.**



® **All RF manipulations validated ® functionality and flexibility; already >50 sources**

® **Production of all beams in the PS using new multi-harmonic source system**

Contribution ID: P-66

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[4] H. Damerau et al., Signal processing for the coupled-bunch feedback in the CERN PS, LLRF15, 2015

[5] D. Perrelet, 1-turn delay feedback module, CERN EDA-02175, 2013