Waveform needs for (selected) RF systems

considerations & examples

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Outline

1. Introduction
2. RF systems overview
3. RF levels: LLRF & HLRF
4. RF system examples: LEIR, PSB, CNAO
5. Waveform requirements - summary
6. Conclusions

Introduction

Talk partially off-topic: not Power Supply-focused!

BUT

- **RF systems:**
  - Important waveforms (or reference functions) "customer" (radial position, cavity voltage, phase control …
  - May be very demanding (implementation-dependent)
  - Joannes responsible for general controls, so topic is of interest…
- **This workshop:**
  - First iteration ➲ probably more questions than answers
  - Excellent initiative to start the ball rolling

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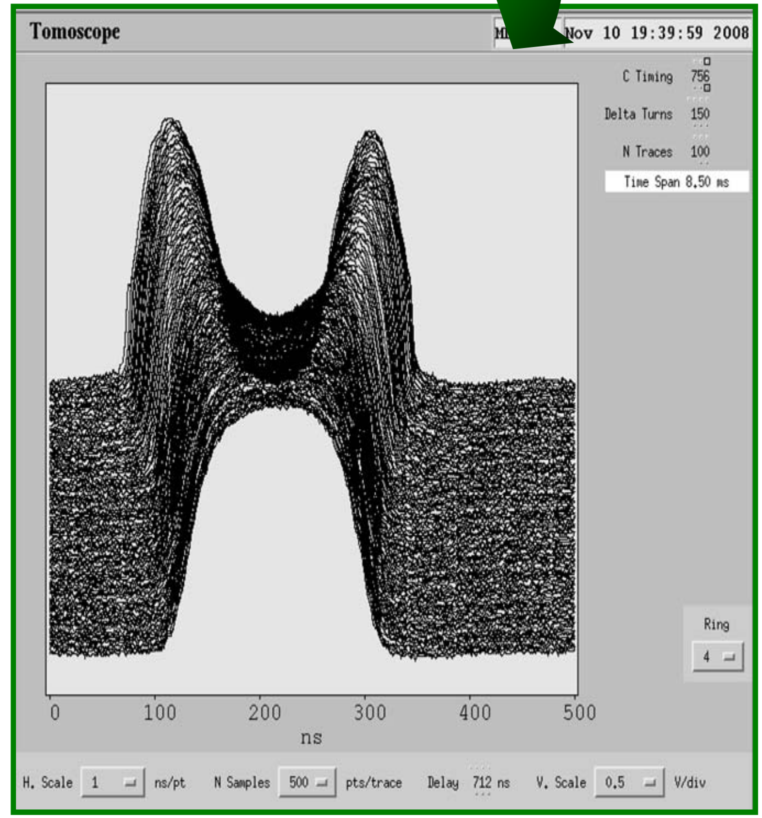
RF systems overview

- **Aim:** bunch & accelerate particles + RF gymnastics.
- Two RF parts:
  - low-level RF = low-power
  - high-level RF = high-power
- Feedforward control & feedback loops:
  - **Beam loops**: beam phase, radial, synchro … beam dynamics plays important role.
  - **Cavity loops**: voltage, tuning, fast RF feedback

Reference functions essential !

- Power supplies:
  - do no receive direct control
  - responsibility typically PO; RF specify them (with HLRF part) & use them.



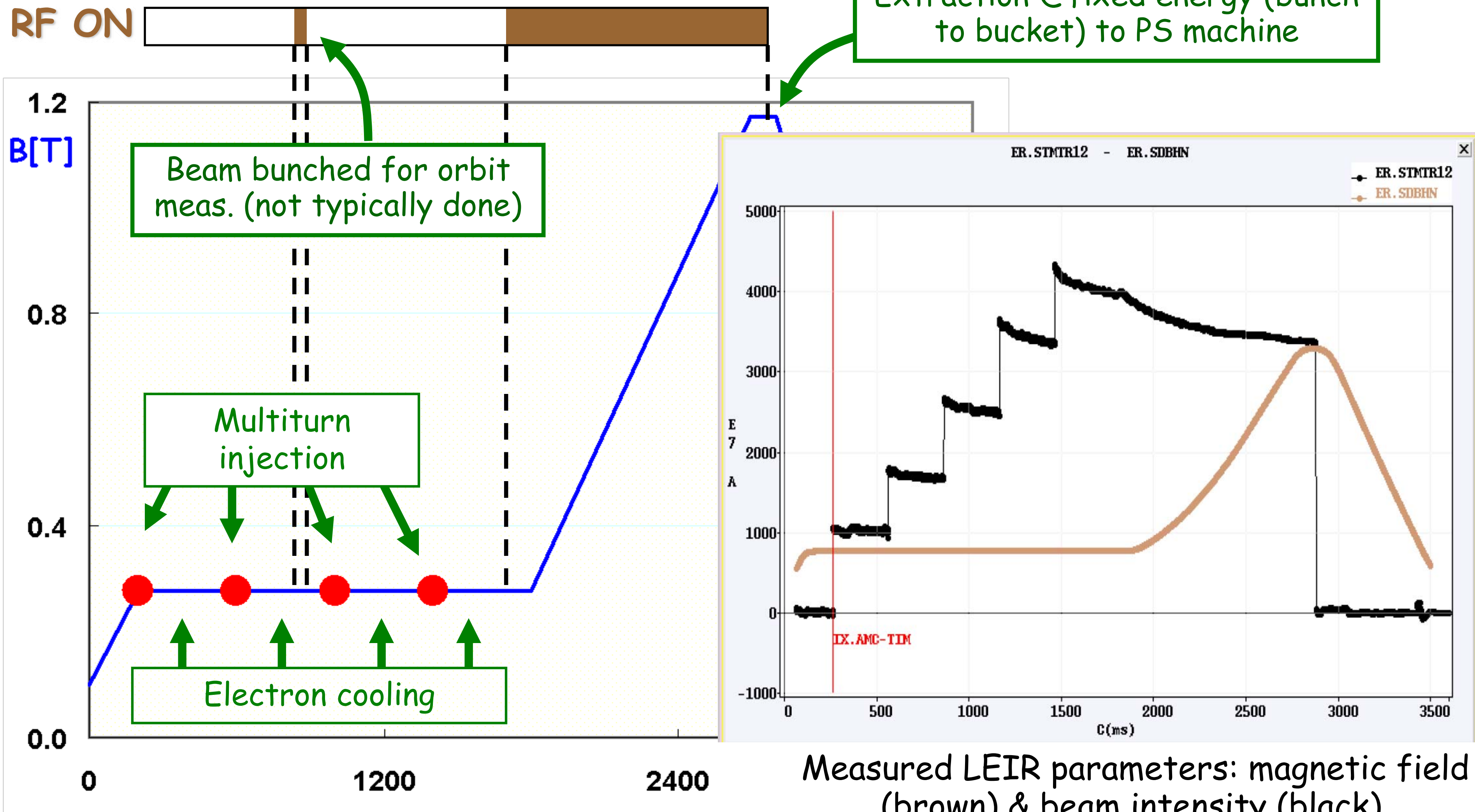
Bunch splitting process in PSB [1] – mountain range view.

RF systems overview – machines considered

- **Machines considered in this talk** : High f_{REV} + high f_{REV} swing.
  @CERN: LEIR and PSB (4 stacked rings).
- **CNAO LLRF** [2]: based upon LEIR LLRF [3] & tested on PSB [4].

Parameter		Unit	LEIR (Pb^{54+})	PSB (p)	CNAO (C_{12}^{6+})
Injection	$f_{REV,I}$	MHz	0.361	0.599	0.47
	T_I	MeV/u	4.2	49.62	7
Extraction	$f_{REV,E}$	MHz	1.423	1.746	2.756
	T_E	MeV/u	72.2	1374.2	400 (max)
Synchrotron frequency	$f_{S,MIN}$	Hz	600	470	521
	$f_{S,MAX}$	Hz	2000	2000	1450
Circumference		m	78	157	78
dB/dt		T/s	1.3 (ex)	2.3 (ex)	3 (max)
Acceleration duration		s	~1	0.5	0.77 (max)

RF systems overview: machine cycle example



Measured LEIR parameters: magnetic field (brown) & beam intensity (black).

LEIR's ***NOMINAL*** cycle - qualitative view.

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RF levels

Responsibility:	RF	RF	PO (RF)
Location:	Local CR	Ring	Ring

Low-level RF system

- Low-power system.
- Beam control loops.
- Cavity tuning & voltage loops.
- Vast majority of reference function are here.

High-level RF system

- High-power system.
- Cavity tuning & voltage loops.
- Fast analogue direct RF feedback loop.
- Interlocks for cavity protection.
- Defines power-supplies specs.

Power-supplies

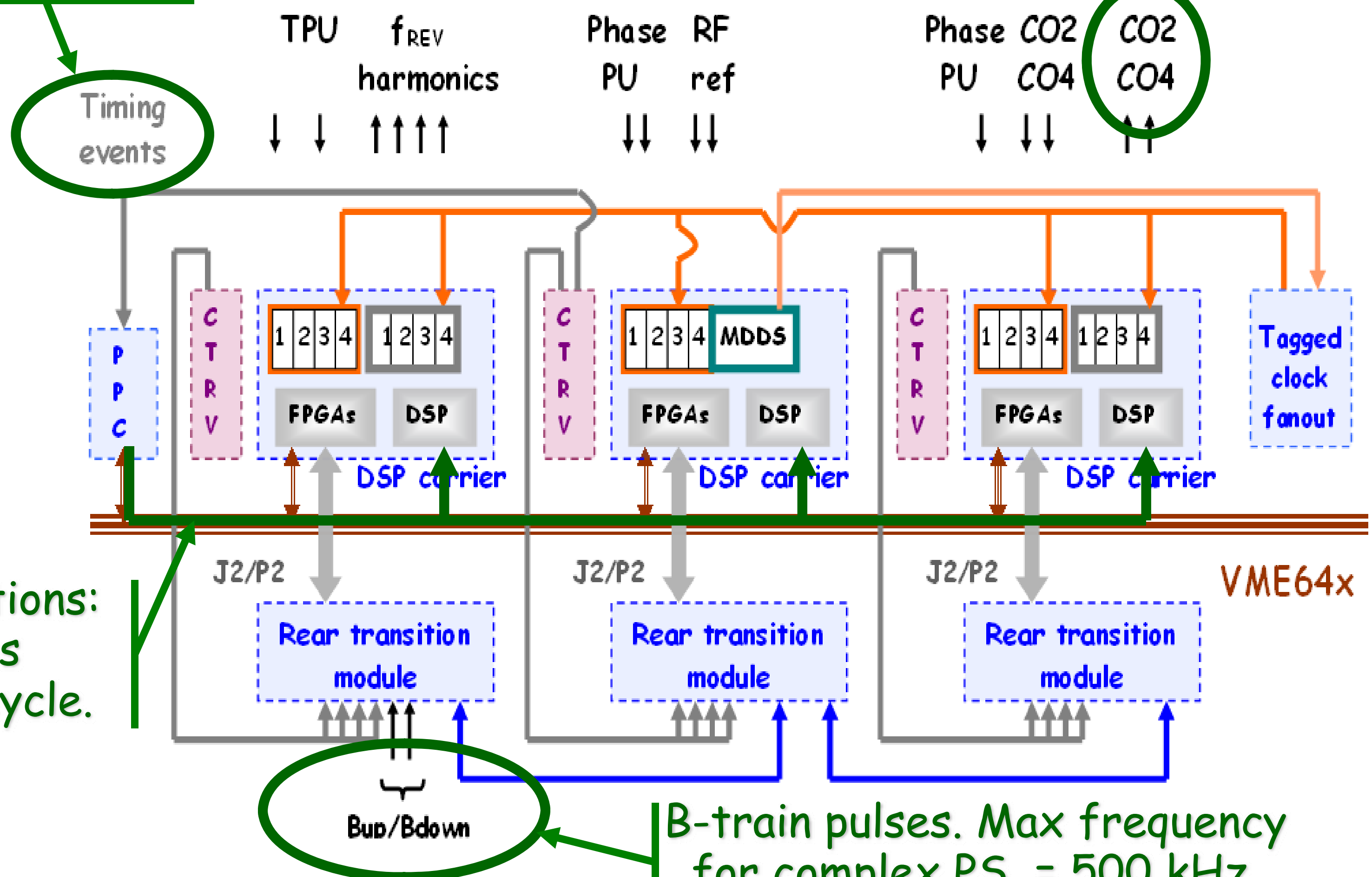
RF levels: LLRF

- **Trend**: digital implementation (powerful & flexible). Strong data processing capabilities needed [5].
- **Bus**
  - **CERN** (new systems): VME(64x) + (currently) PPC master VME.
  - **CNAO**: 25 MHz serial link (fast control) + Ethernet (slow control)
- **BTrain**
  - **CERN**: Analogue pulses (B_{UP}, B_{DOWN}), freq. up to 500 kHz, res. = 0.1 *G*.
  - **CNAO**: f_{REV} from (B_{UP}, B_{DOWN}) & distributed by serial link (300 kHz).
- **Reference functions**
  - **CERN**: Digital tables uploaded to RF system or to analogue-signal-generation h/w before each cycle (up to 200 kHz signal update rate).
  - **CNAO**: distributed via serial link (300 kHz).

RF levels: digital LLRF @CERN

Timings: analogue pulses or software events (tables). Resolution = k·μs.

Analogue signals to cavities



Reference functions: vector tables uploaded each cycle.

B-train pulses. Max frequency for complex PS = 500 kHz.

Digital LLRF system used for PSB LLRF upgrade tests (2008) [1].

RF levels: HLRF

- Often controls not directly but from LLRF only.
- Interlocks for cavity protection **must** be implemented here.
- Voltage + tuning loops typically needed.
- Defines power supplies specs., typically for CW operation.

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RF system example: LEIR

- Fully-digital LLRF [6]:
  - In 2009 to implement cavity voltage loop;
  - Short-circuits cavity in real time by gap-relay.
  - Implements cavity interlock
  - Diagnostic info: 12 signals /cycle observable out of >150.
  - Reference functions: →

Function name	Meaning
EA.FGRSTEER	Radial Steering
EA.FGFREVCORR	Frequency correction
EA.FGRLGAIN	Radial loop gain
EA.FGBEAMPOFF	Beam phase offset
EA.FGVC1H1	Cavity 1 voltage harmonic 1
EA.FGVC1H2	Cavity 1 voltage harmonic 2
EA.FGPC1H2	Cavity 1 harmonic 2 phase
EA.FGVC2H1	Cavity 2 voltage harmonic 1
EA.FGVC2H2	Cavity 2 voltage harmonic 2
EA.FGPC2H2	Cavity 2 harmonic 2 phase

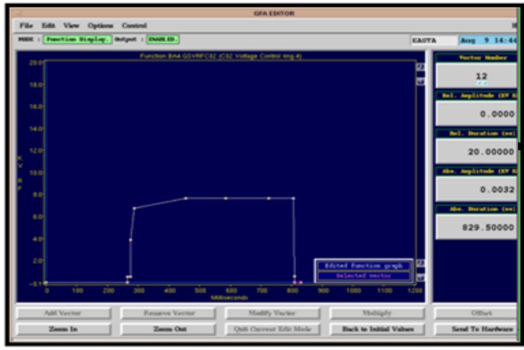
- Wideband cavity, Finemet-based [7]: tuning loop not needed.
- PLC manages cavity operation & safety interlocks.
- Remote cavity control (Level1-Level2) & observation:
  - Diagnostics signals (T, I_{ANODE}, V_{GRID} ...) to be be available asynchronously @1 Hz (FESA s/w limitation).

RF system example: future PSB

- Digital LLRF [1] to be implemented by 2014 (4 rings).
- 3 HLRF systems per ring: C02, C04, C16 [8].
- For historical reasons, power supplies under total RF responsibility.
- Tuning & voltage loops now in HLRF. Under evaluation their move to LLRF.
- Limitations and over-current protection in HLRF.
- Desired cavity voltage sent to cavity as analogue signal (200 kHz update rate).

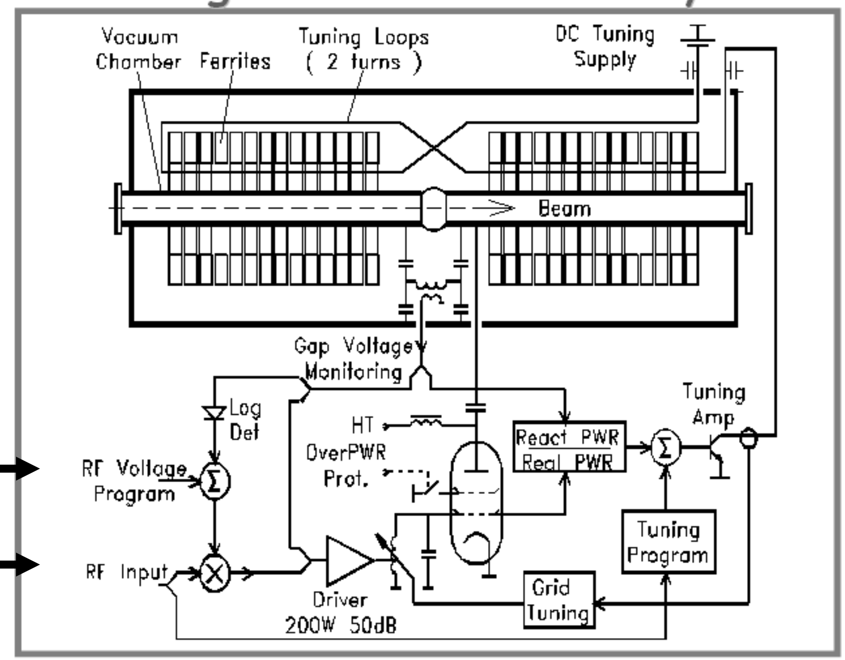
RF system example: future PSB (cont'd)

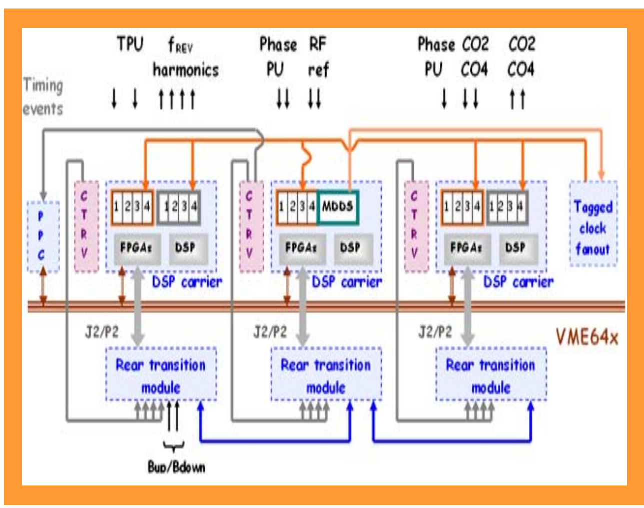
CO2 cavity voltage [kV]

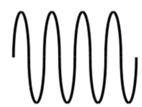


Analogue signal – update rate = 200 kHz

High-level RF CO2 cavity





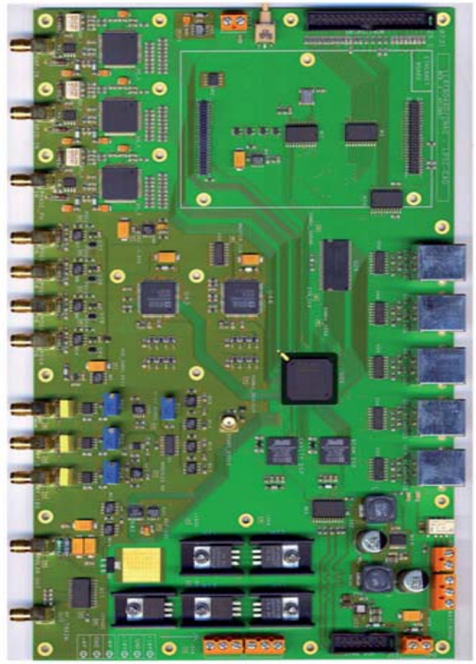


RF-modulated signal from LLRF

Future PSB RF system for CO2 cavity, one ring.

RF system example: CNAO LLRF

- Based on LEIR LLRF, built by LPSC [2] & tested on PSB ring 4 @CERN [4].
- 32-bits serial link for fast controls:
  - up to 300 kHz update rate
  - reference functions = 24 bits
  - other controls (ex: timings) = 8 bits
- Diagnostics data: acquired via Ethernet link. Data time-resolution up to 3 µs.



CNAO LLRF board [2]

- External board calculates frequency from (B-train).
- Reference functions:
  - Frequency.
  - Cavity voltage amplitude
  - Expected cavity polarisation current
  - Beam radial position
  - Stable phase program.

RF system example: CNAO cavity

- From TERA collaboration (Saturne @Saclay).
- Must stay ON for up to 10 sec (slow extraction).
- Power supply status monitored remotely.
- Diagnostics signals (I_{ANODE}, V_{ANODE} , V_{GRID} …) to be observed remotely (up to 1 kHz).

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Waveforms requirements - summary

- **Control waveforms:**
  - Up to ~200 kHz for non-B-train reference functions.
  - Non-B-train reference functions can be pre-set. Most demanding often cavity voltage (iso-adiabatic capture).
  - Depends on max dB/dt if frequency is distributed. B-train resolution of 0.1 G is "standard".
- **Observation:**
  - LLRF to provide many diagnostics data.
  - Data from cavity to be observed (up to 1 kHz observation?)
  - Interlocks HLRF.
- **Interlocks:**
  - Must be implemented in HLRF.
  - Should be implemented in LLRF, too, if possible.

Conclusions

- Waveforms needed for LLRF + HLRF. Rate & type depend on RF system implementation.
- Waveforms control: most demanding (by far) is frequency as a function of B-train.
- Observation:
  - LLRF to provide many diagnostics data.
  - Data from cavity to be observed (up to 1 kHz observation?)
- Interlocks to be implemented in HLRF and possibly in LLRF.
- Power supplies characteristics for RF system depend on HLRF. ➲ Define it asap to get info!

Thanks to M. Paoluzzi (CERN, BE/RF), M. Pullia (CNAO), L. Falbo (CNAO) for useful discussions.

References

[1] M. E. Angoletta, A. Blas, A, Butterworth, A. Findlay, F. Pedersen, ***"PSB LLRF Renovation: Initial Beam Tests of the New Digital Beam Control System"***, BE/RF note under publication.

[2] O. Bourrion, D. Tourres, C. Vescovi, LPSC, ***"LLRF Electronics for the CNAO Synchrotron"***, EPAC '08.

[3] M. E. Angoletta, J. Bento, A. Blas, J. H. Delong (BNL), A. Findlay, P. Matuszkiewicz, F. Pedersen, A. Salom-Sarasqueta, ***"PS Booster Beam Tests of the New Digital Beam Control System for LEIR"***, AB-Note-2005-017-RF.

[4] M. E. Angoletta, A. Findlay (CERN), O. Bourrion, R. Foglio, D. Tourres, C. Vescovi (LPSC Genoble), L. Falbo, S. Hunt (CNAO), D. DeMartinis (INFN), ***"CERN PSB Beam Tests of CNAO Synchrotron's Digital LLRF"***, EPAC '08.

[5] M.E. Angoletta, ***"Digital Low-Level RF"***, EPAC '06.

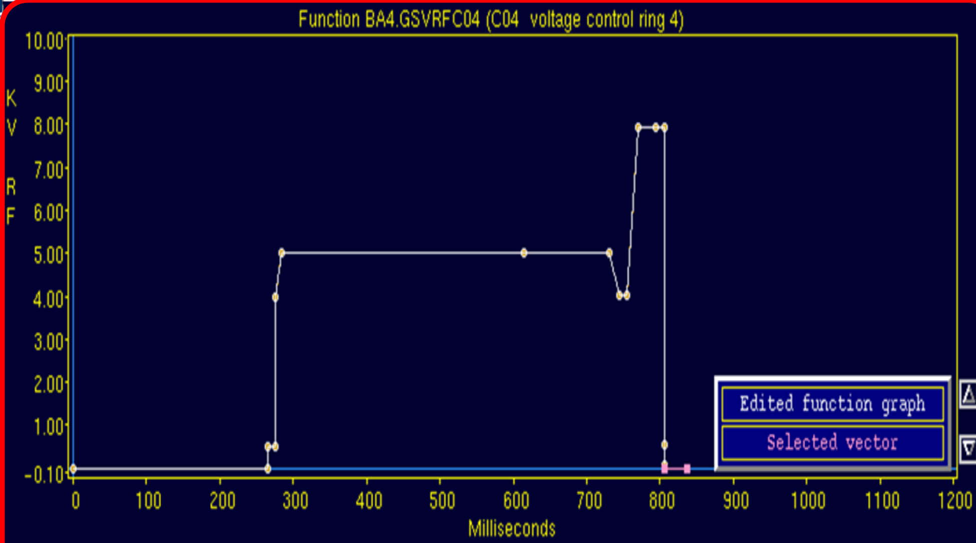
[6] M. E. Angoletta, A. Findlay, ***"First Experience With The New LEIR Digital Beam Control System"***, AB-Note-2006-003-RF.

[7] A. Krusche, M. Paoluzzi, ***"The New Low-Frequency Accelerating Systems for the CERN PS Booster"***, EPAC '98..

[8] R. Garoby, M. Haase, M. Paoluzzi, C. Rossi (CERN), C. Ohmori (KEK), ***"The LEIR RF System"***, PAC '05.

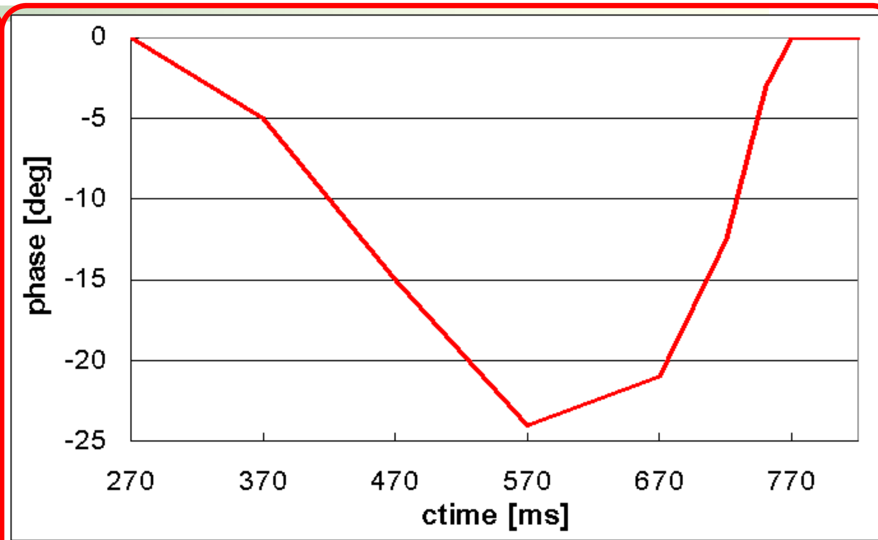
Additional slides

RF levels: example of RF ref. functions



CERN PSB C04 voltage for bunch-splitting.

Analogue voltages (5 µs period) generated by dedicated hardware. (GFAS).



CERN PSB C04 phase wrt C02 phase.

Software tables used in LLRF loops.

NB: Reference functions above

- Uploaded to h/w <u>before</u> each cycle
- Used by CERN Meyrin machines.
- Don't include B-train-related params.