Test Setup for Phase and Position Measurements with Libera Single Pass H*

M.Cargnelutti, M.Žnidarčič, D.Tinta, Instrumentation Technologies, Solkan, Slovenia

Abstract

The instrumentation used in particle accelerators is designed to work in specific conditions and to satisfy the expected performance requirements which are defined a long time before the machine starts to operate. These conditions include the properties of the input and output signals and the environment operating conditions.
A test setup is a smart way to simulate this set of conditions, enabling the evaluation of the instrument performance without the need of the real beam. However, finding the appropriate setup is not trivial, many effects which are not related to the instrument can influence the measurements, e.g. the noise figure of the active components or the impedance mismatching. This poster describes some of the significant issues faced during the evaluation of Libera Single Pass H at the European Spallation Source (ESS).

Introduction

Libera Single Pass H is an instrument intended for phase, position and charge monitoring in hadron and heavy ion LINACs. The device measurements are based on the analysis of two frequency components (i.e. first and second) of the RF signals induced by the beam on the BPM pickups. Position is computed from the BPM inputs using delta over sum formulas while phase is evaluated comparing the BPM signals with a fifth reference input.
The instrument evaluation was carried out at ESS laboratory, to prove the feasibility of operation with ESS beam conditions and requirements, reported in Table 1.
In the overall time frame of 25 working days, almost half of the time was spent to establish the measurement setups and to fine tune them. This gives a picture about the importance of this task, essential to evaluate the real instrument performance.

Parameter	Value	Unit
RF frequency	352.21 and 704.42	MHz
Pulse repetition rate	14	Hz
Pulse duration	2.86	ms
Position meas. range wrt beam pipe	50	%
Phase meas. range	+/- 180	deg
Max input signal level (off-centered)	-3.55 (5.17)	dBm
Min input signal level (off-centered)	-27.98 (-36.7)	dBm
Position measurements accuracy	100	µm
Position measurement resolution	20	µm
Phase measurement accuracy	1	deg
Phase measurement resolution	0.2	deg

Table 1: ESS BPM signal conditions and performance requirements

A generic test setup

The role of a test-setup is to emulate the signals coming from the pickups of the BPMs in the real accelerator. There are several things to consider to establish a good setup. Signal level, harmonic content and the impedance matching between all the components are just examples. Furthermore, mechanical stability of devices and wires is essential.

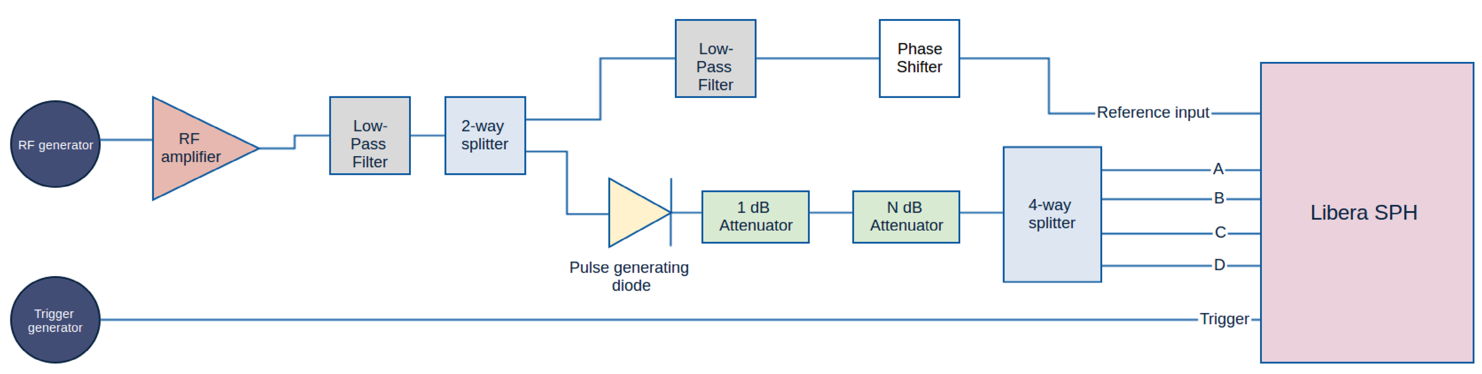

Figure 1: Basic setup for the phase measurements evaluation

Figure 1 presents a test-setup used for the phase measurements. The RF signal is generated and amplified by the RF amplifier. A low-pass filter cleans out the spurious harmonics eventually introduced by the amplifier. The signal is then split in two: the first part is the reference input for the instrument while the second provides the instrument inputs. The role of the pulse generating diode is to simulate the beam signal, later on there is place for attenuators used both to reduce the effect of the impedance mismatching and to control the instrument input level. The trigger signal is a square signal with ESS macropulse repetition frequency . With the phase shifter on the reference path it is possible to change the phase relation between reference and input signals.

Quality of the RF signal

The first thing that might impact the instrument performance evaluation is the RF signal quality, in particular the high noise level and the RF frequency instability. Possible sources of these undesired phenomena are the RF generator and RF amplifiers.
Figure 2 presents in the first two plots the down-converted amplitude signals acquired from Libera SPH, achieved using two Mini Circuits RF amplifiers: TVA-R5-13 and ZRL-700+. Even though the first one provides an higher signal level, the performance is worse. Signals are noisier and there are spikes which might be related to RF frequency instabilities. In the third plot the noise level at the output of both RF amplifiers is compared.

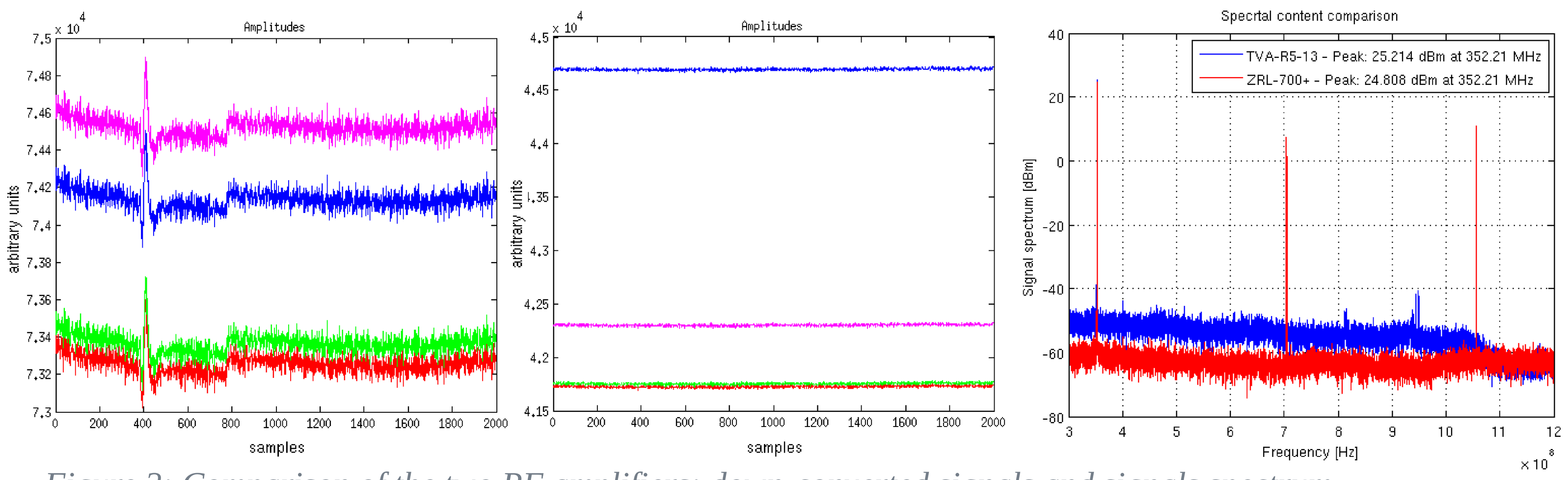

Figure 2: Comparison of the two RF amplifiers: down-converted signals and signals spectrum

The second evaluation is performed using another RF generator (Anritsu MG3692C instead of the TTi TGR2050) combined with the ZRL-700+. The Anritsu generator provides lower noise level and stable frequency. Table 2 presents the resolution of phase and position measurements in three cases, evaluated calculating the standard deviation over 2000 samples.

Setup combination	σ_{ph1} [deg]	σ_{ph2} [deg]	σ_{x1} [µm]	σ_{x2} [µm]	σ_{y1} [µm]	σ_{y2} [µm]
Arnitsu MG3692C and ZRL-700+	0.01	0.06	0.55	4.1	0.5	5.0
TTi TGR2050 and ZRL-700+	0.02	0.11	0.7	3.73	0.5	4.8
TTi TGR2050 and TVA-R5-13	0.07	0.39	2.61	6.10	1.14	9.44

Table 2: Resolution (1st and 2nd harmonic) with different RF generator and RF amplifier combinations

Impedance matching

The characteristic impedance of wires and devices used in the setup is 50 Ohm but components like the diode and the RF amplifier are inherently not perfectly matched. The impedance mismatch generates reflected waves which combine with the incident ones influencing the phase measurements. This can be reduced putting some attenuation either before or after the critical components: in this way the reflected waves are attenuated twice.
Figure 3 presents a phase stability evaluation. It is expected that the phase measurements are not influenced by the input signal level. The left plot shows results achieved with the test-setup in Figure 1, where only 1 dB attenuator is used. The other shows the measurements gathered using a setup where more attenuation is put after the preamp and the diode.

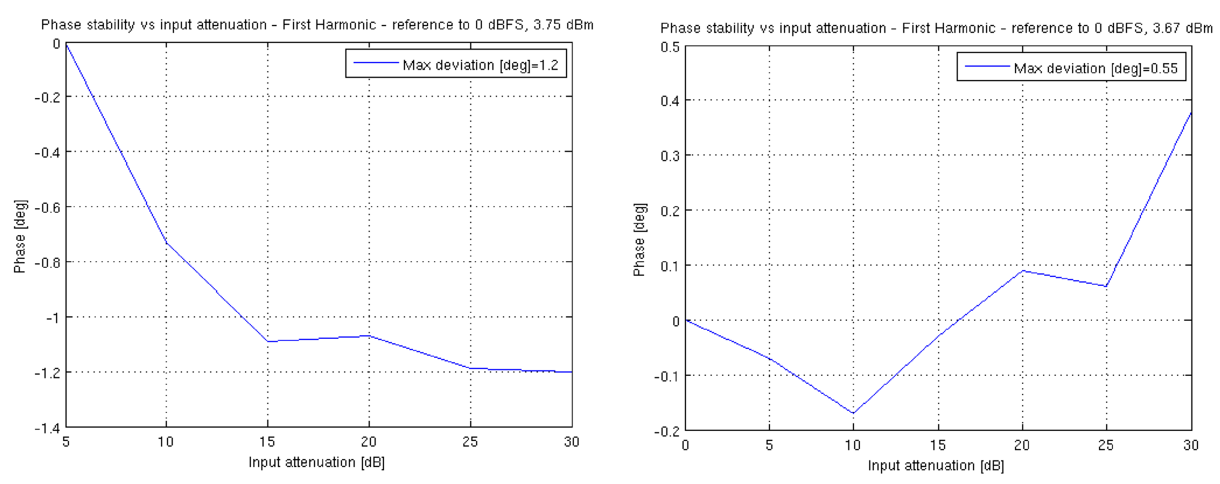

Figure 3: Phase stability measurements using two different test-setups.

Mechanical and temperature stabilization

The phase measurements with Libera Single Pass H, are sensitive to the mechanical stability of the test setup and to the thermal stability of its components. If a wire is bended it accumulates mechanical strengths that require some time for being released, and during this time all the measurements might have drifts due to the strengths relaxation. Drifts can also be observed during the warm up phase of the setup components: temperature has to stabilize. An practical example is provided in Figure 4, where a long-term analysis was started just after the test setup was assembled and devices turned on.

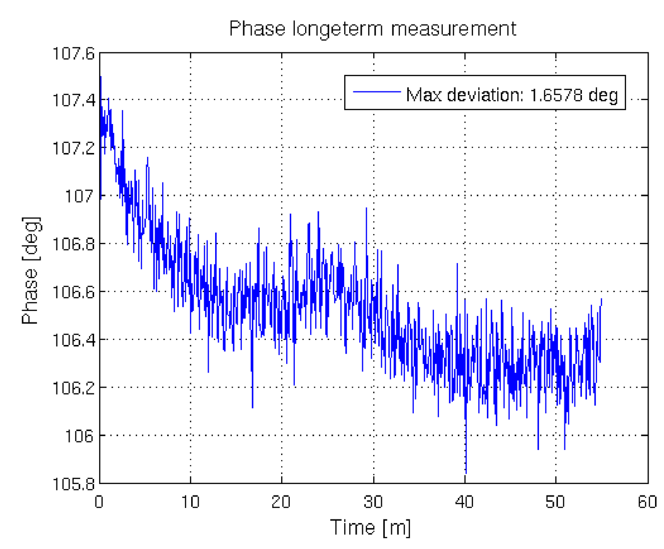

Figure 4: Phase measurements during the setup stabilization.

Conclusions

The evaluation of the performance of an instrument supposed to be used in the machine is important and takes place long before the machine gets operative. In this scenario test-setups are an efficient way to simulate the working conditions which are foreseen for the accelerator, and the measurements provide useful information on the status of the development. Nevertheless, assembling the setup requires time and effort, and neglecting this might lead to results which are far from the real performance of the instrument.
This poster presents several side effects related to the test-setup establishment, based on the experience of the measurements carried out with Libera Single Pass H at ESS laboratories. Considering all these effects and the way to avoid them substantially improved the achieved results.

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Instrumentation Technologies, d. d.,
Velika pot 22, SI-5250 Solkan, Slovenia, **P**: +386 5 335 26 00, **F**: +386 5 335 26 01,
E: info@i-tech.si, sales@i-tech.si, support@i-tech.si, **W**: http://www.i-tech.si

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