THE LHC BEAM PRESENCE FLAG SYSTEM

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Abstract

Before injecting high intensity bunches into the LHC a circulating low intensity pilot bunch must be present to confirm the correct settings of the main machine parameters. For the 2010 LHC run the detection of this pilot beam was done with the beam current transformer system. To increase the redundancy of this important safety function a dedicated beam presence flag system was designed, built and tested with beam to be operationally used in the 2011 run. In this system signals from four electrodes of a beam position monitor (BPM) are processed with separate channels, resulting in a quadruple system redundancy for either LHC beam. Each system channel converts a BPM signal into two logic states, which are then transmitted optically to the machine protection and interlock systems. For reliability the system does not have any remote control or adjustable elements and its only inputs are the beam signals. This paper describes the new LHC beam presence flag system, in particular the analogue front-end based on diode peak detectors.

INTRODUCTION

The described beam presence flag (BPF) system is based on signals from two short-circuited stripline BPMs, one for each LHC beam (BPMC.8R4, electrode distance of 48 mm, length of 150 mm). Using a BPM with four electrodes allows quadruple redundancy of the signal source. However, the electrode signals change with the beam position and to make the BPF threshold levels more beam position independent, the signals from the opposing electrodes are combined and split, as shown in the system block diagram in Fig. 1. For increased robustness the BPM signals are attenuated, limiting the power on the combiners and the following electronics.

The BPM signals for both LHC beams (B1 and B2) are converted into logic signals by two BPF front-end (FE) units, each having 4 identical channels. The resulting 8 logic signals, 4 per beam, are transmitted independently to 4 beam interlock user interfaces, CIBFs [1], with two channels each. The CIBF is a standard building block of the LHC interlock system [2], which receives 2 electrical interlock signals and transmits them through optical links to the interlock system. Only there the 4 independent BPF signals of each beam are combined to a single beam presence flag used in the LHC interlock system.

The chosen distribution of the BPM signals, BPF FEs and CIBFs guaranties that a malfunctioning of one of the system modules will not enable high intensity injections for either beam even if the module gives the unsafe spurious state 'BPF = *true*' while there is no beam in the machine. Malfunctioning with the spurious state 'BPF = *false*' with some beam in the machine would only disable high intensity injections and is considered safe.

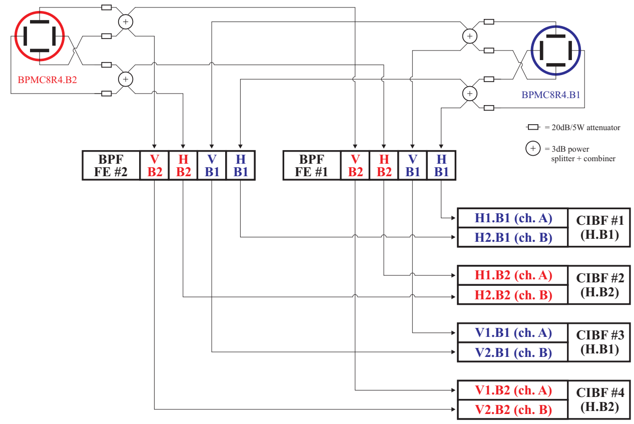

Figure 1: Architecture of the LHC beam presence flag system based on BPM signals.

BPF FRONT-END

The BPF FE is designed for robustness and simplicity and therefore relies only on beam signals. In particular, it does not depend on any interfaces for remote control, calibration or testing. Therefore, it must give 'BPF = *true*' state for all possible LHC beam configurations with unique gain. This implies operation with a small signal for the pilot beam and potential overdrive on the input with the nominal intensity, requiring special protection for the first FE amplifier.

The transition of the output logic states from 'BPF = *true*' to 'BPF = *false*' (T-F) must be generated no later than a few revolution periods after the beam intensity goes below the threshold considered as the limit for safe machine operation (about 10^9 charges). This is required to minimise the probability of injecting high intensity just after the pilot beam has been lost. The opposite transition from '*false*' to '*true*' (F-T) can take place even a second after the pilot bunch has been injected.

The block diagram for one BPF FE channel is shown in Fig. 2, alongside with sketches of signal waveforms in the most important nodes of the circuit.

First the BPM electrode signal, attenuated and combined as described before, is routed through the constant-impedance low pass filter (LPF). Its cut-off frequency of about 150 MHz was chosen to match the BPM signal to the bandwidth of the following stages, in particular of the insulation transformer. The transformer provides a galvanic insulation between the input coaxial cable shields at the LHC vacuum chamber ground and the FE ground, suppressing ground currents on the input cables. Its role is very important, as the system has large gain and even small interference at the input should be avoided. The transformer is followed by a 40 dB amplifier, built with two fast operational amplifiers (op-amps). For increased robustness, on its high

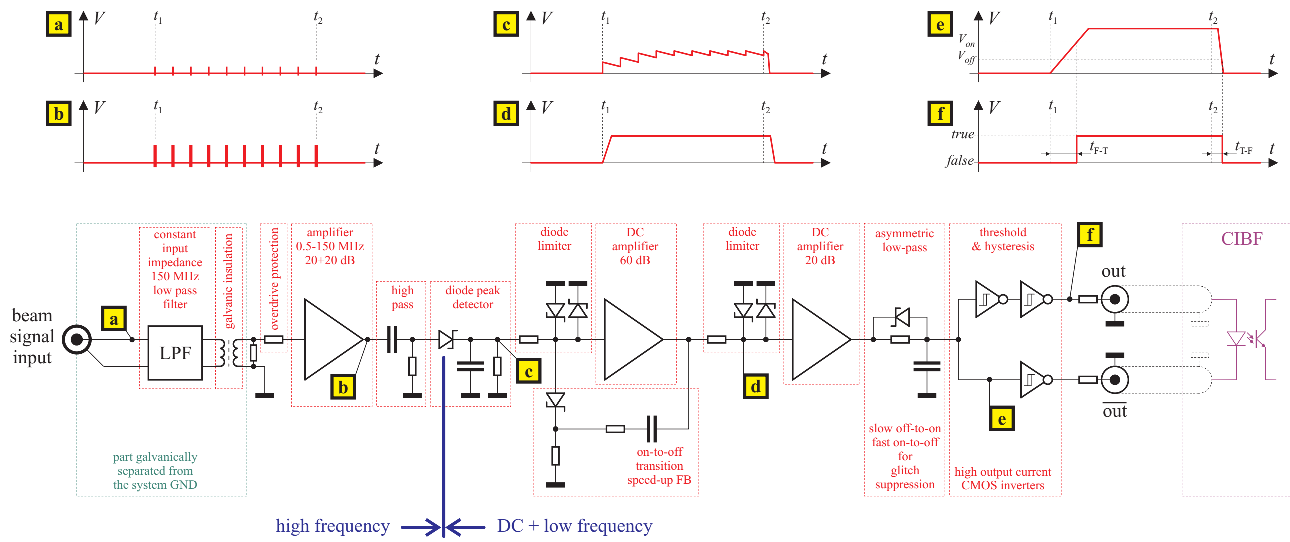

Figure 2: Functional diagram of one channel of the beam presence flag front-end with sketches of signal waveforms in the most important nodes of the circuit. Each FE unit has 4 identical channels.

impedance input there is a protecting series resistor, placed after the transformer termination to conserve good matching even if the op-amp input is heavily overdriven, resulting in signal clamping. The op-amps are powered through relatively large resistors to lower the power supply voltage when the supply current increases due to an overdrive on the output or input.

The amplifier is followed by a simple CR high pass filter improving rejection of low frequency interference, in addition to the transformer and series capacitors between the amplifier stages. The resulting signal goes to the diode peak detector with the RC filter having a time constant of several machine revolution periods. The detector samples the beam pulses at their maxima and holds the voltage between the pulses. Even for the worst case of a single bunch in the machine the ripple on the detector output voltage stays small with respect to the hysteresis of the output CMOS inverters and this way the '*true*' logic state at the FE output persists between the bunches.

The diode detector output voltage is clamped with the subsequent diode limiter, whose main function is to keep the detector voltage small even for large input amplitudes, allowing faster signal decay and therefore faster T-F transitions. Then the signal is amplified with a 60 dB DC amplifier built with a precision op-amp. Its positive feedback loop is enabled only by a diode for fast decaying signals, to speed-up T-F transitions. Once the beam signals become sufficiently small, the amplifier output voltage goes out of the saturation and starts decreasing. This change is fed back to the input, to accelerate the discharge of the capacitor of the diode detector.

Next the signal is limited and amplified, before going through a simple RC low pass filter, with a large time constant for F-T and small for T-F transitions. The filter, referred to in the paper as an asymmetric low-pass filter (ALPF), has some 100 ms time constant for rising signals. Thus, a shorter interference or glitch will not trigger the '*true*' state, making the system very robust for such perturbations. The filter is practically disabled for the critical T-F transitions by the diode parallel to the resistor.

The output of the ALPF drives CMOS inverters producing differential output logic states. These signals are sent to a CIBF as currents driving differentially the LED of its input optocoupler. The inverters have input hysteresis so that even a very slow beam intensity change gives a single transition of the output state.

The BPF FE is housed in a 1U 19" unit accommodating four identical channels. The circuits are powered with two redundant switching power supplies, each having 75-year mean time between failures. The supplies are connected independently to two 230 V sockets receiving power through two residual current circuit breakers. Due to the large system gain the quality of the power supplies is very important, so the switching power supplies are followed by low drop linear regulators. Their filtering capacitors are oversized so that the FE operation is not perturbed by power cuts lasting less than a second.

For increased reliability, all op-amps used are powered at half of their nominal power supplies, namely ±7.5 V. If one of these voltages is not present, the 5 V power supply of the output CMOS inverters is turned off, forcing the system output to the safe '*false*' state.

The BPF FE has buffered diagnostic outputs for monitoring analogue and logic signals as well as power supplies.

MEASUREMENTS

The functionality of the BPF FE is demonstrated with the following measurements. Figure 3 shows an oscilloscope measurement of the worst-case T-F transition. The beam was simulated with a train of short pulses, stopped for the measurement (channel 1, yellow waveform). This caused signal decays at the DC amplifier output (ch. 3 in blue), at the inverter input (ch. 2 in magenta) and finally triggered a T-F transition at the system output (ch. 4 in green). The delay between the last

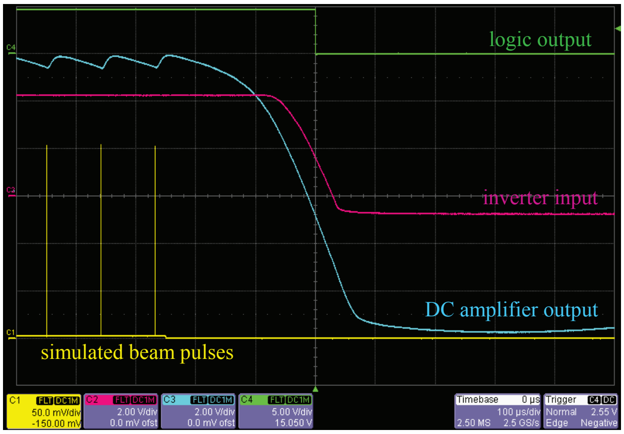

Figure 3: Signals for the worst case ‘*true*’ to ‘*false*’ transition. The actual FE input voltage is 40 dB smaller.

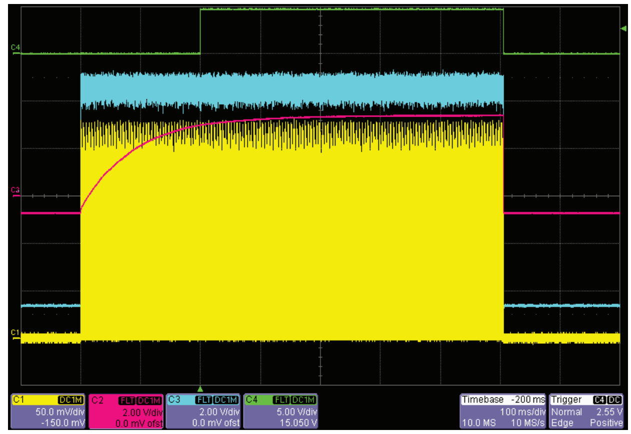

Figure 4: Signals for ‘*false*’ to ’*true*’ and ‘*true*’ to ‘*false*’ transitions, scope channel distribution as for Fig. 3.

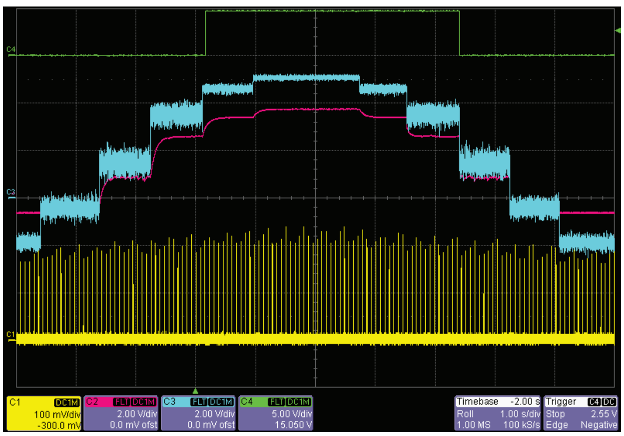

Figure 5: Signals for simulated gradual intensity increase and decrease, scope channel distribution as for Fig. 3.

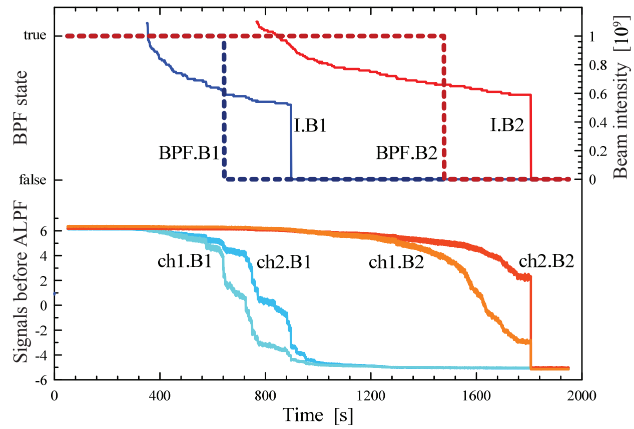

Figure 6: Beam measurement of the BPF system thresholds.

input pulse and the output transition is about 270 µs, that is about 3 LHC revolution periods. This is the worst case, as for smaller input signals the detector voltage is also smaller and the capacitor discharge faster. For larger input signals the speed-up feedback works efficiently, accelerating the detector capacitor discharge.

Figure 4 shows F-T and T-F transitions with the scope channel assignment as before and the same input signal, but on a thousand times longer time scale. Figure 5 presents F-T and T-F transitions for the amplitude of the input signal changing in small steps. The steps are better seen on the processed signals than on the input, as the pulses simulating the beam signal are very short with respect to the scope horizontal scale of 1 s/div.

Figure 6 shows signals acquired while the T-F thresholds were measured with the LHC beams. The upper plot shows the beam currents measured for both beams (I.B1, I.B2) together with the beam presence flags (BPF.B1, BPF.B2). It can be seen that the T-F transition thresholds are about 0.6×10^{9} charges and, despite the very slow beam current decay, there is just one clean transition for each beam. The lower plot shows the corresponding analogue signals on the inputs of the asymmetric low-pass filters that are buffered and connected to the monitoring FE outputs. There are shown signals from only two channels per beam, as they were acquired with a 4-channel oscilloscope.

CONCLUSIONS

The design of the beam presence flag analogue front-end was optimised for reliability, with the beam signals as the only input. The front-end does not have any interface for remote control, calibration or testing and does not use any programmable devices or adjustable components.

Its two units installed in the LHC tunnel use signals from BPM electrodes and provide 4 redundant logic signals per LHC beam. The signals are transmitted optically to the machine interlock system and enable high intensity beam injections. The front-ends are operational since the beginning of the LHC 2011 run, providing reliable beam presence flag signals to the LHC machine protection and interlock systems.

REFERENCES

[1] B. Todd et al., “User Interface to the Beam Interlock System”, EDMS 636589, CERN, 2006.

[2] B. Puccio et al., “The CERN Beam Interlock System: Principle and Operational Experience”, IPAC’ 10.