# The PS Ejection Kicker KFA71-79 Performance for LHC

**K. METZMACHER, L. SERMEUS**

CERN, CH-1211 Geneva 23, Switzerland

## 1. INTRODUCTION

To satisfy the stringent beam parameter specifications for the CERN Large Hadron Collider (LHC) project [1] a kick pulse shape improvement of the PS ejection Full Aperture Kicker (FAK) KFA71-79 is required.

The kicker systems, installed in 1973 (KFA71)[2] and 1977 (KFA79) have performed well up to now with previous SPS and LEP beams, but measurements and calculations made in the late nineties have shown that the kick pulse shape would not satisfy the foreseen LHC proton and ion beams.

This note describes briefly the improvements made so far to the high and low voltage parts of the system and gives an overview of its enhanced performances.

## 2. BEAM REQUIREMENTS

As the final proton and ion beam parameters are not yet definitive, the kick rise time figure used for this study was the original 120ns from .5% to 99.5% with a flat top ripple less than 1% peak to peak (p-p). The fall time is not a matter of concern because the PS machine is emptied at each ejection.

## 3. SYSTEM OVERVIEW

The kicker system consists of twelve magnet modules; nine are located in a vacuum tank in section 71 and three in section 79.

The magnets are of cellular, closed aperture, C-ferrite loaded transmission line type construction. Their characteristic impedance is 15Ω.

Each magnet module is supplied by a dedicated high voltage generator whose simplified layout is shown in Fig. 1.

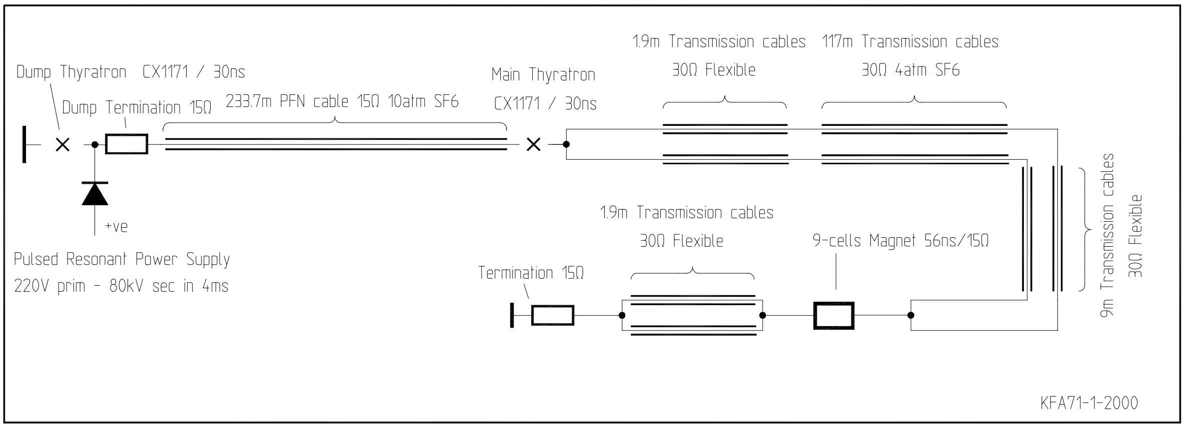


**Fig. 1.** Schematic representation of one ejection module.

The high voltage generator consists of a ~235m $SF_6$ filled Pulse Forming Network (PFN) cable, resonantly charged in 4ms to a maximum voltage of 80kV. The PFN is discharged by a Main Switch (MS) thyratron into the magnet and its terminating resistor via two paralleled $SF_6$ filled transmission cables (Tx). Connections between MS, Tx, magnet and magnet terminator are made via flexible 30Ω cables (two in parallel). The other end of the PFN is connected to a terminating resistor and a Dump Switch (DS) thyratron that allows for kicker pulse length adjustment and added security in case of magnet breakdowns.

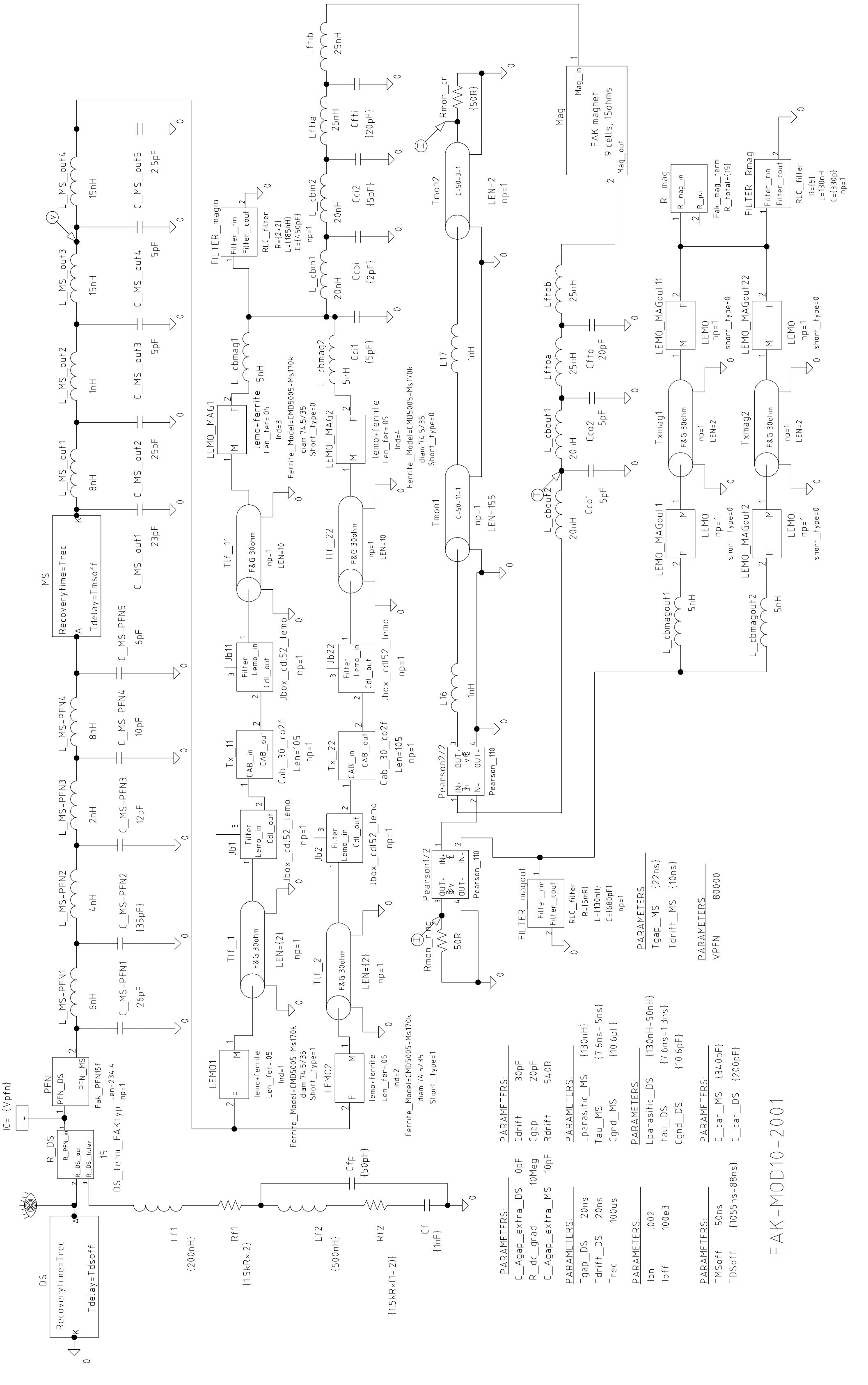


**Fig. 2.** PSPICE schematic circuit for KFA79-Mod10

## 4. KICKER SYSTEM MODELLING

When the kicker system was designed in the seventies for large cross-section beams, kick rise time and flat top uniformity were not so important as they are today. Rise time definitions of (5-95)% or (10-90)% are no longer valid for micrometer beams when the beam emittance blow-up has to be kept to a minimum. A (.5-99.5)% or (1-99)% definition has now to be applied.

This also means that simple simulation models used thirty years ago with very limited dedicated home made programs or commercial ones like ECAP (limited to 50 nodes) and later SPICE have to be replaced by more precise ones to be used in modern simulators like PSPICE.
In order to reach a calculation precision of 1% in fast pulsed kicker systems, each component has to be modelled accurately, including stray inductances and capacitances.
Much simulation work has been performed at TRIUMF (Canada) and CERN in order to improve those models. Other improvements were made by program vendors like MICROSIM (now CADENCE) in order to model accurately lossy cables or saturable ferrite inductors.

Fig. 2. shows the system schematic used for PSPICE simulations. This schematic is hierarchical and each block may contain several sub-circuits.

Calculations made with an up to date model of the system have shown that the rise time (5-95)% given in the WWW kicker data table [3] was misleading. Indeed, the true rise time (5-95)% was 140ns because of the "big hole" down to 91% after the first peak at the 95% level. The rise time (.5-99.5)% was 312ns (far from the 120ns now allowed) because of an important pre-pulse current generated by the consecutive closing of the three gaps of the main switch thyratron. (Fig. 3.)

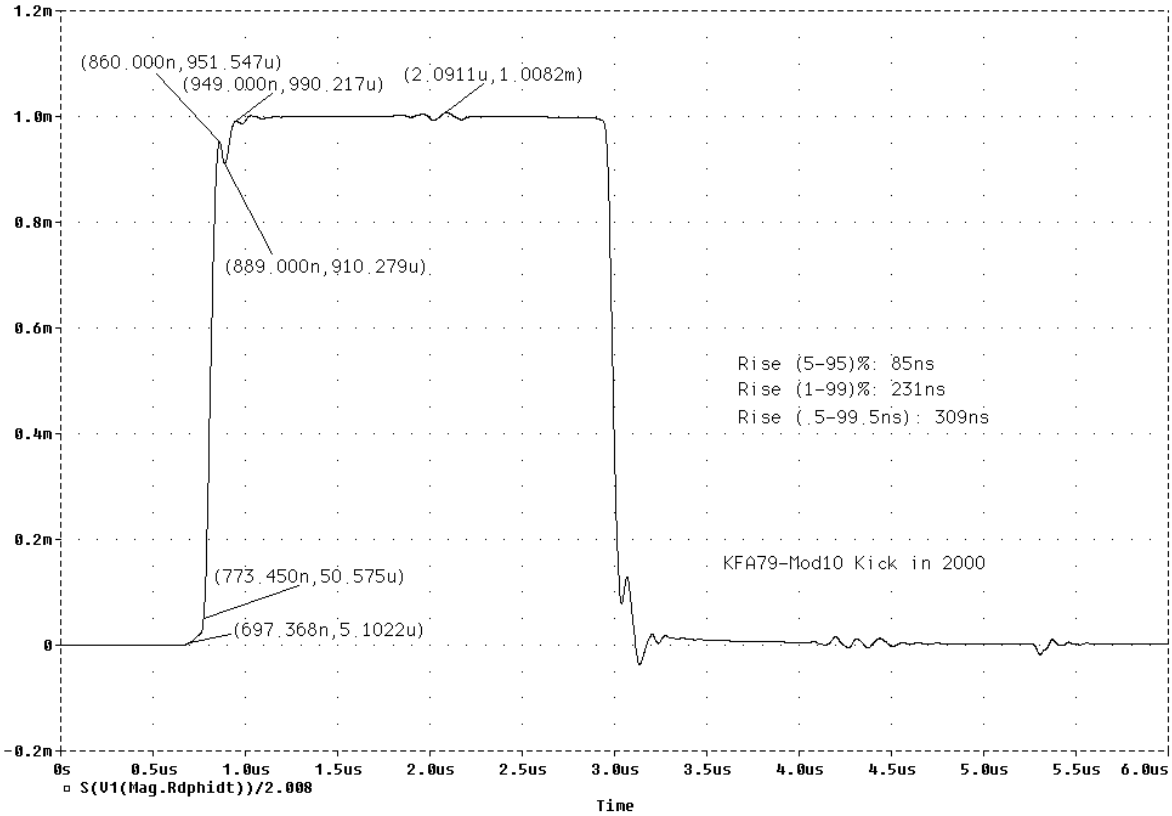


**Fig. 3.** KFA79-Mod10 kick pre-2001 (data couples indicate time and amplitude on the graph)

## 5. KICK WAVEFORM IMPROVEMENTS

Previous studies [4] have shown that the thyratron pre-pulse current could be reduced to an acceptable level by the use of ferrite saturating inductors which represent a high impedance to this small pre-pulse current, then saturate in a few nanoseconds and let the main thyratron current pass through. A further advantage of ferrite use is pulse shaping, resulting in faster leading edge current wave supplying the magnet. Nevertheless, the latter benefit may cause some ripple on the kick flat top if the magnet bandwidth is not large enough.
CMD5005 (from Ceramic Magnetics Inc.) ferrite tubes (OD=74.5mm, ID=35mm, L=50mm) have been placed around the main switch Lemo connectors (cathode side) and around the magnet connection box input Lemo connectors to reduce the pre-pulse amplitude of the kick below .5% of the main pulse.

The "knee" observed on the kick leading edge is mainly due to the series connection of $SF_6$ transmission cables, 9m flexible cables, magnet, 2m flexible cable and magnet terminator. The suppression of flexible cables would have improved the situation but this solution cannot be applied here because of mechanical and space constraints.
A suitable solution to the correct matching of all these elements has finally been found by the connection of R, L, C filters at magnet input, output and terminator input. To allow the connection of these filters, magnet and terminator connection boxes have been redesigned. Magnet connection boxes, which where previously filled with insulating oil (Apiezon C) to hold the 40kV pulse applied are now pressurised with 4 bar of $SF_6$.
This change to a gas avoids possible severe pollution of the machine vacuum in case of a magnet high voltage feedthrough leak.

In order to improve precision the connection boxes are also equipped with Pearson current monitors to measure magnet output currents. Pre-2001 this measurement was made by monitoring the voltage across the last resistor disc of the magnet terminator. This had the inconvenience of unpredictable resistor disc value changes with ageing, resulting in undesired signal amplitude variations.

The change of magnet connection boxes has also required the replacement of the standard PS ion pump chain clamps by new ones of reduced dimensions to allow a possible pump exchange without removal of the boxes.

The final generator layout is shown in Fig. 4. where the new components described above have been added.

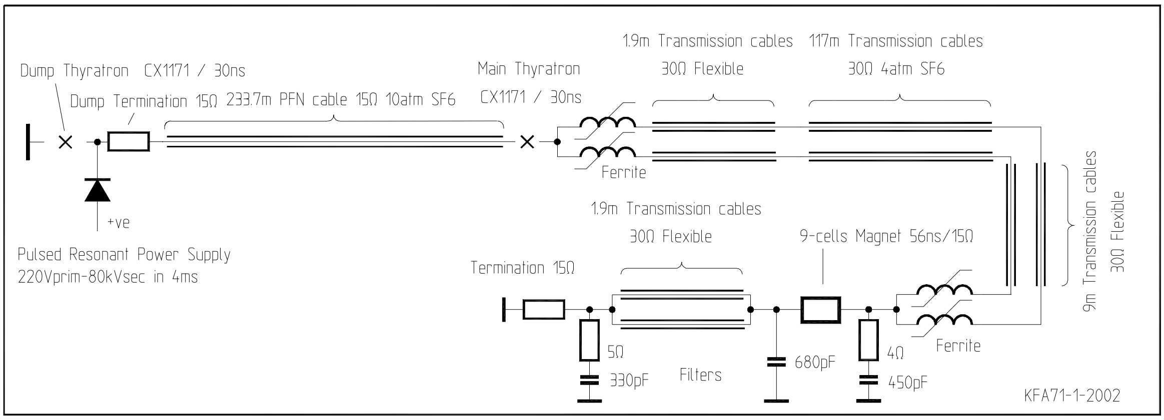


**Fig. 4.** Schematic representation of one modified ejection module.

The calculated kick waveform resulting of these modifications is shown in Fig. 5. There is unfortunately no easy way to measure the kick in the PS machine without moving either the kicker tank itself or the nearest bending magnet in order to introduce a magnetic field measurement probe in the magnet aperture. Calculated magnet currents are compared to the measured ones to check their validity. Magnetic field measurements were also made on the spare KFA71 tank to check the saturating inductor model.

Rise time figures are now within specification and allow some margin for thyratron jitter and performance decrease with tube ageing. The flat top ripple is within the 1% p-p required.

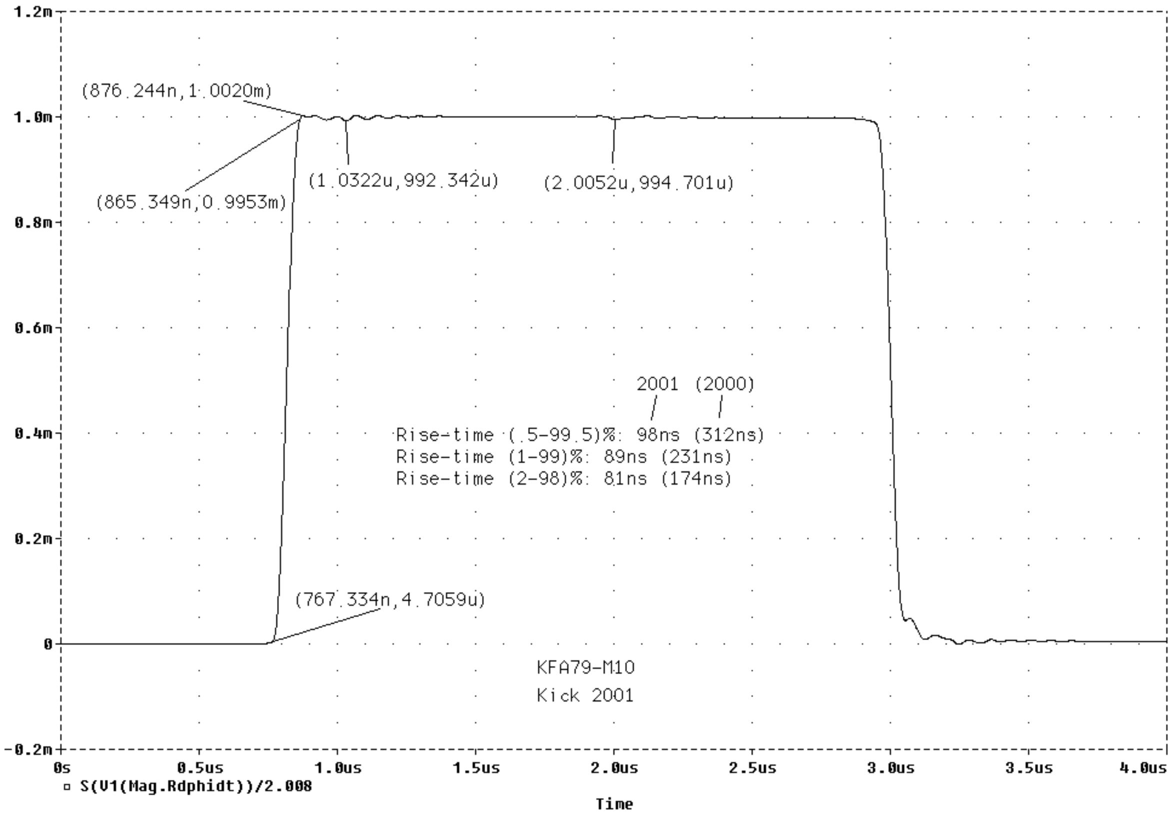


**Fig. 5.** KFA79-Mod10 kick from year 2001

Sensitivity calculations performed have defined the acceptable range of the following parameters:
-magnet terminating resistor value: 14.75Ω < R < 15.125Ω
-Tx flexible cables between magnet and terminator (2 in parallel) should have a resulting impedance of 15 to 15.5Ω. Their length should be limited to 2m.
-Tx flexible cables between $SF_6$ Tx and magnet (2 in parallel) should have a resulting impedance between 15 and 16Ω and a length between 9m and 11m.

At present, only KFA79 tank has been modified during the 2000-2001 PS shutdown. Tank KFA71 will be modified during the 2001-2002 PS shutdown.

## 6. PERFORMANCES AND LIMITATIONS

The main data and performances of the modified ejection kicker system are summarised below:

| | | |
|---|---|---|
| ♦ HV modulators: | No. of generators: | 12 |
| | Generator impedance: | 15Ω |
| | PFN: | $SF_6$ pressurised at 10bar, 15Ω, ~235m cable |
| | Transmission: | 2 $SF_6$ pressurised at 4bar, 30Ω, ~117m cables, in parallel (different lengths for each generator) |
| | Main Switch: | EEV CX1171A/2 (from Marconi Applied Technologies) |
| | Dump Switch: | EEV CX1171A/2 |
| | Max. PFN voltage: | 80kV (positive) |
| | Max. load current: | 2650A |
| ♦ Magnets: | No. of magnets/generator: | 1 |
| | Type: | ferrite loaded delay line |

| | | |
|---|---|---|
| | No. of cells: | 9 |
| | Aperture w×h: | 147mm×53mm |
| | Effective length: | 255mm |
| | Delay: | 56ns |
| | Impedance: | 15Ω |
| ♦ Kick: | ∫Bdl (KFA71) max: | 125.5mT.m |
| | ∫Bdl (KFA79) max: | 41.8mT.m |
| | ∫Bdl flat top uniformity: | ±0.5% |
| | Rise time (.5-99.5)%: | 98ns |
| | Rise time (1-99)%: | 89ns |
| | Fall time (95-5)%: | 84ns |
| | Fall time (98-2)%: | 150ns |
| | Length (max): | ~2100ns (variable) |
| ♦ Filters: | Magnet input R+C: | 4Ω + 450pF |
| | Magnet output C: | 680pF |
| | Mag. Term. R+C: | 5Ω + 330pF |
| ♦ Ferrite: | MS cathode lemos: | CMD5005, tube OD=74.5mm, ID=35mm, L=50mm |
| | Magnet input lemos: | CMD5005, tube OD=74.5mm, ID=35mm, L=50mm |

## 7. CONTROLS AND OPERATION

The pulse generators and the associated controls are located in Building 359.

All KFA71-79 low level control and electronic chassis have been renewed in the year 2001 in order to standardise this equipment with other kicker systems. A local G64-based processor in each of the kicker module control racks acts as an interface between the pulse generator and Device Stub Controllers (DSC's) of the PS control system [5]. The Command/Status protocol (ON-OFF-STAND BY-RESET) is based on the Power Converter protocol [6]. The ejection DSC (DCPSK71) runs a dedicated program, called Kick Strength Unit (KSU), which translates the operational user requirements into kicker exploitable data for reference control value (CCV), fine timing and also effects interlock surveillance and data logging [7].

Communication between the DSC and the G64 crate is via RS232.

The timing pulses for PFN charge and discharge are common to each pulse generator. The former has to be sent 9ms before the latter. PFN discharge timing is ppm adjustable by 1ns steps within a 2µs range.

The Main and Dump Switch thyratron firing time drift is corrected continuously by a dedicated electronics unit in each generator.

The CCV is given in terms of PFN kilovolts within upper limit of 80kVx12=960kV (assuming that all modules are available). The lower limit has been fixed to 30kV, this gives a ppm dynamic range from 30kV to 960kV. A hardware interlock is set to occur for any CCV outside these limits. The effective PFN charging voltage is acquired, displayed on each module, and transmitted to the MCR.

## 8. REFERENCES


[1] M. Benedikt et al. *The PS complex as proton pre-injector for the LHC-Design and implementation report*, CERN 2000-003

[2] D. Fiander, *Hardware for a Full Aperture Kicker System for the CPS*, US Part. Accel. Conf. Chicago 1971. *CERN/MPS/SR 71-5.* http://psdata.web.cern.ch/psdata/www/Kickers/Kickerpublist.html

[3] http://psdata.web.cern.ch/psdata/www/Kickers/psparam.htm

[4] G. Wait et al., *The application of saturating inductors for improving the performance of the Cern PS kicker systems*, Part. Accel. Conf. , Vancouver 1997.

[5] B. Bleus, J. Schipper, *PS Kicker modules G64 control interface,* PS/CA/Note 99-26.

[6] I. Barnett et al. *The CERN Control Protocol for Power Converters,* CERN/PS/92-57 (CO).

[7] B. Bleus, J. Schipper, *General description of the fast ejection kicker control and acquisition system,* PS/PA/Note 96-18.

# 9. APPENDIX

## 9.1 Reference photos

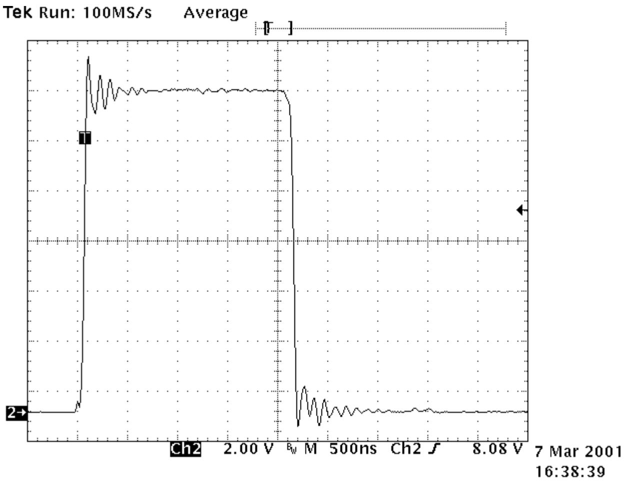


**Fig. 6.** KFA79-10 Pearson CT signal measured in PS ring (magnet output current, 80kV PFN).

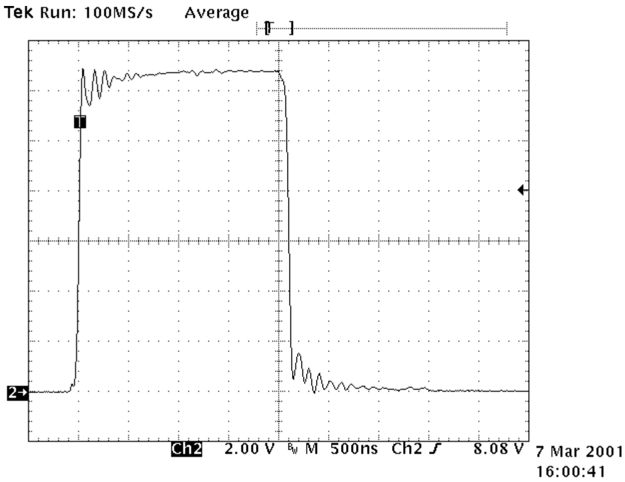


**Fig. 7.** KFA79-10 Pearson CT signal measured in Building 359 after ~170m of transmission (80kV PFN).

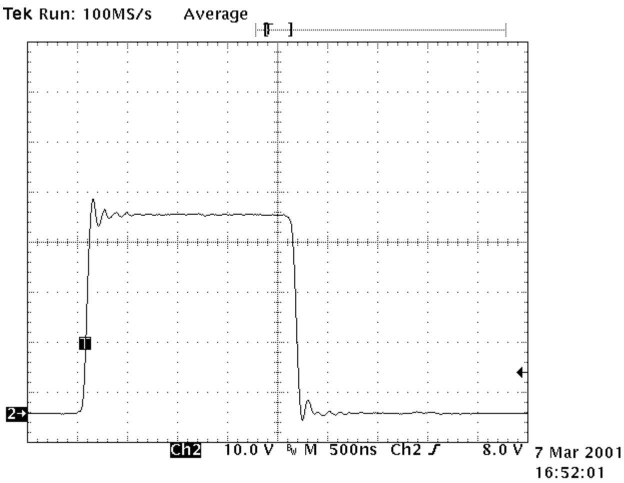


**Fig. 8.** KFA79-10 Terminator pick-up signal measured in PS ring.

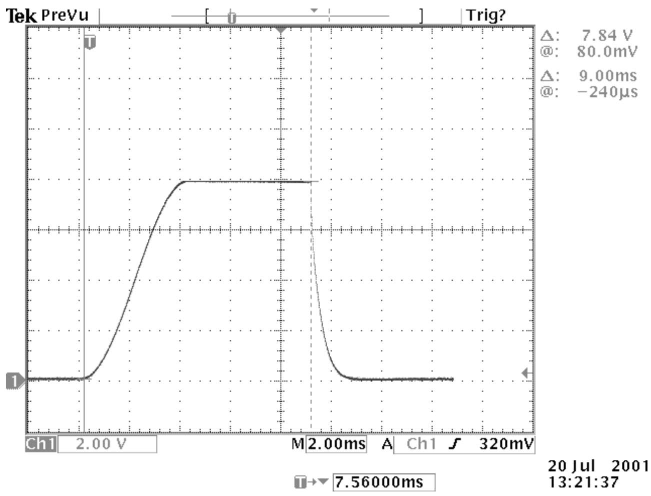


**Fig. 9.** KFA79-10 PFN charging waveform (80kV PFN).

## 9.2 Reference drawings

PS-KM-M20-0990-1: Main switch cathode ferrites modification
PS-KM-M20-1110-0: Connection box assembly
PS-KM-M20-1140-2: R/C filter (4Ω, 450pF)
PS-KM-M20-1160-2: C filter (680pF)
PS-KM-M20-1200-1: Resistor assembly
PS-KM-M20-1180-1: Resistor R/C filter assembly (5Ω, 330pF)

00-526-00.2: Chain clamp ND160 special (from Prophysik A.G. , FL-9491 Ruggell)

Distribution

S. Baird
R. Cappi
J-P. Delahaye
K. Metzmacher
J-P. Riunaud
K. Schindl
PS supervisors

-S. Hancock
-M. Giovannozzi
-D. Manglunki
-E. Métral
-G. Métral
-M. Gourber-Pace
-R. Steerenberg

PS kicker section
-B. Bleus
-S. Deman
-H. Gaudillet
-A. Fowler
-J-C. Freze
-J. Schipper
-L. Sermeus