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ACCELERATOR PHYSICS GROUP

GAP

Proposal for testing a Prototype Stripline Kicker for CLIC DR in ATF2

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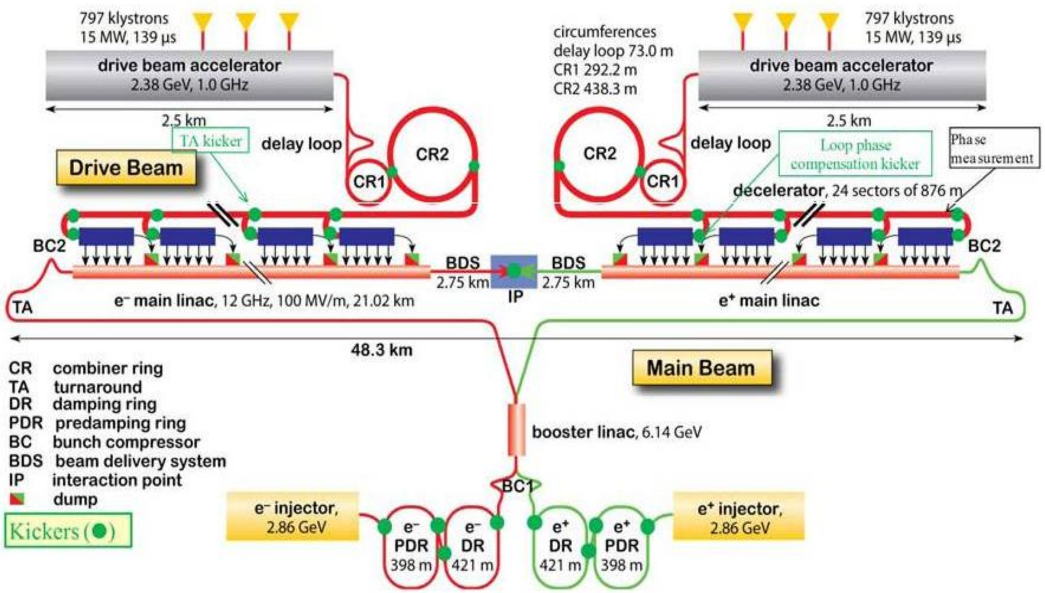
Introduction and Motivation

We propose to install a first prototype stripline kicker, together with the inductive adders for the pulsed power supplies, for testing in a straight section of the extraction line of ATF2. This kicker system is being designed to extract horizontally the beam from the CLIC Damping Rings. The main objective of these tests is the validation of the proposed design from the field stability, field homogeneity and impedance points of view



- Several challenging kicker systems are required to inject the beam into and extract the beam from the PDRs and DRs
- In order to achieve both low beam coupling impedance and broadband impedance matching to the electrical circuit, striplines have been chosen for the kicker elements

A set of protoype striplines will be built by the Spanish company Trinos Vacuum Projects under the Centro de Desarrollo Tecnológico e Industrial (CDTI) program in collaboration with the IFIC and the CIEMAT Accelerators groups

Introduction and Motivation

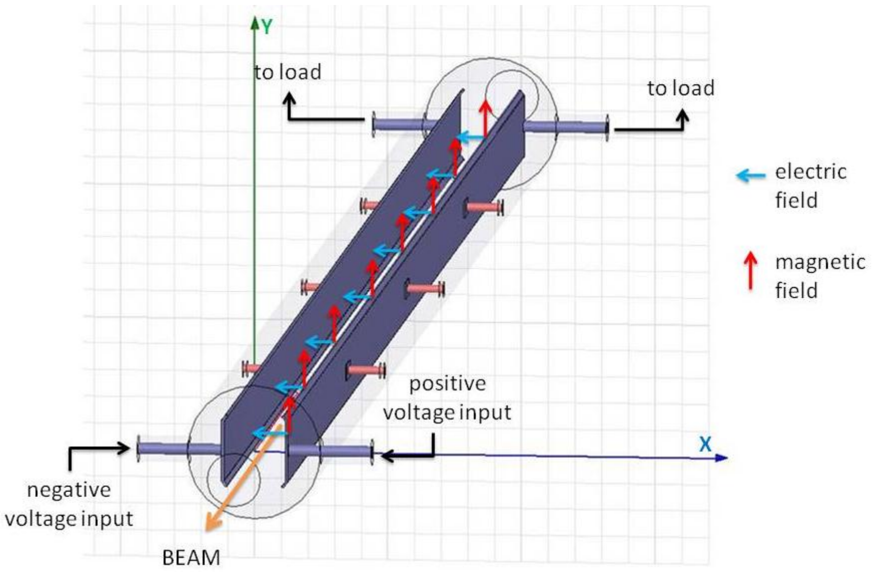
Specifications for the CLIC DR, CLIC PDR and ATF2

Parameter	CLIC PDR		CLIC DR		ATF2		
	1 GHz	2 GHz	1 GHz	2 GHz	1-bunch	3-bunch	20-bunch
Beam energy (GeV)	2.86		2.86		1.30		
Total kick deflection angle (mrad)	2.0		1.5		1.5		
Aperture (mm)	40		20		20		
Effective length (m)	3.4		1.7		1.7		
Field rise time (ns)	428	1000	560	1000	560/1000		
Field fall time (ns)	428	1000	560	1000	560/1000		
Pulse flat top duration (ns)	900	160	900	160	900/160		
Extraction field inhomogeneity (%)	±0.1 (3.5 mm)		±0.01 (1mm)		±0.01 (1mm)		
Repetition rate (Hz)	50		50		1.56		
Vacuum (mbar)	10^{-10}		10^{-10}		10^{-10}		
Pulse voltage per stripline (kV)	± 17.0		± 12.5		± 5.5		
Stripline pulse current (A)	± 335		± 250		± 115		
Longitudinal coupling impedance (Ω)	< 0.05		< 0.05		< 0.05		
Transverse coupling impedance (kΩ/m)	< 200		< 200		< 200		
Peak beam current (A)	70	50	110	120	60	30	20
Bunch length (ps)	10	14	6	5.3	16.7		

Design and Technical Description of the Striplines

1) **Cross section design:** the striplines cross section determines their characteristic impedance and field homogeneity. The cross section is optimized by simulating a slice, orthogonal to the length of the striplines, with HFSS
2) **Beam coupling impedance study:** to take into account the wake fields resulting from the beam passing through the stripline aperture with HFFS and CST Particle Studio

Cross section design

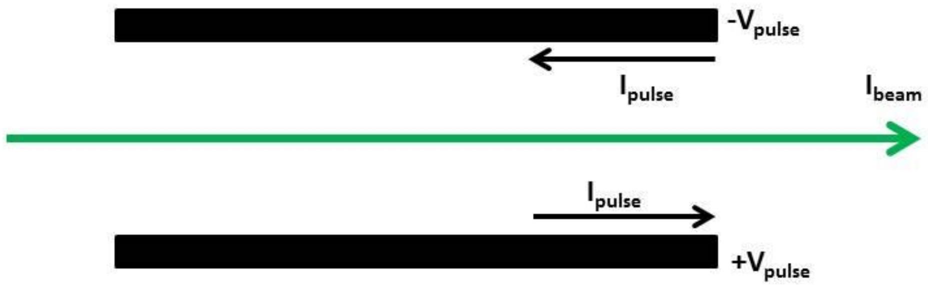


- The striplines consist of two long metallic parallel electrodes fed at the ends by two coaxial feedthroughs inside the beam pipe.
- In order to generate a transverse kick, the ports located downstream of the beam direction should be powered by opposite polarity generators and the upstream ports should be connected to matched resistive loads.

Cross Section Design

KICKER ON = ODD MODE
KICKER OFF = EVEN MODE

KICKER ON



KICKER OFF

- When the electrodes are excited with opposite polarity voltages, the current flow is in opposite directions in each stripline electrode: this is the **odd mode**.
  - ➢ an electromagnetic field is created between the electrodes, giving a transverse kick to the beam

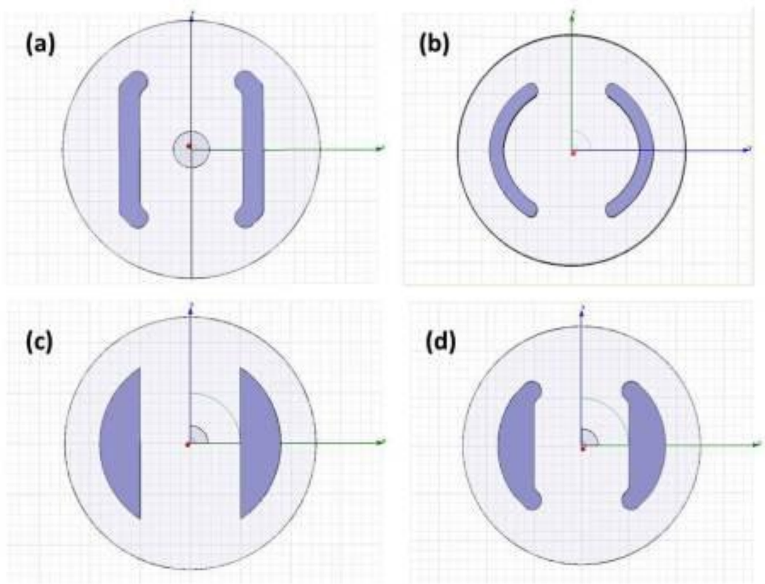
- When unkicked circulating beam passes through the aperture of the striplines, it induces image currents in the electrodes: the direction of current flow is the same in both electrodes – this is the **even mode**.
  - ➢ this generates an electromagnetic field, which gives a longitudinal kick to the beam and can produce beam instabilities.

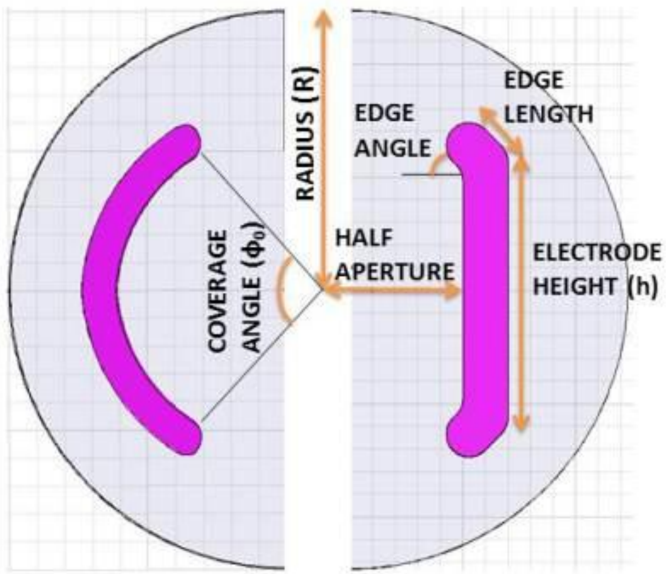
GOAL OF THE STRIPLINES DESIGN FOR THE EXTRACTION KICKER OF CLIC DR:

To achieve 50 Ω characteristic impedance in the even mode, to minimize impedance mismatches seen by the beam, while keeping the odd mode characteristic impedance as close as possible to 50 Ω, in order to avoid reflections when powering the electrodes. Furthermore, a very demanding field inhomogeneity of ± 0.01% in the centre of the stripline aperture, over a circle of 1 mm radius, is required.

Cross Section Design

Four possible electrode cross sections have been considered for the design of the striplines: all of them have a cylindrical stripline beam pipe.





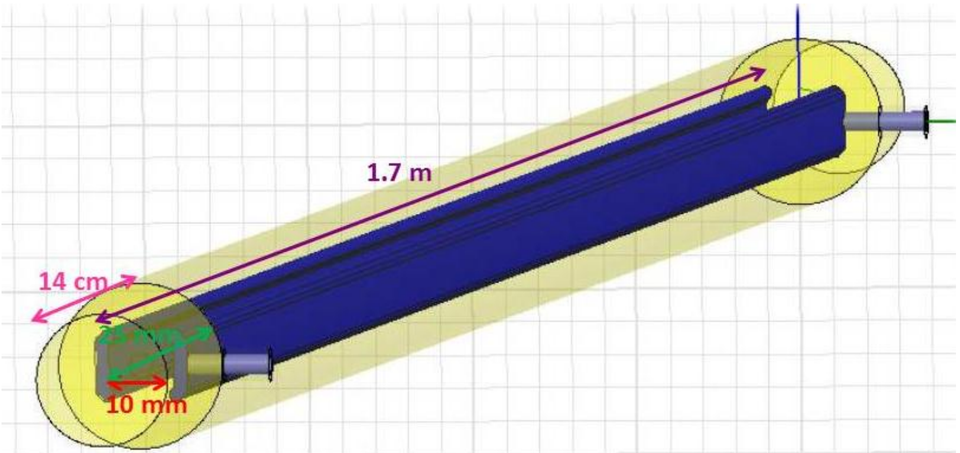
For the CLIC DR extraction kicker, a stripline beam pipe radius of 25 mm is needed to achieve the required field inhomogeneity. With the optimized flat electrodes and a stripline beam pipe radius of 25 mm, the even mode characteristic impedance is 50.2Ω and the odd mode characteristic impedance is 36.8Ω.

- Mechanical tolerances of the electrodes position and inclination angle are presently being studied.
- A study about the material choice of the striplines is being made, taking into account the conductivity, the mechanization properties and the vacuum requirements. The materials proposed are Al, Cu, stainless steel and Mb.

Parameter	Optimum value
Kicker radius	25 mm
Aperture	20 mm
Electrode height	25 mm
Electrode thickness	4 mm
Electrode edge length	5 mm
Electrode edge angle	45°

Beam Coupling Impedance Study

- A charged particle beam travelling inside a vacuum chamber induces electromagnetic fields, known as wake fields, which act back on the beam itself. This gives an additional voltage and energy gain and hence affects the longitudinal beam dynamics: in addition there is a transverse momentum kick which deflects the beam.
- Furthermore, when a charge crosses a vacuum chamber discontinuity, the abrupt change in the cross section of beam pipe causes secondary fields to be reflected at the sharp edges of the transition.
- Knowledge of the electromagnetic interactions, between the charged particle beam and the vacuum chamber, is necessary in order to avoid instability phenomena that may otherwise occur in the CLIC Damping Rings.



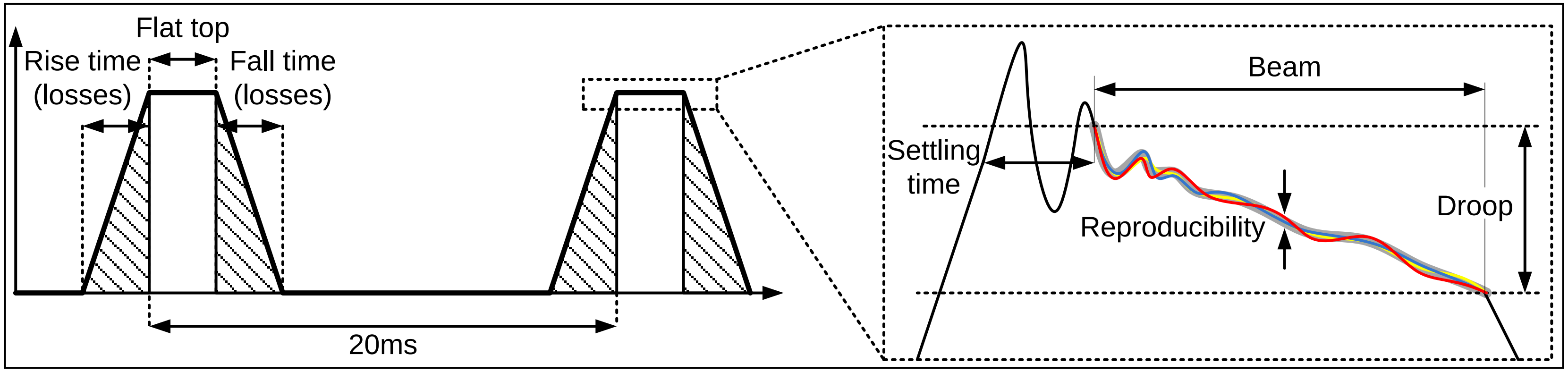
- The beam pipe in the CLIC DR is presently specified to be of 10 mm radius and the stripline beam pipe radius will be 25 mm.
- It has been calculated that a taper length of 125 mm and 140 mm for 1 GHz and 2 GHz baselines, respectively, will be required.

- High voltage vacuum feedthroughs are required to connect the input and output of each stripline electrode to the pulsed power supply and a resistive terminator, respectively.
- It is proposed to use the 15 kV-F-Coaxial UHV feedthrough, from Kyocera.

Studies being carried out:
•Investigate various options for the broadband resistive terminators;
•Know the effects of an impedance mismatch, of the resistive terminator, upon beam coupling impedance;
•Determine whether, for beam coupling impedance reasons, an optimized transition to the feedthrough is required.

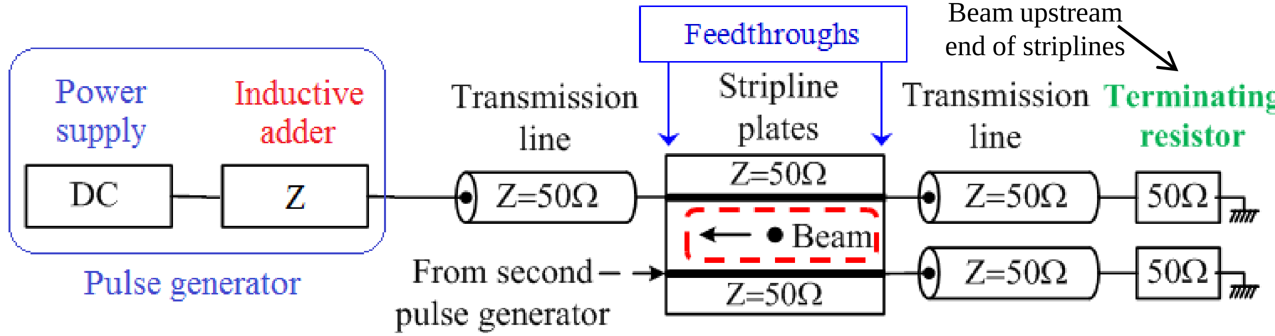
Design and Technical Description of Inductive Adder

CLIC Damping Ring Pulse Definition



- Rise time: needed to reach the required voltage (but includes settling time). 700-1000 ns allowed, **less than 100 ns desired**;
- Settling time: time needed to damp oscillations to within specification;
- Beam: 160 ns time window during which droop and oscillations must be within specification, however because of the kicker mismatch the pulse flattop may be required to be ~650 ns;
- **Flattop stability: maximum of ±2×10^{-4} for combined droop and ripple of DR extraction**. This corresponds to **±2.5 V range for 12.5 k**V output pulse for DR extraction;
- **Reproducibility: maximum difference allowed between any two pulses, ±1×10^{-4};**
- Fall time: time for voltage to return to zero;
- ❖ Minimizing rise and fall times reduces stress on kicker system.
- ❖ To minimize settling time, impedance of system has to be well matched.

DR Kicker with an Inductive Adder

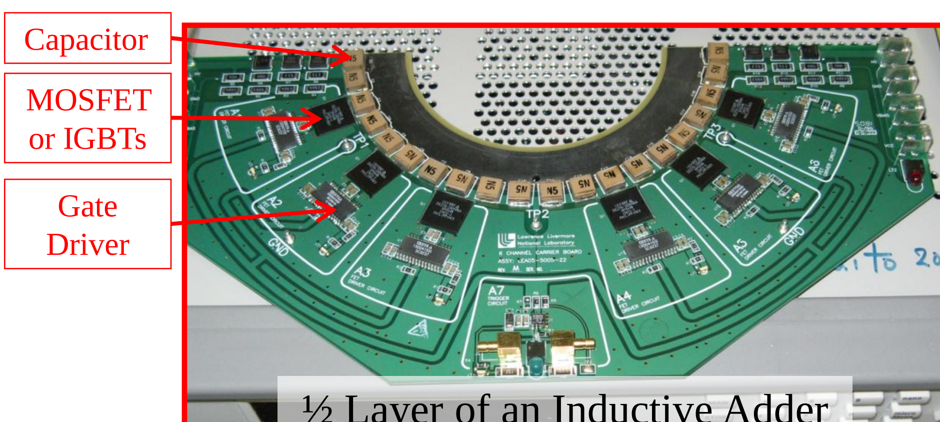


Schematic of CLIC DR Kicker System with an Inductive Adder

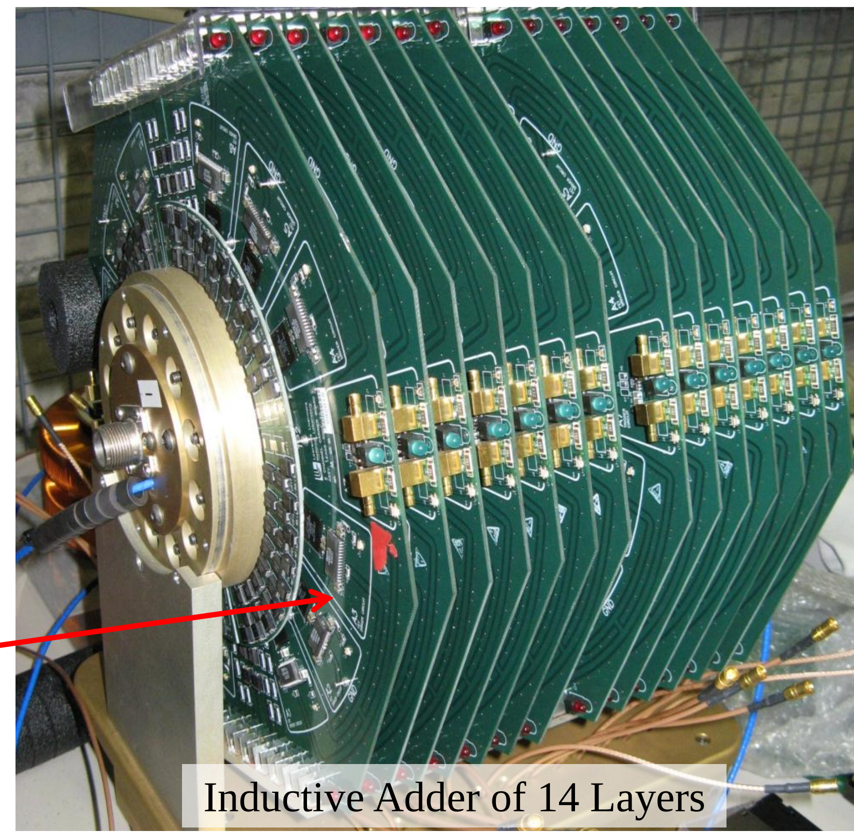
An extensive literature review of existing pulse generators has been carried out: an inductive adder is a very promising means of achieving the demanding specifications for the DR extraction kickers.

Two of the main challenges of DR kickers

- ➢ Impedance matching of **ALL** parts/components over a wide frequency range (… striplines are particularly challenging);
- ➢ Stability of **ALL** parts/components (with time, temperature, ….).

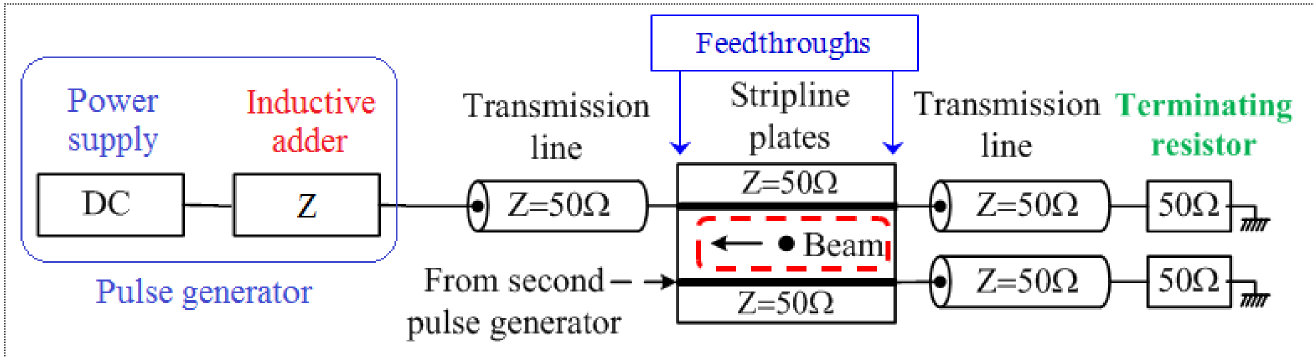


½ Layer of an Inductive Adder



Inductive Adder of 14 Layers

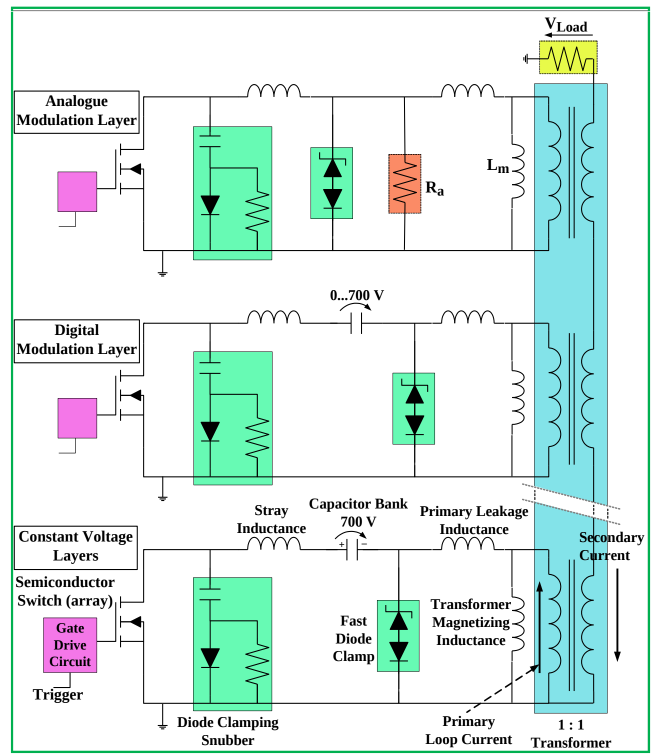
Kicker System with an Inductive Adder



Schematic of kicker system with an inductive adder

Inductive Adder Advantages

- Solid-state switches;
- Control electronics referenced to ground;
- No electronics referenced to high voltage despite the high voltage output of the adder;
- Modularity: the same design can potentially be used for DR and PDR kickers despite the different specifications. The PDR version will require more layers in series;
- Redundancy and machine safety: if one switch or layer fails, the adder still gives a significant portion of the required output pulse;
- Possibility to generate positive or negative output pulses with the same adder: the polarity of the pulse can be changed by grounding the other end of the output of the adder;
- Source impedance is low, hence minimizing number of layers;
- The output voltage can be modulated during the pulse.



Schematic of an inductive adder

Design and Technical Description of Inductive Adder

- The preliminary conceptual design of the Inductive Adder has been carried out. The simulation model has been built and the most promising method, applying analogue modulation to compensate droop of the capacitors, has been tested with the model.

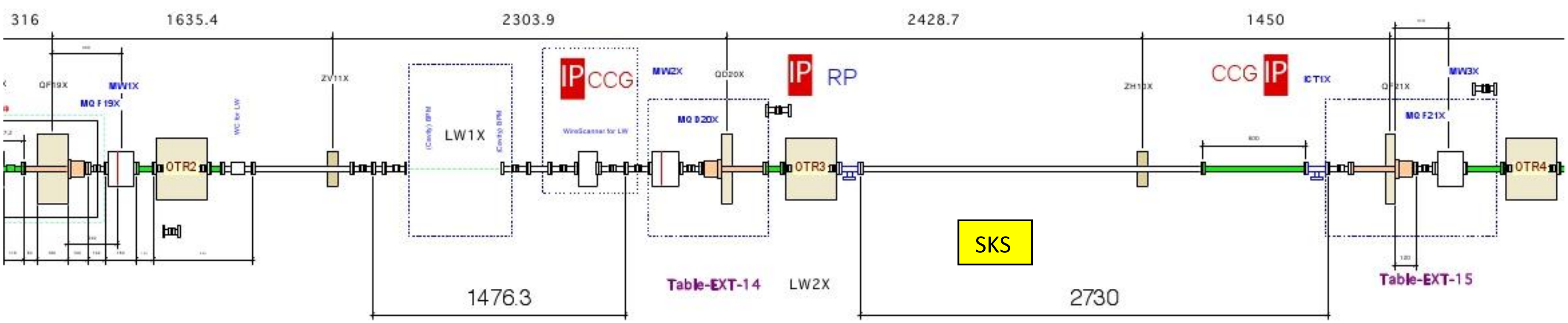
- Recently, tests of the main components; pulse capacitors, semiconductor switches and transformer cores, have been carried out to find the best candidates for the prototype Inductive Adder

- The first prototype layers of the Inductive Adder will be built by the end of year 2012. A full prototype of the Inductive Adder is presently planned to be ready for laboratory tests and measurements in the first half of 2013.

Proposed Location in ATF2

- In order to make the validation tests of the kicker system, we propose to locate the striplines in a straight section with high resolution cavity BPMs to measure the stability and jitter of the beam deflection.

- In accordance with the striplines design, a minimum length of 2 m will be needed, including the tapers. In the figure, it is shown the location, labelled as SKS, where the stripline kicker system could be installed.



- There will inevitably be some impedance mismatch in the pulsed power system, which is composed of inductive adders, coaxial cables, feedthroughs, striplines and resistive terminators. In order to minimize the effects of the impedance mismatches the electrical delay of the power coaxial cables must be as short as reasonably possible: hence the inductive adder should be positioned so as to keep the electrical delay short.

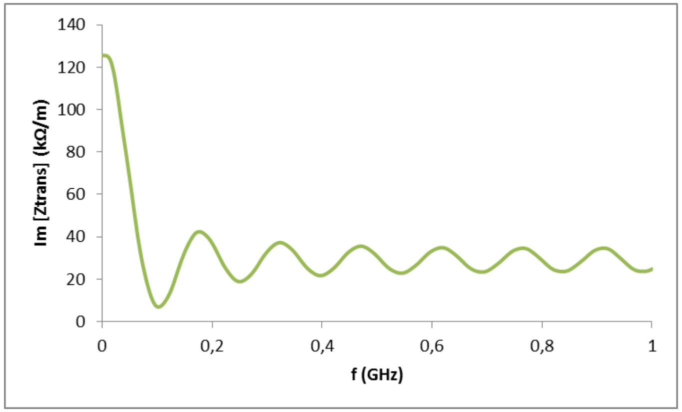
Proposed Measurements in ATF2

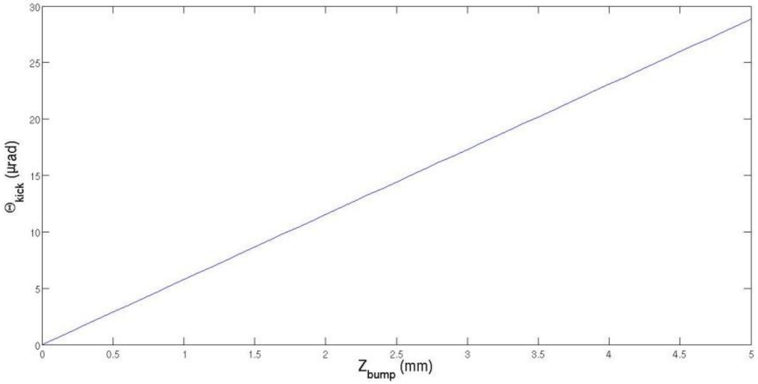
Transverse beam coupling impedance using a closed bump in ATF2

The principle of the method is to locally displace the beam from its axis by applying a closed bump Z_{bump}, and to record the effect of impedance on the trajectory. Once the beam is displaced, its trajectory will be affected by an impedance kick

$$\Theta_{kick} = \frac{I_p Z_{bump}}{E/e} Im(Z_{\perp \mathrm{eff}})$$

Z_{eff} Transverse effective impedance
I_p Peak current
E: energy e: electron charge



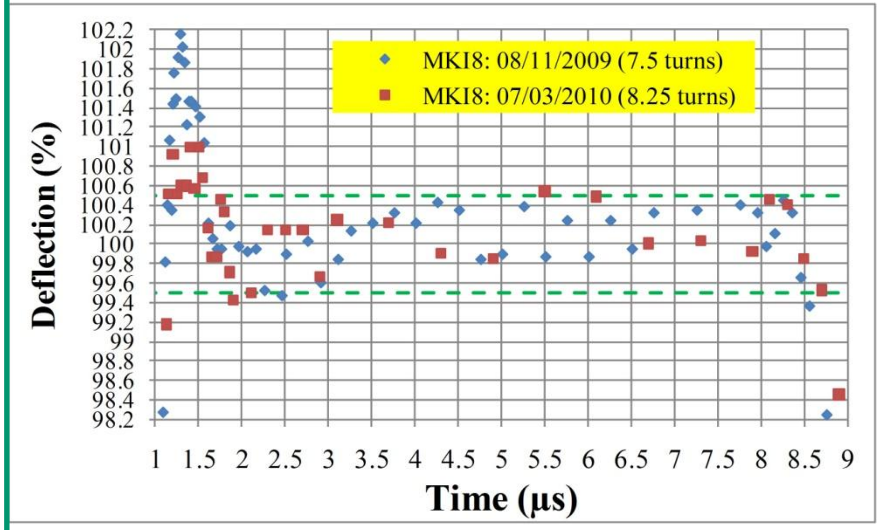


- For a bump amplitude between 1 and 5 mm the kick angle will be in the range of 0-30 μrad.
- When the kicker is OFF **(even mode)**, the bunch will be affected by the kick due to the bump, whereas when the kicker is ON **(odd mode)**, it will be added to the kick provided by the kicker itself.

Pulsed field stability and pulse to pulse stability measurements

- Temporal pulsed field waveform can be measured using a single bunch, by varying the kick delay for the injected bunch and accurately recording the position of the single bunch.

Example measurement for LHC Injection Kickers



- The beam position must be measured with a high accuracy since ripple and droop of the waveform should be less than ±0.01% - thus the beam position must be resolved with a precision better than ±0.01%. The time required will depend upon the number of signals that must be averaged. Upstream witness BPMS are required to measure and remove beam jitter (both position and angle). If the BPM is ~1m downstream of the kicker the observed position shift 1m downstream will be a few mm ⇨ 0.01% of this is few 100nm, which should be achievable with cavity BPMs.

Pulsed field stability and pulse to pulse stability measurements

- Using a similar technique, but with a single beam bunch positioned at a given point in time on the pulsed field, the pulse to pulse stability of the waveform can be measured.

- If the beam position cannot be determined with sufficient resolution, at a given longitudinal position with respect to the kickers, a technique similar to that developed at ATF for measuring the equivalent jitter of a single kicker could be used: the strength of a dipole is adjusted to bring the nominal beam trajectory onto a path parallel with that of the unkicked beam. The dipole must have excellent field uniformity field and stability. All measurements are made with single bunches, i.e. at a particular time on the kick field waveform.

Proposed Schedule and Commissioning

We have essentially finalized the cross section design of the striplines. Once the beam coupling impedance study is finished, the striplines will be manufactured by December 2012. The tests planned by 2013 are the following:

- Laboratory test at CERN: verification of the stripline dimensions, field homogeneity, longitudinal and transverse beam coupling impedance, vacuum performance and high voltage performance.
- Tests and measurements at ALBA: using d.c. power supplies instead of a pulse generator, to determine transverse beam coupling impedance and, if possible, longitudinal beam coupling impedance. Field homogeneity measurements will be carried out with the d.c. power supplies and a closed bump.
- It is planned that two inductive adders will be built and tested by 2014: hence our goal is that the kicker striplines and the two inductive adders are installed in ATF2 during 2014.
- We anticipate being able to commission the kicker system immediately after the kicker has been installed

Manpower

The team is a collaborative effort between the Instituto de Física Corpuscular (IFIC), Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT) and CERN.

The people involved are:

- A. Faus-Golfe, C. Belver Aguilar (IFIC)
- F. Toral, I. Podadera (CIEMAT)
- M. J. Barnes, Y. Papaphilippou, J. Holma (CERN)

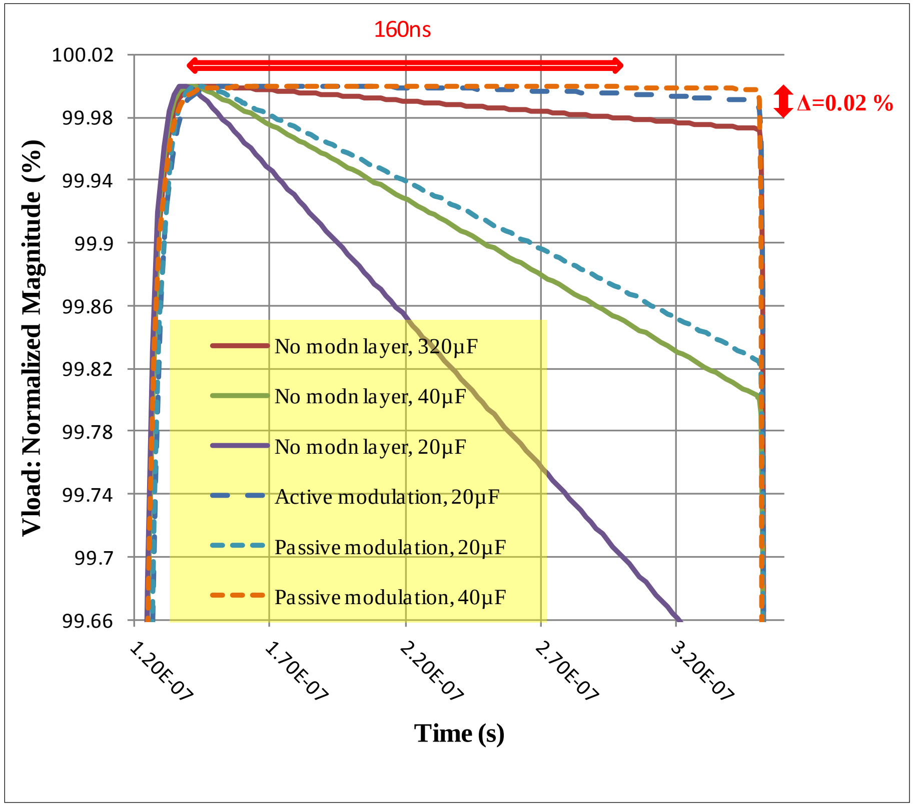
Back up slides

Modulation Schemes

• **Digital modulation**: refers to switching on and off a layer, whose capacitors are pre-charged to a predetermined voltage, during the output pulse. This is a ”coarse” method to modulate the output and cannot be used to compensate droop. However, turn-on of individual switches or layers may be initiated at different times to reduce ripple.

• **Analogue modulation**: a layer is used to compensate the droop of capacitors, significantly reducing the required capacitance per layer:

- ➢ **Passive analogue modulation**: a layer works effectively as an R-L circuit. However there is no ability to change the modulation ”on-line”.
- ➢ **Active analogue modulation**: a layer uses linear switches, and can be used to modulate the flattop during the pulse and provides the ability to change the modulation ”on-line”. Active analogue modulation requires linear semiconductor switches, therefore MOSFETs have been chosen as switches.

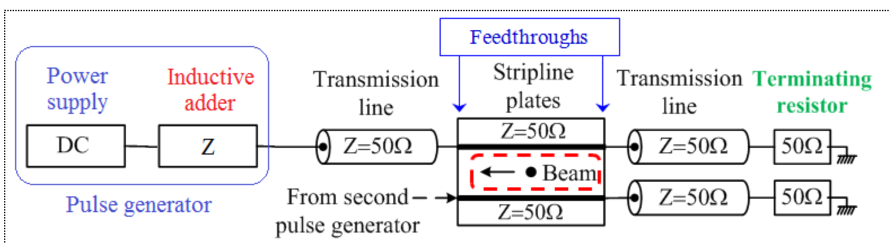


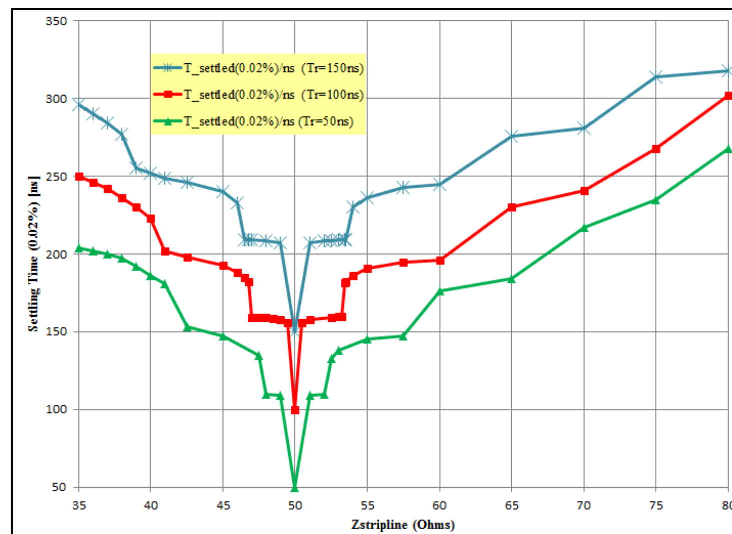
PSpice simulations of the efect of the value of the capacitance per layer upon the flattop droop: (i) with no compensation, (ii) with RL-compensation and (iii) with active analogue modulation.

Challenges and Issues

➢ Due to even/odd mode characteristic impedance optimization, the impedance of the kicker strip-lines will not be 50 ohm as seen by the adder:

- The ***even*** mode characteristic impedance (not pulsed, no virtual ground) is seen by the passing beam and this should be 50 ohm
- The ***odd*** mode characteristic impedance (pulsed with different polarity pulses, virtual ground between strip-lines) is seen by the adder, ~30 ohm. Therefore, the inductive adder will not be matched perfectly to the kicker strip-lines.
- Settling time of the reflections will be ~200…300 ns, therefore the pulse flattop needs to be at least ~500 ns!





Inductive Adder based on Redundancy

The inductive adder primary windings consists of stacked layers of PCBs, each layer will include:

- ✓ multiple capacitors;
- ✓ multiple high power and fast solid-state switches;
- ✓ multiple driver circuits;
- ✓ multiple (4) receivers per layer – number could maybe be increased to improve redundancy.

Hence, although complex, there is redundancy built into the design of the Inductive Adder.

Thus the inductive adder is expected to be reliable!