# A NEW INTEGRATING CURRENT TRANSFORMER FOR THE LHC

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## ABSTRACT

The existing Fast Beam Current Transformers of the LHC have been shown to exhibit both bunch length and bunch position dependency. A new Integrating Current Transformer (ICT) has therefore been developed in collaboration with Bergoz Instrumentation to address these issues. As goals a 0.1 %/mm beam position dependency and 0.1 % bunch length dependency were specified, along with a bandwidth of 100 MHz. This paper describes the working principle of the ICT and presents the laboratory measurement results obtained with the first prototypes at CERN.

## WORKING PRINCIPLE

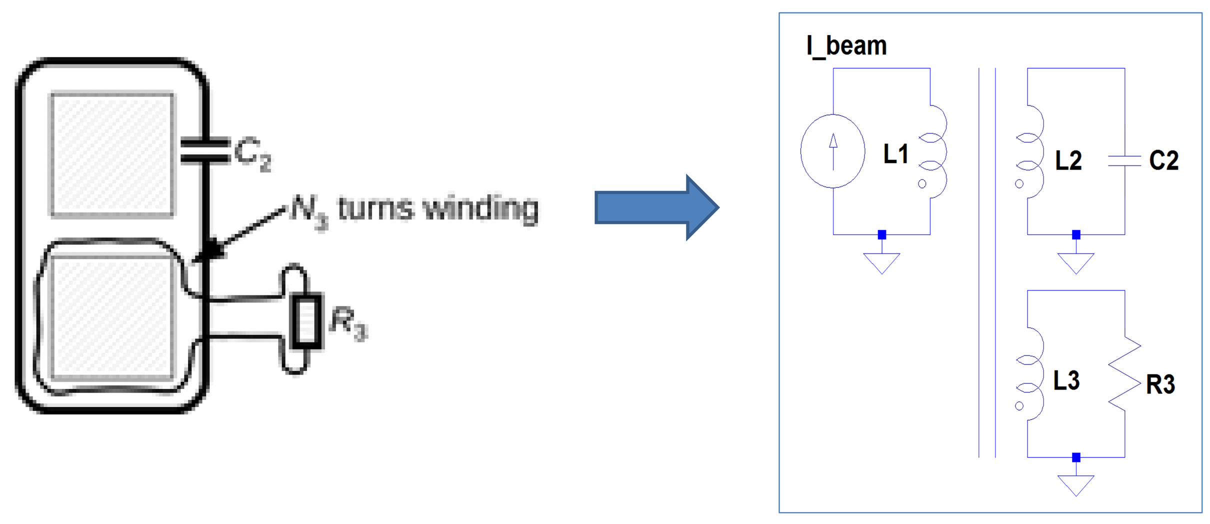
The ICT is designed for accurate measurement of the bunch charge. To accomplish this, almost all information about the longitudinal bunch shape is sacrificed. Its working principle is based on the fact that the value of a pulse's time integral is contained in the lower end of its frequency spectrum, which can be understood from the Fourier transform of a current pulse i(t), e.g. a particle bunch:

$$I(f) = \int_{-\infty}^{+\infty} i(t)\, e^{-i\,2\pi f\, t}\, dt \quad \Rightarrow I(0) = \int_{-\infty}^{+\infty} i(t)\, dt = \mathrm{Q}$$

The beam DC component is just the time integral, i.e. the total bunch charge.

Applying transformer equations one can show that a perfect ICT acts like a damped parallel resonant circuit:

$$U_{R3}(\omega) = -\frac{1}{N_3} I_1 \left( \frac{1}{i\,\omega\, L_3} + \frac{1}{R_3} + \frac{i\,\omega\, C_2}{N_3^2} \right)^{-1}$$



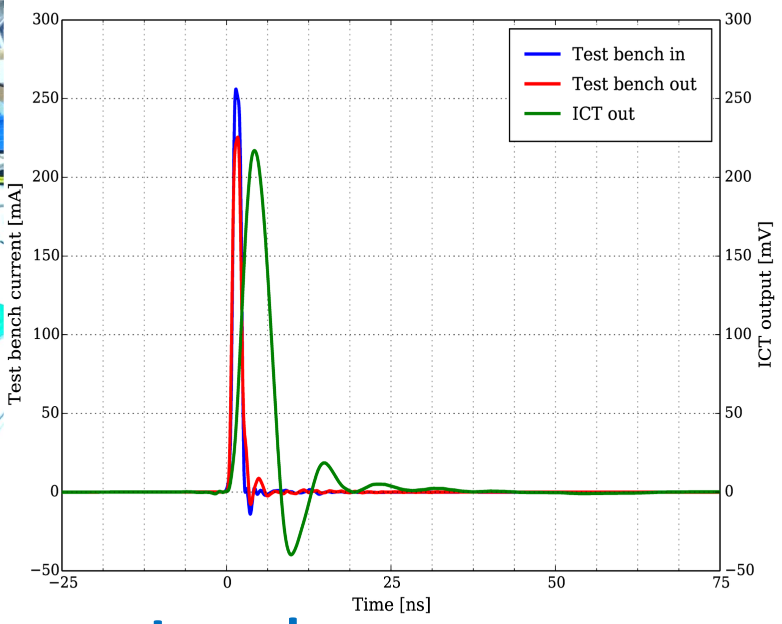

In reality the ICT response is degraded by imperfections and this simplified model is insufficient to explain pulse shapes as shown below. For example, imperfections cause spurious resonances and position dependence. To suppress these effects, it is beneficial to add an unwound core and capacitors, which modify signal transmission from the beam to the read-out.

## LABORATORY MEASUREMENTS

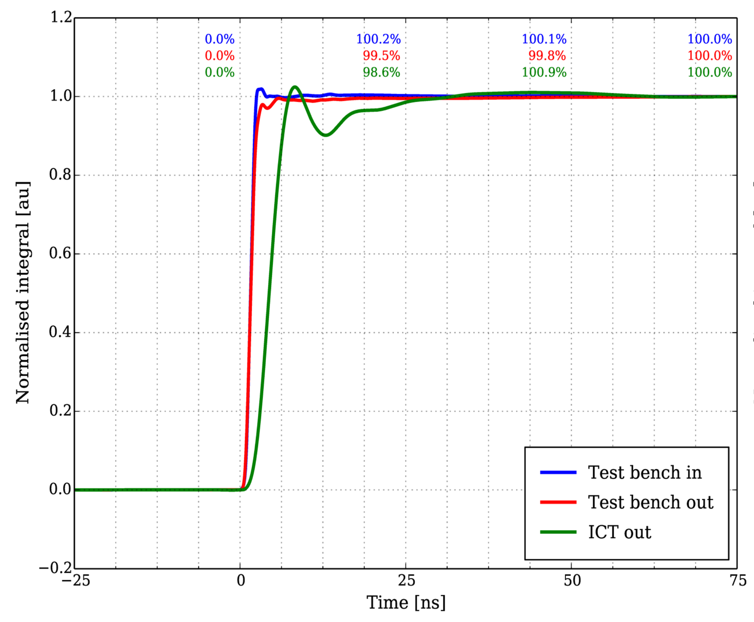
The ICTs were measured on two different test benches. A coaxial 50 ohm test bench optimized for impedance matching was to measure: Impulse response, charge leakage to the following 25 ns bunch slot and bunch length dependency.

A non-coaxial test bench was used to measure position dependency. Here a 7 mm offset antenna was rotated azimuthally 360 degrees and the response measured every 30 degrees.

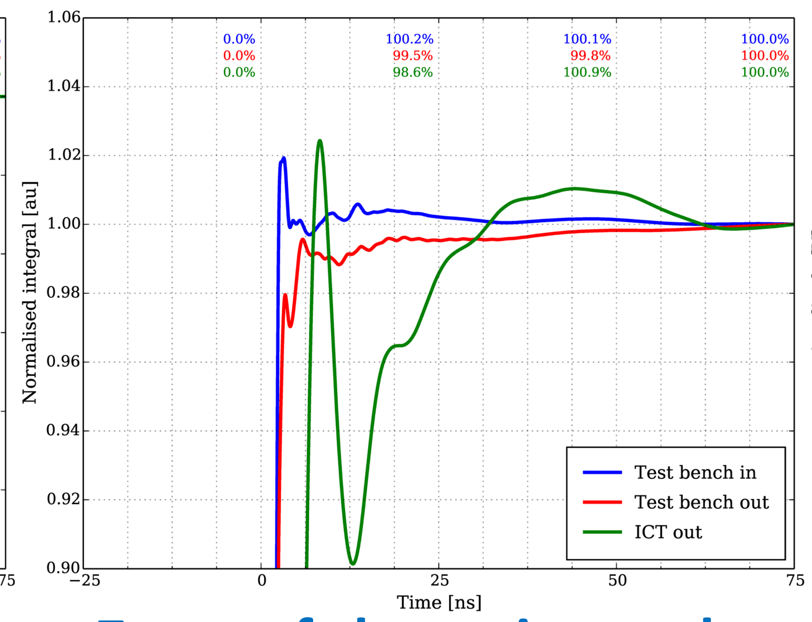
Coaxial test bench



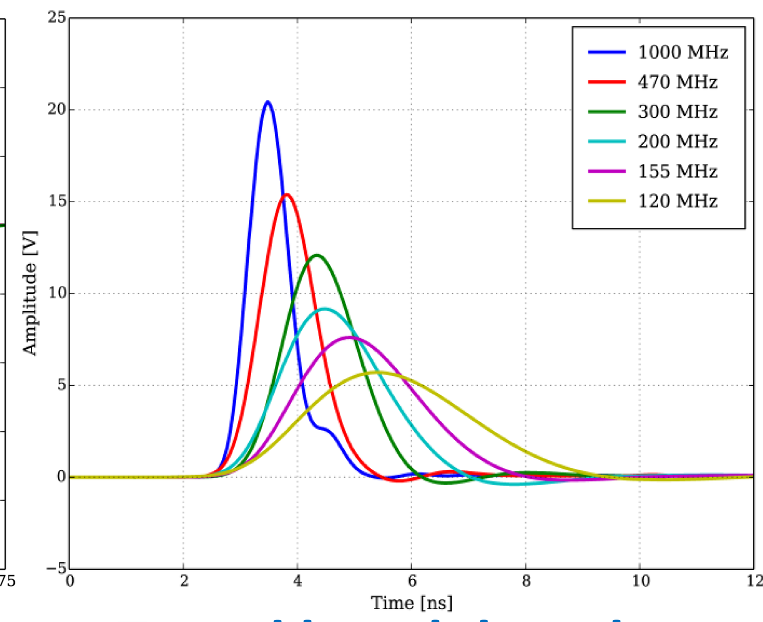

Impulse response



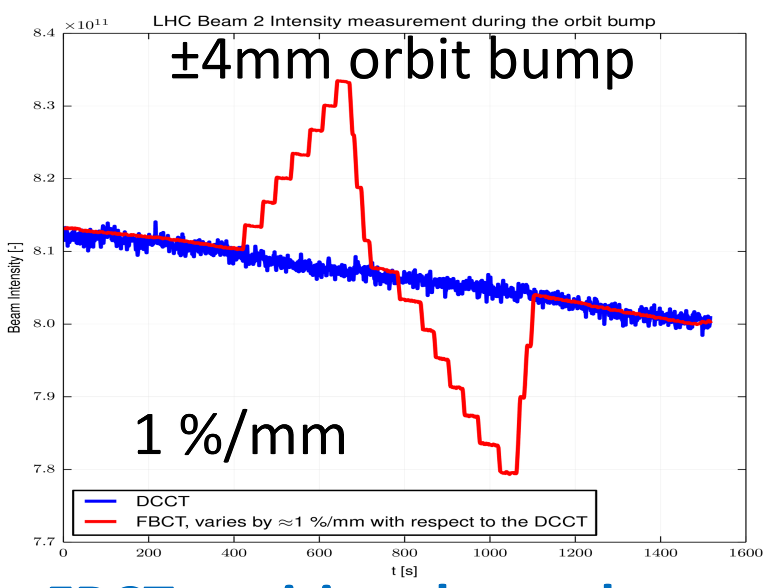

Charge integral



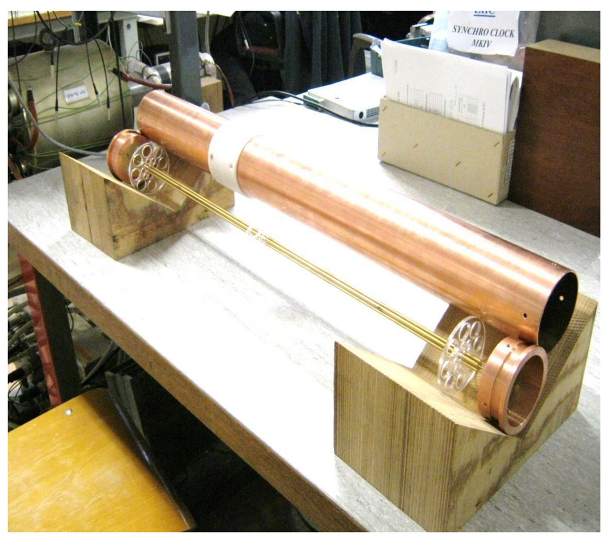

Zoom of charge integral



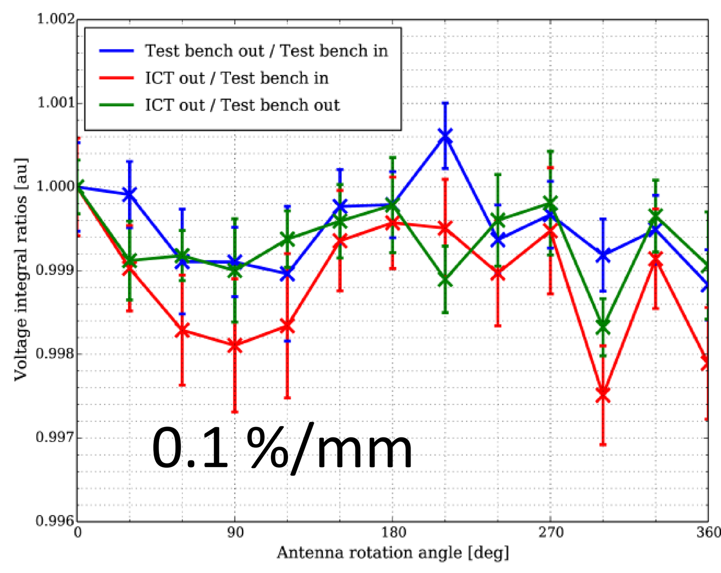

Tested bunch lengths




FBCT position dependency



Non-Coaxial test bench

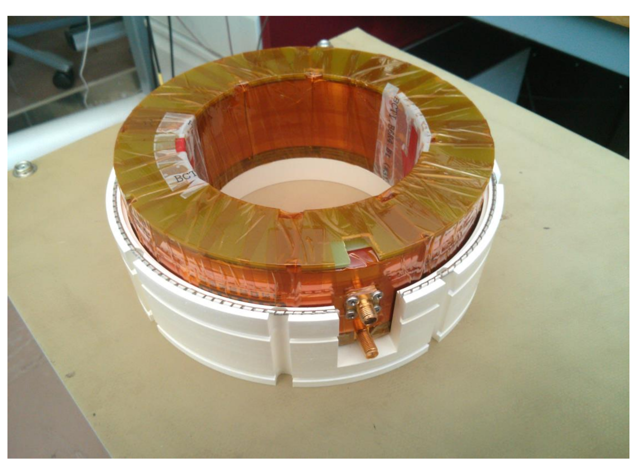


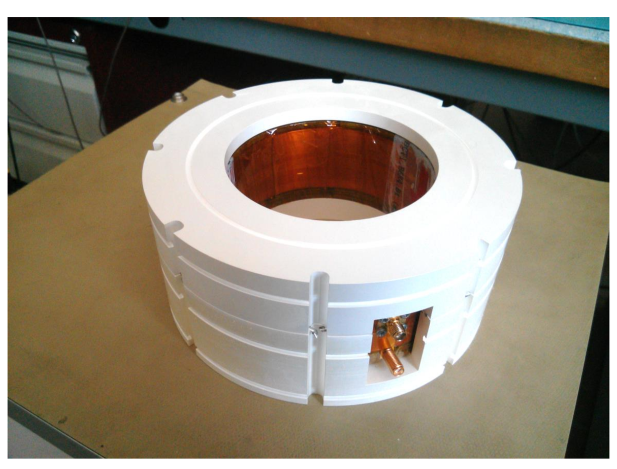

ICT position dependency

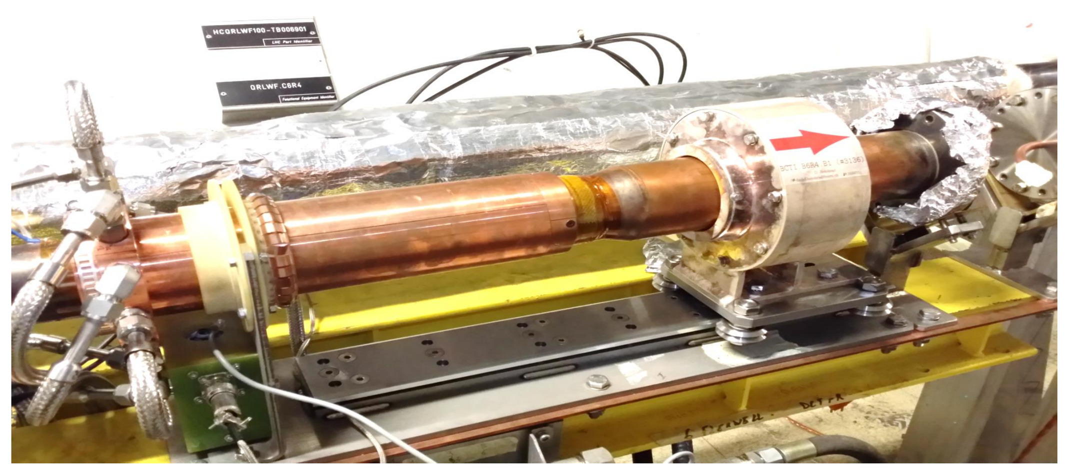
| Parameter | Value |
|---|---|
| Bandwidth | 550 Hz-100 MHz |
| Sensitivity | 0.7 $V_{peak}$ /nC |
| Output pulse width | 7 ns |
| 100% charge integral | 60 ns |
| Beam position dependency [±7mm] | < 0.1 %/mm |
| Bunch length dependency [σ=250-500ps] | < 0.1 % |

Summary of results

## LHC INSTALLATION







## CONCLUSIONS

Two ICTs manufactured by Bergoz Instrumentation were installed in the LHC in June 2014, and are pending measurements with beam by beginning of 2015. The new design, which has been optimized to reduce beam position and bunch length dependency on the measured intensities, is based on filtering frequencies above 100 MHz before the signal reaches the magnetic readout toroid. Laboratory tests have shown very promising results, with less than 0.1 %/mm beam position dependency, and 0.1 % bunch length dependency. The charge leakage from one bunch slot to the next is slightly higher than desired and will need to be corrected for.