Wall-Current-Monitor based Ghost and Satellite Bunch Detection in the CERN PS and LHC accelerators

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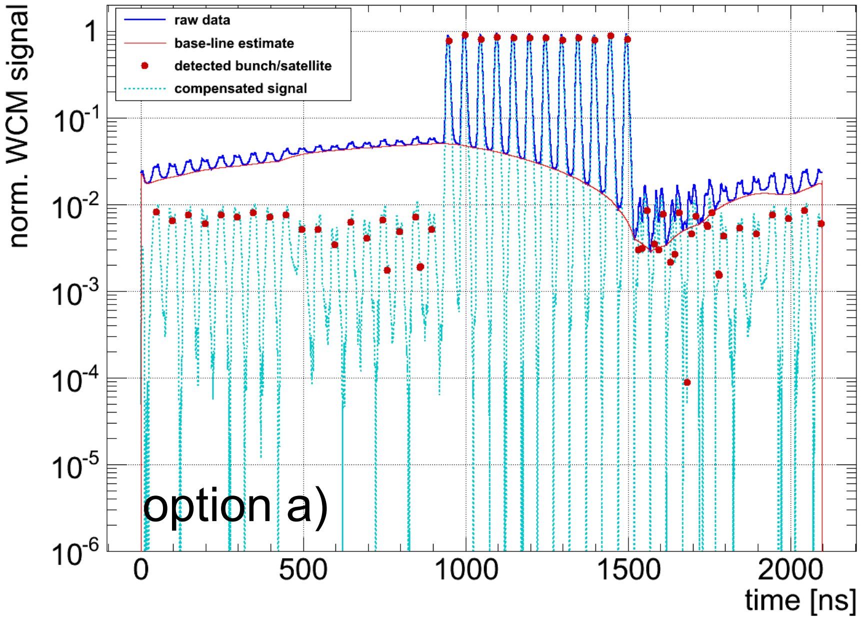
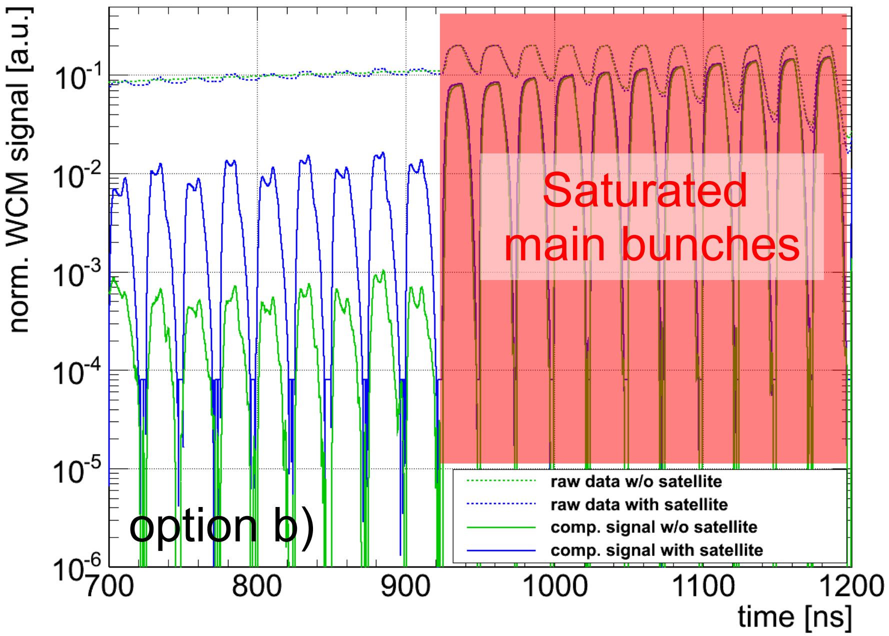
Original publication:

- BI Seminar 2012-06-15 – slides
- BIW'12 Publication – CERN-ATS-2012-249

PS Ghost and Satellite Detection Executive Summary

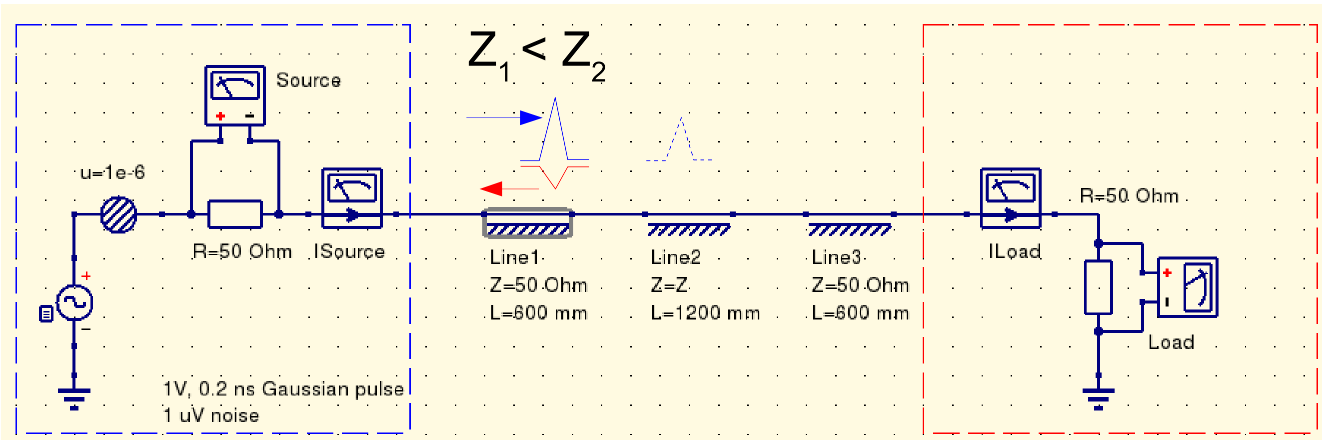
- Nom. empty LHC RF buckets may be filled with minute amounts of particles → aka. 'Satellites' and 'Ghosts' up to 10^{-6} smaller than nominal bunches
- Proof-of-principle: “Can these be detected already in the injectors before the arrive in the LHC using standard wall-current-monitors?”
- Test confirmed that the existing system...
  - can achieve 10^{-5} resolutions @3 GHz over a few turns or single-shot via:
    a) turn-by-turn averaging over a couple of hundred turns
    b) splitting signal and saturating its copy to specifically detect satellites
  - Requires beam-based baseline compensation and reflection control « 1%





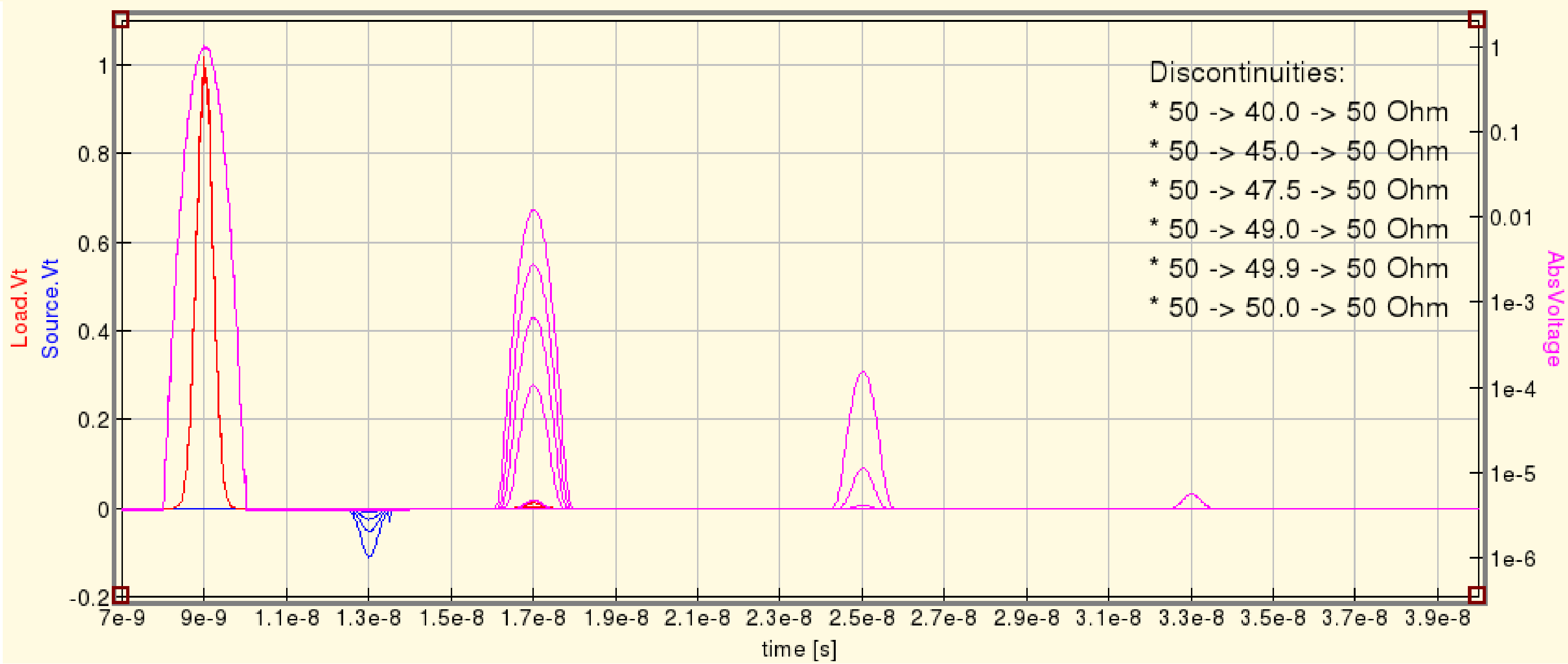
RF Reflections – Definitions

- ...are unavoidable impedance mismatches



$$\rho := \frac{Z_1 - Z_2}{Z_1 + Z_2}$$

$$VSWR := \frac{1-\rho}{1+\rho}$$



Reflections: RF Connector and Cable Geometry

- Selection of common connectors and adapters (H&S):
  - Naively, one would expect these to be inert
  - static and frequency dependent component

VSWR ≤ 1.03 + 0.01·f [GHz]

≤ 1.19 + 0.06·f [GHz]

VSWR ≤ 1.03 + 0.004·f [GHz]

- For comparison, a VSWR of
  - 1.02 ↔ r = 1% ↔ 40 dB
  - 1.03 ↔ r = 1.4% ↔ 36.6 dB
  - 1.05 ↔ r = 2.4% ↔ 32.3 dB

VSWR ≤ 1.025 + 0.007·f [GHz]

≤ 1.05 + 0.015·f [GHz]

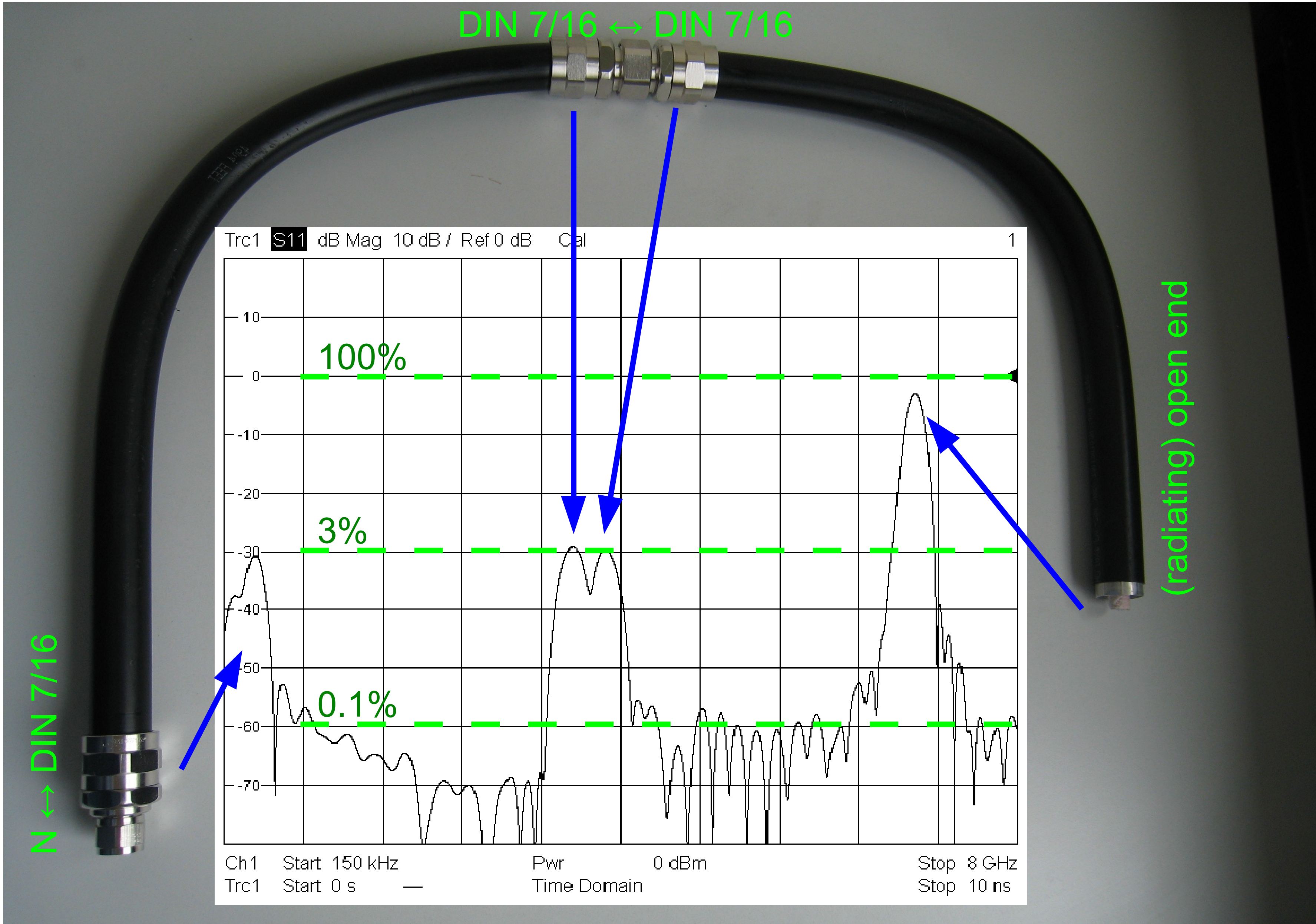
- RF transitions are unavoidable in real life
- %-level reflections are common/normal

VSWR ≤ 1.06 + ~0.01·f [GHz]

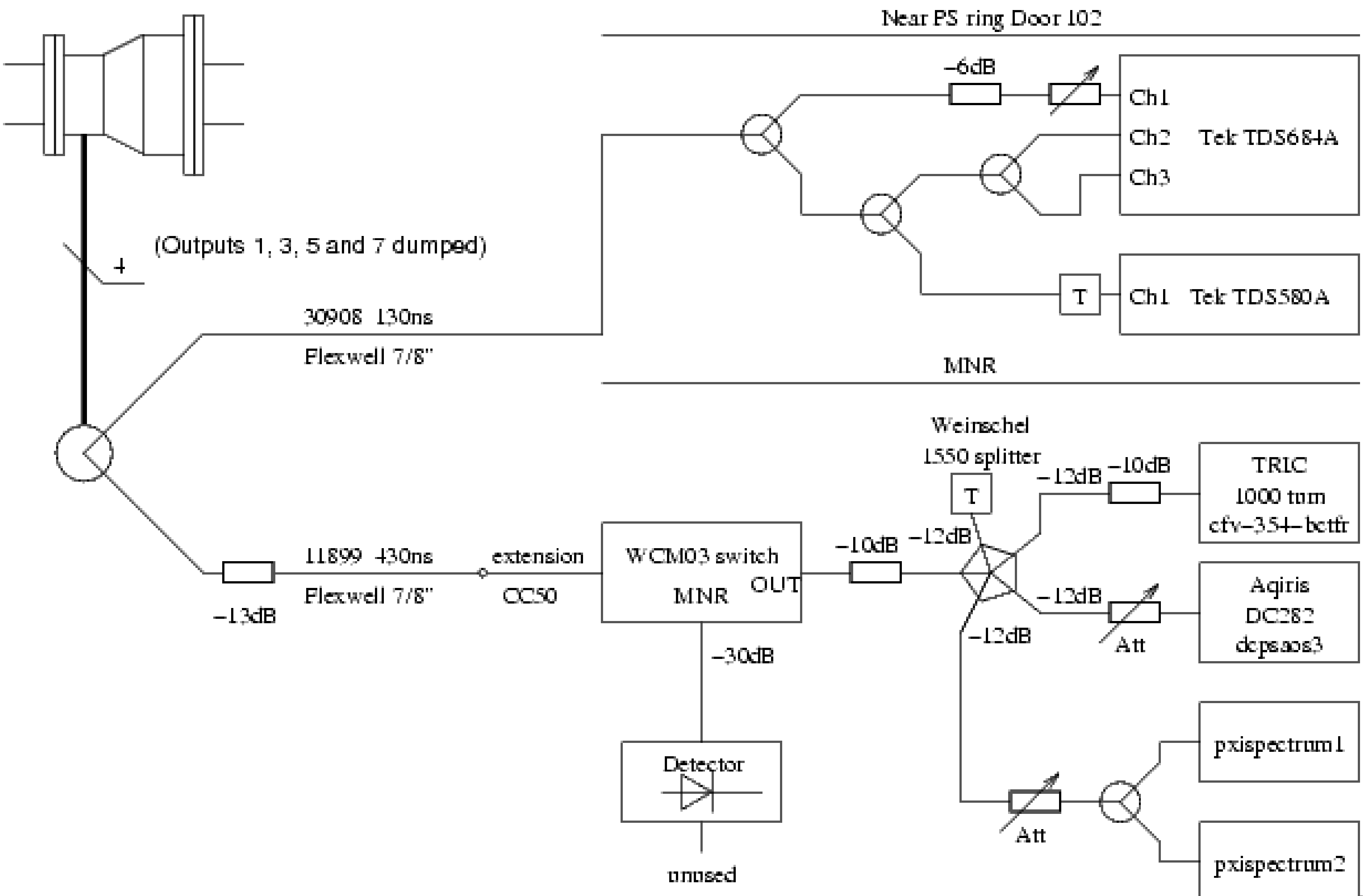
VSWR ≤ 1.02 + 0.03·f [GHz]

≤ 1.05 @ 6GHz

Reflections: RF Connector and Cable Geometry Real-Life Example



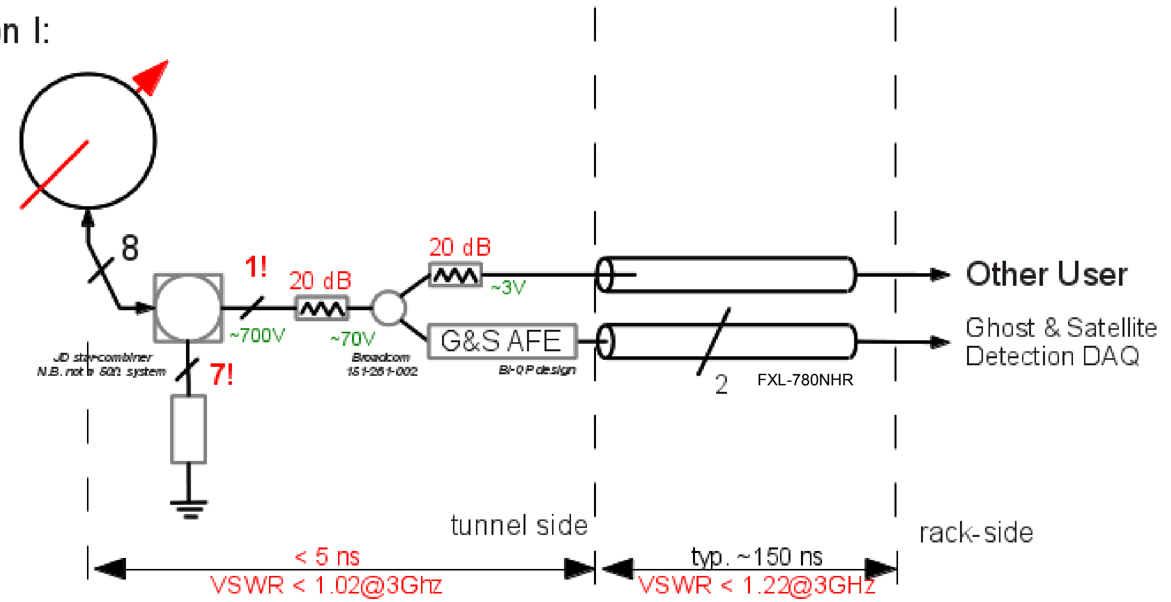
Present PS WCM Cabling Layout



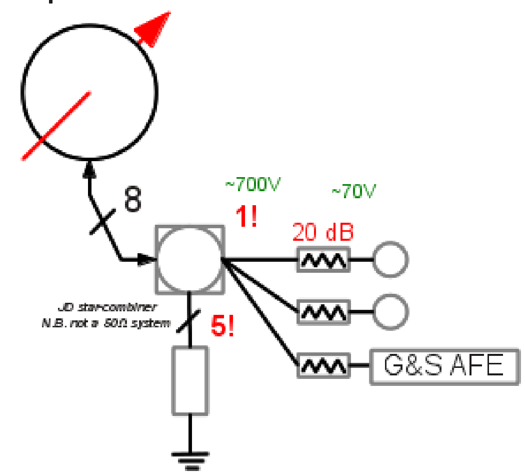
Courtesy J. Belleman

Proposed New PS WCM Cabling Layout (> LS1)

Option I:

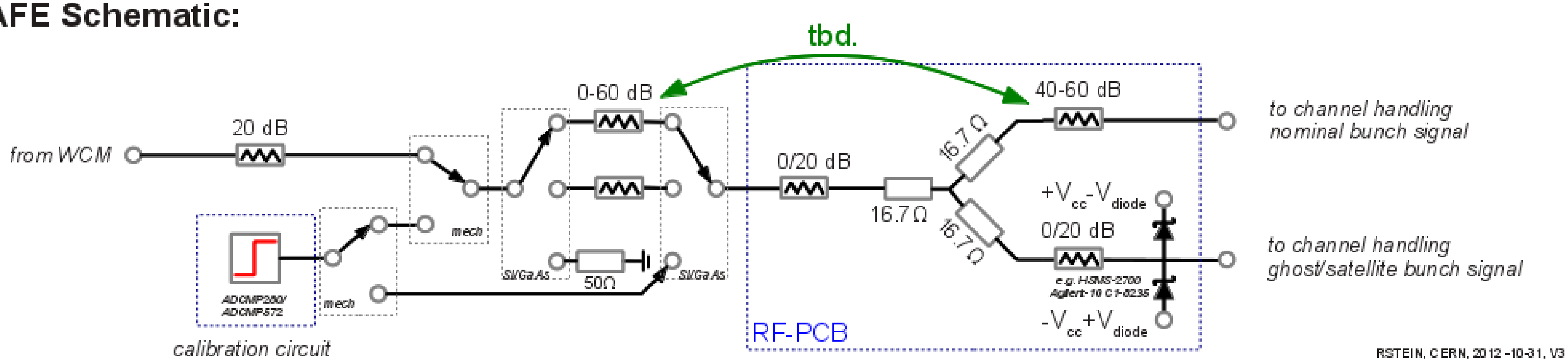


Option II:



Pro: more signal (i.e. ions)
Con: much tighter VSWR requirements
less transient protection

G&S AFE Schematic:



- To be discussed – do we add a second WCM installation to
  a) avoid splitting signal between G&S and other clients?
  b) Divide-and-conquer: nominal (V_{pp}>700V) and pilot/ion beams (V_{pp}>~ 1V)

For Discussion

- Ghost-and-satellite detection on the sub-percent level requires installation systematics (notably reflections and bandwidth) to be controlled better than a percent → can we aim/agree on a VSWR < 1.02 @ 3 GHz specification?

- This implies:
  a) All signal splitting/processing at the WCM, or
  b) after an insulation attenuator of at least 20 dB at the WCM.
  c) qualification with reflectometry before and after every modification

- Of note:
  - High-power levels → recommend protection of DAQ inputs
  - Low signal levels → recommend second WCM dedicated to ions/pilots

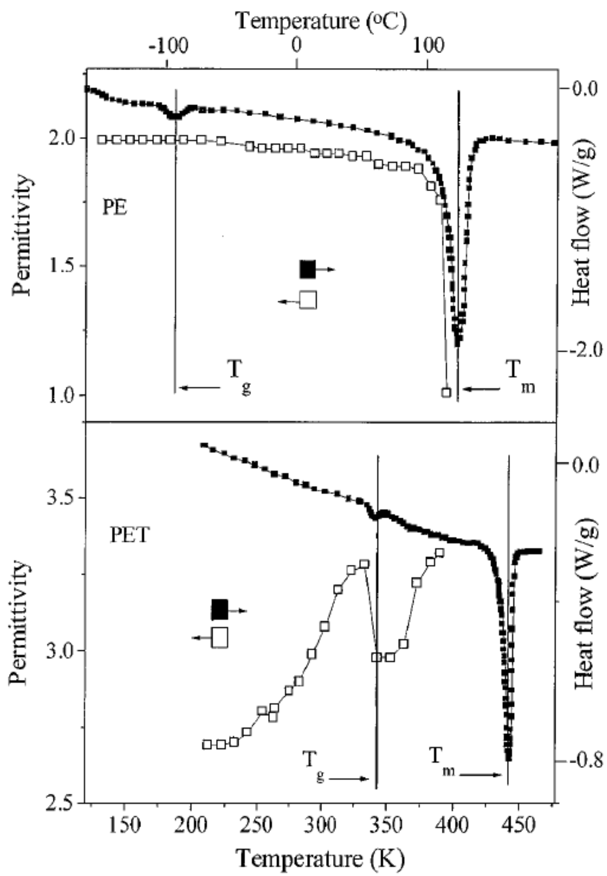
Permittivity and Dependence on Temperature

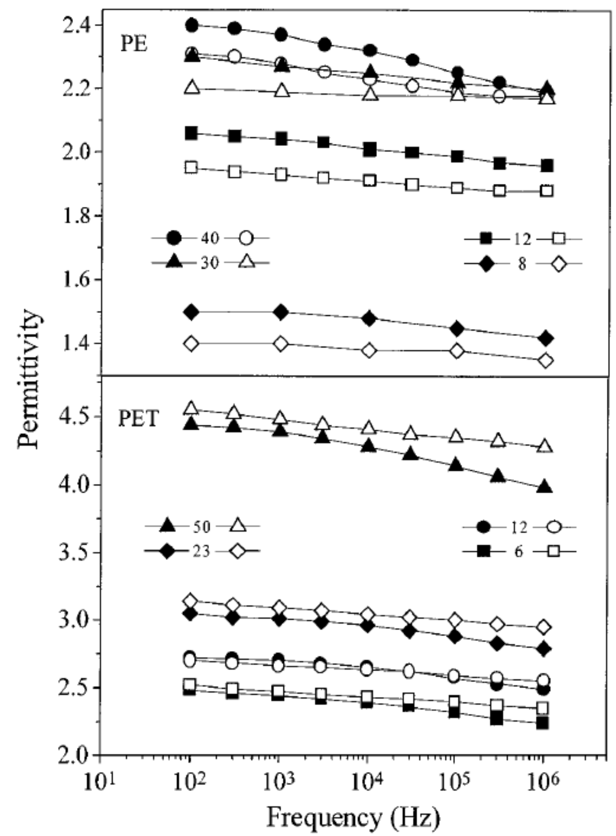
- Permittivity depends on frequency and temperature

N.B. $Z_0 \sim \sqrt{\frac{\mu_r}{\epsilon_r}}$

$$\frac{\partial}{\partial T}\left(\frac{\Delta\epsilon}{\epsilon}\right)\sim\pm 30\,ppm/{}^\circ C \quad (e.g.\,ceramics)$$

$$\frac{\partial}{\partial T}\left(\frac{\Delta\mu}{\mu}\right)\sim 0.1\ldots 1\cdot 10^{-2}/{}^\circ C \quad (typ.\,ferrites)$$





- Highly non-trivial and active research topic
- N.B. PE melts at a very low temperature around 100 °C ↔ ~20 W/m power loss in cables (thanks to S. Smith for pointing this out!)