Microwave diagnostics in the CERN SPS

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- Goal: mitigation of electron cloud in SPS
- Ideas:
  - Amorphous carbon coating
  - Clearing electrodes
- Test of these techniques required
- One possibility: Microwave transmission method – measures **integrated** electron cloud density

- Consider carrier wave signal:

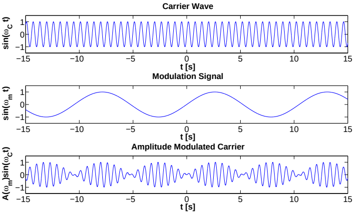
$$V(t) = A \cdot \cos(\omega_C t)$$

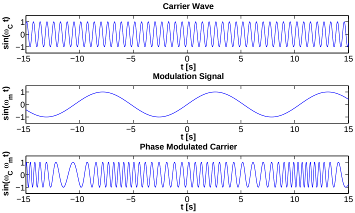
- Amplitude modulation (AM) signal

$$m(t) = A_\mathrm{m} \cos(\omega_\mathrm{m} t)$$

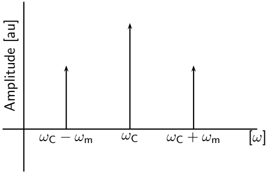
- Phase modulation (PM) signal

$$m(t) = \cos(\omega_\mathrm{m} t)$$

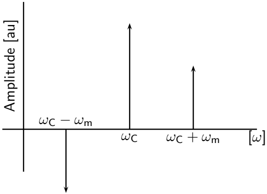




- Amplitude modulation:



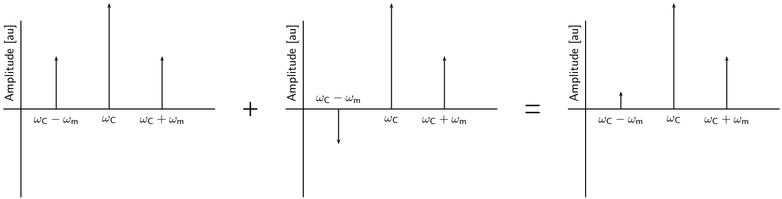
- Phase modulation:



$$V_{AM}(t) = A_C \cos(\omega_C t) + \frac{a\, A_C}{2} \left[\cos((\omega_C + \omega_m)t) + \cos((\omega_C - \omega_m)t)\right]$$

$$V_{PM}(t) = A_C \cos(\omega_C t) + \frac{\beta\, A_C}{2} \left[\cos((\omega_C + \omega_m)t) - \cos((\omega_C - \omega_m)t)\right]$$

- Both forms of modulation $\rightarrow$ unequal height of sidebands

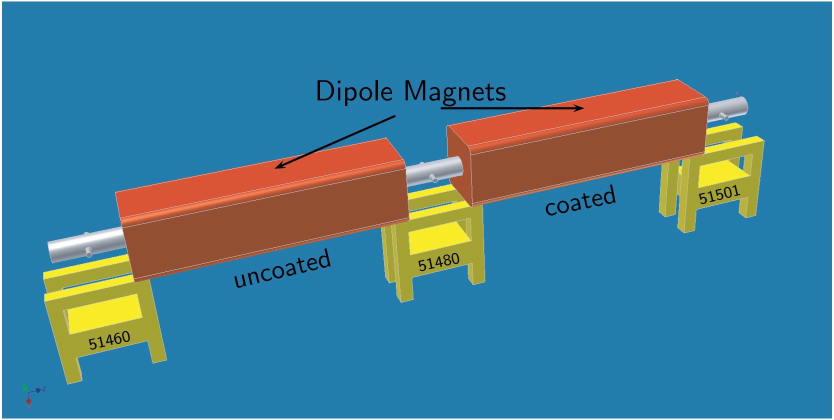


- Principle: Measurement of the induced phase shift of a microwave going through a plasma filled waveguide
- Proportional to electron cloud density:

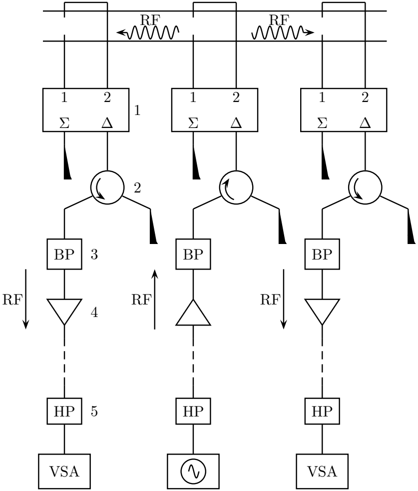
$$\Delta\varphi = \frac{L\,\omega_p^2}{2c\left(\omega^2-\omega_c^2\right)^{\frac{1}{2}}} = \frac{L\sqrt{\frac{n_e e^2}{\epsilon_0 m_e}}^2}{2c\left(\omega^2-\omega_c^2\right)^{\frac{1}{2}}} \cong \frac{L\cdot 3181\,n_e}{2c\left(\omega^2-\omega_c^2\right)^{\frac{1}{2}}}$$

where ω is the injected frequency, L the transmission length, ω_c the cutoff frequency of the waveguide, c the speed of light, ω_p the plasma frequency, e the electron charge, ϵ_0 the permitivity in free space and m_e the electron mass

- Dipoles measured:

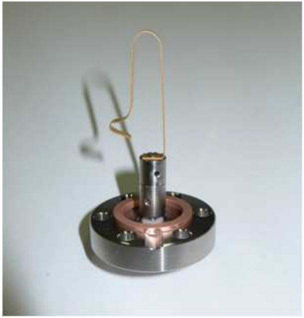


- Schematic layout

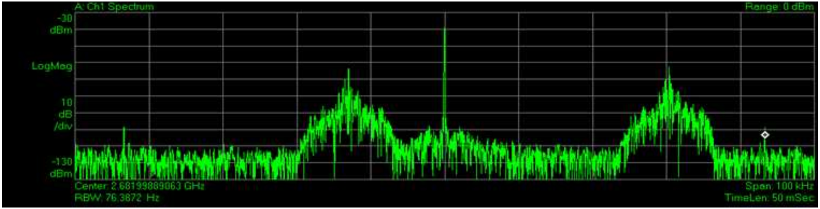


- 1 hybrid
- 2 circulator
- 3 band pass filter
- 4 amplifier
- 5 high pass

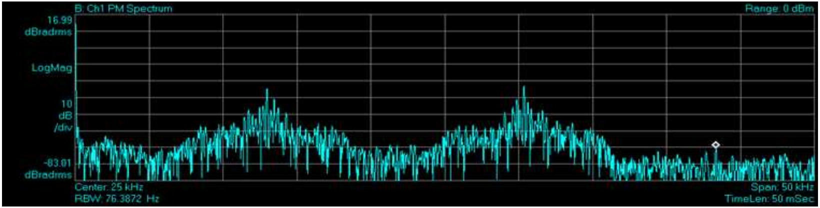
- Antenna and Pumping port



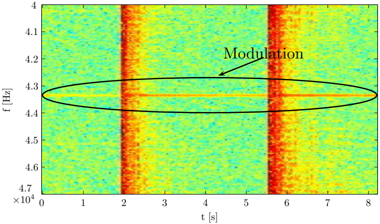
- Measurement screen shot

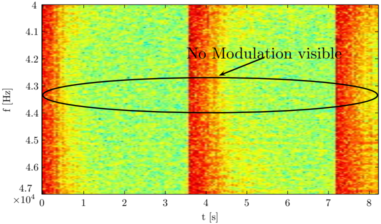


- Demodulation



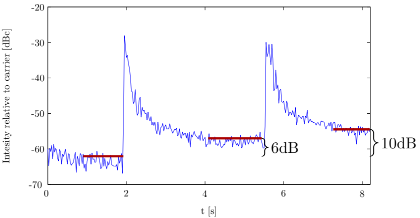
- Spectrum of uncoated and coated magnet

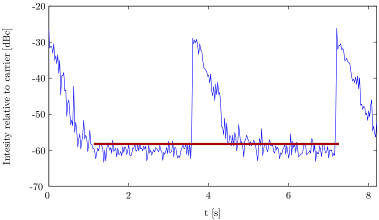




Data taken with 25 ns beam of 4 batches at SPS flat bottom

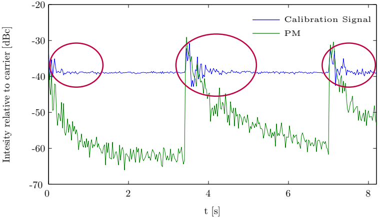
- Time trace of uncoated and coated magnet - coated section minimum 6 dB lower signal



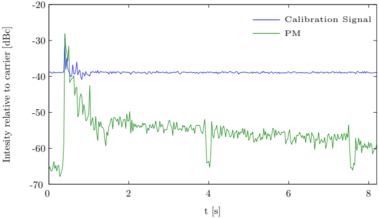


Data taken with 25 ns beam of 4 batches at SPS flat bottom

- Calibration signal

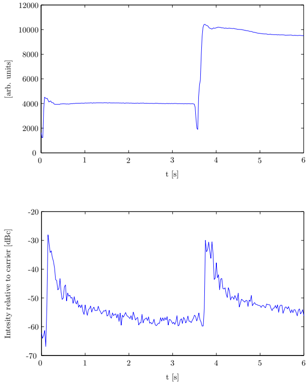


Data taken with 25 ns beam of 4 batches at SPS flat bottom

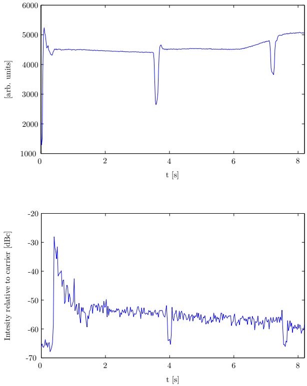


Data taken with 25 ns beam of 1 batch at SPS flat bottom

- Nice agreement between the two methods



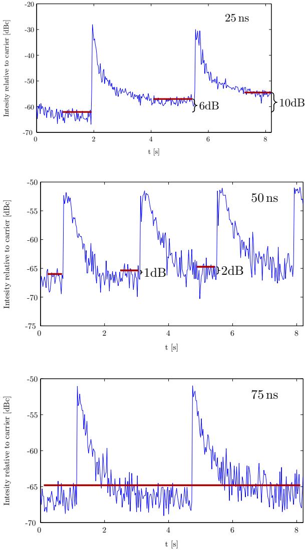
Data taken with 25 ns beam of 4 batches at SPS flat bottom



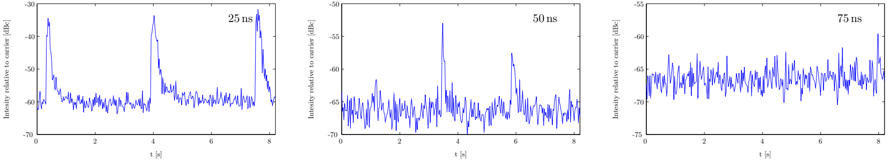
Data taken with 25 ns beam of 1 batch at SPS flat bottom

- Theory prediction:
  - Reduced electron cloud for 50 ns bunch spacing
  - No electron cloud for 75 ns bunch spacing

Data taken with 25 ns beam of 4 batches at SPS flat bottom

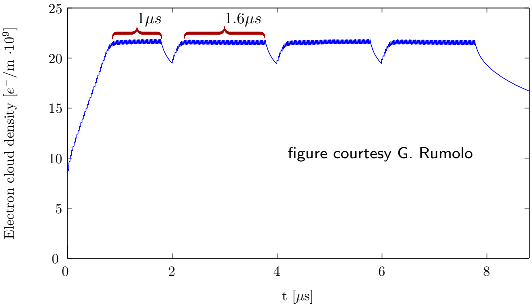


- No signal in coated section for any bunch spacing



Data taken with 25 ns beam of 4 batches at SPS flat bottom

- Microwave transmission method: measurement of integrated electron cloud density
- Sum over growth, plateau and decay of electron cloud:

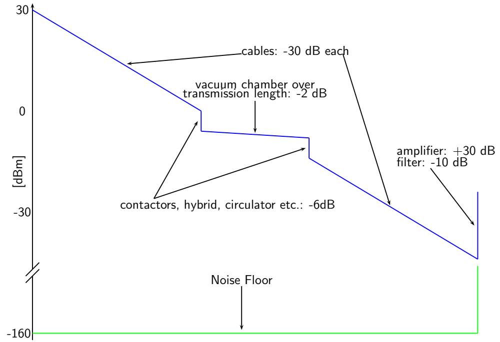


- Quantitative evaluation of measurement: electron cloud density $1.5 \cdot 10^{12}\,\mathrm{m}^{-3}$(peak value)[1]

[1] For further details see: S. Federmann et al., Phys. Rev. ST Accel. Beams 14, 012802 (2011)

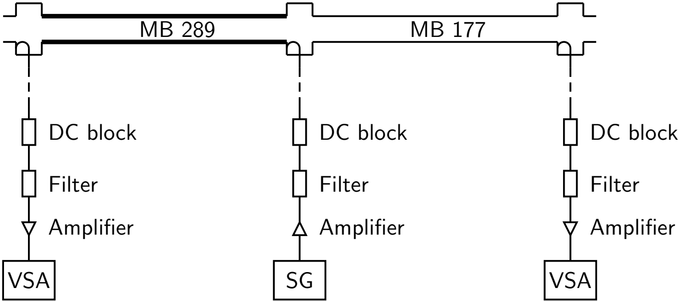
- One problem with setup:
  - Electronics in tunnel exposed to irradiation
  - Consequence: 3 amplifiers died
  - Need setup without electronics in tunnel

- Compensate losses → better coupling needed
- Overview of losses:



- Solution: Improve coupling → remove pumping port shielding

- New setup (only one antenna needed)



- To be tested

Thank you for your attention!