Electron Cloud Measurements

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Motivation

- Electron cloud limits beam intensity and beam quality at high currents
- Coating of the beam pipe might reduce electron cloud
- Present method (microwave transmission method) is suitable to measure **integrated electron cloud density** over transmission length (other methods (e.g. shielded buttons) measure only point like)
- done via measuring phase modulation (PM) of transmitted wave

Theoretical Expectations

- Expected phase difference between injected and received signal can be calculated[1] via

$$\Delta\varphi = \frac{L\omega_p^2}{2c\left(\omega^2 - \omega_c^2\right)^{\frac{1}{2}}}$$

ω_p…. Plasma frequency
ω……Injected frequency (f = 2.68 GHz)
ω_c…. Cutoff frequency (f = 1.23 GHz)
L……length of transmission path (6.5 m)

- $\Delta\varphi$ is proportional to the electron cloud density:

$$\omega_p \cong 56.4\sqrt{n_e}$$

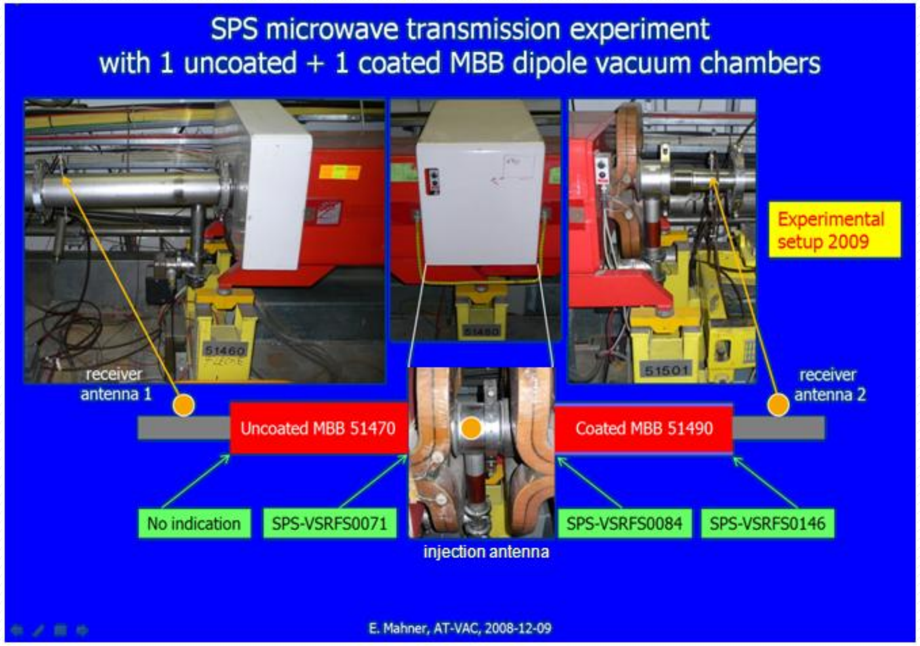
n_e …electron cloud density ≈ 10^{12}

- Expect a phase difference of $\Delta\varphi = 2.3 \cdot 10^{-3}$ rad

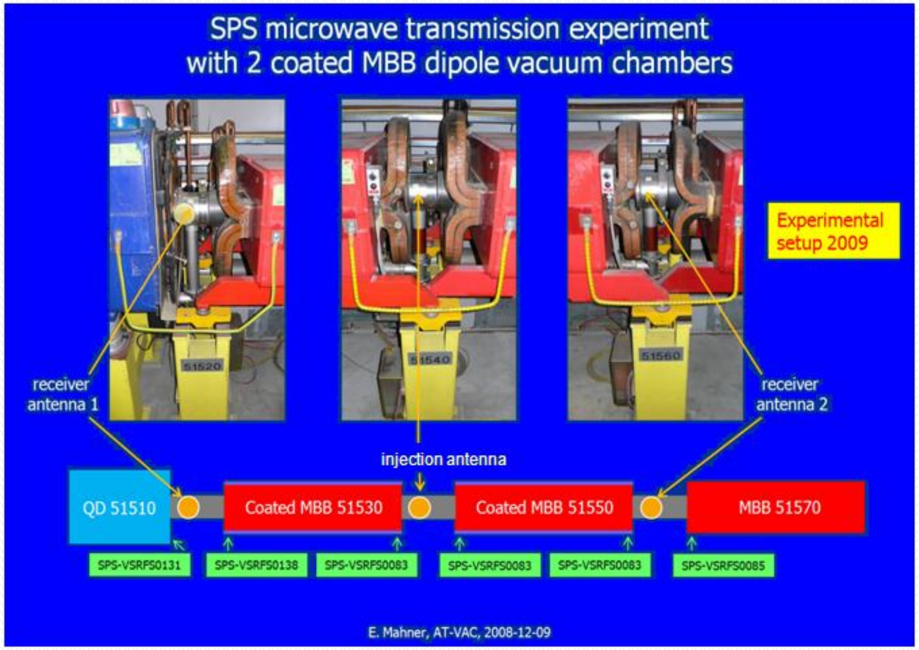
1: S. De Santis, J. M. Byrd, F. Caspers, A. Krasnykh, T. Kroyer, M. T. F. Pivi and K. G. Sonnad; Measurement of Electron Clouds in Large Accelerators by Microwave Dispersion; PRL 100, 094801 (2008)

Experimental Setup

uncoated/coated



coated/coated



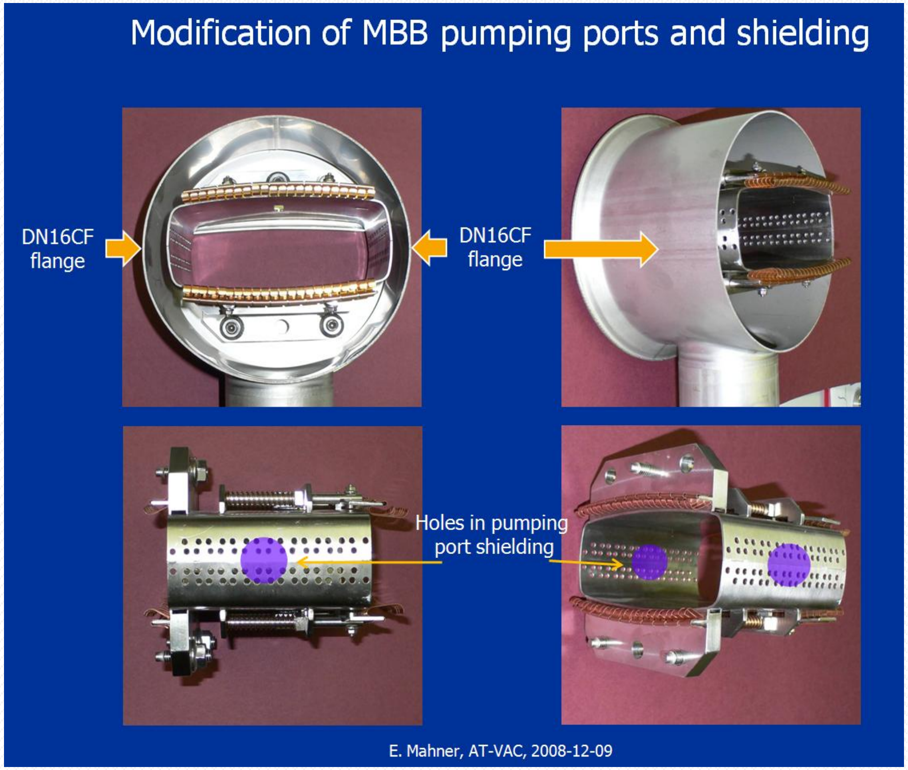
→ In total we have 4 measurement sections

Design Considerations

Requirements:

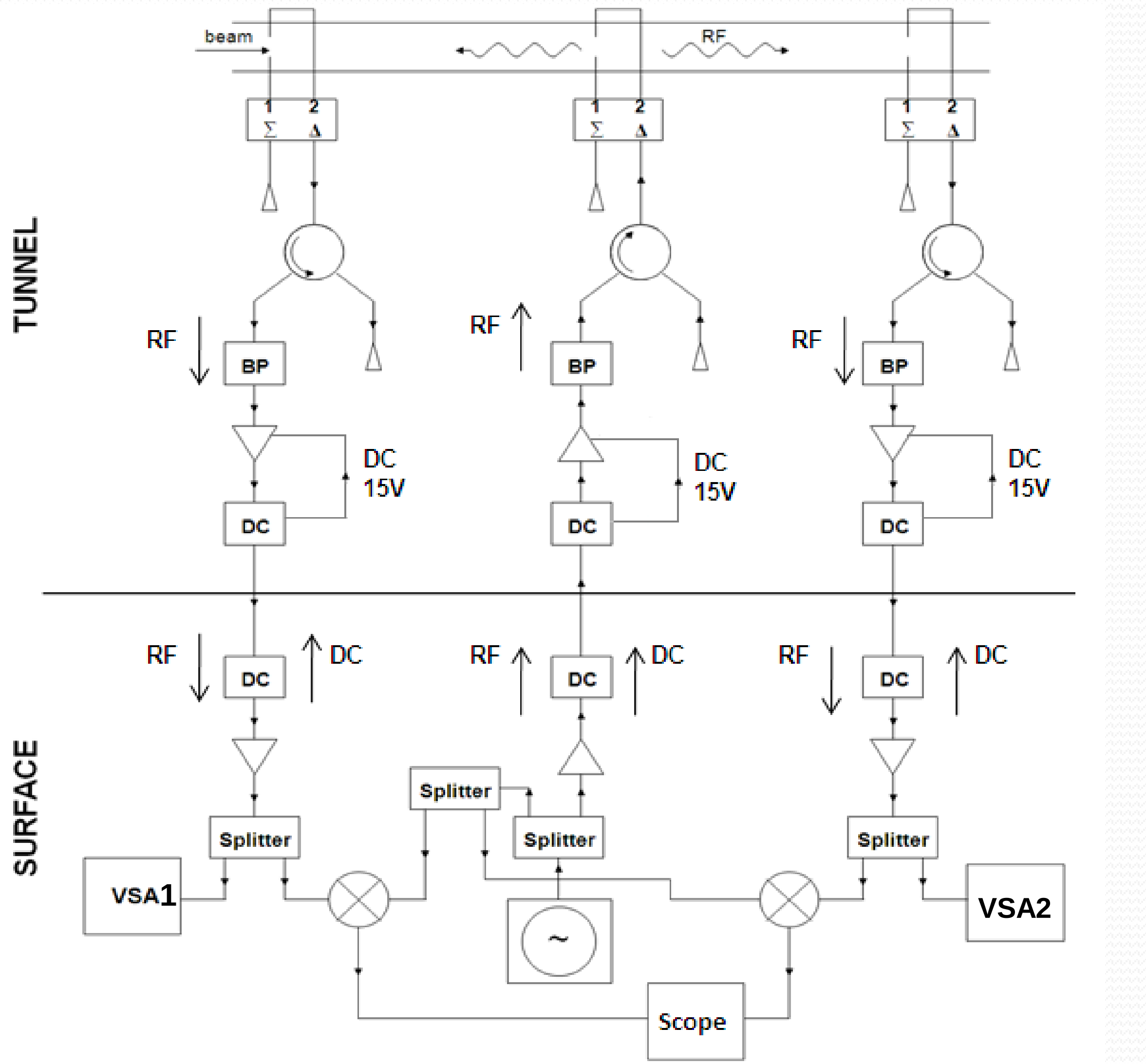
- Severe space constraints (upper picture)
- Need to fit pick ups through two walls

  (beam pipe and RF shield – lower picture)
- Minimization of beam induced signals
- Fairly easy and reasonably fast production and implementation of the pickups



Experimental Setup

Schematic drawing of the setup used in the 2 different (coated/ uncoated) beam pipe sections



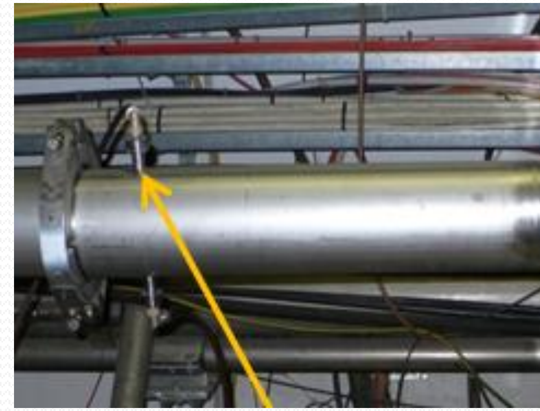
VSA … Vector Spectrum Analyzer

BP …… Band pass

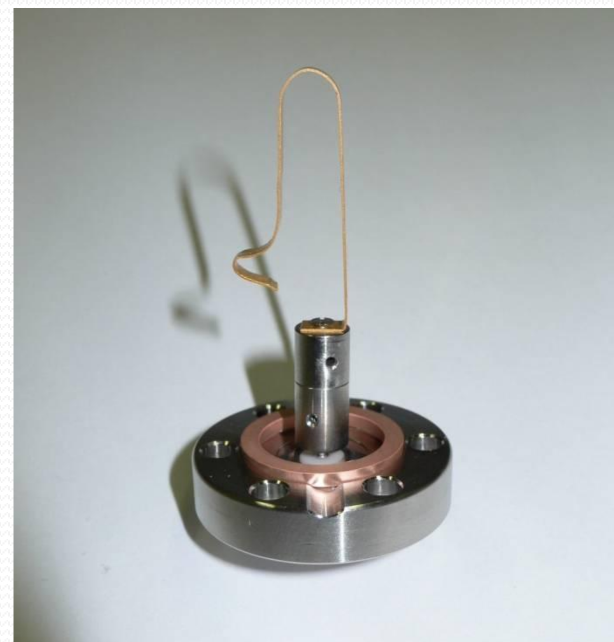
DC ….. Direct current bypass

Experimental Setup

Antennas and buttons used for the SPS microwave transmission experiment (loops in 5 locations = 10 loops)

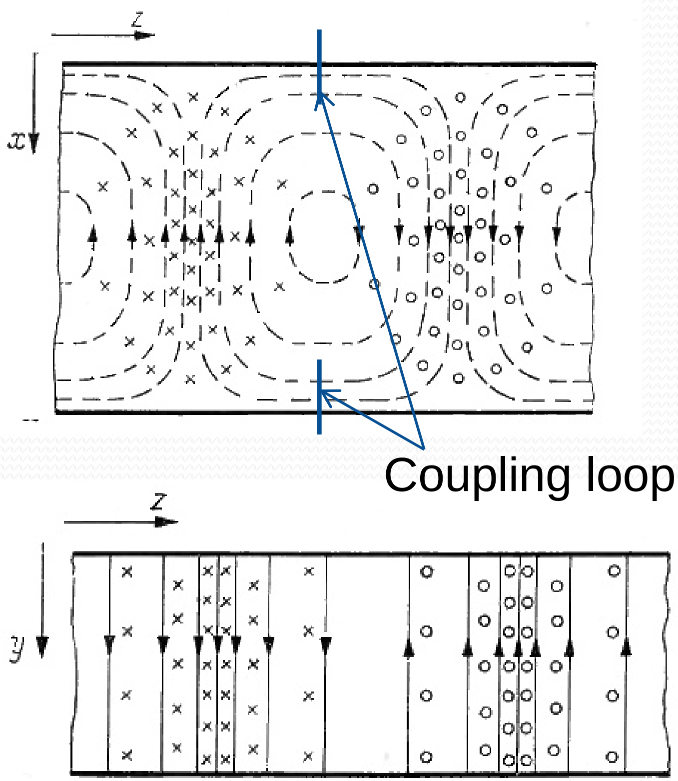


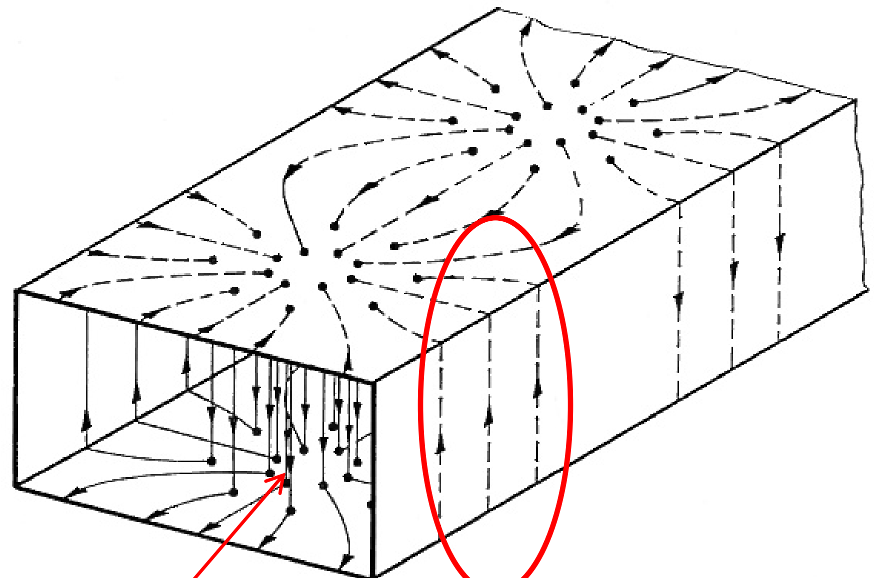
Buttons (not loops!) used in one location only



Visualization of fields and wall currents in a rectangular waveguide (TE_{10})

Magnetic field pattern TE_{10}





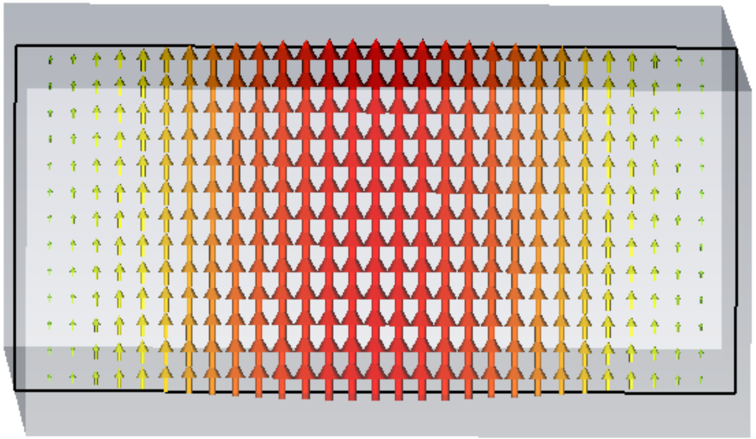
Electric field (displacement current) continuous as wall current and forms closed circles

We have to give the lateral coupling loops an orientation such that they have to interact with the component of the magnetic field in direction of propagation

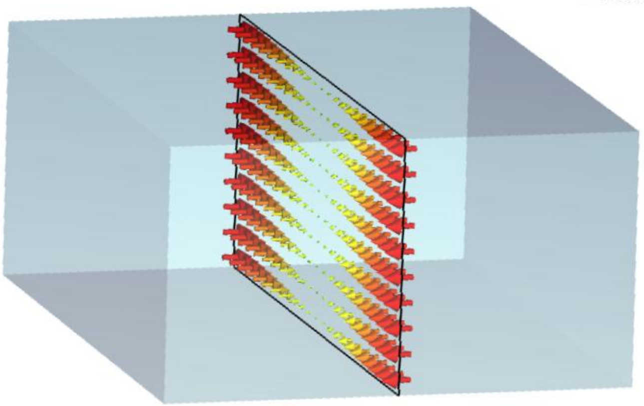
Experimental Setup

Buttons located on top and bottom:

- Couple essentially electrically and E field of the preferred mode (TE10) is highest there
- See a lot of beam induced signals because they are close to the beam
- If the beam is not exactly centered, those picked up signals cannot be suppressed entirely even when operating in the differential mode (button BPM effect)



E field of the TE_{10} mode



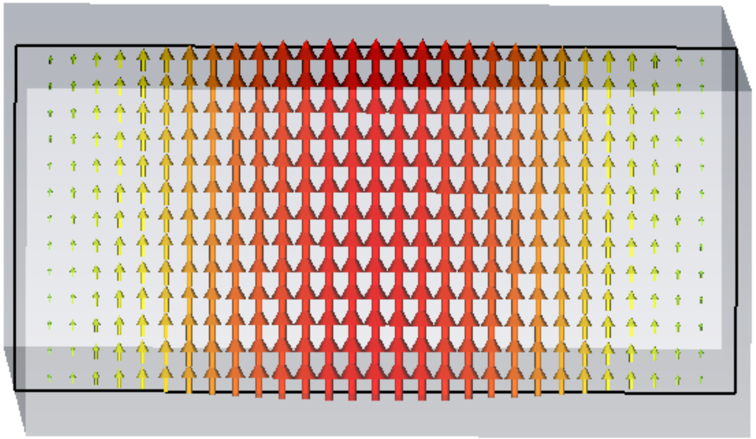
H field of the TE_{10} mode

Experimental Setup

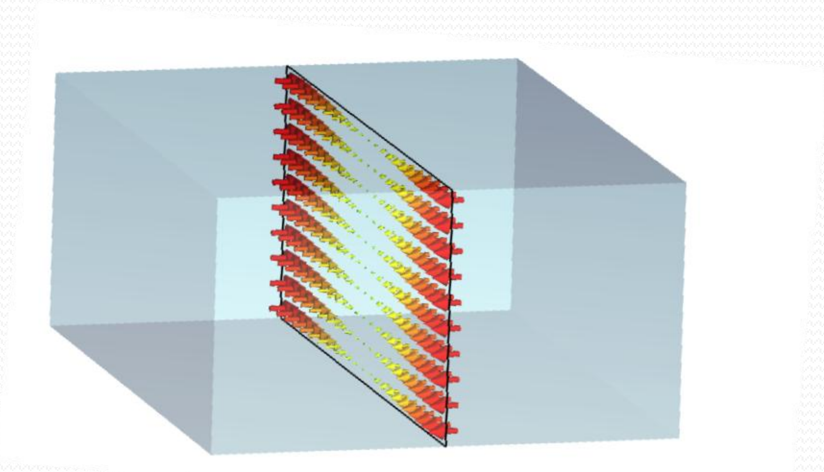
Loop couplers:

- At the lateral (short) side of the waveguide we have low (vanishing) tangential electric field but the maximum of the tangential magnetic field for the TE10 mode

- Loops couple magnetically to the preferred mode (TE10)



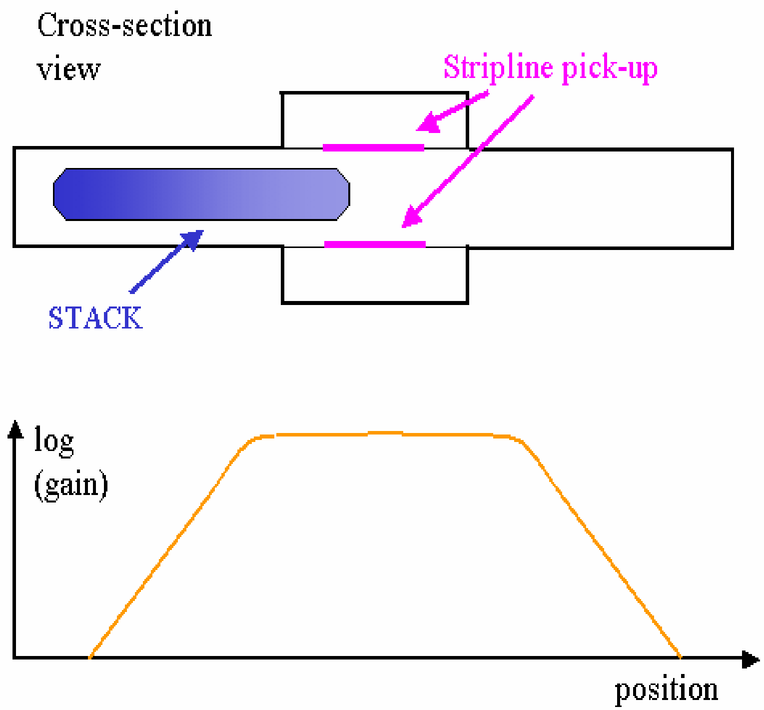
E field of the TE_{10} mode



H field of the TE_{10} mode

Experimental Setup

Simplified cross section of AA stack-tail pick-up



Also TEM like field of beam has already decayed considerably

Gain is roughly proportional to the electric or magnetic component of the TEM like beam field

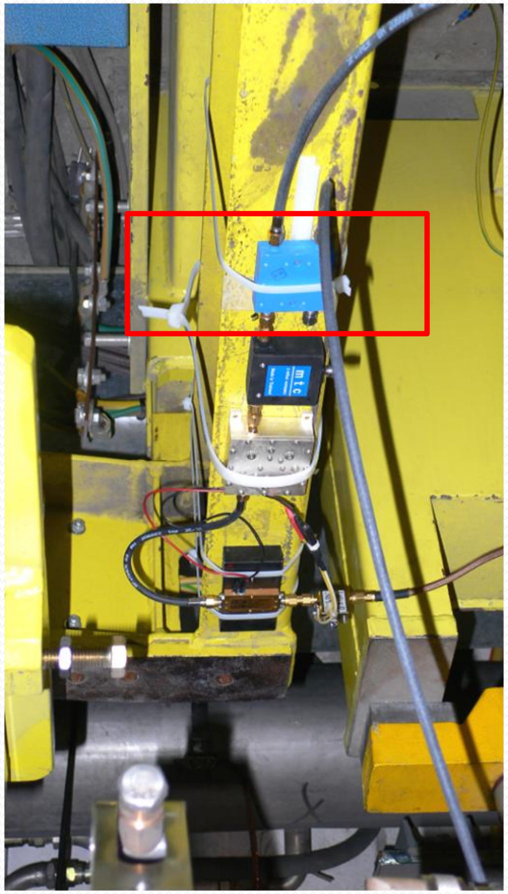
Experimental Setup

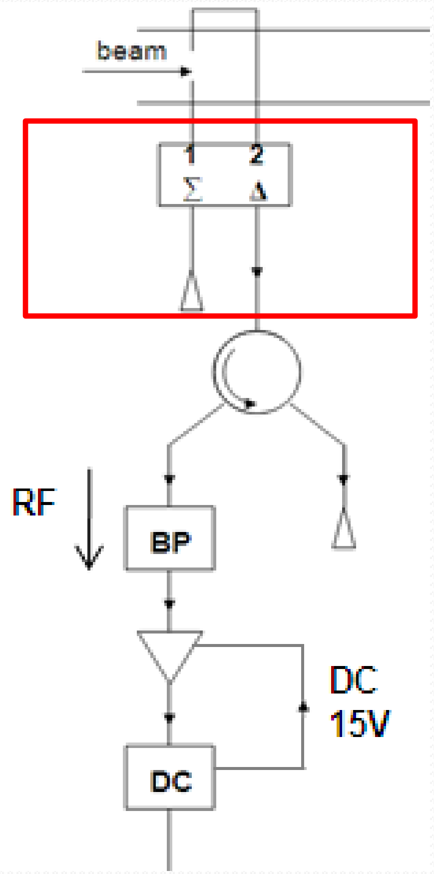
- At one location buttons are installed, but there beam pipe has cylindrical cross section of 100 mm (from previous version of the experiment in 2008), there was no possibility to install loops in the same way as on the other pumping ports
- At all other locations antennas were used to couple magnetically on the short side of the waveguide
- Were adjusted in same direction -> the difference of both signals had to be used since induced currents on each side have a phase difference of 180 degrees – was done using hybrids

Electronics in the Tunnel - receiver path

Hybrid

- provides differential signal for TE10 waveguide mode
- Theoretically, there should be no coupling to the TEM beam mode, however beam always induces waveguide modes at discontinuities (wake field) and those modes couple
- Additionally, loop couplers are not perfect, couple also electrically to a certain extent
- terminated at sum port via 50Ω termination

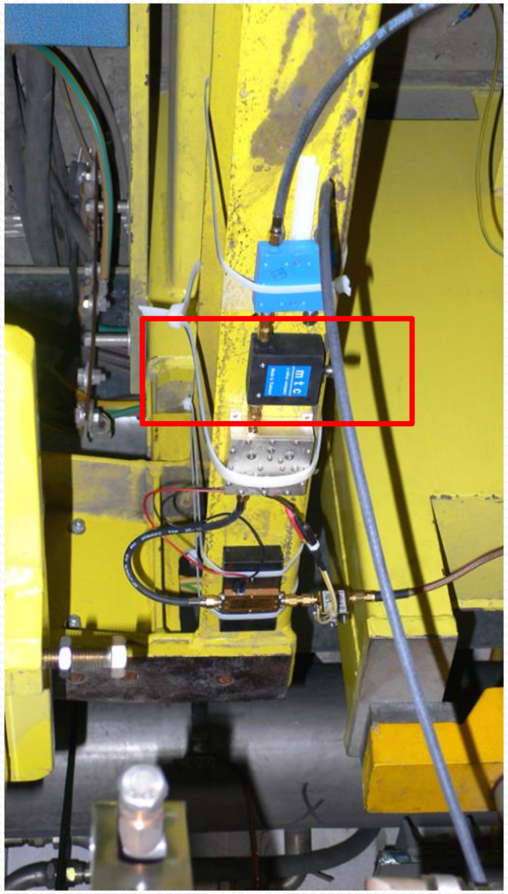


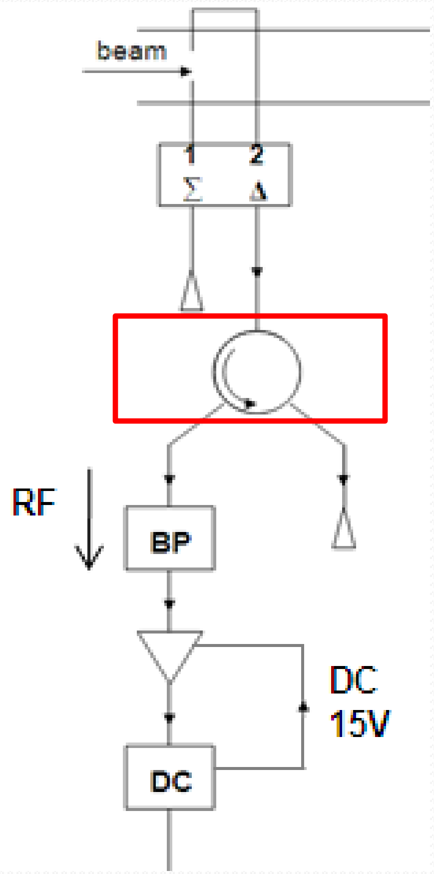


Electronics in the Tunnel - receiver path

Circulator

- Terminated at one port via 50Ω termination
- Terminates the band pass filter on one side, since this filter can only work properly if it is terminated on both sides (on the other side it is terminated via amplifier)
- In case of button pick-ups the circulator also functions as DC return (loop couplers are grounded via beam pipe)

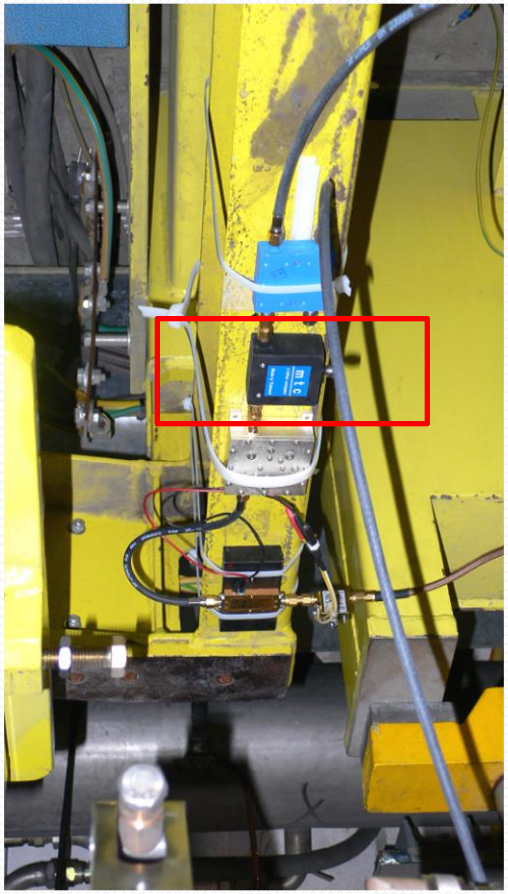


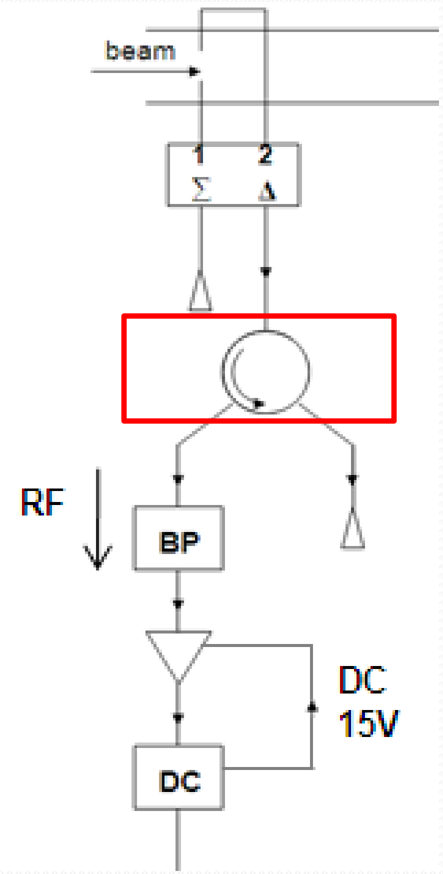


Electronics in the Tunnel - injector path

Circulator

- Terminates band pass filter as well
- Provides protection of transmitter amplifier from beam induced signals in antenna

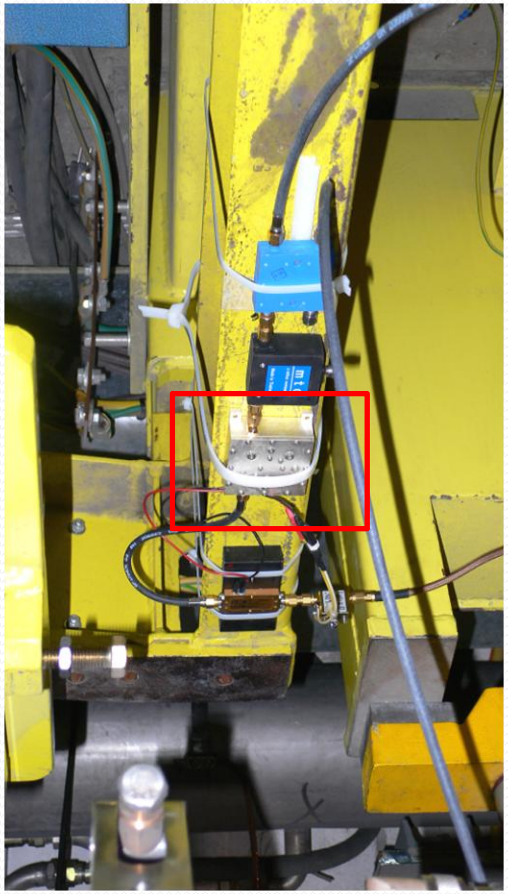


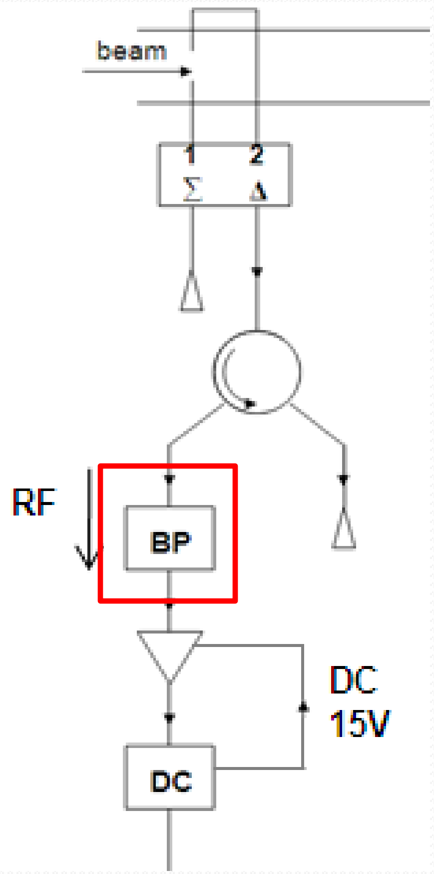


Electronics in the Tunnel - receiver path

Filter (in the picture the old one around 2.5 Ghz is shown)

- We have used single cell cavity filters made in CERN workshop because after installing coupling loops it turned out that reasonable good transmission maximum in the HTF (hardware transfer function) at 2.68 GHz (2.5 GHz before) ⟶ could not use old ones
- Could not know for sure, that filters ordered from industry arrived in time (in fact they were late) ⟶ used home made ones

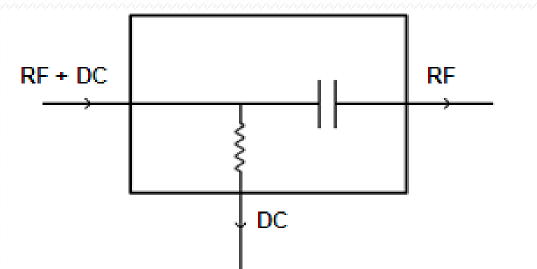




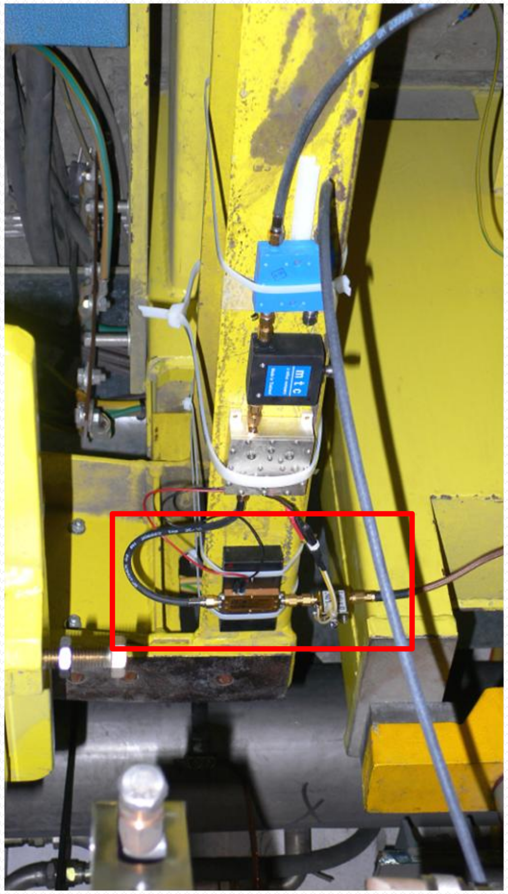
Electronics in the Tunnel - receiver path

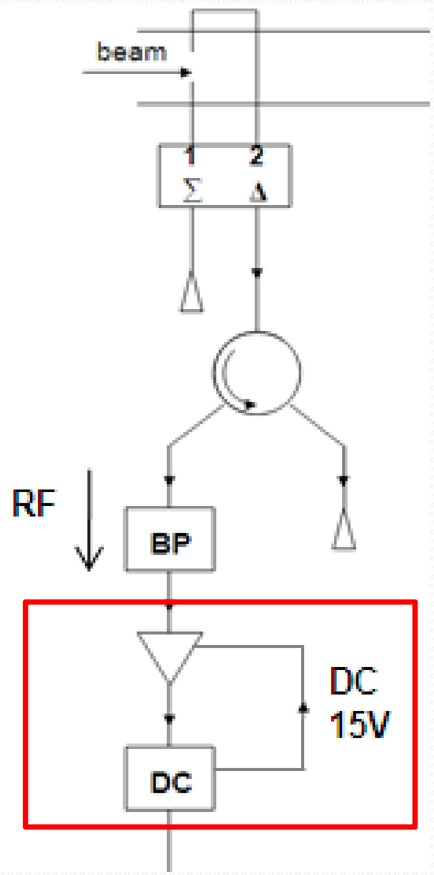
Amplifier and DC bypass (DC feed)

- Wanted to minimize active electronics such as power supplies in the tunnel ⟶ risk of radiation damage
- Could have also provided additional cables but that would have been more expensive
- Working principle of DC bypass:



- DC feed: commonly used e.g. for any terrestrial TV or satellite receiver unit



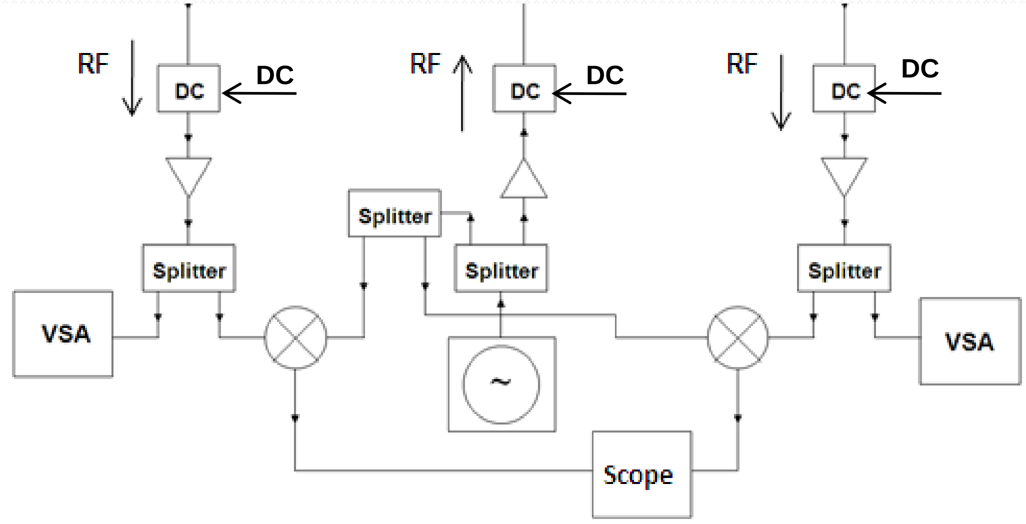


Electronics on surface

Have DC bypass and amplifier as used in the tunnel

Injector path:

- signal generator transmits CW generator signal (2.68 GHz) to a signal divider (splitter)
- One part of the signal goes down to the tunnel
- The other part is needed later as LO signal in the mixers (used as phase detectors)

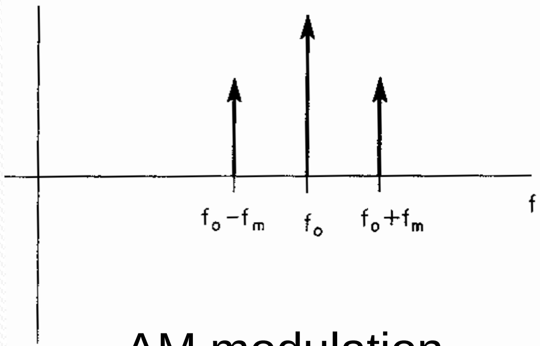


Receiver path:

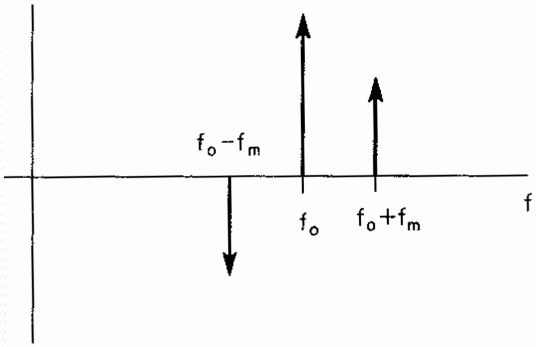
- Signal is splitted after amplification
- One fraction of this signal arrives at the VSA for analysis
- The other fraction is used later as RF in the mixers

AM and PM Modulation

- In general we have three types of modulation:
  - Pure amplitude modulation (AM)
  - Pure phase modulation (PM)
  - Mixture of AM and PM
- In case of a sinusoidal modulation function AM and PM differ in sign in the lower sideband:



AM modulation



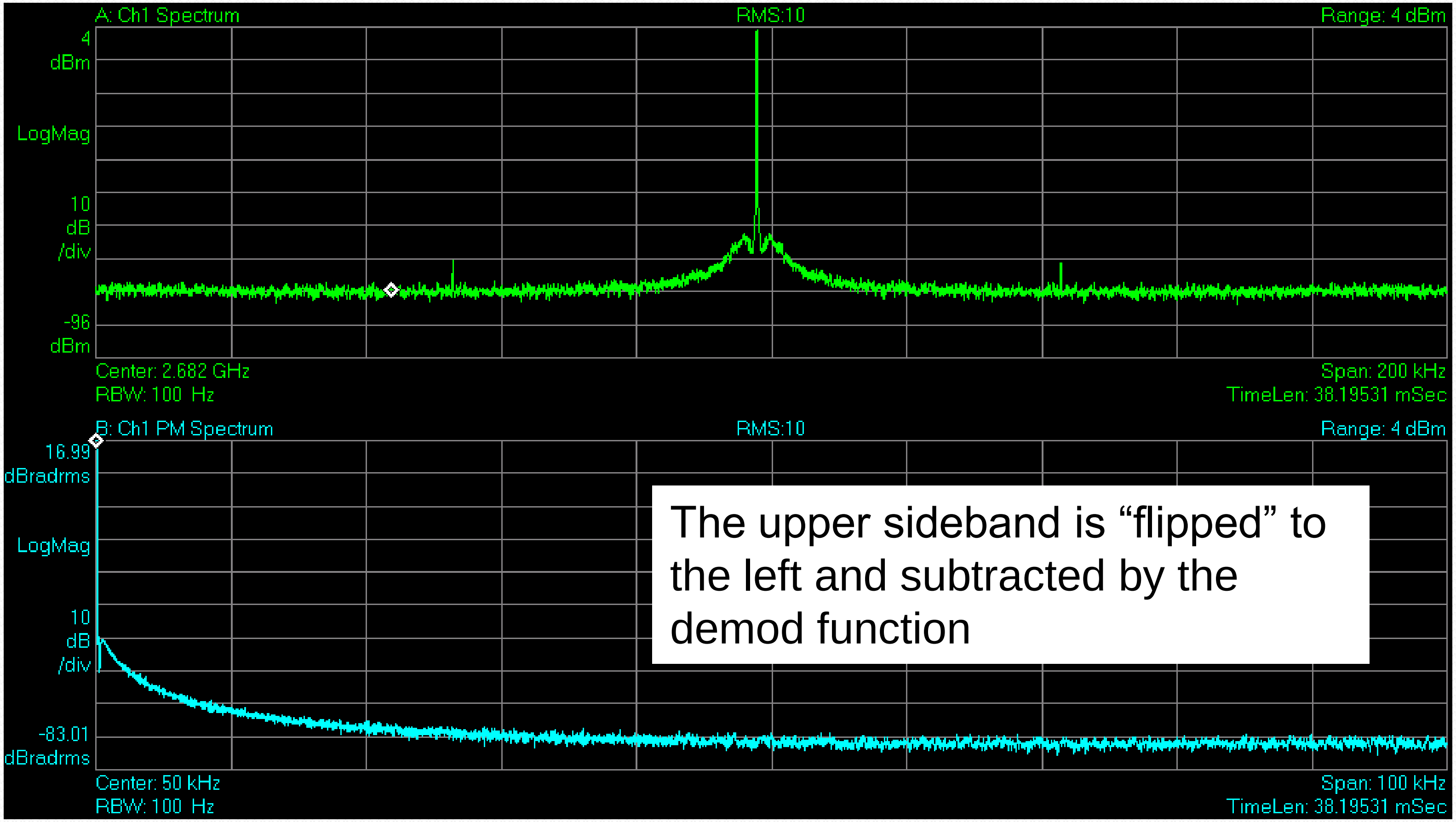
PM modulation

AM: $$v(t) = A_c \cos(2\pi f_c t) + \frac{aA_c}{2}[\cos 2\pi(f_c + f_m)t + \cos 2\pi(f_c - f_m)t]$$

PM: $$v(t) = A_c \cos(2\pi f_c t) + \frac{A_c\beta}{2}[\cos 2\pi(f_c + f_m)t - \cos 2\pi(f_c - f_m)t]$$

A_c….Amplitude of carrier signal, f_c…..Frequency of carrier signal, f_m....Frequency of modulation signal

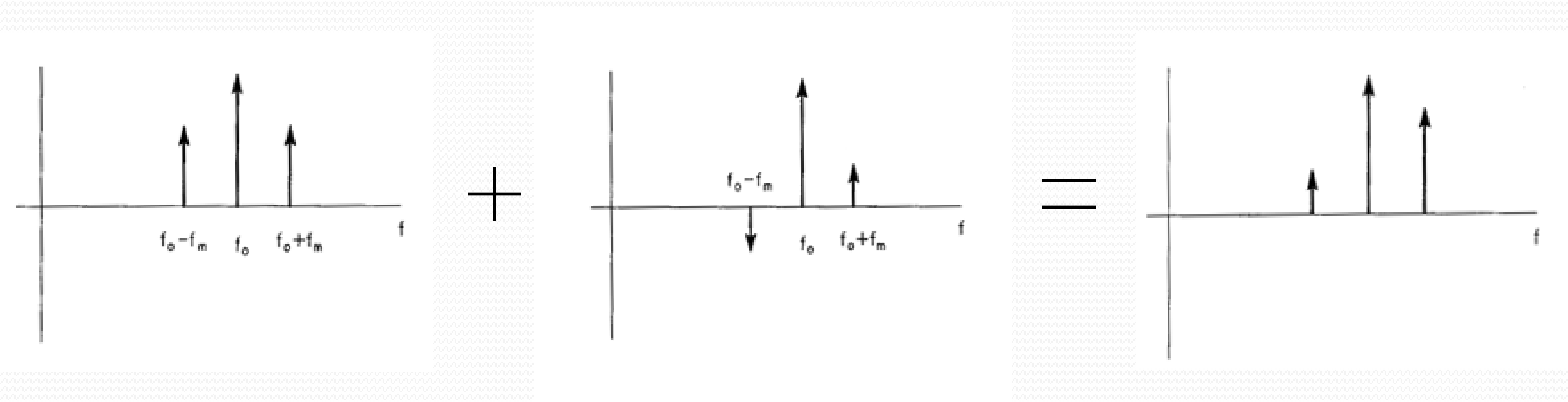
Example for pure AM Modulation



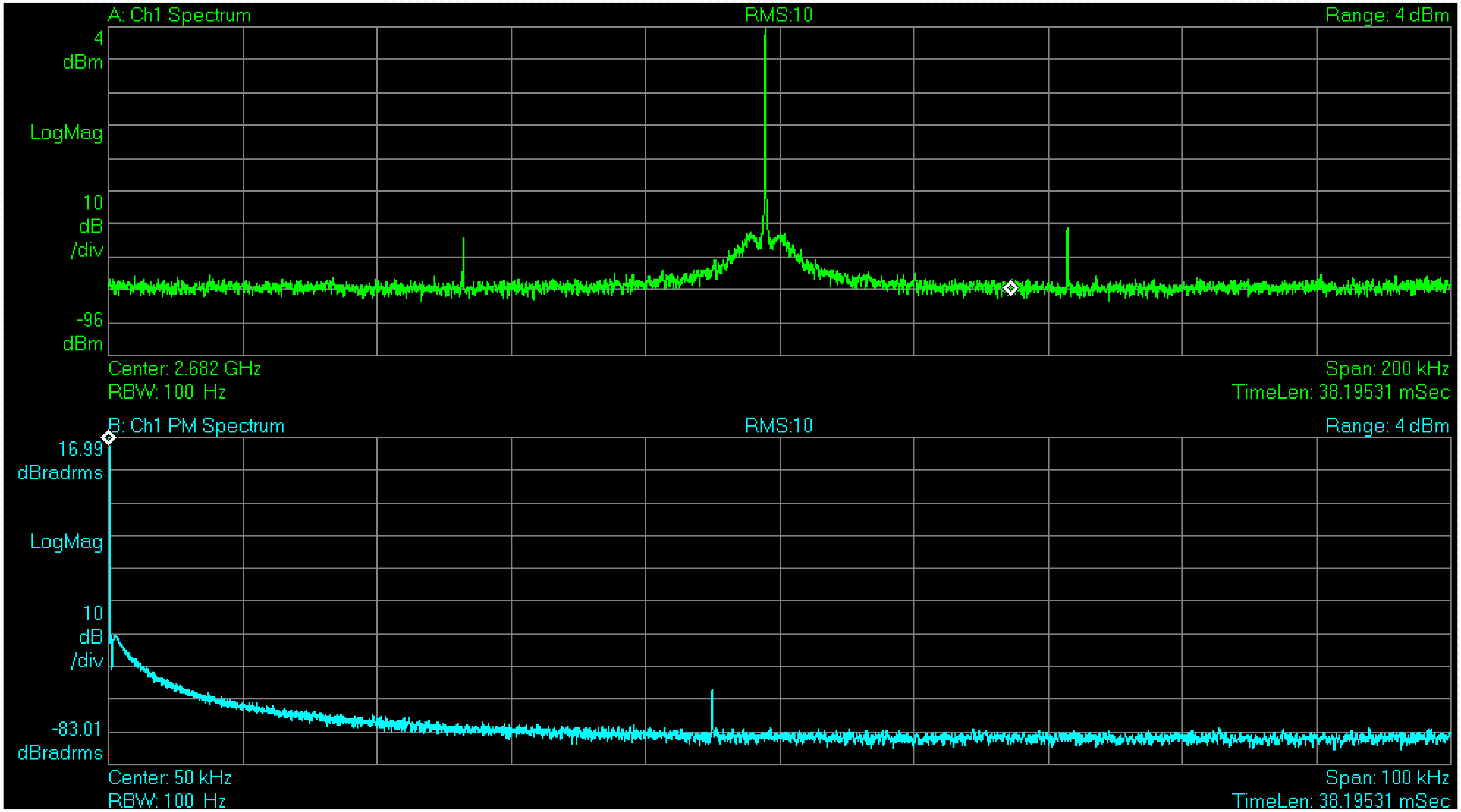
Lower trace (blue): signal after demodulation (note: different span)

AM and PM Modulation

- When we have both (AM + PM) the sidebands have a different height as the two graphs add as vectors:



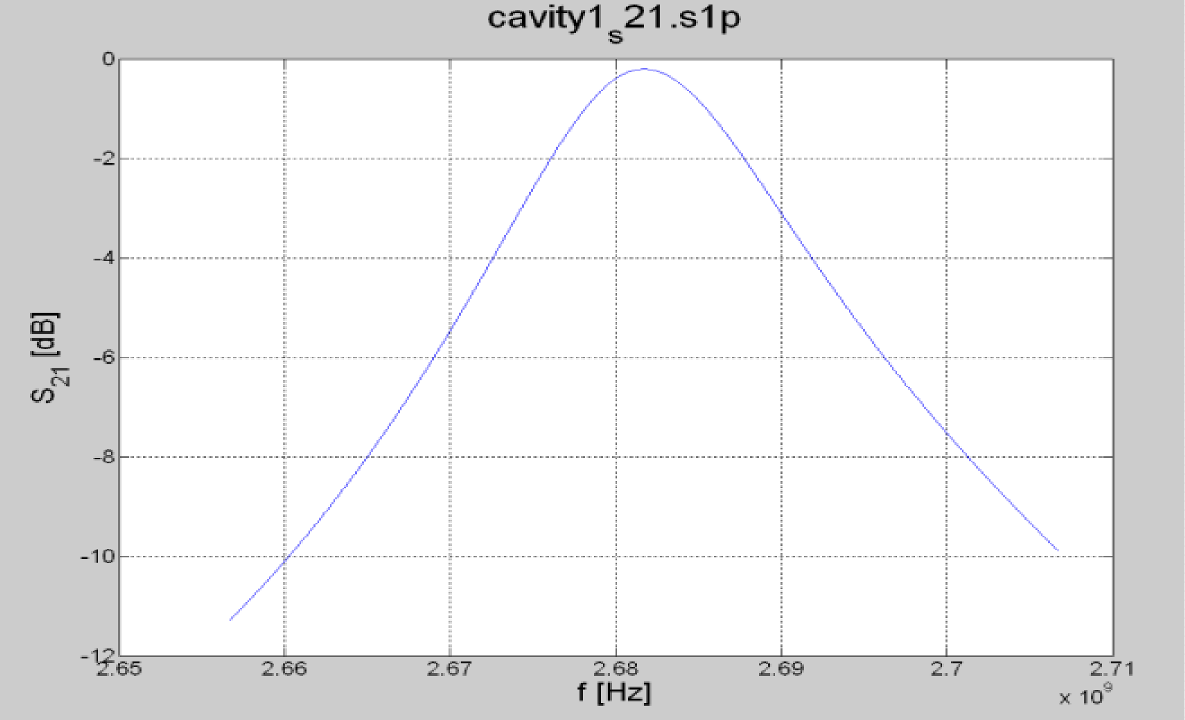
AM and PM Modulation



Lower trace (blue): signal after demodulation (note: different span)

Hardware Transfer Function (HTF), Filter

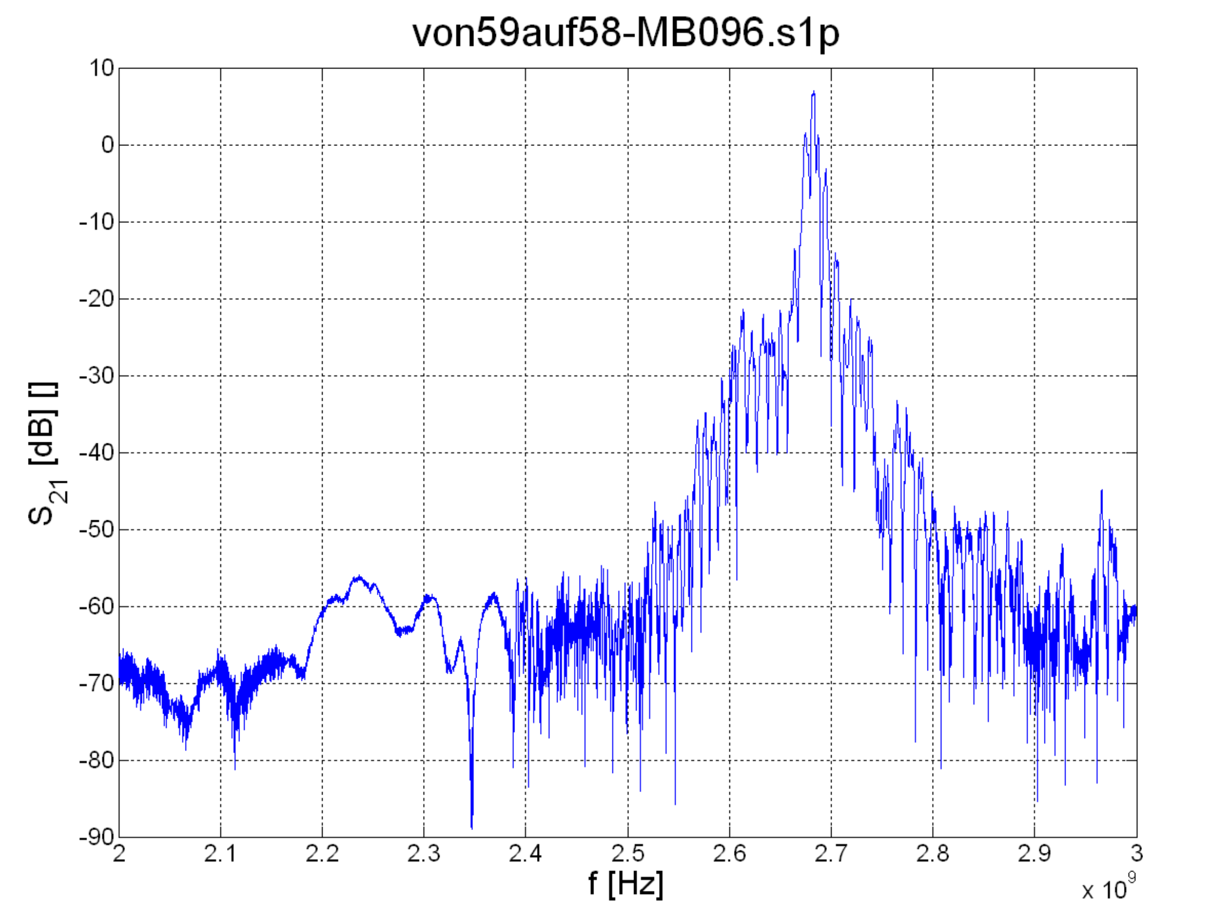
Typical transmission response of filters in use



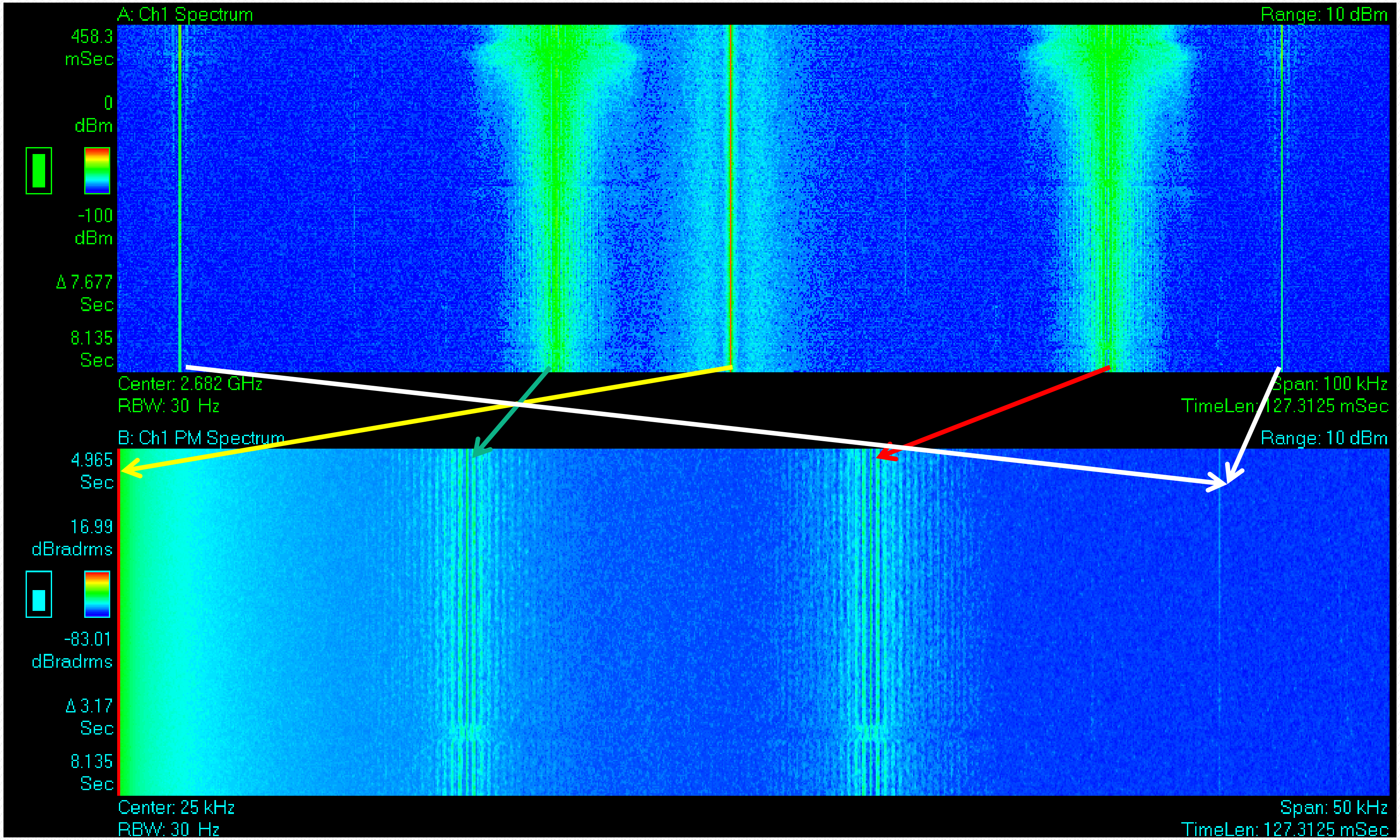
f_c=2.682042 GHz
BW =16.234MHz
Q= 165.19

Hardware Transfer Function (HTF)

HTF of a complete loop:

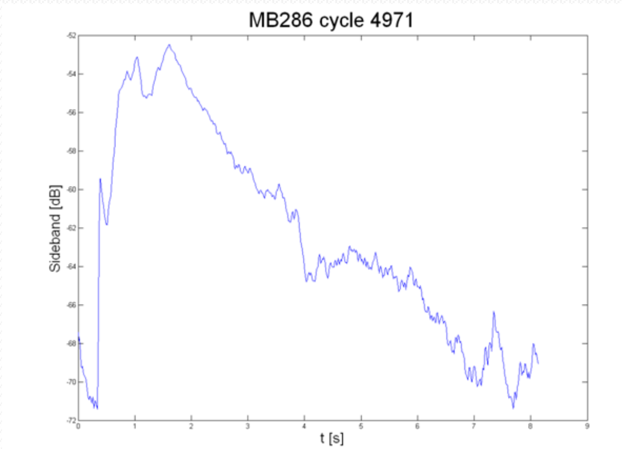


Example of measured signal traces

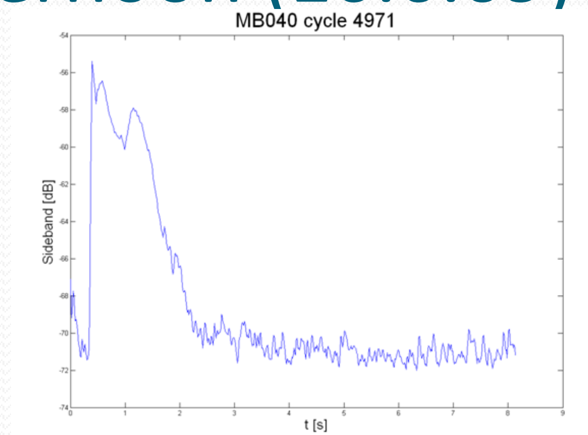


Cyclenr: 4971 , 16.6 2009

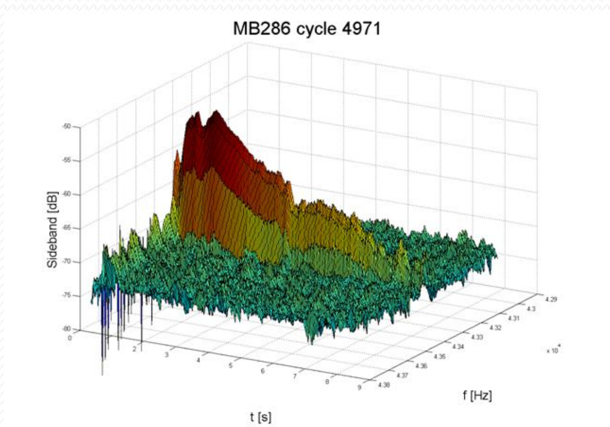
Before scrubbing Tuesday afternoon (16.6.09)



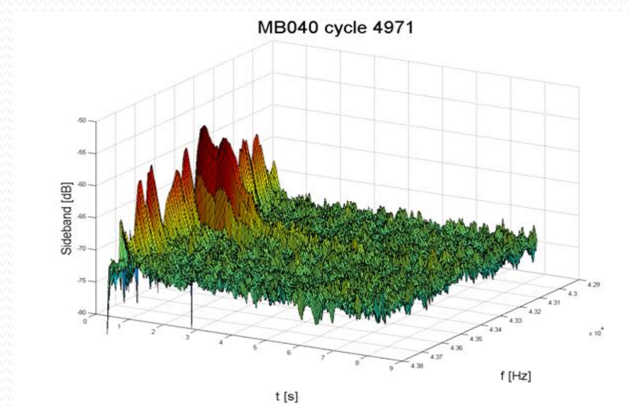
uncoated



coated



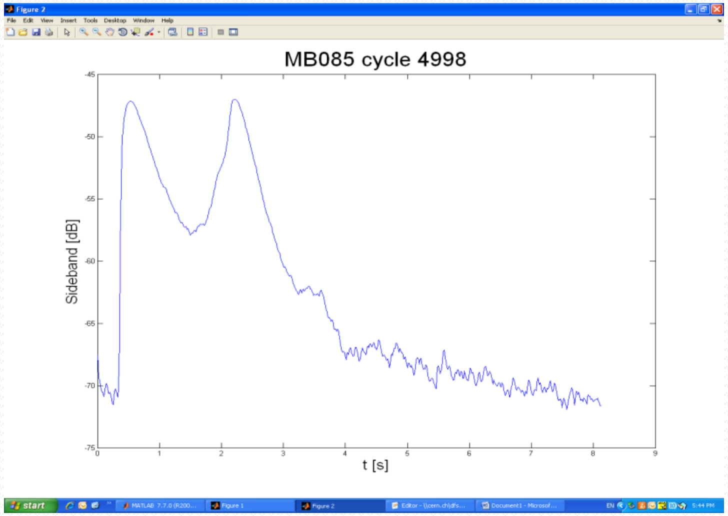
uncoated

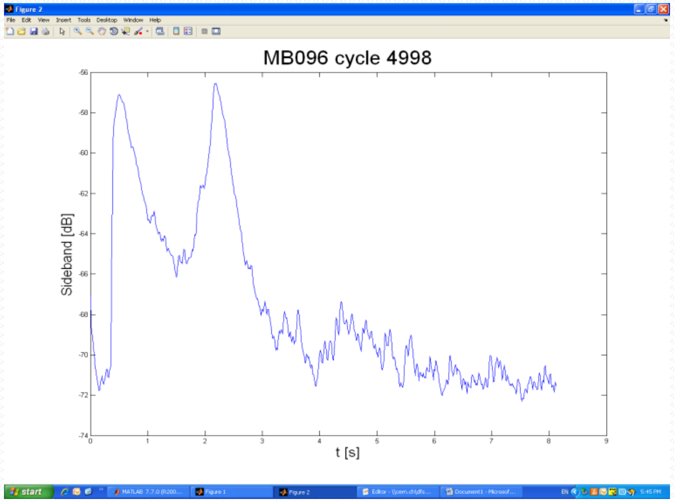


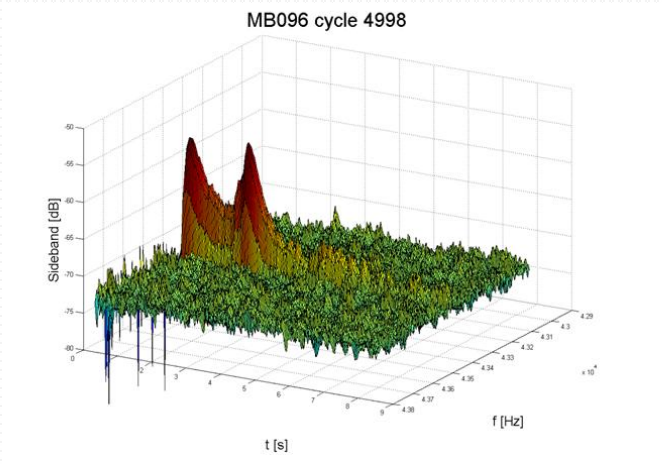
coated

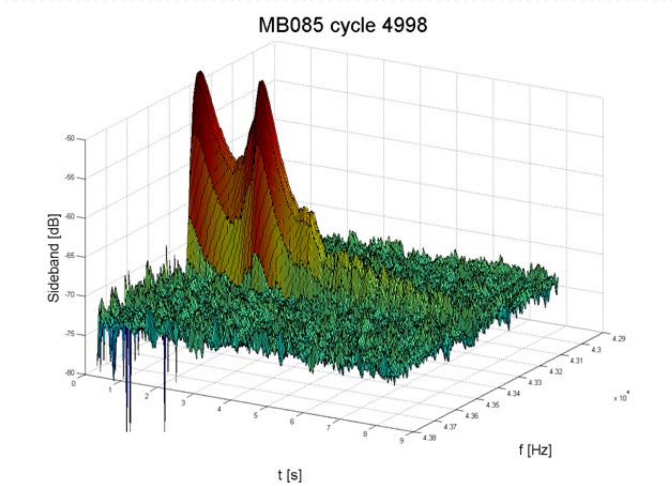
Beam: 1 batch with 72 bunches

Before scrubbing Tuesday afternoon (16.6.09)

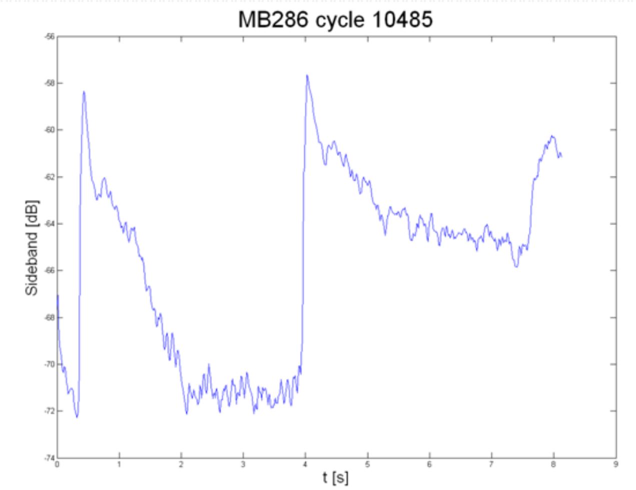


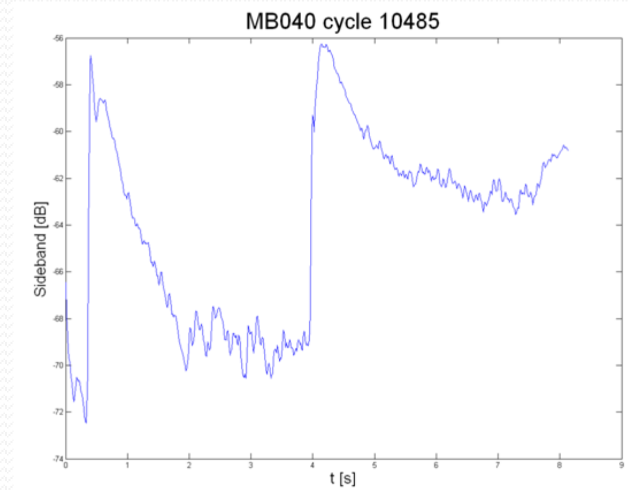






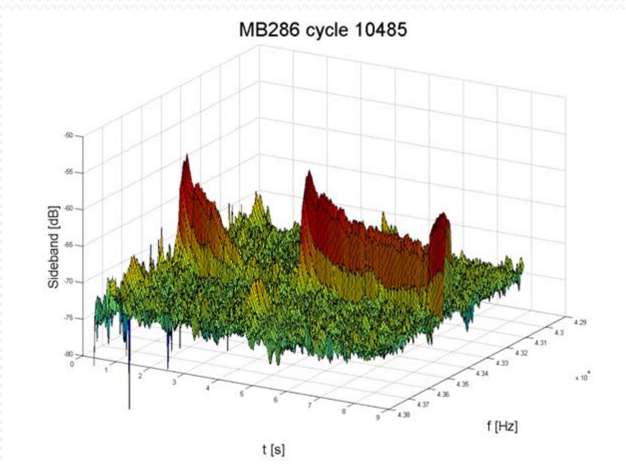
After scrubbing Wednesday night (17.6. 09)

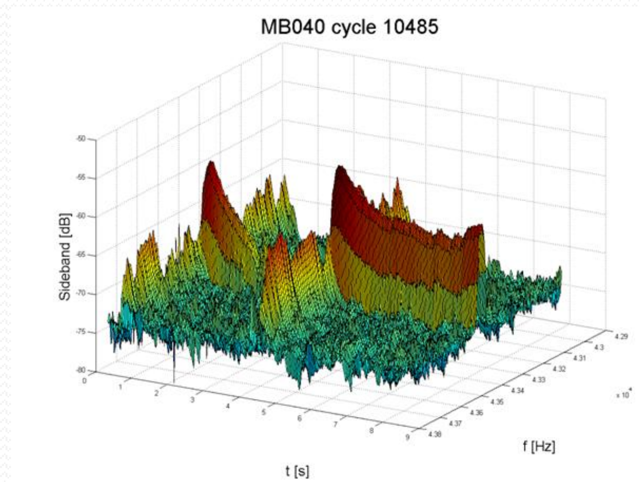




uncoated

coated





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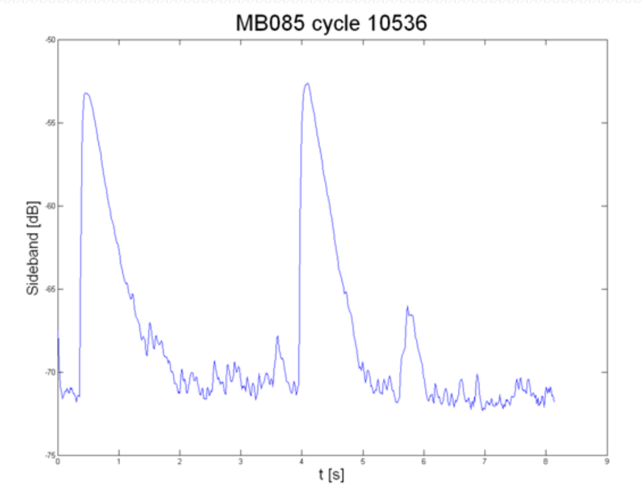
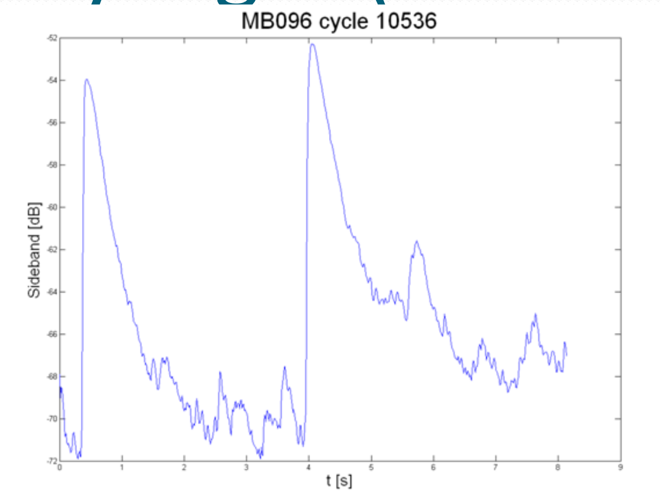
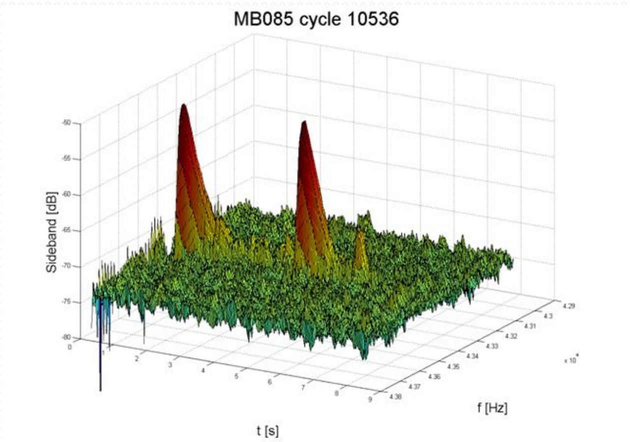
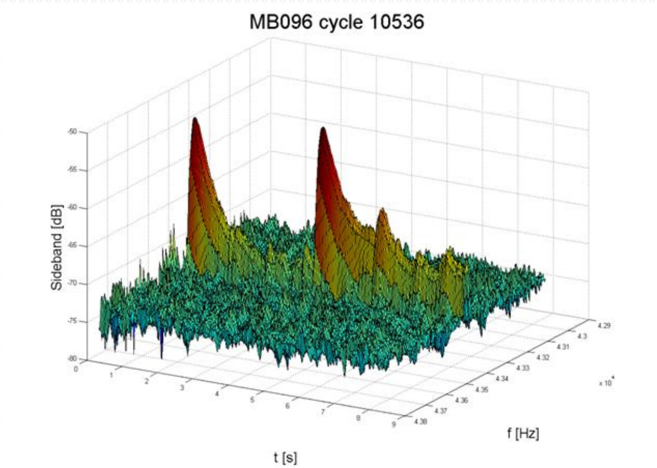


coated



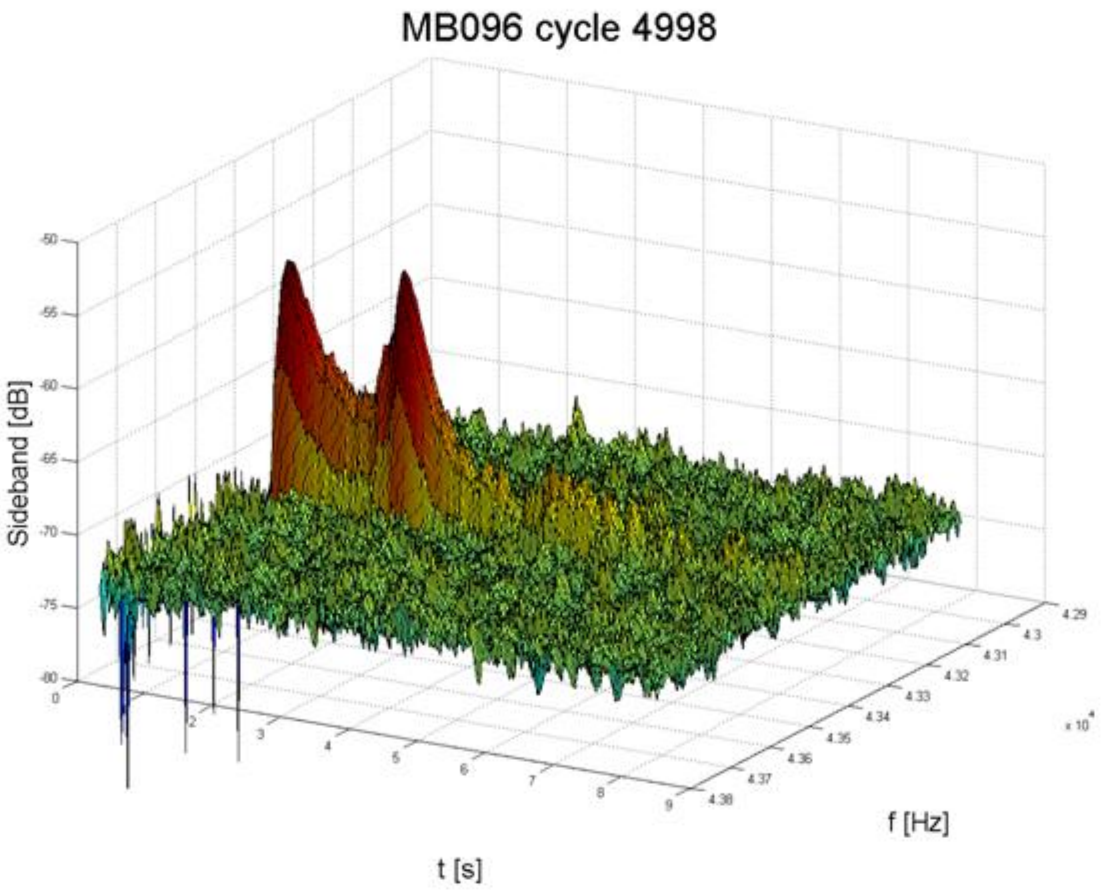
coated





Segment 2

- Coated magnet
- Beam: 1 batch with 72 bunches

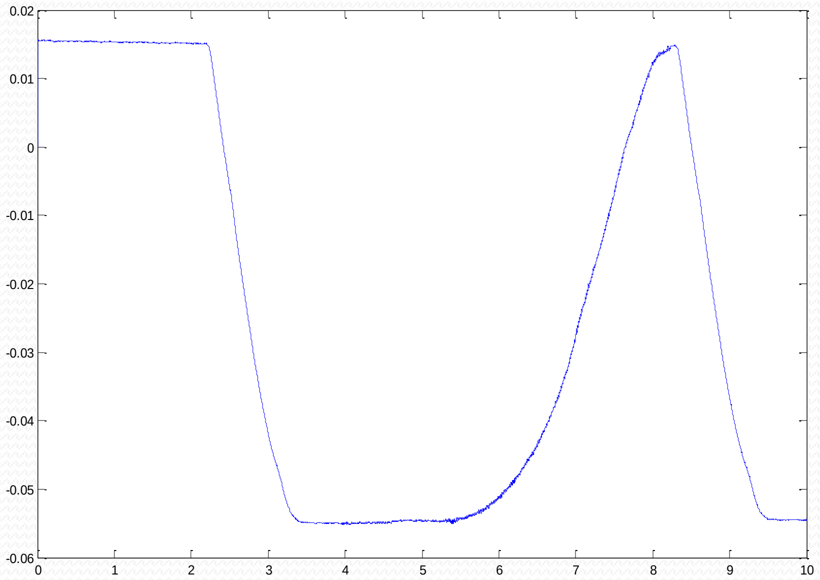


Observation

- PM in case of coated/uncoated magnets not too different
- Idea of possible contamination via supply voltage of the amplifiers
- Tested by inducing a signal at 44 kHz -> see same effect!
- Contamination causes AM/PM conversion larger (?) as the wanted PM by beam
- Not resolvable since we are looking for very small signals

Phase shift caused by magnet ramp

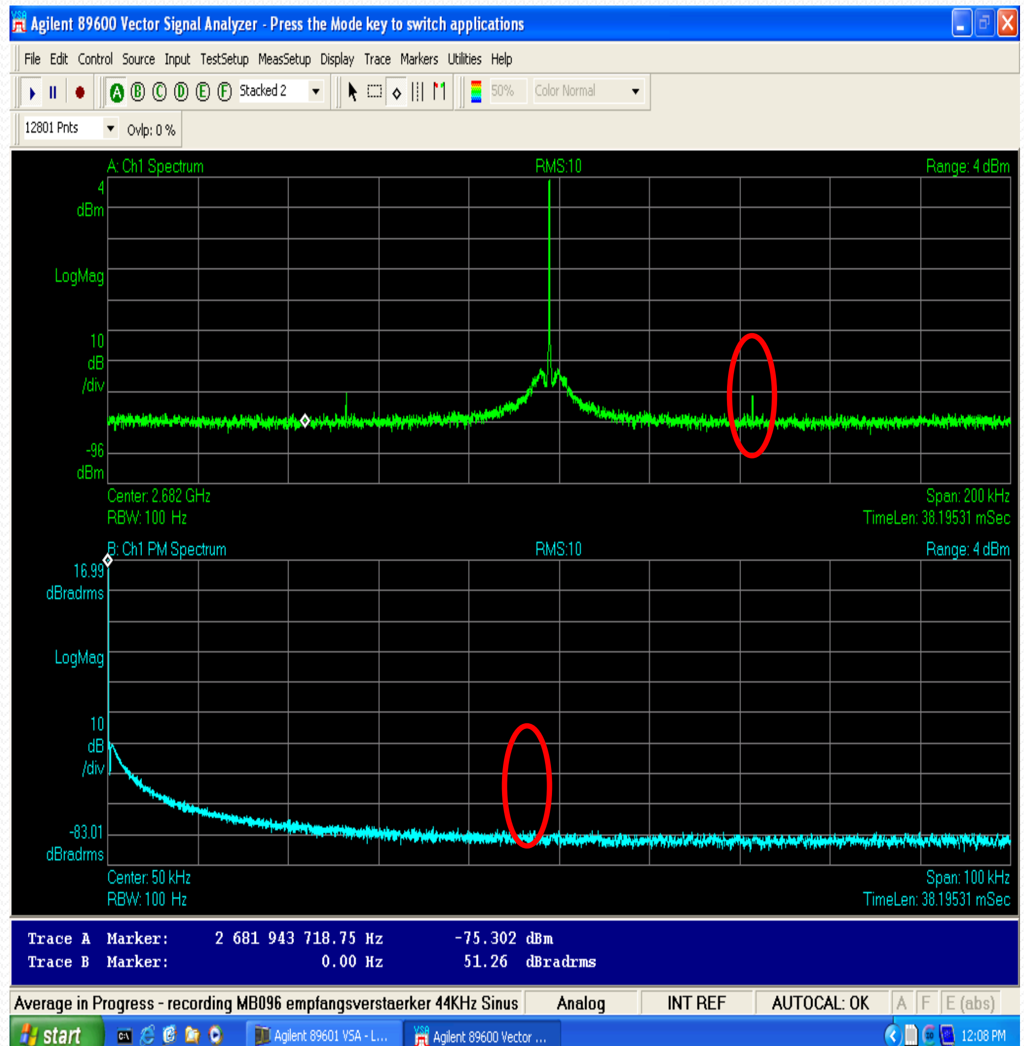
- The figure shows the low pass measurement results presented in preliminary talk
- It can be seen that there is a phase shift corresponding to the magnetic field



May caused by magneto restriction of the magnets and liners following small cutoff and furthermore phase shift

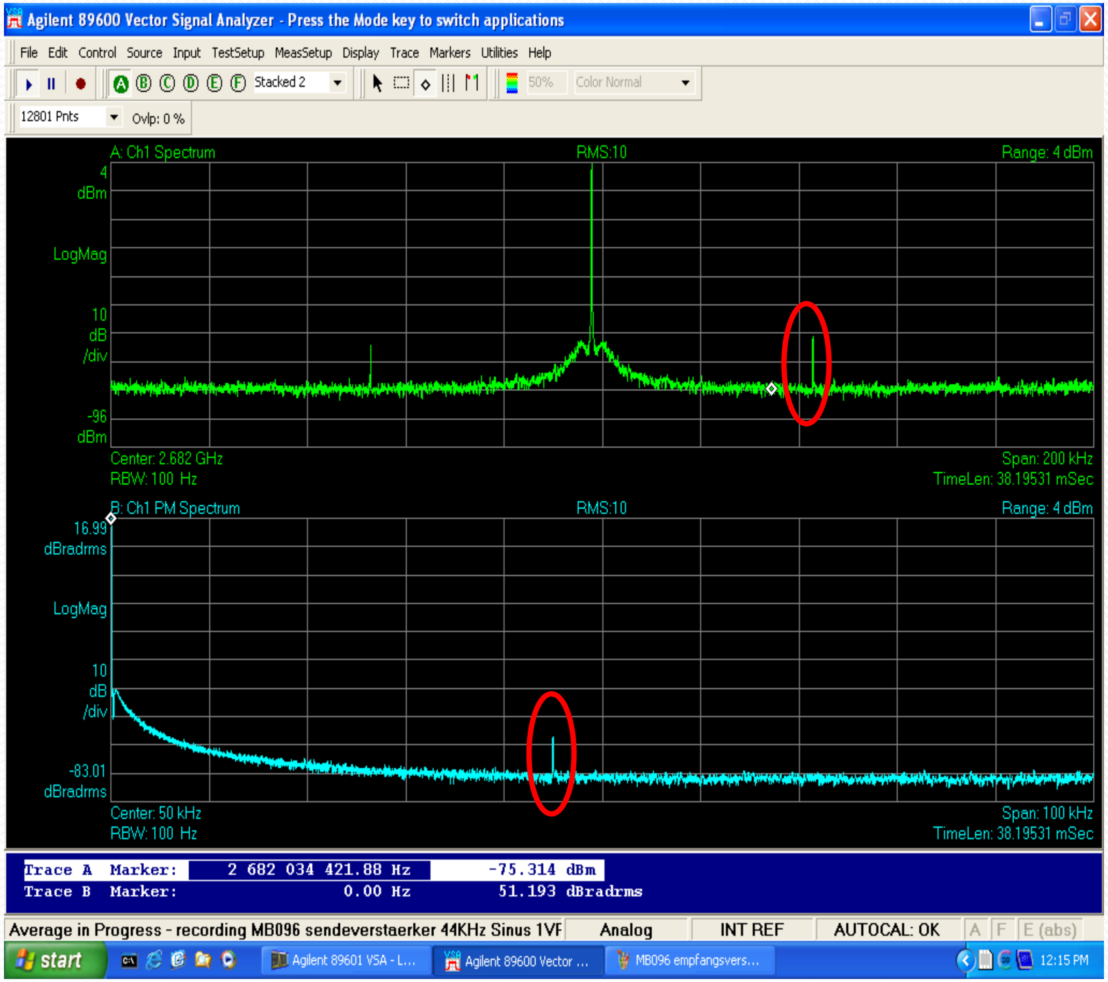
Supply voltage AM modulation test receiver

- Additional to the supply voltage a 44KHz signal with 1Vpp was applied at the surface
- The influence on transmission, especially phase was of interest
- No visible influence at the receiver



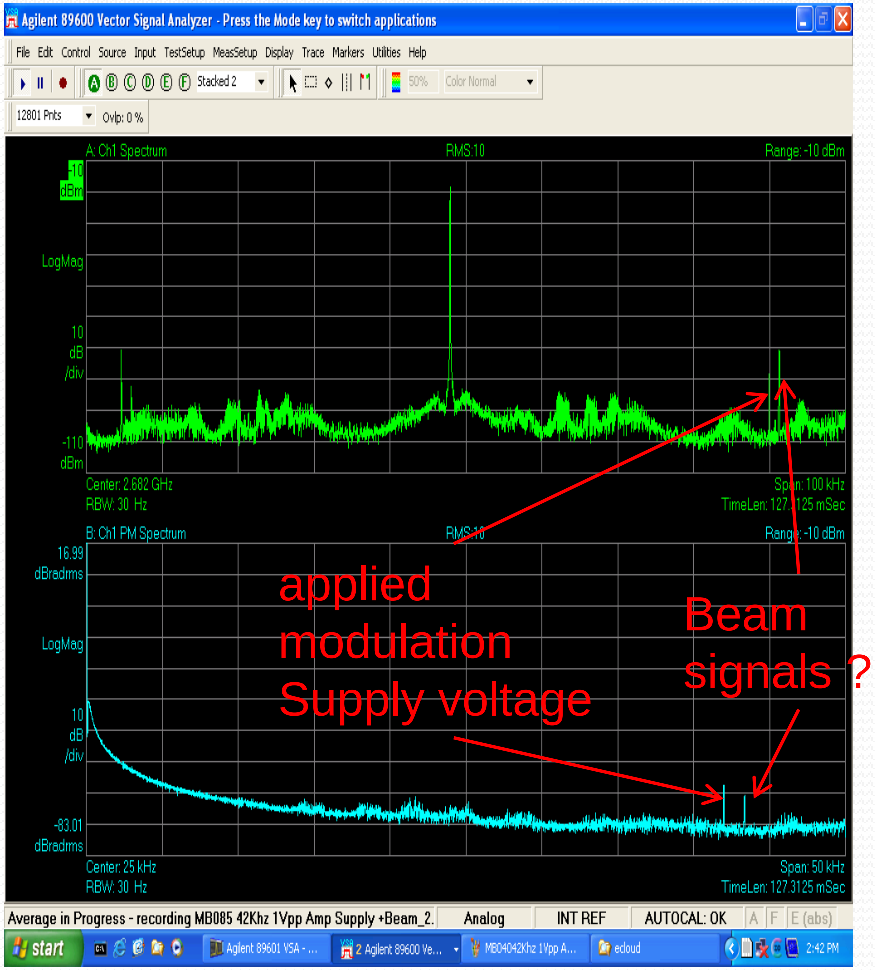
Supply voltage AM modulation test sender

- The sender is more sensitive to the 44KHz signal applied to the supply voltage
- The PM-Demodulation shows a clear peak
- This proves that PM can be caused by the supply voltage



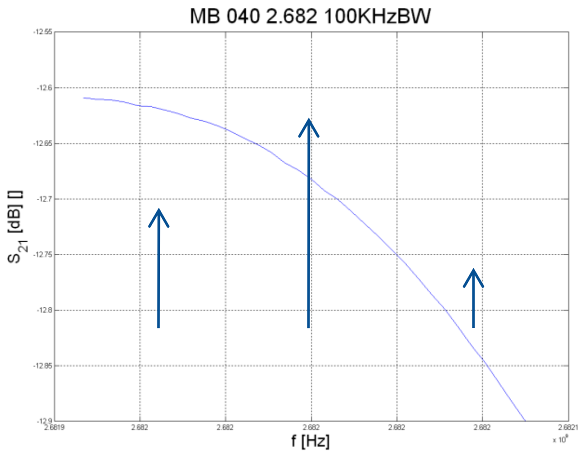
Supply voltage AM modulation transmission with beam

- To check to the measurements cross checks with beam on Friday (19.6. after MD) have been performed
- The applied modulation was in this case at 42KHz and both signals have been compared
- The 44khz line is narrow and therefore it can't caused by beam harmonics in the GHz range



AM-PM conversion

- It's very likely that most of our PM-Signal is caused by AM modulation of the power amplifier in the sender branch
- This is due to the fact that the supply filter start somewhere around 1MHz and the regulation circuit of the amplifier seems to not work perfect at these frequencies
- The AM caused by the beam induced signals on the power supply convert to PM caused by the slope in the HTF

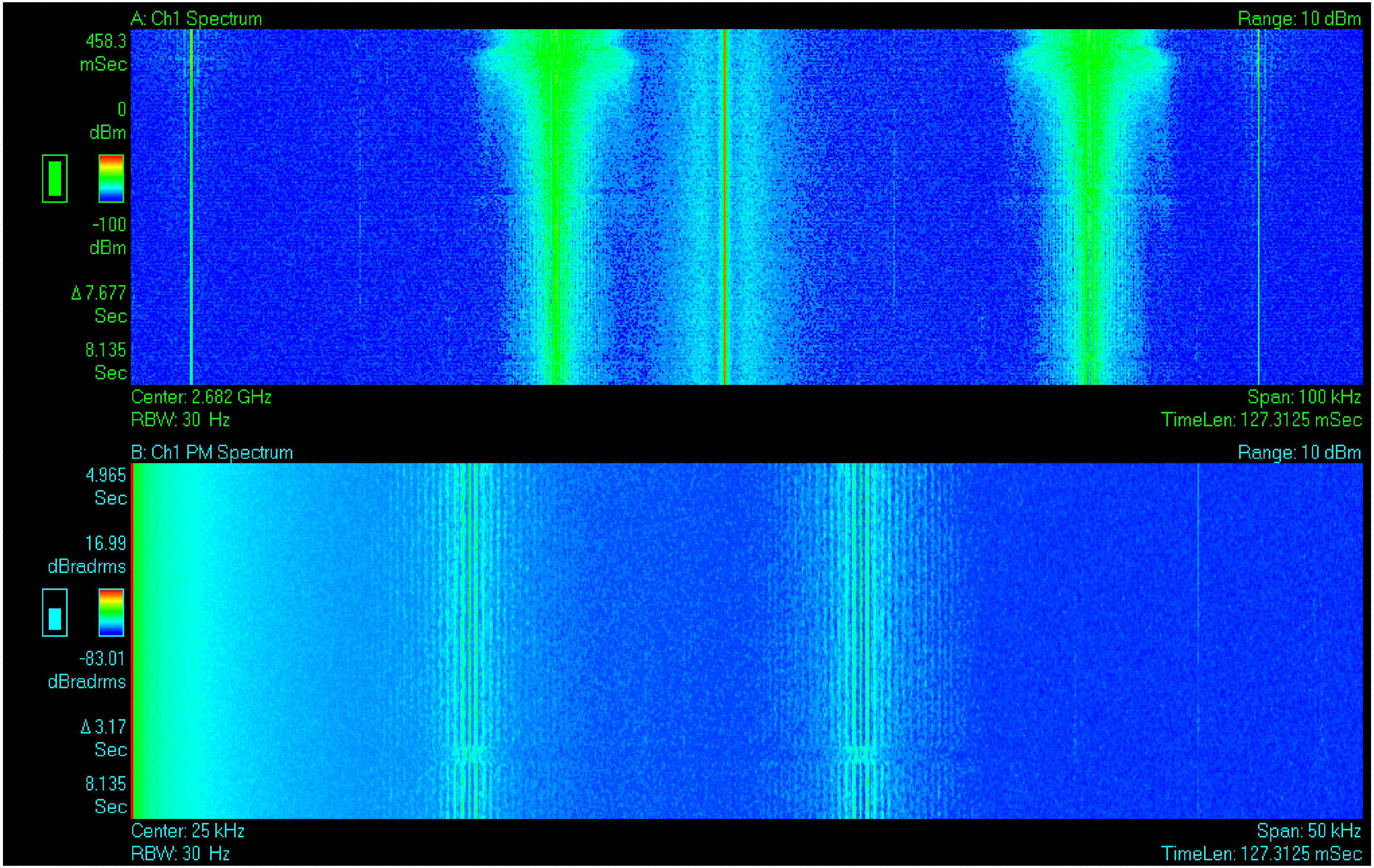


approx. 0.2 dB difference between sidebands

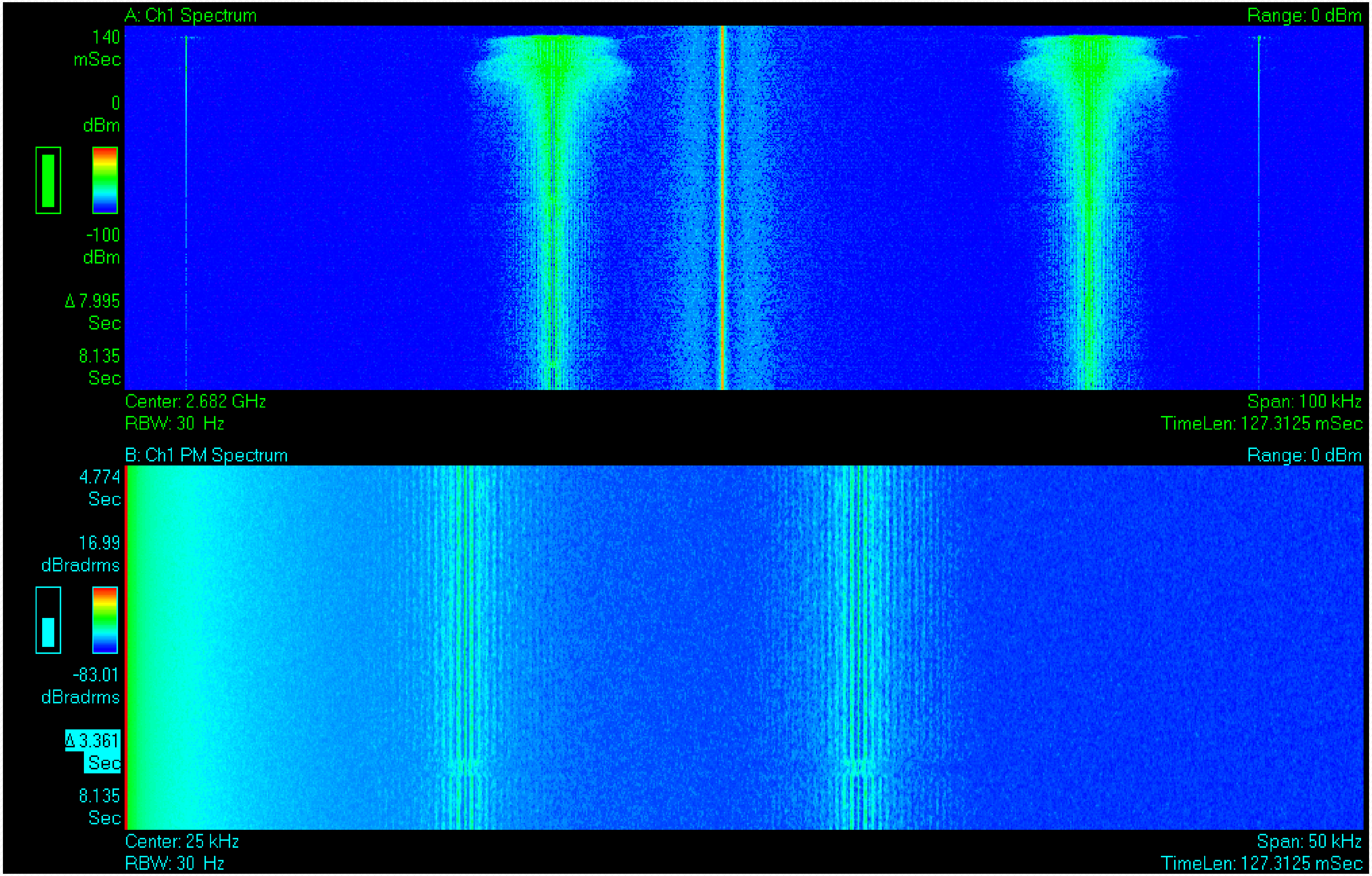
Preliminary conclusion

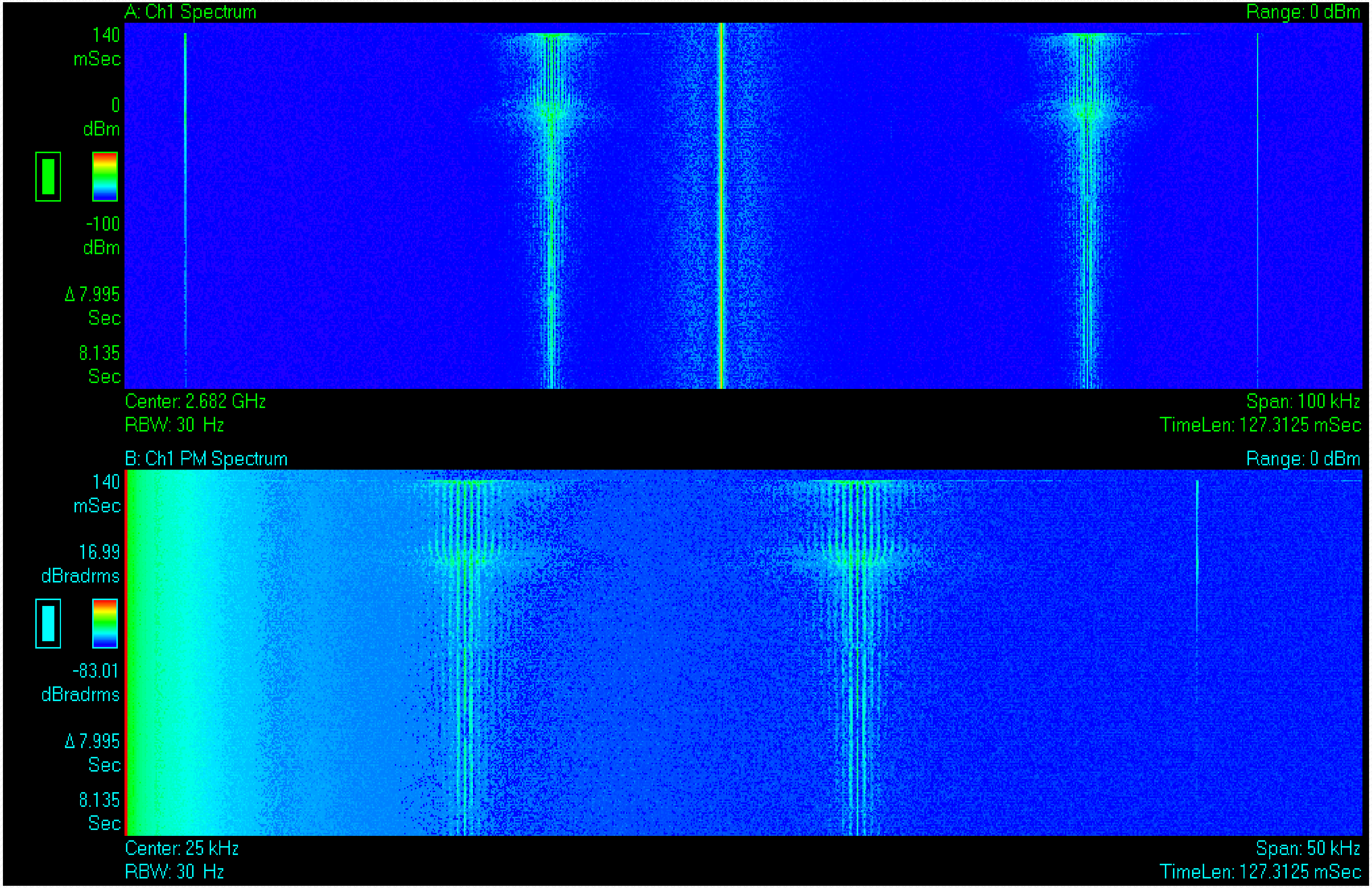
- We have seen a significantly longer PM-signal decay for the uncoated magnet as compared to the coated one during the same cycle during flat bottom before scrubbing
- After scrubbing no difference was noticed any more
- However there are still a number uncertainties and questionmarks (such as parasitic 44KHz in the power supply) to be clarified and mitigated

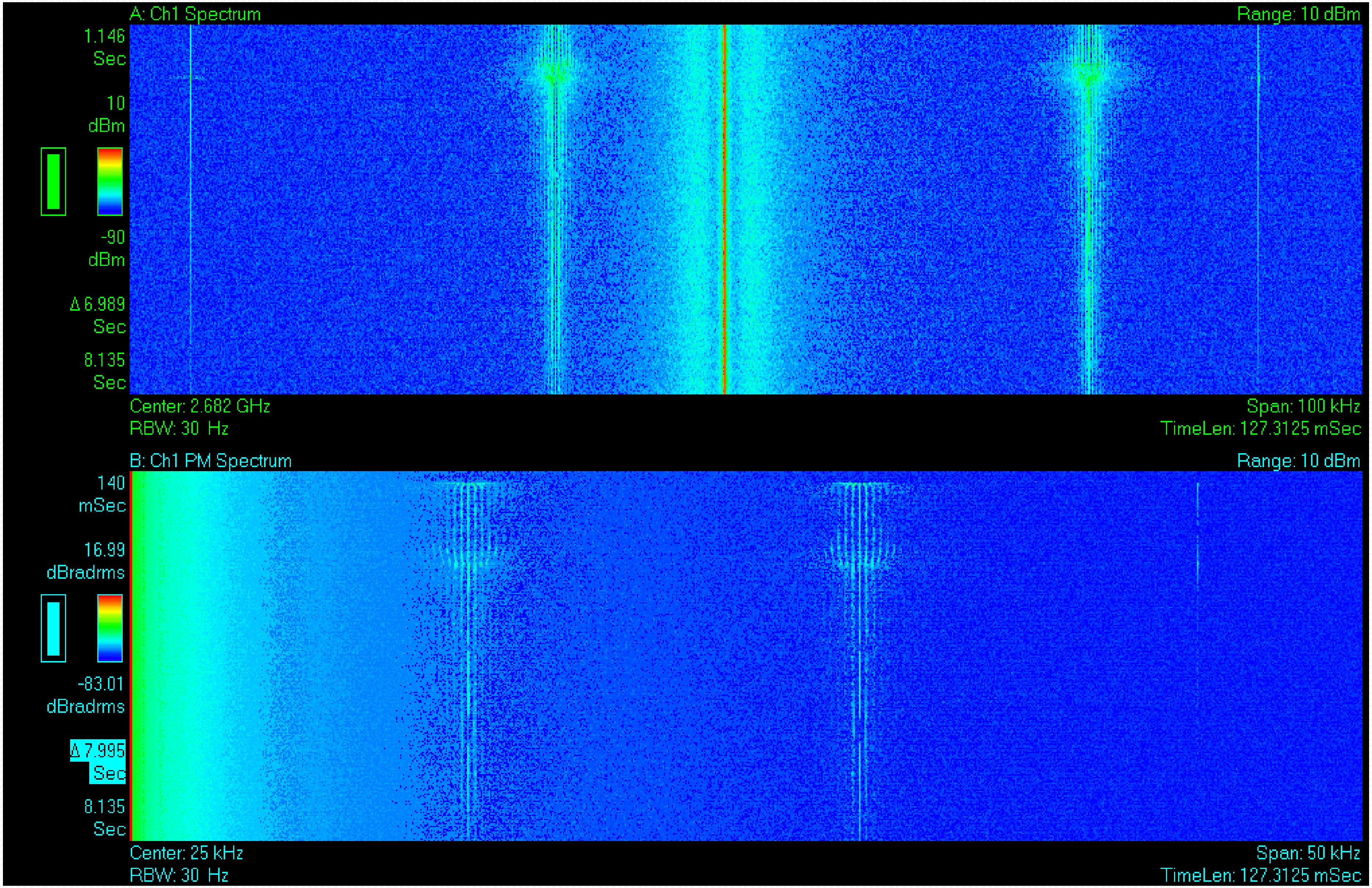
Uncoated MB286 4971



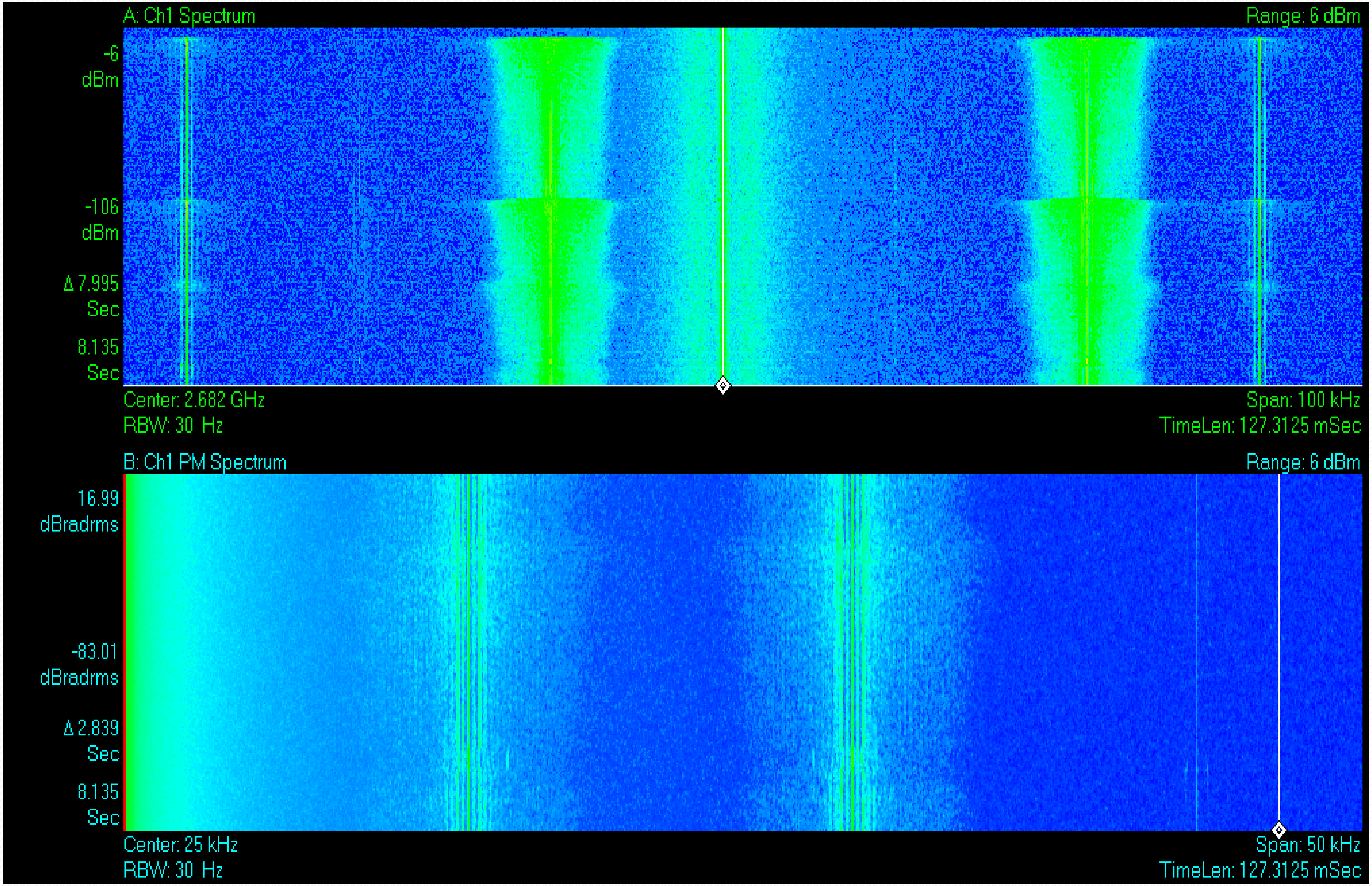
Coated MB040 4971



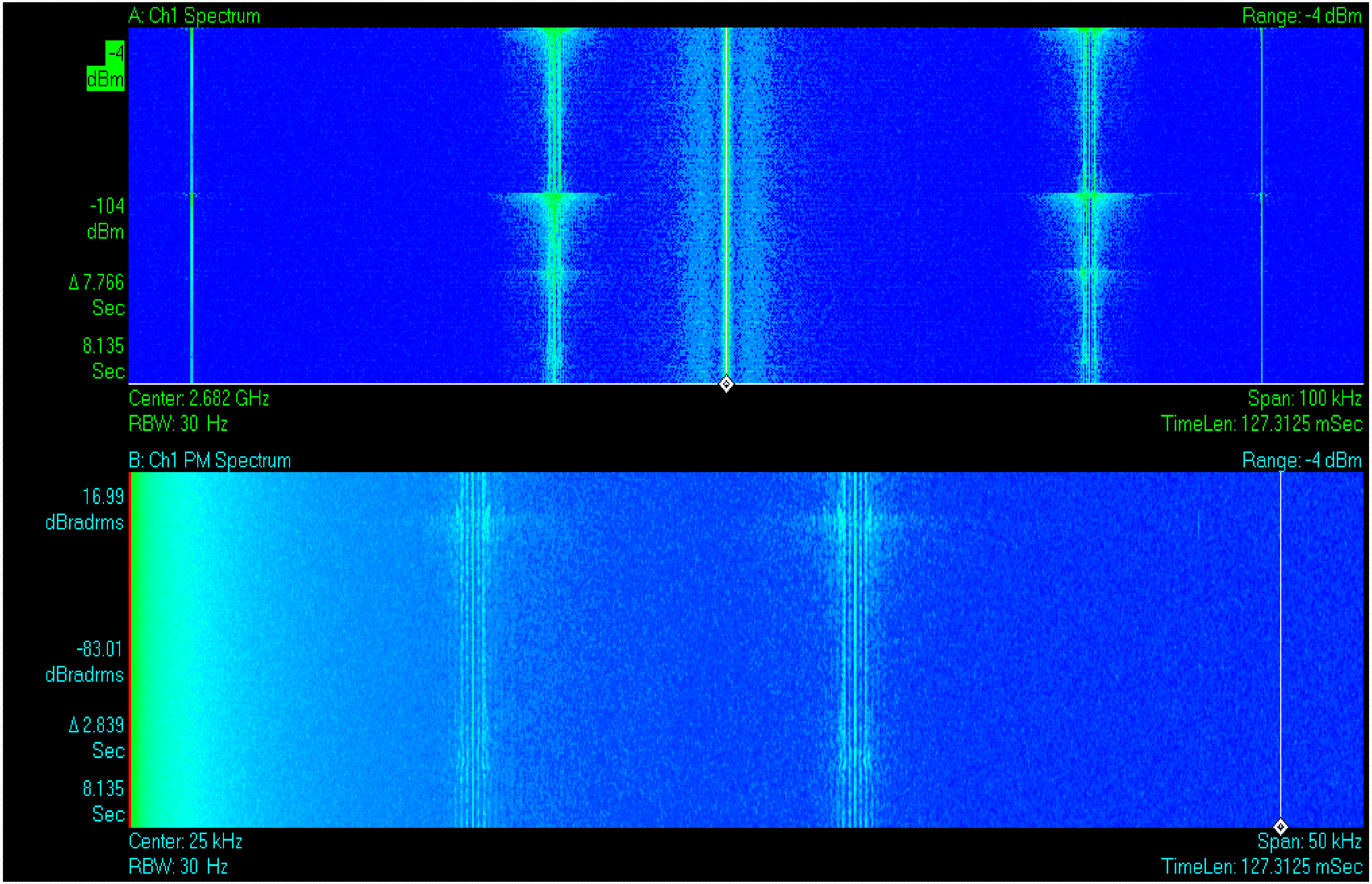

A: Ch1 Spectrum
Range: 0 dBm
140 mSec
0 dBm
-100 dBm
Δ 7.995 Sec
8.135 Sec
Center: 2.682 GHz
RBW: 30 Hz
Span: 100 kHz
TimeLen: 127.3125 mSec
B: Ch1 PM Spectrum
Range: 0 dBm
140 mSec
16.99 dBradrms
-83.01 dBradrms
Δ 7.995 Sec
8.135 Sec
Center: 25 kHz
RBW: 30 Hz
Span: 50 kHz
TimeLen: 127.3125 mSec



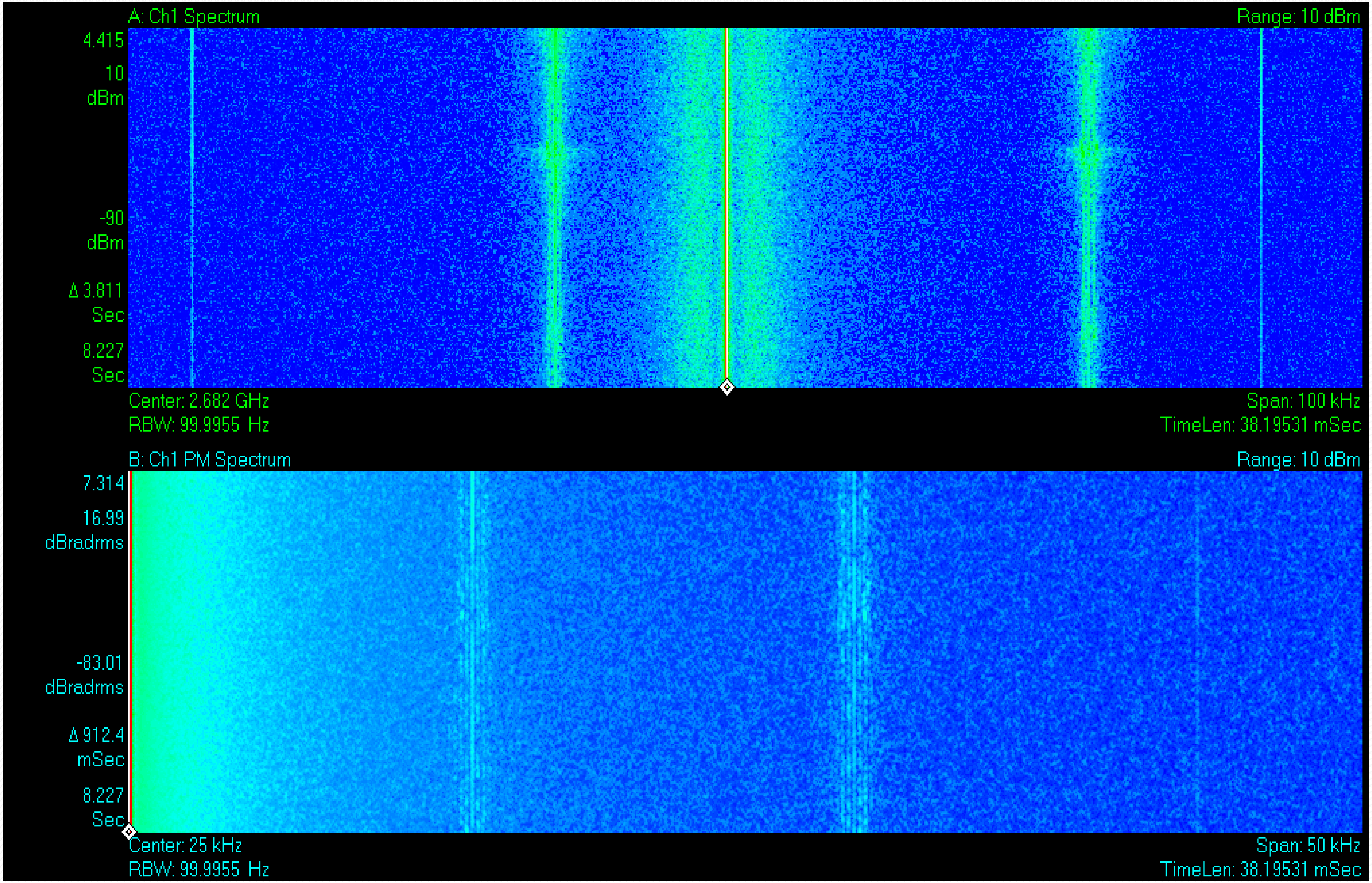
A: Ch1 Spectrum
Range: 10 dBm
1.146 Sec
10 dBm
-90 dBm
Δ 6.989 Sec
8.135 Sec
Center: 2.682 GHz
RBW: 30 Hz
Span: 100 kHz
TimeLen: 127.3125 mSec
B: Ch1 PM Spectrum
Range: 10 dBm
140 mSec
16.99 dBradrms
-83.01 dBradrms
Δ 7.995 Sec
8.135 Sec
Center: 25 kHz
RBW: 30 Hz
Span: 50 kHz
TimeLen: 127.3125 mSec



A: Ch1 Spectrum
Range: 6 dBm
-6
dBm
-106
dBm
Δ 7.995
Sec
8.135
Sec
Center: 2.682 GHz
RBW: 30 Hz
Span: 100 kHz
TimeLen: 127.3125 mSec
B: Ch1 PM Spectrum
Range: 6 dBm
16.99
dBradrms
-83.01
dBradrms
Δ 2.839
Sec
8.135
Sec
Center: 25 kHz
RBW: 30 Hz
Span: 50 kHz
TimeLen: 127.3125 mSec



A: Ch1 Spectrum
Range: -4 dBm
-4 dBm
-104 dBm
Δ 7.766 Sec
8.135 Sec
Center: 2.682 GHz
Span: 100 kHz
RBW: 30 Hz
TimeLen: 127.3125 mSec
B: Ch1 PM Spectrum
Range: -4 dBm
16.99 dBradrms
-83.01 dBradrms
Δ 2.839 Sec
8.135 Sec
Center: 25 kHz
Span: 50 kHz
RBW: 30 Hz
TimeLen: 127.3125 mSec


A: Ch1 Spectrum
Range: 10 dBm
4.415
10
dBm
-90
dBm
Δ 3.811
Sec
8.227
Sec
Center: 2.682 GHz
RBW: 99.9955 Hz
Span: 100 kHz
TimeLen: 38.19531 mSec
B: Ch1 PM Spectrum
Range: 10 dBm
7.314
16.99
dBradrms
-83.01
dBradrms
Δ 912.4
mSec
8.227
Sec
Center: 25 kHz
RBW: 99.9955 Hz
Span: 50 kHz
TimeLen: 38.19531 mSec