Influence of electron energy detuning on the lifetime and stability of ion beam in CSRm

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Ion-Beam Heating Effect Observed at IMP

Proposed by V. Parkhomchuk

Dear colleagues,

I want to very interesting results that was obtained at IMP (China) with interaction detune (energy) electron beam with ion beam. There is questions of "electron heating". Common position (Dag Reistad) was that with increasing different velocity electron beam - ion beam heating effect should decreased. But experiments of our China colleagues show that after change different electron energy more than 400 V development very strong instability. I think it is interesting to have special invited report from IMP about this subject.

Vasily Parkhomchuk

Previous Results

- Background---reported in RuPAC2012
- First attempt (feasible, simple, convenient)
- Previous results
- Not clear
- Chinese Physics C Vol.37 No.1,2013

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Beam Instability Phenomena Observed at HIRFL-CSR in the Presence of Electron Cooling

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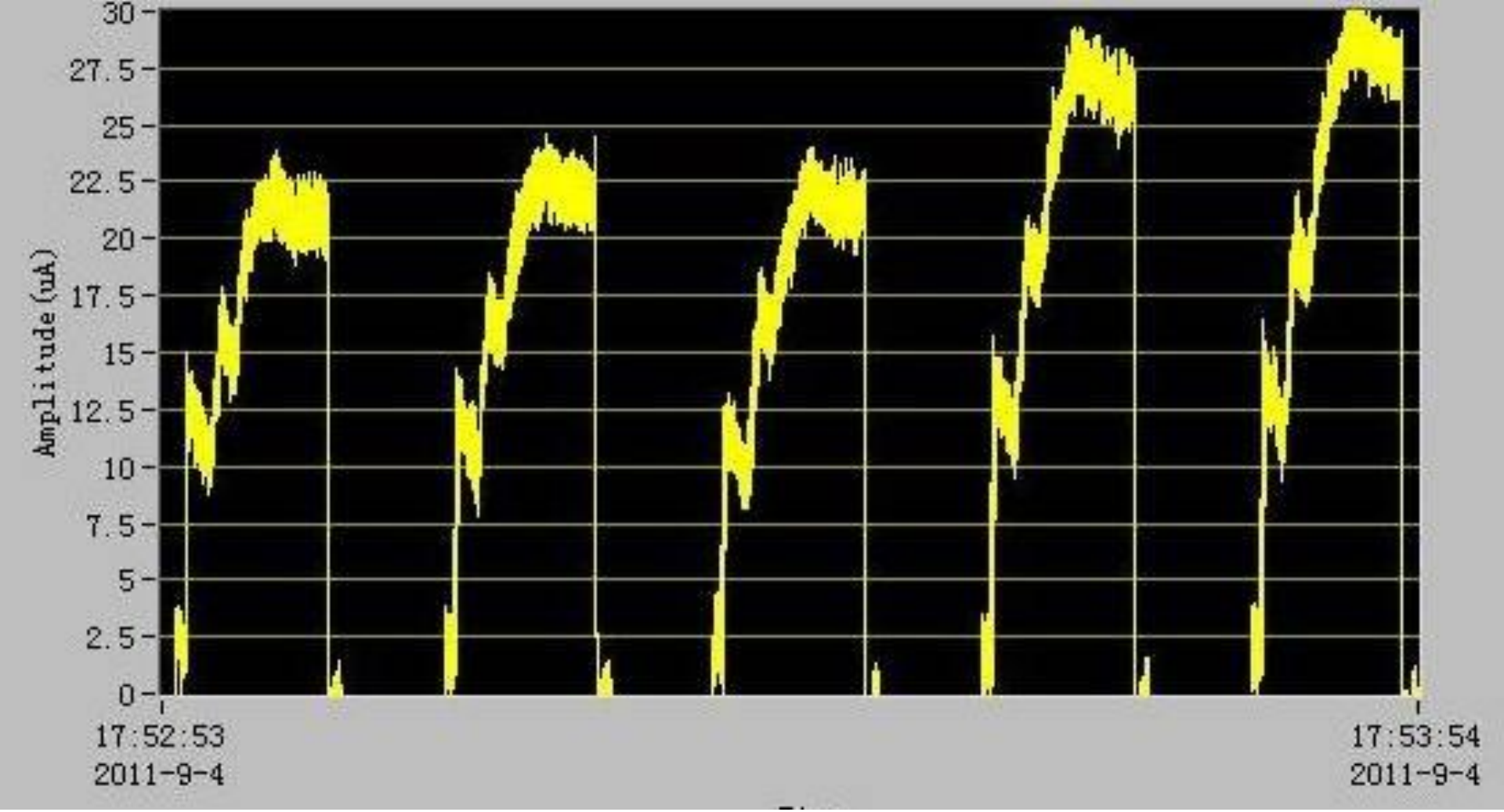


The proton beam disappeared after turn on the electron cooler and electron beam.
There was no obvious cooling and accumulation.
The lifetime of H^+_2 is very short comparing with the results from TSR and CELSIUS.

Electron heating?

Motivation

- Increase the accumulated ion intensity
- Suppression of ion beam instability

Electron heating Features

- Bunched beam
- Lifetime becomes shorter
- Exposed to the electron beam

Possible reasons

- Nonlinear electrical fields from the electron beam

Cure method proposed

- Increase the electron beam diameter
- Modulation of electron beam energy

Main works in CSR

- Experiments on cancer therapy (15% of beamtime)
- Cancer therapy (5% of beamtime)

  (Total / **91patients**(from 2009), **Last year / 18patients**)
- **Mass measurement (next step:SMS)**

(high-precision Schottky Mass Spectroscopy)

- Recombination Experiments (5% of beamtime)

Contents

Experimentally investigated the influence of **electron energy modulation** on the maximum accumulated intensity, lifetime and stability of ion beam in the case of artificially increased the energy spread of electron beam with the help of the detuning system of CSRm cooler.

CSRm, 3.7MeV/u, $^{112}Sn^{26+}$---$^{112}Sn^{35+}$

- Smaller cyclotron SFC
- 33mg/cm^2 Carbon foil before injection
- Coasting beam
- Momentum spread change
- Emittance growth
- Energy loss
- Displacement between electron and ion beam

Beam Acceptance: CSRm

A_h=200 π mm-mrad ($\Delta P/P=\pm 0.15\%$)

A_v=30 π mm-mrad

$\Delta P/P$=1.25% (ε_h=50 π mm-mrad)

Betatron function at cooling section of CSRm:
βx=10.0m, βy=16.7m, Dx=0

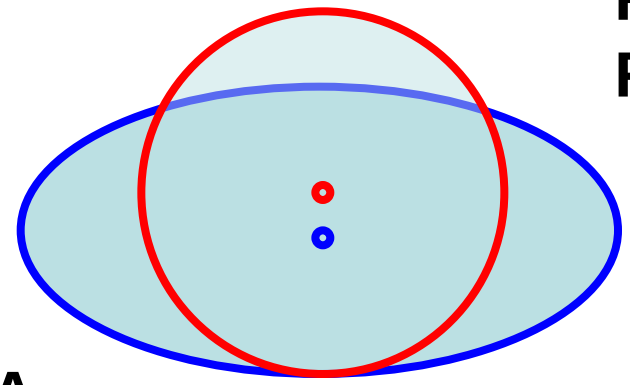
Electron Energy modulation amplitude:
0.01%~~~0.12%

Parameters of Cooling

Electron beam

Ion beam

3.7MeV/u
β=0.089
γ=1.004
T=6.02μS
f=0.166MHz



Electron

$R_{cathode}$=14.5mm
$R_{cooling}$=30.mm

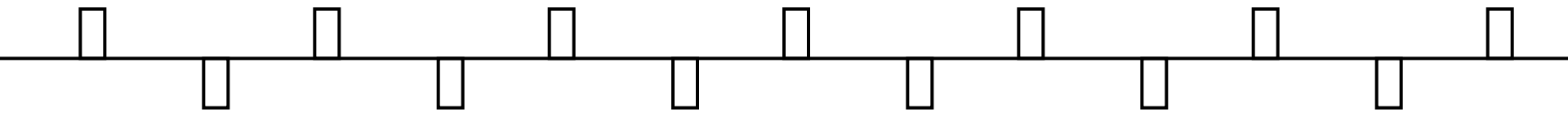
Ion

$R_{horizontal}$=44.7mm
$R_{vertical}$=22.38mm

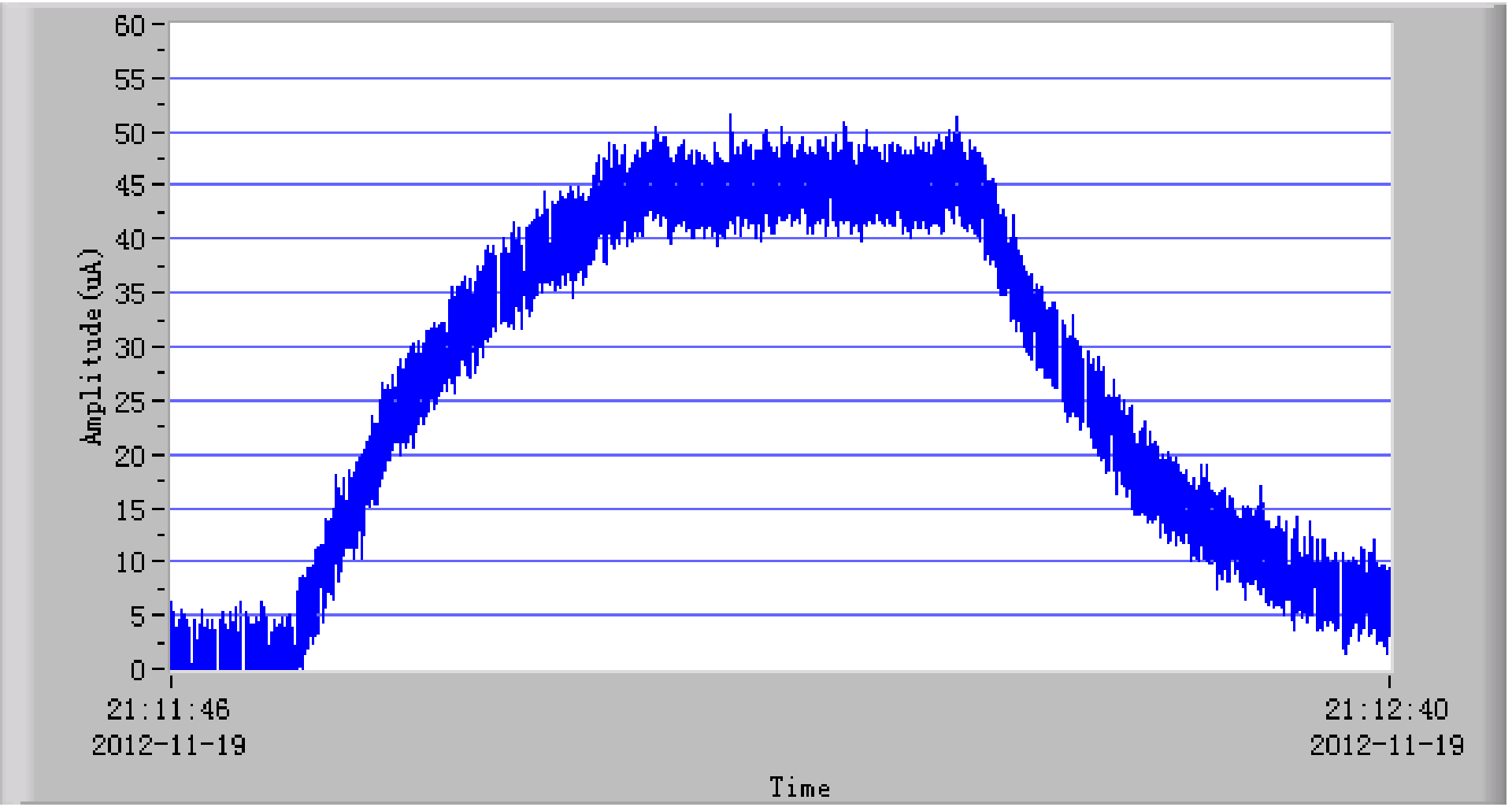
Displacement ?

Ielectron=110mA
Ugrid=0.188kV
Uanode=1.3129kV
Ugrid/Uanode=0.14
Uhv=2.0964kV

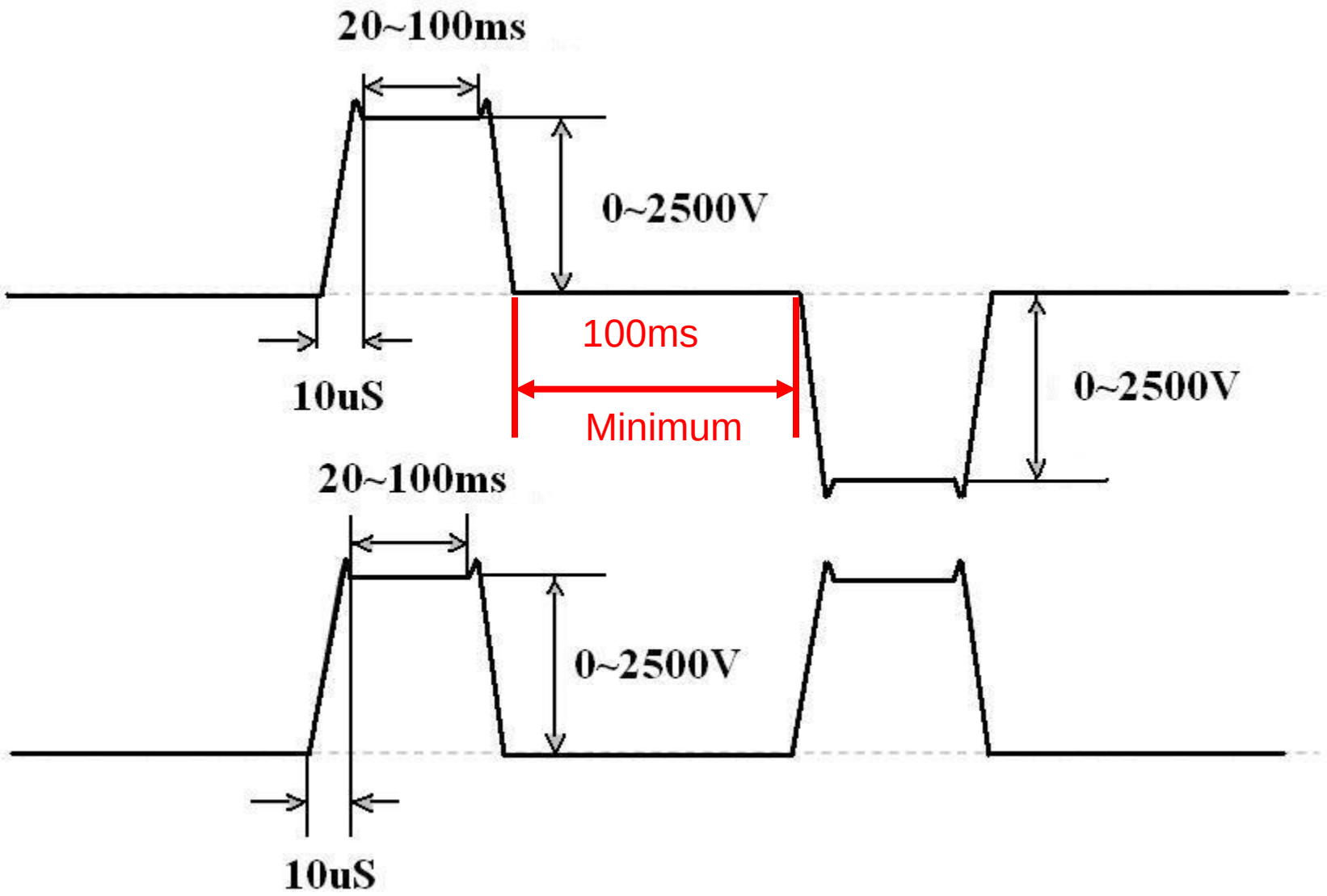
B_{gun}=1562Gauss
$B_{cooling}$=365.5Gauss
K=4.275
expansion factor



Modulation



DCCT signal


20~100ms
0~2500V
100ms
Minimum
10uS
0~2500V
20~100ms
0~2500V
10uS

Parameters during the experiments

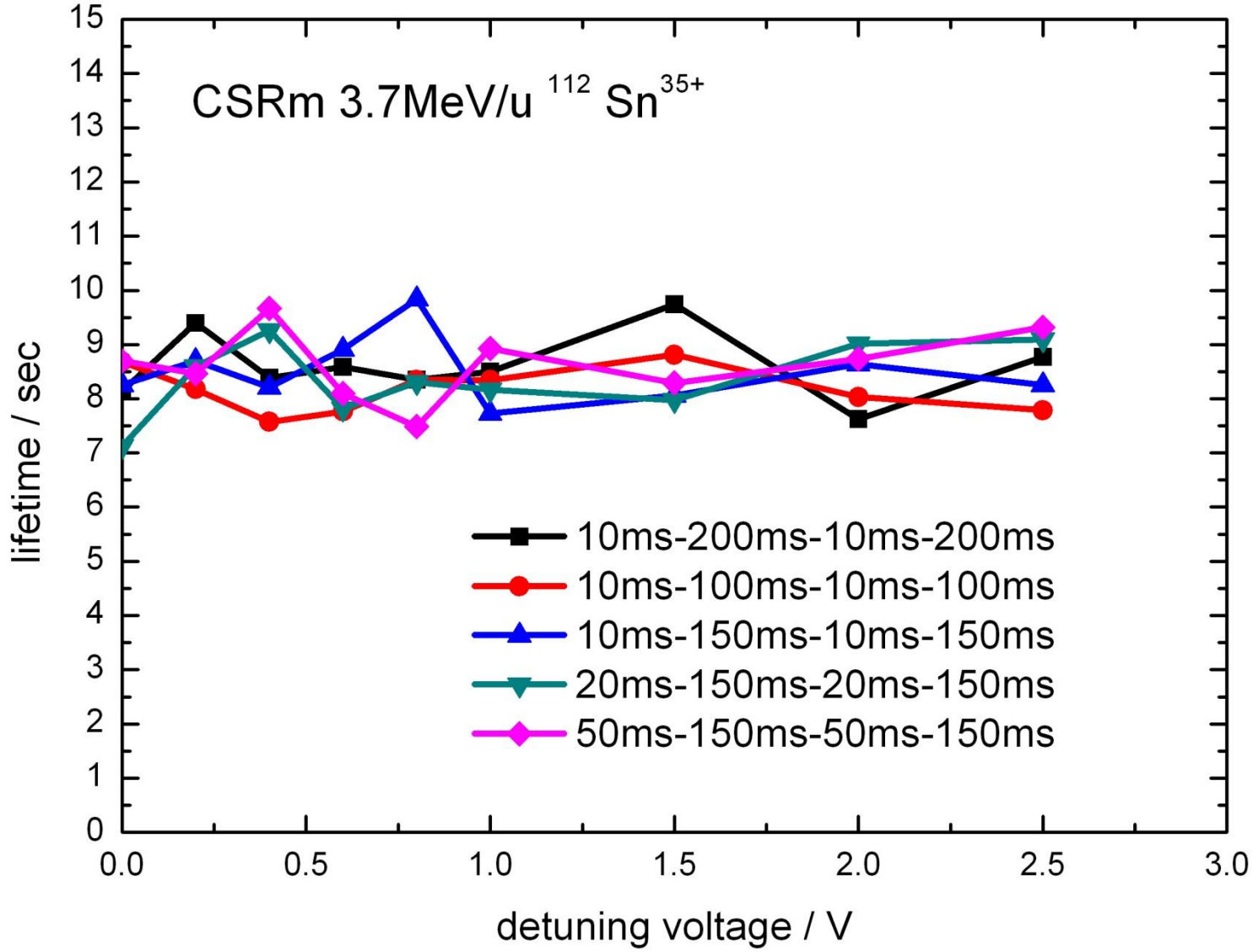
Relative amplitude of modulation	Amplitude of pulse (V)	Positive Pulse Width(**ms**)	Negative pulse width(**ms**)	Interval of pulse(**ms**)	Repetition
(0~2.5)/2.096kV **0.01%~~~0.12%**	**0,0.2,0.4,0.6, 0.8,1.0,1.5, 2.0,2.5**	10	10	200	4.76Hz
(0~2.5)/2.096kV **0.01%~~~0.12%**	**0,0.2,0.4,0.6, 0.8,1.0,1.5, 2.0,2.5**	10	10	100	9Hz
(0~2.5)/2.096kV **0.01%~~~0.12%**	**0,0.2,0.4,0.6, 0.8,1.0,1.5, 2.0,2.5**	10	10	150	6.25Hz
(0~2.5)/2.096kV **0.01%~~~0.12%**	**0,0.2,0.4,0.6, 0.8,1.0,1.5, 2.0,2.5**	20	20	150	5.88Hz
(0~2.5)/2.096kV **0.01%~~~0.12%**	**0,0.2,0.4,0.6, 0.8,1.0,1.5, 2.0,2.5**	50	50	150	5Hz

Ion revolution frequency=0.1656MHz, tune Qx=3.63, Qy=2.61

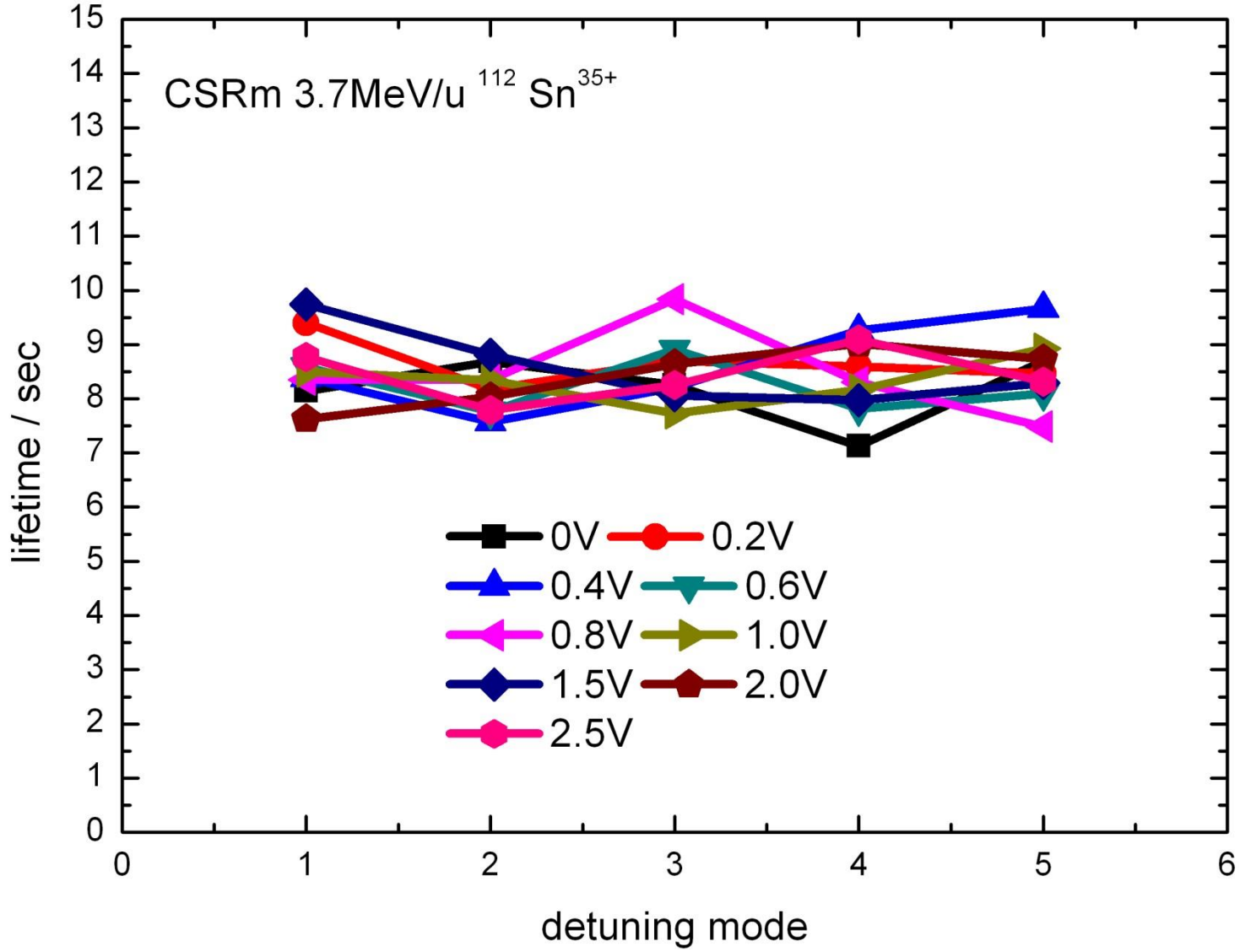
Experiments contents

- 9 steps 0, 0.2V, 0.4V, 0.6V, 0.8V, 1.0V, 1.5V, 2.0V, 2.5V(**0.01%~~~0.12%**)
- 3 pulse width (10ms, 20ms, 50ms)
- 3 pulse interval(100ms, 150ms,200ms)

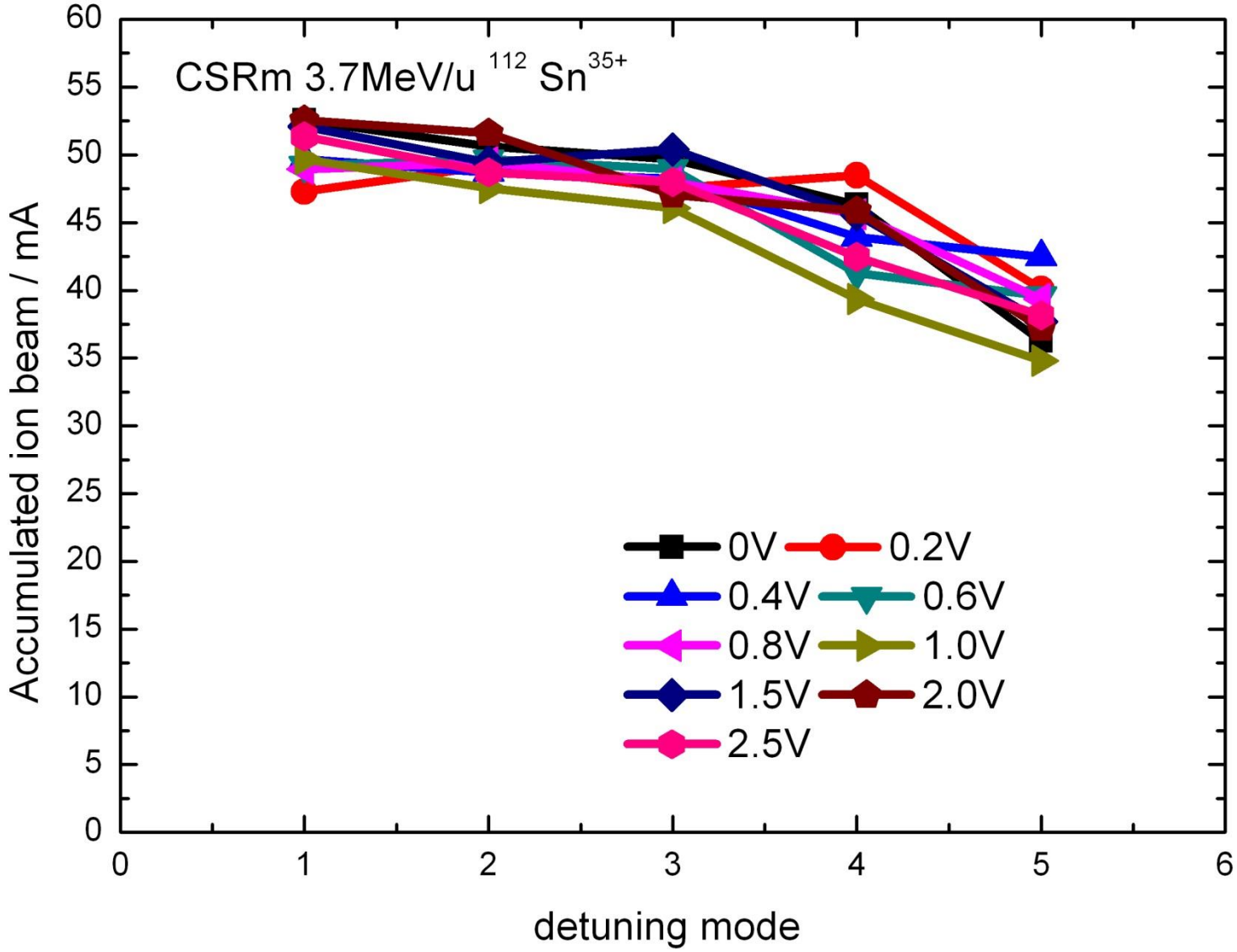
Lifetime and accumulated ion intensity under the different modulation



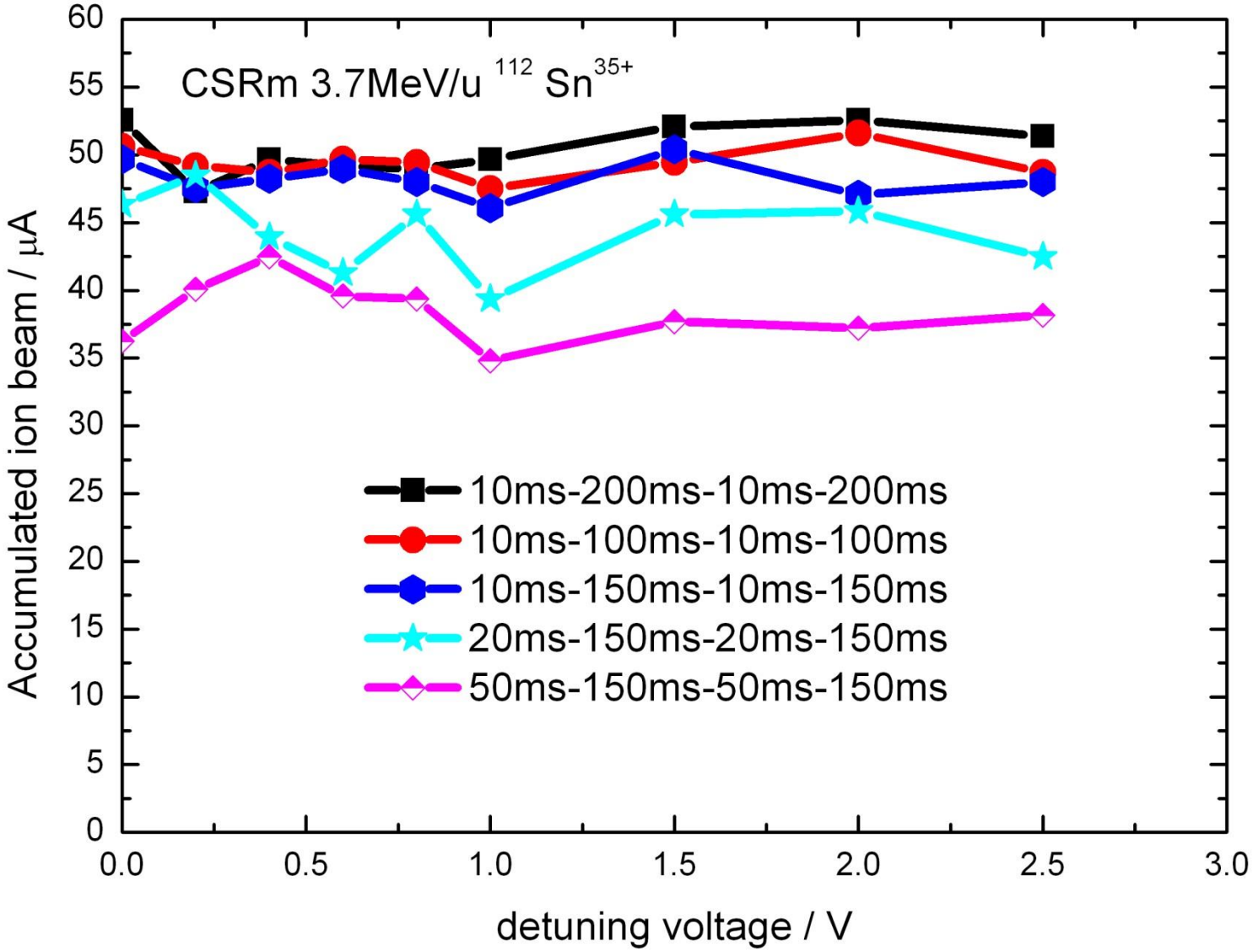
The voltage amplitude of modulation was not sensitive to the lifetime of ion beam.



The voltage amplitude of modulation was not sensitive to the lifetime of ion beam.



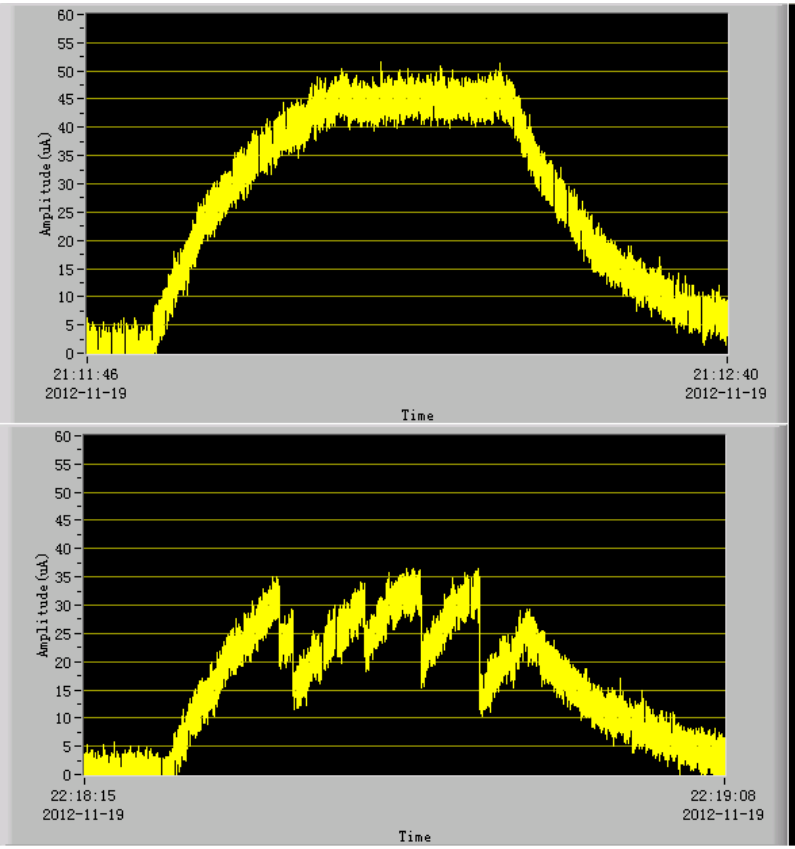
Due to the ion beam intensity gradually became smaller from the injection during the experiments, the accumulated ion intensity became smaller too.

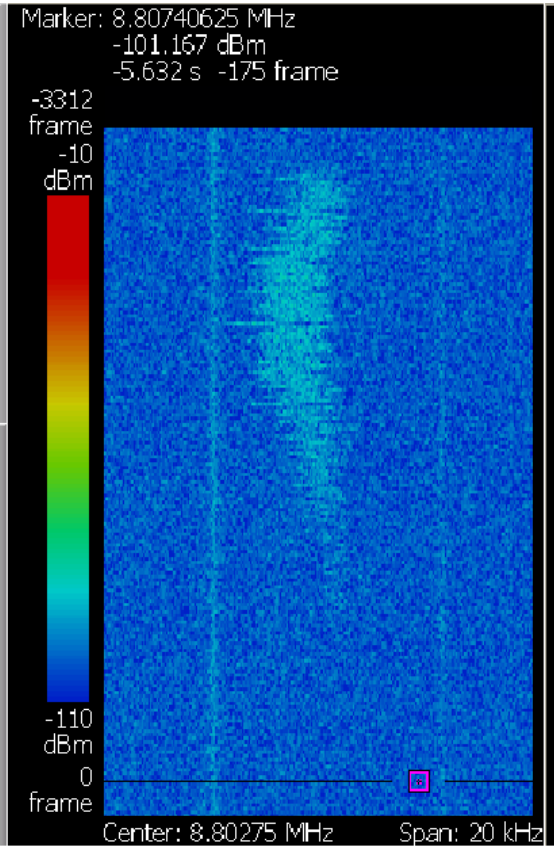


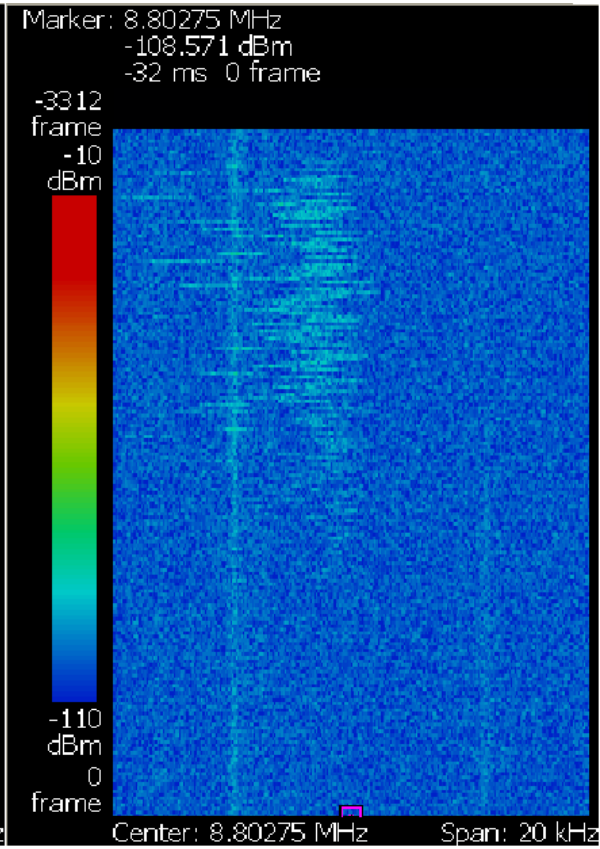
The voltage amplitude of modulation was not sensitive to the accumulated ion intensity.

Some Schottky signals observed in the experiments

2.5V-10ms-10ms-200ms







0V-50ms-50ms-150ms 2.5V-10ms-10ms-200ms 0V-50ms-50ms-150ms

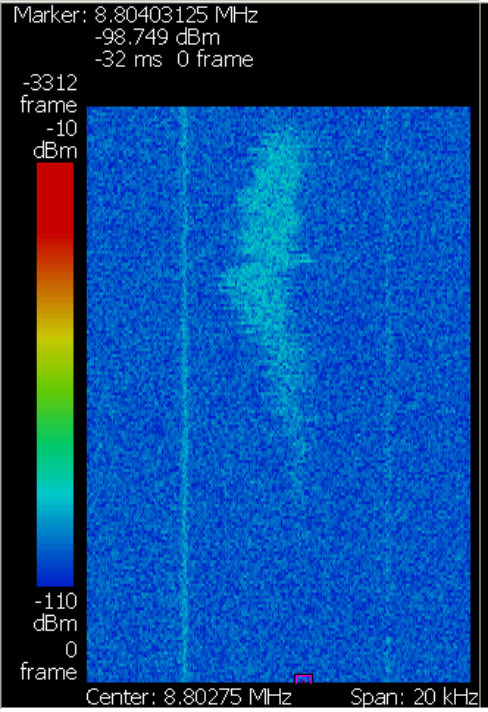
DCCT signal

Schottky signal

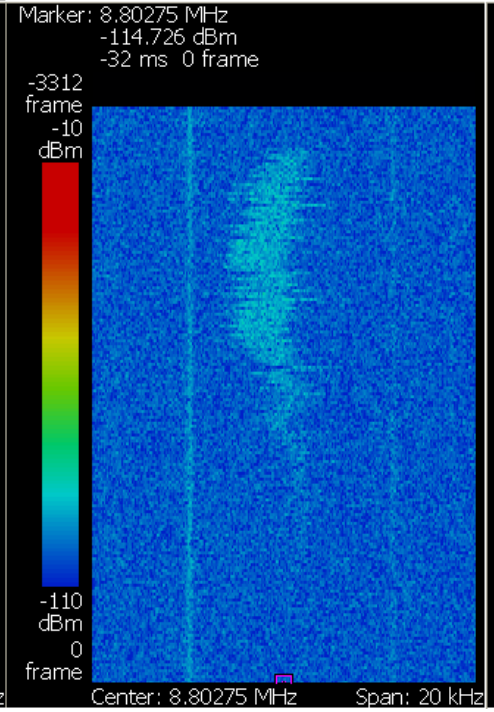
DCCT signal represents the ion intensity

Schottky signal represent the ion velocity or momentum spread, The revolution frequency.

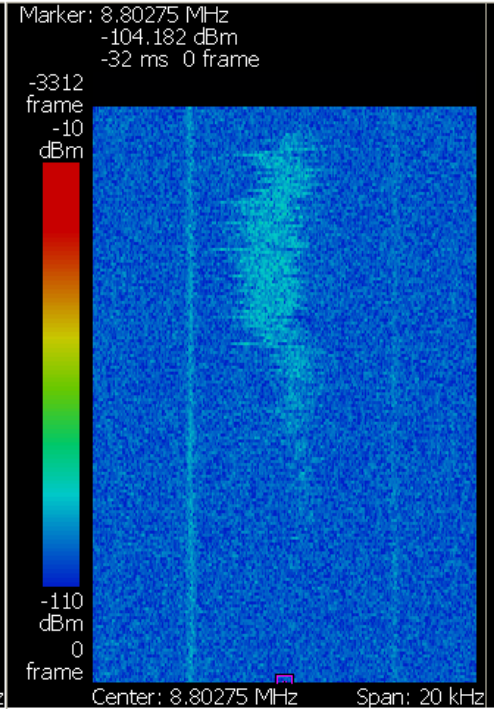
Two signals changed at the same time?



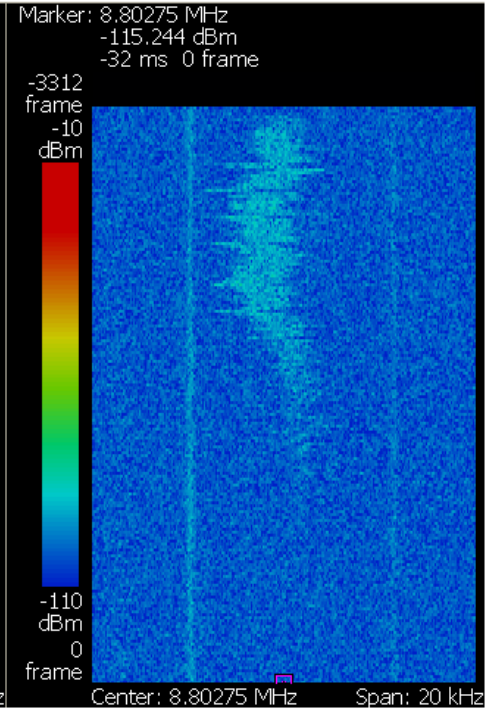
Without modulation



0.2V-10ms-10ms-200ms

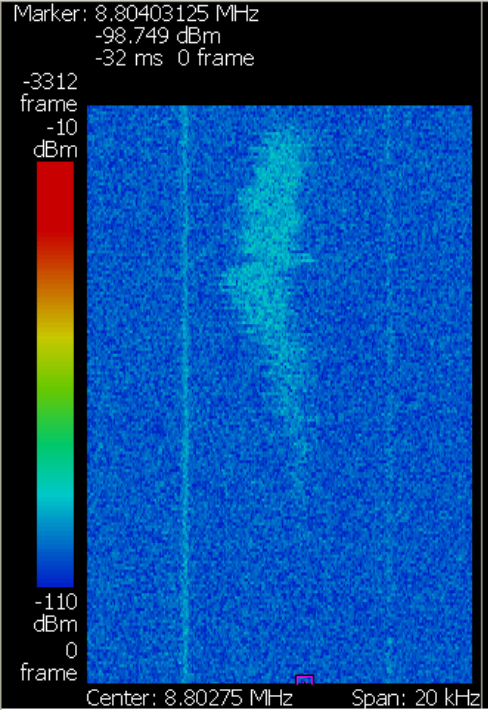


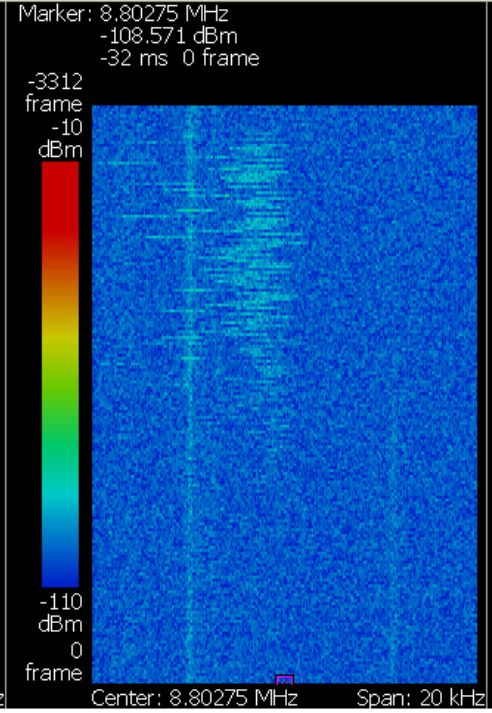
0.4V-10ms-10ms-200ms

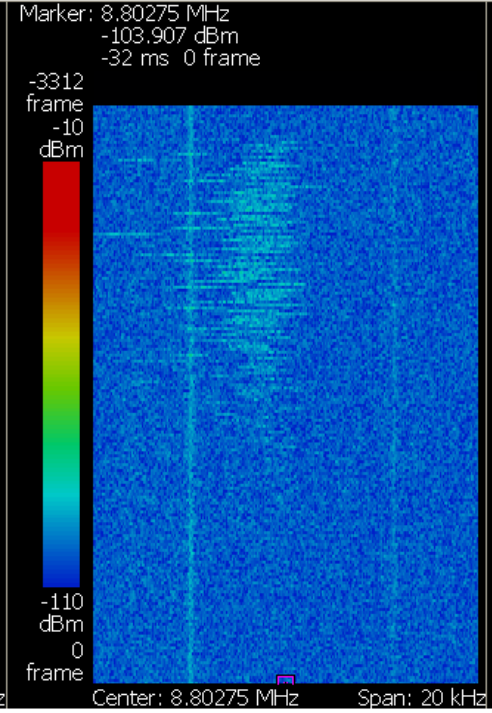


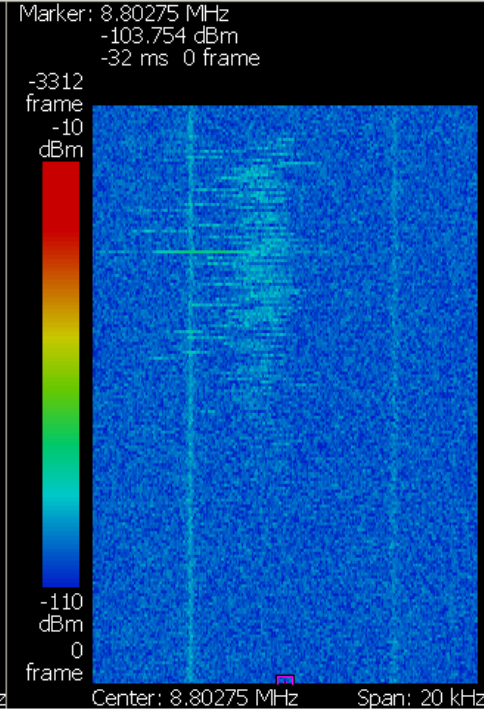
0.6V-10ms-10ms-200m

The evolution of Schottky signal with the modulation amplitude 10ms-200ms-10ms-200ms



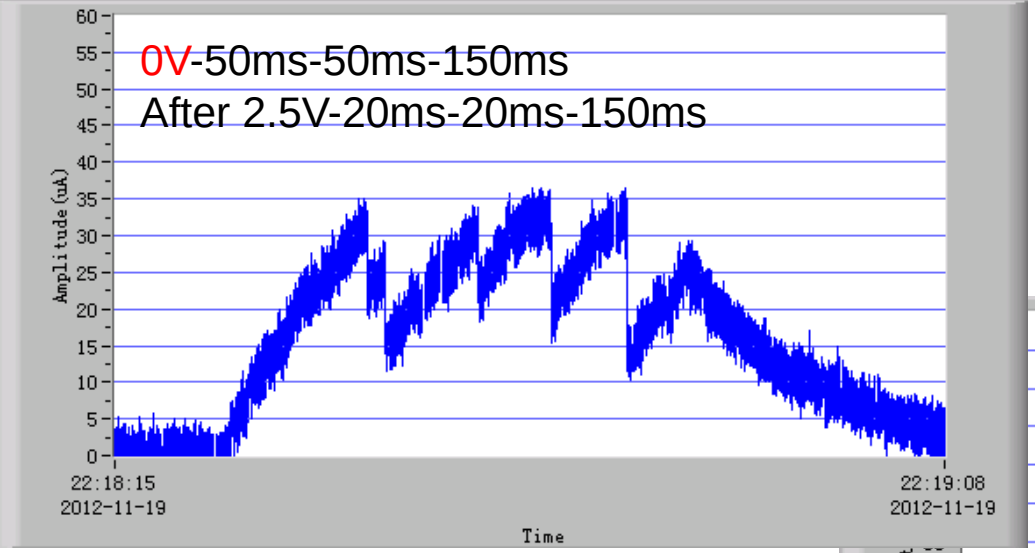


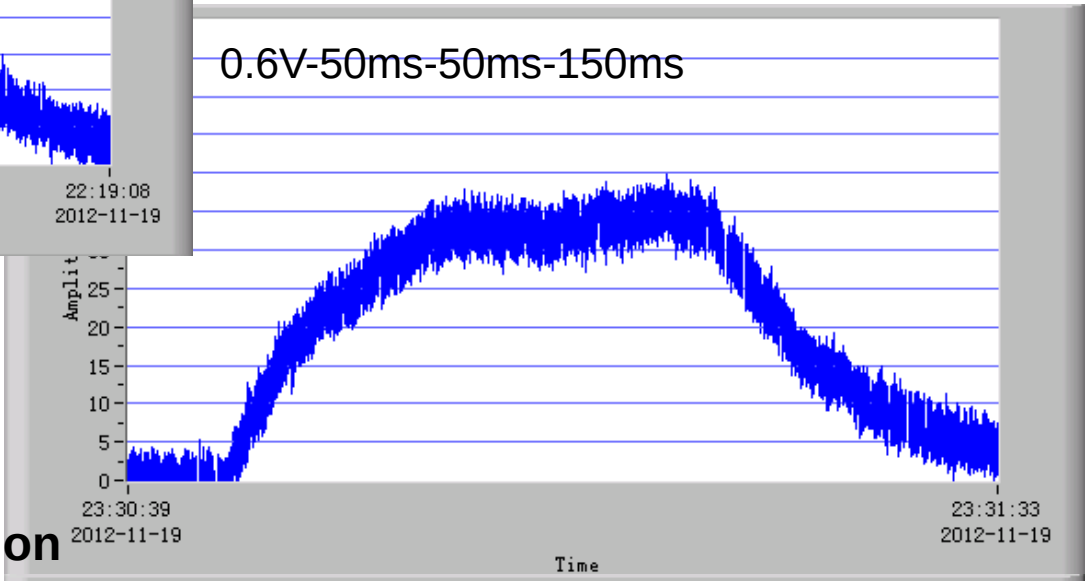




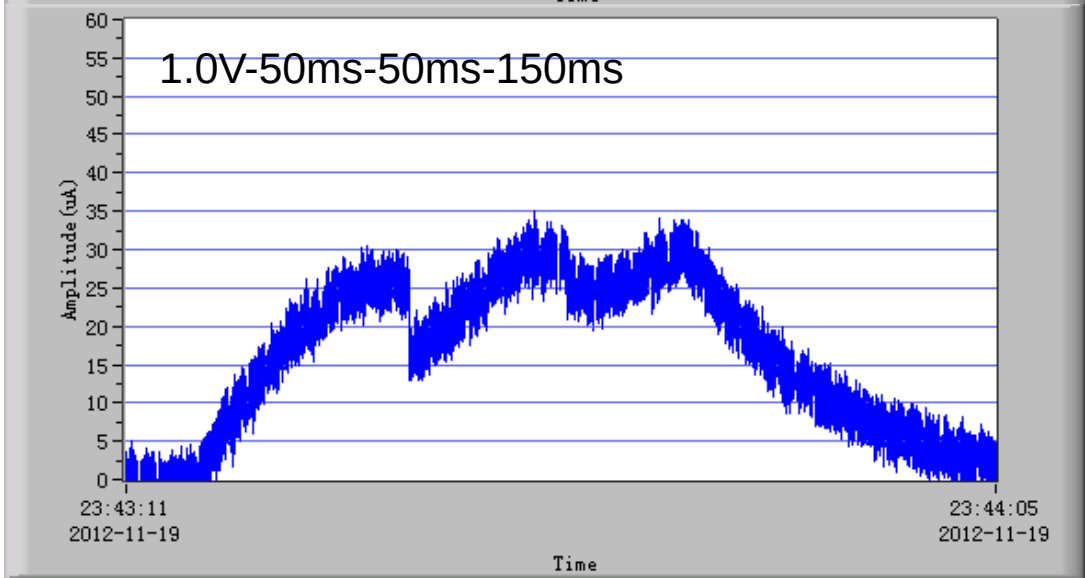
Without modulation 0V-50ms-50ms-150ms 0.6V-50ms-50ms-150ms 1.0V-50ms-50ms-150ms
After 2.5V-20ms-20ms-150ms

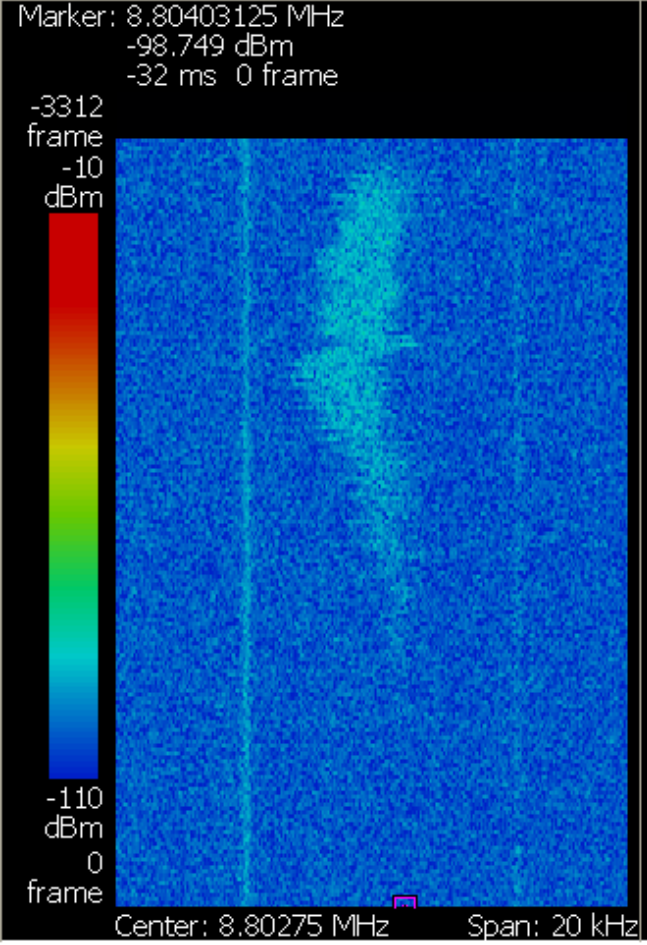
The evolution of Schottky signal with the modulation amplitude
50ms-150ms-50ms-150ms
The amplitude of change was bigger than previous slide
One frequency side was more serious than the other!

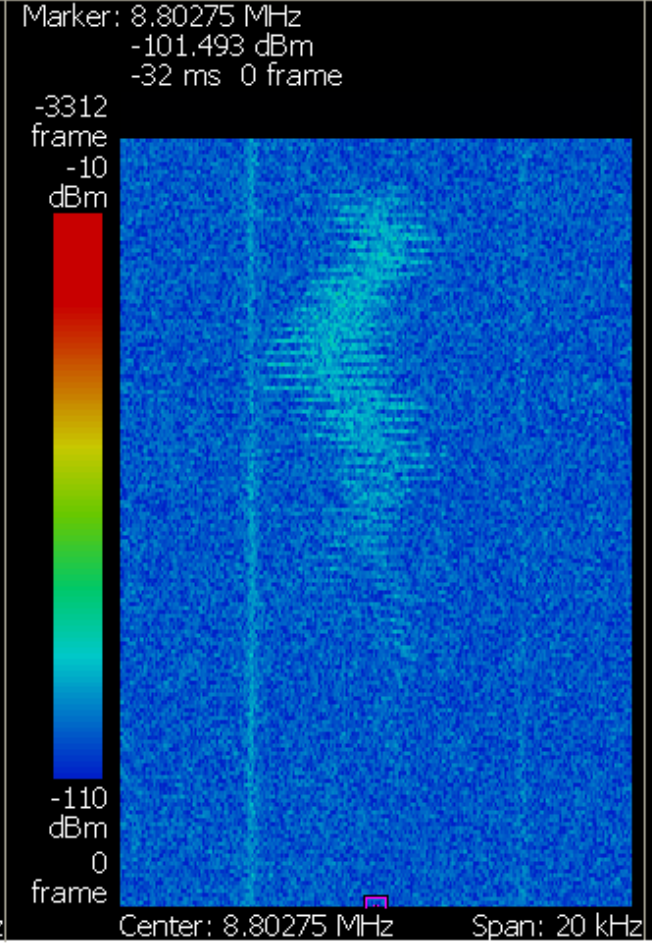


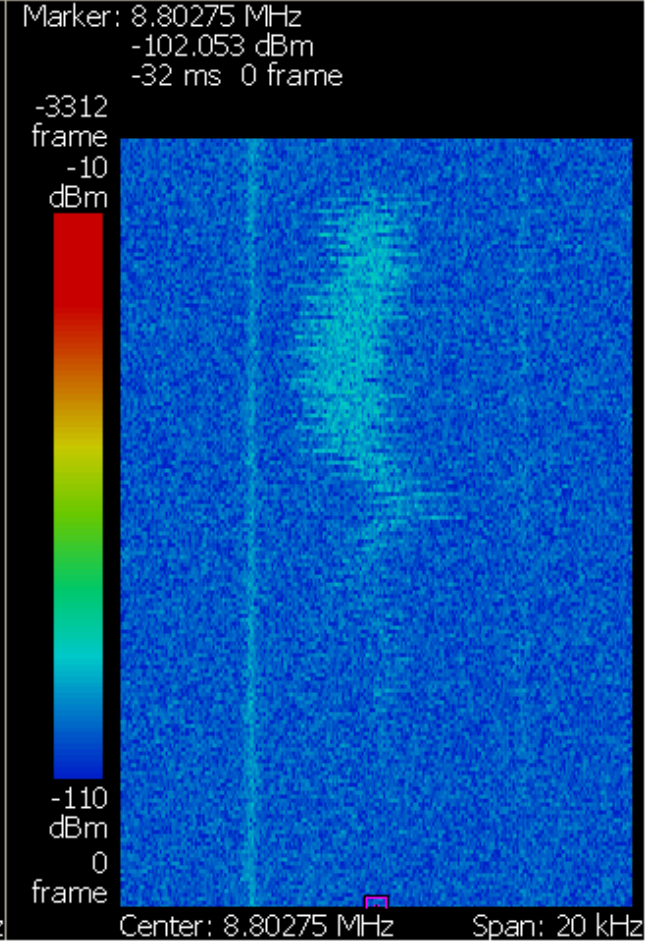


The DCCT signals with the modulation interval
50ms-150ms-50ms-150ms









Without modulation

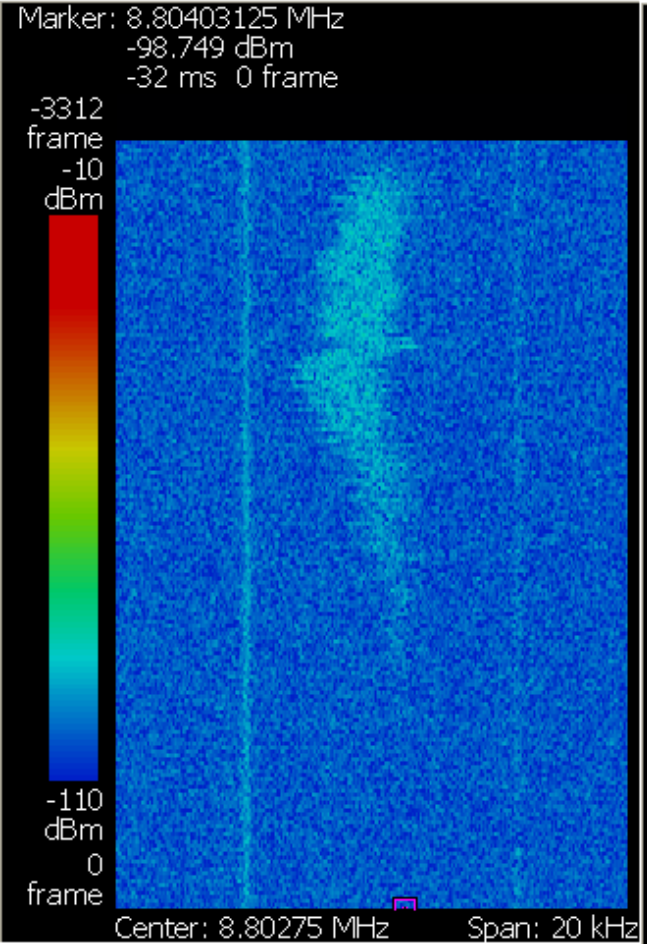
0V-10ms-10ms-100ms

After 2.5V-10ms-10ms-200ms

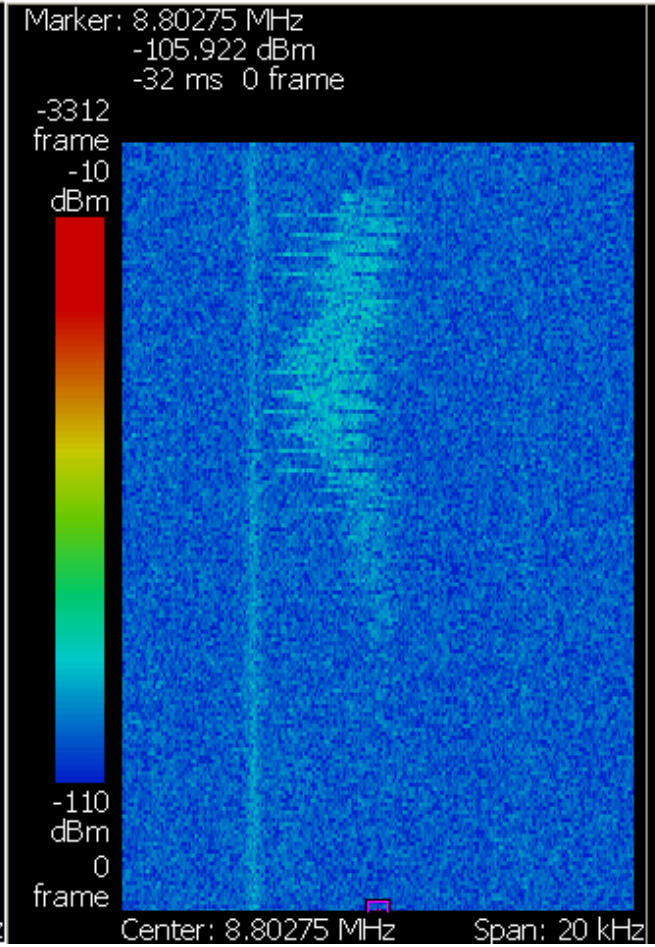
0.6V-10ms-10ms-100ms

Compare between different modulation amplitude,
The modulation was symmetrical.
It seems symmetrical in the Schottky signal in this modulation.

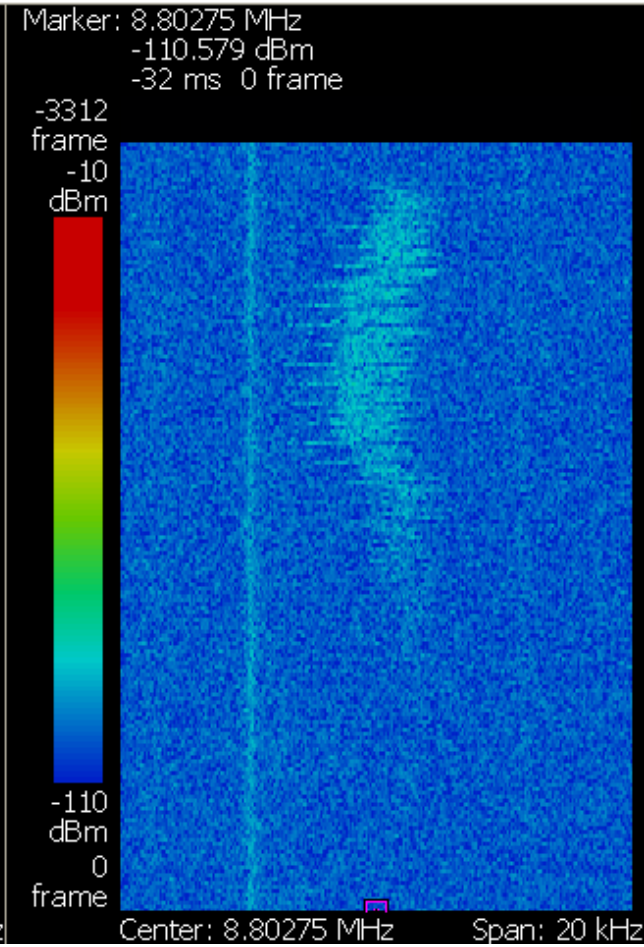
1-10-13



Without modulation



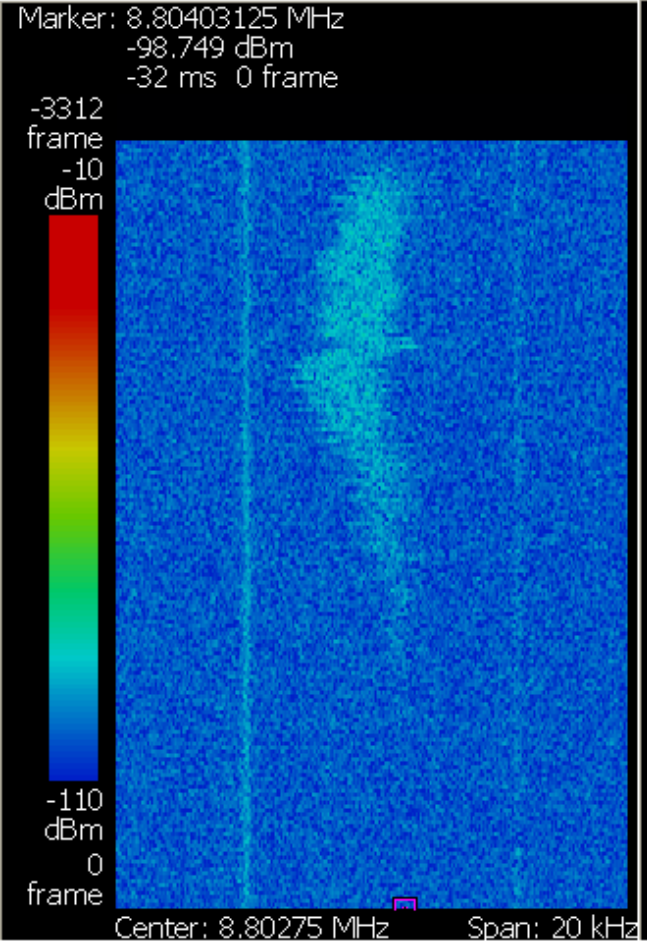
0.6V-10ms-10ms-150ms

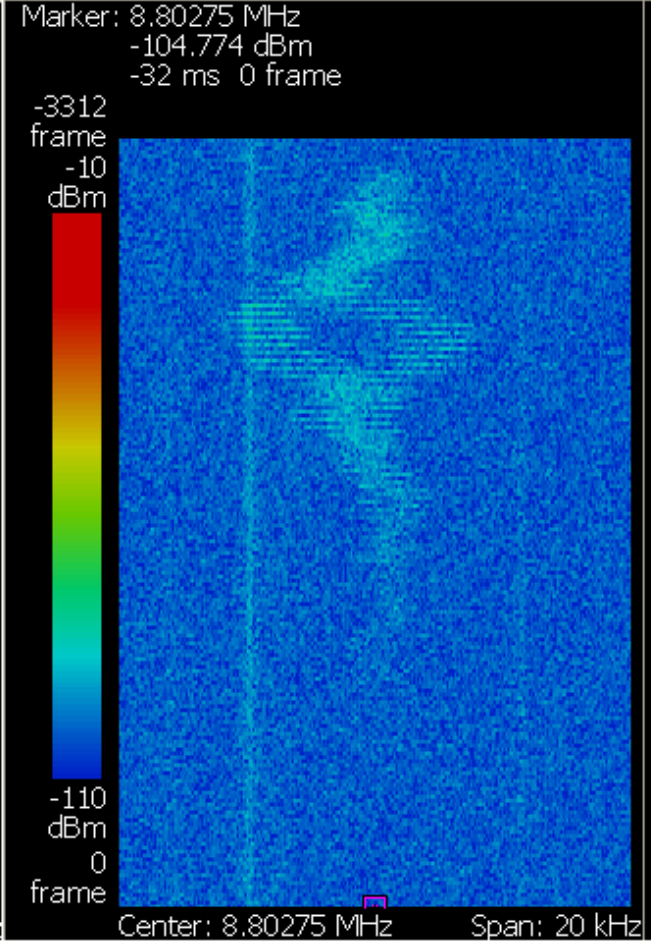


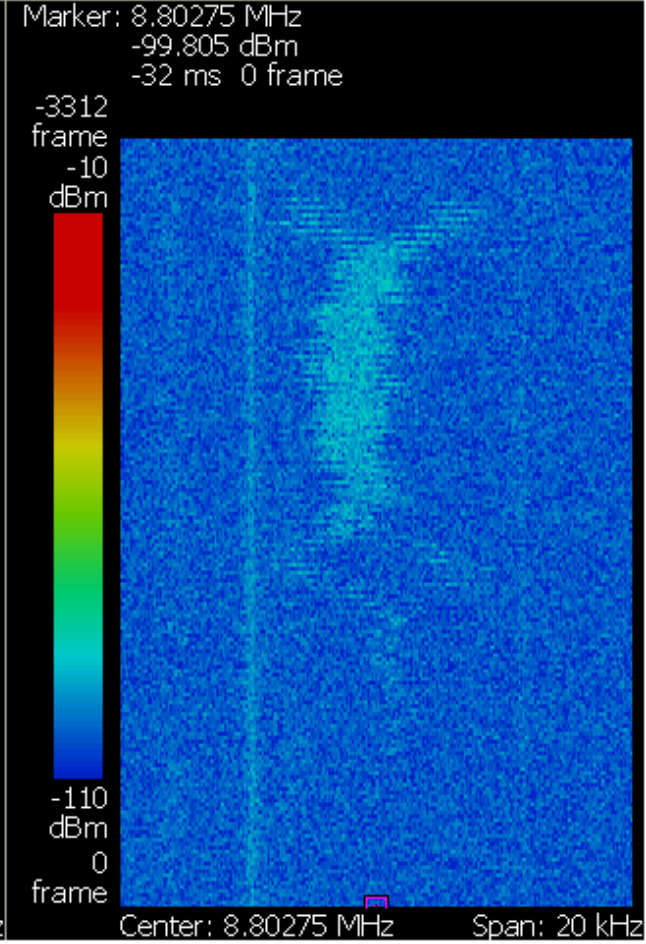
2.5V-10ms-10ms-150ms

Compare between different modulation amplitude,
The modulation was symmetrical.
One frequency side was more serious than the other!

1-22-27





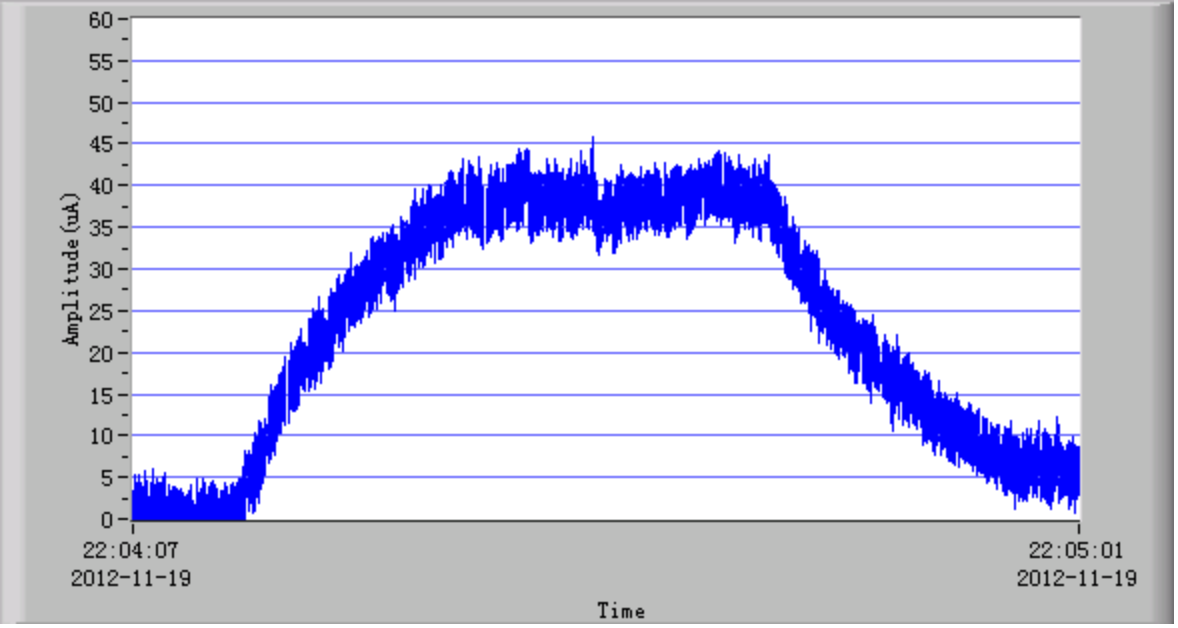


Without modulation

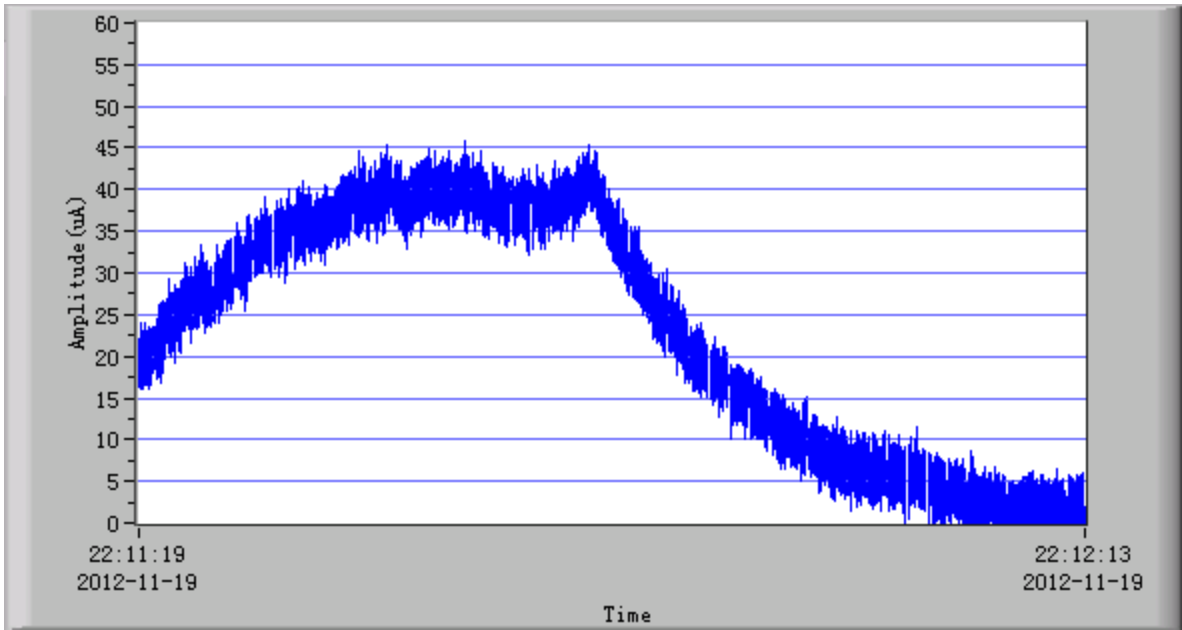
0.8V-20ms-20ms-150ms

1.5V-20ms-20ms-150ms

The Schottky signal was splited into two parts in some modulation
The amplitude of modulation was smaller than 2.5V, 0.12%.

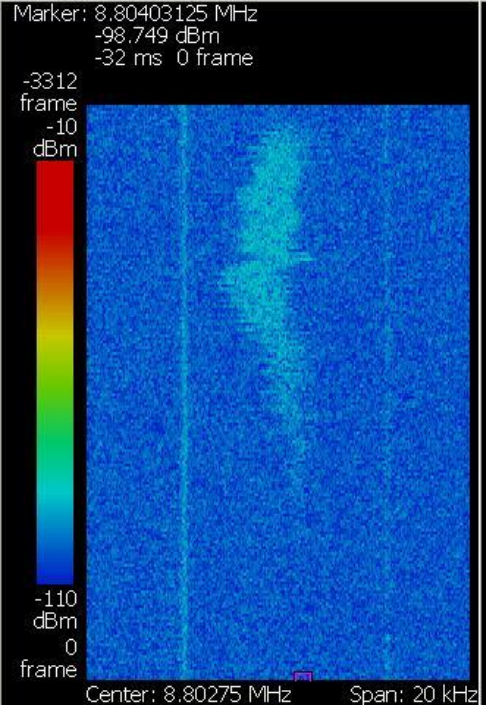


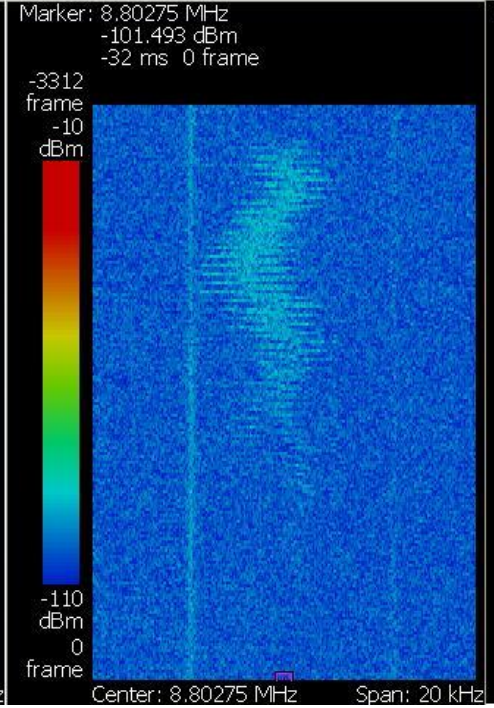
The beam loss was not obvious from the DCCT signals

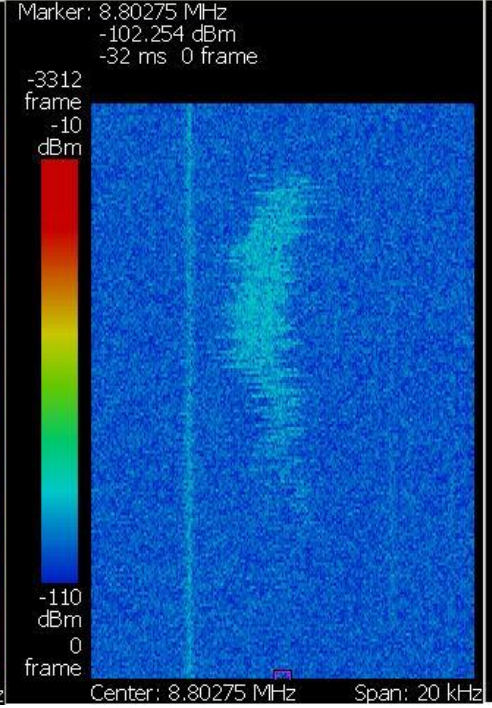


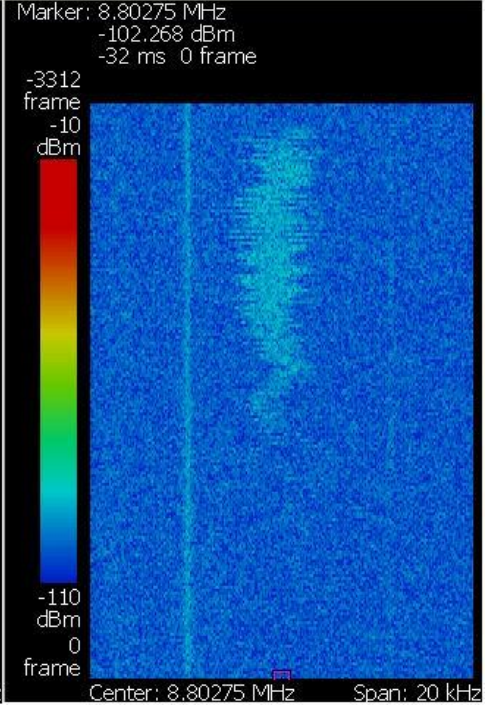
Other Effects

- When the modulation voltage was set as zero and turn off, the modulation effect still appear in the next Schottky signal. The response seems a bit “hysteresis effect” or “Memory effect ”.









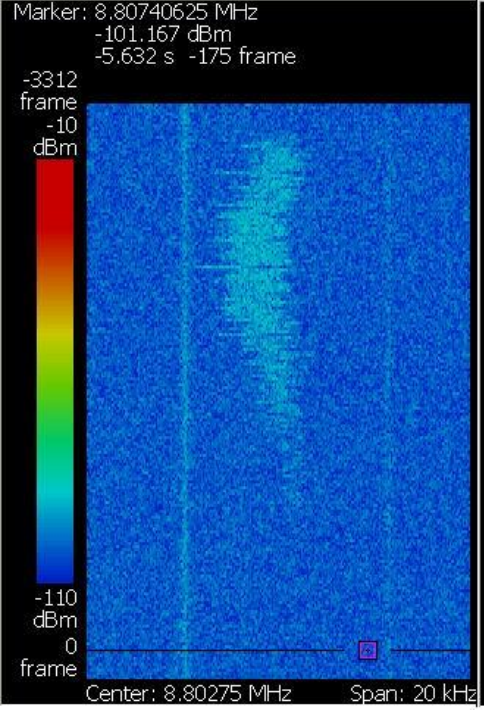
0V-10ms-10ms-200ms

0V-20ms-20ms-150ms

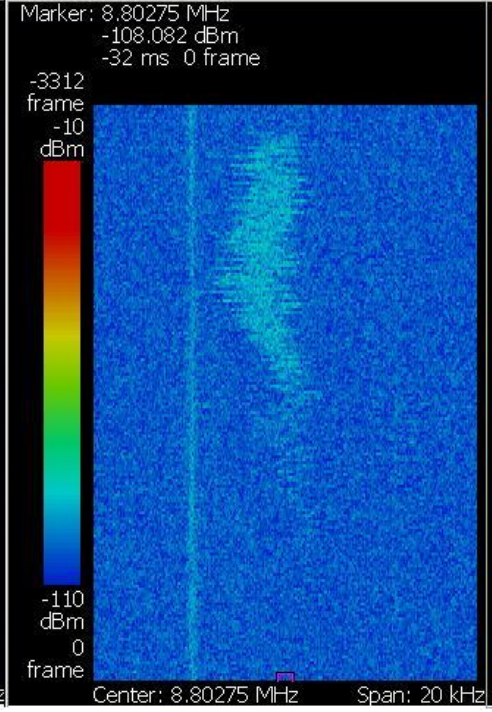
0V-10ms-10ms-100ms **0V**-10ms-10ms-150ms

The voltage amplitude of modulation pulse were zero

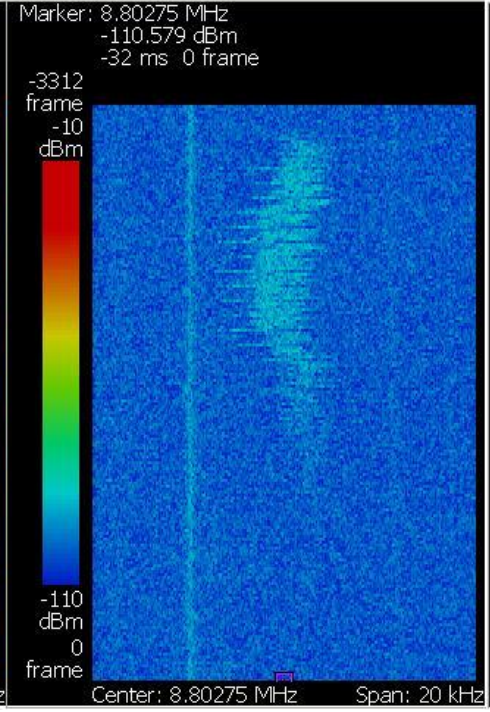
1-10-19-28



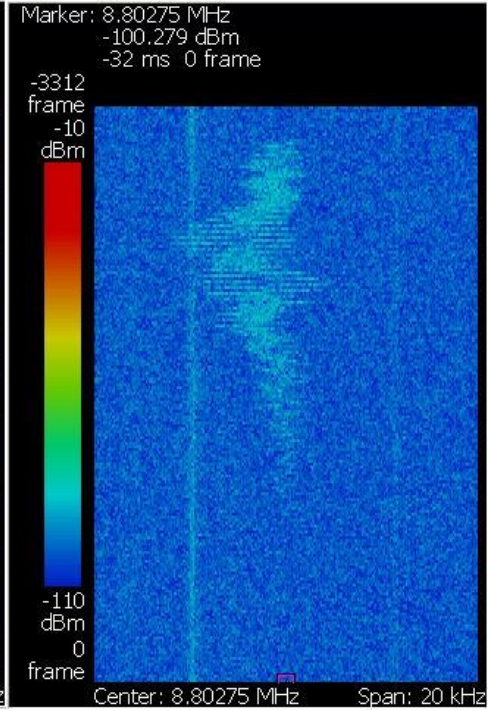
2.5V-10ms-10ms-200ms



2.5V-10ms-10ms-100ms

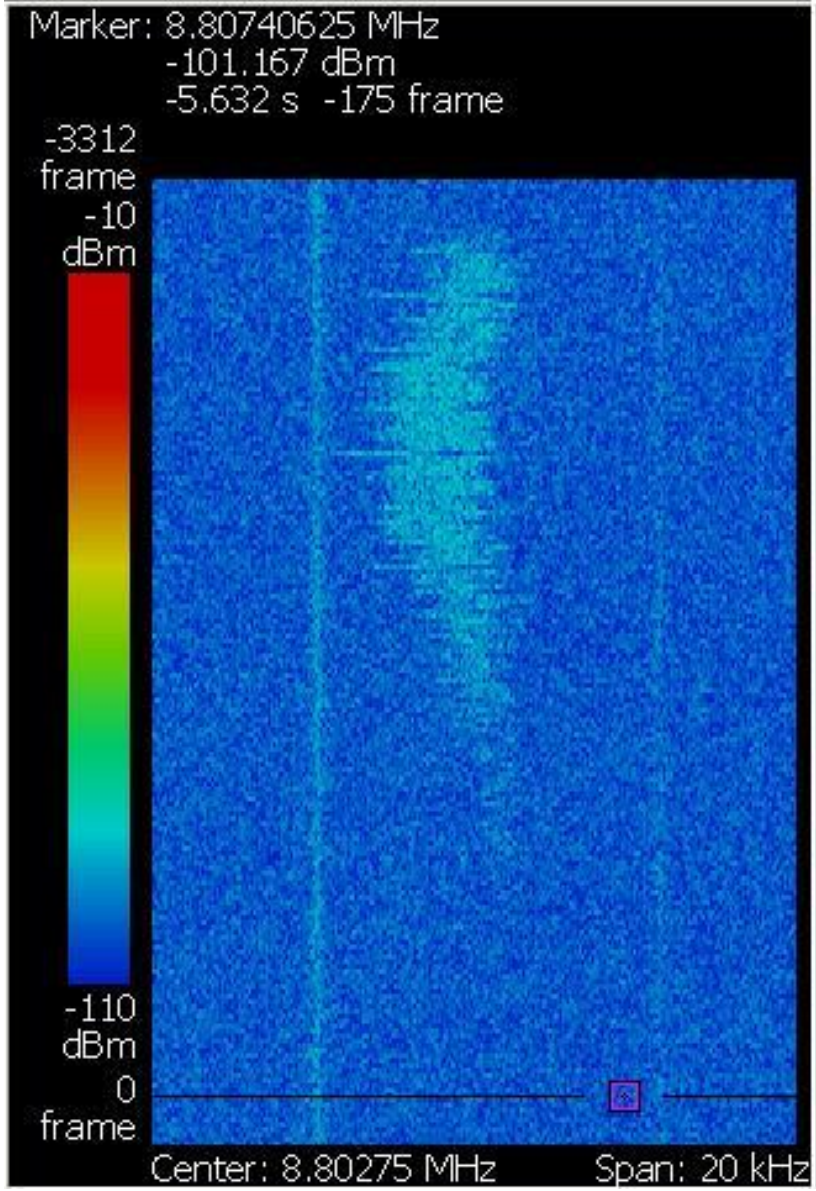


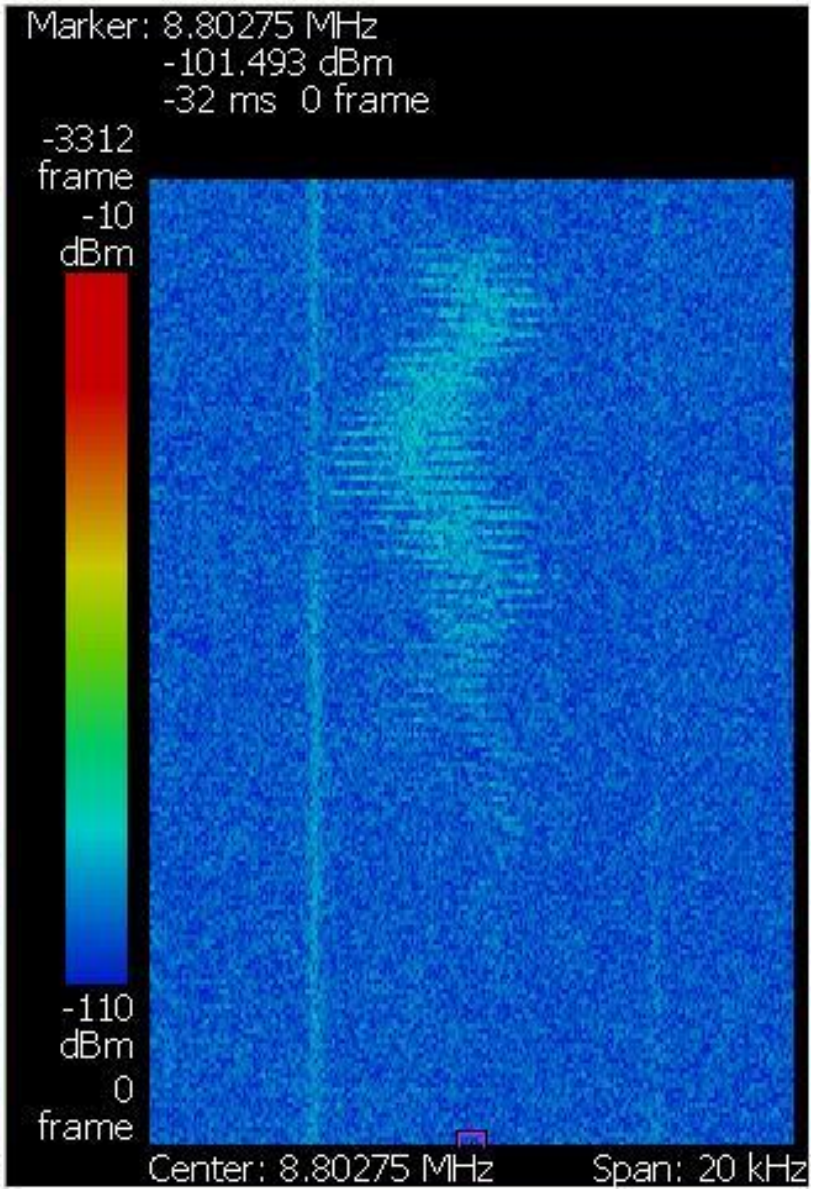
2.5V-10ms-10ms-150ms



2.5V-20ms-20ms-150ms

The voltage amplitude of modulation pulse were 2.5V

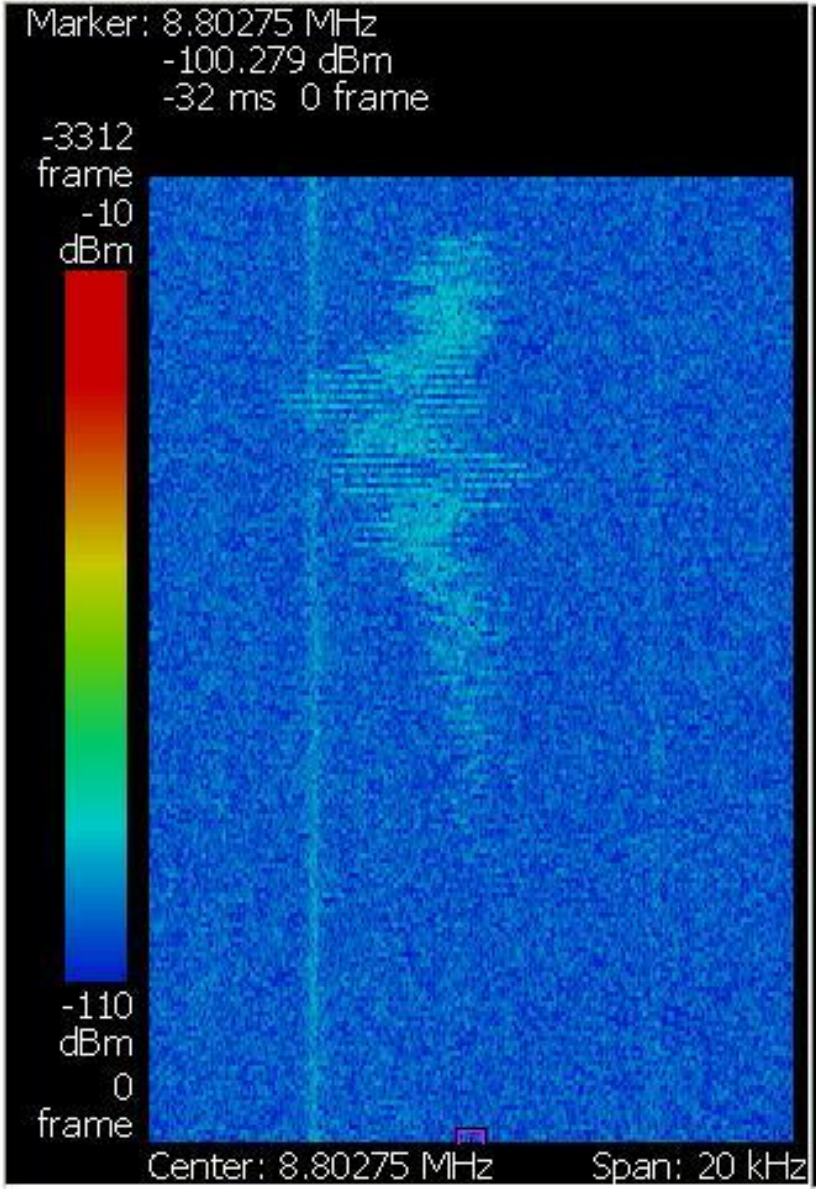


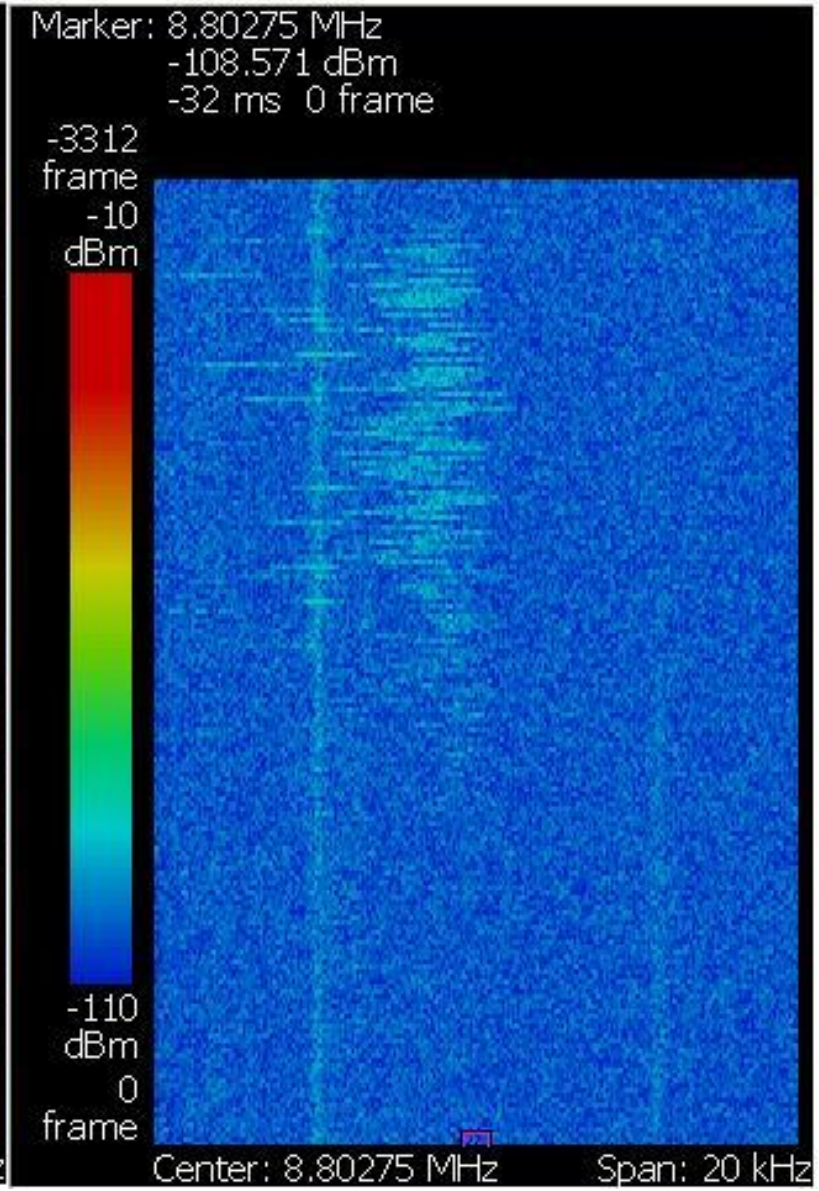


2.5V-10ms-10ms-200ms

0V-10ms-10ms-100ms

Previous Schottky signal





2.5V-20ms-20ms-150ms

0V-50ms-50ms-150ms

Previous Schottky signal

Shortage of this experiment

- Only two signals (DCCT, Schottky probe)
- No information of transverse profile of ion beam
- No enough information from BPM monitors

Width and repetition Frequency of modulation

- **Compare with**:
- Revolution frequency
- Betatron oscillation frequency
- **Compare with**:
- Cooling time
- Injection interval
- Lifetime of ion beam

Electron energy modulation

- The essential of electron energy modulation is augmentation the longitudinal temperature of electron beam.

Gain from this experiment

- Helpful to understand the effects of electron energy instability on the Schottky signal
- Helpful to understand the unexpected negative effects of electron energy modulation.
- Compare with the “electron heating” in the case of bunched proton beam

Summary

- In the condition of this experiments, due to limitation of injected ion beam and its intensity, the accumulated ion beam have not approached the saturation in the storage ring, the space charge limitation have not reached, at the same time, not find the proper modulation frequency and appropriate amplitude, No obvious evidence for increasing the accumulated ion intensity and suppression of instability by electron energy modulation.

Thank You !

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