Hardware (AFP, ssRF)

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b1/Azz Tensor Collaboration Meeting

Outline

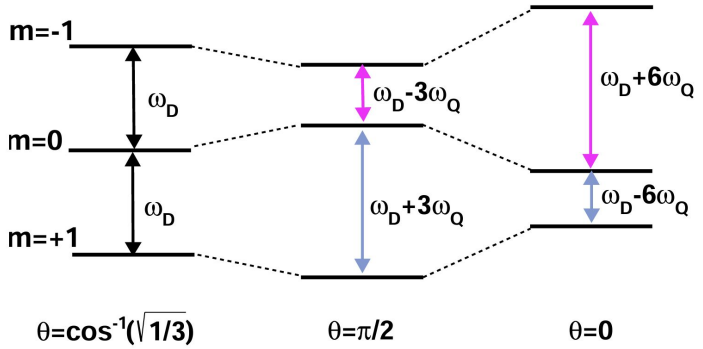
1. Spin 1 system (deuteron)
2. Vector and Tensor Polarizations
3. AFP and ssRF
4. Hardware Status
5. Summary

Spin-1 System (deuteron)

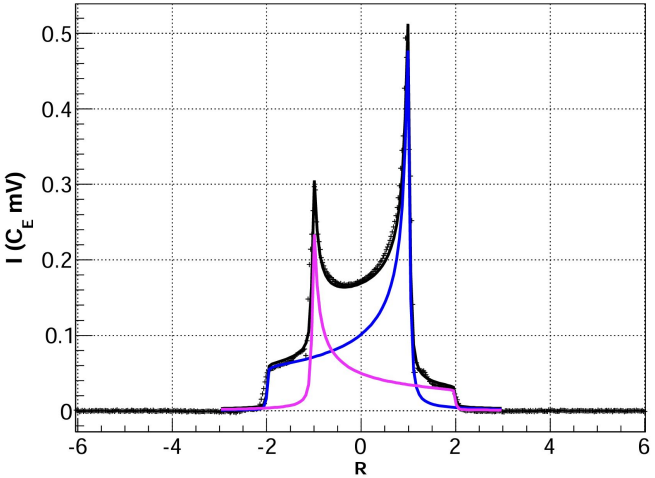
Energy level of a deuteron in a magnetic field

$$E_m = -m\hbar\omega_D + \hbar\omega_Q[(3\cos^2\theta - 1) + \eta\sin^2\theta\cos 2\phi](3m^2 - 2),$$

- $\hbar\omega_D$ is the deuteron Zeeman energy.
- $\hbar\omega_Q$ is the deuteron quadrupole energy.
- The red (blue) lines indicate the transitions from the magnetic sublevels −1 ↔ 0 (0 ↔ 1).

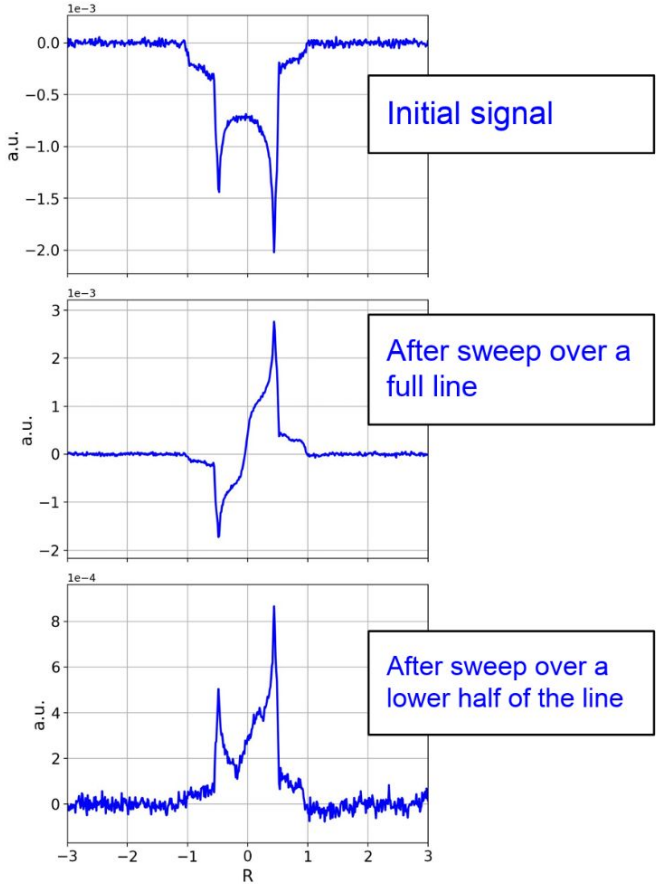


The energy level diagram (not to scale) for deuterons

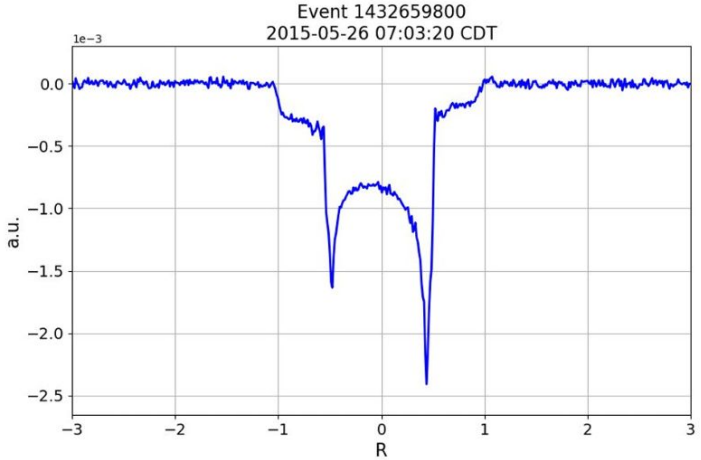


Ref: https://arxiv.org/abs/1707.07065

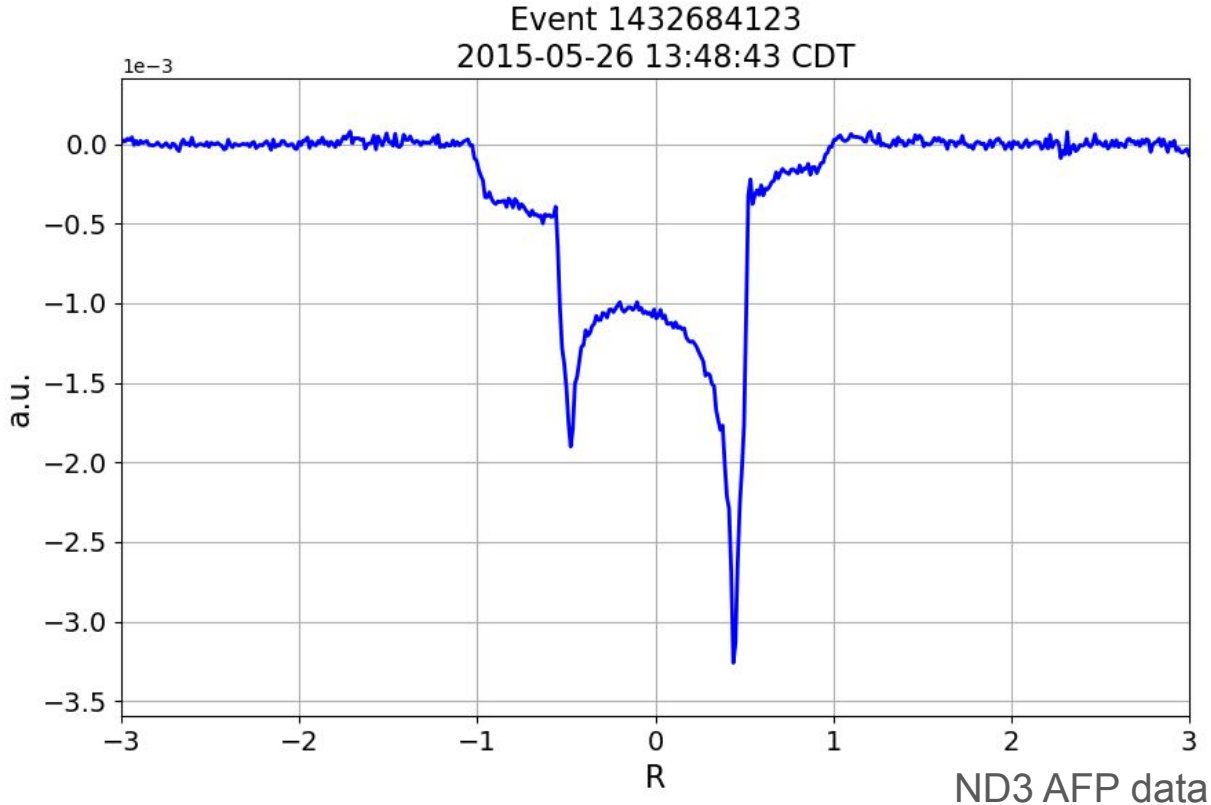
AFP (Adiabatic Fast Passage)



1. Technique to rapidly reverse the direction of nuclear spin polarization.
2. The spin system is placed in a strong magnetic field (H_0) and exposed to an RF field (H_1) perpendicular to it.
3. The sweeping time should less than the relaxation time
4. AFP sweep rate needs to optimized to minimize the polarization loss in AFP.

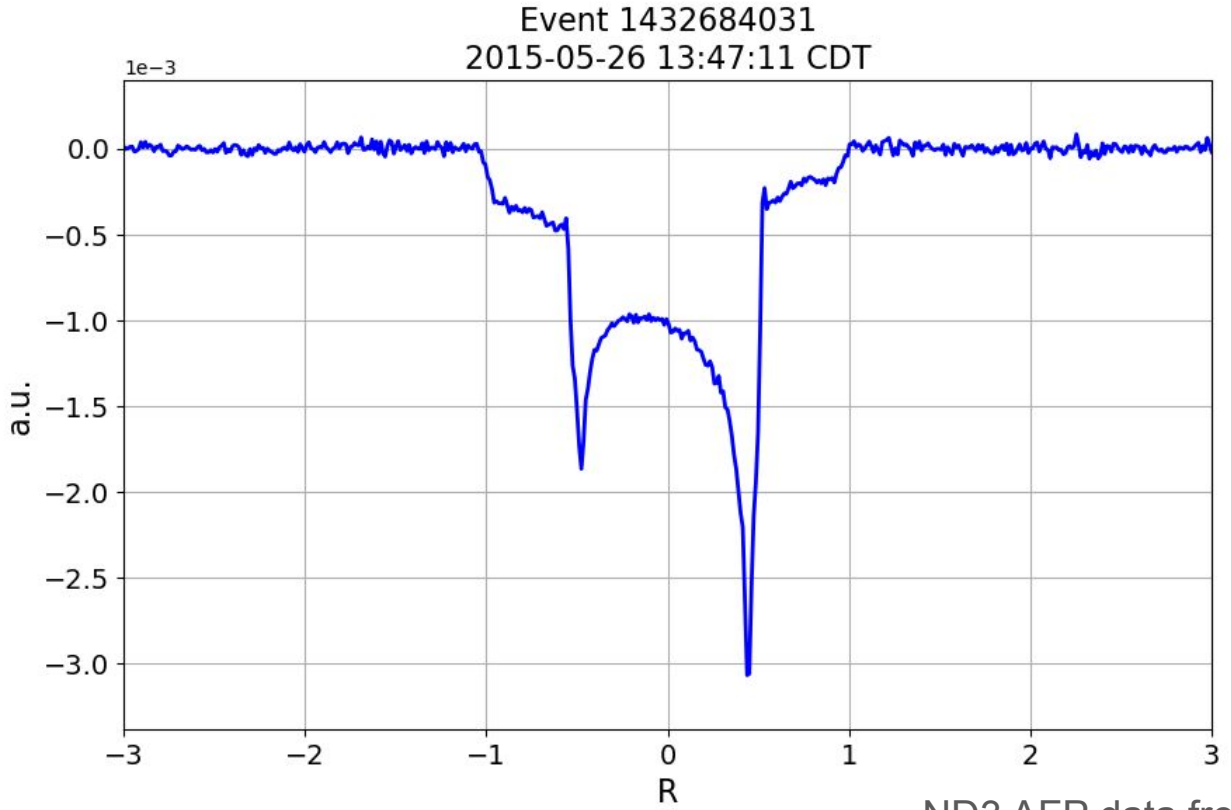


More AFP



ND3 AFP data from UVA (2015)

More AFP



ND3 AFP data from UVA (2015)

AFP efficiency

- AFP was performed on different target materials.
- Spin-flip efficiencies for different materials are shown below (δp = pol. ratio before and after spin-flip)

Nuc.lei	Dopant	Spins/g	δp
ND_3	Irr.	$2x10^{17}$	-0.88
NH_3	Irr.	$2X10^{17}$	-0.57
D-but.	Irr.	$1X10^{17}$	-0.77

Slide is taken from D. Keller
Ref:https://twist.phys.virginia.edu/work/DrellYan2017/DrellYan2016.pdf

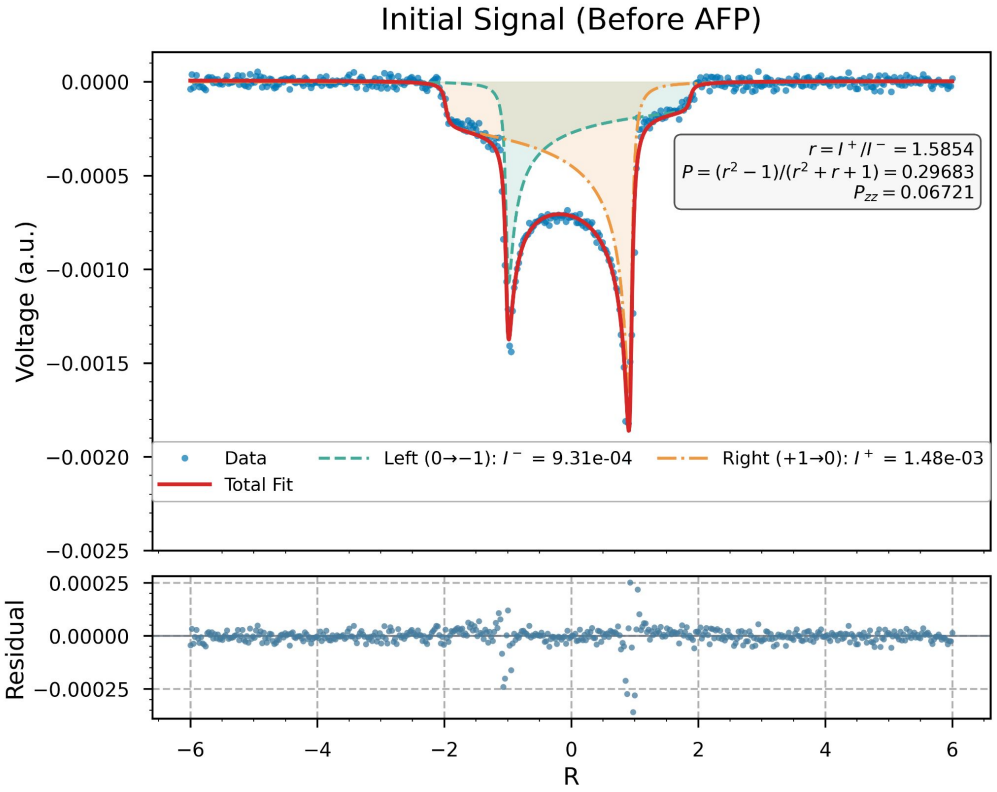
Results from AFP experiments with various nuclei in different target materials

Nuclei	Substance dopant	e^- conc. (spins/g)	δP^{max}
^1H	1-butanol EHBA-Cr(V)	2.0×10^{19}	−0.76
^7Li	^7LiH	low	−0.90
^1H	(irradiated)		−0.90
^{19}F	8-fluoro-1-pentanol	1×10^{20}	−0.37
^1H	TEMPO		−0.40
^2H	1-butanol-d_{10}	2.36×10^{19}	−0.92
	EHBA-Cr(V)-d_{22}	6.35×10^{19}	−0.90

Ref: NIM A 356 (1995) 108

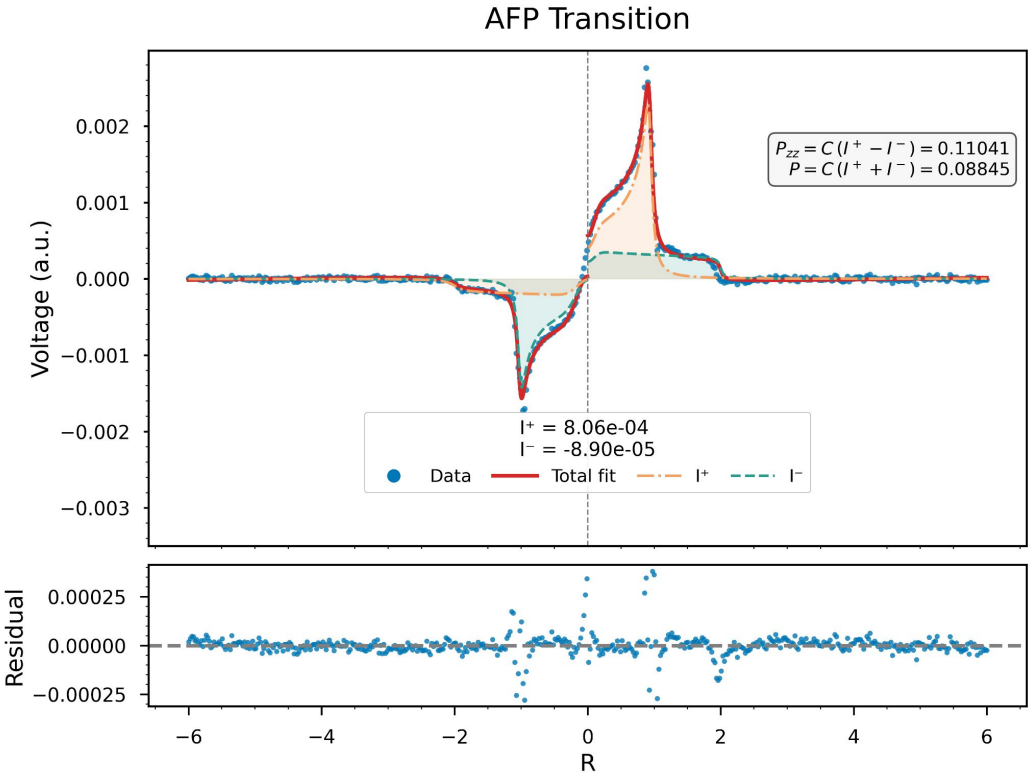
AFP (Adiabatic Fast Passage)

1. At thermal equilibrium, the vector and tensor polarizations of the deuteron signal are measured before performing the AFP process.
2. The calibration constant obtained from this initial state is then used to determine the vector and tensor polarizations during AFP operation.
3. Fit function Dulya like (Dulya et al., NIM A 398, 109 (1997)), using area rather than height (Eur. Phys. J. A (2017) 53: 155).

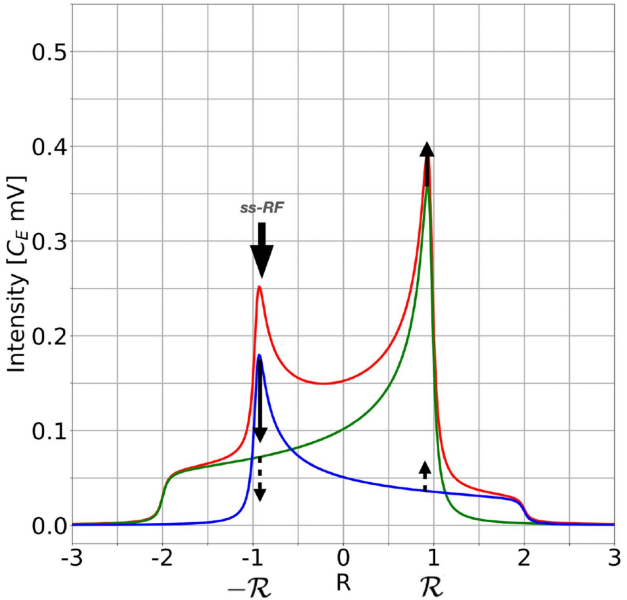


AFP (Adiabatic Fast Passage)

1. **After sweep over a full line**, we calculate the vector and tensor polarizations, where we already know the calibration constant from the initial signal.
2. The central region appears rounded rather than sharp, as predicted by the line-shape theory, because during AFP operation an additional ss-RF effect occurs, burns some area down—particularly in the center.



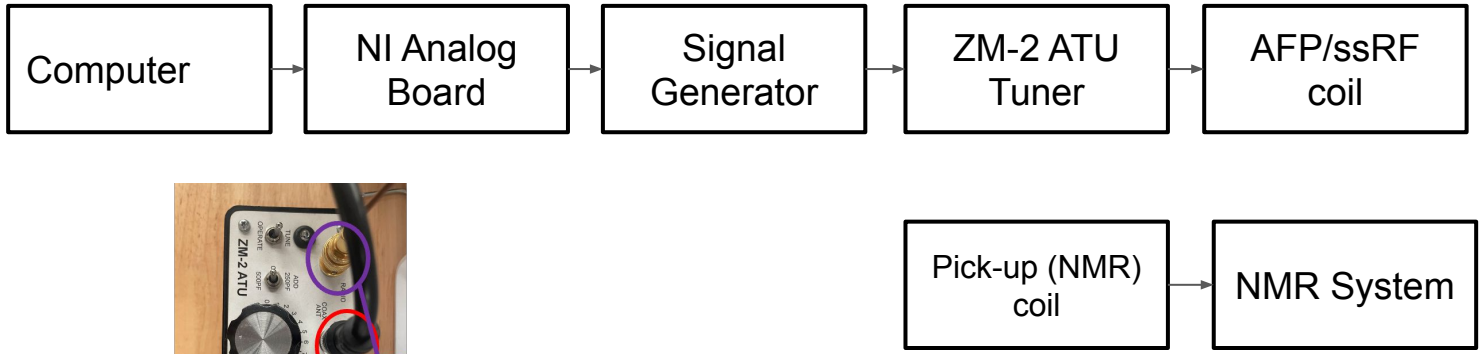
ss-RF (Selective Semi-Saturating RF)



Ref: NIM A 1050 (2023) 168177

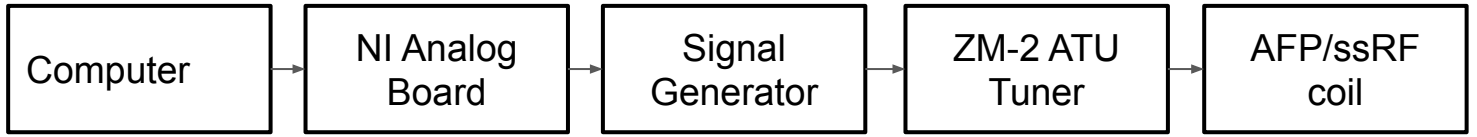
1. Locally drives transitions at specific NMR frequencies to reshape or enhance vector/tensor polarization.
2. ss-RF acts selectively on local bins in frequency domain, allowing non-uniform spin-temperature manipulation.
3. When ss-RF is applied at a frequency region R, it depletes the signal intensity there while simultaneously increasing the intensity at the opposite region −R at half the rate.

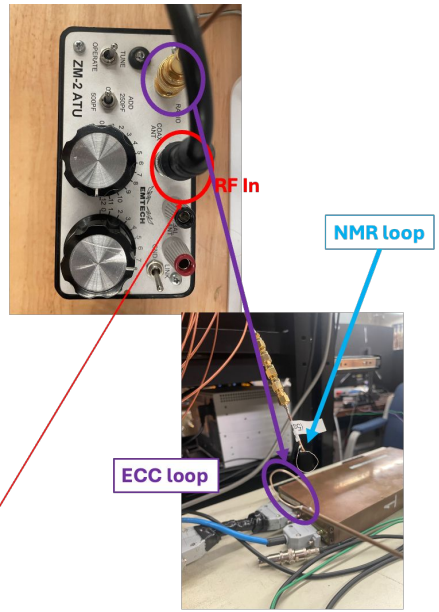
RF modulations on NH3 Baseline: Setup

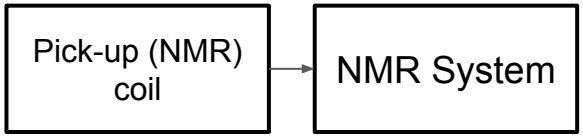


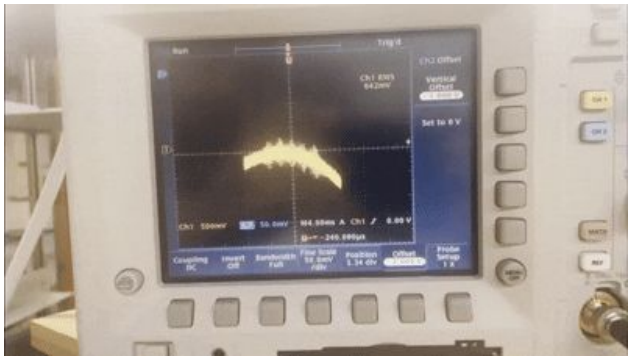
- The max update rate of NI PCIe-6321 is 900k samples/s.
  - **It is fast enough for AFP.**
- The min dwell time of Agilent N5181A is 1 ms. It is not fast enough for AFP.

RF modulations on NH3 Baseline: Test









With mod frequency 400 kHz

Summary

- The AFP method can be highly efficient, especially for achieving spin reversal. At UVA, this technique has been successfully applied to NH3, ND3, and deuterated butanol (D), with high efficiency.
- The ss-RF technique is a powerful complementary method and can be used to enhance tensor polarization.
- We are analyzing the AFP data taken from 2015.
- Hardware and Software Progress:
  - Developing the LabView software for RF Control Coil.
  - Optimizing AFP parameters.
  - Integrating the new AFP cup into the target system.
  - Planning to test AFP with NH3/ND3 this winter.