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Increasing the Signal-to-Noise Ratio of Field NMR Data by means of Pre-Polarization.

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INTRODUCTION

The Surface Nuclear Magnetic Resonance (SNMR) method allows, as the only non-penetrating geophysical method, a direct quantification and characterization of unbound water in the near subsurface. SNMR measurements in densely populated areas, as found almost everywhere in Central Europe, quite often yield S/R ratios smaller than 1. Although advanced strategies to suppress interference signals are meanwhile available, time-consuming stacking is still an unavoidable component of almost every SNMR measurement. This problem becomes even worse in the vadose zone, because its low water contents result in reduced signal amplitudes. The vadose zone is, however, in the focus of recent research in soil and agricultural science, hydrogeology, and even climate science. To overcome this low-amplitude problem and to make the SNMR method available for soil moisture investigations in a depth of 0 - 1 m, Pasquale & Mohnke (2014) propose the use of an additional artificially generated static magnetic field. Their model calculations give reason to expect that in this way the signal amplitudes can be substantially raised and the effort of SNMR measurements in the vadose zone decreased to an acceptable amount.

MRS-MIDI-III INSTRUMENT & PRE-POLARIZATION

For practical testing, we have added to our SNMR measuring system MRS-MIDI-III (Radic et al, 2011) a transmitter for the pre-polarization (PP) of the subsurface. In the center of a 2 meter measuring PP loop a flux density of 500 mT can be generated each time for a few seconds. This increases the nuclear magnetization of the water in the upper 1 meter significantly compared with the magnetization through the earth's magnetic field. An immediately following "conventional" SNMR measurement results in an up to one order of magnitude larger reply signal FID (free induction decay).

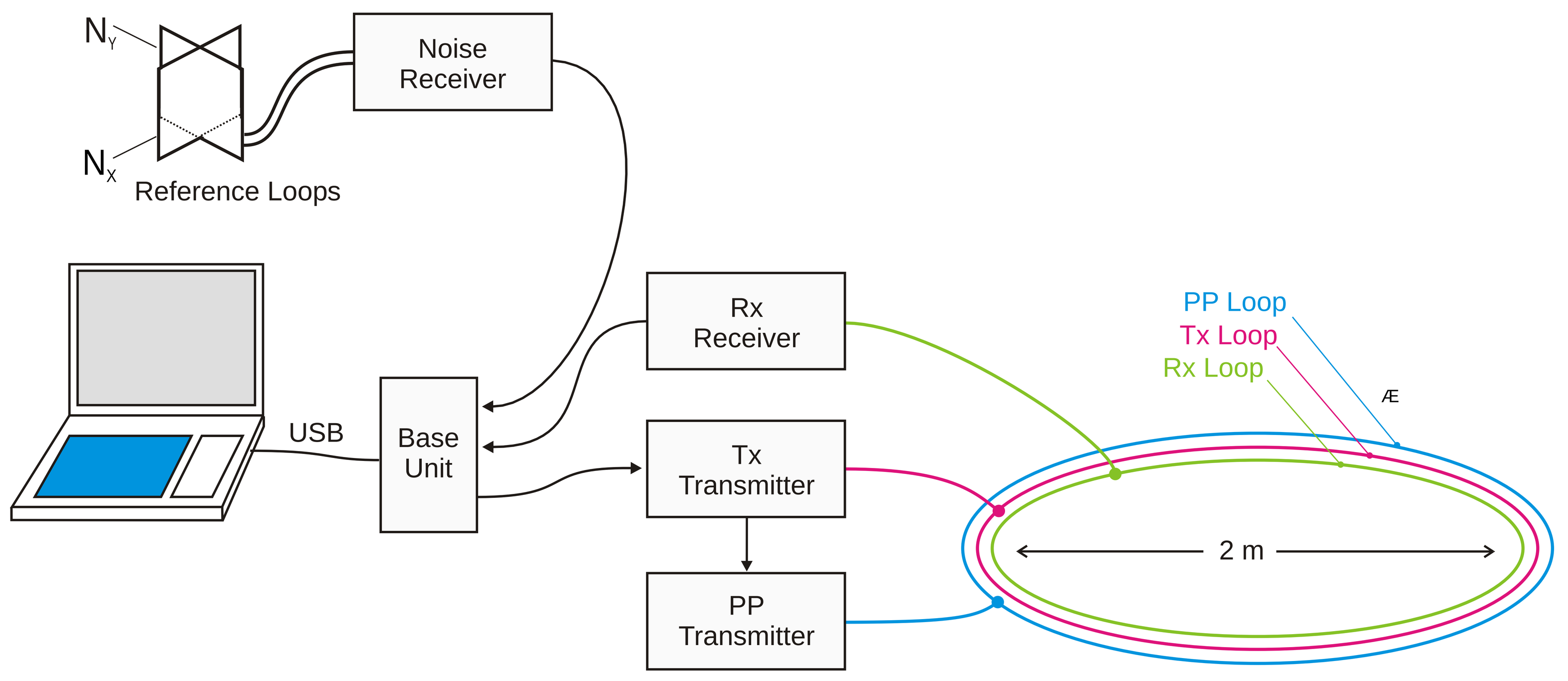

Figure 1: Schema of our SNMR instrument MRS-MIDI-III with pre-polarization.

PRE-POLARIZATION HARDWARE

To generate the desired artificial field we use a pre-polarization loop with 50 turns through which an actively stabilized direct current of 20 A flows. The cable weighs 25kg with a Cu-wire diameter of 6 sq mm, and can still be operated by one person. The shutdown procedure is especially important. A quick shutdown is desired so that the actual SNMR measurement can begin without delay. On the other hand, a too quick shutdown causes an uncontrolled precession of the spins. An "adiabatic" shutdown is necessary. We realize this with amplitude course predetermined by a microprocessor:

$I(t) = 20\,A*(0.5 + \cos(w*t)/2)$ mit $w = 1.8$ kHz und $t = \{0, 2\text{ ms}\}$

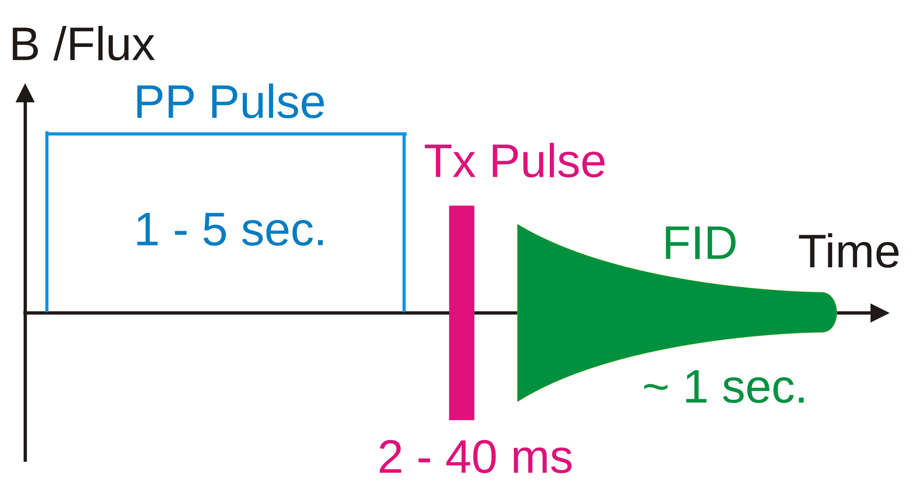

Figure 2: New SNMR Pulse sequence: Pre-Polarization Pulse before Tx excitation Pulse and FID recording.

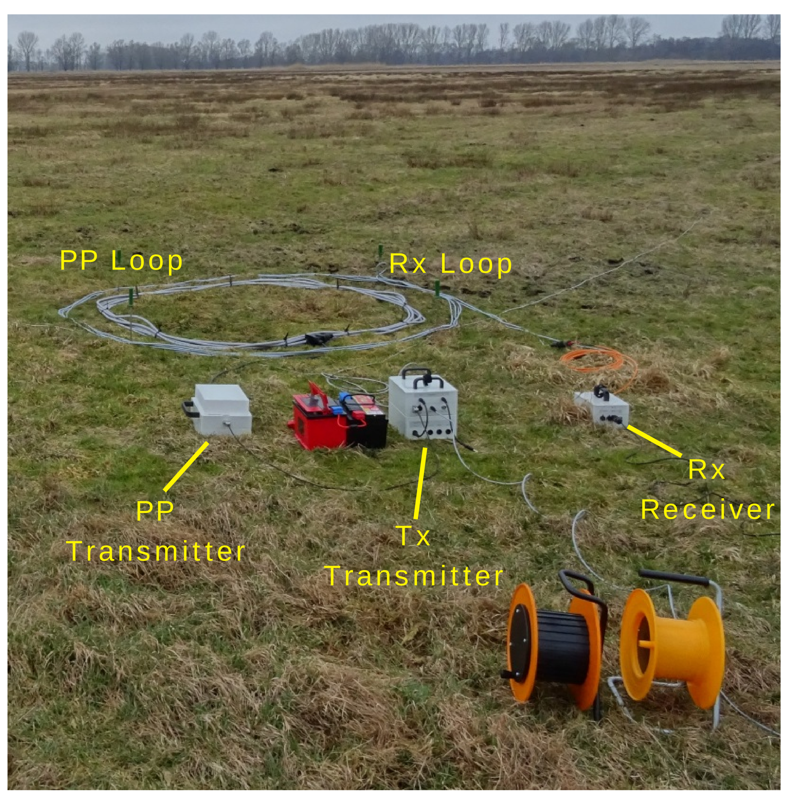

Figure 3: SNMR measuring system MRS-MIDI-III with pre-polarization during a field test.

FIRST FIELD TEST

A first feasibility test took place at our test site near Linum (near Berlin). The adjacent Figure 3 shows the main components of the measuring system: the Tx transmitter with build-in LiFePO4 batteries and the PP transmitter with two car batteries. All three loops (Tx, Rx & PP) lay coincident and have a diameter of 2 meter.

Figure 4a and 4b show, for a pulsemoment q=12 Ams, as an example, the FID record with (a) and without (b) pre-polarization. It is obvious that the use of pre-polarization leads, as predicted, to a significantly larger FID signal (here 8 times larger).

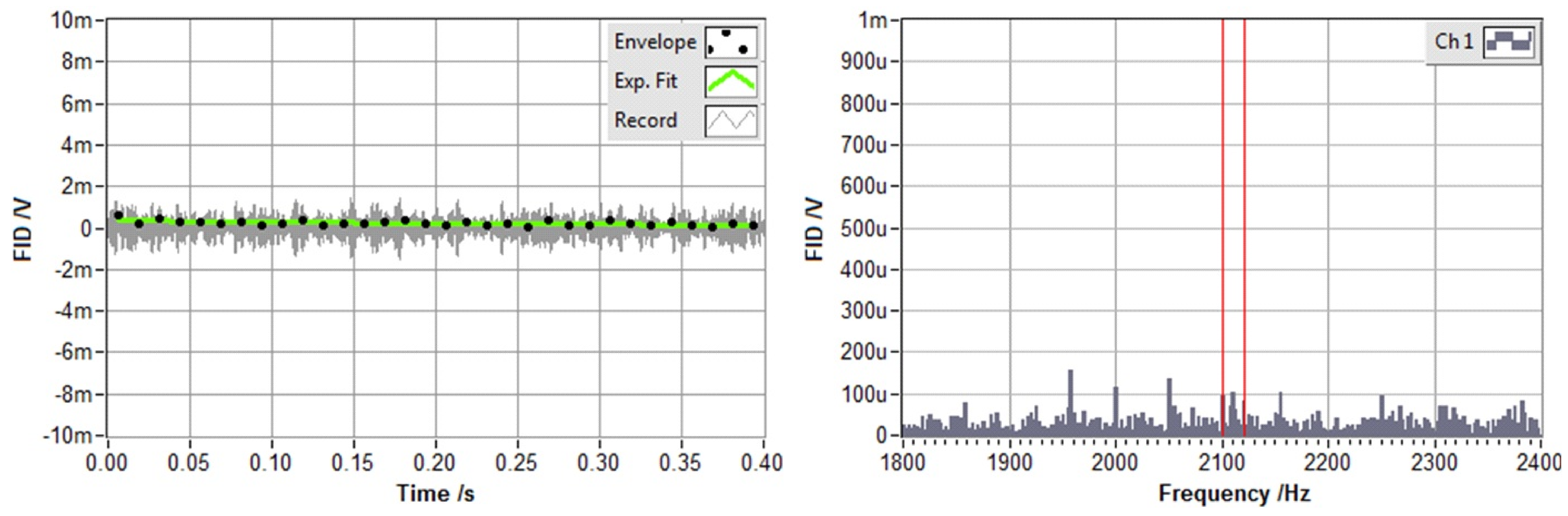

Figure 4a: Result of a "conventional" SNMR measurement for pulse moment Q of 12 Ams. Shown is the 16 times averaged FID voltage signal of the 72-turn Rx loop after a 30,000 times amplification. All loops (Tx, Rx, PP) have a diameter of 2 m. Noise cancelation with Remote Reference Technique. Location: Linum near Berlin.

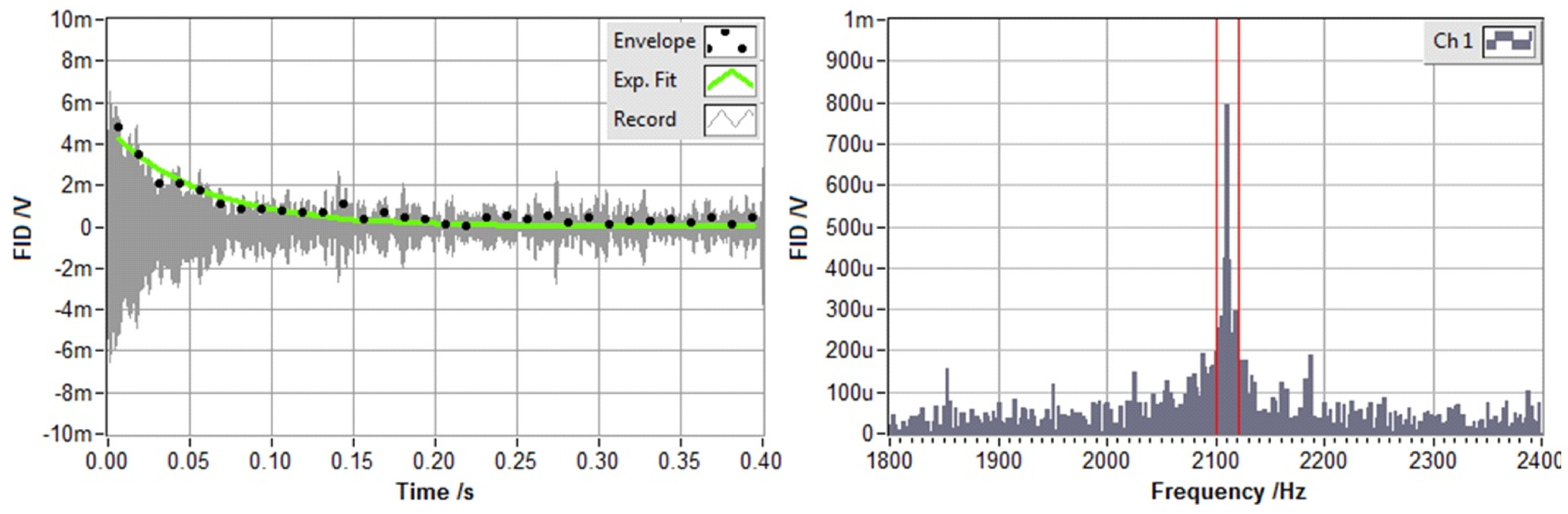

Figure 4b: Same as in Figure 4a, but SNMR measurement with pre-polarization (5 sec).

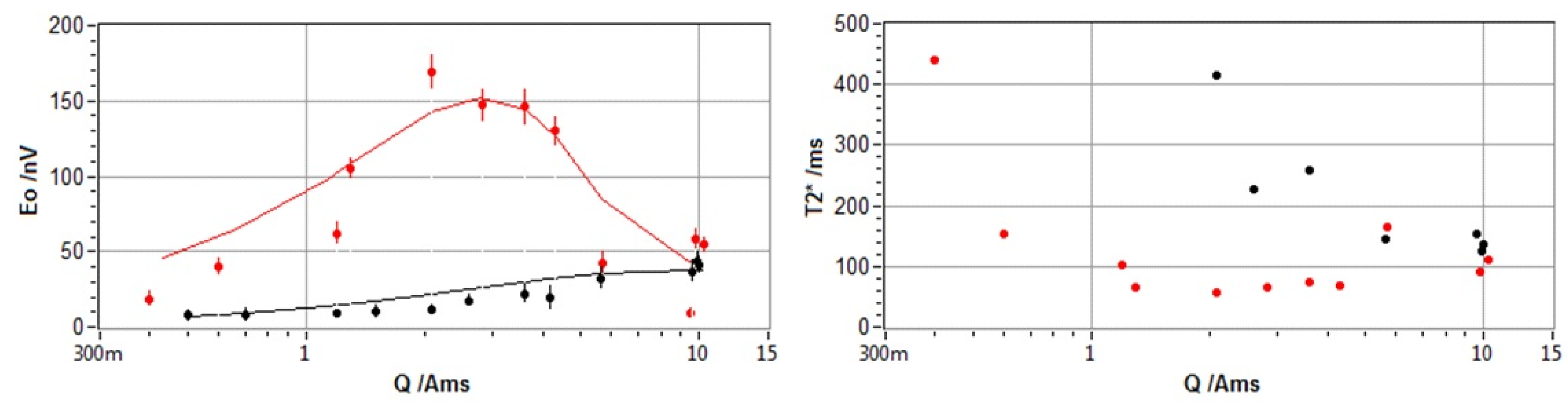

Figure 5: SNMR sounding without (black dots) and with pre-polarization (red dots). Same parameter as in Figure 3. Left: Initial amplitude Eo, right: relaxation time T2. Location: Linum*

In Figure 5 the results of a "conventional" SNMR sounding (black dots) and the results of a sounding using pre-polarization are contrasted (red dots). With pre-polarization, the signal levels of the initial amplitude Eo of the FIDs for nearly all pulse moments are significantly higher. The relaxation times T2* measured with pre-polarization are, as expected for the Vadose Zone, relatively small (70 ms). On the other hand, the relaxation times of the conventional measurement for average and small pulse moments are unrealistically large. The insufficient S/R ratio (<2) is responsible for this.

1-D Q-T-INVERSION

The adjacent graphic shows the result of a 1-dimensional Q-T inversion of the sounding data using pre-polarization as calculated using a beta Version of the software MRSMatlab (Müller-Petke et al., 2016). The inversion result shows the water content as function of relaxation time T2* and depth.

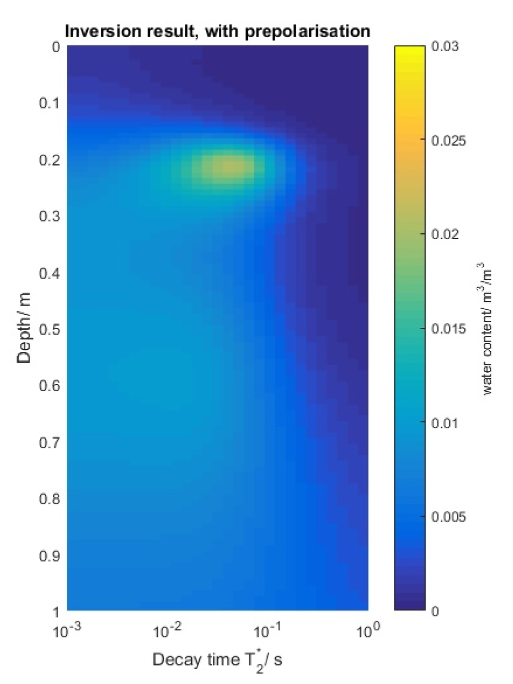

Figure 6: 1-D Q-T inversion result for data with pre-polarization.

CONCLUSION

For the exploration of the Critical Zone (here: 0-1 m), pre-polarization proves to be a very effective method to increase the S/R ratio and, in doing so, the quality of data of the SNMR soundings. This improvement can be used to increase measurement progress or to take measurements in areas with larger technical disturbances. In addition to this, we expect the opening up of new areas of use for the SNMR; for example, the examination of moist zones in tunnels and mines. In the interest of even greater exploratory depths, larger VP field strengths and larger VP loops would be necessary. However, taking into account the current available technical means, the financial and logistical costs would be still too high.

REFERENCES

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