Adiabatic Pulses to improve MRS measurements.

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INTRODUCTION

The Magnetic Resonance Sounding (MRS) Method allows for the direct quantification and characterization of non or weakly bounded water in near surface soil. MRS measurements in densely populated areas, frequently cause S/R ratios of less than 1. This is why last year we have added a transmitter for the pre-polarization (PP) of the soil (RADIC & COSTABEL, 2017) to our MRS apparatus MRS-MIDI-III (RADIC & LEHMANN, 2011). A field of 500 mT can be generated for several seconds within the 2 metre PP-Loop. In doing so, the nuclear magnetisation of the water within the upper 1-2 metres increases up to one magnitude. The directly following “conventional” MRS measurement then stimulates an up to 10 times greater response signal (FID).

Recently we have added a further innovation to our instrument: an adiabatic pulse (AP). A Tx pulse to deviate the protons in the soil is normally constant in regards to frequency and amplitude. However, this causes zones, which lie closely next to each other and which have different negative or positive values of sensitivity. As a consequence, signals are reciprocally cancelled out and the useful signal measured at the surface is weakened. The specific characteristic of adiabatic pulses is that the frequency and/or current change during the pulse. Through this, the distribution of the sensitivity in the soil can be advantageously influenced (Grunewald et al., 2016). Amongst others things, it is therefore possible to achieve an approximately homogeneous distribution of the sensitivity in a defined depth range, which avoids reciprocal cancelled out signals and increases the signal amplitude by a factor of up to 3.

ADIABATIC PULSES

Figure 1 shows three fundamental types of adiabatic pulse forms. 7 parameters are enough to exactly specify all 3 types of pulse in their chronological sequence. One parameter determines the length, the others the pulse forms. Frequency and pulse strength sequences can be determined independently from one another. The pulse strength is determined by the Duty Cycle (DC). The DC is, in a good approximation, proportional to the pulse strength.

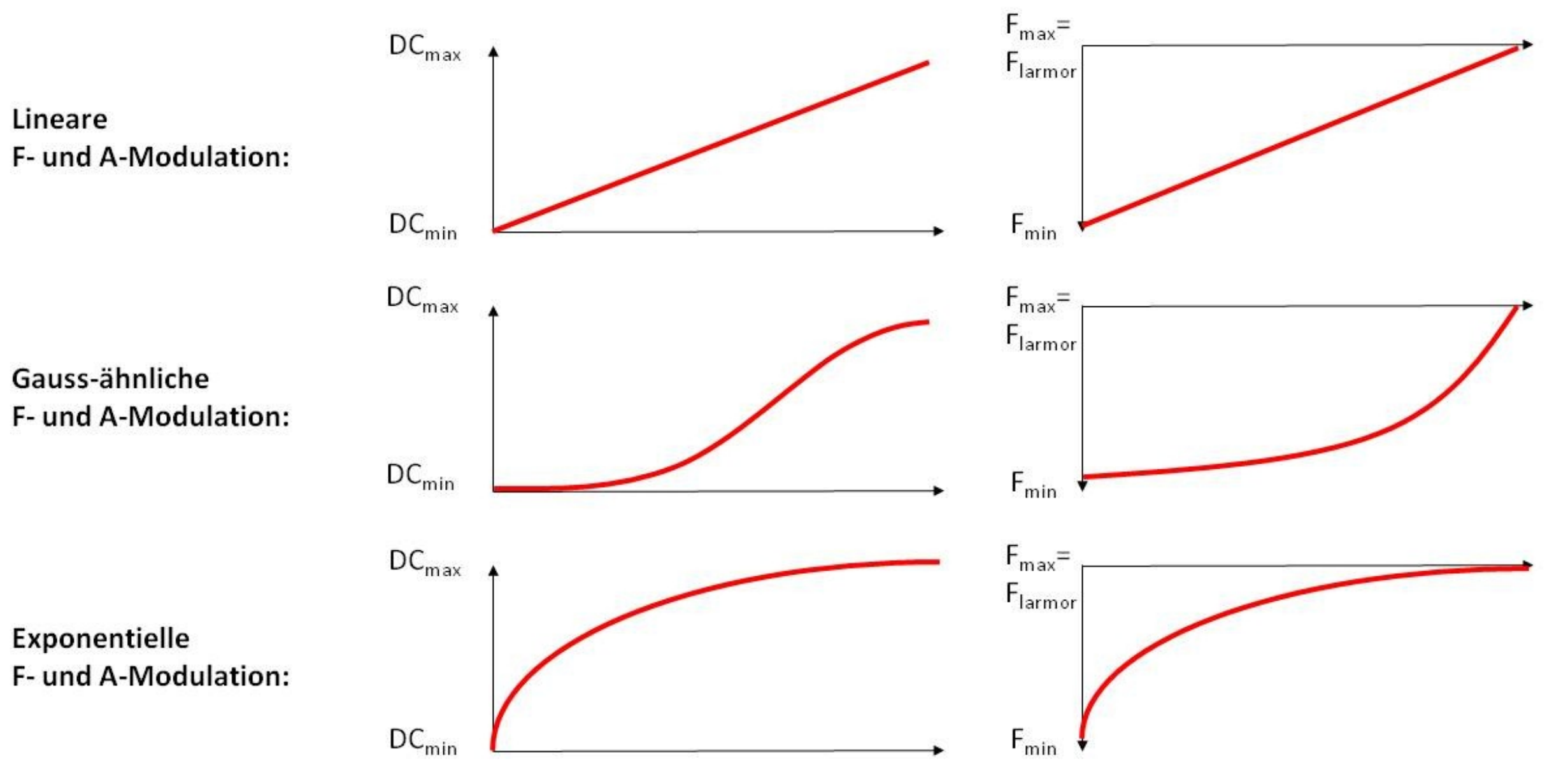


***Figure 1** Implemented adiabatic pulse shape types. 7 parameters specify length and variation of the frequency and strengths of a pulse.*

THE INSTRUMENT

Figure 2 gives an overview of the measuring system MRS-MIDI-III++. A laptop controls the entire instrument through its USB port. At the heart of this is the Base Unit, to which the Tx and the PP transmitters (Px) as well as up to 7 receiver channels (Rx) can be connected. The Tx and the Rx loops are required as a minimum for the MRS measurement. A Px loop with up to a 2 metre diameter can be connected additionally to explore the upper meter. Two further loops serve to monitor noise and suppress noise components in the FID signal (Reference Technique). Figure 3 shows the user interface of our measuring device. The numeric input of the 7 parameters are located in the upper right corner of the monitor (line card: 1. Tx). The resulting nominal process is immediately calculated and shown in the graph below as a continuous line. The evaluation of the in the following measured current (lower left graphic) then gives the actual progression of the frequency (red dots). The transmitter signal voltage has the shape of a square. This signal shape shows, as opposed to a sinus, advantageous qualities because technically it can be generated more easily and there is less heat loss. The pulse strength is determined through the choice of the ratio of the on/off time (the Duty Cycle). In contrast to excitation voltage, the resulting excitation current has the shape of a saw tooth a result of the inductivity of the Rx loop.

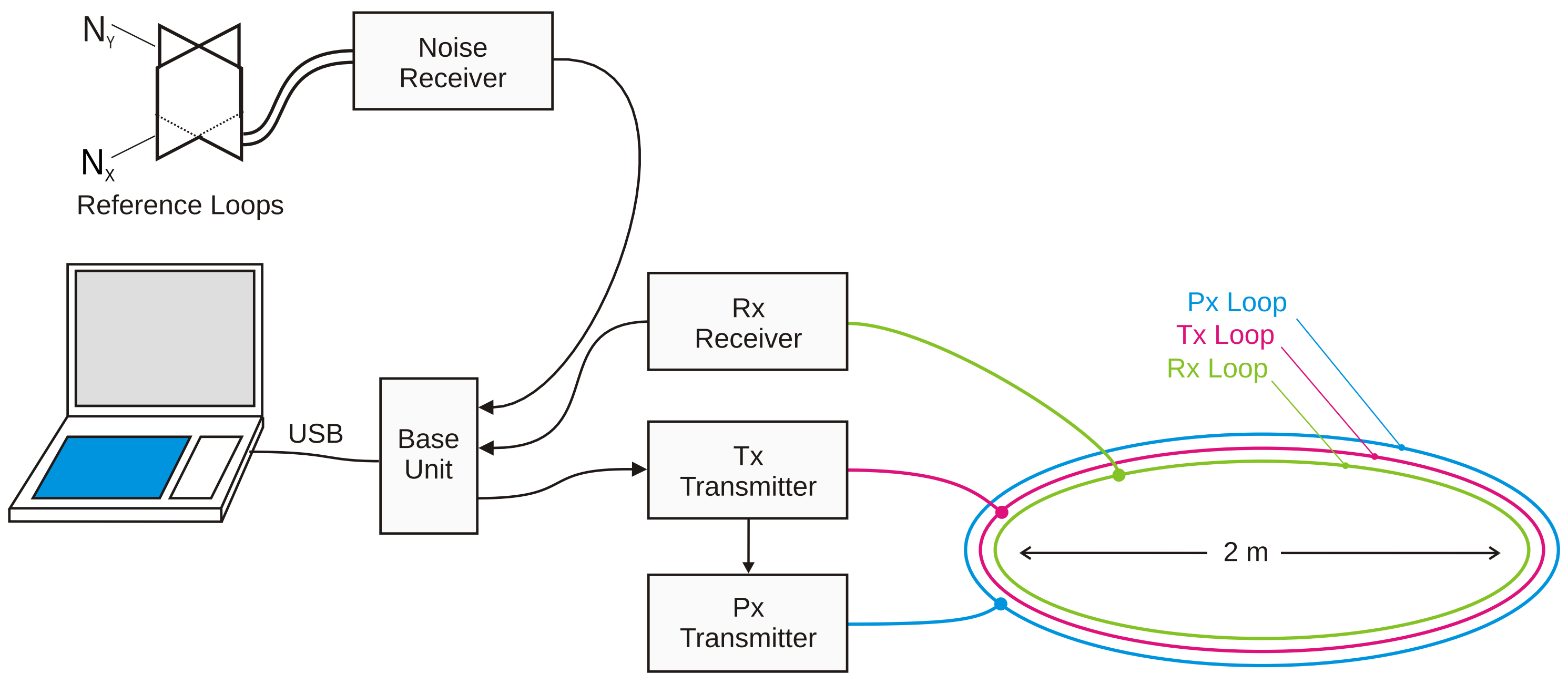
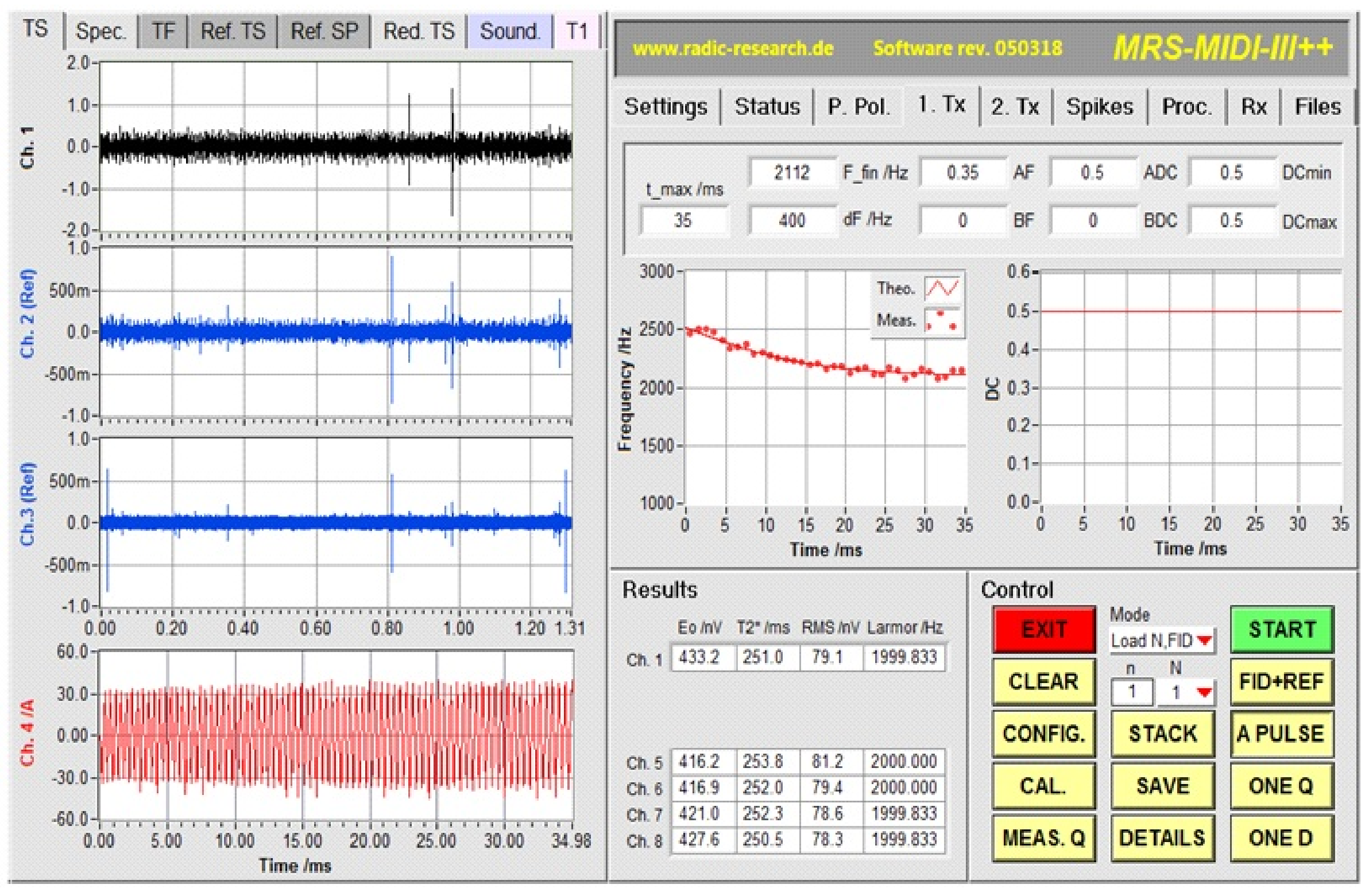


***Figure 2** Block diagram of the MRS-MIDI-III measuring system with pre-polarization and adiabatic pulses.*

The 3 other depictions of the times series show (from top to bottom) the FID measured with the Rx loop (black) and the two horizontal magnetic interference signals measured with the Reference Loops (blue). Below right is the user interface and to the left next to it the results of the numerical evaluation of the FIDs (here only chart one is relevant).



t_max /ms 35; 2112 F_fin /Hz; 400 dF /Hz; 0.35 AF; 0 BF; 0.5 ADC; 0 BDC; 0.5 DCmin; 0.5 DCmax

Mode: Load N,FID; n 1; N 1

Results

	Eo /nV	T2* /ms	RMS /nV	Larmor /Hz
Ch. 1	433.2	251.0	79.1	1999.833
Ch. 5	416.2	253.8	81.2	2000.000
Ch. 6	416.9	252.0	79.4	2000.000
Ch. 7	421.0	252.3	78.6	1999.833
Ch. 8	427.6	250.5	78.3	1999.833

***Figure 3** PC based user interface of the measuring device MRS-MIDI-III++.*

FIRST FIELD TEST

A first field test with adiabatic excitation was carried out at our test site in Linum (close to Berlin). A Tx and a Rx loop were used each with a 10 m x 10 m side length. The Tx loop had one turn, the Rx loop had 12 turns. The Reference Technique was used for improved noise suppression. In addition, the time series were stacked 8 times. The excitation pulse length was in each instance 35 ms. Figure 4 shows that the adiabatic excitation, as expected, caused a stronger NMR signal as a conventional excitation. The average amplitude of the FID (Free Induction Decay) is increased by 20%, the initial amplitude Eo by 52%. It is also striking that the relaxation time T2* of the adiabatic excited FIDs is significantly shorter (167 ms) than those of the conventionally excited FIDs (258 ms). Presumably the broadband adiabatic excitation causes shorter T2* times in the not fully homogenous Earth's magnetic field.

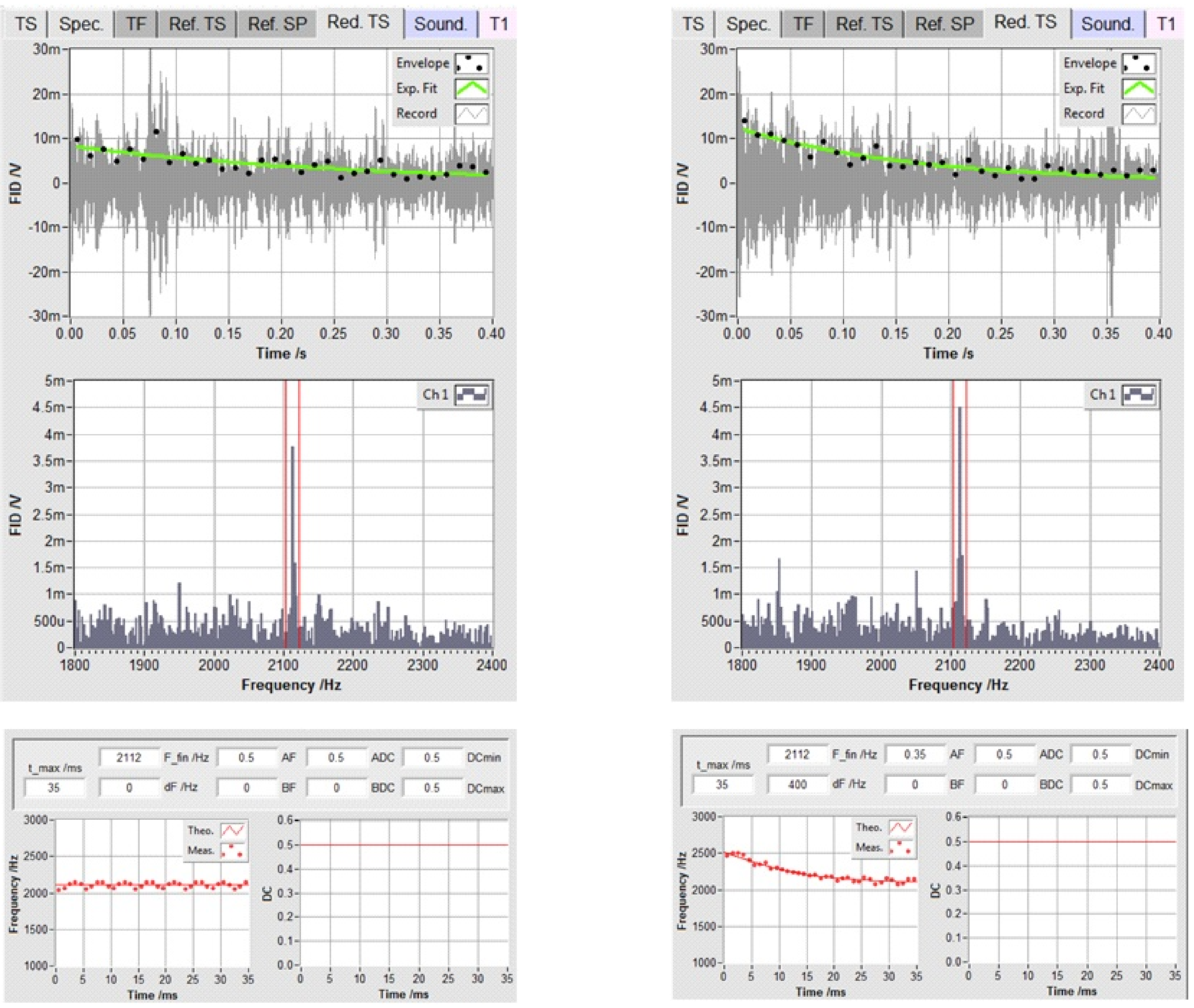


***Figure 4** Comparison of a measurement with a conventional excitation (left) and adiabatic excitation (right). Above: 8 times stacked time series of the FID (Free Induction Decay). Middle: spectral representation of the FIDs. Below: Parameter of each excitation pulse, as well as the given frequency and pulse strength (Duty Cycle).*

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