Response to Referees' Comment on "Apsu: a wireless multichannel receiver system for surface-NMR groundwater investigations" by Lichao Liu et al.

Lichao Liu et al.
lichao@geo.au.dk

To Referee Trevor Irons (gi-2018-1-RC2): Dear Referee, Thank you for reviewing our manuscript and raising issues that help to improve the manuscript. The authors response to all the comments in the following context and a marked-up manuscript is appended.

1 Response to General comments

1. **Comment 4:** Are the scientific methods and assumptions valid and clearly outlined? Yes, the system is described in a fair degree of detail. A better description or citation of differential coils should be included. I would also like to see a description of the power requirements of the receivers, and how long data collection can be performed on a single charge.

   Response and change in manuscript: Two references Nyboe and Sørensen [2012], Chen et al. [2015] addressed the differential Rx coil in airborne TEM are cited. Compared with the traditional coil, the differential coil has three output end: the positive, ground and negative.

   The power consumption of the receiver box is around 6.5 W (12 V, 0.54 A) due to the microprocessor is a low power-consumption FPGA chip. The power consumption will increase by approximately 5 W when the WiFi antenna is used. Also due to the efficiency of the power convert in the board, the 9 Ah lithium battery can support the whole system for 6 - 8 hours. Based on the field experiences, a single battery can be used for a day's measurement.

   Change in manuscript: The sentence *Differential Rx coil is beneficial to cancel the common-mode noise and it is able to reduce the Johnson noise of the coil by half [Nyboe and Sørensen, 2012, Chen et al., 2015]. The typical common mode noise is the induced noise in the leading cable and the wiring of the acquisition board by the coupling noise.* is added.

   A sentence describes the power consumption is added in the 3.1 WiFi network section: *The power consumption of a ApsuRx including the Wi-Fi antenna is around 12 W and 6 - 8 hours of data collection can be performed on a single charge of a 9 Ah battery. Batteries can be hot-swapped in the system without interrupting data collection.*

2. **Comment 5:** Are the results sufficient to support the interpretations and conclusions? The authors claim to have improved upon the SNR of the measurements. However, the field example does not demonstrate a reduced noise floor compared to other available instrumentation. If the authors should substantiate this statement, or remove it from the manuscript.

   Response: Agree, the main features of our wireless receiver are increased Rx loops deployability and reduced effort in field measurements. The collected data is normally dominated by the couping EM noise. The actual gain in SNR obtained with this new field strategy is heavily dependent on the site-specific noise conditions. But it is potential to improve SNR in some scenarios which will be demonstrated in detail later. Due to the practical reason, we cannot compare the developed receivers with the existing system directly.

3. **Comment 7:** Do the authors give proper credit to related work and clearly indicate their own new/original contribution? On page 2, line 10 a description of the first surface NMR instruments cites Legchenko and Valla, 2002 which describes the Iris NUMIS. However, the first surface NMR instrument was the Hydroscope:

   In this circumstance, it would be appropriate to cite the first instrument in addition to the NUMIS.

   Change in manuscript: The reference Semenov [1987] is added.

4. **Comment 8:** Does the title clearly reflect the contents of the paper? It does, however the acronym(?) 'Apsu 'is never defined. If it has some sort of meaning, please define it in the copy somewhere.

   Response: 'Apsu 'is just the name of our system not a acronym. You can also see this link https://en.wikipedia.org/wiki/Abzu.
   It was the name for fresh water from underground aquifers which was given a religious fertilising quality in Sumerian and Akkadian mythology.

5. **Comment 9:** Does the abstract provide a concise and complete summary? It does, however the discussion of SNR improvements either need to be substantiated or removed from the abstract as well.

   Response: Please refer to the second response.

6. **Comment 10:** Is the overall presentation well structured and clear? The paper is well structured, with the exception of §4.3 §4.4 and §5. The dead time discussion and (to some extent) field noise synthetics follows from the field examples. It would be more clear to introduce the field cites as e.g. 'Field Validations 'with subsections dedicated to dead time realizations and noise synthetics. As it stands Schillerslage is introduced twice and Silkeborg once. If the authors want to keep the Silkeborg examples in §4 that would be fine, but I would still recommend moving the dead time to §5 with a new §5.2 describing the data comparisons. If the phase is presented (discussed below), this could be a separate section as well.

   Change in manuscript: The dead time subsection in §4 is moved to the second subsection in §5.

7. **Comment 11:** Is the language fluent and precise? The manuscript is well written. On page 10 line 5 a trailing apostrophe (') is used where a leading apostrophe (‘) should be.

   Change in manuscript: The (') has been changed to (‘) on Page 12 Line 5.

8. **Comment 13:** Should any parts of the paper (text, formulae, figures, tables) be clarified, reduced, combined, or eliminated? See above discussion of §4 and §5.

   Change in manuscript: Please refer to the response to comment 10.

9. **Comment 14:** Are the number and quality of references appropriate? While the use of GPS timing is novel in surface NMR, it is common in the MT/CSEM community. For example the Zonge Zen system. A citation of this prior art would be appropriate and also affirm that GPS timing can reliably be used. Seismic nodal systems also use GPS timing and can be cited.

   Change in manuscript: A reference Sens-Schönfelder [2008] about GPS receiver in seismic is added.

2 Response to suggestions

1. **Comment 1:** The use of the word 'identical 'on P. 3 line 5 to describe the recorded NMR signals should be avoided. This description gives the impression that the two signals have no discernable measure between. 'Practically equivalent 'or some similar verbiage would be preferable.

   Change in manuscript: 'Practically equivalent 'replaces 'identical '.

2. **Comment 2:** The jet colourmap in figure 11 should be replaced with a perceptually uniform one. Additionally, the colormap clips at 0, but the quadrature detection should result in negative values as well. A diverging colormap centred around 0 is highly encouraged for the top two subfigures.

   Response: Due to the phase between two systems are not equal. Only the absolute amplitudes are shown in Fig. 11. Therefore, we can only find values larger than 0.

3. **Comment 3:** Complex inversion is an important consideration in surface NMR, especially with separated transmitters and receivers. Data phase comparisons (or real/imaginary plots) with the GMR are highly encouraged and will confirm that the developed instrumentation is at the bleeding edge of surface NMR instrumentation.

   Response: There exists an internal offset between the measured NMR signal by GMR and the true signal phase. To our knowledge the magnitude of the internal phase for the GMR is not known, or at a minimum is not commonly removed from data without using an inversion process. For this reason we base the comparison on amplitude data.

   Second, our receivers is not critically synchronous with the GMR system. Third, the sampling frequency in two systems are not the same. Hence, the measured phase by GMR and Apsu were not equal in that measurements because of differences in the internal phases that are present in the observed data.. But the measured phase by Apsu matches with the modeled phase from a well-know resistivity model by using our own new-built transmitter. A more rigorous accounting of internal phase corrections for the Apsu system is the subject of a parallel research paper. This non-trivial correction is heavily influenced by the transmitter (which is not discussed in this paper), therefore we prefer to base the validation on the amplitudes.

References

Chen Chen, Fei Liu, Jun Lin, and Yanzhang Wang. Investigation and optimization of the performance of an air-coil sensor with a differential structure suited to helicopter TEM exploration. *Sensors*, 15(9):23325–23340, 2015.

Nicklas Skovgaard Nyboe and Kurt Sørensen. Noise reduction in TEM: Presenting a bandwidth-and sensitivity-optimized parallel recording setup and methods for adaptive synchronous detection. *Geophysics*, 77(3):E203–E212, 2012.

A. G. Semenov. NMR hydroscope for water prospecting. In *Expanded Abstracts*, pages 66–67. Indian geophysical Union, 1987. Proceedings of the Seminar on Geotomography, Hyderabad.

Christoph Sens-Schönfelder. Synchronizing seismic networks with ambient noise. *Geophys. J. Int.*, 174(3):966–970, 2008.