<u>General comments</u>

1. Does the paper address relevant scientific questions within the scope of GI?

    Yes, the paper present a new wireless multichannel receiver system for surface-NMR which was developed to increase the flexibility and efficiency for 3d SNMR surveys and remote reference noise cancellation.

2. Does the paper present novel concepts, ideas, tools, or data?

    Yes the paper present a novel tool to record SNMR data. The novel instrumental concepts are a) differential Rx coils, b) dual acquisition of two gains, and c) wireless connection of Rx units. Especially the wireless connection of Rx units will improve the effective application of established survey and noise cancellation concepts and will trigger novel concepts

3. Are substantial conclusions reached?

    The substantial conclusions should be modified. The "improve" in SNR, which is a proposed goal of the system development (P1/L3; P16/L9), is not explicitly shown.

    -   The noise properties of the system are provided in detail but are not compared to available systems therefore it is not possible to judge if there is any improvement. Also the authors seem to compare several features of Apsu with a NUMIS system (tuned Rx coils, non-continuous RX record) while there are other Rx+Tx systems available which already have this features for more than 10 years (GMR (Vista Clara, Walsh 2008), MIDI (Radic Research, Radic 2006)). I suggest to change the statement "to develop an SNMR instrument with high SNR"
    -   The noise cancellation using reference loop is shown (synthetic) but is not new in SNMR (GMR (Vista Clara, Walsh 2008), MIDI (Radic Research, Radic 2006)).
    -   The benefit of Apsu to be able to place a remote reference loop close to a noise source is not shown or referenced (it is mentioned in the outlook: P14/L16ff). Additionally, I have some doubts if this will work as intended. From my understanding of RNC, putting the Ref far away (several 100 m or up to 1km (P9/L4)) from the Rx, will generally reduce the correlation of the noise measured in both loops, which is essential for RNC. Therefore I would generally suggest to place the Ref as close to the Rx coil as possible without recording (= cancelling) NMR signal, not far away. Please find a reference supporting your findings or do not exaggerating the benefit of far separated Rx and Ref loops for RNC without any proof that this increase SNR.
    -   The wireless connected ApsuRx makes using multiple Ref loops very simple. However, the benefit of using multiple Ref loops is neither presented nor referenced (e.g. Daalgard et al 2012?; Müller-Petke & Costabel 2014). One simple way to show the benefit with the presented data might be to provide subsequent RMS values after RNC(Ref1) and RNC(Ref2)
    -   The new feature of dual recording using two gain factors to reduce the chance of data clipping is well presented in the paper but the benefits are neither shown nor referenced.
    -   The concept and benefit of using differential Ref. coils for SNMR application is also neither shown nor referenced. Please at least provide a reference for its success in another EM method (TEM?)

4. Are the scientific methods and assumptions valid and clearly outlined?

    Yes

5. Are the results sufficient to support the interpretations and conclusions?

    Generally yes.

6. Is the description of experiments and calculations sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)?

Yes the descriptions are generally very detailed and the data is very well presented

7. Do the authors give proper credit to related work and clearly indicate their own new/original contribution?

P2/L24-26: I miss the reference to an existing and commercially available instrument (MIDI, Radic Research (e.g. Radic 2007)) that already features a separated Tx and Rx loop wire and therefore already do continuous Rx records with untuned coils

P4/L7: I miss a reference that several new SNMR instruments already use untuned Rx coils (GMR Walsh 2008, MIDI Radic 2006) for more than 10 years, therefore it is not a new Apsu feature. Additionally, the discussion about the properties of tuned Rx coils seem to be motivated by the comparison with a NUMIS system. Since this does not present the state-of-the-art it could easily be shortened.

8. Does the title clearly reflect the contents of the paper?

Yes

9. Does the abstract provide a concise and complete summary?

Yes

10. Is the overall presentation well structured and clear?

Yes

11. Is the language fluent and precise?

I am not a native speaker myself but the text appears mostly well written. However, there are sentences which seem to lack a proper conjunction e.g. repeatably starting with "The…" several times.

12. Are mathematical formulae, symbols, abbreviations, and units correctly defined and used?

Generally yes. Some minor remarks are provided in the "technical corrections"

13. Should any parts of the paper (text, formulae, figures, tables) be clarified, reduced, combined, or eliminated?

See "technical corrections". Some parts e.g. referring to tuned coils, might be reduced

14. Are the number and quality of references appropriate?

Generally yes

15. Is the amount and quality of supplementary material appropriate?

Yes

Scientific questions/issues

General: Details on the electronics are beyond my expertise!

P2/L14: as I have mentioned in the general section, I am missing the proof or a reference that shows that a Ref loop should be placed far away from the Rx and close to the noise source. Here would be a good place to provide such a reverence.

P4/L19: What are "differential coils" and what are their benefit? Reference them (at least their success in other EM methods) or describe them and show that they can consistently improve SNR for SNMR applications. It is an interesting but after my knowledge unproven concept for SNMR.

P11/16ff: Reference noise cancellation
The RNC scheme is not new (Radic 2006, Walsh 2008). The benefit of Apsu is that the Ref loop can be placed without a wire connection, i.e. quickly and far away from the Tx/Rx. The arising questions are:
   a) is the timing i.e. synchronisation jitter between the units, small enough to use RNC? -> seems perfectly fine
   b) Is there a benefit of using multiple Ref loops (since they are easy to lay out) recording different noise characteristics. Not presented, but could easily be shown by subsequent RNC using both ref datasets and providing the respective improvement in RMS
   c) Is there no harm for the RNC to increase the distance between Rx and Ref to 200m (or up to 1km)? Sadly this is not shown and would require additional experiments. Maybe the authors find a reference to proof this or they should significantly soften their statement that this improves SNR and discuss the drawbacks.

P12/L13-15: I am a little confused by the provided SNR of the envelops in dB (P12/L14)? How is SNR in dB calculated? SNR = $10*log10(100nV/RMS)$ for amplitudes? Therefore 0.4 dB = 100/91 [Sig/RMS] whereas 5.1 dB = 100/31 [Sig/RMS]?

	RMS with RNC	RMS w/o RNC
Filtered	147	
HNC	85	
RNC	62	-
18 times stacking (sqrt(18) ~ 4)	31	91

Something is clearly wrong here! (maybe I am) The noise increases w/o RNC after stacking? Please provide the SNR not only in dB but additionally the RMS value of the noise (or the data misfit) after stacking. Also the achieved reduction of the noise due to stacking is expected to be close to 4, not 2 (w RNC) or even <1 (w/o RNC).

Technical corrections
P1/L12: please make the numbers consistent. The effective dead time of the ApsuRx (including filtering) should be 3.6 ms (+0.4ms?). In the presented example, the distorted section of the NMR record (including Tx effects) is 5.8 ms (which you confusingly also call effective dead time).

P1/L20: check the author guidelines if you need to introduce the acronyms (Surface-NMR) again after the abstract. The same is true for SNR (P2/L9)

P1/L21: I do not think that Lehman-Horn et al 2012 is an appropriate reference for SNMR and aquifer properties. Please check if you find a better suited reference

P2/L14: What is a primary coil? Maybe introduce this phrase at P2/L11 as Tx+Rx which you later adapt to primary channel

Figure 1: "… multichannel surface-NMR receiver system Apsu." Since the system does not allow for Tx (yet). I suggest avoiding any misunderstandings and being consistent to the paper title.

P3/L3: "GPS time signal" instead of "clock"?

P3/L5: provide country for Vista Clara Inc.

P3/L5: What is a "primary channel"? Similar to the previous "primary coil" the definition is unclear

P3/L12: how are the channel "configured"? Please provide some additional information like e.g. "recording parameter etc."

P3/L13: "is connected to an array"

P4/L3-7: the described amplification of Rx using a tuned coil is not state-of-the-art. The description could be shortened and the currently favoured concept of using untuned Rx coils should be presented (Walsh 2008, Radic 2006)

P4/L22: "… into the critically or slightly over-damped state."

P4/L30: check the consistent use of excitation or transmit pulse.

P4/L32: I was a little confused by this sentence. Maybe us " … resistor...prevents any induced current in the Rx loop due to the Tx pulse which can disturbed the magnetic excitation field"

P4/L34: twisted and shielded cable

P5/L8 (Eq. 2) provide ω or introduce it earlier in the text

Figure 4: The acronym AP for access point is explained way after the first reference to Fig. 4. Just write it out

P8/L19: "The GPS module only needs the signal from a single satellite…"

P8/L24-25: the acronyms for synchronization time and time stamp were both already introduced in P8/L22. Just use either the acronyms or the words here.

P8/L30: Provide \lambda in Eq.7? time shift per passed time?

P9/L10, L11 and L17 Consider using "(Fig. X)" instead of "…, Fig. X".

P9/L13-14: What do you mean with this sentence? I am quite sure that I misunderstood this. Is each ApsuRx connected to a single and specific WiFi antenna respectively? If that is the case, you could only connect up to 8 ApsuRx? And you would need to place the Apsu Master in the centre of the layout since every antenna has a limited angle of view?

P9/L15-16: Please check the authors guideline but I think you should skip the blank between X and degree = X°

P9/L17: "provide power" might be misleading " forward"?

P10/L1: " to the AP in the WiFi tower…"

P10/L29: Spell out "Section 2.1"

Figure 6: "Scatter plot of one second of recording from two channels with shortened …"

> The following sentence about bin width and number does not provide any significant information and could be deleted.

> The red line is very thin and barely visible.

P11/L8 (Eq 9) provide ω or introduce it earlier in the text

P11/L17: "We tested the applicability of a reference noise cancellation (RNC) scheme with wireless …"

Figure 7: The red squares are very small and barely visible. Please increase the size of the data points and maybe reduce the number of data points if they are redundant (or provide their STD instead)

Figure 8: The most important line has low variations and is dashed and therefore can hardly be seen. Please consider to flip the line style and show the w/o RNC as a dashed line

> The caption is eye-catchingly short compared to other figure captions and lack information. E.g. add that these are envelopes of an NMR signal to show the performance of RNC etc.

P12/L3: The loop layout of the RNC experiment is not clearly described. Only the distance of the ApsuRx to Rx is provided (200m) and the distance between both Ref (100m). The lacking information is the distance Rx to Ref for both Ref loops. A small sketch might help if the layout is too complex to describe.

P12/L8ff: Can you please provide a reference for this typical SNMR processing scheme

P13/L3 "… which leads to a filter…"

P13/L4 the arising question is how much filter settling time is added (which is answered a few sentences later). But maybe add a comment like or "e.g. 3.6 ms for a 500 Hz butterworth filter" and lead over to the next passage by "an example is provided in the following"

P13/L5 "… using data collected…test site <u>near</u> Hannover" The field example is not yet presented in the paper

P13/L7ff (also Fig 9) please consider to shift the (arbitrary chosen) time axis to t=0 at the end of the pulse which makes the (overall very nice) figure and times easier to read. Many times you provide to need to be subtracted by 91.2ms to be of relevance.

P13/L9: "… quadrature detection…" both is true but stick to one term during the paper

P13/L14: See also abstract. You are not consistent when you talk about the effective deadtime. In the abstract you refer to 4ms (3.6ms + 0.42ms? P13/L3+10) which is only the Rx filtering and here you include the artefact due to excitation current decay (5.8ms). Personally, I think that ApsuRx has an effective dead time of ~4ms but dependent on the used Tx you should clip the data to 6ms to avoid pulse artifacts. Once Apsu includes a Tx you should provide the maybe longer effective deadtime for the whole SNMR system.

Please consider to avoid calling it "effective deadtime" here and change the sentence to "5.8 ms including excitation current decay…"

P14/L3: "…well-established surface-NMR Rx system… "

P14/L6: The Apsu receiver system might be misleading as you presented ApsuRx. Maybe introduce the System consisting of one Apsu Master and two ApsuRx first. E.g. "The used Apsu receiver system consists of one Apsu Master and two ApsuRx, One channel of an ApsuRx was …."

Figure 11: "after being scaled to the GMR signal by the area-turn factor of the coils (1200/800)"

P15/L7: "The signal recorded by the <u>two Rx instruments (GMR, Apsu)</u> were processed…"

P16/8: " …receiver system where <u>multiple</u> Apsu Rx units <u>each</u> connecting … connected to <u>an</u> ApsuMaster"

P16/9: see previous comments on improving SNR. You do not compare the SNR properties of your system to another system. While Apsu might be a significant upgrade to your NUMIS, the in detail presented features to improve SNR (RNC, short dead time) are state-of-the-art (GMR, MIDI Radic). The impact of the new features (Wireless connection (outlook), dual gain recording, differential coils+ Rx) to improve SNR are not shown. Please simply rephrase it to "… the aim of the receiver system is <u>a high</u> SNR and …"

P16/11+16ff: see previous comments on widely separated Rx and Ref loops. Please add a comment that modify this statement. While a long distance between Rx and Ref loops is technically possible with Apus, I have strong doubts that RNC will perform well or even improve SNR