Magn. Reson. Discuss.,
https://doi.org/10.5194/mr-2020-8-AC1, 2020

MAGNETIC RESONANCE
Open Access
Discussions

MRD

Interactive comment

Interactive comment on "ArduiTaM: accurate and inexpensive NMR auto tune and match system" *by* Mazin Jouda et al.

Mazin Jouda et al.

jan.korvink@kit.edu

Received and published: 14 May 2020

Authors: First of all, we would like to thank the reviewer for giving the time and effort to reviewing our manuscript.

Reviewer: General remarks: This contribution offers a way of automated tuning and matching in NMR and MRI using an open-source hardware and software solution with a single board microcontroller. This maybe a good approach for from scratch new system design and refurbishing of older systems. With current commercial NMR probes we are not sure such a system can help to work around some of the commonly encountered problem, that is mechanical hysteresis and slip of the controller rods connecting the stepper motors to the capacitors. A software that "learns" this non ideal behav-

Printer-friendly version

Discussion paper

ior of probes (which is also subject to aging) and can manipulate the actuators more efficiently than a human would be nice. In a production environment (i.e. with high throughput).

Authors: This is a very interesting idea, although the ideal solution would be to make the mechanical system (trimmers, rods, etc.) robust against aging and hysteresis, if not permanently then at least for some long enough time after which the mechanical system can be renewed. Nevertheless, the idea of involving "learning" algorithms is very motivating and can definitely provide solutions to circumvent the mechanical hysteresis problem, and can probably make T&M faster. Just like the difference between a new NMR user and an experienced user.

Reviewer: The method for tuning and matching is not fundamentally “new” as it relies on the well known rf-responses exploited by current commercial hardware. The speed of the process is apparently better, but it is not clear, if the same goal couldn’t be achieved by an adaptive software implementation with existing hardware. Where the proposed solution may be highly beneficial are probes going beyond the current mechanical trimmer capacitor based system using varactors or digital capacitors, as the authors emphasize. NB: I have been looking at the paper mostly from a spectroscopy perspective. Some of my arguments may not apply in an imaging context.

Reviewer: Specific questions and comments: In the “homing routine” for driving the capacitors to their lowest values: How is the stop detected? Steppers do not usually sense that they are stuck and absolute positioning may not maintained when restarting the Arduino. Is there absolute angle sensing on the steppers? Is there a provision against excessive torque being applied?

Authors: The current implementation requires the user to do one-time single-point calibration of the tuning and matching capacitors when attaching ArduiTaM for the first time. This can be easily done by manually rotating the trimmers to their lower value which is recognized by ArduiTaM as the zero position, and by setting the allowed number of turns before the upper value is reached. As long as it is not turned off, ArduiTaM can keep track of stepper motors' positions and ensure that neither limit is exceeded. A simple modification of the code, such that current positions the trimmers are written in the EEPROM of the Arduino, would allow ArduiTaM to keep track of the stepper motors' positions even after being completely powered off. If this one-time single-point calibration step is to be avoided, then a couple of limit switches for the tuning and matching trimmers would be required.

Reviewer: About the steppers: 20 steps per turn sounds like a low number. Could a gearbox be added achieve lower angles. But that could increase the mechanical instability. The first scan of the two capacitors appears to be quite coarse. Depending on the type of probe (high resolution liquids vs. static solids, for example you may to miss the actual minimum (multiply tuned probes may have several minima).

Authors: We are extremely sorry for this typo. In fact the stepper motors we used are SM-42BYG011-25 and have a 1.8 degree/step resolution, thus requiring 200 steps per turn. With this high resolution, it is very unlikely to miss the actual minimum, and that is probably why we never encountered this problem during the experiments. Nevertheless, this is a very valid point and suggests that one has to be very careful when selecting a stepper motor or defining the sweep resolution. Indeed, having a higher stepping resolution and a finer sweep would likely guarantee finding the minimum, but that is unfortunately at the expense of prolonged T&M time.

Reviewer: How does the algorithm handle the sudden "jumps" when changing the capacitances (as experienced in manual tuning T&M, likely caused by release of torsional stress in long connection rods? This is a big problem, also for commercial systems and is (in my opinion) the reason for suboptimal T&M in existing systems.

Authors: In fact we did not encounter this problem during the experiments. This is probably because the mechanical setup was newly built and we used new high quality trimmers and stiff glass fiber rods. Another potential reason is the relatively low operating frequency (45 MHz) where slight capacitance changes are less pronounced. From our experience, we know that trimmer capacitors become loose after going through many tuning cycles. This is most likely the reason behind these jumps. In such a case, the ideal remedy would be to replace the trimmers with fresh ones. Alternatively, one can think of a software solution by always comparing three or four consecutive S11 points and check for dramatic jumps so that incorrect points can be reacquired.

Reviewer: Could the hardware/software combo be extended to other tuning/matching modalities, like frequency pushing effects or spin noise? [J Mag Res 193 (2008) 153; J Biomol NMR 45 (2009) 241; ChemPhysChem 15 (2014) 3639] Considering the fact that the impedance of the pre-amplifier and the transmission line from the rf-coil to the pre-amp play a major role in high efficiency tuning, the scope of the approach, which apparently requires switching between the envelope detector and the proper detection preamplifier may be applicable to, for example, cryogenically cooled probes.

Authors: The short answer is yes! The long answer is as follows; ideally, both the output impedance of the power amplifier and the input impedance of the preamplifier should be exactly equal to the characteristic impedance of the coaxial cables (usually 50 Ohm). If this is the case, then matching the coil in the excitation phase by minimizing its reflected power necessarily means that the coil will also be matched to the preamplifier in the reception phase. Practically, these impedances as well as the characteristic impedance of the coaxial cable might slightly differ from 50 Ohm resulting in slight discrepancy between the matching conditions in the excitation and reception phases. Usually this discrepancy is small and thus negligible. However, it might become significant in certain circumstances as for example high frequency systems and high Q probes. In such cases, one solution to tackle this problem is to measure this discrepancy on the spectrometer where ArduiTaM is to be installed and to feed this measurement as an offset frequency to the ArduiTaM such that when the minimum reflection is achieved in the excitation phase at the offset frequency the matching condition is fulfilled in the reception phase at the Larmor frequency. This should work robustly as long as the Larmor frequency does not drift considerably.

Conclusion: The paper offers new ideas to approach the practical problems of automatic tuning, but some additional discussion addressing the issues mentioned above would increase its impact. It is probably more of a technology demonstration than purely scientific innovation. In my opinion, the paper will be of largest benefit for researchers designing new probes in the field of imaging and solid state NMR. It may also be a starting point for designing future high resolution / high sensitivity NMR probe systems.

Interactive comment on Magn. Reson. Discuss., https://doi.org/10.5194/mr-2020-8, 2020.