Review Report on PhD Thesis

Faculty: **Central European Institute of Technology**
Brno University of Technology in Brno

Academic year: **2021/2022**

Student: **Ing. Antonín Sojka**

Doctoral study program: **Advanced Materials and Nanosciences**

Field of study: **Advanced nanotechnology and microtechnology**

Supervisor: **doc. Ing. Petr Neugebauer, Ph.D.**

Reviewer: **Prof Graham Smith (School of Physics and Astronomy, University of St Andrews)**

PhD thesis title: **Development of a Novel Terahertz Magnetic Resonance Spectroscopy for Spin Dynamics Investigations**

Topicality of doctoral thesis:

This thesis is essentially about the design of a novel wideband high field EPR instrument with a focus on coherent rapid frequency scan techniques using a fast Arbitrary Waveform Generator (AWG) or synthesisers. In contrast, commercial low field rapid-scan systems are normally implemented using field modulation. Making EPR (or NMR) measurements in high magnetic fields has a well known set of spectroscopic and sensitivity advantages. However, it is much more technologically challenging to implement EPR measurements at very high fields, as resonant frequencies are now in the sub-mm-wave regime. This requires a mixture of advanced optical, and wideband microwave and rf techniques, and is a major scientific undertaking.

The main part of the thesis is 107 pages, but detailed Appendices and References take it to beyond 150 pages. It consists of 6 main chapters. The first chapter is a broad introduction that reviews previous work. The second chapter introduces EPR, and third chaper introduces specific high frequency techniques used in the development of the instrument. The fourth chapter describes the high-field EPR set-up and general construction. The fifth chapter then describes the design of a large number of clever sample-holders, which are central to the performance of any wideband EPR spectrometer. The last chapter describes initial rapid scan results from the full system at very high frequencies.

Meeting the goals set:

The major goal was to design, build and test a novel high frequency spectrometer that incorporated a large number of elements and specific novel implementations associated with specific sub-systems. This has resulted in four peer-reviewed papers and a major review chapter, and IMO it is highly likely that there will be many more publications as a direct result of this work. (And typically the original instrument builder/designer does not really get enough credit for this). I think the design aspect has been very successful and to get an instrument of this type, from scratch to first measurements is an impressive achievement that will have given Antonin a broad and in-demand skill-set. The thesis clearly shows that Antonin is a talented design engineer.

Problem solving and dissertation results:

It is probably fair to say that the first full experimental results (obtained at the very end of the PhD) do not yet reflect the full potential of the instrument (in terms of sensitivity) – but still show significant capability (relative to peer instruments). My suspicion is that the loss in sensitivity is partly related to the detection module and the specific way that coherent detection is implemented. However, I believe this module is from an external supplier and was outwith the control of the student. Antonin has made a number of sensible suggestions for issues that should be investigated further.

However, the thesis shows plenty of evidence of careful characterisation of sub-systems and practical solving of problems that arose during the project, including those related to standing waves, sample handling, crogenics, vacuum transfer systém, alignment and overall system design.

Importance for practice or development of the discipline:

This instrument is at the cutting edge of modern EPR instrumentation. I think it is clear that very wideband techniques (using an AWG), rapid scan, and high field EPR will all be major enabling research themes in the future, and this will be a very productive characterisation tool. There are other systems with some design similarities (Stuttgart, Kobe), - with Stuttgart being the closest, however there are many design elements here that are both novel and sophisticated.

Formal adjustment of the thesis and language level:

(4) The study is duly completed by a state doctoral examination and the defense of a dissertation, which proves the ability and readiness for independent activity in research or development or for independent theoretical and creative artistic activity. The dissertation must include original and published results or results accepted for publication.)

Some of the English is not completely perfect, or even a little clumsy in places, and could be improved, but the meaning is always clear. I have sent suggestions to the student. However, overall the thesis is presented to a high standard. There are 4 significant peer-reviewed publications and a major review chapter.

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Questions and comments:

I understand that there is time for 3 or 4 questions at the viva from each examiner and the following are suggested in that vein. I have sent a more detailed list of suggestions/comments to the student directly.

1) A question – which I ask at every scientific viva - is "Can you tell me where most of the actual time was spent during the project, and which bit of work in the thesis are you most proud of?" (on the basis that what is written in a thesis is often not reflective of the actual work required).

2) The thesis has rapid frequency scan (at high frequencies) at its heart . I think it is clear that sensitivity gains for rapid scan are to be expected relative to cw in cases where the spins saturate easily. I'm not certain that the advantages are so clear when comparing to pulse techniques (in conjunction with field scan) or when relaxation times are short. Can you comment in more detail on this, very briefly acknowledging existing theory, and possibly pointing to any potential differences in the field/frequency regime that you work in. Your answer could also refer to the associated measurement of T2 relaxation times.

3) I believe the first full experimental tests were only possible at the end of the PhD work – and possibly don't yet match theoretical expectations of sensitivity. What are your main suspicions for what is not currently working (apart from the suggestions in the thesis regarding interference), and What would you have done next if you had another year of your PhD to work on the project.

4) Can you comment on the main design principles behind the sample holders, in terms of microwave design e.g.mode matching, single-mode operation, and induction mode.

5) In the quasi-optics you have a separate optical path for the LO, designed to equalise path lengths. Wouldn't it have been simpler to implement this extra path length at an IF or lower frequency, possibly in conjunction with a sub-harmonic mixer? Why don't you have problems with mixer saturation for the co-polar path?

Conclusion:

Designing, building and testing a very high field EPR spectrometer from scratch, with novel excitation and detection schemes is a major scientific task that requires Microwaves, Optics, Electrical Engineering, Mechanical Engineering, and Cryogenic and Design Engineering, and a substantial number of associated experimental skills. I am well aware of the amount of work that must have gone into the design, integration and testing of each sub-system and individual component. I found the design work on the sample holders to be particularly novel and interesting, and the whole spectrometer is an impressive piece of engineering. The applicant is lead or co-author on a major review chapter, and several peer reviewed articles associated with this work, and 11 conference presentations/posters. I am also confident that many future PhD students/researchers will be beneficiaries of the developed instrument. The work has an international profile and on that basis….

In my opinion, the reviewed thesis **fulfills** all requirements posed on theses aimed for obtaining a PhD degree. This thesis **is ready** to be defended orally, in front of the respective committee.

St Andrews, Scotland, (05/04/2022)

Professor Graham Smith