

The paper by Schatz et al addresses a very important and interesting topic related to MR/MRI studies of electrochemical cells. On the surface the necessity of a strong static field, B_0 , switched magnetic fields G_x , G_y and G_z , in addition to a radio frequency excitation field B_1 , would seem to be problematic in a device that must contain significant conductive and often metallic structures namely electrodes and current collectors for the electrochemical device and ancillary electrical connections. Nevertheless, remarkable progress has been made with MR/MRI studies of electrochemical cells.

Schatz and coworkers have done a good job of assembling and describing the issues. MR/MRI practitioners are very enthusiastic about in operando studies but traditional battery researchers and industry are often resistant, since the batteries employed for in operando MR/MRI studies usually don't look like realistic and familiar batteries.

Resolution of this issue in the context of EM compatibility (B_0 , $G_{x,y,z}$ and B_1) is very important for wider acceptance of MR/MRI battery in operando studies.

The authors have done a good job of assembling and assessing the pertinent literature with I fear one significant exception. On page 3 the authors assign to Zhang and Zwanziger (2011) the idea of a parallel plate resonator (PPR) for RF excitation in fuel cells. The Zhang and Zwanziger paper is however about the design of an MR compatible electrochemical cell in a 5 mm NMR tube. It is not about a parallel plate resonator, nor a fuel cell. I think the authors may have been intending to reference another work with the same last name of the first author, also in 2011, Zhang and Balcom "Magnetic Resonance Imaging", in 'PEM Fuel Cell Diagnostic Tools', Eds. Wang, H., Yuan, X. and Li, H., Taylor and Francis, Oxford, UK (2011) 229-254.

This paper summarized work by Zhang related to use of the PPR in nafion based fuel cells. The work summarized came from two JMR papers in 2008, one from J Power source 2011 and Can J Chem 2011. The later paper explicitly describes and analyzes the PPR.

The PPR resonator was designed to satisfy the EM compatibility issues outlined in the Schatz paper. I will address this further below but first I will mention that the fuel cell studies of 2008 to 2011 were more recently rejuvenated for studies of lithium ion batteries. There have been a number of published studies, but I will highlight two in particular, (i) Aguilera JMR 2021 (cover photo for the issue). This paper employed extensive use of simulation to design the PPR and critically introduced a cartridge like removable cell. The cell has electrodes that are parallel to the plates of the PPR with all of the attendant EM compatibility benefits. The cartridge is removable permitting multiplexing of samples and the 7Li battery cartridge looks like a battery to traditional battery people. (ii) Goward and co workers have continued to use the PPR resonator and battery cartridge idea in a series of

studies, notably Sanders et al Carbon (2022) wherein they showed both imaging and spectroscopic studies of a lithium ion battery. The PPR / battery cartridge was proven to be a sensitive implementation in the Sanders paper because of the significant sample volume, which is implicit in the resonator design.

But now why does the PPR / cartridge idea work and how does it help EM compatibility? It is easy to explain in words. These reasons are interwoven in the papers mentioned, but the simplest summary is probably the Zhang 2011 chapter. RF shielding must be avoided so that means B1 parallel to the electrodes and other conductive structures as Schatz and coworkers describe. If the electrochemical cell is a capacitor-like design (as in the 7Li cartridge and nafion fuel cell studies) with parallel conductive surfaces (electrodes), there are two possible orientations for B_0 (parallel and perpendicular to the plates). The B_0 direction will be z of course. It is advantageous for the B_0 field, in terms of minimizing susceptibility distortion of the static field experienced by the sample, for the B_0 field to be oriented parallel to the conducting surfaces. Okay there are two ways to be parallel to the plates but one of them must be the direction of the B1 field. It must be perpendicular to B_0 and parallel to the plates. Let's identify this B1 direction as x. The B_0 field, z, once again is parallel to the conductive surfaces of the battery and RF probe. In this geometry then the electrolyte will span the space between the electrodes which will be y.

There is a more subtle but very important consideration for why this geometry is advantageous. It is well known but not always fully appreciated that the G_x , G_y and G_z gradients *all* have z directed fields that vary in the chosen direction (G_x is dB_0/dx with B_0 z directed). Eddy currents will be at their worst when a z directed field impinges, perpendicular, to a conductive surface and gradients are switched. The emf driving eddy currents results from the time rate of change of flux *through the conducting surface*. The worst case for eddy currents will be a z directed field impinging on a planar conductor that is transverse. The PPR / cartridge combination with the conductors parallel to B_0 have minimal conducting cross section in the B_0 direction meaning that the emf induced is minimized, minimizing eddy currents. This is true regardless of the direction in which one wishes to do imaging. The above reasoning does not require detailed simulation, it is simple EM considerations, but it is backed up by simulation.

Schatz and coworkers employ electrodes that are perpendicular to the B_0 field with gradients that are z directed. This is required given the initial geometry of their cell, magnet and gradient coil. That does not mean they can't achieve good results, they do achieve good results. It does however mean the underlying geometry is non-ideal from an EM compatibility point of view.

The above line of reasoning would be advantageous to include or at least to reference in the paper. It is easy for people to get lost in results and simulation.

On a significant but less serious note, the authors at various times state that SPI, SPRITE, constant time, and chemical shift imaging profile approaches to imaging are advantageous. The implementation that is not explicitly stated, that is similar, is spin echo SPI. The first three methods are FID based. The later two are based on spin echoes. They are similar because spatial encoding is purely by phase encode gradients. This is advantageous because if there are susceptibility induced B_0 distortions, pure phase encoding will not lead to geometric distortion. The distorted B_0 field instead results in a local image contrast (T_2^* or T_2) which may be removed or controlled through choice of imaging parameters. The pure phase encode approach is also robust to image distortion due to eddy currents. With frequency encode imaging eddy currents distort the image geometry. An inhomogeneous static field will also lead to image distortion in frequency encode imaging. These two effects can make it difficult to discriminate B_1 inhomogeneity effects, from B_0 inhomogeneity effects, from eddy current effects with frequency encode imaging. Eddy currents manifest in pure phase encode image as a change in the image field of view, but not geometric distortion of the object geometry.

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