Ultra high field MRI systems present a number of unique challenges to the system designer and integrator beyond simply scaling up the performance of a lower field system. The primary areas of concern are the magnet, gradient coils and drivers, and RF coils and coil interface. The art of system integration lies in identifying sufficiently clear performance targets for each of the subsystems and ensuring that those targets are met in a way that preserves the overall performance of the system. The following discussion identifies for each of these areas the key performance requirements that are changed at higher field strengths, methods to address those requirements, and how those methods affect the rest of the system. As this is an area of ongoing research and development, many of the specific solutions presented here are likely to be superseded in the future, but the general approach to the problem should remain valid. While a complete description of every aspect of system design and integration of UHFMRI systems is beyond the scope of this chapter, the following is intended to provide practical guidance in addressing the more common problems in siting or operating a UHFMRI system.

1. INTRODUCTION

The focus of this chapter is on system integration, which may be defined as the art of aligning the performance capabilities of available system components with the performance expectations of the users, altering and extending those capabilities as needed. A difficulty arises in that these alterations have both intended and unintended consequences, and users’ expectations frequently place potential modifications in conflict.

An example of such a conflict is the bore diameter. To minimize the discomfort of experimental subjects it is highly desirable to increase the available bore diameter as much as possible. However, increasing the bore diameter weakens the...
gradients as the fifth power of the radius (for a shielded gradient coil), creating a conflict with the need for stronger gradients at higher field strengths to overcome the increased chemical shift dispersion and patient-induced static field distortions due to differences in diamagnetic susceptibility between tissue and air. Addressing this conflict remains an area of active research [1].

One can list the characteristics of each of the subsystems that a system integrator must address, keeping in mind that these parameters are far from sufficient to specify a design for each of these components.

2. MOTIVATION FOR UHFMRI

Since the 1980s, one clear trend in the development of magnetic resonance imaging systems for human research applications has been the drive to higher and higher field strengths, from the first 1.5T and 2T systems in the early 1980s, to the first 4T systems [2–4] in the late 1980s, and the 8T [5], 7T, and 9.4T systems of the 1990s and the current decade. While the drive for higher field strength mirrors that of analytical NMR, focused on increasing chemical shift range and enhanced signal from nuclei with low gyromagnetic ratios, much of the focus to date in UHFMRI for humans has been on increasing sensitivity for proton imaging applications, allowing anatomical imaging with higher spatial resolution, and using the higher sensitivity to examine dynamic and functional aspects (including blood oxygenation level-dependent contrast (BOLD) and other measures of brain activity). Significant advances will certainly be made in spectroscopy applications (1H as well as low gamma nuclei), including the use of hyperpolarized materials, but the main focus over the last few years has been imaging applications.

In designing a 7T system, then, one must envision a clinical MR system with a greatly expanded performance envelope, and herein lies the greatest practical difficulty — while clinical MR systems are certainly large in number, developing a new system requires significant levels of effort, particularly to provide for the support infrastructure needed to bring the product to the market successfully. The limited number of sites able to make use of such a system, combined with the high material costs for the components and the technical complexity of the development, make the commercial aspects of these systems extremely difficult to manage, and will continue to be key practical limitations to their adoption for clinical use for many years to come.

The primary motivation for UHFMRI, then, is increasing sensitivity and using that higher sensitivity for improved spatial or temporal resolution. Sensitivity is typically quantified in terms of the signal-to-noise ratio. There is an extensive literature devoted to comparison of signal-to-noise ratios across field strengths [6–8], which may be summarized as follows:

- For a given volume of thermally polarized material, the maximum signal increases quadratically with field strength, one factor arising from the Curie susceptibility and one factor from Lenz’s law of in-