

frequency domain is linearly dependent on the measurement time the maximum possible measurement time should be used. Unfortunately the exponential attenuation of the FID signal broadens the frequency spectrum thereby determining the ultimate resolution of the magnetic resonance image.

A much more difficult problem is the data collection time. In the procedure described above each measurement is made assuming all the magnetic moments are at rest. Since the spin-lattice relaxation time is on the order of a second this implies that only a single FID can be measured per second. Since a three-dimensional image requires at least a million data points this is a severe restriction.

In practice, pulse sequences have been designed that allow more than one FID to be measured during the  $T_1$  relaxation time. This can be done using a combination of gradients and selective gradients to only excite a single plane within the object and also using selective spin-echo pulses to measure more than one projection (or Fourier transform) within a single plane.

#### 4.5 Bibliographic Notes

Because of the absence of any refraction or diffraction, with x-rays the problem of tomographic imaging reduces to reconstructing an image from its line integrals. A mathematical solution to the problem of reconstructing a function from its projections was given by Radon [Rad17] in 1917. More recently, some of the first investigators to examine this problem either theoretically or experimentally (and often independently) include (in a roughly chronological order): Bracewell [Bra56], Oldendorf [Old61], Cormack [Cor63], [Cor64], Kuhl and Edwards [Kuh63], DeRosier and Klug [DeR68], Tretiak *et al.* [Tre69], Rowley [Row69], Berry and Gibbs [Ber70], Ramachandran and Lakshminarayanan [Ram71], Bender *et al.* [Ben70], and Bates and Peters [Bat71]. A detailed survey of the work done in computed tomographic imaging till 1979 appears in [Kak79].

Detailed information about a number of the applications described in this book is also covered in books by Macovski [Mac83] and Herman [Her80]. For information about alternate approaches to single photon emission tomography the reader is referred to [Kno83]. A more detailed presentation of ultrasound tomography can be found in [Cra82], [Car78b]. Additional information about the physical basis of nuclear magnetic resonance can be found in a number of chemistry and physics texts including [Sha76], [Far71], [Man82], [Pyk82]. The algorithms used to reconstruct images using NMR information are described in [Cho82], [Hin83], [Man82], [Pyk82].

The reader is also referred to [Kak79], [Kak81] for a survey of medical tomographic imaging. For applications in radio astronomy, where the aim is to reconstruct the "brightness" distribution of a celestial source of radio waves from its strip integral measurements taken with special antenna beams, the reader is referred to [Bra56], [Bra67]. For electron microscopy applications, where one attempts to reconstruct the molecular structure of

complex biomolecules from transmission micrograms, the reader should look to [Cro70], [Gor71]. The applications of this technique in optical interferometry, where the aim is to determine the refractive index field of an optically transparent medium, are discussed in [Ber70], [Row69], [Swe73]. The applications of tomography in earth resources imaging are presented in [Din79a], [Lyt80]. For information about a large number of industrial applications the reader is referred to [OSA85].

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