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# This Week's Citation Classic

**Ernst R R & Anderson W A.** Application of Fourier transform spectroscopy to magnetic resonance. *Rev. Sci. Instr.* 37:93-102, 1966.
[Analytical Instrument Division, Varian Associates, Palo Alto, CA]

**Fourier transform nuclear magnetic resonance (NMR) has become the accepted technique for recording NMR spectra in liquids and in solids. Both its superior sensitivity and its versatility have been essential for the remarkable success of NMR in numerous fields from physics to medicine. [The *SCI*® indicates that this paper has been cited in over 330 publications since 1966.]**

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"The very low sensitivity of nuclear magnetic resonance (NMR) in comparison to other spectroscopies has worried researchers since its discovery. During the early years, the main emphasis had been put on perfecting instruments. In the early-1960s, several groups also started to consider improvements of measurement techniques. Signal averaging had been proposed to improve sensitivity, although at the expense of performance time, and the optimum passage conditions were carefully analyzed in the hope of some additional gain.

"When I joined Varian Associates in fall 1963, my supervisor, Weston Anderson, was already experimenting with a multiple channel spectrometer concept. Parallel acquisition of numerous data points instead of sequential scanning was the basic idea which should have led to the long desired breakthrough. It turned out that such a multiple channel spectrometer would be enormously expensive although it worked well in principle.

"In 1964, we tried to find a more practical realization of this concept. At first an efficient source for the numerous excitation frequencies was required. A repetitive sequence of delta pulses was a rather obvious choice. The second problem, the separation of the responses of the various spectral elements, was also quite easy to solve. Knowing some basic facts from linear response theory, it was obvious that the response to the delta pulses is just the Fourier transform of the desired spectrum. This completed the concept of Fourier transform NMR spectroscopy.

"Of course many researchers before knew this very basic relationship; however, we seem to have been the first to realize the inherent remarkable gain in sensitivity which is given by the square root of the number of spectral elements. It was a timely discovery. Laboratory computers just became available and online data processing feasible. Nevertheless, it took several years before the first Fourier transform NMR spectrometer became commercially available.

"In 1964, we certainly did not foresee that this simple concept could revolutionize NMR. Initially, we did not have an online computer available. The free induction decays were acquired in a time averaging computer and punched on paper tape. The paper tape had to be carried from Palo Alto to IBM in San Jose to transfer the data to a bunch of cards. With the cards we went to the Palo Alto Computer Service Center where the Fourier transformation and the plotting were done. The entire process took about 48 hours in comparison with a normal spectrum being run in just ten minutes! Nevertheless, we claimed in our paper a substantial time saving—and the readers believed it!

"Nowadays, except for the very inexpensive routine instruments, all NMR spectrometers utilize pulse excitation. Most of the advanced modern techniques of NMR require pulse stimulation and Fourier transformation,[1] including relaxation time measurements, polarization transfer, two-dimensional spectroscopy, and multiple quantum spectroscopy; even human beings are nowadays subjected to pulses in the context of NMR imaging.

"Looking back, it is not too astonishing that our paper got many citations. The message is simple and attractive. To the user it saves time and money and for the instrument companies it allowed them to increase returns by the development of new instruments."

1. **Shaw D.** *Fourier transform N.M.R. spectroscopy*. New York: Elsevier, 1976. 357 p.