

Chapter 5: Signals and Noise

- Signal to Noise Ratio
- Types of Noise
- Signal to Noise Ratio Enhancement
 - Signal Averaging
 - Filtering

Signal-Noise Ratio

- The **signal** is what you are measuring that is the result of the **presence** of your analyte
- Noise is **extraneous** information that can interfere with or alter the signal.
- It can not be completely eliminated, but hopefully reduced!
 - Noise is considered random!
 - **indeterminate**

SIGNAL VS. NOISE

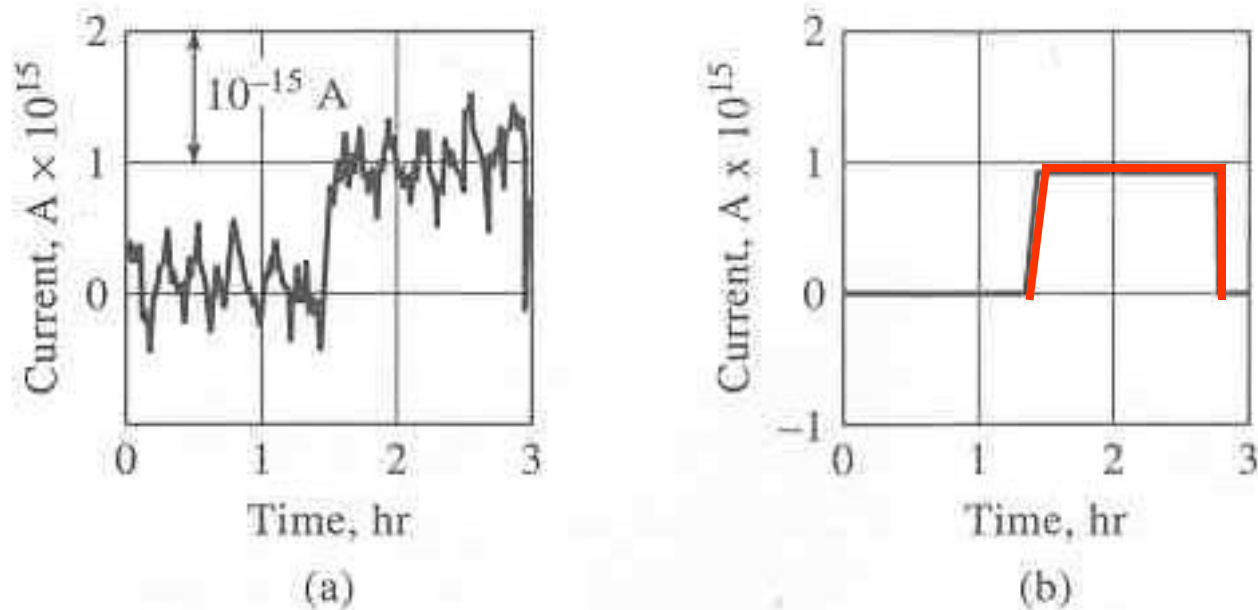


Figure 5-1 Effect of noise on a current measurement: (a) experimental strip-chart recording of a 0.9×10^{-15} A direct current, (b) mean of the fluctuations. (Adapted from T. Coor, *J. Chem. Educ.*, 1968, 45, A594. With permission.)

- Since noise can not be eliminated (it is random), we are more interested in the S/N ratio than the intensity of the noise

$$\frac{\text{Signal}}{\text{Noise}} = \frac{\text{mean}}{\text{standard deviation}} = \frac{\bar{X}}{s}$$

- This is mathematically the inverse of the RSD, or we can say that.....

$$\frac{S}{N} = \frac{1}{\text{RSD}}$$

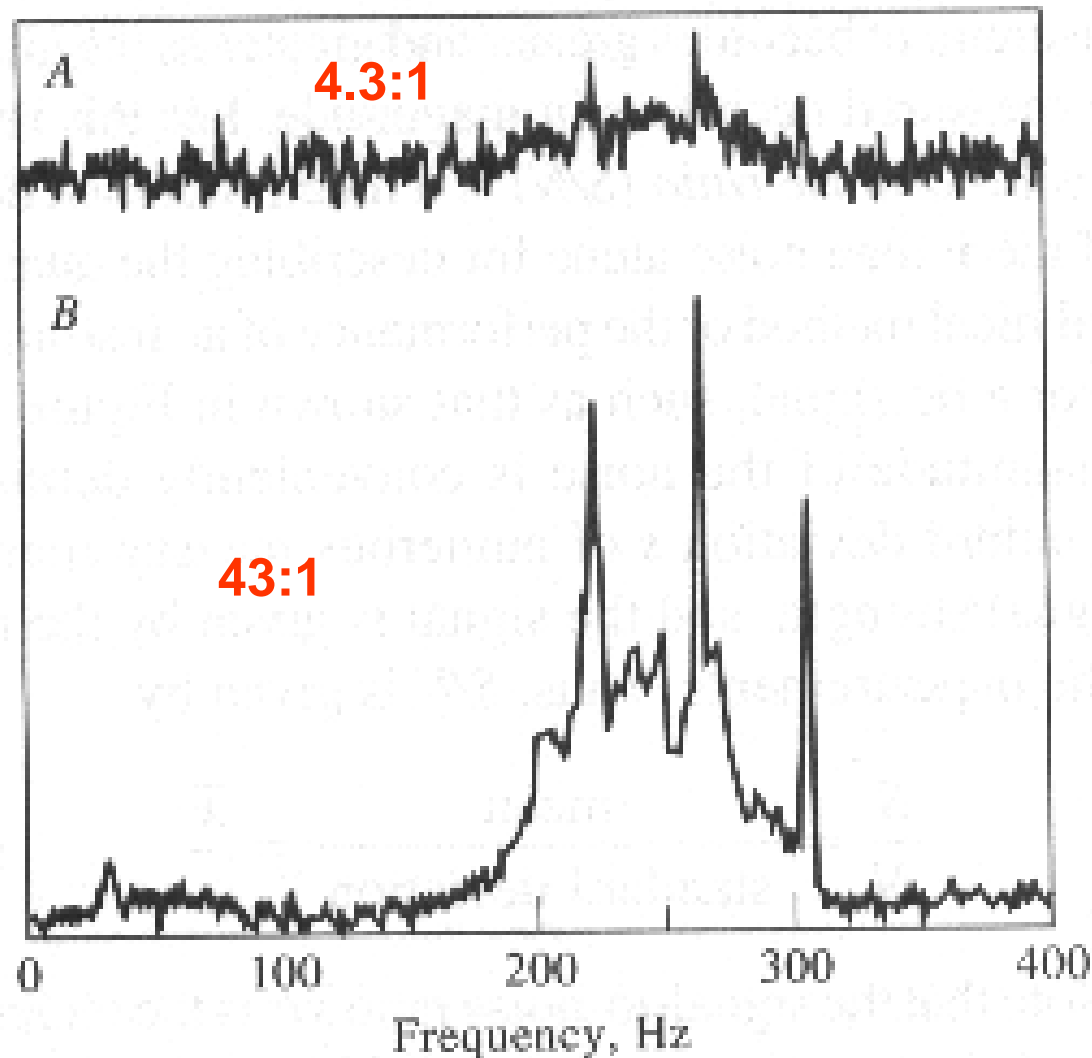


Figure 5-2 Effect of signal-to-noise ratio on the NMR spectrum of progesterone: *A*, $S/N = 4.3$; *B*, $S/N = 43$.
(Adapted from R. R. Ernst and W. A. Anderson, *Rev. Sci. Inst.*, 1966, 37, 101. With permission.)

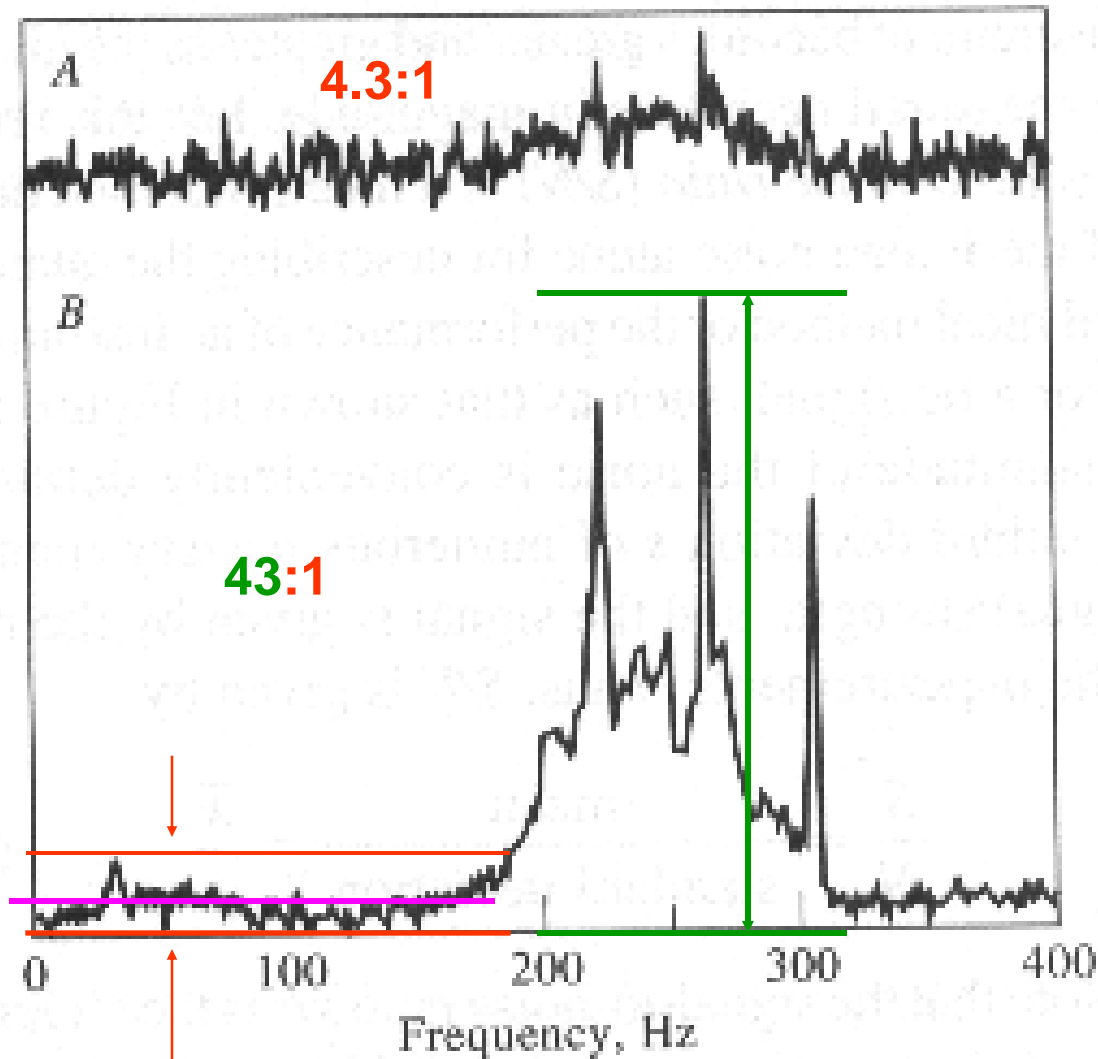


Figure 5-2 Effect of signal-to-noise ratio on the NMR spectrum of progesterone: A, $S/N = 4.3$; B, $S/N = 43$.
(Adapted from R. R. Ernst and W. A. Anderson, *Rev. Sci. Inst.*, 1966, 37, 101. With permission.)

S/N Objective?

- Reduce as much of the noise as possible by carefully controlling conditions
 - Temperature, power supply variations, etc. etc. etc.
- Increase the signal to noise ratio
 - **THIS IS THE NAME OF THE GAME!**
 - More signal vs. noise means a lower STDEV!
 - More precise measurement
 - Lower STDEV means a lower **LOD**
 - Lower limits of detection
- A S/N ratio of 3 is usually the minimum that is acceptable.

Types of Noise.....

- **Chemical Noise**

- Undesired chemical reactions
- Reaction/technique/instrument specific

- **Instrumental Noise**

- Affects all types of instruments!
- Can often be controlled physically (e.g. temp) or electronically (software averaging)

Instrumental Noise

- Thermal (Johnson) Noise:
 - Thermal agitation of electrons affects their “smooth” flow.
 - Due to different velocities and movement of electrons in electrical components.
 - Dependent upon both temperature and the range of frequencies (frequency bandwidths) being utilized.
 - Can be reduced by reducing temperature of electrical components.
 - **Eliminated at absolute zero.**
 - Considered “white noise” occurs at all frequencies.
 - V_{rms} ! On the back of your audio component!

■ Shot Noise:

- Occurs when electrons or charged particles cross junctions (different materials, vacuums, etc.)
- Considered “white noise” occurs at all frequencies.
- Due to the statistical variation of the flow of electrons (current) across some junction
 - Some of the electrons jump across the junction right away
 - Some of the electrons take their time jumping across the junction

■ Flicker Noise

- Frequency dependent
- Significant at frequencies less than 100 Hz
- Magnitude is inversely proportional to frequency
- Results in long-term drift in electronic components
- Can be reduced by using resistors that are metallic, wire wound

- **Environmental Noise: Room should be cold??**

- **Unlimited possible sources**

- **Can often be eliminated by eliminating the source**

- Other noise sources can not be eliminated!!!!!!

- **Methods of eliminating it...**

- Moving the instrument somewhere else

- Isolating /conditioning the instruments power source

- Controlling temperature in the room

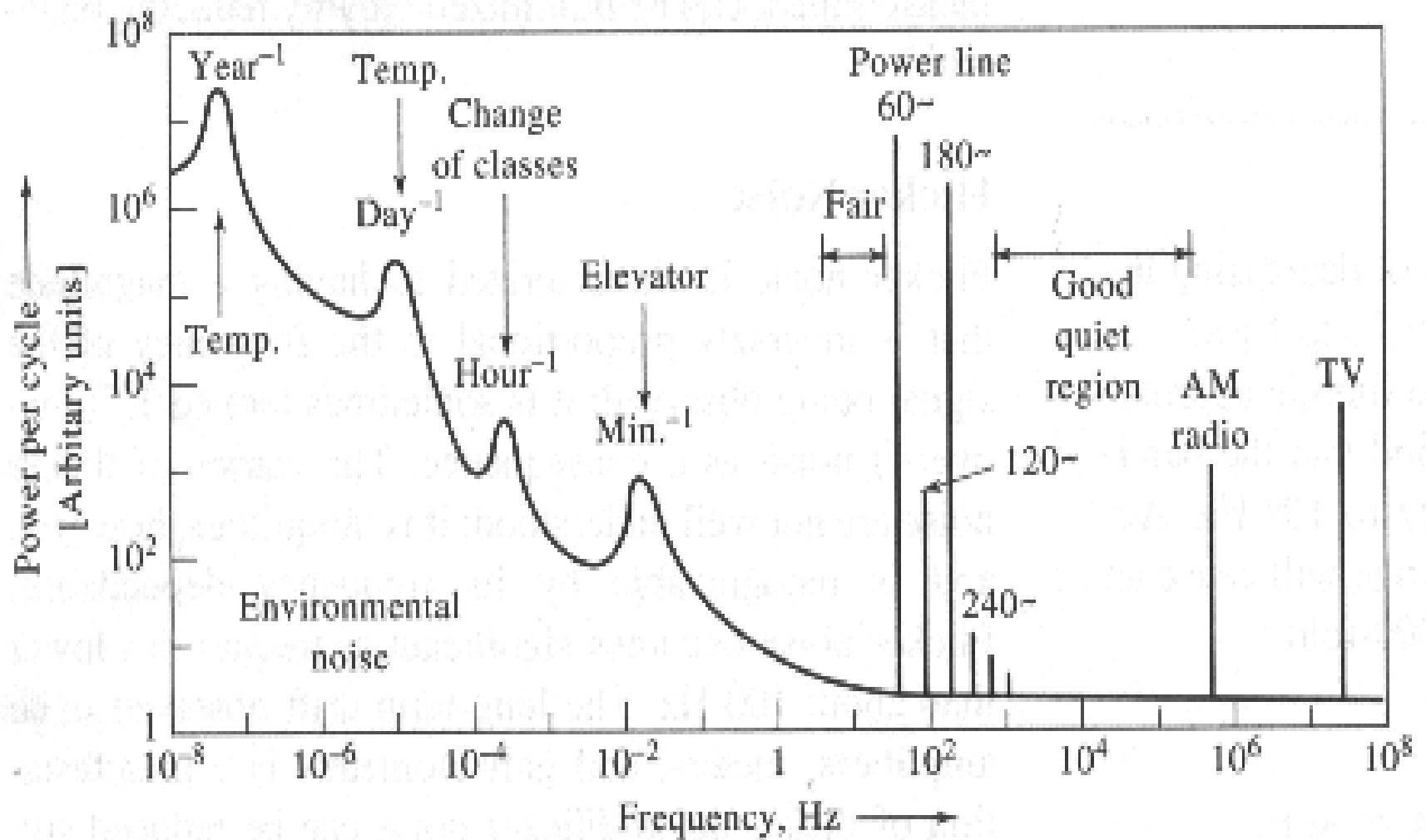
- Control expansion/contraction of components in instrument

- Eliminating interferences

- Stray light from open windows, panels on instrument

- Turning off radios, TV's, other instruments

NOISE SPECTRUM



Signal Averaging

(one way of controlling noise)

- Ensemble Averaging
 - Collect multiple signals over the same time or wavelength (for example) domain
 - EASILY DONE WITH COMPUTERS!
- Calculate the mean signal at each point in the domain
- **Re-plot the averaged signal**
- Since noise is random (some +/ some -), this helps reduce the overall noise by cancellation!

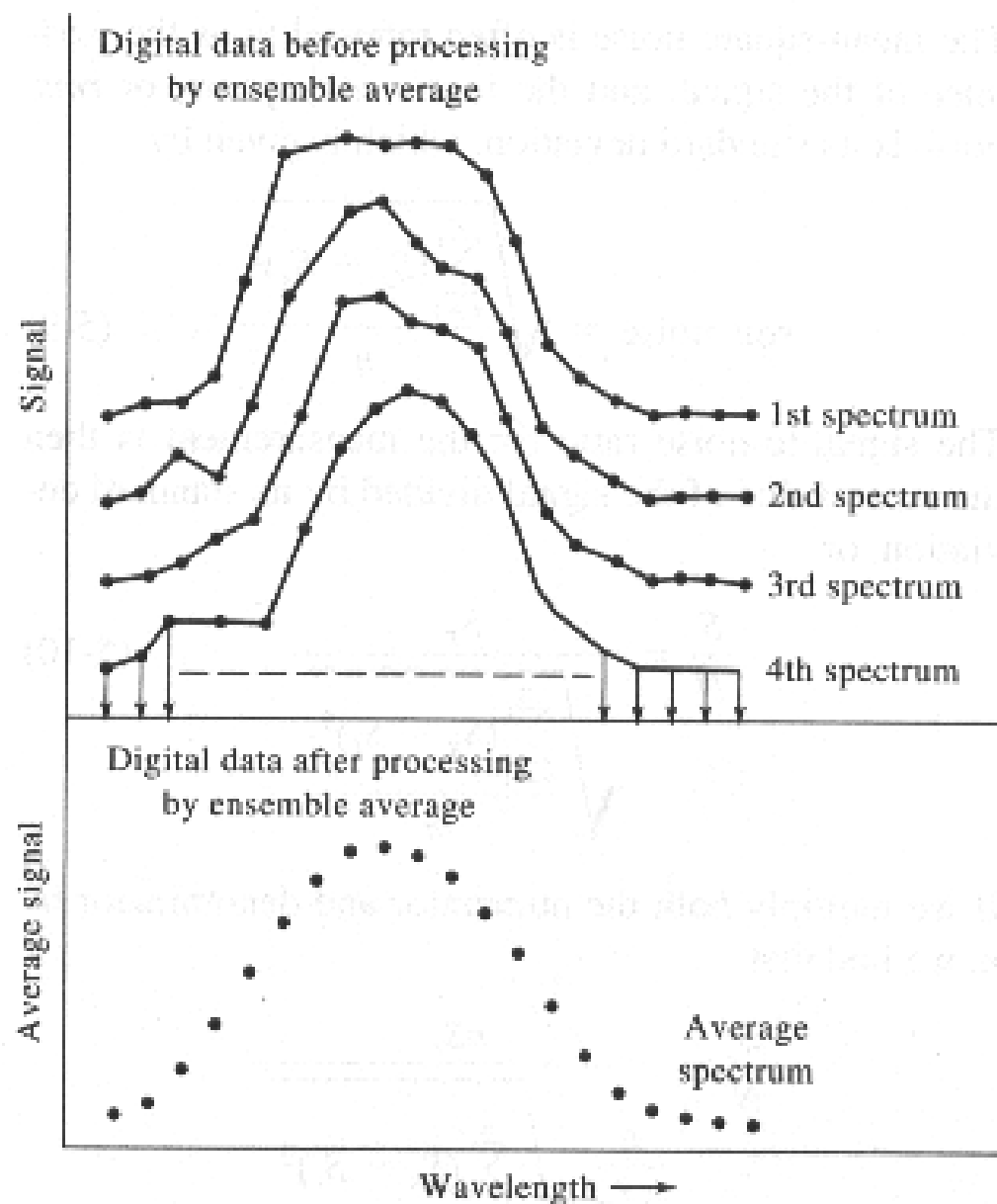
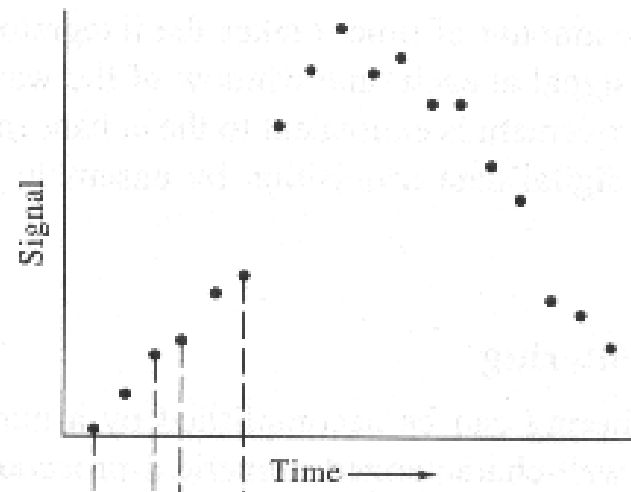


Figure 5-9 Ensemble averaging of a spectrum. (From D. Binkley and R. Dessy, *J. Chem. Educ.*, 1979, 6, 150. With permission.)

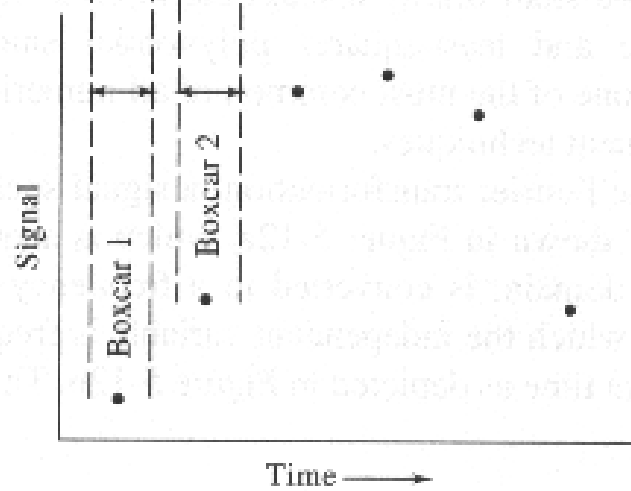
■ Boxcar Averaging

- Take an average of 2 or more signals in some domain
- Plot these points as the average signal in the same domain
- Can be done with just one set of data
- You lose some detail in the overall signal

5C Signal-To-Noise Enhancement



(a)



(b)

S/N is good \rightarrow KEEP ADDING!

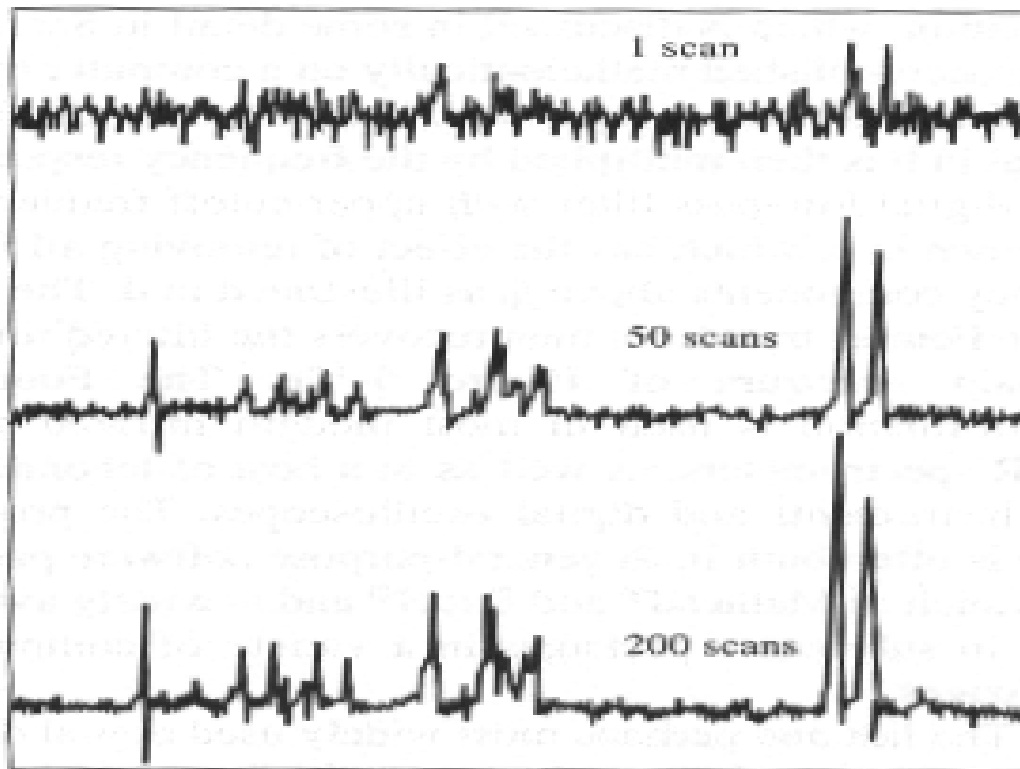


Figure 5-10 Effect of signal averaging. Note that the vertical scale is smaller as the number of scans increases. The signal-to-noise ratio is proportional to \sqrt{n} . Random fluctuations in the noise tend to cancel as the number of scans increases, but the signal accumulates; thus, S/N increases.