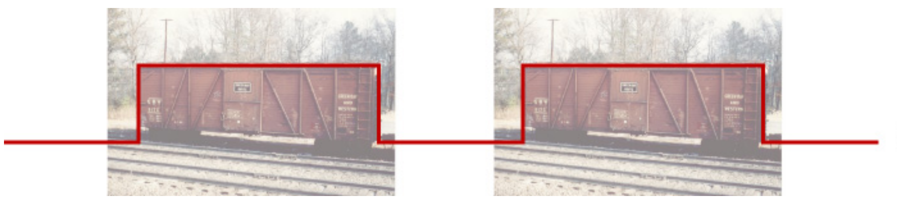
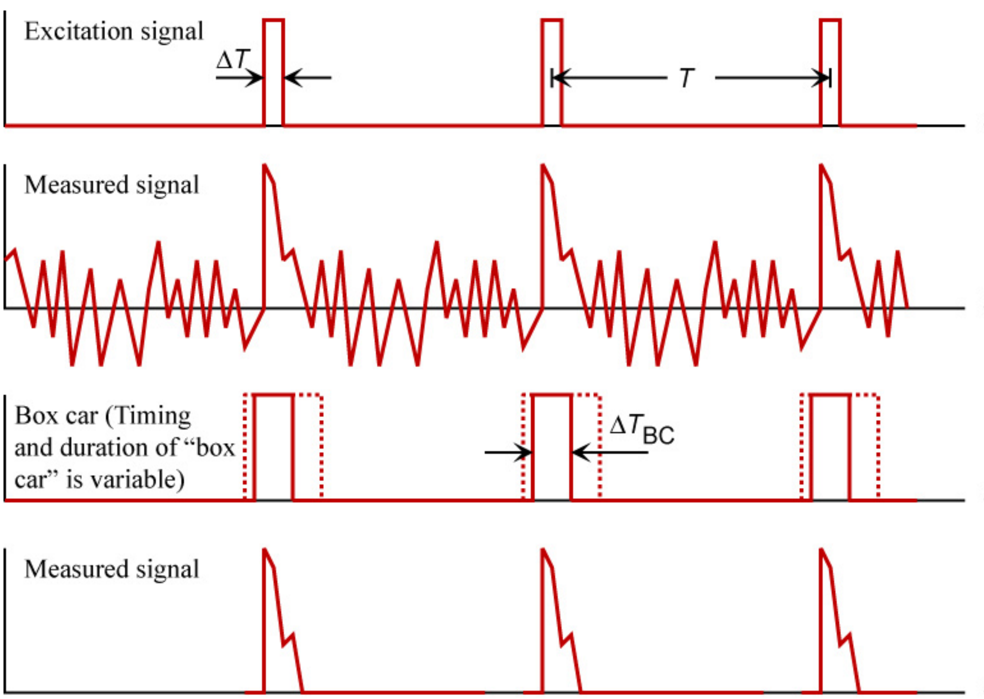
Box-car integrator

- The box-car integrator is used for the detection of noisy pulsed signals.
- Box-car integrator enables *gated detection*.
- What is a box car?

- Why a box-car integrator is called that way?



- Typical signals:



- Excitation signal is pulsed.
- Measured signal is noisy. However, during the times of excitation, the signal/noise ratio improves.
- Box car integrator integrates over a number of pulsed excitation events.

- The box-car integrator improves the signal/noise ratio by

  (i) ***Gating the detection***. What is the improvement in signal/noise ratio attainable by gating? (Answer: Improvement is given by the factor $T / \Delta T_{BC}$)

  (ii) ***Averaging over multiple pulses***. An improvement in the signal/noise ratio is attained by averaging over N pulses. What is the magnitude of the improvement? (Answer: Improvement is given by $(N)^{1/2}$)

- How does the duration of the gated detection influence the signal/noise ratio?
- Is there an optimum duration of the gated detection?
- What is indicated by *exponential integration* on the front panel of the box-car integrator?
- What is indicated by *linear integration* on the front panel of the box-car integrator?
- Under what experimental conditions is lock-in amplification preferable?
- Under what experimental conditions is box-car integration preferable?

Appendix: Magnitude of improvement in signal/noise ratio by averaging.

Assume that a signal has the magnitude V_{signal} and noise has a magnitude V_{noise} (assume that V_{noise} is the standard deviation of the noise signal). Because the noise signals measured at two different times are uncorrelated, the resulting noise signal is given by the root of the sum of the squares of the standard deviations of the stochastic signals, i.e. $V_{\text{noise}}{}^2 = (V_{\text{noise},1})^2 + (V_{\text{noise},2})^2$ (in statistics this quantity is known as the cross-correlation of two independent events). Thus the averaged signal after N measurements is given by

$$V = \frac{1}{N} \sum_{\text{pulse } i=1}^{N} V_{\text{signal},i} + \frac{1}{N} \sqrt{\sum_{\text{pulse } i=1}^{N} V_{\text{noise}}^2} = V_{\text{signal}} + \frac{1}{\sqrt{N}} \sqrt{\overline{V_{\text{noise}}^2}} \ .$$

Thus the signal/noise ratio after N measurements is given by

$$\frac{V_{\text{signal}}}{V_{\text{noise}}} = \frac{V_{\text{signal}}}{\frac{1}{\sqrt{N}} \sqrt{\overline{V_{\text{noise}}^2}}} \propto \sqrt{N} \ .$$