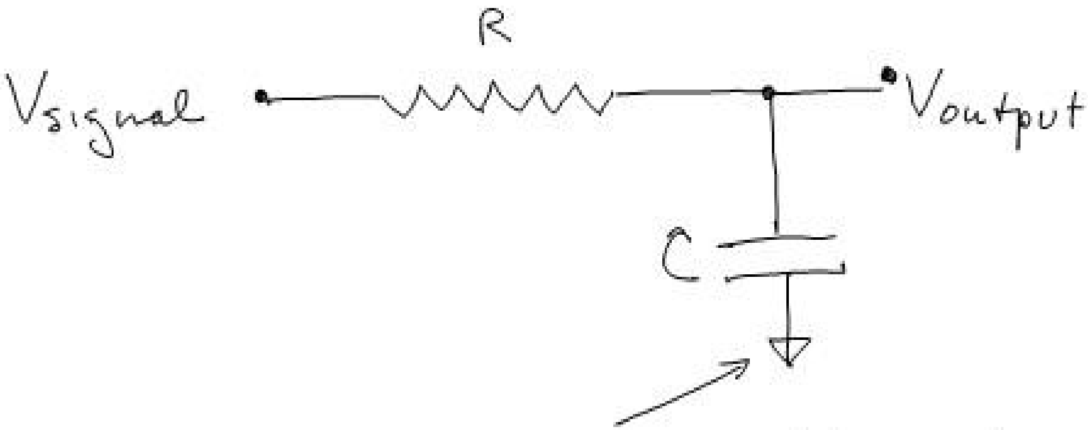
assignment (15)

(15) Show that a resistor and capacitor connected as shown constitute a simple low-pass filter, i.e., high frequency components of the signal are attenuated, whereas low frequency components appear at the output.

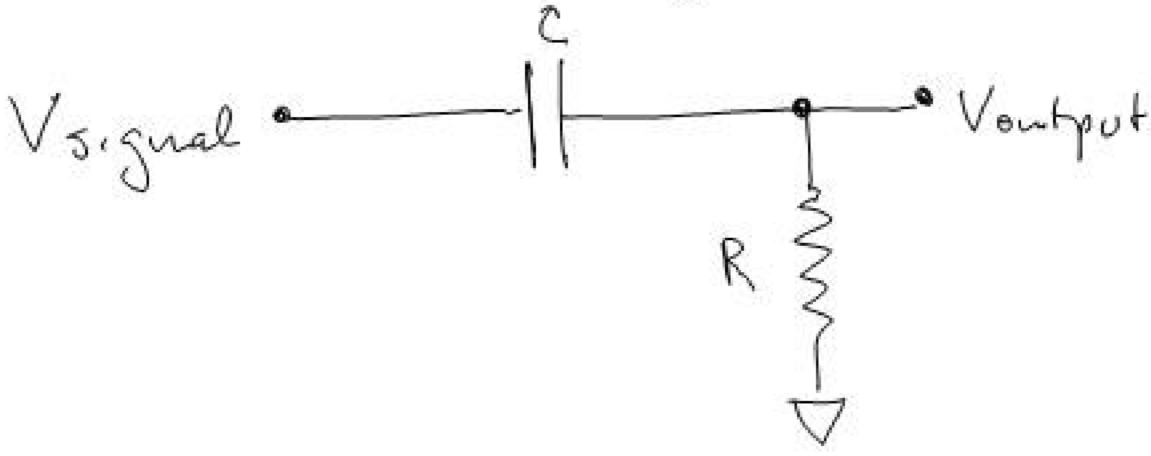


This symbol means "ground"; it is "common" to input & output voltages.

Plot a graph of $\frac{|V_{output}|}{|V_{signal}|}$ as a function of frequency, and decide at what frequency $|V_{output}| = |V_{signal}|/2$

assignment (16)

(16) Similarly, show that this resistor and capacitor constitute a high-pass filter, etc.



next topic ...

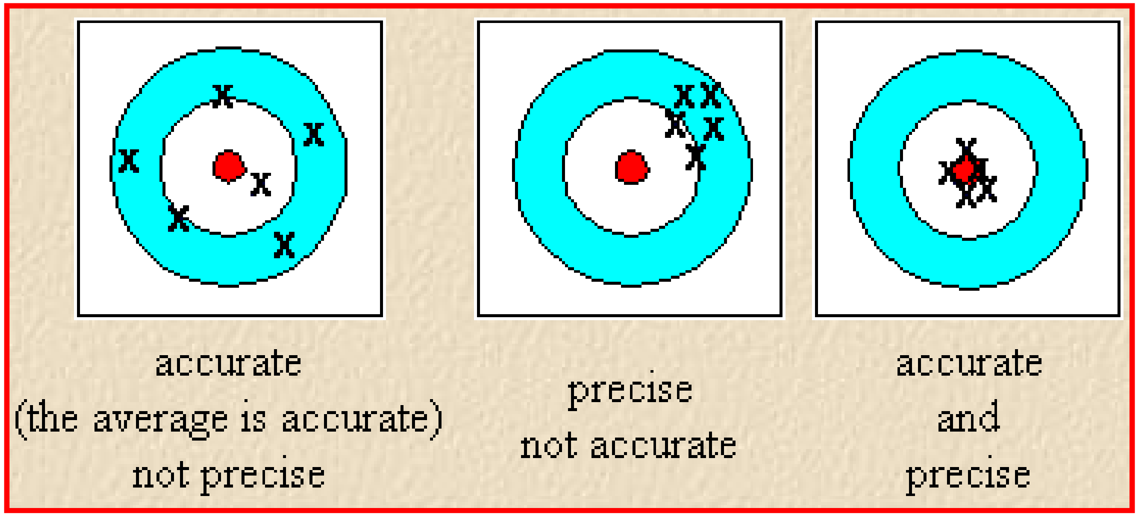
- errors and uncertainties in measurement
- combining errors/uncertainties
  - to find the net error/uncertainty in a quantity calculated from several component measurements, assuming you know the individual error/uncertainty in each component (*error propagation*)
  - to find the net error/uncertainty you can realize if you make and combine several measurements of the same quantity, perhaps using different sensors, instruments, or sensing principles (*sensor fusion*)

key points to take away ...

- accuracy & precision of single measurements
- combining errors/uncertainties
  - a result calculated from multiple different uncertain measurements *must* have a *relative* uncertainty worse than the worst component's *relative* uncertainty
  - a result calculated from multiple uncertain measurements of the same measurand, e.g., by making the measurement several times with different instruments, *must* have an *absolute* uncertainty better than the best individual measurement's *absolute* uncertainty

accuracy & precision

- accuracy: how close is your measurement to the correct value? (whatever “correct” means ...)
- precision: what is the spread of your measurements around the value you found?



error & uncertainty

- the difference between error & uncertainty is ... well ... that's actually a little uncertain ...
- generally "uncertainty" is used more-or-less interchangeably with the resolution of the measuring instrument ...
- and error is used more-or-less interchangeably with the inaccuracy of the result
  - errors you can characterize by the statistical distribution of the measurements you actually make
  - errors you can only estimate, i.e., guess
  - fundamental arguments among mathematicians etc about whether the same arithmetic applies to both

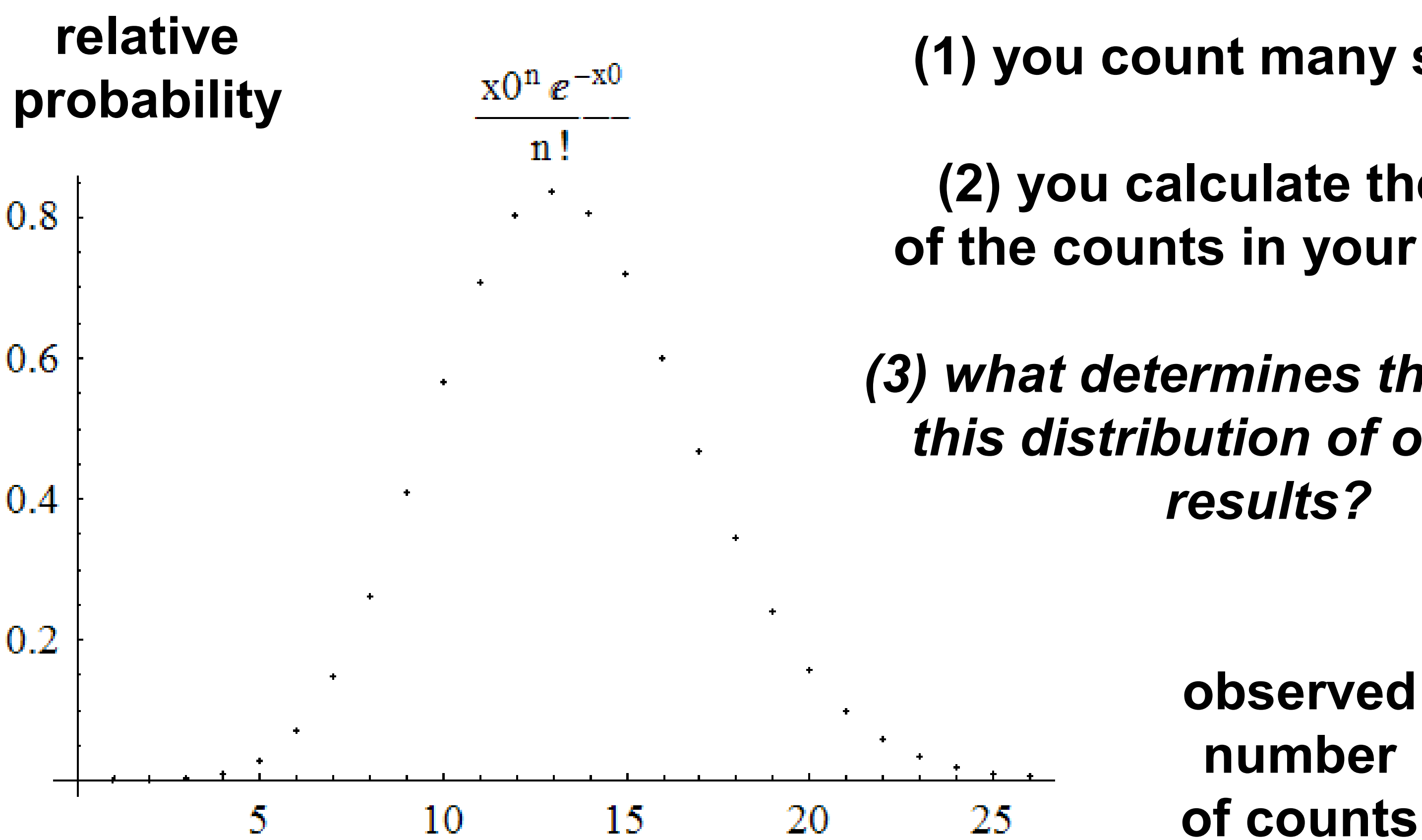
distribution of measurements whose outcome is an integer count

measurements whose outcomes are integer counts

(1) you count many samples

(2) you calculate the mean of the counts in your samples

(3) what determines the width of this distribution of observed results?



assignment

(20) The World Series problem:

a) Get ~100 years of outcomes of the World Series; http://www.baseball-almanac.com/ws/wsmenu.shtml is one of many compilations on the web.
b) If the teams are equally matched then the probability of the series going 4, 5, 6, or 7 games is equivalent to coin flipping; plot actual outcomes vs. corresponding coin-flip probabilities.
c) Now compare the probabilities you calculated with the actual data. Does the series generally run shorter or longer than you would expect? What are some reasons actual and expected might differ?

assignment (17)

(17) Explain why (15) might alternately described as an "integrator", while (16) might correspondingly be described as a "differentiator". Relate to

$$\frac{d}{dt} \leftrightarrow i\omega \quad \text{and} \quad \int dt \leftrightarrow \frac{1}{i\omega}$$

where $\omega = 2\pi f$, f = frequency.

more good words to think about:
integrator ↔ averager or smoother
differentiator ↔ edge or transition detector

summary, then details

- narrow banding "squeezes out" noise but not signal
  - problem: to keep the system "on station"
- lock-in amplifier (a.k.a. synchronous amplifier, synchronous rectifier, phase sensitive detector, etc)
  - stays "on station" because you have the reference signal
  - squeezes out noise in phase *and* frequency domains
- generalization: some forms of modern spread spectrum communication coding, e.g., CDMA (code division multiple access) for GPS, cell phones, etc.

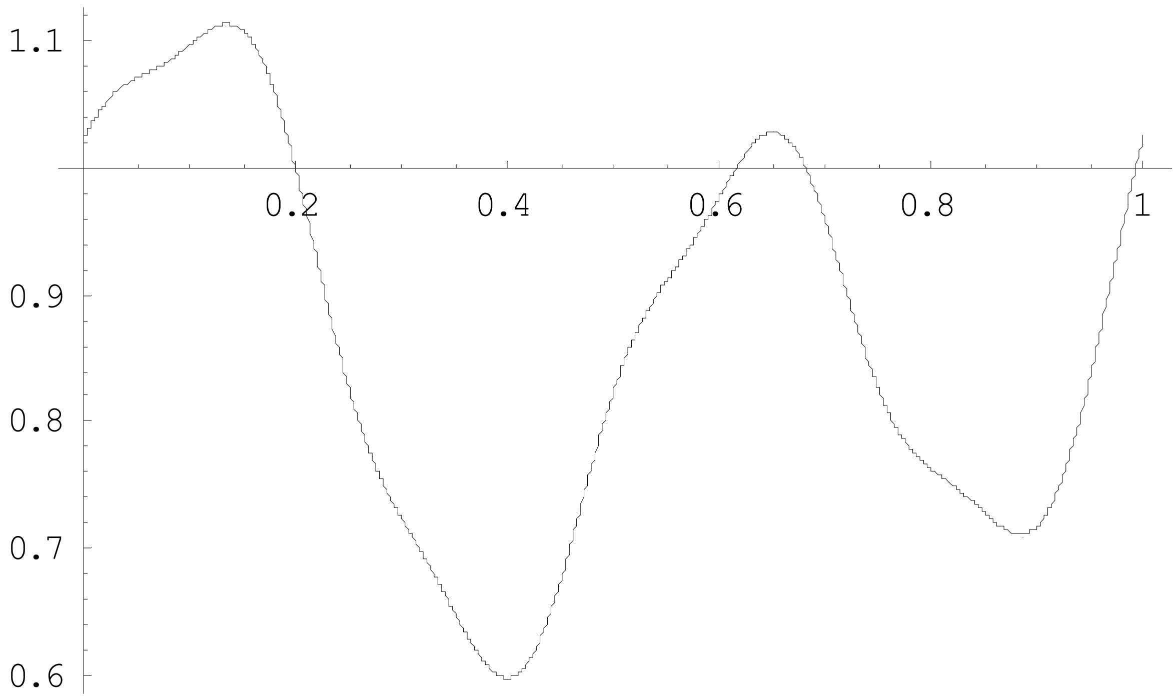
the concept expressed as code

- ordinary passive “full-wave rectifier”:
  - Abs[signal(t)] = signal(t)>0 ? signal(t):-signal(t)
- synchronous rectifier:
  - SyncAbs[signal(t), reference(t)] =
    reference(t)>0 ? signal(t):-signal(t)
  - reference(t) takes on many application- and economics-dependent forms:
    - multiply by cos(ω_{ref} t): typical analog modulation
    - on/off: typical mechanical or digital modulation
    - pseudo-random word: typical broadband system
      - CDMA cell phone communication
      - GPS satellite navigation system

graphical illustration

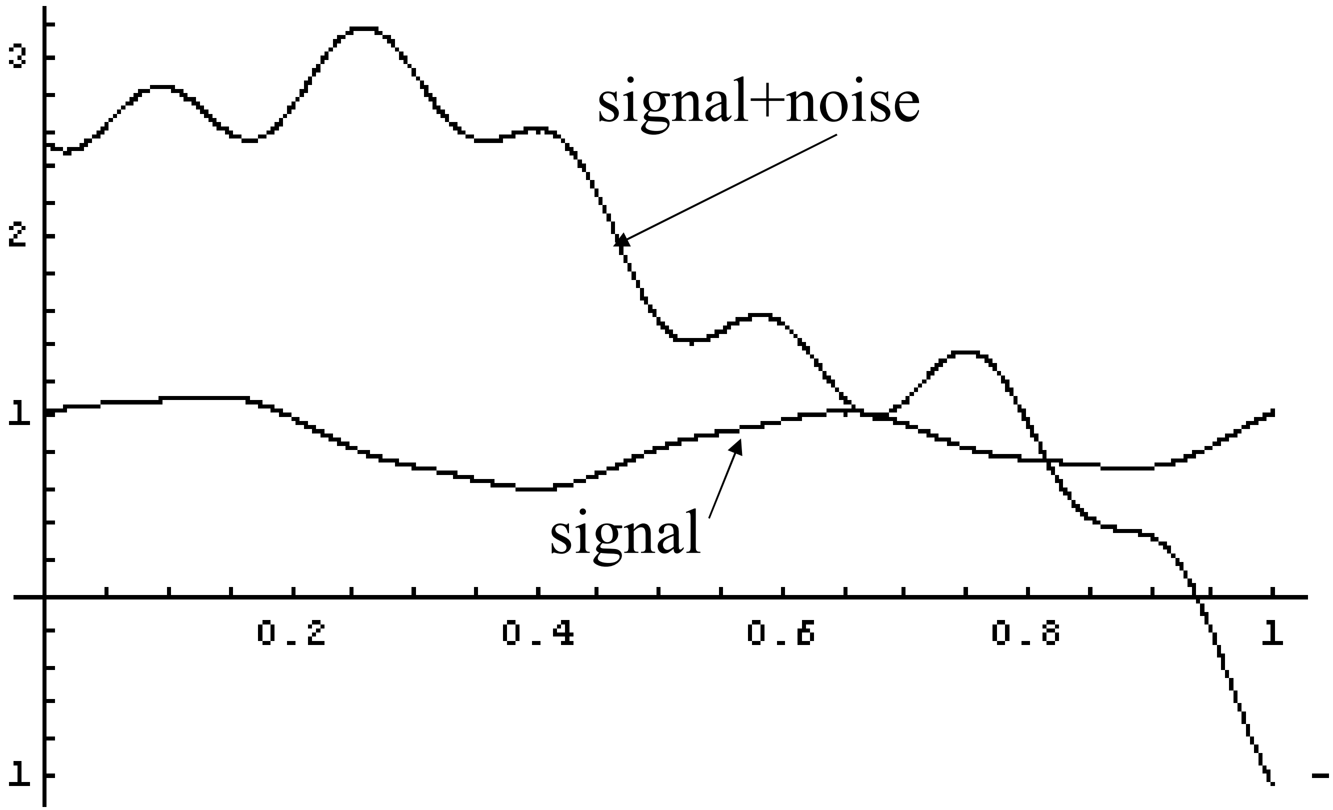
(1) consider an illustrative "slowly varying" signal

$S[t] = 1.0 - 0.8t + 0.8t^2 + 0.2 \sin[4\pi t]+0.025 \cos[12\pi t]$

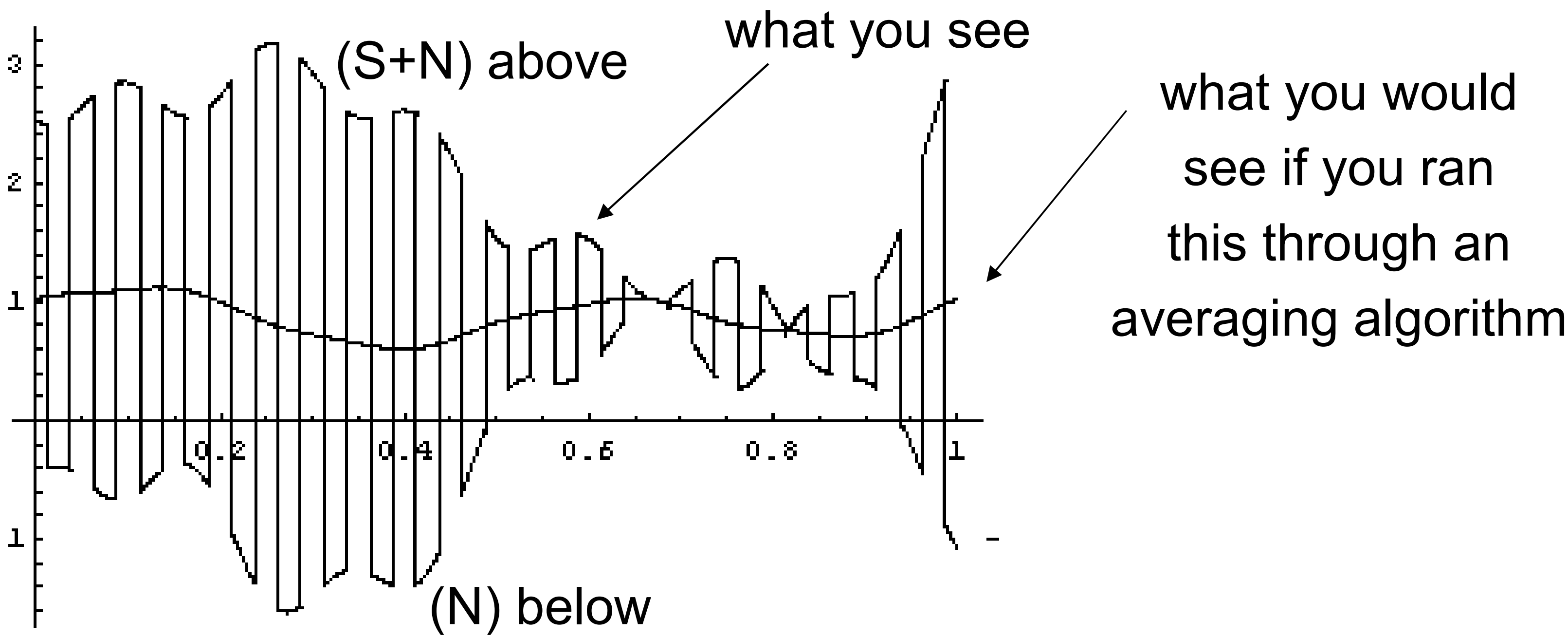


(2) now **bury the signal in a much larger sea of noise**:

noise[t] = 2.+.4t-4.t²-.5Sin[4πt+π/6.] - .25Cos[12πt-π/12.]

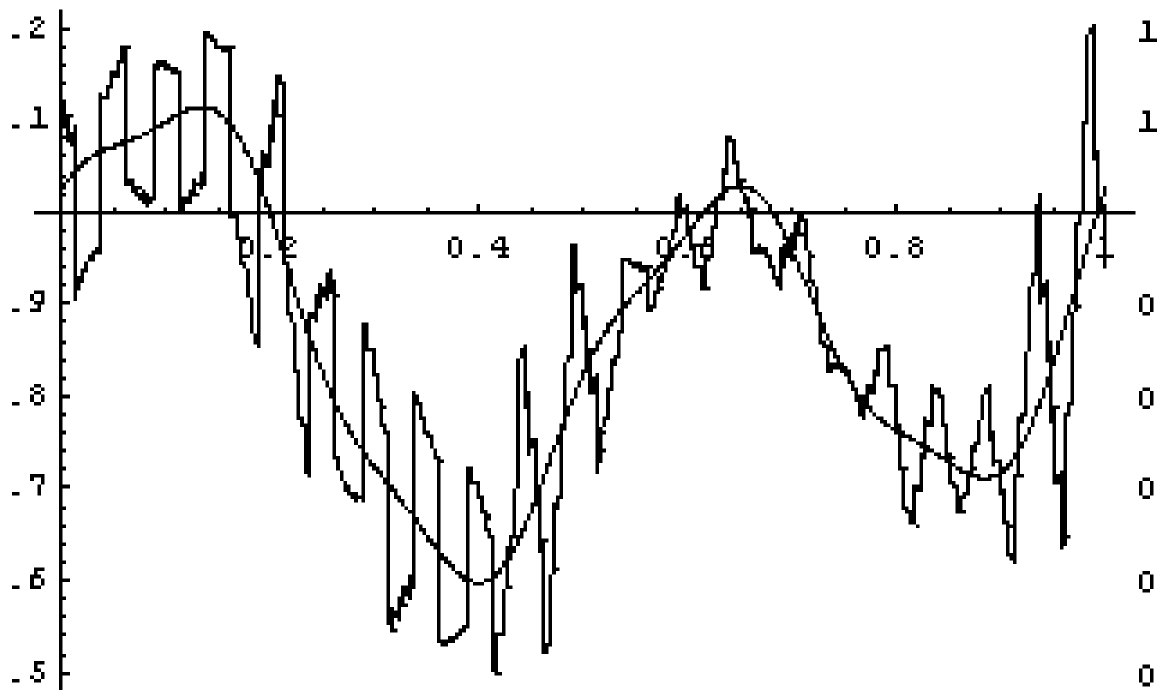


(3) when the signal (but not the noise) is modulated
this is how the synchronous rectifier output looks:



notice that the average value (the solid line)
faithfully reconstructs the original signal …
now we need to actually implement the averaging

(4) here it is after processing by a 21-point sliding average:



heavier filtering would faithfully restore the original signal, distorted (under favorable conditions only slightly) by the noise that happens to be in the frequency and phase band accepted by the process

summary …

- if you can give your signal (but not the noise) some sort of “signature” you can pull it back out it of a lot of noise
- if you chop or sinusoidally modulate it and use a detection method that looks for the modulation frequency you win nicely
- if you use a detection method that looks for the modulation frequency *and its phase* then you win spectacularly
- more complex signatures, e.g., CDMA, provide even better noise rejection

assignment

18) The three major cell phone systems are CDMA, TDMA, and GSM. xDMA describes both the system and the coding method; GSM describes a system that uses a kind of “phase shift coding” (PSC). Identify (e.g., by web search) and document one service provider who uses each coding method. Briefly describe the essential idea underlying each coding method. [Note: you may find that they are not mutually exclusive, e.g., some systems use both PSC and TDMA.]

last few topics we covered ...

- basic transduction & measurement
- sensors that deliver electronic signals
  - voltage sources & current sources
  - device parameters (resistance, capacitance, …)
    - force a voltage, measure the current
    - force a current, measure the voltage
- mother nature’s efforts to thwart sensing
  - fundamental noise (thermal, shot, “flicker”)
  - technical noise (the environment)
- some tricks to make the best of it
  - narrow banding in frequency domain
  - coding to narrow-band in phase domain

remember well ...

- *usually* signal accumulates faster than noise
  - e.g., integrated signal power ~ measuring time
    integrated noise power ~ measuring time^{½}
    so S:N ratio gets **better** as time^{½}
  - *but not always!*
    - *e.g., in an inertial navigation system signal-to-noise ratio of a position measurement gets **worse** as time$^{3/2}$*

assignment

19) Numerically simulate a one-dimensional "integrated random walk": you are in a sealed-cabin with an accelerometer; you know your starting position, and you start with zero velocity; integrating the accelerometer output gives your velocity, integrating again gives your displacement from initial position; but the accelerometer output has random noise on it. Show that your simulation suggests $\Delta v \sim t^{1/2}$ and $\Delta x \sim t^{3/2}$.