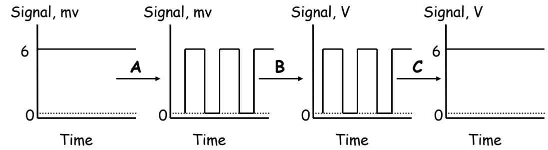
January 28, 2005

- **No Class: Monday, Jan 31st**
- **Office Hours™**
  - 1:10 – 2:10 pm, Monday, A223 Cook
    - Not next week (no class Monday Jan 31st!)
  - 1-2 pm, Thursday, 300 Waterman
  - 3-4 pm, Friday, 300 Waterman

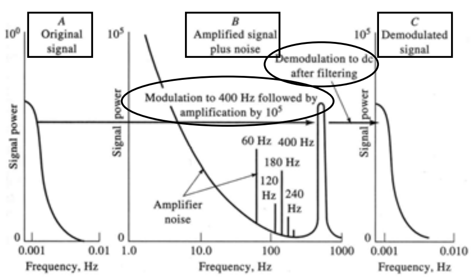
Tuned Amplification: *Chopper Amplifiers*

- If we *amplify* the signal **at the modulation frequency**, then we can also *increase the signal* while we *reduce the noise:*



A: *modulate* **B**: *amplify* **C**: *demodulate*

Chopper Amplifiers: In the Frequency Domain



Lock-In Amplification

- Tuned (chopper) amplification is limited by stability of f_o reference
  - -this limits the effective Δf to about 1 Hz
- *Lock-in* amplification tunes the amplifier to *both* f_o as well as the **phase** of the signal
  - -results in an effective reduction of Δf to about 0.01 Hz

Signal Averaging

- Need a *repeatable* signal (time domain method)
- Sum digitally-stored replicate signals
- How does this improve S/N?

Signal: increases *linearly* with number (n) of replicate signals

Noise: increases as $(n)^{1/2}$

So, **S/N** increases as $(\mathbf{n})^{1/2}$

Signal Averaging: Example

- Suppose we wish to *mass* a **10-mg** object on an analytical balance (σ = *0.1 mg*)

For a single (n =1) measurement:
S = 10. mg, N = 0.1 mg → **S/N** = ***100***

For n = 4:
S = *n x 10. mg* = 4 x 10. mg = *40. mg*
N = $\sigma_T = (n(\sigma)^2)^{1/2}$ = $(4(0.1)^2)^{1/2}$ = 2(0.1) = *0.2 mg*
S/N = 40./0.2 = ***200***

For n = 16: **S/N** = ***400***

Signal Averaging: General

- In general, we can say:

$$(S/N)_n = (n)^{1/2}\,(S/N)_{n=1}$$

•Diminishing returns:

Suppose, it takes 1 second per measurement?

S/N	n	Time
3	1	1 sec
6	4	4 sec
30	100	100 sec
300	10,000	2.8 ***hours***
3000	1,000,000	11.6 ***days***

More Signal Averaging

- **Signal must be digitized . . .** *How?*
- **Digitization frequency?**
  -Nyquist Theorem
- **Precision of digitization?**
  - how many bits?
  8-bit = 2^8 = *256* (0.4 %)
  12-bit = 2^{12} = *4096* (0.02 %)