EECS 373

Introduction to Embedded System Design

Robert Dick
University of Michigan

Lecture 14: Interface circuits and wireless

2 April 2024

Review

- Power integrity
- Solenoids
- Motors
  - DC
  - Stepper
  - Servo
  - Linear
  - H bridges
- Shaft encoders

What's left in the course

- 4 April: Project Checkpoint 2: update report.
  - Progress.
  - Changes in plans.
- 11, 16, 18 April: Student presentations.
  - 10-minutes / team.
  - Report on current state of project, but can indicate plans for coming days.
  - Send me slides by evening before presentation.
  - We'll assign dates via a Piazza post shortly.
  - Must open with 30-second self-contained pitch.

30-second pitch

- What problem are you trying to solve?
- How does your solution work from the perspective of the person with the problem?
- What was your technical approach?

Outline

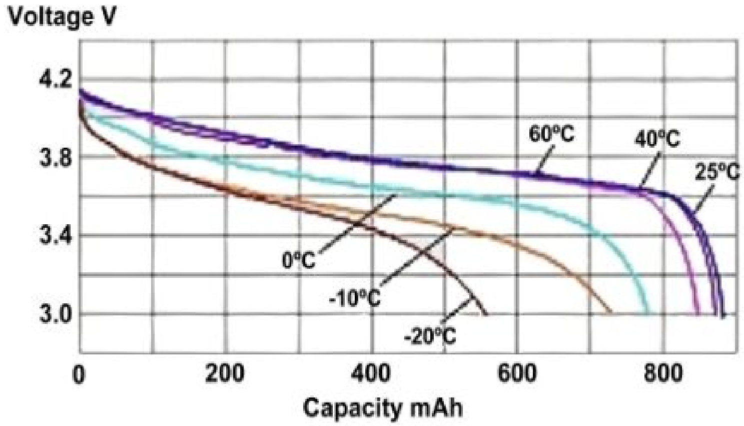
- **Power supplies**
- Voltage regulators
- Signal conditioning
- Wireless communication

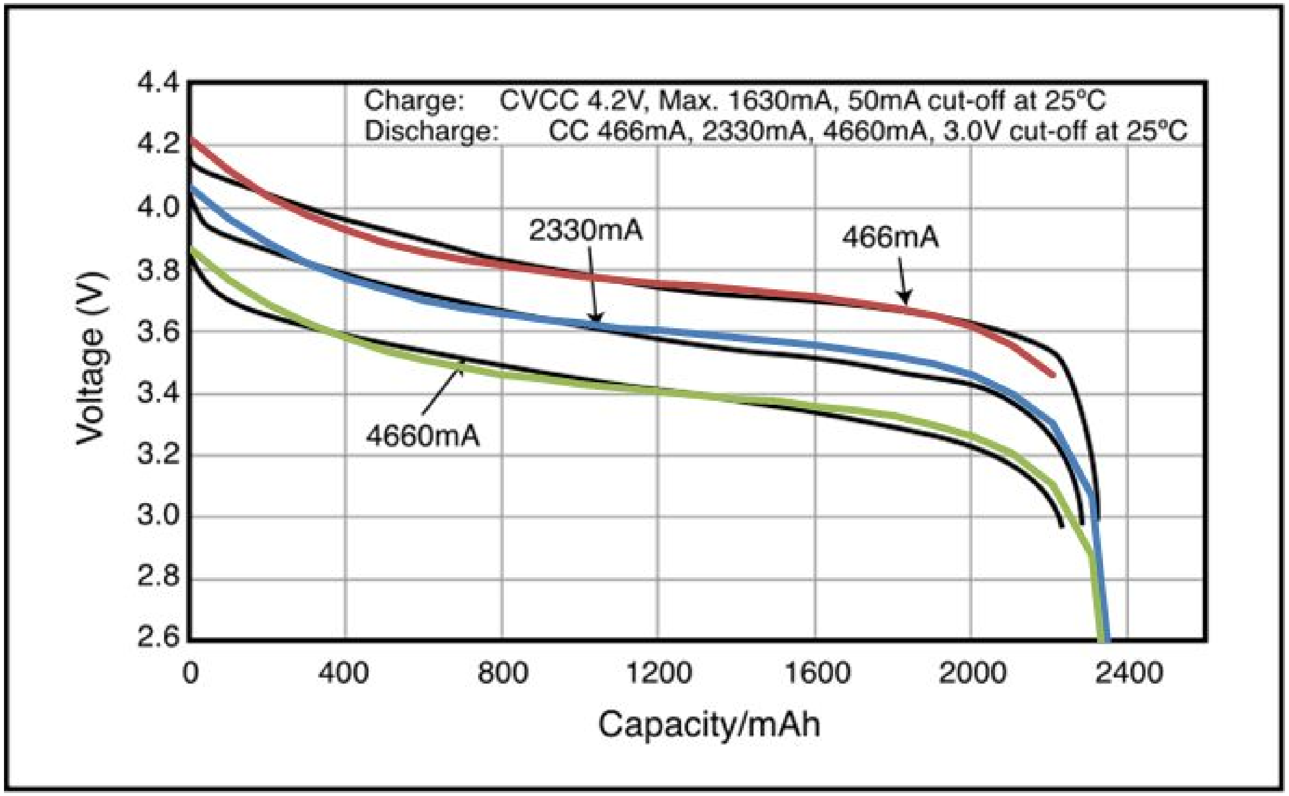
Power supplies

- Goals (Why?).
  - Always stably output desired voltage.
  - V requirements may change w. time.
- Reality
  - Available voltage wrong sometimes or always.
  - High parasitics for raw energy source.
    - L → dI/dt = droops/spikes w. current var.

Battery discharge curve

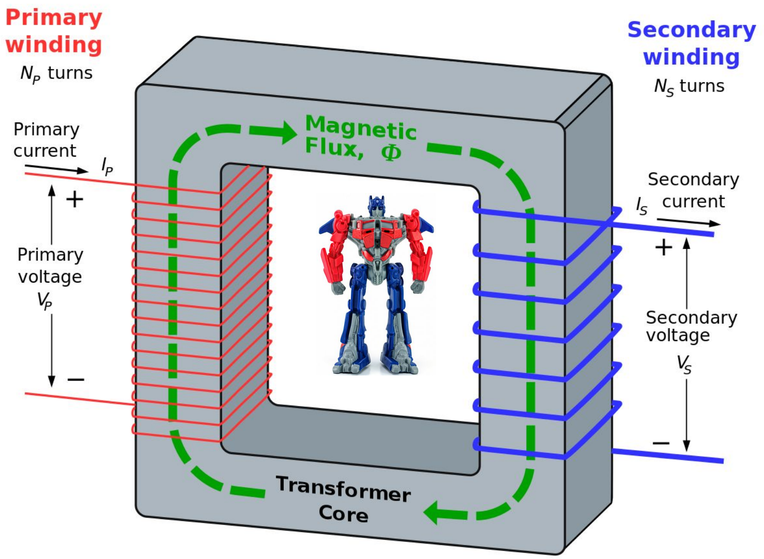
- Beware startup peak.
- Parasitics matter.
  - Rint, Rsd, Cint, Lint.
- T matters.





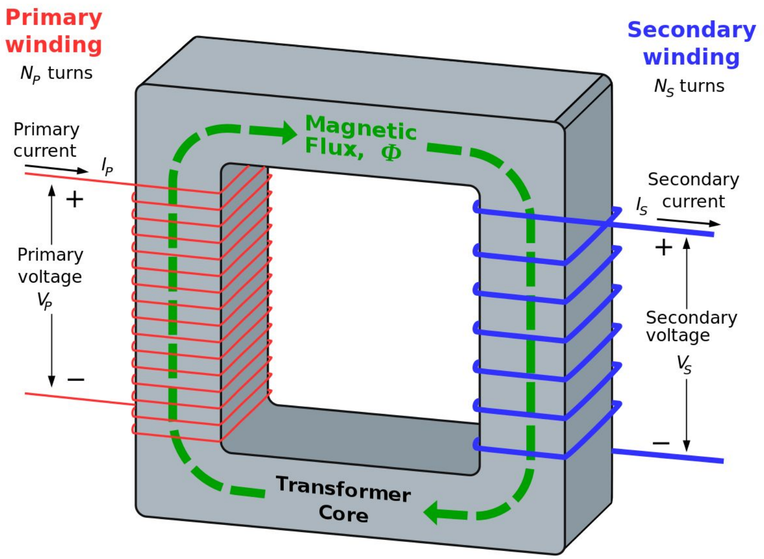
AC-AC

- Winding ratio.
  - Step up or down voltage.
- Expensive and bulky.



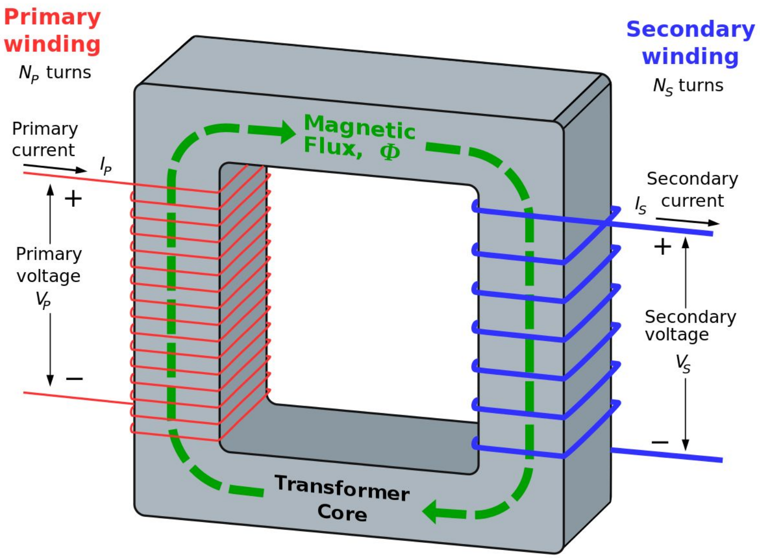
AC-AC

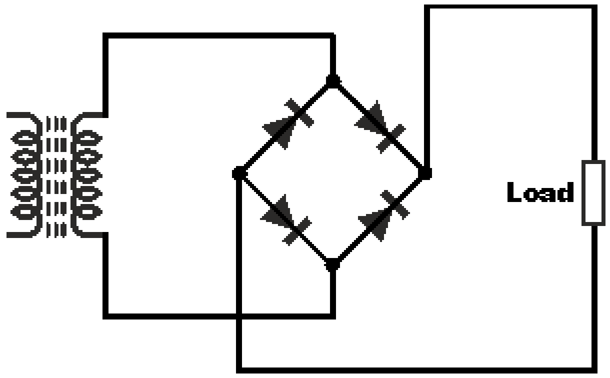
- Winding ratio.
  - Step up or down voltage.
- Expensive and bulky.



AC-DC

- Vp/Vs = Np/Ns = Is/Ip.
- Need DC.
- Full-wave rectifier.
- What does this do to waveform?
- How to make stable? C.
- Tolerate changing input V? Zener.





Outline

- Power supplies
- **Voltage regulators**
- Signal conditioning
- Wireless communication

Linear DC-DC

- Simple, Zener-based.
- Inefficient for large V conversion.
- Will give reading material for review.

Charge pump DC-DC

- Charge C.
- Stack with source.
- Repeat.
- Not great for high power.
- Good for communication.
- Can control charging period to control V.

Buck switching DC-DC

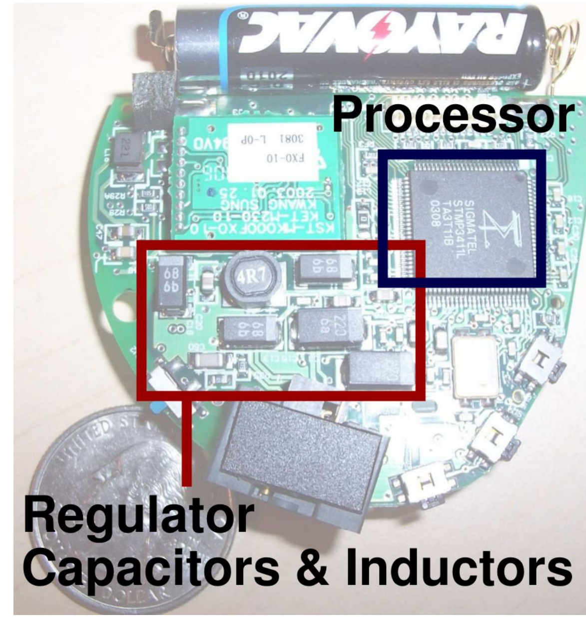
- Efficient.
- Step-down, only.
- Max output = Vin – Vloss.

Buck-boost switching DC-DC

- Efficient.
- Step up or down.
  - 0X → 2X.
- Inverting.

None

- Don't always need regulator.
- They're only around 85% efficient.
- Terrible for usually-sleeping systems.
- Built-in battery C is useful.
- Can components can tolerate full swing?
  - Consider LiIon start-up peak!
- See my paper with S. Kim at https://robertdick.org/publications/
- Also see DC-DC converter primer on website.



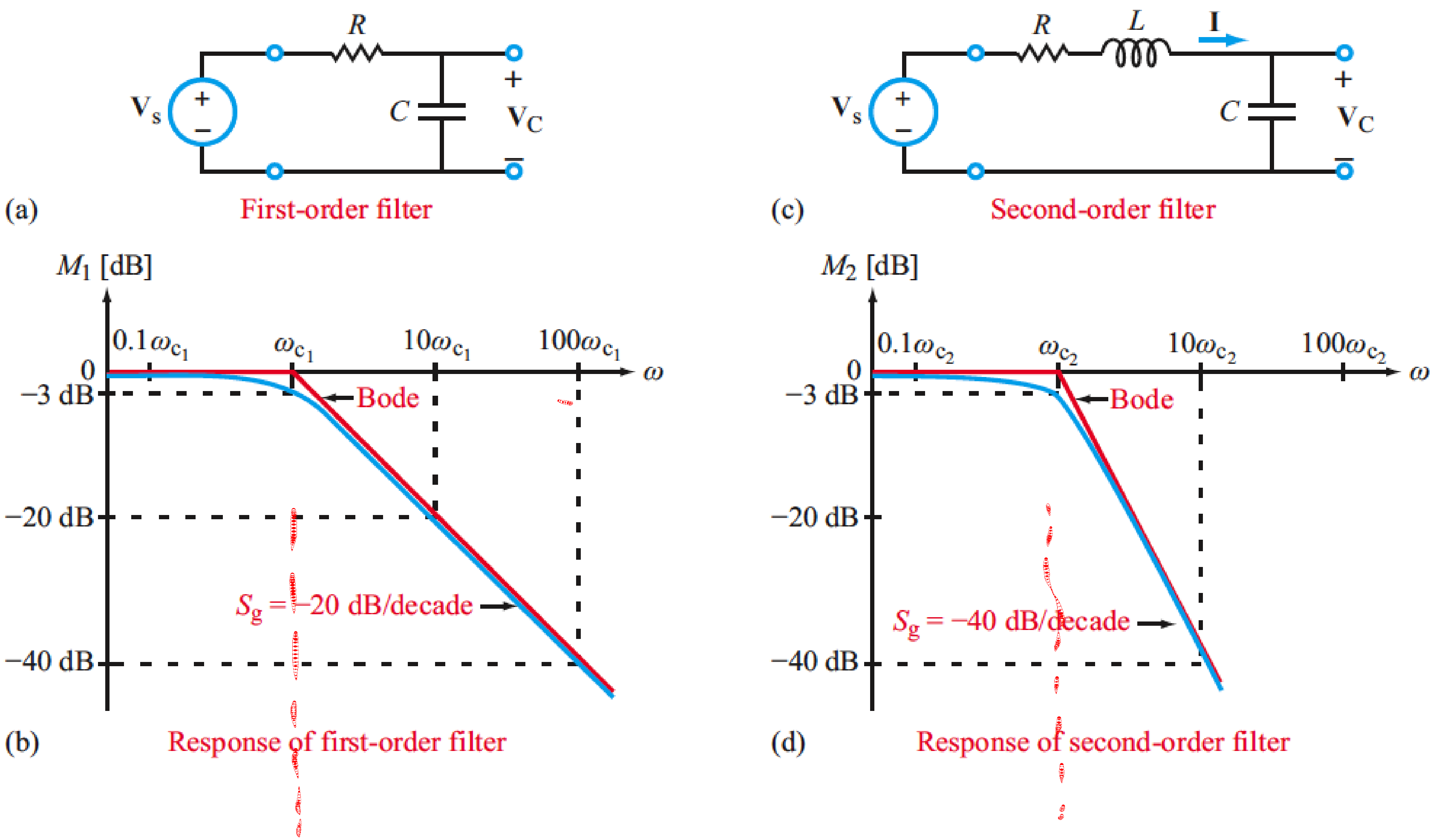
Outline

- Power supplies
- Voltage regulators
- **Signal conditioning**
- Wireless communication

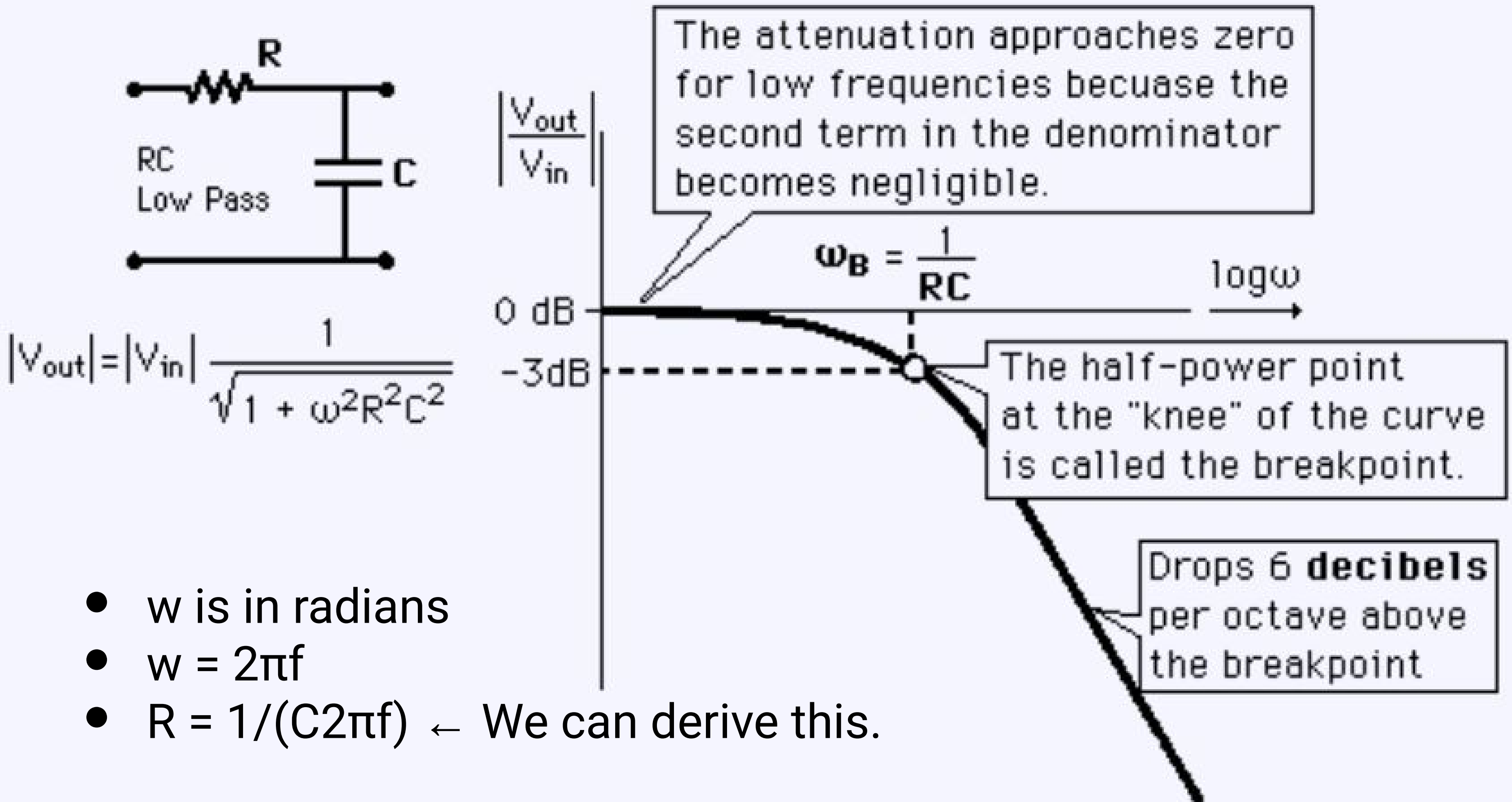
Signal conditioning

- Why? Bare sensor characteristics clash with ADC.
- Problems with many sensor outputs.
  - High internal resistance.
  - Voltage range mismatch.
  - Unwanted frequencies.
  - Fluctuating near-DC offset.
- Solutions.
  - Low-pass/high-pass/notch filters.
  - Amplifiers.

Filter order



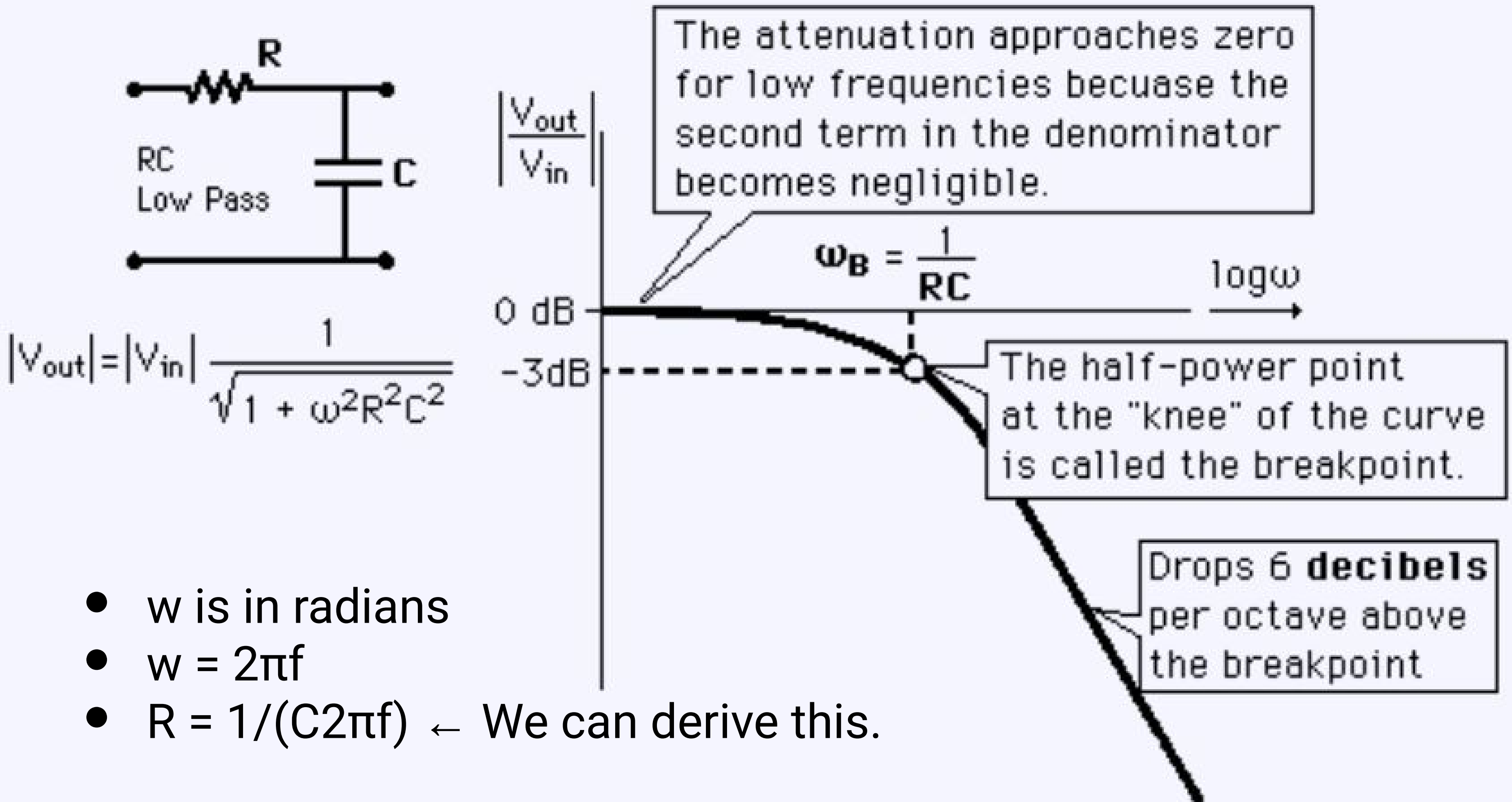
Designing the anti-aliasing filter



- w is in radians
- w = 2πf
- R = 1/(C2πf) ← We can derive this.

- Goal: cutoff f = 30 Hz. Given: C = 0.1 μF.
- Question: R = ?
- Example.

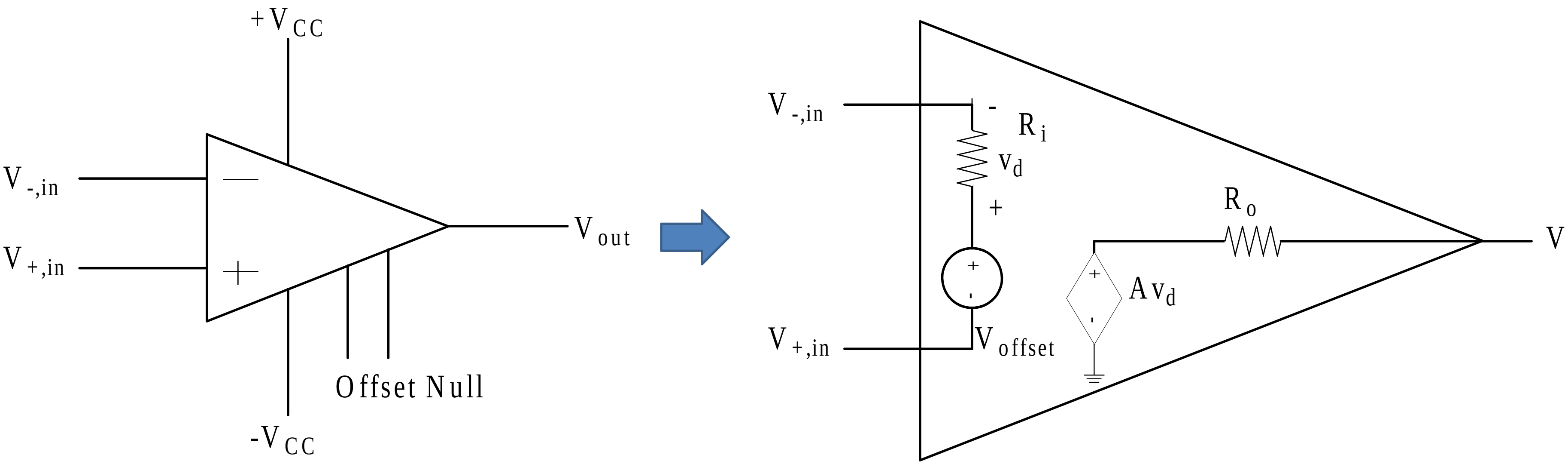
Designing the anti-aliasing filter



- w is in radians
- w = 2πf
- R = 1/(C2πf) ← We can derive this.

- Goal: cutoff f = 30 Hz. Given: C = 0.1 μF.
- w = 2πf, 1/(RC) = 2πf, R = 1/(2πfC) = 1/(2π[30 Hz][0.1μF])
- R = 53 kΩ

Op-amp model

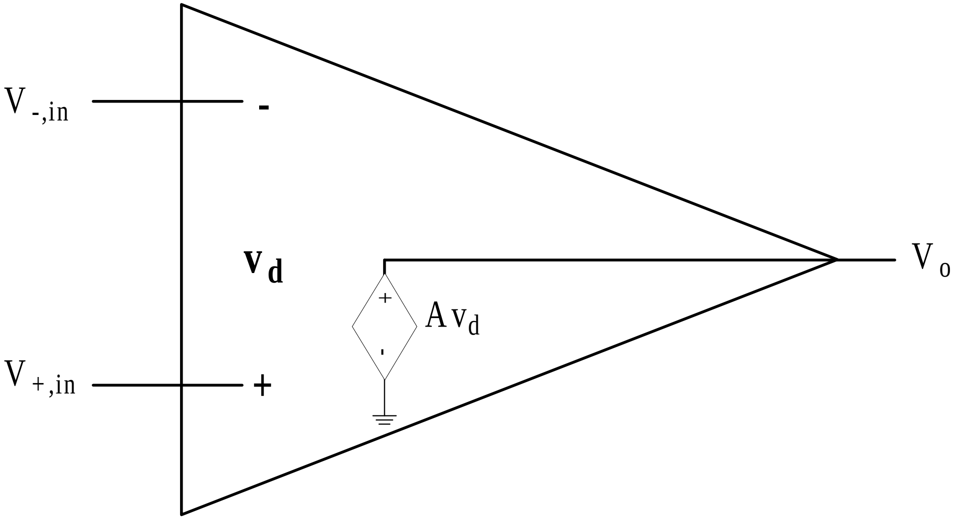


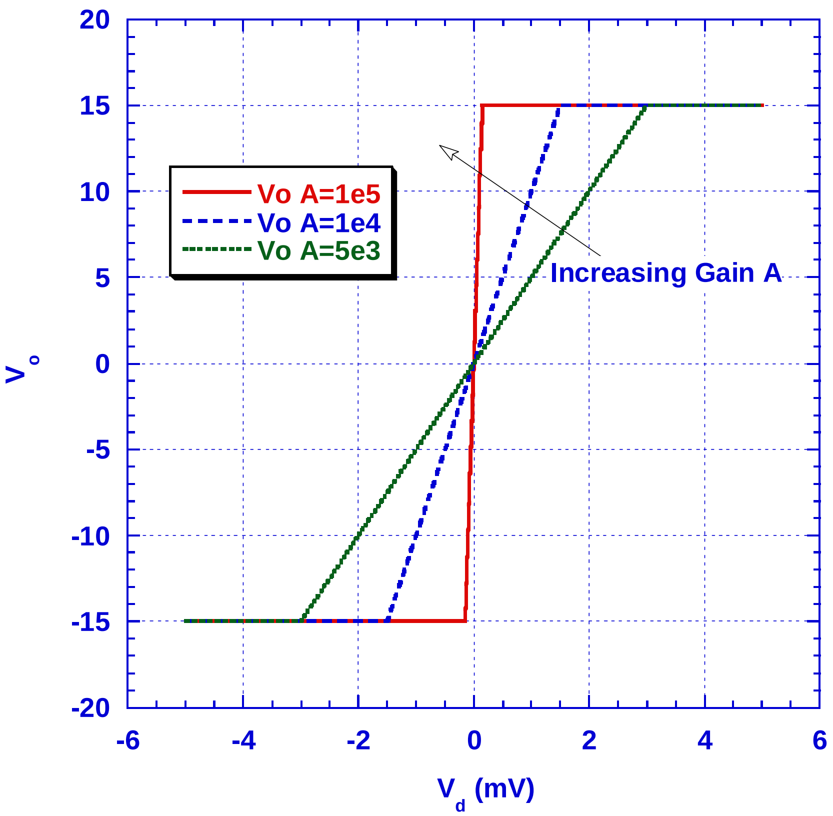
Ri = 2 MΩ
Voffset = 4 mV
A = 20M
R0 = 75 Ω

- Nonlinear behavior not represented in model.
- Consider power supply V.

Ri < ∞
Voffset ≠ 0 V
A < ∞
R0 > 0 Ω

Ideal op-amp model





Ri → ∞

Voffset = 0 V

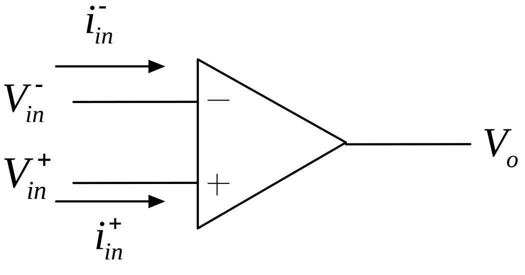
A → ∞

R0 = 0 Ω

Op-amp “Golden Rules”

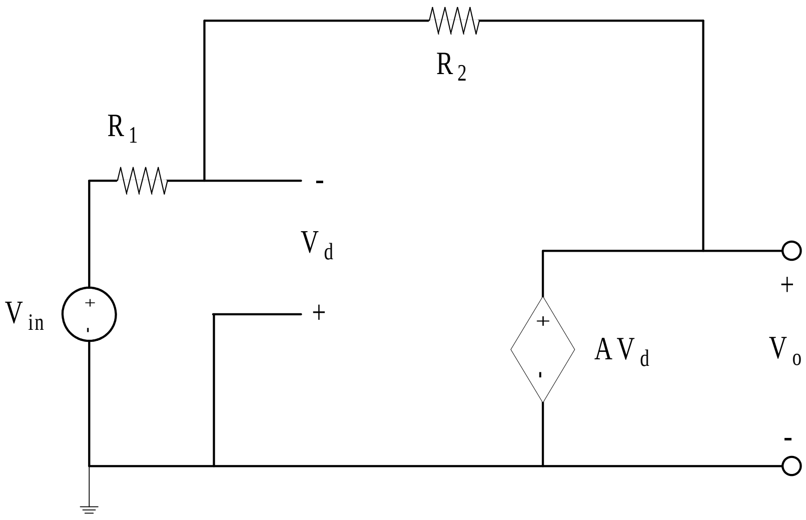
For negative feedback

- Gain is infinite so input voltages equal.
- Input resistance infinite so input current zero.
- I.e., op-amp does what is needed to make $Vin^- = Vin^+$.

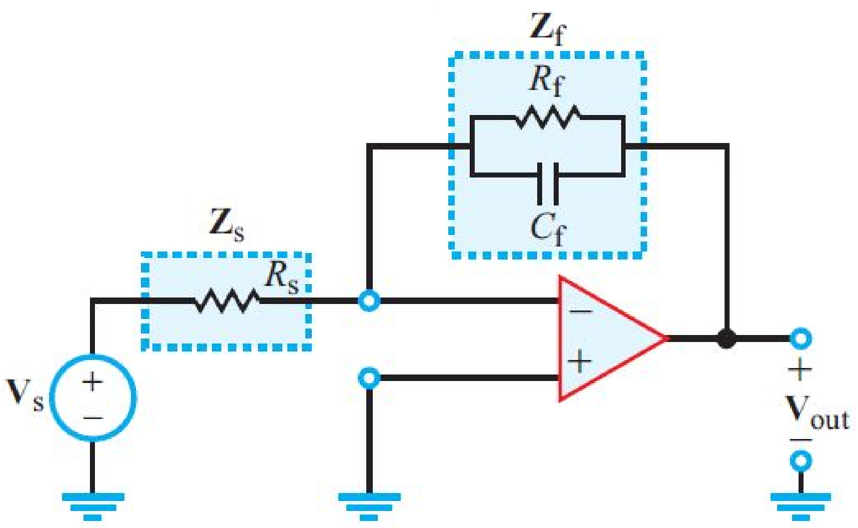


Nodal analysis for inverting case

- Ideal assumptions simplify problem greatly.
- Dependent voltage source will work to set Vd=0V.
- Solve for current into Vd- node.
- Solve for Vo/Vin.
- Inverting: to make Vd=0V, Vo must be negative.
- Can also design non-inverting amplifiers.



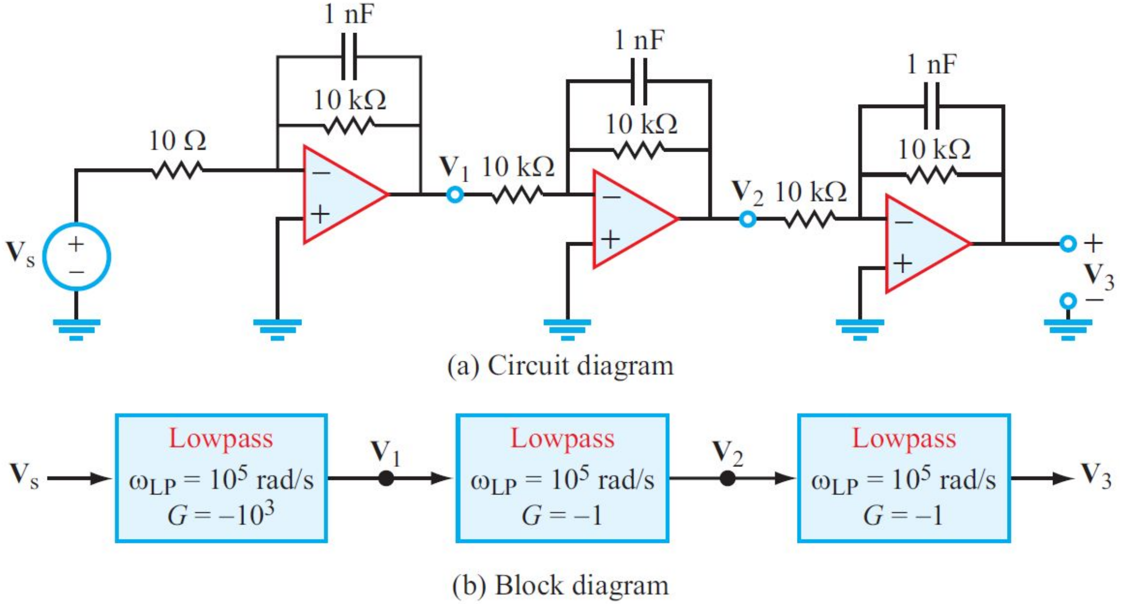
First-order active inverting lowpass filter

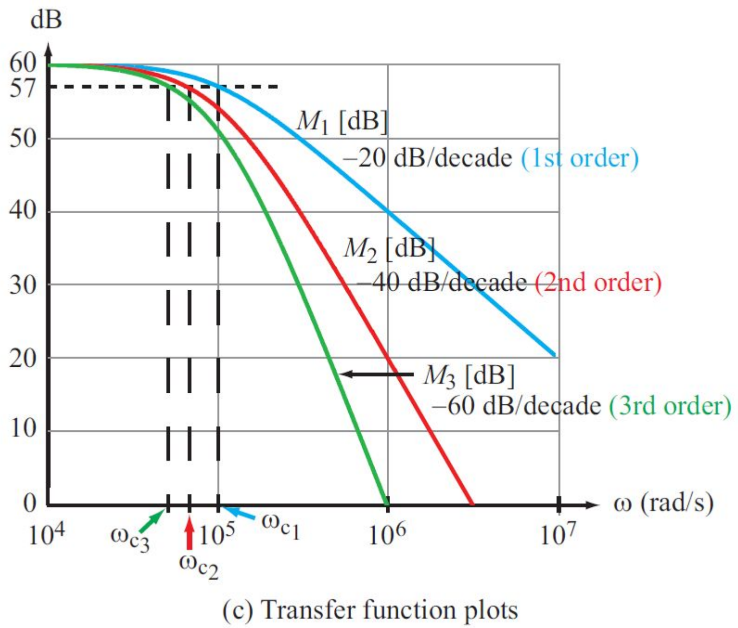


- Low-f: Impedance is determined by Rf.
- High-f: Impedance drops.
- -Zf/Zs → high-f attenuated.
- Can analyze in frequency- / s-domain.

Cascading of active filters

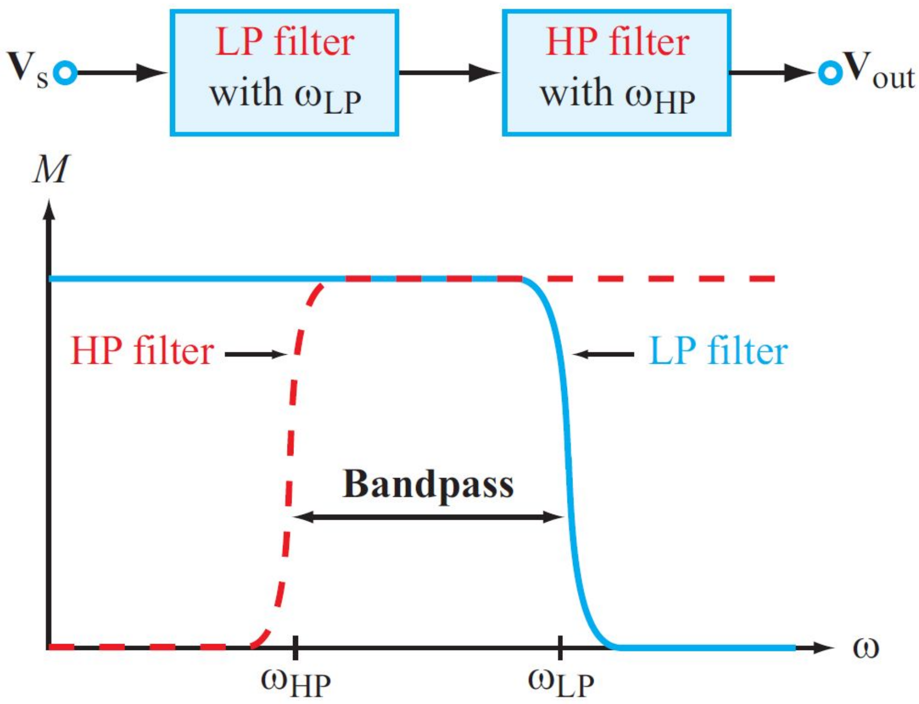
Create a higher-order filter by cascading.



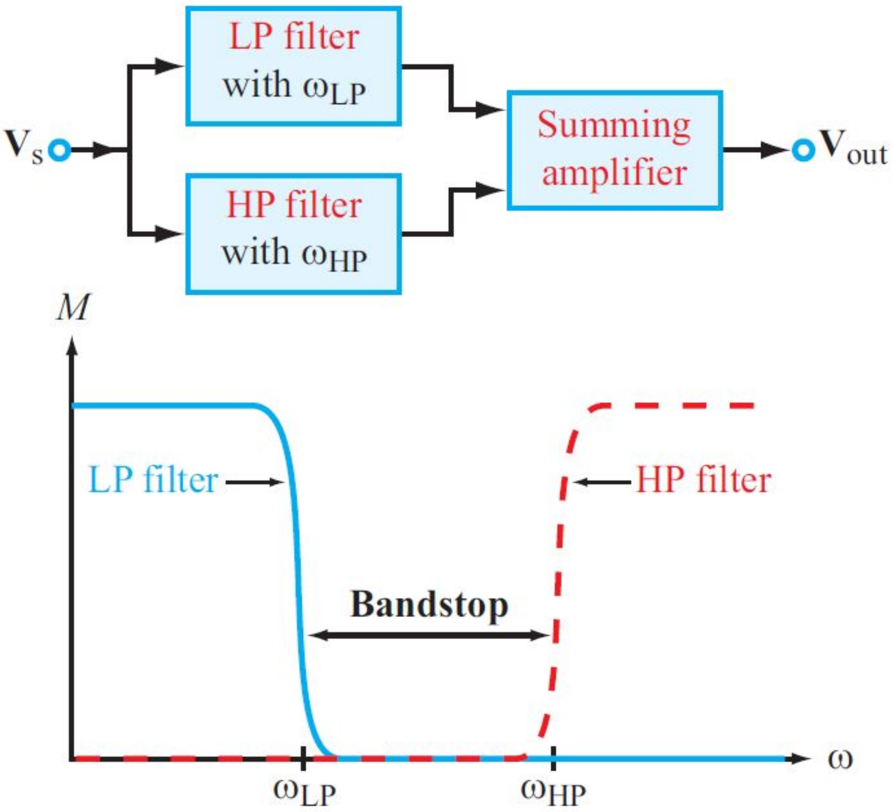


Cascading active filters

Create band filters by cascading.



(a) Bandpass filter



(b) Bandreject filter

Instrumentation amplifiers

- Amplifies differential signal.
- Rejects ground (common-mode) noise.
- Most designs use multiple op amps.

References

- Paul Horowitz and Winfield Hill, “The Art of Electronics.”
- Howard M. Berlin, “Design of OP-AMP Circuits.”
- Any decent introductory circuits book.
- Application notes from op amp manufacturers.

Outline

- Power supplies
- Voltage regulators
- Signal conditioning
- **Wireless communication**

Wireless communication

- Reliability.
- Power.

Wireless environment

- Noise.
- Absorption.
- Reflection.
  - Multipath.
- Environmental conditions.

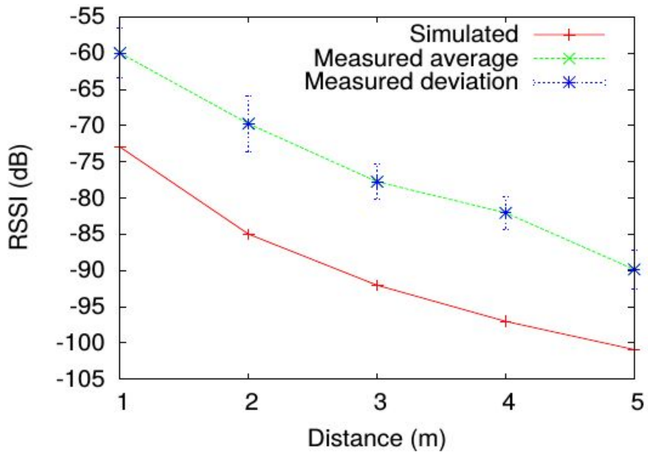


Figure 6.10: Comparison of measured and simulated RSSIs with nodes sitting on the ground.

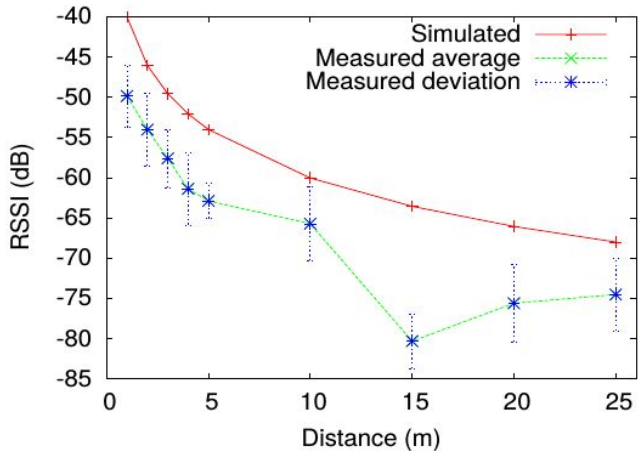
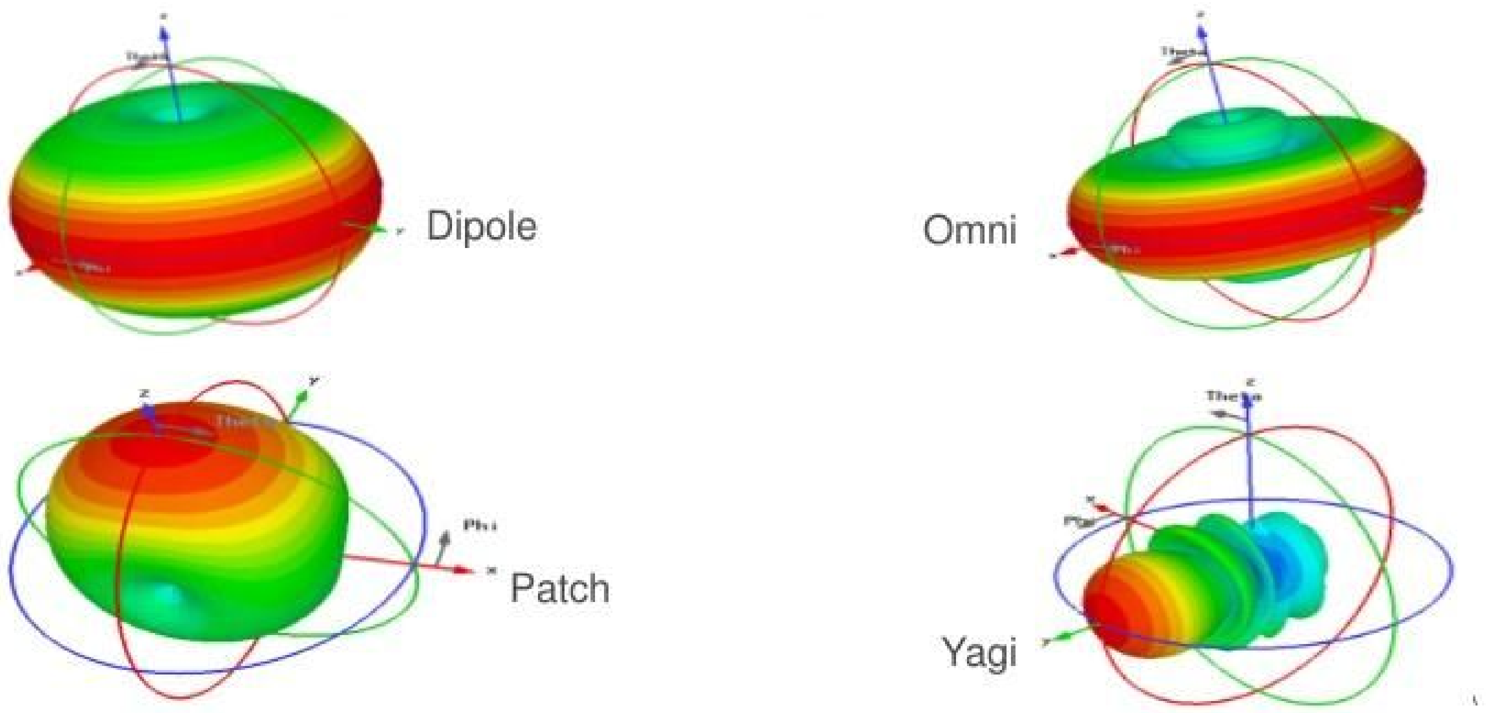


Figure 6.11: Comparison of measured and simulated RSSIs with nodes raised 0.95 m from ground.

Anisotropic radiation patterns



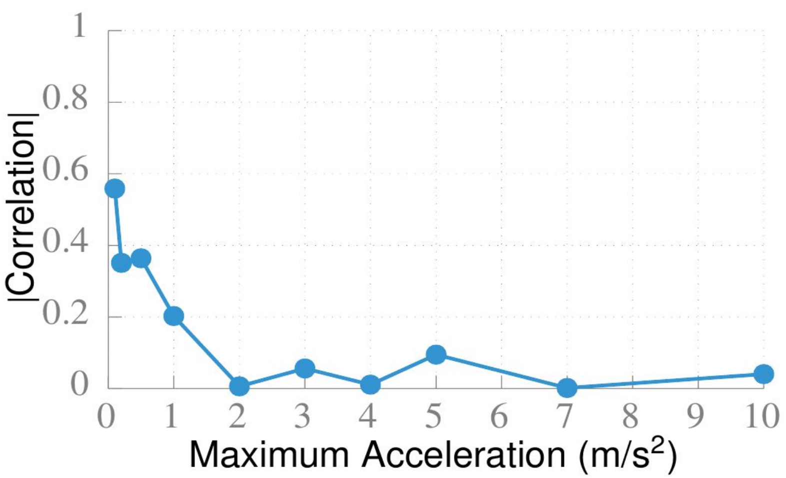
Credit to fpvlair.com for image.

Wireless motion

- Antenna motion.
- Conductive material motion.

Table 2.3: Classification Performance

Environment	Sensitivity (%)	Specificity (%)
Office I	99.6	96.5
Office II	100.0	87.7
Cafeteria	91.4	86.6
Outdoor	95.9	61.1



Communication power

1. Antenna.
2. Electronics.

Radiated energy

- Radiated power depends on distance.
  - Hit target SNR at receiver.
  - P_r: received power.
  - P_t: transmitted power.
  - $P_r \alpha P_t (1/d)^{\gamma}$.
  - γ often around 3 or 4.
- Small antennas may be inefficient.
- Power into amp often > 4 times transmitted power.

Communication energy

- Circuit power is roughly constant and independent of distance.
  - On order of 1-10mW.
- For large distances, transmission energy dominates.
- For short distance, circuit energy should also be considered.

Communication energy

For a particular radio

- Const. on power consp.: 2 mW.
- Additional const. trans. power consp.: 10 mW.
- For zero output power.
- Power-dependent trans. efficiency: 25%

What is total power consumption for 10 mW output power?

Communication power and multi-hop

- Are two hops better than one?
- Superlinear increase in energy with distance.
- Constant energy hit regardless of distance.

Processing vs. transmitting

- Transmitting 1-bit costs same as executing orders of magnitude more instructions.
- Can save on transmission costs by intelligently processing data before transmitting!
- Data aggregation/fusion.
- Local processing.
- See Embedded Intelligence in the Internet-of-Things article at https://robertdick.org/publications/ .

Dynamic power management

- Dynamic power management also useful for communication power.
- Turn radio off when nothing to send/receive.
- Note while off can **not** receive.

- Taking into account DPM can change transceiver trade-offs.
  - Better to send slow or send fast and sleep?

Hibernation

When to wake up?

Possibilities

1. At regular intervals.
   - Need synchronization.
2. Trigger by stimulus.
   - E.g., heat-sensitive circuit.

Course summary

- Early course
  - State of computing (implementation technologies).
  - Embedded system design challenges.
  - Establishing product-market fit.
- Mid course
  - Iterative design-debug process, design for debug.
  - Understanding how embedded system building blocks work.
  - Tried to draw on personal experience so you don't suffer from the same mistakes I made.
- Late course
  - Making your project work.
  - Presenting your ideas to others.

Done.