

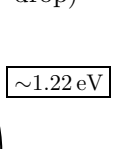
ECE 327: *Electronic Devices and Circuits Laboratory I*

Notes for Lab 3 (Voltage Regulators Lab)

1. Introduce voltage regulators (very basic, lots more available)
 - Steady, accurate, and temperature-independent voltage references are critical to electronics.
 - Uses:
 - * Constant current sources
 - * Voltmeters, Ohmmeters, Ammeters
 - * Precision ADCs
 - * Temperature sensors (i.e., make use of strong temperature dependence)
 - Drift over time proportionally bounded by \sqrt{t} (random “drunken” walk)
 - * Initial drift is greatest, then slow
 - * Rate is sped up with heat
 - * Manufacturer uses “burn-in” to stabilize reference before shipping
 - Types: *Shunt* (parallel with load, shunt current away) and *series* (series with load, voltage drop)
 - Regulator specifications (different **units** specify different formulas used; **lower** is always better)
 - *Dropout (DO) voltage* and *Low-drop-out (LDO) regulators*
 - *Line regulation* (for lab, use V/V **and** %/V units)
 - *PSRR* ratio (for lab, approximate AC spec using DC values)
 - *Load regulation* (for lab, use % units)
 - *Bypass capacitors* (jargon: “caps” and “puff”)
 - Stray inductance (e.g., long wires) is low-pass filter to current spikes
 - * Prevents components from getting sharp steps of current (i.e., reduces bandwidth/speed)
 - * Causes voltage ripples at other components (voltage dips from induced $v_L = L \frac{di_L}{dt}$ emf)
 - Capacitors provide low impedance for high frequencies ($sL \rightarrow \infty$, $sL \parallel 1/(sC) \rightarrow 0$ as $s \rightarrow \infty$)
 - * $i_C = C \frac{dv_C}{dt}$, so large C can provide large i with little voltage change
 - * Capacitor “props up” steady DC reference
 - * Store energy at slow times to provide current at fast times
 - * Use short capacitor legs and place capacitors close to components
 - * Typically place capacitors at supply and at individual components
 - * Design: large capacitor banks (low \parallel resistance, high \parallel capacitance); populate *as needed*
 - * Big caps: See inside power supply for example; other examples everywhere
2. Switching regulators/DC-to-DC converters/“switchers” (ECE 628) — very efficient (95%!) but *noisy*
 - Use **storage elements** (e.g., inductors) and **switches** like gear trains
 - Work like gear trains for speed (voltage) and torque (current) where $P = iv = \tau\omega$
 - Power conserved: change voltage and current *relationship* (impedance transformation)
 - AC transformers do the same thing, but don’t need switches (power lines and gear trains)
 - All varieties
 - “Buck” (step voltage **down** to drive high current load)
 - “Boost” (step voltage **up** with less current available)
 - Inverting (change voltage and current “**direction**”, like an **idler gear**)

3. Linear regulators (Dissipative! Inefficient! Power–distortion tradeoff?)

- Diodes: Backward and forward
 - Forward-biased junction’s “built in” barrier potential acts as reference
 - * “Rubber diode” wraps feedback around diode for gain and regulation
 - Breakdown at sufficiently large reverse-bias voltages (nondestructive in theory)
 - * *Zener breakdown*: Quantum tunneling of electrons (positive probability of leakage)
 - * *Avalanche breakdown*: Electron hits atom hard enough to release electron which...
 - * Unsafe (too high to be practical — current will melt/fry device)
- Zener diodes (symbol’s “hat” is a “Z” that stands for “Zener” and looks like $i-v$ curve)
 - Designed for *safe* reverse breakdown then small incremental resistance R_{on}
 - * Zener breakdown dominates for low voltages ($< 5\text{ V}$)
 - * Avalanche breakdown dominates for high voltages ($> 6\text{ V}$)
 - * In between, electrons leak easily; *very* low R_{on} and great performance
 - Constructive circuit example (i.e., the laboratory experience):
 - (i) Start with Zener shunt (part 1 of lab) with good line regulation but bad load regulation
 - (ii) Add emitter follower “pass transistor” for better load regulation
 - (iii) Add “rubber diode” transistor feedback for tunable output (line regulation? fix?)
 - (iv) Add current limiter (part 2) to prevent destroying load (regulator $I_{sc} \times V_{in}$ on short!)
 - (v) Add current foldback (part 3) to save regulator (and provide for higher current)
 - *Double-Anode Zener Diode* (DAZD): Two opposite-biased Zeners for clipping/protection
- *Bandgap references* (e.g., [LM317](#)) for precision electronics
 - Zener negatives:
 - * Inconvenient voltages, especially for low power
 - * Require high current
 - * Depend on temperature (note: pos. Zener tempco can balance neg. diode tempco)
 - * Poor regulation (line and load)
 - * Most are *very* noisy
 - Instead, use *bandgap reference*: temperature-compensated *forward-biased* diode (1.25 V drop)
 - The concept:
 - * Diodes have negative tempco (i.e., diode drop falls with rising temperature)
 - * BJT current sources have positive tempco (think about it)
 - * Run BJT current through a resistor to get voltage with positive tempco
 - * Combine positive and negative tempco voltages to get zero tempco voltage (silicon bandgap!)



~1.22 eV

4. Laboratory experience

- When taking plots save as CSV or BMP (or snap a CLEAR picture)
 - Show units, label axes, identify waveforms (e.g., “input”)
 - Horizontal and vertical divisions should be clear
 - In most cases, channel grounds should be shown
- Use handouts for guidance on particular circuits
 - Detailed laboratory procedures (look for * in contents), explanations, pin-outs
- Follow lab *book* (detailed instructions in supplementary text)
- **Keep two** off-the-shelf (OTS) 10 V **regulators** with bypass caps (may delay until later labs)

5. Laboratory reports — **SEE HANDOUT FOR STRATEGIES**

- **As always**, show data *points* in plots (i.e., not just interpolation).
- When comparing regulators, consider combining data across all regulators on a single plot.
- Give **units** for dropout voltage, line regulation (2), PSRR, load regulation, voltages, and currents.