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 $v_L = L\frac{\mathrm{d}i_L}{\mathrm{d}t}$ emf)
     - Capacitors provide low impedance for high frequencies ($sL \to \infty$, $sL \| 1/(sC) \to 0$ as $s \to \infty$)
       * $i_C = C\frac{\mathrm{d}v_C}{\mathrm{d}t}$, 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 $\|$ resistance, high $\|$ 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 V)
            - Avalanche breakdown dominates for high voltages (> 6 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 $I_{\text{sc}} \times V_{\text{in}}$ 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!)

$\sim$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 bge 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.