# 18-220 Exam Review

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Bunch of practice problems for 18-220. Problems are sorted by lecture, and can be focused on

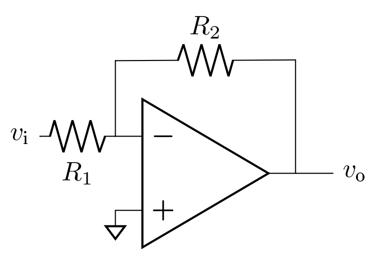
- Lab
- Lecture
- Homework problems

## Lecture 2

Introduction to how we view circuits, abstractions and modeling.

You learn about op-amps, what they are used for, and how to solve problems with them in the ideal and non-ideal contexts.

1. What are the assumptions for an ideal op-amp? Also mention that implications they have to help us solve opamp circuit problems.
2. What is the transfer function ($v_o/v_i$) for an inverting op-amp?




3. What happens when our opamp is not ideal, and has
   - Nonzero input current?
   - Finite input resistance?
   - Finite output impedance?
4. What is voltage/current gain?
5. Derive the transfer function for an inverting opamp with finite gain.

## Equations

$$V = IR \tag{1}$$

Ohm's law, $V$ is the voltage, $I$ is the current and $R$ is the resistance. Probably the most important fundamental equation used to solve circuit problems.

$$\lambda = \frac{c}{f}, \tag{2}$$

where $\lambda$ is the wavelength, $f$ is the frequency, and $c = 3 \times 10^8$ m/s.

## Lecture 3

We learn about diodes and MOSFETs.

1. A diode is made from a P and N type. Explain how these two regions build a diode.
2. Draw the I-V curve for a diode, and label the different regions.
3. We model a diode has having an exponential relationship between the current and the voltage after it is on, that is
$$I \propto e^V,$$
but this means that if we were to turn up the $V$, the current could potentially be very large. What do you expect to happen in real life if you were to turn the voltage up very high across a diode, assuming you have no current limiting in the power supply?
4. In light of question 3, how do we modify a pure diode circuit to help limit the current?
5. What are the 3 parts of a MOSFET?
6. Write down the MOSFET equations and their operating regions. (You don't have to memorize these, but you probably should or else you will be too slow on exams)
7. Draw the $I_{\mathrm{DS}} - V_{\mathrm{DS}}$ curve for a MOSFET, with varying $V_{\mathrm{GS}}$.
8. Draw the $I_{\mathrm{DS}} - V_{\mathrm{GS}}$ curve for a MOSFET, labeling $V_{\mathrm{TH}}$.
9. What does it mean for a MOSFET to be "on"?
10. Why do we say there is no current through the gate of the MOSFET?
11. Why do we say the triode region for a MOSFET behaves *linearly*?
12. How many volts is a digital high pin when it is on in an Arduino?
13. In the lab, why can't you see the IR diode turn on and off?

## Equations

The diode equation is
$$i_{\mathrm{D}} = I_{\mathrm{S}}\left(e^{v_{\mathrm{D}}/V_{\mathrm{T}}} - 1\right). \tag{3}$$
The N-MOSFET equations are
$$I_{\mathrm{D}} = \frac{1}{2}\mu_{\mathrm{n}} C_{\mathrm{ox}} \frac{W}{L}(V_{\mathrm{GS}} - V_{\mathrm{TH}})^2 \qquad (\text{Saturation, } V_{\mathrm{DS}} > V_{\mathrm{GS}} - V_{\mathrm{TH}})$$
$$I_{\mathrm{D}} = \frac{1}{2}\mu_{\mathrm{n}} C_{\mathrm{ox}} \frac{W}{L}\left(2(V_{\mathrm{GS}} - V_{\mathrm{TH}})V_{\mathrm{DS}} - V_{\mathrm{DS}}^2\right) \qquad (\text{Triode, } V_{\mathrm{DS}} < V_{\mathrm{GS}} - V_{\mathrm{TH}})$$

## Lecture 4

More MOSFETs and their applications.

1. Why do we say a MOSFET behaves like a VCCS (voltage-controlled current source) in saturation?
2. What imperfection in saturation do nanoscale MOSFETs suffer from?
3. Explain how we get gain from a MOSFET, and what region we have to be in. Extra: why does the other region not work for gain?
4. Draw the following digital gates with MOSFETS:

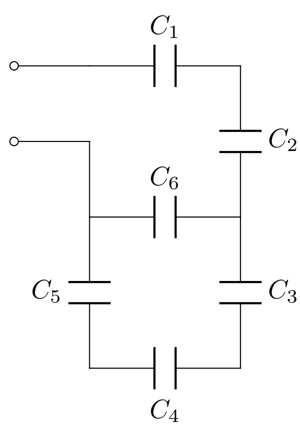
- NOT
- OR
- AND
- XOR

5. Draw a CMOS circuit and explain its advantages to just a MOSFET.
6. Why is it useful to to use MOSFETs as switches? For example, in LAB1 we used a MOSFET as switch to turn on the IR LED, but why didn't we just turn a digital out pin ON and OFF instead of having the MOSFET in between?

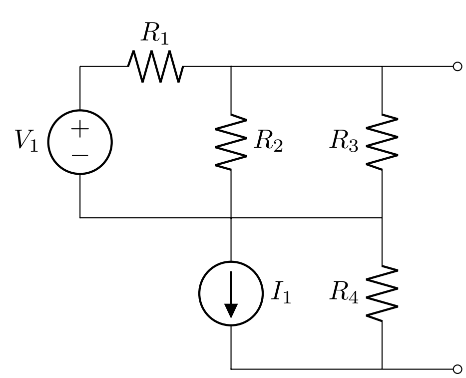
## Lecture 5

Lab1, capacitors, parasitic capacitance in MOSFETs and effect on high frequency action, Thevenin and Norton equivalents.

1. Why is the Manchester Encoding useful?
2. Why does your MOSFET have a frequency limit at which it can operate at?
3. Know the parallel and series capacitance formulas.
4. What is the equivalent capacitance of the following circuit?




5. What are Thevenin and Norton equivalents? Why do we use them?
6. Find the Thevenin and Norton equivalent for the following circuit, [1]




[1] Do it symbolically, it will make you a stronger problem solver. Otherwise, plug in some numbers for yourself

7. Why are nonlinear equations hard to solve? (Don't just say nonlinear means things are complicated, try to give a more specific reason. If you need a hint, think about what techniques you use to solve linear equations)
8. Know the charge and energy equations for a capacitor.

## Equations

Capacitor energy equations,

$$E = \frac{C \cdot V^2}{2}, Q = C \cdot V$$

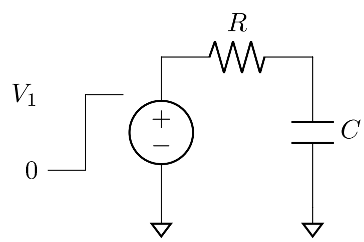
Thevenin and Norton relation

$$V_{\mathrm{T}} = I_{\mathrm{N}} \cdot R_{\mathrm{EQ}}$$

## Lecture 6

Power, RC circuits.

1. What are initial conditions of a circuit, and why do we care about them when we solve for differential equations?
2. If you don't by now, you should definitely know how to use KVL, KCL in circuit problems.
3. Solve the RC step problem,

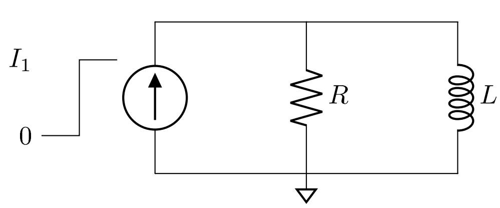



4. We believe in the conservation of energy, but in real life, if you have an oscillation circuit, e.g. LC, it will eventually stop oscillating. Where is the energy "conserved"?
5. What does a capacitor behave like when it is fully charged/discharged?

## Lecture 7

Inductors, RL circuits, DC regulation.

1. How does an inductor store energy?
2. Solve the following RL circuit, with a step input,




3. How does an inductor behave when it is uncharged/charged?
4. Explain how a DC motor works.

5. Draw a full-wave rectifier circuit, and explain how it works.
6. Why do we use capacitors to "smooth" our circuit signals?
7. How is a zener diode different from a diode?
8. In Lab 2, how is the more efficient regulator different from the initial regulator?
9. How do we regulate voltage in Lab 2?
10. Why do we not need to regulate current in Lab 2?

## Lecture 8

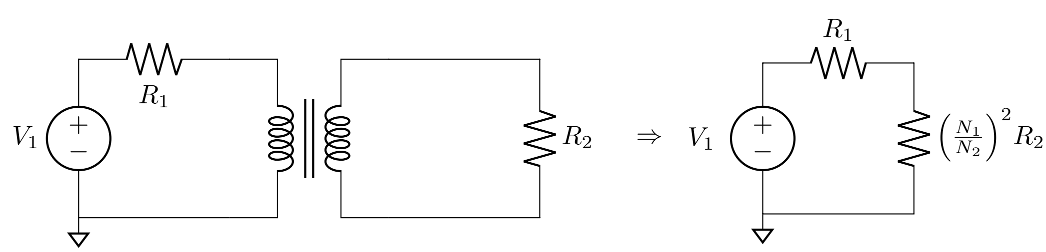
Inductor design, transformers.

1. You have probably heard "parasitic capacitance" and "parasitic inductance" many times now in this course. What do they mean? Why do we call them "parasitic"?
2. What is mutual inductance?
3. What are transformers and why are they useful?
4. What is the ideal transformer model? Draw it.
5. How do we find the equivalent resistance of a resistor on the secondary side of a tranformer?
6. There are several forms of non-idealness for a transformer. In our class, we consider
   - Imperfect ($k \neq 1$)
   - Non-ideal (general)

   for each, explain their implications and how we solve circuit problems with these non-ideal properties.

## Equations

Transformer equivalent impedance



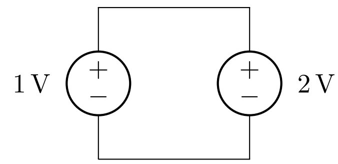

## Lecture 9

Nodal analysis. MNA is basically just setting up a system of linear equations.

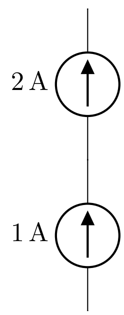
1. If you don't already know, if you have $N$ unknowns, you need $N$ linearly independent equations to solve for these $N$ variables.[2]
2. Why are the following circuits illegal?

[2] Linearly independent means you can't derive any of the equations from the other set of the equations. At a high level, a linear independent equation is giving us more, unique information.

- Circuit 1




- Circuit 2




3. When we say there is "no true ground," what do we mean by that? How can you use this to your advantage when solving MNA problems?
4. What special steps do we have to take in MNA for the following elements?
   - Voltage source
   - Current source
   - Capacitor
   - Inductor
5. Understand how to use superposition to solve circuit problems.

## Equations

MNA Steps:

1. Choose a ground
2. Fill in known values
3. Write dependent equations for special elements
4. Write full set of equation with KCL

## Lecture 10

LC, RLC circuits, switching power converters.

1. We can use a voltage divider to create any voltage $\in [0, V]$ from a voltage source with maximum voltage $V$. Why do we bother to use switching power converters?
2. How does a switching power converter work? What are the steps, and what components do we need at each step?
3. Draw the following converters, and derive the equations that relate the input voltage, duty cycle, and output voltage.[3]

[3] Even though you can just memorize the final equations, you are sometimes asked to derive them on exams.

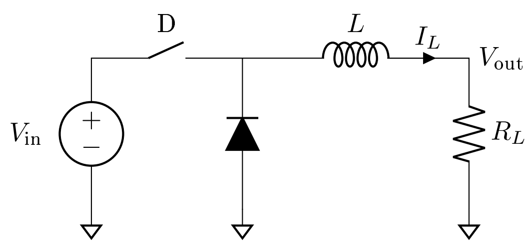
- Buck
- Boost
- Flyback (Buck-Boost)

4. Draw an LC oscillator. How does it behave? Write down the differential equation that dictates its operation.
5. In this class, the steps for solving a differential equation are
   1. Homogeneous solution, we usually assume in the form $Ae^{st}$
   2. Particular solution
   3. Initial Conditions

   It's a good idea to format your solutions to problems like this so it's easier for you and the grader.
6. Draw an RLC oscillator (there are multiple forms). How is it different from an LC circuit? Derive the differential equation for an RLC circuit.
7. Draw a overdamped, critically damped, and underdamped time response for an RLC circuit.

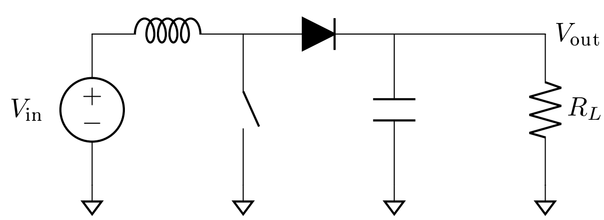
## Equations

Buck converter



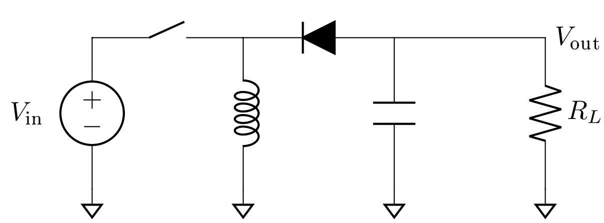

$$\frac{V_{\text{out}}}{V_{\text{in}}} = D$$

Boost converter




$$\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{1}{1-D}$$

Flyback (Buck-Boost)



$$\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{-D}{1-D}$$

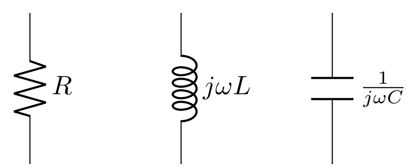
## Lecture 11

Frequency domain analysis, resonance.

1. Why is it useful to analyze circuits in the frequency domain?
2. What are the equivalent impedances for the following elements in the frequency domain?
    - Capacitor
    - Inductor
    - Resistor
3. Draw a RC low-pass filter, and derive its transfer function
4. Draw a RC hi-pass filter, and derive its transfer function
5. How do you convert from the frequency response transfer function to the phasor solution?
6. Why is there a spike on the RLC frequency response graph? How can we modify $R$ to change this peak?

## Equations

Complex impedances




## Lecture 12

Antennas and coaxial cables.

1. How does a coaxial cable work?
2. What are the reflection coefficients of a coax cable circuit with
    - A short circuit?
    - An open circuit?
    - A load with resistance $Z_L$?
3. How do we use reflection signals to figure out how long a coax cable is?
4. Why would we want to match the impedance for a coaxial cable?

## Equations

Antenna equations

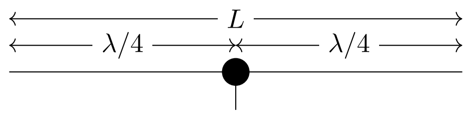



Figure 1: Half-wave dipole antenna

$$L = \frac{1}{2}\lambda$$

Coaxial cable model

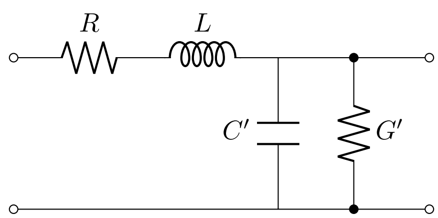



Figure 2: Model for a Coaxial Cable

Reflection coefficient for coaxial cable

$$\Gamma = \frac{Z_L - Z_S}{Z_L + Z_S},$$

where $Z_L$ is the impedance of the load and $Z_S$ is the characteristic impedance.

## Lecture 13

Introduction to RFID circuits.

1. Draw an RFID scanner tag circuit schematic for tha scanner and tag side
2. Why do we need to tune the RFID tags to be at the resonant frequency of the scanning circuit?
3. What is amplitude modulation and how do we use it to transmit data? Why don't we just send the bits directly instead of modulating them?
4. Know that geometry (number of turns, width, height, shape) dictates the inductance of your coil. Also know what would increase/decrease your inductance. You might get a question about "hey this person made an inductor but is getting $X$ response on the plot. What do you suggest they do to make their scanning circuit more accurate?"

## Lecture 14

1. What are the steps to demodulate a signal?
2. What is the 3 dB point? Why is it named that, and what does it indicate about your Bode plot?
3. Make a circuit that is
   (a) Low-pass, using
      i. RC
      ii. RL

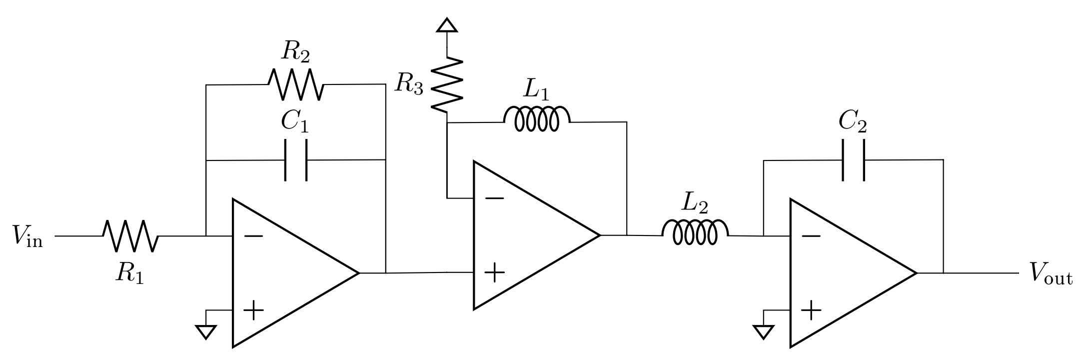
   (b) High-pass, using
      i. RC
      ii. RL
   (c) Band-pass, using RLC

4. What is the difference between an active and a passive filter?

## Lecture 15

Important lecture as bode plots/transfer functions/feedback are fundamental to this entire unit. Know how to draw bode plots. If you have your Bode plots down, they are free points on an exam.

1. Using an op-amp and R, L, C, make
   (a) A low-pass filter
   (b) A high-pass filter
   (c) A bandpass filter
2. Why do op-amp filters allow us to concatenate filters together?
3. What is a limitation of lower-order filters, and why might we want to use a higher-order filter?
4. Given
$$\frac{10j\omega(1+\frac{j\omega}{100})}{(1+\frac{j\omega}{10})(1+\frac{j\omega}{10^4})(1+\frac{j\omega}{10^4})}, \tag{4}$$
   find the
   (a) Gain at $\omega = 1\,\text{rad/s}$
   (b) Gain at $\omega = 100\,\text{kHz}$
   (c) List all the poles (including multiplicity)
   (d) List all the zeros (including multiplicity)
   (e) Sketch the Bode plots for both magnitude and phase
   (f) What is the phase and gain margin?
5. For the following circuit,




   (a) Find the transfer function.
   (b) Find all poles an zeros.
   (c) What type of filter is this?
   (d) Draw the Bode plot for magnitude and phase
   (e) What is the phase and gain margin?

## Lecture 16/17

There's some review on bode plots but the main focus for this one should be op-amp limitations and how feedback comes in for analysis of non-ideal opamps. This is also a meaty topic for exam questions.

1. Describe the assumptions for an ideal opamp.
2. Why would the opamp behavior change with temperature variation?
3. Why do we say an ideal op-amp is like a voltage controlled voltage source (VCVS)?
4. Why do we not want positive gain at 180°?
5. Draw a general feedback diagram with labels, and derive the equation for $v_o/v_i$
6. Describe the process for finding the following. Draw diagrams too!
   (a) Loop gain
   (b) Open loop gain
   (c) Closed loop gain
   (d) Write the equation that relates LG, OLG, CLG (Black's formula)
7. How can compensation capacitors help with stability?
8. Write the feedback functions for a Butterworth Filter

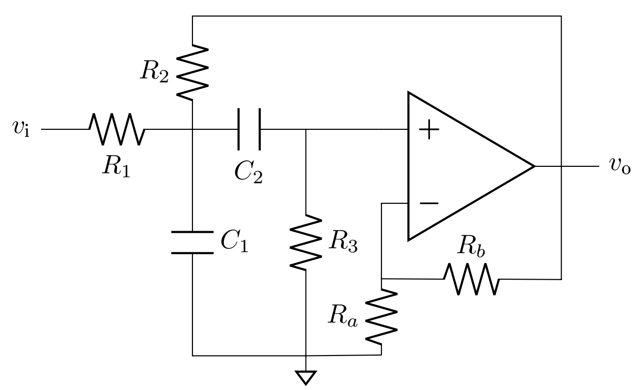



Figure 3: Butterworth Filter

   (a) OLG
   (b) LG
   (c) CLG
   (d) Ideal opamp gain
9. For an ideal opamp, what do we want of the
   (a) Input impedance
   (b) Output impedance

## Lecture 18

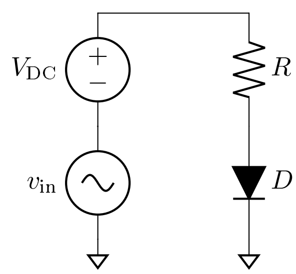
Linearization, why we do it and why it's important.

1. Why do we prefer to have all of our elements to be linear in analysis?
2. Describe the process for finding (this is more of a review question)
   (a) Thevenin equivalent
   (b) Norton Equivalent
   (c) Input impedance
   (d) Output impedance
3. Understand why you might use a Taylor series for a nonlinear element
4. Briefly understand what the Newton method is doing

## Lecture 19

Operating circuits at AC around a DC operating point, small signal analysis.

1. Given the following circuit,




Assume the diode can be modified with the standard diode equation, with $V_T = 0.026\,\mathrm{V}, I_S = 1 \times 10^{-12}\,\mathrm{A}$

   (a) If $V_{DC} = 5\,\mathrm{V}$, find the required $R$ to achieve a bias current of $30\,\mathrm{mA}$through the diode.
   (b) At this DC operating point, what is the change in current with respect to the change in voltage?
   (c) What is the change in current with respect to the change in the *operating voltage point*?
   (d) If we want to increase $V_{DC} = 12\,\mathrm{V}$ and still maintain $30\,\mathrm{mA}$through the diode, what resistor can we add in parallel to $R$ to get our desired operating point?
   (e) We observed two operating points in this problem, $V_{DC} = 5\,\mathrm{V}, 12\,\mathrm{V}$. Which operating point gives a bigger current swing?

## Lecture 20

Small signal models, DC operating points, and analyzing small signal gain at various DC operating points.

1. What is a DC operating point?
2. How is small signal different from large signal?
3. Why do we care about small signal gain?
4. Why is nonlinear gain generally bad?
5. What region do we want to operate our MOSFETs in our gain circuits? Why do the other regions not work?

## Lecture 21

Large signal analysis for MOSFETs, using MOSFETs to create an amplifier.

1. What is a characteristic of the I-V graph of a MOSFET in the saturation region? Why is this useful for analog amplifiers?
2. Given a MOSFET amplifier circuit, what are the steps to finding the small signal gain?

## Lecture 22

Nonlinear feedback systems, Colpitts oscillator.

1. Why is negative feedback important for the stability of an opamp?
2. Why is positive feedback useful for oscillators?
3. What are some applications of oscillator circuits?
4. Draw a Colpitts oscillator and briefly describe how each component works.
5. Derive the LG, OLG, and CLG of a Colpitts oscillator circuit.
6. Explain why a potentiometer can be used to create a voltage divider.

## Lecture 23

Wireless communication, radio technologies.

1. Name a few communication technologies that preceded wireless communication.
2. Name a few scientists that contributed to wireless technologies, their approximate time period, and what their contribution was.
3. What is the Electromagnetic Spectrum? What is its relation to the radio spectrum and the visible light spectrum?
4. Draw the schematic for a basic radio transmitter and receiver.
5. Explain how AM modulation is done, and why we need it.
6. What is the function of the Colpitts oscillator in Lab 6?
7. Why do you need a buffer circuit in Lab 6? A buffer circuit has a gain of 1, which won't change the input signal shape, so why is it necessary? (*Hint: try removing your buffer from your Lab 6 circuit*)

## Lecture 24

1. What geometric pattern are cellular stations distributed in? (*Hint: Think about the bees*)
2. What operation does a mixer circuit perform?
3. What is a coupling capacitor used for?

## Lecture 25

Radio receivers, different types of radio architectures. For exam purposes, you mostly just need to know facts and trivia about this topic.

1. What is the primary job of a radio receiver?
2. Why are envelope detectors used in radios? What are some limitations?
3. Draw the components of the superheterodyne receiver architecture, and explain how it selects channels.

## Formulas

- Ohm's law
$$V = IR \tag{5}$$
$V$ is the voltage, $I$ is the current and $R$ is the resistance. Probably the most important fundamental equation used to solve circuit problems.

- Power
$$P = VI = I^2R = \frac{V^2}{R} \tag{6}$$

- Thevenin and Norton relation
$$V_\mathrm{T} = I_\mathrm{N} \cdot R_\mathrm{EQ} \tag{7}$$

- MNA Steps:
  1. Choose a ground
  2. Fill in known values
  3. Write dependent equations for special elements
  4. Write full set of equation with KCL

- Wave equation
$$\lambda = \frac{c}{f}, \tag{8}$$
where $\lambda$ is the wavelength, $f$ is the frequency, and $c = 3 \times 10^8\,\mathrm{m/s}$.

- Diode equation
$$i_\mathrm{D} = I_\mathrm{S}\left(e^{v_\mathrm{D}/V_\mathrm{T}} - 1\right) \tag{9}$$

- The N-MOSFET equations are
$$I_\mathrm{D} = \frac{1}{2}\mu_\mathrm{n} C_\mathrm{ox}\frac{W}{L}(V_\mathrm{GS} - V_\mathrm{TH})^2 \qquad \text{(Saturation, } V_\mathrm{DS} > V_\mathrm{GS} - V_\mathrm{TH}\text{)}$$
$$I_\mathrm{D} = \frac{1}{2}\mu_\mathrm{n} C_\mathrm{ox}\frac{W}{L}\left(2(V_\mathrm{GS} - V_\mathrm{TH})V_\mathrm{DS} - V_\mathrm{DS}^2\right) \qquad \text{(Triode, } V_\mathrm{DS} < V_\mathrm{GS} - V_\mathrm{TH}\text{)}$$
the current is zero when the MOSFET is off, when $V_\mathrm{GS} < V_\mathrm{TH}$.

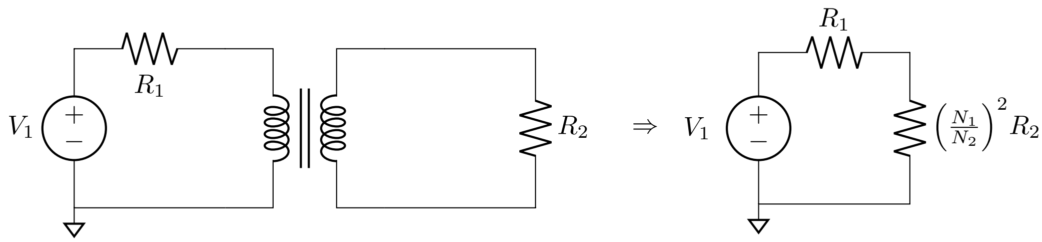
- Capacitor equation
$$i_C(t) = C\frac{\mathrm{d}V_C(t)}{\mathrm{d}t} \tag{10}$$

- Capacitor energy equations
$$E_L = \frac{1}{2}CV_C^2, Q = C \cdot V \tag{11}$$

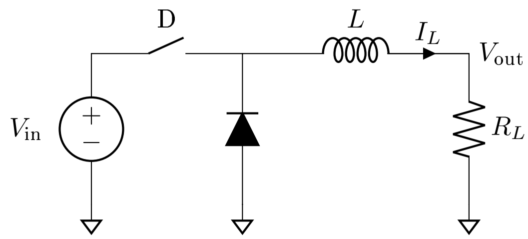
- Inductor equation
$$v_L(t) = L\frac{\mathrm{d}i_L(t)}{\mathrm{d}t} \tag{12}$$

- Inductor energy equations
$$E_L = \frac{1}{2}LI_L^2 \tag{13}$$

- Transformer equivalent impedance

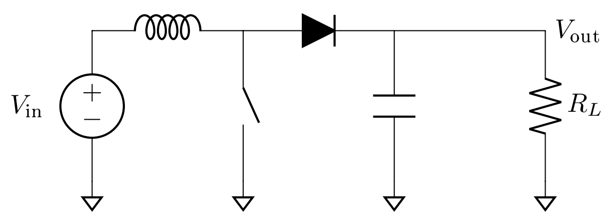



- Buck converter



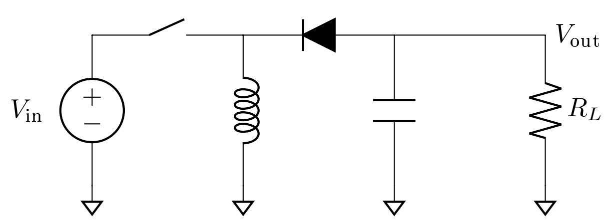

$$\frac{V_{\text{out}}}{V_{\text{in}}} = D \tag{14}$$

- Boost converter




$$\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{1}{1-D} \tag{15}$$

- Flyback (Buck-Boost)




$$\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{-D}{1-D} \tag{16}$$

- Resonant frequency of LC circuit

$$\omega = \frac{1}{\sqrt{LC}} \tag{17}$$

- Antenna equations

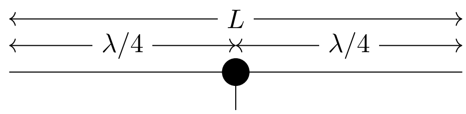



Figure 4: Half-wave dipole antenna

$$L = \frac{1}{2}\lambda \tag{18}$$

- Coaxial cable model

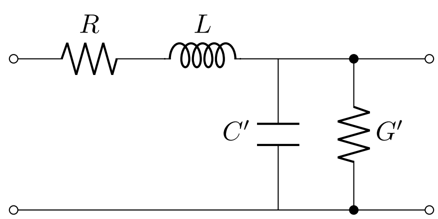



Figure 5: Model for a Coaxial Cable

- Reflection coefficient for coaxial cable
$$\Gamma = \frac{Z_L - Z_S}{Z_L + Z_S}, \tag{19}$$
where $Z_L$ is the impedance of the load and $Z_S$ is the characteristic impedance.

- Hertz to radians
$$f = \frac{\omega}{2\pi} \tag{20}$$

- Decibel to absolute gain relation
$$\text{Gain(dB)} = 20\log_{10}\frac{V_{\text{out}}}{V_{\text{in}}} \tag{21}$$

- Canonical transfer function
$$\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{-Aj\omega/\omega_{\text{z}}}{(1 + j\omega/\omega_1)(1 + j\omega/\omega_2)} \tag{22}$$

## Scientists

You will need to know about some scientists for the final.

1. **Alessandro Volta:** first demonstrated electrochemical reactions to provide electrical energy.
2. **James Watt:** Scottish, patented the steam engine in 1769. The unit Watt, electrical and mechanical power, is named after him.
3. **Faraday:** showed that a force is produced on a current by a magnetic field.
4. **Lenz:** Russian physicist who discovered that current induced in a coil du to a magnetic flux change through the coil will always be such that it opposes the change that caused it.
5. **Fourier:** Found that signals can be decomposed into an infinite sum of sine and cosines.
6. **Marconi:** In 1901 held a 200 m wire in the air with a kite to receive the first radio signal across the Atlantic Ocean

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