Audio Electronics

I. Transformers

a. Intro

i. Two or more inductors placed back to back to each other wrapped around a core.

ii. Magnetic field created when AC current passes through inductor, and visa versa (Faraday's Law)

iii. When two inductors are placed next to each other, a magnetic field in one will generate current in the other

iv. Input is primary coil, output is secondary coil

v. Number of turns in each inductor determines the strength of the field in the first and the current in the second.

b. Isolation Transformers

i. No physical contact is made with transformers, preventing ground loops.

ii. Ground loops occur when there is more than one path to ground and electrons circle around the loop instead of going to ground, leading to noise.

iii. Important in studios with lots of gear, or racked devices connecting to ground through the chassis

iv. Transformers used on inputs and outputs of these devices to physically isolate them

v. Usually have a 1:1 turns ratio

vi. More expensive isolation transformers need to be used in order to pass all audible frequencies, however simple isolation transformers can be used for debugging.

vii. Faraday's Law only applies for AC. DC currents won't be passed with transformers, making them DC blockers.

c. Input/Output Phase Relationship

i. Direction of turns in the inductor determines if the input and output are in or out of phase

ii. Dot convention used where transformers are marked to know whether or not the output is in phase

iii. Phase not always relevant, assumed to be in phase if unmarked

d. Input/Output Amplitude Relationships

i. The **turns ratio** is primary : secondary coils and this determines input/output amplitude.

ii. Relationship: $a = np/ns = Vp/Vs = Is/Ip$

iii. Can be used for simple calculations

iv. Some power is realistically lost to heat. However, power can never increase.

e. Step up and Step Down

i. Maximum voltage is ideal for audio gear, transformers can be used to maximize voltage.

ii. "stepping up" voltage, **step up** transformer

iii. Reducing voltage is a **step down** transformer

iv. There is a limit to how much voltage can be amplified with transformers.

v. When increased current no longer increases the magnetic field, coil is **saturated.**

vi. Driving coil past saturation point leads to distortion

vii. Voltage or current shouldn't be amplified more than +25dB

viii. Often used in high power amplifiers in cars
ix. Step down transformers used convert electricity at wall into DC voltage more suitable for gear

f. Impedance Adjusting
i. Most common use in audio is adjusting impedence, especially between mic and pre amp
ii. Amps designed to deliver to high impendence and loudspeakers have a low load impedance.
iii. Transformer used to transform load impedance to satisfy both devices.
iv. This is due to **load reflection**, the basic way transformers operate
v. Impedance between source and load always adjusted when using transformers
vi. Np/ns = Vp/Vs = Is/Ip = $\sqrt{}$ **Zp/** $\sqrt{}$ **ZL**
vii. Use this to calculate turns ratio necessary for adjusting impedance a certain amount

g. Balanced/Unbalanced Conversion
i. Make use of multiple coil transformers
ii. In multiple coil transformers, there are multiple turns ratios, if ratios identical, primary will appear at each of the secondaries with same amplitude
iii. Splitting transformer has on primary and two secondary coils, used in DI boxes to convert unbalanced to balanced signal
iv. Splitter can be reversed, transformer based DI boxes are useful because they work in both directions.
v. Placing a center tap on the transformer allows it to serve balanced/unbalanced use or that of a simple transformer
vi. Multi-tapping a secondary transformer also allows for connection to different load impedances

h. Bandwidth
i. Parasitic capacitances and inductances form between coils and have a band pass response on the frequency
ii. Cheap transformers can only pass about 80Hz to 3kHz, while high quality ones can pass all audible frequencies

i. CMRR
i. Transformers used for mic preamps to convert signal and cancel out noise
ii. Quality of noise subtraction is specified by Common Mode Rejection Mode
iii. Applying same signal to each input is known as common mode signal
iv. Rejection ratio given in db, higher value, better the subtraction.

II. The Op-Amp

a. Intro
i. Three types of amplification: voltage, current, and power
ii. Mic preamps, effects, and synths are based upon voltage amplification, done through op amp
iii. Op amps are mostly voltage amplification
iv. Negative feedback often used to stabilize signal and give wider bandwidth, giving better fidelity for less amplification
v. Op amp contains voltage amplifier, has <u>high input impedance</u> <u>and low output impedance</u>
vi. Acts as a high impedance load and low impdance source

vii. Amplifies voltage and current with external power
viii. 2 input pins and one output (**differential input)**
ix. Packaged in 8 pin assembly called dual inline package, with two op amps inside sharing a power supply

b. Comparator
   i. Op amps can be open or closed loop
   ii. Open loop mode when two sources applied and a load
   iii. If two sources connected to each pin, equation is: Vout=(+Va-Vb)(Open loop gain)
   iv. Open loop gain often in vicinity of 10,000 to 1,000,000
   v. Despite large gain, voltage cannot exceed voltage of "rails" and will **rail out** if output tries to exceed supply
   vi. This circuit is basically used to return a positive or negative number based on which source is greater
   vii. A use for this is as a gate
   viii. This is one of the few circuits where output will exceed the supply

c. Closed Loop Mode Amplifiers
   i. Op Amps much more useful when feedback loops used
   ii. Negative feedback is when output is fed back to inverting input and positive feedback is when output is fed back to non inverting input
   iii. Amplifiers/attenuators use negative feedback. Oscillators use positive feedback.
   iv. Exception is a filter using positive feedback and 100% negative feedback to stabilize amp

d. Inverting Negative Feedback
   i. When positive terminal is connected to ground and input connected to negative terminal, with feedback to the negative terminal equation is: Vout= -Vin(Rf/Ri)
   ii. Voltage amplified when Rf>Ri, attenuated when Rf<Ri, unity when 1:1.
   iii. Resistors larger than 100K can cause amp to become unstable as it approaches open loop gain mode
   iv. Feedback stabilizes output to lower the gain
   v. In ideal op amp, no current flows into either terminal and the difference in input voltages is 0.
   vi. Equation can be obtained by simplifying circuit based on principles of ideal op amp

e. Non-Inverting Negative Feedback
   i. Signal into (+) terminal with feedback loop on negative terminal
   ii. Vout=Vin(1+Rf/Ri)
   iii. Again, equation can be obtained by simplifying op amp based on basic principles
   iv. Cannot be used as attenuator, only amplifier

f. Unity Gain Buffer
   i. When Rf=0 on a non-inverting feedback amp, it becomes a unity-gain buffer
   ii. Input=Output, however input impedance is infinite and output impedance is almost zero, desirable effects for connecting gear
   iii. Useful for plugging instruments into various devices
   iv. Also can be used to drive long cables.
   v. Cables have parasitic capacitance between hot and cold wires that acts as a low pass filter and lacks high frequencies
   vi. Follows equation: fc=1/2piZguitarC

        vii. Zguitar can be controlled using unity gain buffer, eliminating the problem

    g. Gain versus Bandwidth
        i. Non ideal op amps also have a capacitor inside of them and are prone to instability and oscillation
        ii. Parasitic capacitances lead to positive feedback, causing high frequency limitations
        iii. Negative feedback helps solve this, but lowers gain
        iv. Lower the gain, greater the bandwidth
        v. Systems should be able to amplify frequencies up to 20kHz
    h. Single Supply Biasing
        i. Many pedal boxes etc are run on one 9V battery
        ii. At bipolar operation, 0V input is 0V output as well
        iii. In unipolar operation, 9V is connected to positive and negative is connected to ground
        iv. Bias voltage must be applied so that negative frequencies can occur as well
        v. With a 9V source, you will want the half supply voltage, or Vhs=4.5V
        vi. To bias the circuit, you have to also connect the 9 volt source to the negative input and use a resistor divider to get Vhs
        vii. Capacitors should be placed at all inputs and outputs to prevent DC voltage from flowing through circuit
    i. Capacitor Stuff
        i. All op amps produce some inherent output DC voltage
        ii. This means capacitors need to be placed to get rid of all DC voltage
        iii. However, capacitors last the least time and can lead to problems in the circuit after a short time
        iv. Also, introducing capacitors can lead to filtering and adds to impedance
        v. Manufacturers try to use as few capacaitors as possible
        vi. There is often a ripple in the DC voltage source which can be heard in the signal, so bypass capacitors are placed in parallel with the source for any changes to go to ground.
        vii. These can also be used with single supply biased amps
        viii. Parasitic capacitance at the input can combine with the feedback resistor to create high frequency oscillations at the output
        ix. Placing this in parallel with Rf will cause all high frequencies to feedback completely and are eliminated

III. MOAR OP AMPS
    a. Intro
        i. Using these op amp designs, entire mixing systems with presamps, equalizer, panning, etc can be created
        ii. Single supply biasing, bypass caps, coupling caps all can be added
        iii. Devices can be connected together in series
    b. Input/Output Buffer
        i. Adding these to the input/output can increase performance
        ii. Input buffer creates a high input impedence
        iii. Unity gain novinverting amp usually used
        iv. Output buffer can be inverting or non inverting and used to give maximum current drive
    c. Mic Preamps

i. Preamps need to satisfy impedance and balancing requirements
ii. Also need to provide high voltage gain since microphones get very low voltage levels
iii. Need high gain AND high input impedance
iv. High-Z
1. 20K impedance and 20 mV output
2. Unbalanced signal
v. Low-Z
1. Impedanceof 200 ohms and 2 mV output
2. Balanced
3. Can use another transformer or a differential amplifier
vi. See diagrams in book

d. Filters and Equalizers
i. Fixed low pass and high pass filters using op amps are common to get rid of excess noise/low freqs
ii. Variable filters important for equalizers, especially those using shelving filters
iii. See diagrams in book
iv. Common use of fixed filters is in crossovers for loudspeakers
v. Different drivers reproduce different frequencies.
vi. These can be active or passive
vii. Third order Butterworth crossovers address most of the design issures
viii. Sallen-Key, utilizes both positive and negative feedback
ix. Used as crossovers, no gain or Q or variable shit
x. Shelving Filters
1. Most widely used filter
2. Baxandall filter employs both high and low shelving at same time
xi. Graphic EQ
1. Bank of parallel bandpass/bandstop
2. Have fixed center frequency and adjustable boost/cut and Q
xii. Parametric EQ
1. Adjustable boost, cut, center frequency, and Q
2. Simpler than graphic EQ

e. Balanced Line Driver
i. Requires closest to ideal as possible op amps
ii. Converts unbalanced into balanced signal
iii. Simple and uses similar valued resistors
iv. Resistors must be mached with tight tolerance
v. Inverting amps have high input impedance

f. Oscillators
i. Positive feedback
ii. No input voltage
iii. Square wave, triangle wave, sine wave
iv. Square wave created by going from positive to negative rail
v. Lowpass filter added leads to sine wave

IV. Tubes
a. Edisons light bulb: Filament inside of glass vaccum, which when currents passed through creates light. Gave off black soot though.
b. Positively charged plate added to collect electrons and soot, controlling flow of electrons

within the vaccum

c. Second plate added as well to control the flow of electrons
d. Second plate is **cathode,** first plate is **anode**, they make up the **diode.**
e. Diode
    i. Plate is positively charged in order for electrons to flow
    ii. If you applied an AC voltage to the plate, current would only flow during the positive portion
f. Half-Wave Rectification
    i. Allows positive portions of AC waveform to pass through
    ii. Plate is the input and cathode is the output
g. Full wave rectification
    i. Inverts negative portions of the input and combine them with the positive portions
    ii. Can be made with multiple diodes, most often two diodes and a transformer
    iii. Two plates shared in a tube
    iv. Summed at the cathode
    v. Center tapped transformer is used to feed the inverted and noninverted signals into the tube
    vi. This tube is used to concerted a 60Hz 120VAC signal into 250 V DC.
    vii. The humps of the fully rectified signal are smoothed out to create a flat line using filters that get rid of the Ac portion.
h. Triode
    i. Extra plate added, allowing constant positive charge for one plate, and extra plate to control the flow of electrons
    ii. Type of screen called **control grid**
    iii. If negative field is applied, electron flow towards positive plate will slow
    iv. When grid at 0V, maximum flow, when no electrons flow, this is the curoff.
    v. By controlling grid voltage with an audio signal, you can get proportionally large changes in current flow with small changes in voltage
    vi. Often multiple triodes will be used