Physics of Musical Sound

Class 36

Read Section V

Especially Chaps. 19, 20, & 22

Electronic Terms

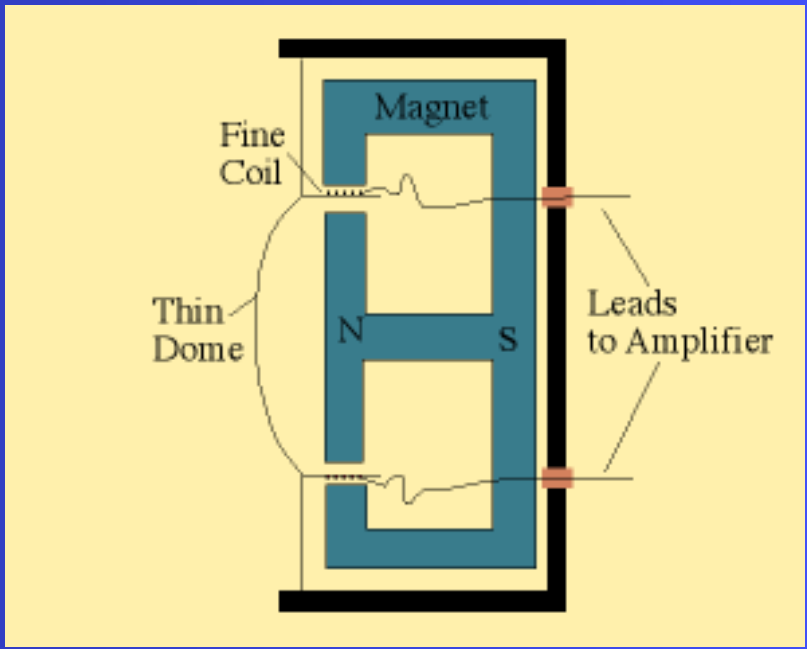
- Charge
  - A fundamental property of the elementary particles from which the world is built. Two kinds which we call POSITIVE and NEGATIVE. Charges exert forces on nearby charges. We can think of charge as a kind of fluid that can move around in CONDUCTORS.
- CURRENT
  - Moving charge makes current, measured in AMPERES (AMPS), amount per second, like current in a stream.
- VOLTAGE
  - Current flow is driven by electric forces that create a pressure that we call VOLTAGE (VOLTS).
- RESISTANCE
  - How hard it is to make current flow. Long thin wires (like long thin tubes) are high resistance and short fat wires (like short fat tubes) are low. Units are OHMS.
- POWER
  - Flowing current can do work so it carries POWER = VxI.

Electronic Reproduction

- Transducers
  - Convert Energy from one form to another
  - Microphone converts pressure variations or velocity of air into an electrical current.
  - Loudspeaker converts electrical current into movement of a speaker cone and so into pressure variations in the air.
- Amplifiers
  - Change the size of a signal, ideally without altering anything else about it.
- Processors
  - Alter the shape or nature of a signal in some way.
  - Some work directly on signal, some convert signal into a set of numbers and then operate on the numbers.

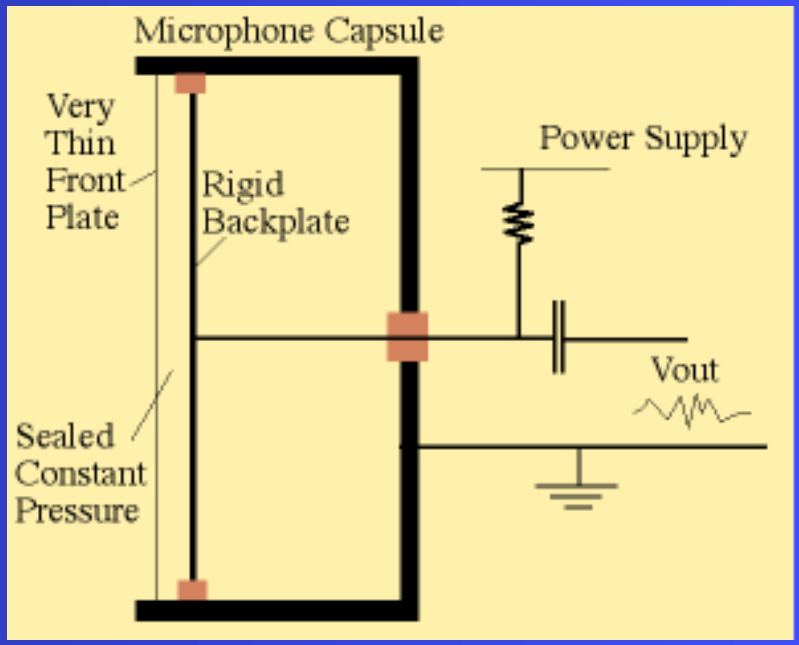
Dynamic Microphone

- Thin wire coil with many turns mounted between poles of a strong magnet.
- Coil is connected to thin, stiff dome which is flexibly mounted.
- Moving air moves the dome backwards and forwards.
- As wires move through magnetic field a current is forced through them.
- Current is proportional to velocity of air in wave.



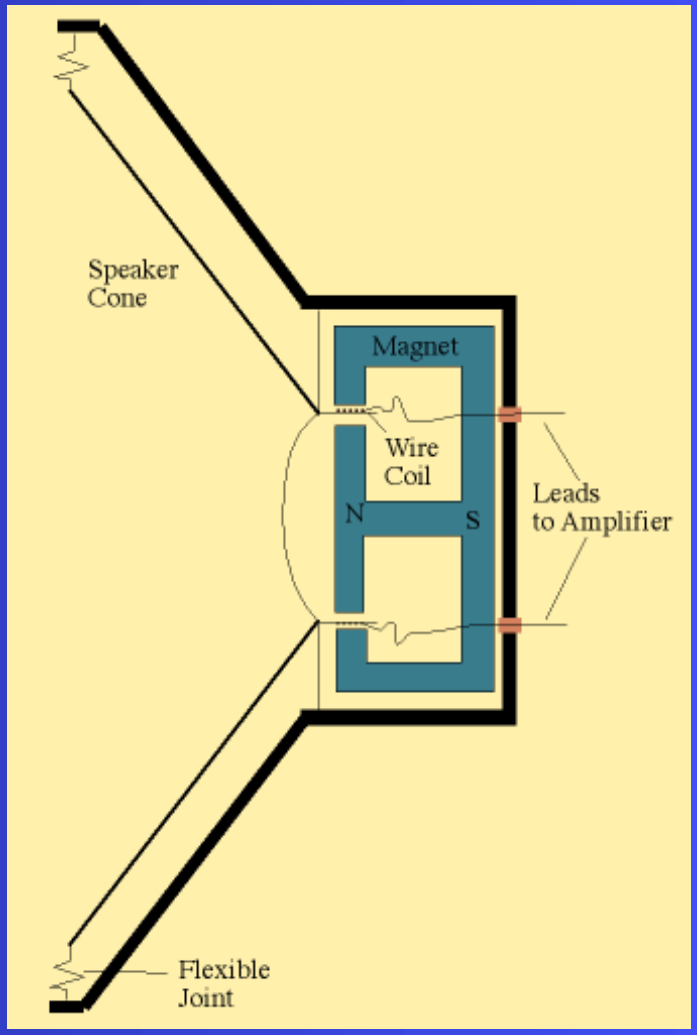
Capacitance Microphone

- Very thin metal foil arranged over a sealed cell with a metal back.
- Apply a voltage between foil and back, makes charges form on them.
- Air pressure changes fore the thin plate to move in and out.
- As foil moves, negative charge on plate attracts positive charges in backplate creating current in wire.
- Current is proportional to pressure of air in wave.



Loudspeaker

- Stiff cone is suspended from a heavy metal frame so it can move in and out.
- Cone connected to coil of wire that sits between magnet poles.
- Current from the amplifier flows through the coil and feels a magnetic force.
- That force makes cone move in and out, pushing the air along with it.
- Get a sound wave out whose pressure is related to the current in the wire.
- Make large and small version for low and high frequencies.



Amplifier

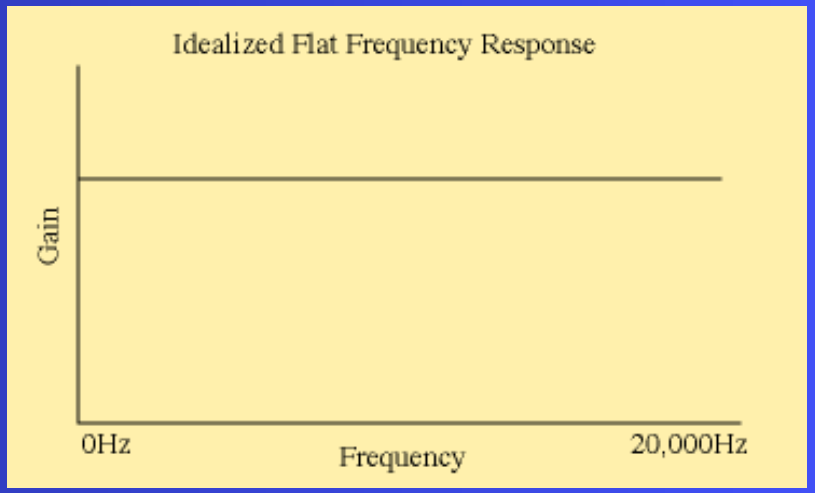
- Increases the size of a signal
  - Gain is $\frac{\text{Power Out}}{\text{Power In}}$. It is usually given in dB.
  - Pre-amps operate on very small signals, typically microvolts, and raise them to useable level, typically 0.3-1.2V, called Line Level..
    - Need very low noise (nV) and quite high gain (40-60dB or 100x to 1000x)
    - Pre-amps increase the signal voltage but cannot supply much power to the output.
  - Power Amplifiers take the line level signals and amplify them again. They only increase the voltage 1-100 fold but can supply very large output currents and so have very large Power gains.
  - General purpose amplifiers should not affect sound in any way but volume. Amps. For specific purposes may be chosen for non-ideal characteristics that are deemed pleasing. Eg. Many electric guitarists like vacuum tube amps because their imperfections are different from solid-state amps.

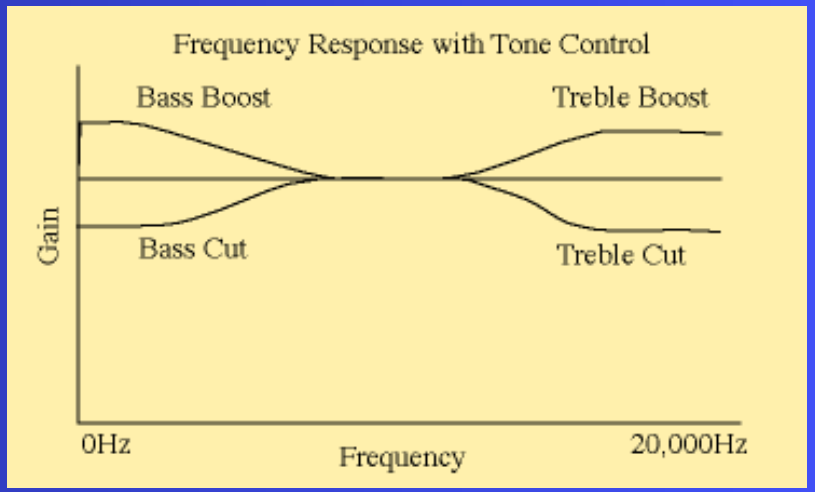
Amplifier

- Gain
  - Should be constant over the audio range, at least 20Hz-20kHz. Called flat response.
  - Real amplifiers should be flat to ±1dB over range.
- Linearity
  - Output signal should be a faithful copy of input signal.
  - Measured as Total Harmonic Distortion.
    - Pass signal through amplifier and record output. Subtract a best fit copy of original signal. Average difference over a few seconds. THD is $\frac{\text{Power in Difference}}{\text{Power in Signal}}$ expressed as %
  - Good amplifiers should have THD << 0.1%.
- Cross-talk
  - Extent to which a signal on one channel bleeds into another.
  - Ideally none, realistic values >100dB separation possible.

Analogue Signal Processing

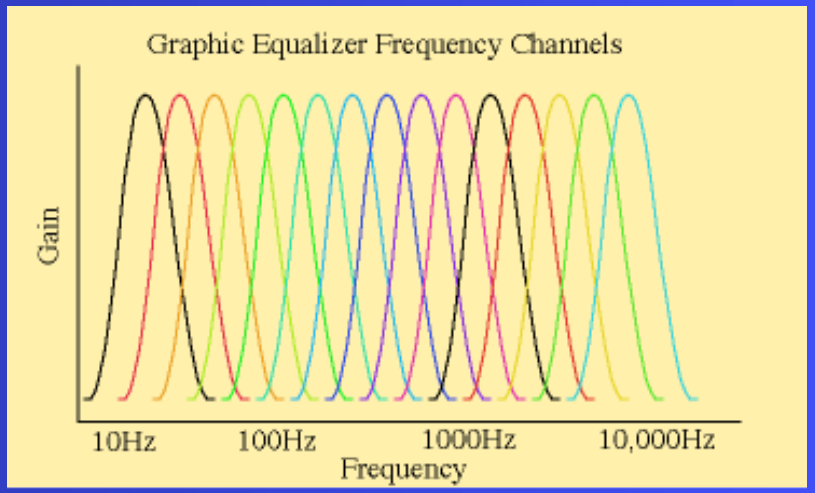
- A signal processor alters the sound signal in some way other than just its size.
- Example:-
  - Tone controls alter the amount of bass or treble in the signal. They make fairly coarse alterations in the sound.
  - You can control the amount of boost or cut but not the frequency at which it occurs.





Analogue Signal Processing

- Graphic Equalizer
- Like a tone control but with many frequency channels.
- Allows control of gain for each channel independently.
- Used to tailor frequency response to system to environment and needs of the user.



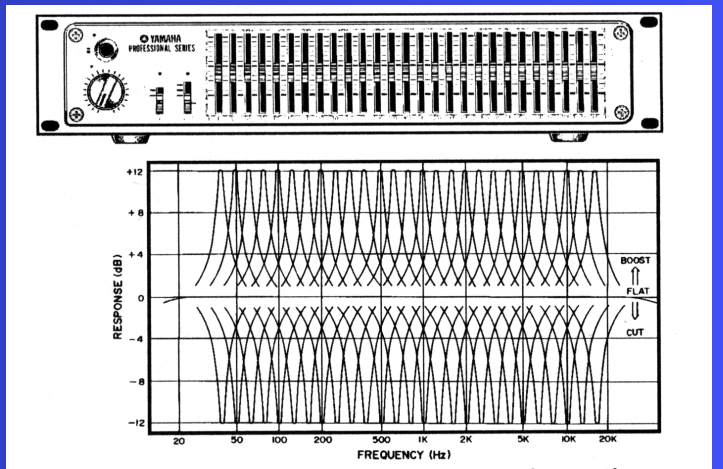
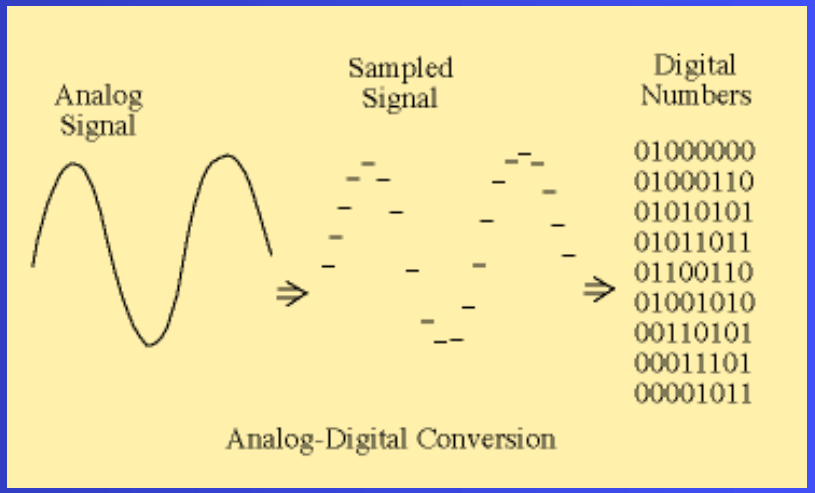
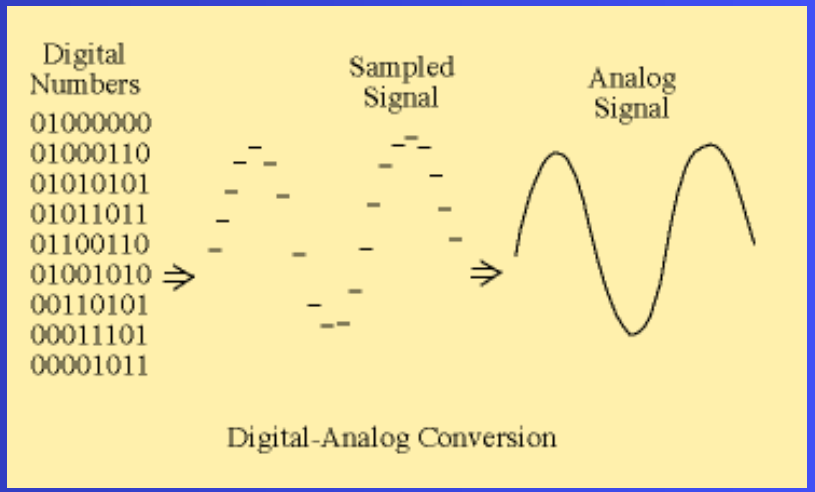


Figure 14-8. A one-third octave graphic equalizer

Digital Signals

- Can convert a time varying voltage signal to a stream of numbers representing the signal with an Analog-Digital converter (A-D or ADC)
- Can convert a stream of numbers to a time varying voltage with a Digital-Analog converter (D-A or DAC).





Converter Characteristics

- Sample Rate
  - Number of conversions made per second.
  - Require at least two samples for each full cycle of a wave so that maximum frequency that you can digitize is half the sample rate. This is called the Nyquist frequency.
    - Thus to digitize sound we must sample at least 40,000 times per second to capture the complete audible range.
    - CDs are recorded and played at 44,100 samples/sec (44.1ks/s) and so can go a little beyond the highest audible frequency.
    - Pro. audio systems use higher sampling rates, eg. 96ks/s, to make sure that the maximum amount of info is present in the original samples from which a final recording is made.

Converter Characteristics

- Sample Size
  - Given as number of bits in the binary representation of the number.
  - More bits means more different sound levels can be represented and so a more accurate picture of the sound can be made.
  - 8-bits gives 256 different levels. Enough to produce recognizable speech but very limiting for music.
  - 16-bits gives 65,536 different levels.This is enough to record music with a total dynamic range of about 93dB.
  - Professional mastering systems use up to 24 bits, about 16 million levels, and can represent a wider dynamic range than you can hear.

Digital Plusses and Minuses

- Allows perfect copies to be made as often as you want. Duplicate the numbers and you have duplicated the record.
  - All analog recording techniques suffer from a loss of quality, introduction of noise, when they are copied.
- You can process the numbers in any way that you want. You can even make up numbers for new sounds that have no other existence.
- Takes a LOT of space. 1 minute of stereo CD quality sound takes about 10MB of storage.
- You can compress the digital information by large amounts and still keep extremely high sound quality. This allows you to beat the space problem to a large extent.

Sound Synthesis

- Analog vs. Digital
  - Analog—came first, 1950's. Generate an electric signal with oscillators, filters, mixers, envelope generators and play into an amplifier. Eg. Moog, Yamaha DX-7.
  - Digital—practical since 1980's. Generate sequence of numbers by algorithm and turn into voltage with digital-analog converter. Can emulate anything, including analog synths. Modern computers can do this with synthesizer programs eg. Reaktor.
  - Samplers—record sounds from world and play back with shifted pitch. Mellotron was analog version, modern are digital.

Analog Synthesizer Units 1

- Oscillator
  - Generates periodic voltages as primary sound sources
  - Wave shapes available might include simple sine, square, triangle, and sawtooth.
  - Frequency usually contolled by a voltage generated by a keyboard.
- Mixer
  - Adds two or more sounds together without altering them.
- Filter
  - Enhances or removes certain frequencies
  - Low Pass lets low f through and blocks high
  - High Pass is reverse, Band Pass only passes a range
  - May be wide band or narrow.
  - May be voltage controlled for wah-wah effects

Analog Synthesizer Units 2

- Envelope Generator
  - Takes a constant amplitude sound and varies the amplitude as time passes.
  - Gives sounds their characteristic evolution.
- Low Frequency Oscillator
  - Runs slowly <100Hz, usually adjustable fixed rate
  - Used to wobble some parameter not as direct sound
  - Can give vibrato and tremolo effects
- Noise Generator
  - Adds non-periodic random noise to sound.
- Ring Modulator
  - Vout = V1 * V2 gives complex sounds that evolve in non-harmonic ways. Think Dr. Who.

Additive Synthesis

- Build sounds by adding harmonics using lots of sinewave oscillators.
- Best known Hammond Organ
  - Uses metal rods with toothed wheels to generate pitches and adds together.
  - Drawbars allow player to select amplitude of each harmonic
  - Does not provide envelope control so organ-like sound.
  - Traditionally paired with Leslie rotating speaker for complex vibrato/tremolo phasing effect.

Subtractive Synthesis

- Like voice—start with sound with many harmonics, often sawtooth.
- Feed through one or more filters to adjust spectrum by removing some harmonics—subtractive synthesis.
- Then mix one or more and put through envelope generator.

Envelope Generator

- Commonest ADSR
  - Attack, Decay, Sustain, Release