Audio Electronics

AUDIO ELECTRONICS

1. Initial Concepts

What is an Atom

An Atom is a smallest particle of which all matter is made. It has a positively charged nucleus and a field of negatively charged particles called electrons orbiting around the nucleus

a. Nucleus- The nucleus consists of two particles, a neutral Neutron and a positively charged Proton
b. Electrons – The electrons are negatively charged and they rotate around the nucleus of the atom.

Sources and Kind of Electricity (AC / DC)

It is assumed that electricity is simply - electrons in motion. The movement of electrons as a means of transferring energy from one molecule of a substance to another is determined by how much potential difference exists to initiate this movement. Potential difference is analogous to potential energy.

There are various ways in which electrical potential difference can be created, one of such is the use of chemicals.

Chemical sources- the most common source of electricity is the cell which uses conducting plates in chemical solutions to generate electricity.

Cells- There are different kinds of Cells. Some are higher voltage than others and some are re-chargeable but all produce what is known as Direct Current DC.

Mechanical sources- Another source of electricity is the conversion of mechanical energy to electrical energy. One of such uses electromagnetism.

Electromagnetism- A magnet is a piece of metal that has a field of force around out in a particular direction. This field of force is like lines of force. When a conductor is made to move through this lines of force, it creates a potential difference within the conductor which exerts a force on the electrons. The electrons will then move causing electricty to flow. The direction of flow of electrons will reverse once the direction of movement of the conductor is reversed. This movement and oscillation of electrons will continue until the conductor stops moving.

This kind of electricity is called Alternating Current AC, more on AC later.

2. Electricity

a. Potential Difference- The term potential difference refers to a kind of force that causes electron movement. The unit of PD is Volts. (V)
b. Current- Current is therefore the electrons in movement. The unit of current is Amps. (A)
c. Resistance- and resistance, describes how difficult it is to move. The Unit of Resistance is the Ohms. Electricity can be likened to water in a pipe. The size of the pipe is the resistance, the water the electricity and the tap the Voltage source. If you want more water to pass through (more current) you either increase the water pressure (Voltage) or you increase the size of the pipe (Reduce resistance).
d. Power- Electric power is the amount of work electricity can do. It is a measure of the rate of transfer of energy. Power is the ultimate aim of electrical energy. The unit of power is Watts (W). Electric power in our model above will be how much water is transferred in a specific length of time. This

means, to get the more water to pass in less time (more power) you either increase the pipe size (reduce the resistance), or increase the water pressure (Potential Difference).

e. Ohm's Law- These four quantities, Voltage, resistance, Current and power, are related by the ohm's law. The law states that

V = I *R Eq. 1

Where V is voltage in Volts

I is Current in Amps

And R is resistance in Ohms.

Power = V*I Eq. 2

Substituting using eq. 1 in eq. 2 gives $\mathbf{P = V^2 / R}$ or

$\mathbf{P = I^2 R}$

3. Circuits

a. Series Circuits- A circuit is a closed path through which electrical energy flows. IN a circuit, you have a voltage source, a load, wires/cables to connect the elements of the circuit and a switch or some means of controlling the flow of electricity. A series Circuit is a circuit where the current path is not broken. This means you can traces the path of the current on the circuit diagram with a pencil without lifting the pencil. In other words, the same current flows through all the circuit components.

i. Voltage – The voltage in a series circuit is different for each component except when the components have the same resistance. The voltage is a measure of the current flowing and the resistance of the component.

ii. Current- the current is equal throughout the circuit for a series circuit. All components receive the same amount of current. **Current** is expressed as flow rate of electrons per second and is commonly measured in Amperes or Amps.

1/1000 amps = 1 milliamp (mA).

1 Amp is equivalent to 1 Coulomb of electricity where a coulomb = 6.25×10^{18}

iii. Total resistance- the total resistance in a series circuit is simply an addition of the individual resistance.

$R_{Total} = R_1 + R_2 + R_3 \ldots\ldots$

b. Parallel Circuits- in a parallel circuit, the current breaks up to travel several paths through the circuit and components do not all receive the same amount of current. The current breaks up in relation to how much resistance is on each path. The more the resistance, the less the current on that path.

i. Voltage- the voltage in a parallel circuit is constant and equal across all components
ii. Current- the current drawn by each component in a parallel circuit depends on its resistance and the circuit voltage.
iii. Total Resistance- total resistance in a parallel circuit is a little more tricky

$$1 / R_{Total} = 1/ R_1 + 1 / R_2 + 1 / R_3$$

Practical Applications

Resistance is encountered in Audio in all instances. Some important instances are:

Cable Resistance and Heat loss – When current flows through a conductor, the resistance of the conductor creates a load on the current that it has to overcome to get to the other side. This resistance causes the current to lose some of its ability to do work. This power loss is in the form of heat and can be calculated as

Power Loss due to heat generated = $I^2 \times R$

This is important with speakers.

Speaker Loading –The resistance of the cable used to hook up a speaker is in series with the resistance of the speaker as well, this increases the load seen by the amplifier's output stage and this deteriorates the quality of the output signal.

Power Supply considerations – A power source is often limited by the maximum Voltage it can deliver and the maximum amount of current it can sustain. When hooking up equipment like amps to a source, it is important to note how much maximum current will be drawn from that source and if the source can handle it. This can be easily calculated using the power rating on all the equipment and the Voltage specification for the source. For example, a 1000 Watt amp will draw 4A from a 250 V Source when powered fully.

Speaker to amp matching – the total load (resistance) seen by an amp can be calculated based on the resistance values of the speakers and whether they are connected in series or parallel.

4. Electromotive force (EMF)

To produce a flow of current in any electrical circuit, a source of electromotive force or potential difference is necessary. The available sources are as follows:

i. Electrostatic machines, which operate on the principle of inducing electric charges by mechanical means
ii. Electromagnetic machines, in which current is generated by mechanically moving conductors through a magnetic field or a number of fields ;
iii. Voltaic cells, which produce an electromotive force through electrochemical action
iv. Devices that produce electromotive force through the action of heat ;
v. Devices that produce electromotive force by the action of light ; and
vi. Devices that produce electromotive force by means of physical pressure, for example, the piezoelectric crystal

5. Magnetism and Electricity

in the late 18th and early 19th centuries, the theories of electricity and magnetism were investigated simultaneously. In 1819 an important discovery was made by the Danish physicist Hans Christian Oersted, who found that a magnetic needle could be deflected by an electric current flowing through a wire. This discovery, which showed a connection between electricity and magnetism, was followed up by the French scientist André Marie Ampere, who studied the forces between wires carrying electric currents, and by the French physicist Dominique François Jean Arago, who magnetized a piece of iron by placing it near a current-carrying wire.

In 1831, the English scientist Michael Faraday discovered that moving a magnet near a wire induces an electric current in that wire, the inverse effect to that found by Oersted: Oersted showed that an electric current creates a magnetic field, while Faraday showed that a magnetic field can be used to create an electric current.

What is a magnet- the magnetic properties of materials are classified in a number of different ways. One classification of magnetic materials—into *diamagnetic, paramagnetic,* and *ferromagnetic*—is based on how the material reacts to a magnetic field.

- Diamagnetic materials, when placed in a magnetic field, have a magnetic moment induced in them that opposes the direction of the magnetic field. This property is now understood to be a result of electric currents that are induced in individual atoms and molecules. These currents, according to Ampere's law, produce magnetic moments in opposition to the applied field. Many materials are diamagnetic; the strongest ones are metallic bismuth and organic molecules, such as benzene, that have a structure that enables the easy establishment of electric currents.
- Paramagnetic behaviour results when the applied magnetic field lines up all the existing magnetic moments of the individual atoms or molecules that make up the material. This results in an overall magnetic moment that adds to the magnetic field.
- A ferromagnetic substance is one that, like iron, retains a magnetic moment even when the external magnetic field is reduced to zero. This effect is a result of a strong interaction between the magnetic moments of the individual atoms or electrons in the magnetic substance that causes them to line up parallel to one another. In ordinary circumstances these ferromagnetic materials are divided into regions called *domains;* in each domain, the atomic moments are aligned parallel to one another. Separate domains have total moments that do not necessarily point in the same direction. Thus, although an ordinary piece of iron might not have an overall magnetic moment, magnetization can be induced in it by placing the iron in a magnetic field, thereby aligning the moments of all the individual domains. The energy expended in reorienting the domains from the magnetized back to the demagnetized state manifests itself in a lag in response, known as *hysteresis.*

Magnetic materials can also be categorized on the basis of whether they retain the magnetism after the field is removed.

If they retain the magnetism, the substance is called a magnetically hard material and these are ferromagnetic substances. These are used in the manufacture of speakers.

If they lose the magnetism after the field is removed, they are called magnetically soft materials. These are diamagnetic and paramagnetic materials. Used in tape heads of tape decks.

The symbol for magnetic flux is ϕ and as mentioned earlier, the unit is the Weber (Wb). Weber is defined as the flux that, if reduced to zero, when linked to a coil of one turn will induce an e.m.f. of 1 Volt.

Flux density is the concentration of flux and the unit is weber/meter^2 . The Symbol is B. The weber is too large a unit in audio for example to specify the flux/meter on tape weber/meter2 is too large, instead, nanoweber/meter2 is used. Nano is 10-9 . A typical recorded signal on magnetic tape will have a flux per meter in the region of 300 nWb/meter.

6. Alternating Current

Electric Motors and Generators, group of devices used to convert mechanical energy into electrical energy, or electrical energy into mechanical energy, by electromagnetic means. A machine that converts mechanical energy into electrical energy is called a generator, alternator, or dynamo, and a machine that converts electrical energy into mechanical energy is called a motor. In audio, the device that converts mechanical energy or any other type of energy into electrical energy is called an input transducer and one that converts electrical energy into mechanical energy (speaker cone movement) is called an output transducer. Therefore theories and principles that apply to generators and motors applies to input and output transducers.

Two related physical principles underlie the operation of generators and motors. The first is the principle of electromagnetic induction discovered by the British scientist Michael Faraday in 1831. If a conductor is moved through a magnetic field, or if the strength of a stationary, conducting loop is made to vary, a current is set up or induced in the conductor. The converse of this principle is that of electromagnetic reaction, first observed by the French physicist André Marie Ampere in 1820. If a current is passed through a conductor located in a magnetic field, the field exerts a mechanical force on it.

When a conductor is moved back and forth in a magnetic field, the flow of current in the conductor will change direction as often as the physical motion of the conductor changes direction. Several devices generating electricity operate on this principle, producing an oscillating form of current called alternating current. Alternating current has several valuable characteristics, as compared to direct current, and is generally used as a source of electric power, both for industrial installations and in the home.

An alternating current is a sine wave. It is exactly like the audio we studied already, only this time it represents electricity. When audio is converted to its electrical analogue it exists as AC.

AC current has voltage amplitudes and peak values. It also has rms voltage, frequency and phase.

For an AC supply, the amount of work the supply can do is related not to its peak amplitude but to its rms value. Rms is the same here as it was for sound waves.

6.1 Phase

AC can be in or out of phase. Because AC has a frequency, it has a period and therefore a phase. For standard power supplies (UK) you have 50Hz AC line.

In a standard 3 phase set up you would have three phases 120 degrees out of phase with each other. The sum at any one point of these three would be zero.

A common way of bringing the three phases back together is a star connection which provides 230V between each arm and 400V 3-phase.

6.1 Mains Plug

The mains wiring have colour codes. The brown wire is live (L), the blue wire goes to the Neutral (N) and the green/yellow wire goes to the Earth.

7. **Safety devices**

The high levels of current and voltage that exists in AC distribution systems demands some that some safety measures be put in place. Some of these measured are discussed below.

Fuses

A fuse is piece of conductor which has a maximum current carrying capacity exceeding which it will melt down. When a fuse melts, you say it 'blows'. For domestic rating the most common fuses are 1, 3, 5 and 13A. Fuses are rated by the amount of current they can handle.

For mains supply, there are two types of safety units

i. Residual Current devices (RCDs)- these devices compare the current going in from the live side with that returning to the neutral, if they are not equal a trip operates and the supply is cut.
ii. Earth leakage current devices (ECD)0 these devices operate by detecting a flow of current to the earth.

8. The AC Circuit

The AC circuit is similar to the DC circuit, but differs in that AC is oscillating therefore, frequency dependent characteristics come into play. The fact that AC oscillates is one reason why sound can be converted into electricity.

Voltage in an ac circuit

In an AC circuit, the voltage can be either positive or negative. The voltage considered is the rms voltage. RMS is computed in the same way as for sound waves. The unit is still Volts.

Current in an ac Circuit

Current in an AC circuit can either be positive or negative. the unit is still amps.

Resistance in an AC Circuit

Due to the oscillating nature of Alternating Current, some other factors related to the frequency of oscillation arise. Two of these factors resist the flow of current in relation to the frequency of oscillation. This is reactance. There are two types of reactive elements which differ according to how changes in frequency affect them.

It becomes immediately obvious that reactance plays a big part audio. For one it is a major design factor in filter circuits like cross over networks for passive multi-driver loudspeaker designs (more on this later in the course).

Capacitance

Capacitor, or electrical condenser, is a device that is capable of storing an electrical charge. In its simplest form a capacitor consists of two metal plates separated by a non-conducting layer called the dielectric. When one plate is charged with electricity from a direct-current or electrostatic source, the other plate will have induced in it a charge of the opposite sign; that is, positive if the original charge is negative and negative if the charge is positive. The electrical size of a capacitor is its capacitance, the amount of electric charge it can hold.

Capacitors are limited in the amount of electric charge they can absorb; they can conduct direct current for only an instant but function well as conductors in alternating-current circuits. This property makes them useful when direct current must be prevented from entering some part of an electric circuit.

Capacitance is the ability of a circuit system to store electricity. The capacitance of a capacitor is measured in **farads** and is determined by the formula

$$C = q / V$$

where q is the charge (in coulombs) on one of the conductors and

V is the potential difference (in volts) between the conductors.

The capacitance depends only on the thickness, area, and composition of the capacitor's dielectric.

Dielectric, or insulator, is a substance that is a poor conductor of electricity and that will sustain the force of an electric field passing through it. This property is not exhibited by conducting substances. Two oppositely charged bodies placed on either side of a piece of glass (a dielectric) will attract each other, but if a sheet of copper is instead interposed between the two bodies, the charge will be conducted by the copper.

In most instances the properties of a dielectric are caused by the polarization of the substance. When the dielectric is placed in an electric field, the electrons and protons of its constituent atoms reorient themselves, and in some cases molecules become similarly polarized. As a result of this polarization, the dielectric is under stress, and it stores energy that becomes available when the electric field is removed. The polarization of a dielectric resembles the polarization that takes place when a piece of iron is magnetized. As in the case of a magnet, a certain amount of polarization remains when the polarizing force is removed. A dielectric composed of a wax disk that has hardened while under electric stress will retain its polarization for years. Such dielectrics are known as electrets.

The effectiveness of dielectrics is measured by their relative ability, compared to a vacuum, to store energy, and is expressed in terms of a dielectric constant, with the value for a vacuum taken as unity. The values of this constant for usable dielectrics vary from slightly more than 1 for air up to 100 or more for certain ceramics containing titanium oxide. Glass, mica, porcelain, and mineral oils, often used as dielectrics, have constants ranging from about 2 to 9. The ability of a dielectric to withstand electric fields without losing insulating properties is known as its dielectric strength.

Dielectrics, particularly those with high dielectric constants, are used extensively in all branches of electrical engineering, where they are employed to increase the efficiency of capacitors.

Capacitors are produced in a wide variety of forms. Air, mica, ceramics, paper, oil, and vacuums are used as dielectrics, depending on the purpose for which the device is intended.

The Resistance in an AC circuit is dependent on the 'resistance' introduced by the capacitance in the circuit. This resistance is called reactance and it is given by the equation

$$X_c = 1 / 2\pi fc$$ The unit is the ohms

This equation shows that capacitive reactance is dependent on Frequency.

Inductance

When the current in a conductor varies, the resulting changing magnetic field cuts across the conductor itself and induces a voltage in it. This self-induced voltage is opposite to the applied voltage and tends to limit or reverse the original current. This effect is more pronounced if the different sections of an AC conductor are close to together as in the case of a long cable coiled up. The field around each length of the wire adds up within the coil to create a high inductive reactance (resistance due to inductance) in the wires. This will affect the signal going through.

The amount of self-induction of a coil, its inductance, is measured by the electrical unit called the **henry**, named after the American physicist Joseph Henry, who discovered the effect. The inductance is independent of current or voltage; it is determined only by the geometry of the coil and the magnetic properties of its core.

Due to this characteristic of inductance, there is an associated 'resistance' that an inductance imposes on an AC circuit and this 'resistance' is called inductive reactance. The reactance of this inductance in a circuit is dependent on the Frequency of the Alternating current.

Inductive reactance can be found from

$$X_L = 2\pi fL$$ The unit is the ohms

The combination of resistance with capacitive reactance and inductive reactance in an AC circuit is called impedance.

Therefore resistance in an AC circuit is called impedance.

The effect of having an inductor and capacitor in a circuit affects the total impedance of the circuit. Because these two are also opposite in nature, if frequency increases, one increase while the other reduces. This creates an effect called resonance.

Resonance (electronics)

Resonance is a condition in a circuit in which the combined impedances of the capacity and induction to alternating currents cancel each other out or reinforce each other to produce a minimum or maximum impedance at a specific frequency.

Resonance occurs at a given frequency, called the resonant frequency, for each circuit, depending upon the amounts of inductance and capacitance in the circuit. And this is the frequency where the combined effect of the Capacitor and inductor either reach a maximum or minimum.

If an alternating voltage of the resonant frequency is applied to a circuit in which capacity and inductance are connected in series, the impedance of the circuit drops to a minimum and the circuit will conduct a maximum amount of current. When the capacitance and inductance are connected in parallel, the opposite is true: The impedance is extremely high and little current will pass.

Resonant circuits are used in electric equipment, such as filters, to select or reject currents of specific frequencies. Filters of this type, in which either the capacity or the inductance of the circuit can be varied, are used to tune radio and television receivers to the frequency of the transmitting station so that the receiver will accept that frequency and reject others.

9. Introduction to transformers

When an alternating current passes through a coil of wire, the magnetic field about the coil expands and collapses and then expands in a field of opposite polarity and again collapses. If another conductor or coil of wire is placed in the magnetic field of the first coil, but not in direct electric connection with it, the movement of the magnetic field induces an alternating current in the second coil. If the second coil has a larger number of turns than the first, the voltage induced in the second coil will be larger than the voltage in the first, because the field is acting on a greater number of individual conductors. Conversely, if the number of turns in the second coil is smaller, the secondary, or induced, voltage will be smaller than the primary voltage.

The action of a transformer makes possible the economical transmission of electric power over long distances. If 200,000 watts of power is supplied to a power line, it may be equally well supplied by a potential of 200,000 V and a current of 1 amp or by a potential of 2000 V and a current of 100 amp, because power is equal to the product of voltage and current. The power lost in the line through heating is equal to the square of the current times the resistance. Thus, if the resistance of the line is 10 ohms, the loss on the 200,000 V line will be 10 watts, whereas the loss on the 2000 V line will be 100,000 watts, or half the available power

In a transformer the coil into which the power is fed is called the primary, the one in which the power is taken from is called a secondary. The two coils have different number of turns in them. The ratio

Number of turns in primary/number of turns in secondary

Is called the turns ratio and is usually denoted by n.

A transformer in which the secondary voltage is higher than the primary is called a step-up transformer;

If the secondary voltage is less than the primary, the device is known as a step-down transformer.

The product of current times voltage is constant in each set of coils, so that in a step-up transformer, the voltage increase in the secondary is accompanied by a corresponding decrease in the current.

There are four types of transformers

- Voltage step-up
- Voltage step-down
- Current step-up
- Current step-down

Because transformers allow the flow of electricity from one point in the circuit to another without any physical contact, they can be used as isolation devices for common mode signals. Common mode signals are signals that are in phase. (will be further explained under the audio lines and patchbays). Because they are in pahse, the net induced current across the transformer is zero. They cancel out.

10. Introduction to transistors

Transistor, in electronics, common name for a group of electronic devices used as amplifiers or oscillators in communications, control, and computer systems. Until the advent of the transistor in 1948, developments in the field of electronics were dependent on the use of thermionic vacuum tubes, magnetic amplifiers, specialized rotating machinery, and special capacitors as amplifiers. The transistor is a solid-state device consisting of a tiny piece of semiconducting material, usually germanium or silicon, to which three or more electrical connections are made.

The Figure 1 below is an example of a Vacuum tube. Before transistors, these devices were used for amplification purposes. Some audio engineers still swear by them for their supposed warmth and acceptable coloration of the sound especially at lower frequencies.

The figure 2 below is of a circuit board with resistors and capacitors but also with transistors. The sealed metal containers house the transistors.

As the performance of all electronics is affected by heat, transistors and vacuum tubes have an effect on audio signals that varies with the design and how hot they are. This effect will be discussed later.

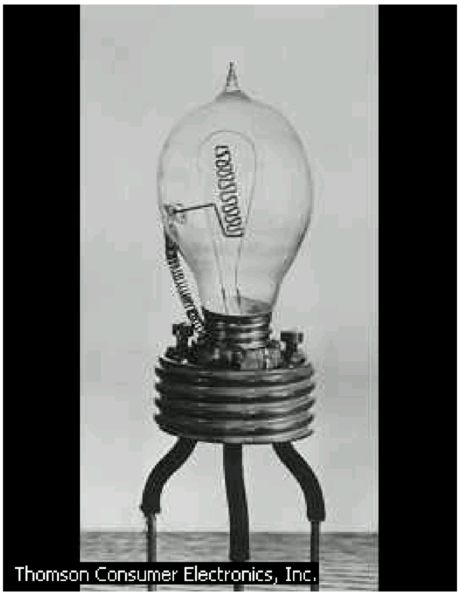

Figure 1

Figure 2