Summary for Written Test 2 **Sounds & Circuits** 2021 v1.1 by THOMAS VAN KLINK

Creative Technology – M2: Smart Environments.

According to test information for Test 2 "Circuits".

Information taken from lectures, assignments, references and books.

Lecture 4 (slides 37-66)

Electrical systems	Analog	All physical quantities like temperature or force can be represented by currents or voltages.
		Fulfils only one function, dedicated and thus fast.
	Digital	Smaller and faster than analog electronics.
		All quantities must be digitized (AD conversion).
		One circuit per function but cheap.
	Software	Can be updated → large flexibility
		Relatively slow and more power consuming, cannot do all functions digitally.
		Requires suitable environment (computer).

The smartphone	Analog	Transmitter, receiver of GSM, GPS, Bluetooth, Wi-Fi.
		Microphone and audio amplifier.
		Power management, touchscreen, and image sensor (camera).
	Digital	Dedicated communication protocols (GSM, UMTS, GPS, LTE) .
		Calculation resources.
	Software	OS, GUI, file management, applications, control of digital and analog parts.

Analogies

Certain mathematical relations hold in more than one domain.

Understanding in one domain can help understanding other domains.

For example: Electrons in a circuit ↔ Water flow in pipes.

Charge

$Q,\ Q(t), q(t)$

Positive and negative; charges of same sign repel, opposites attract.

Unit: coulomb (C), elementary charge: $q = -1.6 * 10^{-19}\ C$.

Electrons carry the negative charges, they can move "freely" through the material.

Analogy of Charge

Electrical domain:	Hydraulic domain:
Charge: $Q, q(t)$ in C.	Volume: $V, V(t)$ in m^3.
The amount of charge.	The amount of water molecules.

Current $I, I(t), i, i(t)$

Current is the flow of charge, the amount of charge per unit of time.

Unit: A (Ampère), $A = C/s$.

Positive current flows from $+ \rightarrow -$, electrons flow $- \rightarrow +$.

If I is constant: $I = \frac{Q}{t}$ $Q = I * t$

If I is dynamic: $i(t) = \frac{\mathrm{d}q(t)}{\mathrm{d}t} = \frac{\mathrm{d}}{\mathrm{d}t} q(t)$

Analogy of current

Electrical domain:	Hydraulic domain:
Current: $I, i(t)$ in $A(C/s)$	Flow: $\phi(t)$ in m^3/s
The amount of charge per time unit.	The amount of water molecules per time unit.

Voltage $V, U, v, u, v(t), u(t)$

Potential difference between two points in an electrical circuit.

Unit: V(Volt), $V = J/C$ $J = Joule$

Electric potential ↔ Voltage

Analogy of voltage

Electrical domain:	Hydraulic domain:
Voltage: $V, v(t)$ in V.	Pressure: $p(t)$ in Pa.
The pressure on the charge carrier.	The force on the amount of water molecules.

A voltage (difference) is the quantity that gets electrons moving. It is a driving force/push.

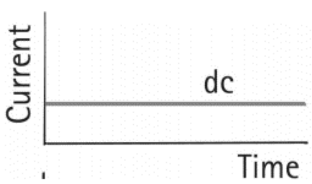
***DC** (Direct Current)* Static situation, can apply to all quantities (charge, current, voltage).

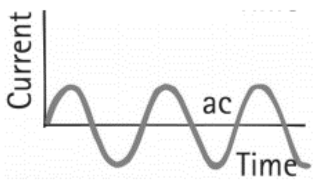
Denoted by capitals: Charge Q, Voltage V, Current I.

***AC** (Alternating Current)* Dynamic situation, can apply to all quantities (charge, current, voltage).

Donated by small letters: Charge $q(t)$, Voltage $v(t)$, Current $i(t)$.

DC and AC





Lecture 5

Electric circuit

An electric device that provides a path for electrical current (electrons) to flow.

Conductor

Charge can easily flow through conductors, they are represented by lines. (●———●)

They correspond to wires or PCB lines in physical circuits.

The voltage between both ends will be zero regards less of the current.

Ideal conductor ↔ short circuit

Circuit points that are connected with ideal conductors can be considered a single note.

Resistance

R

Unit: Ω (Ohm), $R = V/A$

In a material: $R = \rho * \frac{l}{A}$

$\rho =$ material property

$l =$ length of material (m)

$A =$ area of material (m^2)

Resistors can be physical components (resistors), practical values: $0.1\Omega - 1G\Omega$.

Ohm's law

$v = i * R$

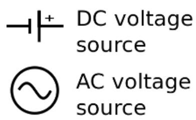
Relation between voltage and current for an ideal resistor.

$V = I * R$ $\quad$ $I = \frac{V}{R}$ $\quad$ $R = \frac{V}{I}$

Voltage source

Delivers a sustained flow of charged particles in a circuit.

Maintains a difference in electrical potential (voltage).



Ideal voltage source

The voltage at the terminals is independent of the delivered current (no internal loss)

Inside a source current flows from $- \rightarrow +$. In theory: shorting source → infinite current.

Ideal current source

The current trough the terminals is independent of the voltage at the terminals.

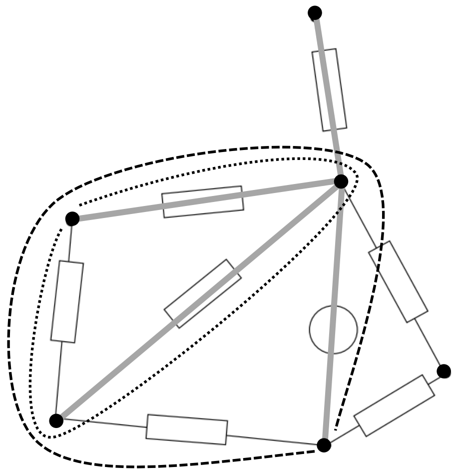
In theory: open clamps → infinite voltage.

Example: a solar cell, more sun will deliver more current but not more voltage.

Electrical networks A network is a set of interconnected elements.

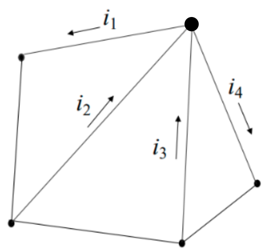
With:

- Nodal points / nodes
- Branches
- Loop
- Mesh (encloses no other loops)



1st Kirchhoff law (K.C.L) $\sum i_{node} = 0$

The current law or node rode of Kirchhoff (charge conservation).



$-i_1 + i_2 + i_3 - i_4 = 0$

Approaching is +

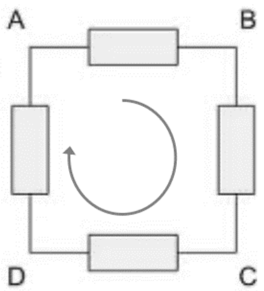
Leaving is –

$\sum incoming\ currents - \sum outgoing\ currents = 0$

$\sum incoming\ currents = \sum outgoing\ currents$

2nd Kirchhoff law (K.V.L) $\sum v_{loop} = 0$

The voltage law or loop rule of Kirchhoff (energy conservation law).



$V_{AB} + V_{BC} + V_{CD} + V_{DA} = 0$

$\sum voltage\ rises - \sum voltage\ drops = 0$

$\sum voltage\ rises = \sum voltage\ drops$

Notation of polarities UK: Uses arrows towards highest potential, source is a rise of potential, resistors a drop

USA / Europe: + denotes highest potential, — denotes lowest potential, source is a rise of potential, resistors a drop.

Connecting

Series

A single pathway circuit for electron flow.

Current through all elements is the same. $I = I_{R1} = I_{R2} = I_{R3}$

Voltage gets divided over elements. $V_{source} = V_{R1} + V_{R2} + V_{R3}$

A break anywhere in the circuit results in an open circuit → no electron flow.

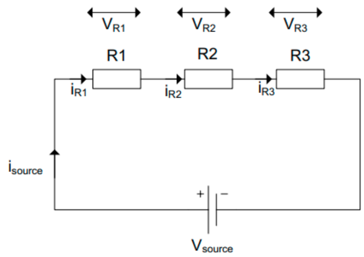
Ohm's law holds per resistor and for the whole circuit:

$$V_{source} = I_{source} * R_{tot}$$

$$V_{R1} = I_{source} * R_1$$

$$V_{R2} = I_{source} * R_2$$

$$V_{R3} = I_{source} * R_3$$



Parallel

2 or more elements are in parallel if they are connected to the same nodes.

Current gets divided over parallel branches. $I = I_{R1} + I_{R2} + I_{R3}$

Voltage through all elements is the same. $V_{source} = V_{R1} = V_{R2} = V_{R3}$

A break in the path of a resistor → current can still flow in other paths.

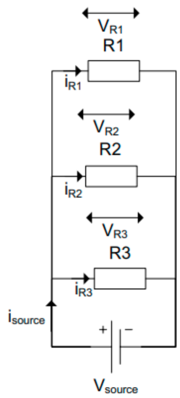
Ohm's law holds per resistor and for the whole circuit:

$$V_{source} = I_{source} * R_{tot}$$

$$V_{R1} = I_{R1} * R_1$$

$$V_{R2} = I_{R2} * R_2$$

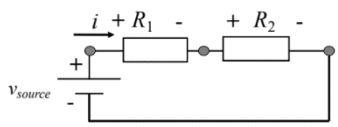
$$V_{R3} = I_{R3} * R_3$$



Resistors

Series

$$R_s = R_1 + R_2$$

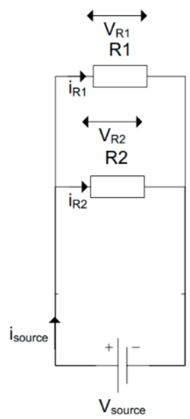


Parallel

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$$

For example (2 resistors):

$$R_p = \frac{R_1 * R_2}{R_1 + R_2}$$

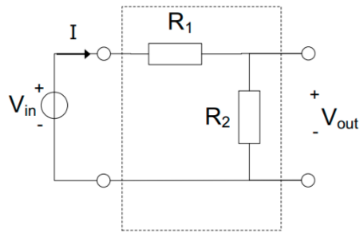


Power in circuits $P = V * I$

Power, Unit: W (Watt), $W = J/s$

For use with resistors: $P = \frac{V^2}{R}$ $P = I^2 * R$

Voltage divider A common circuit that can create a desired output voltage (V_{out}) smaller or equal to the input voltage (V_{in}).



Analysis:

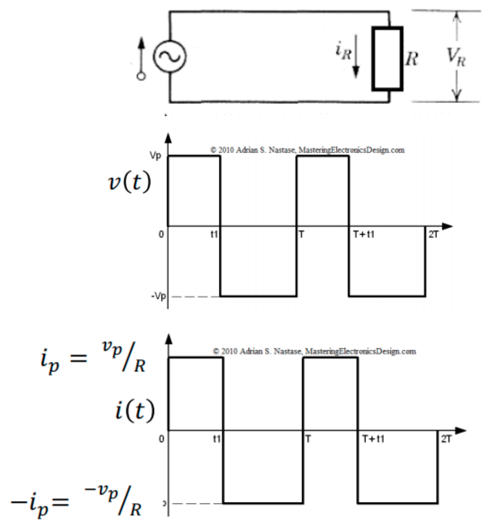
K.V.L.	$V_{in} = V_{R1} + V_{R2} = V_{R1} + V_{out}$
K.C.L	$I = I_{R1} = I_{R2}$
Ohm's law	$V_{out} = I * R_2$
Total resistance	$R_{tot} = R_1 + R_2$
Output voltage	$V_{out} = \frac{R_2}{R_1+R_2} * V_{in}$
H (dotted line)	$H = \frac{R_2}{R_1+R_2}$
System formula	$V_{out} = H * V_{in}$ with $0 \leq H \leq 1$

Lecture 6

AC signals Dynamic and changes polarities.

Making the basic periodic signals, for example the square wave:

$V = i * R$ $i = \frac{v}{R}$



Using the sine wave again:

$s(t) = \mathrm{A}\sin(2\pi f t)$

$v(t) = v_p \sin(2\pi f t) = v_p \sin(\omega t)$

$i(t) = i_p \sin(2\pi f t) = i_p \sin(\omega t)$

with the angular frequency $\omega = 2\pi f = \frac{2\pi}{T}$

Sine wave in R

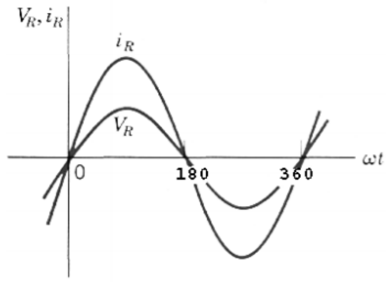
$V = i * R$ $\qquad i = \frac{v}{R}$

Alternating voltage → alternating current

$v = v_p \sin(\omega t)$ $\qquad i = i_p \sin(\omega t)$

$i = \frac{v_p}{R} \sin(\omega t)$

i and v are in phase, (o-degree phase shift).



Differentiation

$\frac{d}{dx}(x) = 1$

$\frac{d}{dx}(ax) = a$

$\frac{d}{dx}(x^n) = nx^{n-1}$

$\frac{d}{dx}(\sin x) = \cos x$

$\frac{d}{dx}(\cos x) = -\sin x \ (x)$

Integration

$\int 1dx = x + C$

$\int adx = ax + C$

$\int x^n dx = \frac{x^{n+1}}{n+1} + C\,, n \neq -1$

$\int \sin x\, dx = \cos x + C$

$\int \cos x\, dx = \sin x + C$

Sine waves for EE

Three reasons:

Natural signals (tides, solar position, year cycle, sunset – sunrise).

Basis in signal analysis and system description, only periodic signal that remains similar in shape after differentiation or integration.

Any periodic signal can be written as a sum of sines (Fourier).

Sine wave

Information

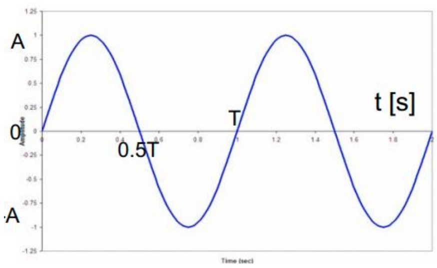
$i = i_p \sin(\omega t + \ \phi) \ \ t \geq 0$

i_p = amplitude, ϕ = initial phase

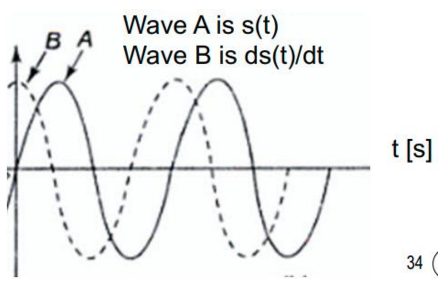
Integrating or differentiating sine waves can only change amplitude or phase. So *not* the frequency.

Differentiating

$s(t) = A \sin(\omega t)$



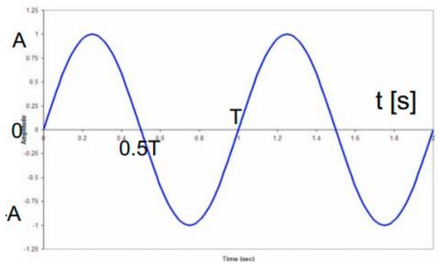
$\frac{ds(t)}{dt} = A * \omega * \cos{(\omega t)}$



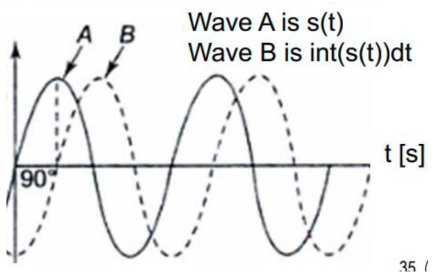
Sine wave Differentiating Wave B (derivative) leads wave A

Amplitude of B has changed compared to A

Integrating $s(t) = A\sin(\omega t)$



$S(t) = \int s(t)dt = \frac{-A}{\omega}\cos(\omega t) + C$



Wave B lags wave A.

Amplitude of B has changed compared to wave A.

Possible vertical shift due to C.

Phase shift When $\phi_1 > \phi_2$, signal 1 leads (is in front of) signal 2.

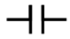
When $\phi_1 < \phi_2$, signal 1 lags (is behind of) signal 2.

Summary

Signal s(t)	**Math description**	**ds(t)/dt**	$\int s(t)dt$
Square	Zero order (constant), Steep slope at transitions	0, Spikes at transitions of s(t)	First order (linear functions) → triangle
triangle	First order (linear functions)	Zero order (constant) → square wave	Second order (parabola functions)
(co)sine	(co)sine functions	(co)sine, Leads s(t) by π/2 Amplitude change	(co)sine, Lags s(t) by π/2 Amplitude change Possible vert. shift

Capacitor

A buffer or storage for electric charge Q. Measure in C.

 Capacitor

Unit: F(Farad), $\frac{A}{V/s} = \frac{A}{V} = F$

Total charge on capacitor is Q. *Not* $2Q$. It does not change, only moves.

Due to charge separation, a voltage V will arise.

The higher the charge → the higher the voltage

Linear relationship: $Q = C * V$ $\quad C = \frac{Q}{V}$ $\quad V = \frac{Q}{C}$

$C =$ capacitance of capacitor

Small voltages give large amounts of charge.

Large capacitors fill up slower than smaller ones.

Capacitance: $C = \varepsilon G = \frac{\varepsilon A}{D}$

$\varepsilon =$ Dielectric constant (F/e), a property of the isolation medium.

$d =$ plate distance in m

$A =$ plate area in m^2

i, v relationship: $i_C(t) = C\frac{dV_c(t)}{dt}$

$V_C(t) = \frac{1}{C}\int i_C(t)\,dt$

Function: Capacitors tend to stabilise voltage across them.

No infinite high current change is possible.

A capacitator acts as a differentiator for voltage sources.

A capacitator acts as an integrator for current sources.

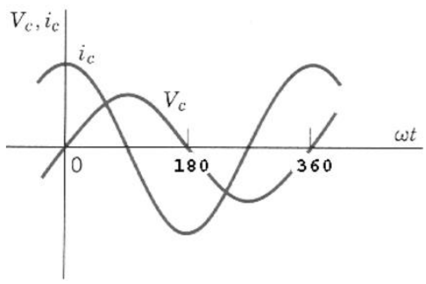
Sine wave in C

$i = C\frac{dv}{dt}$ $\quad i = \frac{1}{C}\int i dt$

$v = v_p \sin(\omega t)$ $\quad i = i_p \cos(\omega t)$

$i = v_p \omega \sin(\omega t)$

$i = v_p \omega \sin\left(\omega t + \frac{1}{2}\pi\right)$



i and v are out of phase, (i leads v by $\frac{1}{2}\pi$ or 90°).

Inductor

Buffer of magnetic flux linkage.

 Inductor

Unit: H (Henry), $\frac{V}{A/s} = \frac{Vs}{A} = H$

Maintains motion (flow) → Inertia (traagheid).

Due to a magnetic field a current flow is induced (and vice versa).

Inductor i, v relationship:

$$V_L(t) = L\frac{di_l(t)}{dt}$$

$$V_C(t) = \frac{1}{L}\int v_L(t)\,dt$$

If there is a large L value, then a small current i will give a large voltage v.

Function

Inductors tend to stabilize the current though it.

No infinite high voltage change possible.

An inductor acts as an <u>integrator</u> for voltage sources.

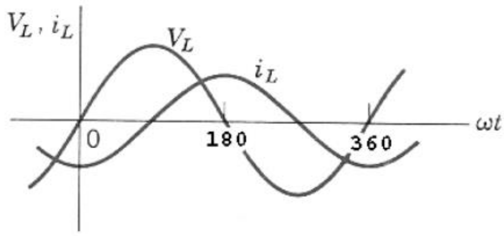
Sine wave in L

$v = L\frac{di}{dt}$ $\qquad i = \frac{1}{L}\int vdt$

$v = v_p \sin(\omega t)$ $\qquad i = -i_p \cos(\omega t)$

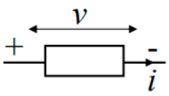
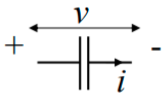
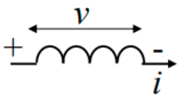
$$i = -\frac{V_p}{\omega L}\cos(\omega t)$$

$$i = \frac{V_p}{\omega L}\sin\left(\omega t - \frac{1}{2}\pi\right)$$



i and v are out of phase, (i lags v by $\frac{1}{2}\pi$ or 90°).

Overview

Resistance		$v = i * R$	$i = \frac{v}{R}$	Ω	Ohm
Capacitance		$v = \frac{1}{C}\int idt$	$i = C\frac{dv}{dt}$	F	Farad
Inductance		$v = L\frac{di}{dt}$	$i = \frac{1}{L}\int vdt$	H	Henry