ANALOG & DIGITAL CIRCUITS

Module Leader: Professor Vasile Dadarlat, PhD

STRUCTURE

- LECTURES: 2 Hours/Week
- LAB: 2 Hours/Week

MODULE OVERVIEW

- Contents of Lectures
  1. Introduction; Basic presentation for: pulse signal, RC circuits, pulse transformer
  2. Switching regime of the semiconductor devices
  3. Analog Circuits: Operational Amplifiers, Power supply sources, Oscillators
  4. Digital Circuits: Parameters of the integrated logic circuits
  5. Families of integrated logic circuits
  6. Digital circuits for bus design
  7. Trigger Schmitt circuits
  8. Flip-flops
  9. Semiconductor Memories
  10. A/D & D/A Converters
  11. Microcontrollers (sample 80C51 family)
- Attendance
  – Following regulations

LAB OVERVIEW

- Structure
  - Simulation of circuit behavior
  - Circuits parameters in static & dynamic regime
  - Applications & Design
  - Theoretical problems & discussions

- Attendance
  - Compulsory

BIBLIOGRAPHY

- ftp://ftp.utcluj.ro/pub/users/dadarlat/CircuiteAnalogice&Numerice
- Dădârlat, V., Peculea A., “Circuite Analogice si Numerice”, UTPress, 2006
- Dădârlat, V., “Circuite şi dispozitive numerice”, Ed. Mediamira, Cluj-Napoca, 1999
- Dădârlat, V., Peculea A., “Circuite Numerice”, Laboratory guide, Ed. Casa Cartii de Stiinta, 2000

ASSESSMENT

- Lab exam
- Written Exam (theory, problems)
- Grading constraints: minimum of 5 for theory, problems, lab
- Grade = 0.4 * theory + 0.3 * problems + 0.3 * lab
- Module Credits: 5

FEEDBACK

1. Introduction; Basic presentation for: pulse signal, RC circuits, pulse transformer
2. Switching regime for semiconductor devices
3. Analog Circuits: Operational Amplifiers, Power supply sources, Oscillators
4. Parameters of integrated logic circuits
5. Families of integrated logic circuits
6. Digital circuits for designing interconnecting bus
7. Trigger Schmitt circuits
8. Flip-flops
9. Semiconductor Memories
10. A/D & D/A Converters
11. Microcontrollers

<u>Mark from 1 (Low) to 5 (Highest) your personal degree of knowledge for each notion</u>

Chapter 1: Basic presentation for: electric signals, pulse signal, RC linear circuits, pulse transformers

- Electric signal - basics
- Electric pulse: Definition, parameters, pulse generating using elementary signals
- RC circuits (pulse transformers)
- RC circuits response to elementary signals

Electric Signals - basics

Defined as function of one/more variables, bearing information about the physical nature of a phenomenon

Classification after number of variables:

unidimension

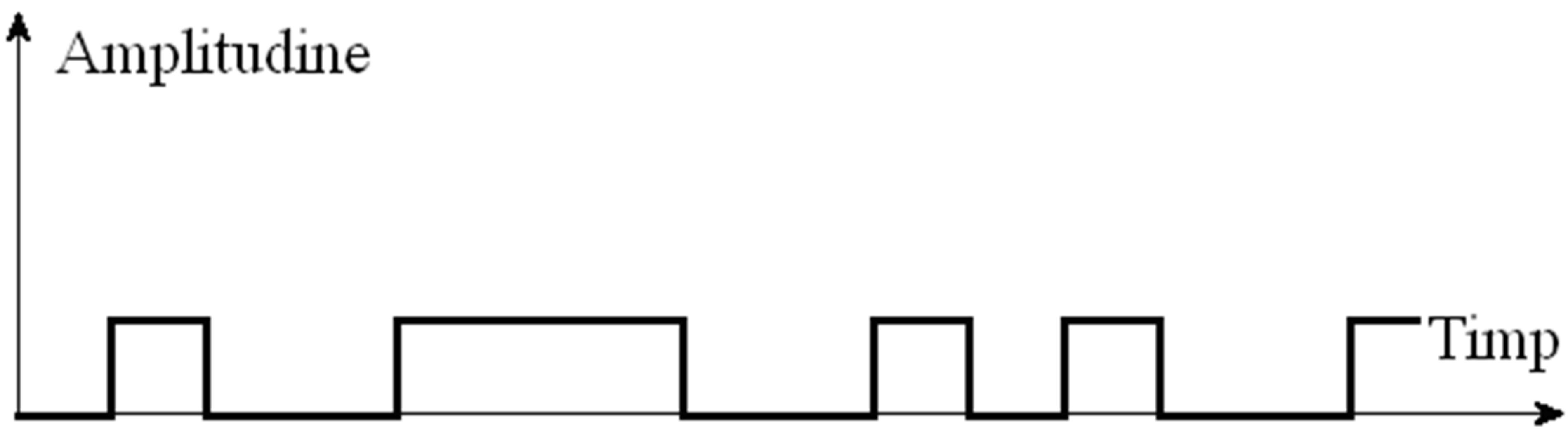
multidimension

Classification after behaviour in time domain:

continuous – continuous variation; may present any value

discrete – waveform maintains a constant level, then switches suddenly to another level

analogic



digital

Classification after simetry:

even – simetrical with regard to the vertical axis or to the time origin

odd - anti-simetrical with regard to time origin

Classification after periodicity:

periodical - $\nu(t) = \nu(t \pm nT_0)$ for any value of t.

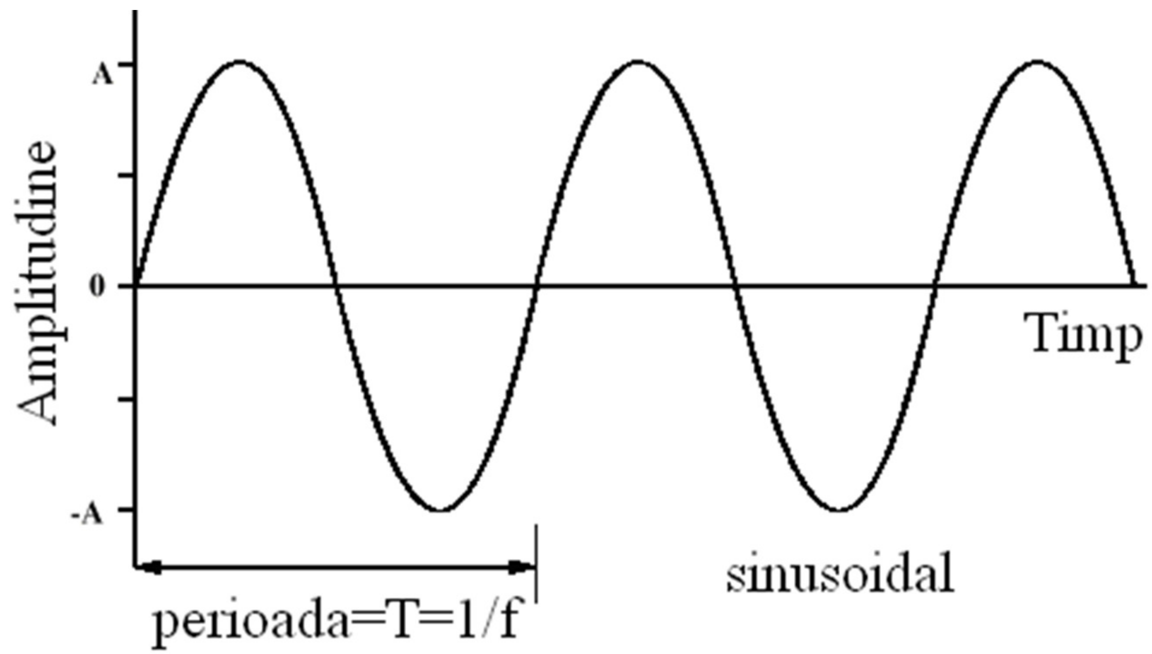
T_0 means signal's *period*.

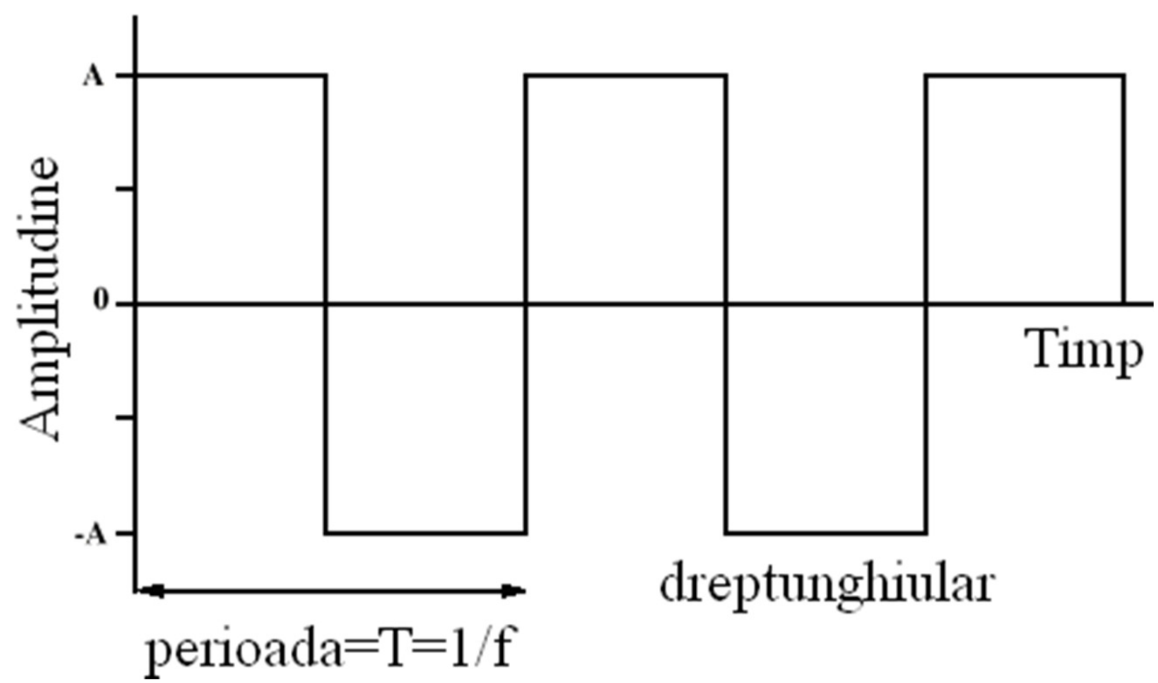
Reverse of period defines signal's *frequency* : $f = 1/T_0$.

Based on frequency, there is defined *angular frequency* :

$$\omega = 2\pi f$$

non-periodical – $\nu(t) \neq \nu(t \pm nT_0)$


A
0
-A
Amplitudine
Timp
sinusoidal
perioada=T=1/f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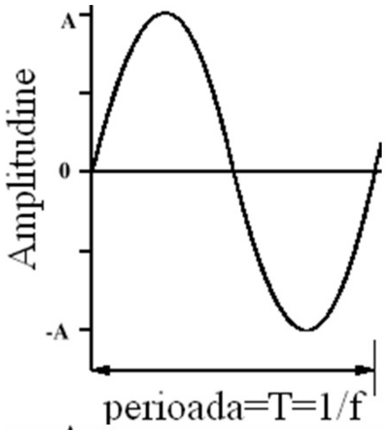
Elementary signals

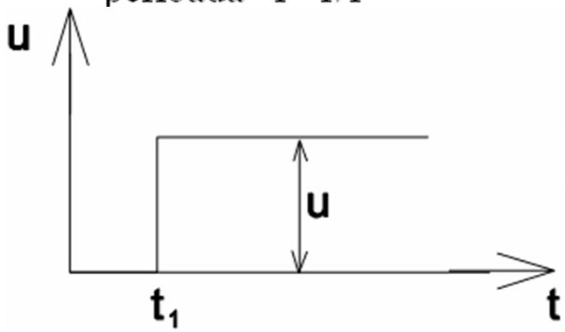
- **Sinus**



$\nu(t) = A\cos(\omega_0 t + \phi) = A\cos(2\pi f_0 t + \phi)$

A – amplitude, ω_0 – angular frequency, f_0 – frequency, ϕ - phase

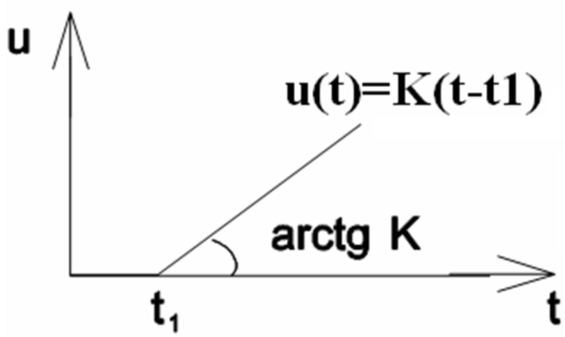
- **Step signal**



$u(t) = U$, for $t \geq= t_1$

$u(t) = 0$, for $t < t_1$

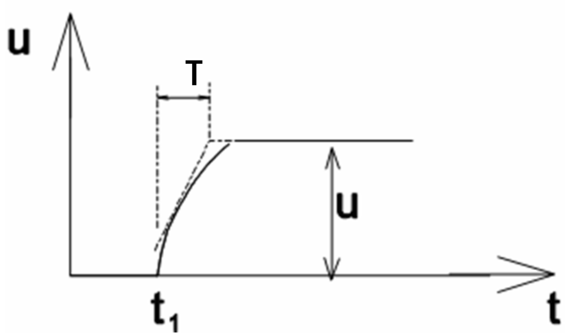
- **Ramp**



$u(t) = k\cdot(t-t_1)$, for $t \geq t_1$

$u(t) = 0$, for $t < t_1$

- **Exponential**



$u(t) = U(1 - e^{-(t-t_1)/\tau})$, for $t \geq t_1$

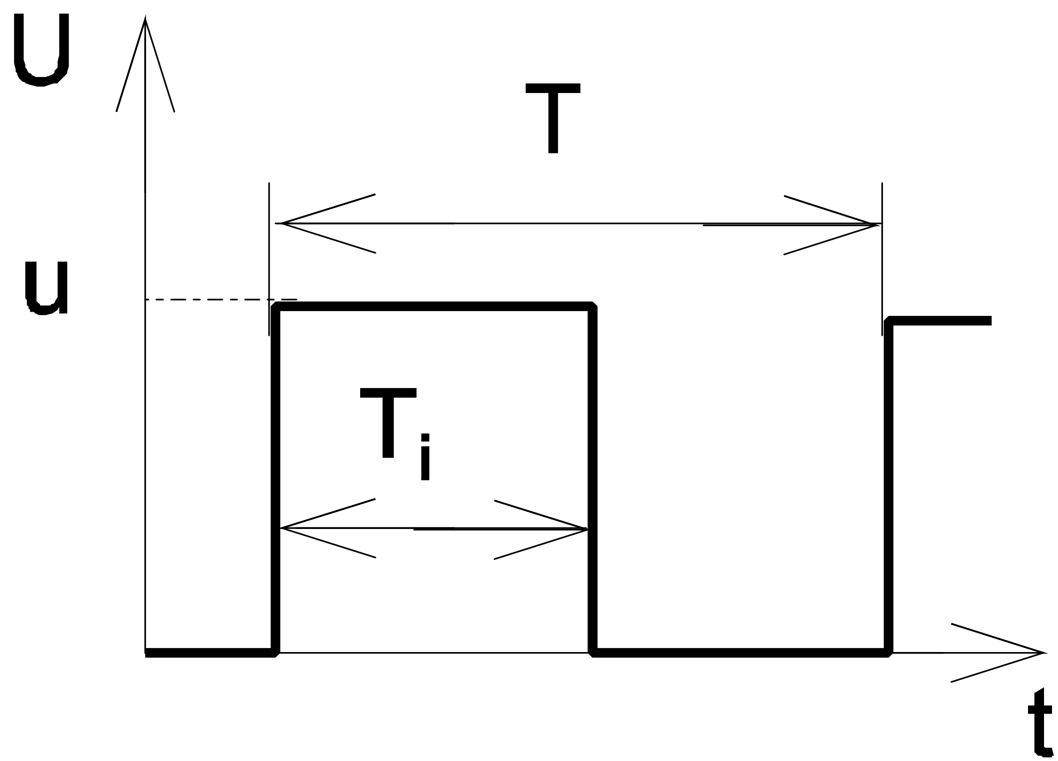
$u(t) = 0$, for $t < t_1$

τ – time constant of signal

Definition of pulse

PULSE: a voltage or current signal that has its value different from a constant value (that can also be zero), only for a temporary short enough period, smaller or comparable with the transitory period of the circuit that is transmitting the signal

Shape of an ideal pulse



U – pulse amplitude

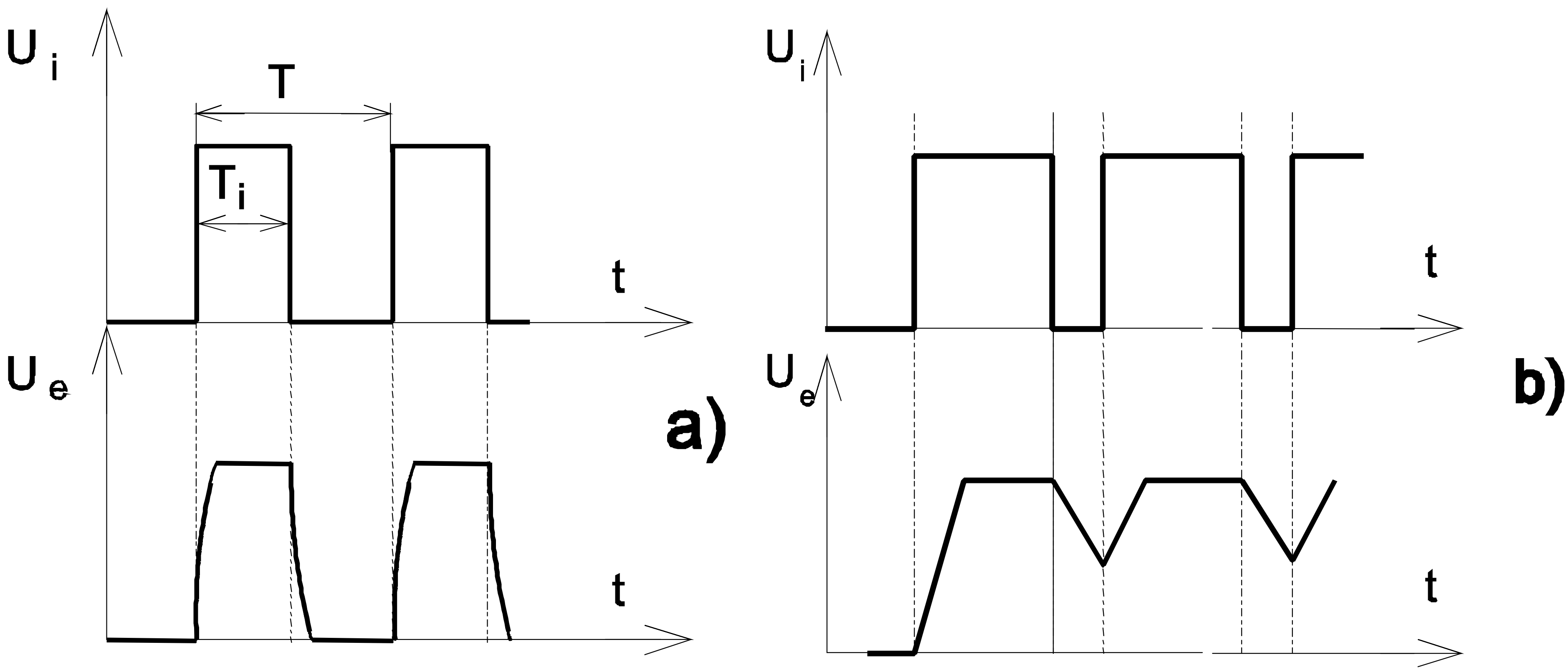
Ti – pulse duration (width)

T – pulse repetition period

Relation between the transitory regime of a circuit and the pulse signal

- Any state switch of a circuit implies generation of a transitory regime, taking a bounded time τ
- For a pulse signal, the swing times between levels must be lower or comparable with the period of the transitory regime
- For a pulse the repetition period T must be much greater than the duration of the transitory regime

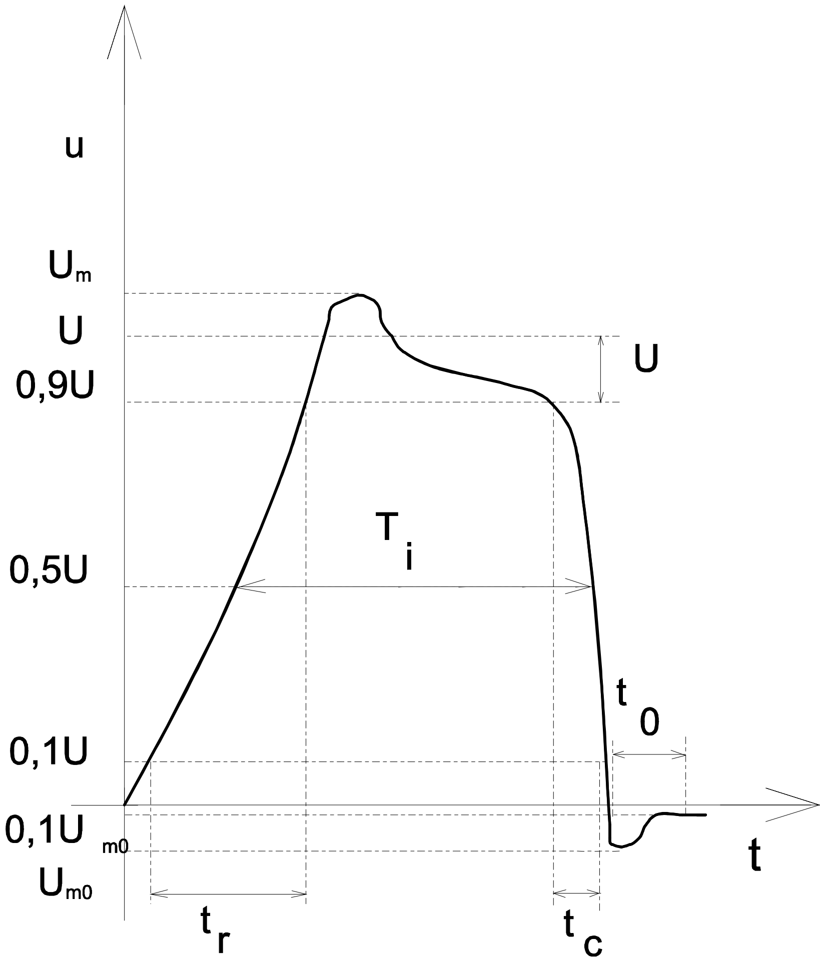
Pulse period versus transitory time



Right values

Wrong definition

Shape of a real pulse



U – pulse amplitude

U_m – over-exceeding amplitude (overshoot)

U_{m0} – under-exceeding amplitude (preshoot)

ΔU – voltage drop on a level (ringing)

T_i – pulse width

t_r – rising time - time of leading (anterior) edge)

t_c – fall-down time - time of trailing (posterior) edge

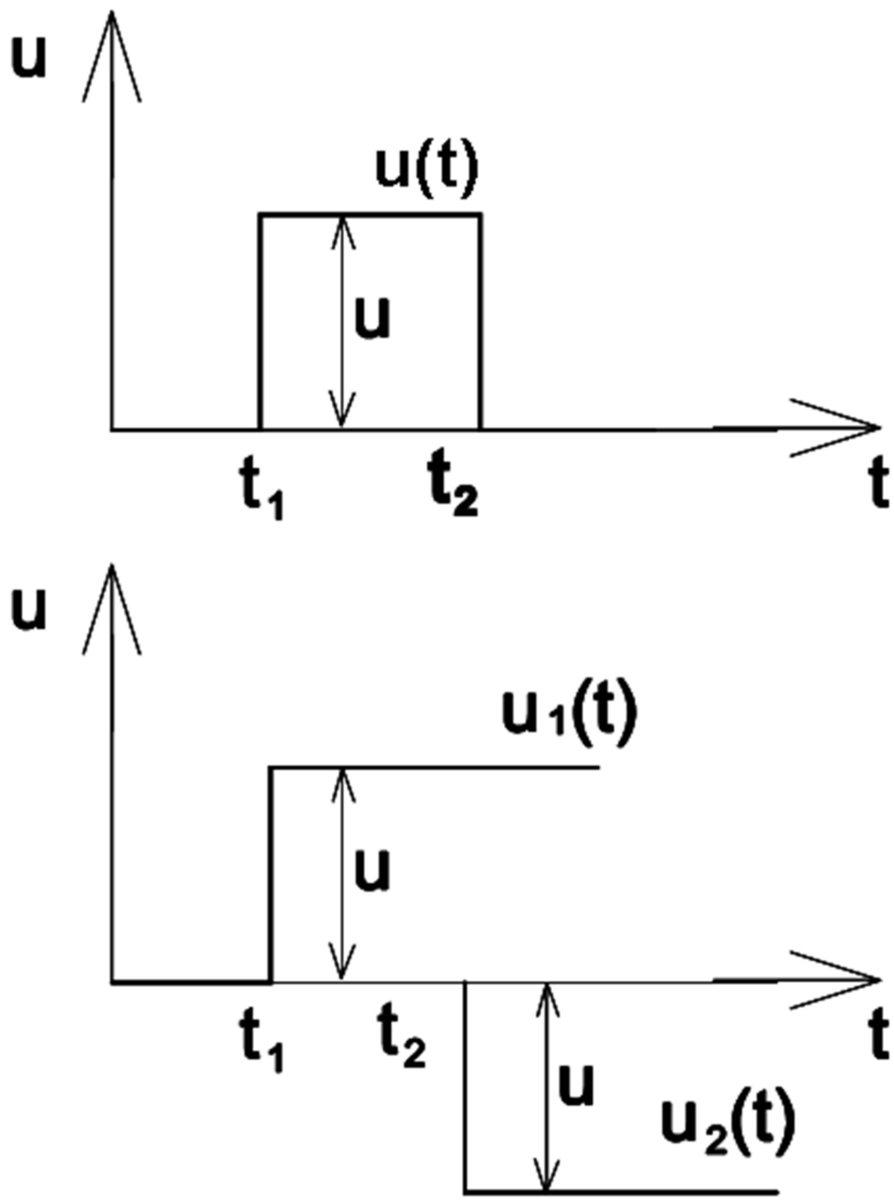
t_0 – reverse return time

T – repetition period

f_u – space factor: $f_u = T_i/T$

f – repetition frequency: f=1/T

Generating a pulse by composing some elementary signals

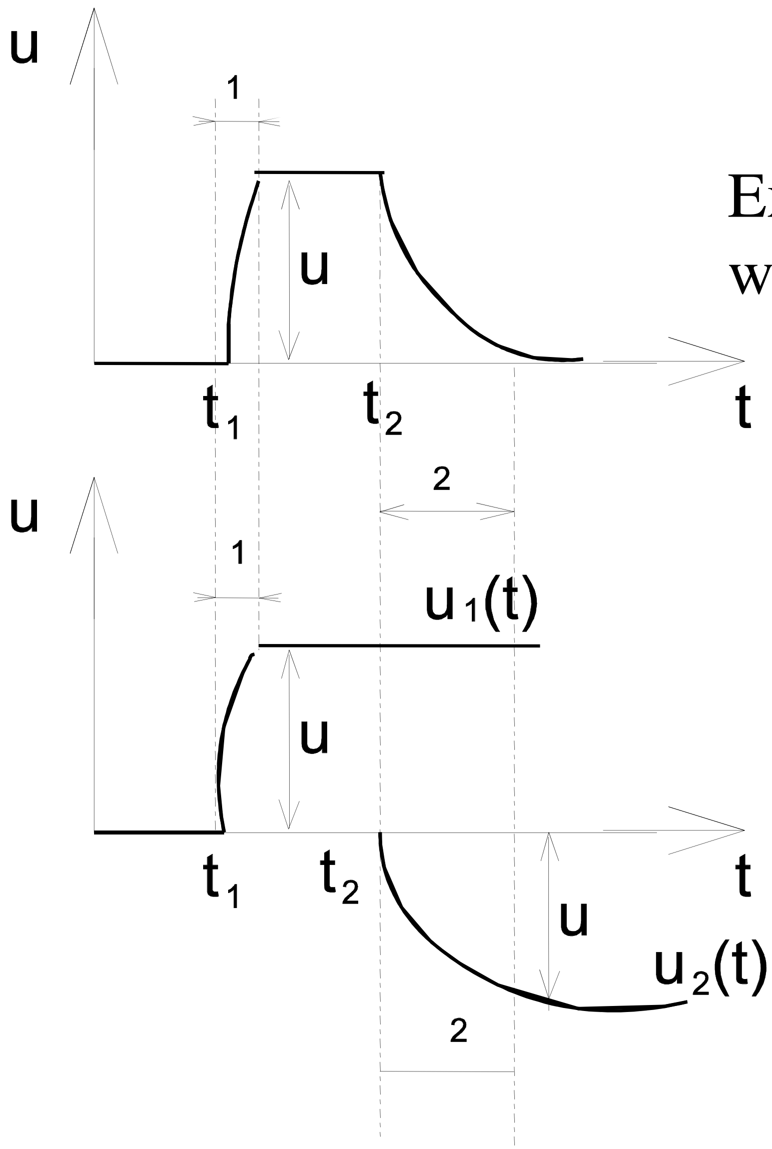


$u(t)=u_1(t)+u_2(t)$

$u_1(t)$ – positive single step signal

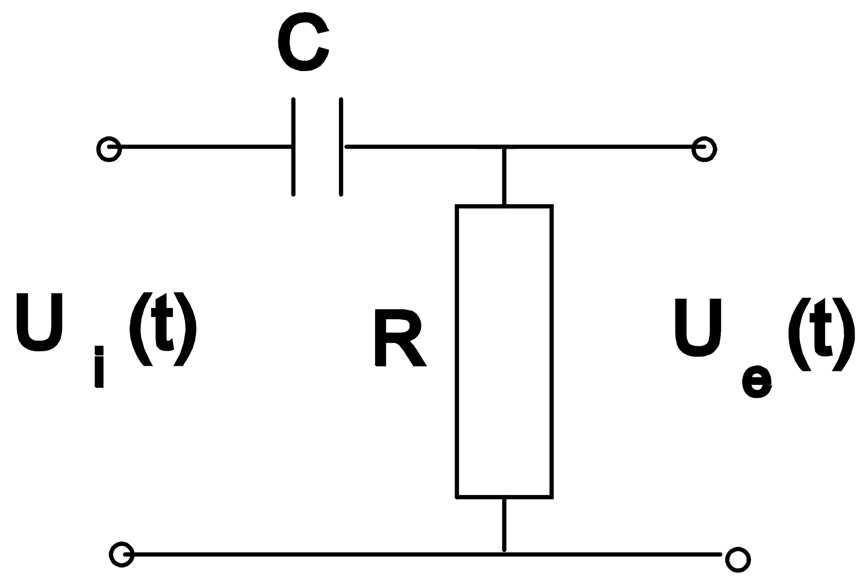
$u_2(t)$ – negative single step applied at t_2

Generating a pulse by composing some elementary signals

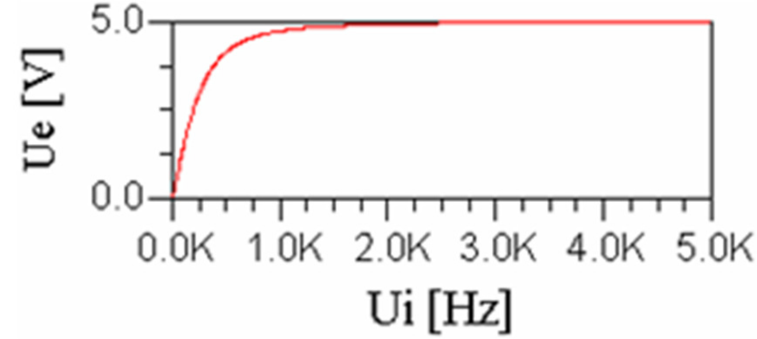


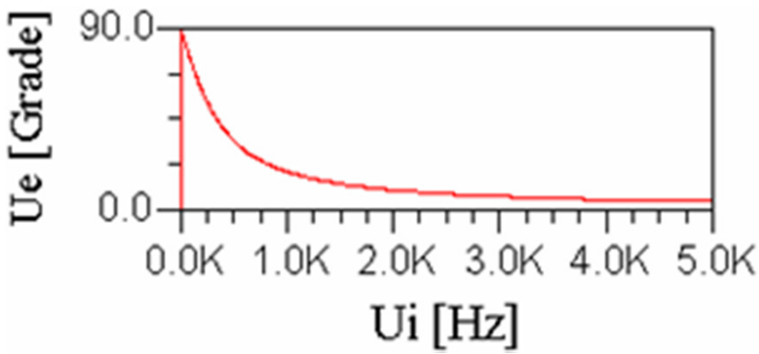
Example with two exponential signals with different signal time constants

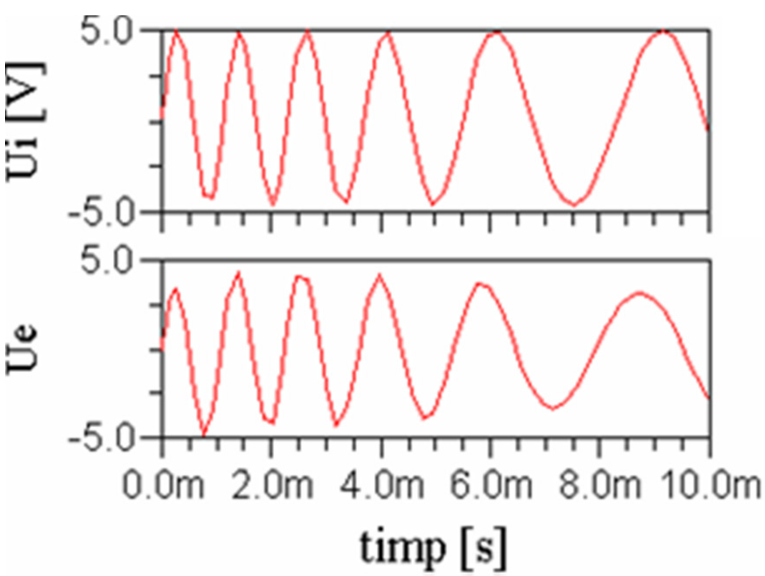
RC high-pass filter



- capacitor reactance varies inversely proportional with the frequency
- circuit behaves like a voltage divider whose dividing ratio depends on frequency
- resistance times the capacitance (R×C) is the time constant; it is inversely proportional to the cutoff frequency :the output power is half the input (-3 dB)







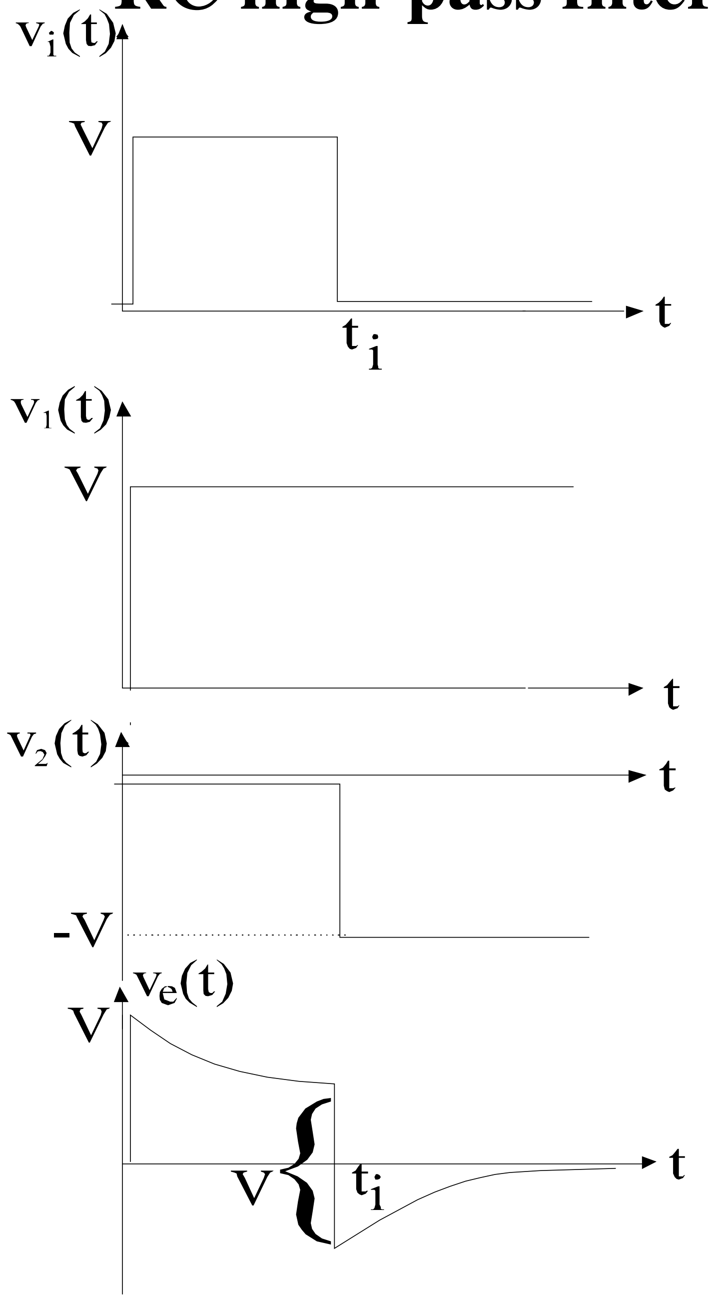
Circuit Response for a sinus input signal

- $U_i = |U_i| e^{j\omega t}$, $\omega = 2\pi f$
- $U_e = |U_e| e^{j(\omega t - \varphi)}$
- Circuit response is a sinus signal with attenuated amplitude $A(\omega)$ and a phase shift $\varphi(\omega)$

$$A(\omega) = \frac{1}{\sqrt{1 + \left(\frac{1}{\omega RC}\right)^2}}$$

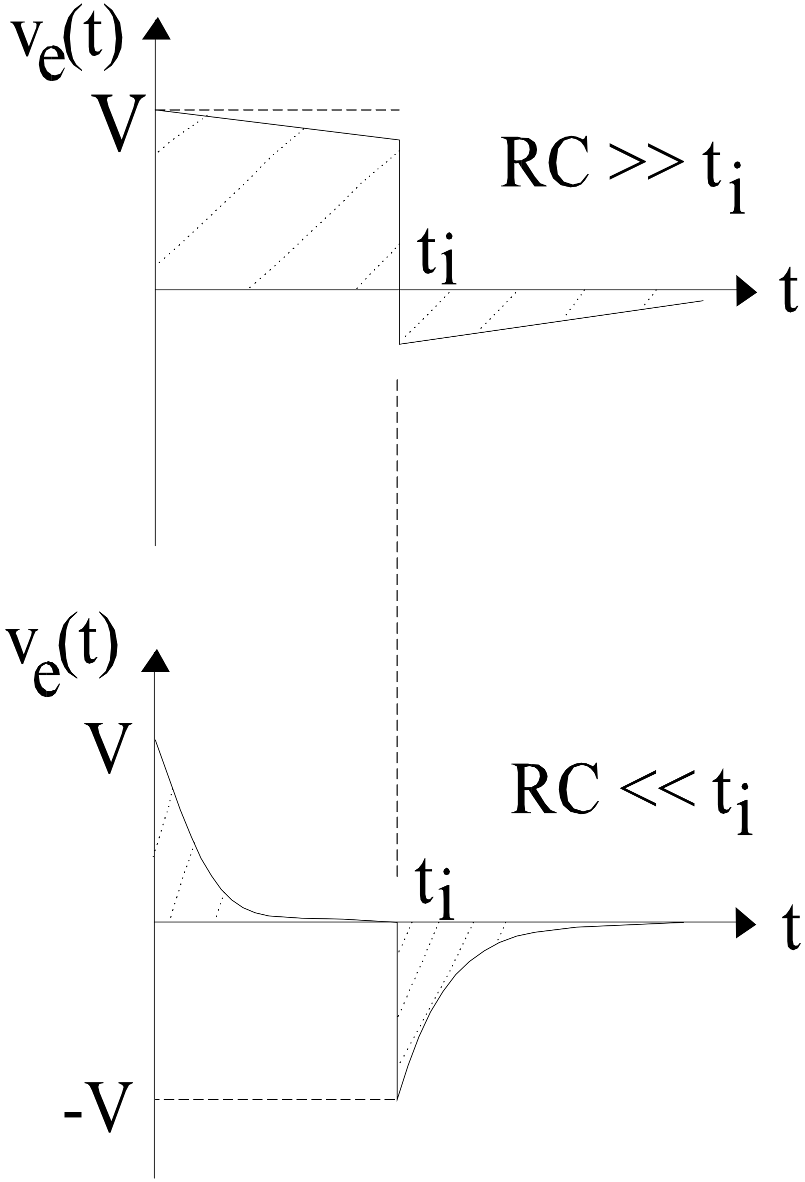
$$\phi(\omega) = arctg\left(\frac{1}{\omega RC}\right)$$

RC high-pass filter – response at a pulse input signal



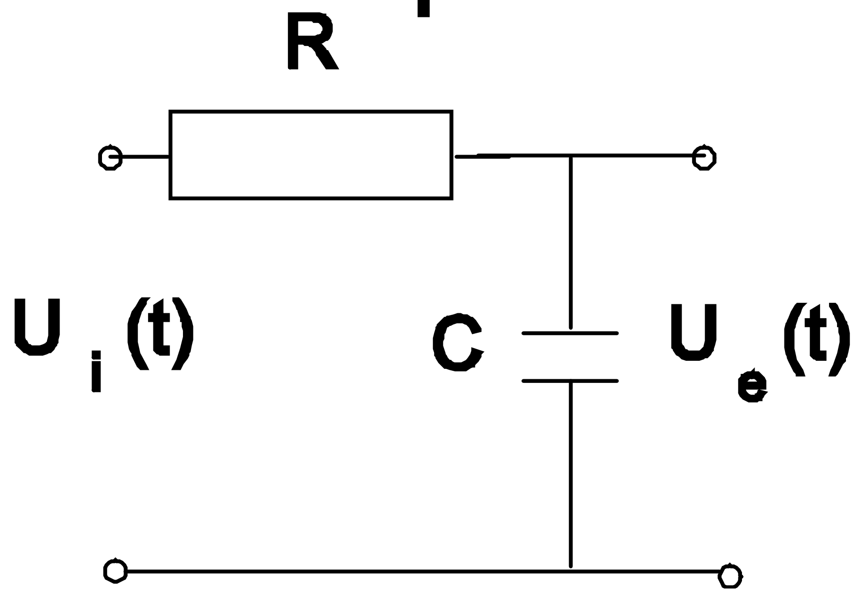
- Pulse generated using two step signals of amplitudes: +V şi –V, applied at moments t=0 and respectiv. $t=t_i$
- continuous (dc) component of the input signal does not appear at the output
- circuit is also called separation circuit, and is used for separating direct current circuits

RC high-pass filter – response at a pulse input signal (cntd)

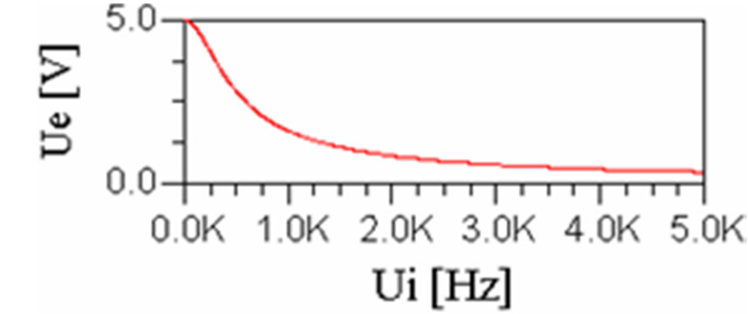


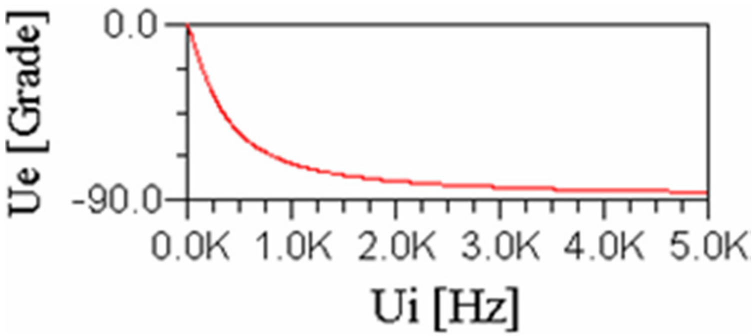
- the area above the abscissa is always equal to the area below the abscissa (time axis)
- to obtain negligible distortions, it is necessary to choose an RC time constant much higher than the impulse length t_i
- circuit can be used as a **differentiating circuit**, with the condition that the time constant is much smaller than the impulse length

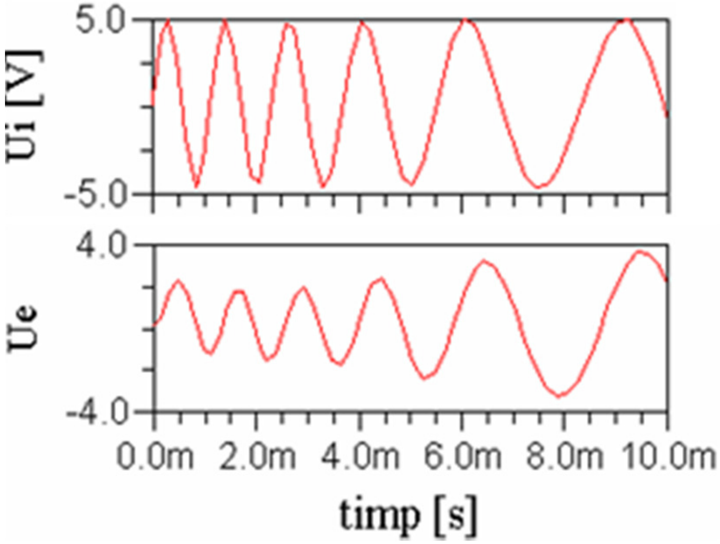
RC low-pass filter



- Opposite to the high-pass filter
- harmonics with higher frequencies appear at the output with a higher attenuation than the low frequency harmonics







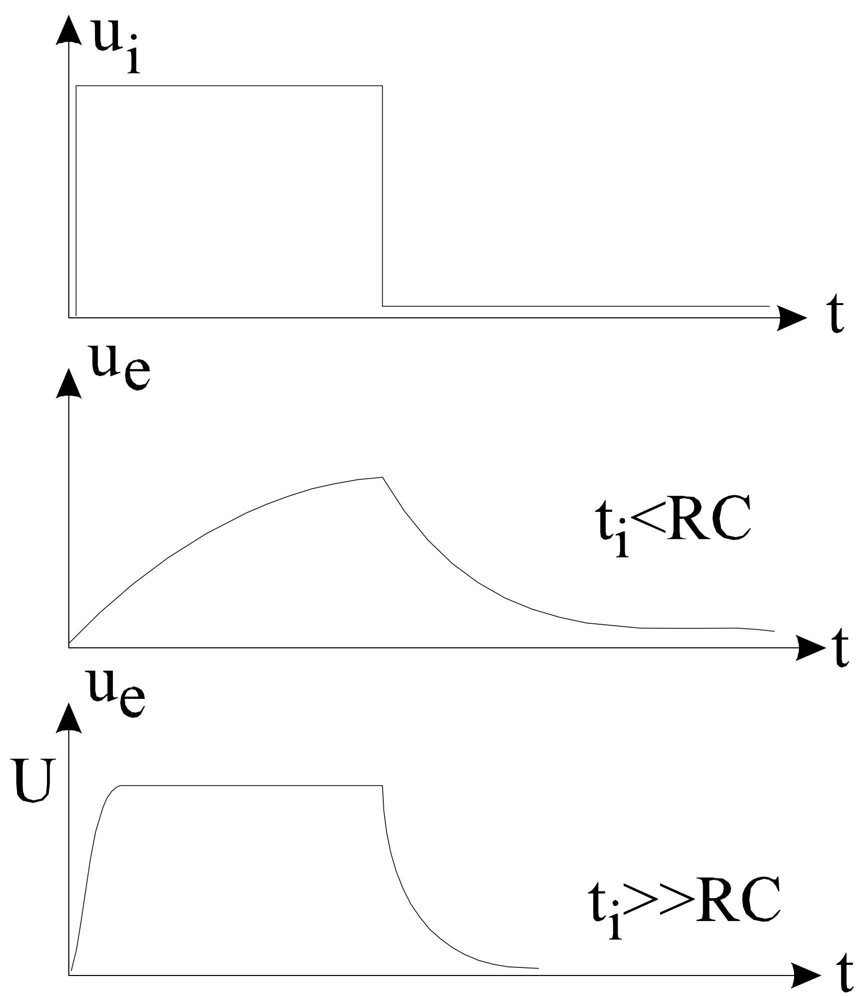
Circuit Response for a sinus input signal

- $U_i = |U_i| e^{j\omega t}$, $\omega = 2\pi f$
- $U_e = |U_e| e^{j(\omega t - \varphi)}$
- Circuit response is a sinus signal with attenuated amplitude $A(\omega)$ and a phase shift $\varphi(\omega)$

$$A(\omega) = \frac{1}{\sqrt{1 + (\omega RC)^2}}$$

$$\phi(\omega) = -arctg(\omega RC)$$

Circuit Response for a single step input signal



- In order for the distortions introduced by the circuit upon the impulse type input signal to be negligible, it is necessary for the circuit's elements to satisfy the relation RC« t_i
- If the voltage drop on the resistance much greater than on the capacitor: U_C « U_R, the response of the circuit will represent the integral of the input signal with respect to time
- circuit is used for pulse remaking, like an integrator circuit

Calculus of RC circuits response

- Response of a linear circuit with one time constant to a single-step input signal follows the equation:

$$y(t) = y(\infty) + \left[y(0) - y(\infty)\right]e^{-\frac{t}{\tau}}$$

- Time t=t”-t’ for what output y(t) switches its value from y(t’) to y(t”); may be calculated with equation:

$$t = t'' - t' = \tau \ln \frac{y(\infty) - y(t')}{y(\infty) - y(t'')}$$

Calculus of RC circuits response

- Response of a RC circuit to any input signal may be calculated with the Duhamel integral if the response to a single-step input is known:

$$e(t) = i(0)A(t) + \int_0^t \frac{di(t)}{dt}\bigg|_{t=\tau} A(t-\tau)\,d\tau$$

- i(t) – input signal
- i(0) – input signal value at moment t=0
- e(t) – circuit response (output)
- A(t) – circuit response to a single-step input signal with an amplitude of 1

Alternative forms of Duhamel integral

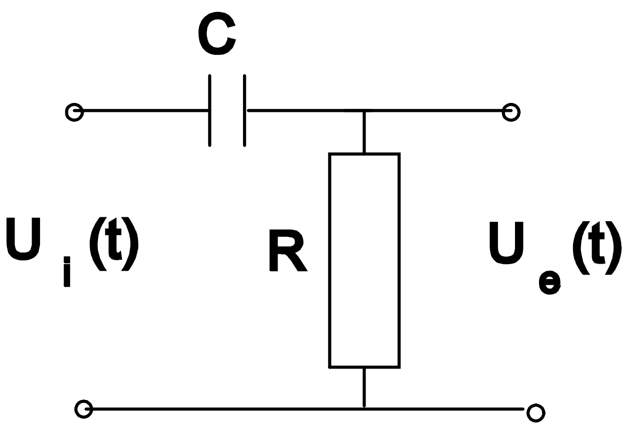
$$e(t) = i(t)A(0) + \int_0^t \frac{dA(t)}{dt}\bigg|_{t=\tau} i(t-\tau)\,d\tau$$

$$e(t) = i(0)A(t) + \int_0^t \frac{di(t)}{dt}\bigg|_{t=t-\tau} A(\tau)\,d\tau$$

$$e(t) = i(t)A(0) + \int_0^t \frac{dA(t)}{dt}\bigg|_{t=t-\tau} i(\tau)\,d\tau$$

Problems

An exponential type signal is applied at the input of a high-pass filter. Calculate and draw the circuit response.



Duhamel integral will be used.
Firstly will be calculated the response of this circuit to a single step unit signal, e.g. the function A(t):

$$u_e(t) = u_e(\infty) + \left[u_e(0) - u_e(\infty)\right]e^{-\frac{t}{\tau}}$$

$u_e(\infty)=0$; $u_e(0)=1$; circuit time constant $\tau = R \cdot C$

$u_e(t) = A(t) = e^{-t/RC}$

The exponential input signal: $u_i(t) = U(1-e^{-t/T})$

Applying Duhamel integral: $$u_e(t) = u_i(0)A(t) + \int_0^t \frac{du_i(t)}{dt}\Big|_{t=\tau} A(t-\tau)d\tau$$

With: $A(t) = e^{-t/RC}$ and $u_i(0)=0$ and:

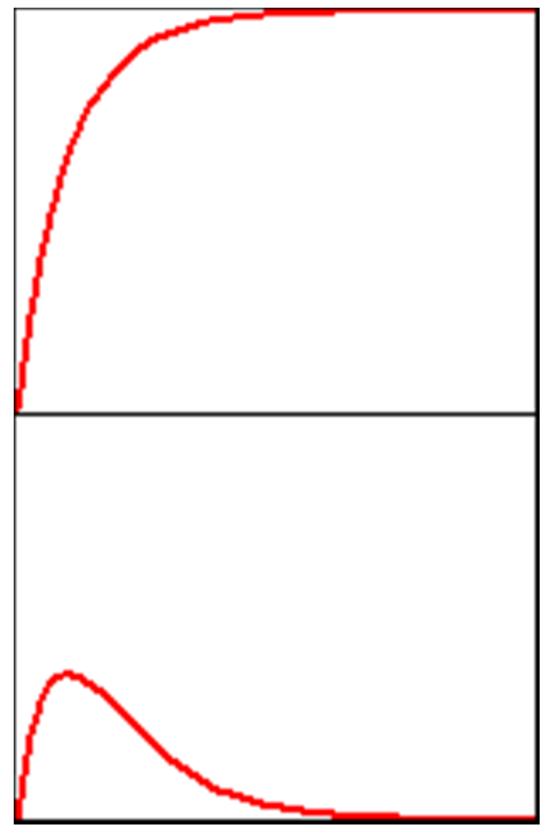
$$\frac{du_i(t)}{dt}\Big|_{t=\tau} = \frac{U}{T} e^{-\frac{t}{T}}\Big|_{t=\tau} = \frac{U}{T} e^{\frac{\tau}{T}}$$

Applying the integral:

$$u_e(t) = \int_0^t \frac{U}{T} e^{\frac{-\tau}{t}} \cdot e^{\frac{-(t-\tau)}{RC}} d\tau = \frac{U}{T} e^{-\frac{t}{RC}} \int_0^t e^{\tau\frac{T-RC}{TRC}} d\tau$$

And finally:

$$u_e(t) = \frac{U}{1-\frac{T}{RC}}\left(e^{-\frac{t}{T}} - e^{-\frac{t}{RC}}\right)$$



Proposed problems

1. Same problem for the low-pass filter.

2. Consider a high-pass filter, with components: $R=10k\Omega$, $C=100nF$. Applying at input a single step signal with amplitude of 5V, calculate the time needed for the output signal to reach the value of 2V.