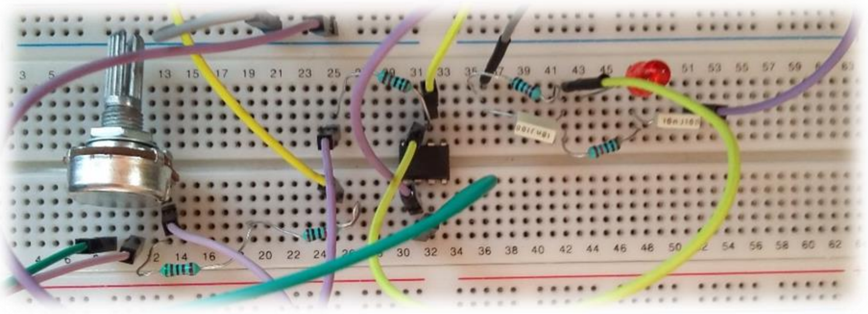


FUNDAMENTAL ELECTRONIC CIRCUITS

Assist. prof. Laura-Nicoleta IVANCIU, Ph.D.

C12-13 – 555 Timer. Class D amplifier.

Contents

- Intro
- 555 Timer
- Class D amplifier

➢ Signal generators/oscillators - revisited

- circuits which produce/generate a variable output signal, of a certain shape (sinusoidal, rectangular, triangular, sawtooth) and frequency, in the absence of a variable input signal (power supplies only)

- convert DC signals (power supplies) into AC signals

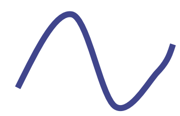
- must contain reactive components (capacitor, inductor)

➢ Types of signal generators - revisited

Based on the shape of the output signal:

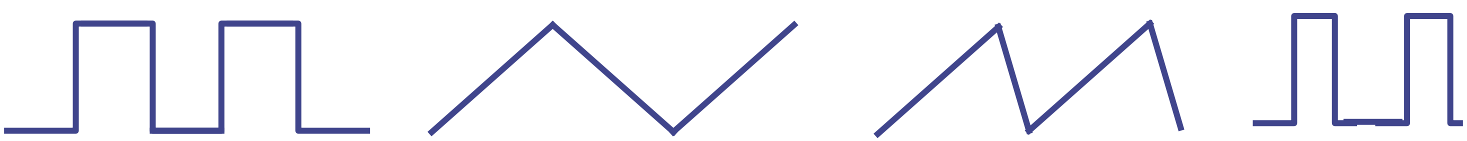
- sinusoidal oscillators (aka *linear* or *harmonic* oscillators)

  C10, Lab 11, Seminar 6



- nonsinusoidal oscillators (aka *relaxation* oscillators)

  C11, Seminar 7



rectangular triangular sawtooth pulse

➢ Relaxation oscillators – principle and usage

- aka multivibrators

= circuits made of a feedback loop containing a switching device (transistor, comparator, relay, OpAmp) that repetitively charges a capacitor or inductor through a resistance until it reaches a threshold level, then discharges it again.

The period/frequency of the oscillations depends on the time constant of the C or L circuit.

- produce low frequency signals
- easier to design than linear oscillators
- easier to integrate (no inductors)

Applications: blinking lights, electronic beepers, horizontal deflection circuits in CRT oscilloscopes, voltage controller oscillators (VCOs).

Drawbacks: more phase noise, poor frequency stability

➢ Relaxation oscillators – types

What is a stable state?
What does it take for the circuit to switch between states?

Based on the number of stable states:

- no stable states – astable multivibrator

- the circuit permanently switches between the two unstable states

- one stable state – monostable multivibrator

- a trigger/pulse causes the circuit to enter the unstable state. The circuit returns to the stable state by itself, after a certain period.

- two stable states – bistable multivibrator (flip-flop or latch)

- the circuit is stable in either state. An external trigger/pulse is used to switch between states.

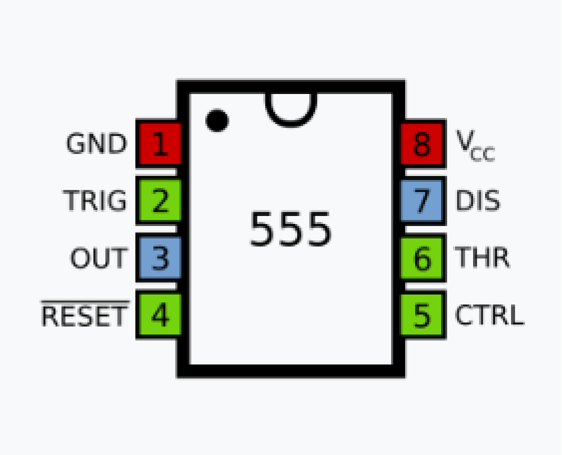
LM555 - features

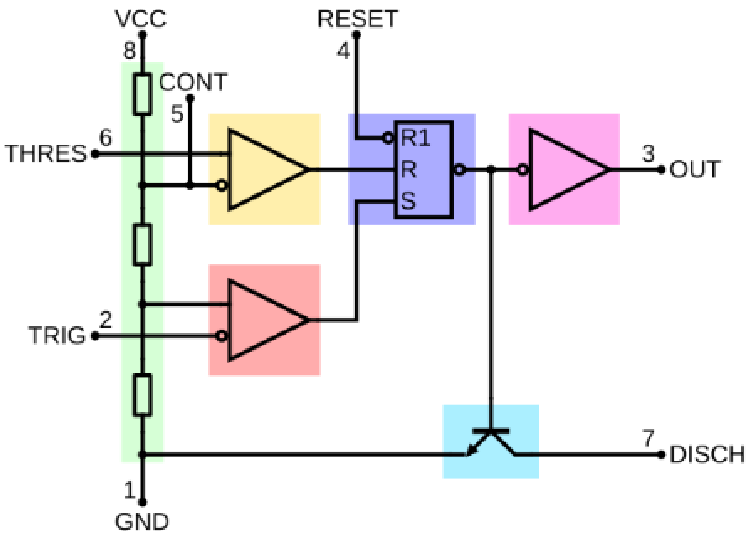
Designed in **1971** by Hans Camezind
- highly stable IC
- used to generate time delays or oscillation
- timing from microseconds through hours
- adjustable duty cycle
- output can source or sink 200 mA
- output and supply TTL compatible
- temperature stability better than 0.005% per °C

Versions:
- LM555 - in bipolar technology
- LMC555 - in CMOS technology

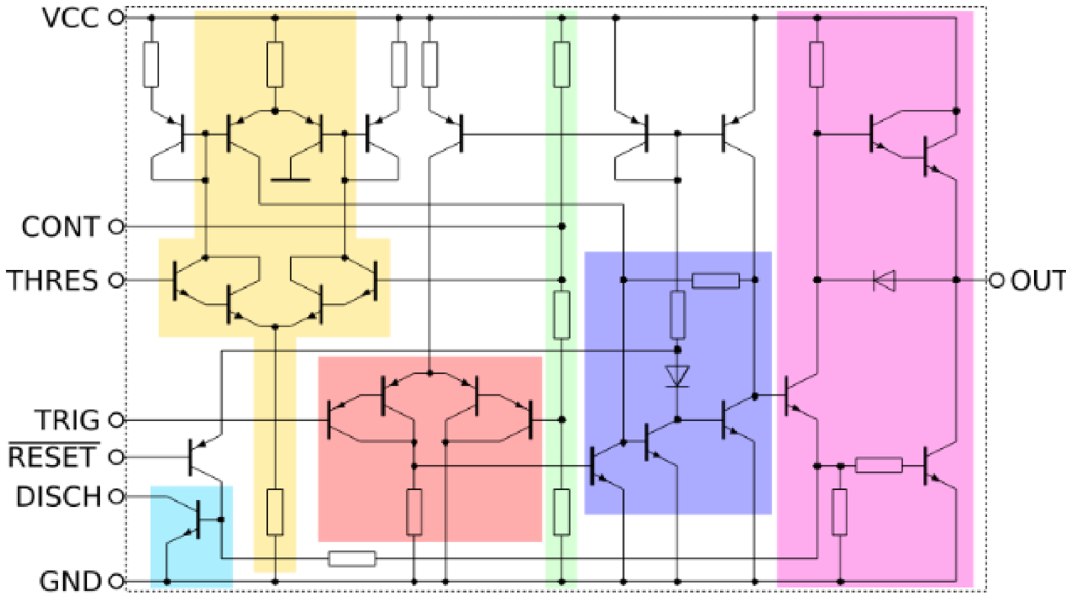
Used as:
- astable/monostable/bistable circuit
- rectangular and triangular signal generator

➢ LM555 – structure and operation





555 internal block diagram[1]



555 internal schematic of bipolar version

LM555 – structure and operation

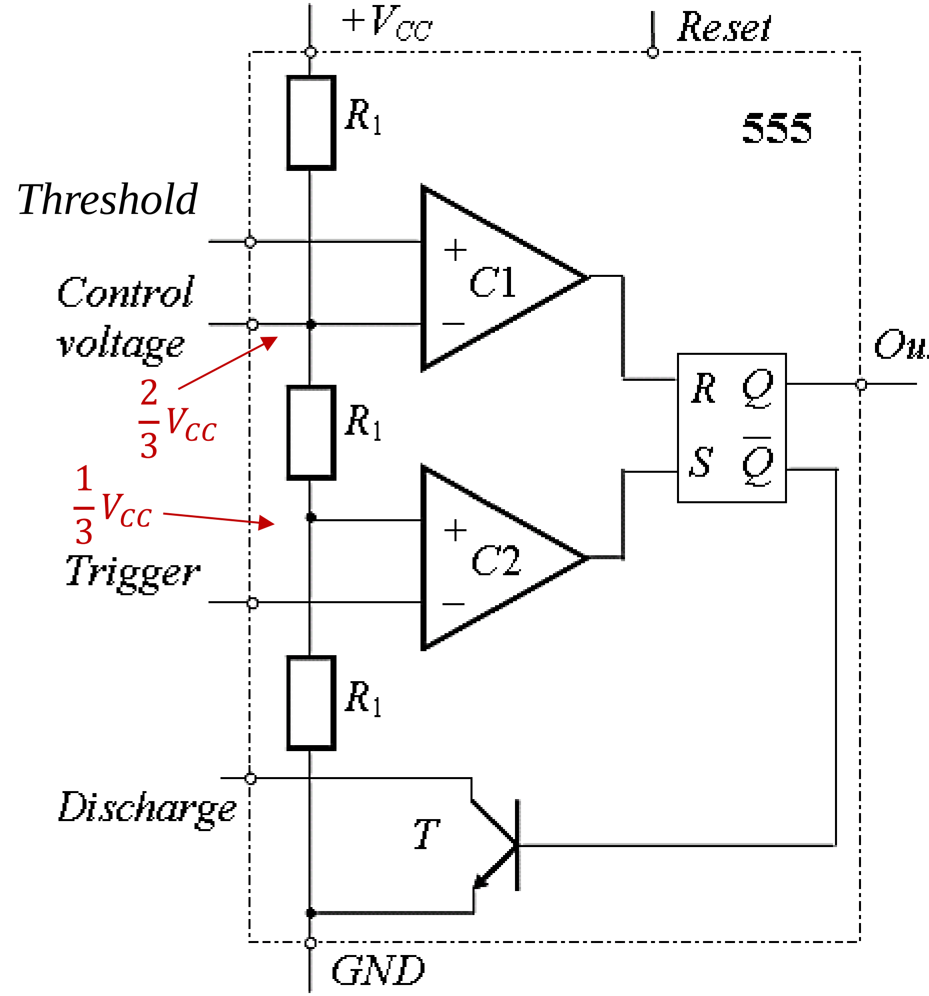
V_{cc} = 5…15 V
R_1 = 5 KΩ (hence the name of the IC)

C1 – non-inverting simple comparator
- compares *Threshold* to $\frac{2}{3}V_{CC}$

$$v_{O,C1} = \begin{cases} 0, & Threshold < \frac{2}{3}V_{CC} \\ V_{CC}, & Threshold > \frac{2}{3}V_{CC} \end{cases}$$

C2 – inverting simple comparator
- compares *Trigger* to $\frac{1}{3}V_{CC}$

$$v_{O,C2} = \begin{cases} 0, & Trigger > \frac{1}{3}V_{CC} \\ V_{CC}, & Trigger < \frac{1}{3}V_{CC} \end{cases}$$

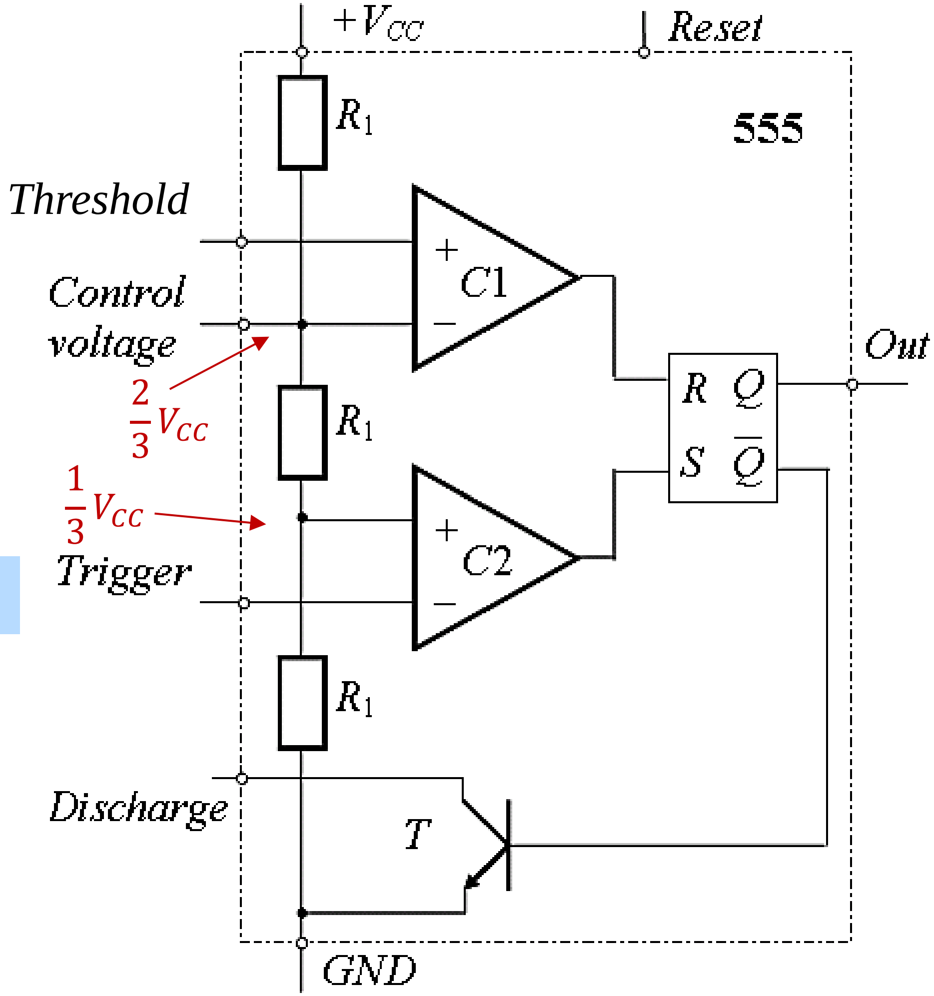


➢ LM555 – structure and operation

$$v_{O,C1} = \begin{cases} 0, & Threshold < \frac{2}{3}V_{CC} \\ V_{CC}, & Threshold > \frac{2}{3}V_{CC} \end{cases}$$

$$v_{O,C2} = \begin{cases} 0, & Trigger > \frac{1}{3}V_{CC} \\ V_{CC}, & Trigger < \frac{1}{3}V_{CC} \end{cases}$$

R	S	Q	$\bar{Q}$
L	L	no change	no change
H	L	L	H
L	H	H	L
H	H	forbidden	forbidden



LM555 – structure and operation

$$v_{O,C1} = \begin{cases} 0, & Threshold < \frac{2}{3}V_{CC} \\ V_{CC}, & Threshold > \frac{2}{3}V_{CC} \end{cases}$$

$$v_{O,C2} = \begin{cases} 0, & Trigger > \frac{1}{3}V_{CC} \\ V_{CC}, & Trigger < \frac{1}{3}V_{CC} \end{cases}$$

R	S	Q	$\bar{Q}$
L	L	no change	no change
H	L	L	H
L	H	H	L
H	H	forbidden	forbidden

$Thresh$	$Trig$	$v_{O,C1}$	$v_{O,C2}$	R	S	Q	$\bar{Q}$	T	Out
$< \frac{2}{3}V_{CC}$	$< \frac{1}{3}V_{CC}$	0	V_{CC}	L	H	H	L	off	V_{CC}
$> \frac{2}{3}V_{CC}$	$> \frac{1}{3}V_{CC}$	V_{CC}	0	H	L	L	H	on	0
$< \frac{2}{3}V_{CC}$	$> \frac{1}{3}V_{CC}$	0	0	L	L	no change	no change	no change	no change

➢ Astable multivibrator w/ LM555

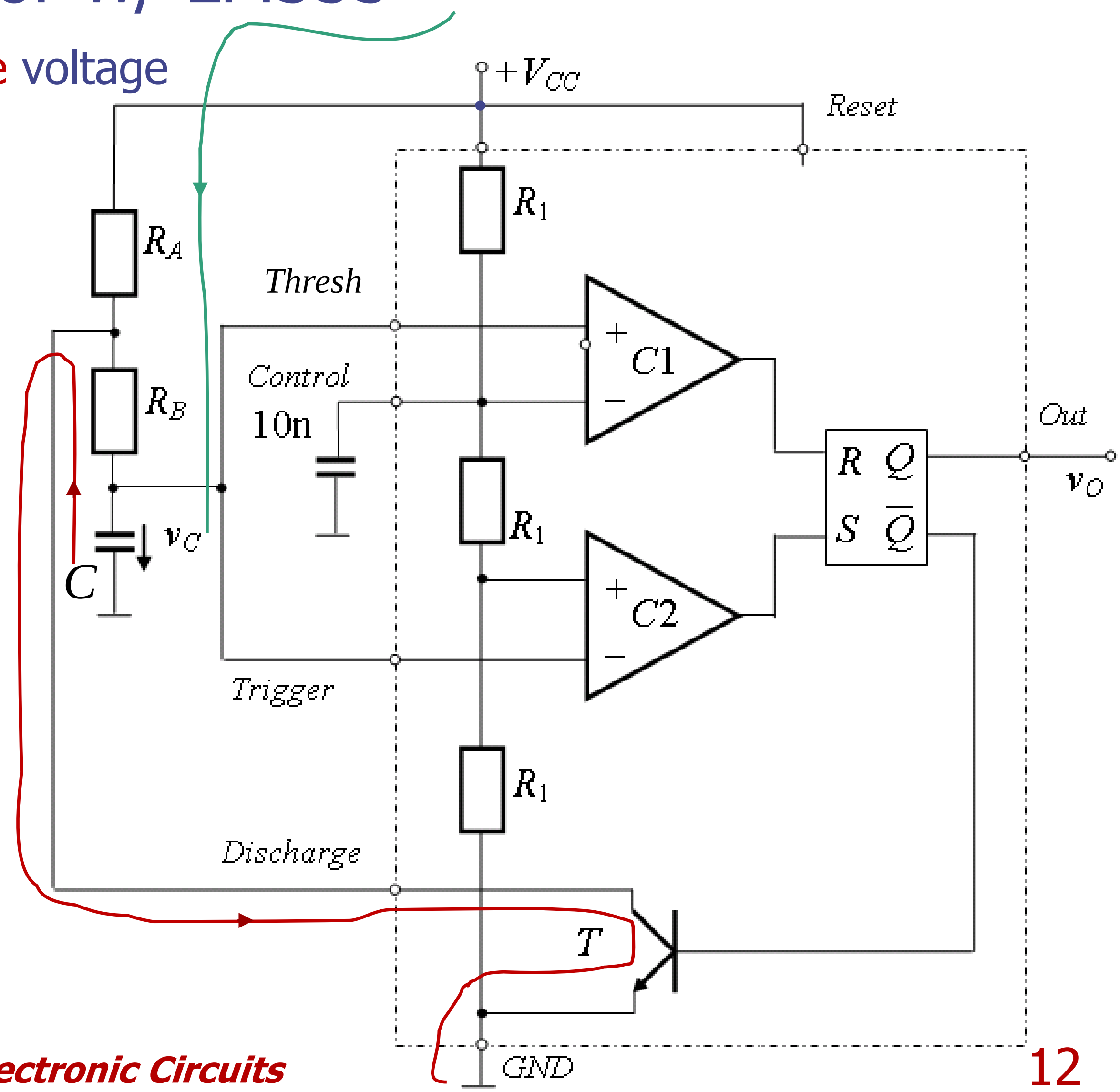
Thresh & *Trigger* receive the same voltage

- charging *C*

$$\tau_c = (R_A + R_B)C$$

- discharging *C*

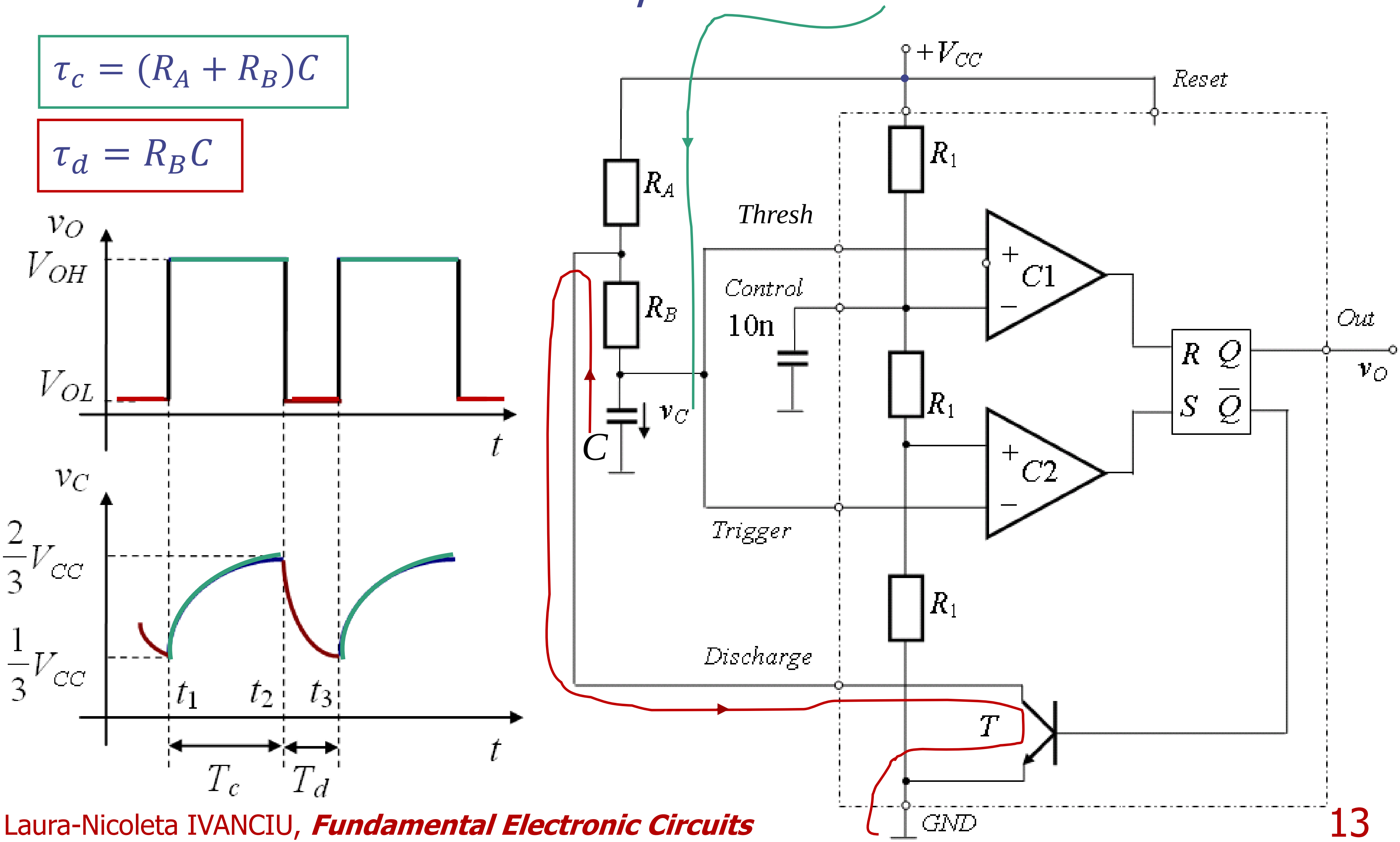
$$\tau_d = R_B C$$



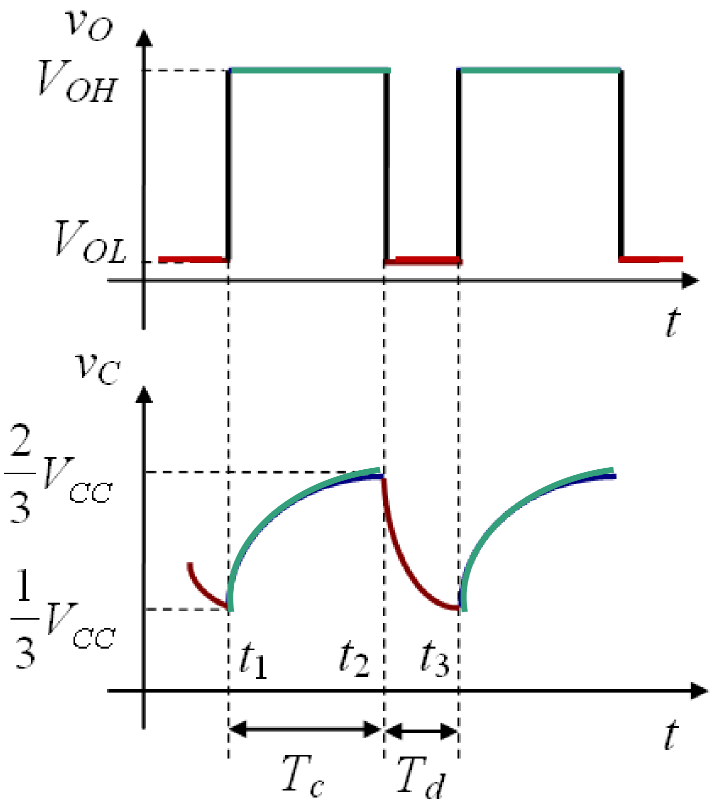
Astable multivibrator w/ LM555

$$\tau_c = (R_A + R_B)C$$

$$\tau_d = R_B C$$



➢ Astable multivibrator w/ LM555



$$v_C(t) = v_C(0)e^{-\frac{t}{\tau}} + \left(1 - e^{-\frac{t}{\tau}}\right)v_C(\infty)$$

$t \in (t_1, t_2)$

$$\frac{2}{3}V_{CC} = \frac{1}{3}V_{CC}e^{-\frac{T_c}{\tau_c}} + \left(1 - e^{-\frac{T_c}{\tau_c}}\right)V_{CC}$$

$$T_c = (R_A + R_B)C\ln 2 \approx 0.69(R_A + R_B)C$$

$t \in (t_2, t_3)$

$$\frac{1}{3}V_{CC} = \frac{2}{3}V_{CC}e^{-\frac{T_d}{\tau_d}} + \left(1 - e^{-\frac{T_d}{\tau_d}}\right) \cdot 0$$

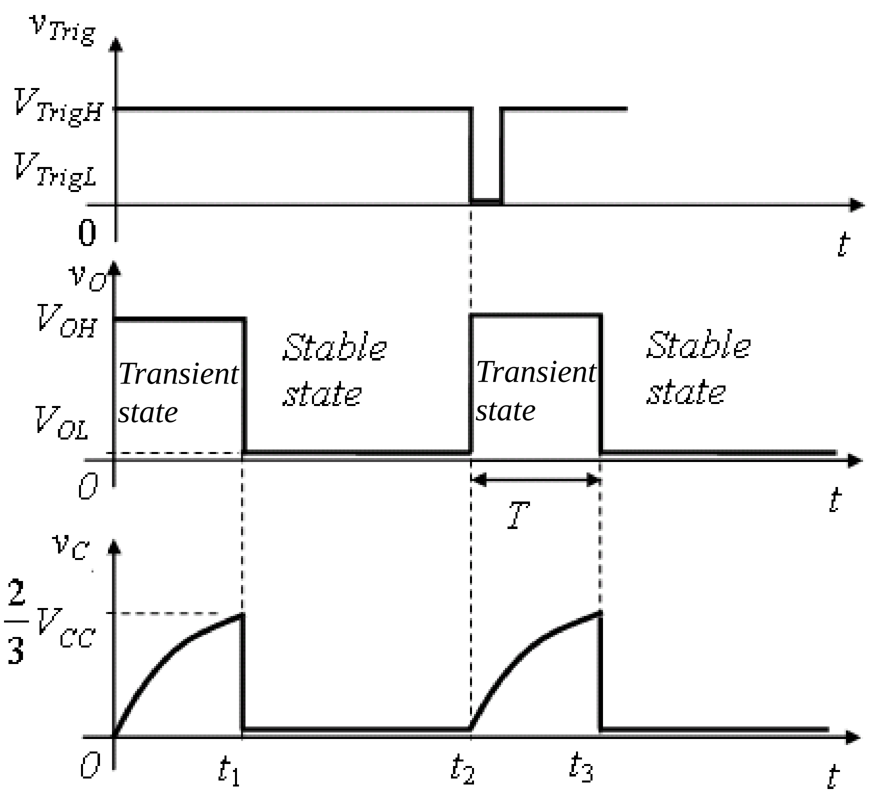
$$T_d = R_B C\ln 2 \approx 0.69 R_B C$$

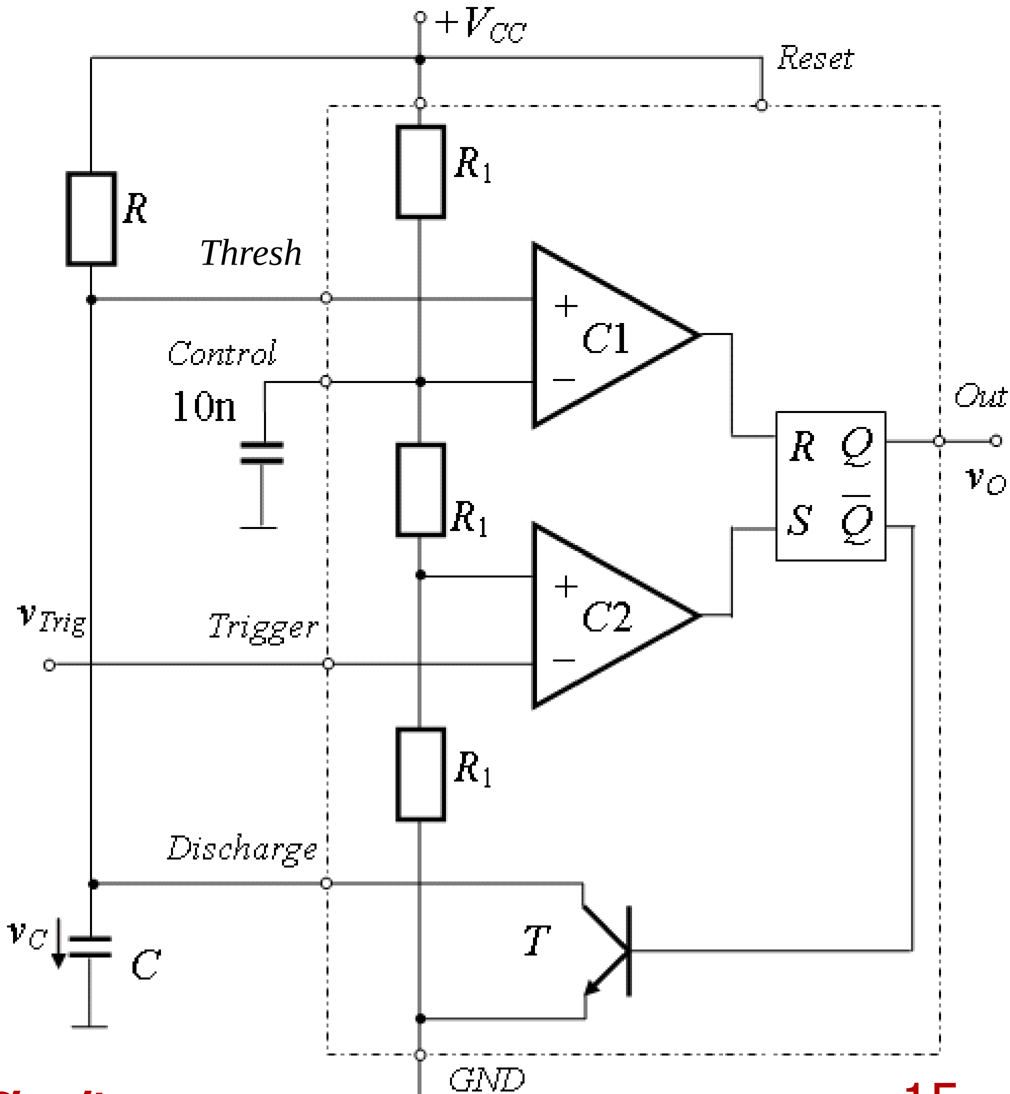
$$T = T_c + T_d = (R_A + 2R_B)C\ln 2 \approx 0.69(R_A + 2R_B)C$$

Duty cycle $$\delta = \frac{T_c}{T_c + T_d} = \frac{R_A + R_B}{R_A + 2R_B}$$

➢ Monostable multivibrator w/ LM555

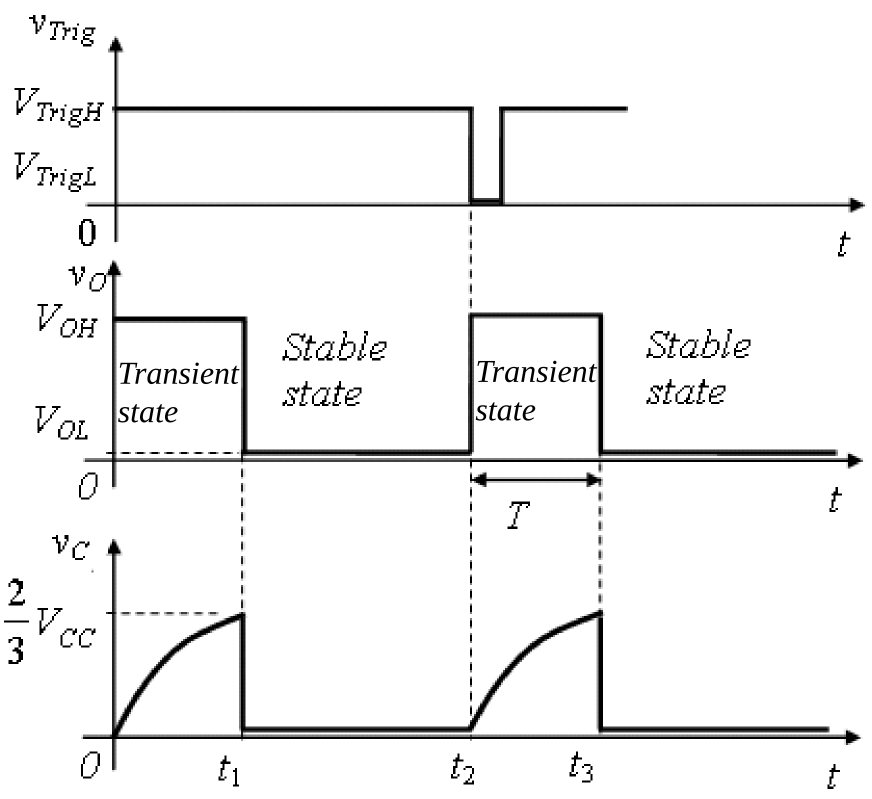
v_{Trig} can come from a sensor/pushbutton





➢ Monostable multivibrator w/ LM555

v_{Trig} can come from a sensor/pushbutton



$$V_{TrigH} > \frac{1}{3}V_{CC}$$

$$V_{TrigL} < \frac{1}{3}V_{CC}$$

$$t \in (t_2, t_3) \qquad \tau = RC$$

$$\frac{2}{3}V_{CC} = 0 \cdot e^{-\frac{T}{\tau}} + \left(1 - e^{-\frac{T}{\tau}}\right)V_{CC}$$

$$T = RC \ln 3 = 1.1RC$$

T – timing period

➢ Rectangular and triangular signal generator w/ LM555

Thresh & *Trigger* receive the same voltage

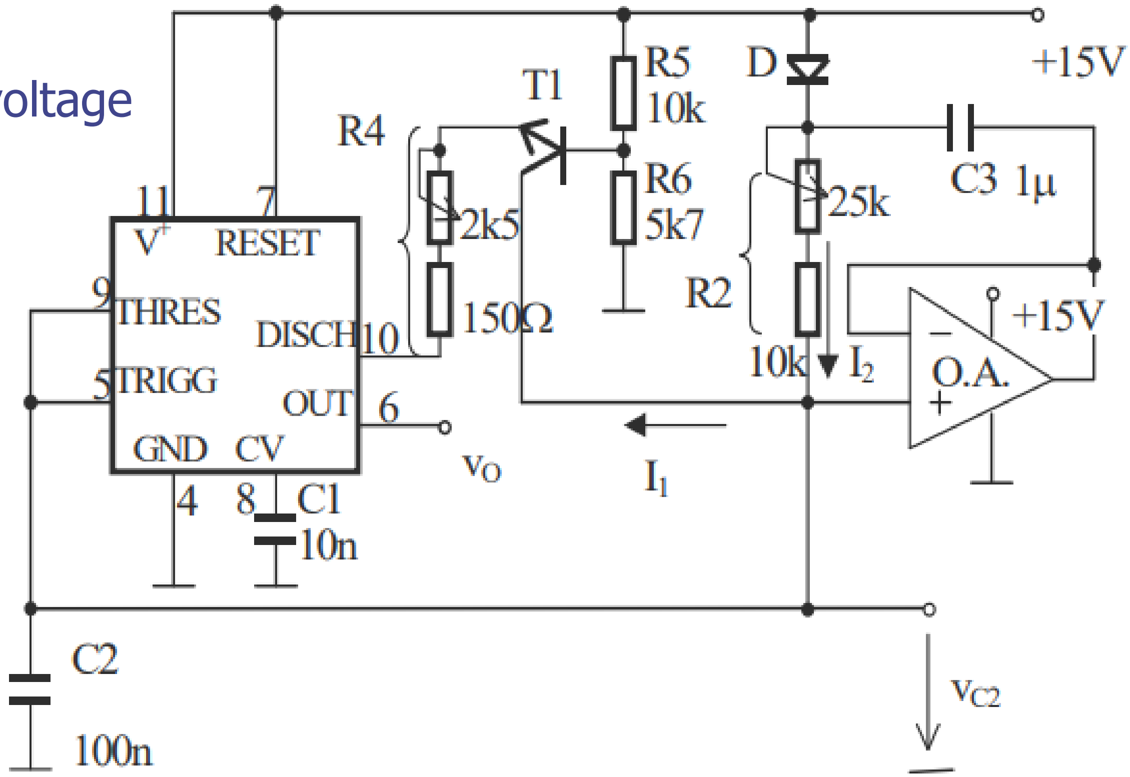
Current I_2 charges C

Current I_1 discharges C

OpAmp – total NF, $V+ = V- = V_{OA}$

v_O – rectangular, 0…15 V

v_{C2} – triangular, 5…10 V



Prove that I_1 and I_2 are constant!

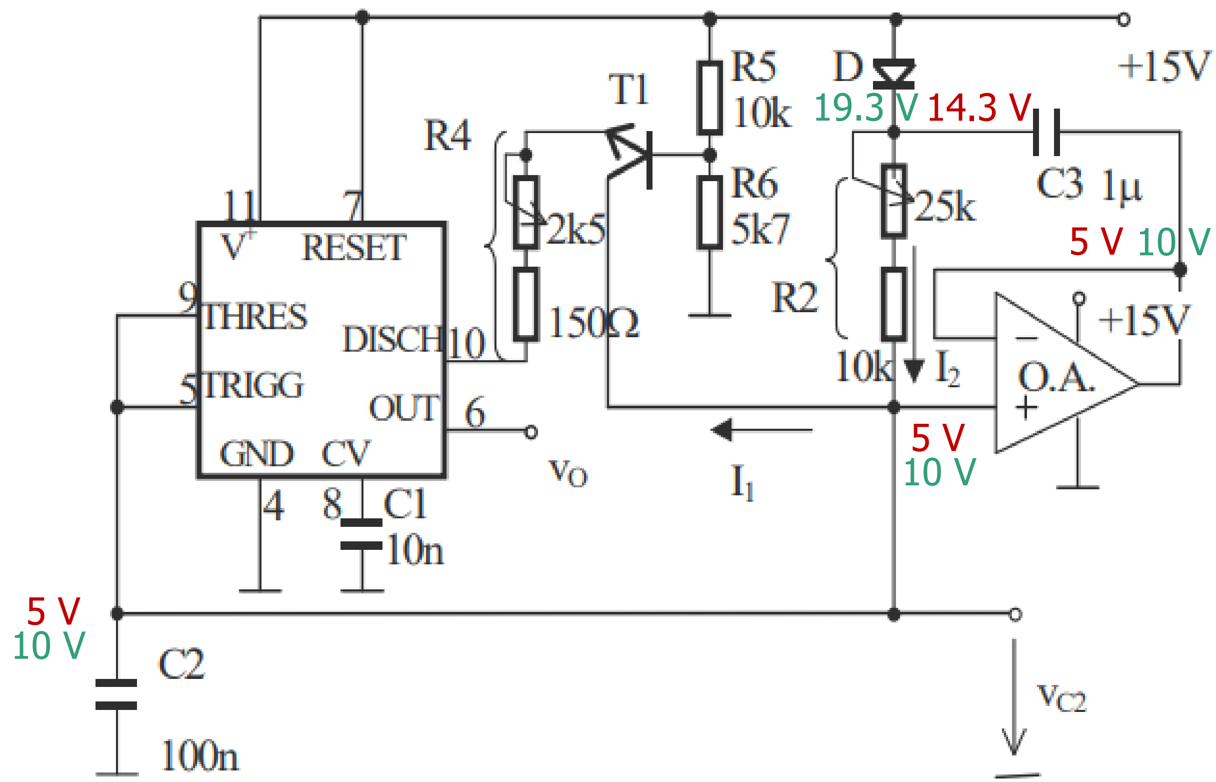
➢ Rectangular and triangular signal generator w/ LM555

v_{C2} = 5 V
D – on
C_3 - charges
v_{C3} = (14.3 - 5) V = 9.3 V

v_{C2} – increases up to 10 V
C_3 – stays charged
D – turns off
v_{C3} = 9.3 V

$v_{R2} = v_{C3}$ = 9.3 V

$I_2 = 9.3/R_2$ = constant

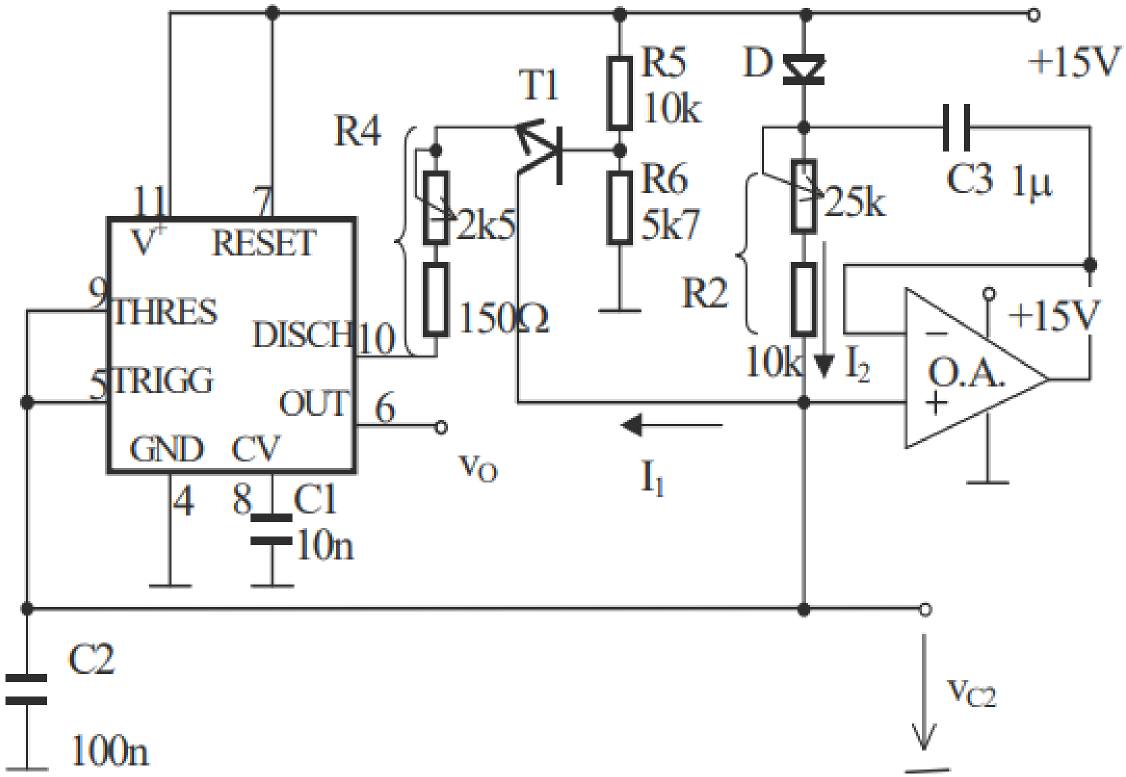


➢ Rectangular and triangular signal generator w/ LM555

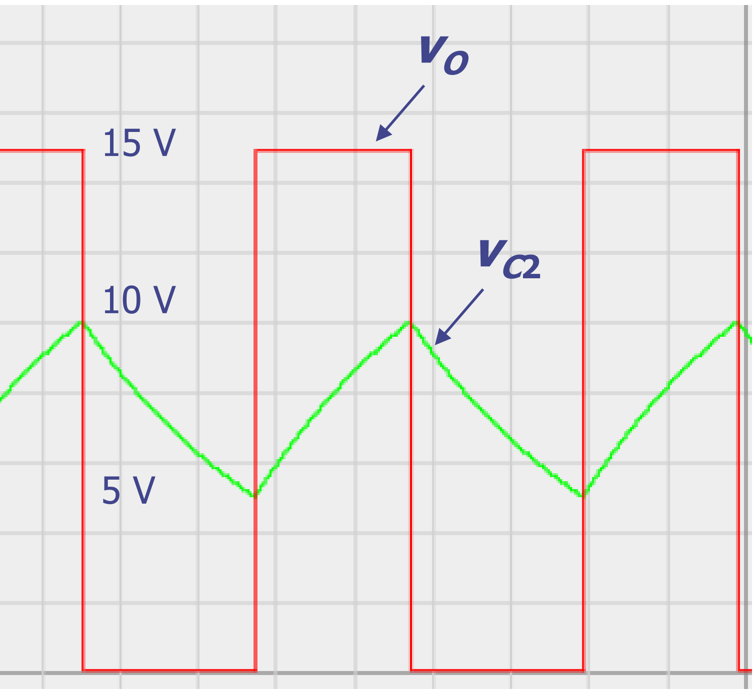
$$V_{R6} = \frac{R_6}{R_5 + R_6} \cdot 15$$

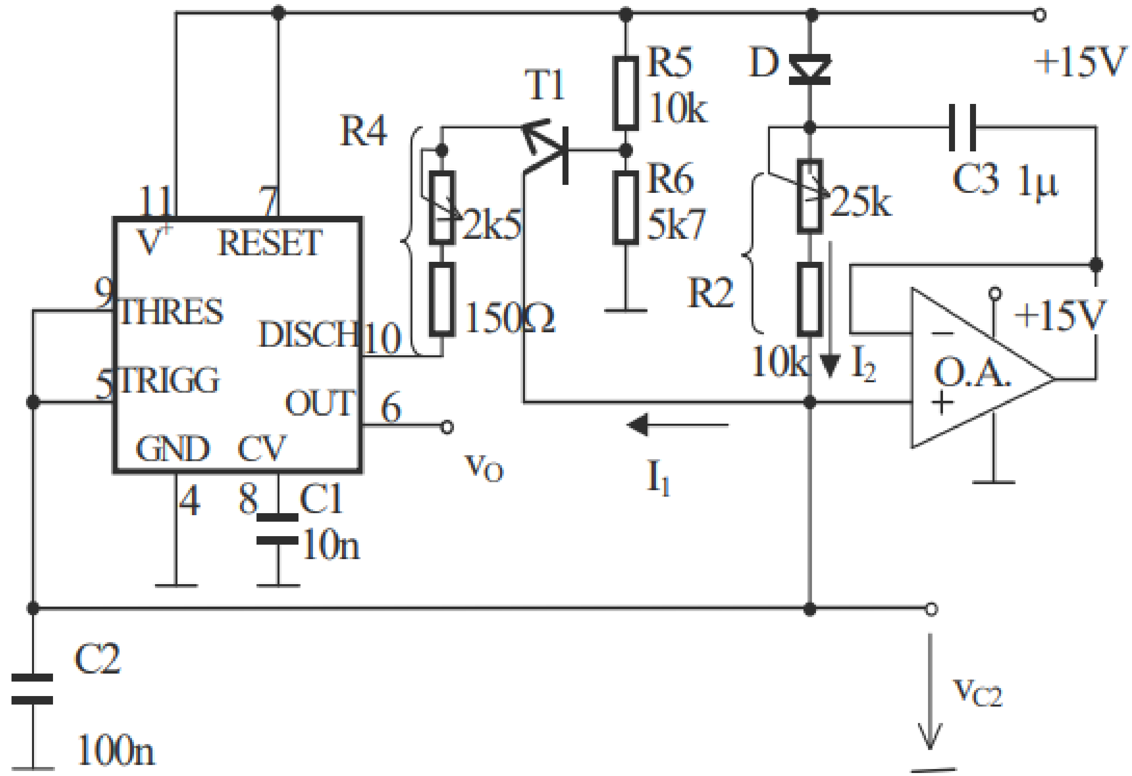
$$I_1 = \frac{V_{R6} - V_{BE,on}}{R_4} = \frac{V_{R6} - 0.7}{R_4}$$

$$I_1 = \text{constant}$$



➢ Rectangular and triangular signal generator w/ LM555





$I_2 = 9.3/R_2$ - charging

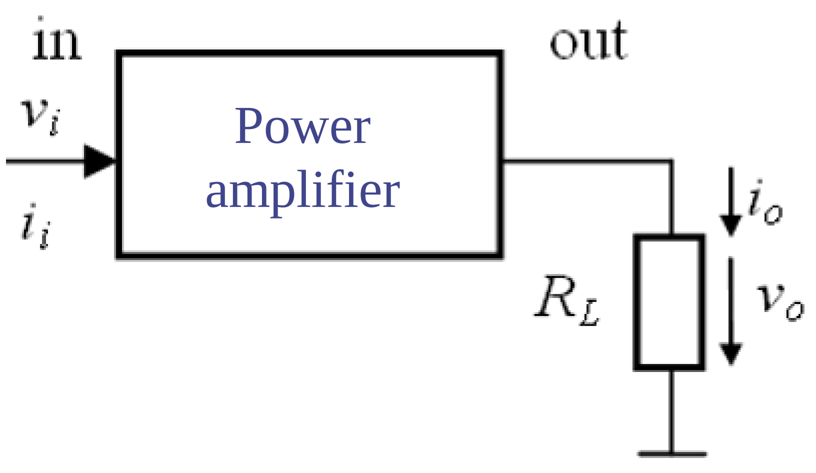
$I_1 = \frac{V_{R6}-0.7}{R_4}$ - discharging

R_2 and R_4 - adjustable duty cycle

➢ Power amplifiers - revisited

Power amplifier = a circuit which provides little or no voltage gain, but **significant** current gain

= large signal or output amplifier

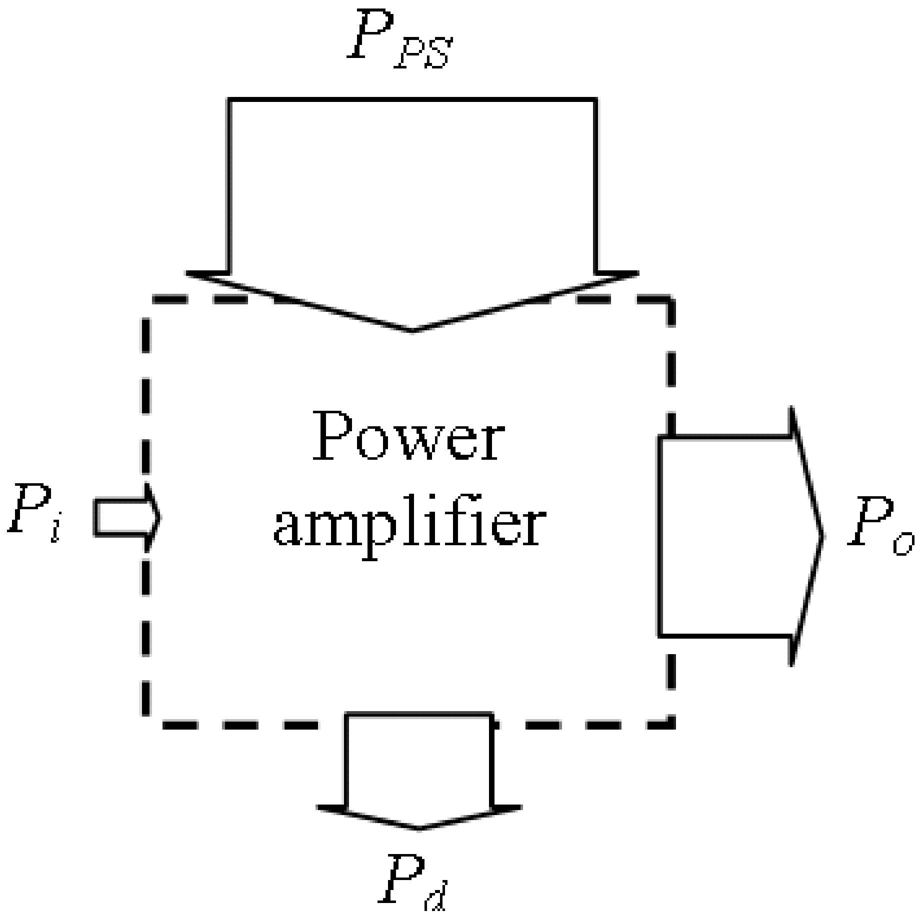


$v_o \approx v_i \qquad A_v \approx 1$

$i_o > i_i \qquad A_i > 1$

$$p_o = v_o \cdot i_o$$
$$p_i = v_i \cdot i_i$$
$$p_o > p_i$$

➢ Power amplifiers - revisited



$$P_i + P_{PS} = P_d + P_o$$

P_i - power from the input source
P_{PS} - power drawn from the power supplies
P_d - dissipated power (heat)
P_o - power delivered at the output (on R_L)

$$P_i << P_{PS}$$

$$\eta = \frac{P_o}{P_{PS}}$$

efficiency of the stage

η [%] or $\eta \in (0, 1)$

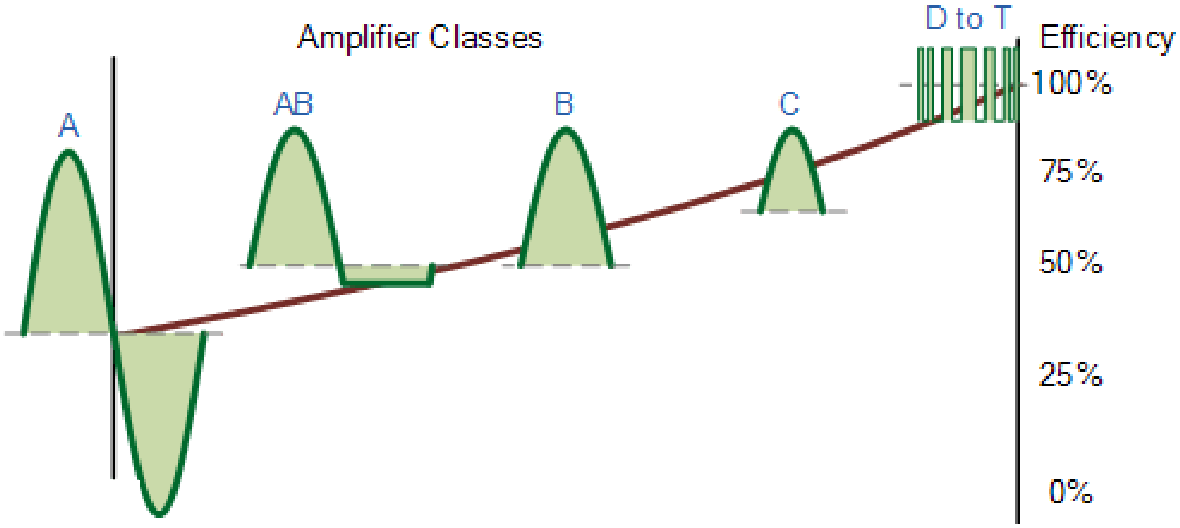
➢ Power amplifiers - revisited

The classes are defined in relation to the interval of time in which the amplifier device (transistor) is active, expressed as a fraction of the period of the input signal.

Classes: A, B, AB, C, D, E, F, G, I, S, T, etc

efficiency of the stage

$$\eta = \frac{P_o}{P_{PS}}$$



The less time T is active during a period, the higher the efficiency

Power amplifiers - revisited

Class	Conduction interval	Max. efficiency	Notes
A	$t_c = T$	25%	Small-signal amplifiers
B	$t_c = T/2$	78.5%	Audio amplifiers; crossover distortions
AB	$T/2 < t_c < T$	78.5%	Audio amplifiers; no crossover distortions
C	$t_c < T/2$	90%	RF transmitters
D	switching mode	80%-95%	PWM and passive filtering
E	switching mode	90%	RF transmitters
G	more efficient version of class AB		
H	similar to class G	100%	Power supply modulated by the signal
I	similar to class B, switching mode		Interleaved PWM amplifier
S, T	similar to class D, switching mode		

➢ Class D power amplifier - intro

- **switching amplifier** based on pulse-width modulation (**PWM**) techniques

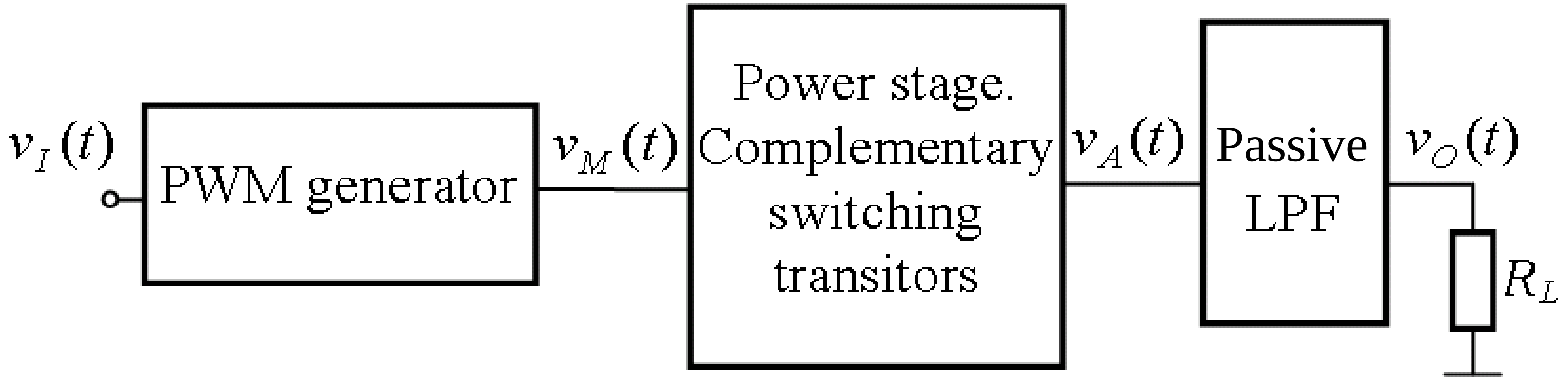
Purpose: high efficiency 80% - 95%

The reduction of the power dissipated by the amplifying transistors is due to the switching operation mode.

- increase in efficiency and reduction of the physical dimensions of the heatsink

Usage: portable equipment, battery operated equipment, equipment with space constraints, etc.

➢ Block diagram & operating principle

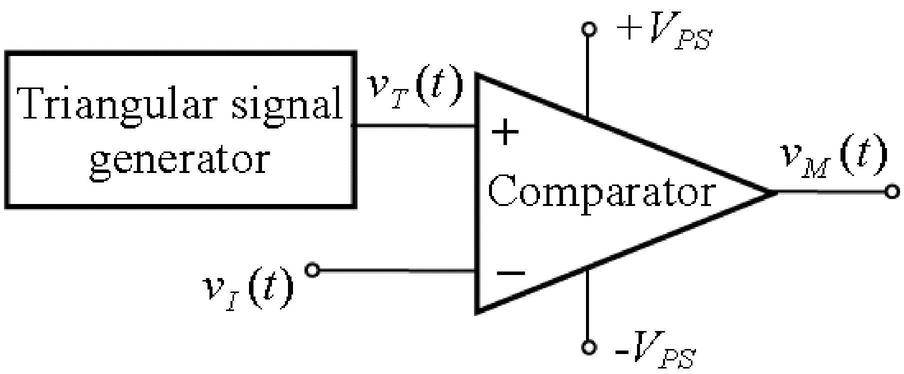


The input signal v_I is converted into a pulse-width-modulated (PWM) signal v_M with a much higher frequency (switching frequency).

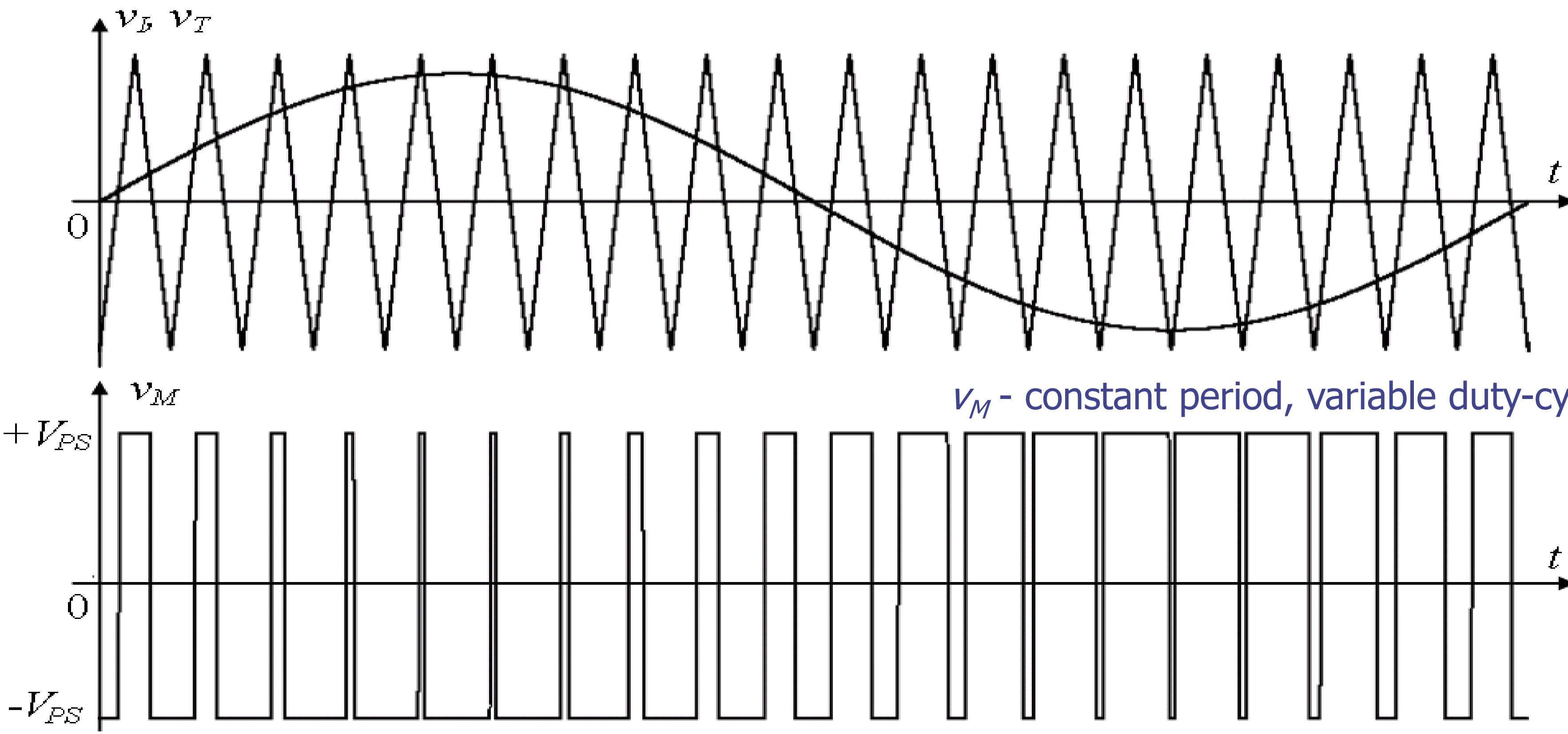
v_M has a constant period but variable duty-cycle, modulated by the instantaneous value of the input signal.

Reconstruction of the useful signal
LP filtering: the fundamental frequency is extracted from the amplified PWM signal v_A while the switching frequency and superior harmonics and components are removed.

- PWM generator

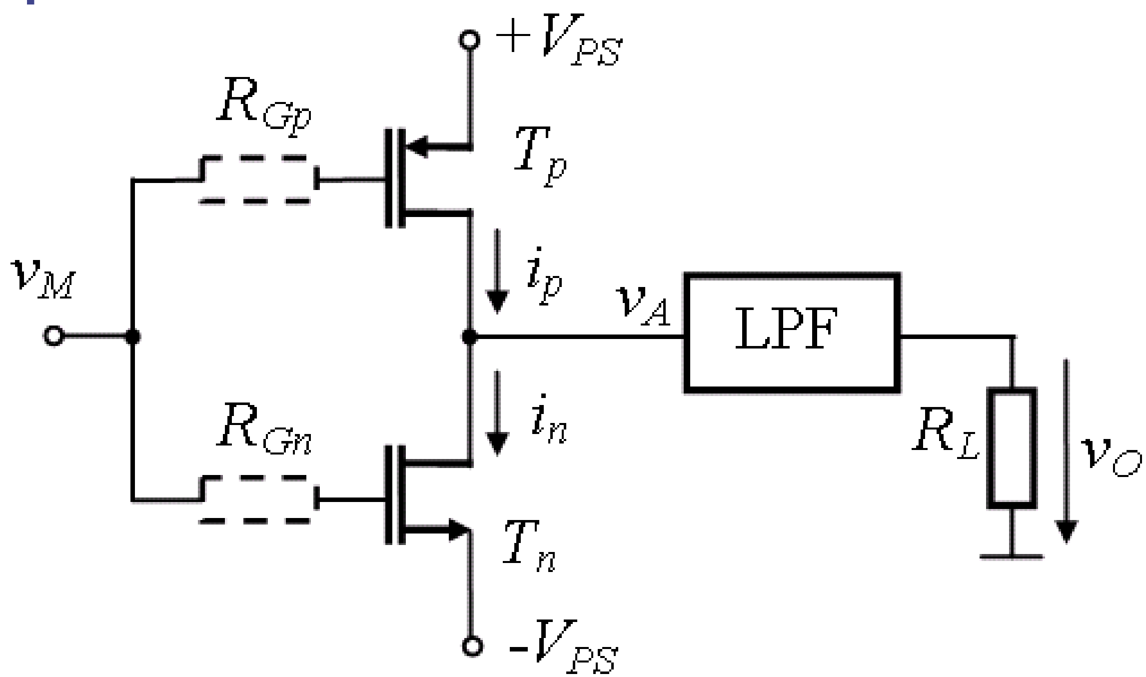


frequency of v_T >> frequency of v_I



v_M - constant period, variable duty-cycle

➢ Power stage + LPF



Each transistor commutation happens in a finite time.

During the commutation, there is a (small) power dissipation across the transistors.

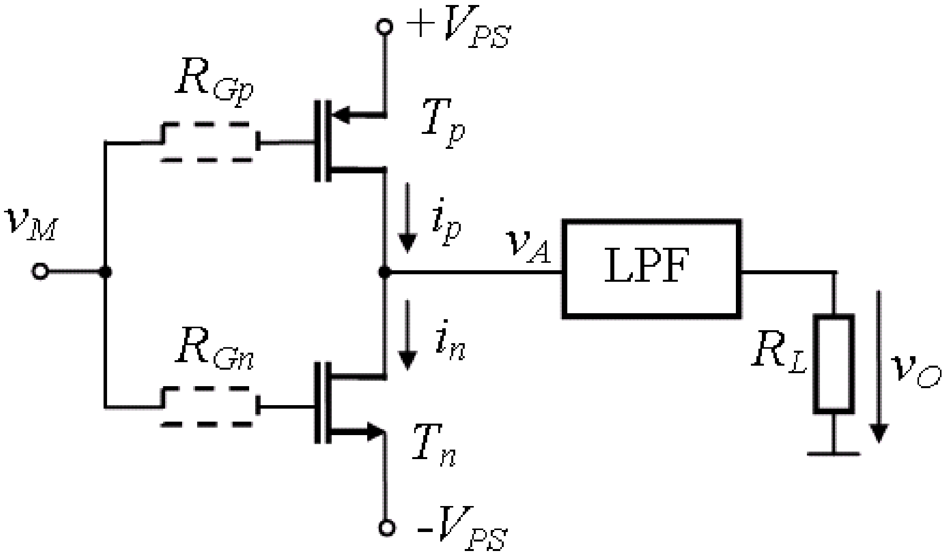
$v_{M_L} = -V_{PS}$ T_p (on), T_n (off) $v_A = +V_{PS}$

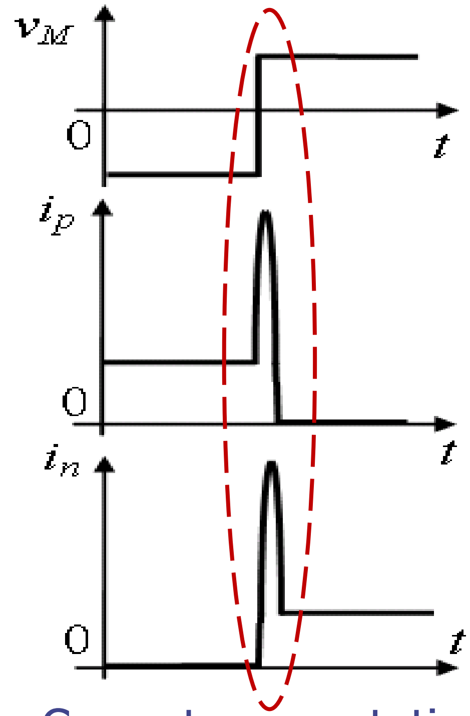
$v_{M_H} = +V_{PS}$ T_p (off), T_n (on) $v_A = -V_{PS}$

At the frequencies of the input signal, the equivalent LPF impedance should be sufficiently low (zero).

Inverting current amplifier (MOSFET logic inverter)

- Power stage + LPF - problem





Current commutation for

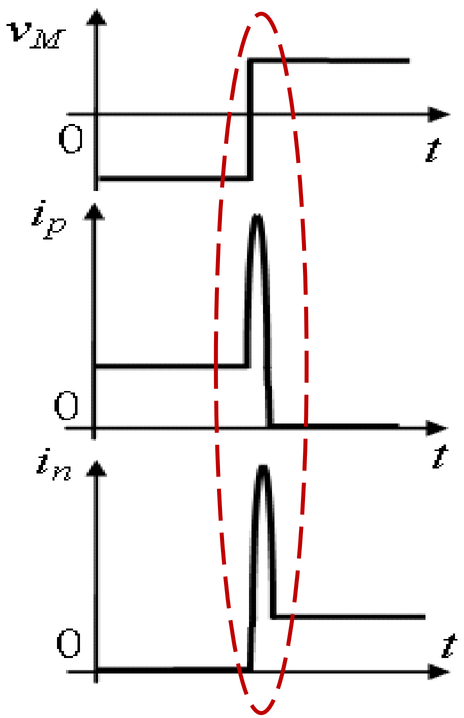
T_p : (on) -> (off)

T_n : (off) -> (on)

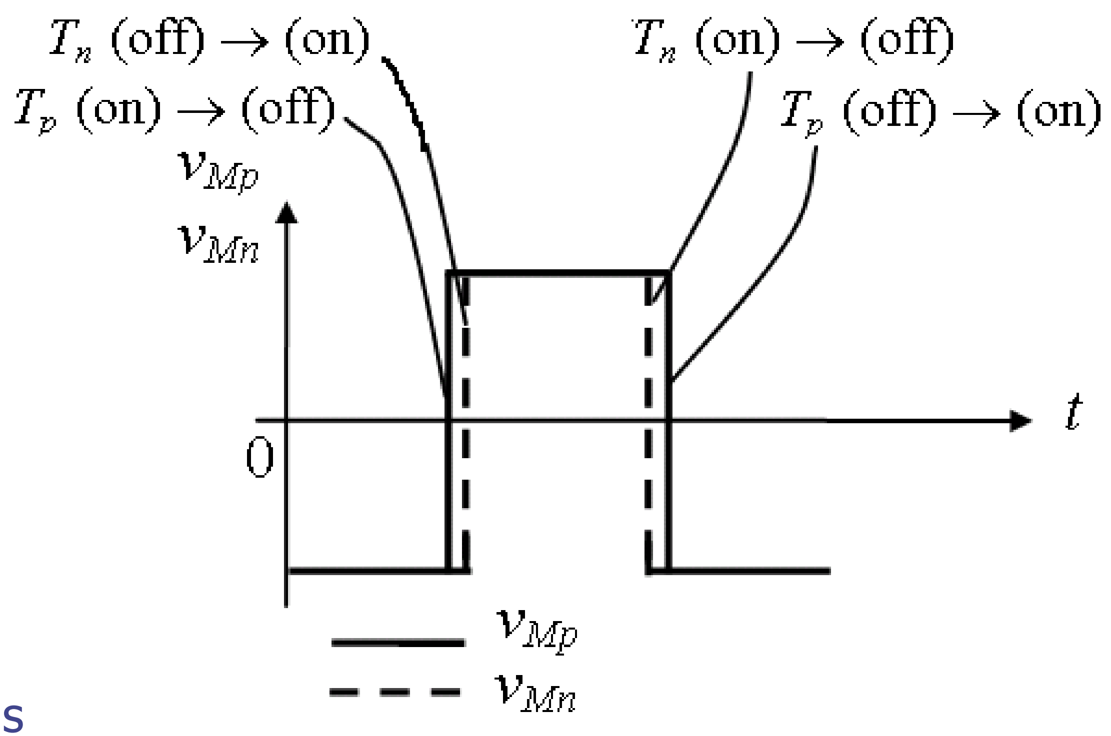
- the conducting transistor can not be turned off instantly
- there is a time interval when both transistors are on, resulting in a high current pulse between supplies, through the transistors
- can lead to transistor failure

Solution?

➢ Power stage + LPF - solution



The control signal for (off)->(on) must be delayed in comparison with the control signal for (on)->(off)

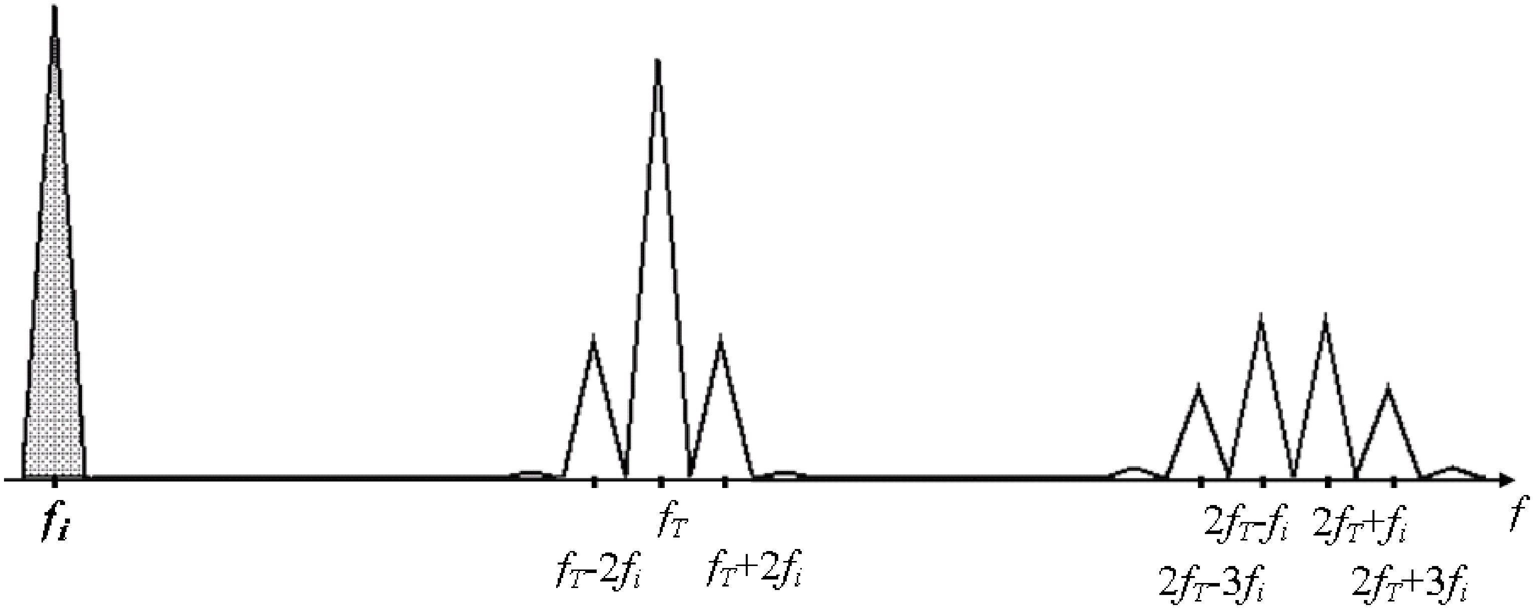


Control of the transistors using different (delayed) control signals

➢ Passive LPF - necessity

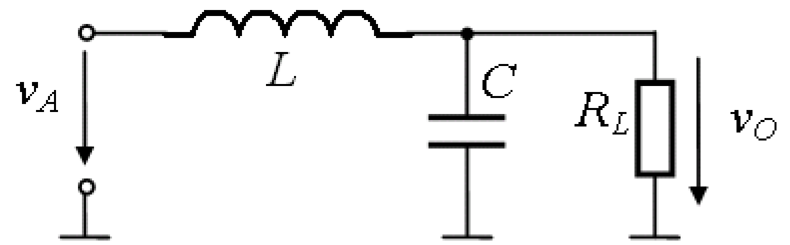
The frequency spectrum of the pulse-width-modulated signal contains input signal frequency (f_i), switching frequency (f_T), and harmonics:

$$f_i \quad, f_T, f_T \pm 2f_i, 2f_T \pm f_i, 2f_T \pm 3f_i$$



The LPF gets rid of any frequency above f_i allowing the reconstruction (demodulation) of the input signal.

➢ Passive LPF - circuit



single stage, second order LC filter

$$F(j\omega) = \frac{v_O(j\omega)}{v_I(j\omega)} = \frac{1}{1 + j\omega LC\frac{1}{R_L C} + (j\omega)^2 LC}$$

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

$$Q = \omega_0 R_L C$$

$$F(j\omega) = \frac{1}{1 + j\frac{\omega}{\omega_0}\frac{1}{Q} + \left(j\frac{\omega}{\omega_0}\right)^2}$$

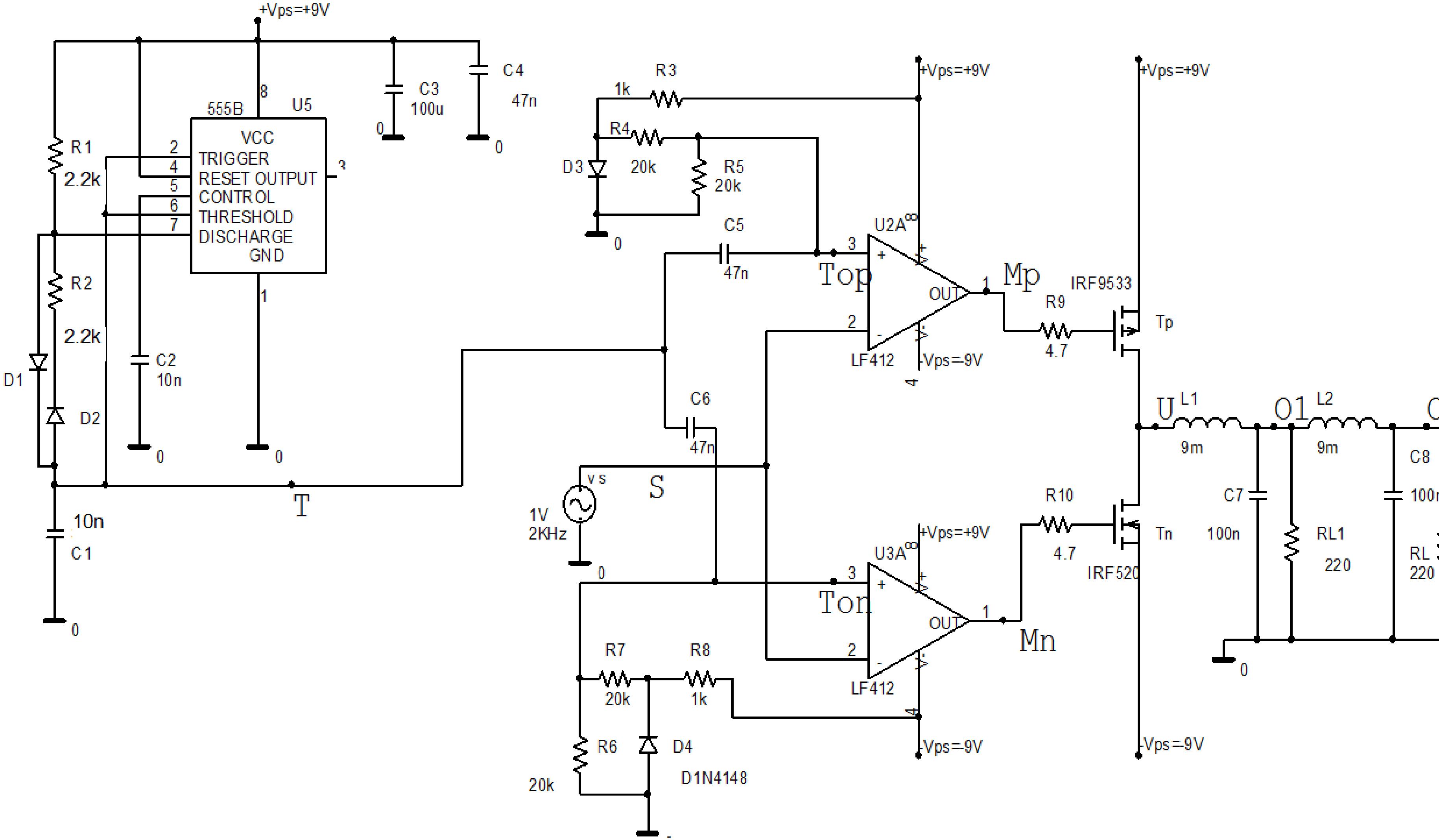
The filter should highly attenuate f_T

$f_0 < (1/10)f_T$ - for at least 40dB attenuation at f_T

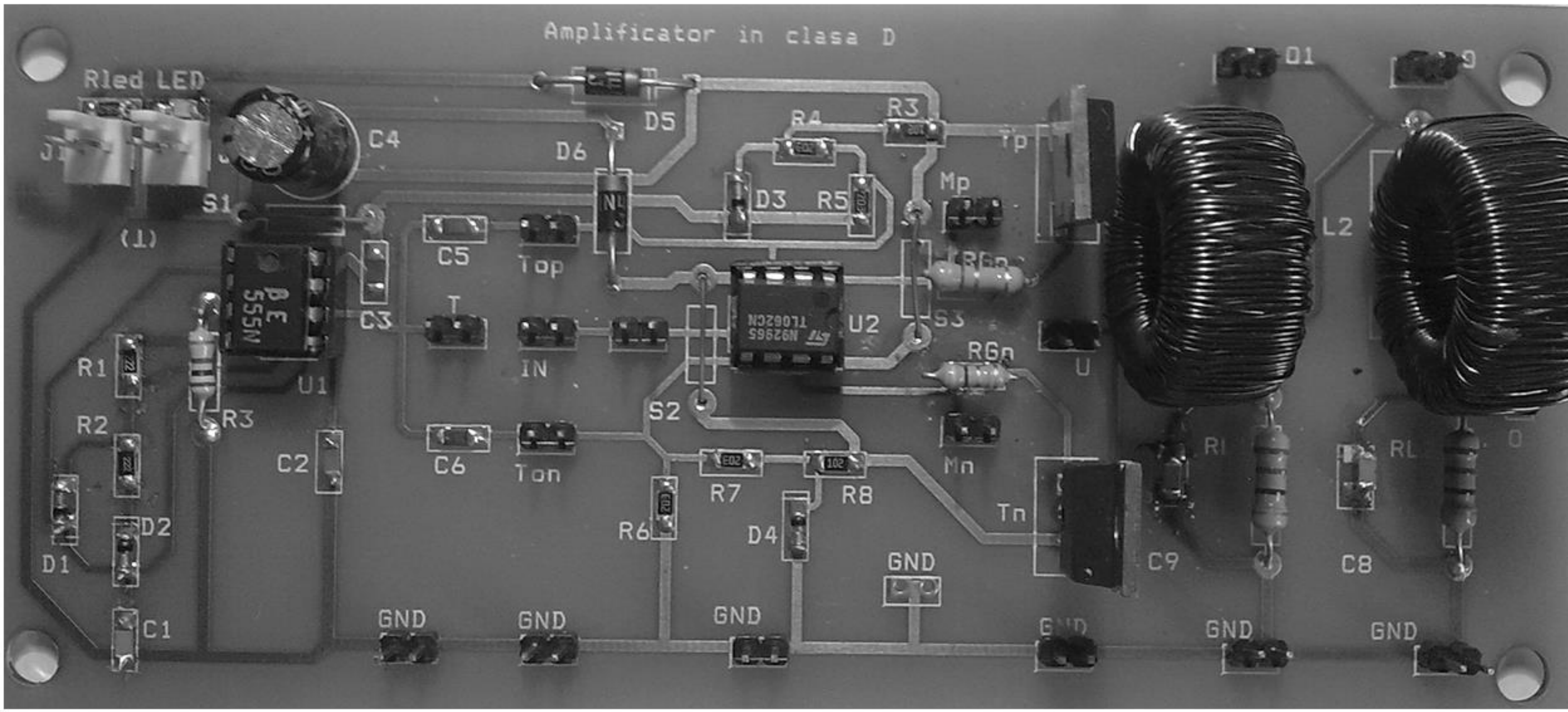
Switching frequency should be at least 10 times greater than the maximum signal frequency.

Q=0.707 provides a frequency response that introduces -3dB at corner frequency.

➢ Class D amplifier – complete circuit

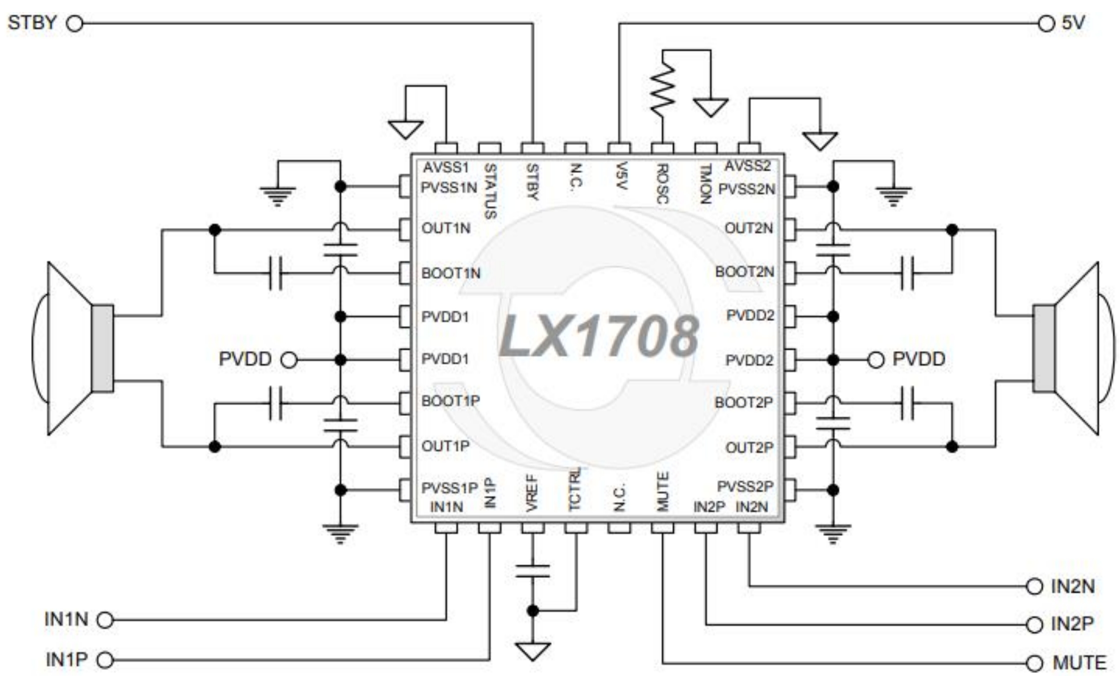


- Class D amplifier – complete circuit



➢ Class D amplifier – specialized integrated circuits

- LX1721/1722: Class-D Stereo Power Amplifier Controller
- LX1725 : 15W X 2 30W BTL CLASS-D AUDIO AMPLIFIER
- LX1708: 15W+15W Stereo Filterless Class D Amplifier



Summary

- Intro
- 555 Timer
- Class D amplifier

Next week: Recap. Preparation for the exam.