INTEGRATED CIRCUITS AND APPLICATIONS

- **Text Books:**
  1. **Digital Design, Morris Mano, 4th Edition**
  2. **Linear Integrated Circuit, D. Roy Choudhury 4th edition, New Age International Pvt. Ltd.**
  3. **Op-Amps & Linear ICs, Ramakanth A, Gayakwad , PHI**

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SYLLABUS

1. Part-1 DIGITAL INTEGRATED CIRCUITS

- Introduction
- Various logic families
- CMOS logic families

2. Part-2 LINEAR INTEGRATED CIRCUITS

- Integrated circuits.
- Op-Amp Applications
- Active Filters & Oscillators
- Timers & Phase Locked Loop

3. Part-3 DATA CONVERTER INTEGRATED CIRCUITS

- D-A & A-D Converters

PART-1

DIGITAL INTEGRATED CIRCUITS

Introduction

- **Introduction to digital integrated circuits.**
  - CMOS devices and manufacturing technology. CMOS inverters and gates. Propagation delay, noise margins, and power dissipation. Sequential circuits. Arithmetic, interconnect, and memories. Programmable logic arrays. Design methodologies.

- **What will you learn?**
  - Understanding, designing, and optimizing digital circuits with respect to different quality metrics: cost, speed, power dissipation, and reliability

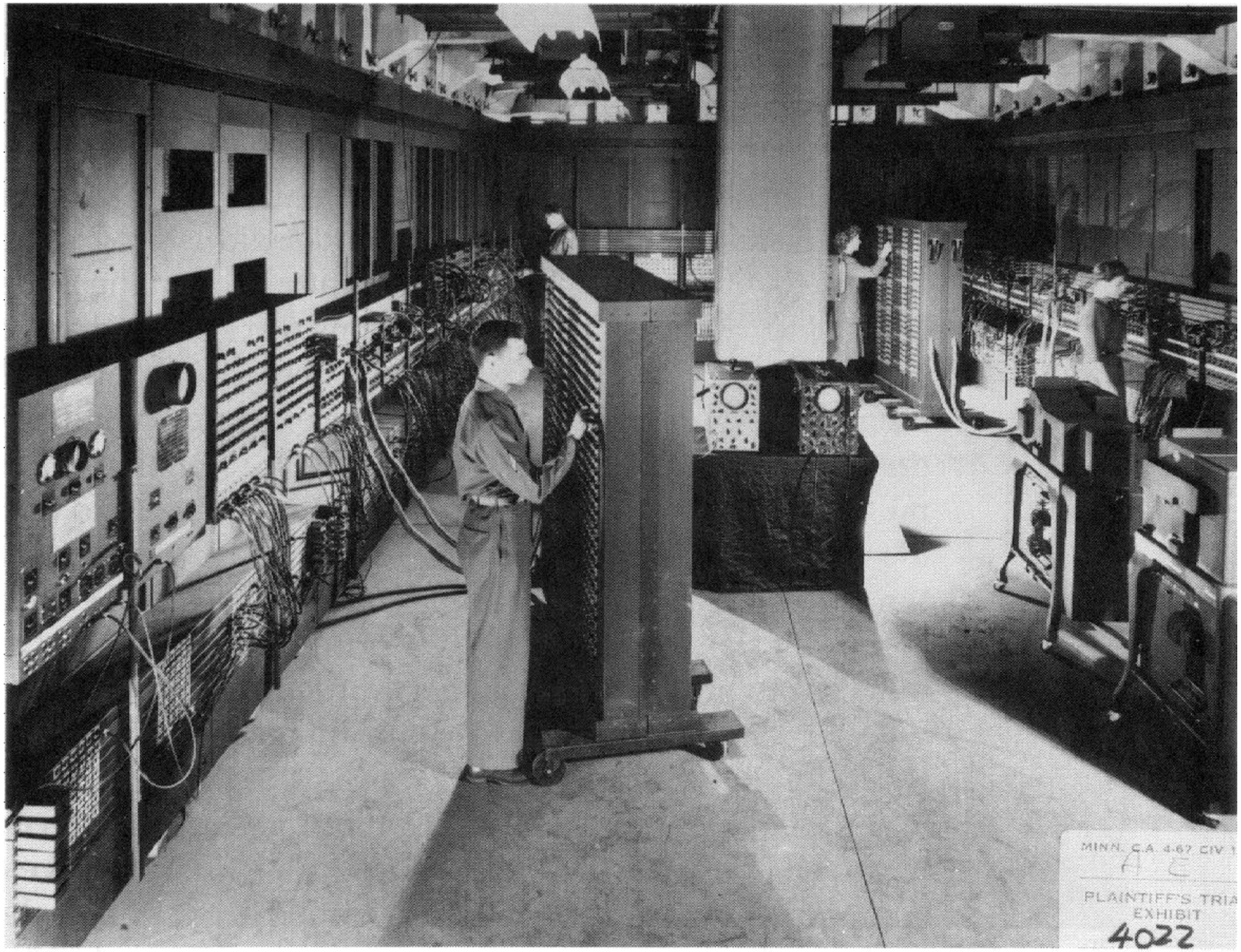
Digital Integrated Circuits

- Introduction: Issues in digital design
- The CMOS inverter
- Combinational logic structures
- Sequential logic gates
- Design methodologies
- Interconnect: R, L and C
- Timing
- Arithmetic building blocks
- Memories and array structures

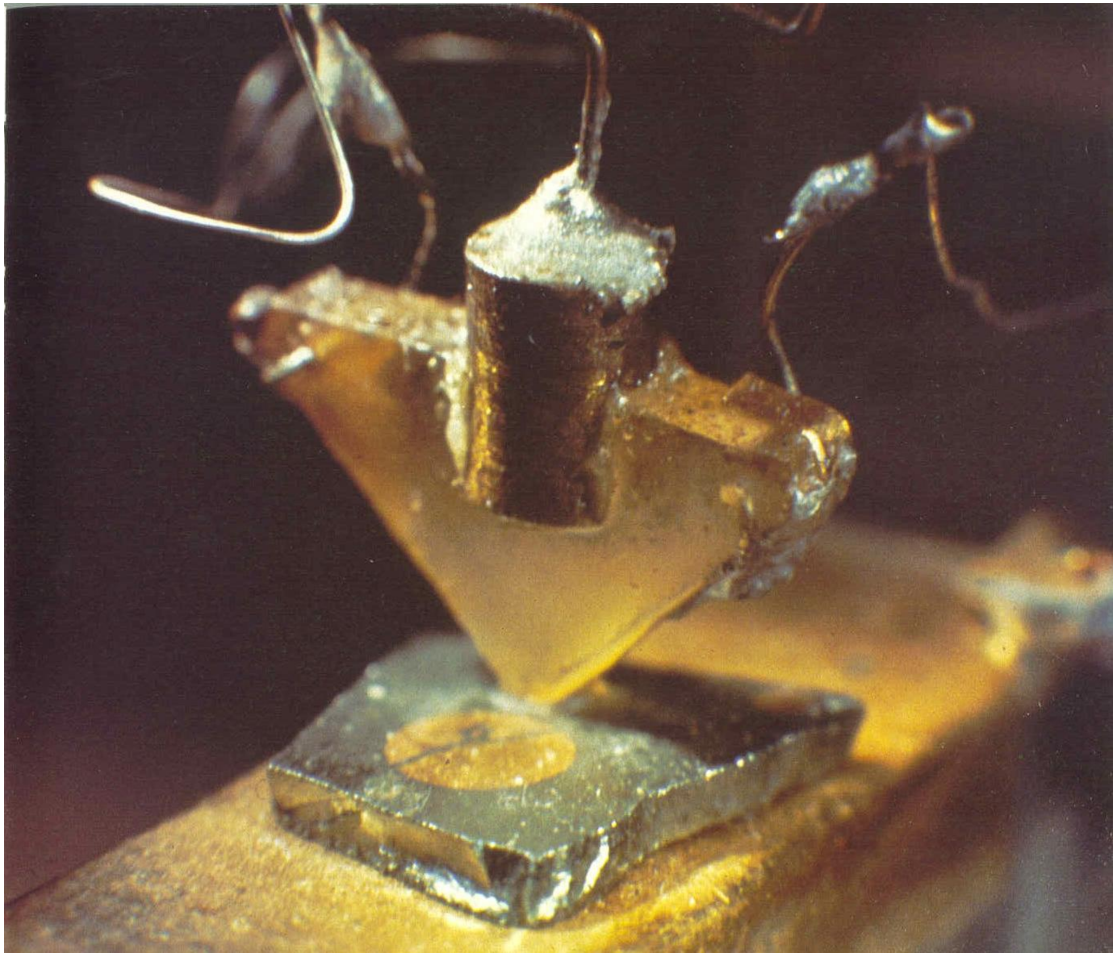
Introduction

- Why is designing digital ICs different today than it was before?
- Will it change in future?

ENIAC - The first electronic computer (1946)

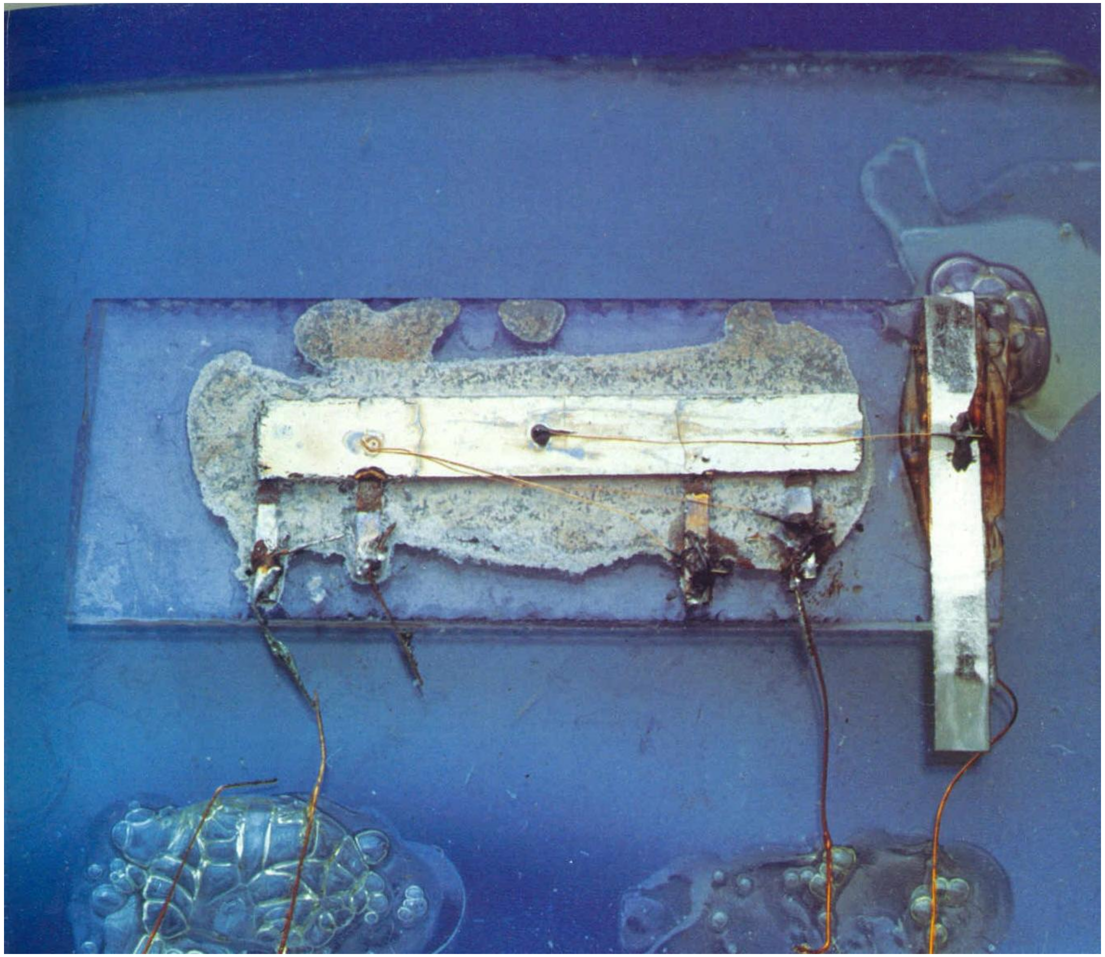


The Transistor Revolution



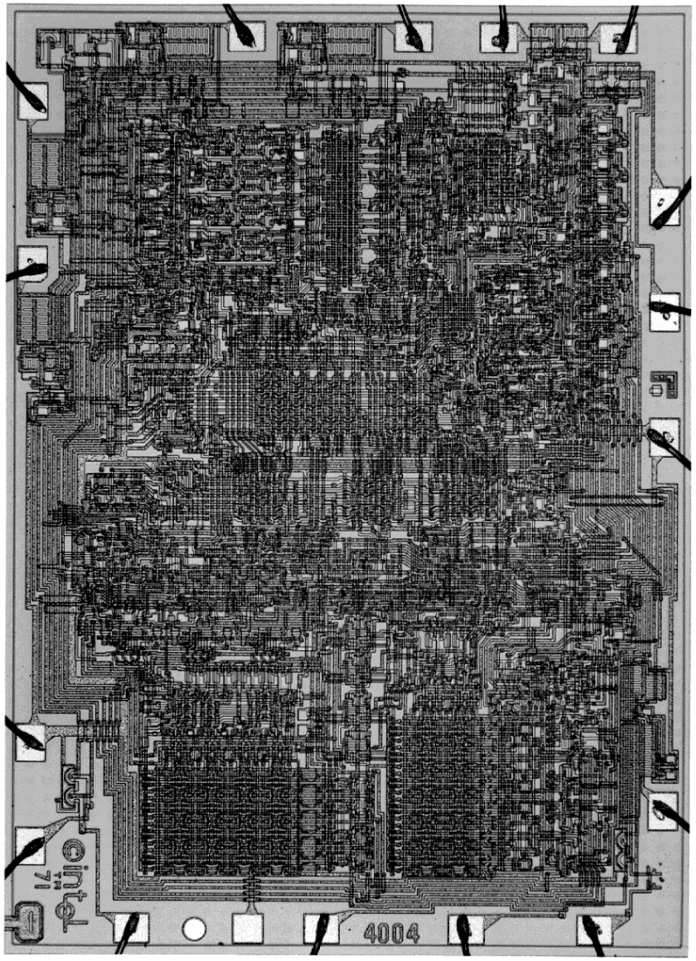
First transistor
Bell Labs, 1948

The First Integrated Circuit



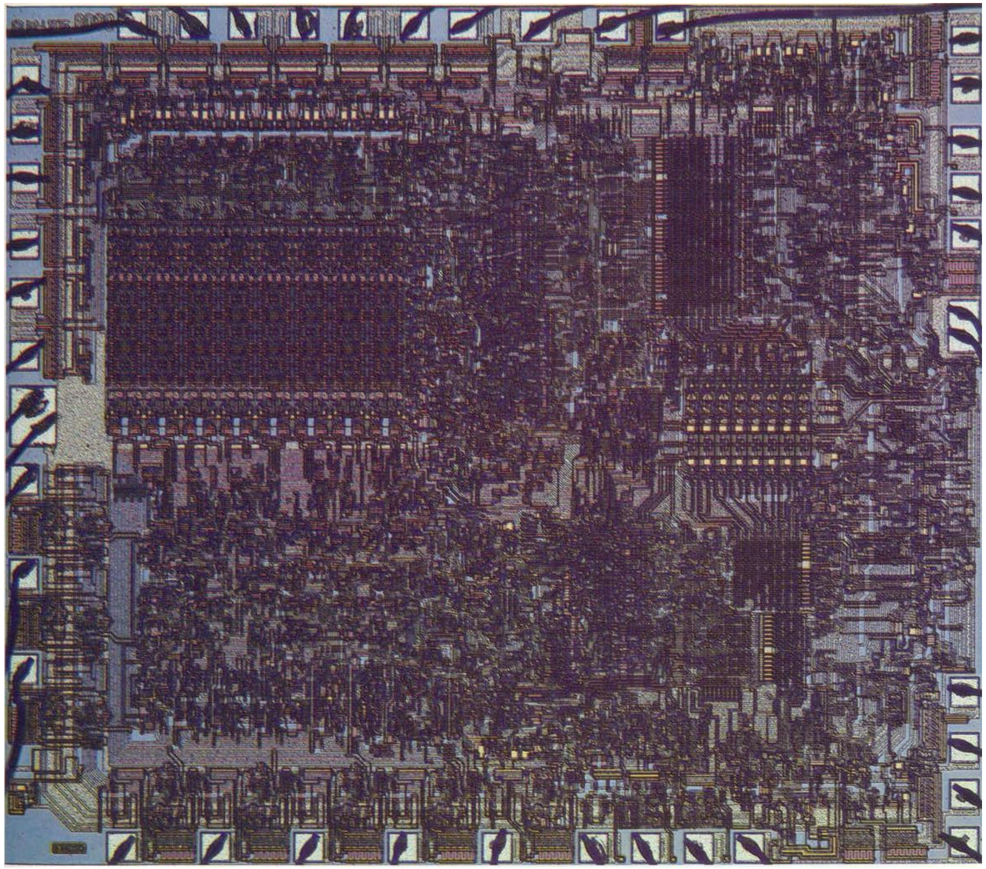
First IC
Jack Kilby
Texas Instruments
1958

Intel 4004 Micro-Processor



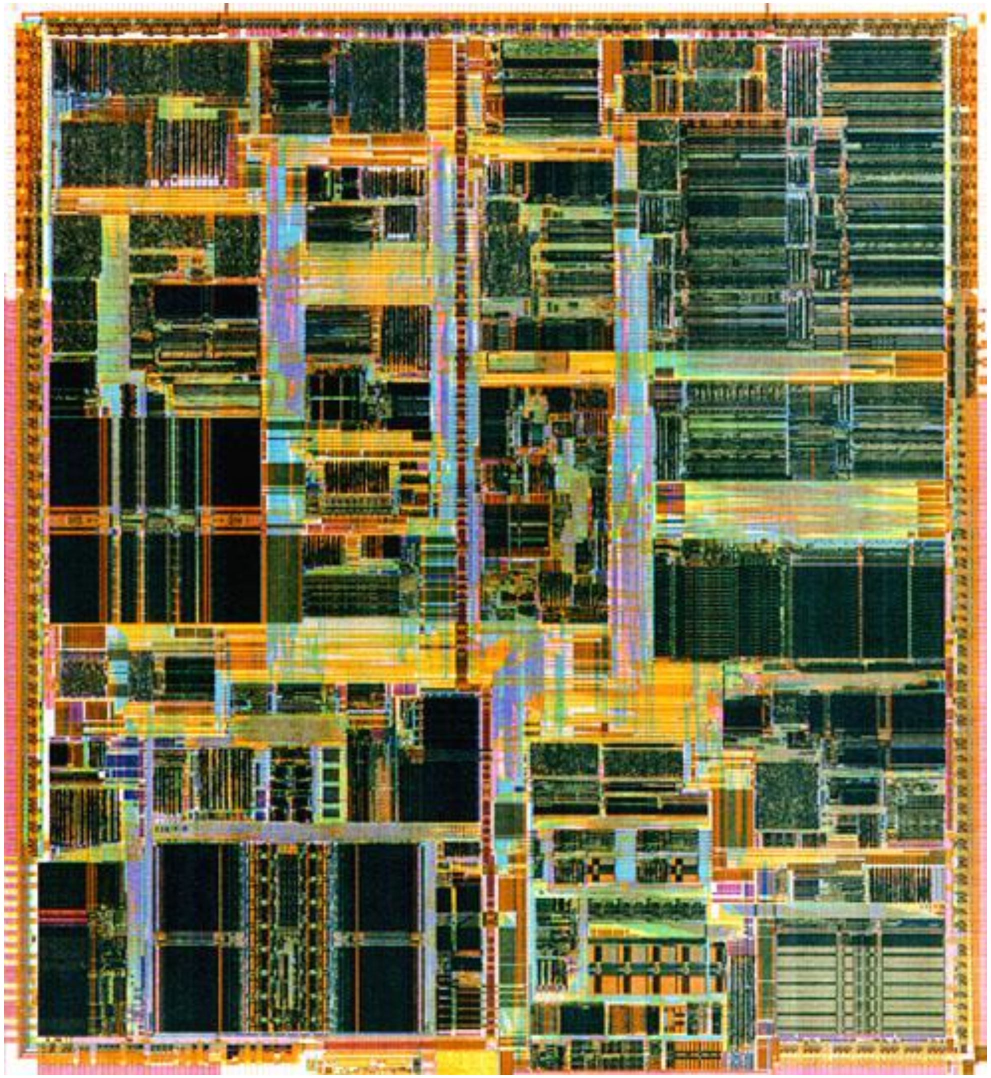
1971
1000 transistors
1 MHz operation

Intel 8080 Micro-Processor



1974
4500 transistors

Intel Pentium (IV) microprocessor

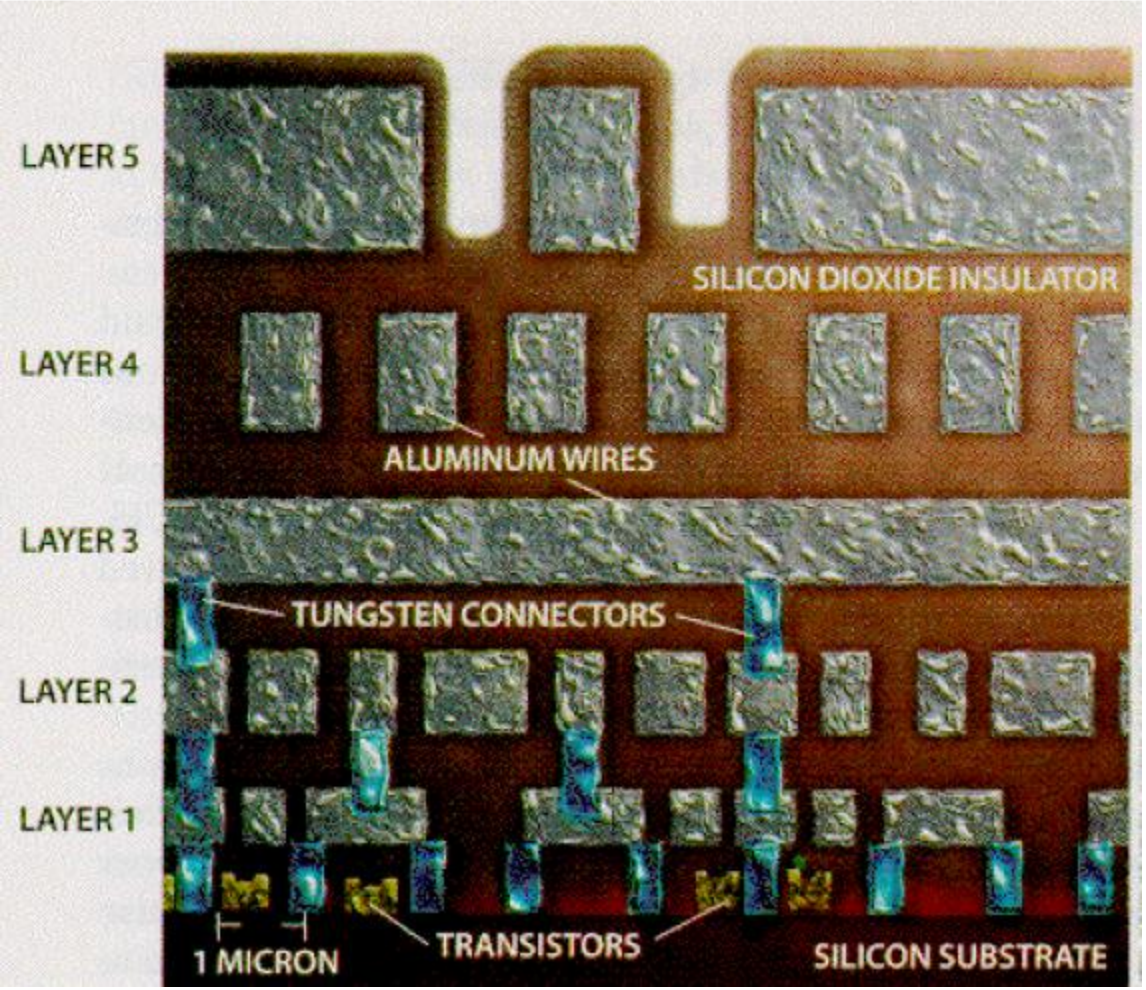


2000
42 million transistors
1.5 GHz

Basic Components In VLSI Circuits

- Devices
  - Transistors
  - Logic gates and cells
  - Function blocks
- Interconnects
  - Local interconnects
  - Global interconnects
  - Clock interconnects
  - Power/ground nets

Cross-Section of A Chip



CMOS transistors

3 terminals in CMOS transistors:

- G: Gate
- D: Drain
- S: Source

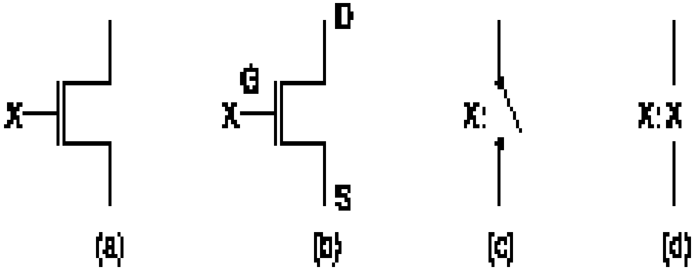


FIGURE 1
Symbol and Switch Model for n-Channel Transistor

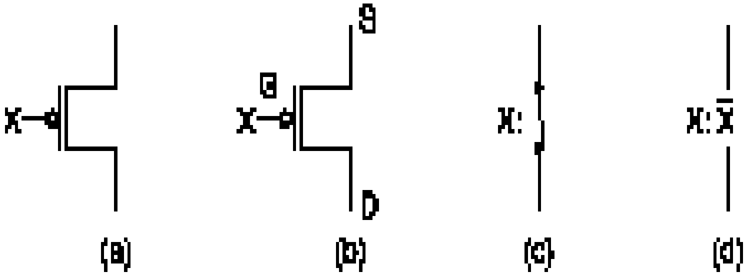
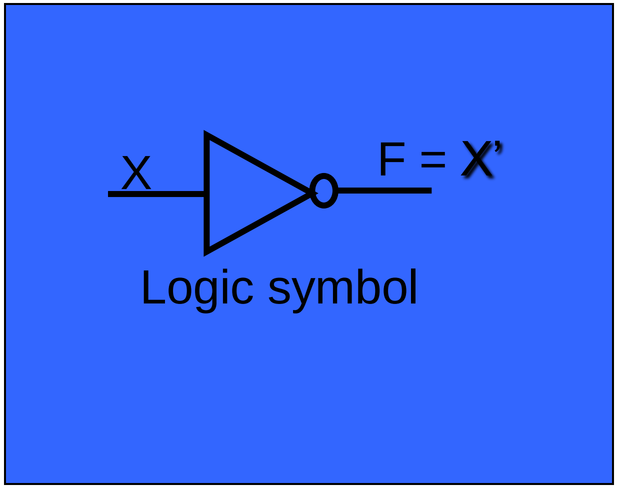


FIGURE 2
Symbol and Switch Model for p-Channel Transistor

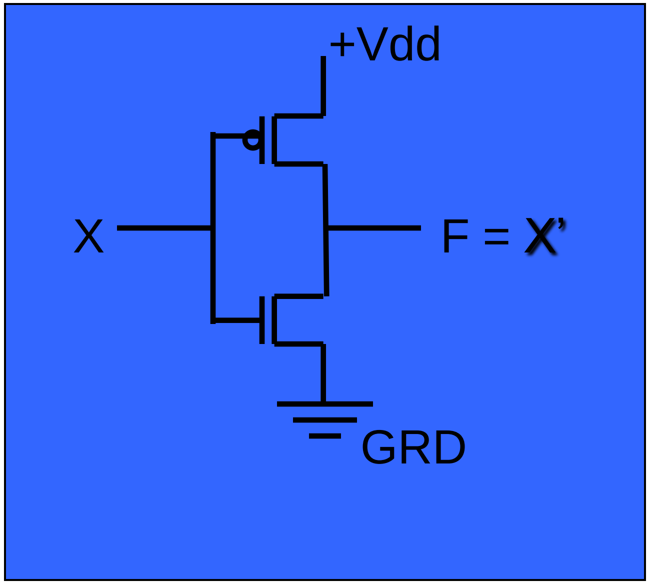
nMOS transistor/switch
X=1 switch closes (ON)
X=0 switch opens (OFF)

pMOS transistor/switch
X=1 switch opens (OFF)
X=0 switch closes (ON)

An Example: CMOS Inverter



Logic symbol

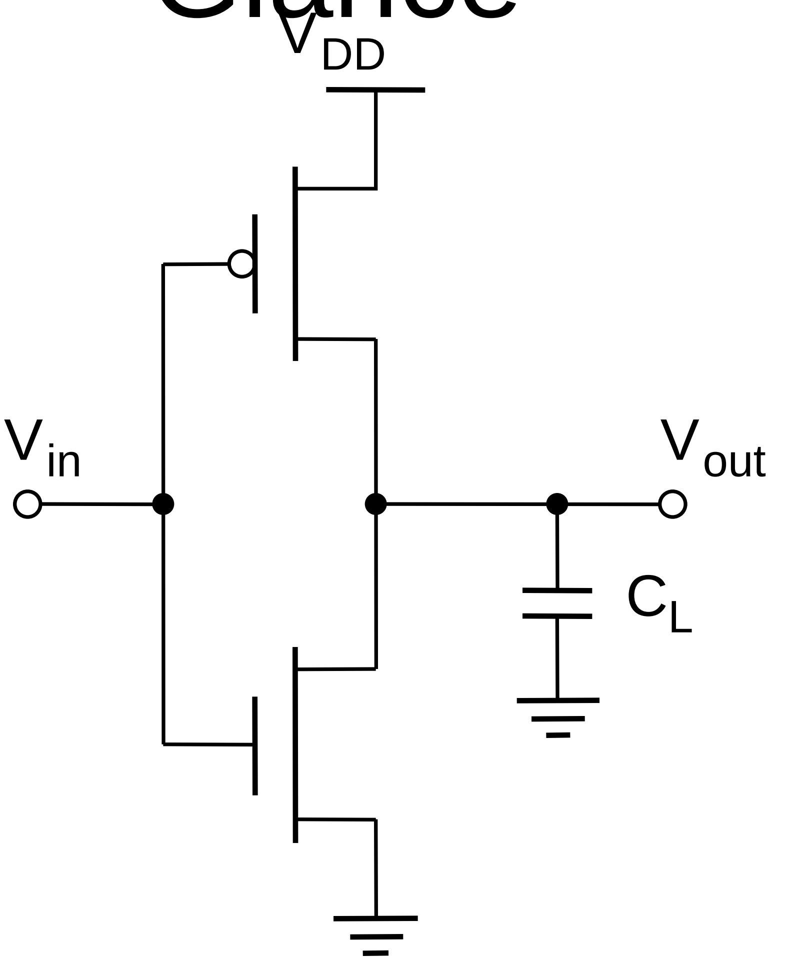


Transistor-level schematic

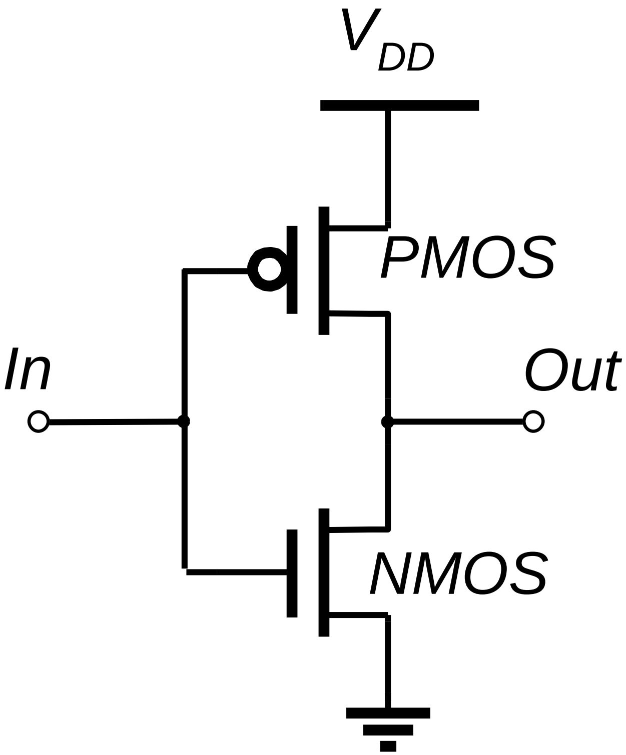
Operation:

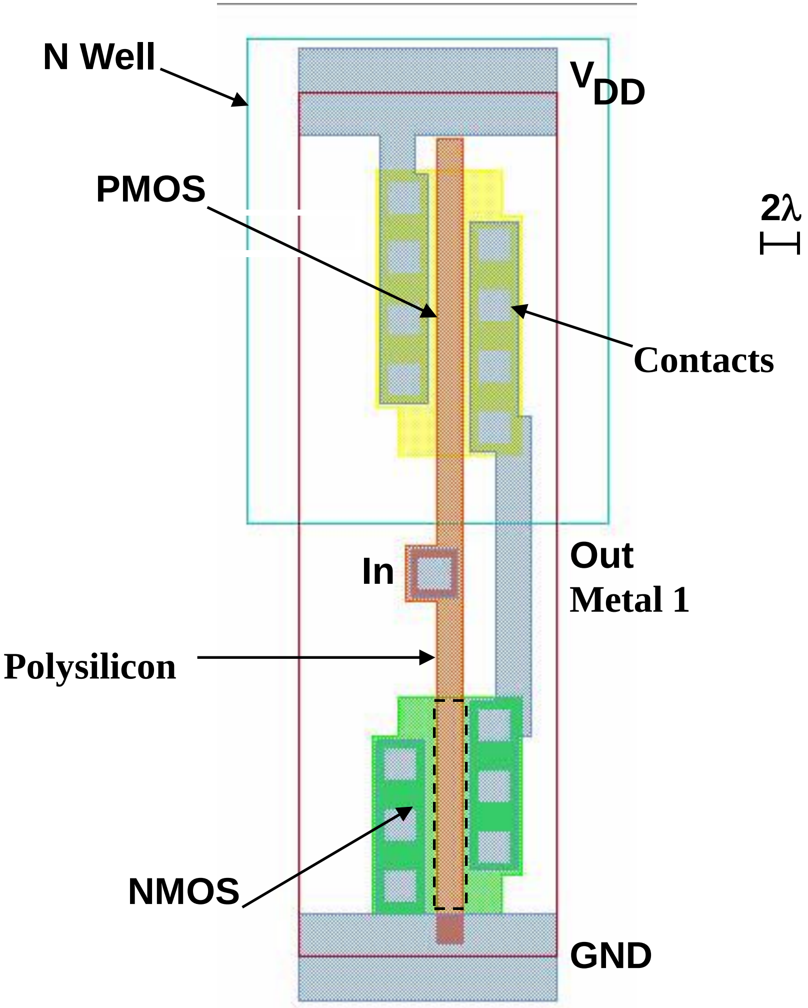
- X=1 → nMOS switch conducts (pMOS is open) and draws from GRD → F=0
- X=0 → pMOS switch conducts (nMOST is open) and draws from +Vdd → F=1

The CMOS Inverter: A First Glance



CMOS Inverter

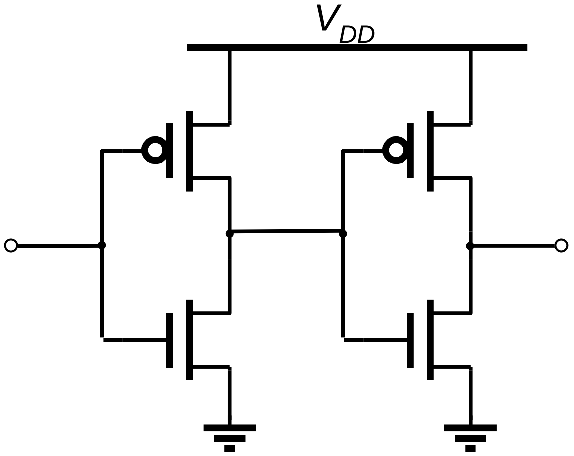


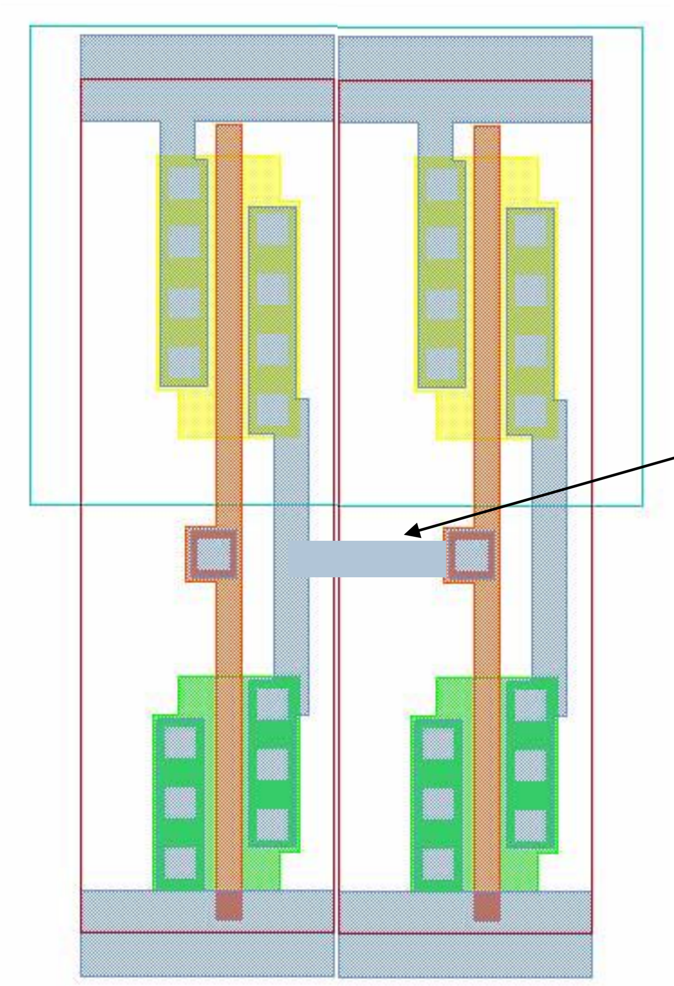


Two Inverters

Share power and ground

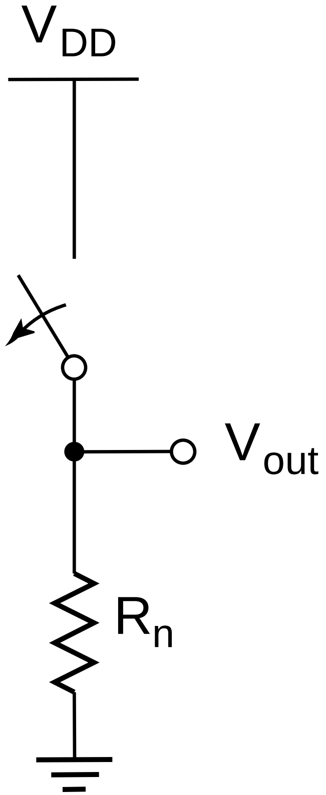
Abut cells



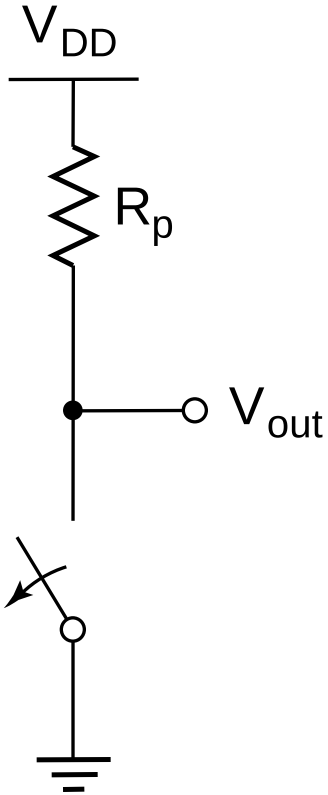


Connect in Metal

CMOS Inverter
First-Order DC Analysis



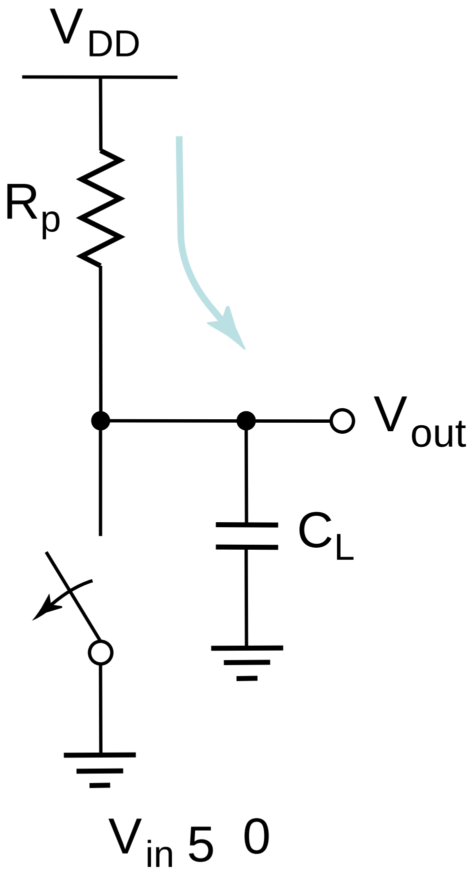
V_{in} 5 V_{DD}



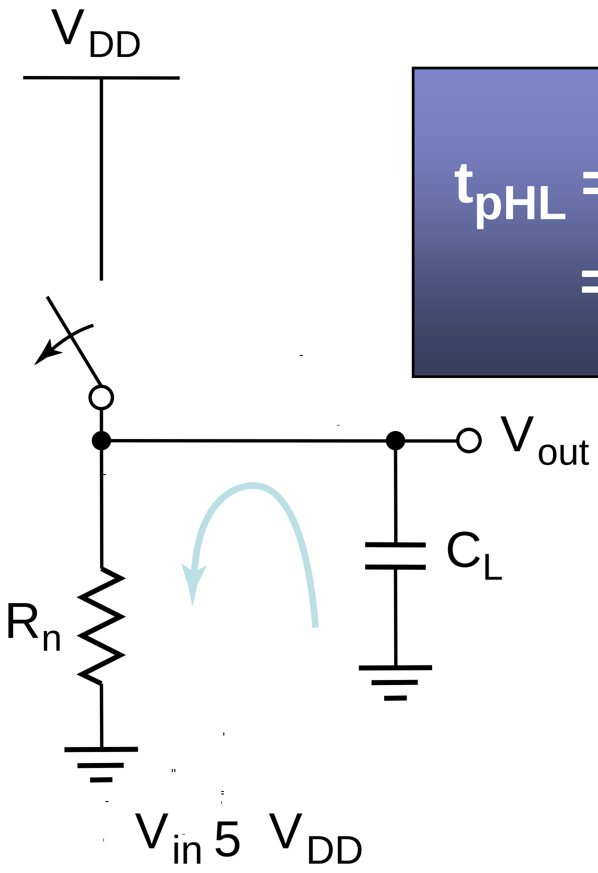
V_{in} 5 0

$V_{OL} = 0$
$V_{OH} = V_{DD}$
$V_M = f(R_n, R_p)$

CMOS Inverter: Transient Response



(a) Low-to-high



(b) High-to-low

$$t_{pHL} = f(R_{on}.C_L)$$

$$= 0.69\ R_{on}C_L$$

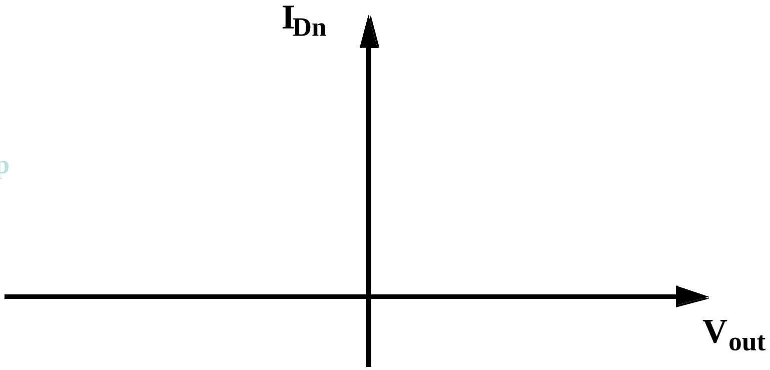
Voltage Transfer Characteristic

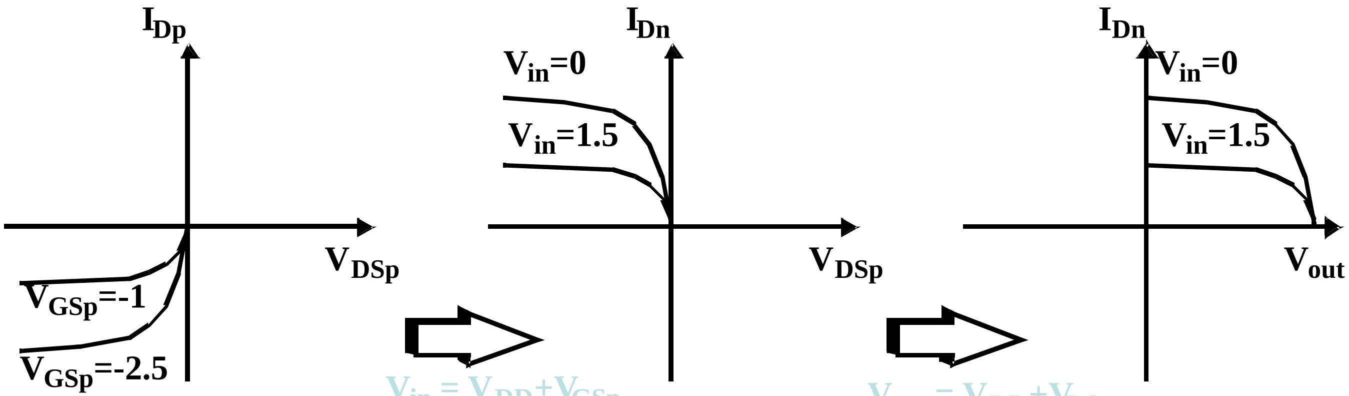
PMOS Load Lines

$V_{in} = V_{DD} + V_{GSp}$

$I_{Dn} = - I_{Dp}$

$V_{out} = V_{DD} + V_{DSp}$



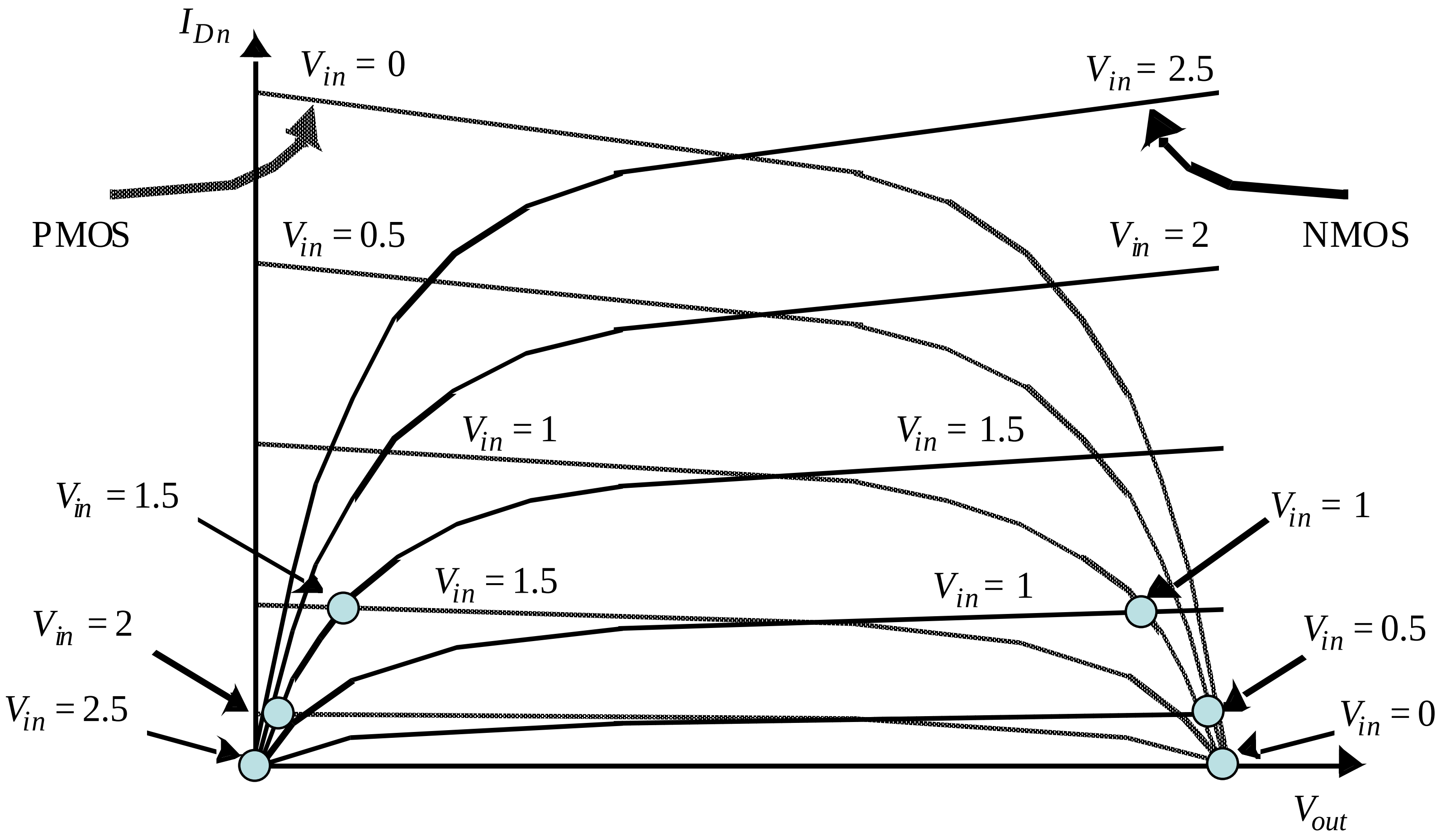


$V_{in} = V_{DD} + V_{GSp}$

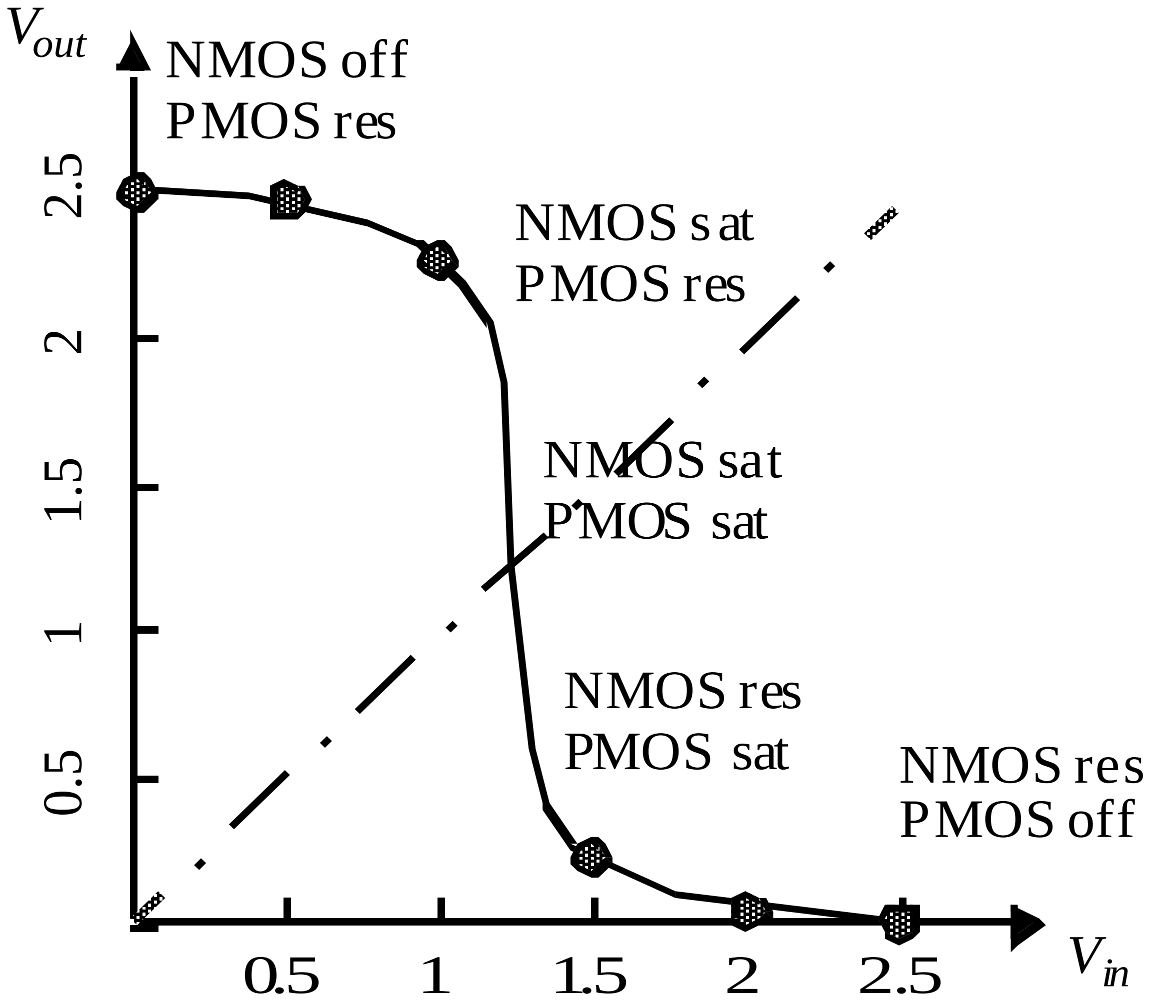
$I_{Dn} = - I_{Dp}$

$V_{out} = V_{DD} + V_{DSp}$

CMOS Inverter Load Characteristics



CMOS Inverter VTC



NMOS off
PMOS res

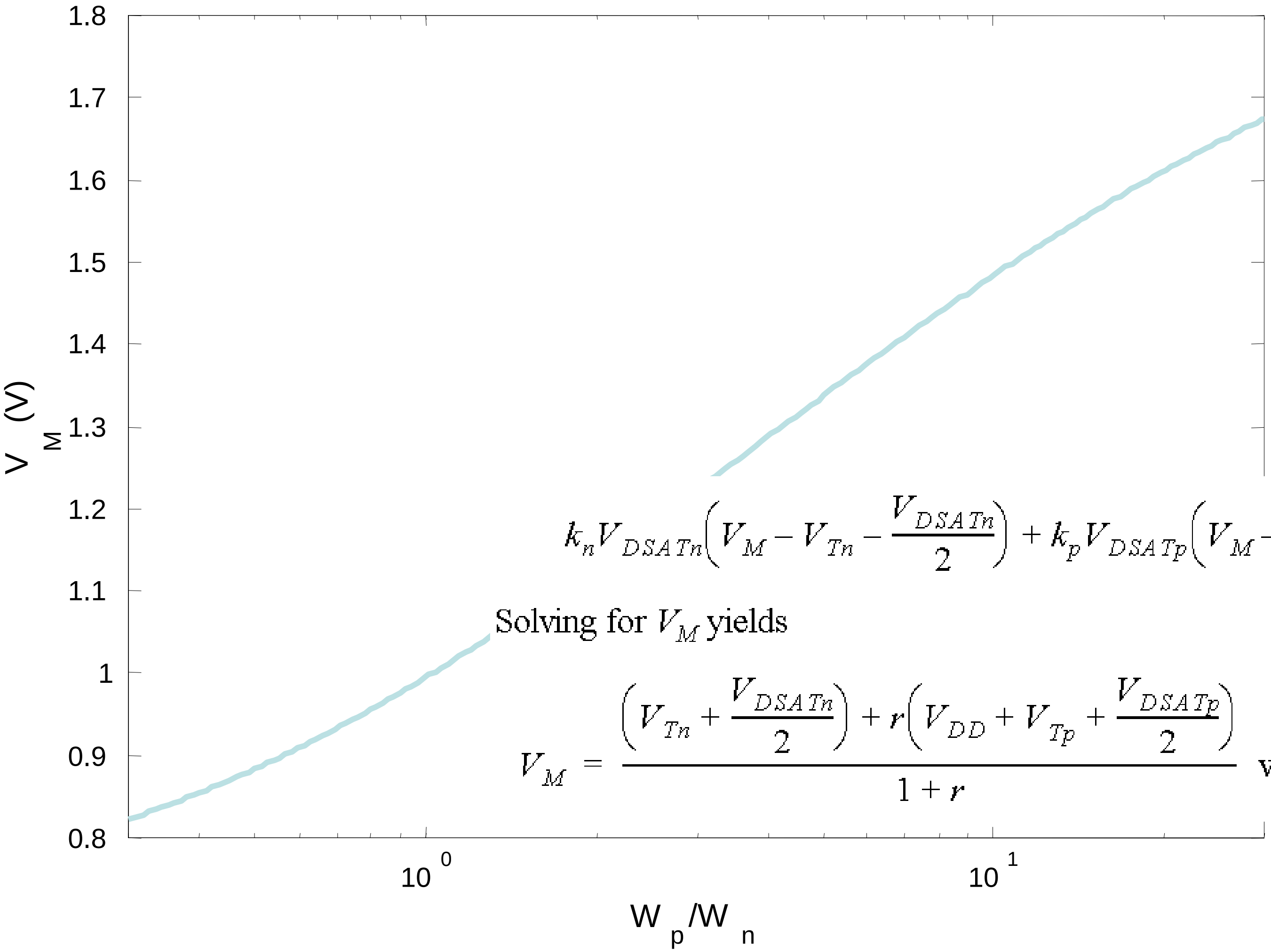
NMOS sat
PMOS res

NMOS sat
PMOS sat

NMOS res
PMOS sat

NMOS res
PMOS off

Switching Threshold as a function of Transistor Ratio

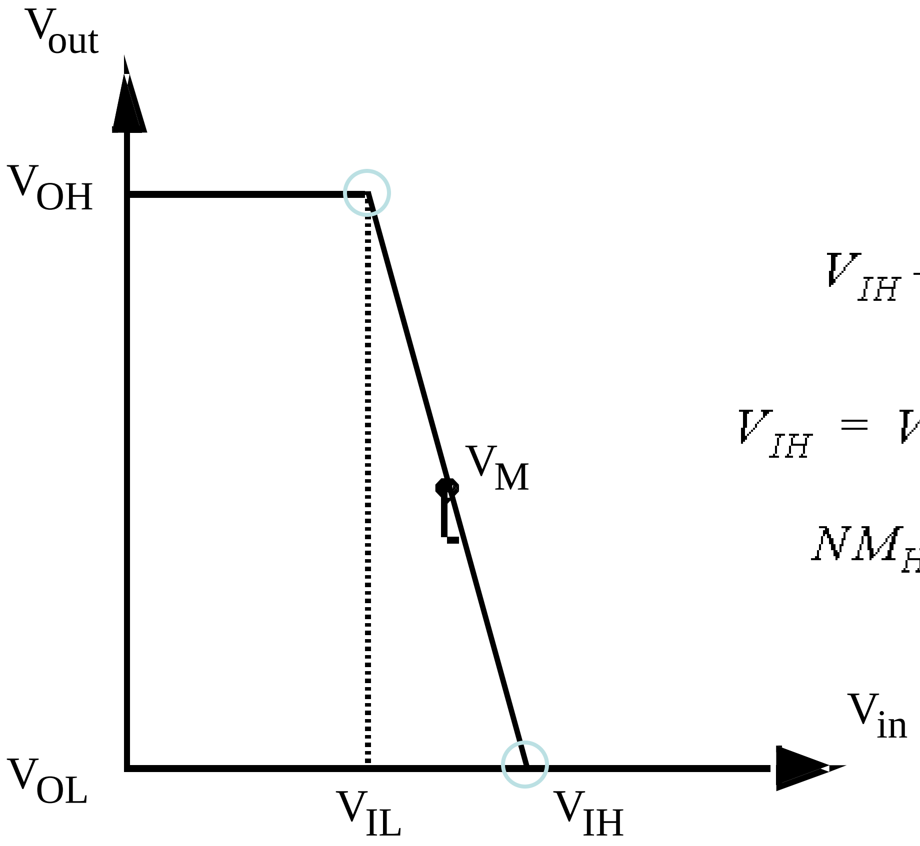


$$k_n V_{DSATn}\left(V_M - V_{Tn} - \frac{V_{DSATn}}{2}\right) + k_p V_{DSATp}\left(V_M - V_{DD} - V_{Tp} - \frac{V_{DSATp}}{2}\right) = 0$$

Solving for V_M yields

$$V_M = \frac{\left(V_{Tn} + \frac{V_{DSATn}}{2}\right) + r\left(V_{DD} + V_{Tp} + \frac{V_{DSATp}}{2}\right)}{1 + r} \quad \text{with} \quad r = \frac{k_p V_{DSATp}}{k_n V_{DSATn}} = \frac{\upsilon_{satp} W_p}{\upsilon_{satn} W_n}$$

Determining V_{IH} and V_{IL}



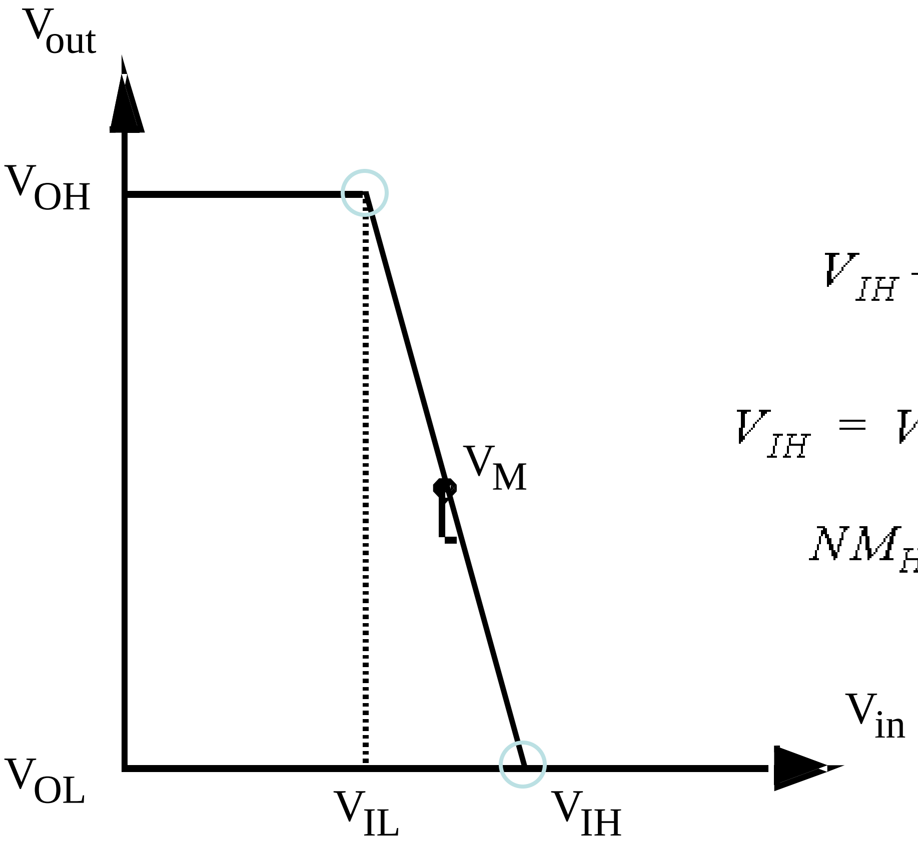
A simplified approach

$$V_{IH} - V_{IL} = -\frac{(V_{OH} - V_{OL})}{g} = \frac{-V_{DD}}{g}$$

$$V_{IH} = V_M - \frac{V_M}{g} \qquad V_{IL} = V_M + \frac{V_{DD} - V_M}{g}$$

$$NM_H = V_{DD} - V_{IH} \qquad NM_L = V_{IL}$$

Determining V_{IH} and V_{IL}



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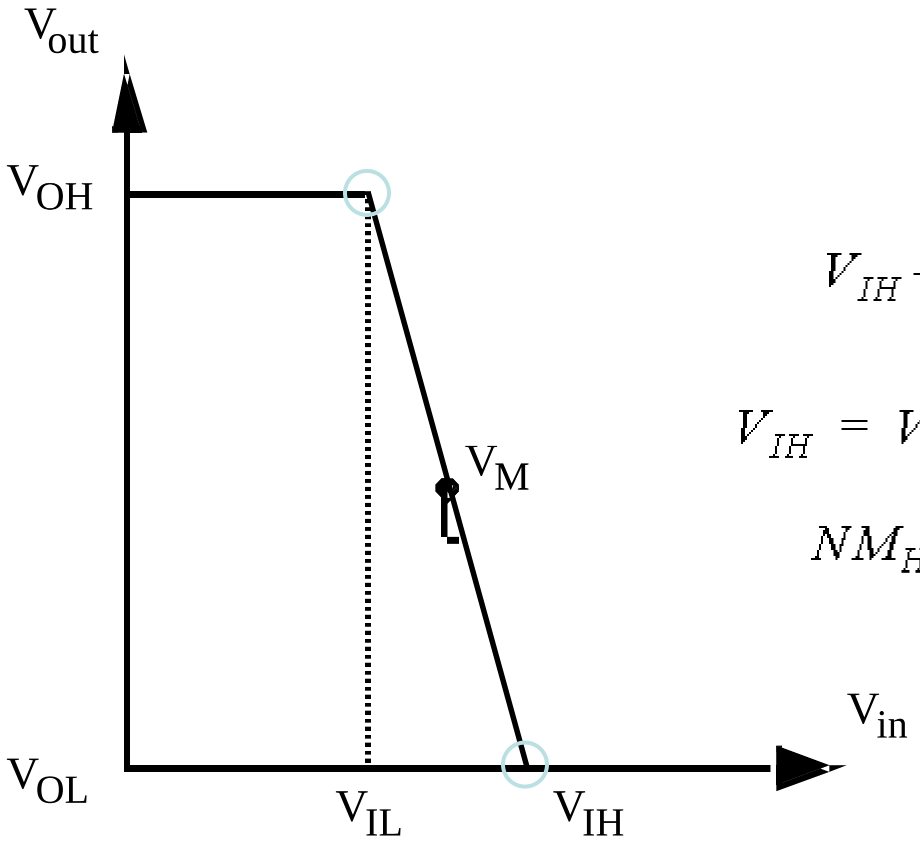

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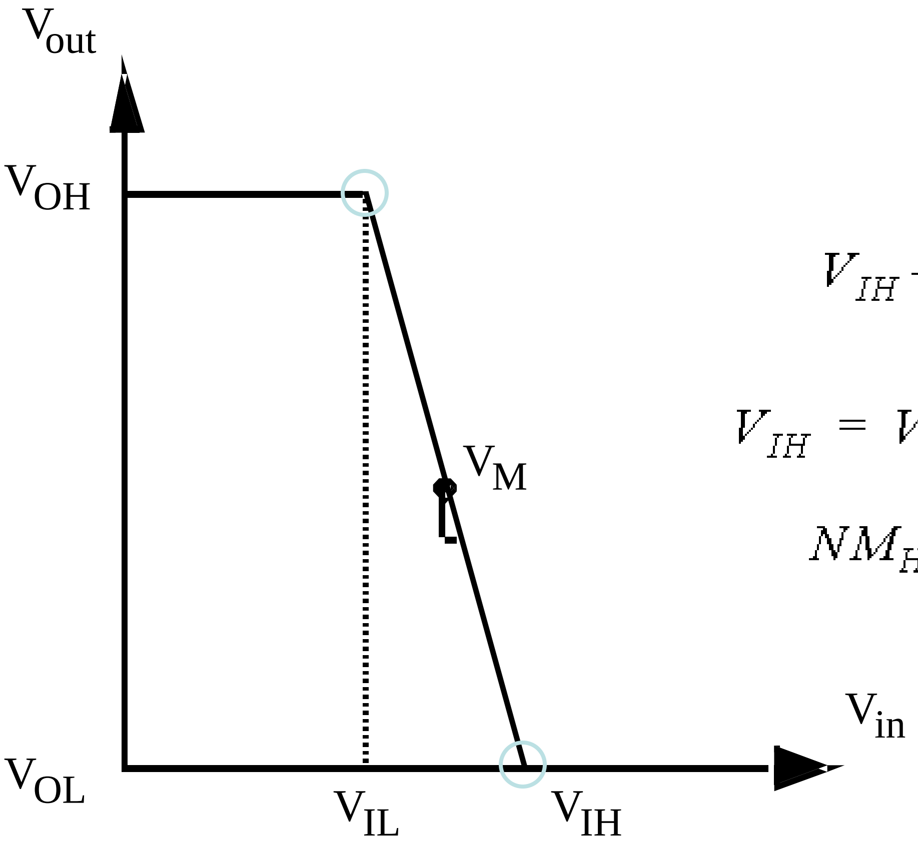

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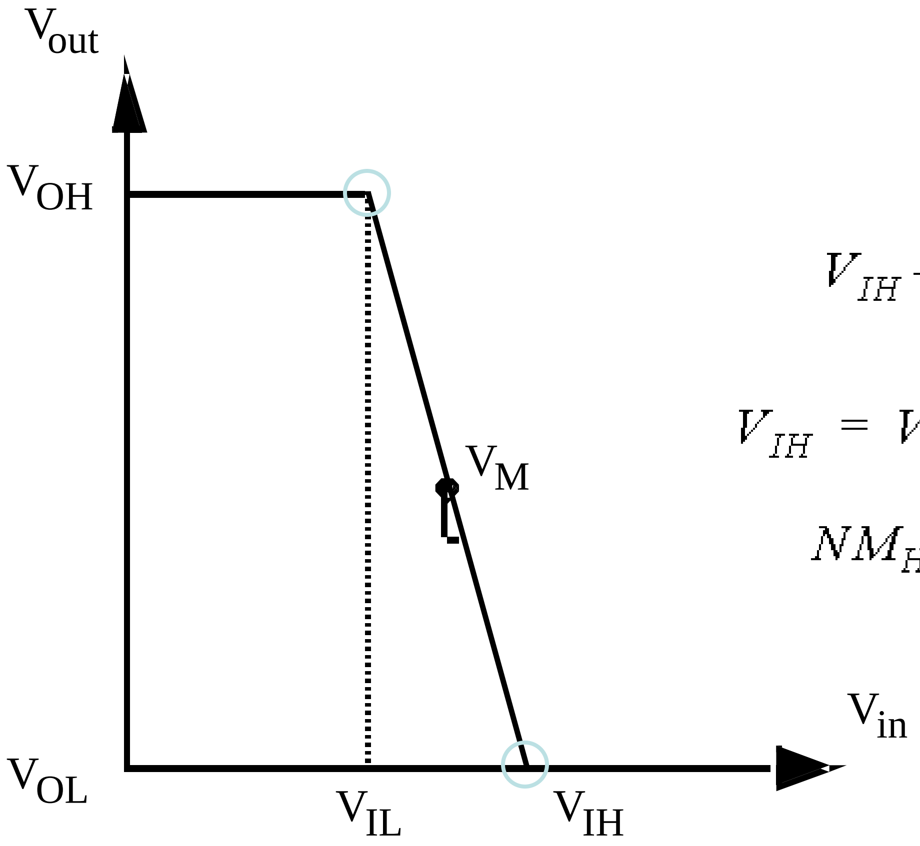

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PART-2

LINEAR INTEGRATED CIRCUITS

UNIT-I
INTEGRATED CIRCUITS

- Classification,
- Chip size & circuit complexity,
- Ideal & Practical Op-Amp,
- Op-Amp Characteristics - DC & AC Characteristics,
- 741 Op-Amp & its features,
- Modes of operation – Inverting and Non-Inverting, differential.

INTEGRATED CIRCUITS

An integrated circuit (IC) is a miniature ,low cost electronic circuit consisting of active and passive components fabricated together on a single crystal of silicon. The active components are transistors and diodes and passive components are resistors and capacitors.

Advantages of integrated circuits

1. Miniaturization and hence increased equipment density.
2. Cost reduction due to batch processing.
3. Increased system reliability due to the elimination of soldered joints.
4. Improved functional performance.
5. Matched devices.
6. Increased operating speeds.
7. Reduction in power consumption

CLASSIFICATION OF ICs

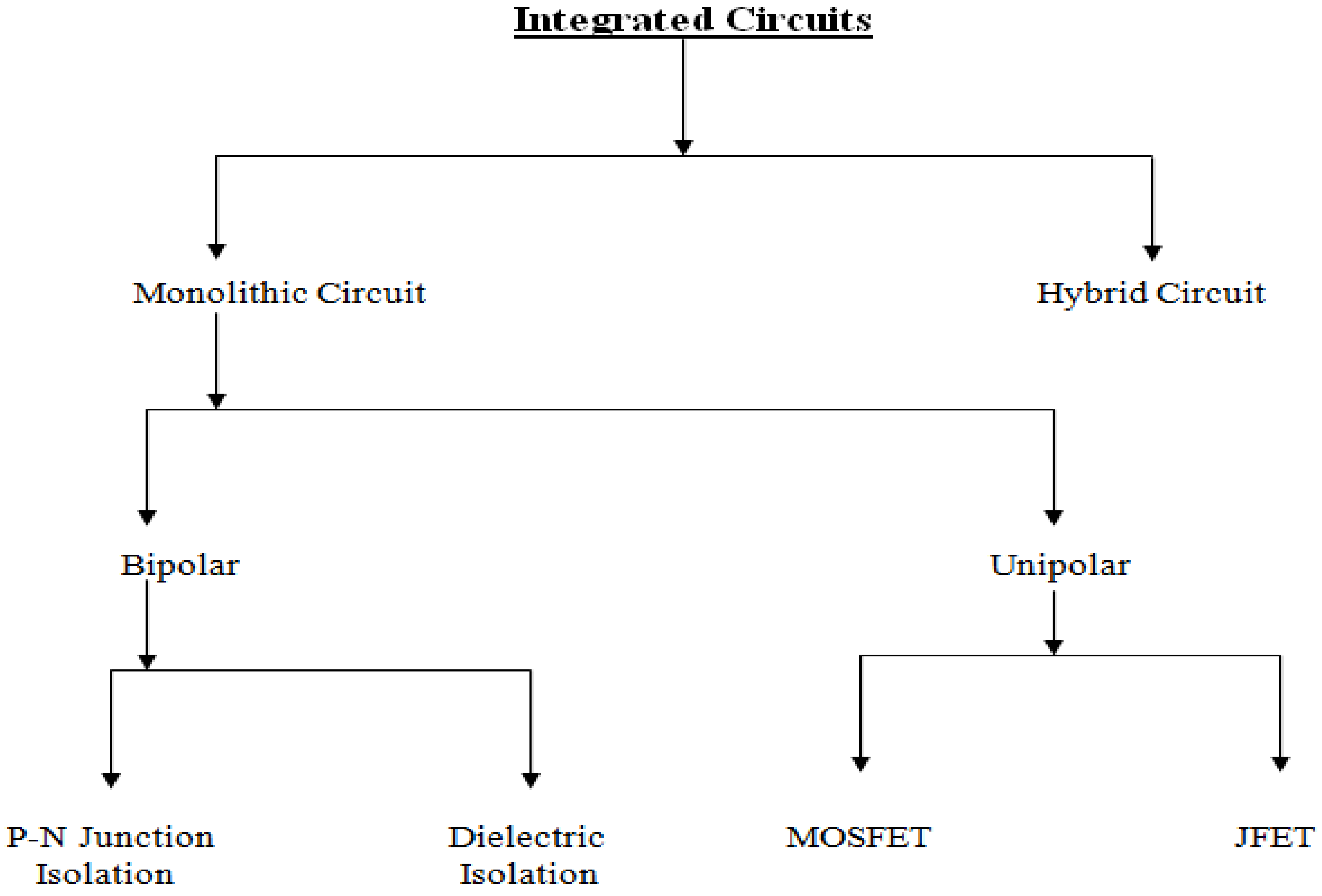
Integrated circuits offer a wide range of applications and could be broadly classified as:

1.Digital Ics
2. Linear Ics

Based on these two requirements. Two distinctly different IC Technology namely

1.Monolithic Technology and
2. Hybrid Technology

CLASSIFICATION OF ICs



Integrated Circuits

Monolithic Circuit

Hybrid Circuit

Bipolar

Unipolar

P-N Junction Isolation

Dielectric Isolation

MOSFET

JFET

Classification of ICs

CIRCUIT COMPLEXITY &CHIP SIZES

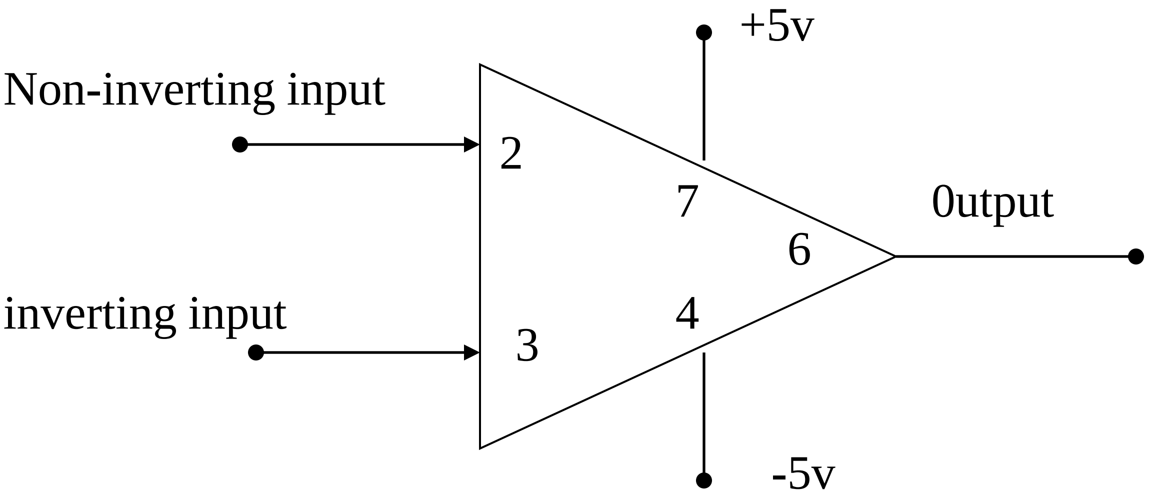
- In the early days (up until the 1950s) the electronics device Technology was dominated by the vacuum tube
- Now days electronic is the result of the invention of the transistor in 1947
- The invention of the transistor by William B, Shockley , Walter H,brattain and john Barden of bell telephone laboratories was followed by the development of the integrated circuit
- The size and complexity of Ics have increased rapidly
- A) Invention of Transistor (Ge) 1947
- B) Development of silicon transistor 1955-1959
- C) Silicon planar technology 1959
- D) First Ics , Small Scale Integration (SSI) 1960-1965
- E) Medium scale Integration (MSI) 1965-1970
- F) Large scale integration (LSI) 1970- 1980
- G)Very Large scale integration (VLSI) 1980- 1990
- H) Ultra Large scale integration (ULSI) 1990-2000
- I) Giant - scale integration (GSI)

OPERATIONAL AMPLIFIER

An operational amplifier is a direct coupled high gain amplifier consisting of one or more differential amplifiers, followed by a level translator and an output stage.

It is a versatile device that can be used to amplify ac as well as dc input signals & designed for computing mathematical functions such as addition, subtraction ,multiplication, integration & differentiation

Op-amp symbol



IC packages available

1. Metal can package.
2. Dual-in-line package.
3. Ceramic flat package.

Ideal characteristics of OPAMP

- Infinite voltage gain A_d
- Infinite input resistance R_i, so that almost any signal source can drive it and there is no loading of the input source.
- Zero output resistance R_O, so that output can drive an infinite number of other devices.
- Zero output voltage when input voltage is zero.
- Infinite bandwidth so that any frequency signal from 0 to infinite Hz can be amplified without attenuation.
- Infinite common mode rejection ratio so that the output common mode noise voltage is zero.
- Infinite slew rate, so that output voltage changes occur simultaneously with input voltage changes.

INTERNAL CIRCUIT OF IC 741

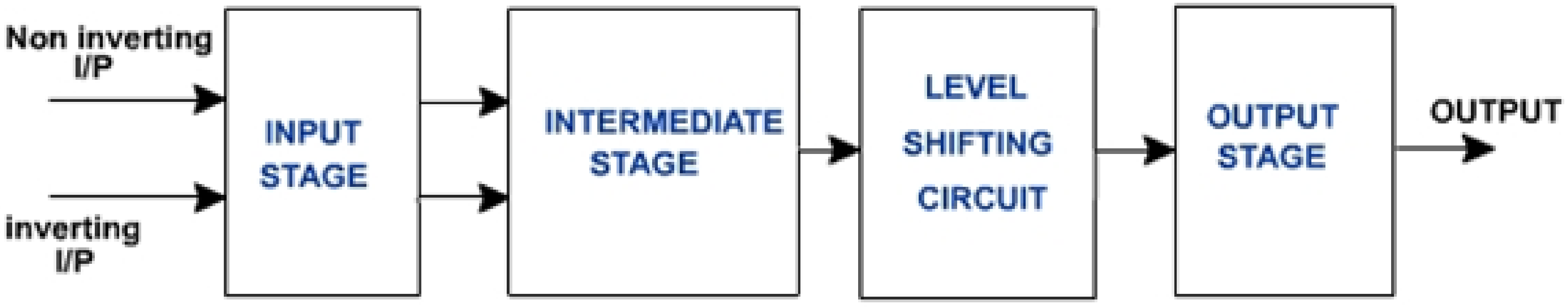


Fig. 1

DIFFERENTIAL AMPLIFIER

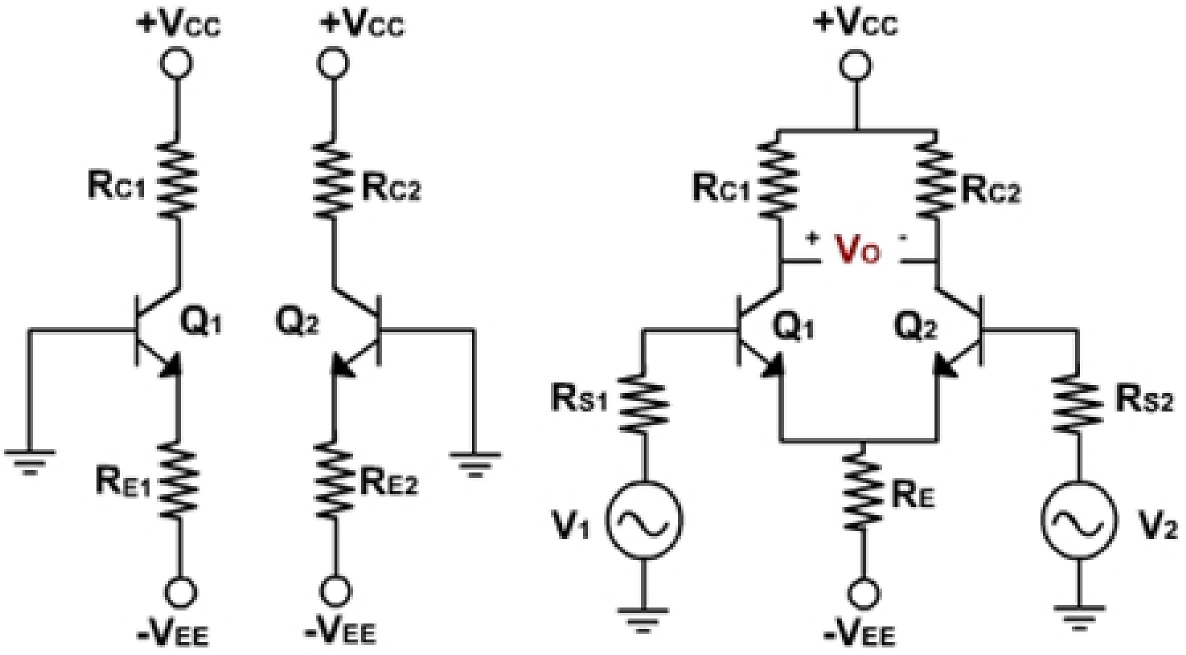


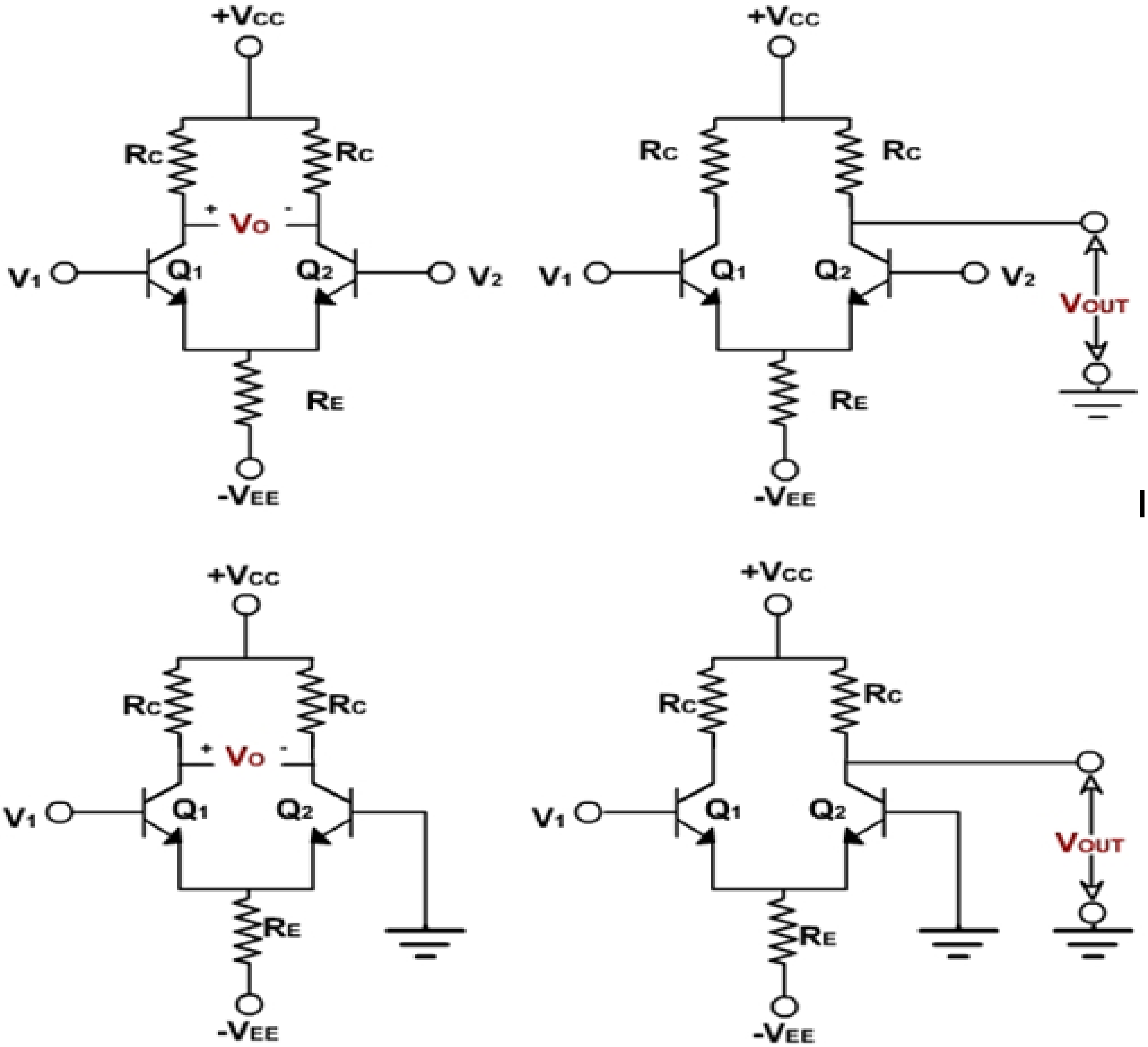
Fig. 1

MODES OF DIFFERENTIAL AMPLIFIER

The four differential amplifier configurations are following:

- Dual input, balanced output differential amplifier.
- Dual input, unbalanced output differential amplifier.
- Single input balanced output differential amplifier.
- Single input unbalanced output differential amplifier.

Different configurations of DA



LEVEL TRANSLATOR & BUFFER

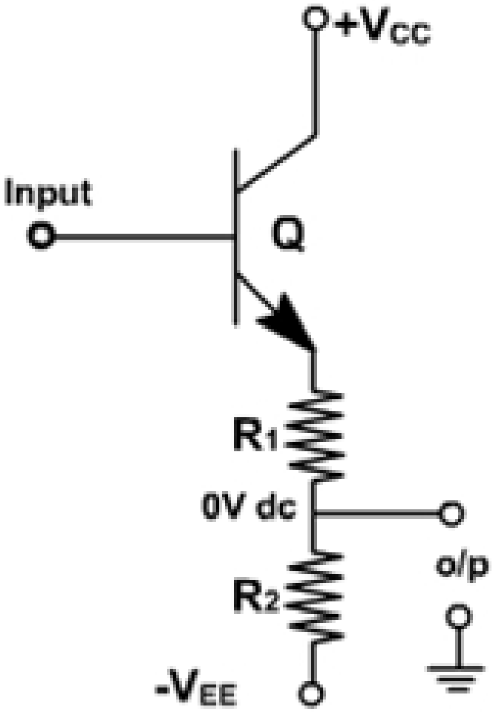


Fig. 2

IC 741 COMPLETE CIRCUIT

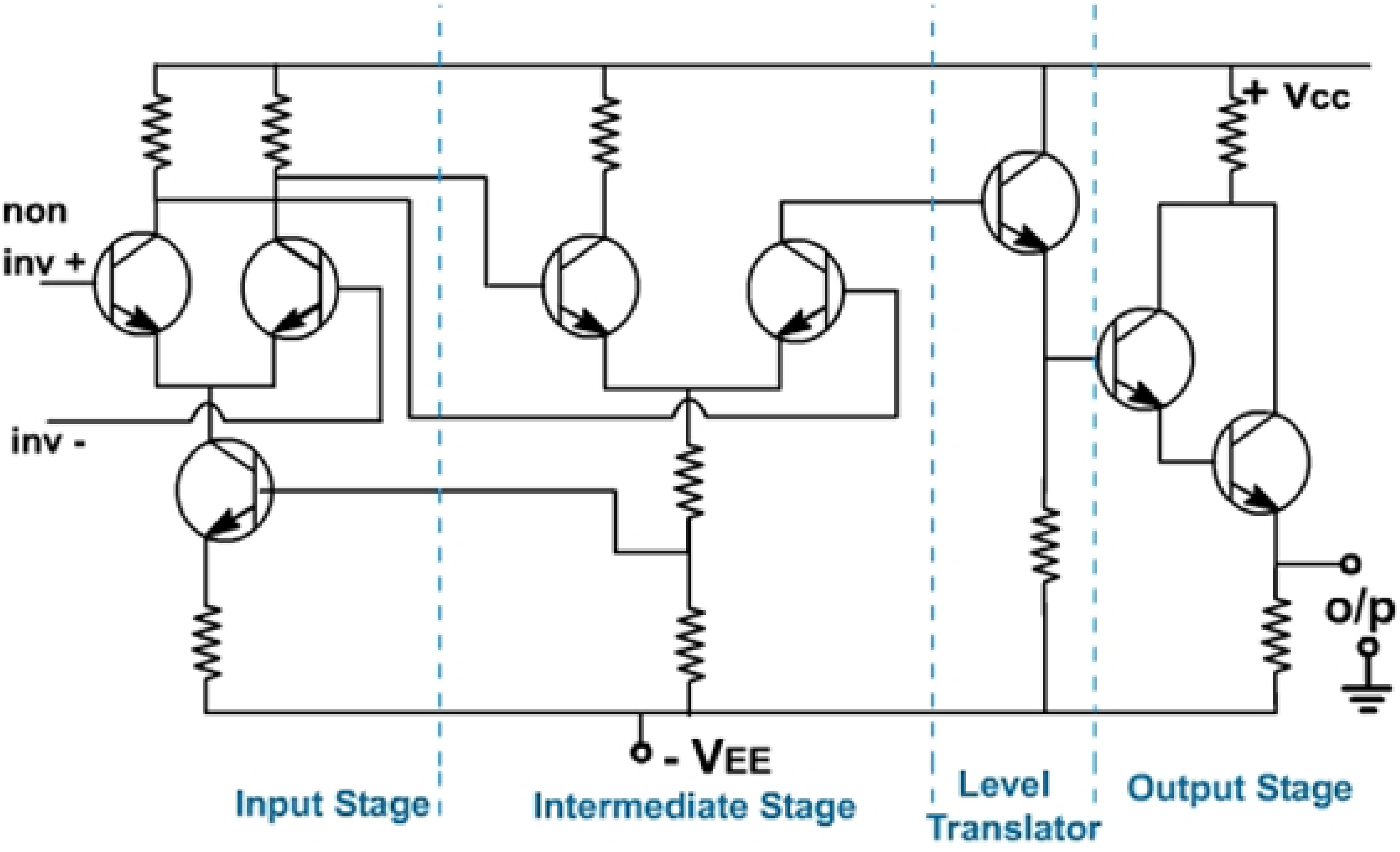
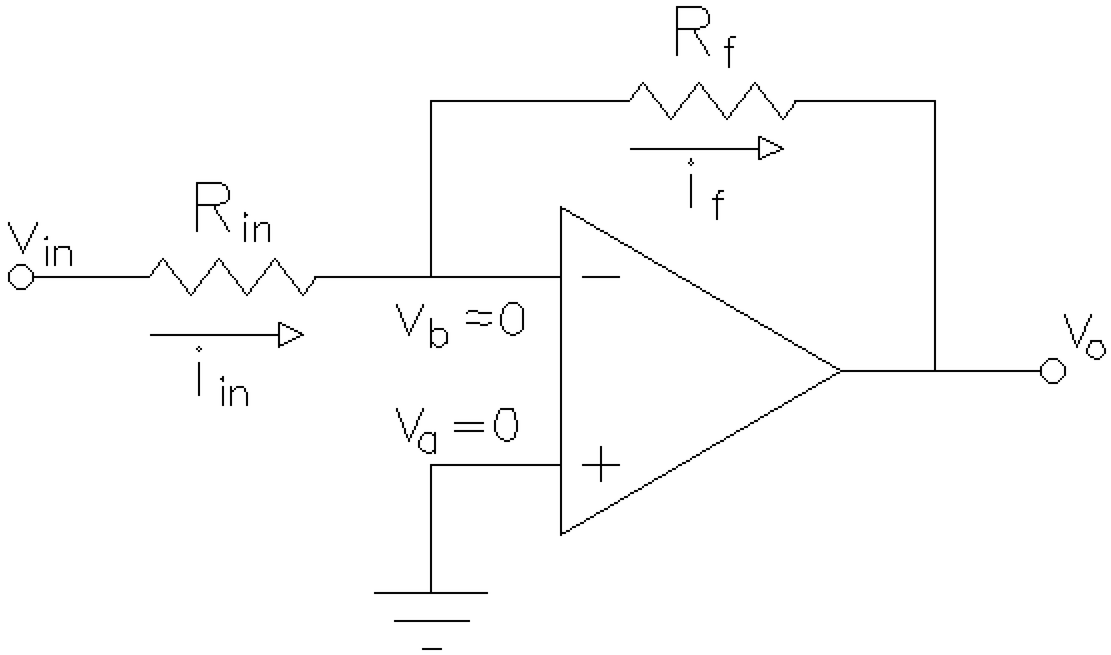


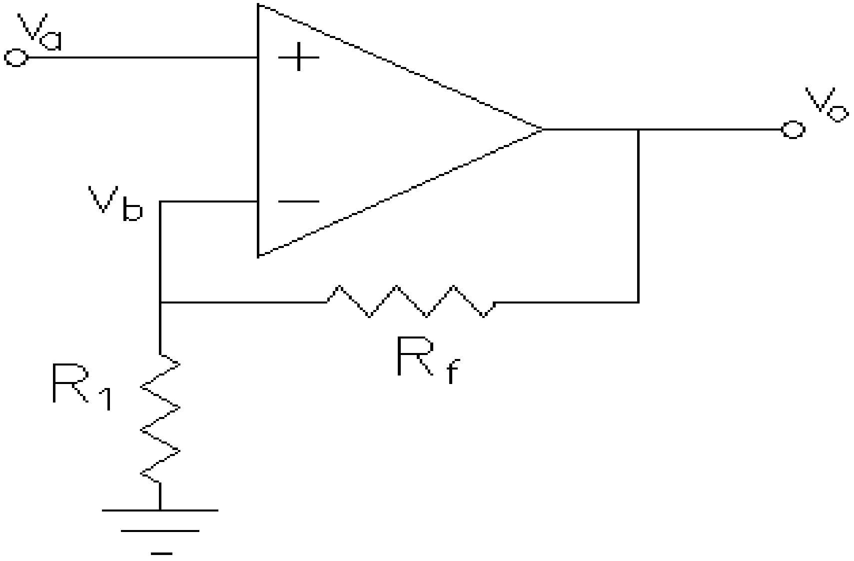
Fig. 4

Inverting Op-Amp



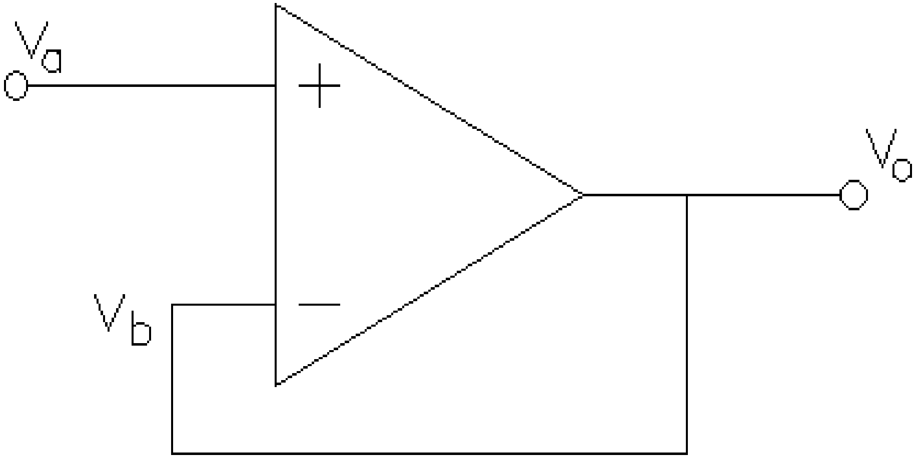
$$V_{OUT} = -V_{IN} \frac{R_f}{R_1}$$

Non-Inverting Amplifier



$$V_{OUT} = V_{IN}\left(1 + \frac{R_1}{R_2}\right)$$

Voltage follower



$$V_{OUT} = V_{IN}$$

DC characteristics

Input offset current

The difference between the bias currents at the input terminals of the op- amp is called as input offset current. The input terminals conduct a small value of dc current to bias the input transistors. Since the input transistors cannot be made identical, there exists a difference in bias currents

DC characteristics

Input offset voltage

A small voltage applied to the input terminals to make the output voltage as zero when the two input terminals are grounded is called input offset voltage

DC characteristics

Input offset voltage

A small voltage applied to the input terminals to make the output voltage as zero when the two input terminals are grounded is called input offset voltage

DC characteristics

Input bias current

Input bias current IB as the average value of the base currents entering into terminal of an op-amp

$$I_B=\frac{I_B^{+} + I_B^{-}}{2}$$

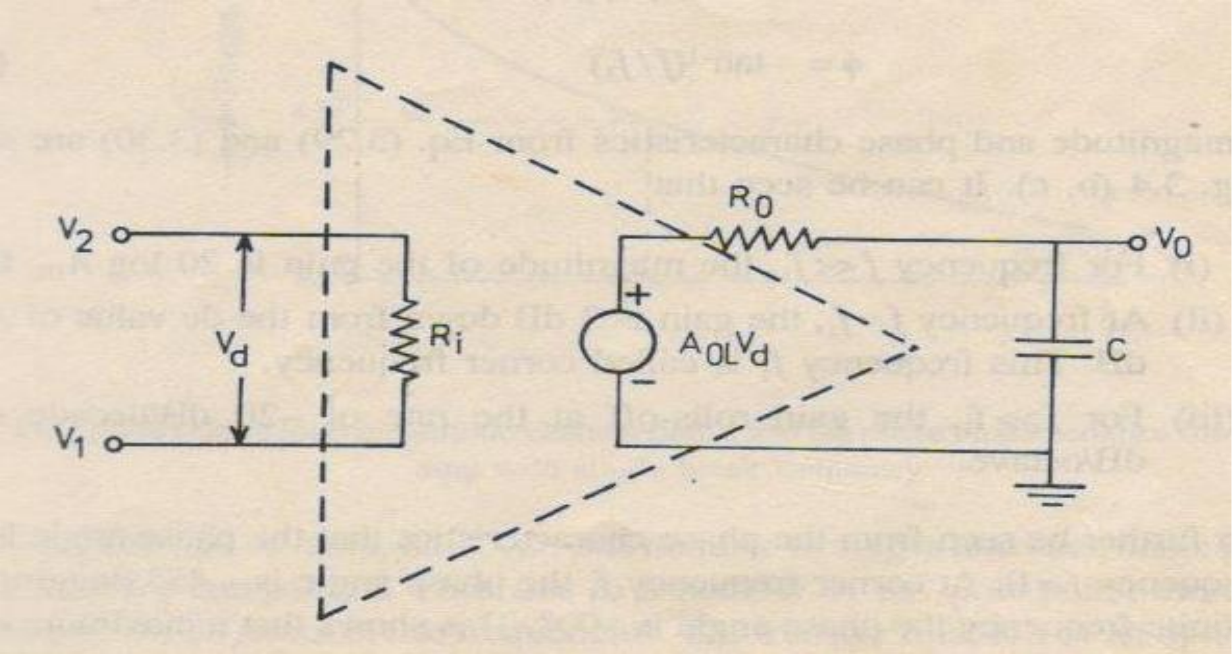
DC characteristics

THERMAL DRIFT

Bias current, offset current and offset voltage change with temperature. A circuit carefully nulled at 25^{o}c may not remain so when the temperature rises to 35^{o}c. This is called drift.

AC characteristics

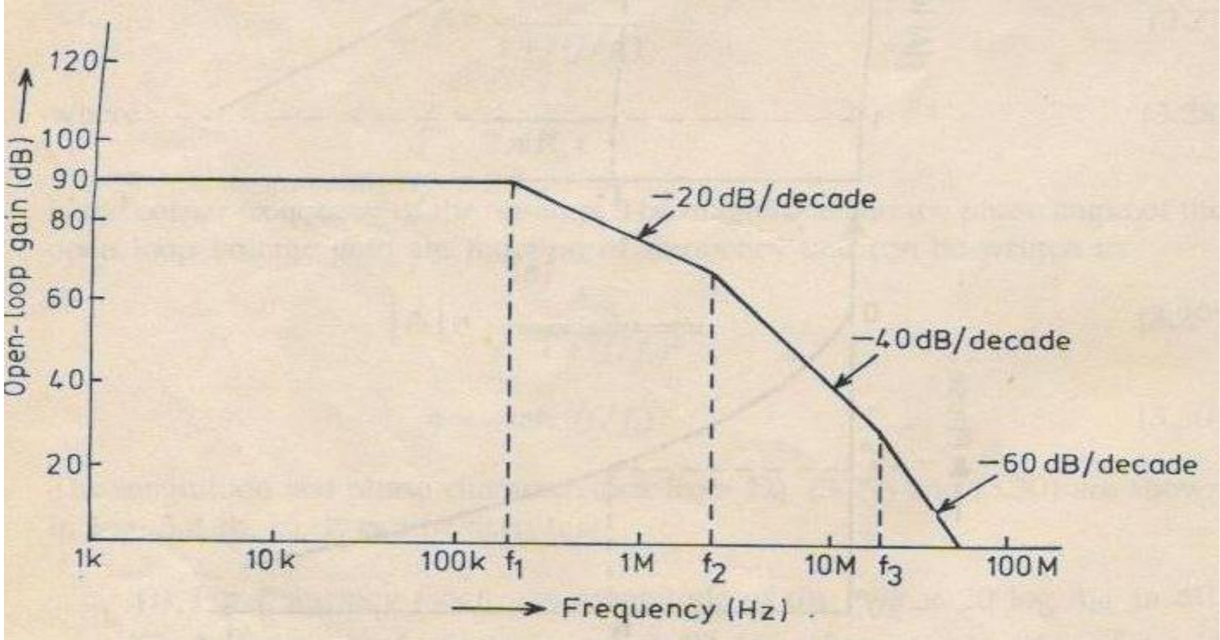
Frequency Response



HIGH FREQUENCY MODEL OF OPAMP

AC characteristics

Frequency Response



OPEN LOOP GAIN VS FREQUENCY

Frequency compensation methods

- Dominant- pole compensation
- Pole- zero compensation

Slew Rate

- The slew rate is defined as the maximum rate of change of output voltage caused by a step input voltage.

- An ideal slew rate is infinite which means that op-amp’s output voltage should change instantaneously in response to input step voltage

Need for frequency compensation in practical op-amps

- Frequency compensation is needed when large bandwidth and lower closed loop gain is desired.

- Compensating networks are used to control the phase shift and hence to improve the stability

Applications of Op Amp

BASIC APPLICATIONS OF OP-AMP

- Scale changer/Inverter.
- Summing Amplifier.
  - Inverting summing amplifier
  - Non-Inverting summing amplifier.
- Subtractor
- Adder - Subtractor

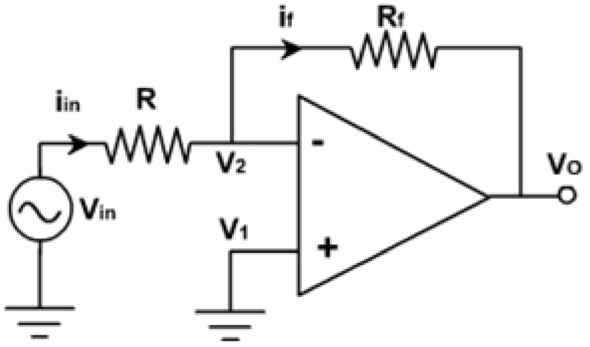
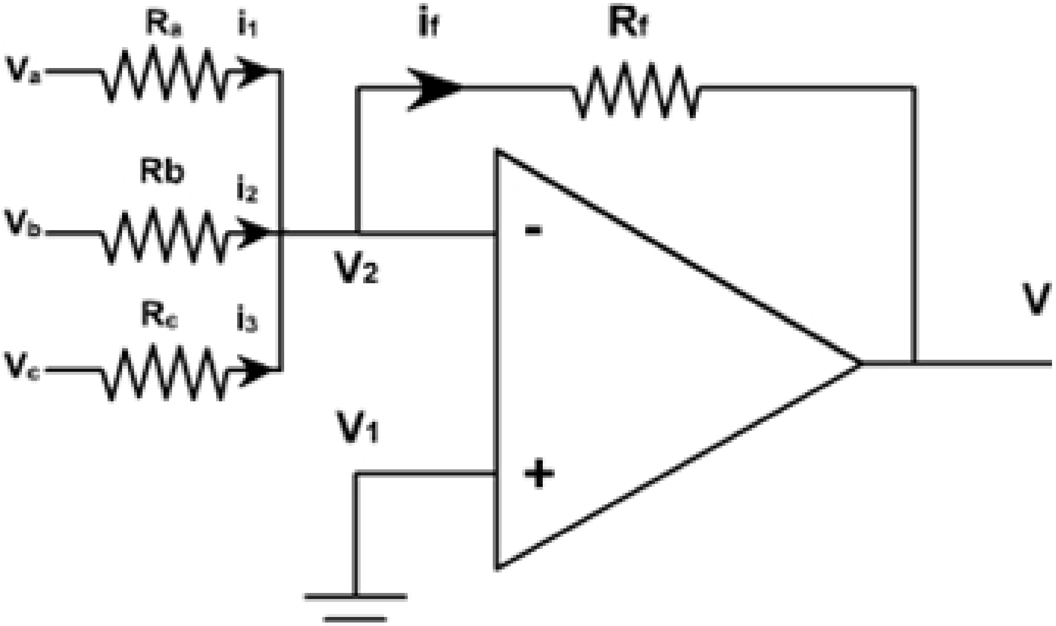
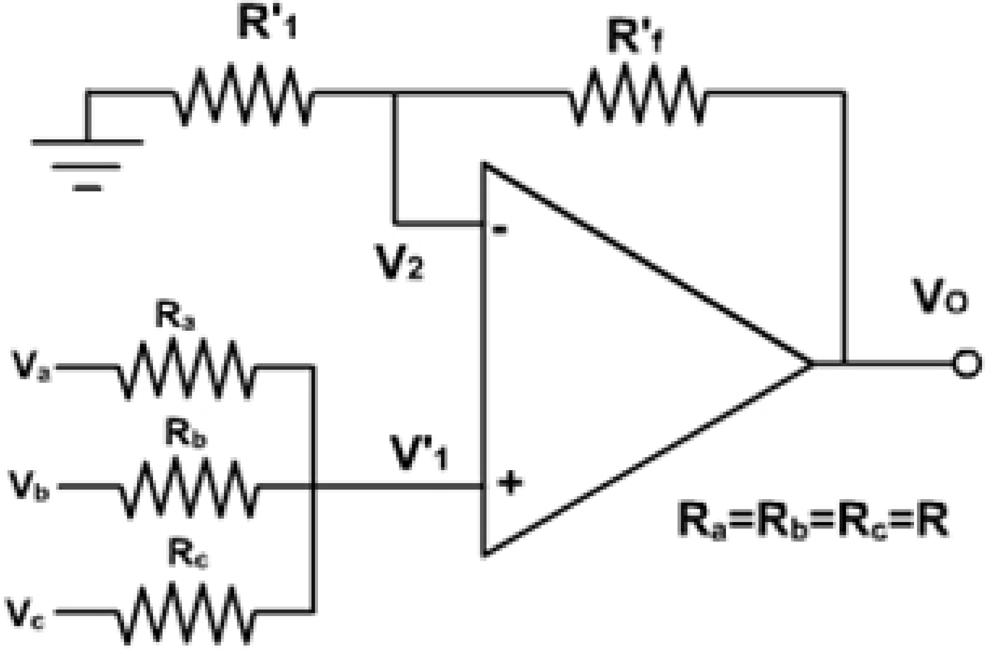
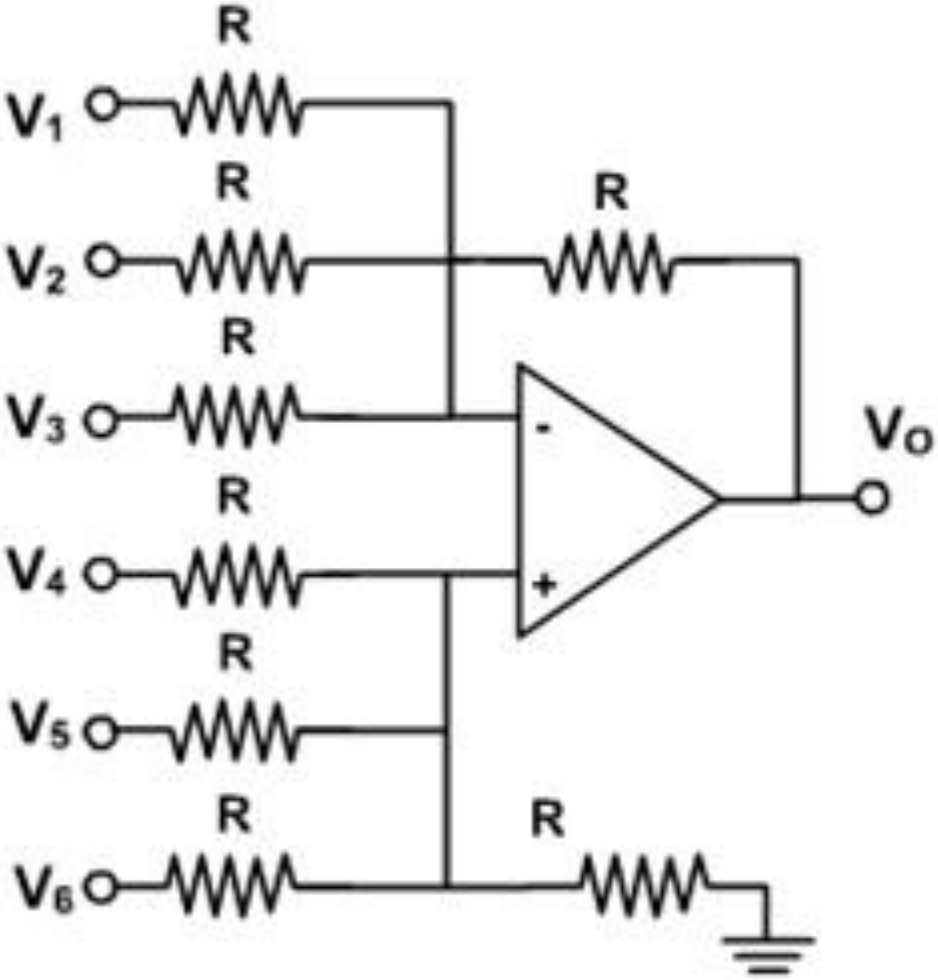


Fig. 1


R_a
i_1
i_f
R_f
V_a
Rb
i_2
V_b
-
V_2
V
R_c
i_3
V_c
V_1
+

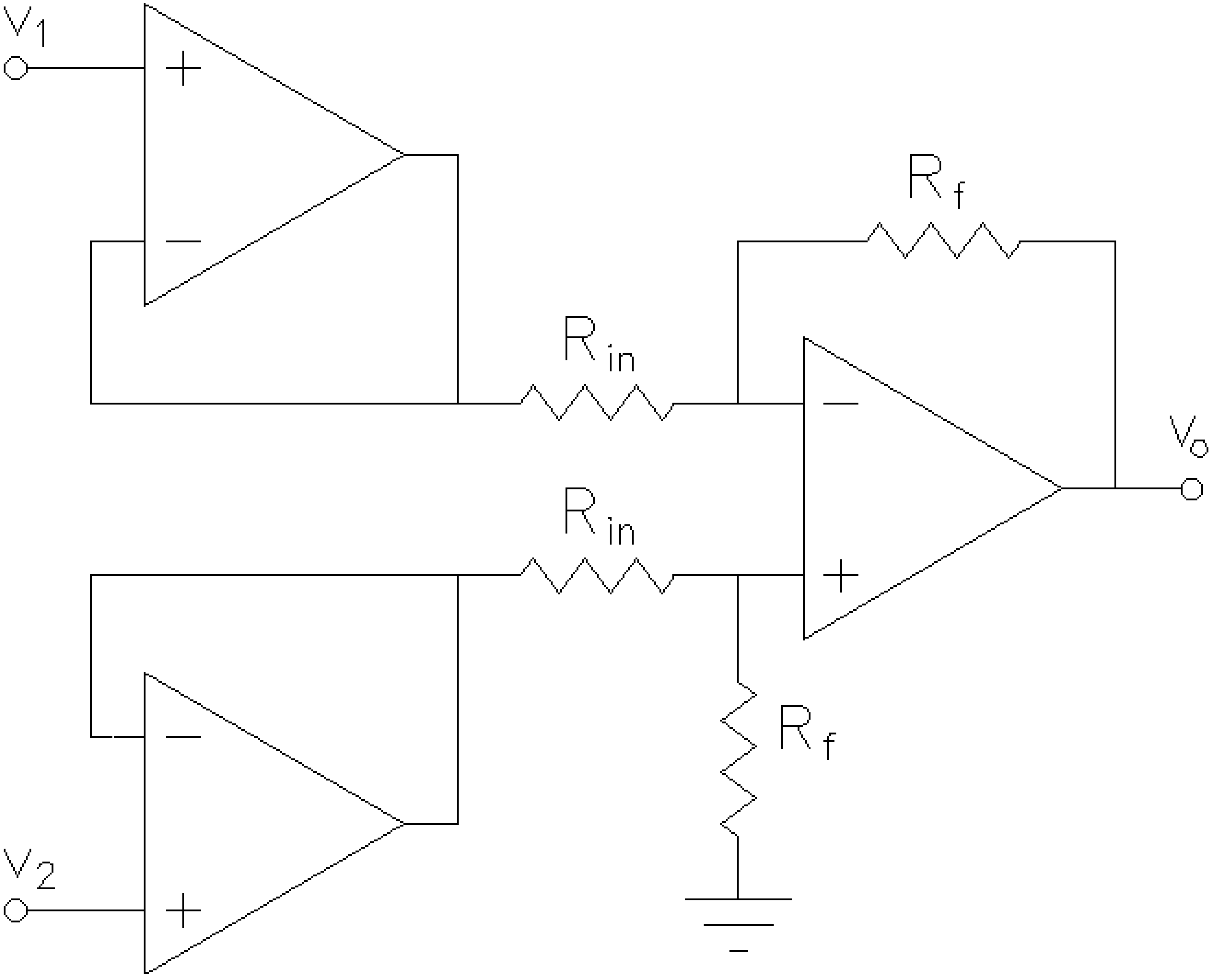

R'1
R'f
V2
VO
Ra
Va
Rb
V'1
Vb
Rc
Vc
-
+
Ra=Rb=Rc=R


R
V1
R
R
V2
R
V3
Vo
R
V4
R
V5
R
R
V6

Instrumentation Amplifier

In a number of industrial and consumer applications, the measurement of physical quantities is usually done with the help of transducers. The output of transducer has to be amplified So that it can drive the indicator or display system. This function is performed by an instrumentation amplifier

Instrumentation Amplifier

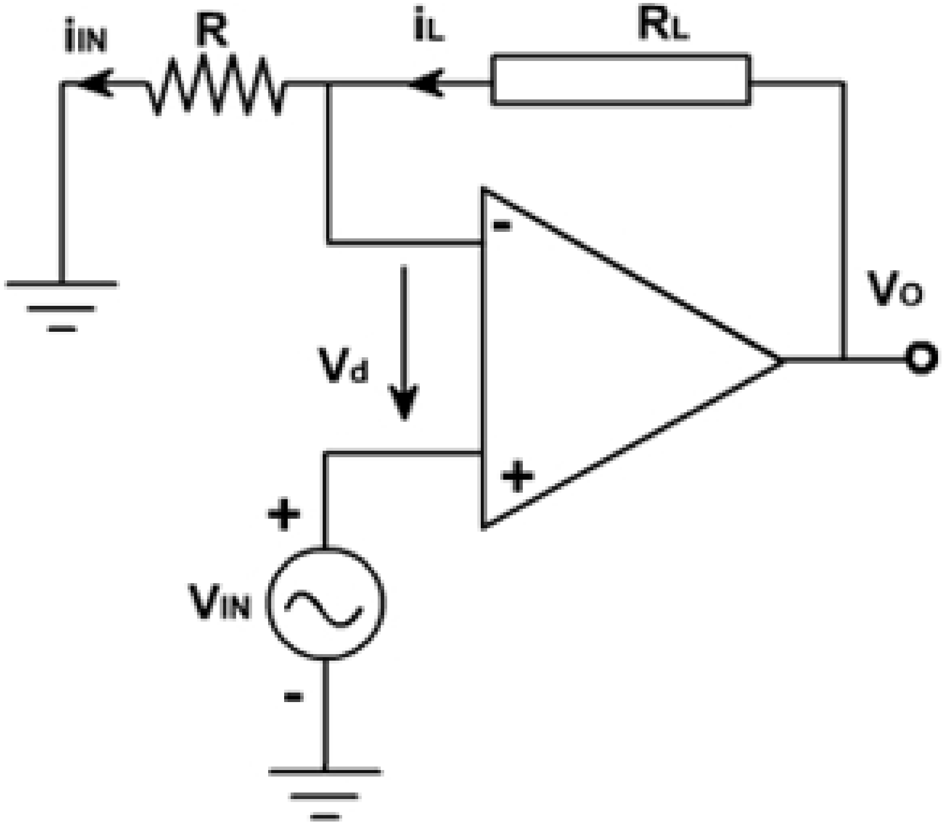


Features of instrumentation amplifier

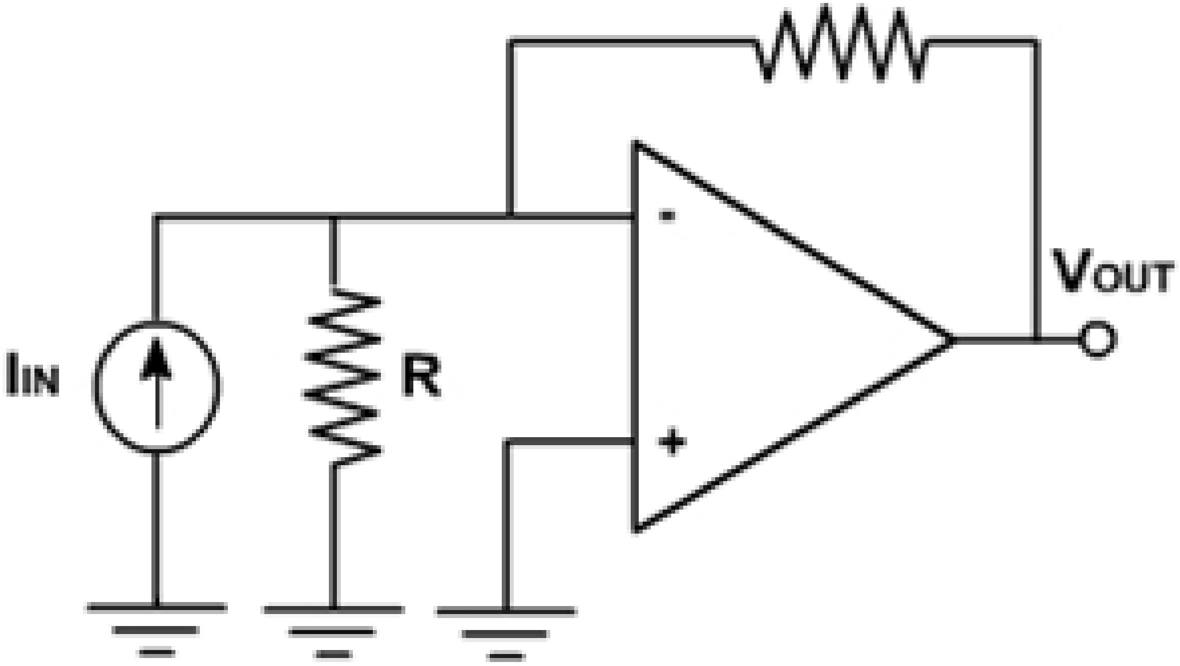
1. high gain accuracy
2. high CMRR
3. high gain stability with low temperature co-efficient
4. low dc offset
5. low output impedance

AC AMPLIFIER

V to I Converter



I to V Converter



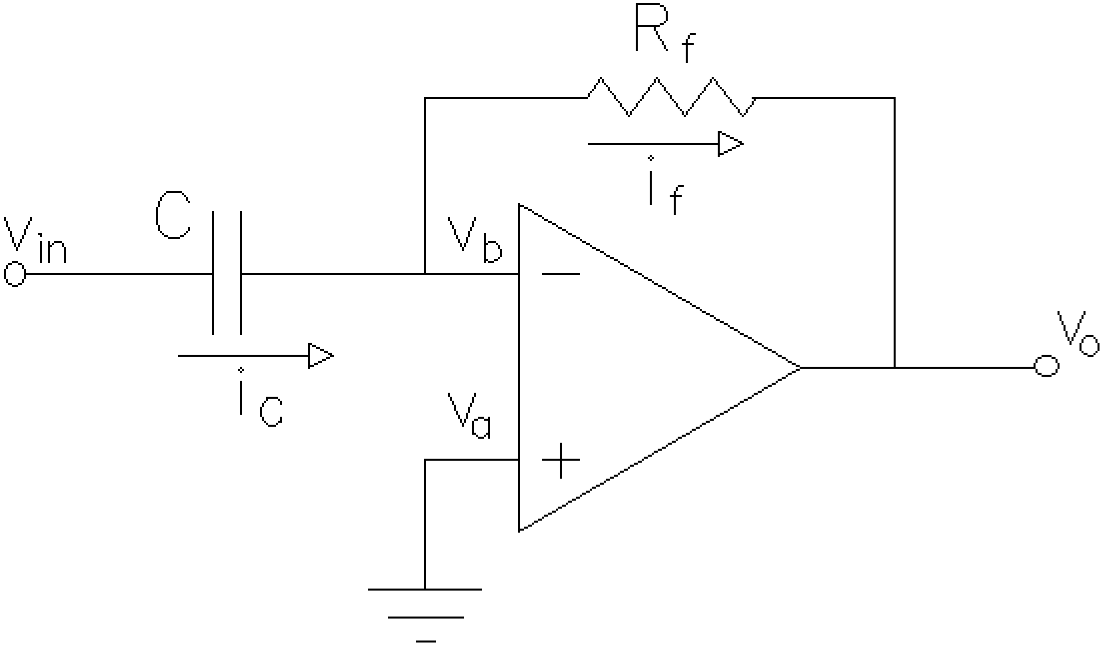
Sample and hold circuit

A sample and hold circuit is one which samples an input signal and holds on to its last sampled value until the input is sampled again. This circuit is mainly used in digital interfacing, analog to digital systems, and pulse code modulation systems.

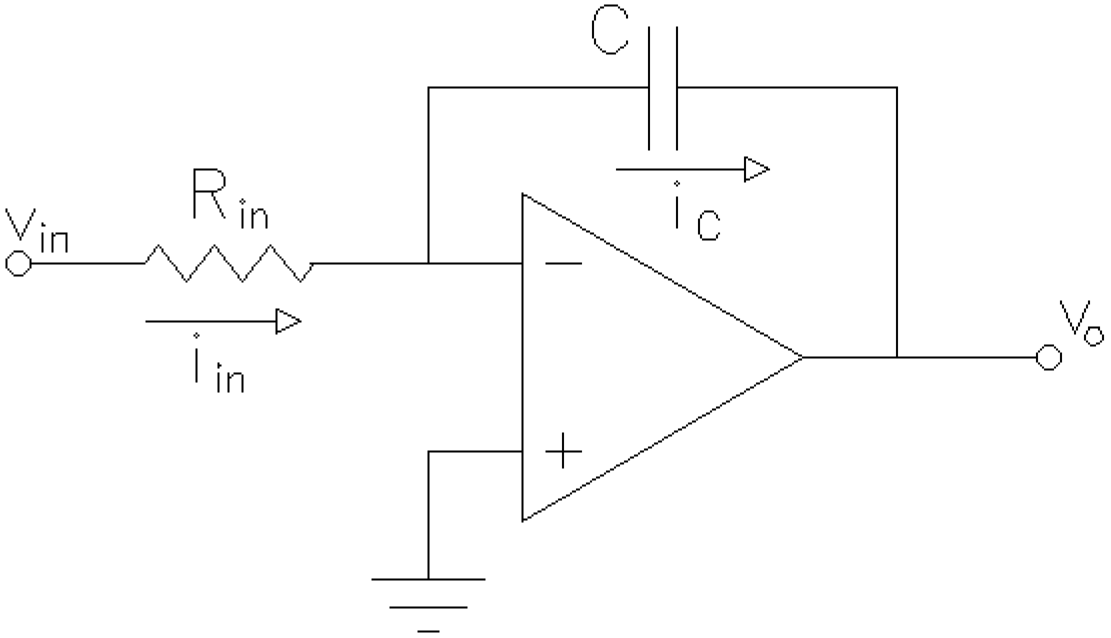
Sample and hold circuit

The time during which the voltage across the capacitor in sample and hold circuit is equal to the input voltage is called sample period.The time period during which the voltage across the capacitor is held constant is called hold period

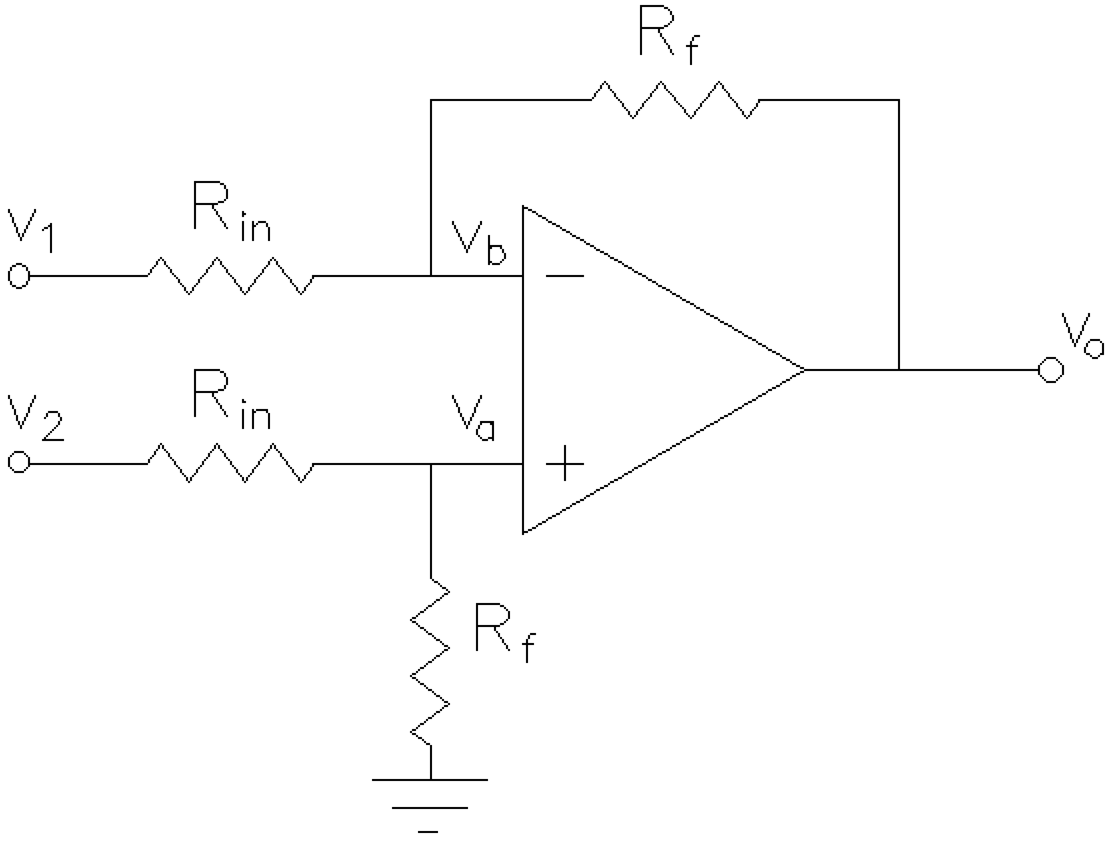
Differentiator



Integrator



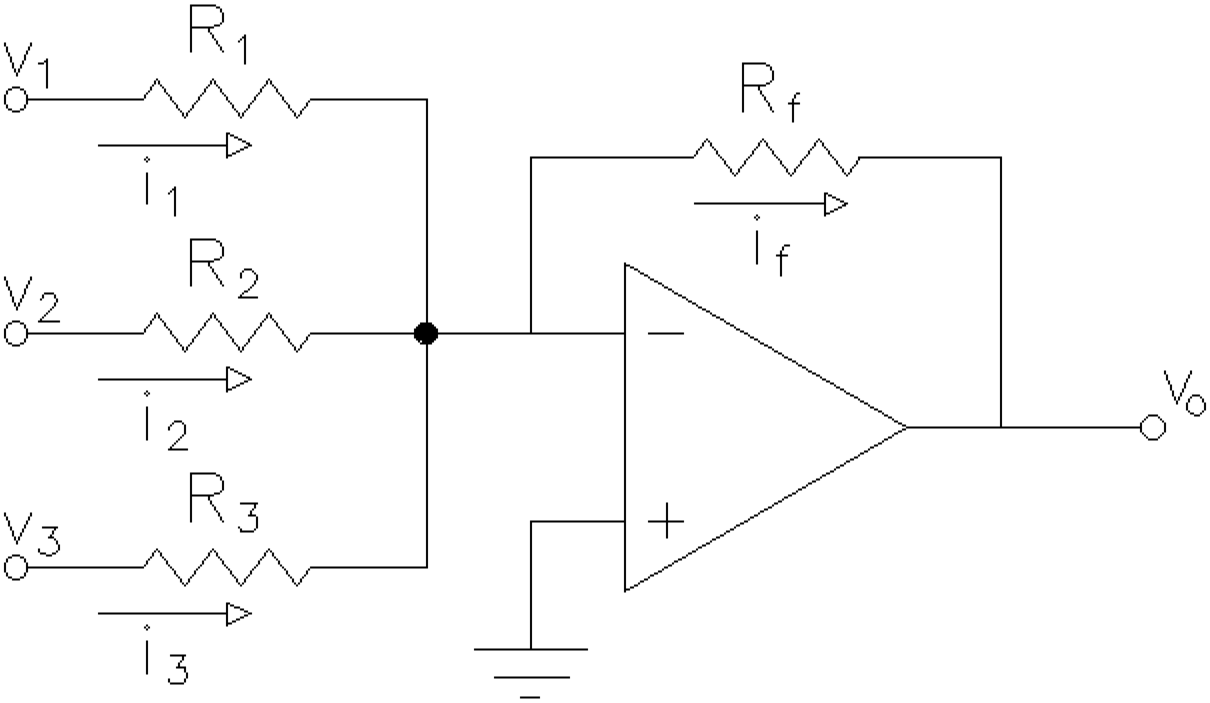
Differential amplifier



Differential amplifier

This circuit amplifies only the difference between the two inputs. In this circuit there are two resistors labeled R_{IN} Which means that their values are equal. The differential amplifier amplifies the difference of two inputs while the differentiator amplifies the slope of an input

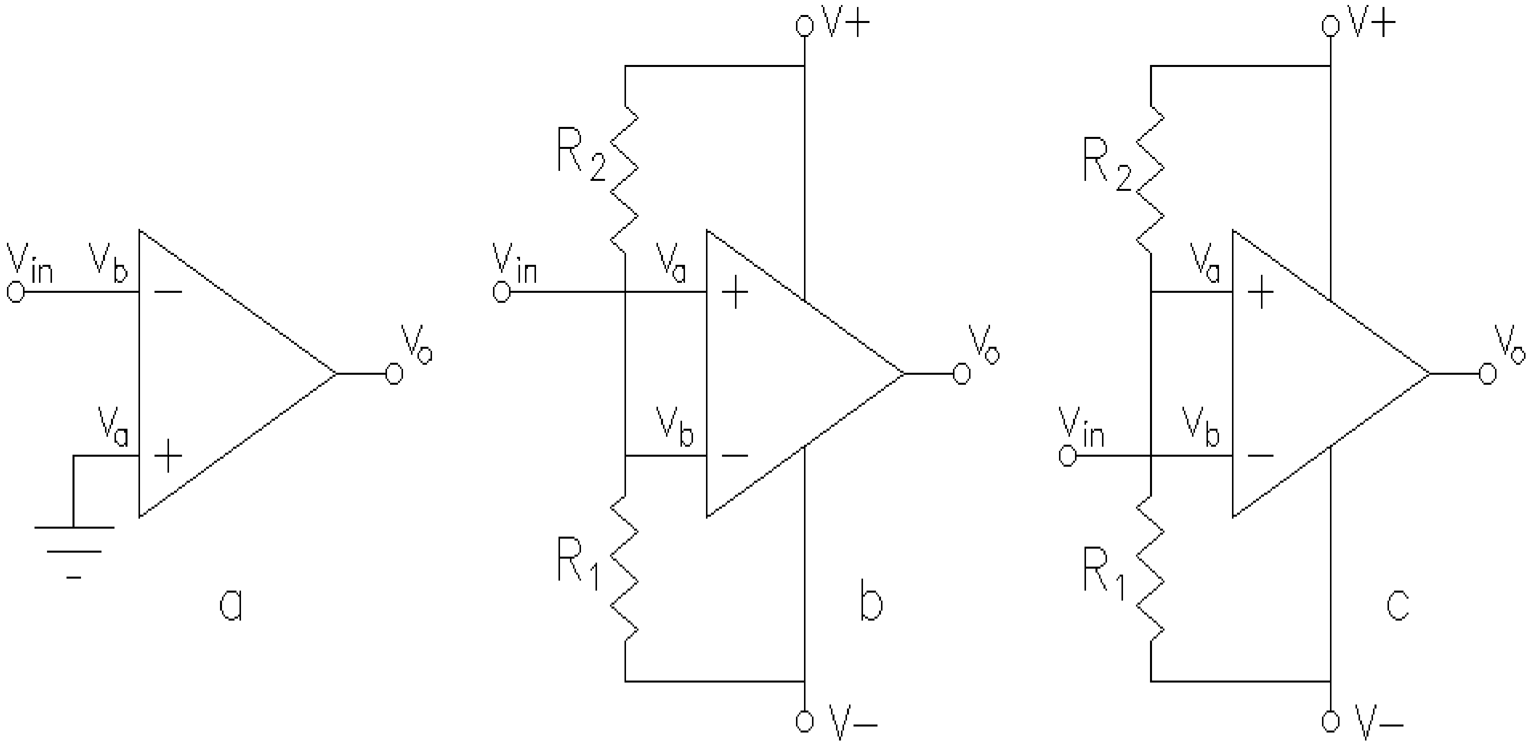
Summer



Comparator

A comparator is a circuit which compares a signal voltage applied at one input of an op- amp with a known reference voltage at the other input. It is an open loop op - amp with output + Vsat

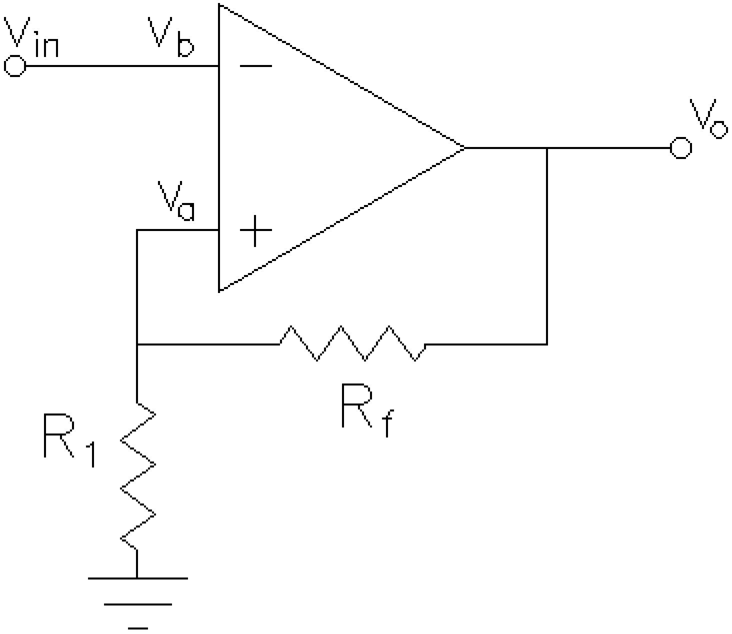
Comparator



Applications of comparator

1. Zero crossing detector
2. Window detector
3. Time marker generator
4. Phase detector

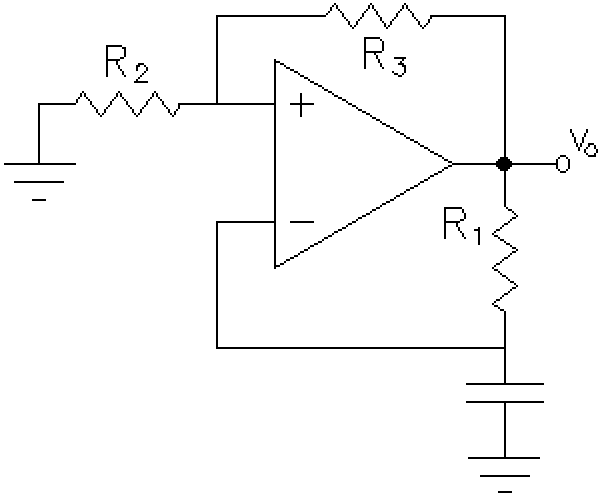
Schmitt trigger



Schmitt trigger

Schmitt trigger is a regenerative comparator. It converts sinusoidal input into a square wave output. The output of Schmitt trigger swings between upper and lower threshold voltages, which are the reference voltages of the input waveform

square wave generator



Multivibrator

Multivibrators are a group of regenerative circuits that are used extensively in timing applications. It is a wave shaping circuit which gives symmetric or asymmetric square output. It has two states either stable or quasi- stable depending on the type of multivibrator

Monostable multivibrator

Monostable multivibrator is one which generates a single pulse of specified duration in response to each external trigger signal. It has only one stable state. Application of a trigger causes a change to the quasi-stable state.An external trigger signal generated due to charging and discharging of the capacitor produces the transition to the original stable state

Astable multivibrator

Astable multivibrator is a free running oscillator having two quasi- stable states. Thus, there is oscillations between these two states and no external signal are required to produce the change in state

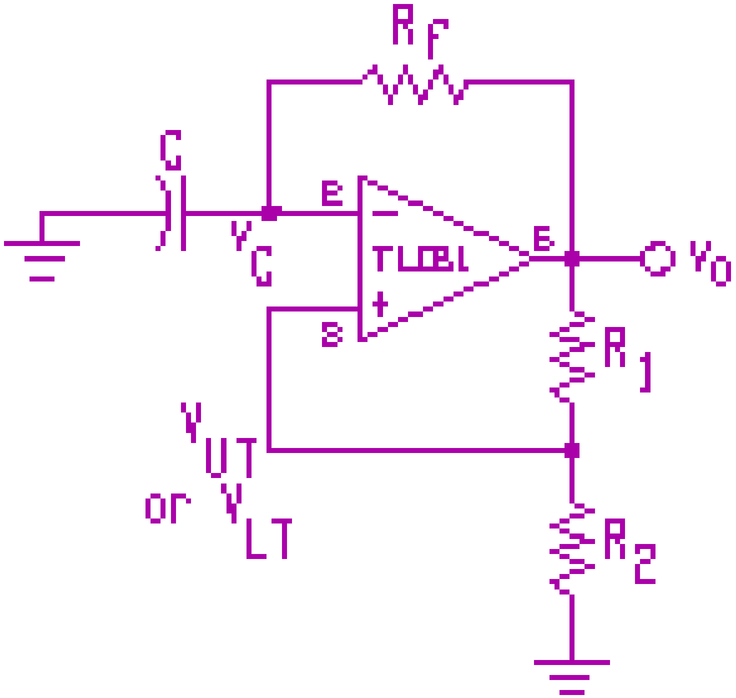
Astable multivibrator

Bistable multivibrator is one that maintains a given output voltage level unless an external trigger is applied . Application of an external trigger signal causes a change of state, and this output level is maintained indefinitely until an second trigger is applied . Thus, it requires two external triggers before it returns to its initial state

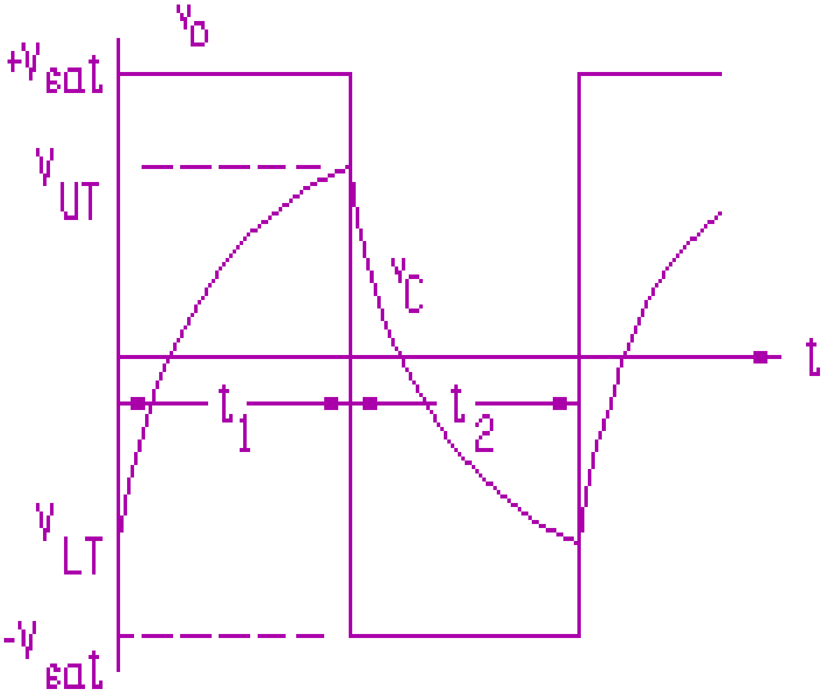
Bistable multivibrator

Bistable multivibrator is one that maintains a given output voltage level unless an external trigger is applied . Application of an external trigger signal causes a change of state, and this output level is maintained indefinitely until an second trigger is applied . Thus, it requires two external triggers before it returns to its initial state

Astable Multivibrator or Relaxation Oscillator



Circuit



Output waveform

Equations for Astable Multivibrator

$$V_{UT} = \frac{+V_{sat}R_2}{R_1 + R_2}; \quad V_{LT} = \frac{-V_{sat}R_2}{R_1 + R_2}$$

Assuming
$|+V_{sat}| = |-V_{sat}|$

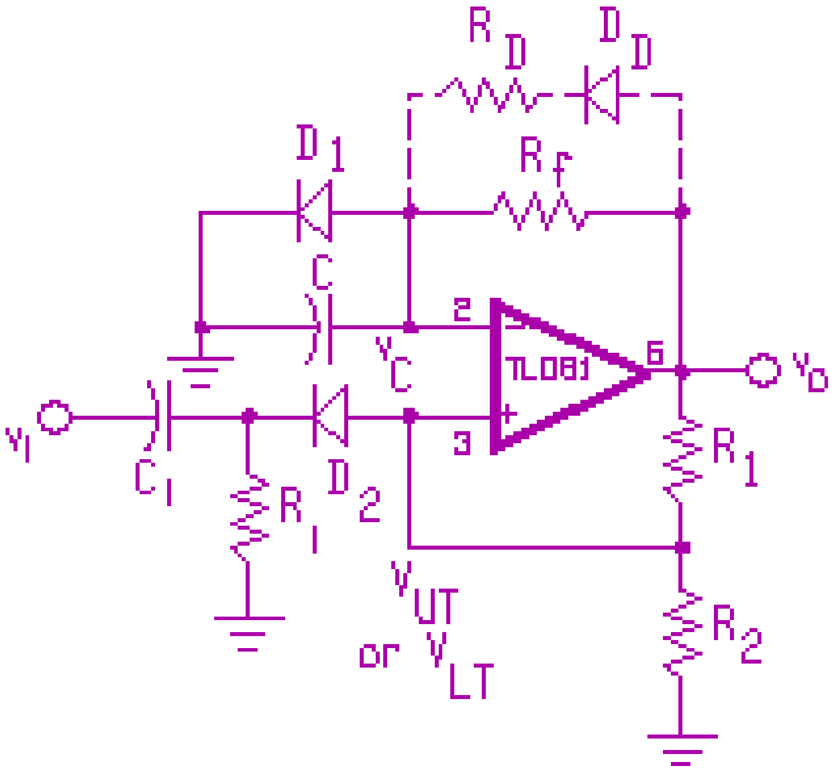
$$T = t_1 + t_2 = 2\tau \ln\left(\frac{R_1 + 2R_2}{R_1}\right)$$

where
☺ = R_fC

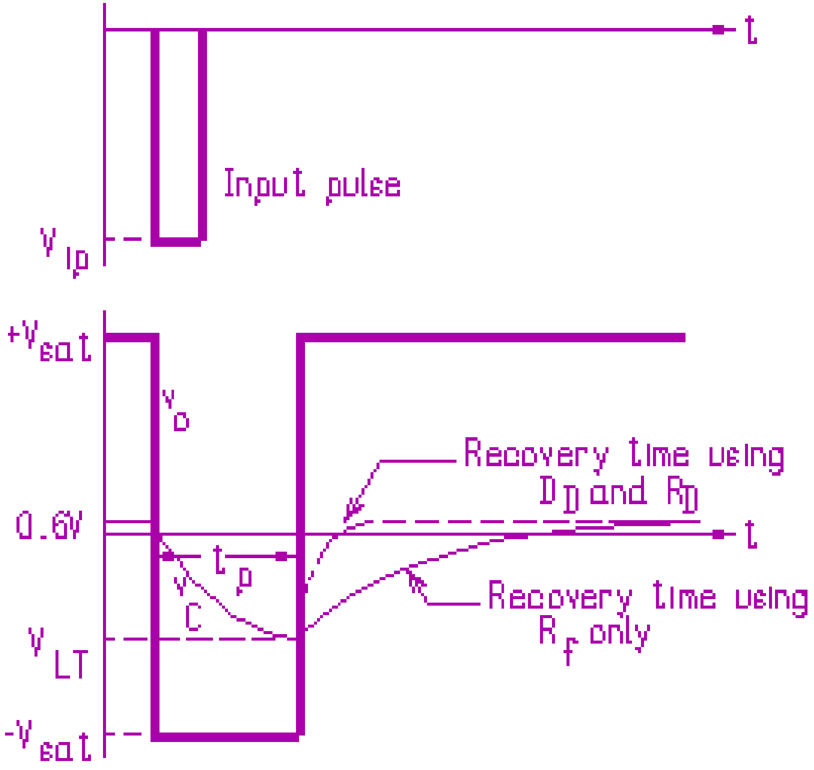
If R_2 is chosen to be 0.86R_1, then $T = 2R_fC$ and

$$f = \frac{1}{2R_fC}$$

Monostable (One-Shot) Multivibrator



Circuit



Waveforms

Notes on Monostable Multivibrator

- Stable state: $v_o = +V_{sat}$, $V_C = 0.6$ V
- Transition to timing state: apply a -ve input pulse such that $|V_{ip}| > |V_{UT}|$; $v_o = -V_{sat}$. Best to select R_iC_i ✂ $0.1R_fC$.
- Timing state: C charges r
through R_f. Width of timir

$$t_p = R_f C \ln\left(\frac{|V_{sat}| + 0.6}{|V_{sat}| + V_{LT}}\right)$$

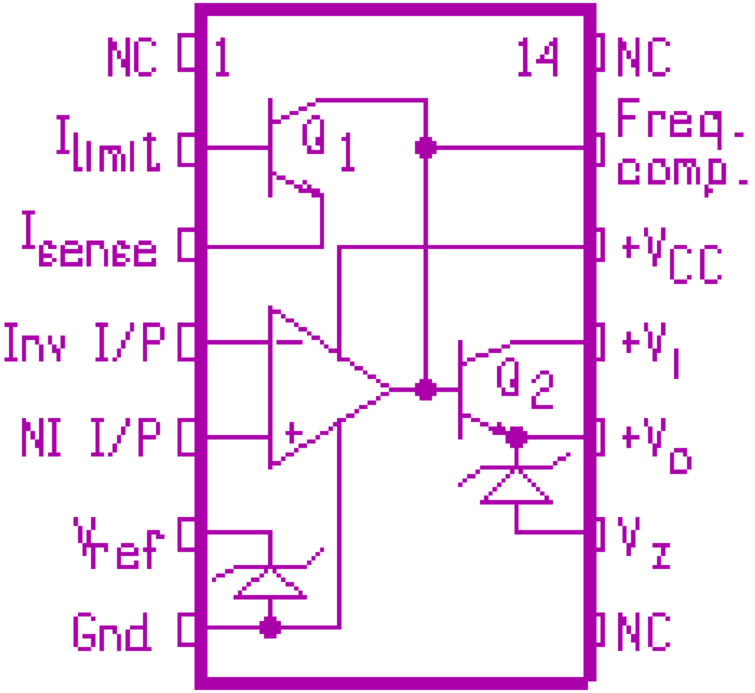
  - If we pick $R_2 = R_1/5$, then $t_p = R_fC/5$.
  - Recovery state: $v_o = +V_{sat}$; circuit is not ready for retriggering until $V_C = 0.6$ V. The *recovery time* 📫 t_p. To speed up the recovery time, R_D (= $0.1R_f$) & C_D can be added.

INTRODUCTION TO VOLTAGE REGULATORS

IC Voltage Regulators

- There are basically two kinds of IC voltage regulators:
  - Multipin type, e.g. LM723C
  - 3-pin type, e.g. 78/79XX
- Multipin regulators are less popular but they provide the greatest flexibility and produce the highest quality voltage regulation
- 3-pin types make regulator circuit design simple

Multipin IC Voltage Regulator



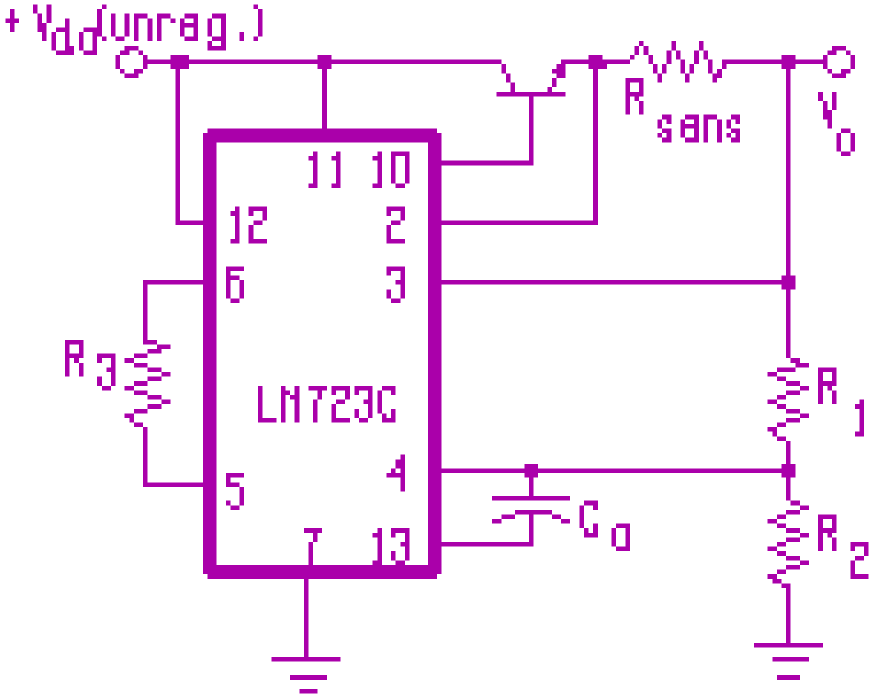
LM 723C Schematic

- The LM723 has an equivalent circuit that contains most of the parts of the op-amp voltage regulator discussed earlier.
- It has an internal voltage reference, error amplifier, pass transistor, and current limiter all in one IC package.

LM723 Voltage Regulator

- Can be either 14-pin DIP or 10-pin TO-100 can
- May be used for either +ve or -ve, variable or fixed regulated voltage output
- Using the internal reference (7.15 V), it can operate as a high-voltage regulator with output from 7.15 V to about 37 V, or as a low-voltage regulator from 2 V to 7.15 V
- Max. output current with heat sink is 150 mA
- Dropout voltage is 3 V (i.e. $V_{CC} > V_{o(max)} + 3$)

LM723 in High-Voltage Configuration



External pass transistor and current sensing added.

Design equations:

$$V_o = \frac{V_{ref}(R_1 + R_2)}{R_2}$$

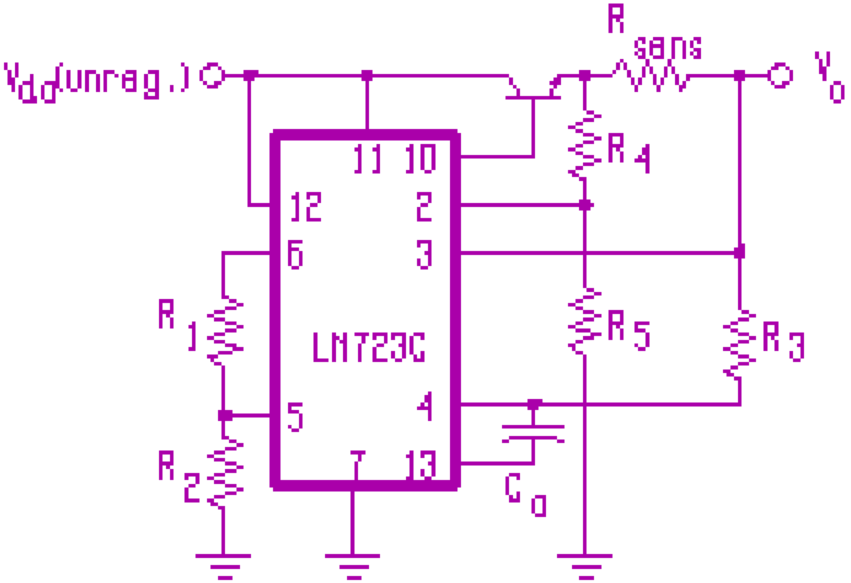
$$R_3 = \frac{R_1 R_2}{R_1 + R_2}$$

$$R_{sens} = \frac{0.7}{I_{\max}}$$

Choose $R_1 + R_2 = 10\ \mathrm{k}\Omega$, and $C_c = 100$ pF.

To make V_o variable, replace R_1 with a pot.

LM723 in Low-Voltage Configuration



With external pass transistor and foldback current limiting

$$V_o = \frac{R_2 V_{ref}}{R_1 + R_2}$$

$$I_{L(max)} = \frac{R_4 V_o + 0.7(R_4 + R_5)}{R_5 R_{sens}}$$

$$I_{short} = \frac{0.7(R_4 + R_5)}{R_5 R_{sens}}$$

$$R_{sens} = \frac{0.7 V_o}{I_{short}(V_o + 0.7) - 0.7 I_{L(max)}}$$

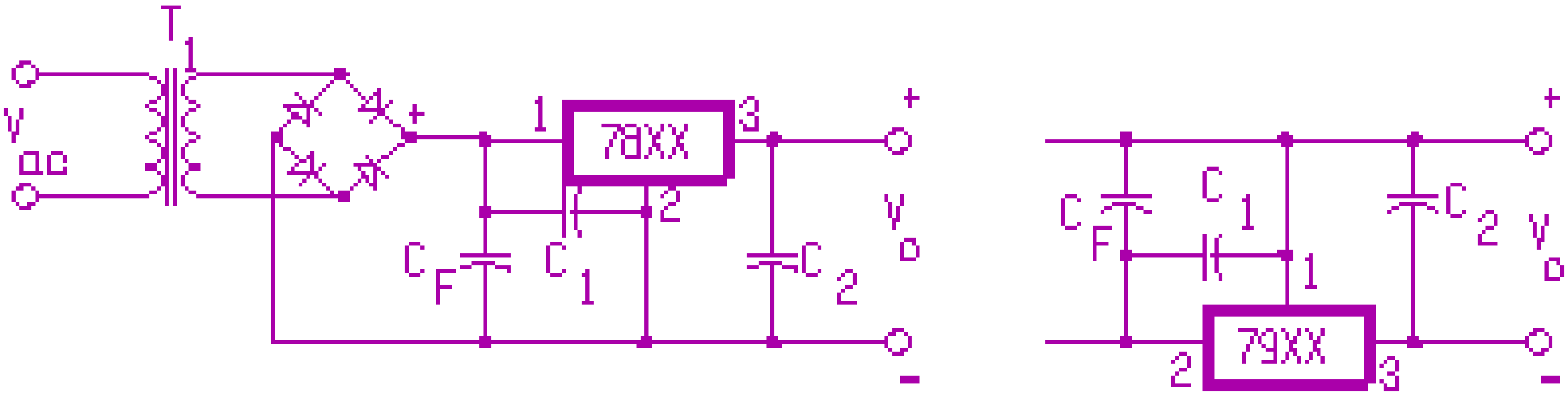
Under foldback condition:

$$V_o' = \frac{0.7 R_L (R_4 + R_5)}{R_5 R_{sens} - R_4 R_L}$$

Three-Terminal Fixed Voltage Regulators

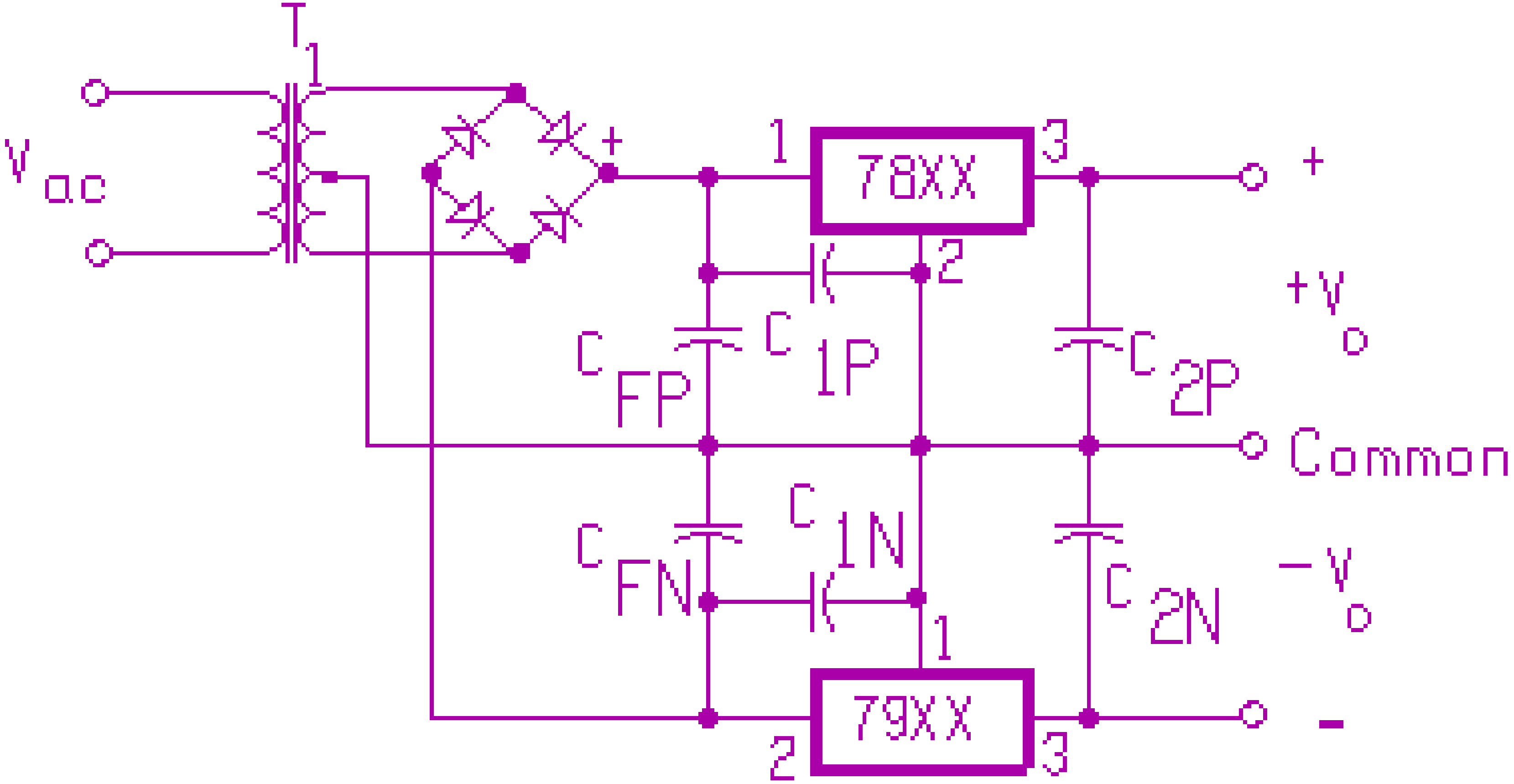
- Less flexible, but simple to use
- Come in standard TO-3 (20 W) or TO-220 (15 W) transistor packages
- 78/79XX series regulators are commonly available with 5, 6, 8, 12, 15, 18, or 24 V output
- Max. output current with heat sink is 1 A
- Built-in thermal shutdown protection
- 3-V dropout voltage; max. input of 37 V
- Regulators with lower dropout, higher in/output, and better regulation are available.

Basic Circuits With 78/79XX Regulators

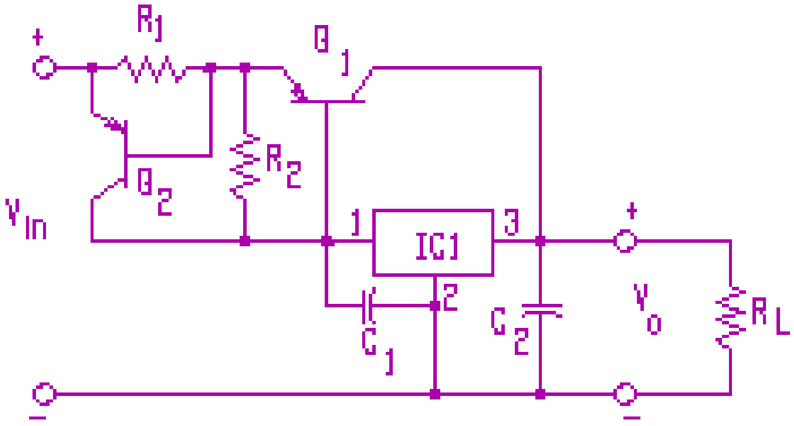


- Both the 78XX and 79XX regulators can be used to provide +ve or -ve output voltages
- C_1 and C_2 are generally optional. C_1 is used to cancel any inductance present, and C_2 improves the transient response. If used, they should preferably be either 1 μF tantalum type or 0.1 μF mica type capacitors.

Dual-Polarity Output with 78/79XX Regulators



78XX Regulator with Pass Transistor



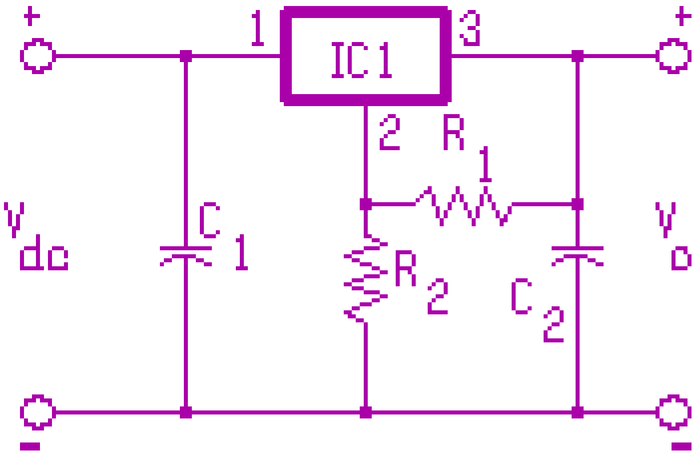
$$R_1 = \frac{0.7}{I_{\max}}$$

$$R_2 = \frac{0.7}{I_{R2}}$$

- Q_1 starts to conduct when $V_{R2} = 0.7$ V.
- R2 is typically chosen so that max. I_{R2} is 0.1 A.
- Power dissipation of Q_1 is $P = (V_i - V_o)I_L$.
- Q_2 is for current limiting protection. It conducts when $V_{R1} = 0.7$ V.
- Q_2 must be able to pass max. 1 A; but note that max. V_{CE2} is only 1.4 V.

78XX Floating Regulator

- It is used to obtain an output > the V_{reg} value up to a max.of 37 V.
- R_1 is chosen so that R_1 ✄ 0.1 V_{reg}/I_Q, where I_Q is the … of



$$V_o = V_{reg} + \left(\frac{V_{reg}}{R_1} + I_Q \right) R_2$$

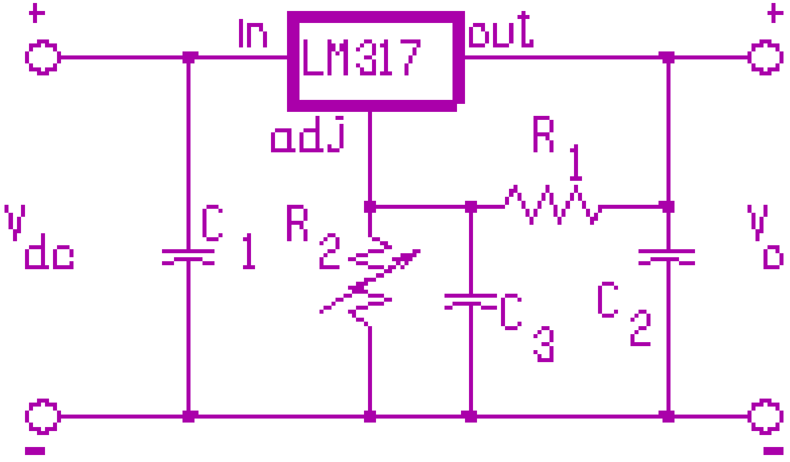
or

$$R_2 = \frac{R_1 (V_o - V_{reg})}{V_{reg} + I_Q R_1}$$

3-Terminal Variable Regulator

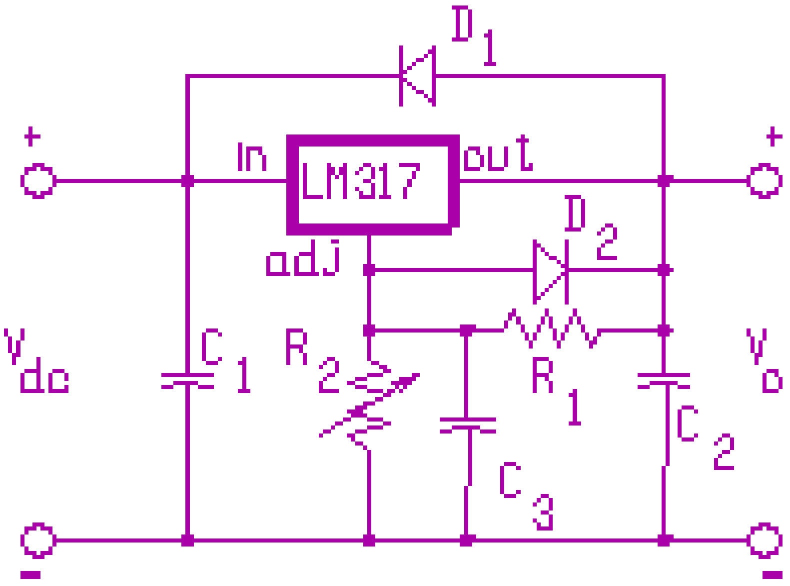
- The floating regulator could be made into a variable regulator by replacing R_2 with a pot. However, there are several disadvantages:
  - Minimum output voltage is V_{reg} instead of 0 V.
  - I_Q is relatively large and varies from chip to chip.
  - Power dissipation in R_2 can in some cases be quite large resulting in bulky and expensive equipment.
- A variety of 3-terminal variable regulators are available, e.g. LM317 (for +ve output) or LM 337 (for -ve output).

Basic LM317 Variable Regulator Circuits



(a)

Circuit with capacitors to improve performance



(b)

Circuit with protective diodes

Notes on Basic LM317 Circuits

- The function of C_1 and C_2 is similar to those used in the 78/79XX fixed regulators.
- C_3 is used to improve ripple rejection.
- Protective diodes in circuit (b) are required for high-current/high-voltage applications.

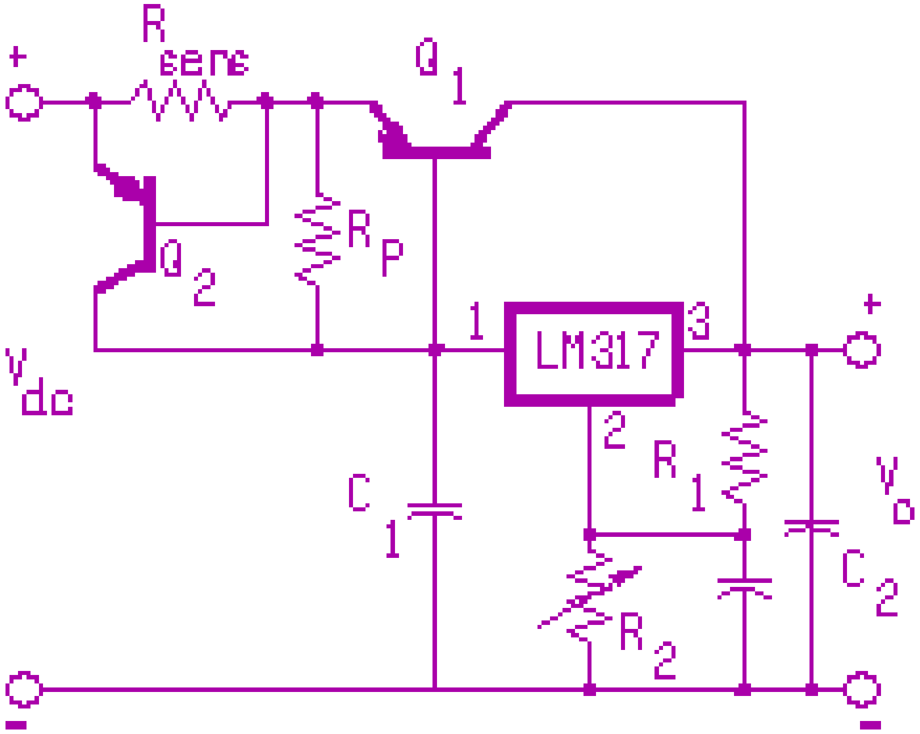
$$V_o = V_{ref} + \left(\frac{V_{ref}}{R_1} + I_{adj} \right) R_2$$

where $V_{ref} = 1.25$ V, and I_{adj} is the current flowing into the adj. terminal (typically 50 μA).

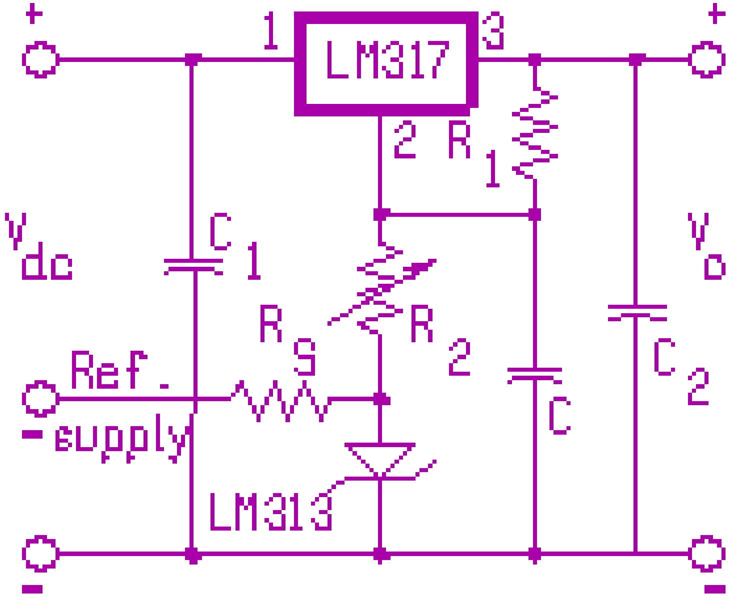
$$R_2 = \frac{R_1 (V_o - V_{ref})}{V_{ref} + I_{adj} R_1}$$

$R_1 = V_{ref} / I_{L(min)}$, where $I_{L(min)}$ is typically 10 mA.

LM317 Regulator Circuits



Circuit with pass transistor and current limiting



Circuit to give 0V min. output voltage

UNIT-III

ACTIVE FILTERS AND OSCILLATORS

INTRODUCTION

Filter

Filter is a frequency selective circuit that passes signal of specified Band of frequencies and attenuates the signals of frequencies outside the band

Type of Filter

1. Passive filters
2. Active filters

Passive filters

Passive filters works well for high frequencies. But at audio frequencies, the inductors become problematic, as they become large, heavy and expensive.For low frequency applications, more number of turns of wire must be used which in turn adds to the series resistance degrading inductor’s performance ie, low Q, resulting in high power dissipation

Active filters

Active filters used op- amp as the active element and resistors and capacitors as passive elements. By enclosing a capacitor in the feed back loop , inductor less active filters can be obtained

some commonly used active filters

1. Low pass filter
2. High pass filter
3. Band pass filter
4. Band reject filter
5. All pass filter

Active Filters

- Active filters use op-amp(s) and RC components.
- Advantages over passive filters:
  - op-amp(s) provide gain and overcome circuit losses
  - increase input impedance to minimize circuit loading
  - higher output power
  - sharp cutoff characteristics can be produced simply and efficiently without bulky inductors
- Single-chip universal filters (e.g. switched-capacitor ones) are available that can be configured for any type of filter or response.

Review of Filter Types & Responses

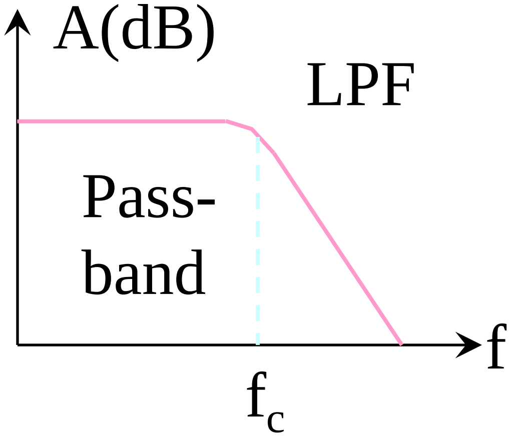
- 4 major types of filters: low-pass, high-pass, band pass, and band-reject or band-stop
- 0 dB attenuation in the passband (usually)
- 3 dB attenuation at the *critical* or *cutoff frequency*, f_c (for Butterworth filter)
- Roll-off at 20 dB/dec (or 6 dB/oct) per *pole* outside the passband (# of poles = # of reactive elements). Attenuation at any frequency, f, is:

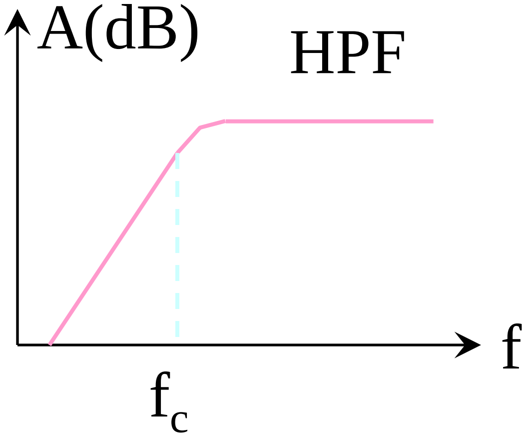
$$atten.(dB)\,at\ f = \log\left(\frac{f}{f_c}\right) x\, atten.(dB)\,at\ f_{dec}$$

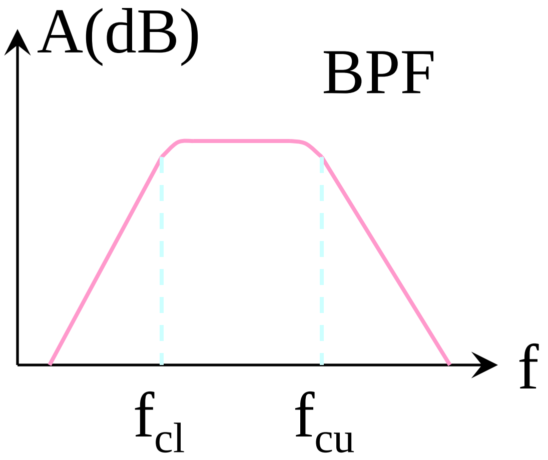
Review of Filters (cont’d)

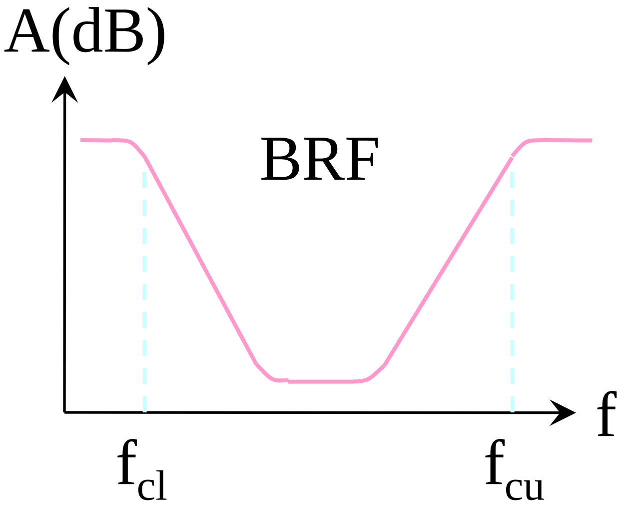
- Bandwidth of a filter: BW = f_{cu} - f_{cl}
- Phase shift: 45^o/pole at f_c; 90^o/pole at >> f_c
- 4 types of filter responses are commonly used:
  - Butterworth - maximally flat in passband; highly non-linear phase response with frequecny
  - Bessel - gentle roll-off; linear phase shift with freq.
  - Chebyshev - steep initial roll-off with ripples in passband
  - Cauer (or elliptic) - steepest roll-off of the four types but has ripples in the passband and in the stopband

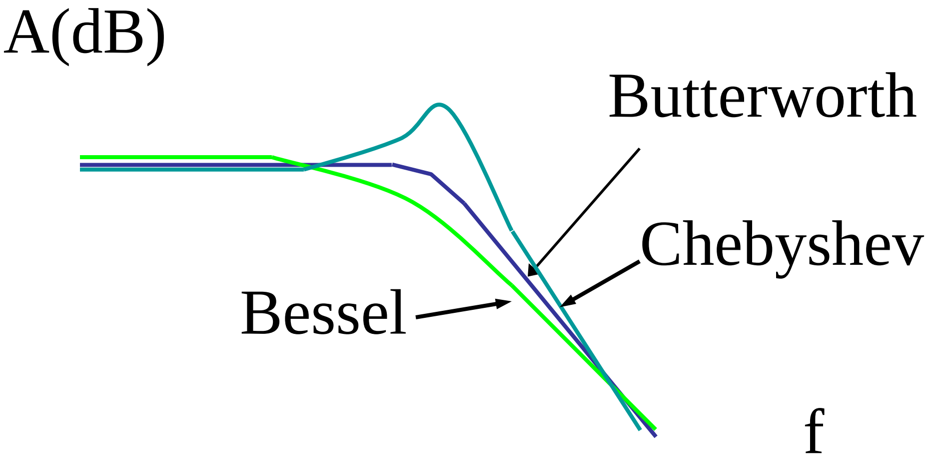
Frequency Response of Filters



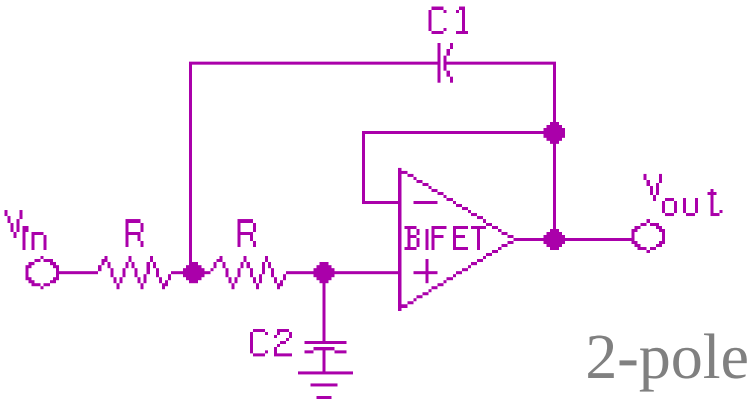




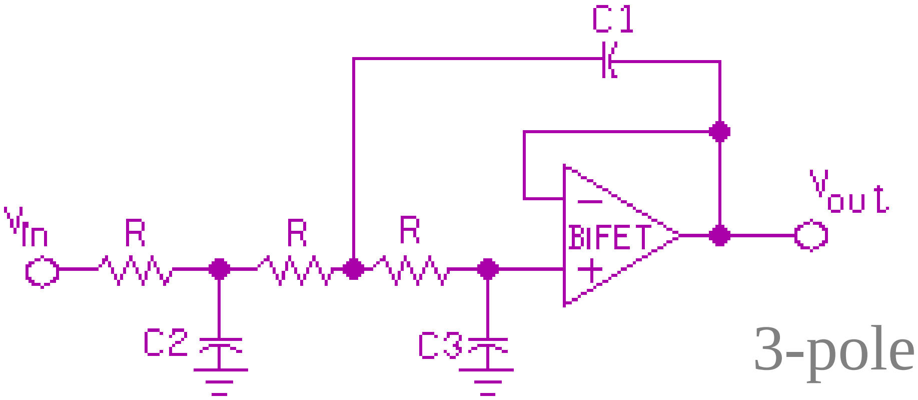




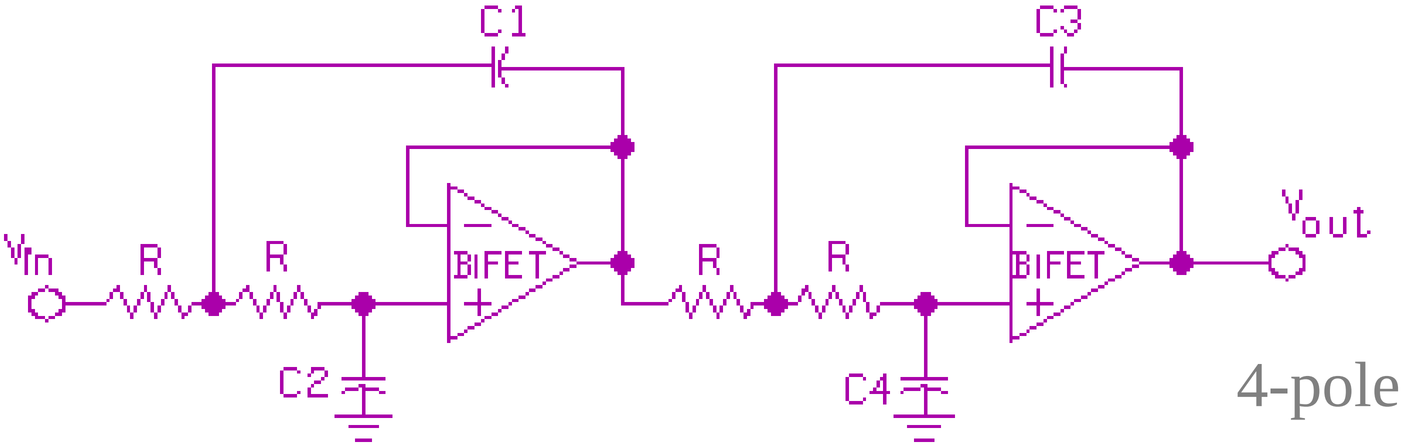
Unity-Gain Low-Pass Filter Circuits



2-pole



3-pole



4-pole

Design Procedure for Unity-Gain LPF

- Determine/select number of poles required.
- Calculate the frequency scaling constant, $K_f = 2\pi f$
- Divide normalized C values (from table) by K_f to obtain frequency-scaled C values.
- Select a desired value for one of the frequency-scaled C values and calculate the impedance scaling factor:

$$K_x = \frac{frequency - scaled\ C\ value}{desired\ C\ value}$$

  - Divide all frequency-scaled C values by K_x
  - Set $R = K_x\ \Omega$

An Example

Design a unity-gain LP Butterworth filter with a critical frequency of 5 kHz and an attenuation of at least 38 dB at 15 kHz.

The attenuation at 15 kHz is 38 dB

⑧ the attenuation at 1 decade (50 kHz) = 79.64 dB.

We require a filter with a roll-off of at least 4 poles.

K_f = 31,416 rad/s. Let’s pick C_1 = 0.01 μF (or 10 nF). Then

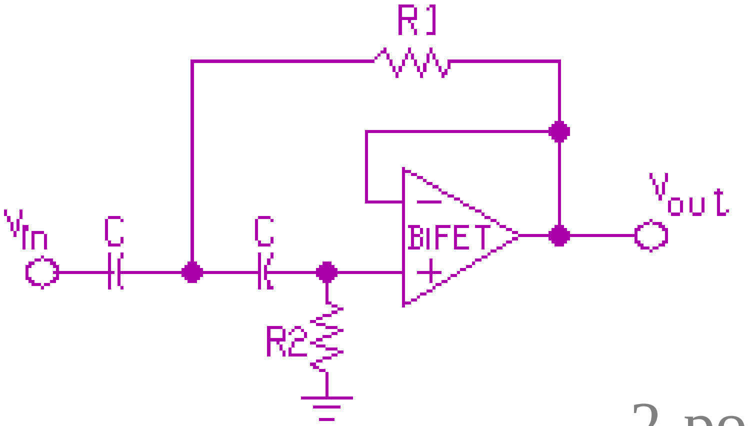
C_2 = 8.54 nF, C_3 = 24.15 nF, and C_4 = 3.53 nF.

Pick standard values of 8.2 nF, 22 nF, and 3.3 nF.

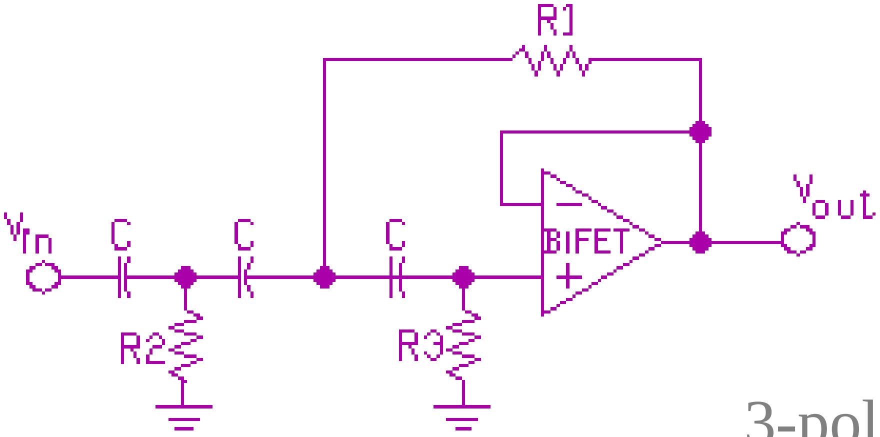
K_x = 3,444

Make all R = 3.6 kΩ (standard value)

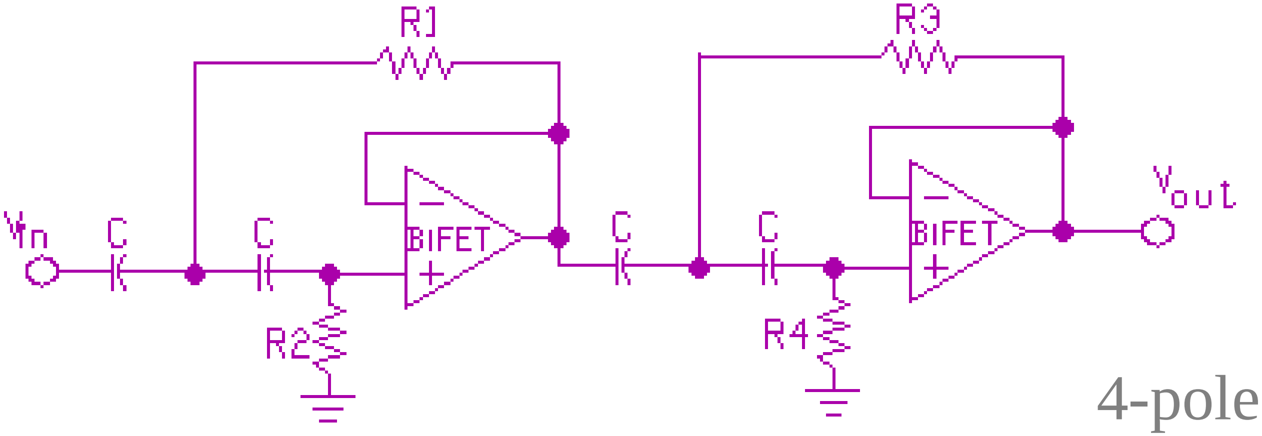
Unity-Gain High-Pass Filter Circuits



2-pole



3-pole



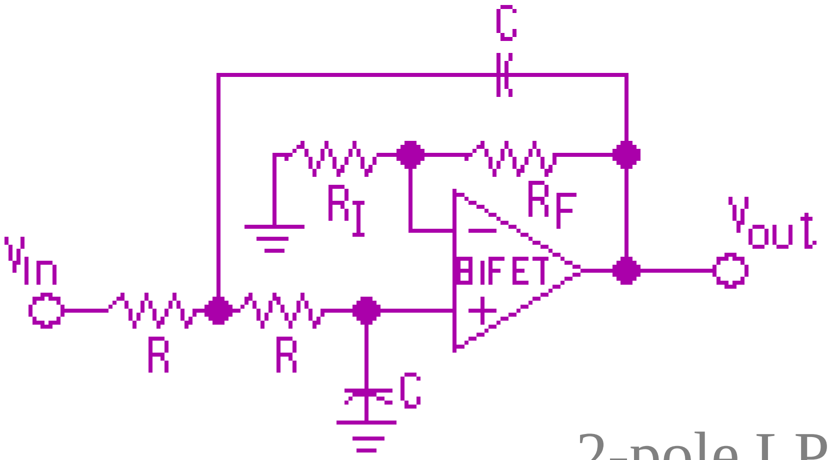
4-pole

Design Procedure for Unity-Gain HPF

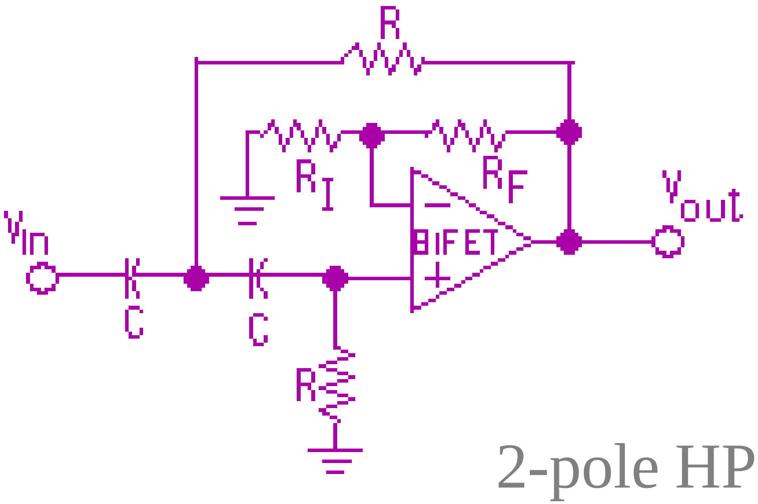
- The same procedure as for LP filters is used except for step #3, the normalized C value of 1 F is divided by K_f. Then pick a desired value for C, such as 0.001 μF to 0.1 μF, to calculate K_x. (Note that all capacitors have the same value).
- For step #6, multiply all normalized R values (from table) by K_x.

E.g. Design a unity-gain Butterworth HPF with a critical frequency of 1 kHz, and a roll-off of 55 dB/dec. (Ans.: C = 0.01 μF, R_1 = 4.49 kΩ, R_2 = 11.43 kΩ, R_3 = 78.64 kΩ.; pick standard values of 4.3 kΩ, 11 kΩ, and 75 kΩ).

Equal-Component Filter Design



2-pole LPF



2-pole HPF

Same value R & same value C are used in filter.

Select C (e.g. 0.01 μF), then:

A_v for # of poles is given in a table and is the same for LP and HP filter design.

$$A_v = \frac{R_F}{R_I} + 1$$

Example

Design an equal-component LPF with a critical frequency of 3 kHz and a roll-off of 20 dB/oct.

Minimum # of poles = 4

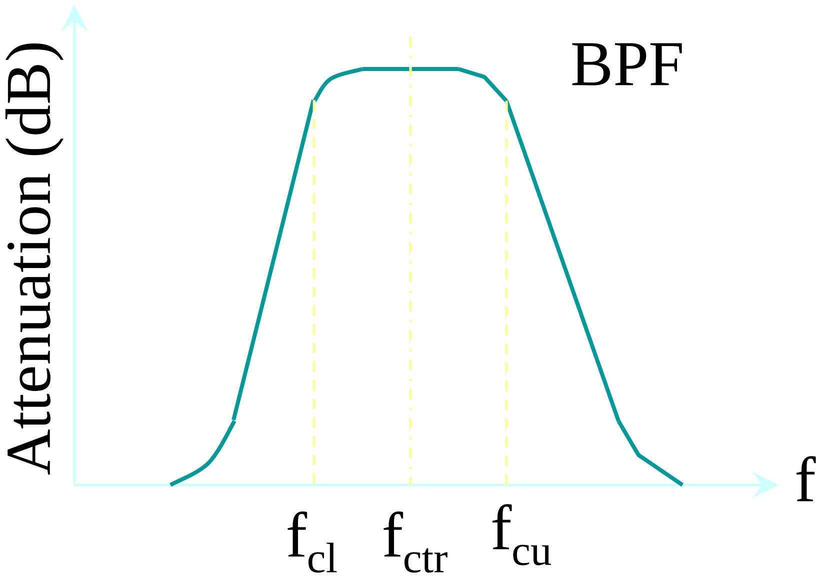
Choose C = 0.01 μF; ⑧ R = 5.3 kΩ

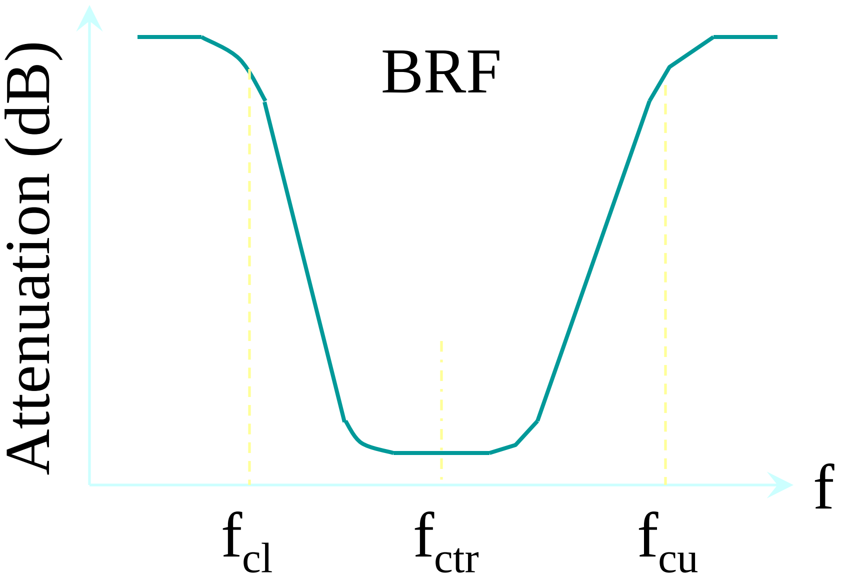
From table, A_{v1} = 1.1523, and A_{v2} = 2.2346.

Choose R_{I1} = R_{I2} = 10 kΩ; then R_{F1} = 1.5 kΩ, and R_{F2} = 12.3 kΩ .

Select standard values: 5.1 kΩ, 1.5 kΩ, and 12 kΩ.

Bandpass and Band-Rejection Filter





The quality factor, Q, of a filter is given by:

$$Q = \frac{f_{ctr}}{BW}$$

where BW = f_{cu} - f_{cl} and

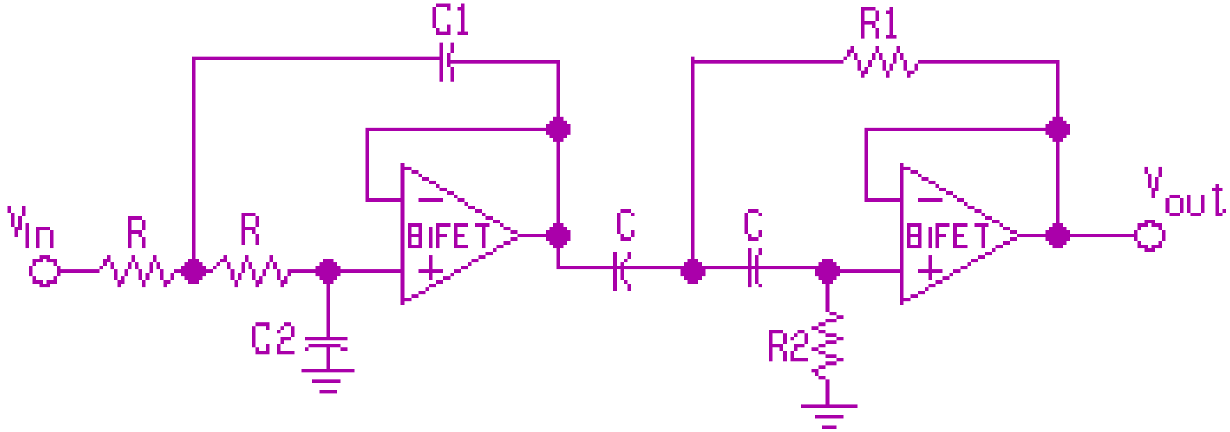
$$f_{ctr} = \sqrt{f_{cu} f_{cl}}$$

More On Bandpass Filter

If BW and f_{centre} are given, then:

$$f_{cl} = \sqrt{\frac{BW^2}{4} + f_{ctr}^2} - \frac{BW}{2}\ ;\ f_{cu} = \sqrt{\frac{BW^2}{4} + f_{ctr}^2} + \frac{BW}{2}$$

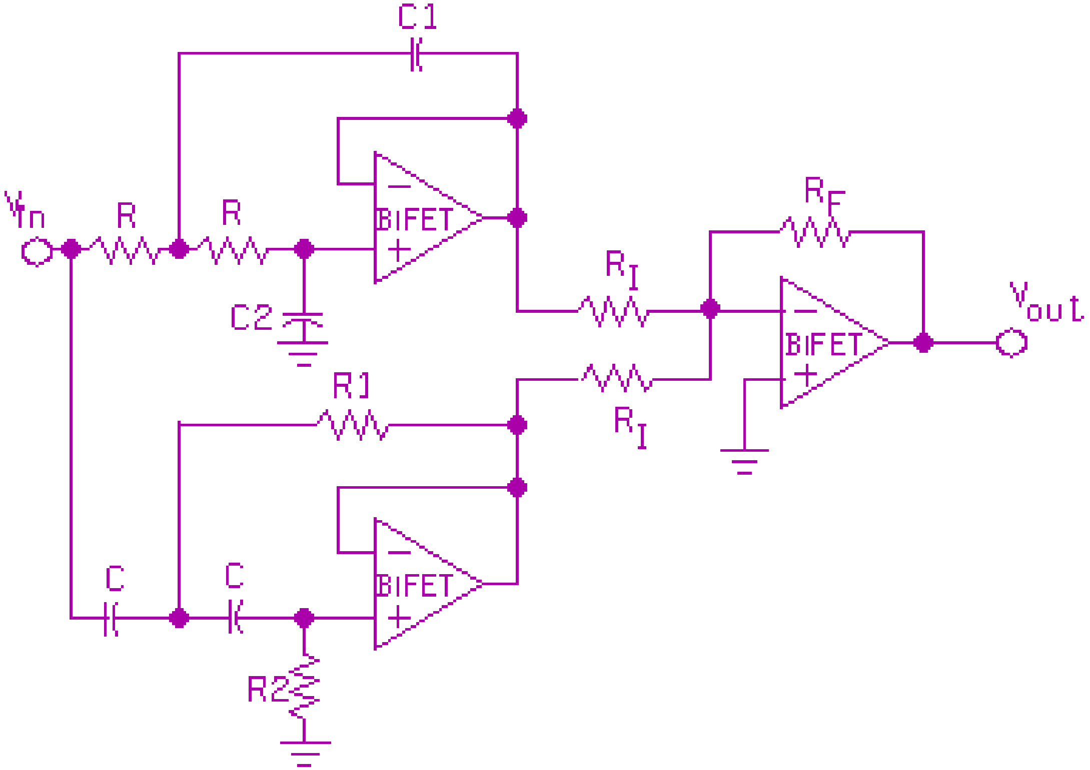
A *broadband* BPF can be obtained by combining a LPF and a HPF:



The Q of this filter is usually > 1.

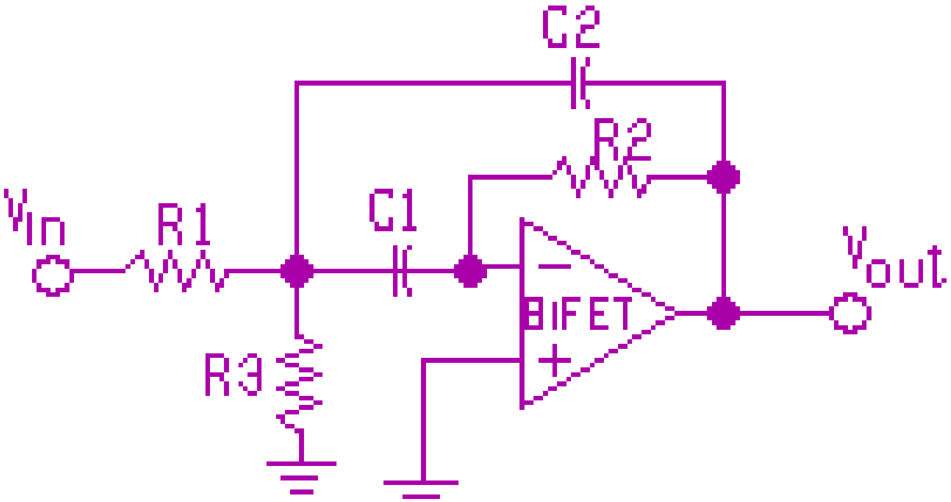
Broadband Band-Reject Filter

A LPF and a HPF can also be combined to give a broadband BRF:



2-pole band-reject filter

Narrow-band Bandpass Filter



$$BW = \frac{f_{ctr}}{Q} = \frac{1}{2\pi R_1 C}$$

C1 = C2 = C

$R_2 = 2\,R_1$

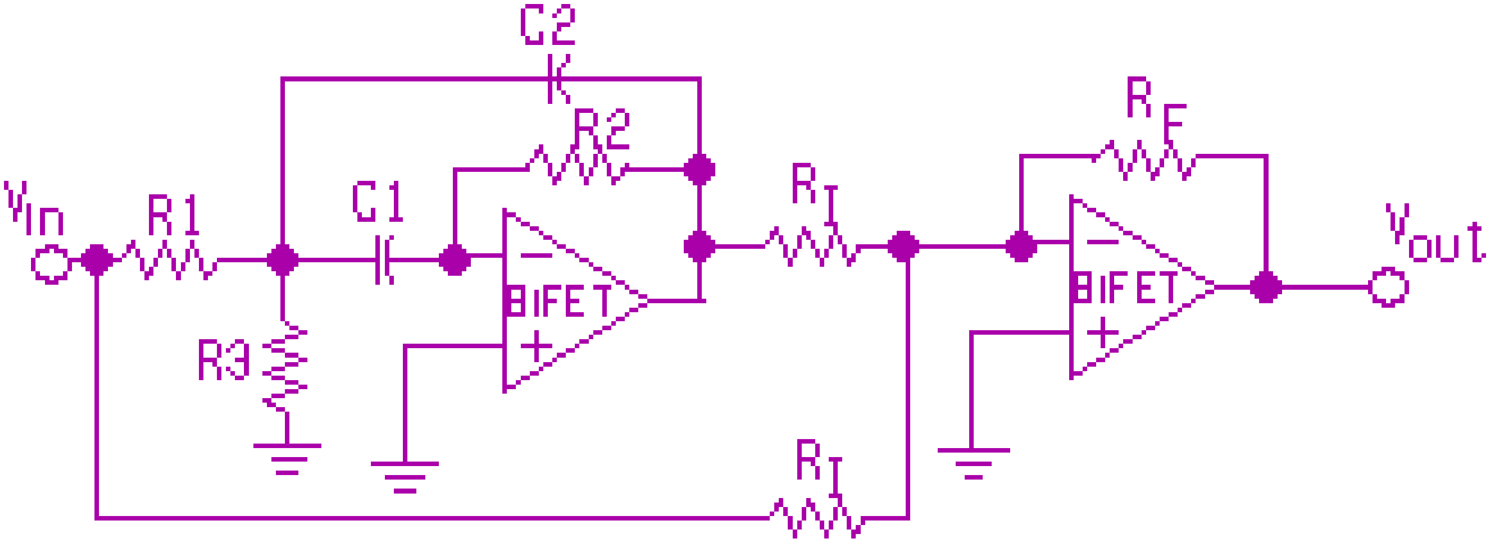
$$R_3 = \frac{R_1}{2Q^2 - 1}$$

$$f_{ctr} = \frac{1}{2\sqrt{2}\pi R_1 C}\sqrt{1 + \frac{R_1}{R_3}}$$

R_3 can be adjusted or trimmed to change f_{ctr} without affecting the BW. Note that Q < 1.

Narrow-band Band-Reject Filter

Easily obtained by combining the inverting output of a narrow-band BRF and the original signal:



The equations for R1, R2, R3, C1, and C2 are the same as before. $R_I = R_F$ for unity gain and is often chosen to be >> R1.

ALL PASS FILTER

OSCILLATORS

PRINCIPLE OF OPERTION OF OSCILLATORS

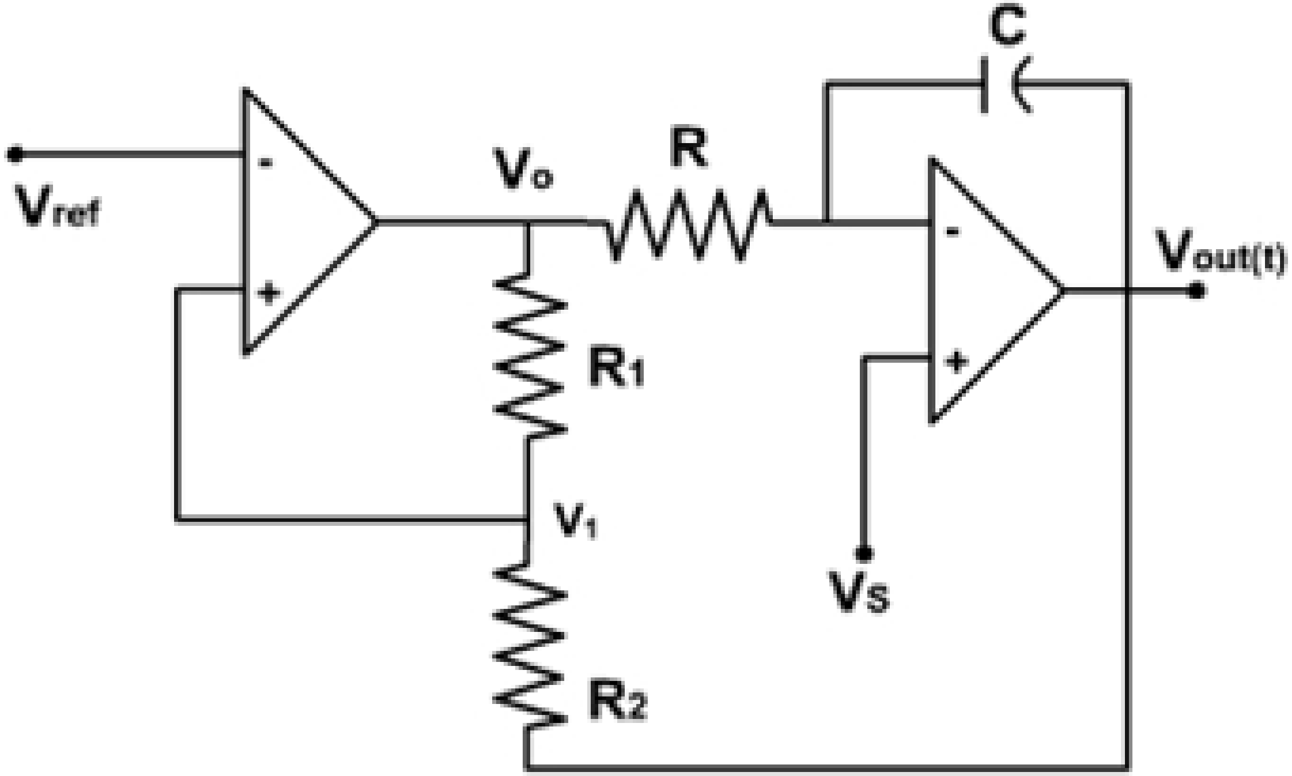
TYPES OF OSCILLATORS

RC PHASE SHIFT OSCILLATOR

WEIN BRIDGE OSCILLATOR

WAVEFORM GENERATORS

TRIANGULAR WAVE GENERATOR



SAWTOOTH WAVE GENERATOR

SQUARE WAVE GENERATOR

UNIT-IV

TIMERS & PHASE LOCKED LOOP

555 IC

The 555 timer is an integrated circuit specifically designed to perform signal generation and timing functions.

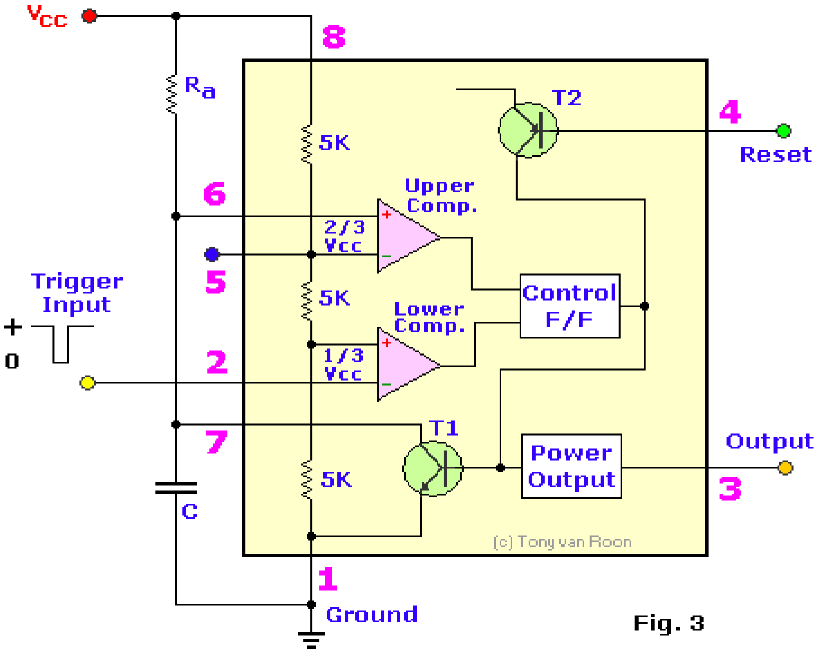


Fig. 3

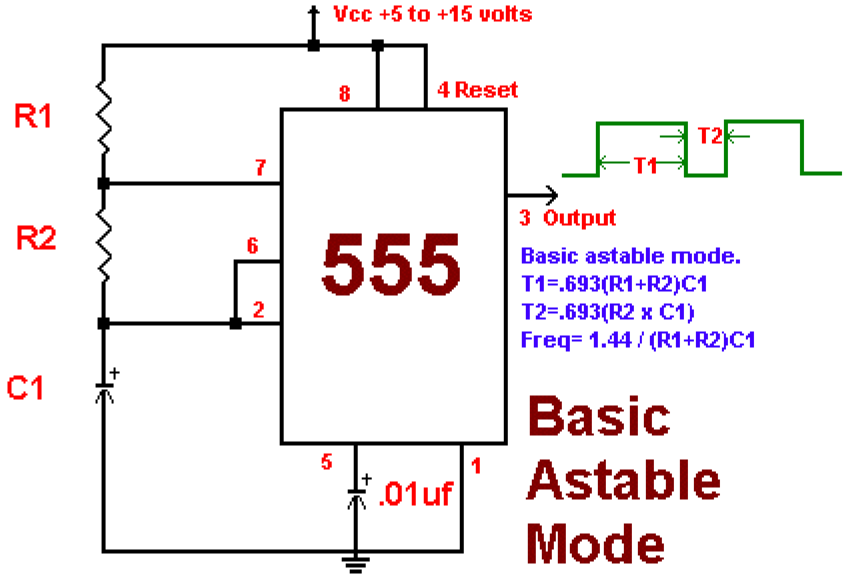
Features of 555 Timer Basic blocks

1. It has two basic operating modes: monostable and astable
2. It is available in three packages. 8 pin metal can , 8 pin dip, 14 pin dip.
3. It has very high temperature stability

Applications of 555 Timer

1. astable multivibrator
2. monostable multivibrator
3. Missing pulse detector
4. Linear ramp generator
5. Frequency divider
6. Pulse width modulation
7. FSK generator
8. Pulse position modulator
9. Schmitt trigger

Astable multivibrator



Basic astable mode.
T1=.693(R1+R2)C1
T2=.693(R2 x C1)
Freq= 1.44 / (R1+R2)C1

Basic Astable Mode

Astable multivibrator

- When the voltage on the capacitor reaches (2/3)Vcc, a switch is closed at pin 7 and the capacitor is discharged to (1/3)Vcc, at which time the switch is opened and the cycle starts over

Monostable multivibrator

-

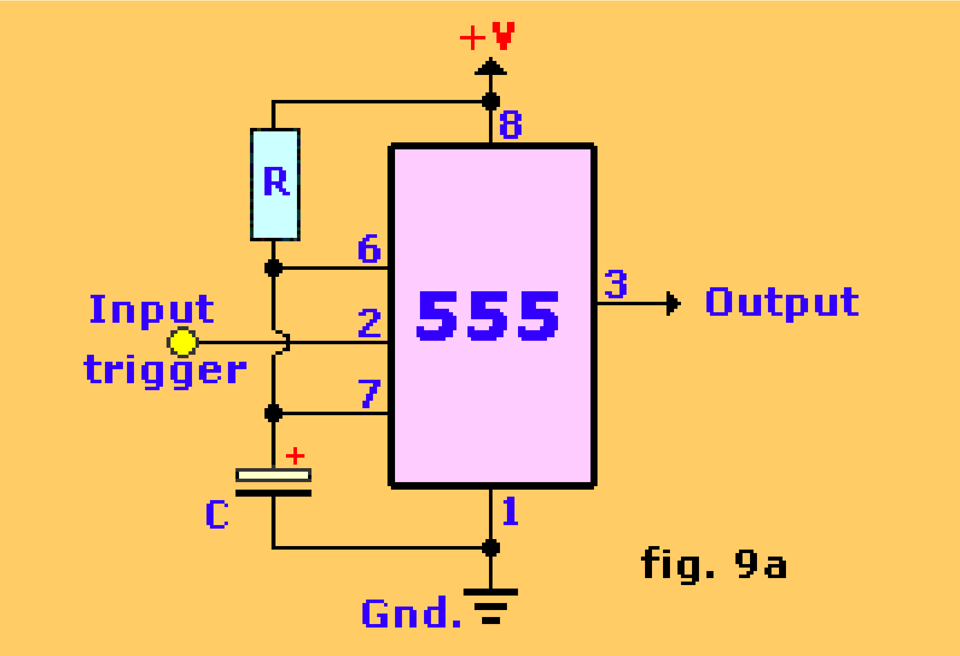


fig. 9a

Voltage controlled oscillator

A voltage controlled oscillator is an oscillator circuit in which the frequency of oscillations can be controlled by an externally applied voltage

The features of 566 VCO

1. Wide supply voltage range(10- 24V)
2. Very linear modulation characteristics
3. High temperature stability

Phase Lock Looped

A PLL is a basically a closed loop system designed to lock output frequency and phase to the frequency and phase of an input signal

Applications of 565 PLL

1. Frequency multiplier
2. Frequency synthesizer
3. FM detector

PART-B
DATA CONVERTERS
INTEGRATED CIRCUITS

UNIT-V
D-A & A-D CONVERTERS

Classification of ADCs

1. Direct type ADC.
2. Integrating type ADC

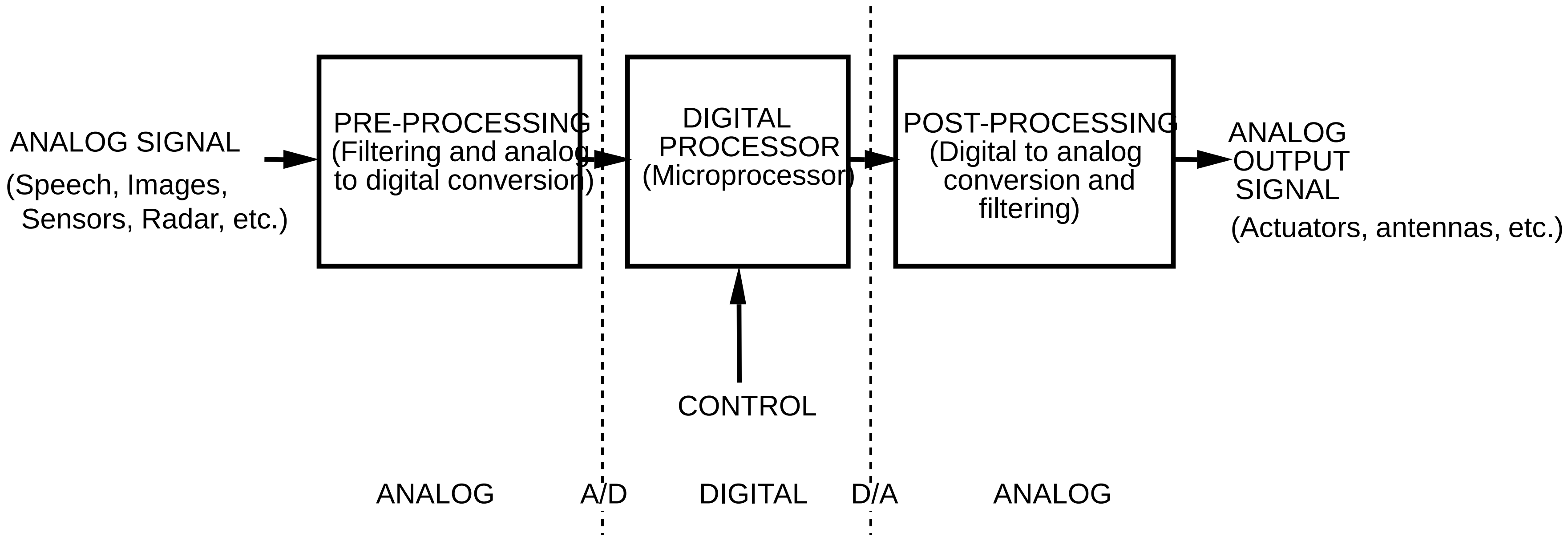
Direct type ADCs

1. Flash (comparator) type converter
2. Counter type converter
3. Tracking or servo converter.
4. Successive approximation type converter

Integrating type converters

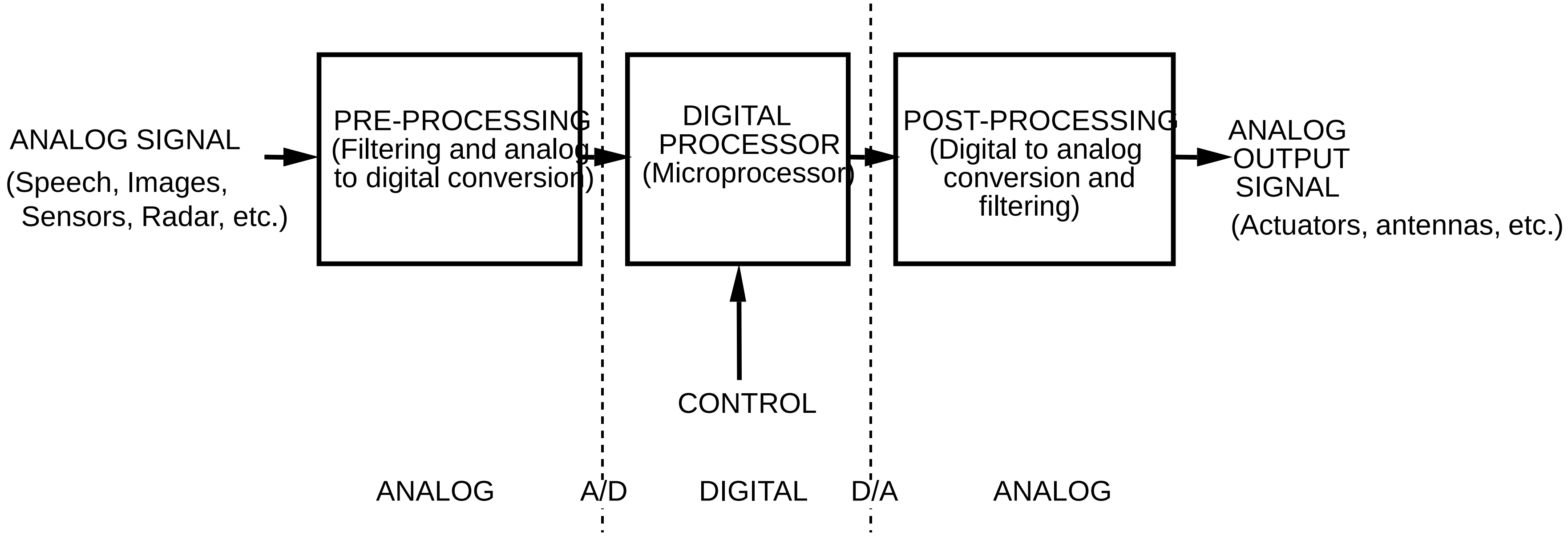
An ADC converter that perform conversion in an indirect manner by first changing the analog I/P signal to a linear function of time or frequency and then to a digital code is known as integrating type A/D converter

The need for Data Converters



In many applications, performance is critically limited by the A/D and D/A performance

The need for Data Converters



ANALOG SIGNAL

(Speech, Images, Sensors, Radar, etc.)

PRE-PROCESSING (Filtering and analog to digital conversion)

DIGITAL PROCESSOR (Microprocessor)

POST-PROCESSING (Digital to analog conversion and filtering)

ANALOG OUTPUT SIGNAL

(Actuators, antennas, etc.)

CONTROL

ANALOG A/D DIGITAL D/A ANALOG

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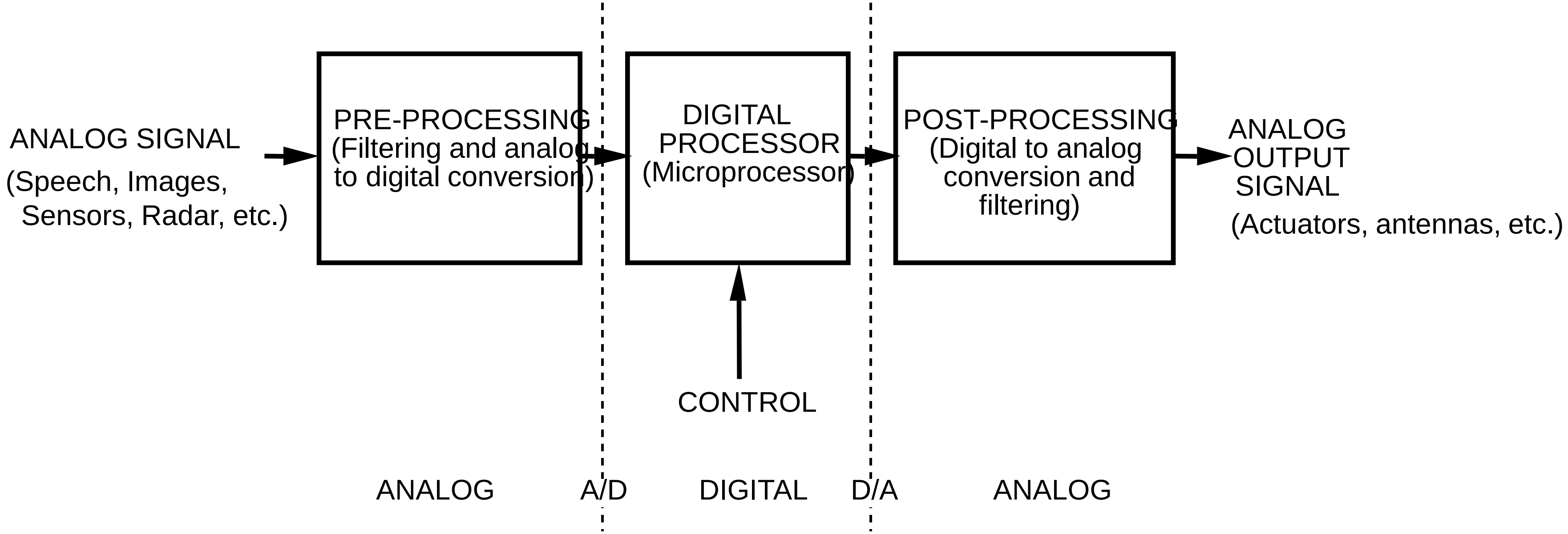

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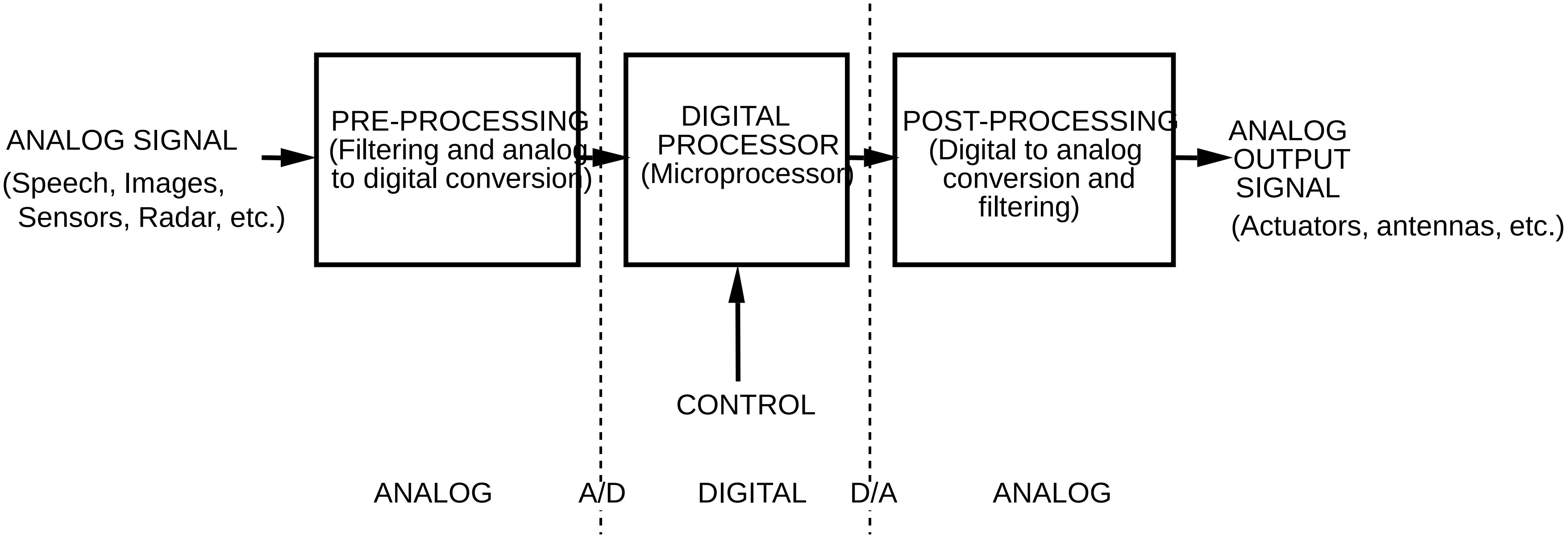

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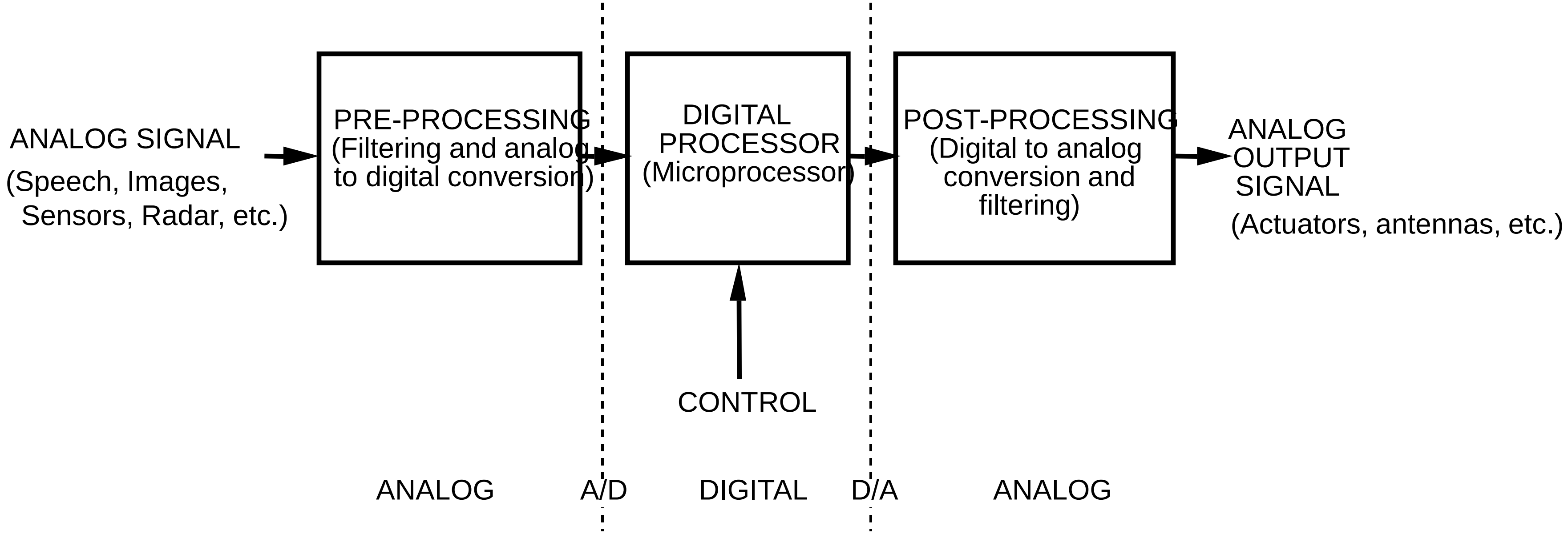

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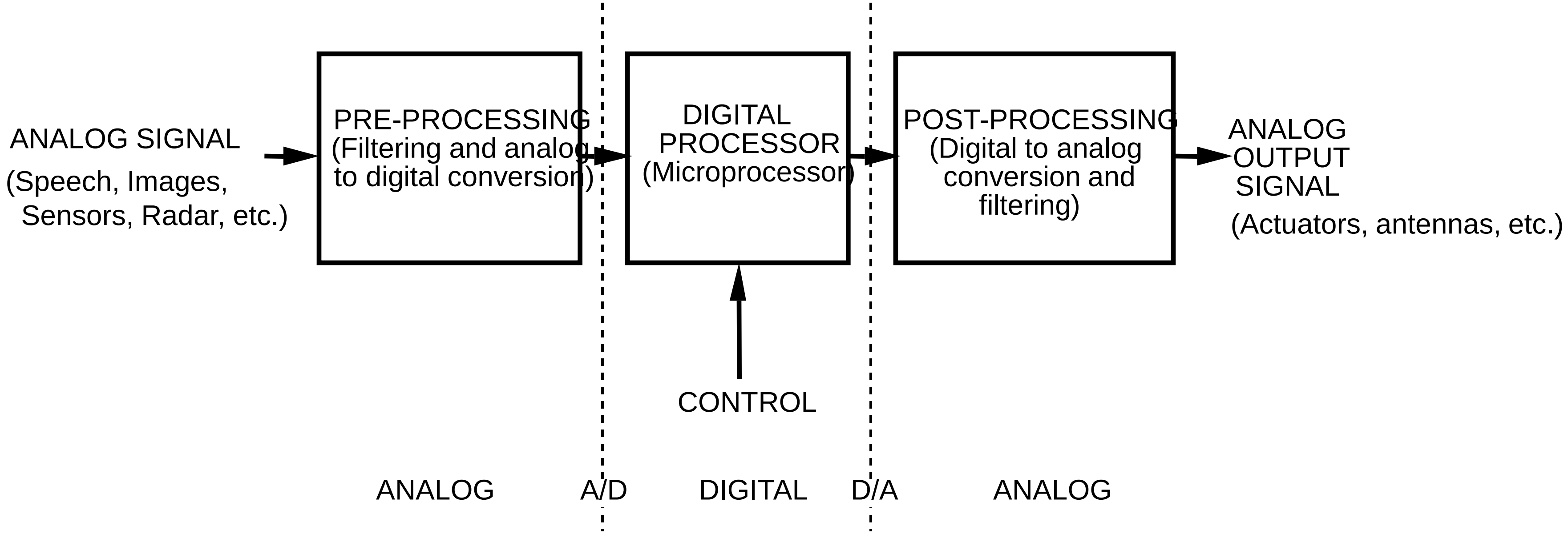

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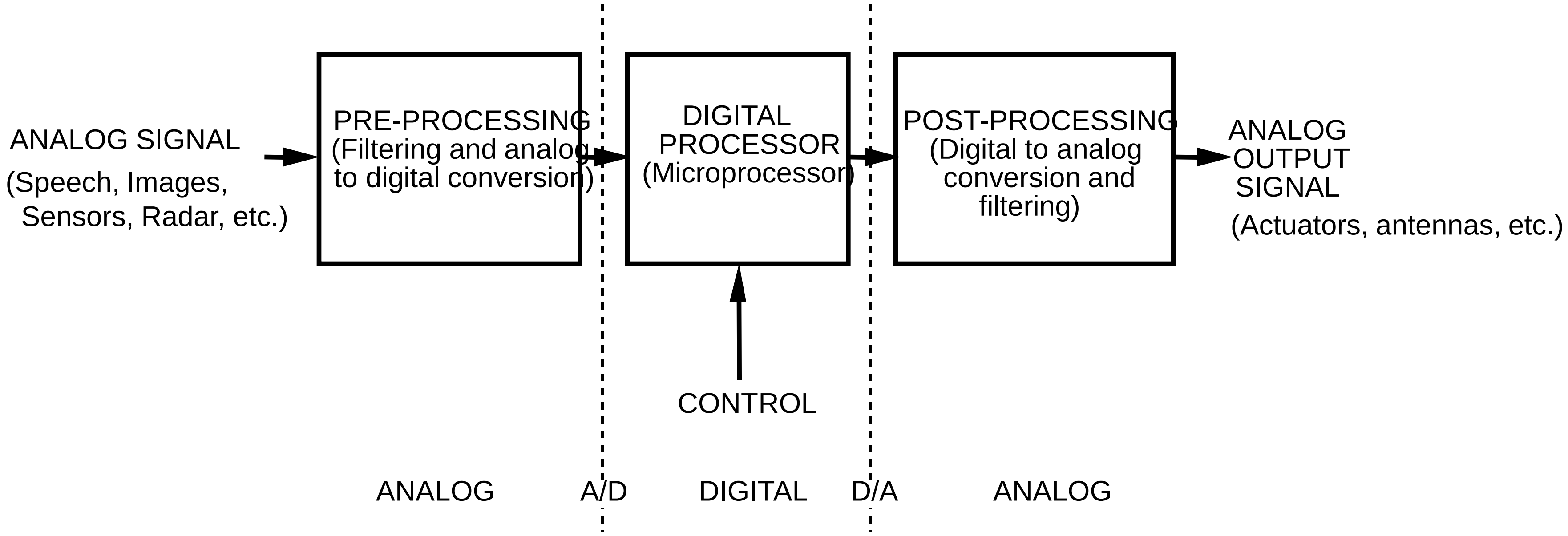

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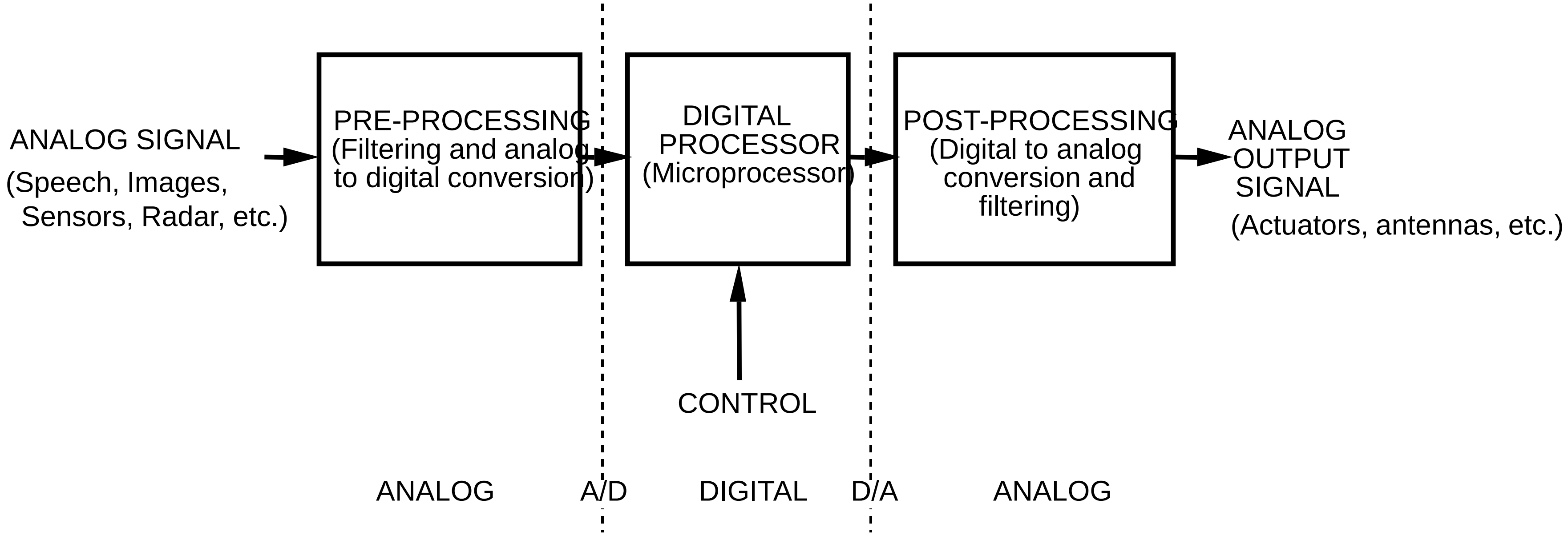

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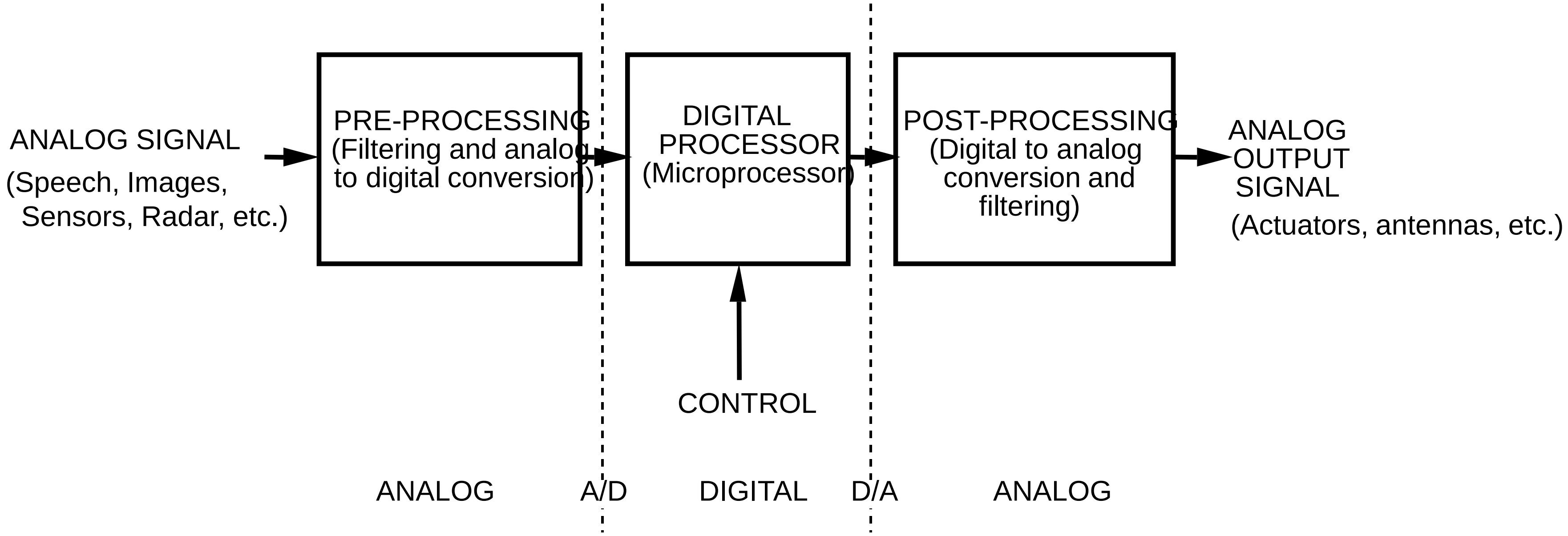

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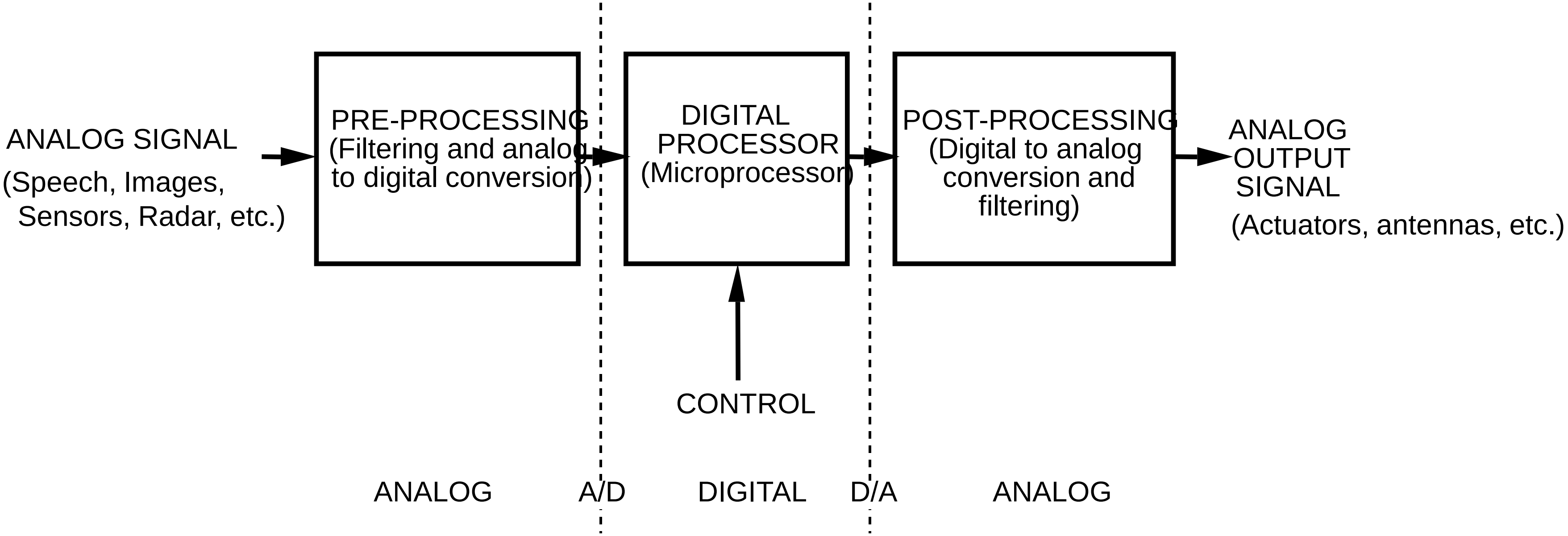

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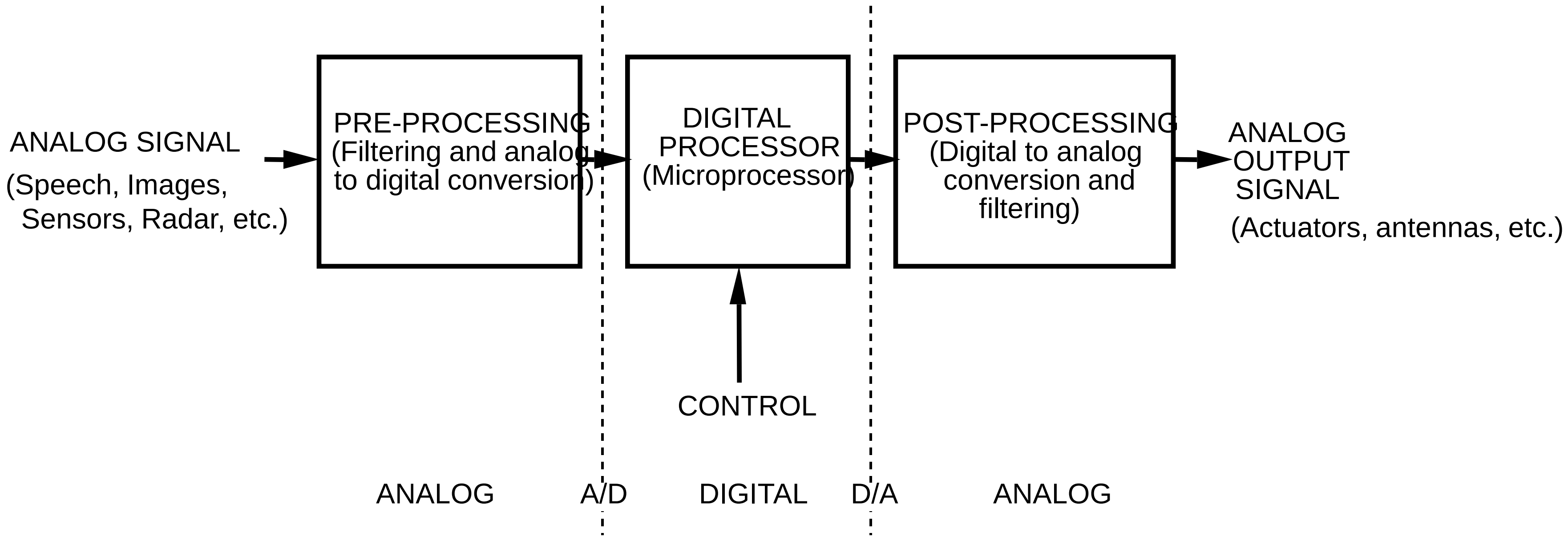

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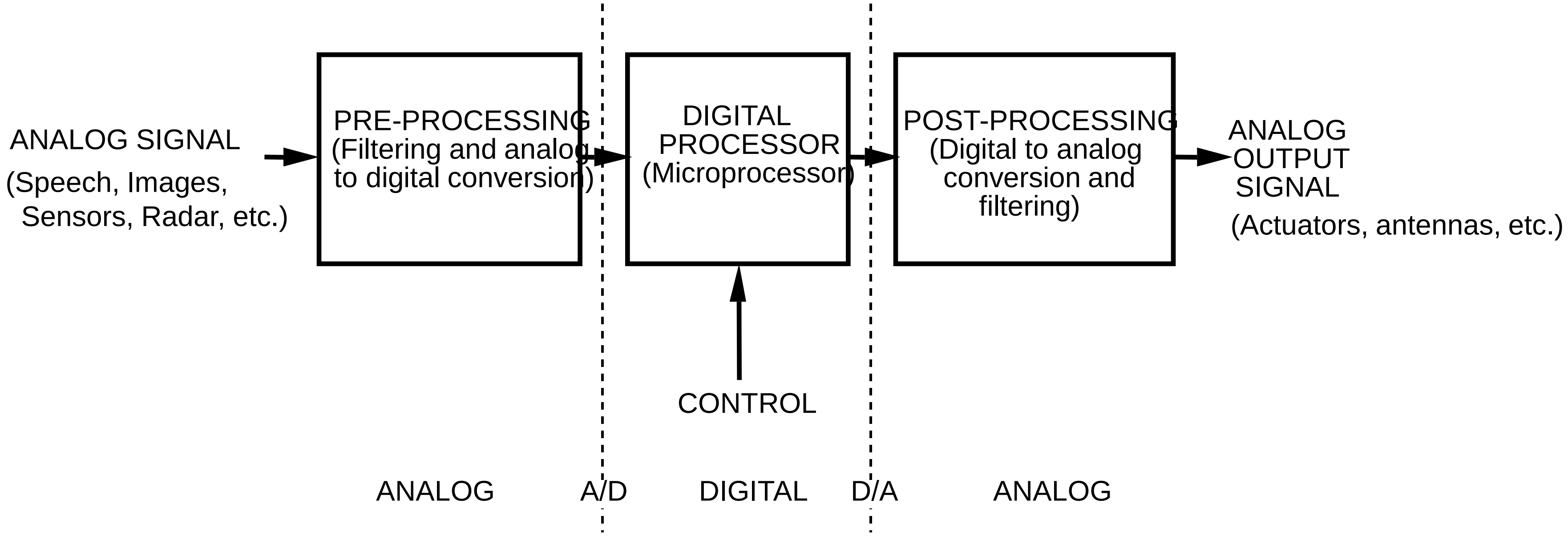

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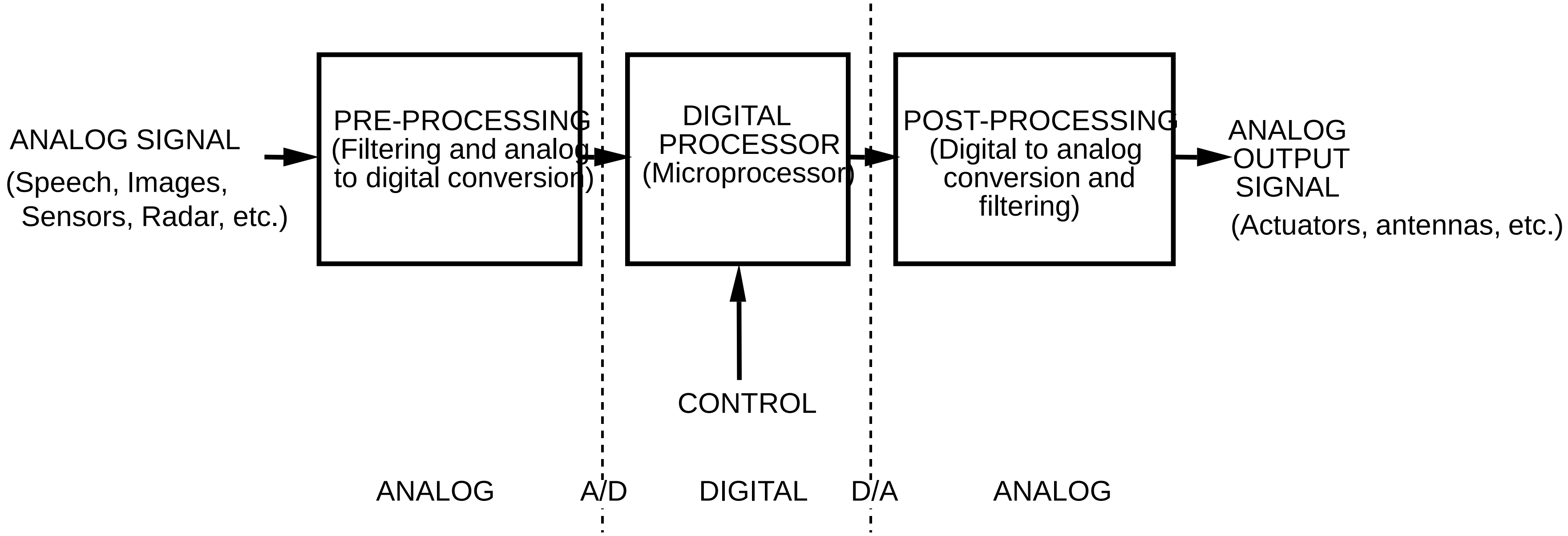

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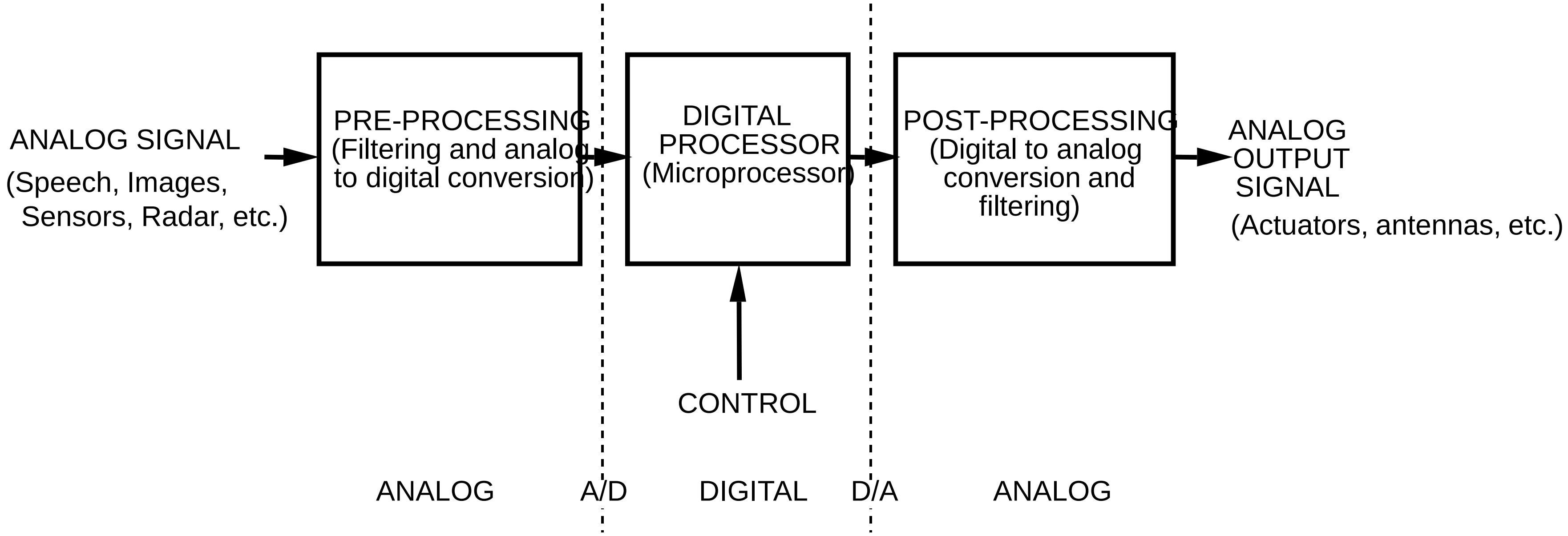

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