Republic of Iraq

Ministry of Higher Education and Seintific Reserch University of AL-Anbar

College of Engineering

Electrical Engineering Department

Electronic I

By

Hatem Fahd Al-Duliamy

2018-2019

UNIVERSITY OF ANBAR

COLLEGE OF ENGINEERING

ELECTRICAL ENGINEERING DEPARTMENT

Electronic I

Third Class

Chapter 12

Chapter 12_Power Amplifiers

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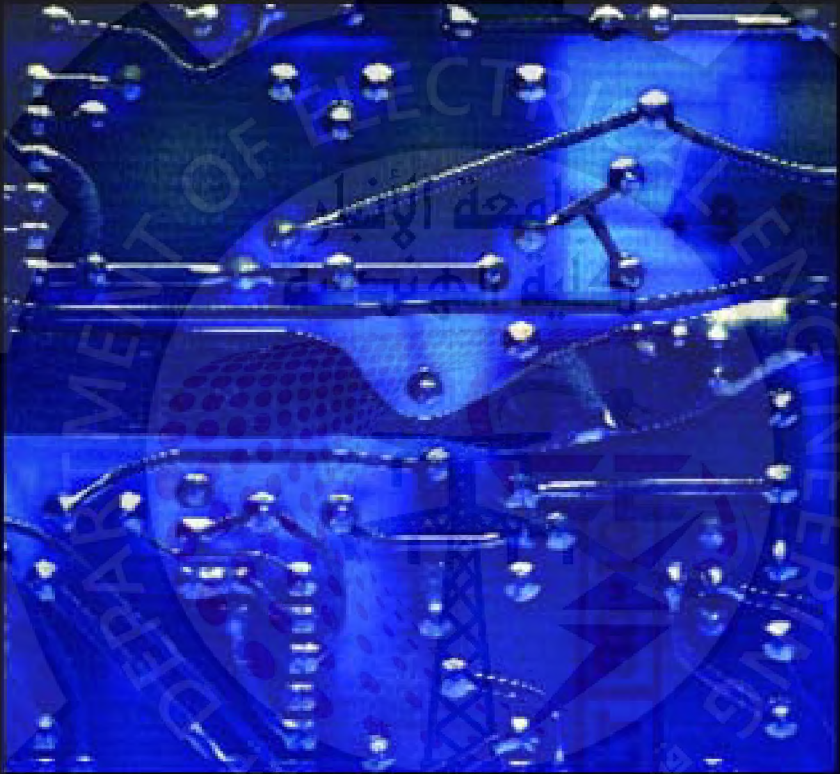
ELECTRONIC DEVICES AND CIRCUIT THEORY

TENTH EDITION



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Chapter 12
Power Amplifiers

Definitions

In small-signal amplifiers the main factors are:

- Amplification
- Linearity
- Gain

Since large-signal, or power, amplifiers handle relatively large voltage signals and current levels, the main factors are:

- Efficiency
- Maximum power capability
- Impedance matching to the output device

Amplifier Types

Class A

The amplifier conducts through the full 360° of the input. The Q-point is set near the middle of the load line.

Class B

The amplifier conducts through 180° of the input. The Q-point is set at the cutoff point.

Class AB

This is a compromise between the class A and B amplifiers. The amplifier conducts somewhere between 180° and 360° . The Q-point is located between the mid-point and cutoff.

more…

Amplifier Types

Class C

The amplifier conducts less than 180 of the input. The Q-point is located below the cutoff level.

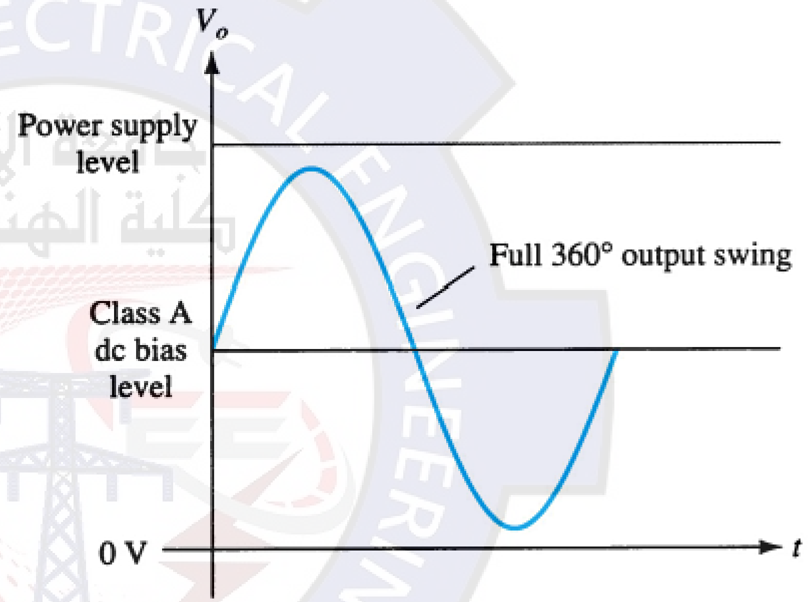
Class D

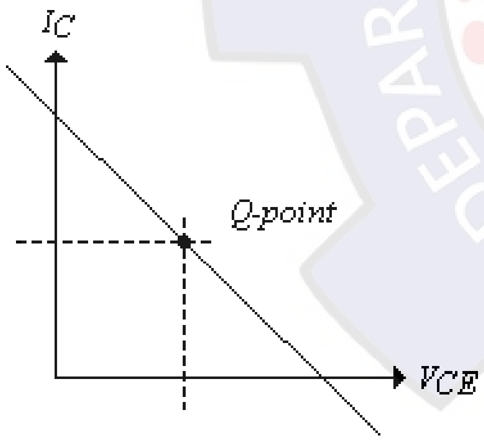
This is an amplifier that is biased especially for digital signals.

Class A Amplifier

The output of a class A amplifier conducts for the full 360° of the cycle.

The Q-point is set at the middle of the load line so that the AC signal can swing a full cycle.

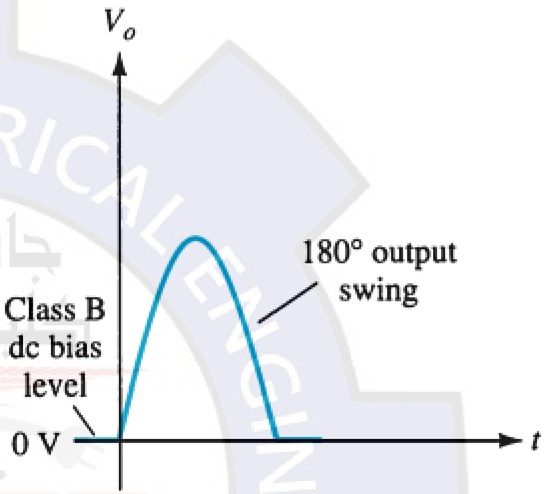


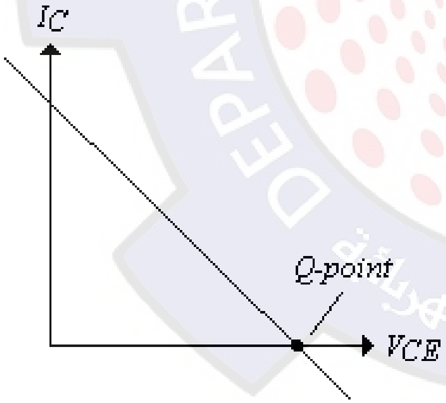


Remember that the DC load line indicates the maximum and minimum limits set by the DC power supply.

Class B Amplifier

A class B amplifier output only conducts for 180° or one-half of the AC input signal.



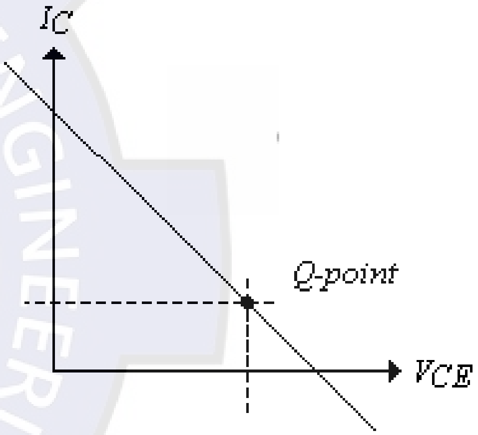


The Q-point is at 0V on the load line, so that the AC signal can only swing for one-half cycle.

Class AB Amplifier

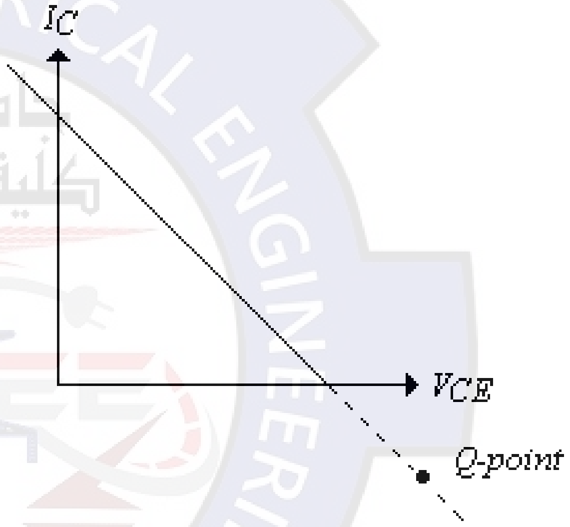
This amplifier is a compromise between the class A and class B amplifier—the Q-point is above that of the Class B but below the class A.

The output conducts between 180° and 360° of the AC input signal.

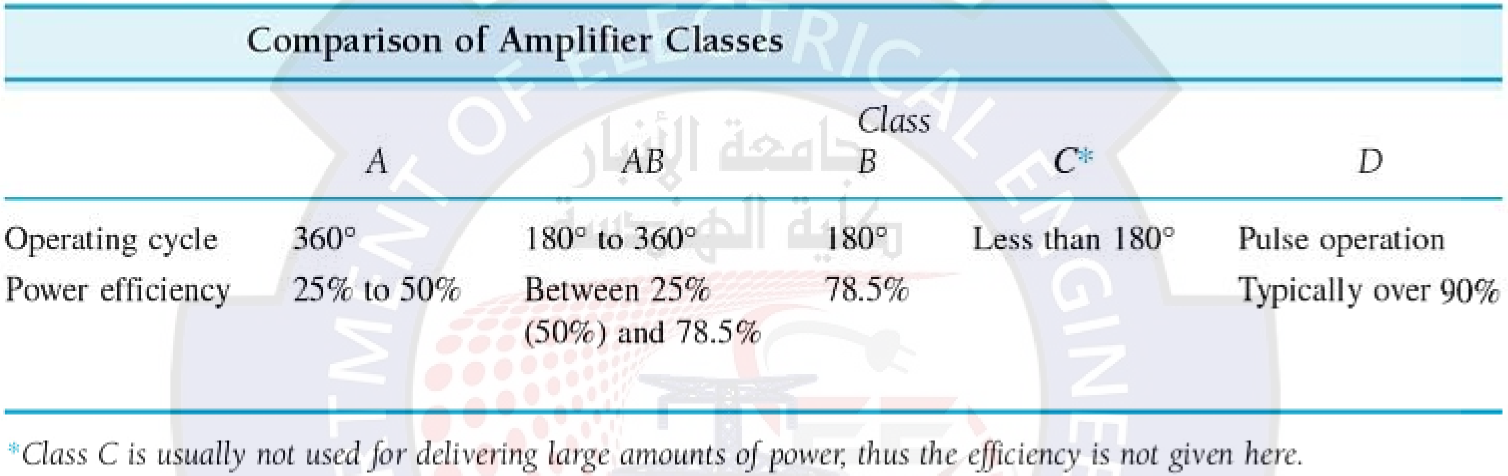


Class C

The output of the class C conducts for less than 180° of the AC cycle. The Q-point is below cutoff.



Amplifier Efficiency



Comparison of Amplifier Classes

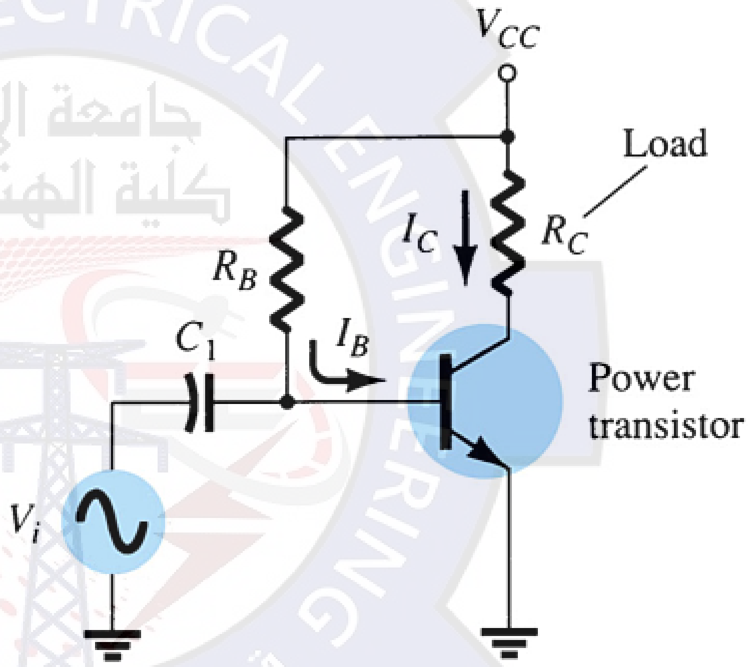
	Class A	 AB	 B	 C*	 D
Operating cycle	360°	180° to 360°	180°	Less than 180°	Pulse operation
Power efficiency	25% to 50%	Between 25% (50%) and 78.5%	78.5%		Typically over 90%

*Class C is usually not used for delivering large amounts of power, thus the efficiency is not given here.

Efficiency refers to the ratio of output to input power. The lower the amount of conduction of the amplifier the higher the efficiency.

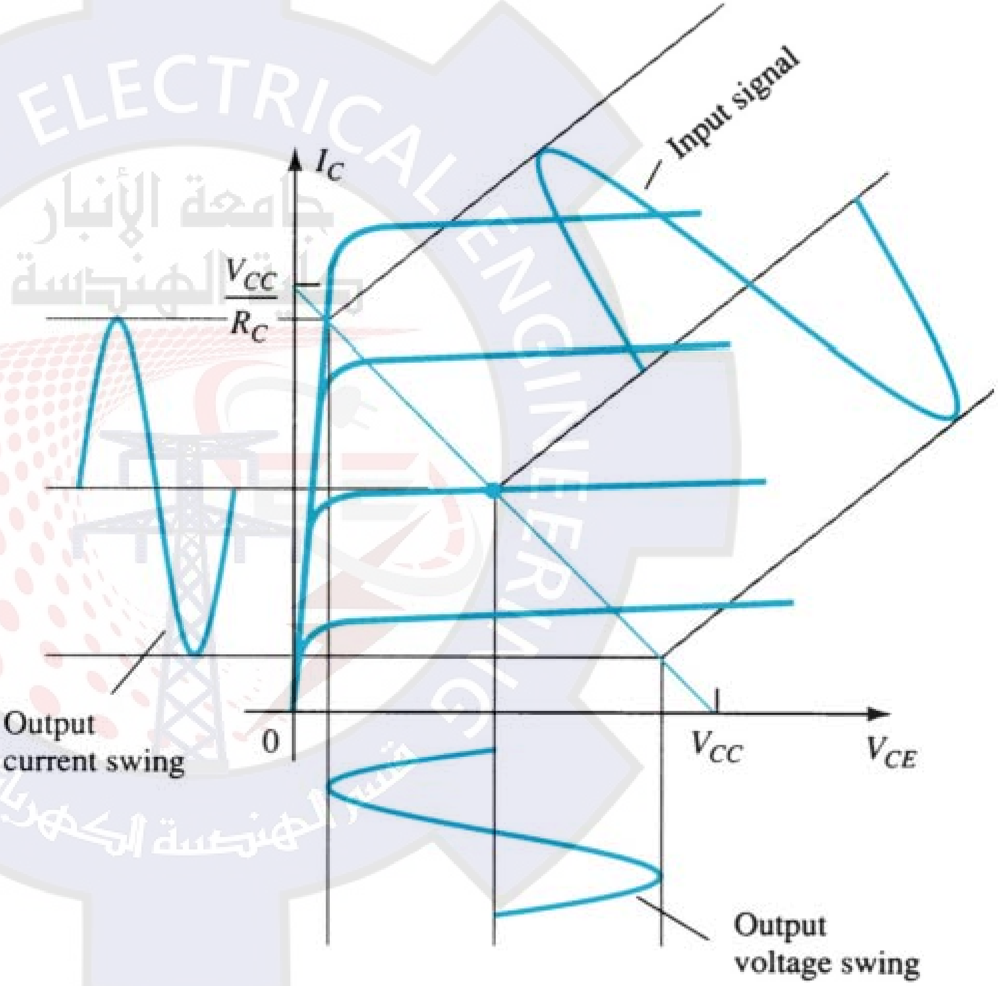
Series-Fed Class A Amplifier

This is similar to the small-signal amplifier except that it will handle higher voltages. The transistor used is a high-power transistor.



Series-Fed Class A Amplifier

A small input signal causes the output voltage to swing to a maximum of V_{cc} and a minimum of 0V. The current can also swing from 0mA to I_{CSAT} (V_{CC}/R_C)



Series-Fed Class A Amplifier

Input Power

The power into the amplifier is from the DC supply. With no input signal, the DC current drawn is the collector bias current, I_{CQ}.

$$P_{i(dc)} = V_{CC} I_{CQ}$$

Output Power

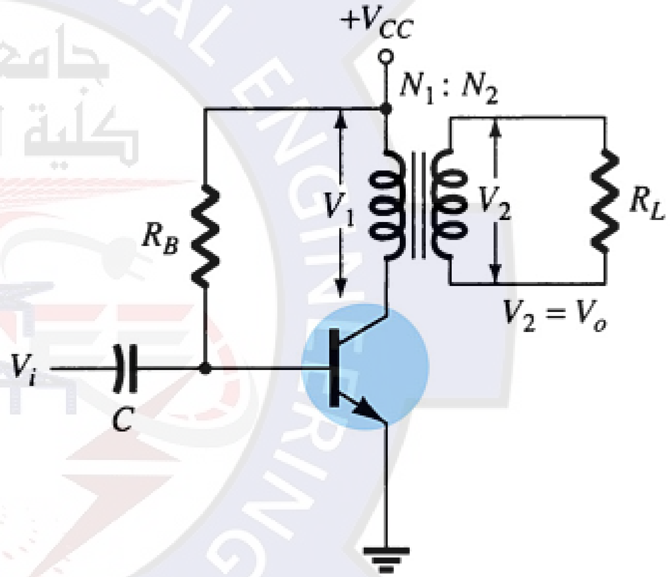
$$P_{o(ac)} = \frac{V^2_{C(rms)}}{R_C} \quad \text{or} \quad P_{o(ac)} = \frac{V^2_{CE(p-p)}}{8R_C}$$

Efficiency

$$\%\eta = \frac{P_{o(ac)}}{P_{i(ac)}} \times 100$$

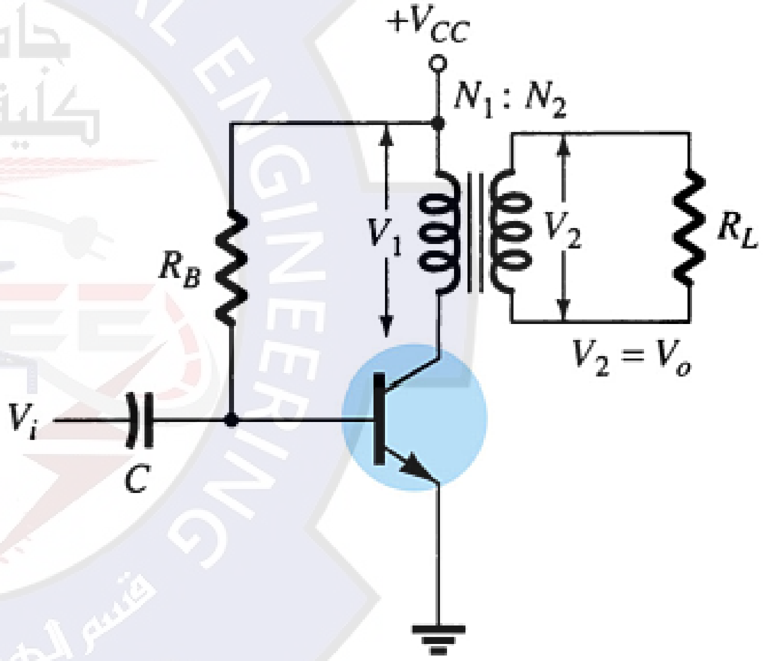
Transformer-Coupled Class A Amplifier

This circuit uses a transformer to couple to the load. This improves the efficiency of the Class A to 50%.



Transformer Action

A transformer improves the efficiency because it is able to transform the voltage, current, and impedance



Voltage Ratio

$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

Current Ratio

$$\frac{I_2}{I_1} = \frac{N_1}{N_2}$$

Impedance Ratio

$$\frac{R'_L}{R_L} = \frac{R_1}{R_2} = \left(\frac{N_1}{N_2}\right)^2 = a^2$$

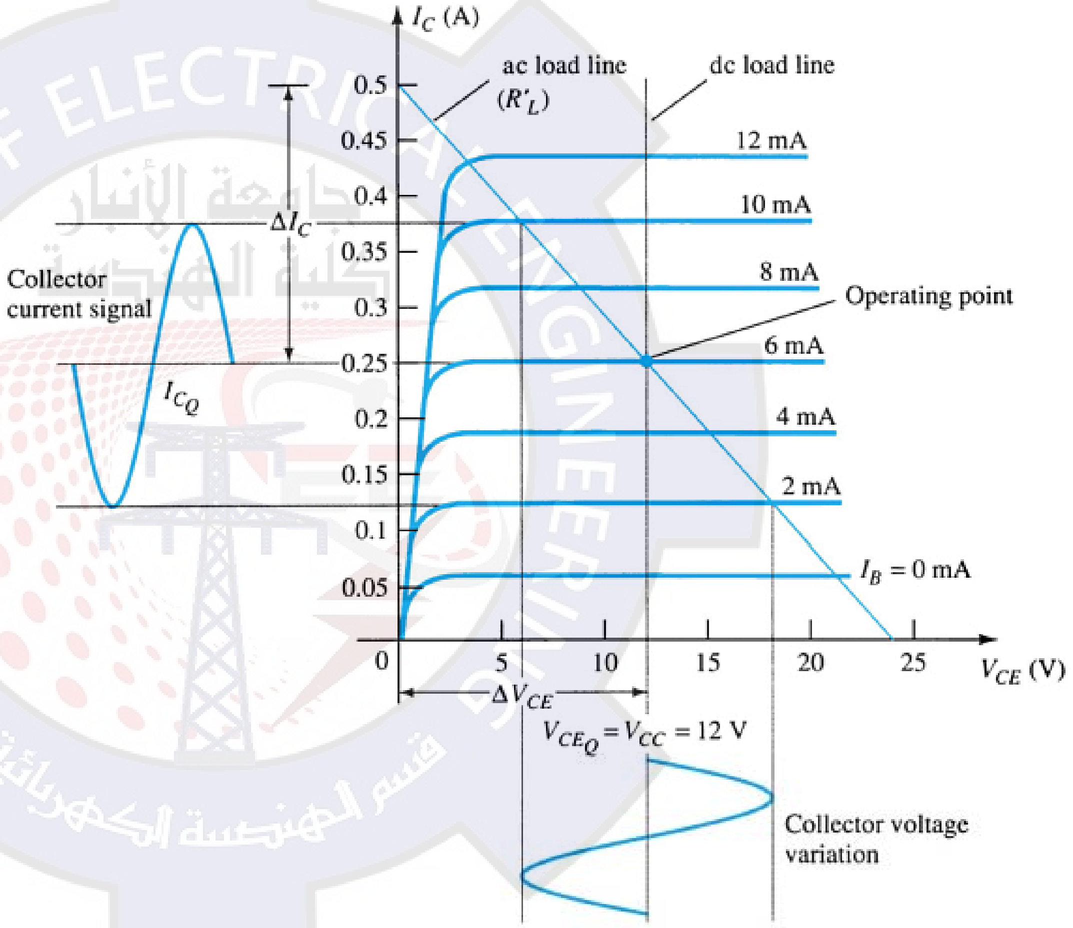
Transformer-Coupled Class A Amplifier

DC Load Line

As in all class A amplifiers the Q-point is established close to the midpoint of the DC load line.

AC Load Line

The saturation point (I_{Cmax}) is at V_{cc}/R'_L and the cutoff point is at V_2 (the secondary voltage of the transformer). This increases the maximum output swing because the minimum and maximum values of I_C and V_{CE} are spread further apart.



Transformer-Coupled Class A Amplifier

Signal Swing and Output AC Power

The voltage swing:

$$V_{CE(p-p)} = V_{CE\,max} - V_{CE\,min}$$

The current swing:

$$I_{C\,max} - I_{C\,min}$$

The AC power:

$$P_{o(ac)} = \frac{(V_{CEmax} - V_{CEmin})(I_{Cmax} - I_{Cmin})}{8}$$

Transformer-Coupled Class A Amplifier Efficiency

Power input from the DC source:

$$P_{i(dc)} = V_{CC} I_{CQ}$$

Power dissipated as heat across the transistor:

$$P_Q = P_{i(dc)} - P_{o(ac)}$$

Note: The larger the input and output signal, the lower the heat dissipation.

Maximum efficiency:

$$\%\eta = 50\left(\frac{V_{CEmax} - V_{CEmin}}{V_{CEmax} + V_{CEmin}}\right)^2$$

Note: The larger V_{CEmax} and smaller V_{CEmin}, the closer the efficiency approaches the theoretical maximum of 50%.

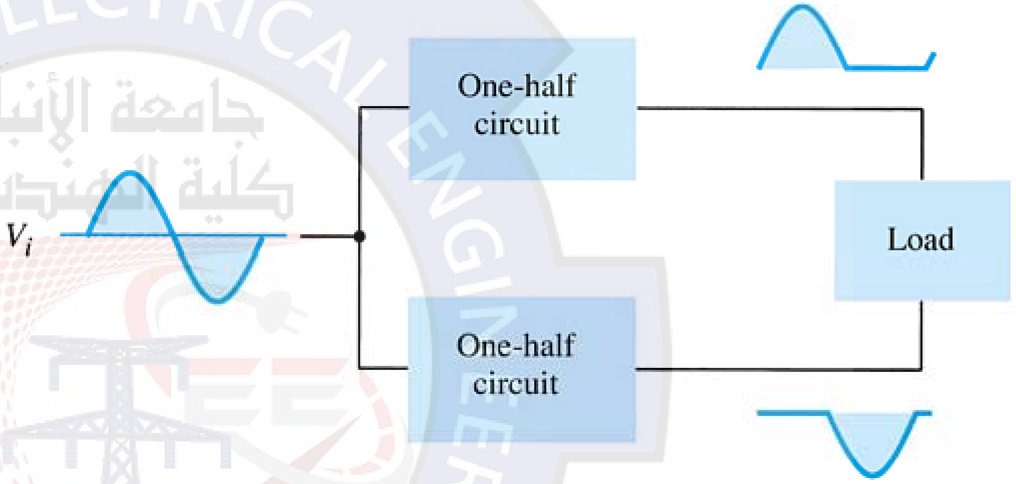
Class B Amplifier

In class B, the transistor is biased just off. The AC signal turns the transistor on.

The transistor only conducts when it is turned on by one-half of the AC cycle.

In order to get a full AC cycle out of a class B amplifier, you need two transistors:

- An *npn* transistor that provides the negative half of the AC cycle
- A *pnp* transistor that provides the positive half.



Class B Amplifier: Efficiency

The maximum efficiency of a class B is 78.5%..

$$\%\eta = \frac{P_{o(ac)}}{P_{i(dc)}} \times 100$$

$$\text{maximum } P_{o(dc)} = \frac{V_{CC}^2}{2R_L}$$

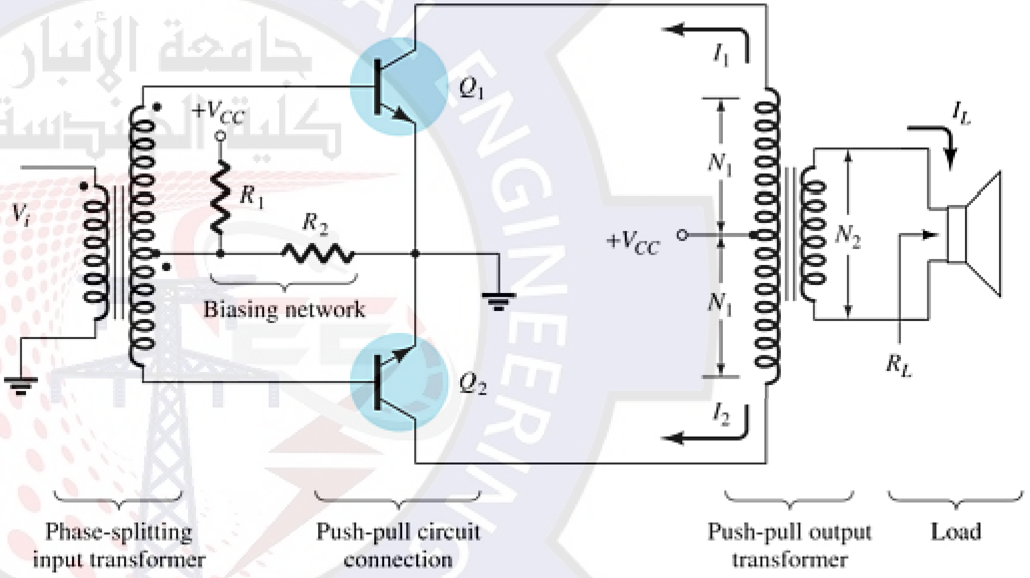
For maximum power, $V_L = V_{CC}$

$$\text{maximum } P_{i(dc)} = V_{CC}(\text{maximum } I_{dc}) = V_{CC}\left(\frac{2V_{CC}}{\pi R_L}\right) = \frac{2V^2{}_{CC}}{\pi R_L}$$

Transformer-Coupled Push-Pull Class B Amplifier

The center-tapped transformer on the input produces opposite polarity signals to the two transistor inputs.

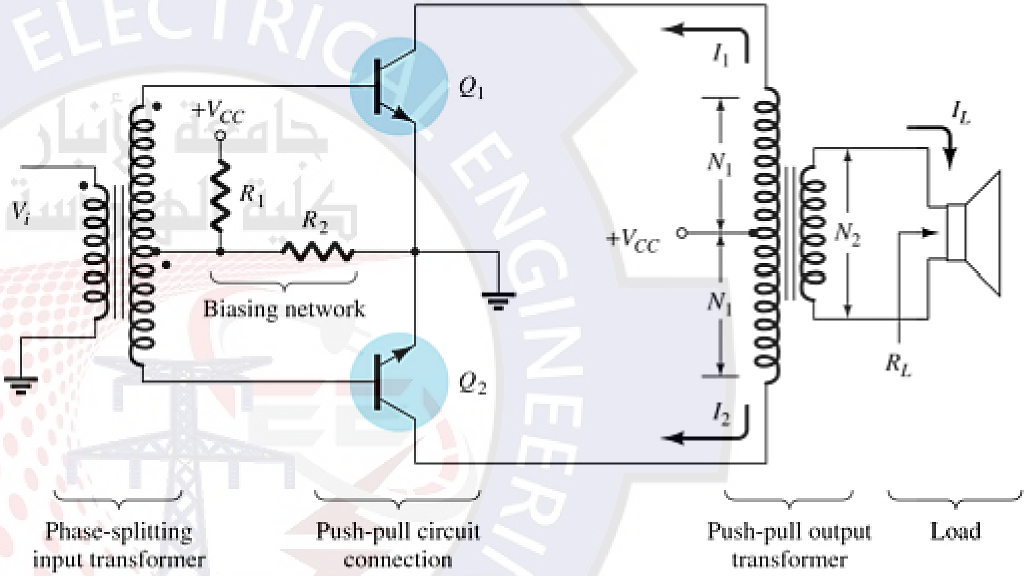
The center-tapped transformer on the output combines the two halves of the AC waveform together.



Class B Amplifier Push-Pull Operation

- During the positive half-cycle of the AC input, transistor Q_1 (*npn*) is conducting and Q_2 (*pnp*) is off.

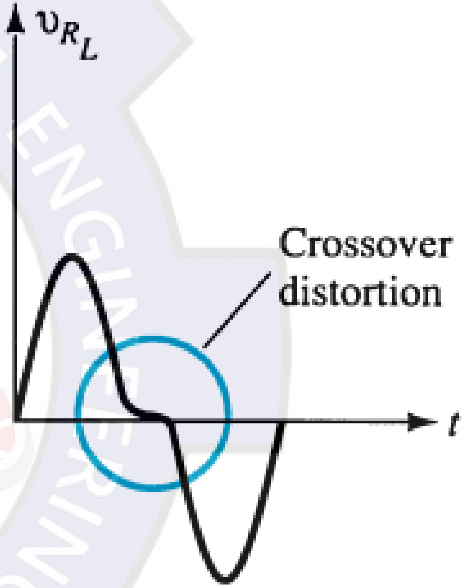
- During the negative half-cycle of the AC input, transistor Q_2 (*pnp*) is conducting and Q_1 (*npn*) is off.



Each transistor produces one-half of an AC cycle. The transformer combines the two outputs to form a full AC cycle.

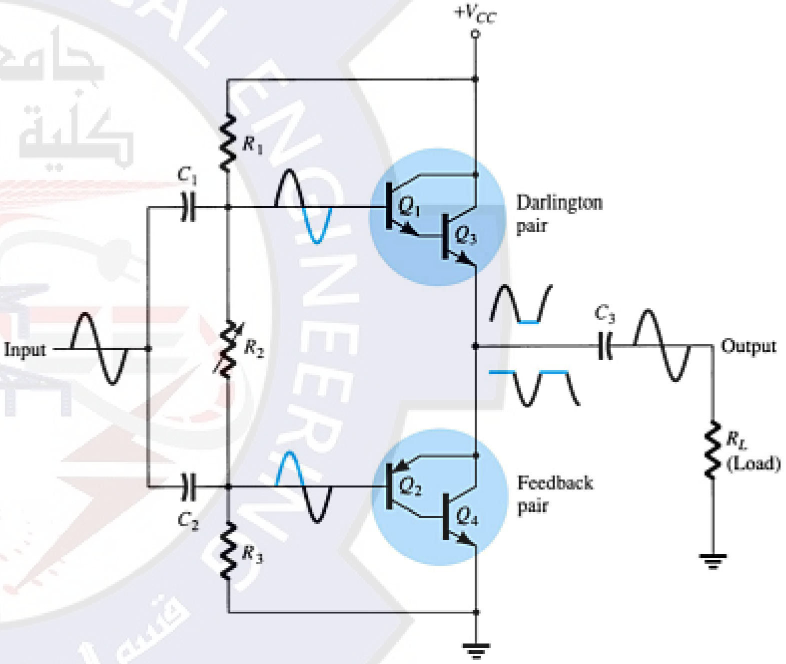
Crossover Distortion

If the transistors Q_1 and Q_2 do not turn on and off at exactly the same time, then there is a gap in the output voltage.



Quasi-Complementary Push-Pull Amplifier

A Darlington pair and a feedback pair combination perform the push-pull operation. This increases the output power capability.



Amplifier Distortion

If the output of an amplifier is not a complete AC sine wave, then it is distorting the output. The amplifier is non-linear.

This distortion can be analyzed using Fourier analysis. In Fourier analysis, any distorted periodic waveform can be broken down into frequency components. These components are harmonics of the fundamental frequency.

Harmonics

Harmonics are integer multiples of a fundamental frequency.

If the fundamental frequency is 5kHz:

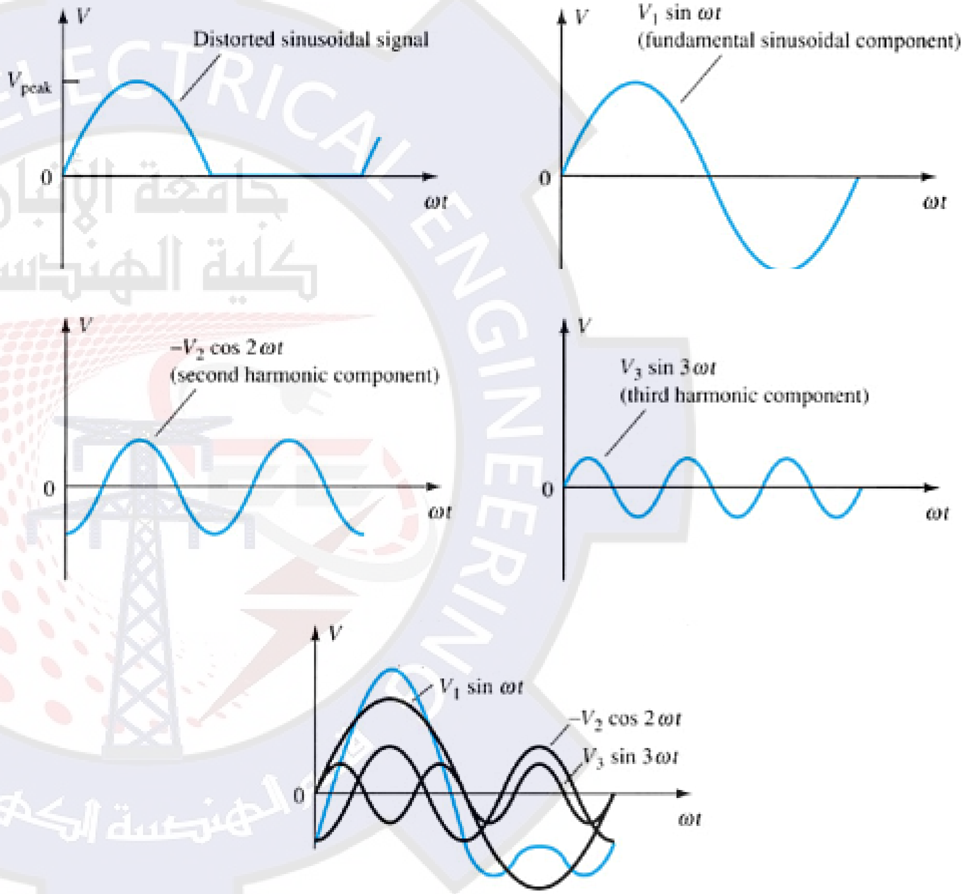
1st harmonic	**1 x 5kHz**
2nd harmonic	**2 x 5kHz**
3rd harmonic	**3 x 5kHz**
4th harmonic	**4 x 5kHz**

etc.

Note that the 1st and 3rd harmonics are called odd harmonics and the 2nd and 4th are called even harmonics.

Harmonic Distortion

According to Fourier analysis, if a signal is not purely sinusoidal, then it contains harmonics.



Harmonic Distortion Calculations

Harmonic distortion (D) can be calculated:

$$\% \text{ nth harmonic distortion} = \%D_n = \left|\frac{A_n}{A_1}\right| \times 100$$

where

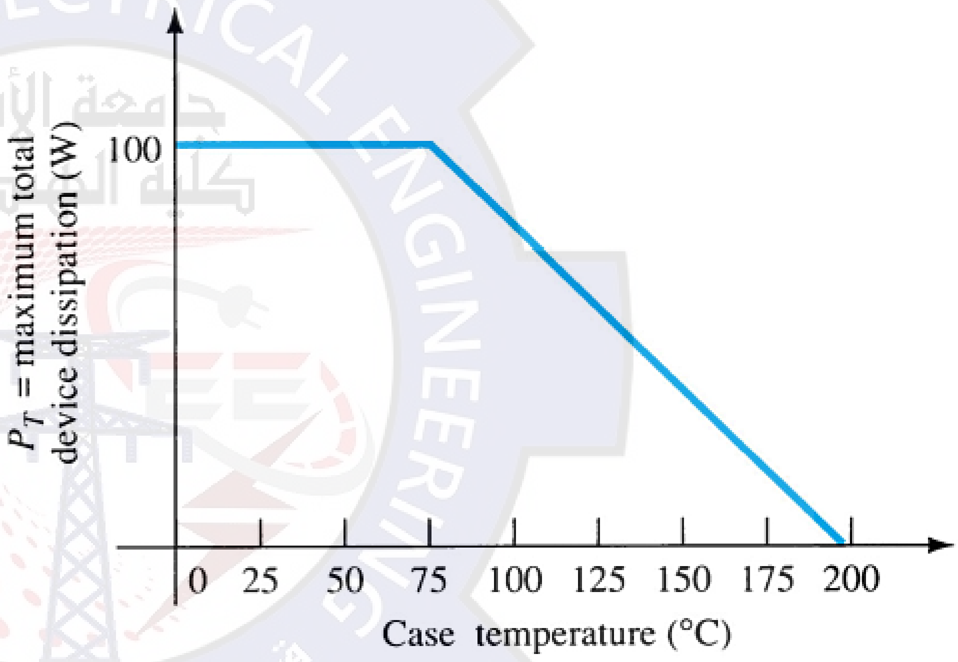
A_n is the amplitude of the fundamental frequency
A_n is the amplitude of the highest harmonic

The total harmonic distortion (THD) is determined by:

$$\% \text{THD} = \sqrt{D_2^2 + D_3^2 + D_3^2 + \cdots} \times 100$$

Power Transistor Derating Curve

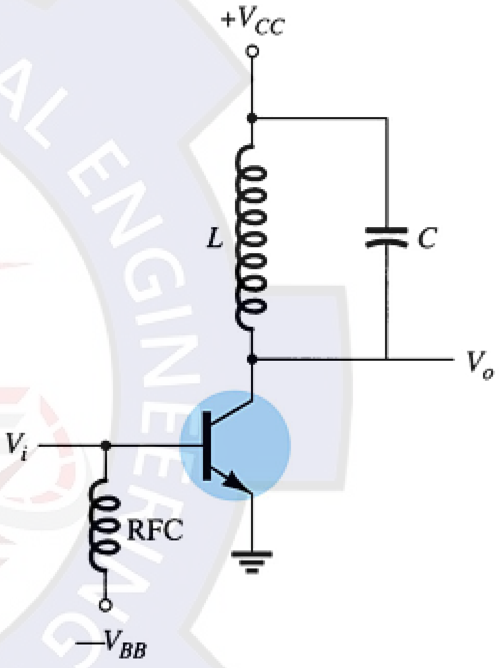
Power transistors dissipate a lot of power in heat. This can be destructive to the amplifier as well as to surrounding components.



Class C Amplifiers

A class C amplifier conducts for less than 180°. In order to produce a full sine wave output, the class C uses a tuned circuit (LC tank) to provide the full AC sine wave.

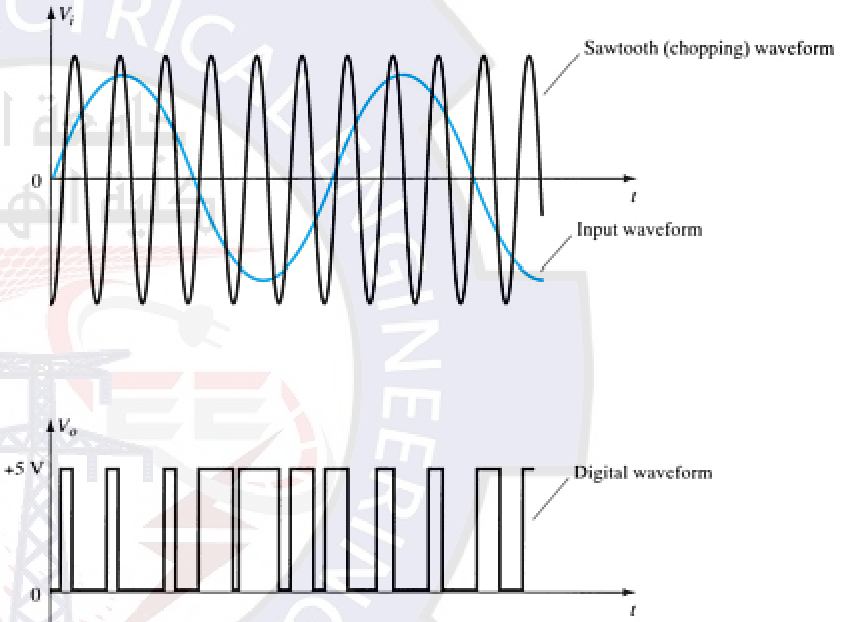
Class C amplifiers are used extensively in radio communications circuits.



Class D Amplifier

A class D amplifier amplifies pulses, and requires a pulsed input.

There are many circuits that can convert a sinusoidal waveform to a pulse, as well as circuits that convert a pulse to a sine wave. This circuit has applications in digital circuitry.



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Chapter 13

Chapter 13_ Linear-Digital ICs

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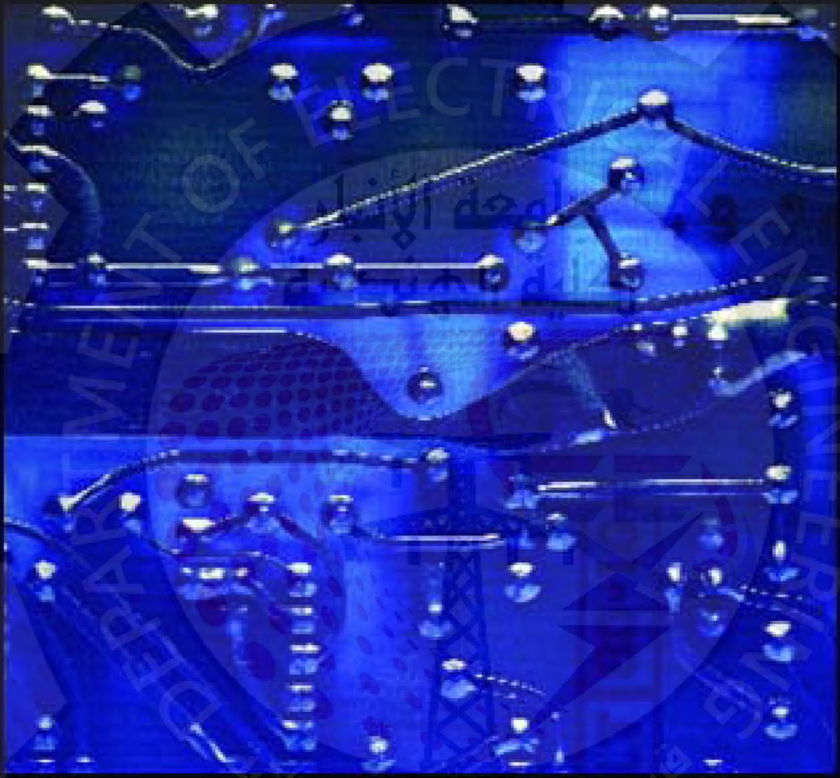

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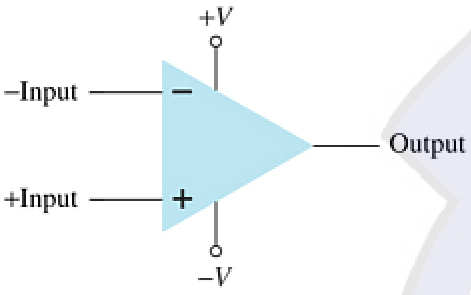
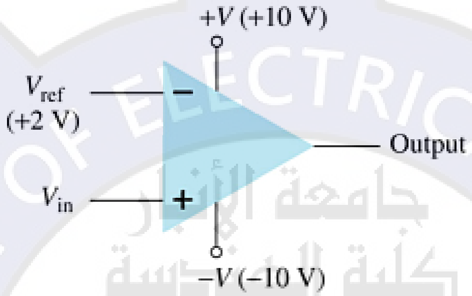
Chapter 13
Linear-Digital ICs

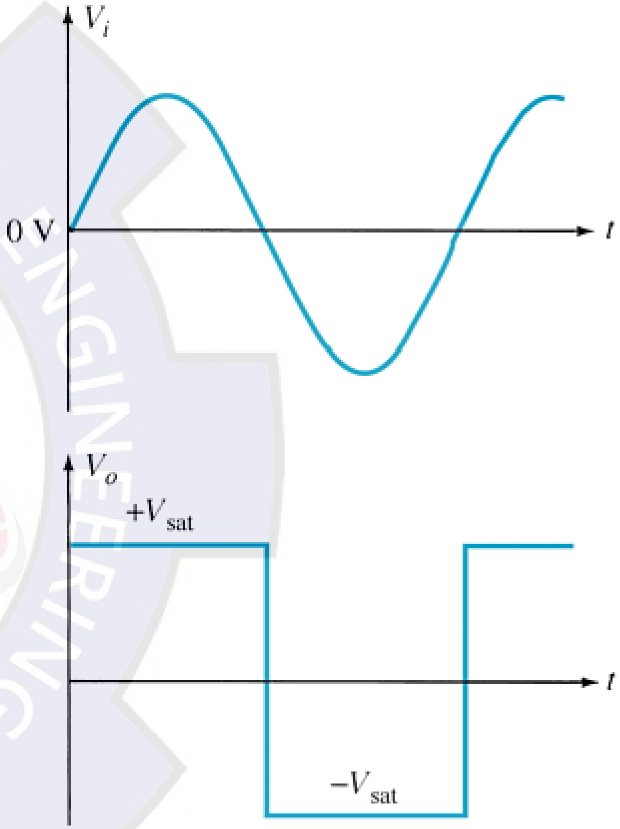
Linear Digital ICs

Comparators
Digital/analog converters
Timers
Voltage-controlled oscillators
Phase-locked loop circuits
Interface circuits

Comparator Circuit







The operation is a basic comparison. The output swings between its maximum and minimum voltage, depending upon whether one input (V_{in}) is greater or less than the other (V_{ref}).

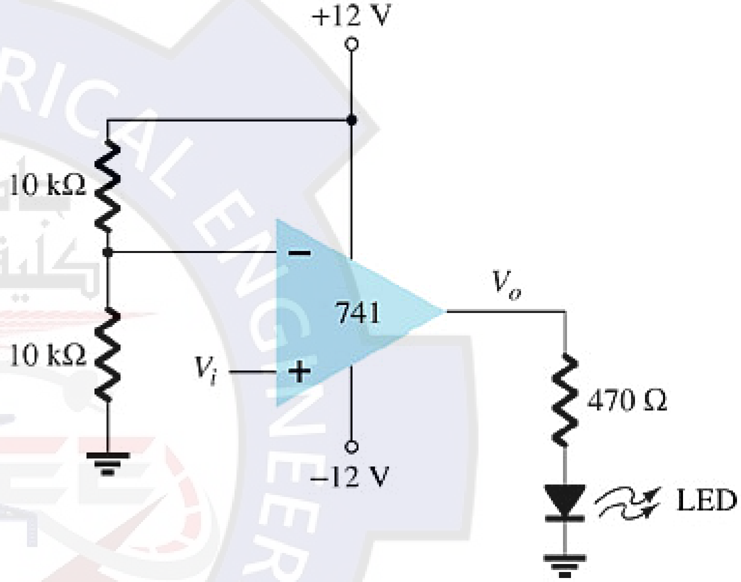
The output is always a square wave where:

- **The maximum high output voltage is $+V_{SAT}$.**
- **The minimum low output voltage is $-V_{SAT}$.**

Noninverting Op-Amp Comparator

For a noninverting op-amp comparator:

- **The output goes to $+V_{SAT}$ when input V_i is greater than the reference voltage.**
- **The output goes to $-V_{SAT}$ when input V_i is less than the reference voltage.**



Example:

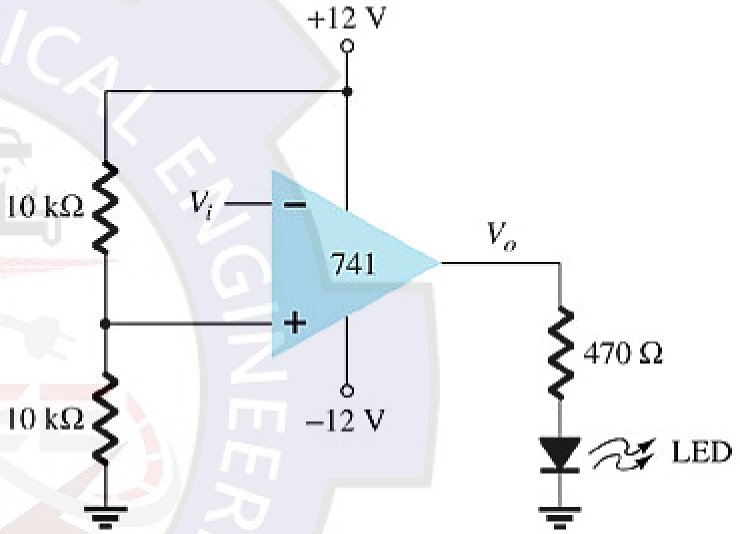
- **V_{ref} in this circuit is +6V (taken from the voltage divider)**
- **$+V_{SAT} = +V$, or +12V**
- **$-V_{SAT} = -V$ or −12V**

When V_i is greater than +6V the output swings to +12V and the LED goes on.
When V_i is less than +6V the output is at −12V and the LED goes off.

Inverting Op-Amp Comparator

For an inverting op-amp comparator:

- **The output goes to $-V_{SAT}$ when input V_i is greater than the reference voltage.**
- **The output goes to $+V_{SAT}$ when input V_i is less than the reference voltage.**



Example:

- **V_{ref} in this circuit is +6V (taken from the voltage divider)**
- **$+V_{SAT} = +V$, or +12V**
- **$-V_{SAT} = -V$ or −12V**

When V_i is greater than +6V the output swings to −12V and the LED goes off.
When V_i is less than +6V the output is at +12V and the LED goes on.

Comparator ICs

Advantages:

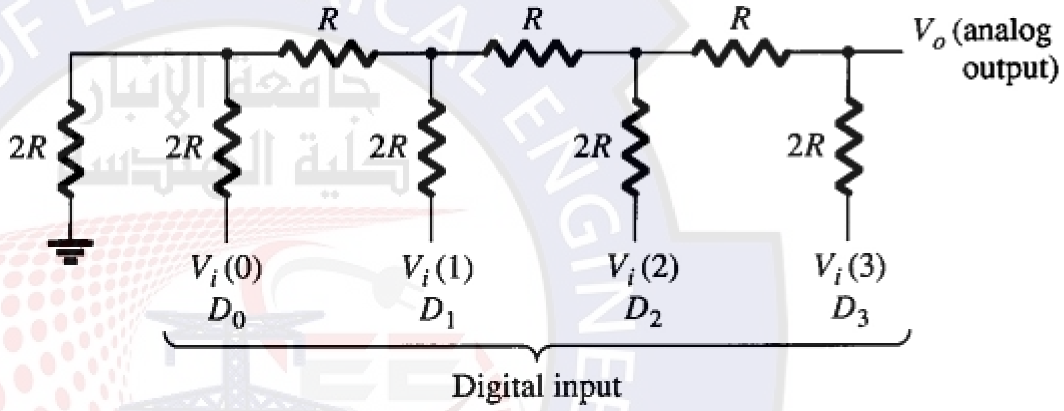
- **Faster switching**
- **Built-in noise immunity**
- **Outputs capable of directly driving loads**

Digital-Analog Converters

Types:

- **Digital-to-analog converters (ADCs)**
- **Analog-to-digital converters (DACs)**

Digital-to Analog Converter: Ladder Network Version



Output Voltage, V_o:

$$V_o = \frac{D_0 \times 2^0 + D_1 \times 2^1 + D_2 \times 2^2 + D_3 \times 2^3}{2^4} V_{ref}$$

Voltage Resolution:

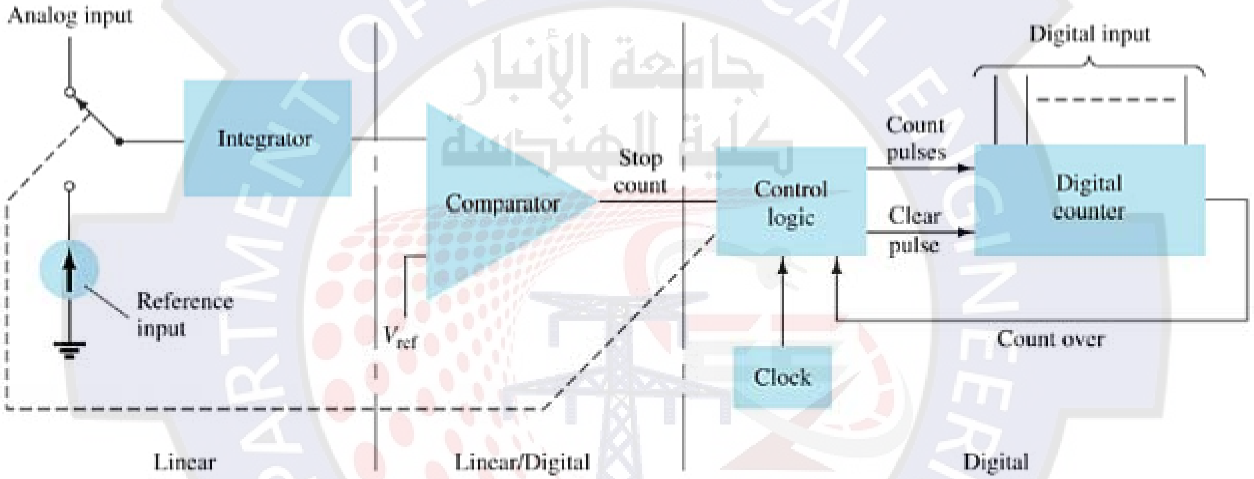
$$\frac{V_{ref}}{2^4}$$

Analog-to-Digital Converters

Types:

- **Dual Slope Conversion**
- **Ladder Network Conversion**

Analog-to-Digital Conversion
Dual Slope Conversion



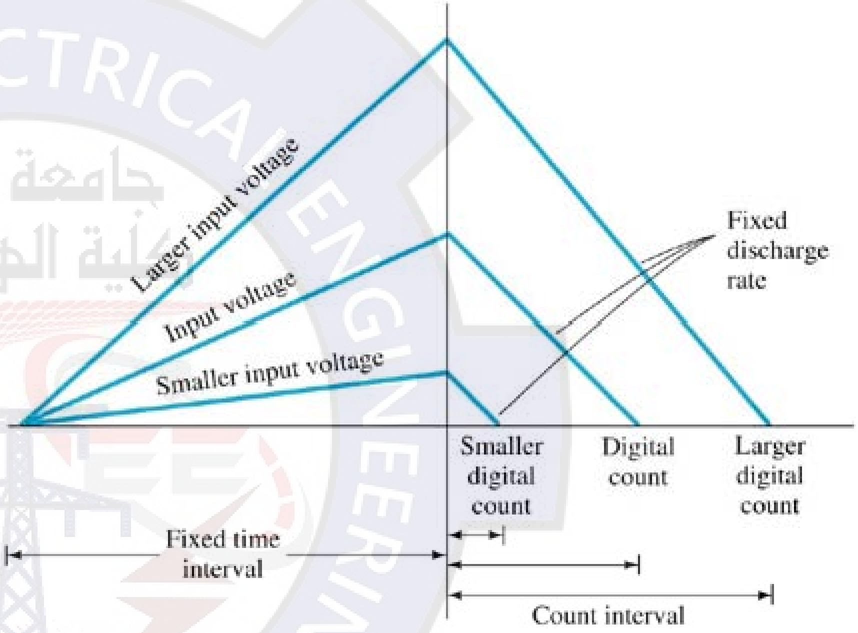
The analog input voltage is applied to an integrator or ramp-generator circuit.

The digital output is obtained from a digital counter that is operated during both positive and negative slope (ramp) intervals of the integrator.

Dual Slope Conversion

Rising Slope

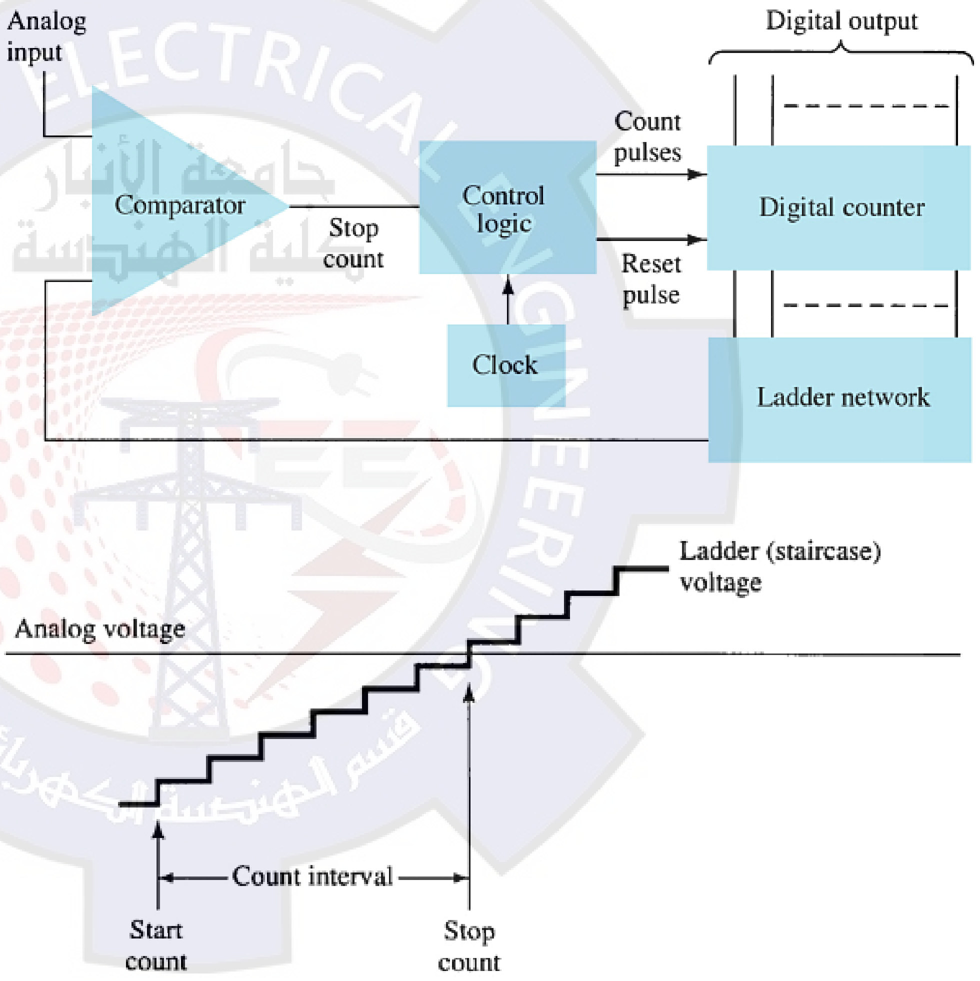
For a fixed interval the analog voltage is applied to the integrator. The integrator output rises to some positive level. This positive voltage is applied to a comparator. At the end of the fixed interval, the counter is reset to 0. An electronic switch connects the integrator input to a fixed input or reference voltage.



Falling Slope

The integrator output decreases at a fixed rate. The counter advances during this time. When the integrator output (connected to the comparator input) falls below the reference level of the comparator, control logic stops the counter.The digital counter output is the digital conversion of the analog input.

Ladder Network Conversion



A digital counter advances from zero while a ladder network converts the digital count to a staircase analog voltage.

When the staircase voltage into the comparator equals the analog input voltage, the counter stops.

The last count is the digital conversion of the analog input.

Resolution of Analog-to-Digital Converters

The resolution depends on the amount of voltage per step (digital bit):

$$\frac{V_{ref}}{2^n}$$

where n is the number of digital bits

Example: **A 12-bit ADC with a 10V reference level has the following resolution:**

$$\frac{V_{ref}}{2^n} = \frac{10V}{2^{12}} = 2.4mV$$

Analog-to-Digital Conversion Time

The conversion time depends on the clock frequency of the counter.

$$T_{conv} = \frac{2^n}{f}$$

where

T_{conv} = conversion time (seconds)
n = number of binary bits
f = clock frequency for the counter

Example: A 12bit ADC with a 1MHz clock has a maximum conversion time.

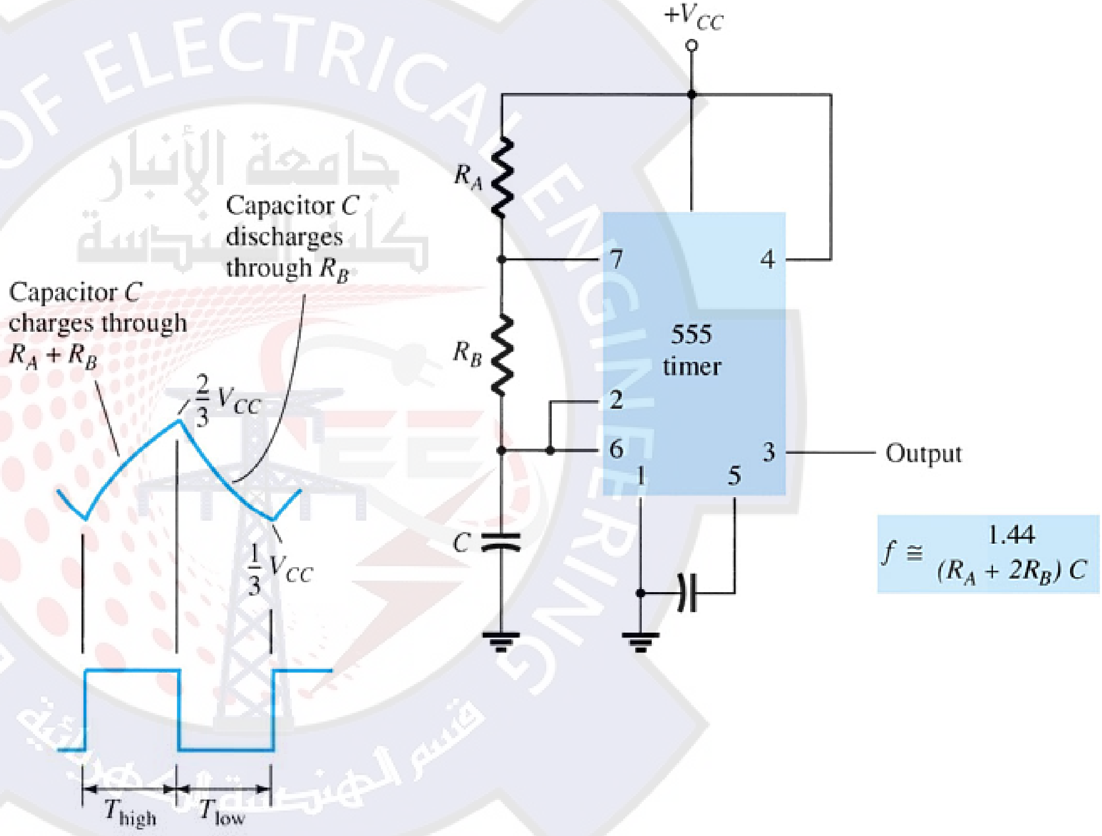
$$2^{12}\left(\frac{1}{1\text{MHz}}\right) = 4.1\text{ms}$$

555 Timer Circuit

The 555 Timer is an example of a versatile Timer IC.

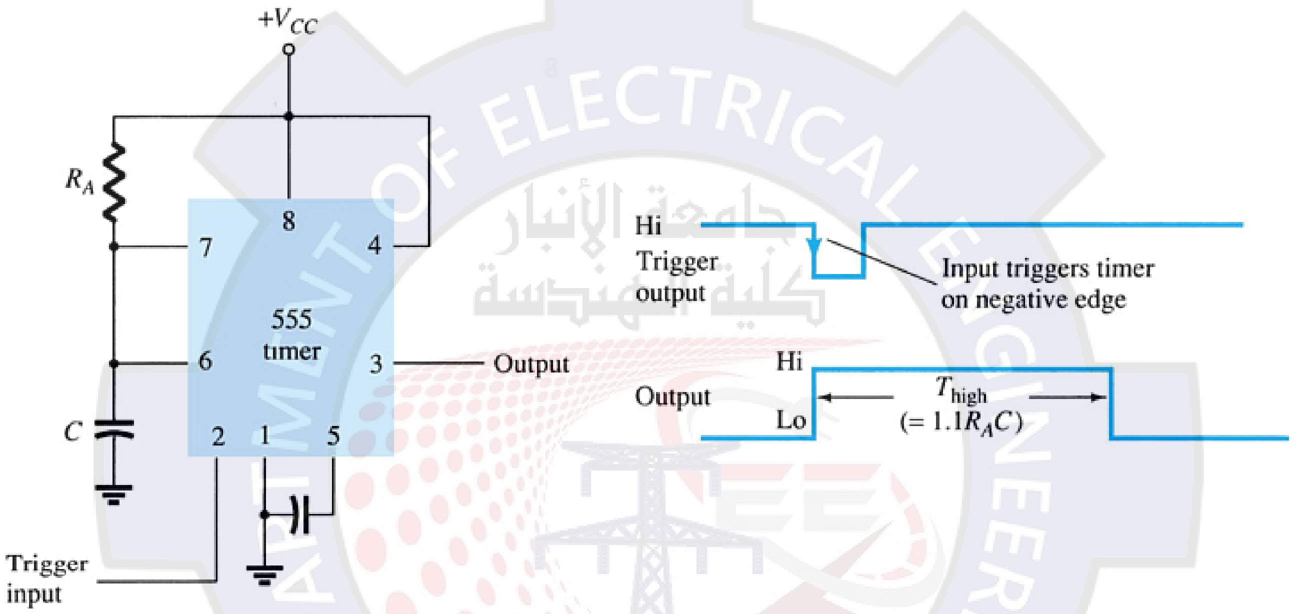
Astable Operation

The timer output is a repetitive square wave. The output frequency can be calculated as shown here.



$$f \cong \frac{1.44}{(R_A + 2R_B)\,C}$$

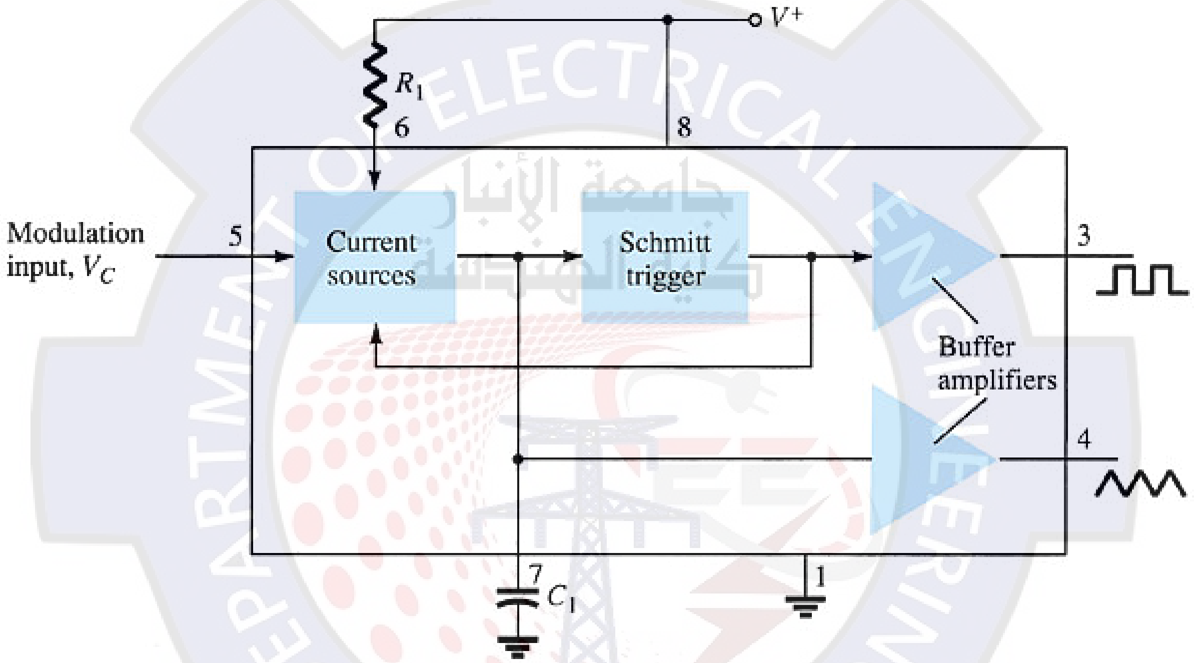
555 Timer Circuit



Monostable Operation

The timer output is a one shot pulse. When an input is received it triggers a one shot pulse. The time for which the output remains high can be calculated as shown.

Voltage-Controlled Oscillator

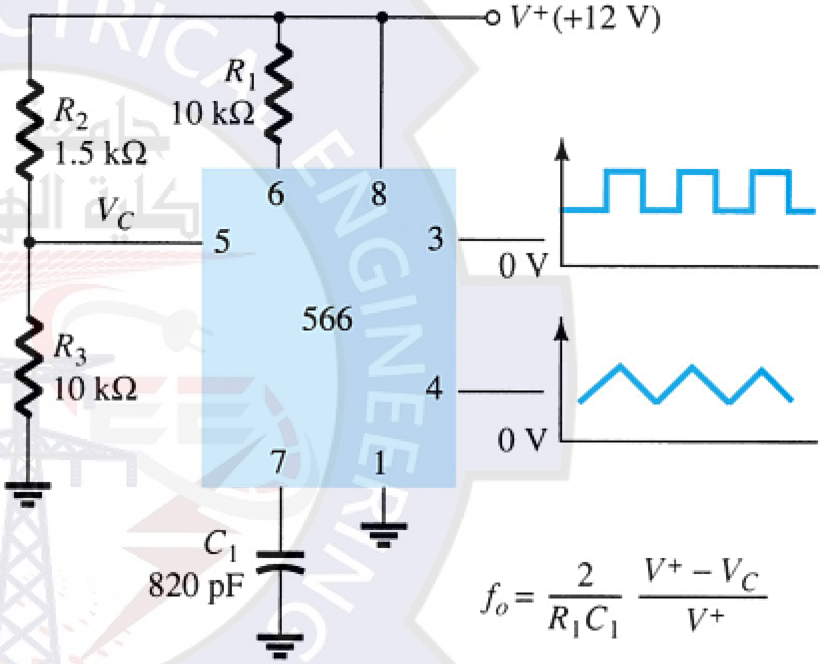


The oscillator output is a variable frequency square wave or triangular wave. The output frequency depends on the modulation input voltage (V_C).

566 Voltage-Controlled Oscillator

The output frequency can be calculated as shown in the graph.

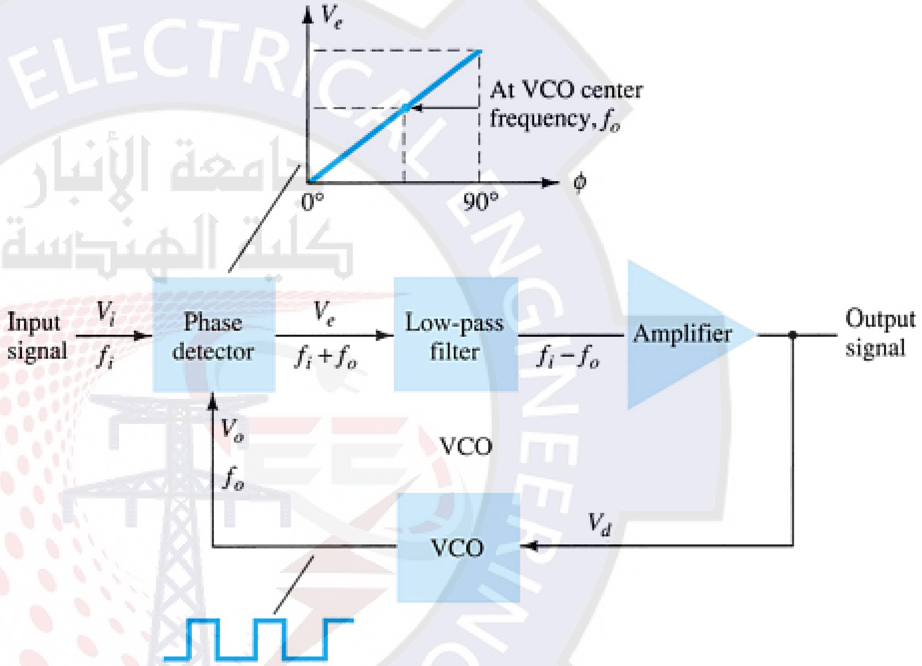
Note that the formula also indicates other circuit parameters that affect the output frequency.



$$f_o = \frac{2}{R_1 C_1}\,\frac{V^+ - V_C}{V^+}$$

Phase-Locked Loop

The input signal is a frequency and the output signal is a voltage representing the difference in frequency between the input and the internal VCO.



Basic Operation of the Phase-Locked Loop

Three operating modes:

Lock

$f_i = f_{VCO}$

Tracking

$f_i \neq f_{VCO}$, but the f_{VCO} adjusts until $f_{VCO} = f_i$

Out-of-Lock

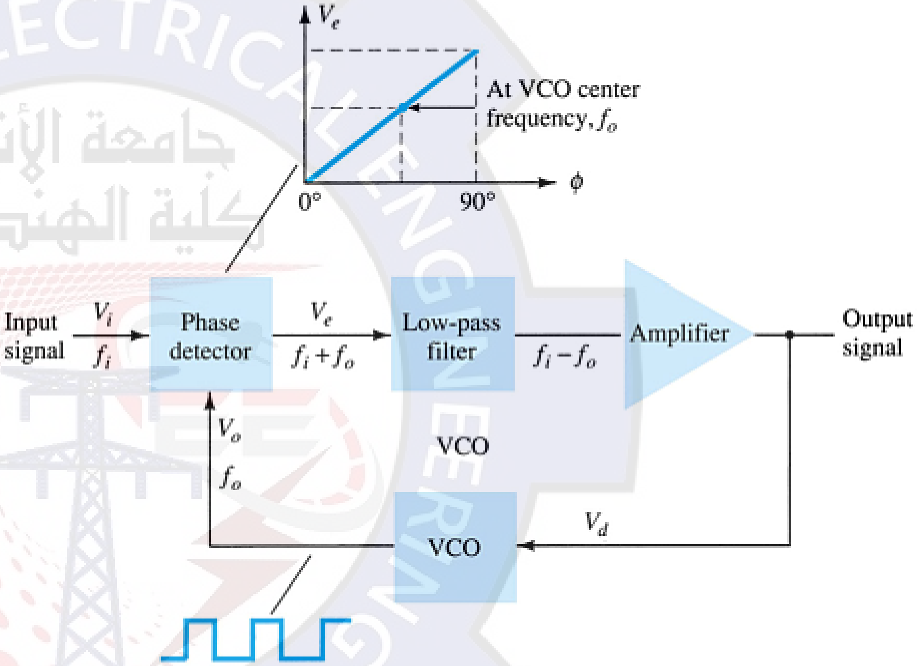
$f_i \neq f_{VCO}$, and they never will be the same

Phase-Locked Loop: Lock Mode

The input frequency and the internal VCO output frequency are applied to the phase comparator.

If they are the same, the phase comparator output voltage indicates no error.

This no-error voltage is filtered and amplified before it is made available to the output.



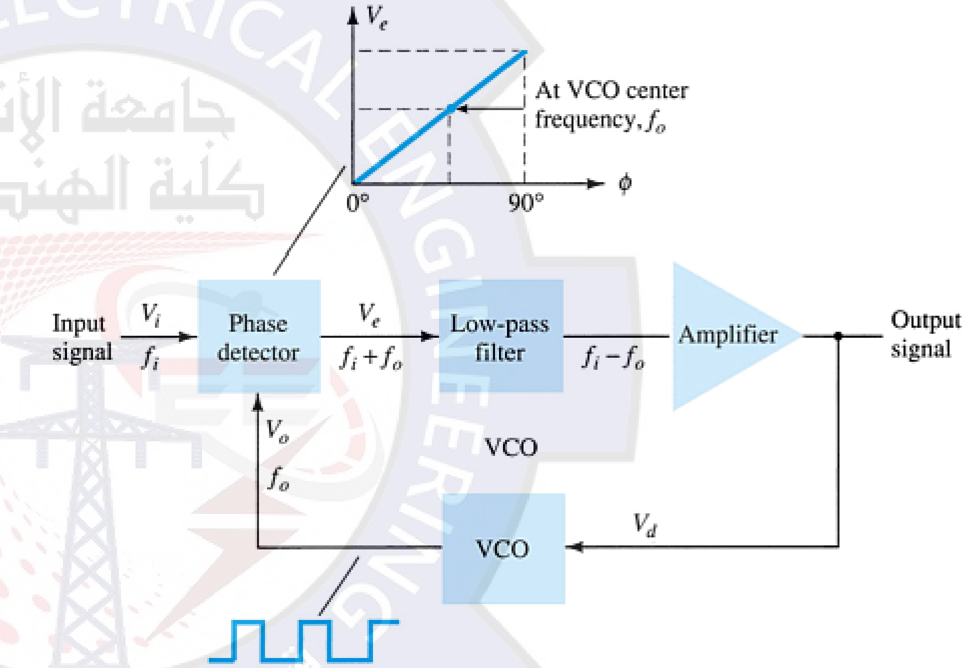
The no-error voltage is also applied to the internal VCO input to maintain the VCO's output frequency.

Phase-Locked Loop: Tracking Mode

If the input frequency *does not* equal the VCO frequency then the phase comparator outputs an error voltage.

This error voltage is filtered and amplified and made available to the output.

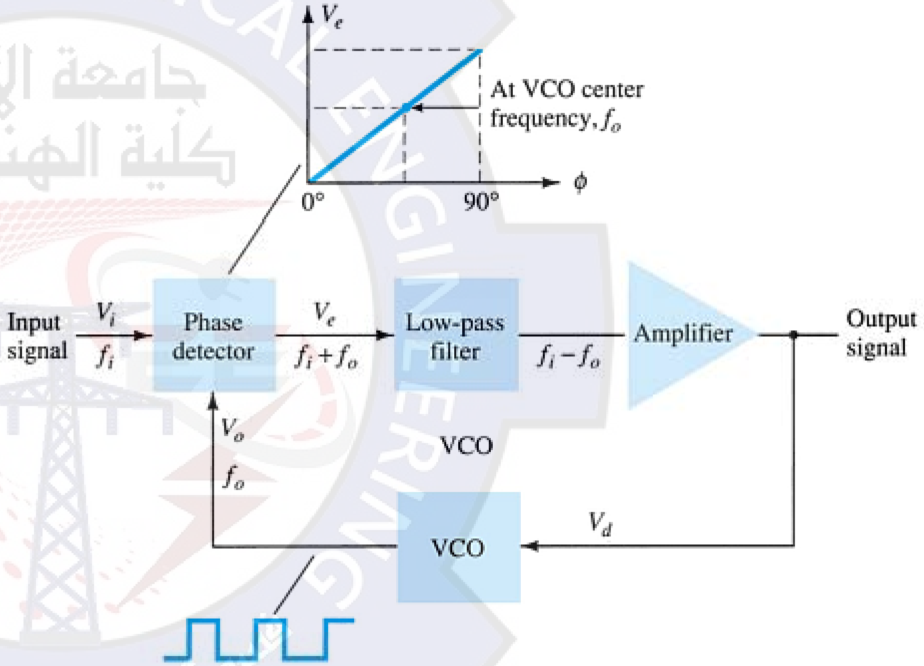
The error voltage is also applied to the VCO input. This causes the VCO to change output frequency.



This looping continues until the VCO has adjusted to the new input frequency and they are equal again.

Phase-Locked Loop: Out-of-Lock Mode

If the input frequency *does not* equal the VCO frequency and the resulting error voltage does not cause the VCO to catch up to the input frequency, then the system is out of lock. The VCO will never equal the input frequency.



Phase-Locked Loop: Frequency Ranges

Lock Range—The range of input frequencies for which the VCO will track.

Capture Range —A narrow range of frequencies into which the input frequency must fall before the VCO can track. If the input frequency falls out of the lock range it must first enter into the capture range.

Phase-Locked Loop

Applications:

- **FM demodulator**
- **Frequency Synthesizer**
- **FSK decoder**

Interface Circuitry

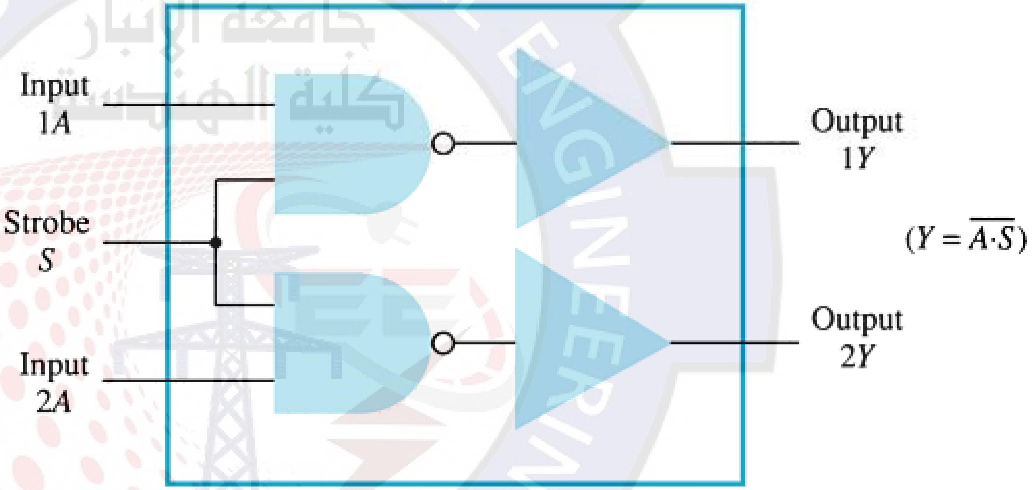
Interface circuitry:

- **Driving loads**
- **Producing output signals at proper voltage or current levels**
- **Impedance matching**
- **Strobing or timing signals**

Interface Circuitry: Dual Line Drivers

The input is TTL digital logic signal levels.

The output is capable of driving TTL or CMOS devise circuits.

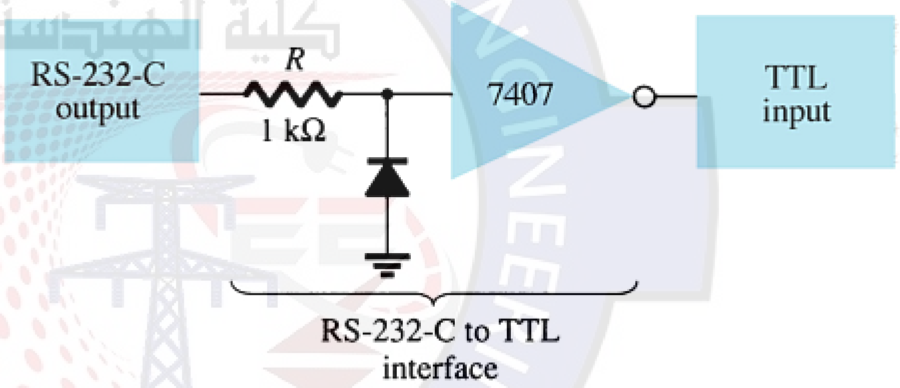


$(Y = \overline{A \cdot S})$

RS-232-to-TTL Converter

The input is RS-232 electronic industry standard for serial communications.

The output will drive TTL circuitry.



$(Y = \overline{A \cdot S})$

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Hatem Fahd Al-Duliamy

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Multivibrator

Hatem Fahd Al-Duliamy

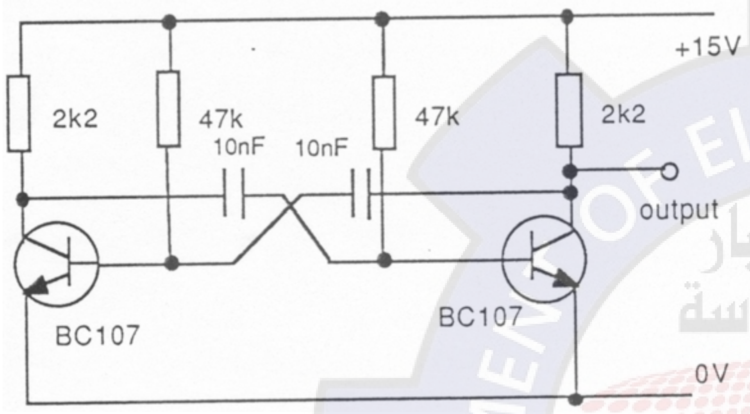
2018-2019

Multivibrators

- A multivibrator is used to implement simple **two-state systems** such as oscillators, timers and flip-flops.
- Three types:
  - **Astable** – neither state is stable.
    Applications: oscillator, etc.
  - **Monostable** - one of the states is stable, but the other is not;
    Applications: timer, etc.
  - **Bistable** – it remains in either state indefinitely.
    Applications: flip-flop, etc.

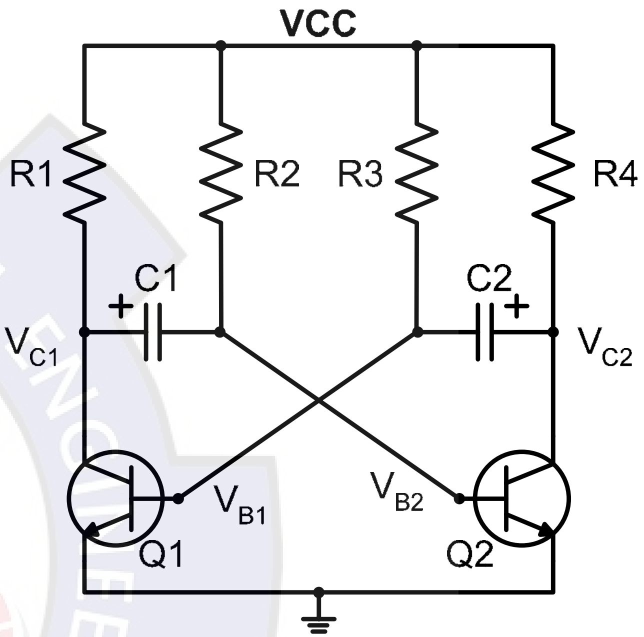
Reference: http://en.wikipedia.org/wiki/Multivibrator

Astable Multivibrator



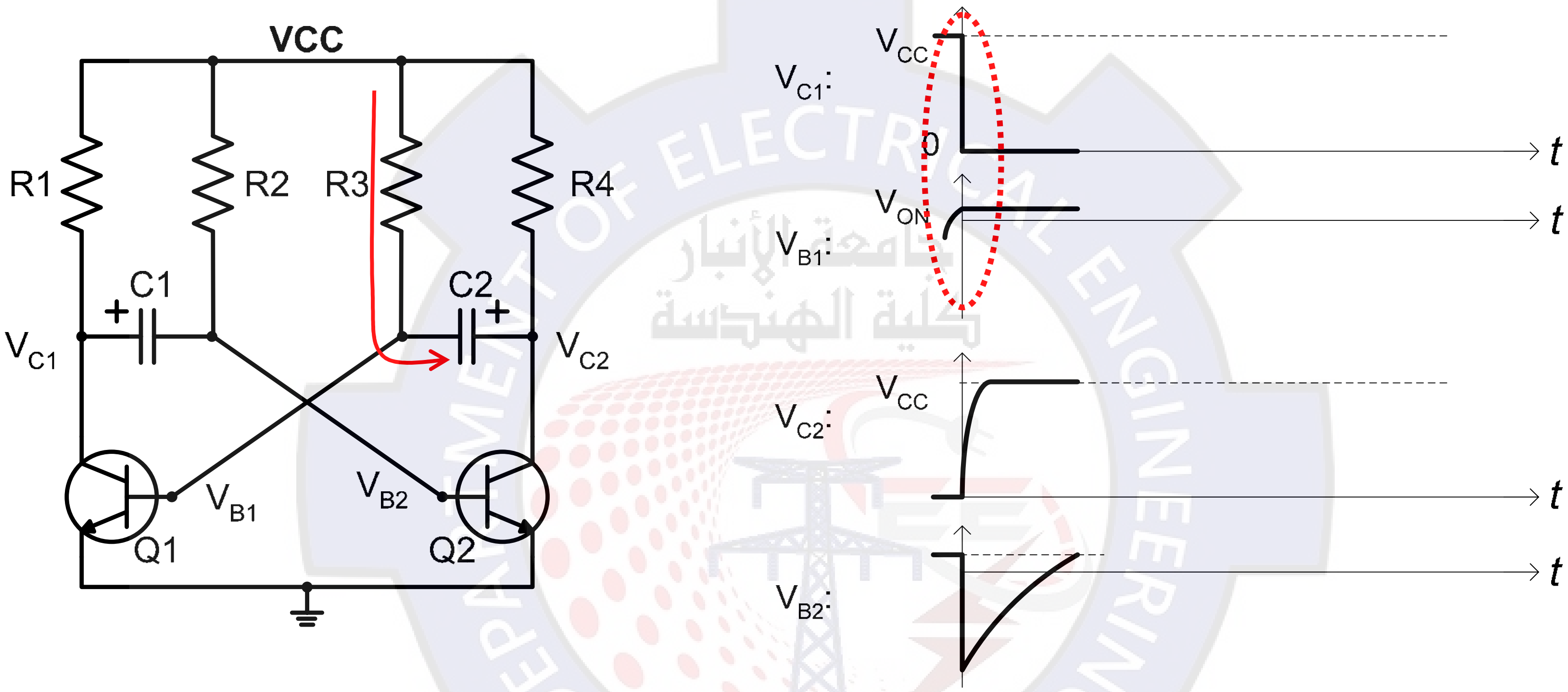
Circuit in Experiment A4

Redrawn



- Consists of two amplifying devices cross-coupled by resistors and capacitors.
- Typically, $R_2 = R_3$, $R_1 = R_4$, $C_1 = C_2$ and $R_2 >> R_1$.
- The circuit has two states
  - State 1: V_{C1} LOW, V_{C1} HIGH, Q_1 ON (saturation) and Q_2 OFF.
  - State 2: V_{C1} HIGH, V_{C2} LOW, Q_1 OFF and Q_2 ON (saturation).
- It continuously oscillates from one state to the other.

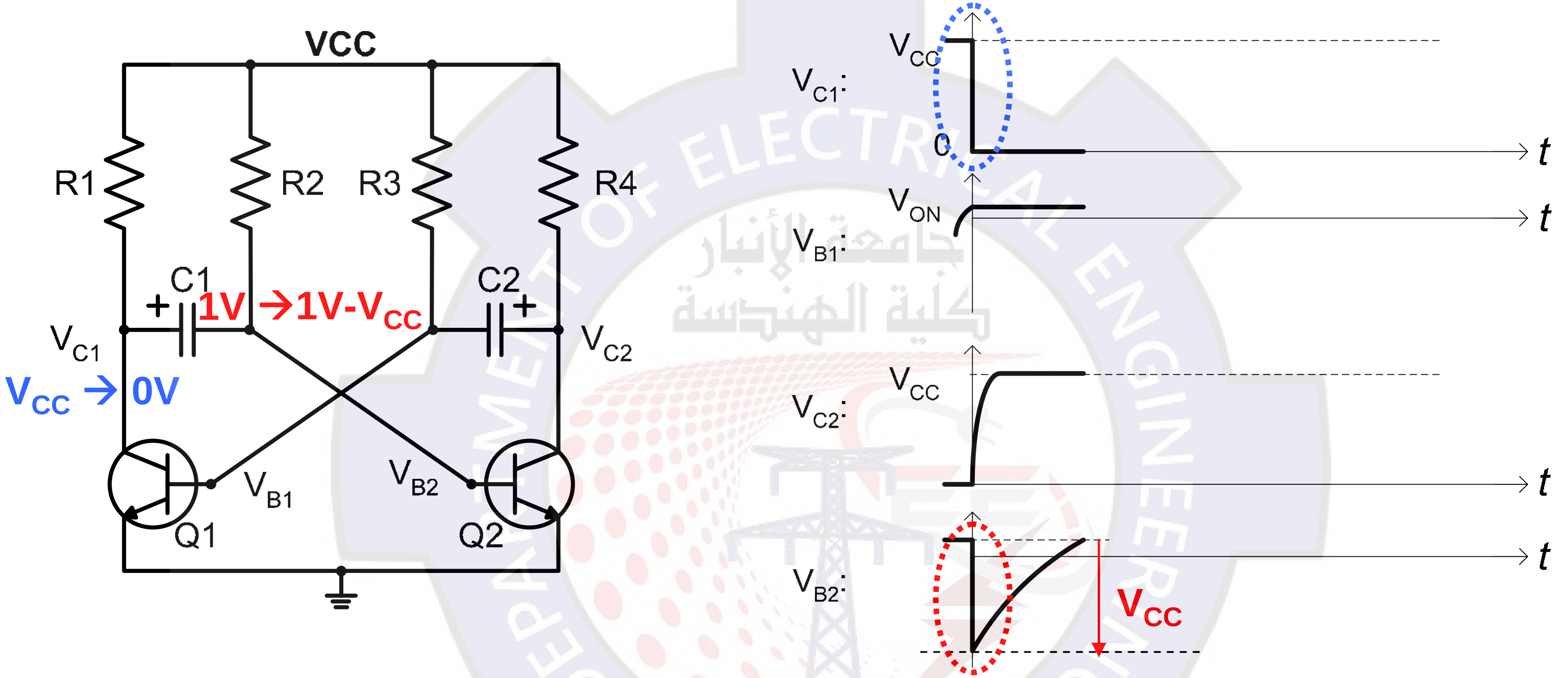
Basic Mode of Operation



State 1:

- V_{B1} charges up through R_3 from below ground towards V_{CC}.
- When V_{B1} reaches V_{ON} (of $V_{BE,}$ ≈1V), Q_1 turns on and pulls V_{C1} from V_{CC} to V_{CESat} ≈ 0V.
- Due to forward-bias of the BE junction of Q_1, V_{B1} remains at 1V.

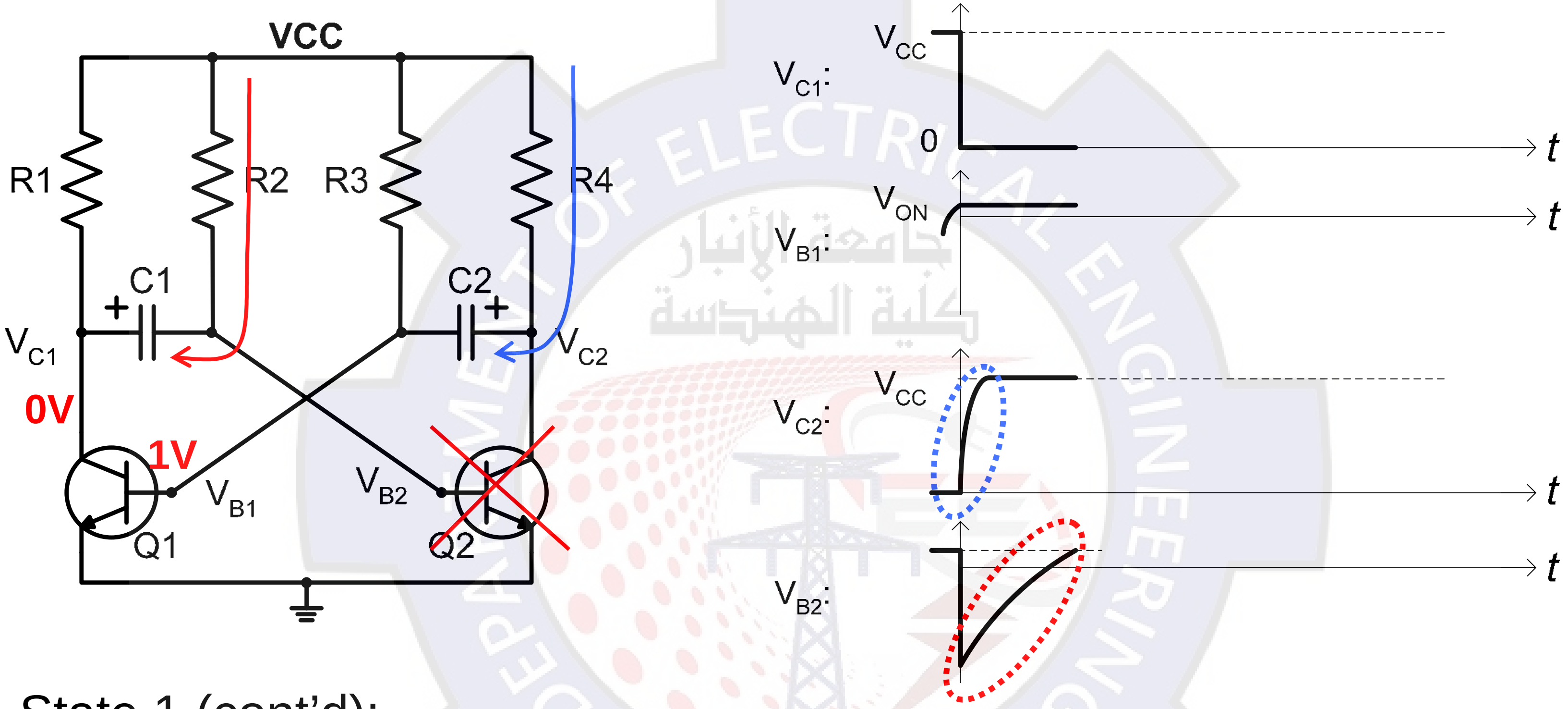
Basic Mode of Operation



State 1 (cont'd):

- As C_1's voltage cannot change instantaneously, V_{B2} drops by V_{CC}.

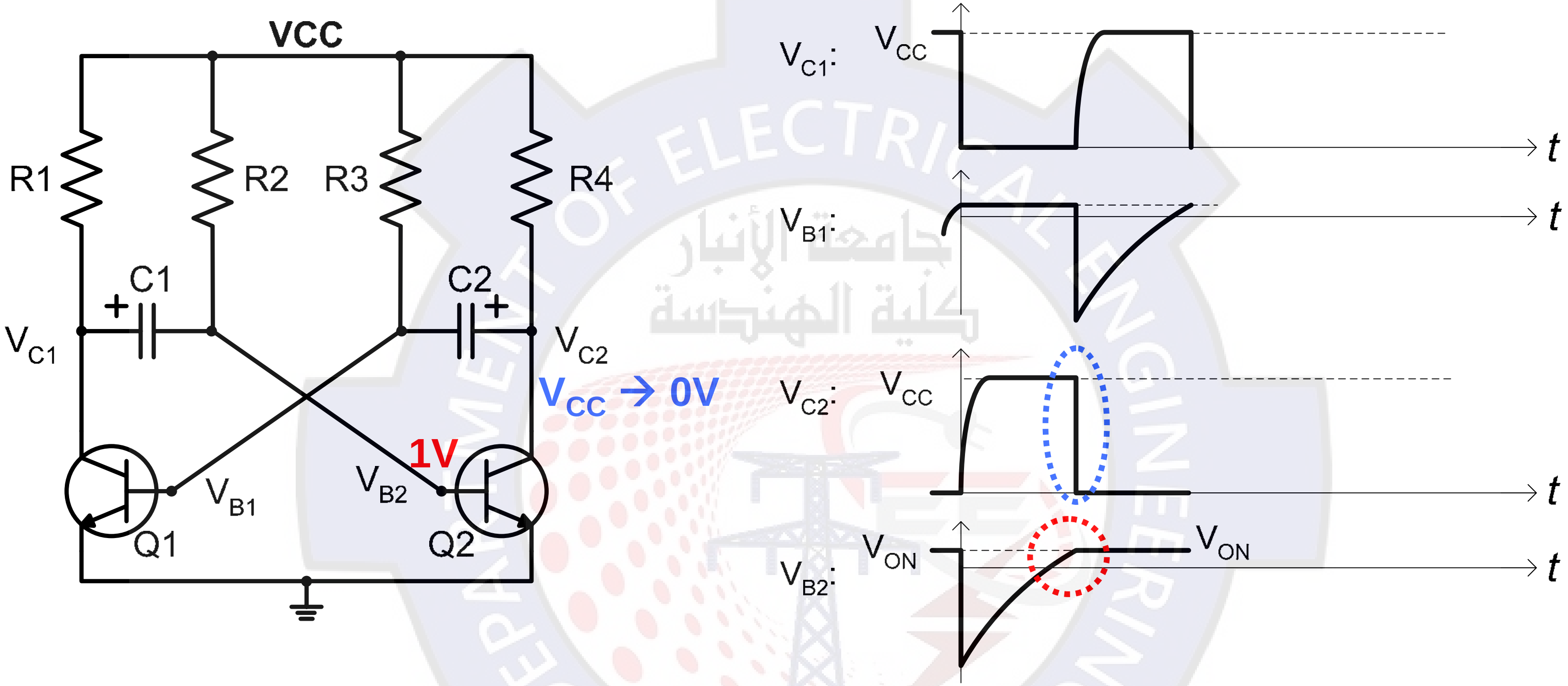
Basic Mode of Operation



State 1 (cont'd):

- Q_2 turns off and V_{C2} charges up through R_4 to V_{CC} (speed set by the time constant R_4C_2).
- V_{B2} charges up through R_2 towards V_{CC} (speed set by R_2C_1, which is slower than the charging up speed of V_{C2}).

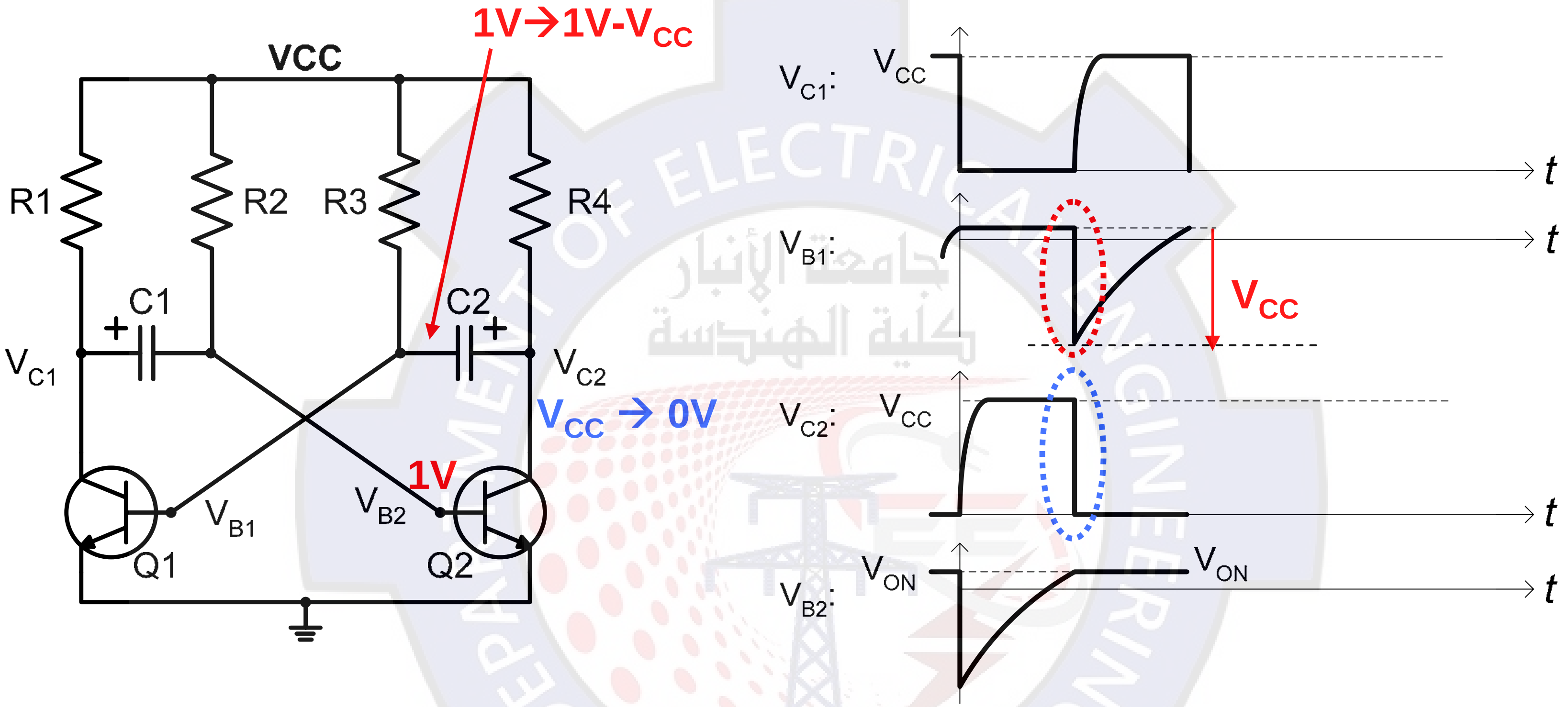
Basic Mode of Operation



State 2:

- When V_{B2} reaches V_{ON}, Q_2 turns on and pulls V_{C2} from V_{CC} to 0V.
- V_{B2} remains at V_{ON}.

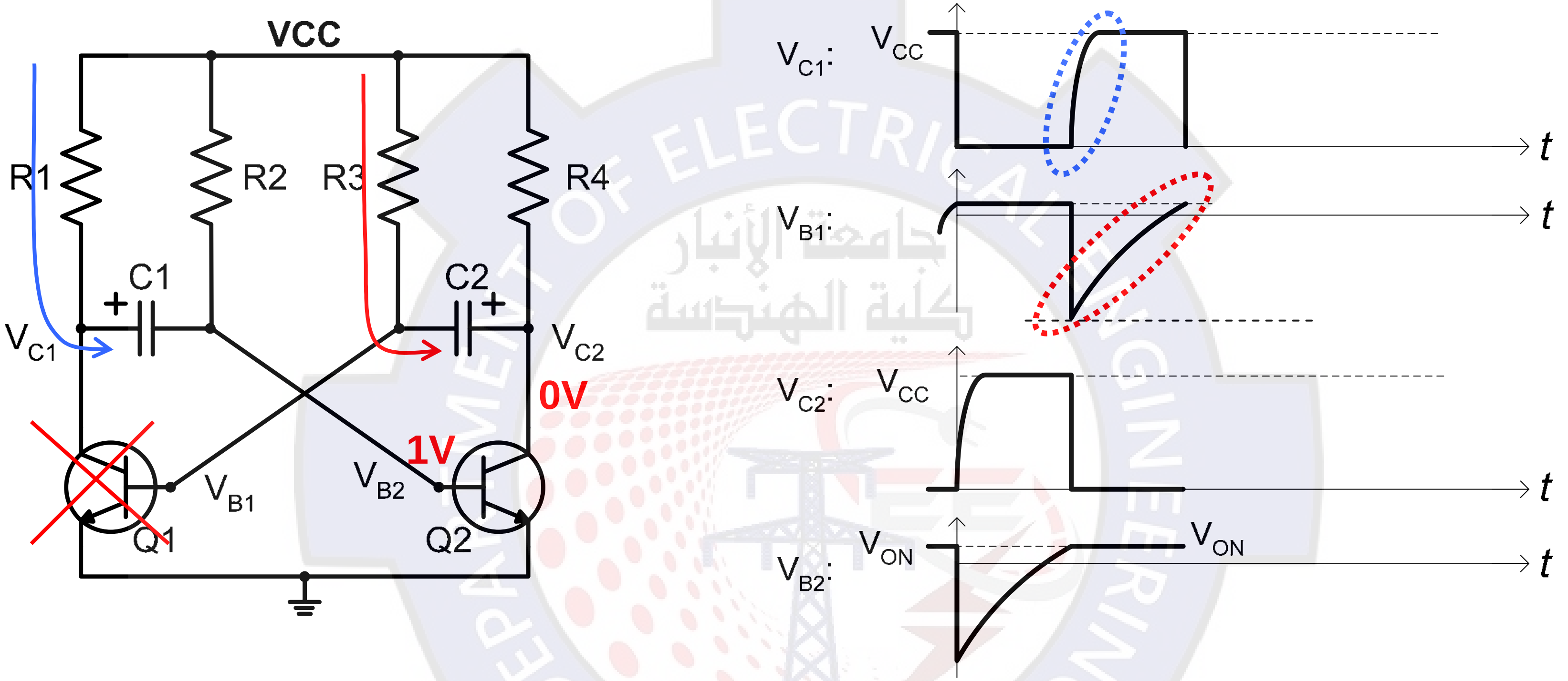
Basic Mode of Operation



State 2 (cont'd):

- As C_2's voltage cannot change instantaneously, V_{B1} drops by V_{CC}.

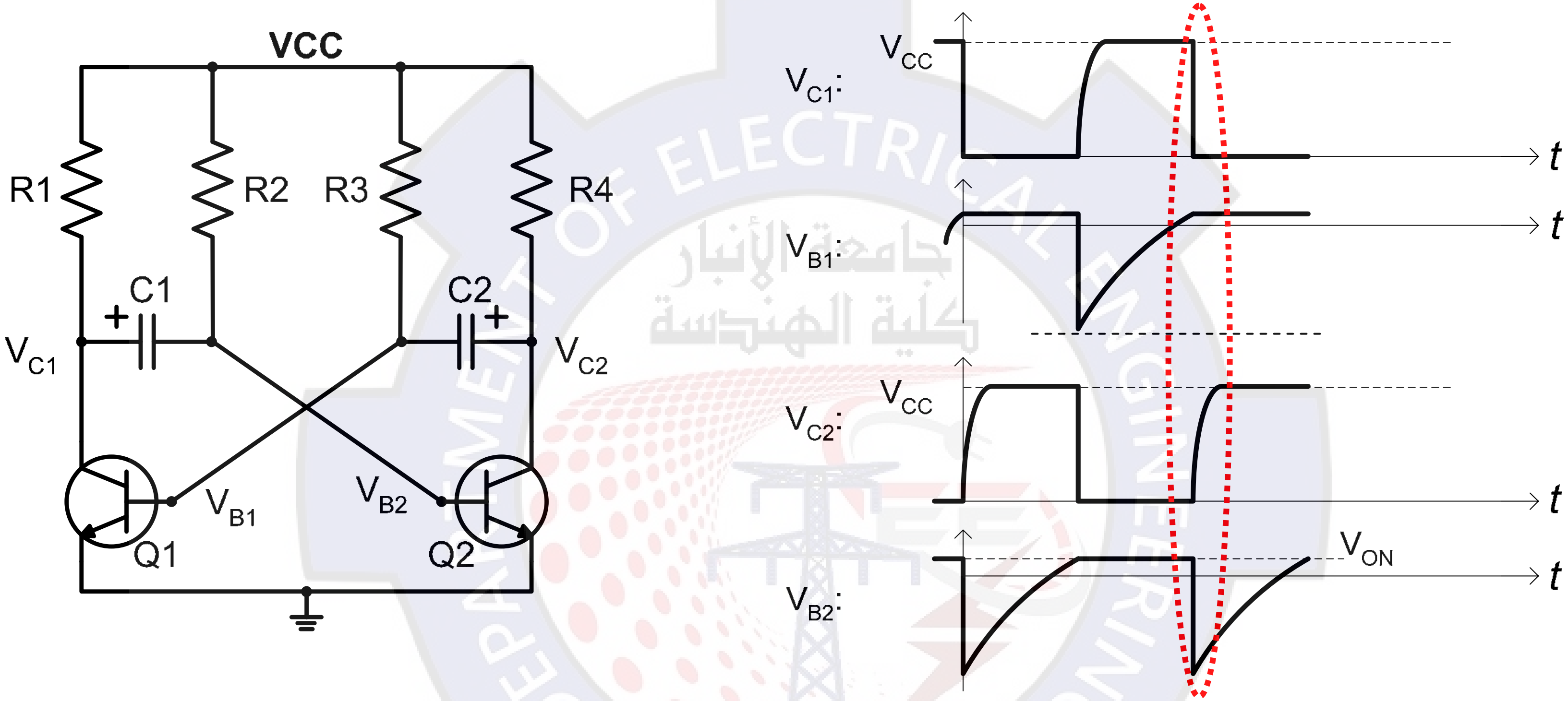
Basic Mode of Operation



State 2 (cont'd):

- Q_1 turns off and V_{C1} charges up through R_1 to V_{CC}, at a rate set by R_1C_1.
- V_{B2} charges up through R_3 towards V_{CC}, at a rate set by R_3C_2, which is slower.

Basic Mode of Operation

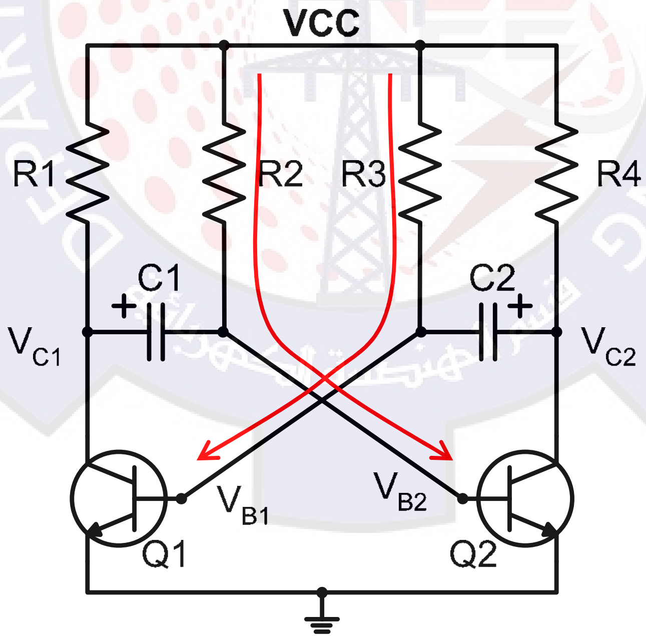


Back to state 1:

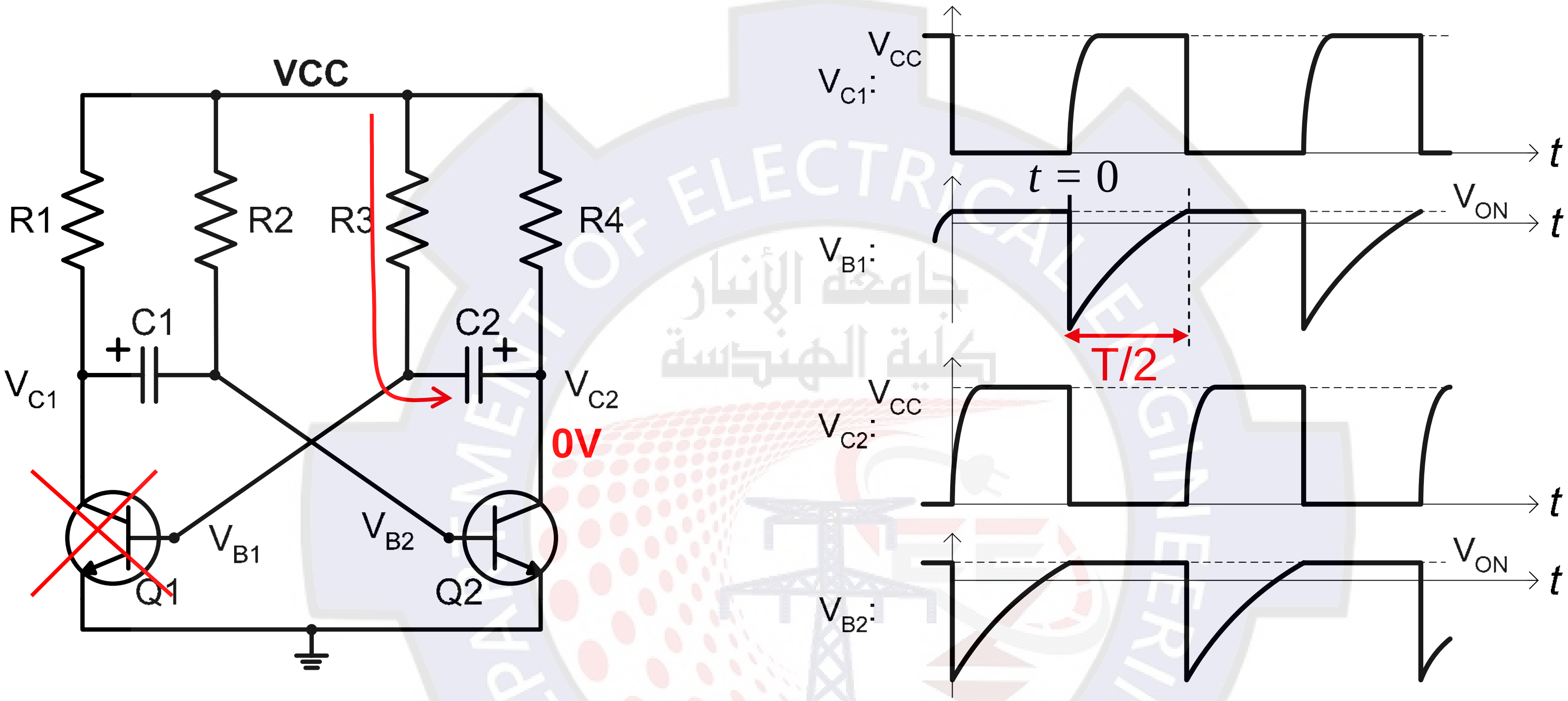
- When V_{B1} reaches Von, the circuit enters state 1 again, and the process repeats.

Initial Power-Up

- When the circuit is first powered up, neither transistor is ON.
- Parasitic capacitors between B and E of Q_1 and Q_2 are charged up towards V_{CC} through R_2 and R_3. Both V_{B1} and V_{B2} rise.
- Inevitable slight asymmetries will mean that one of the transistors is first to switch on. This will quickly put the circuit into one of the above states, and oscillation will ensue.



Multivibrator Frequency



$$v_{B1} = (V_{ON} - V_{CC}) + (2V_{CC} - V_{on})(1 - e^{-t/R_3C_2})$$

$$\approx -V_{CC} + 2V_{CC}(1 - e^{-t/R_3C_2}) \quad \text{for } V_{ON} \ll V_{CC}$$

At t = T/2, v_{B1}=V_{ON}: $$V_{ON} = -V_{CC} + 2V_{CC}(1 - e^{-T/2R_3C_2})$$

Multivibrator Frequency

$$V_{ON} = -V_{CC} + 2V_{CC}(1 - e^{-T/2R_3C_2})$$

$$\therefore V_{CC} \approx 2V_{CC}(1 - e^{-T/2R_3C_2}) \quad \text{for } V_{ON} << V_{CC}$$

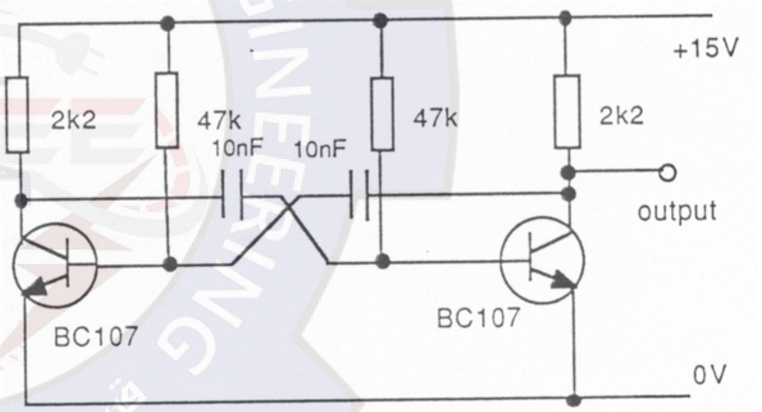
$$\therefore 1 = 2(1 - e^{-T/2R_3C_2})$$

$$\therefore e^{-T/2R_3C_2} = 0.5$$

$$\therefore -\frac{T}{2R_3C_2} = -\ln 2$$

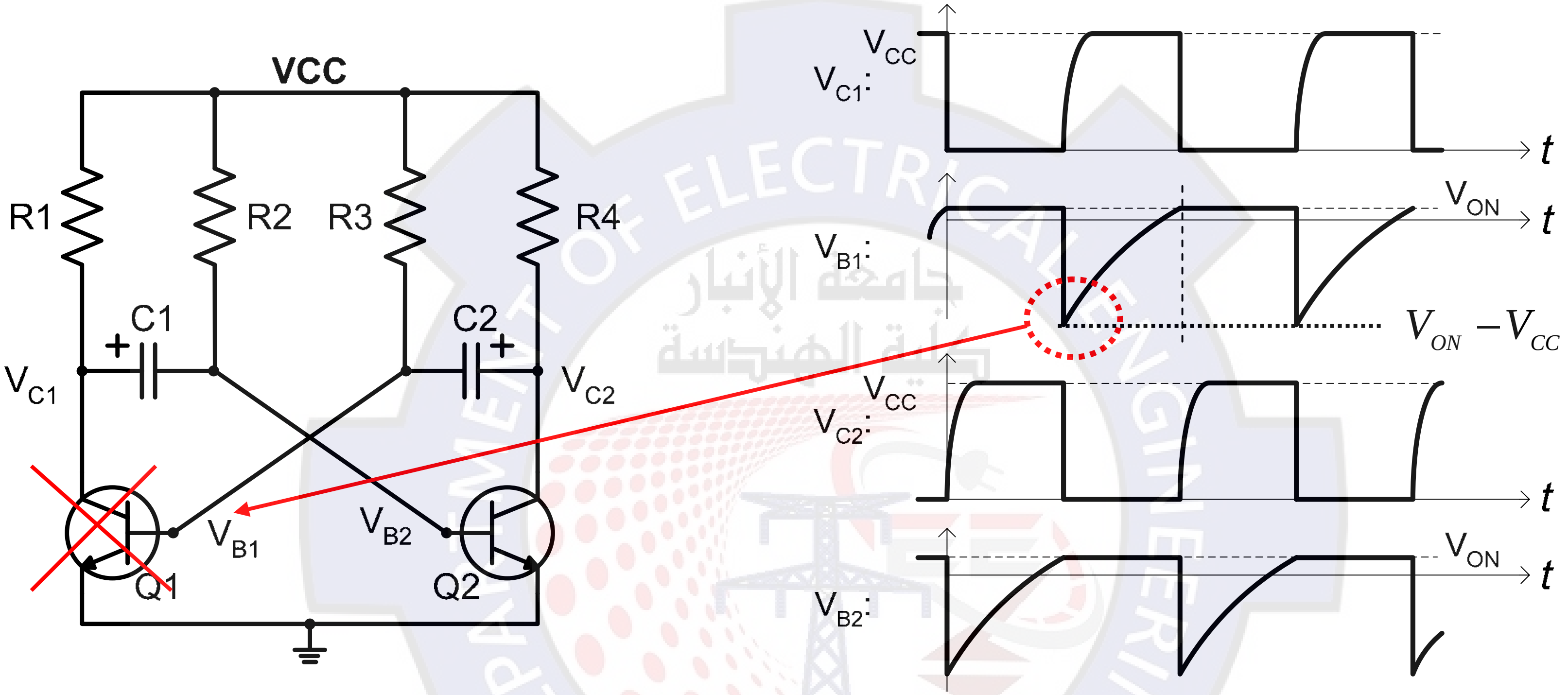
$$\boxed{\therefore T = 2(\ln 2)R_3C_2}$$

or $$\boxed{f = \frac{1}{2(\ln 2)R_3C_2}}$$



For the above component values, f =1.53kHz.

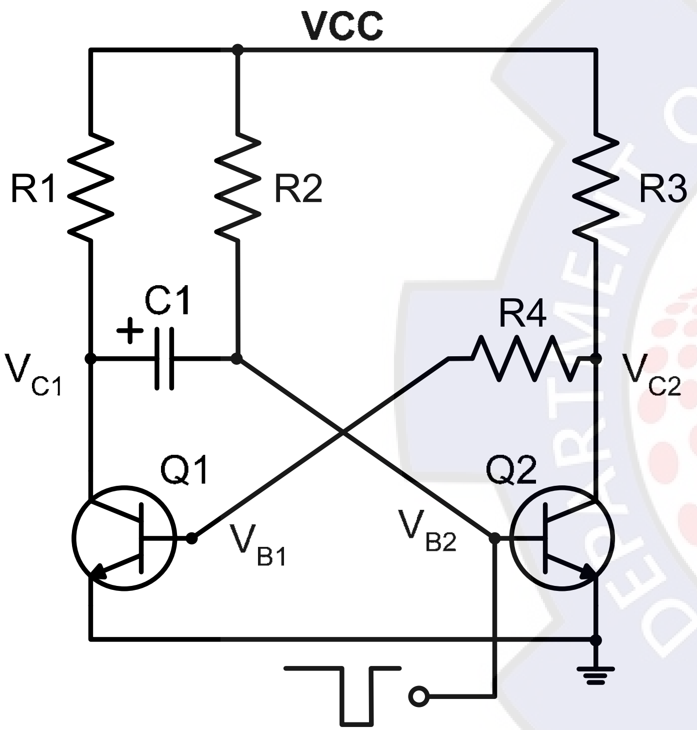
Supply Voltage Limit



- When V_{B1} is negative, BE junction of Q_1 is reverse-biased.
- Suppose the breakdown voltage of this junction is V_{break} (positive). then to avoid breakdown,

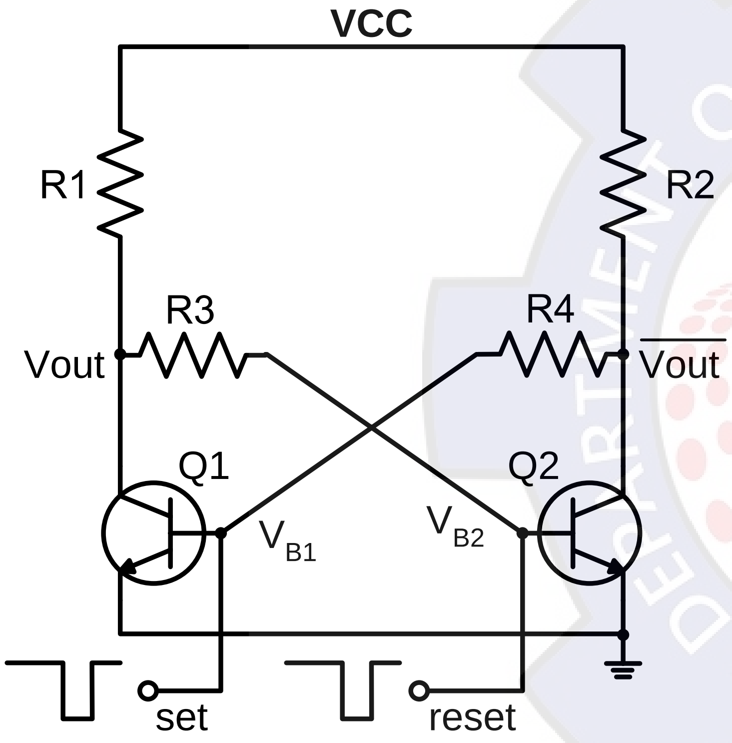
$$V_{ON} - V_{CC} > -V_{Break} \quad \Rightarrow \boxed{V_{CC} < V_{ON} + V_{Break}}$$

Mono-stable Multivibrator



- Capacitive path between V_{C2} and V_{B1} removed.
- Stable for one state (state 2 here)
  - Q_1 OFF and Q_2 ON
  - V_{C1} High, V_{C2} Low
- When V_{B2} is momentarily pulled to ground by an external signal
  - V_{C2} rises to V_{CC}
  - Q_1 turns on
  - V_{C1} pulled down to 0V
  - Enter state 1 temporarily
- When the external signal goes high
  - V_{B2} charges up to V_{CC} through R_2
  - After a certain time T, V_{B2}=V_{ON}, Q_2 turns on
  - V_{C2} pulled to 0V, Q_1 turns off
  - Enters state 2 and remains there
- Can be used as a timer

Bi-stable Multivibrator



- Both capacitors removed
- Stable for either state 1 or 2
- Can be forced to either state by Set or Reset signals
- If Set is low,
  - Q_1 turns off
  - V_{C1} (V_{out}) and V_{B2} rises towards V_{CC}
  - Q_2 turns on
  - V_{C2} (/V_{out}) pulled to 0V
  - V_{B1} is latched to 0V
  - Circuit remains in state 2 until Reset is low
- If Reset is low
  - Similar operation
  - Circuit remains in state 1 until Set is low
- Behave as an RS flip-flop

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Hatem Fahd Al-Duliamy

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Chapter 14

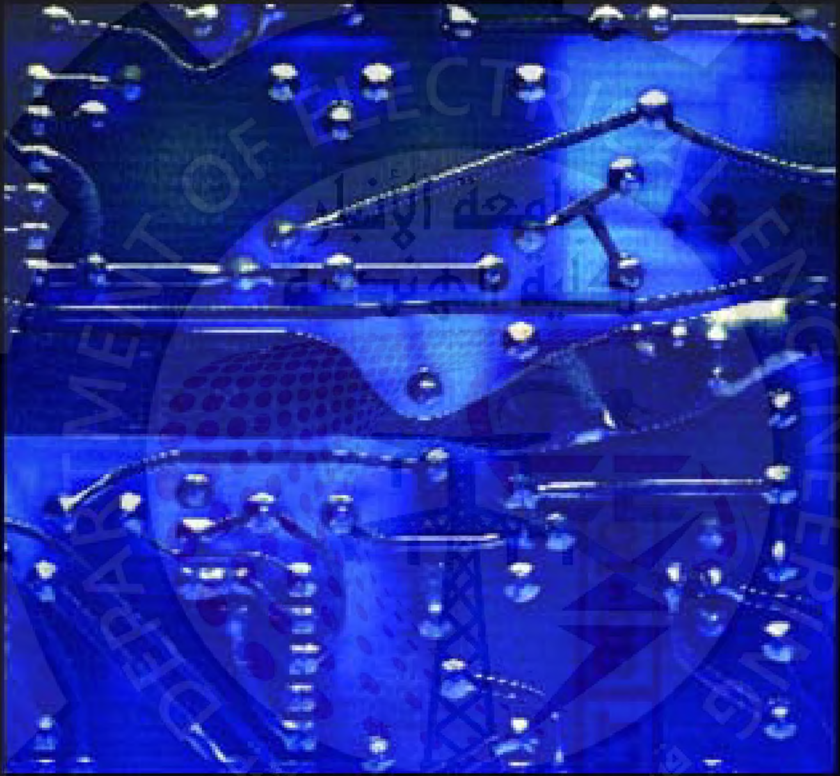
Chapter 14_ Feedback and Oscillator Circuits

Hatem Fahd Al-Duliamy

2018-2019

ELECTRONIC DEVICES AND CIRCUIT THEORY

TENTH EDITION



BOYLESTAD

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Chapter 14
Feedback and Oscillator Circuits

Feedback Concepts

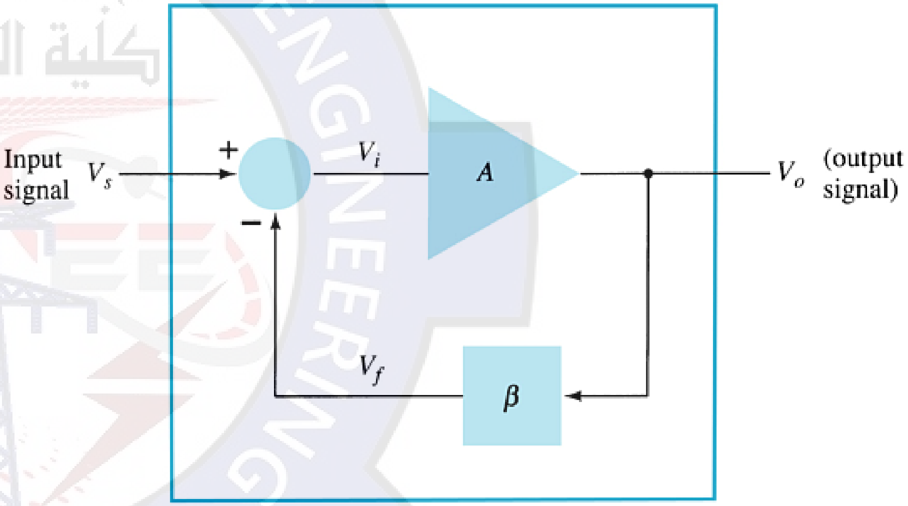
The effects of negative feedback on an amplifier:

Disadvantage

- Lower gain

Advantages

- Higher input impedance
- More stable gain
- Improved frequency response
- Lower output impedance
- Reduced noise
- More linear operation



Feedback amplifier

Feedback Connection Types

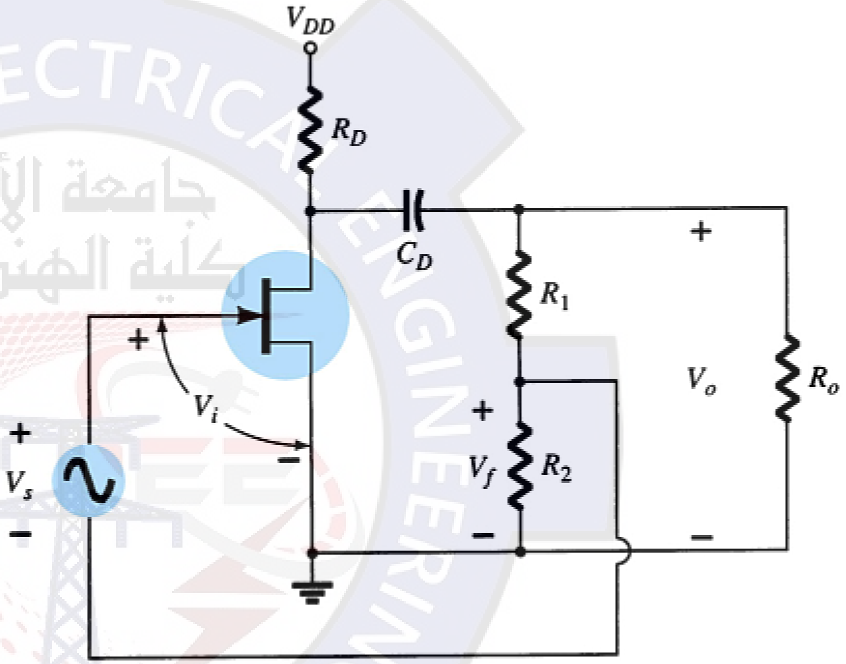
- **Voltage-series feedback**
- **Voltage-shunt feedback**
- **Current-series feedback**
- **Current-shunt feedback**

Voltage-Series Feedback

For voltage-series feedback, the output voltage is fed back in series to the input.

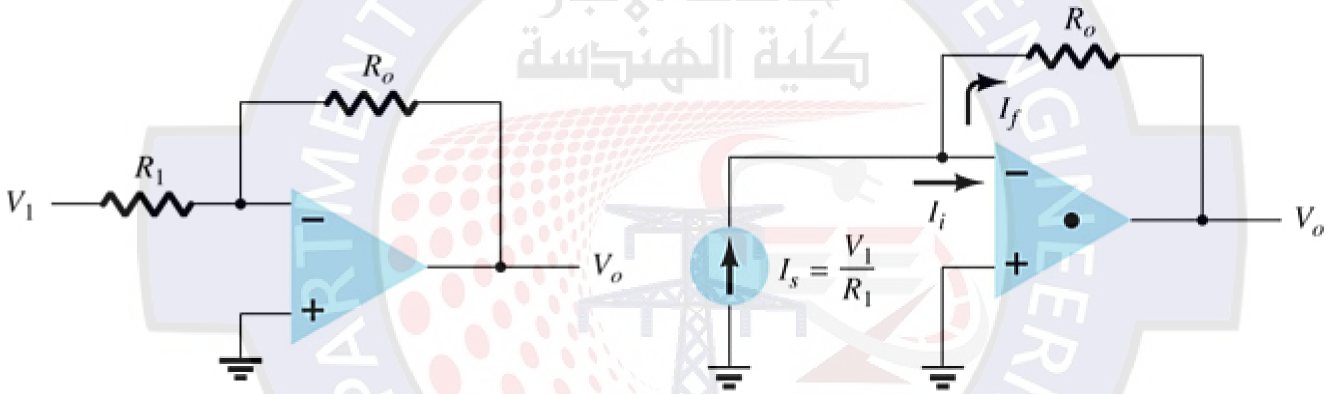
The feedback gain is given by:

$$A_f \cong \frac{1}{\beta} = \frac{R_1 + R_2}{R_2}$$



Voltage-Shunt Feedback

For a voltage-shunt feedback amplifier, the output voltage is fed back in parallel with the input.

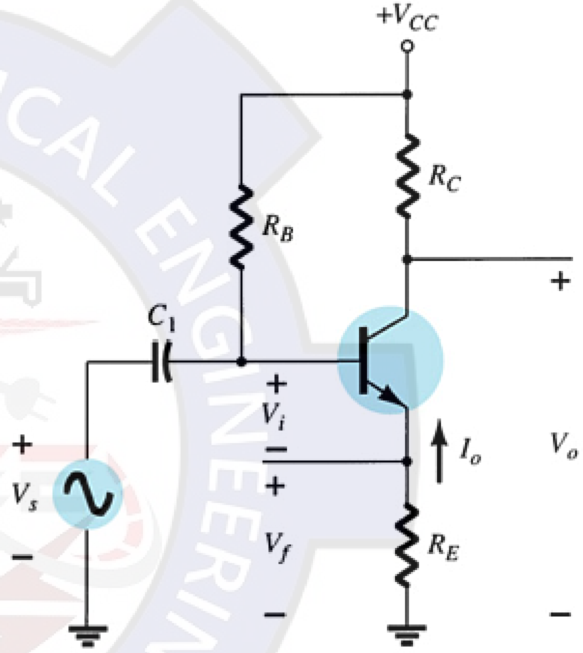


The feedback gain is given by

$$A_f = -\frac{R_o}{R_i}$$

Current-Series Feedback

For a current-series feedback amplifier, a portion of the output current is fed back in series with the input.

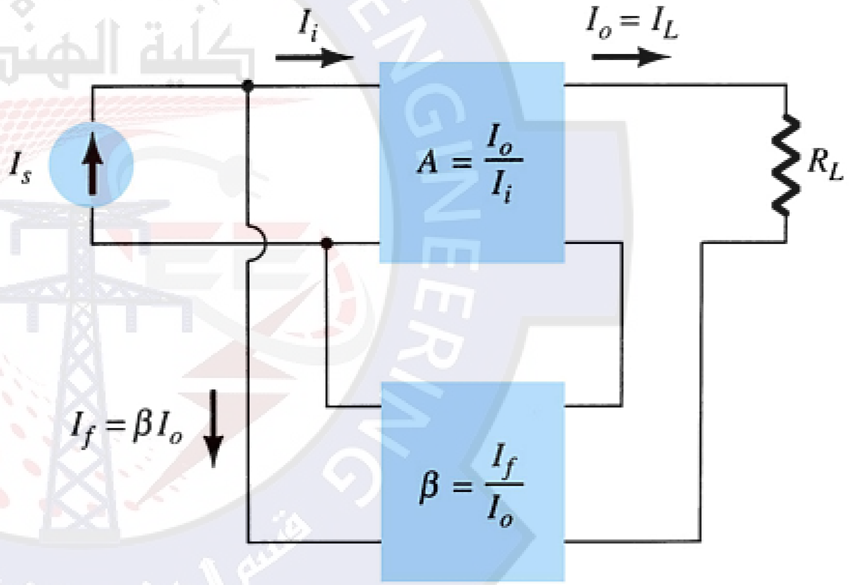


To determine the feedback gain:

$$A_f = \frac{I_o}{V_s} = \frac{A}{1+\beta A} = \frac{-h_{fe}/h_{ie}}{1+(-R_E)\left(\dfrac{-h_{fe}}{h_{ie}+R_E}\right)} \cong \frac{-h_{fe}}{h_{ie}+h_{fe}R_E}$$

Current-Shunt Feedback

For a current-shunt feedback amplifier, a portion of the output current is directed back in parallel with the input.



The feedback gain is given by:

$$A_f = \frac{I_o}{I_s}$$

Summary of Feedback Effects

Summary of Gain, Feedback, and Gain with Feedback

		Voltage-Series	Voltage-Shunt	Current-Series	Current Shunt
Gain without feedback	A	$\frac{V_o}{V_i}$	$\frac{V_o}{I_i}$	$\frac{I_o}{V_i}$	$\frac{I_o}{I_i}$
Feedback	b	$\frac{V_f}{V_o}$	$\frac{I_f}{V_o}$	$\frac{V_f}{I_o}$	$\frac{I_f}{I_o}$
	A_f	$\frac{V_o}{V_s}$	$\frac{V_o}{I_s}$	$\frac{I_o}{V_s}$	$\frac{I_o}{I_s}$

Effect of Feedback Connection on Input and Output Impedance

	Voltage-Series	Current-Series	Voltage-Shunt	Current-Shunt
Z_{if}	$Z_i\,(1+\beta A)$ (increased)	$Z_i\,(1+\beta A)$ (increased)	$\frac{Z_i}{1+\beta A}$ (decreased)	$\frac{Z_i}{1+\beta A}$ (decreased)
Z_{of}	$\frac{Z_o}{1+\beta A}$ (decreased)	$Z_o\,(1+\beta A)$ (increased)	$\frac{Z_o}{1+\beta A}$ (decreased)	$Z_o\,(1+\beta A)$ (increased)

Frequency Distortion with Feedback

- **If the feedback network is purely resistive, then the gain with feedback will be less dependent on frequency variations. In some cases the resistive feedback removes all dependence on frequency variations.**

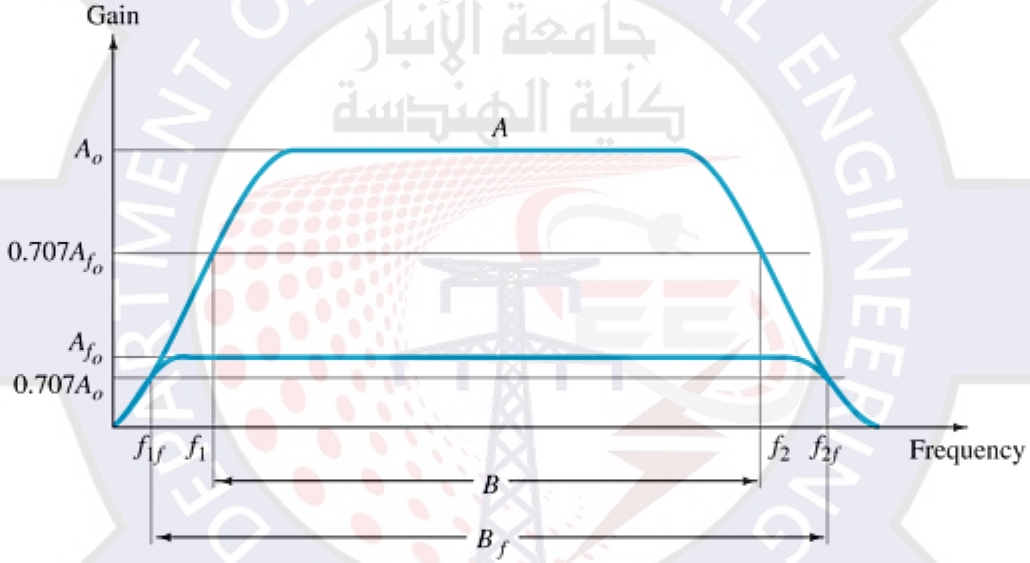
- **If the feedback includes frequency dependent components (capacitors and inductors), then the frequency response of the amplifier will be affected.**

Noise and Nonlinear Distortion

- **The feedback network reduces noise by cancellation. The phase of the feedback signal is often opposite the phase of the input signal.**
- **Nonlinear distortion is also reduced simply because the gain is reduced. The amplifier is operating in midrange and not at the extremes.**

Bandwidth with Feedback

Feedback increases the bandwidth of an amplifier.



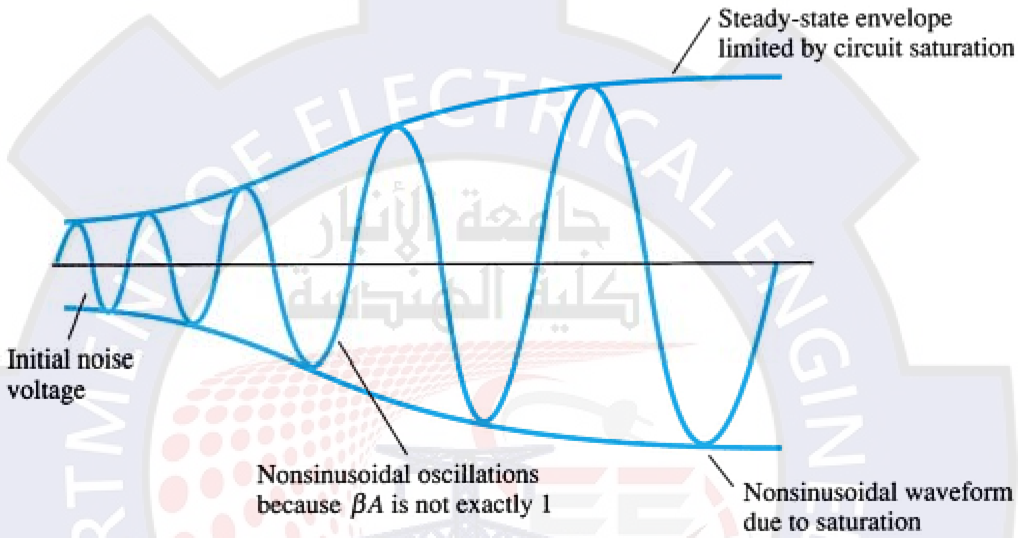
Gain Stability with Feedback

Gain calculations with feedback are often based on external resistive elements in the circuit. By removing gain calculations from internal variations of β and g_m, the gain becomes more stable.

Phase and Frequency Considerations

At higher frequencies the feedback signal may no longer be out of phase with the input. The feedback is thus positive and the amplifier, itself, becomes unstable and begins to

Oscillator Operation



The feedback signal must be positive.

If the feedback signal is not positive or the gain is less than one, the oscillations dampens out.

The overall gain must equal one (unity gain).

If the overall gain is greater than one, the oscillator eventually saturates.

Types of Oscillator Circuits

Phase-shift oscillator
Wien bridge oscillator
Tuned oscillator circuits
Crystal oscillators
Unijunction oscillator

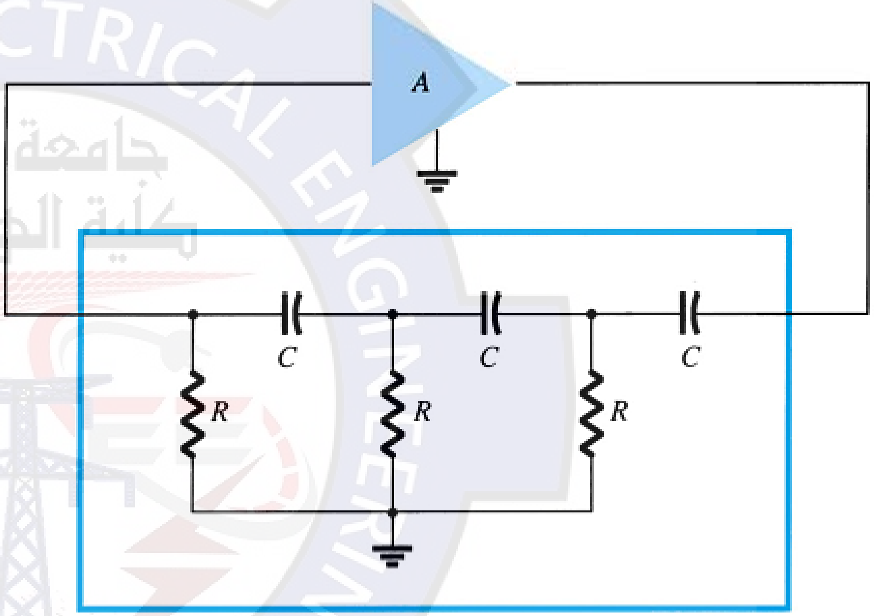
Phase-Shift Oscillator

The amplifier must supply enough gain to compensate for losses. The overall gain must be unity.

The RC networks provide the necessary phase shift for a positive feedback.

The values of the RC components also determine the frequency of oscillation:

$$f = \frac{1}{2\pi RC\sqrt{6}}$$



Feedback network

more…

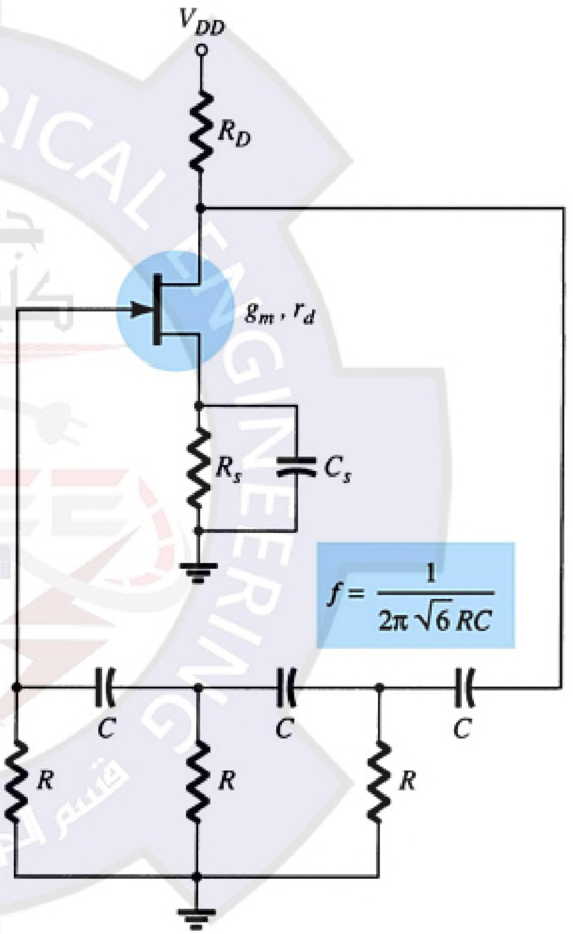
Phase-Shift Oscillator

The amplifier must supply enough gain to compensate for losses. The overall gain must be unity.

The RC networks provide the necessary phase shift for a positive feedback.

The values of the RC components also determine the frequency of oscillation:

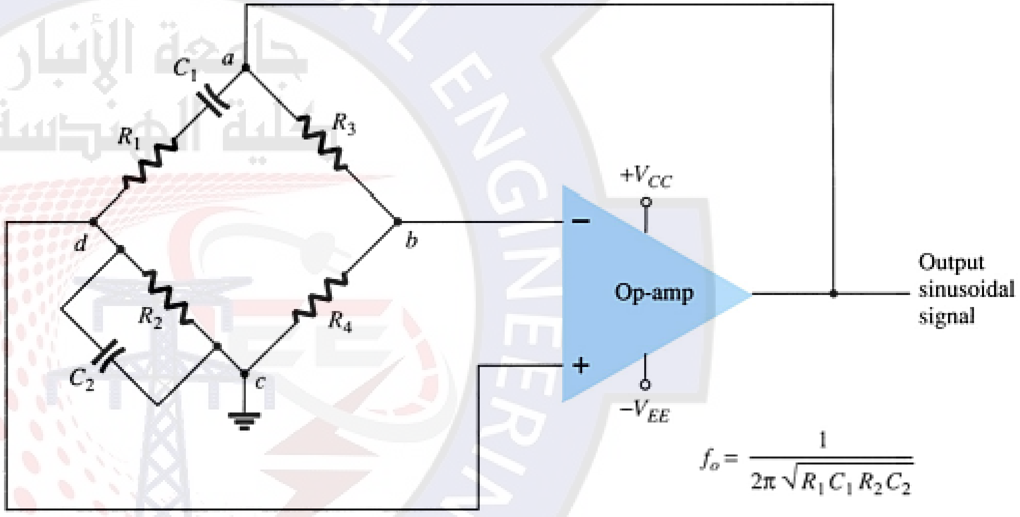
$$f = \frac{1}{2\pi\sqrt{6}RC}$$



Wien Bridge Oscillator

The amplifier must supply enough gain to compensate for losses. The overall gain must be unity.

- The feedback resistors are R_3 and R_4.
- The phase-shift components are R_1, C_1 and R_2, C_2.



$$f_o = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}}$$

Tuned Oscillator Circuits

Tuned oscillators use a parallel LC resonant circuit (LC tank) to provide the oscillations.

There are two common types:

- **Colpitts**—The resonant circuit is an inductor and two capacitors.
- **Hartley**—The resonant circuit is a tapped inductor or two inductors and one capacitor.

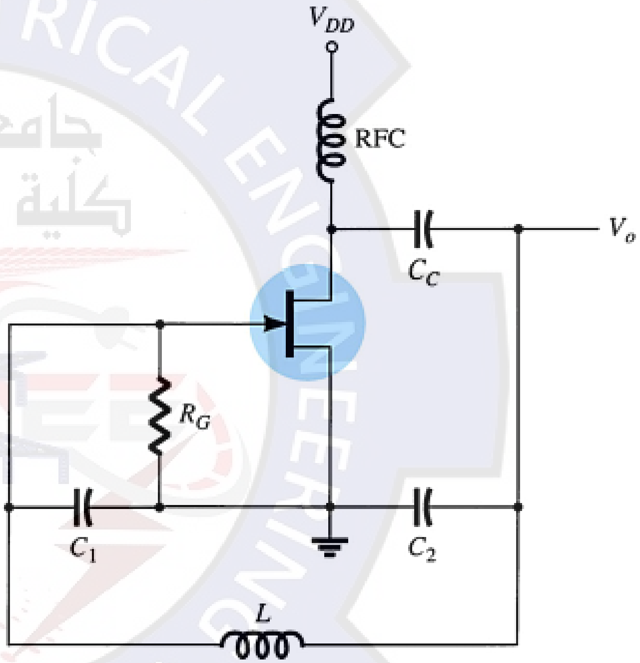
Colpitts Oscillator Circuit

The frequency of oscillation is determined by:

$$f_o = \frac{1}{2\pi\sqrt{LC_{eq}}}$$

where:

$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$



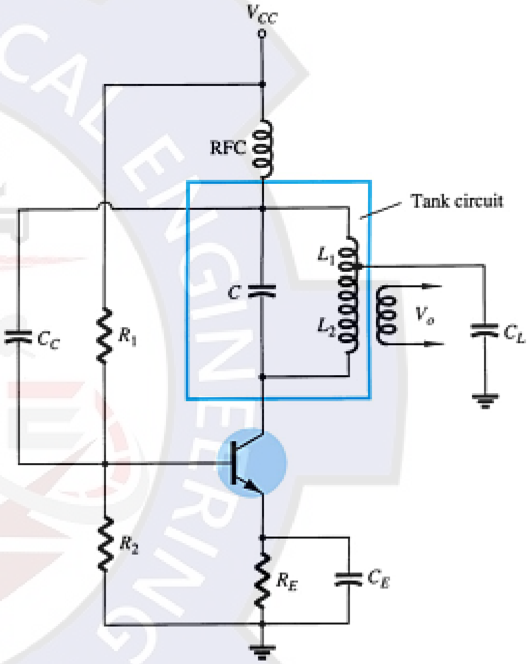
Hartley Oscillator Circuit

The frequency of oscillation is determined by:

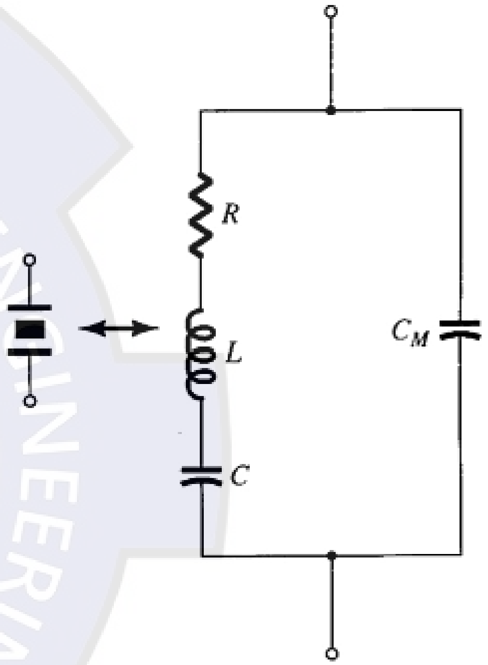
$$f_o = \frac{1}{2\pi\sqrt{L_{eq}C}}$$

where:

$$L_{eq} = L_1 + L_2 + 2M$$



Crystal Oscillators



The crystal appears as a resonant circuit.

The crystal has two resonant frequencies:

Series resonant condition

- **RLC determine the resonant frequency**
- **The crystal has a low impedance**

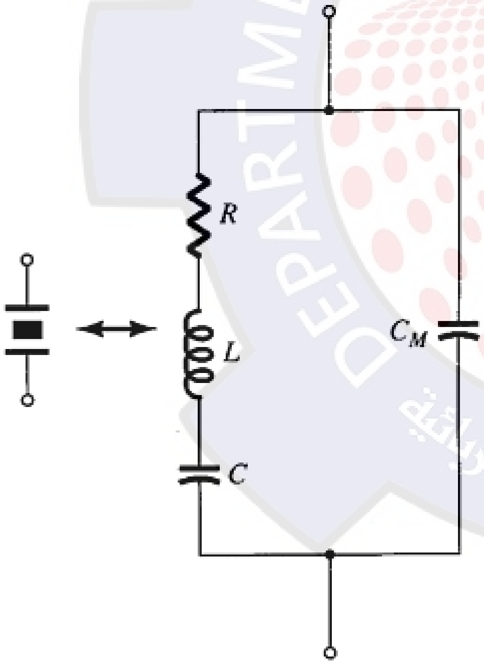
Parallel resonant condition

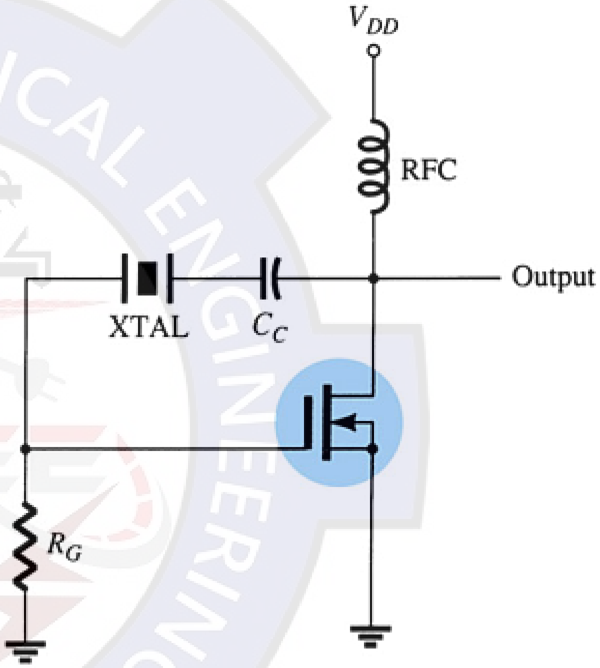
- **RL and C_M determine the resonant frequency**
- **The crystal has a high impedance**

The series and parallel resonant frequencies are very close, within 1% of each other.

Series Resonant Crystal Oscillator

- RLC determine the resonant frequency
- The crystal has a low impedance

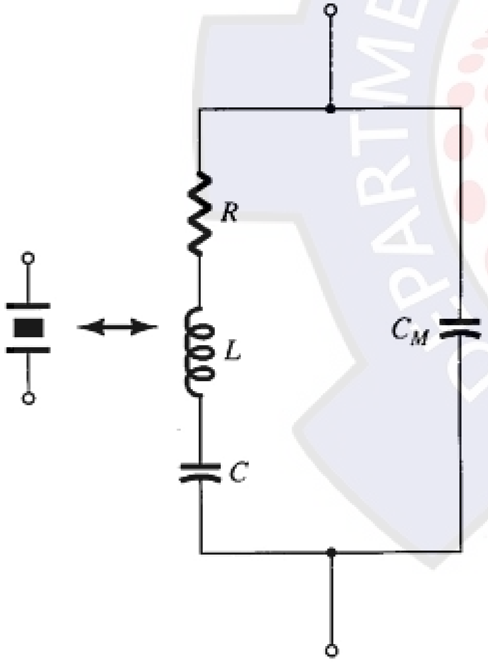


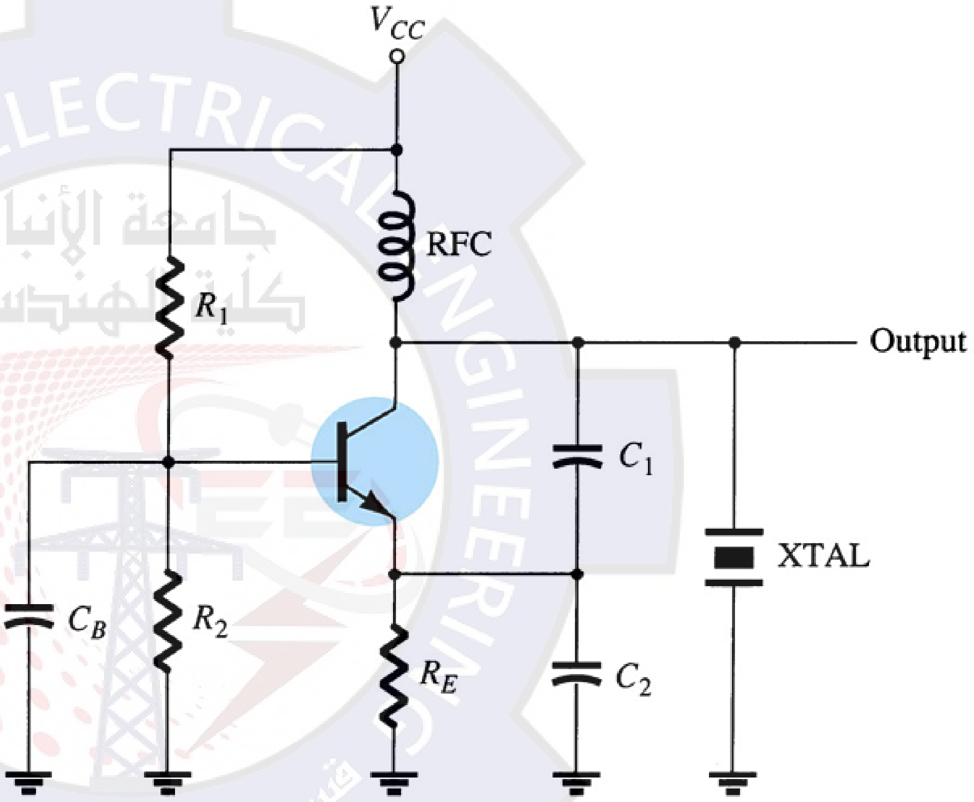


Parallel Resonant Crystal Oscillator

- R_L and C_M determine the resonant frequency

- The crystal has a high impedance



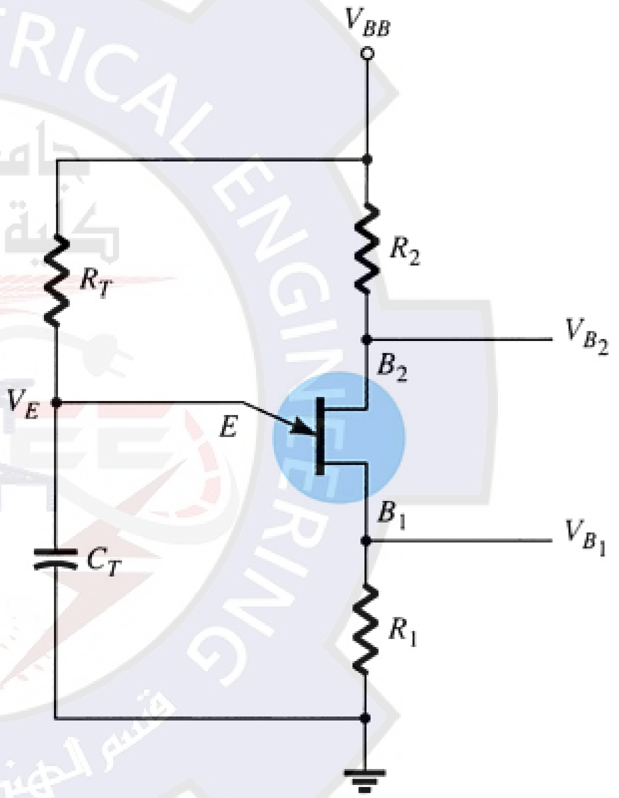


Unijunction Oscillator

The output frequency is determined by:

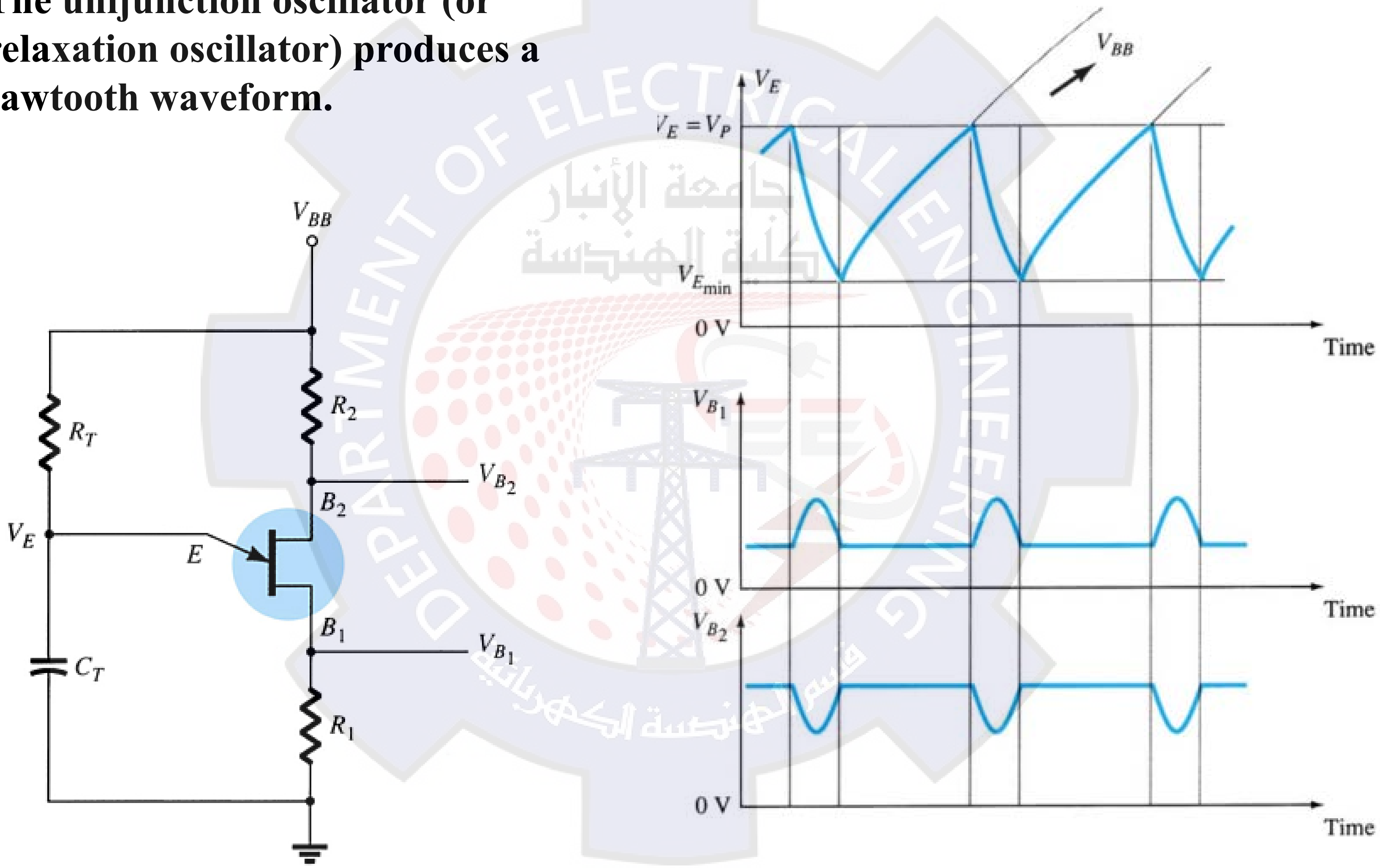
$$f_o = \frac{1}{R_T C_T \ln[1/(1-\eta)]}$$

Where η is a rating of the unijunction transistor with values between 0.4 and 0.6.



Unijunction Oscillator Waveforms

The unijunction oscillator (or relaxation oscillator) produces a sawtooth waveform.



Republic of Iraq
Ministry of Higher Education and Seintific Reserch University of AL-Anbar
College of Engineering
Electrical Engineering Department

Electronic II

By

Hatem Fahd Al-Duliamy

2018-2019

UNIVERSITY OF ANBAR

COLLEGE OF ENGINEERING

ELECTRICAL ENGINEERING DEPARTMENT

Electronic II

Third Class

Chapter 15

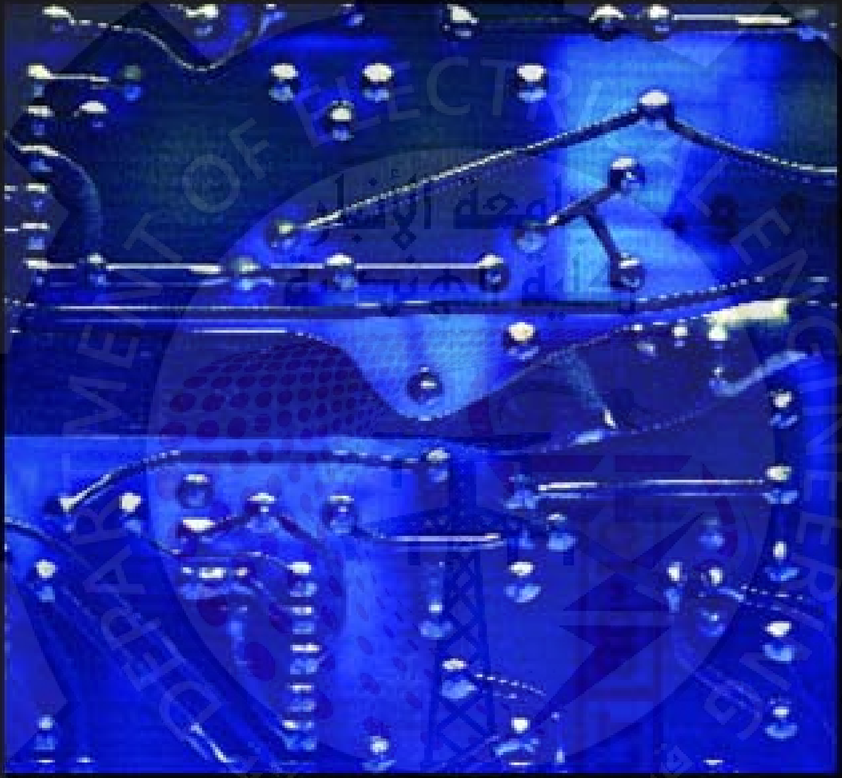
(Chapter 15_ Power Supplies (Voltage Regulators

Hatem Fahd Al-Duliamy

2018-2019

ELECTRONIC DEVICES AND CIRCUIT THEORY

TENTH EDITION



BOYLESTAD

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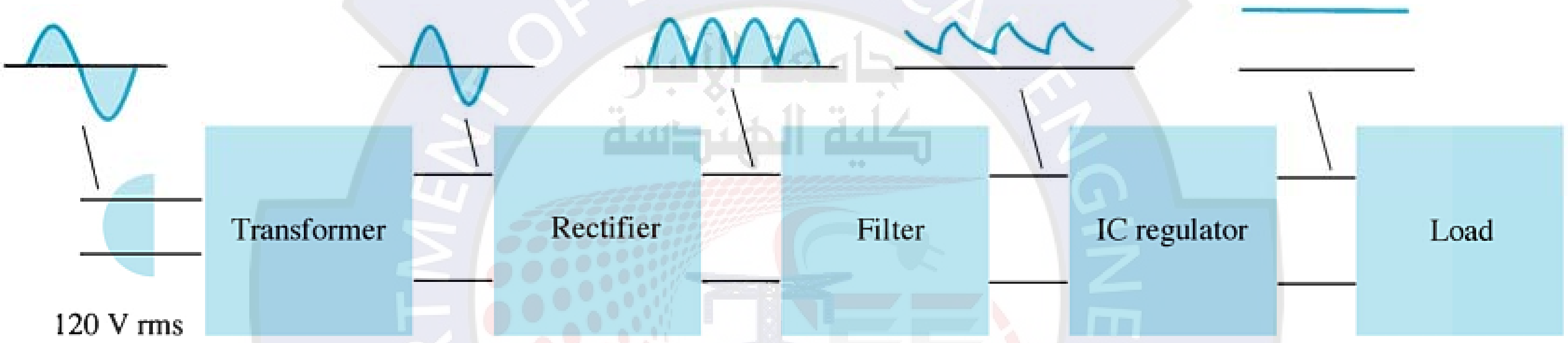
Chapter 15
Power Supplies
(Voltage Regulators)

Power Supply Diagram



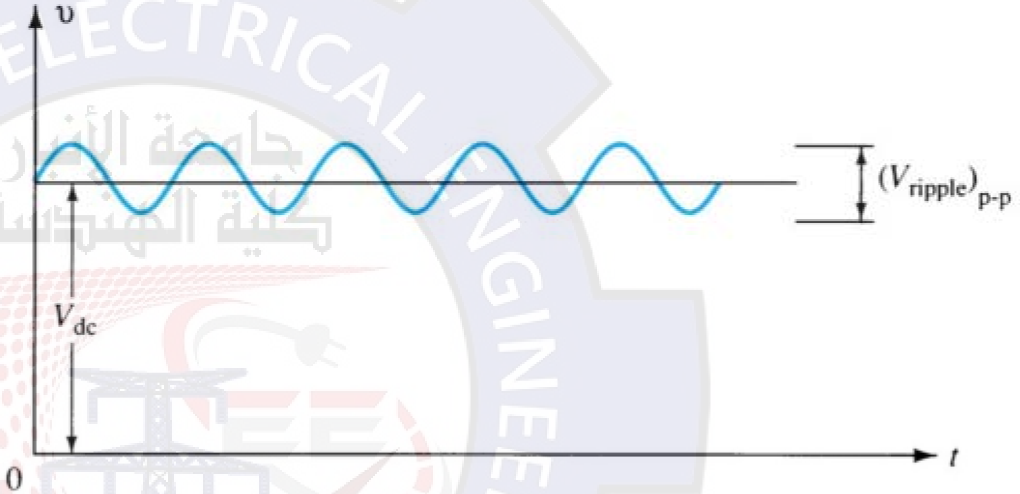
Filter Circuits

- The output from the rectifier section is a pulsating DC.

- The filter circuit reduces the peak-to-peak pulses to a small ripple voltage.

Ripple Factor

After the filter circuit a small amount of AC is still remaining. The amount of ripple voltage can be rated in terms of **ripple factor** (r).



$$\%r = \frac{\text{ripple voltage (rms)}}{\text{dc voltage}} = \frac{V_{r(rms)}}{V_{dc}} \times 100$$

Rectifier Ripple Factor

Half-Wave

DC output:

$$V_{dc} = 0.318V_m$$

AC ripple output:

$$V_{r(rms)} = 0.385V_m$$

Ripple factor:

$$\%r = \frac{V_{r(rms)}}{V_{dc}} \times 100$$

$$= \frac{0.385V_m}{0.318V_m} \times 100 = 121\%$$

Full-Wave

DC output:

$$V_{dc} = 0.636V_m$$

AC ripple output:

$$V_{r(rms)} = 0.308V_m$$

Ripple factor:

$$\%r = \frac{V_{r(rms)}}{V_{dc}} \times 100$$

$$= \frac{0.308V_m}{0.636V_m} \times 100 = 48\%$$

Types of Filter Circuits

Capacitor Filter

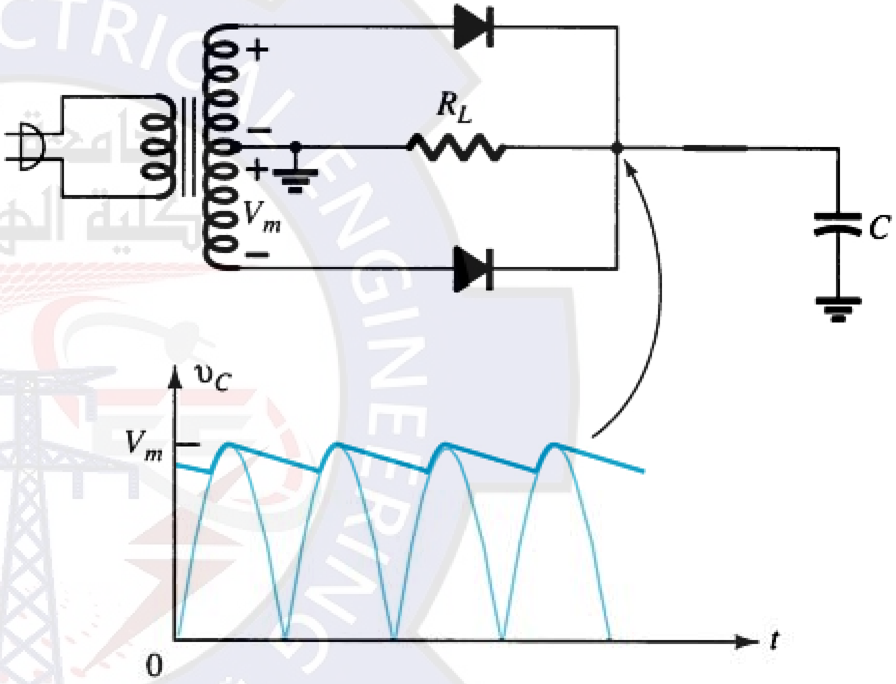
RC Filter

Capacitor Filter

Ripple voltage

$$V_{r(rms)} = \frac{I_{dc}}{4\sqrt{3}fC} = \frac{2.4I_{dc}}{C} = \frac{2.4V_{dc}}{R_LC}$$

The larger the capacitor the smaller the ripple voltage.



DC output

$$V_{dc} = V_m - \frac{I_{dc}}{4fC} = V_m - \frac{4.17I_{dc}}{C}$$

Ripple factor

$$\%r = \frac{V_{r(rms)}}{V_{dc}} \times 100 = \frac{2.4I_{dc}}{CV_{dc}} \times 100 = \frac{2.4}{RLC} \times 100$$

Diode Ratings with Capacitor Filter

The size of the capacitor increases the current drawn through the diodes—the larger the capacitance, the greater the amount of current.

Peak Current vs. Capacitance:

$$I = \frac{CV}{t}$$

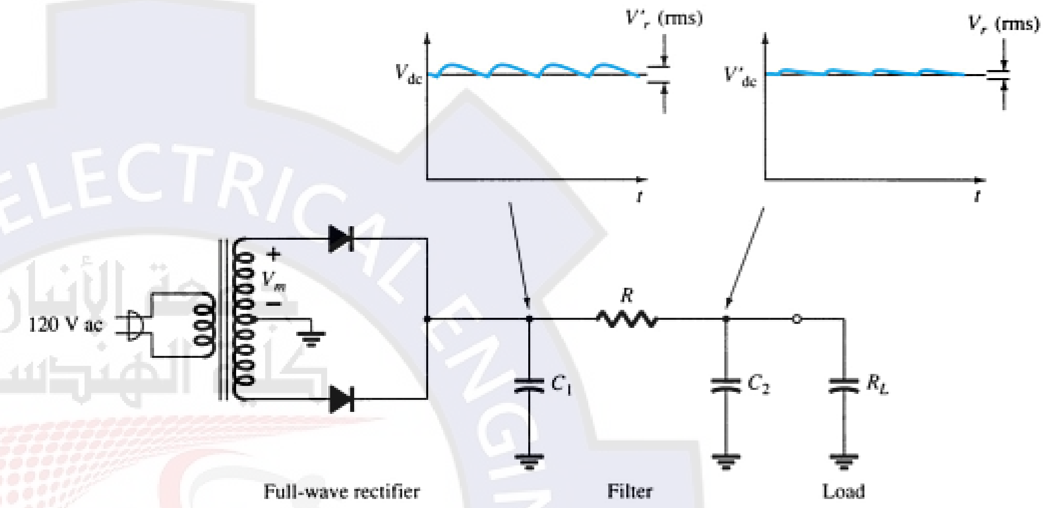
where

C = capacitance

V = change in capacitor voltage during charge/discharge

t = the charge/discharge time

RC Filter Circuit



Adding an RC section further reduces the ripple voltage and decrease the surge current through the diodes.

$$V'_{r(rms)} \approx \frac{X_C}{R} V_{r(rms)}$$

$V'_{r(rms)}$ = ripple voltage after the RC filter
$V_{r(rms)}$ = ripple voltage before the RC filter
R = resistor in the added RC filter
X_C = reactance of the capacitor in the added RC filter

$$\%V_R = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$$

V_{NL} = no-load voltage
V_{FL} = full-load voltage

Voltage Regulation Circuits

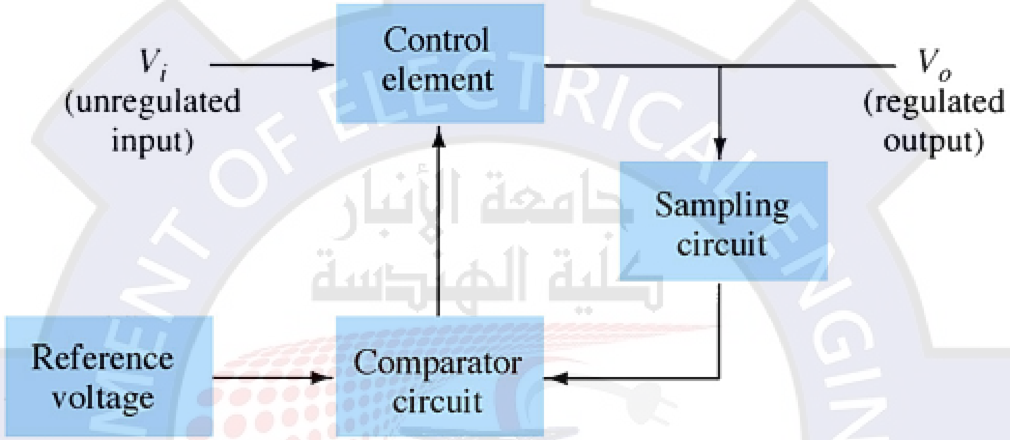
There are two common types of circuitry for voltage regulation:

- **Discrete Transistors**
- **IC's**

Discrete-Transistor Regulators

Series voltage regulator
Current-limiting circuit
Shunt voltage regulator

Series Voltage Regulator Circuit

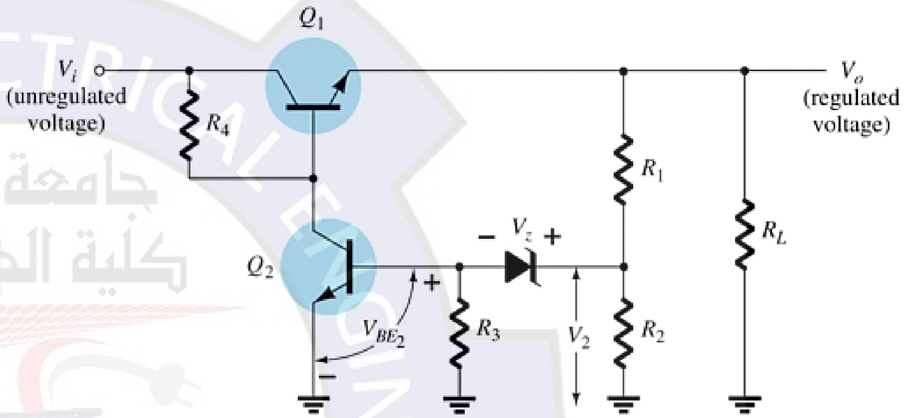


The series element controls the amount of the input voltage that gets to the output.

If the output voltage increases (or decreases), the comparator circuit provides a control signal to cause the series control element to decrease (or increase) the amount of the output voltage.

Series Voltage Regulator Circuit

- R_1 and R_2 act as the sampling circuit
- Zener provides the reference voltage
- Q_2 controls the base current to Q_1
- Q_1 maintains the constant output voltage



When the output increases:

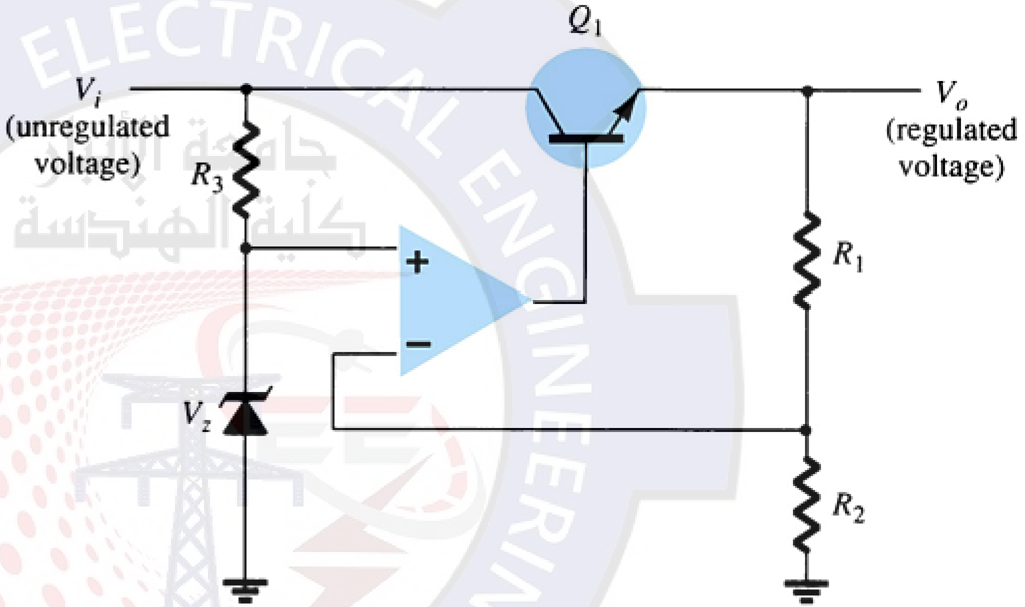
1. The voltage at V_2 and V_{BE} of Q_2 increases
2. The conduction of Q_2 increases
3. The conduction of Q_1 decreases
4. The output voltage decreases

When the output decreases:

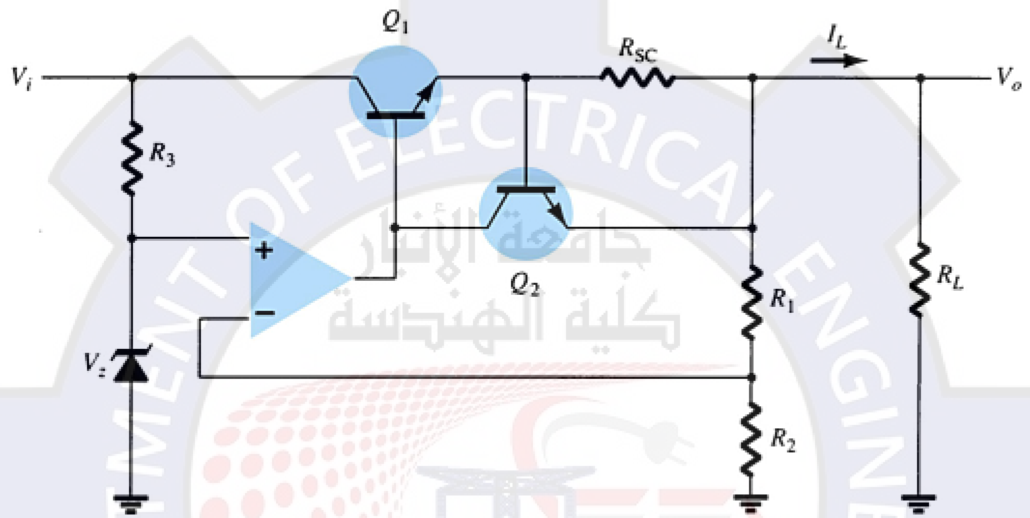
1. The voltage at V_2 and V_{BE} of Q_2 decreases
2. The conduction of Q_2 decreases
3. The conduction of Q_1 increases
4. The output voltage increases

Series Voltage Regulator Circuit

The op-amp compares the Zener diode voltage with the output voltage (at R_1 and R_2) and controls the conduction of Q_1.



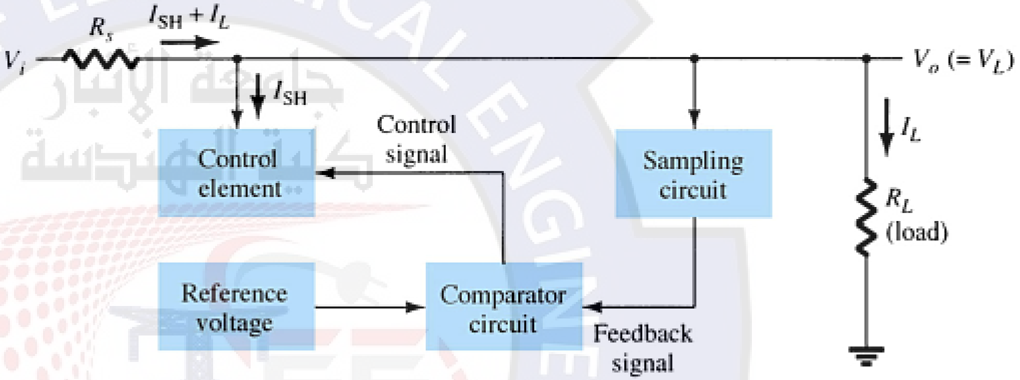
Current-Limiting Circuit



When I_L increases:

- The voltage across R_{SC} increases
- The increasing voltage across R_{SC} drives Q_2 on
- Conduction of Q_2 reduces current for Q_1 and the load

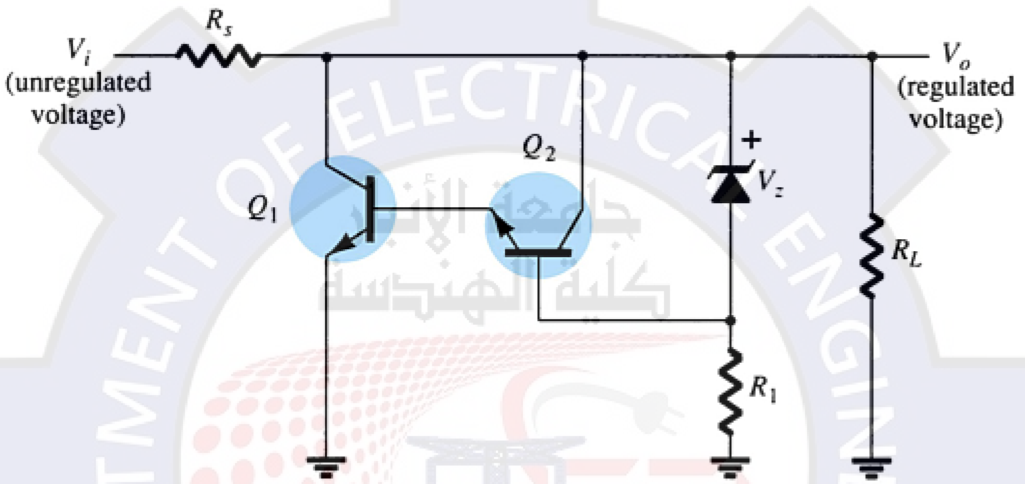
Shunt Voltage Regulator Circuit



The shunt voltage regulator shunts current away from the load.

The load voltage is sampled and fed back to a comparator circuit. If the load voltage is too high, control circuitry shunts more current away from the load.

Shunt Voltage Regulator Circuit



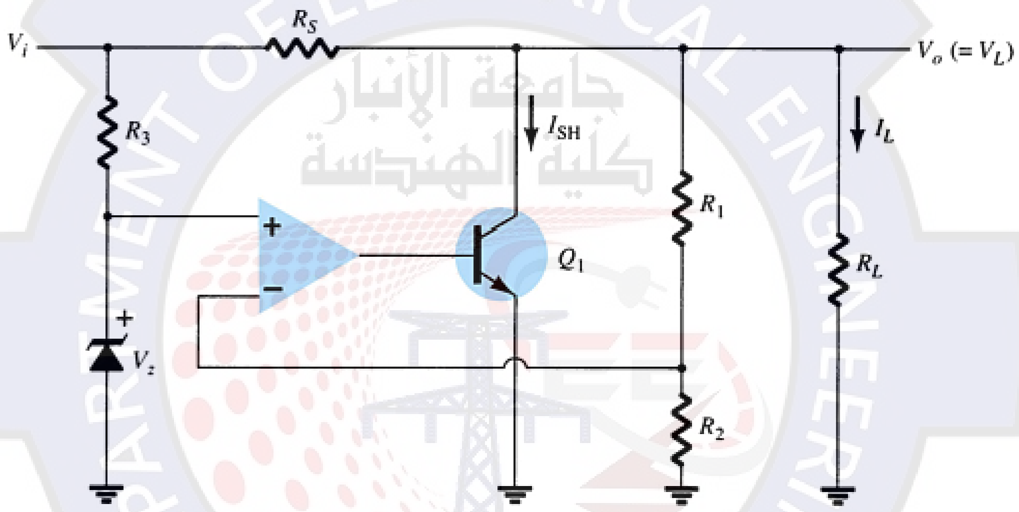
When the output voltage increases:

- The Zener current increases
- The conduction of Q_2 increases
- The voltage drop at R_s increases
- The output voltage decreases

When the output voltage decreases:

- The Zener current decreases
- The conduction of Q_2 decreases
- The voltage drop at R_s decreases
- The output voltage increases

Shunt Voltage Regulator Circuit



IC Voltage Regulators

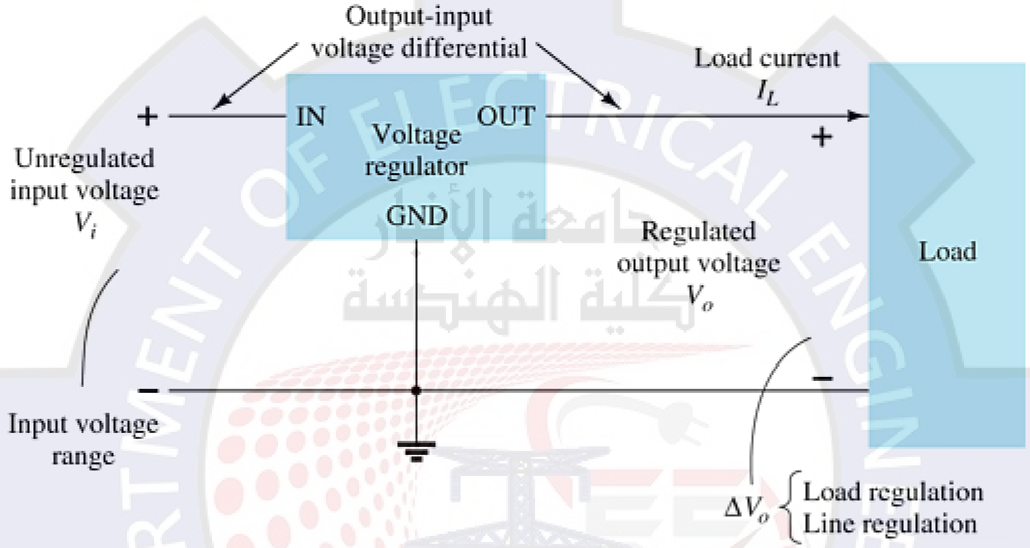
Regulator ICs contain:

- **Comparator circuit**
- **Reference voltage**
- **Control circuitry**
- **Overload protection**

Types of three-terminal IC voltage regulators

- **Fixed positive voltage regulator**
- **Fixed negative voltage regulator**
- **Adjustable voltage regulator**

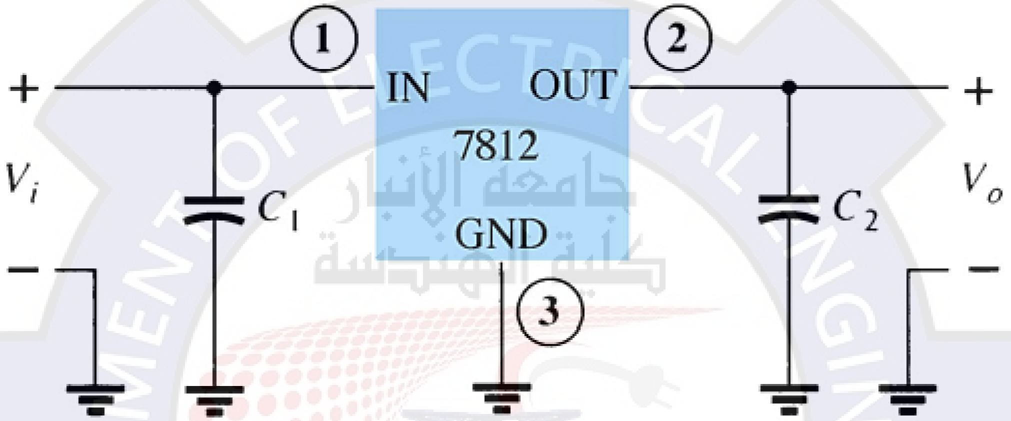
Three-Terminal Voltage Regulators



The specifications for this IC indicate:

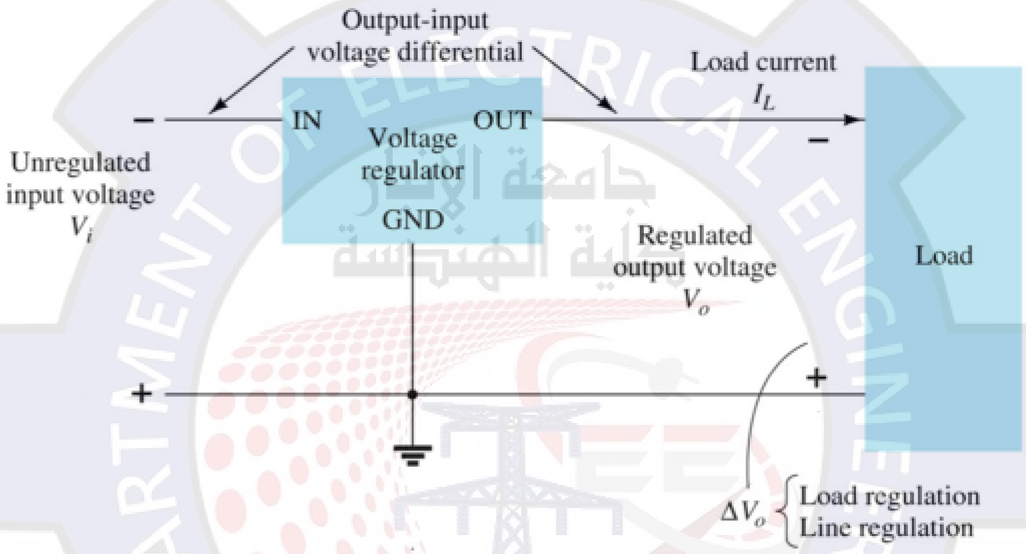
- **The range of input voltages that can be regulated for a specific range of output voltage and load current**
- **Load regulation—variation in output voltage with variations in load current**
- **Line regulation—variation in output voltage with variations in input voltage**

Fixed Positive Voltage Regulator



These ICs provide a fixed positive output voltage.

Fixed Negative Voltage Regulator

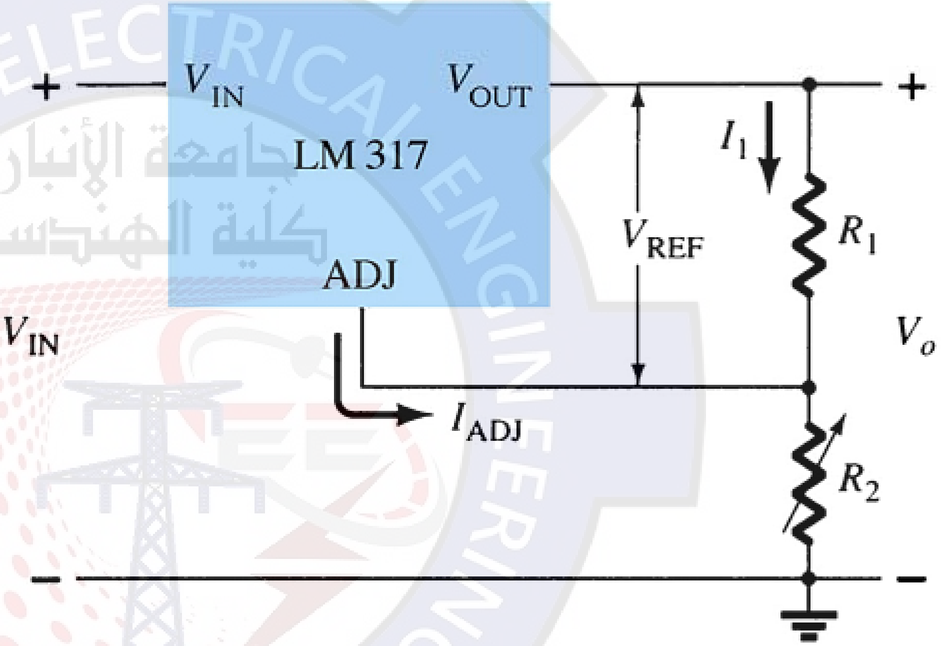


These ICs output a fixed negative output voltage.

Adjustable Voltage Regulator

These regulators have adjustable output voltages.

The output voltage is commonly selected using a potentiometer.



Practical Power Supplies

DC supply (linear power supplies)
Chopper supply (switching power supplies)
TV horizontal high voltage supply
Battery chargers