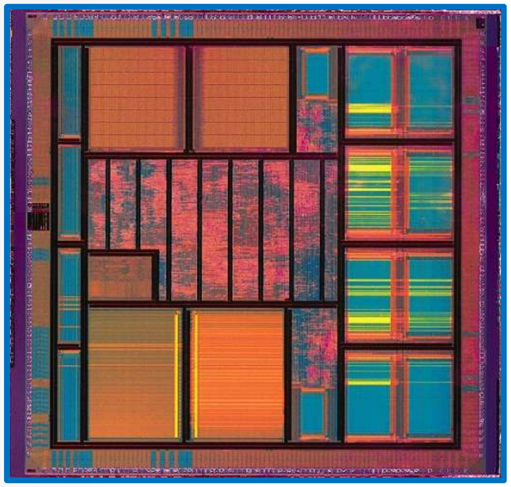
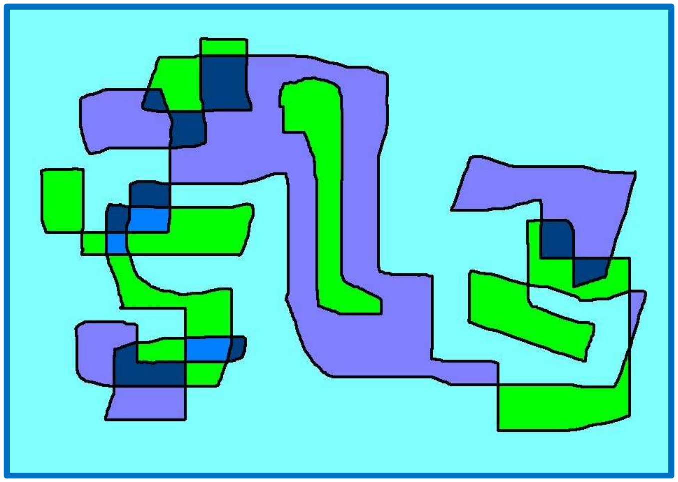
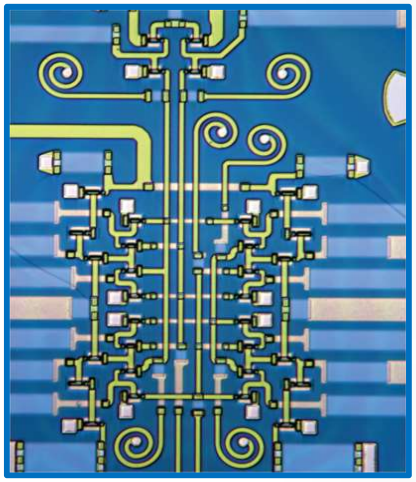


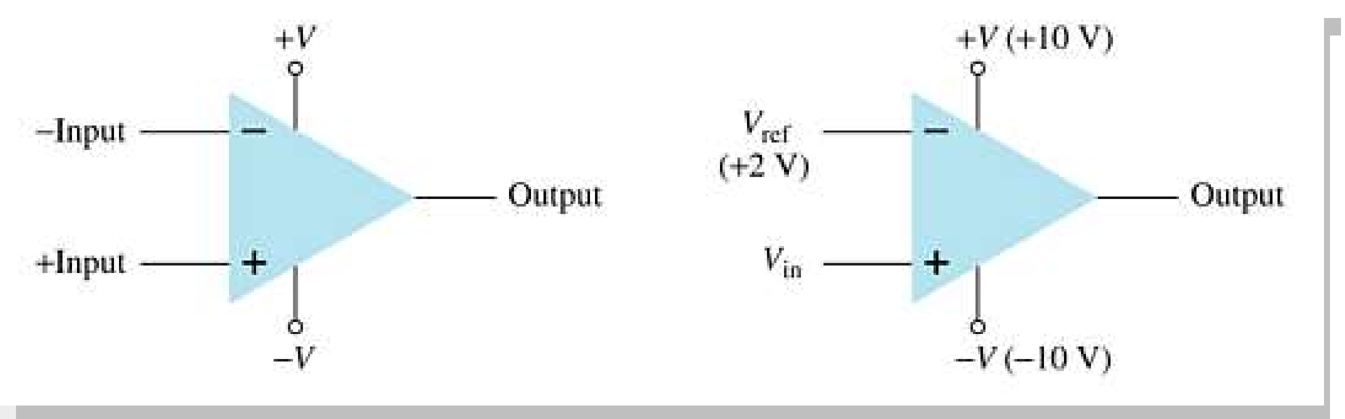


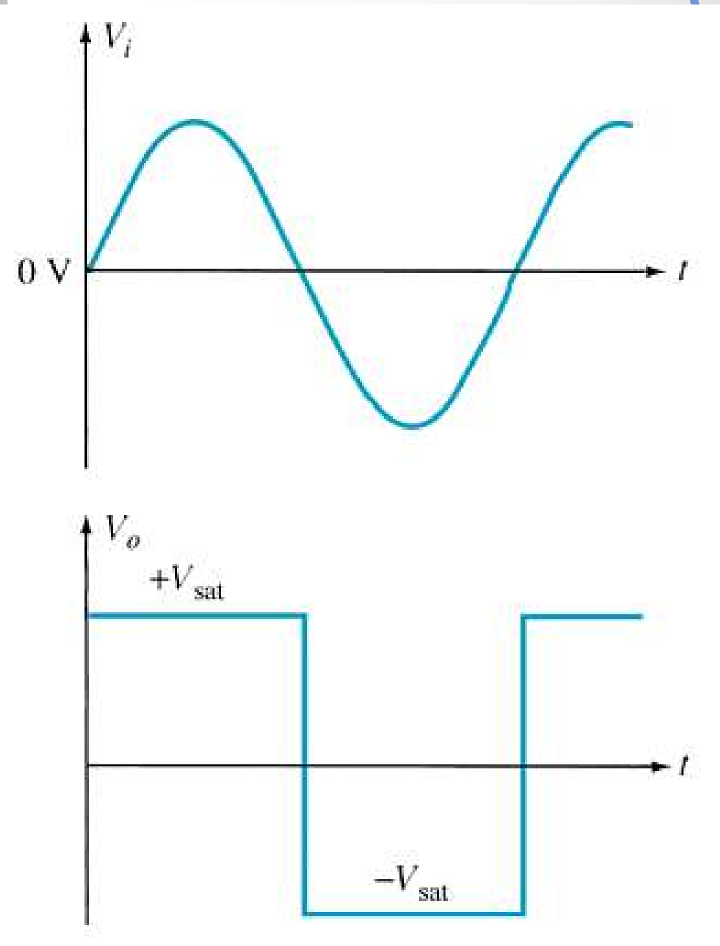


ENE/EIE 211 : Electronic Devices and Circuit Design II

Lectures 12: Oscillators, Regulators and Phase-Locked Loop

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:

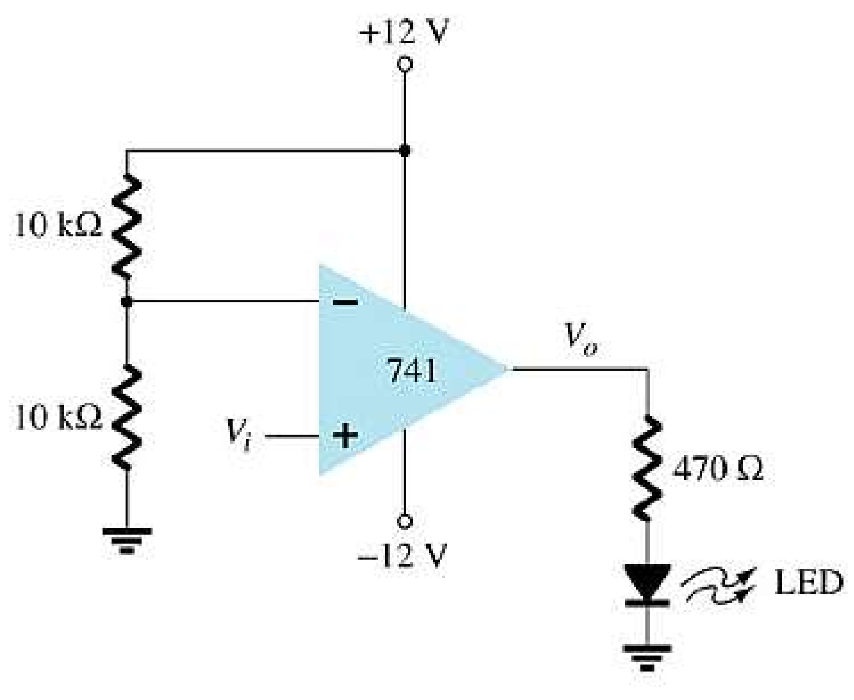
- The maximum high output voltage is $+V_{SAT}$.
- The minimum low output voltage is $-V_{SAT}$.

$$V_{in+} > V_{in-} \text{ then } V_{out} = +V_{sat}$$
$$V_{in+} < V_{in-} \text{ then } V_{out} = -V_{sat}$$

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:

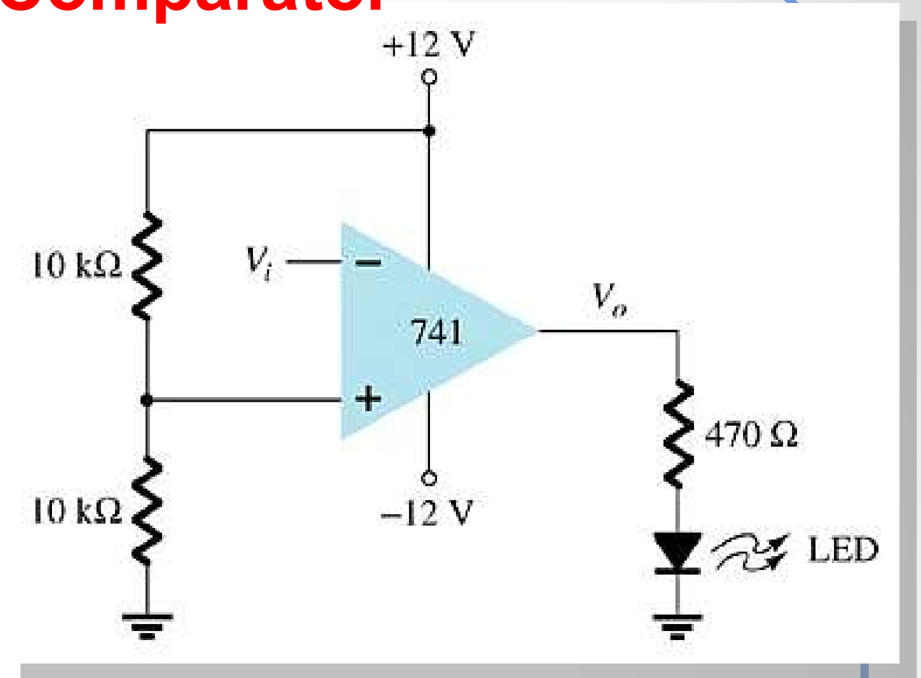
- V_{ref} in this circuit is +6V (taken from the voltage divider)
- $+V_{SAT}$ = +V, or +12V
- $-V_{SAT}$ = -V or –12V

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

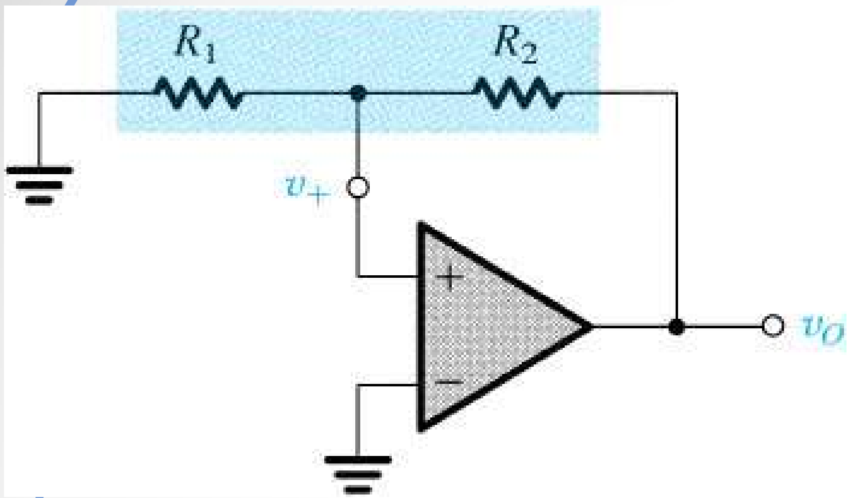
When V_i is greater than +6V the output swings to –12V and the LED goes off.
When V_i is less than +6V the output is at +12V and the LED goes on.

Schmitt Trigger Oscillator

The non-linear oscillators or function generators belong to a special class of circuits known as multivibrators. There are 3 types of multivibrator: bistable, monostable and astable.

- The bistable multivibrator has two stable states. The circuit can remain in either stable state indefinitely and moves to the other stable state only when appropriately triggered.
- The monostable multivibrator has one stable state in which it can remain indefinitely. It also has a quasi-stable state to which it can be triggered and in which it stays for a predetermined interval. When this interval expired, the monostable multivibrator returns to its stable and remains there, awaiting another triggering signal. Sometimes, this action is called one shot.
- The astable multivibrator has no stable states.

Bistable Multivibrators



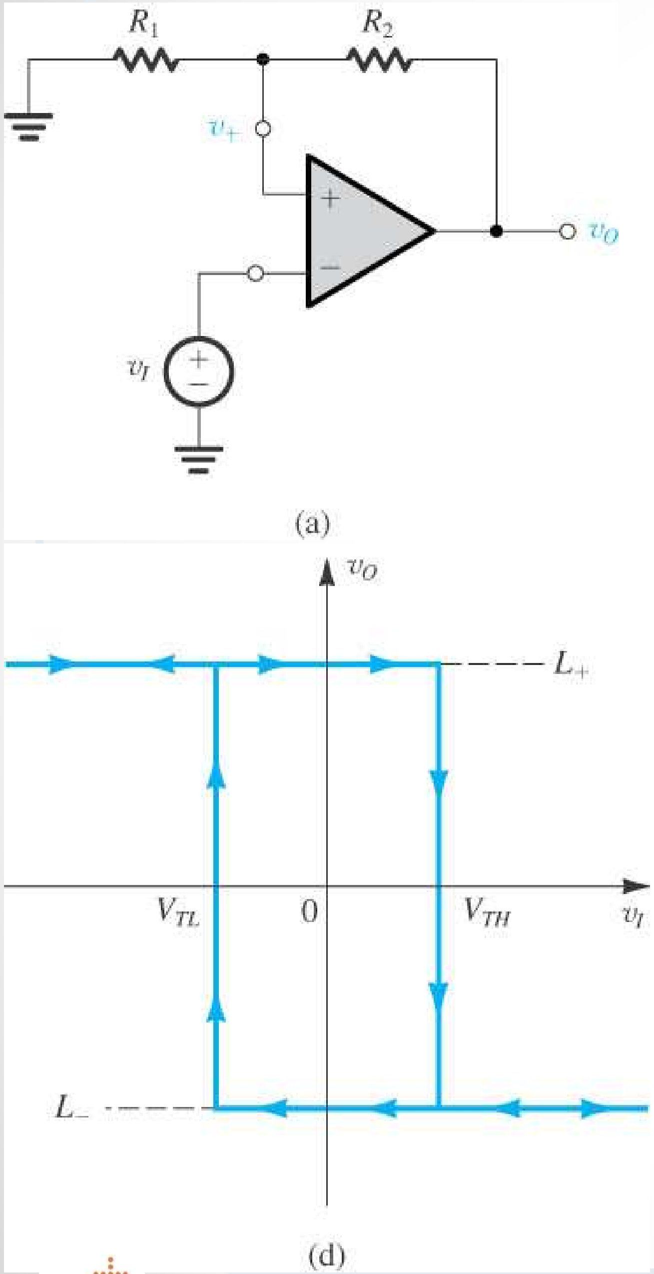
Bistability is obtained by connecting a dc-amplifier in a positive feedback loop having a loop gain greater than unity, as shown. It consists of an op-amp with a resistive voltage divider in the positive-feedback path.

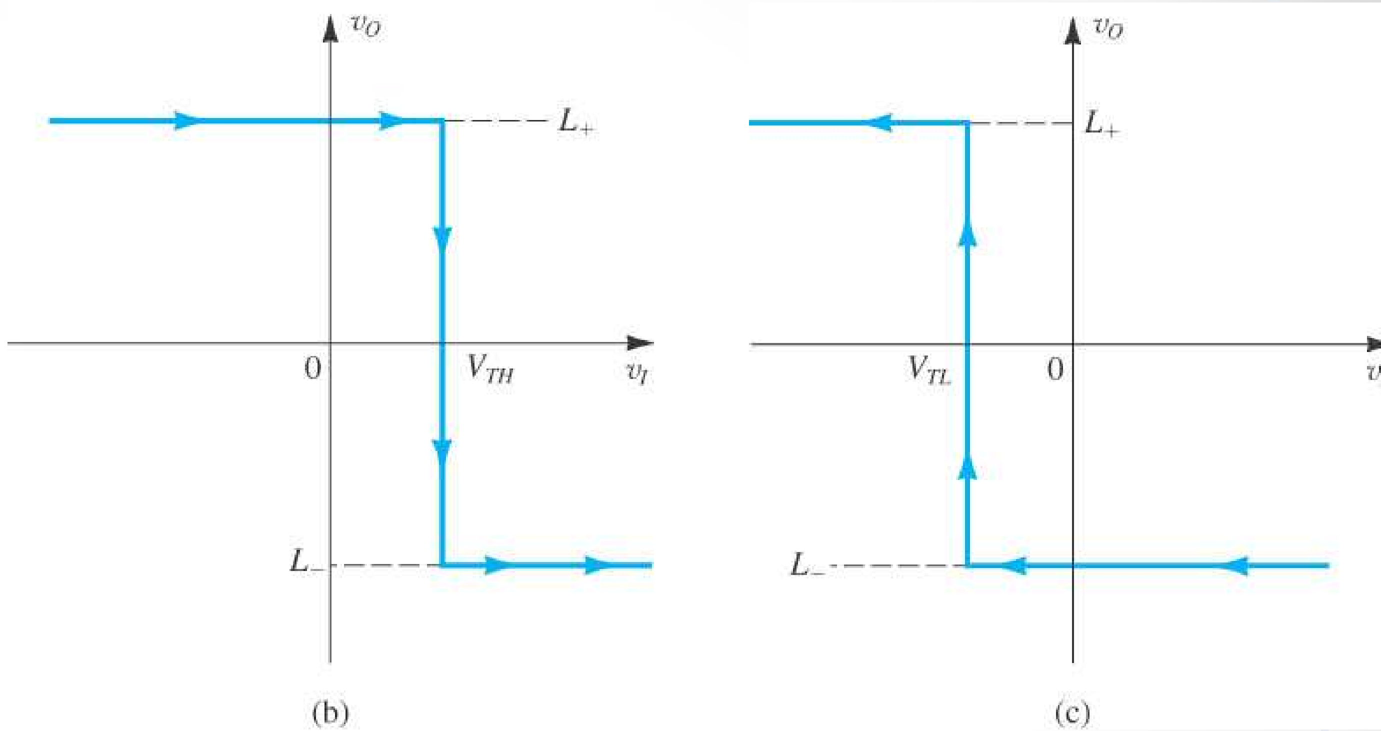
First, assume v+ is near ground potential. Electrical noise causes small positive increment in the v+.

This signal will be amplified by the large open-loop gain A of op-amp, and a much larger signal will be resulted at vo. The voltage divider will feed a fraction $\beta = R_1/(R_1 + R_2)$ of the output signal back to the v+. If $A\beta > 1$, the fed-back signal will be greater than the original increment in v+. This regenerative process continues until eventually op-amp saturates with its output voltage at the positive saturation level, $v_o = L_+$. When this happens, $v_+ = L_+R_1/(R_1 + R_2)$, which is positive and thus keeps op amp in positive saturation.

Had we assumed the noise causes v+ to go in the negative direction, we would have got $v_o = L_-$ and $v_+ = L_-R_1/(R_1 + R_2)$, which is the second state.

Transfer Characteristics of the Bistable Circuit

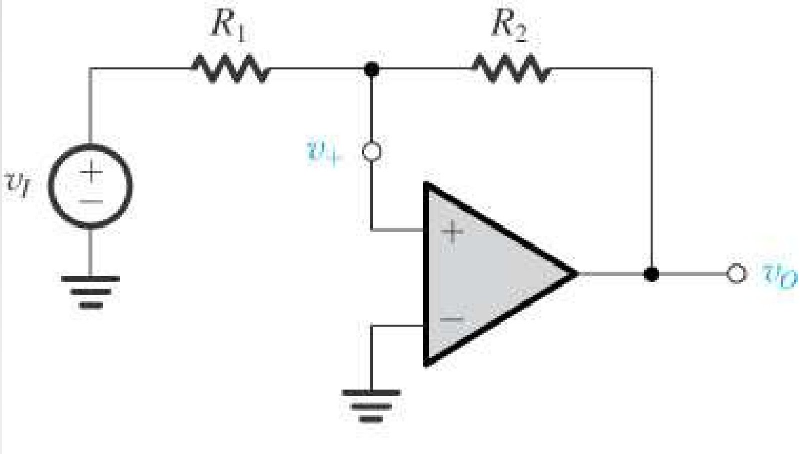




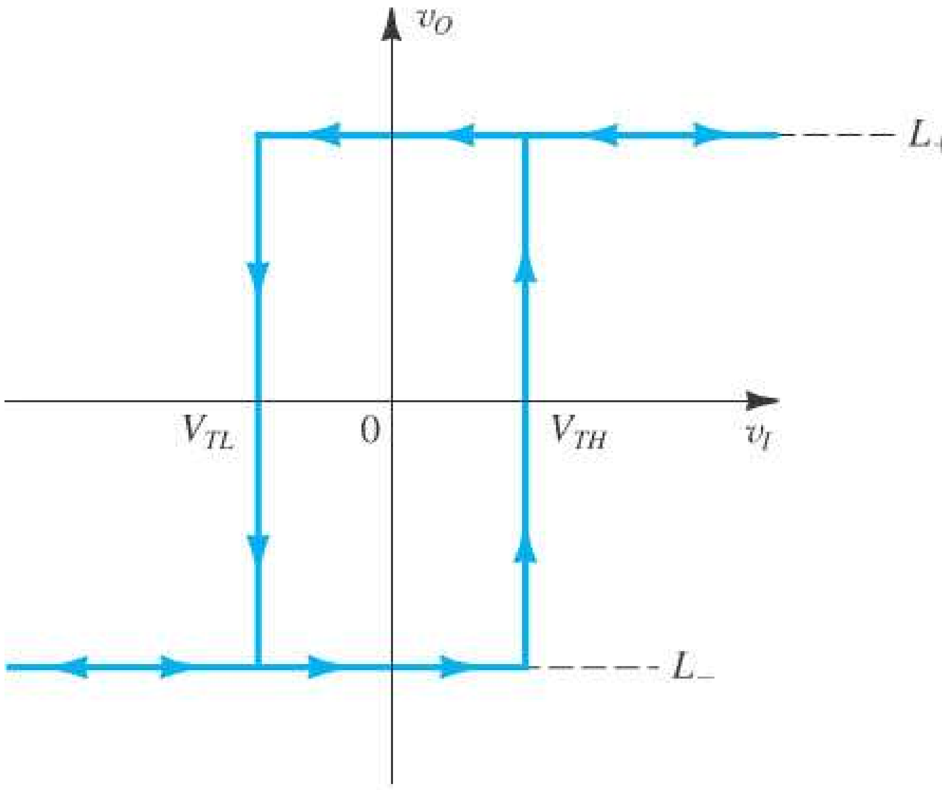
The circuit changes state at different values of vi, depending on whether vi is increasing or decreasing. Thus the circuit is said to exhibit hysteresis; the width of the hysteresis is the difference between the high threshold V_{TH} and the low threshold V_{TL}. Also note that the bistable ckt is in effect a comparator with hysteresis.

Notice that since the ckt switches from the positive state to the negative state as vi is increased past V_{TH}, the ckt is said to be inverting.

A Bistable circuit with noninverting transfer characteristics



(a)



(b)

From the superposition principle,

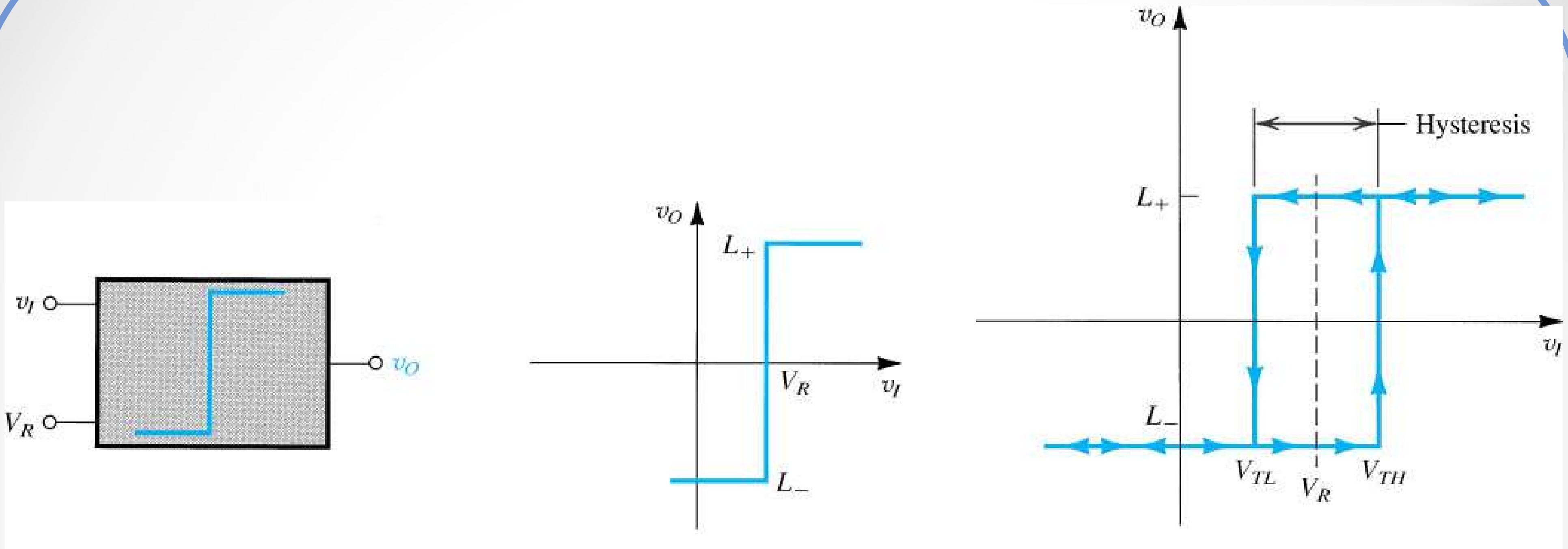
$$v_+ = v_I \frac{R_2}{R_1 + R_2} + v_O \frac{R_1}{R_1 + R_2}$$

V_{TL} can be found by substituting vo = L+,

V_+ = 0 and vi = V_{TL}, the result is $V_{TL} = -L_+(R_1 / R_2)$

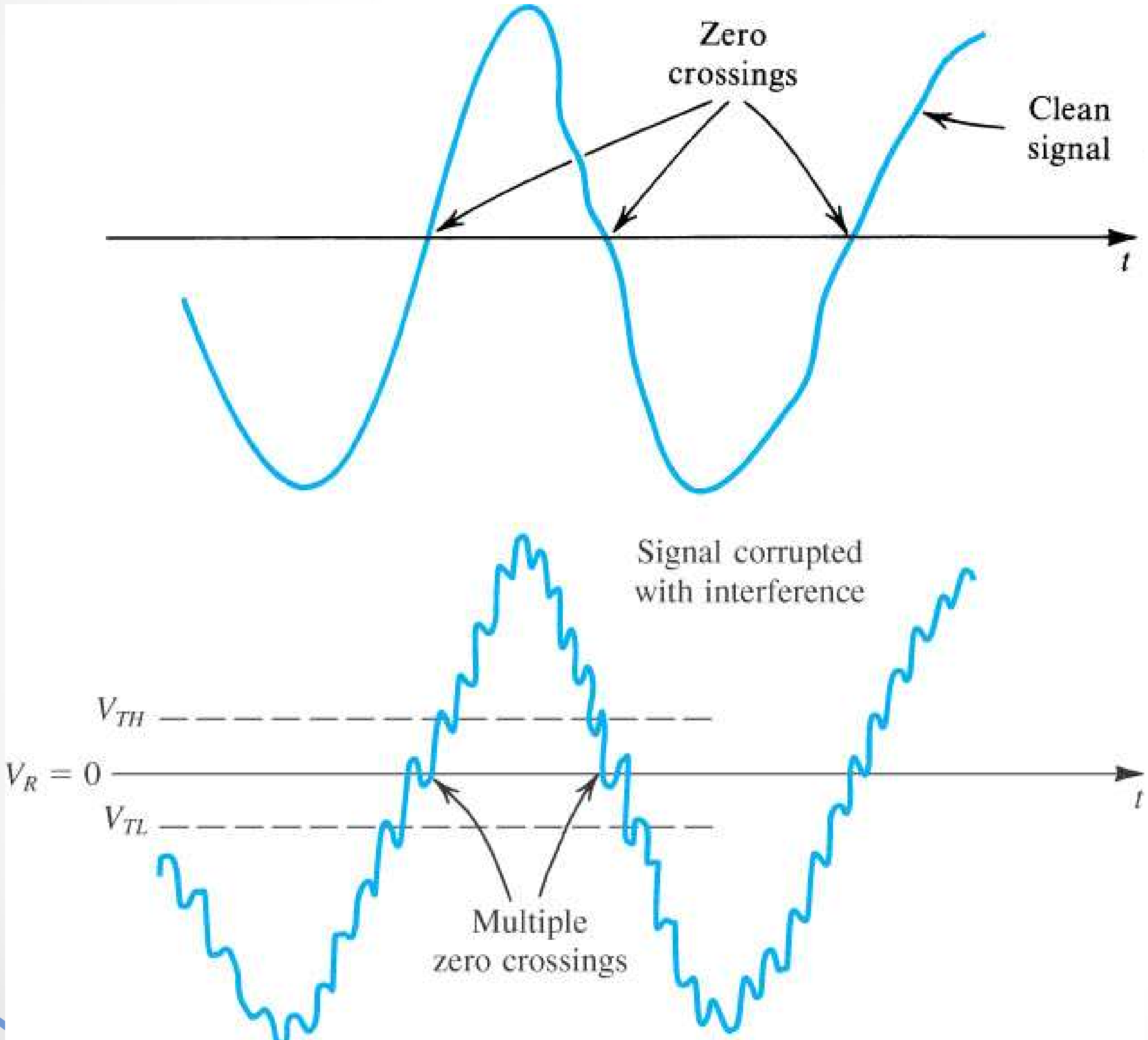
Similarly, we will find that $V_{TH} = -L_-(R_1 / R_2)$

Application of bistable circuit as a comparator



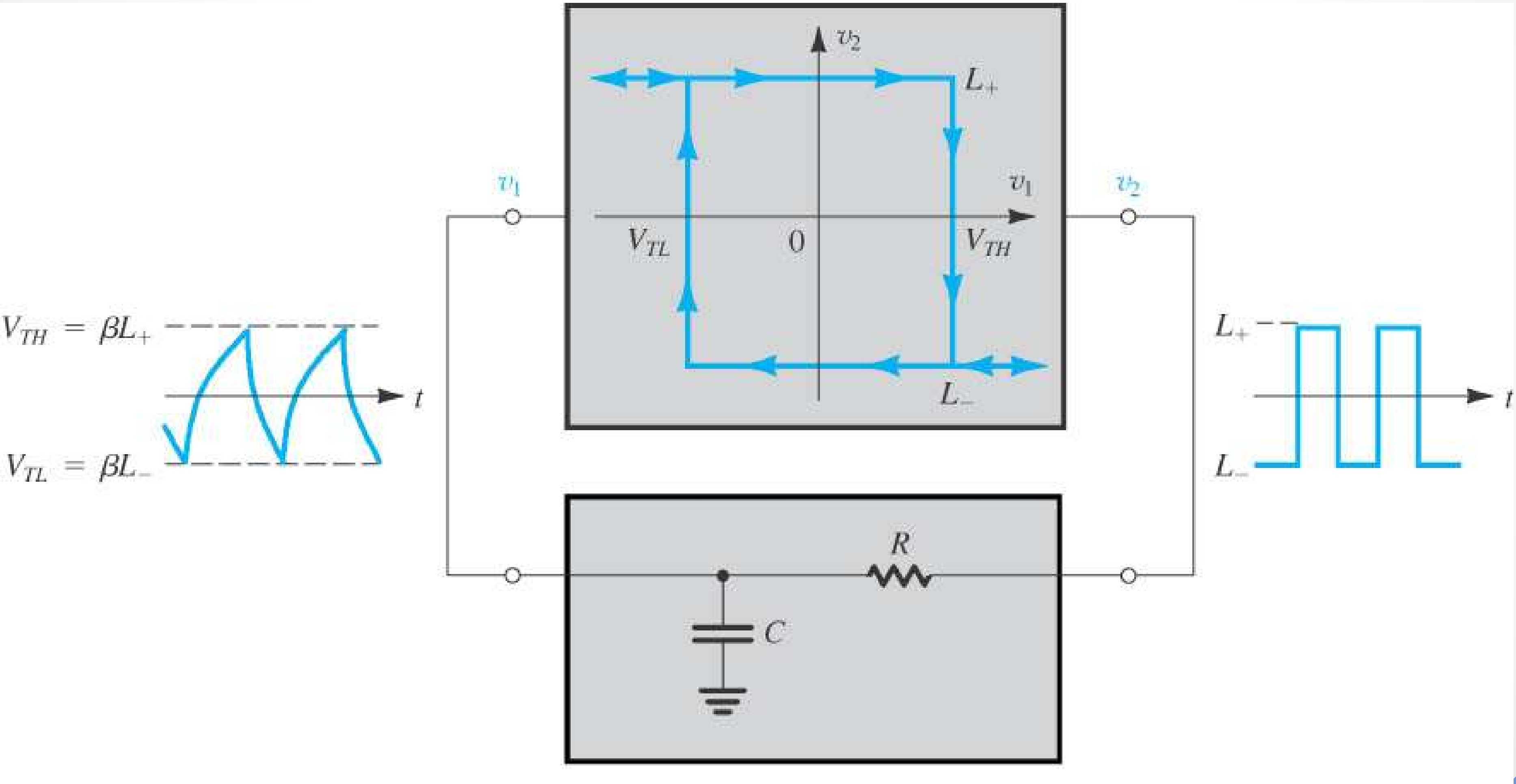
(a) (b)

The use of hysteresis in the comparator characteristics as a means of rejecting interference.



Generation of Square and Triangular Waveforms Using Astable Multivibrators

Connecting a bistable multivibrator with inverting transfer characteristics in a feedback loop with an RC circuit results in a square-wave generator.

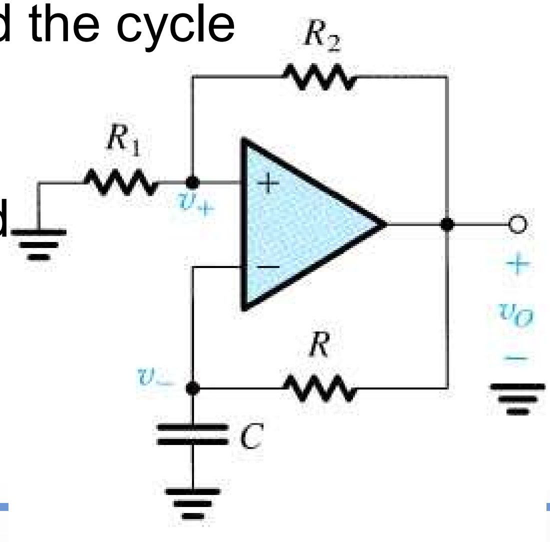


(a)

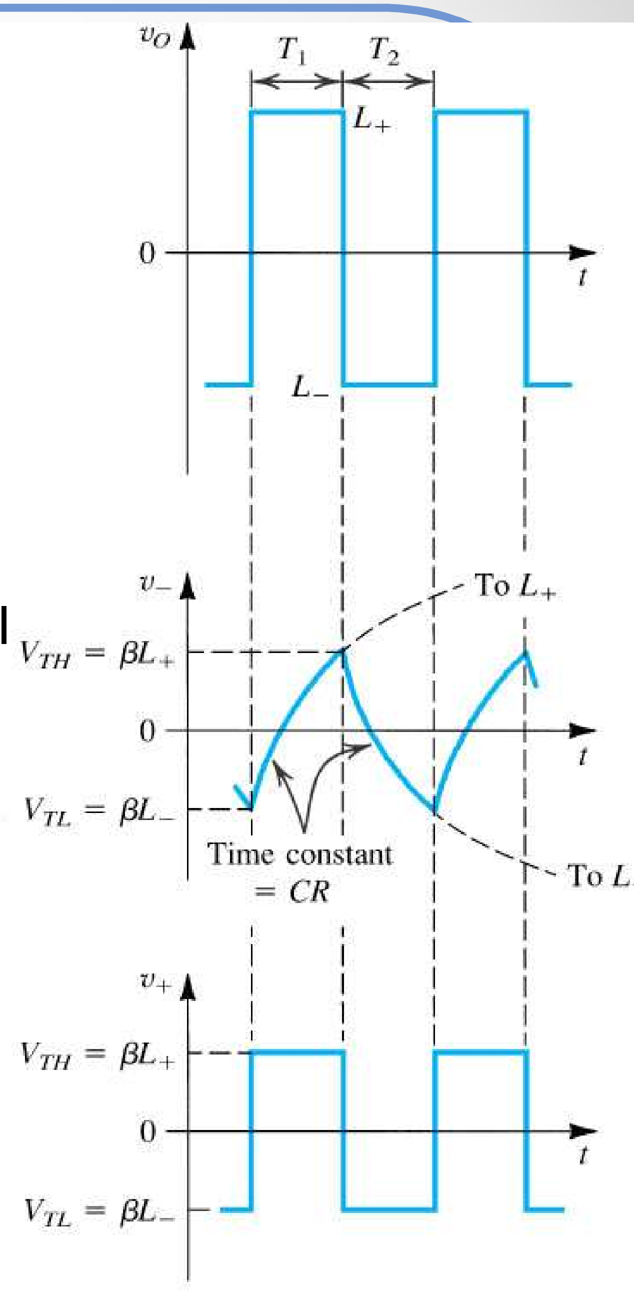
Let the bistable multivibrator be at state L_+. Capacitor C will charge toward this level through resistor R. Thus the voltage across C (or v_-) will rise exponentially toward L_+ with a time constant $\tau = RC$. Meanwhile, $v_+ = \beta L_+$.

This situation continues until v- reaches $V_{TH} = \beta L_+$ at which point the bistable multivibrator will switch to the other stable state in which vo = L_- and $v_+ = \beta L_-$. The capacitor will then start discharging and its voltage, v-, will decrease exponentially toward L_-. The new state will prevail until v_- reaches the $V_{TL} = \beta L_-$, at which time the multivibrator switches to the positive-output state, the capacitor begins the charge, and the cycle repeats itself.

The astable circuit oscillates and produces a square waveform at the output of the op amp, as shown.



(b)



(c)

The period T of the square wave can be found as follows: During the charging interval T_1, the voltage v_- across the capacitor at any time t, with t = 0 at the beginning of T_1, is given by

$$v_- = L_+ - (L_+ - \beta L_-)e^{-t/\tau}$$

where τ = RC. Substituting $v_- = \beta L_+$ at $t = T_1$ gives

$$T_1 = \tau \ln \frac{1-\beta(L_-/L_+)}{1-\beta}$$

Similarly, during the discharge interval T_2 the voltage v_- at any time t, with t = 0 at the beginning of T_2, is given by

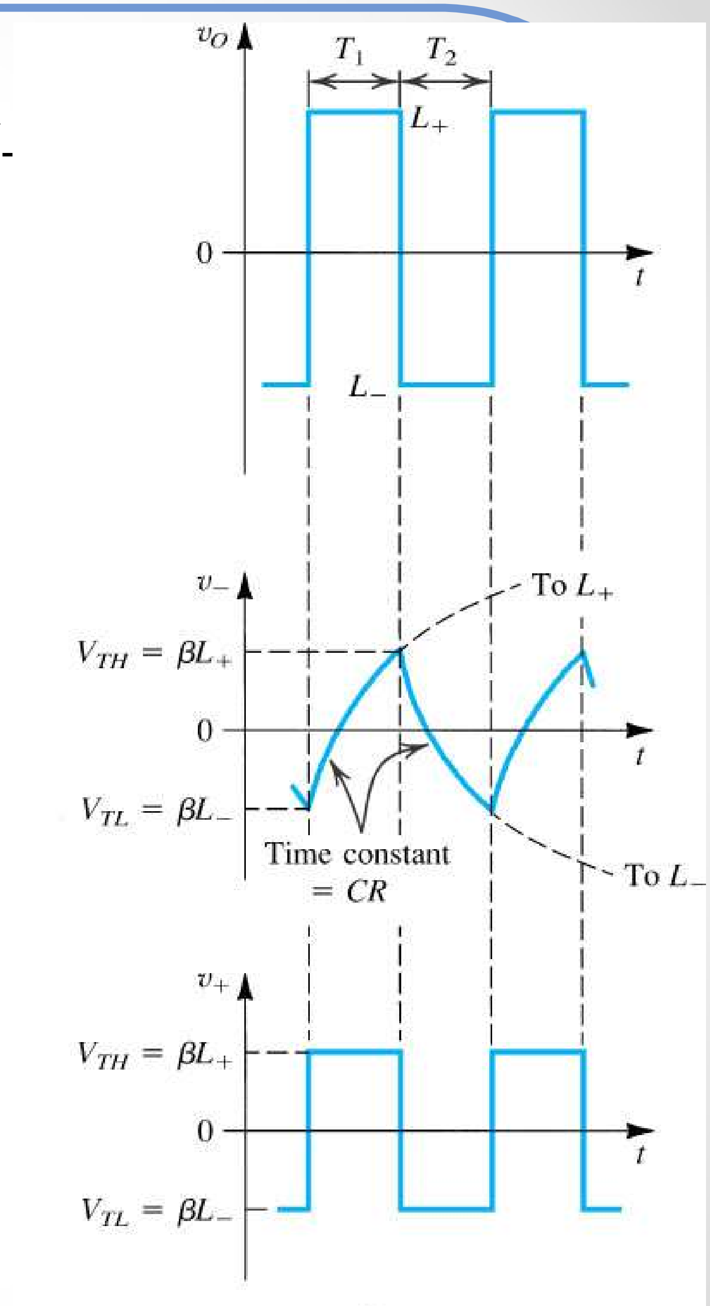
$$v_- = L_- - (L_- - \beta L_+)e^{-t/\tau}$$

Substituting $v_- = \beta L_-$ at $t = T_2$ gives

$$T_2 = \tau \ln \frac{1-\beta(L_+/L_-)}{1-\beta}$$

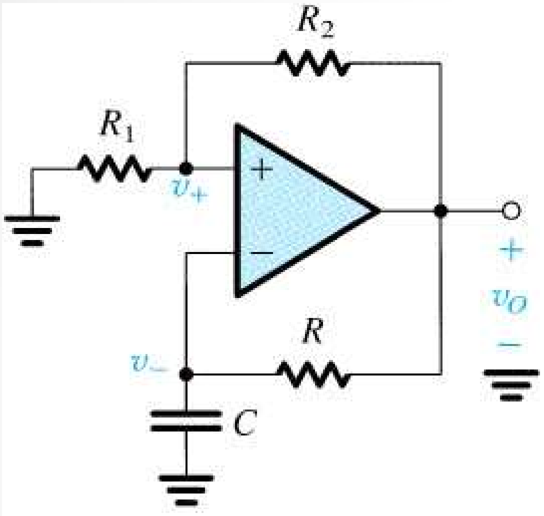
Substituting $T = T_1 + T_2$, and $L_+ = -L_-$, we'll get

$$T = 2\tau \ln \frac{1+\beta}{1-\beta}$$



(c)

Example: for the ckt below, let the op-amp saturation voltages be ±10 V, R1 = 100 kΩ, R2 = R = 1 MΩ and C = 0.01 μF. Find the freq of oscillation.

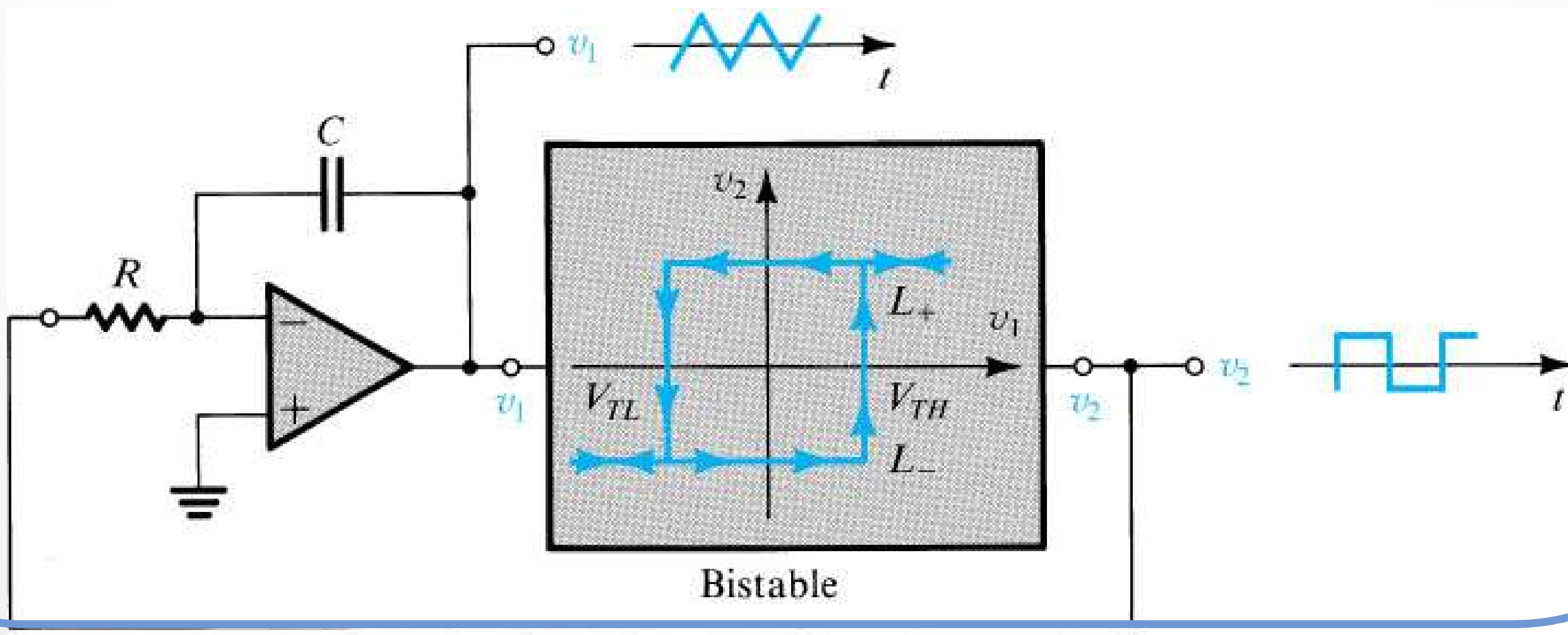


(b)

Generation of Triangular Waveforms

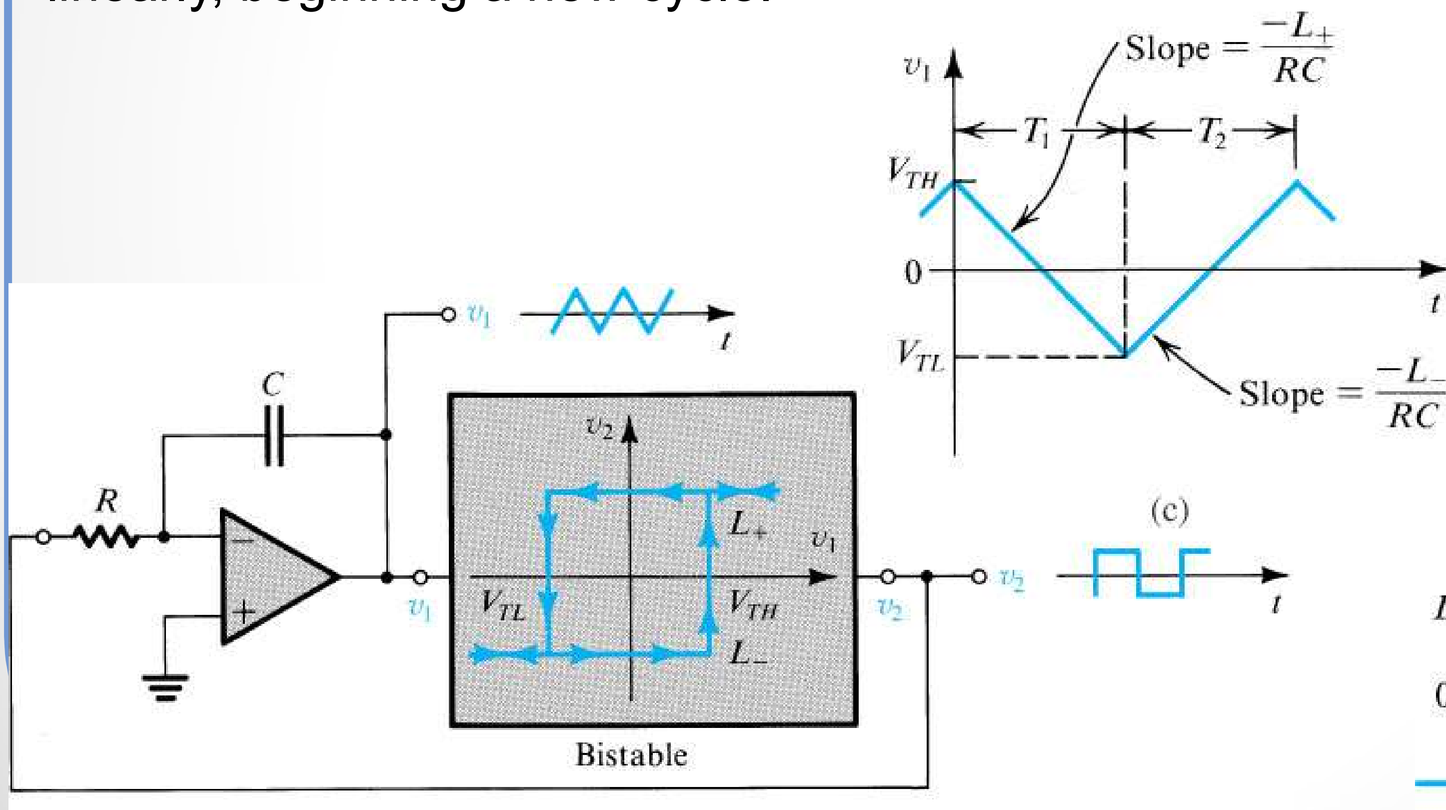
The exponential waveform generated in the astable ckt can be changed to triangular by replacing the low-pass RC circuit with an integrator. The integrator causes linear charging and discharging of the capacitor, thus providing a triangular waveform.

Let the output of the bistable ckt be at L_+. A current equal to L_+/R will flow into R and through C, causing the output of the integrator to linearly decrease with a slope of $-L_+/CR$. This will continue until the integrator output reaches the lower threshold V_{TL} of the bistable ckt, at which point it will switch states, its output = L_-. (cont. on the next page.)



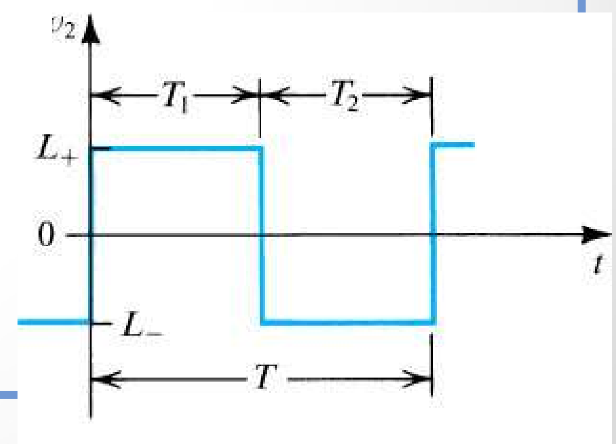
(a)

Once the output switches to L_-, the current through R and C will reverse direction and its value will be $|L_-|/R$. The integrator out put will start to increase linearly with a positive slope of $|L_-|/CR$. This will continue until the integrator output voltage reaches the positive threshold of bistable ckt, V_{TH}. At this point the bistable ckt switches, its output becomes positive (L_+), the current into the integrator reverses direction, and the output of the integrator starts to decrease linearly, beginning a new cycle.



(c)

(a)



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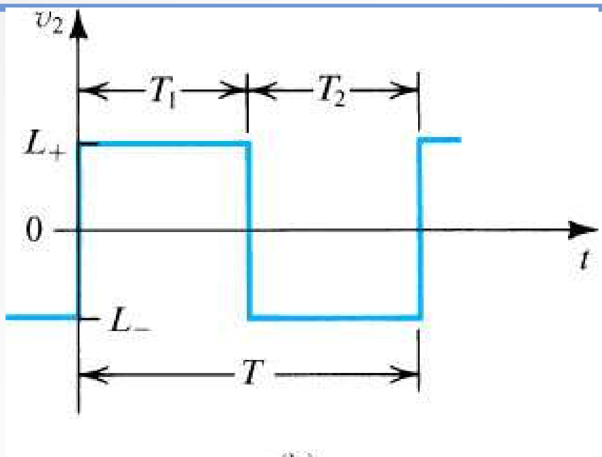
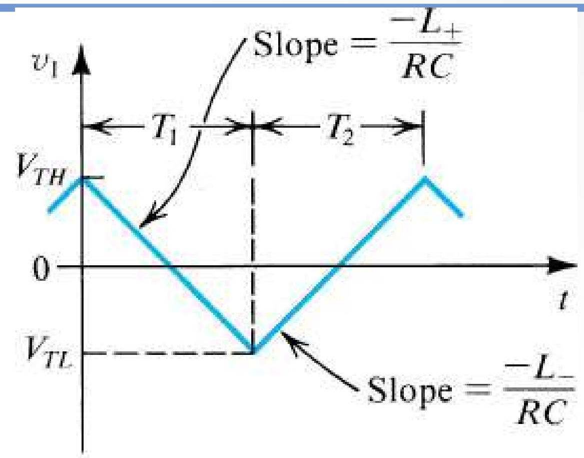


(b)



(c)

To find T, we observe that during T_1, $\frac{V_{TH}-V_{TL}}{T_1}=\frac{L_+}{CR}$, from which we obtain

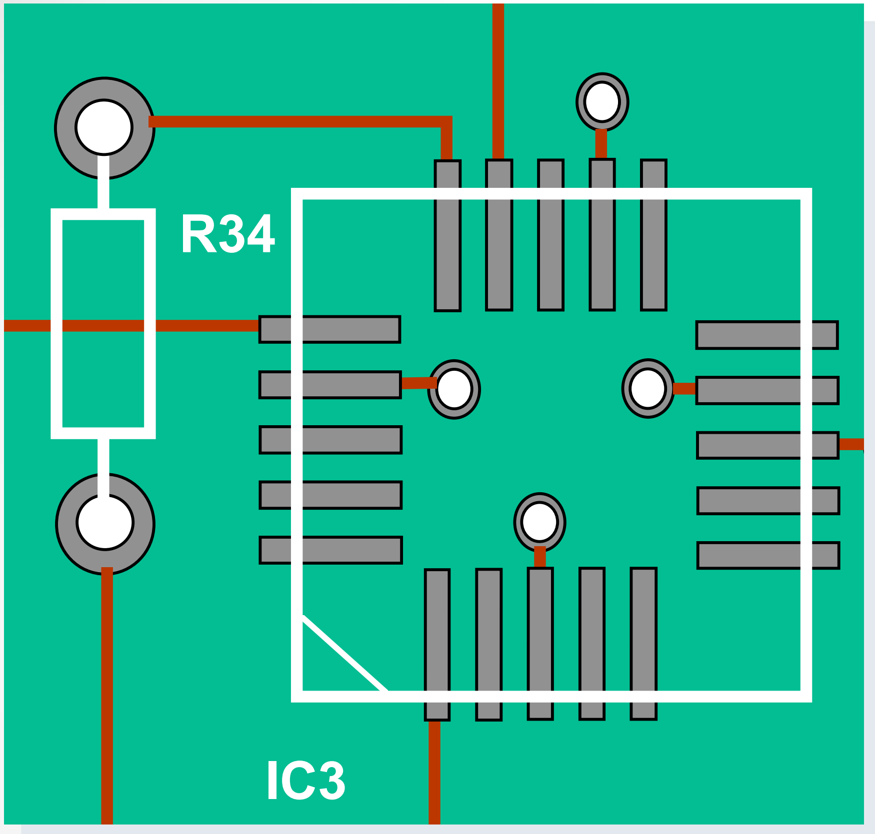
$$T_1 = CR\frac{V_{TH}-V_{TL}}{L_+}$$

Similarly, during T_2, we have $\frac{V_{TH}-V_{TL}}{T_2}=-\frac{L_-}{CR}$, from which we obtain

$$T_2 = CR\frac{V_{TH}-V_{TL}}{-L_-}$$

The period T = T_1 + T_2. Thus, to obtain symmetrical square waves we design the bistable ckt to have

$$L_+ = -L_-$$



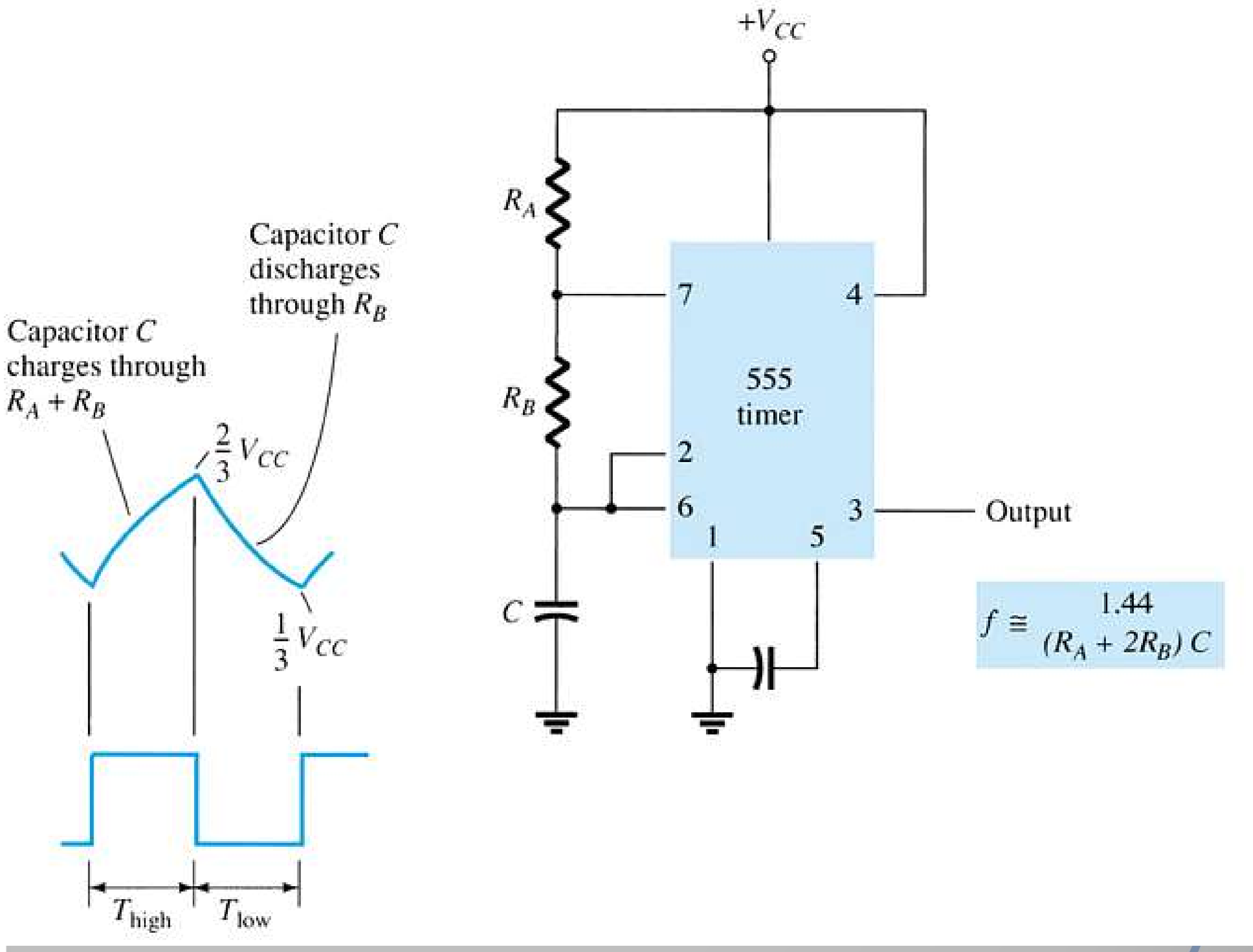
Voltage Regulator and Phase-Locked Loop

555 Timer Circuit

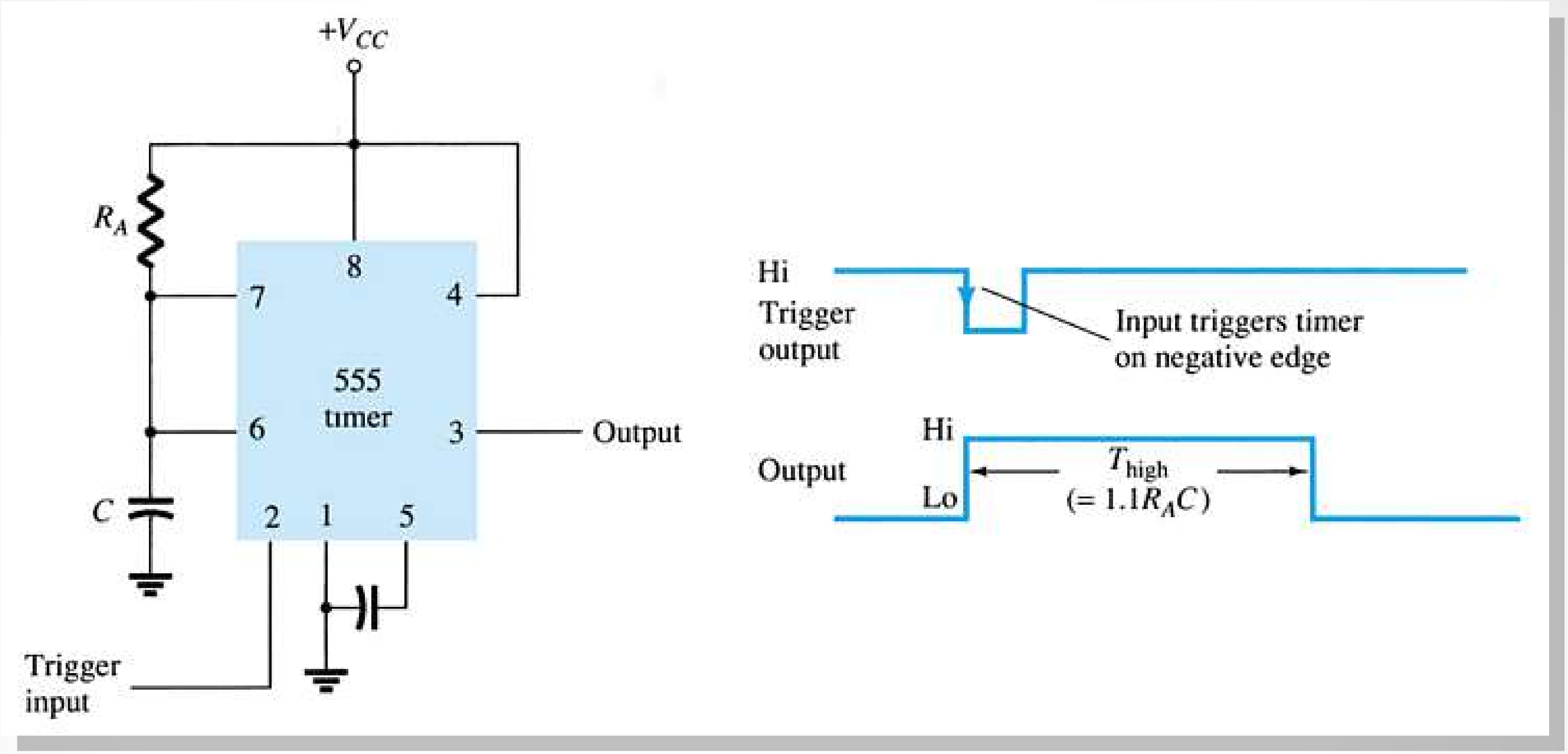
The 555 Timer is an example of a versatile timer IC.

Astable Operation

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



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 Regulation Circuits

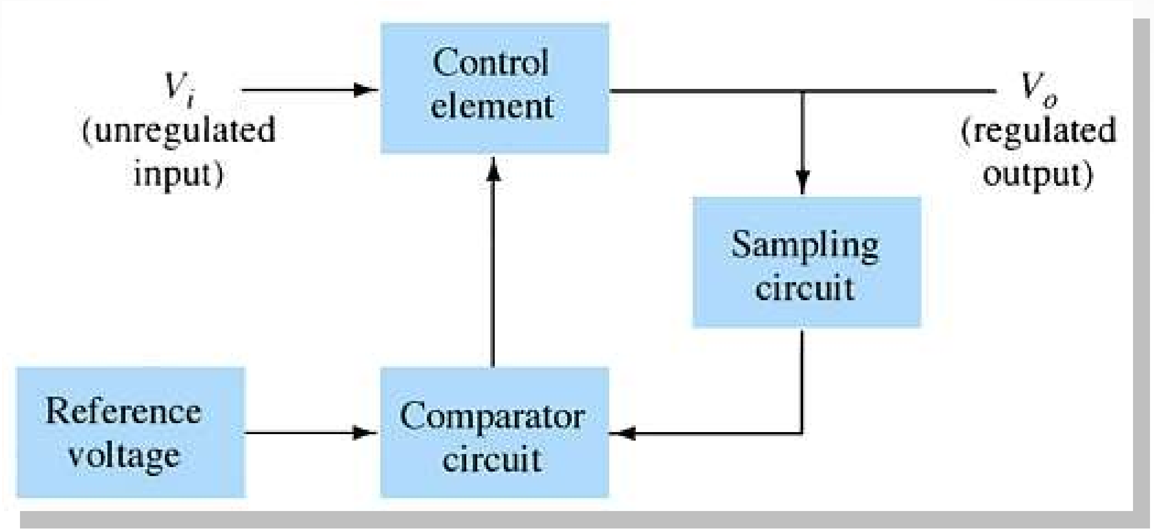
There are two common types of circuitry for voltage regulation:

- Discrete Transistors
- IC's

Discrete-Transistor Regulators

Series voltage regulator
Current-limiting circuit
Shunt voltage regulator

Series Voltage Regulator Circuit

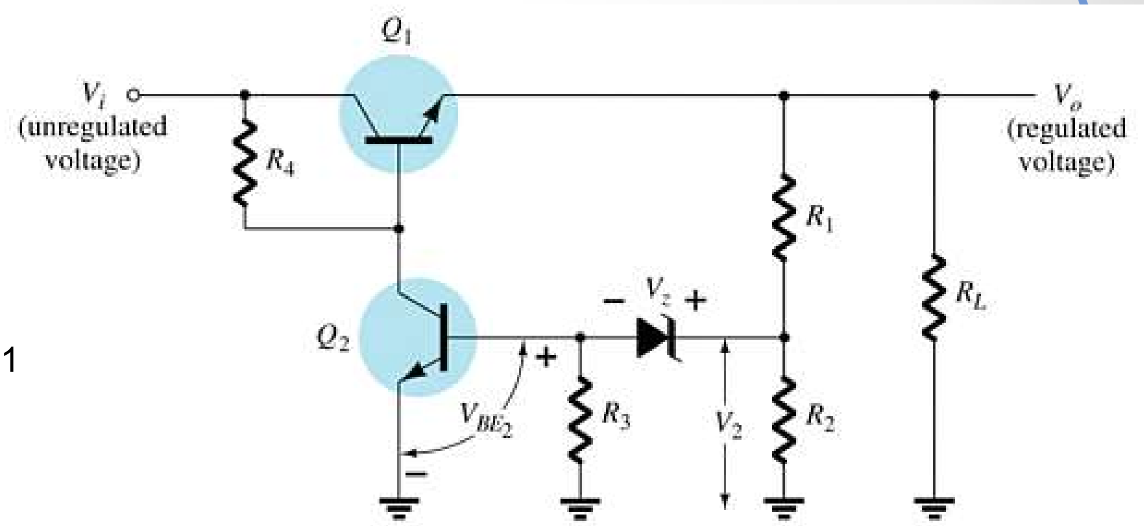


The series element controls the amount of the input voltage that gets to the output.

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:

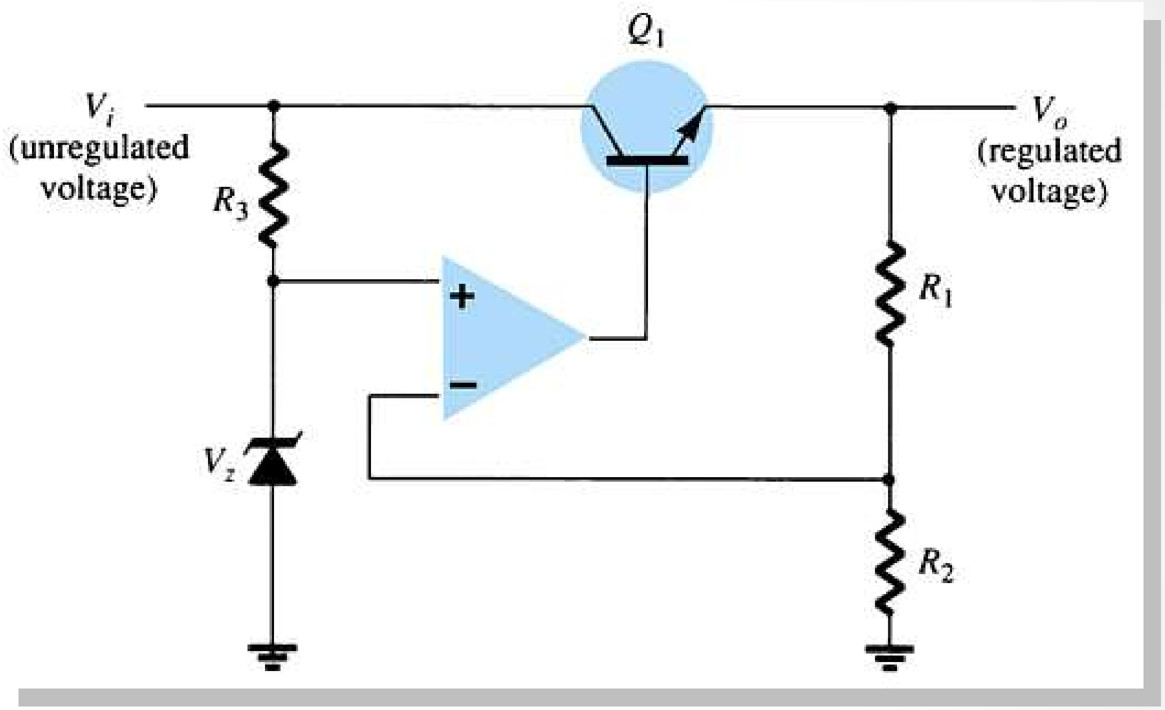
1. The voltage at V_2 and V_{BE} of Q_2 increases
2. The conduction of Q_2 increases
3. The conduction of Q_1 decreases
4. The output voltage decreases

When the output decreases:

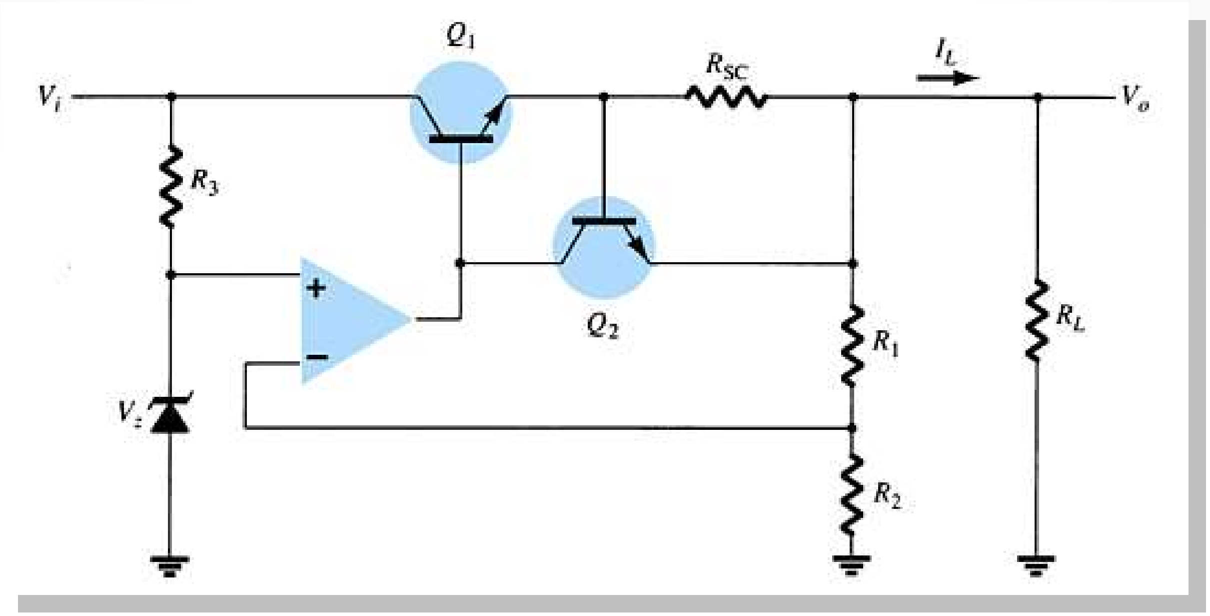
1. The voltage at V_2 and V_{BE} of Q_2 decreases
2. The conduction of Q_2 decreases
3. The conduction of Q_1 increases
4. The output voltage increases

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

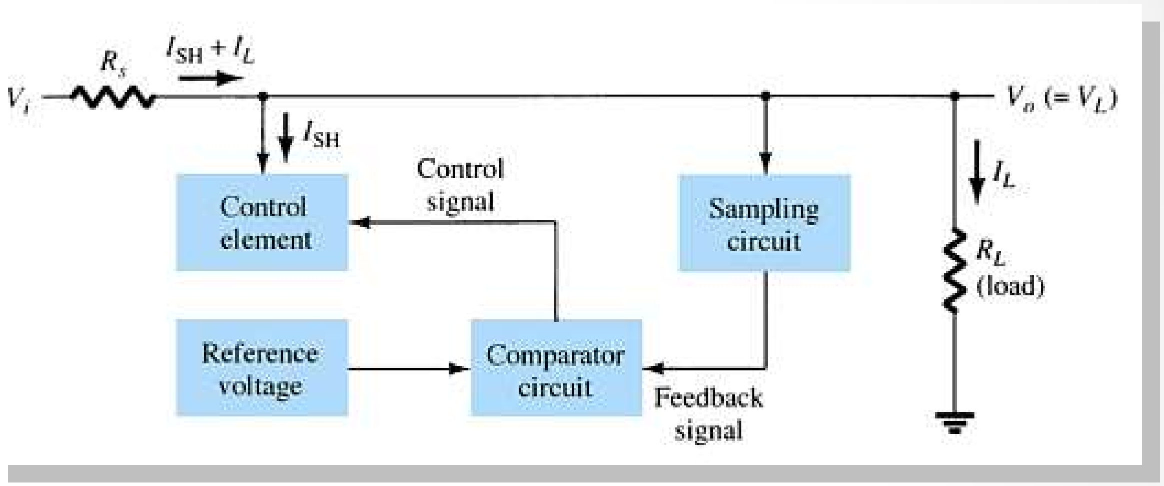


When I_L increases:

- 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

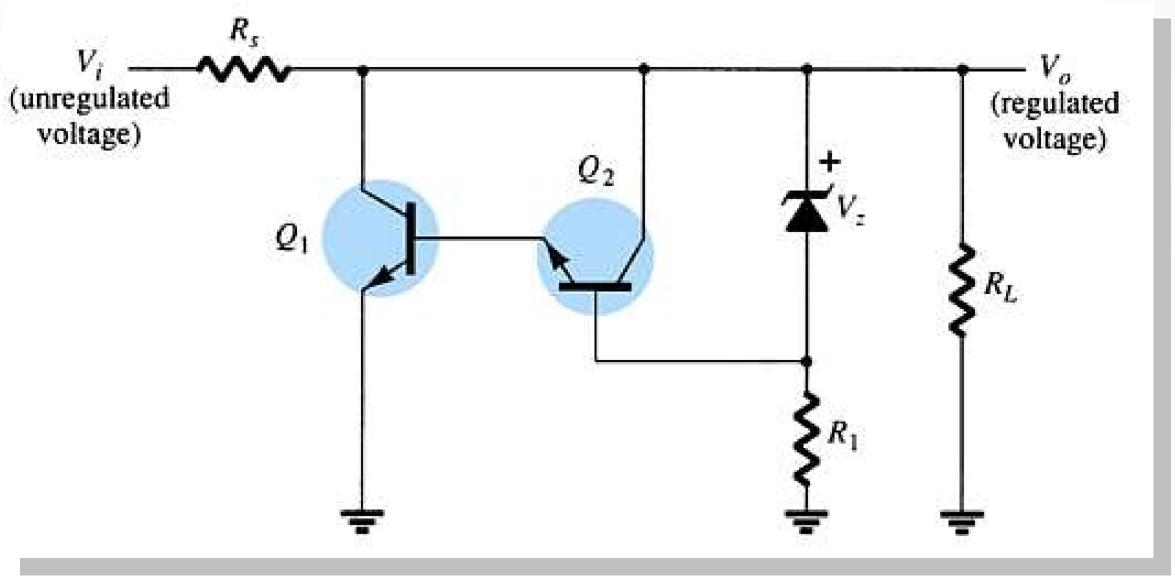
Shunt Voltage Regulator Circuit

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



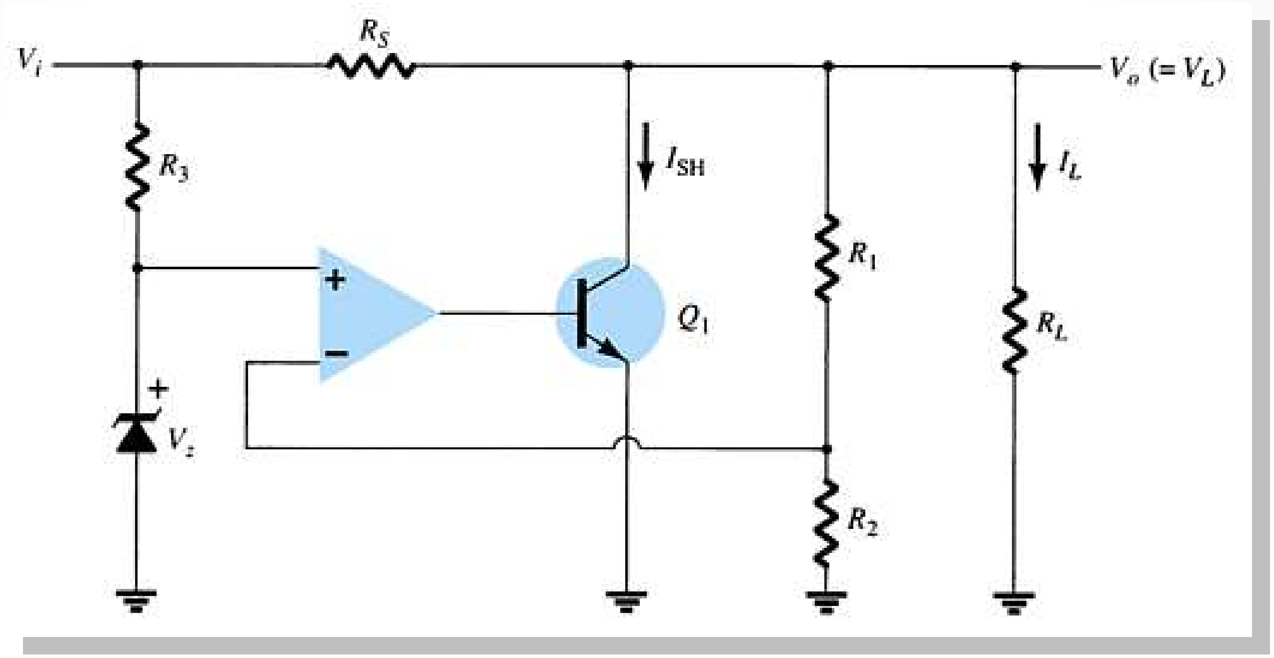
When the output voltage increases:

- 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

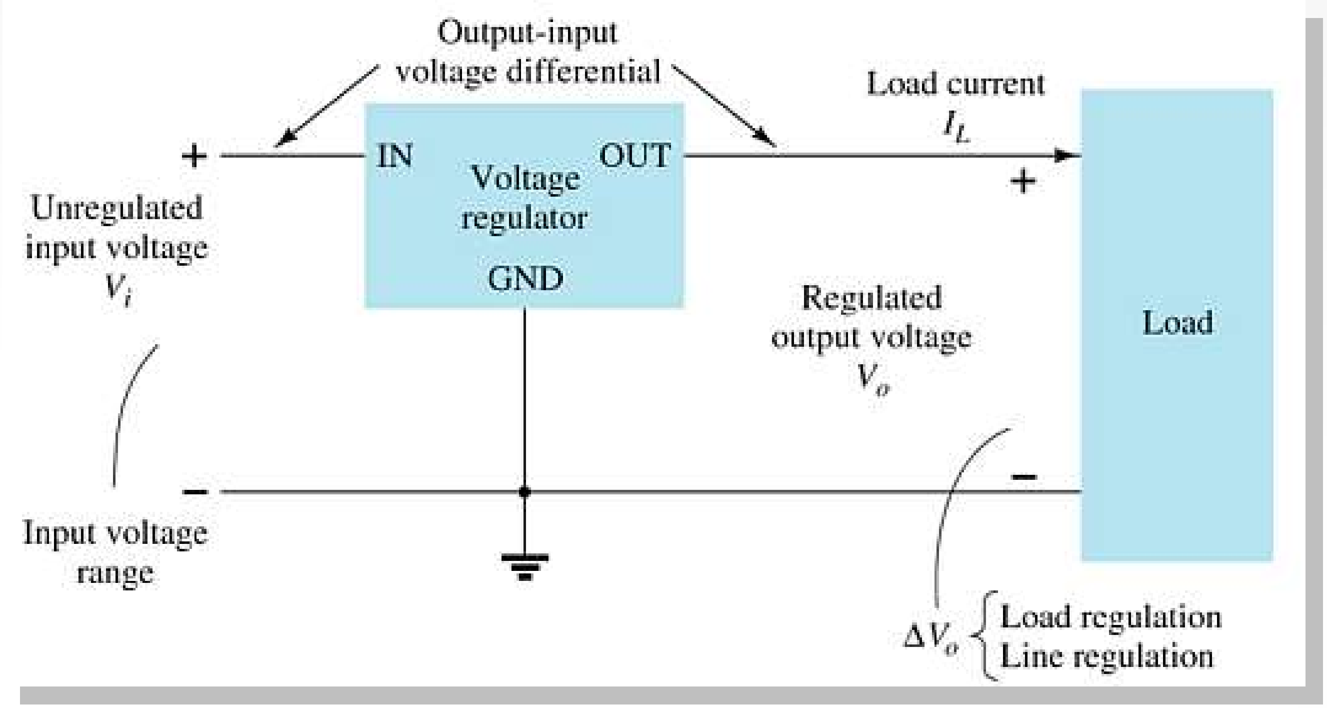
Regulator ICs contain:

- 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

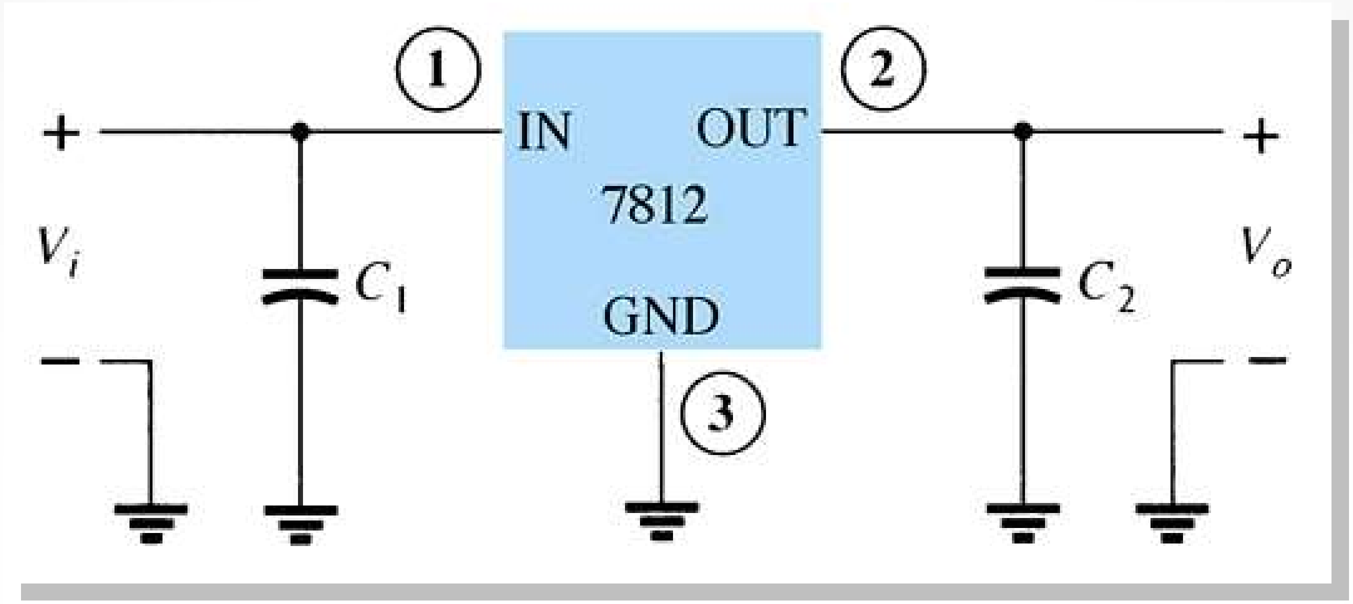
Three-Terminal Voltage Regulators



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

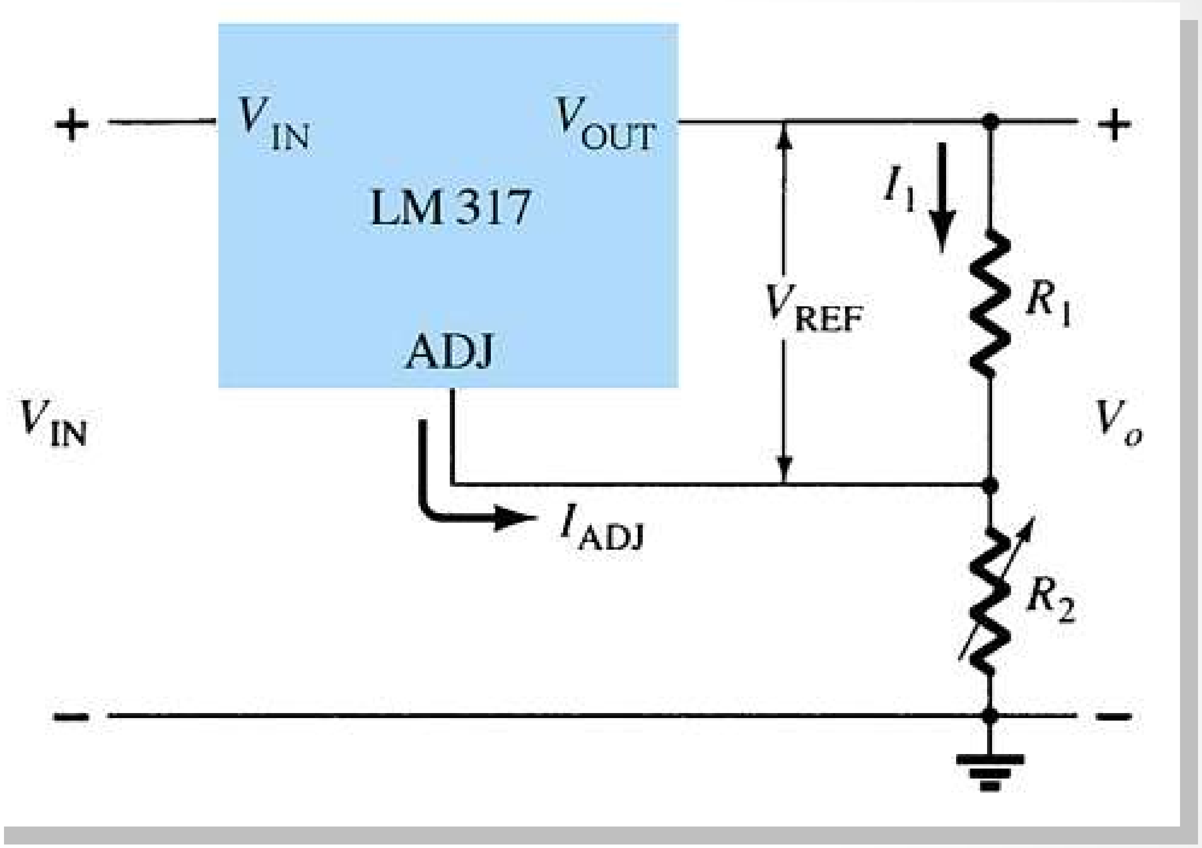


These ICs provide a fixed positive output voltage.

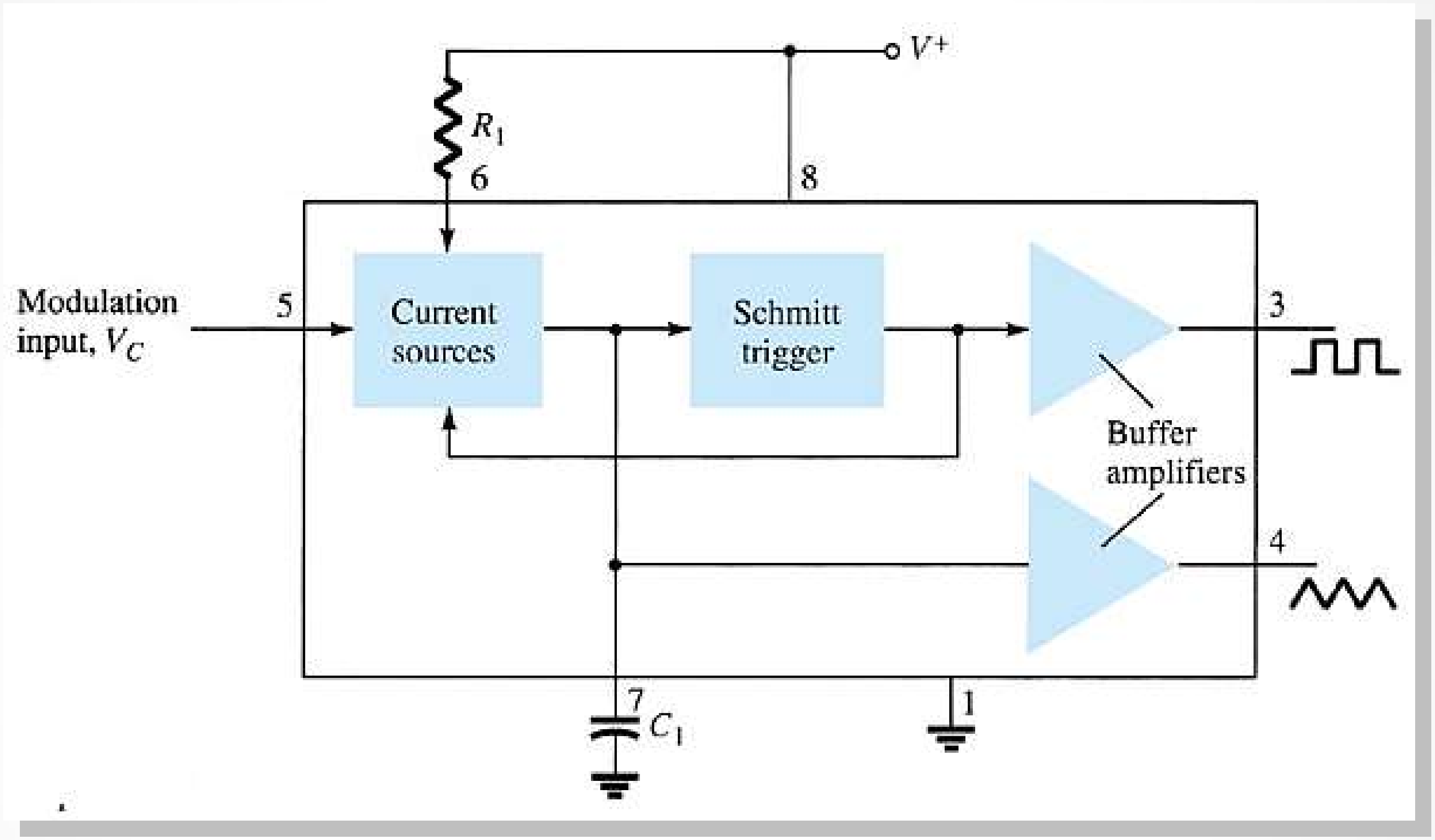
Adjustable Voltage Regulator

These regulators have adjustable output voltages.

The output voltage is commonly selected using a potentiometer.



Voltage-Controlled Oscillator

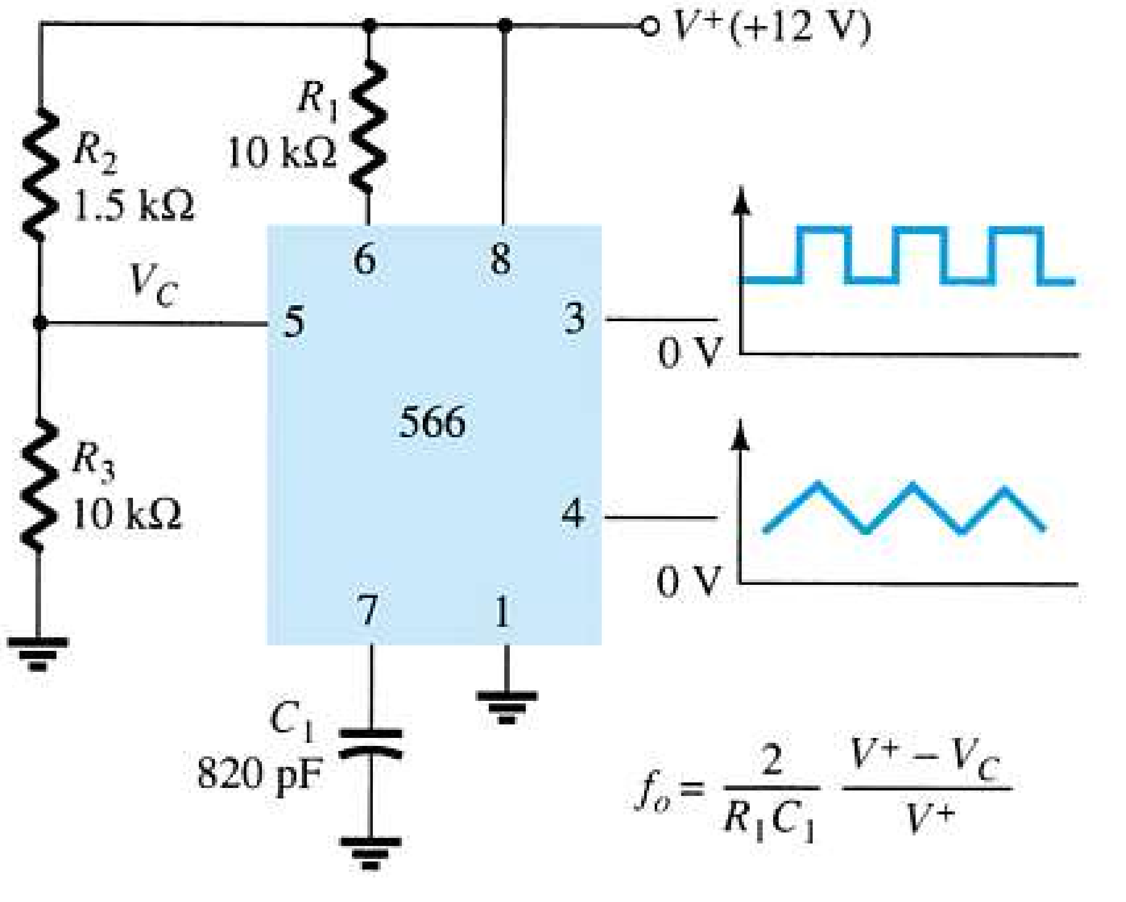


The oscillator output is a variable frequency square wave or triangular wave. The output frequency depends on the modulation input voltage (V_C).

566 Voltage-Controlled Oscillator

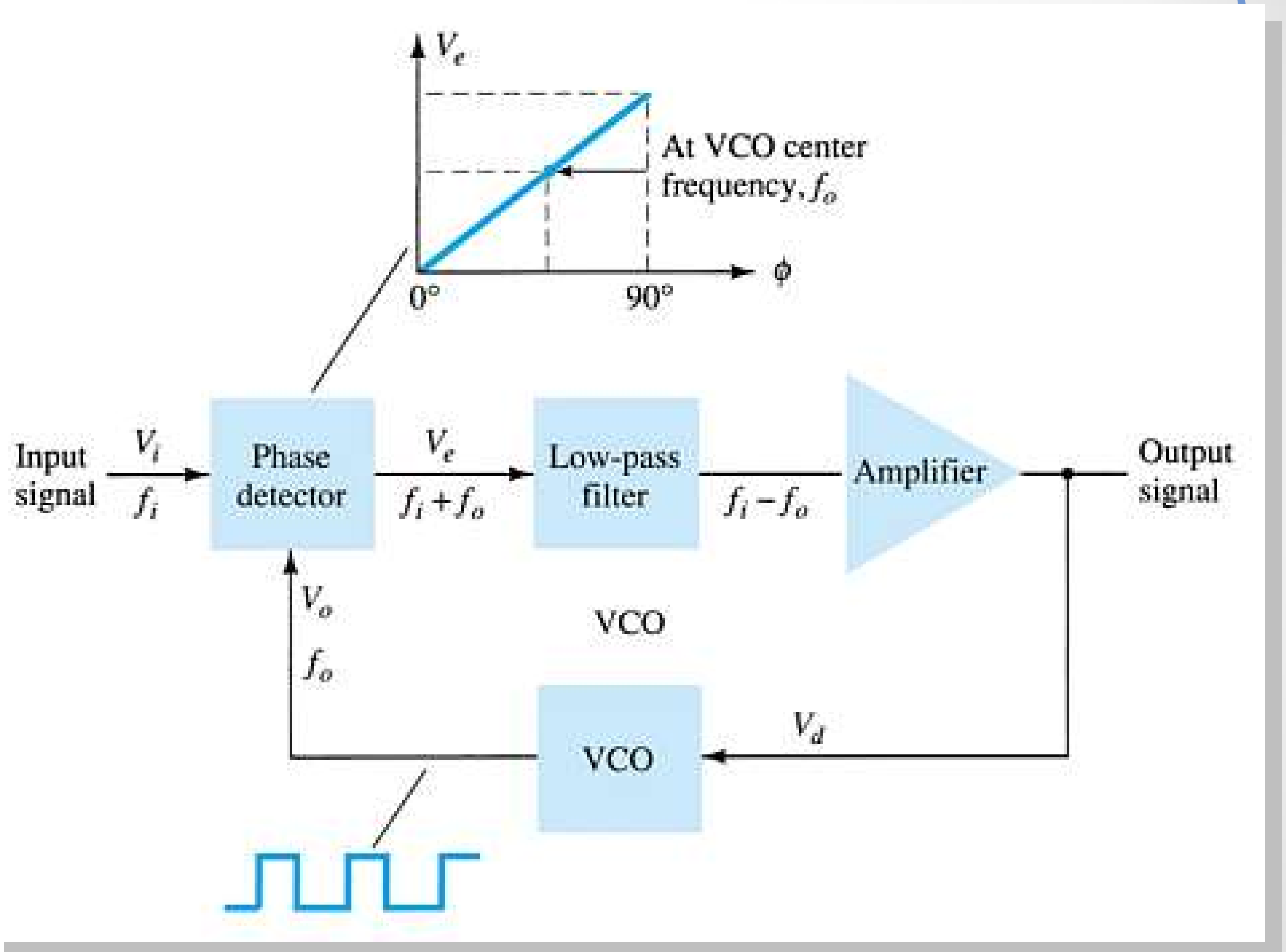
The output frequency can be calculated as shown in the graph.

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



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

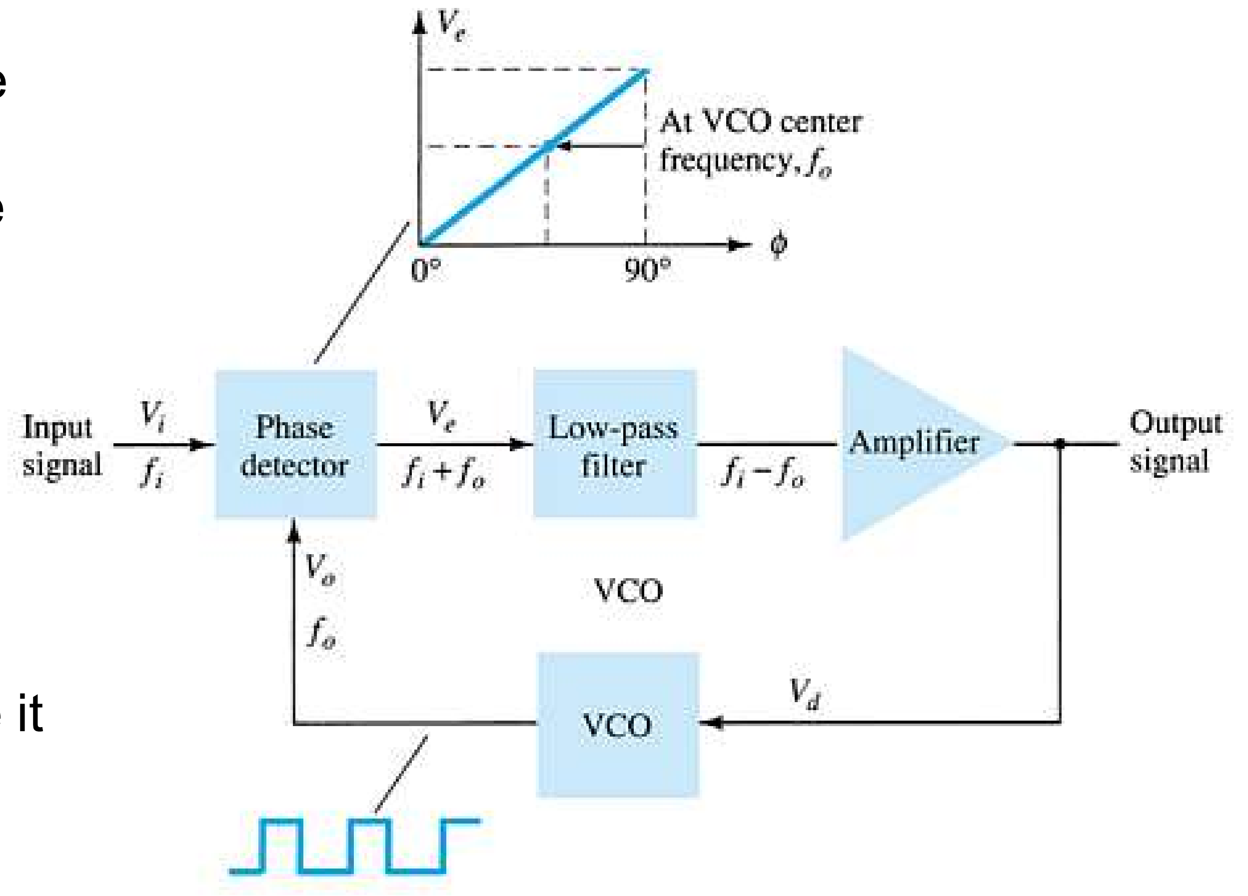
$f_i \neq f_{VCO}$, and they never will be the same

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.



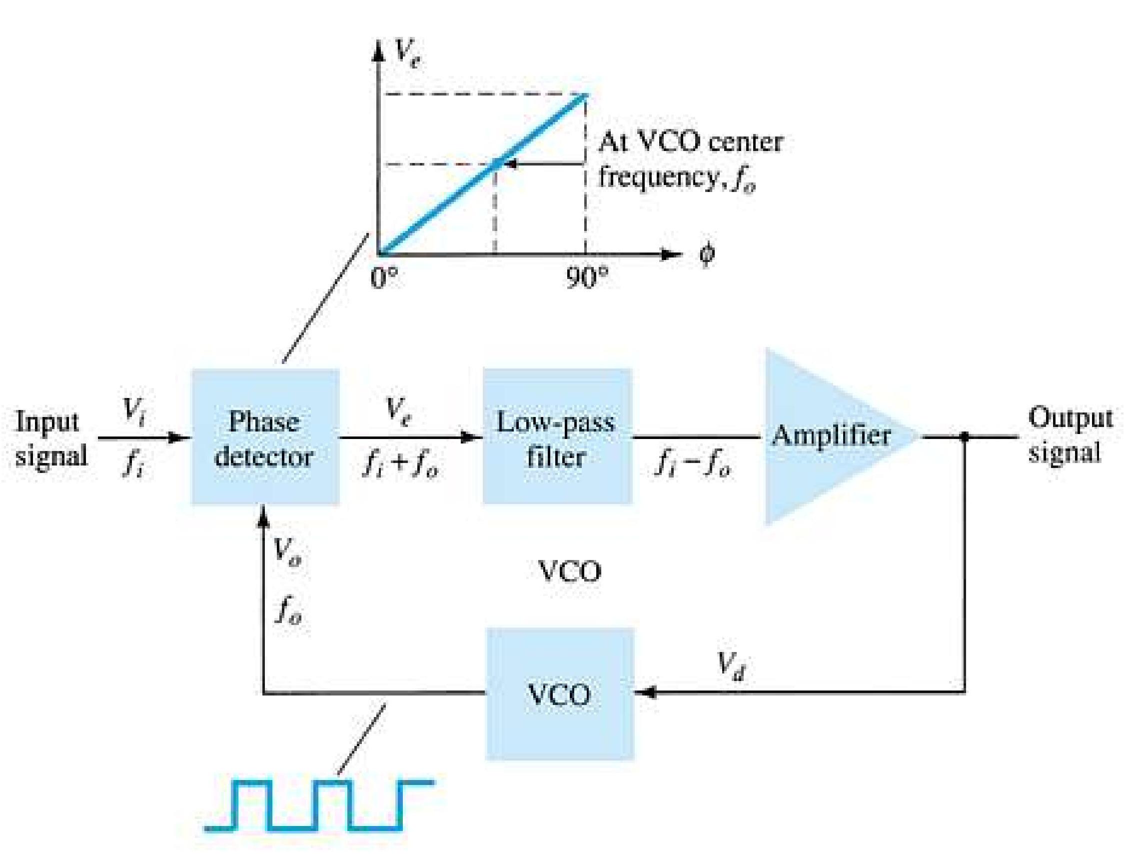
The no-error voltage is also applied to the internal VCO input to maintain the VCO's output frequency.

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.

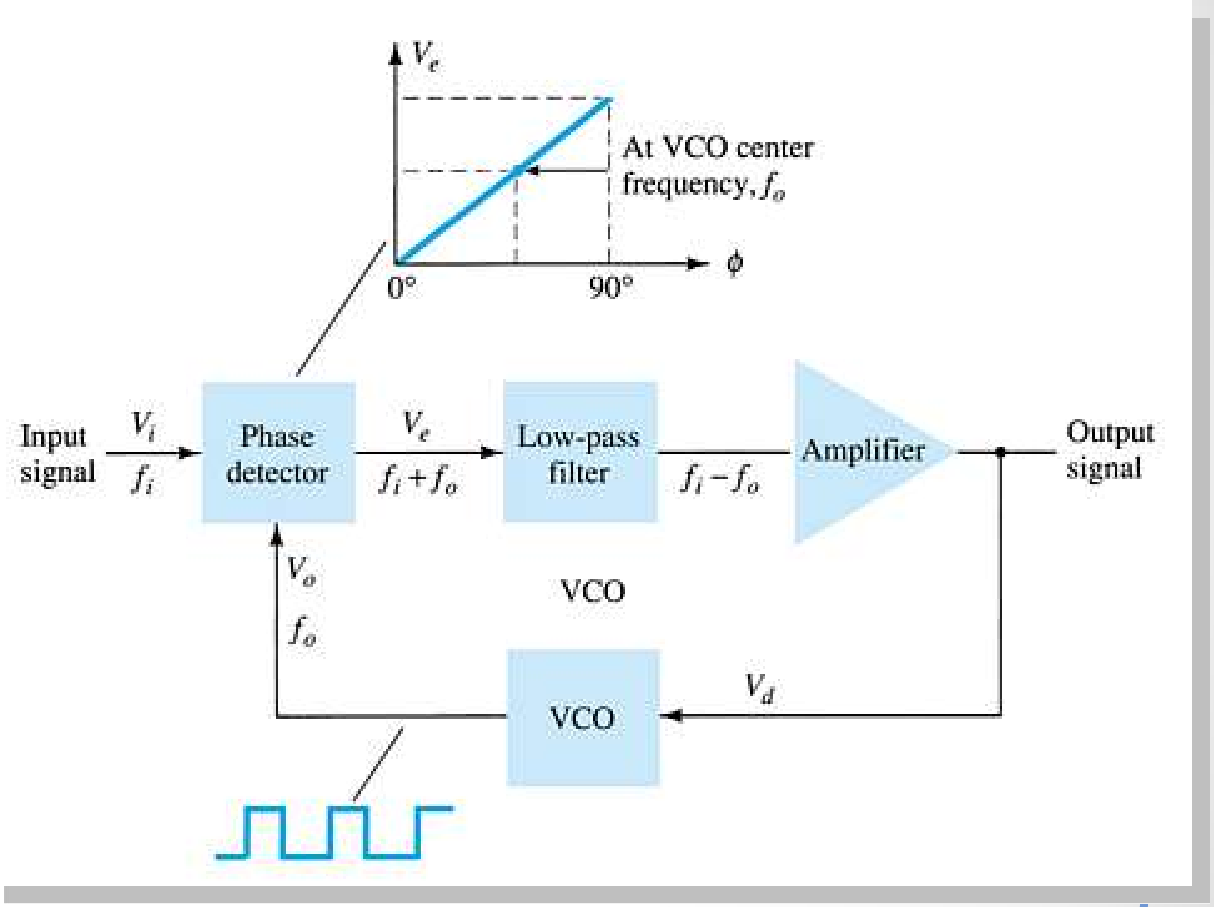
The error voltage is also applied to the VCO input. This causes the VCO to change output frequency.



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.

Applications:

- FM demodulator
- Frequency Synthesizer
- FSK decoder

References

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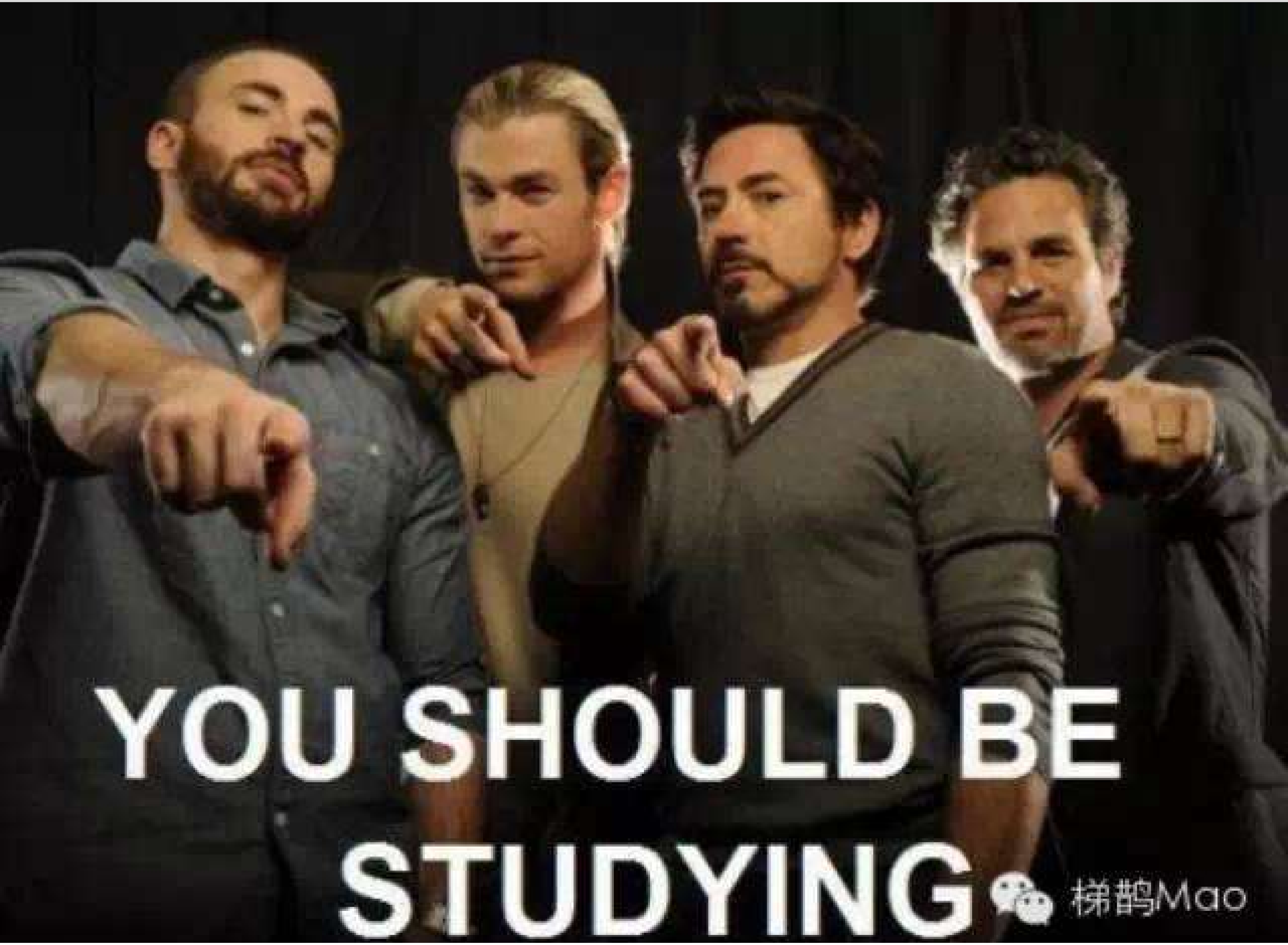
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