

Analog Electronics

Unit 8

Unit 8. Non linear functions with OAs

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Without hysteresis

With hysteresis

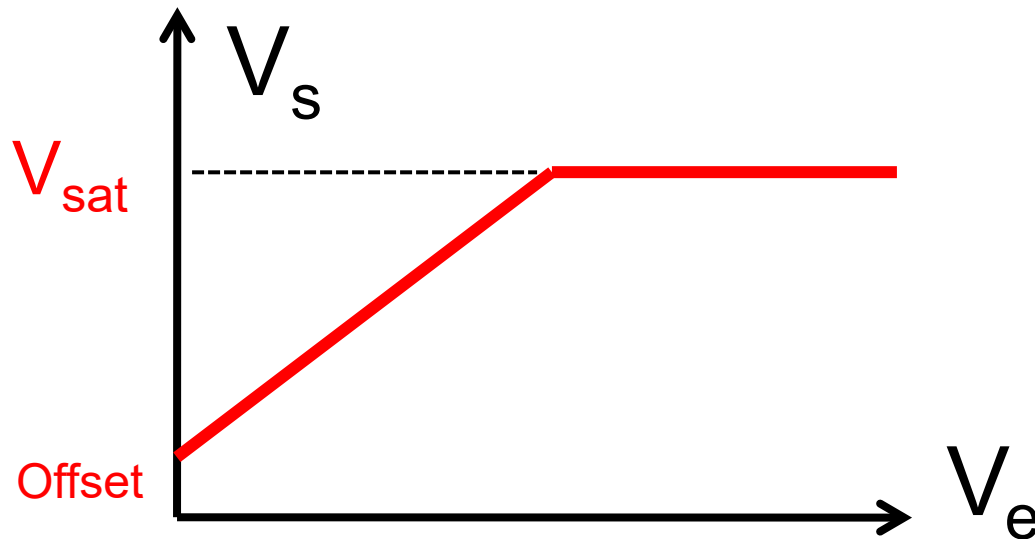
Oscillators

Multivibrator based on OA (Oscillators)

Precision Rectifiers

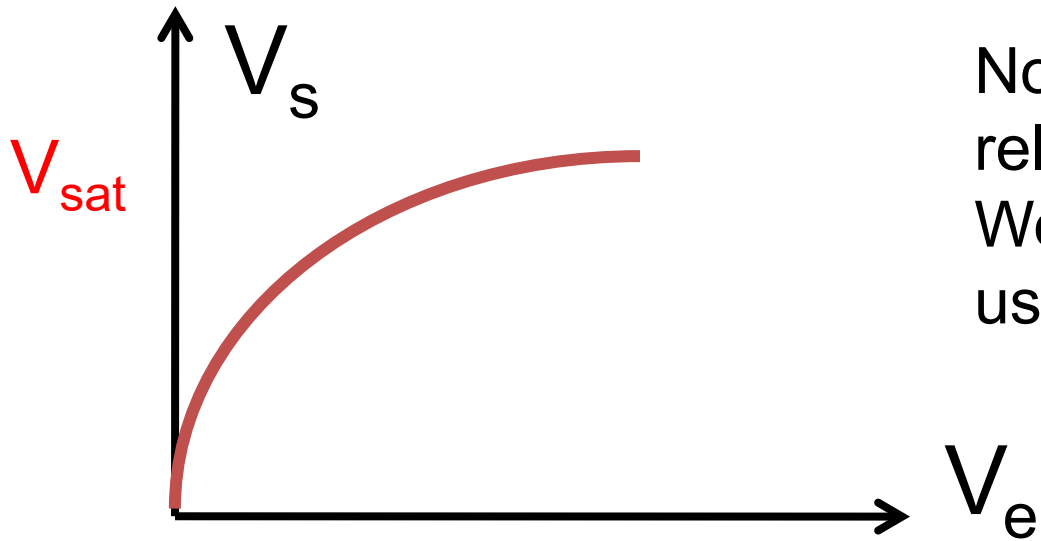
Logarithmic and antilogarithmic converters

Introduction: linear system



Is it linear?

Introduction: nonlinear system



Non linear relationships:
Well defined, stable,
useful

Non linear functions with OAs

Implementation

OA with
NEGATIVE
Feedback
+
NON linear elements
(diodes, transistors)

OA with
NO
feedback

OA with
POSITIVE
Feedback

Examples

Rectifier

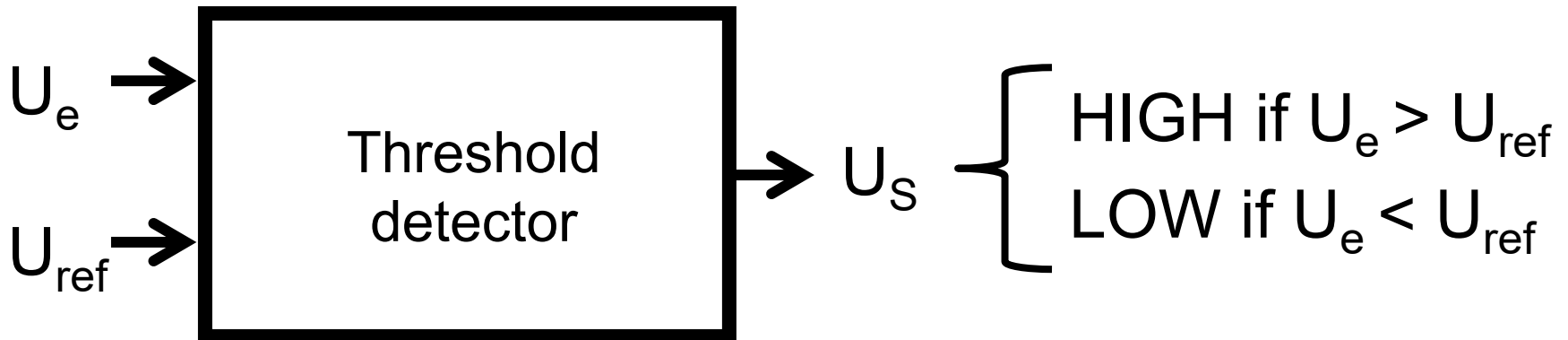
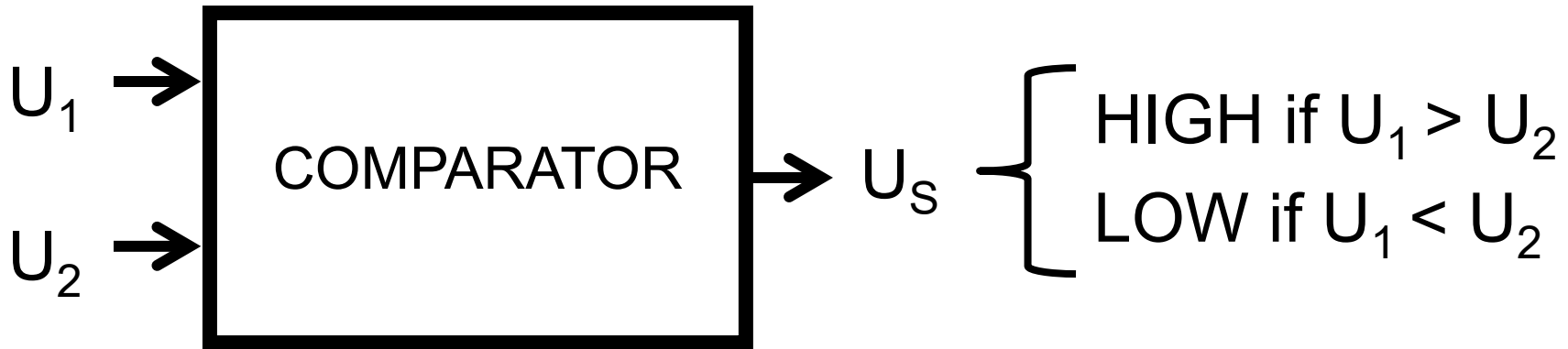
Log and antilog
amplifier

Comparator
without hysteresis

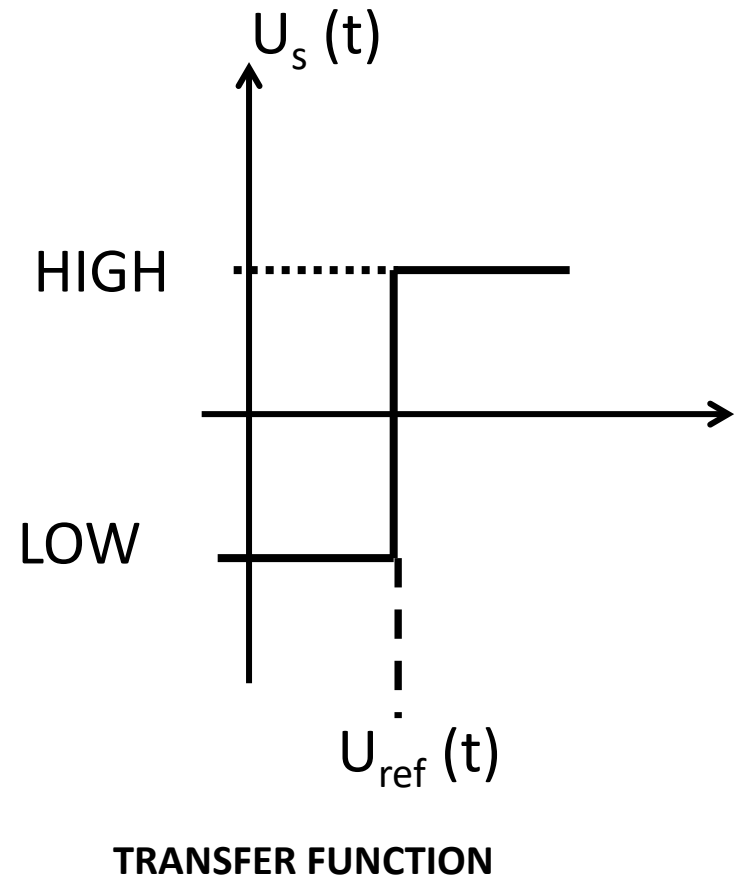
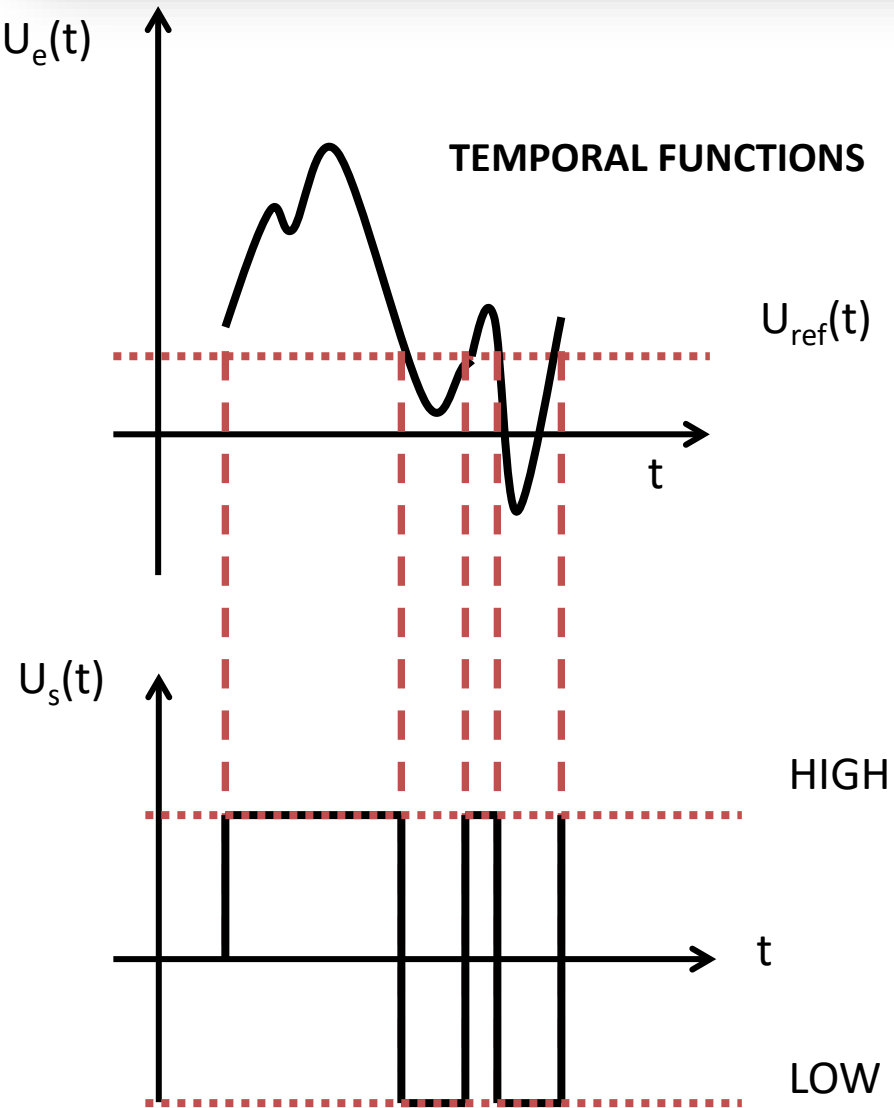
Comparator
with hysteresis

Multivibrator

Comparator



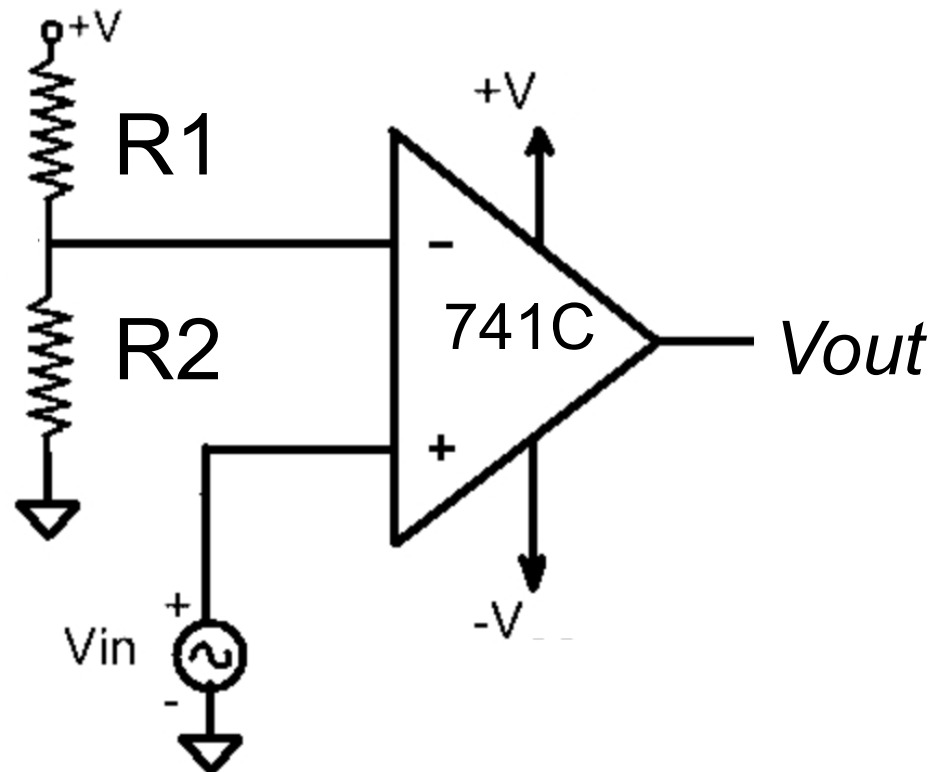
Threshold detector



Threshold detector

T8P1. Represent the transfer function (V_{out} versus V_{in}) if $R1=4\text{ k}\Omega$, $R2=1\text{ k}\Omega$ ($V=\pm 15\text{ V}$)

Represent V_{out} as a function of time if $V_{in}=4\cdot\text{sen}(2\pi\cdot 100\cdot t)$



How to obtain an output signal TTL compatible (5 V)?

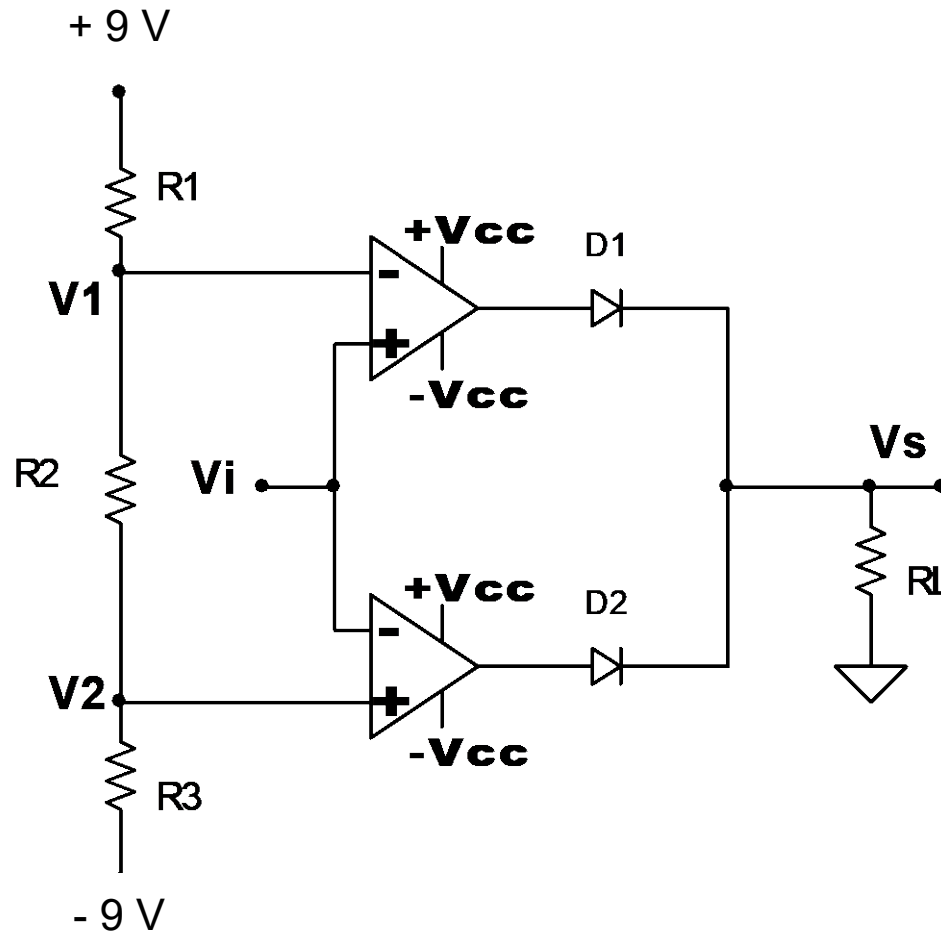
T8P2. Ex May 2009. P2. Si $R1=R2=R3$

1. Calcula los valores de $V1$ y $V2$.

2. Analiza el circuito y representa la función de transferencia.

3. Representa la evolución de Vs si Vi es una señal tringular de 5 V de amplitud (pico) y 1 kHz, sin nivel DC.

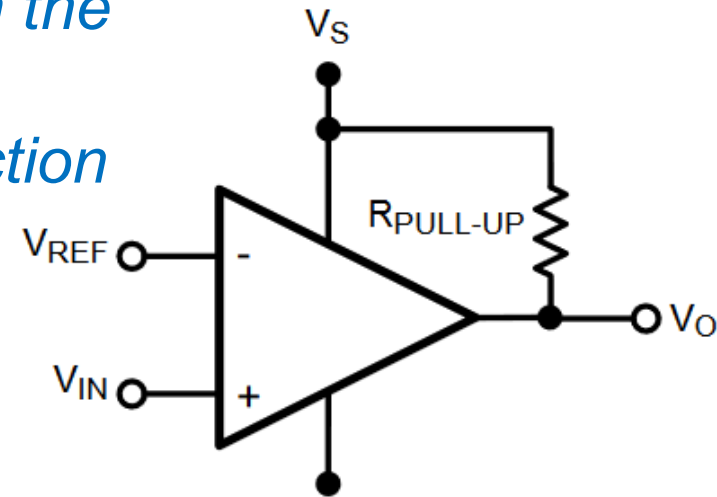
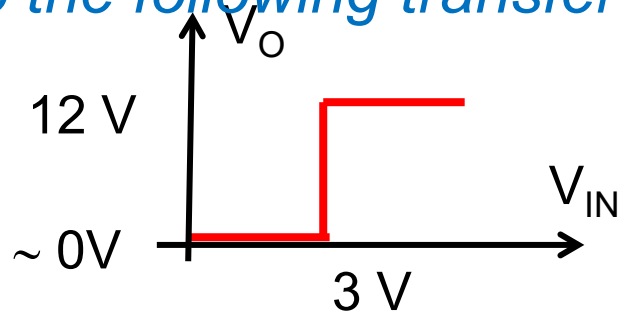
741C (± 10 V)



Threshold detector

T8P3. Design a threshold detector with the LM397

According to the following transfer function



LM397

SNOS977F – MAY 2001 – REVISED MAY 2016

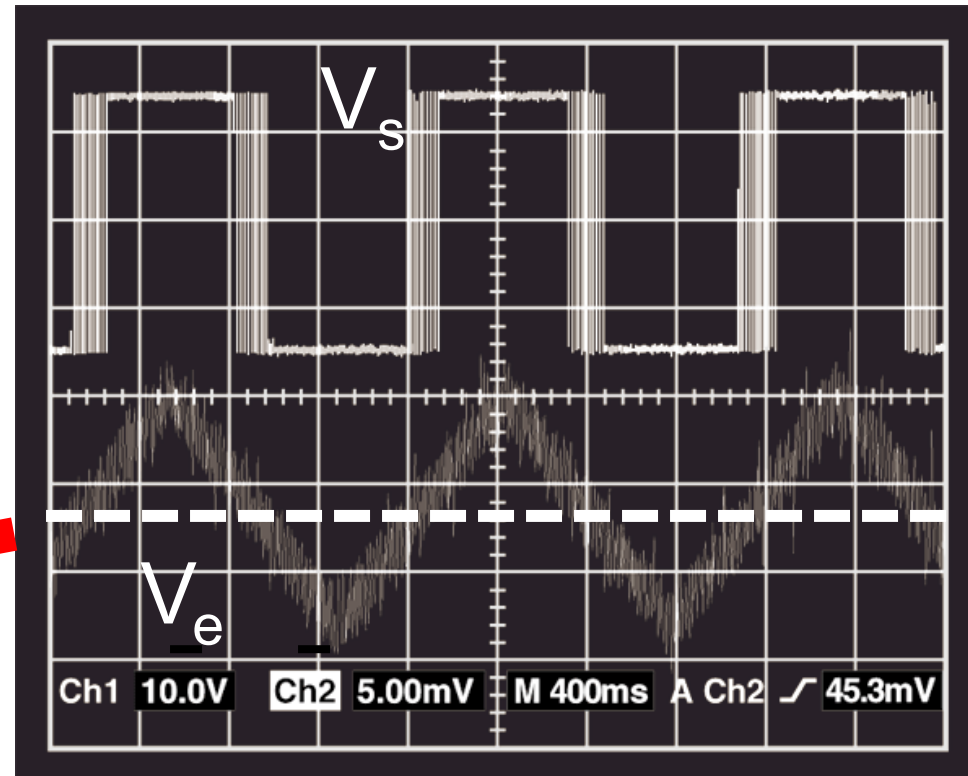
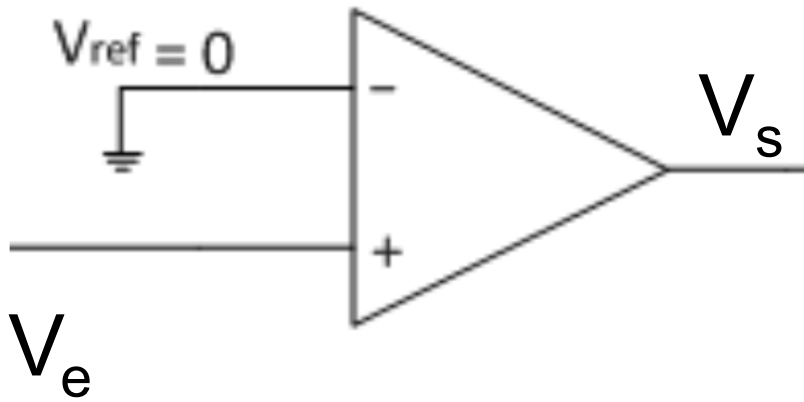
LM397 Single General-Purpose Voltage Comparator

6.5 Electrical Characteristics

Unless otherwise specified, all limits are ensured for $T_A = 25^\circ\text{C}$, $V_S = 5\text{ V}$, $V^- = 0\text{ V}$, $V_{CM} = V^+/2 = V_O$.

PARAMETER	TEST CONDITIONS	MIN ⁽¹⁾	TYP ⁽²⁾	MAX ⁽¹⁾	UNIT
V_{OL} Output voltage low	$I_O = -4\text{ mA}$, $V_{IN}^+ = 0\text{ V}$, $V_{IN}^- = 1\text{ V}$		180	400	mV
				700	
I_O Output sink current	$V_{IN}^+ = 1\text{ V}$, $V_{IN}^- = 0\text{ V}$, $V_O = 1.5\text{ V}$	6	13		mA

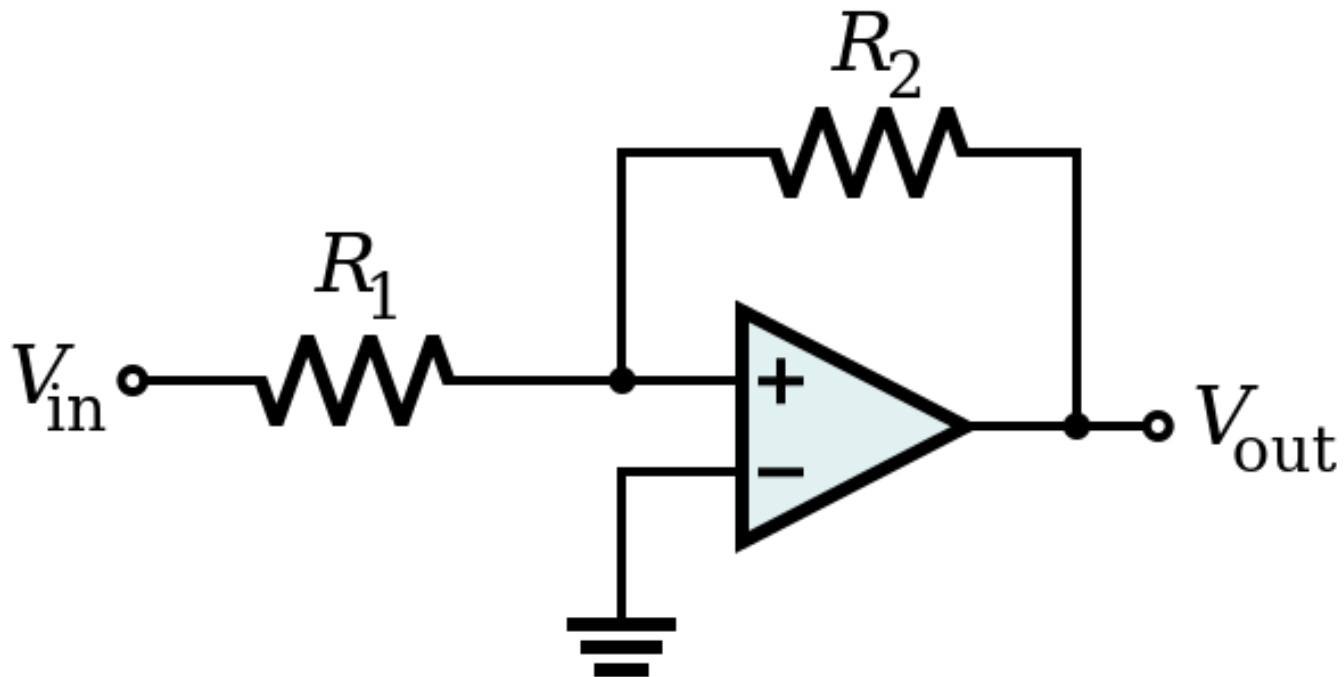
Threshold detector



Hysteresis comparator

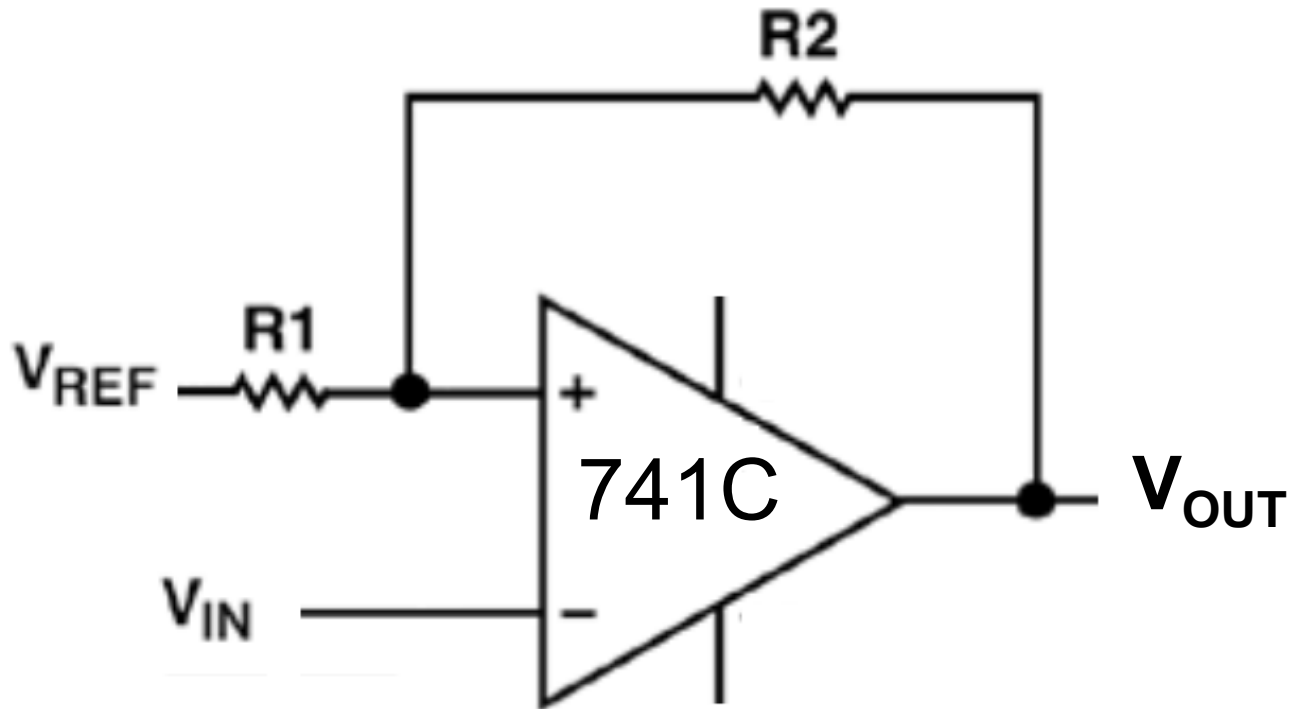
GOAL: To reduce instabilities at the output due to noise

METHOD: Positive feedback



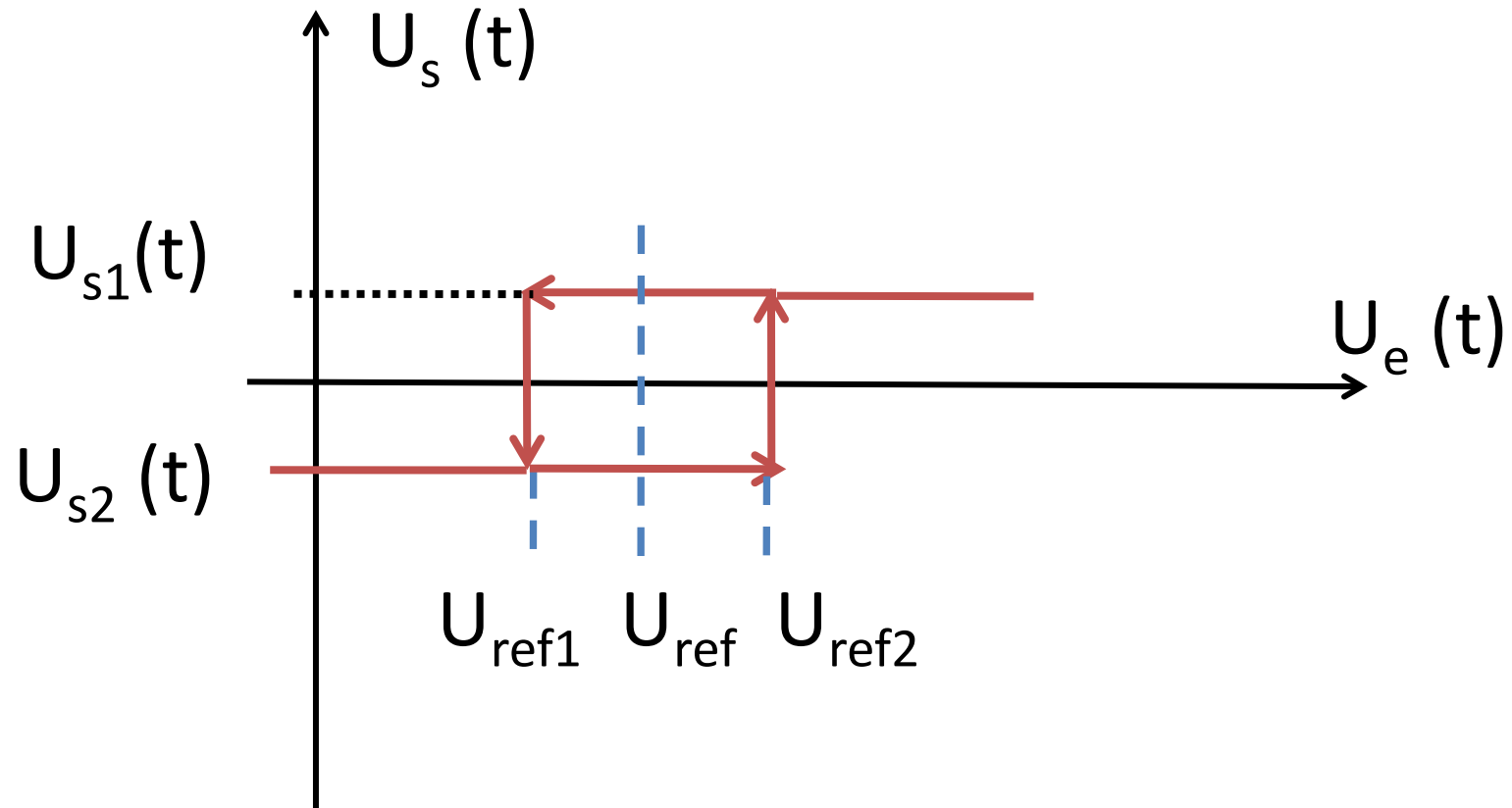
Hysteresis comparator

T8P4. Represent the transfer function (V_{OUT} vs V_{IN}) and the time course of V_{OUT} if V_{IN} is a triangular signal of 10 V (pp) and 1 kHz with no DC level ($R1=1\text{ k}\Omega$, $R2=2\text{ k}\Omega$, $V_{REF} = 1\text{ V}$, $\pm 15\text{ V}$)



Hysteresis comparator

Solution: Hysteresis comparator

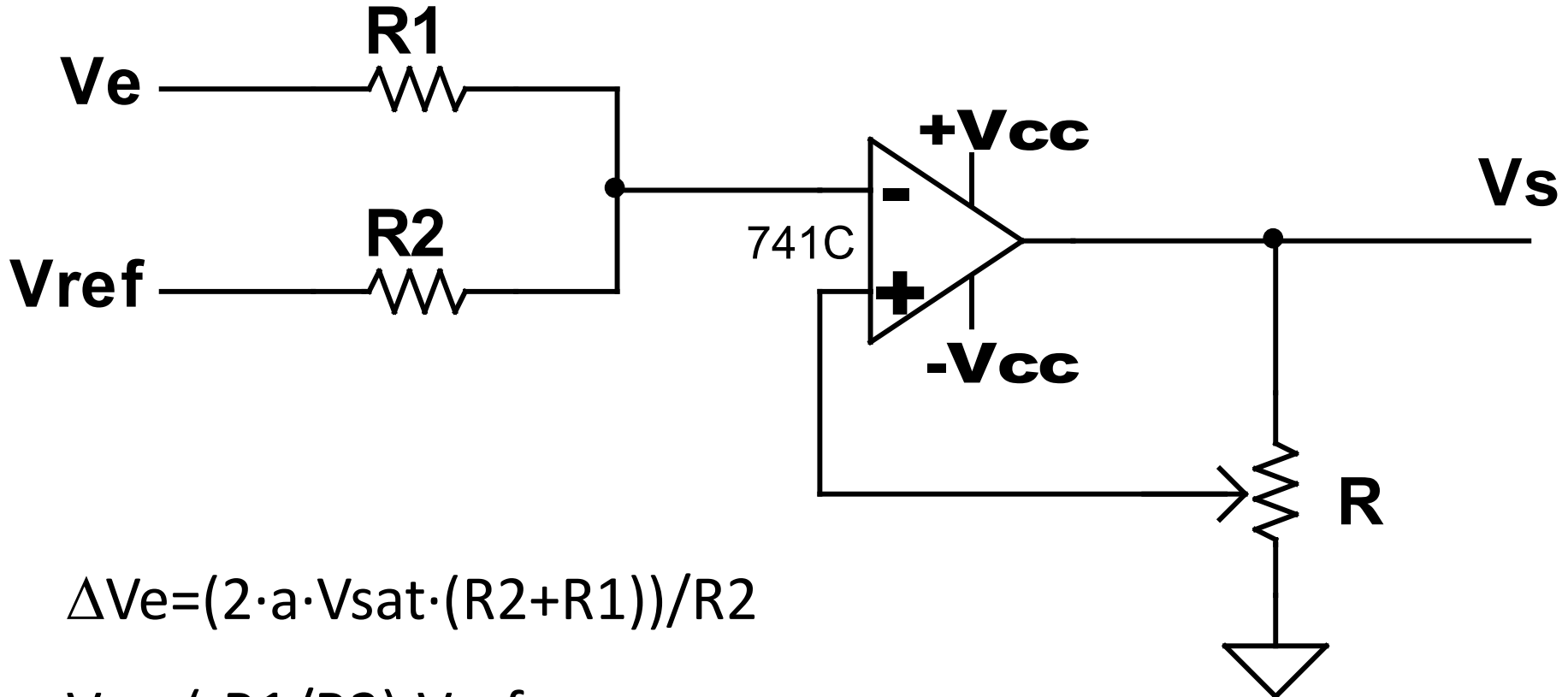


$$\Delta U_e = |U_{ref2} - U_{ref1}|$$

$$U_m = \frac{U_{ref1} + U_{ref2}}{2}$$

Hysteresis comparator

*T8P5. Dibujar la función de transferencia (V_s frente a V_e)
 $R1=1\text{ k}\Omega$, $R2=2\text{ k}\Omega$, $V_{ref} = 1\text{ V}$, $\pm 15\text{ V}$, Potenciómetro $a=1/3$*



$$\Delta V_e = (2 \cdot a \cdot V_{sat} \cdot (R2 + R1)) / R2$$

$$V_m = (-R1 / R2) \cdot V_{ref}$$

Hysteresis comparator

T8P6. Represent the transfer function

(V_O vs V_{IN})

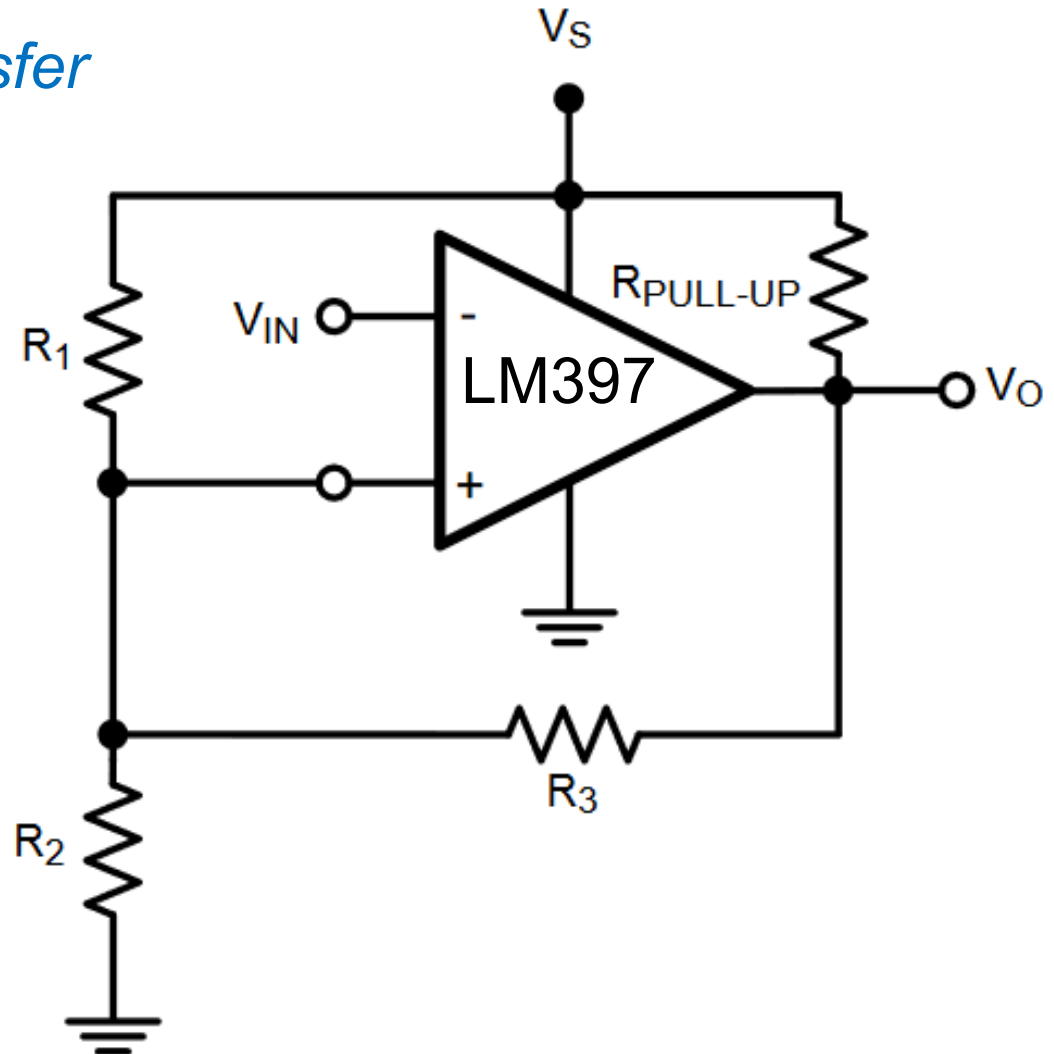
$R_1=1\text{ k}\Omega$

$R_2=2\text{ k}\Omega$

$R_3=3\text{ k}\Omega$

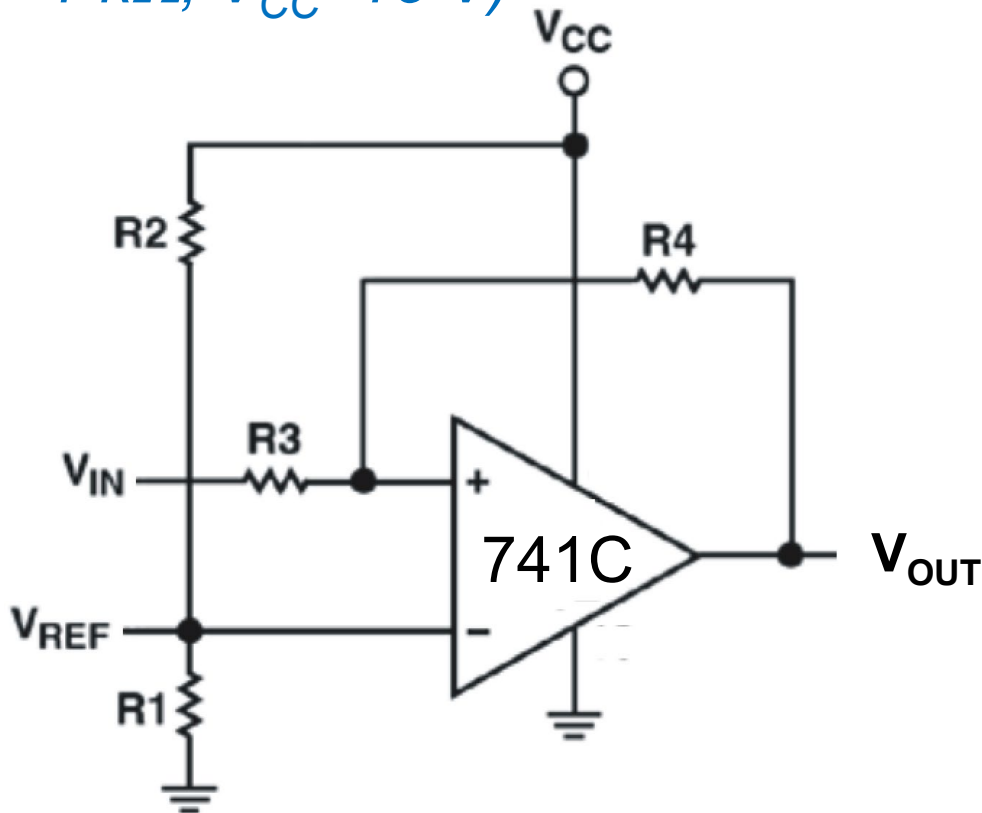
$V_S=5\text{ V}$

$R_{PULL-UP}=10\text{ k}\Omega$



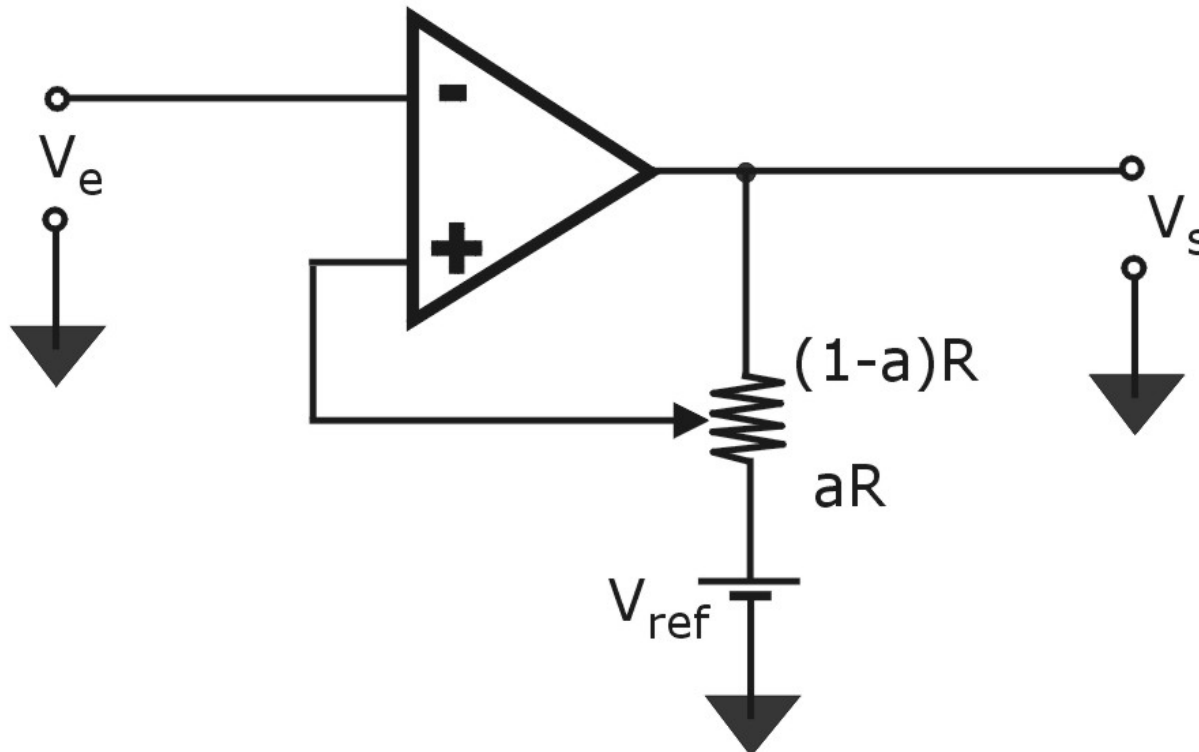
Hysteresis comparator

T8P7. Represent the transfer function (V_{OUT} vs V_{IN}) and the time course of V_{OUT} if V_{IN} is a triangular signal of 12 V (pp) and 100 Hz with no DC level ($R1=1\text{ k}\Omega$, $R2=4\text{ k}\Omega$, $R3=1\text{ k}\Omega$, $R4=1\text{ k}\Omega$, $V_{CC}=15\text{ V}$)



T8P8. Ex January 2007. P3.

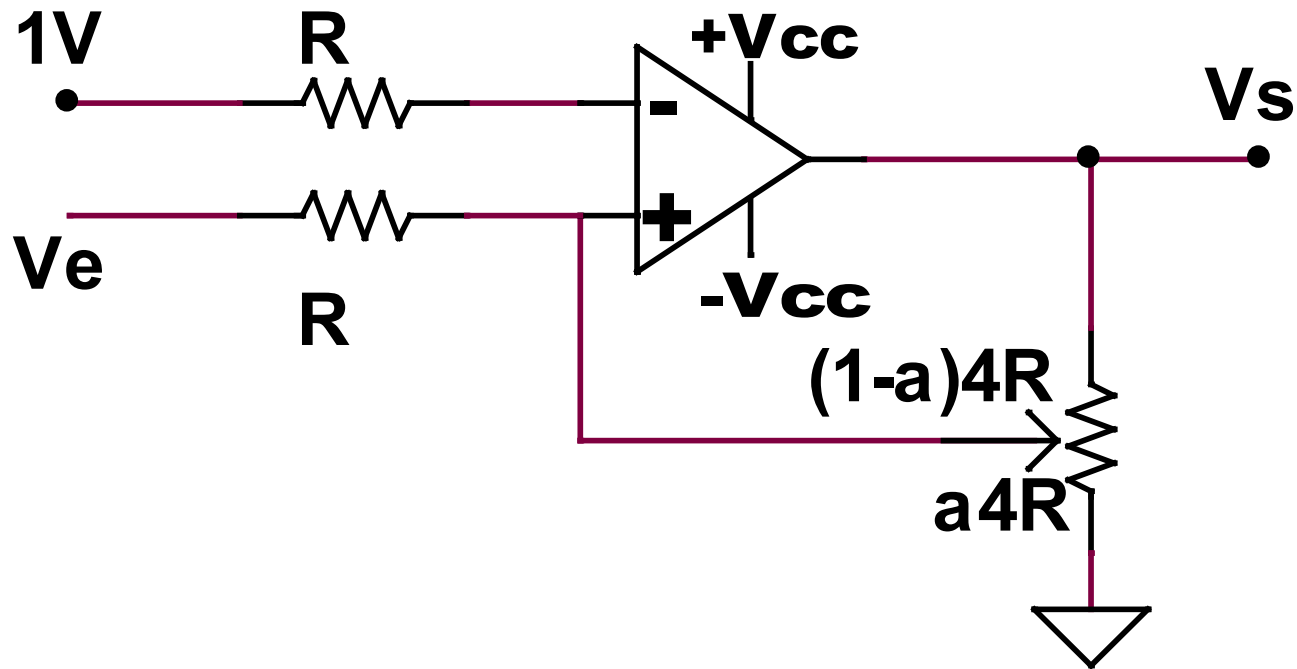
1. Dibujar la función de transferencia (V_s frente a V_e) indicando el valor exacto de los puntos de corte con los ejes de abscisas y ordenadas
 2. Dibujar la forma de onda $V_s(t)$ si V_e es una triangular de 6 V (pp) y un nivel de continua de 3 V (frecuencia de 100 Hz)
- DATOS: $\pm V_{sat} = \pm 13$ V, $V_{ref} = 5$ V, $a=0.1$, $R=1$ k Ω



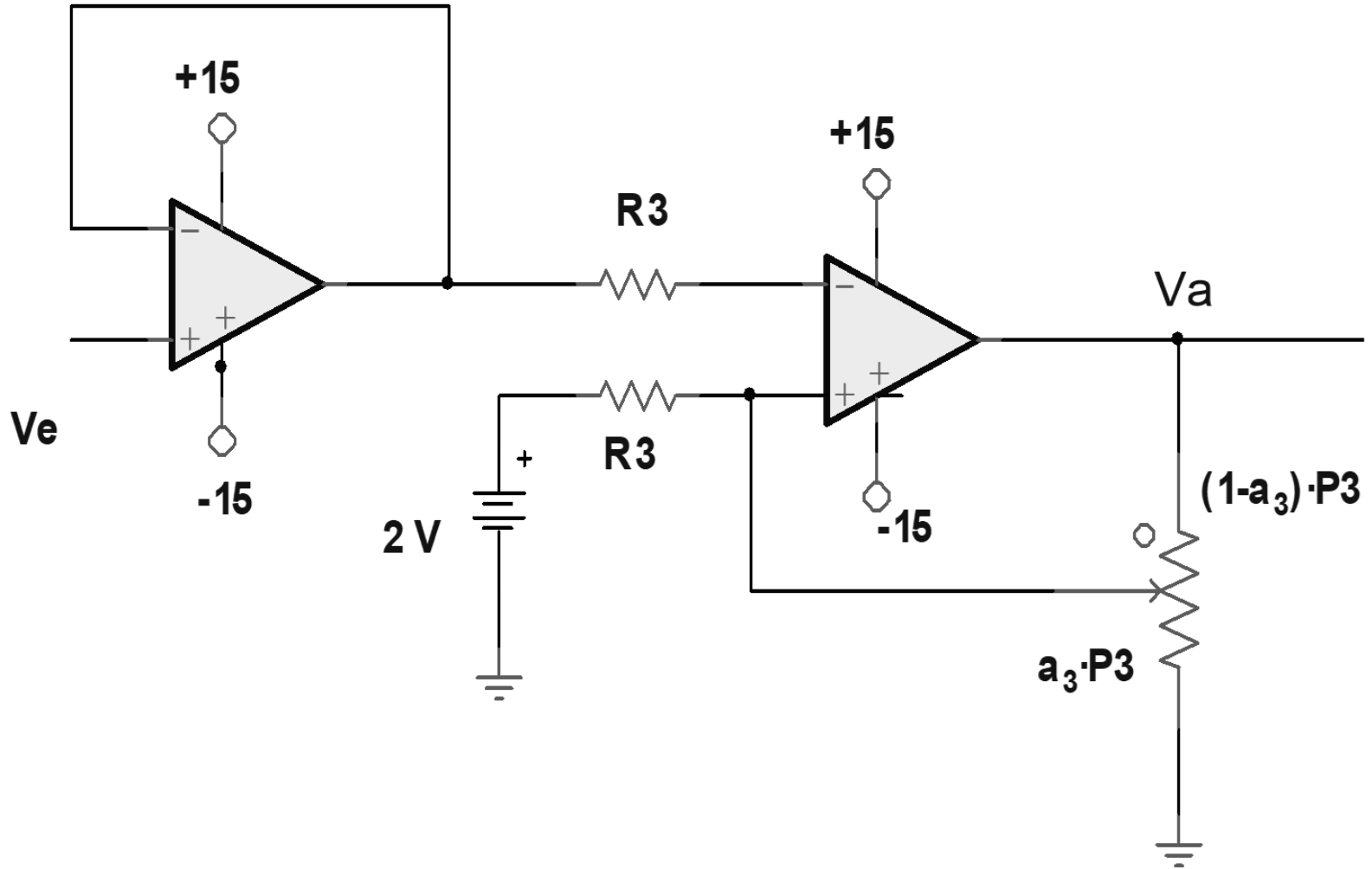
T8P9. Ex January 2011. P3.

Para generar una señal cuadrada a partir de una señal senoidal V_e se dispone del circuito de la figura ($V_{cc} = 15\text{ V}$).

1. Si el potenciómetro está en su posición intermedia, analizar el circuito y representar la función de transferencia.
2. Representar la evolución temporal de V_s , si V_e es una señal senoidal de valor medio nulo, frecuencia 1 kHz y amplitud de pico 10 V .
3. ¿Cómo podría regularse el ciclo de trabajo de la señal de salida?
4. Representar la señal de salida para las posiciones límite del potenciómetro.

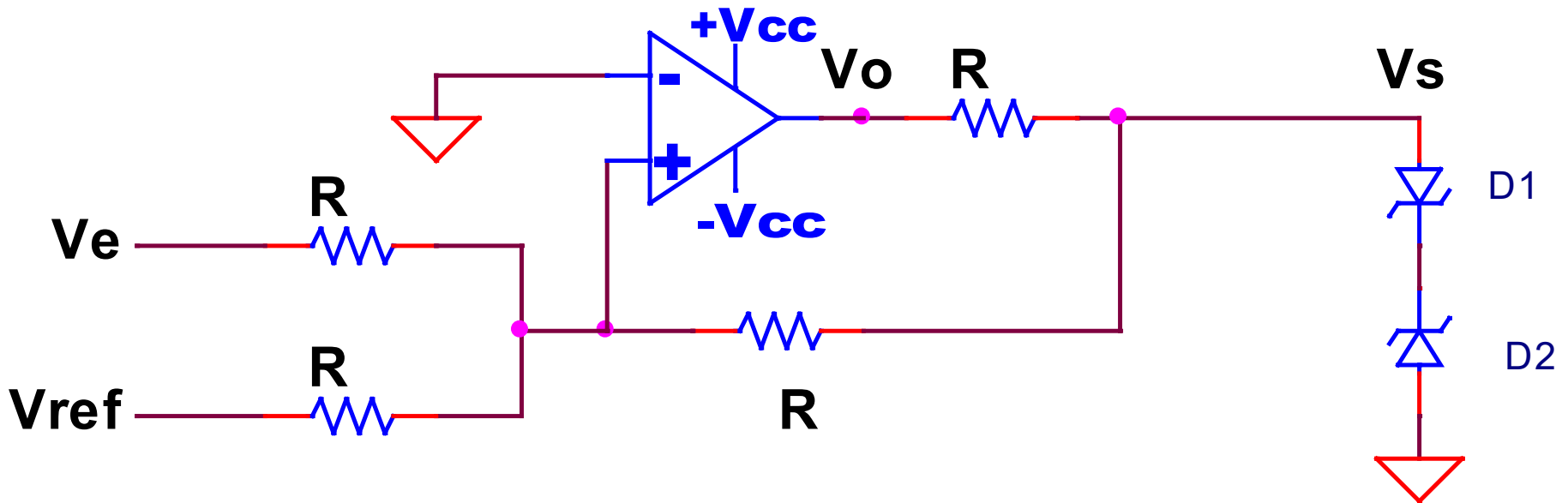


T8P10. Lab Exp 5. Representa la función de transferencia
 $R3=10\text{ k}\Omega$, $P3=500\text{ k}\Omega$, $a_3=0.9$, $\pm V_{sat}=\pm 15\text{ V}$

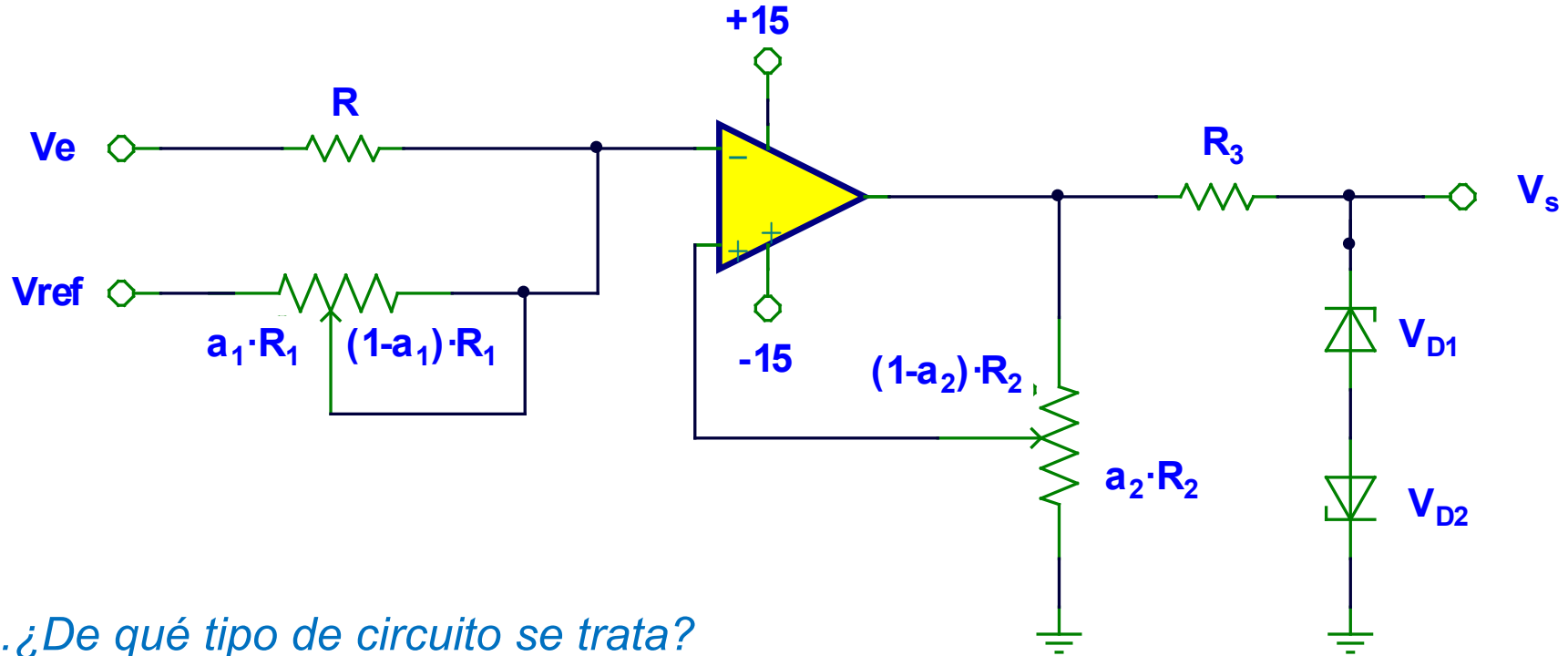


T8P11. Ex January 2009. P3.

1. Indica los valores que puede tomar V_o y V_s .
 2. Dibuja la función de transferencia.
 3. Representa gráficamente la evolución de V_o y V_s si V_e es una señal senoidal de 10 V de pico y 10 Hz, y valor medio nulo.
- DATOS: $V_{cc} = \pm 15$ V, $V_{Z1} = V_{Z2} = 5$ V, $V_{ref} = 2$ V



T8P12. P36. Se desea realizar el control de temperatura de un invernadero. La tensión de salida proveniente del sensor de temperatura es V_e . La salida V_s debe ser compatible con TTL 5V.



1. ¿De qué tipo de circuito se trata?

2. Dibujar la función de transferencia

Datos: $R=10\text{ k}\Omega$, $R_1=10\text{ k}\Omega$, $a_1=0.5$, $R_2=10\text{ k}\Omega$, $a_2=0.5$, $V_{z1}=V_{z2}=5\text{ V}$, $V_{ref}=1\text{V}$.

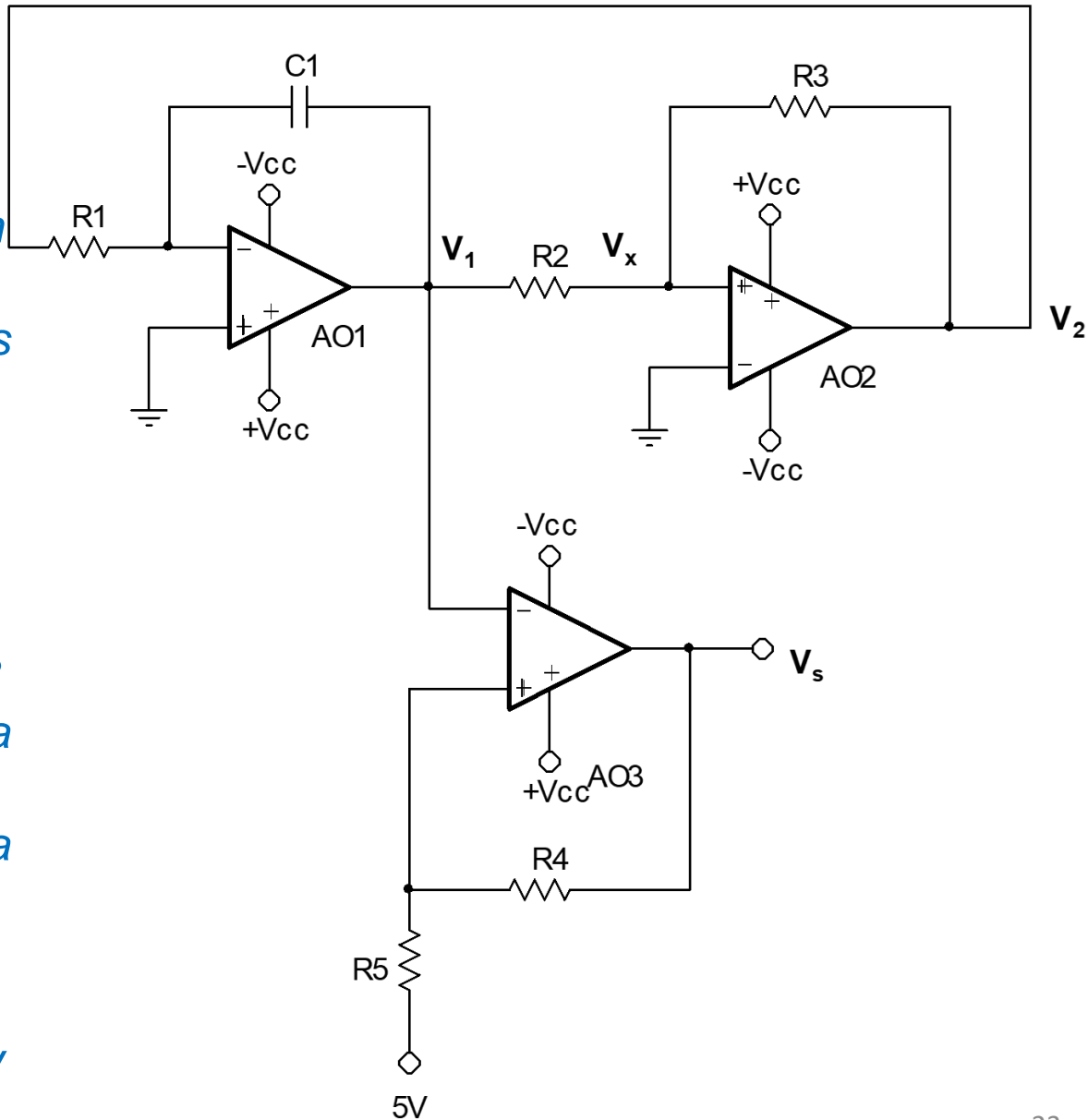
3. Dibujar la evolución de V_s si V_e es una senoidal de 10 V (pico) sin nivel DC.

4. Calcular los límites entre los que puede variar a_2 para que V_s sea un tren de pulsos (es decir, para que exista ciclo de histéresis). Considerar: $R=10\text{ k}\Omega$, $R_1=10\text{ k}\Omega$, $R_2=10\text{ k}\Omega$, $a_1=0.5$, $V_z=5\text{V}$, $V_{ref}=1\text{V}$

T8P13. Ex June 2005. P2.

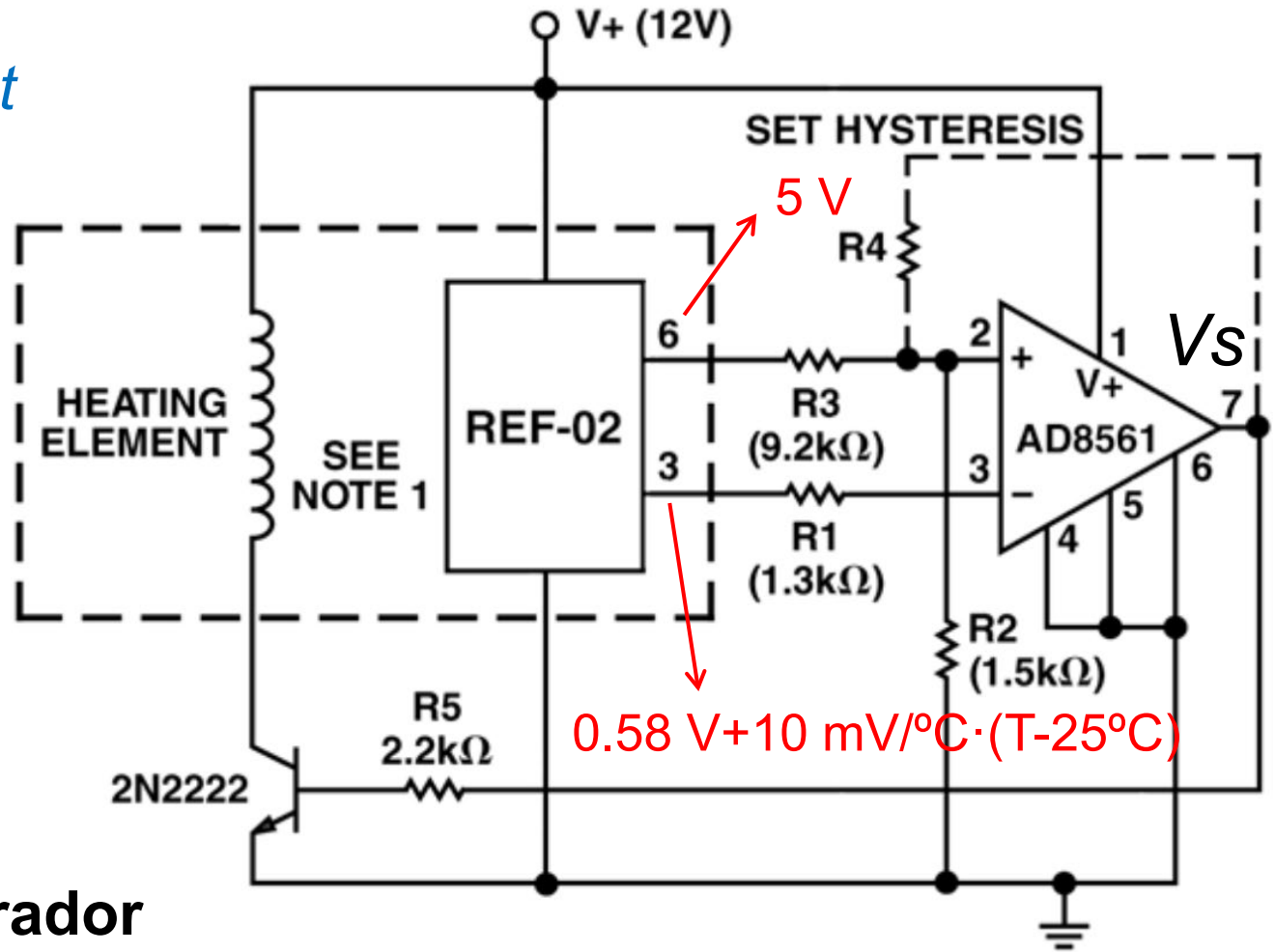
1. Expresión de la tensión V_1 en función de V_2 en el dominio frecuencial y temporal.
2. Expresión de V_x en función de V_1 y V_2 .
3. Valores de V_x y V_2 para los que se produce la conmutación del AO2
4. Dibujar la evolución temporal de V_1 y V_2
5. ¿Qué tipo de circuito constituye la etapa de salida?
6. Representa gráficamente la función de V_s/V_1
7. Representa gráficamente la evolución de V_s y V_1

Datos: $R_1 = R_2 = R_3 = R_4 = R_5 = 1 \text{ k}\Omega$, $C_1 = 10 \text{ nF}$, $V_{cc} = 15 \text{ V}$



Hysteresis comparator

T8P14. Represent the transfer function (V_S vs Temperature) And explain the operation $R4=20\text{ k}\Omega$



AD8561. Comparador

DIGITAL OUTPUTS

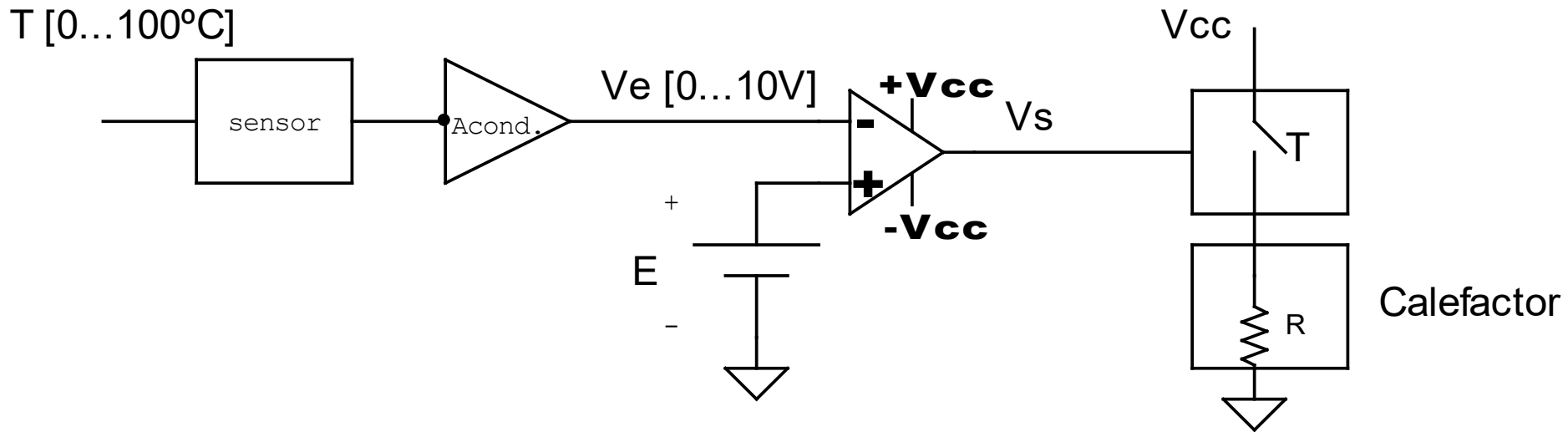
Logic "1" Voltage
 Logic "1" Voltage
 Logic "0" Voltage

V_{OH}
 V_{OH}
 V_{OL}

$I_{OH} = -50\ \mu\text{A}, \Delta V_{IN} > 250\ \text{mV}$
 $I_{OH} = -3.2\ \text{mA}, \Delta V_{IN} > 250\ \text{mV}$
 $I_{OL} = 3.2\ \text{mA}, \Delta V_{IN} > 250\ \text{mV}$

3.5			V
2.4	3.5		V
	0.25	0.4	V

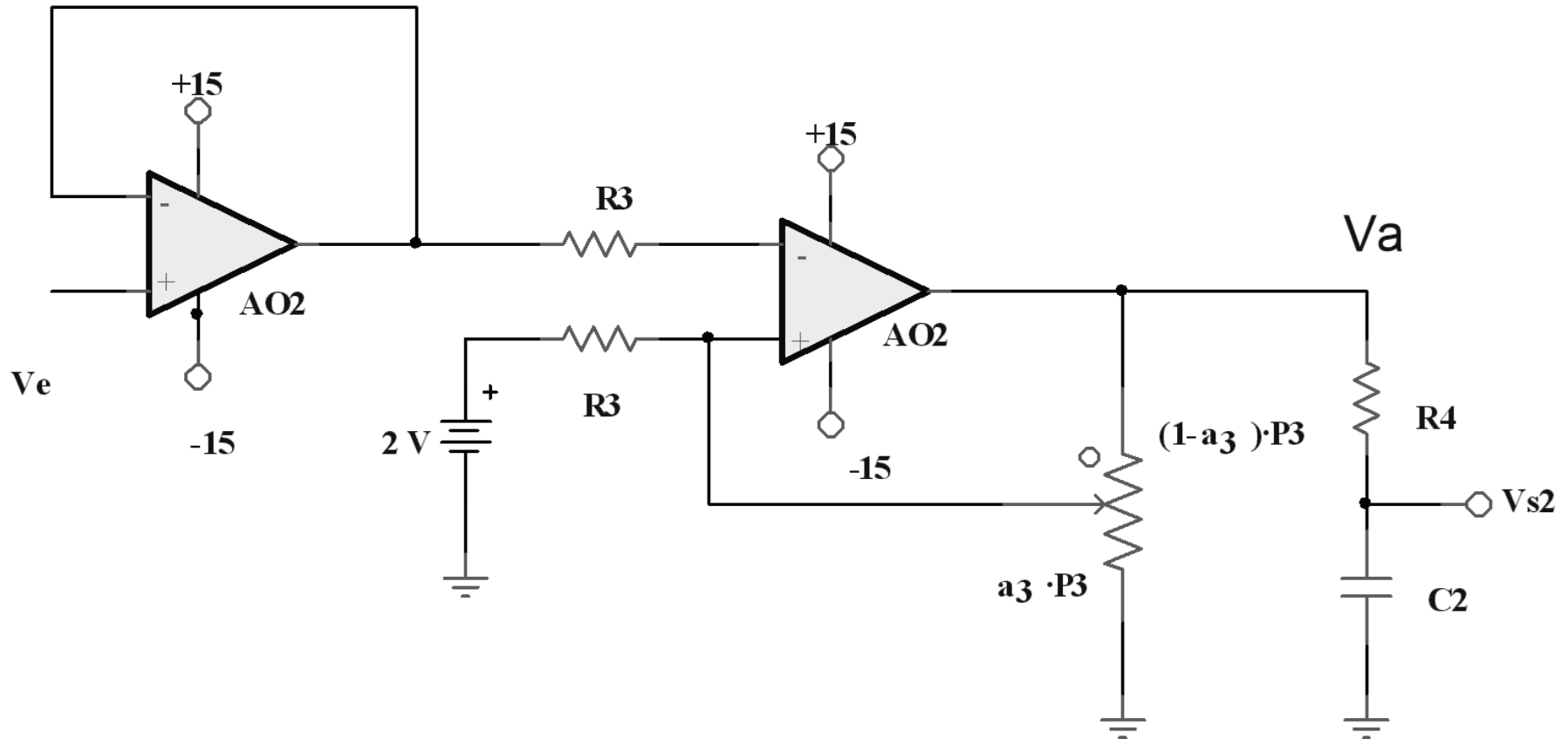
T8P15. P39. Diseñar un regulador de temperatura para un sistema de calefacción basado en el siguiente circuito



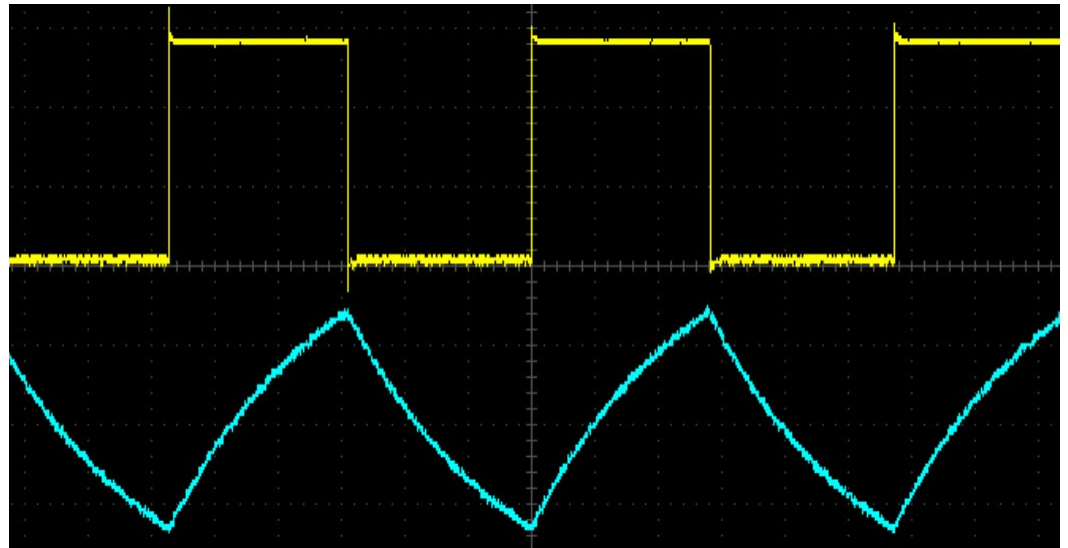
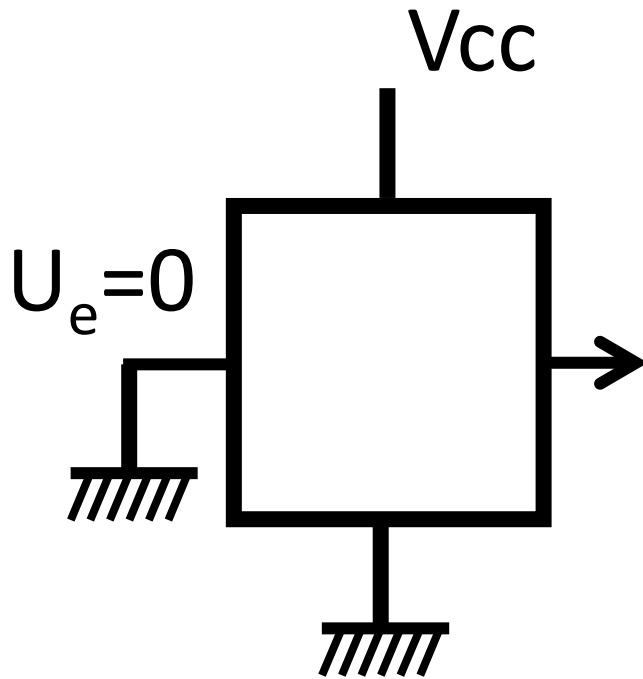
Si $T < 21^{\circ}\text{C}$, V_s debe poder cerrar el interruptor T y el calefactor se activa. Si $T > 21^{\circ}\text{C}$, el calefactor se desactiva.

- 1. Calcula el valor de E y dibuja la función de transferencia $V_s = f(T)$.*
- 2. ¿Qué problema tiene este circuito? Dibujar la curva de la T^a en función del tiempo para explicarlo. Proponer un esquema alternativo de modo que la temperatura nunca supere los 23°C y no sea inferior a 19°C . Diseñar cada uno de los elementos del sistema propuesto.*

*T8P16. Lab Exp 5. Justificar porqué al conectar C2 y R4 a la salida del circuito, se obtiene un regulador de DC
¿Cómo podemos variar el nivel de DC? $R4 = 470\text{ k}\Omega$, $C2 = 560\text{ nF}$*

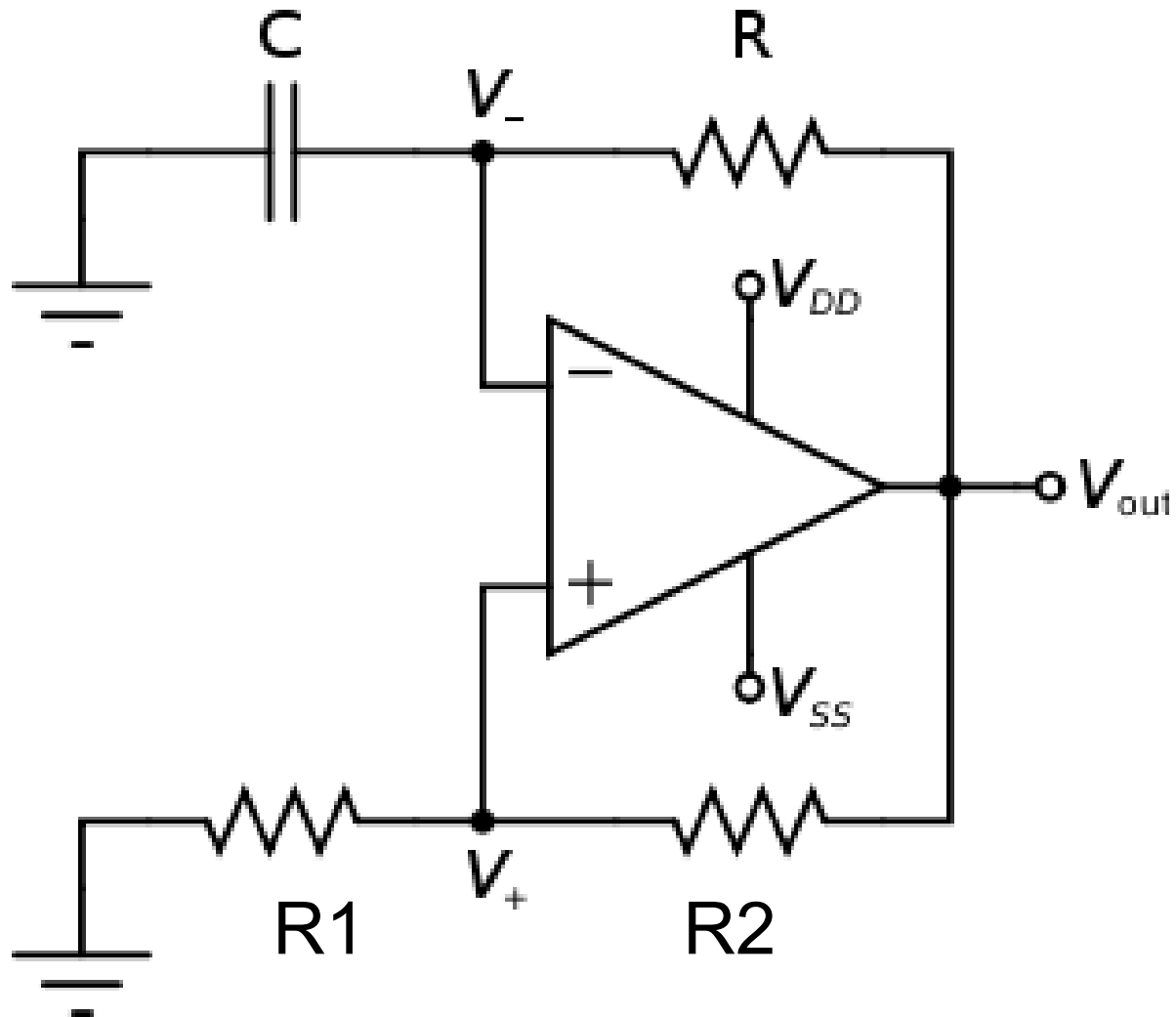


Oscillators



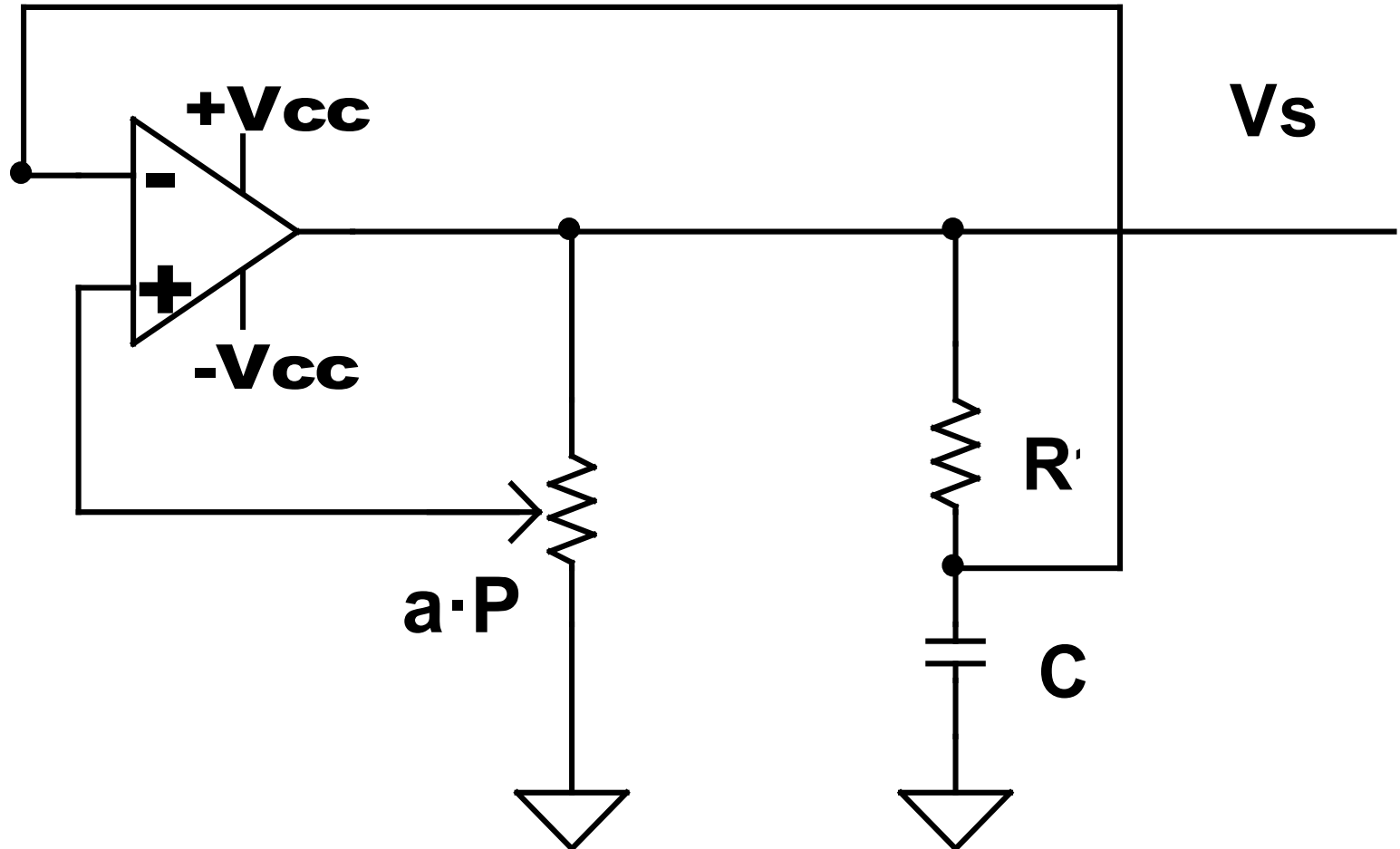
$U_s(t)$ amplitude and fixed frequency (f_{osc})

Multivibrator (oscillator based on OA)



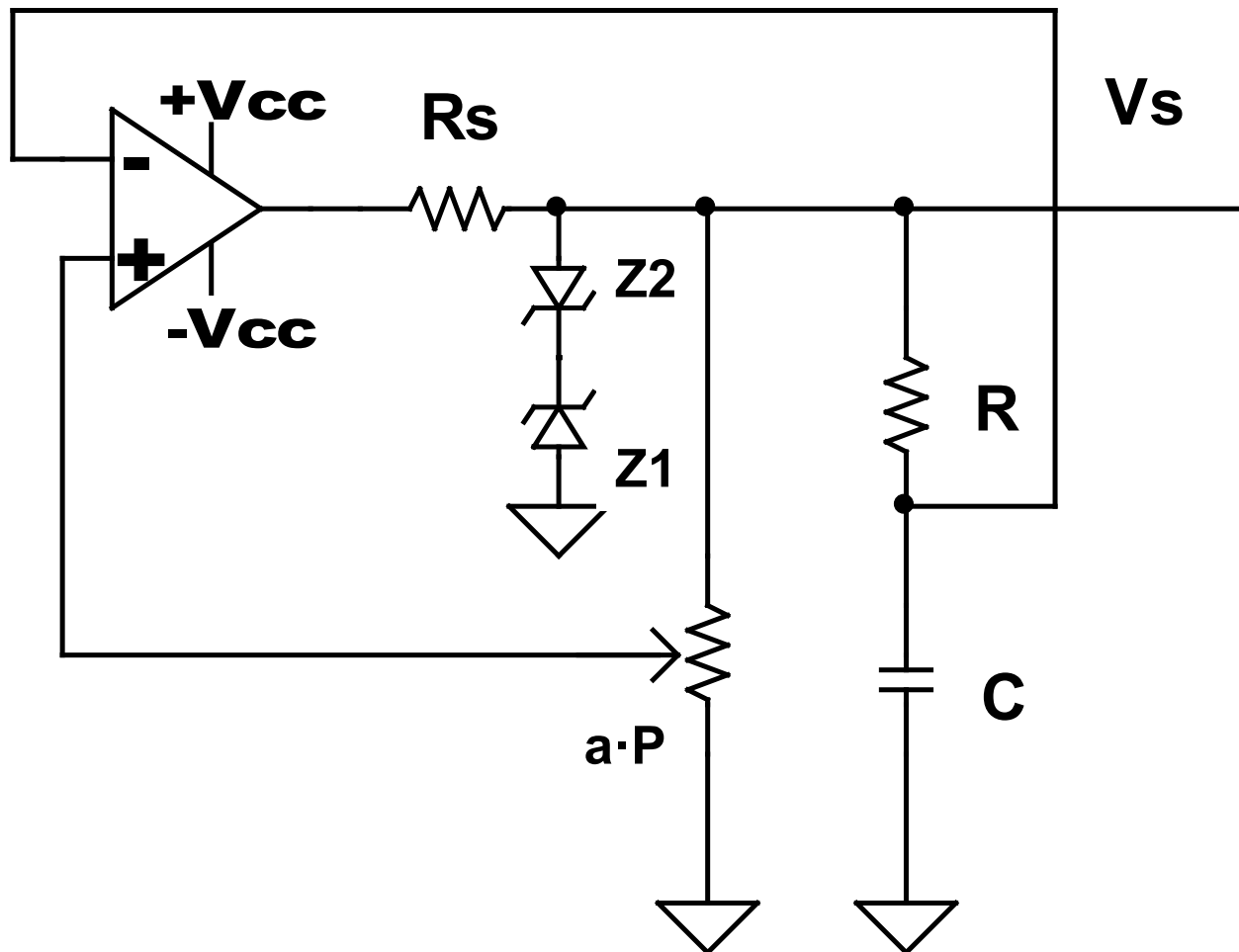
Multivibrator

T8P17. Obtain the expression of the oscillation frequency as a function of R , C , P , and a



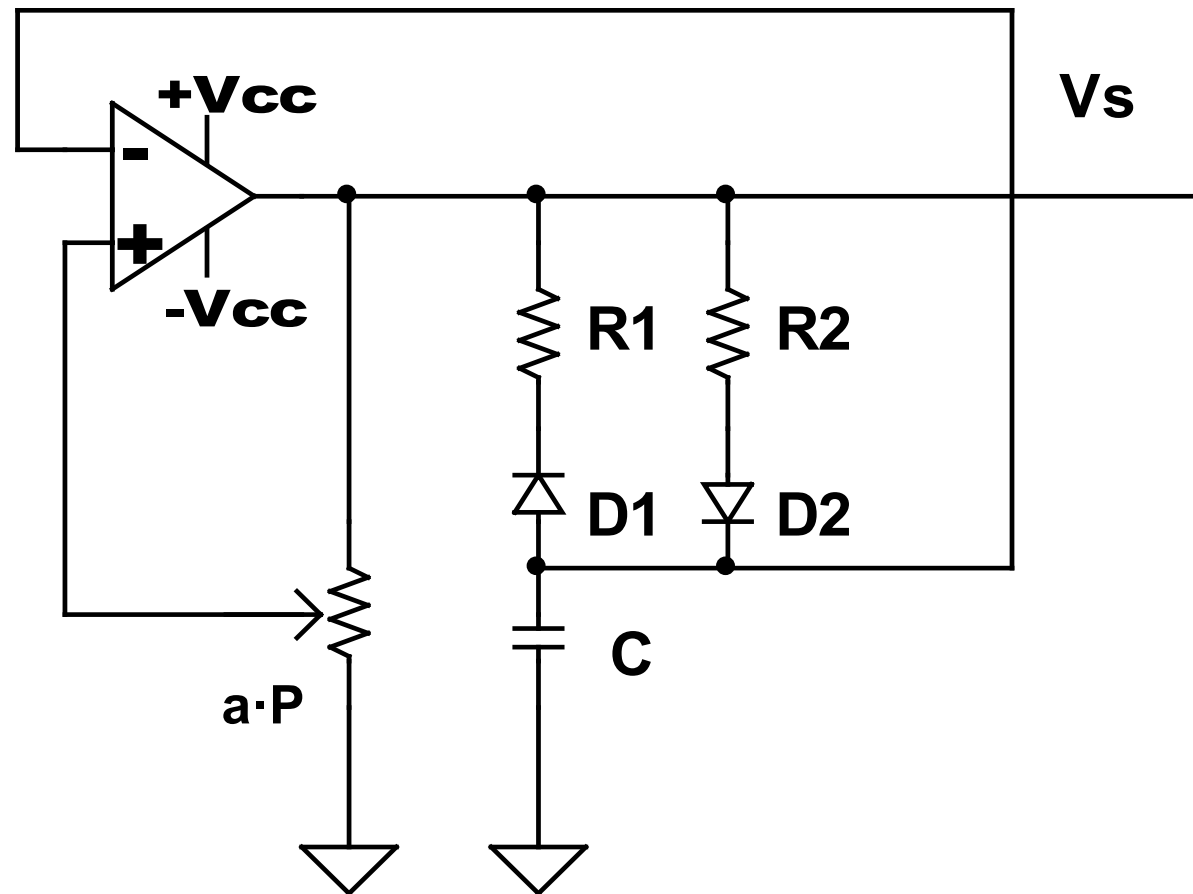
Multivibrator

T8P18. Explain how the net R_s -Zeners modifies the multivibrator features (frequency and amplitude of V_s)



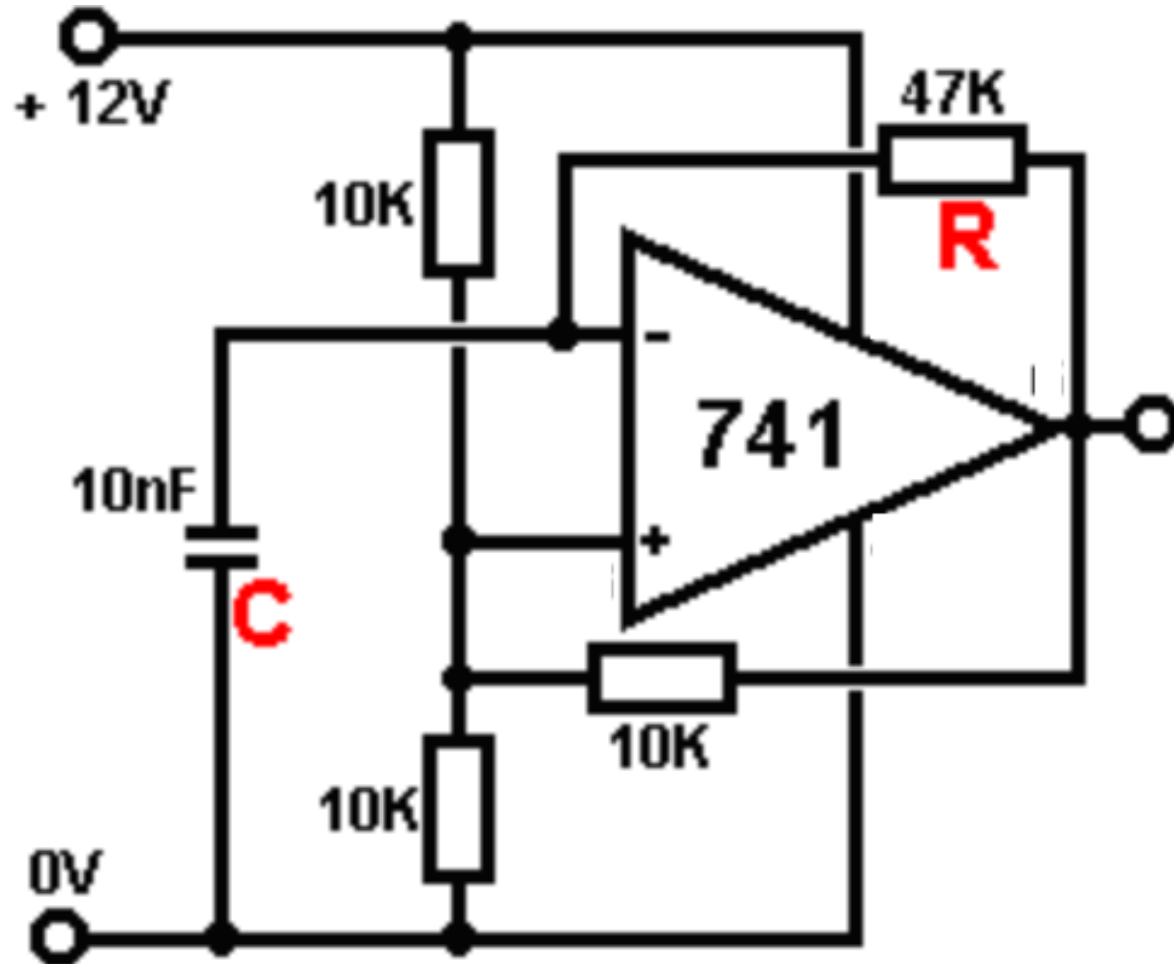
Multivibrator

T8P19. Explain how the net of resistors $R1$ y $R2$ with diodes $D1$ and $D2$ modifies the multivibrator features (frequency and amplitude of V_s)



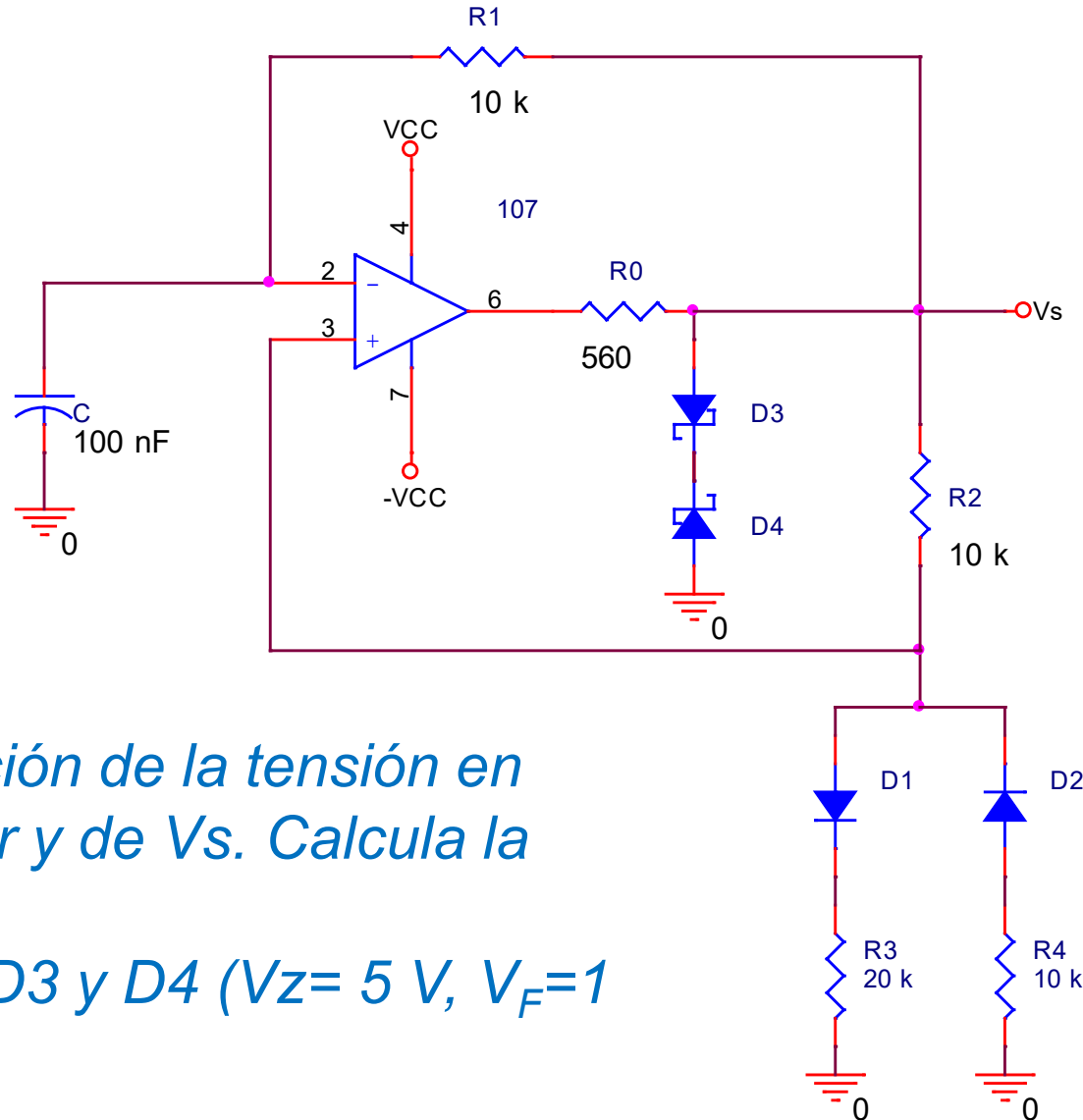
Multivibrator

T8P20. Calculate the frequency and amplitude of the output signal



T8P21. Ex June 2010. P3.

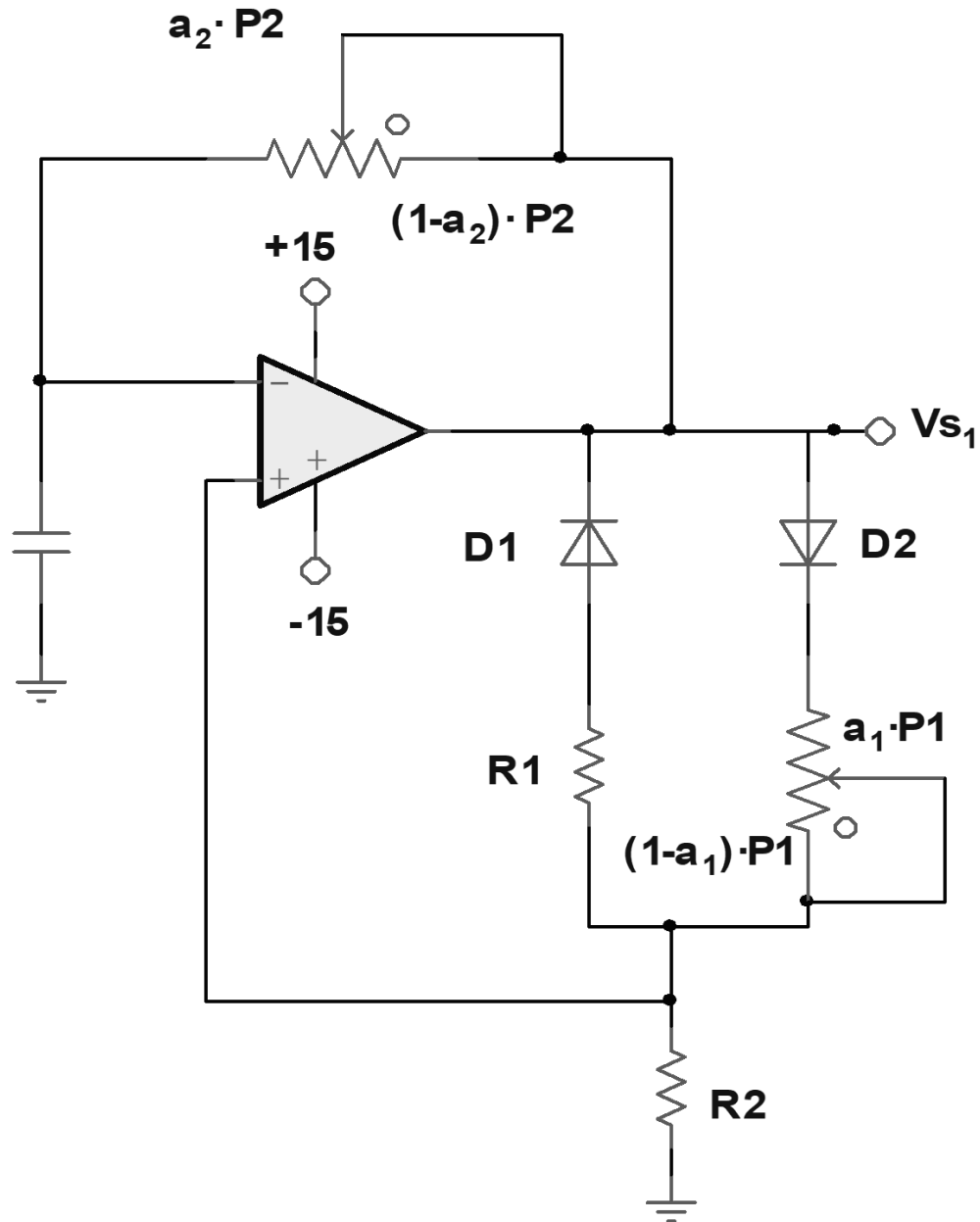
1. ¿Entre qué valores oscilará la tensión de salida del operacional?
2. ¿Entre qué valores variará la tensión de salida V_s ?



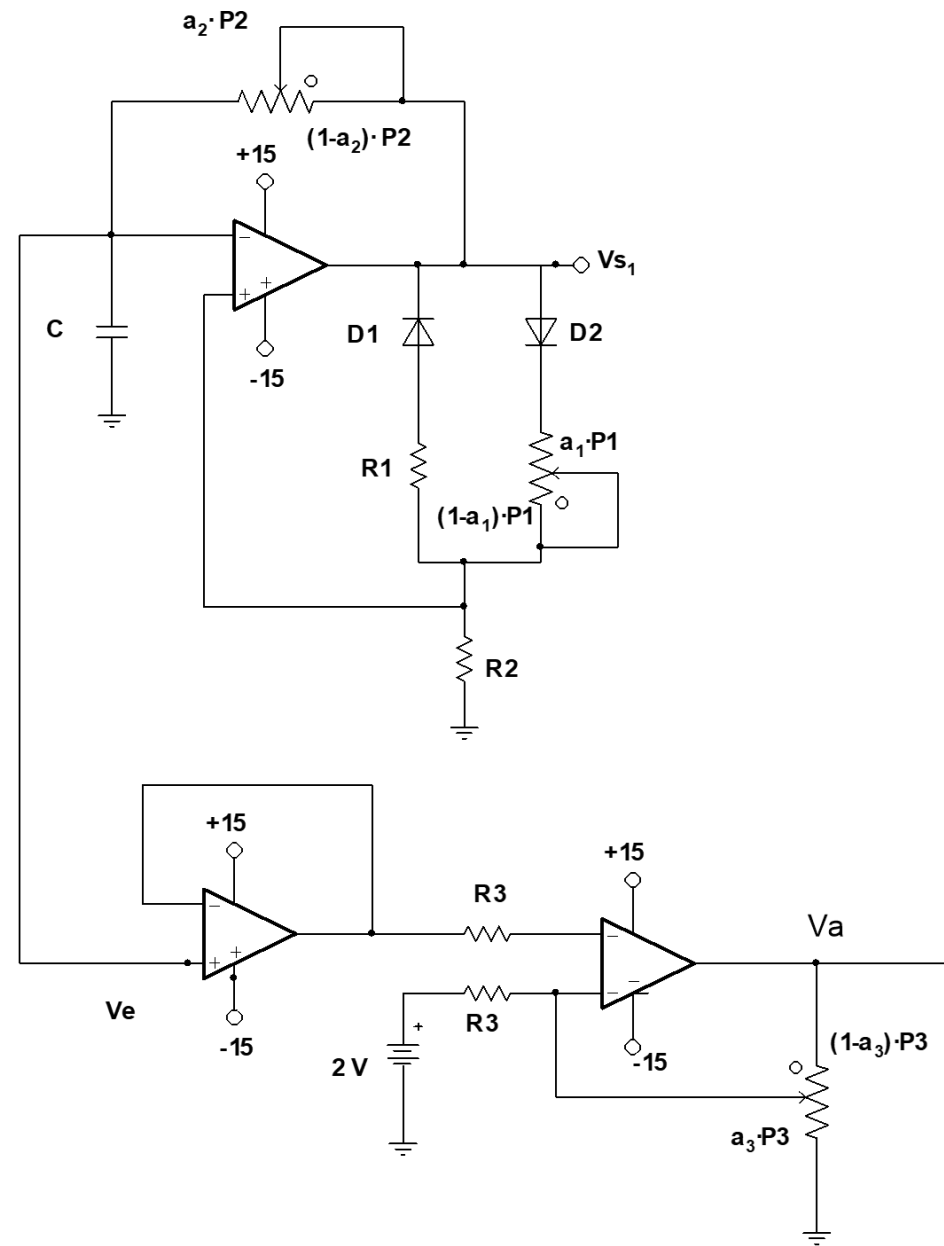
3. Representa la evolución de la tensión en bornes del condensador y de V_s . Calcula la frecuencia de V_s

Datos: $\pm V_{cc} = \pm 15 \text{ V}$, $D3$ y $D4$ ($V_z = 5 \text{ V}$, $V_F = 1 \text{ V}$) ($D1$ y $D2$ ideales)

T8P22. Lab Exp 5. Obtén la expresión de al frecuencia de oscilación

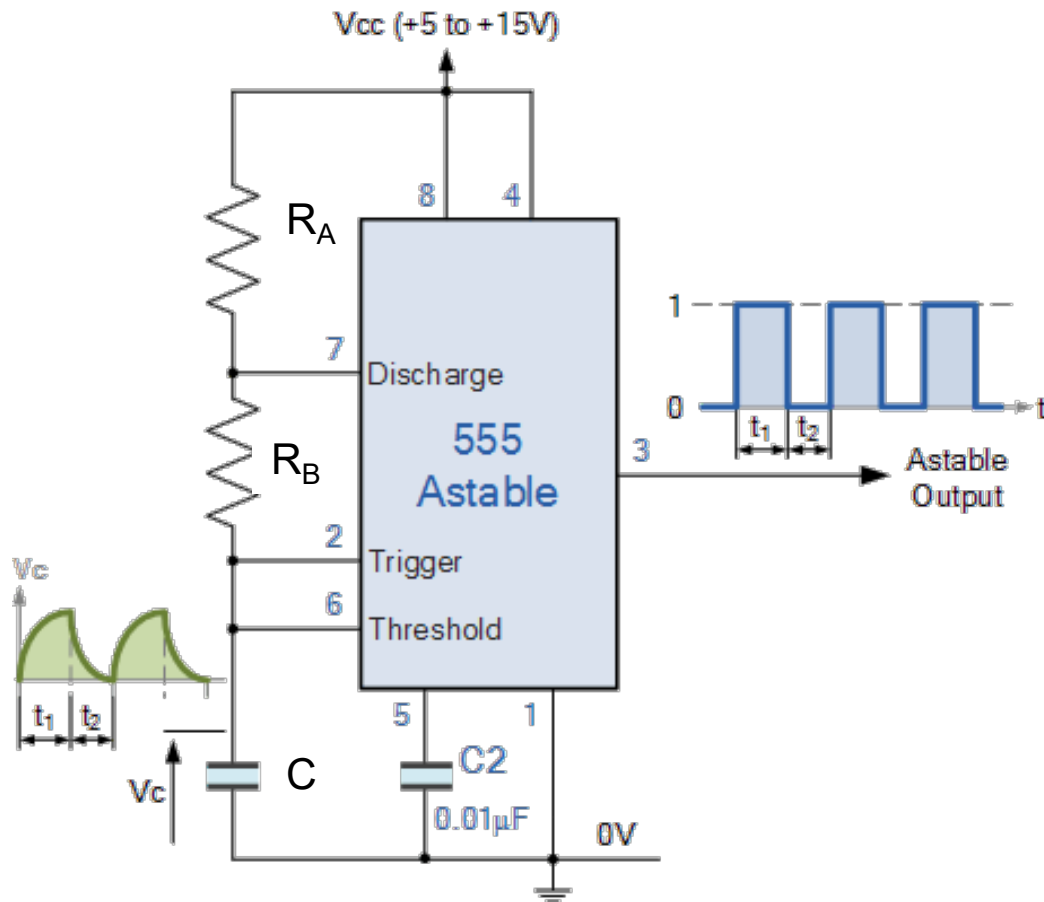


T8P23. Lab Exp 5. Si V_{s1} tiene un ciclo de trabajo del 50 % y una frecuencia de 1 kHz, representa la evolución de V_e y V_a ($a_3=0.9$)



Integrated Multivibrator LM555

Astable configuration (oscillator)



The charge time (output high) is given by:

$$t_1 = 0.693 (R_A + R_B) C$$

And the discharge time (output low) by:

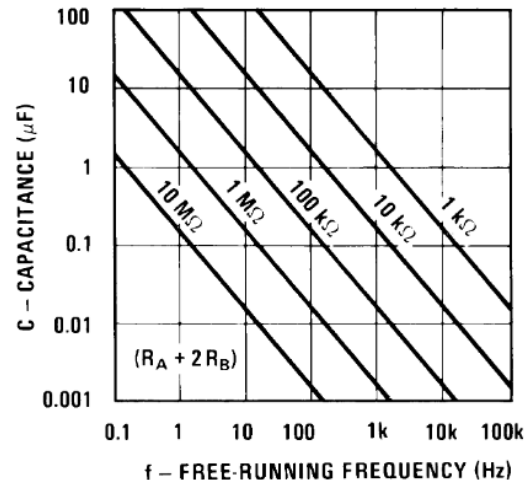
$$t_2 = 0.693 (R_B) C$$

Thus the total period is:

$$T = t_1 + t_2 = 0.693 (R_A + 2R_B) C$$

The frequency of oscillation is:

$$f = \frac{1}{T} = \frac{1.44}{(R_A + 2R_B) C}$$



$$D = \frac{R_B}{R_A + 2R_B}$$

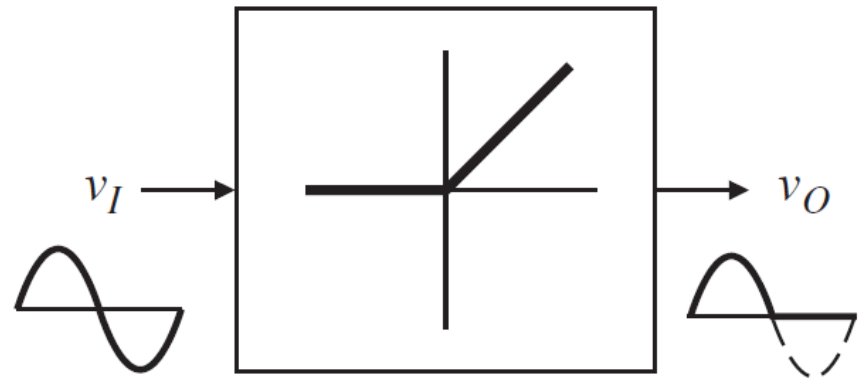
duty cycle

Precision Rectifiers

Half wave rectifier

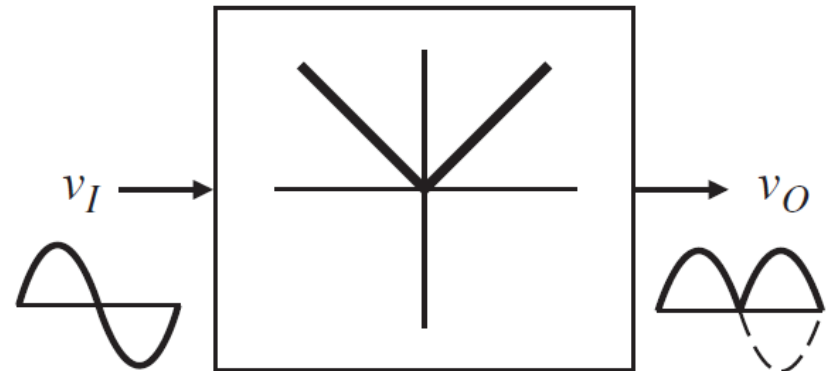
$$v_O = v_I \text{ for } v_I > 0$$

$$v_O = 0 \text{ for } v_I < 0$$



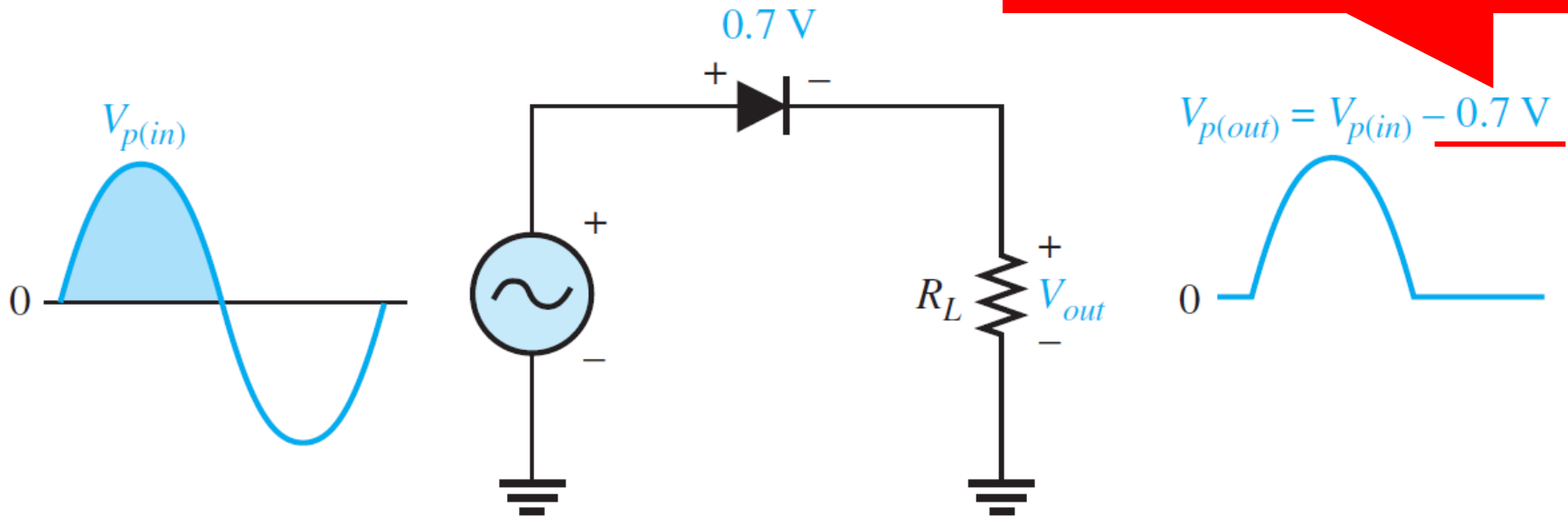
Full wave rectifier

$$v_O = |v_I|$$



Precision Rectifiers

Half wave rectifier

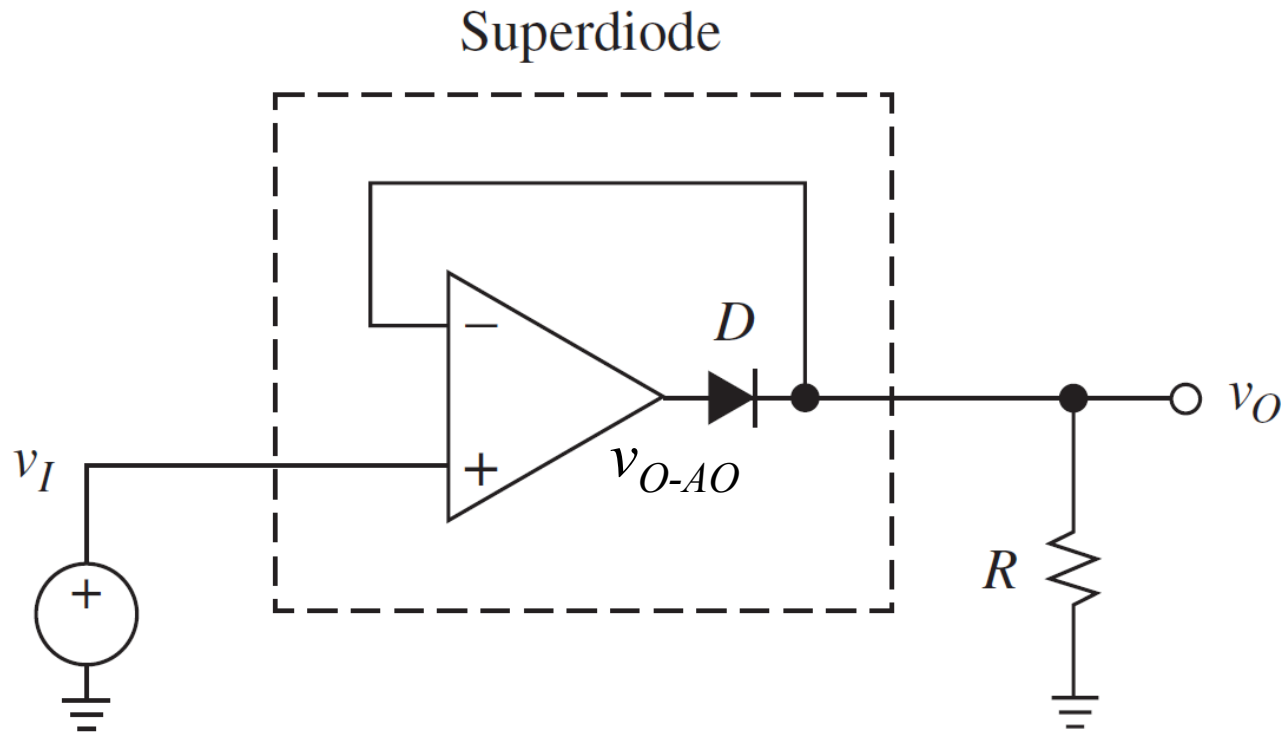


SOLUTION:

Direct polarizing voltage ($\sim 0.7\text{ V}$) included in the negative feedback loop of the OA.

Precision Rectifiers

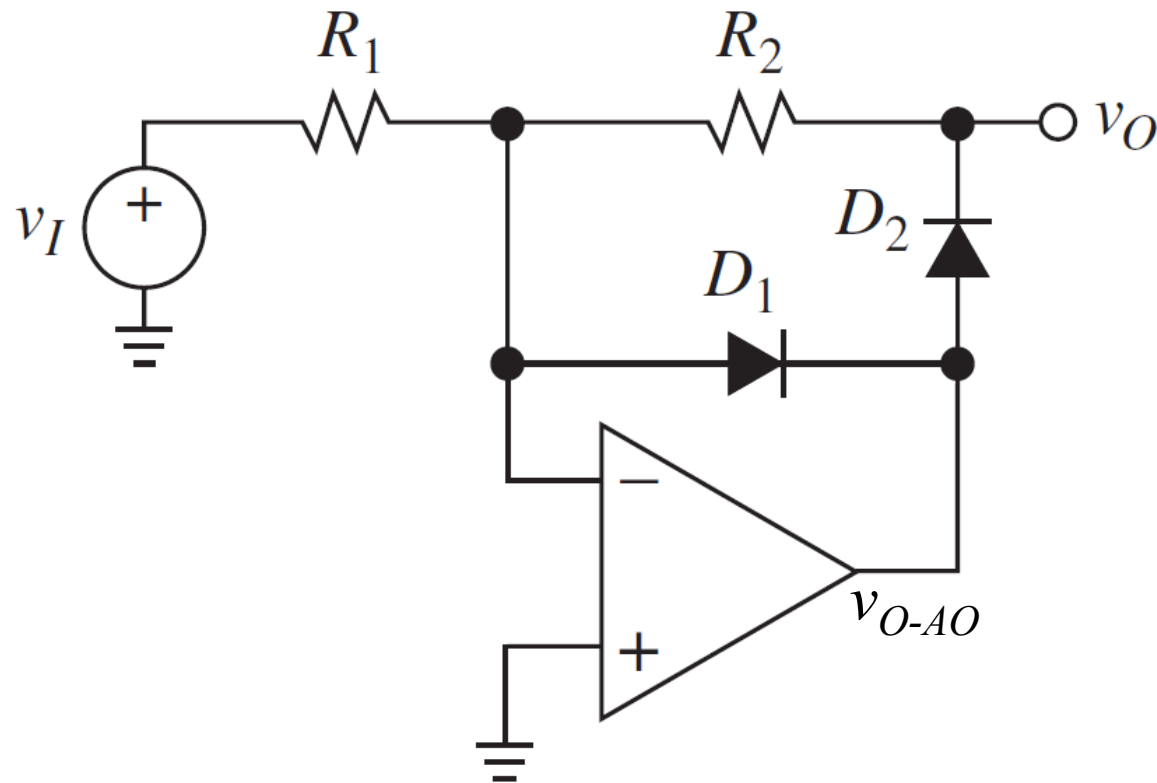
Half wave rectifier with OA



T8P24. Analyze the circuit

Precision Rectifiers

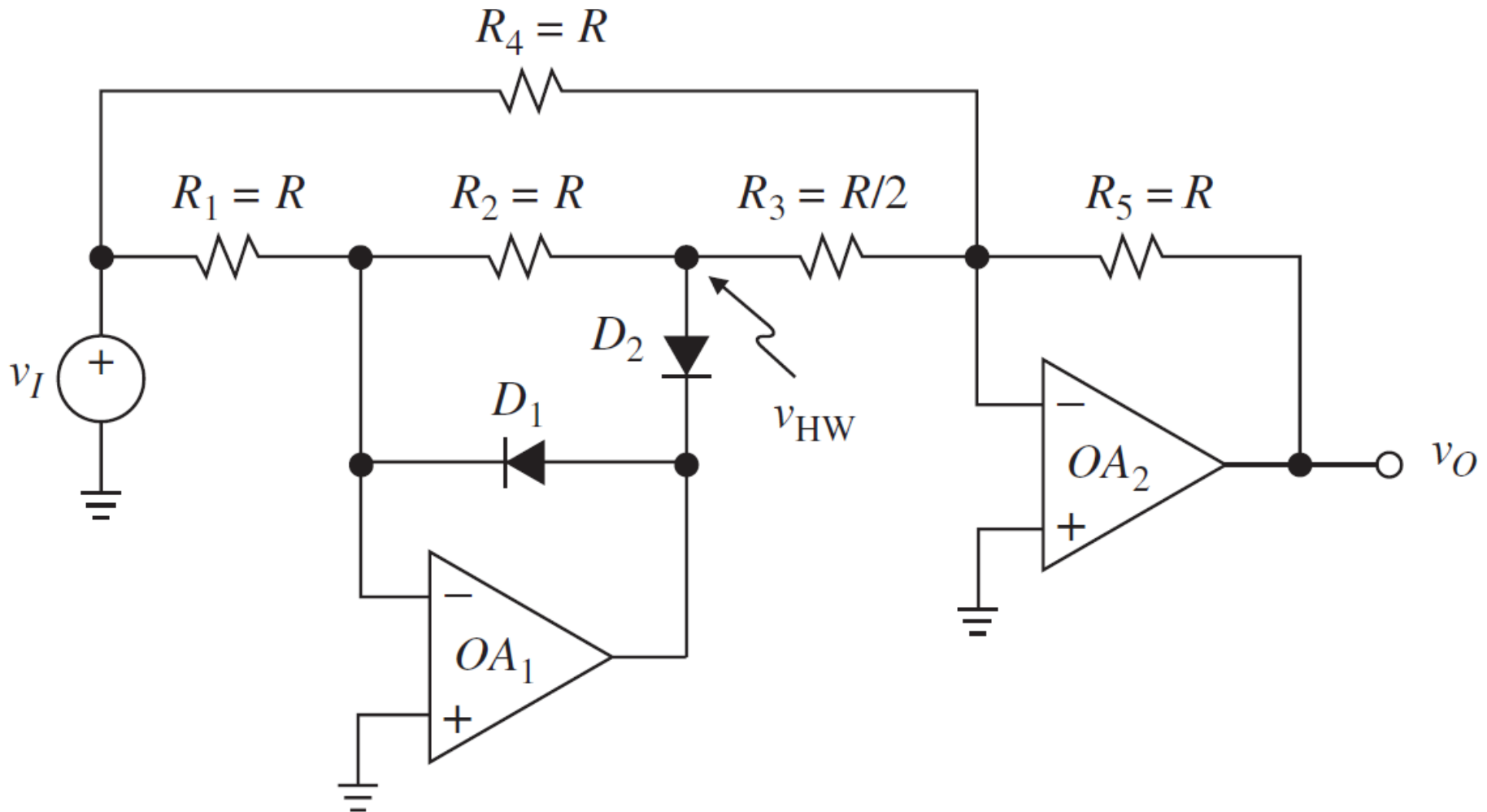
Half wave rectifier with OA



T8P25. Analyze the circuit

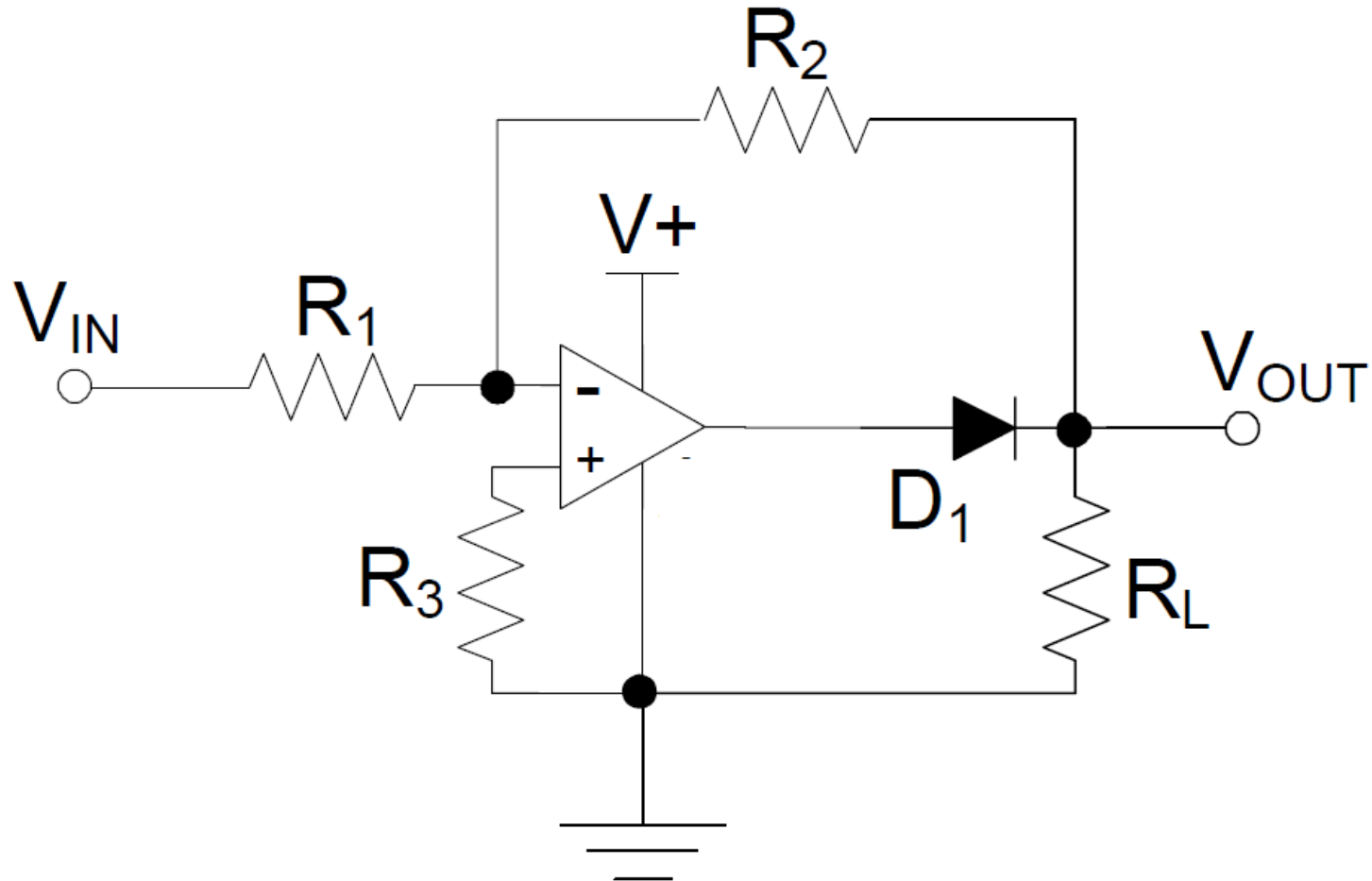
Precision Rectifiers

T8P26. Obtain the transfer function v_O versus v_I



Precision Rectifiers

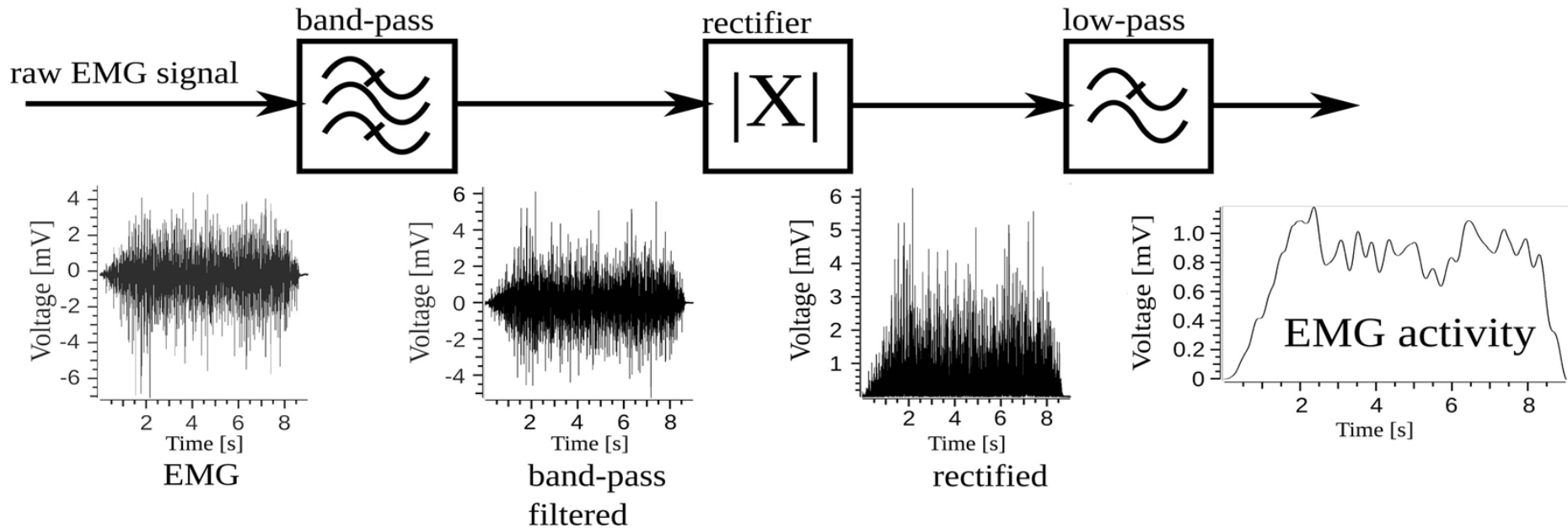
T8P27. Obtain the transfer function v_{OUT} versus v_{IN}
 $R_1=R_2=1\text{ k}\Omega$, $R_L=100\text{ k}\Omega$, $R_3=0.5\text{ k}\Omega$



Precision Rectifiers

APPLICATION

Electromyography (EMG)



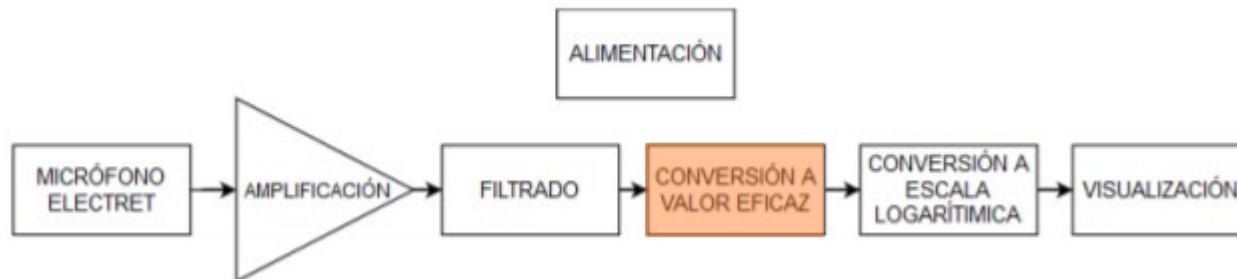
Precision Rectifiers

APPLICATION

Sound level meter (Sound pressure level L_p)

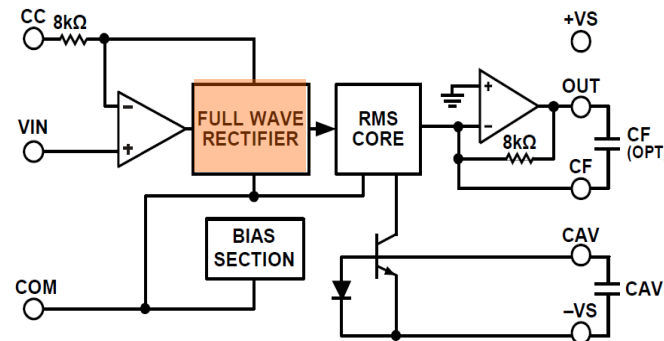
$$L_p = 20 \log_{10} \left(\frac{p}{p_0} \right) \text{ dB}$$

p is the **RMS** value of the sound pressure



Low Cost, Low Power,
True **RMS**-to-DC Converter

ANALOG DEVICES AD736



Precision rectifiers

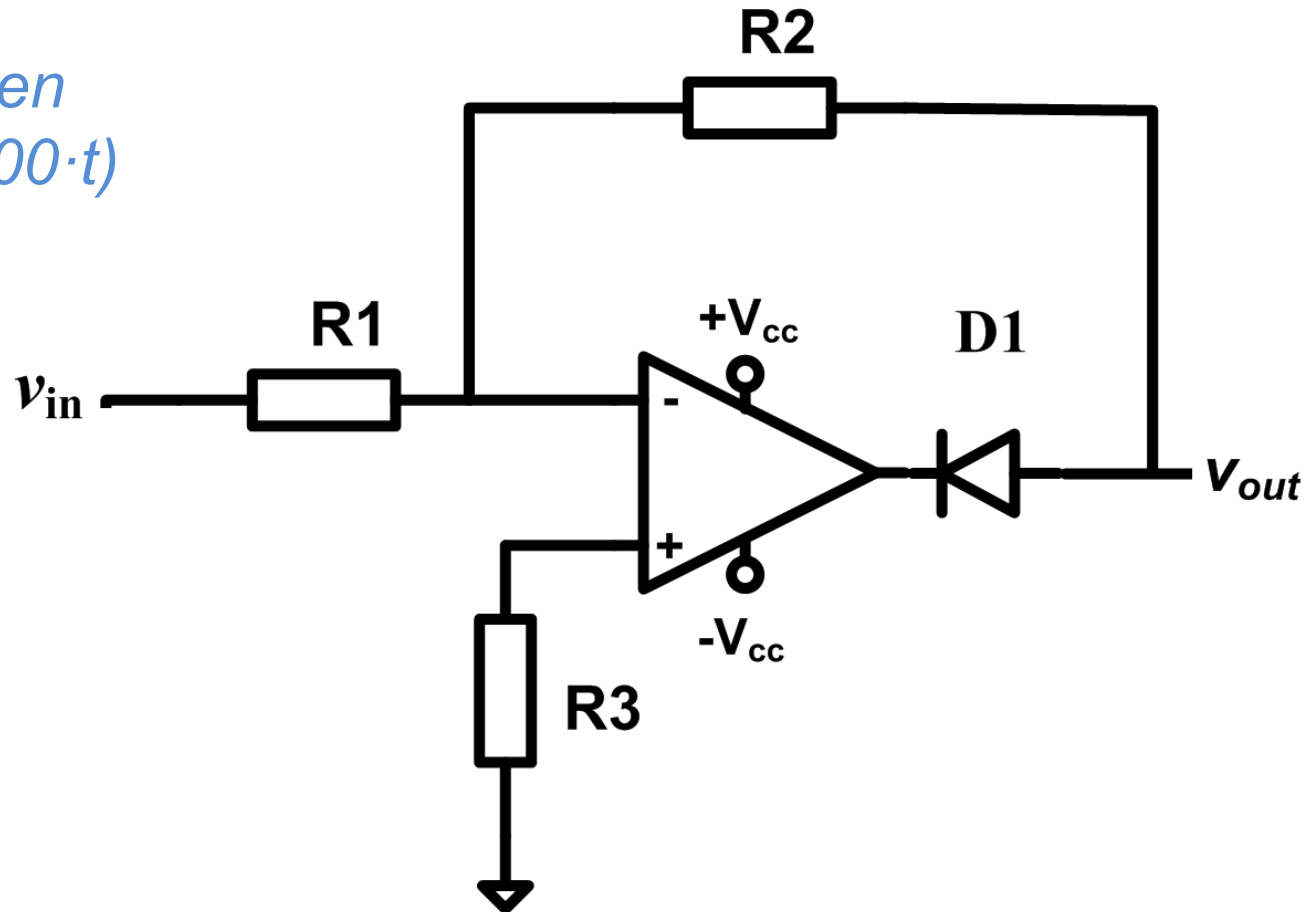
Obtain the transfer function V_{out} vs V_{in}

$R3=1\text{ k}\Omega$, $R2=10\text{ k}\Omega$, $R1=2\text{ k}\Omega$, LM741C, $V_{cc}=\pm 15\text{ V}$

D1: $V_{AK}=0.7\text{ V}$

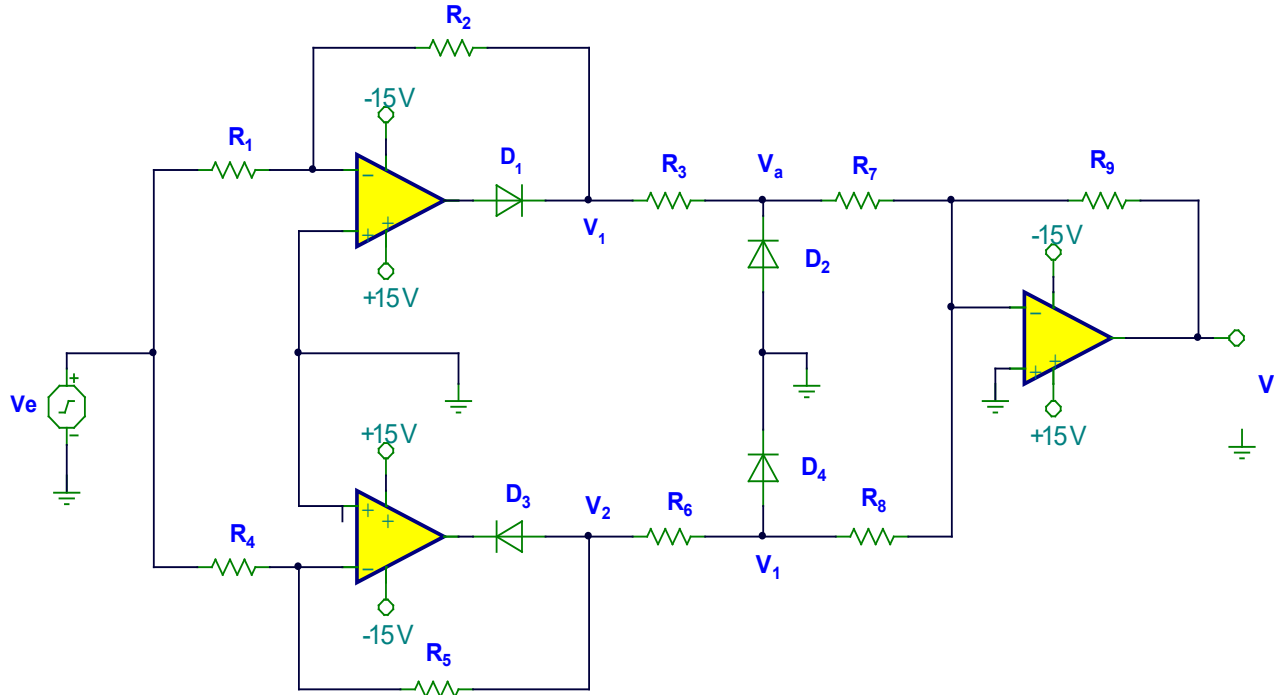
Represent v_{out} when

$v_{in}=1+3\cdot\text{sen}(2\pi\cdot 100\cdot t)$

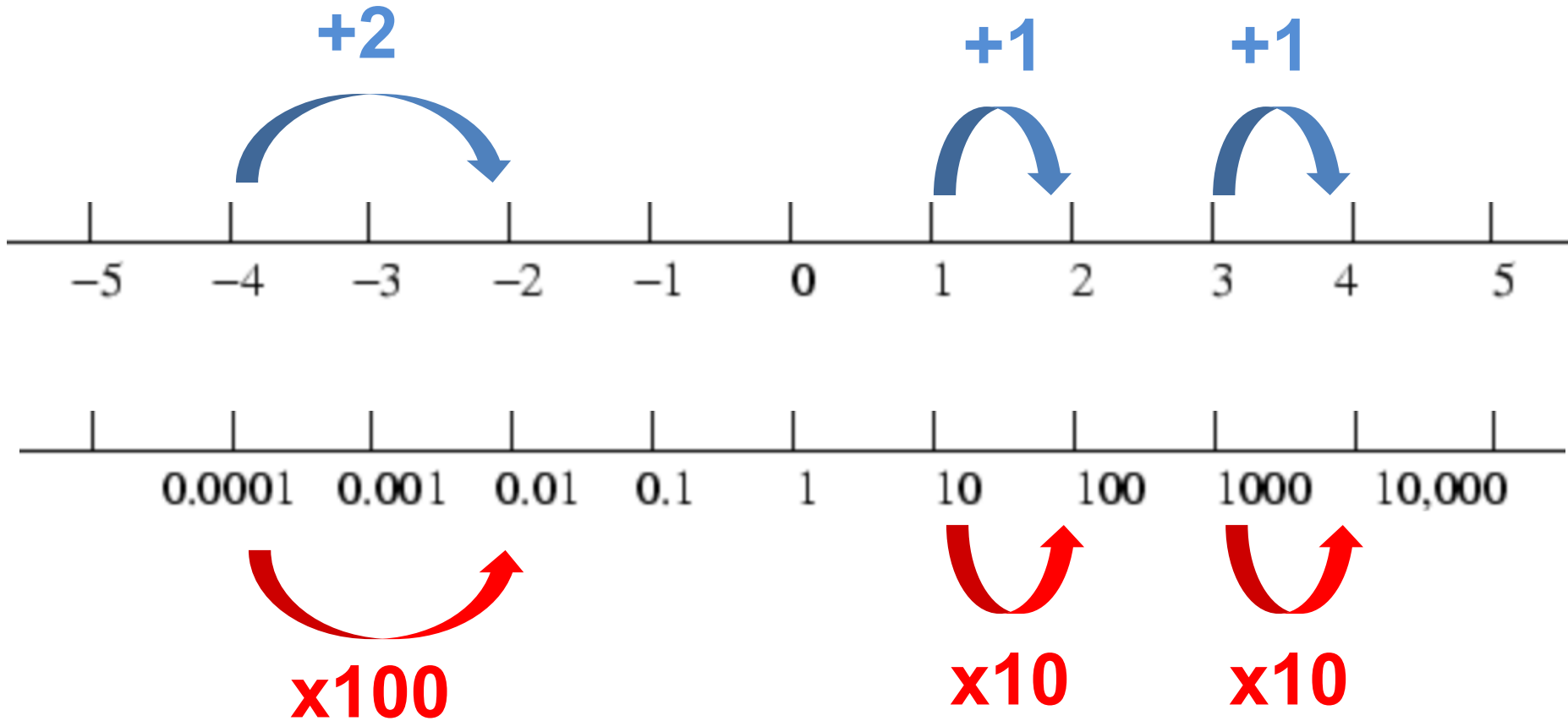


T8P26. P37. Se desea realizar la rectificación de una señal senoidal, así como su atenuación. En el circuito de la figura, suponiendo todas las resistencias iguales a $1\text{ k}\Omega$, los diodos ideales y una tensión de entrada senoidal de $V_e = 8 \cdot \sin(\omega t)$ V. Calcular:

1. Tensiones V_1 y V_2 y su representación en función del tiempo, para cada uno de los semiperiodos de la tensión de entrada.
2. Tensiones V_a y V_b y su representación en función del tiempo.
3. Tensión de salida V_0 y su representación en función del tiempo.
4. ¿Qué ocurre si quitamos los diodos D_2 y D_4 ?, ¿Tienen alguna utilidad?

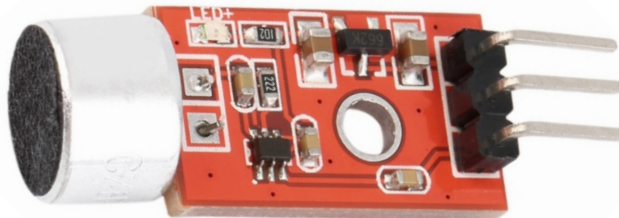
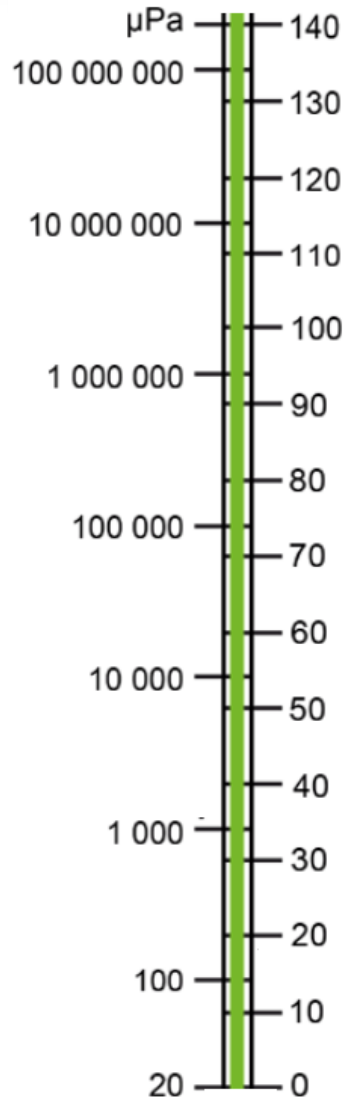


Logarithmic converters



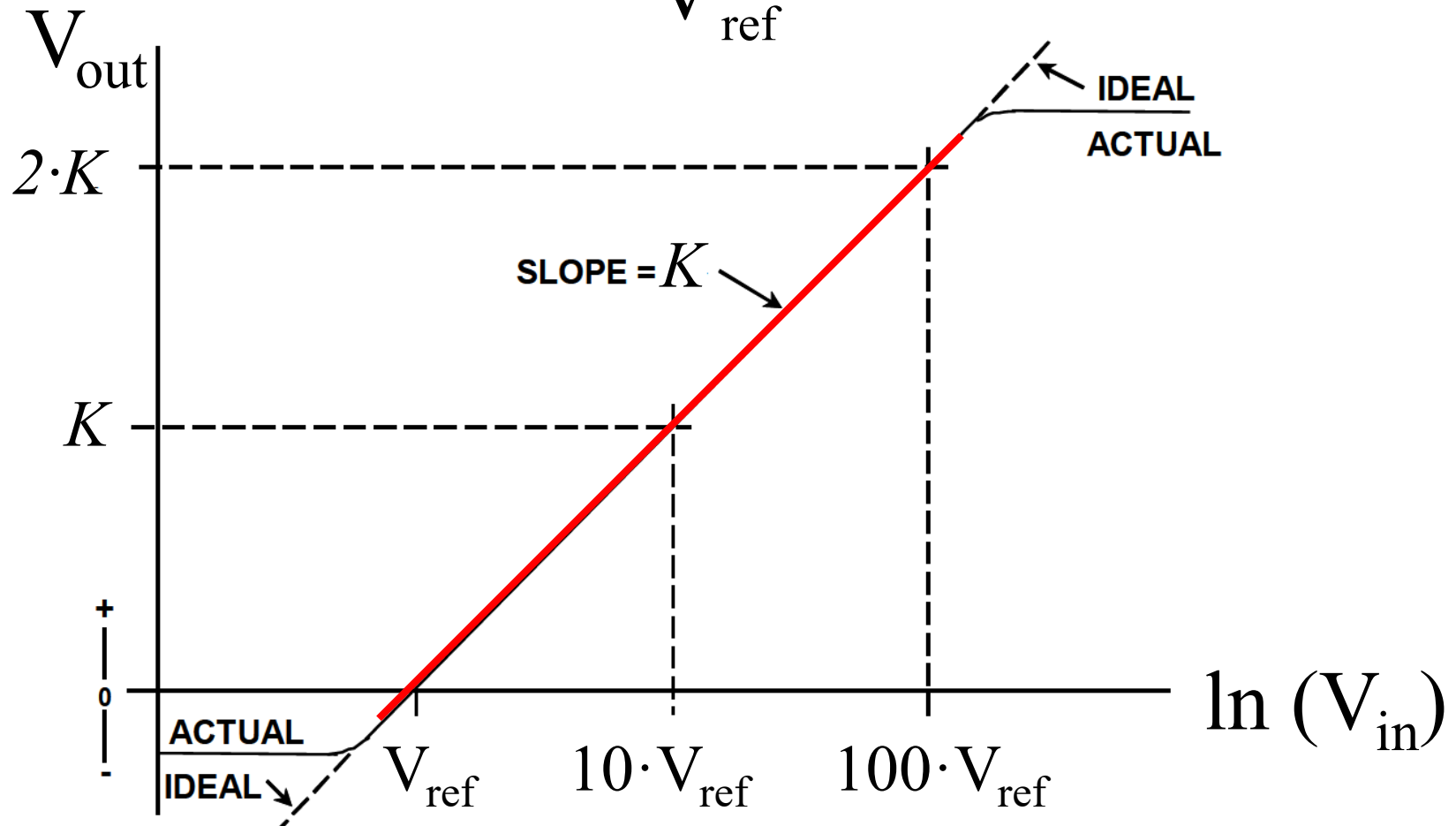
Logarithmic converters

The logarithmic scale is used when the range of the signal is big, several magnitude orders (ex. Sound level)

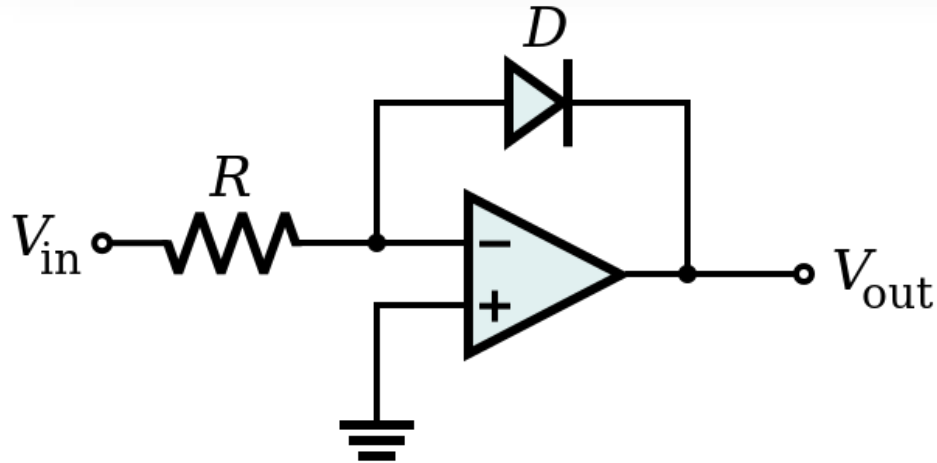


Logarithmic converters

$$V_{\text{out}} = K \cdot \ln \left| \frac{V_{\text{in}}}{V_{\text{ref}}} \right|$$



Logarithmic converters

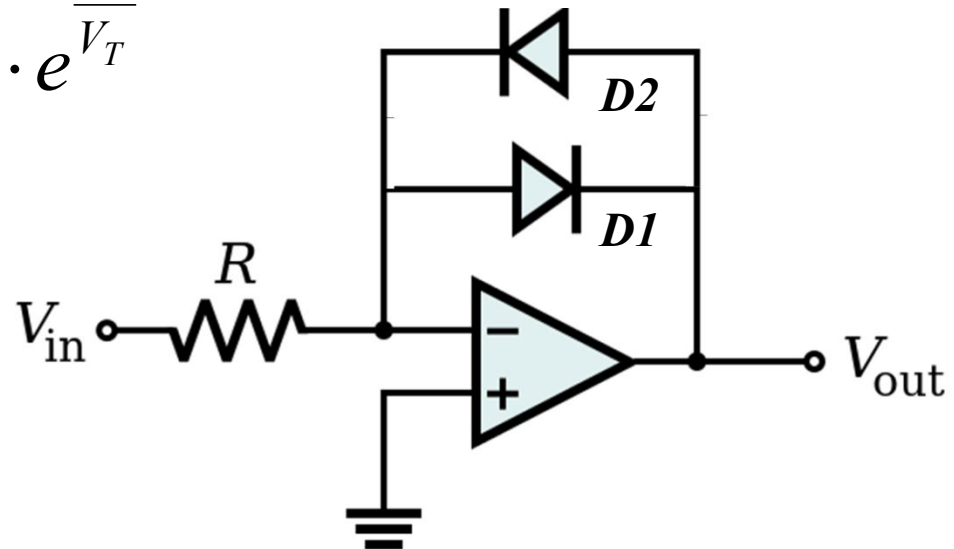


$$V_{out} = -V_T \cdot \ln \left| \frac{V_{in}}{R \cdot I_{sat}} \right|$$

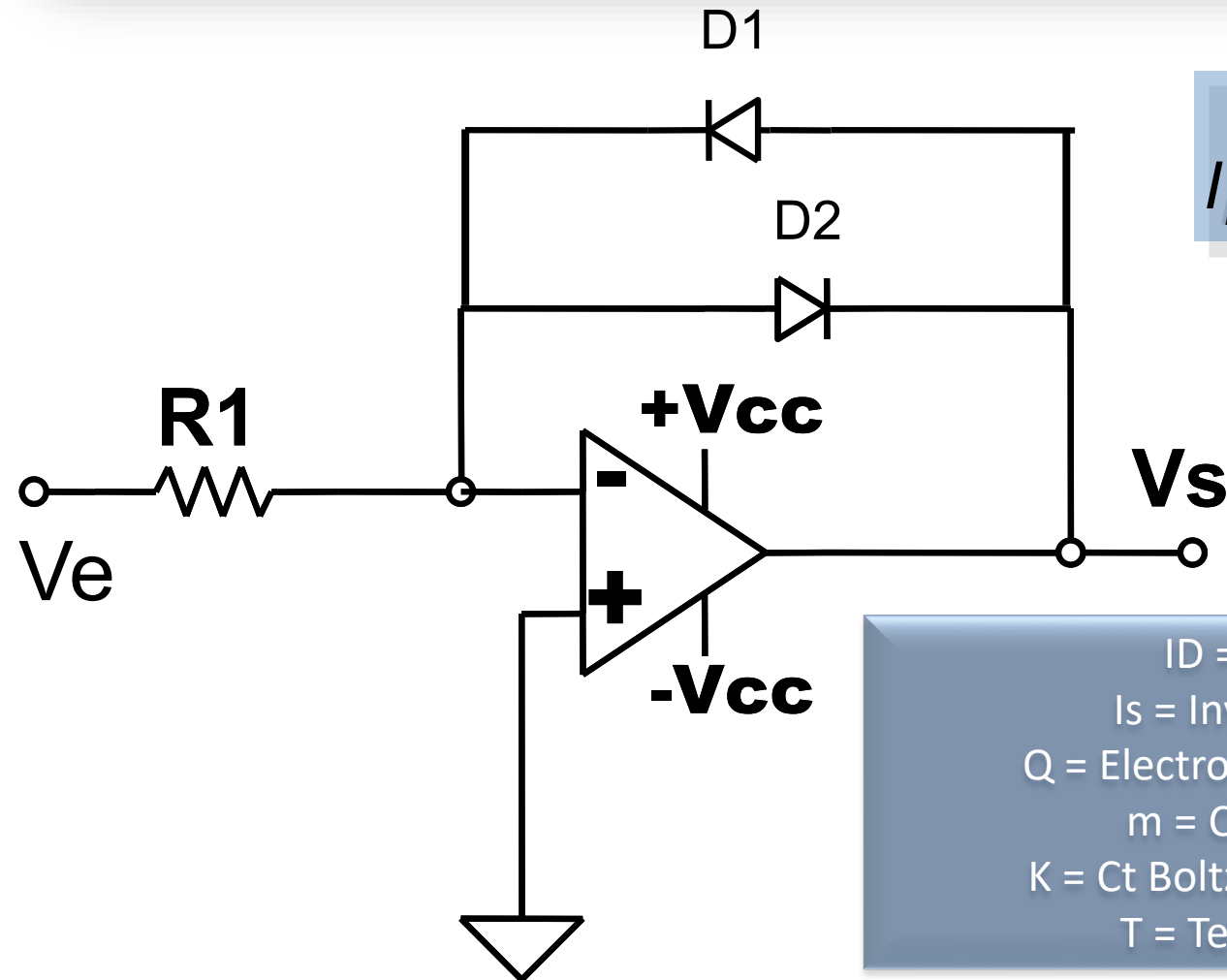
$$I_D = I_{sat} \cdot \left(e^{\frac{V_D}{V_T}} - 1 \right) \approx I_{sat} \cdot e^{\frac{V_D}{V_T}}$$

$$I_D \gg I_{sat}$$

$$V_T = mKT/q$$



Logarithmic converters



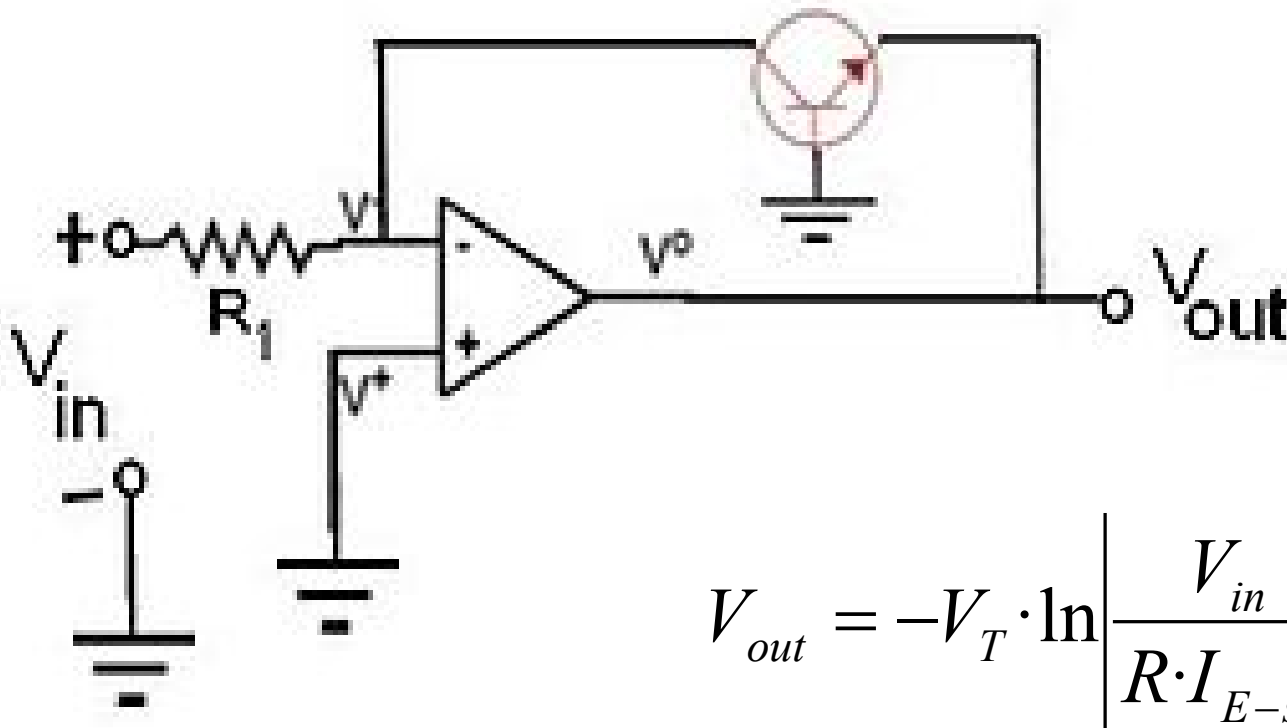
$$I_D = I_s \cdot \left(e^{\frac{q \cdot V_D}{mKT}} - 1 \right)$$

$$V_S = -V_T \cdot \ln \left(\frac{V_e}{R_1 \cdot I_s} \right)$$

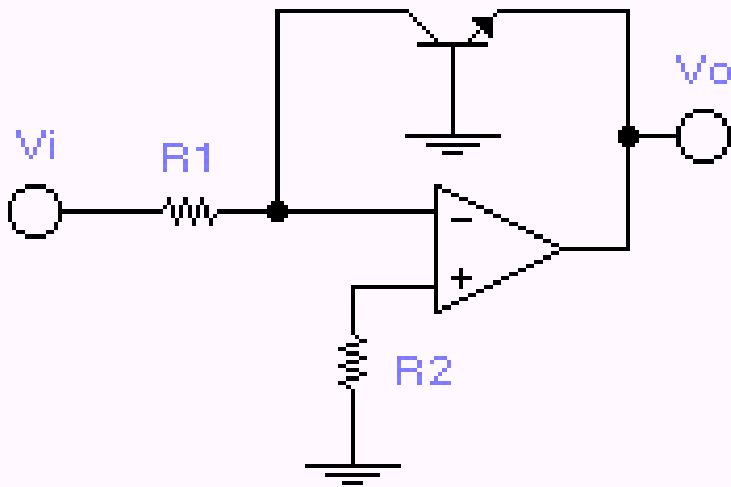
I_D = Diode current
 I_s = Inverse leak current
 Q = Electron charge = $1.6 \cdot 10^{-19}$ C
 m = Ct exp, 1(Ge), 2(Si)
 K = Boltzmann, $1.38042 \cdot 10^{-23}$
 T = Temperature Kelvin

Logarithmic converters

Transdiode Configuration



Logarithmic converters



Configuration transdiode

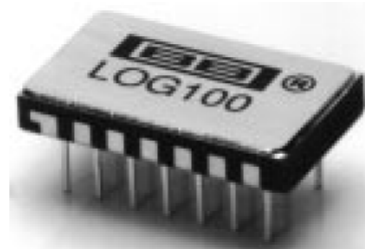
$$V_{CE} = V_{CB} + V_{BE}$$

$$V_{CB} = 0 \Rightarrow V_{CE} = V_{BE}$$

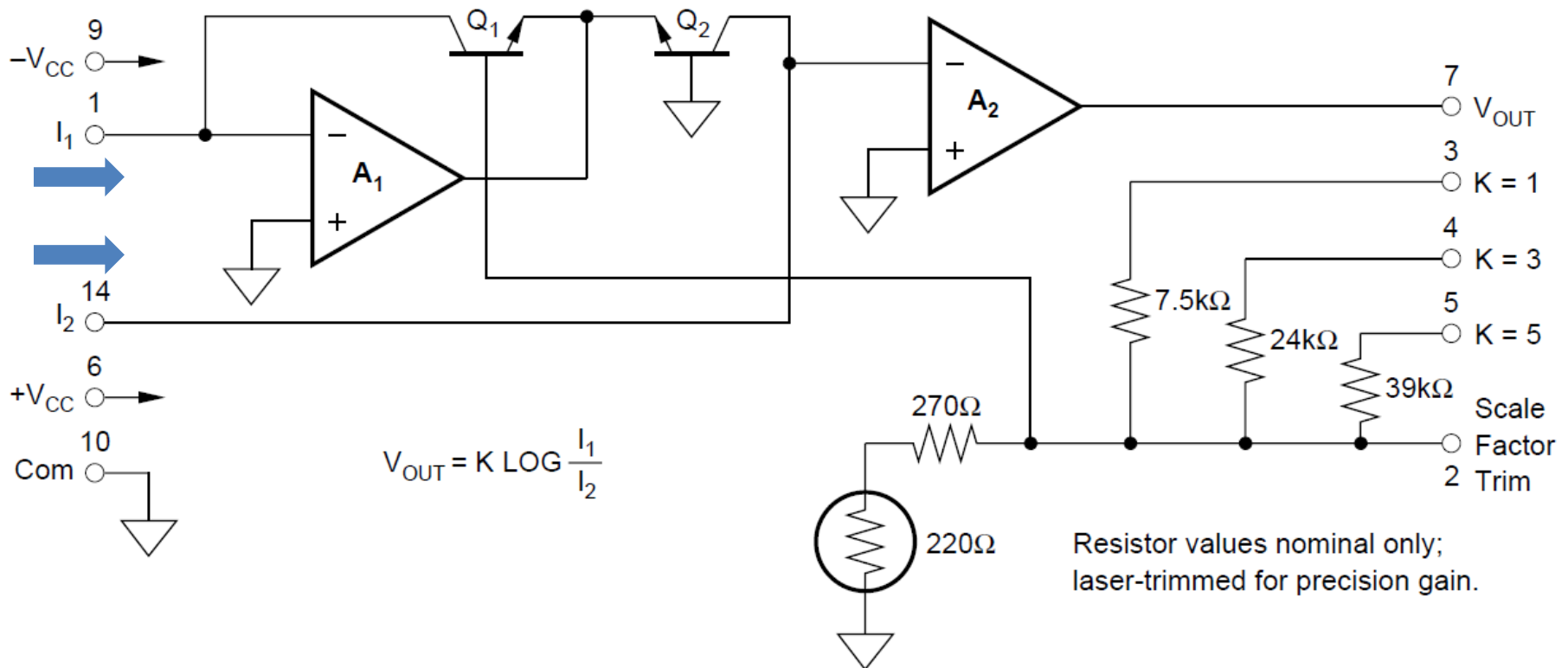
$$I_E = I_{es} \cdot \left(e^{\frac{q \cdot V_{BE}}{mKT}} - 1 \right)$$

$$V_S = -V_T \cdot \ln \left(\frac{V_i}{R_1 \cdot I_{ES}} \right)$$

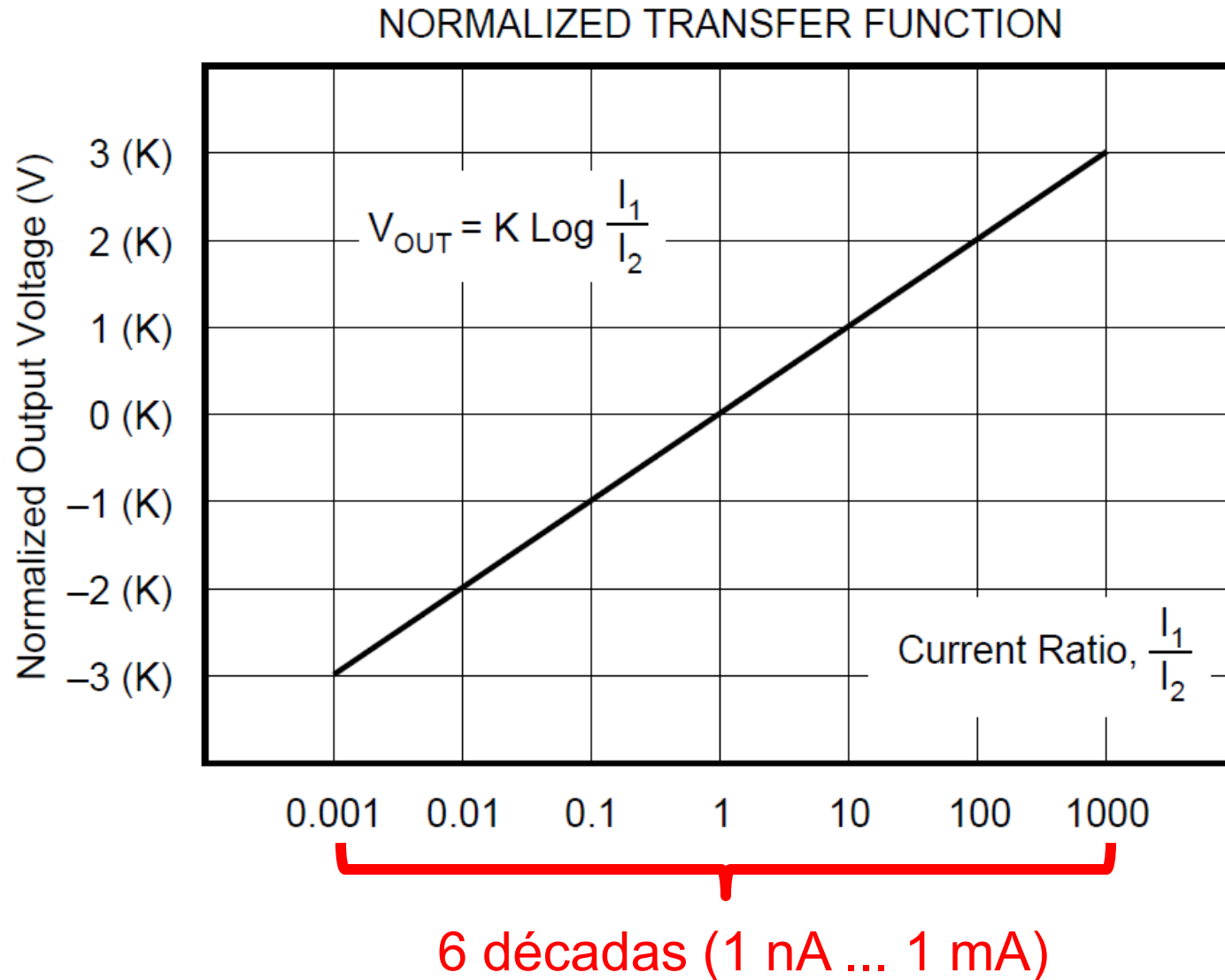
Logarithmic converters



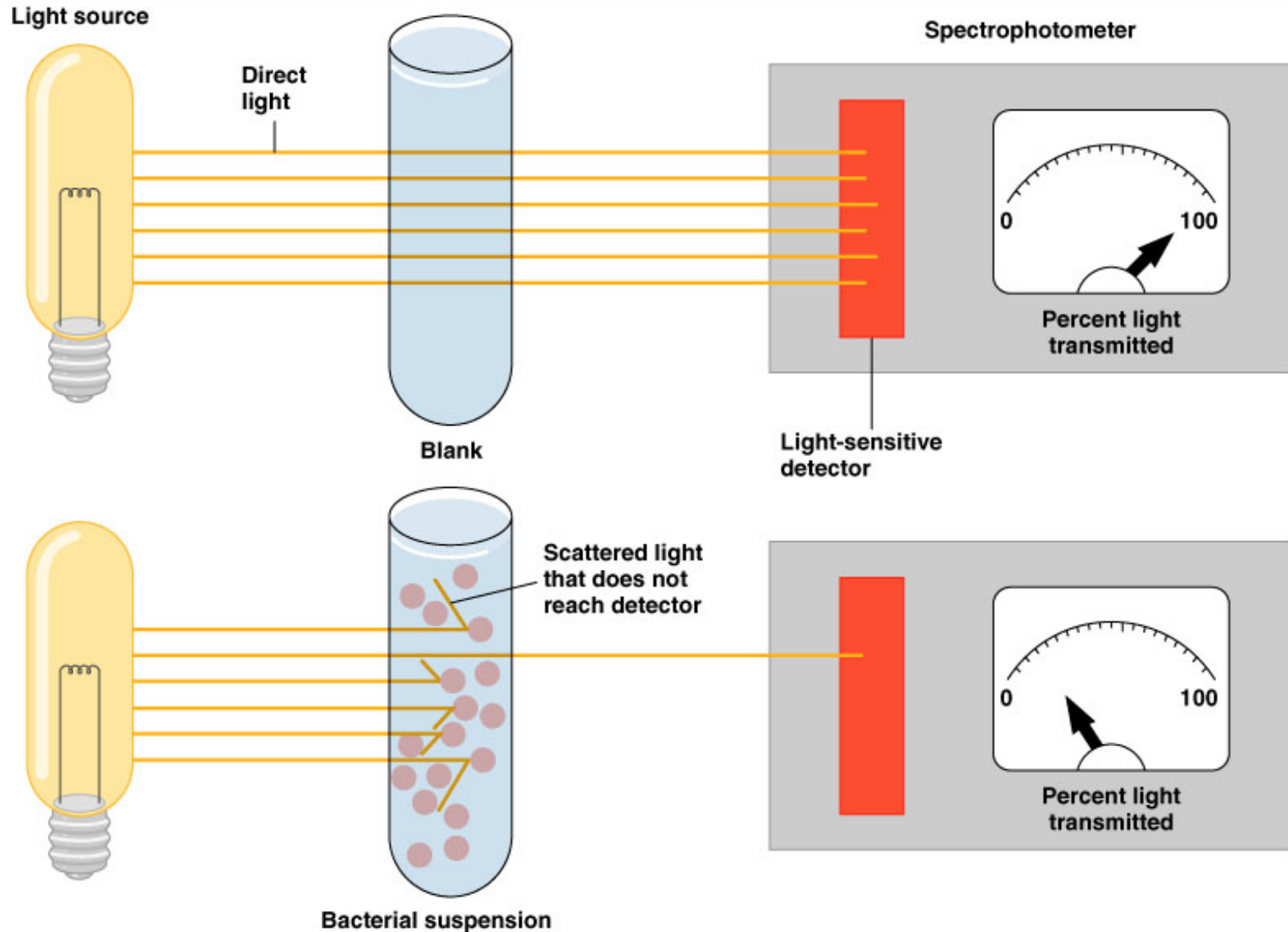
LOG100



Logarithmic converters

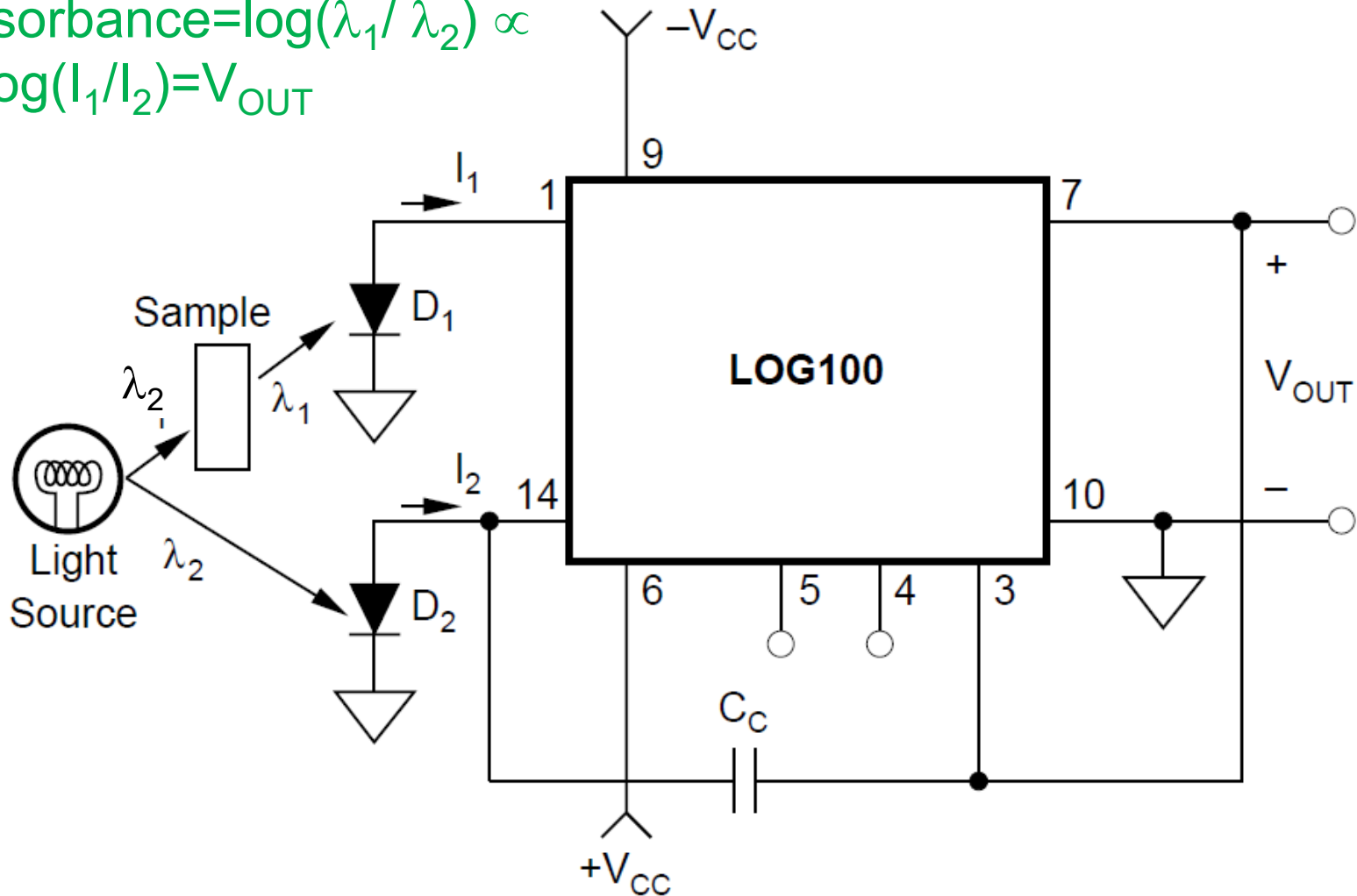


Logarithmic converters. Application



Logarithmic converters. Application

$$\text{Absorbance} = \log(\lambda_1 / \lambda_2) \propto K \cdot \log(I_1 / I_2) = V_{\text{OUT}}$$



Logarithmic converters

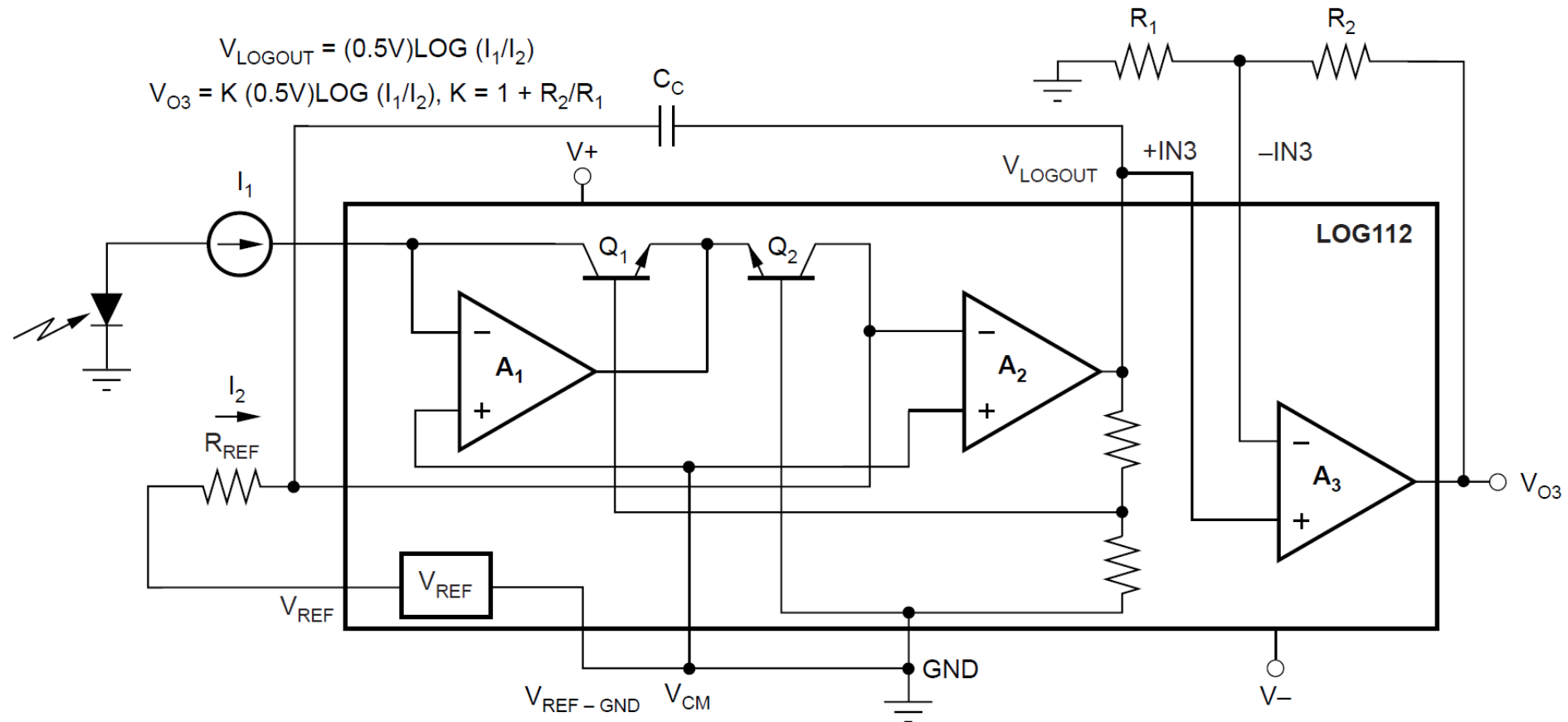


LOG112
LOG2112

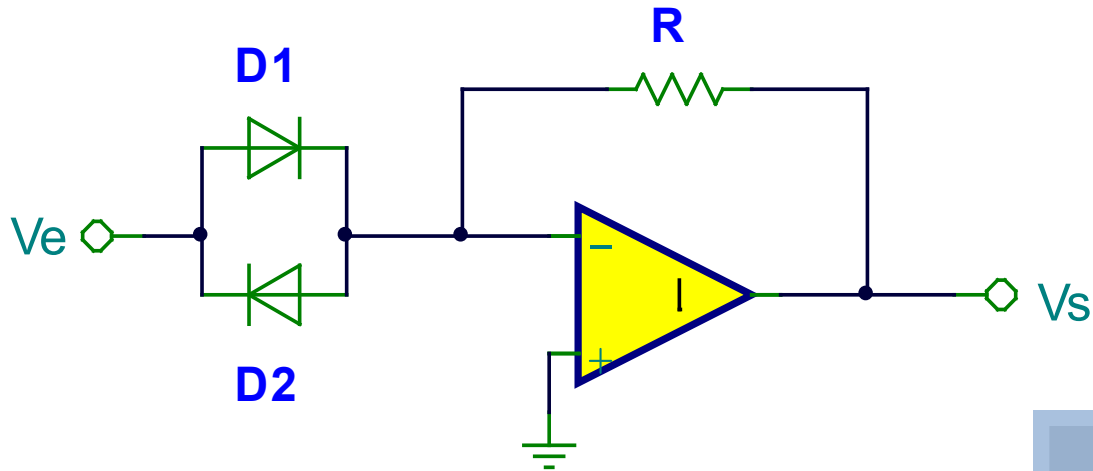


$$V_{\text{LOGOUT}} = (0.5V)\text{LOG}(I_1/I_2)$$

$$V_{O3} = K(0.5V)\text{LOG}(I_1/I_2), K = 1 + R_2/R_1$$



Antilogarithmic converters

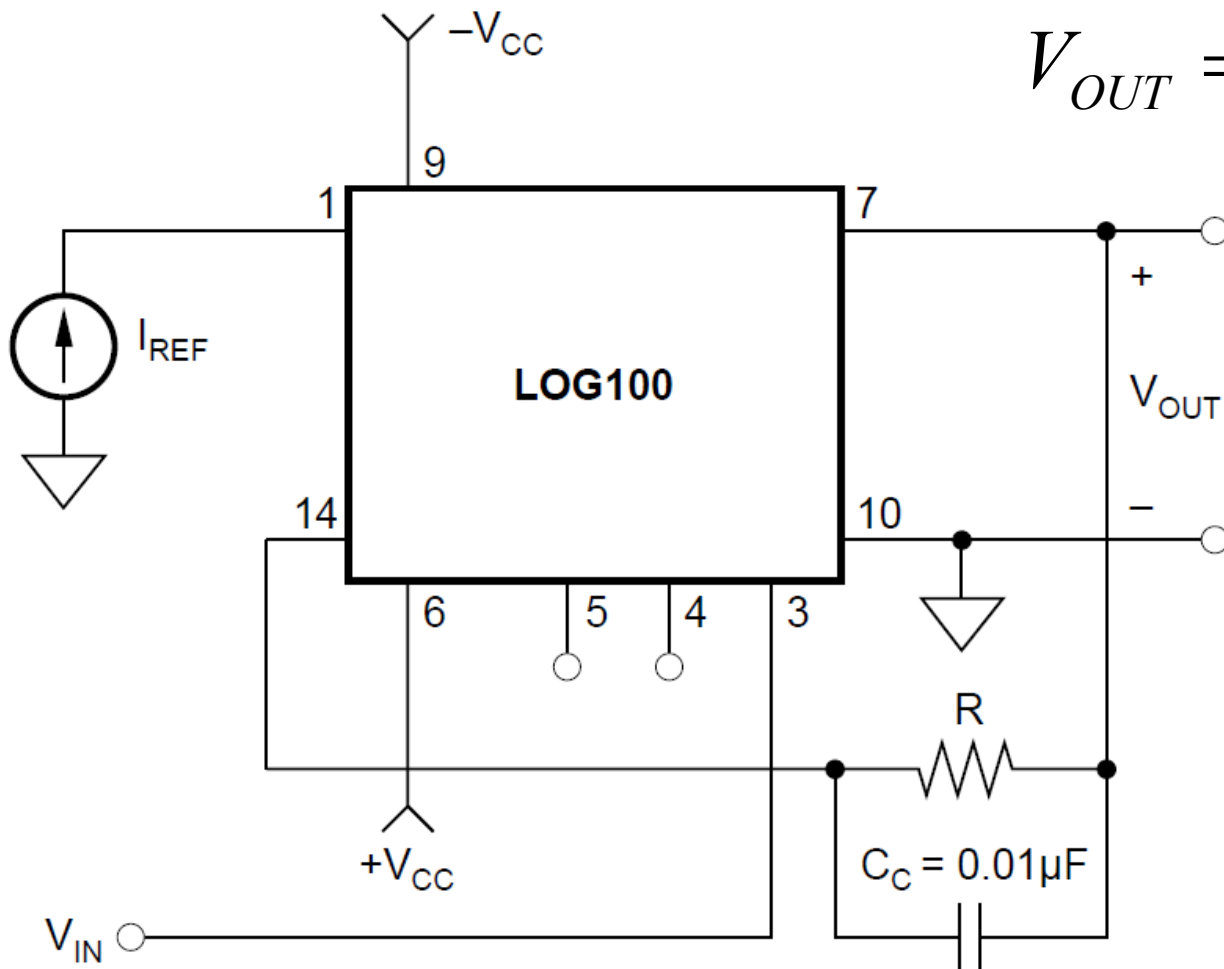


$$V_s \cong -R \cdot I_s \cdot e^{\frac{V_e}{V_T}}$$

I_s = Inverse diode leak current

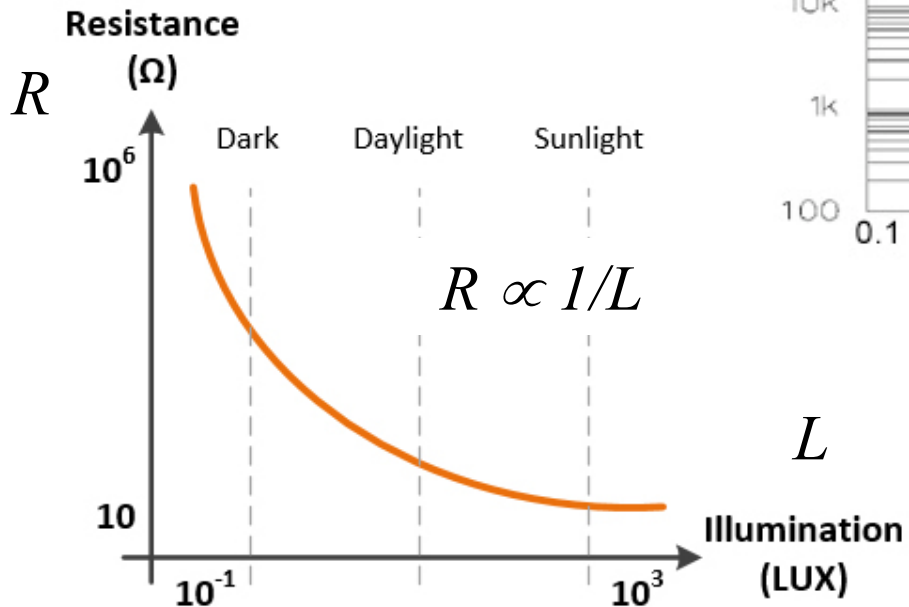
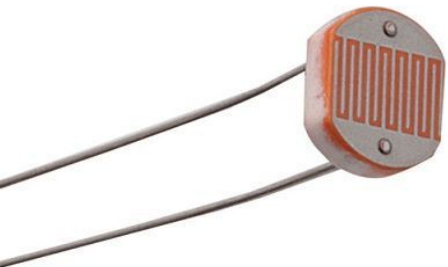
$V_T = K * T / q$ thermic voltage

Antilogarithmic converters

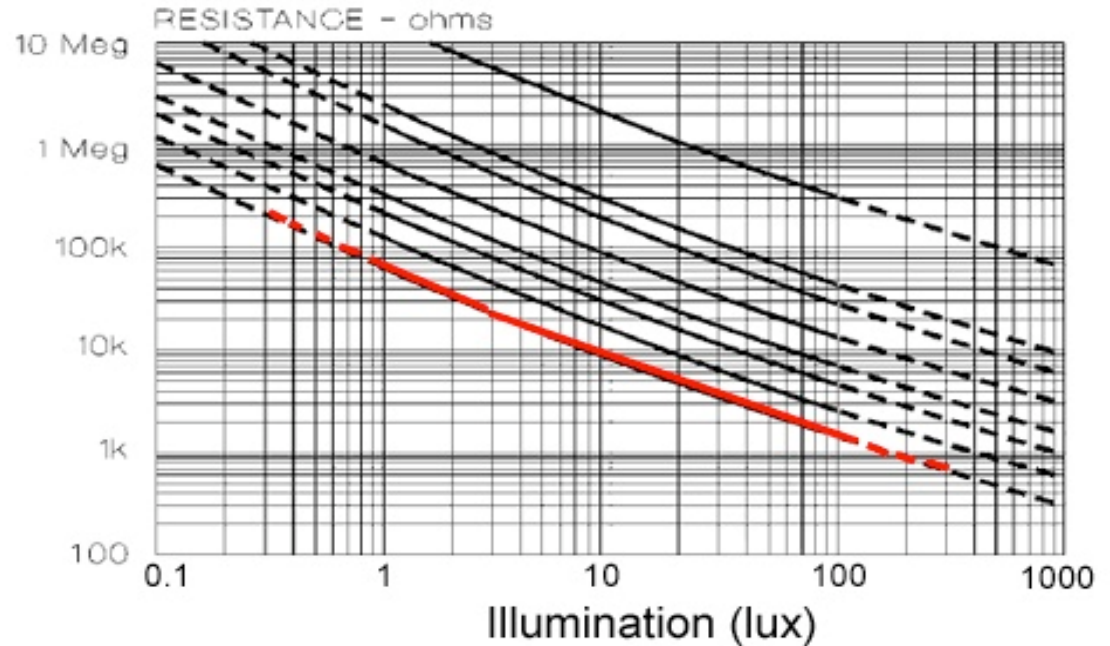


$$V_{OUT} = I_{REF} \cdot R \cdot e^{-V_{in} / K}$$

Logarithmic converters. Application



Resistance vs. Illumination

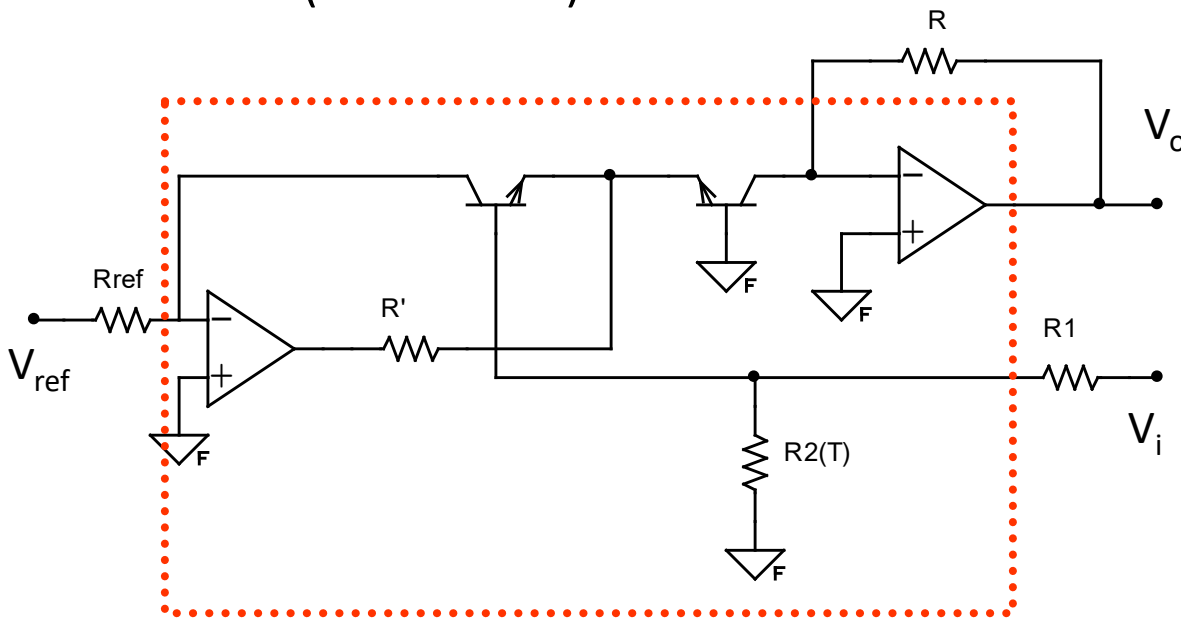


L

$$\log R \propto (-\log L)$$

Antilogarithmic converters

LOG100 (Burr Brown)



$$V_o = V_r * e^{-k(V_i/V_T)}$$

$$k = R_2 / (R_1 + R_2)$$

$$V_r = R V_{ref} / R_{ref}$$

P42. Las señales V_{i1} y V_{i2} , provenientes de dos fotodetectores son señales de respuesta exponencial y para llevar a cabo la linealización de éstas, se ha implementado un convertidor logarítmico diferencial en el cual se compensa el efecto de la temperatura:

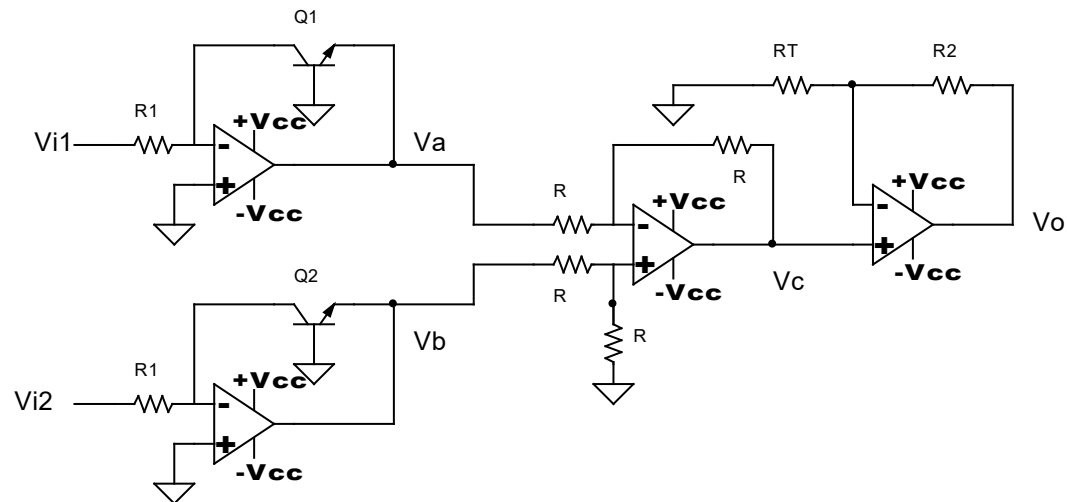
1. Expresar V_a en función de V_{i1} y de la Temperatura.
2. Expresar V_b en función de V_{i2} y de la Temperatura.
3. Expresar V_c en función de V_{i1} y V_{i2} y de la Temperatura.
4. Expresar V_o en función de V_{i1} y V_{i2} y de la Temperatura, considerando que R_T es una resistencia variable linealmente con la temperatura.
5. Justificar la utilidad de este circuito.

Se supondrán los siguientes datos como constantes:

Constante de Boltzman K

Carga del electrón

Corrientes inversas de los transistores.



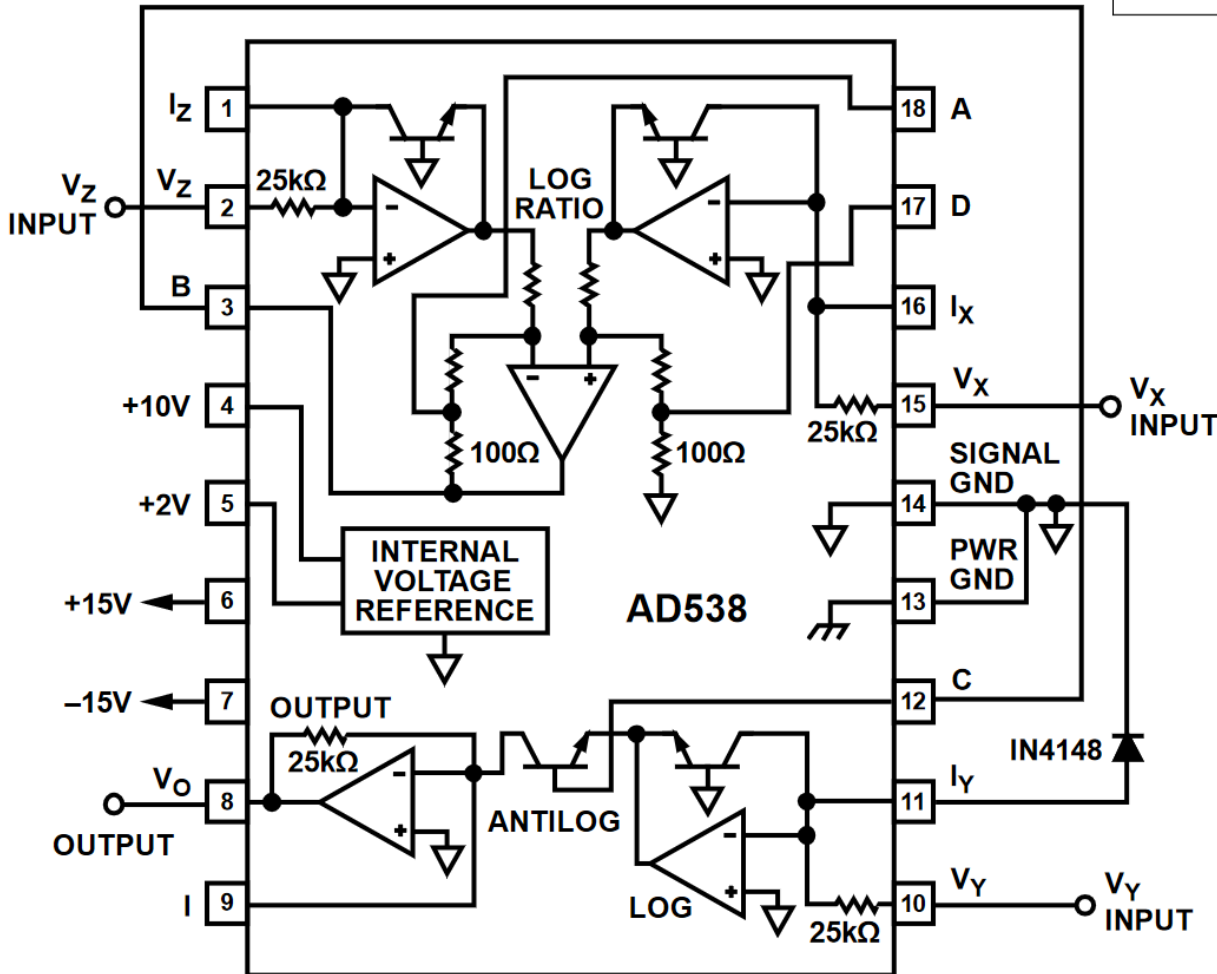
Convertidores log-antilog

Aplicación: multiplicadores



Real-Time Analog
Computational Unit (ACU)

AD538



$$V_O = V_Y \left(\frac{V_Z}{V_X} \right)$$