Laboratório 2
Signal Conditioning

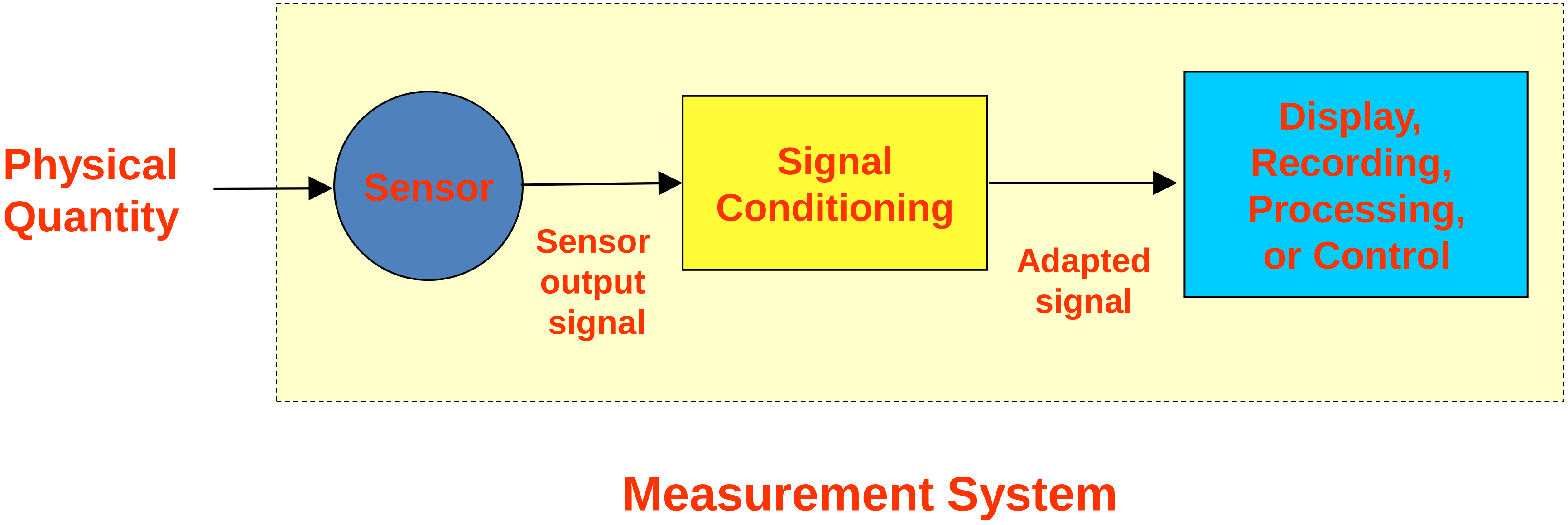
Referências Bibliográficas

ME3200 – Analog Electronic Courseware

Kester W, BRIDGE CIRCUITS, In: http://www.analog.com/static/imported-files/seminars_webcasts/49470200sscsect2.PDF

Signal Conditioning

Signal Conditioning in Generalized Measurement System



1 The output signal from a sensor usually does not have the suitable characteristics for displaying, recording, transmission, or processing. Common issues with the sensor output signal:

- Low amplitude
- Contains noise
- Not in the voltage or current form to be directly interpreted by electronics systems
- In analog form, the signal cannot be recorded or processed by digital systems

2 **Signal conditioning**: the processing of the sensor signal to adapt the signal to the requirements of the next stage in a measurement system.

3 **Signal conditioner**: the interfacing circuit between the sensor and the data recording or processing system that performs the necessary signal adaptation.

4 **Example:**

Many sensors require some form of excitation (voltage source, current source ou circuit) for them to operate.

Strain gauges and **RTDs** are two common examples.

Transducers (Examples)

Force and Pressure Sensors

- Force and pressure are generally measured indirectly through the deflection of an alternate surface.

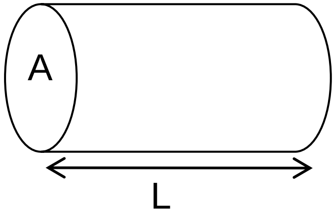
- Mechanisms include:
  - measuring the displacement of the elastic material resulted from an application of force/pressure, such as using potentiometers or LVDTs to measure the deflection of a spring
  - **measurement of the resistance change due to the deformation of conductors, e.g., strain gauges**
  - measuring the electrical signal produced by the piezoelectric materials upon deformation, e.g., piezoelectric load cell

- **Resistive strain gauges and piezoelectric materials can be incorporated into the structures with different shapes to measure the force/pressure in different conditions — load cell.**

Strain Gauges

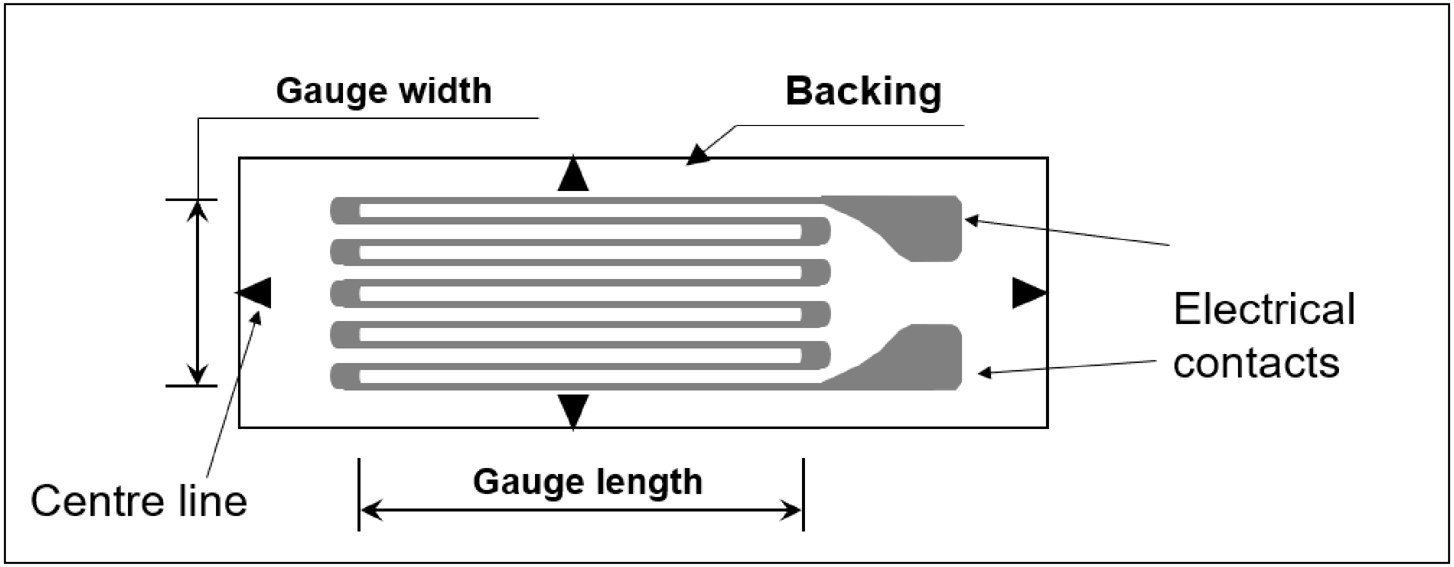
- Resistive strain gauge consists of a conductor; of which the resistance changes when it deforms upon an application of force/pressure.
- Resistance of the conductor is determined by its dimensions and material, depending on:
  - material's resistivity (ρ_e)
  - cross-sectional area (A)
  - length (L)

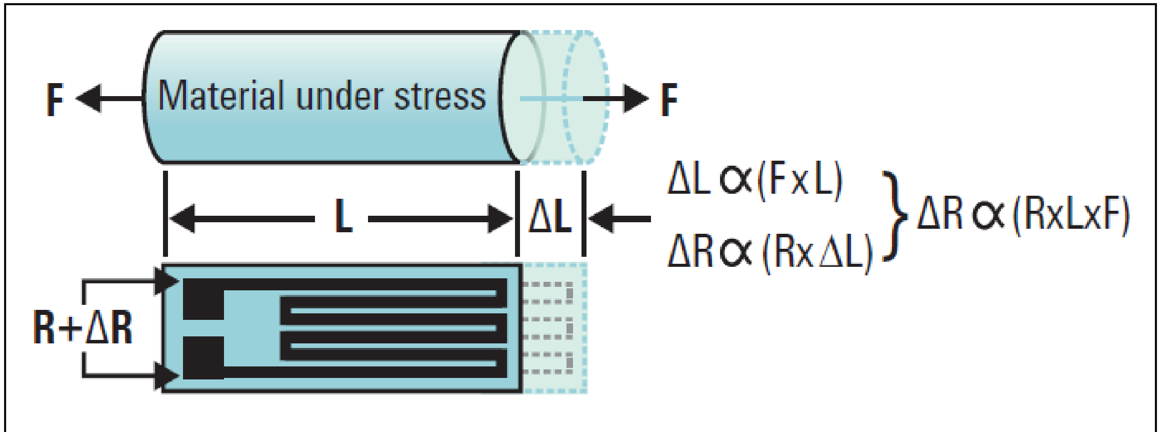
$$\boxed{R = \frac{\rho_e L}{A}}$$



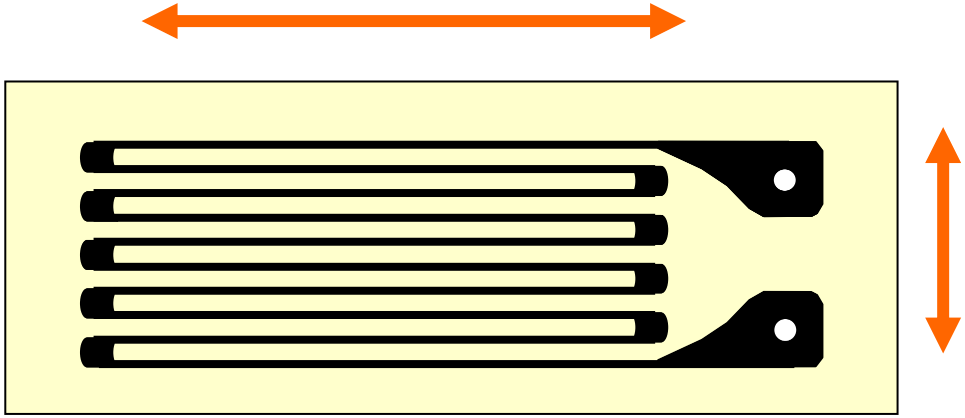
- **As the conductor is stretched, *L* increases and *A* decreases, resulting in an increase of *R*.**
- **Compressing the wire has the opposite effect.**
- Thus, strain ($\partial L/L$) is converted to change in resistance.
- Can be used to measure force without the use of moving mechanical parts — strain gauge mounted on the structure where force is applied, deformed as the structure is stretched or compress.
- Strain gauges have small resistances and experience very small resistance changes upon deformation .
- **Wheatstone bridge circuit is commonly used to condition a strain gauge, producing the voltage output.**

- Available as conductor (copper, etc.) traces printed on an insulator back





Stress (F), strain (ΔL) and strain gauge response (ΔR)



Sensitive to strains in the Axial direction

Much less sensitive to strains in lateral direction

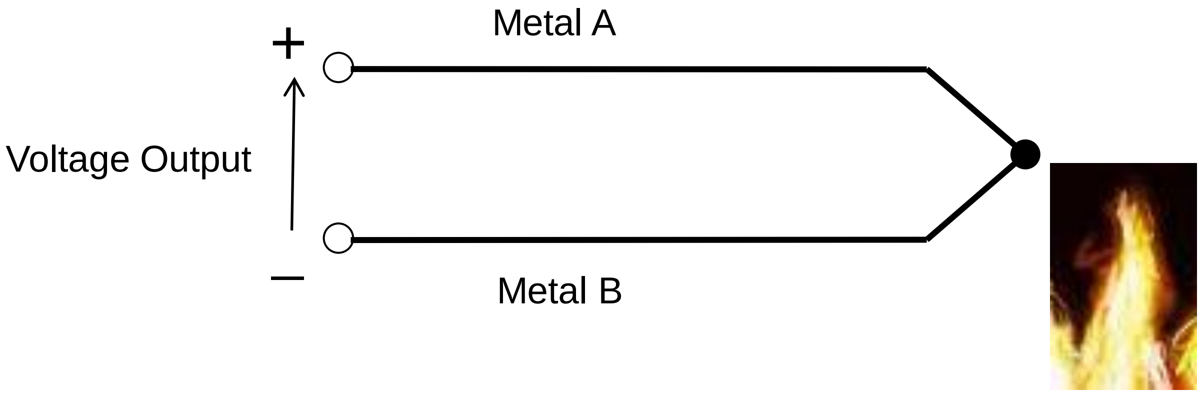
- Strain measurable by strain gauge is restricted to one direction.
- General measurement problem involves strain in more than one direction.
- Three strain gauges arranged in different directions are used for a three-dimensional strain measurement — strain gauge rosette.

Temperature Sensors

- Typical temperature sensors:
  - thermocouple
  - resistance temperature detector (RTD)
  - thermistor
  - solid state temperature sensor

Thermocouple

- A thermocouple is made by the joining of two dissimilar metals.
- Operates based on the Seebeck effect — a small voltage is generated when the junction formed by the two dissimilar metals is heated.



Thermocouple Output

- The **output voltage *E*** of a simple thermocouple circuit is usually written in the form

$$E = AT + BT^2/2 + CT^3/3$$

- *T* is the temperature is degrees Celsius.
- *E* is based on a reference junction temperature at 0 °C. The constants *A*, *B*, and *C* are dependent on the thermocouple material.

Common Types of Thermocouple

Type	Positive Material	Negative Material	Accuracy	Range °C	Comments
B	Pt, 30%Rh	Pt, 6%Rh	0.5%	50 to 1820	Good at high temperatures, no reference junction compensation required.
E	Ni, 10%Cr	Cu, 45%Ni	0.5% or 1.7°C	–270 to 1000	General purpose, low and medium temperatures
J	Fe	Cu, 45%Ni	0.75% or 2.2°C	–210 to 1200	High temperature, reducing environment
K	Ni, 10%Cr	Ni, 2%Al 2%Mn 1%Si	0.75% or 2.2°C	–270 to 1372	General purpose high temperature, oxidizing environment
N	Ni, 14%Cr 1.5%Si	Ni, 4.5%Si 0.1%Mg	0.75% or 2.2°C	–270 to 1300	Relatively new type as a superior replacement for K Type.
R	Pt, 13%Rh	Pt	0.25% or 1.5°C	–50 to 1768	Precision, high temperature
S	Pt, 10%Rh	Pt	0.25% or 1.5°C	–50 to 1768	Precision, high temperature
T	Cu	Cu, 45%Ni	0.75% or 1.0°C	–270 to 400	Good general purpose, low temperature, tolerant to moisture.

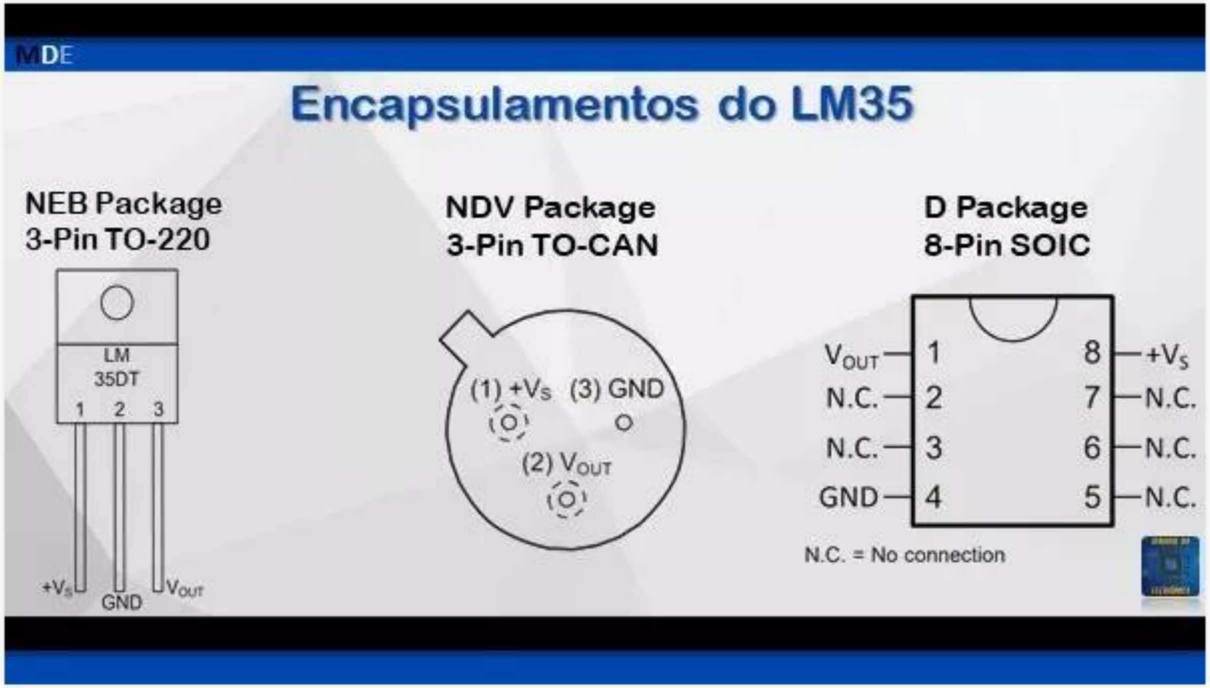
Comparison between RTD and Thermocouple

- RTDs can be more accurate than thermocouples
- RTDs have an output response that is more linear than thermocouples
- RTDs tend to be more stable than thermocouples (less change in response over time)

Resistance Temperature Dependent (RTD)

O LM35 é um sensor de temperatura de estado sólido encontrado em diversos tipos de encapsulamentos com uma tensão de saída linearmente proporcional à temperatura em graus Celsius.

Este sensor de temperatura produz um sinal de tensão que varia 10mV para cada ºC, sendo que ele é capaz de operar em uma escala de temperatura que pode variar entre -55ºC até 150ºC.



Encapsulamentos do sensor LM35!

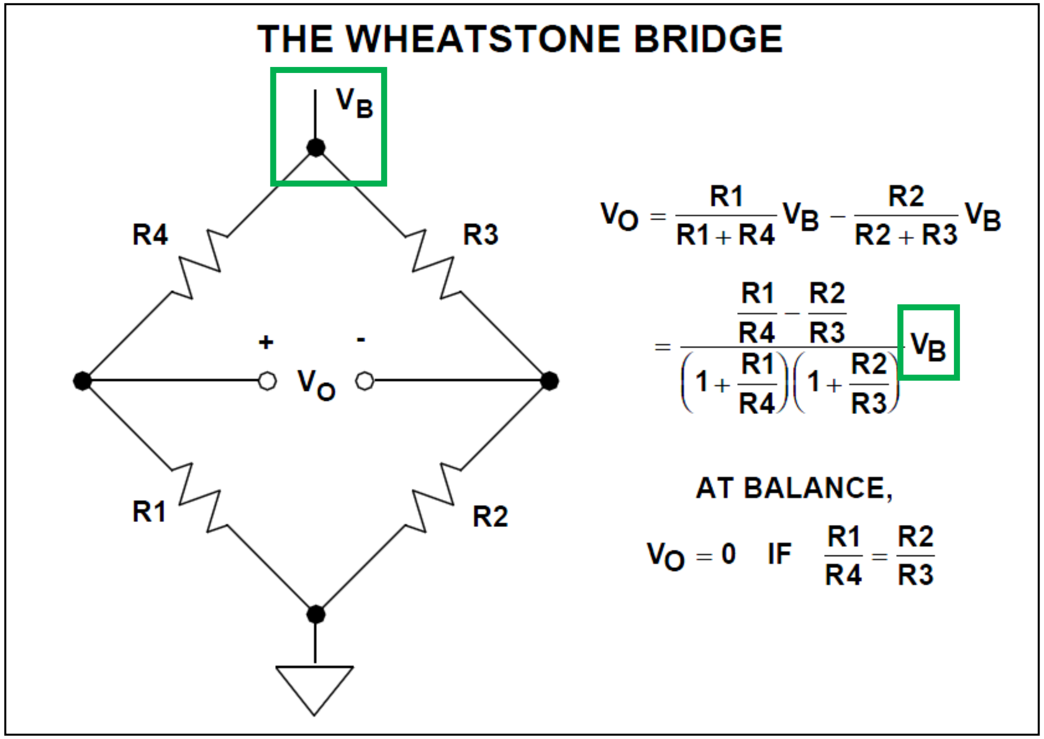
Bridge Circuits

Bridge Circuit

1

Resistive sensors such as resistance temperature detectors (RTD) and **strain gages** produce small percentage changes in resistance in response to a change in a physical variable such as temperature or force.

One technique for measuring resistance is to force a constant current through the resistive sensor and measure the voltage output. This requires both an accurate current source and an accurate means of measuring the voltage.



THE WHEATSTONE BRIDGE

$$V_O = \frac{R1}{R1+R4}V_B - \frac{R2}{R2+R3}V_B$$

$$= \frac{\frac{R1}{R4} - \frac{R2}{R3}}{\left(1+\frac{R1}{R4}\right)\left(1+\frac{R2}{R3}\right)}\boxed{V_B}$$

AT BALANCE,

$$V_O = 0 \quad \text{IF} \quad \frac{R1}{R4} = \frac{R2}{R3}$$

2 Because very small resistance changes are common, **the output voltage change may be as small as tens of millivolts, even with V_B = 10 V** (a typical excitation voltage for a load cell application).

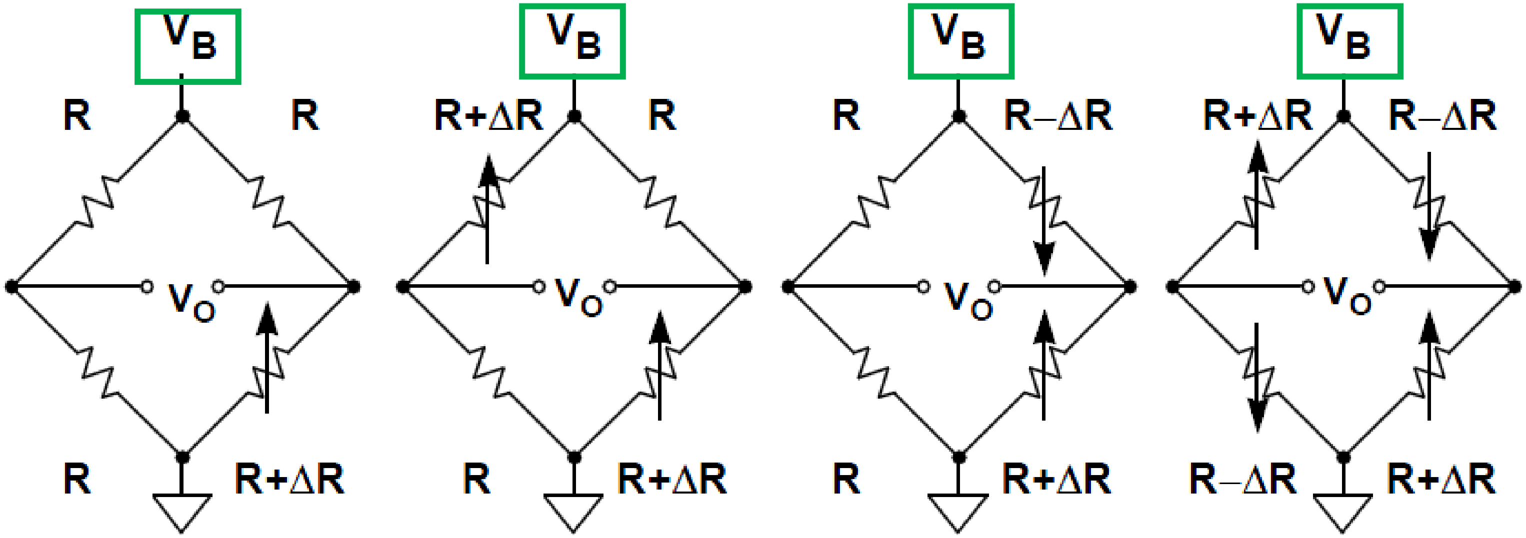
3 The deviation of the variable resistor(s) about the nominal value is proportional to the quantity being measured, such as strain (in the case of a strain gage) or temperature (in the case of an RTD).

4 The **sensitivity** of a bridge is the ratio of the maximum expected change in the output voltage to the excitation voltage. For instance, if V_B = 10V, and the fullscale bridge output is 10mV, then the sensitivity is 1mV/V.

5 **Typical bridge sensitivites are 1mV/V to 10mV/V**. Although large excitation voltages yield proportionally larger fullscale output voltages, they also result in higher power dissipation and the possibility of sensor resistor self-heating errors. On the other hand, low values of excitation voltage require more gain in the conditioning circuits and increase the sensitivity to noise.

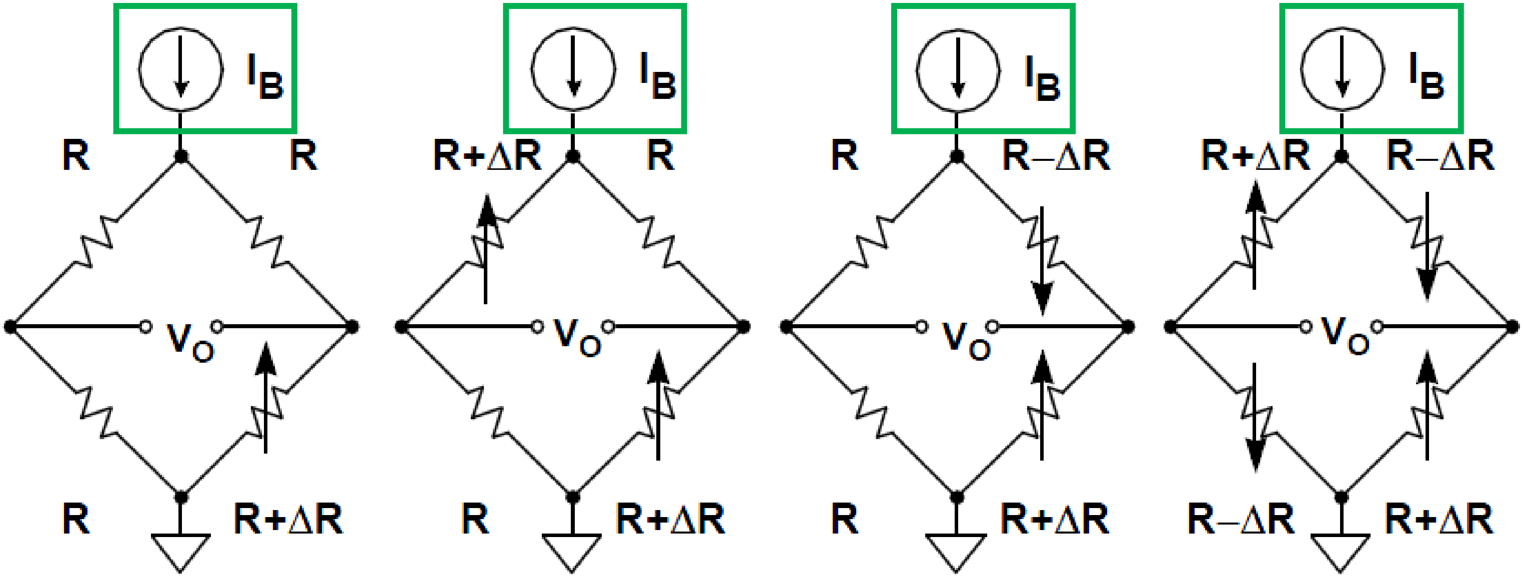
6 Regardless of its value, **the stability of the excitation voltage or current directly affects the overall accuracy of the bridge output**. Stable references and/or ratiometric techniques are required to maintain desired accuracy.

OUTPUT VOLTAGE AND LINEARITY ERROR FOR CONSTANT VOLTAGE DRIVE BRIDGE CONFIGURATIONS



V_O:	$\frac{V_B}{4}\left[\frac{\Delta R}{R+\frac{\Delta R}{2}}\right]$	$\frac{V_B}{2}\left[\frac{\Delta R}{R+\frac{\Delta R}{2}}\right]$	$\frac{V_B}{2}\left[\frac{\Delta R}{R}\right]$	$V_B\left[\frac{\Delta R}{R}\right]$
Linearity Error:	0.5%/%	0.5%/%	0	0
	(A) Single-Element Varying	(B) Two-Element Varying (1)	(C) Two-Element Varying (2)	(D) All-Element Varying

OUTPUT VOLTAGE AND LINEARITY ERROR FOR CONSTANT CURRENT DRIVE BRIDGE CONFIGURATIONS

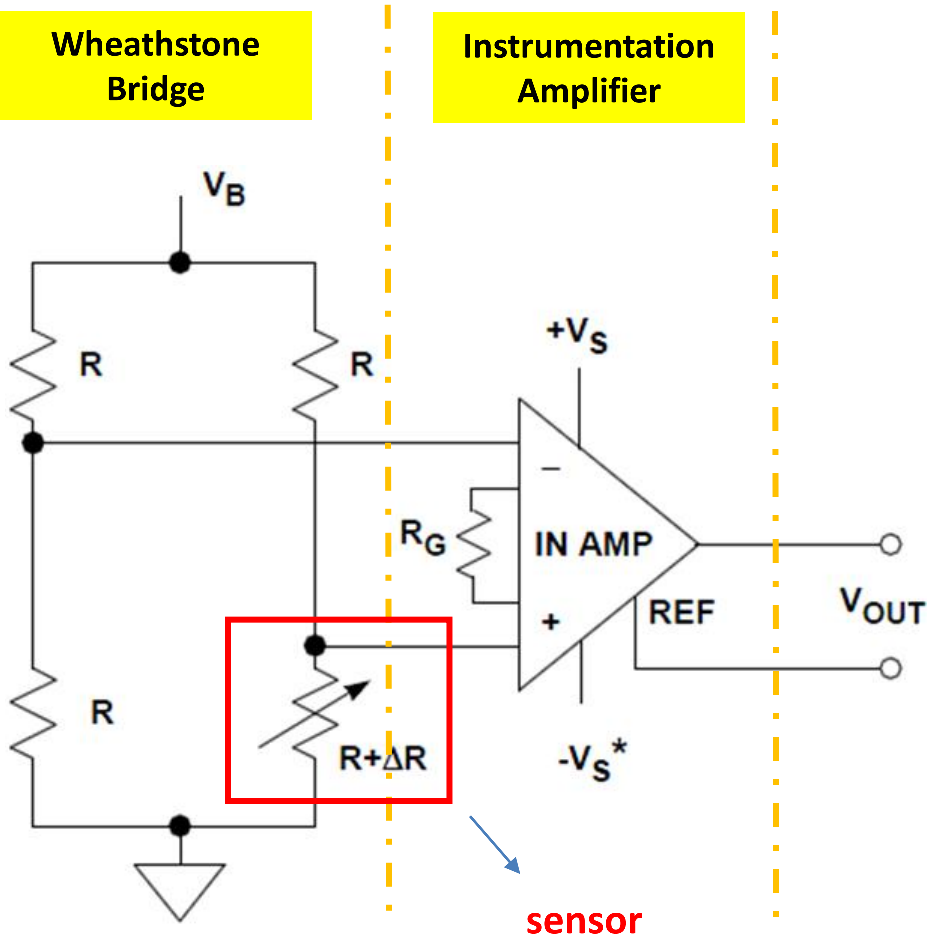


V_O:	$\frac{I_B R}{4}\left[\frac{\Delta R}{R + \frac{\Delta R}{4}}\right]$	$\frac{I_B}{2}\left[\Delta R\right]$	$\frac{I_B}{2}\left[\Delta R\right]$	$I_B\left[\Delta R\right]$
Linearity Error:	0.25%/%	0	0	0
	(A) Single-Element Varying	(B) Two-Element Varying (1)	(C) Two-Element Varying (2)	(D) All-Element Varying

Bridge Circuit

Wheathstone Bridge

Instrumentation Amplifier



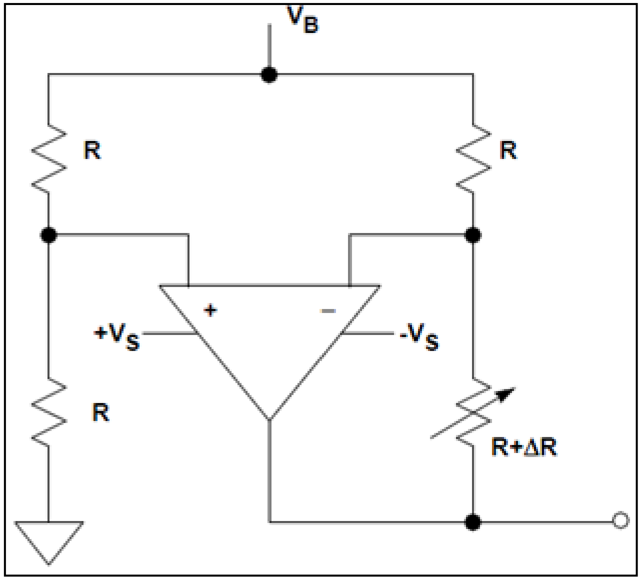
sensor

$$V_{OUT} = \frac{V_B}{4}\left[\frac{\Delta R}{R + \frac{\Delta R}{2}}\right]\left[GAIN\right]$$

example 1

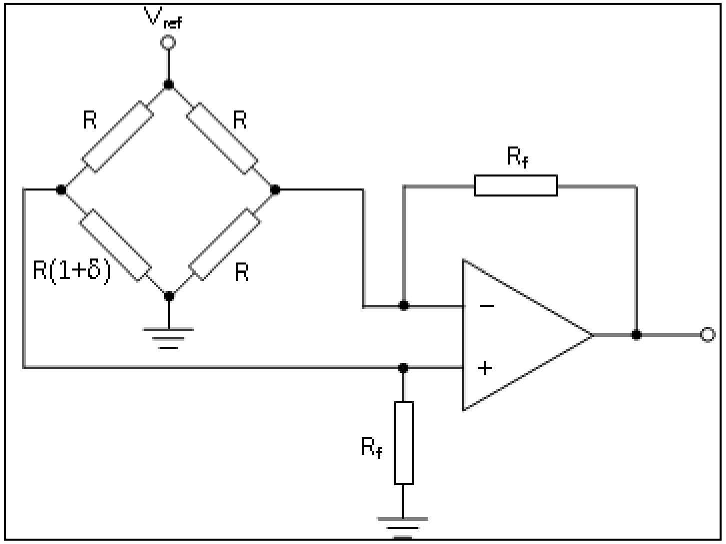
Bridge Circuit

LINEARIZING A SINGLE-ELEMENT VARYING BRIDGE



$$V_{OUT} = -V_B\left[\frac{\Delta R}{2R}\right]$$

example 2

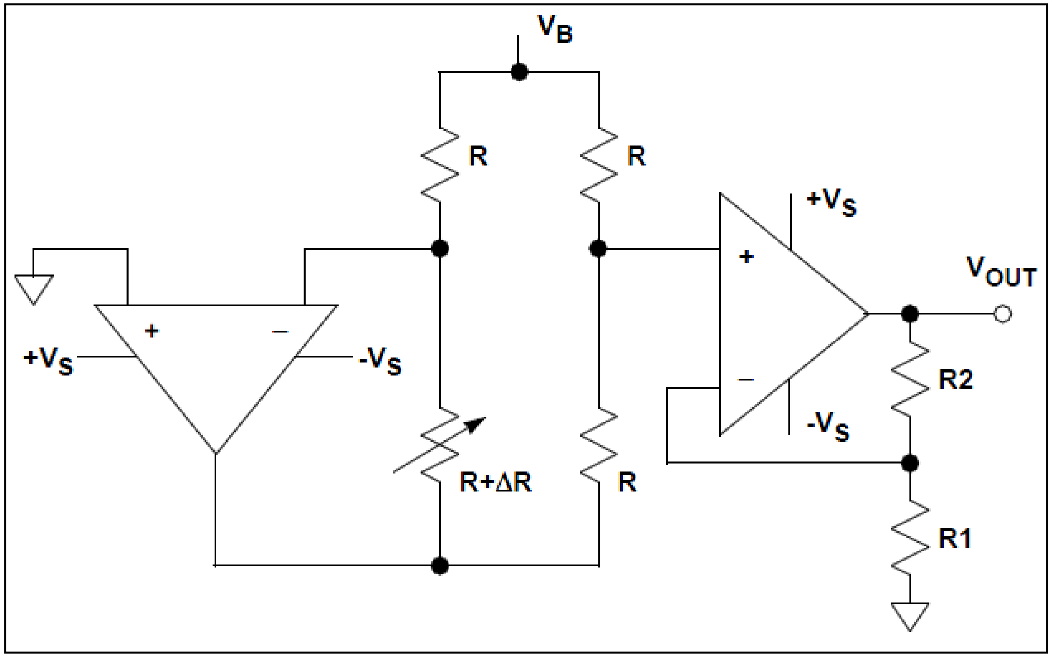


$$V_{OUT} = V_{ref}\left(\frac{\delta}{2}\right)\left(\frac{R_f}{R}\right)$$

example 3

Bridge Circuit

LINEARIZING A SINGLE-ELEMENT VARYING BRIDGE



$$V_{OUT} = \frac{V_B}{2}\left[\frac{\Delta R}{R}\right]\left[1+\frac{R2}{R1}\right]$$

example 4

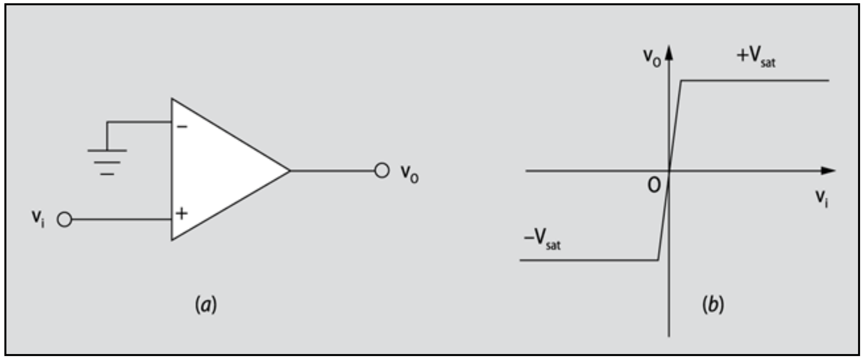
Comparadores

Referências Bibliográficas

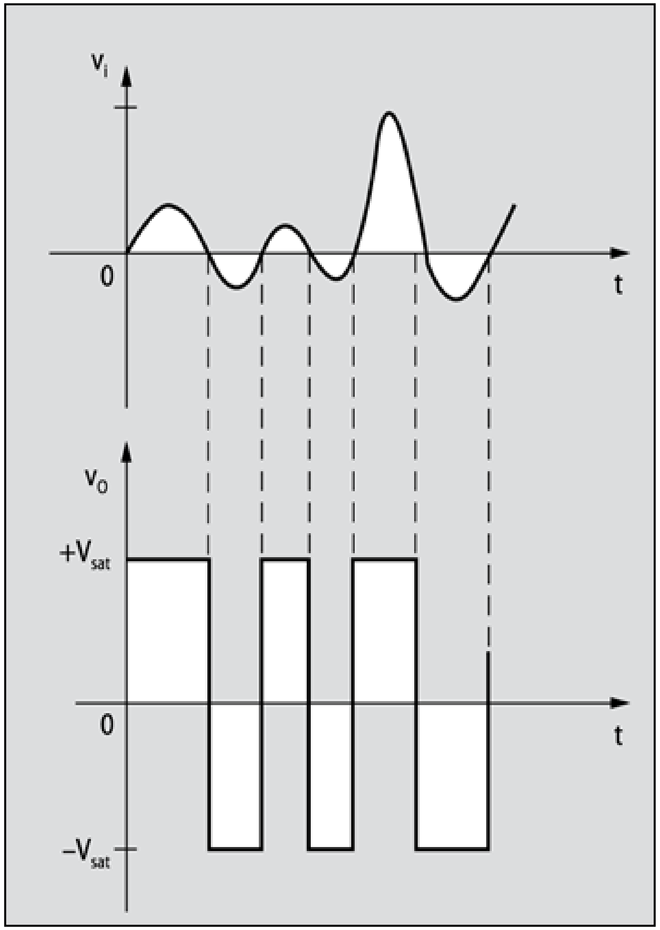
Pertence AJ, Amplificadores Operacionais e Filtros Ativos

Exemplo 1

Comparador Não-Inversor



$$V_o = \begin{cases} +V_{sat} \text{ se } V_1 > 0 \\ -V_{sat} \text{ se } V_1 < 0 \end{cases}$$

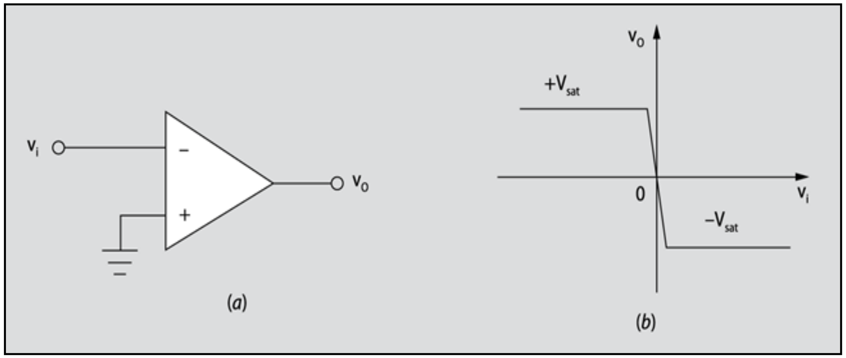


Exemplo de Ação

Exemplo 2

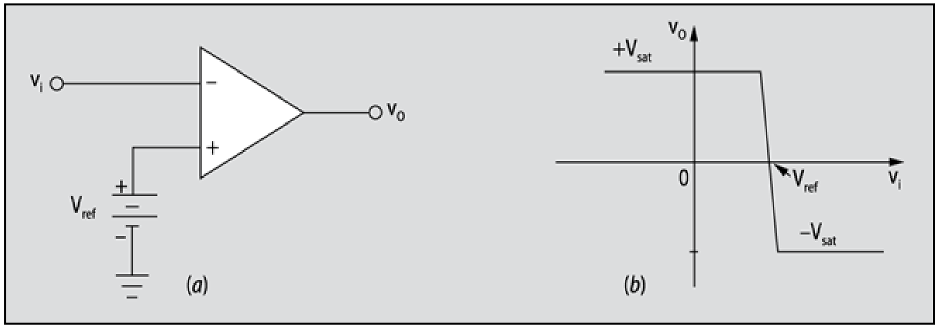
Comparador Inversor

Referência=0



$$v_o = \begin{cases} +V_{sat} \text{ se } v_i < 0 \\ -V_{sat} \text{ se } v_i > 0 \end{cases}$$

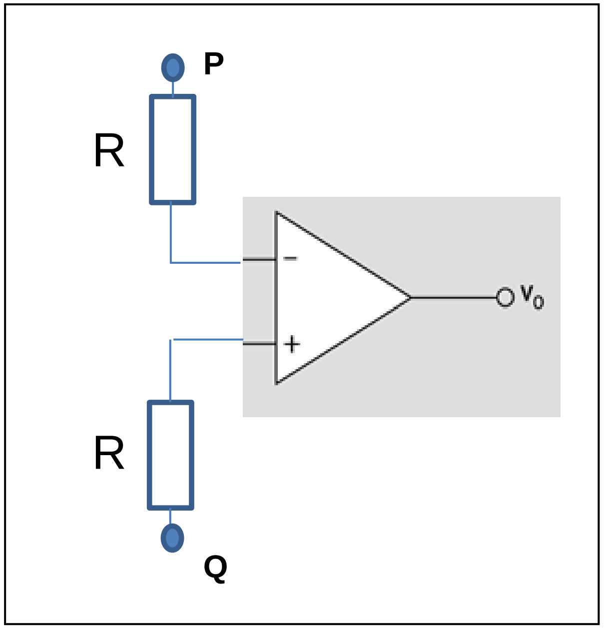
Referência ≠ 0



$$v_o = \begin{cases} +V_{sat} \text{ se } v_i < v_{ref} \\ -V_{sat} \text{ se } v_i > v_{ref} \end{cases}$$

Exemplo 3

Comparador



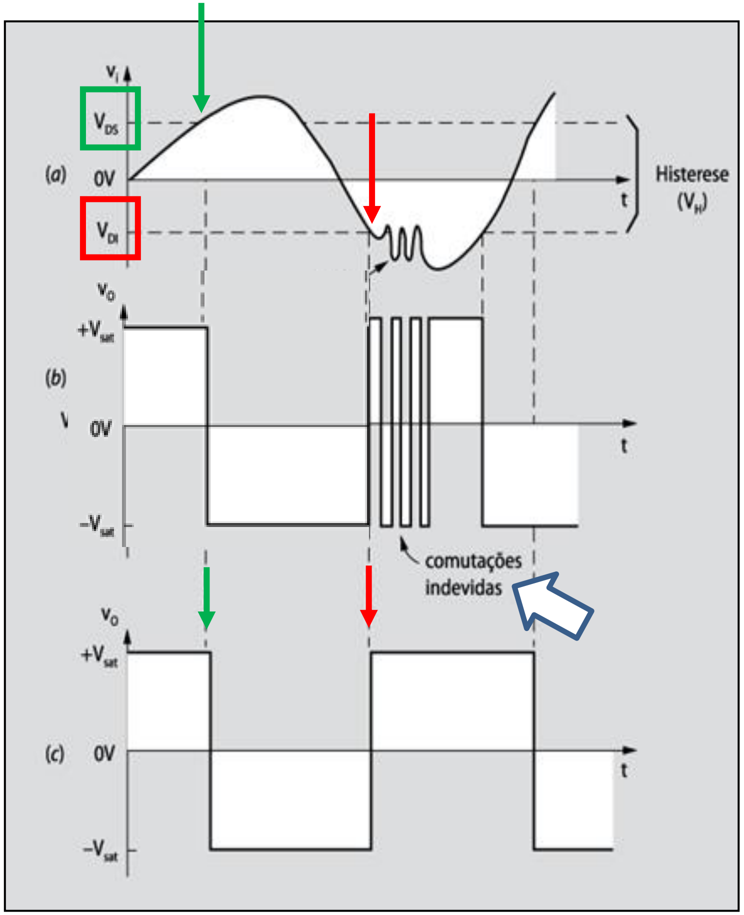
$$v_o = \begin{cases} +V_{sat} \text{ se } v_p = v_p < 0 \\ -V_{sat} \text{ se } v_p = v_p > 0 \end{cases}$$

Exemplo 4

Comparador Regenerativo (Schmitt Trigger)

Regenerativo é sinônimo de histerese (atraso).

Um circuito possui histerese quando apresenta atraso na mudança do seu estado de saída (EFEITO) apesar das condições de entrada (CAUSA) haverem sido alteradas.



- O projetista deverá possuir uma noção da ordem de grandeza do valor pico a pico da tensão de ruído presente no sinal e estabelecer dois níveis de referência:

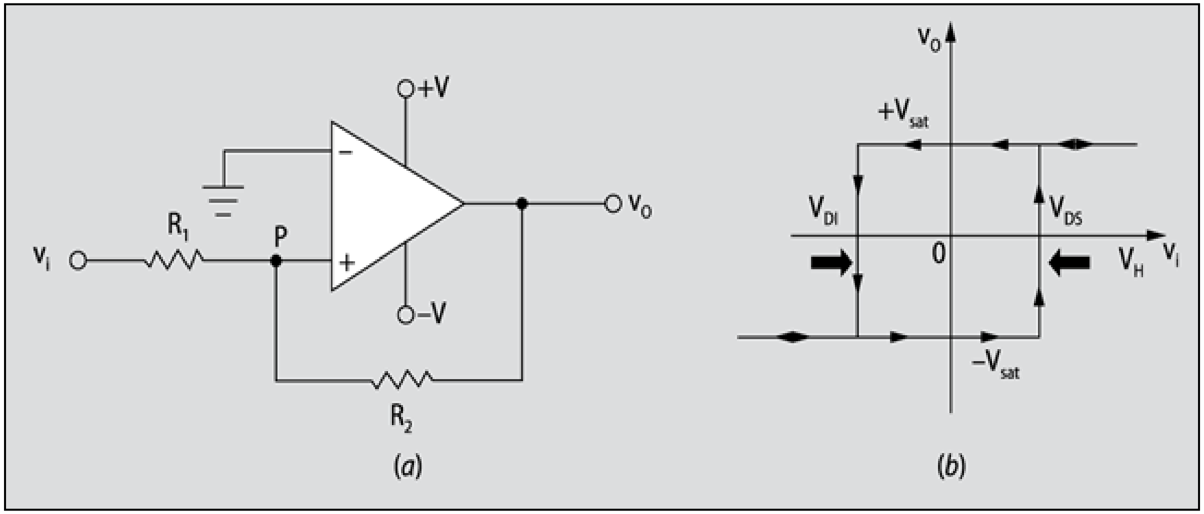
- **V_{DI} – tensão de disparo inferior**
  V_{DS} – tensão de disparo superior

- **V_H – tensão de histerese**

$$V_H = V_{DS} - V_{DI}$$

- As comutações ocorrem quando o sinal, após ter atingido os níveis de disparo **V_{DI}** ou **V_{DS}**, atingir o outro nível de disparo.

Comparador Regenerativo Não Inversor

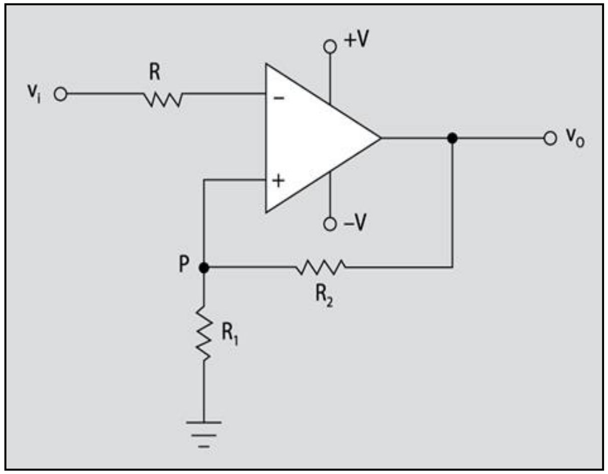


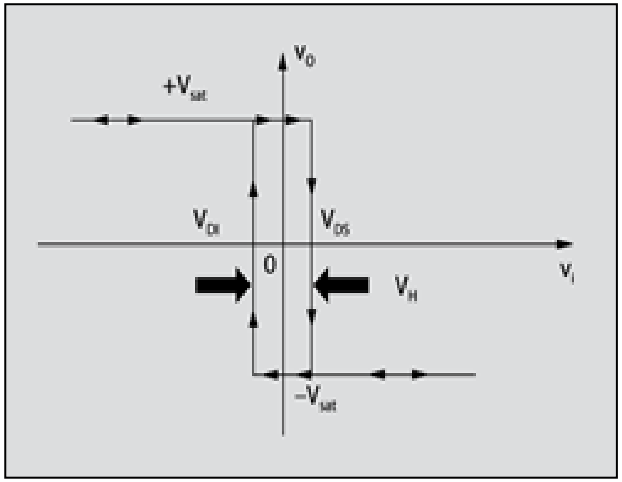
(a) (b)

$$V_{DS} = \frac{R_1}{R_2} \cdot (+V_{sat})$$

$$V_{DI} = \frac{R_1}{R_2} \cdot (-V_{sat})$$

Comparador Regenerativo Inversor

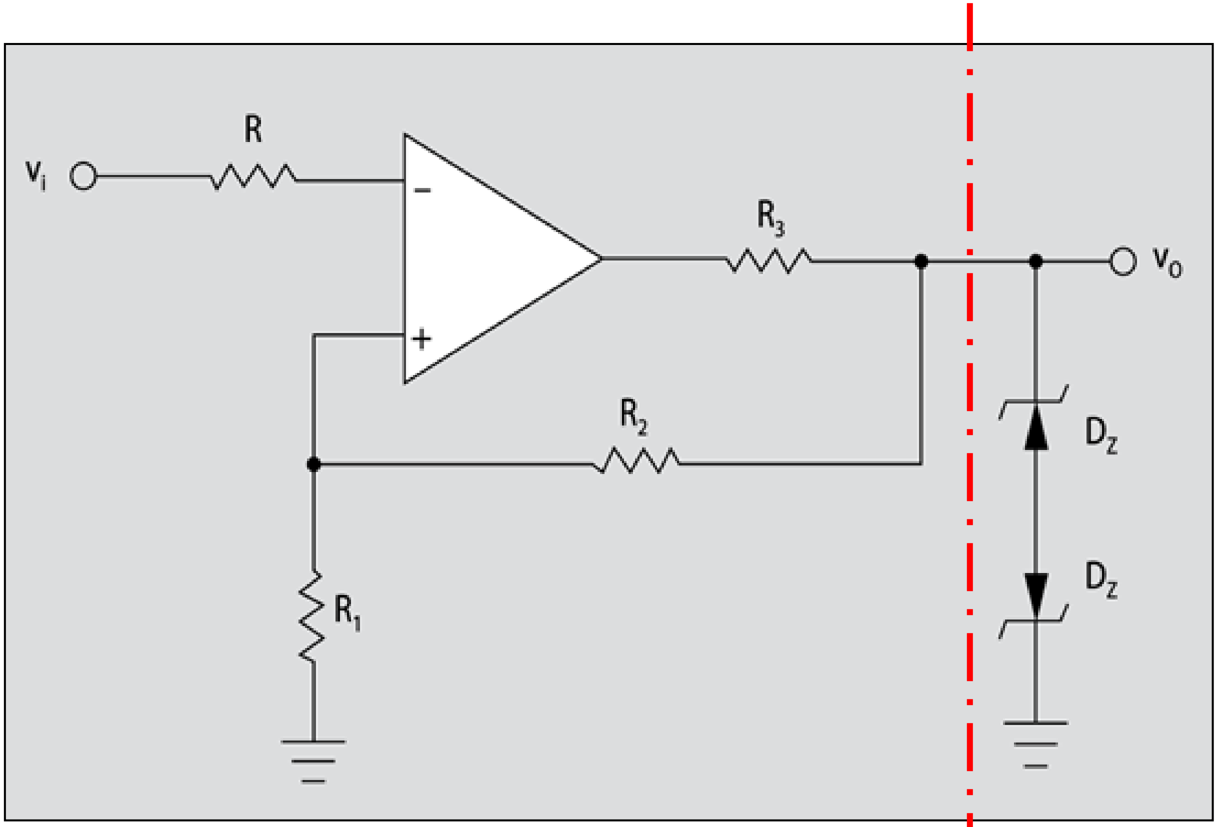




$$V_{DS} = \frac{R_1}{R_1 + R_2} \cdot \left(+V_{sat}\right)$$

$$V_{DI} = \frac{R_1}{R_1 + R_2} \cdot \left(-V_{sat}\right)$$

Comparador Regenerativo Inversor
(com limitador de tensão)



Comparador Inversor Regenerativo

Limitador de Tensão

Circuitos Integrados Dedicados a Comparação

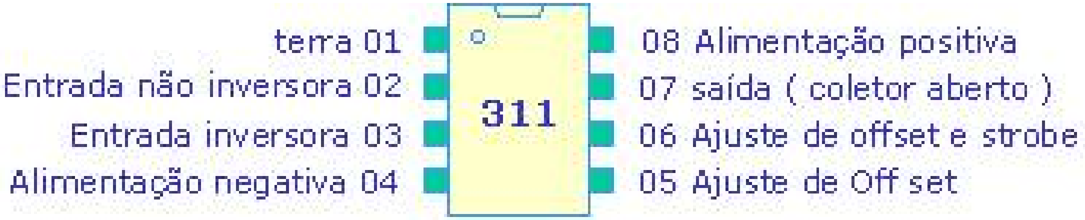
A necessidade de comparação de sinais, principalmente em sistemas de controle, levou fabricantes de semicondutores a produzirem circuitos integrados dedicados à comparação, entre os quais se destacam o LM339 e o LM311.

O comparador LM311

Se o projetista desejar mais velocidade de comutação, o comparador recomendado é o LM311 (da ordem de 200ns), também permite interface com circuitos lógicos.

O circuito integrado:

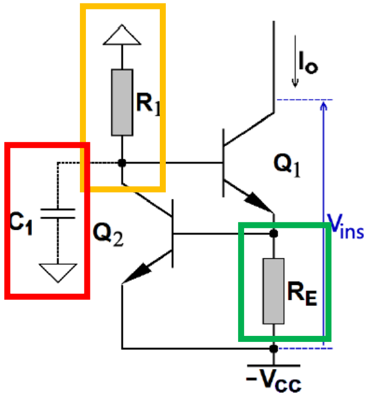
São projetados para operar com fonte simétrica, tipicamente ±15V ou assimétrica 5V, para interface com sistemas lógicos.



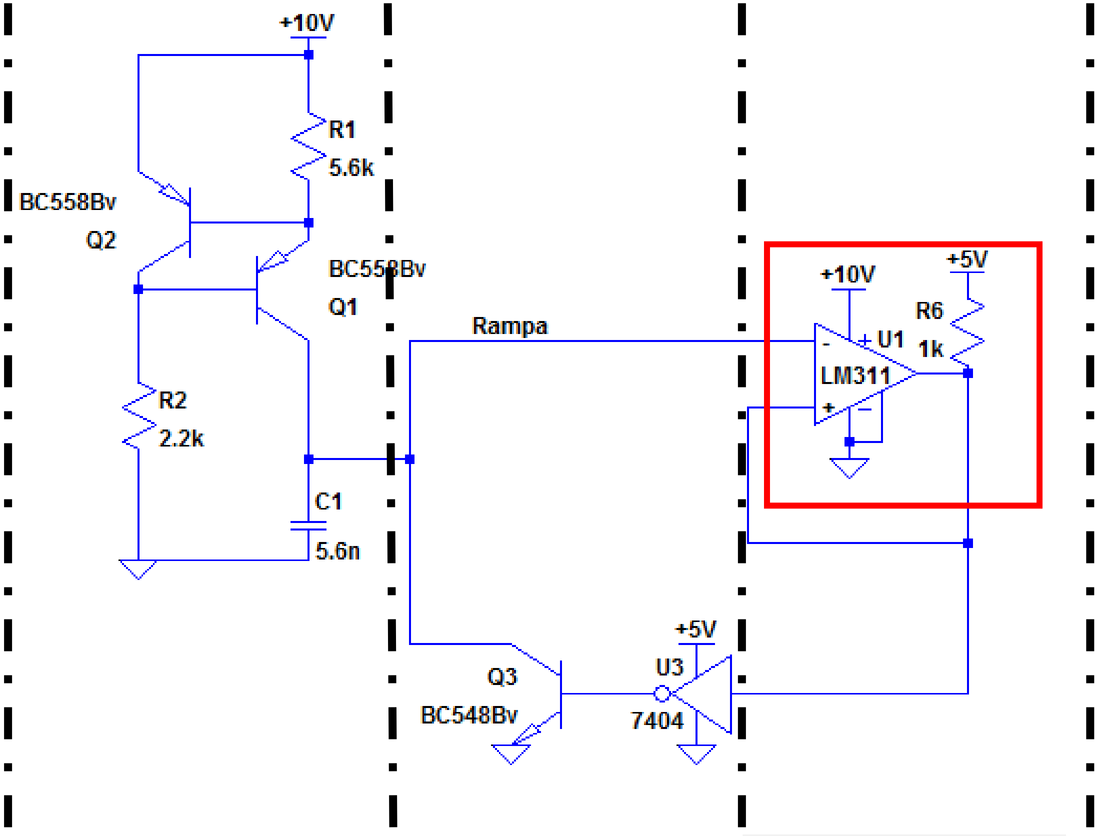
The temperature sensor **LM35** used in the ME3200 Electronic Instrumentation Kit has full-scale temperature sensitivity from **0** to **100° C** and a resolution of **10 mV per degree Celsius**. In other words, the analog output voltage ranges from **0** to **1 V** for temperatures between **0** and **100° C**.

Oscilador em Rampa

Fonte de Corrente de Wilson Modificada



$$I_o = \left(\frac{V_{BE2}}{R_E} + \frac{I_{C2}}{\beta_2}\right) \times \frac{\beta_1}{\beta_1+1} \cong \frac{V_{BE2}}{R_E}$$

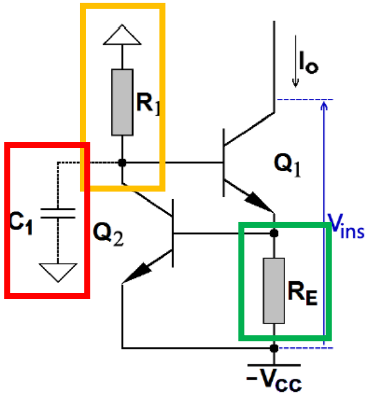


Fonte de Corrente de Wilson Modificada

Chave

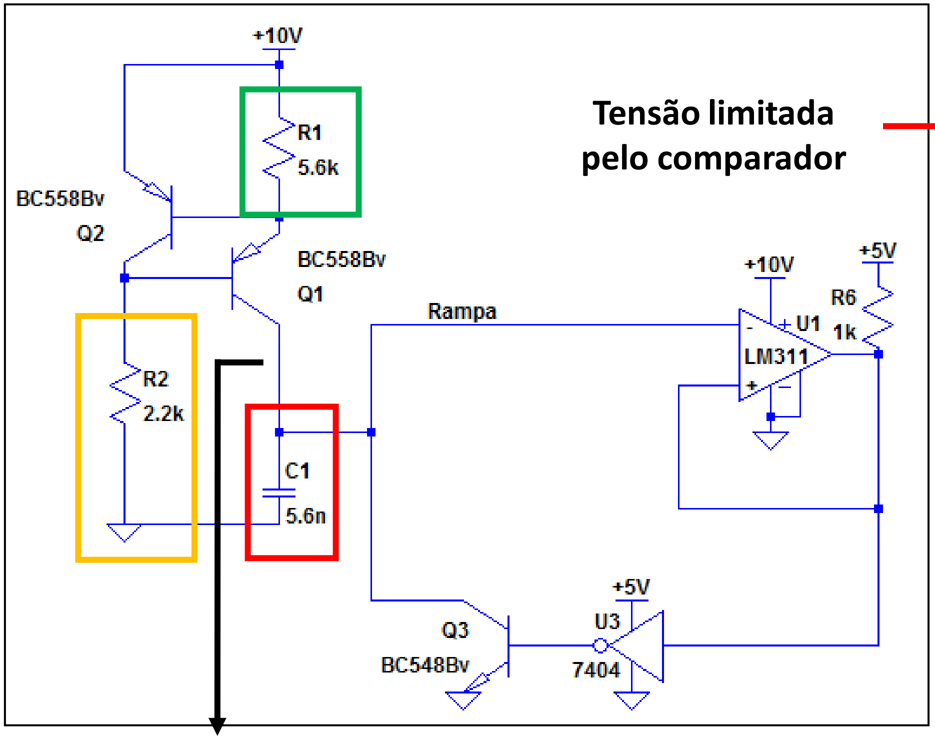
Comparador com histerese

Oscilador em Rampa

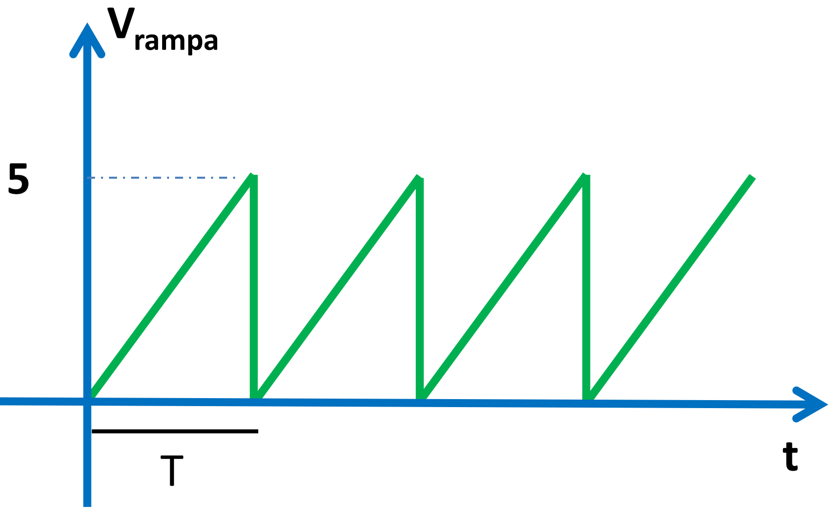


$$I_o = \left(\frac{V_{BE2}}{R_E} + \frac{I_{C2}}{\beta_2}\right) \times \frac{\beta_1}{\beta_1+1} \cong \frac{V_{BE2}}{R_E} \quad [1]$$

Fonte de Corrente
de Wilson Modificada



Tensão limitada pelo comparador



$$i_C = c\frac{dv_C}{dt} \Rightarrow \underbrace{\frac{v_{be}}{R_1}}_{[1]} = C\,\frac{5-0}{T} \Rightarrow \boxed{f = \frac{v_{be}}{5R_1C}}$$

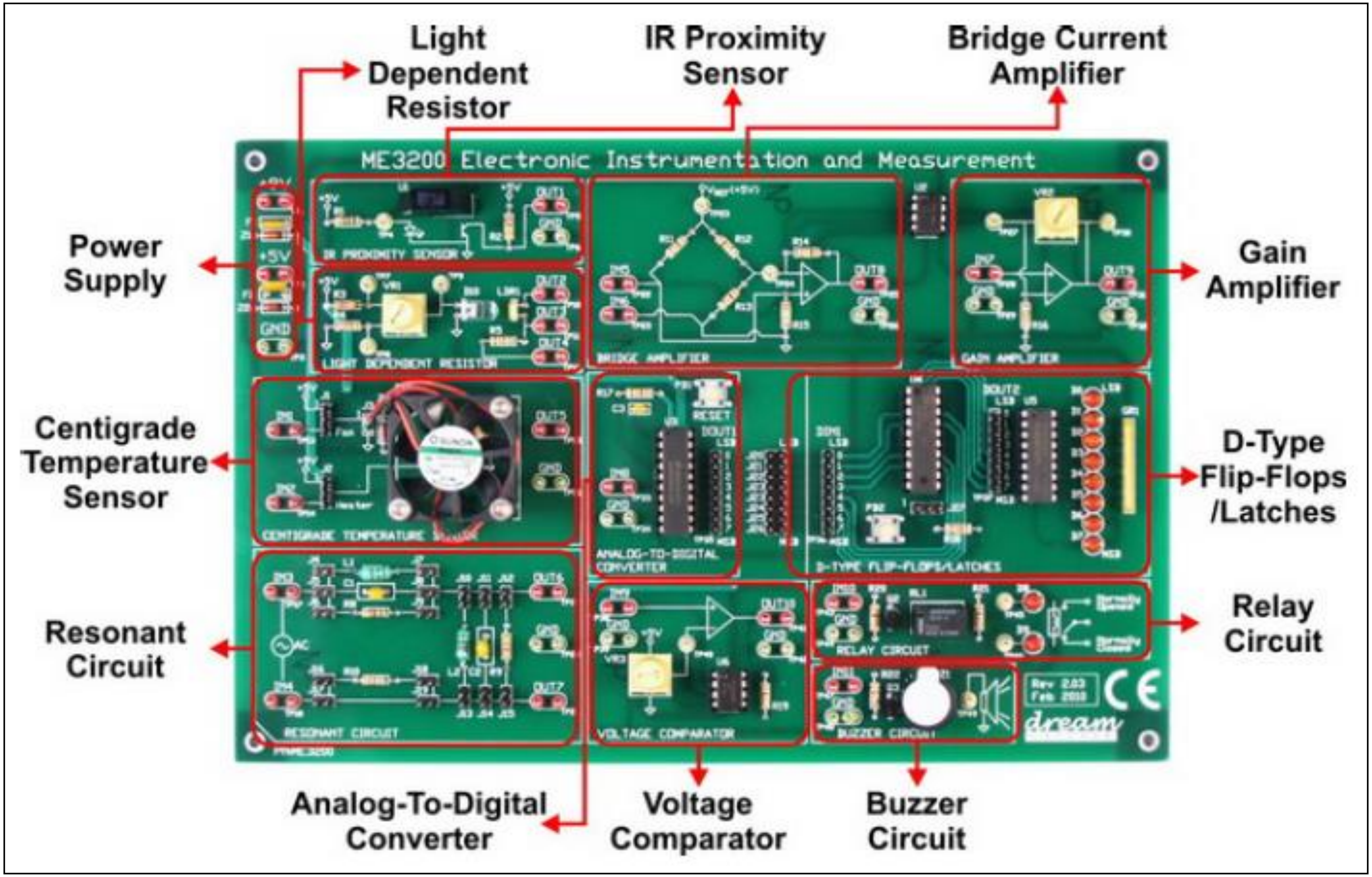
i_O = constante

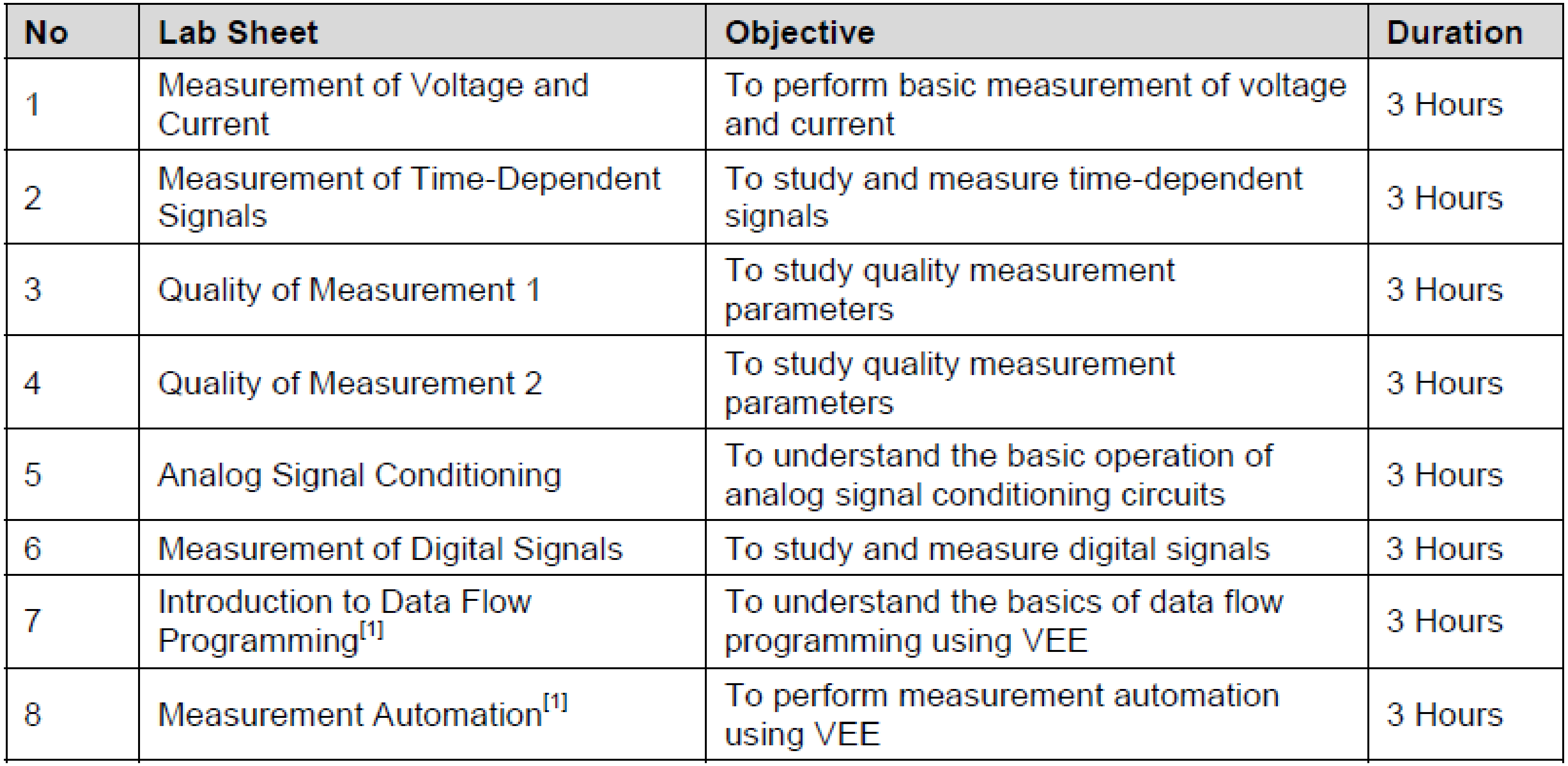
⇓

V_C é linear

Roteiro Experimental
(Educational Kit
ME3200 - Electronic Instrumentation and Measurement - Part 1)

ME3200 Electronic Instrumentation Kit

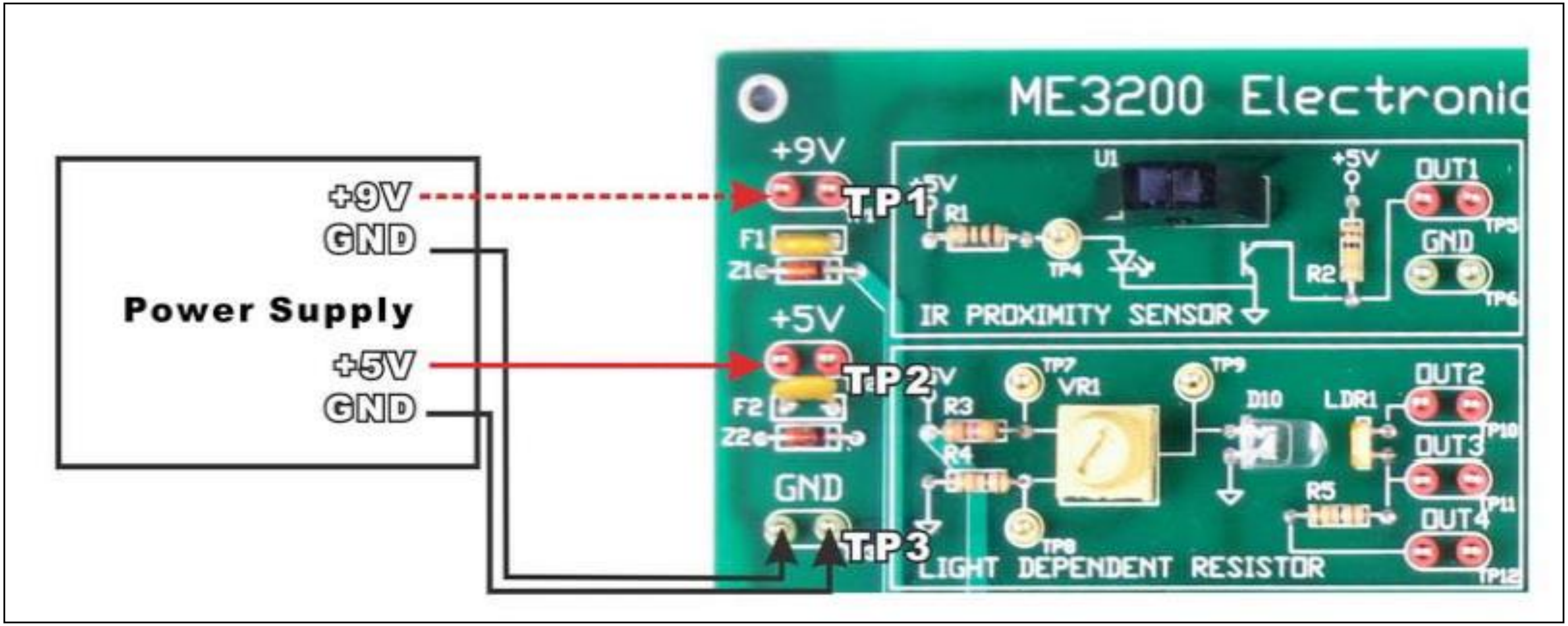




No	Lab Sheet	Objective	Duration
1	Measurement of Voltage and Current	To perform basic measurement of voltage and current	3 Hours
2	Measurement of Time-Dependent Signals	To study and measure time-dependent signals	3 Hours
3	Quality of Measurement 1	To study quality measurement parameters	3 Hours
4	Quality of Measurement 2	To study quality measurement parameters	3 Hours
5	Analog Signal Conditioning	To understand the basic operation of analog signal conditioning circuits	3 Hours
6	Measurement of Digital Signals	To study and measure digital signals	3 Hours
7	Introduction to Data Flow Programming[1]	To understand the basics of data flow programming using VEE	3 Hours
8	Measurement Automation[1]	To perform measurement automation using VEE	3 Hours

Power Supply

Power on the ME3200 Electronic Instrumentation Kit



1. The ME3200 Electronic Instrumentation Kit requires two power supplies **(+5 V** and **+9 V)** in order to operate.
2. Turn on the power supply unit. Set the dual channel output voltages to exactly **+5 V** and **+9 V,** respectively. Set both current limits to **1.0 A**.
3. Next, connect the power supply to the ME3200 Electronic Instrumentation Kit as shown in Figure 2.

Measurement of Digital Signals

SEL393- Laboratório de Instrumentação Eletrônica I
Laboratory 2 – Signal Conditioning

2.1 Power On the ME3200 Electronic Instrumentation Kit

1. The ME3200 Electronic Instrumentation Kit requires two power supplies (+5 V and +9 V) in order to operate.

2. Turn on the power supply unit. Set the dual channel output voltages to exactly +5 V and +9 V, respectively. Set both current limits to 1.0 A. After the power supply is configured, disable all the power supply outputs. Next, connect the power supply to the ME3200 Electronic Instrumentation Kit as shown in 2.1.

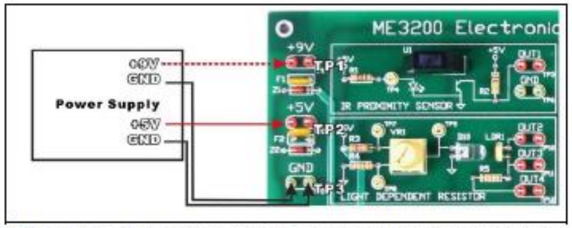


Fig. 2.1 – Connections Between the Power Supply and the ME3200 Electronic Instrumentation Kit

3. Connect the **+9V** of the power supply output to test points **TP1** and **GND** to **TP3** of the ME3200 Electronic Instrumentation Kit respectively.

4. Connect the **+5V** of the power supply output to the test points **TP2** and **GND** to **TP3** of the ME3200 Electronic Instrumentation Kit respectively.

5. Make sure that the polarities of the terminals are correctly connected. Refer to Table 2.1 to verify your connections.

Table 2.1 – Connection Between the Power Supply and the ME3200 Electronic Instrumentation Kit

ME3200 Electronic Instrumentation Kit	Power Supply Unit
+9 V Terminal, TP1	+9V Terminal
GND Terminal, TP3	GND Terminal
+5 V Terminal, TP2	+5V Terminal
GND Terminal, TP3	GND Terminal

6. After the connections are verified, enable the power supply outputs. The annunciators on the display panel of the power supply should be turned on. This indicates that the power supply is providing a constant voltage supply to the ME3200 Electronic Instrumentation Kit.

7. If the **CC** annunciator is on, disable the power supply output. Check if this is due to the current limit setting or a faulty connection. Refer to your lab instructor for verification.

2.2 Analog to Digital Conversion (Introduction)

An analog-to-digital converter (ADC) is a device that converts continuous signals (analog voltage) into discrete digital values that are proportional to the magnitude of the continuous signals. The ADC is usually available as an integrated circuit. Fig.2. shows the electrical symbol for an analog-to-digital converter (ADC).

Fig.2.2 – Electrical Symbol for Analog-to-Digital Converter (ADC)

The operations of an ADC can be divided into two processes, which are sampling and quantization. Sampling is done by a sample and hold circuit that will produce values at a predefined sampling interval for digitization. Quantization is a process where the analog values at discrete time intervals are converted into discrete binary values. During the quantization process, the ADC uses an integer value from a predefined and finite list of values in order to represent each of the analog samples. Each of the integer value in the list represents a fraction of the full-scale voltage range of the ADC.

The resolution of an ADC refers to the smallest change in voltage that the ADC able to detect. It also refers to the voltage that is represented by one least significant bit (LSB) in the converted digital value. Since the ADC generates a binary output that corresponds to a fraction of its full-scale voltage range, V_{FSR}, the full-scale voltage range will depend on the reference voltage, V_{ref} supplied to the ADC. For bipolar operation, the V_{FSR} will depend on two reference voltage pins on the ADC, which are V_{ref+} and V_{ref-}. However, for single-ended operation, there is only one reference voltage pin on the ADC, which is V_{ref} , while V_{ref-} is grounded internally. Therefore, the full scale voltage is as follows:

Bipolar Operation:	$V_{FSR} = V_{ref+} - V_{ref-}$
Single-Ended Operation:	$V_{FSR} = V_{ref}$

Another element that determines the resolution of an ADC will be the number of bits, **N** for an ADC. An N-bit ADC can product 2^N possible output combinations, with $2^N - 1$ intervals between two successive values. These values are in the range of M from **0** to $2^N - 1$ (unsigned integer). Therefore, the resolution of an N-bit ADC is as follows:

$$Q = \frac{V_{FSR}}{2^N}$$

where Q is the resolution in volts per step

V_{FSR} is the full-scale voltage range

N is the number of bits for an ADC

For example, a 3-bit ADC with V_{FSR} = **8** V can convert an analog input to one in **eight** different levels with **seven** intervals; the ADC voltage resolution is 8 V/8 Steps = **1000 mV/step**. The converted digital output value can be interpreted by multiplying the voltage resolution with the ADC digital output value,

$$Converted\ Voltage, V_{ADC} = \frac{V_{FSR}}{2^N} \times (ADC\ Digital\ Output\ Value)$$

The ADC digital output value refers to the **M**th step of the digital signal. By referring back to the previous example, we can determine the converted voltage on the 5th step (Mth step) = 1000 mV/step X 5 = 5000 mV. This means that at the 5th step (in digital form as 101), the converted voltage at that particular level is 5 V.

Fig. 2.3 shows the Analog-to-Digital Conversion module on the ME3200 Electronic Instrumentation Kit. This module consists of three main portions, which are the 8-bit ADC (ADC0804LCN), D-Type Flip-Flops/Latches (74HCT373N), and also the Digital Signal Display.

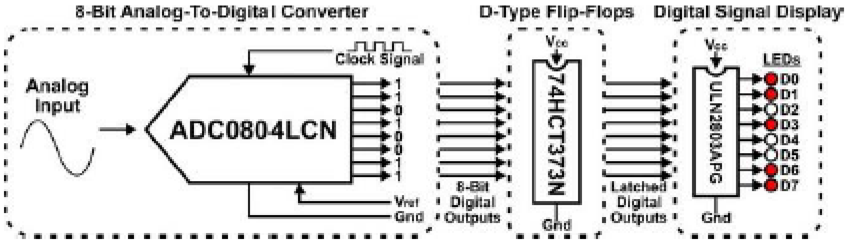


Fig. 2.3 – Analog to Digital Conversion Module on the ME3200 Electronic Instrumentation Kit

The 8-Bit ADC converts the analog input, and outputs it as 8 bits digital signal. The D-Type Flip-Flops latch the 8 bits data and sends the data to the LED display driver (ULN2803APG) in order to display the digital signal through the LEDs.

The LED **D0** and LED **D7** represent the **least significant bit (LSB)** and **most significant bit (MSB)** of the converted digital signal respectively. The LEDs are turned on (set to high) to display the particular bits for the digital signal. Fig. 2.3 shows that the D-type Flip-Flops latch the converted digital signal **1101 0011,** and LEDs **D0, D1, D3, D6,** and **D7** are turned on in order to represent the digital signal.

2.2 Analog to Digital Conversion
(Measurement of the Digital Signal)

1. Fig. 2. shows the 8-Bit ADC (**U3**) and D-Type Flip-Flops/Latches (**U4**) on the ME3200 Electronic Instrumentation Kit. An analog input signal is fed into the input of ADC in order to perform analog to digital conversion. The converted digital signal is latched by the D-Type Flip-Flops/Latches. The signal can be latched either manually (by pressing the push button, **PB2**) or automatically, according to the position of the jumper **J28**. The latched digital signal is displayed by the LEDs as shown in Fig. 2.. The ADC can be reset by pressing the push button, **PB1**.

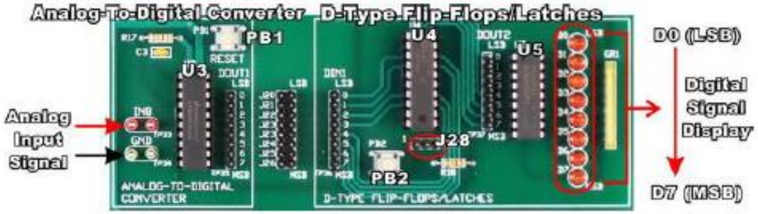


Fig. 2.4 – ADC and D-Type Flip-Flops/Latches on the ME3200 Electronic Instrumentation Kit

2. Connect the jumper **J28** to **positions 1** and 2 as shown in Fig. **2.5**. This will allow you to latch the converted digital signal manually by pressing the push button **PB2**.

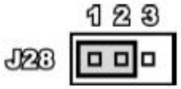


Fig. 2.5 – Position of the Jumper J27

3. Connect all jumpers from **J20** to **J27** as shown in Fig. **2.** if they are not yet connected. This will allow the converted digital signal to be latched by the D-Type Flip-Flops/Latches.

4. Enable the power supply outputs.

5. Connect the red probe and black probe of function generator to the **IN8** terminal **(TP33)** and the **GND** terminal **(TP34)** respectively as shown in Fig. **2.**.

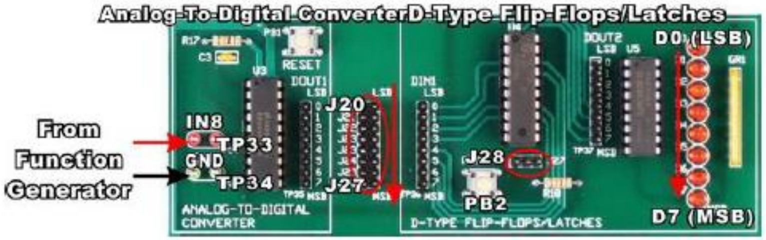
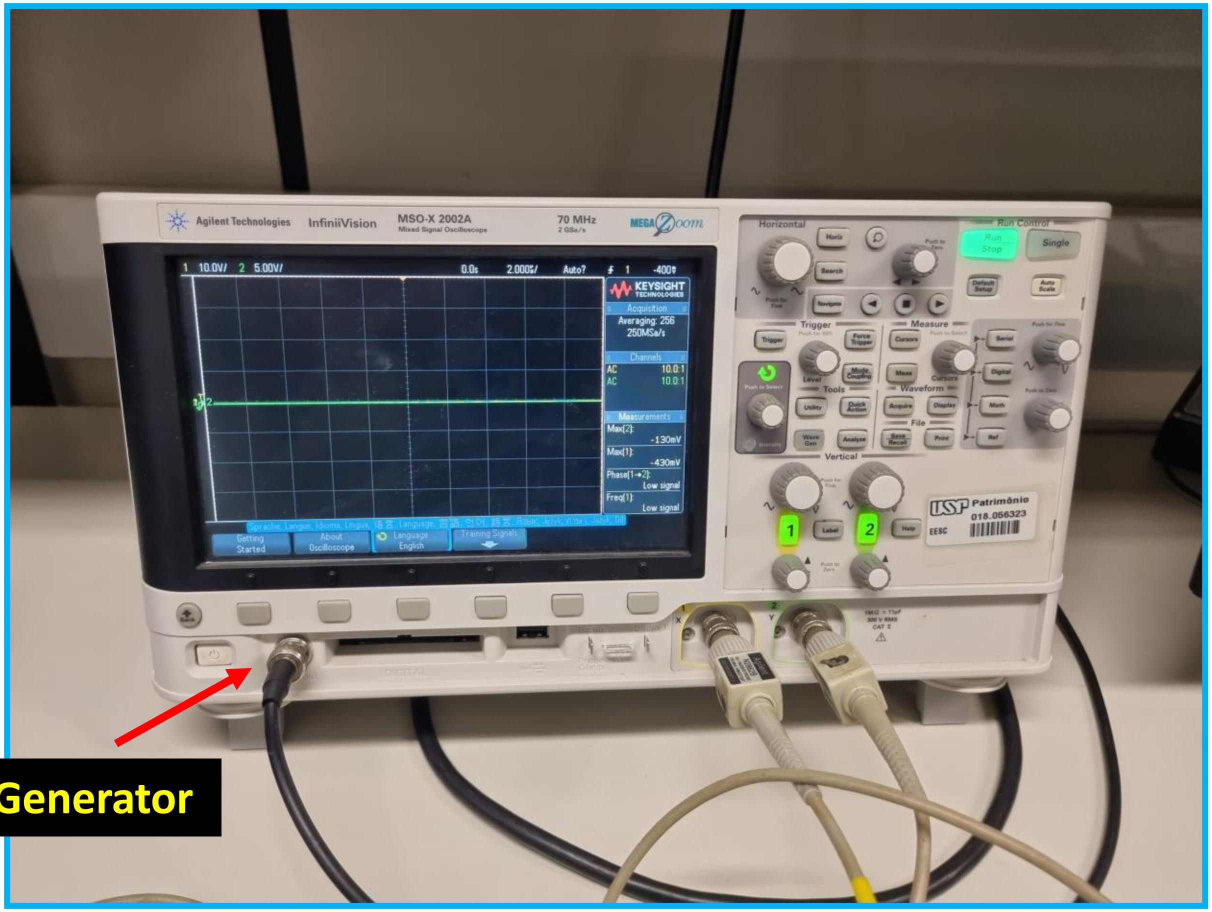


Fig. 2.6 – Connections Between the Function Generator and the ADC

O gerador de sinal de um osciloscópio digital utilizando tensões DC pode ser utilizado para avaliar o conversor AD.



Signal Generator

6. From the function generator, you can select the **DC Volts** feature and set the desired constant dc voltage as an analog signal to the ADC.

7. Calculate the voltage resolution, **Q** (Volt/Step) of the ADC if it is a single-ended operation with the **Vref = 5 V** and it is an **8-bit** ADC.

8. Press the push button, **PB2** on the D-Type Flip-Flops/Latches in order to latch the digital signal and output it to the LEDs.

9. Observe and record the display of LEDs in **Erro! Fonte de referência não encontrada.**1. This is the converted digital signal.

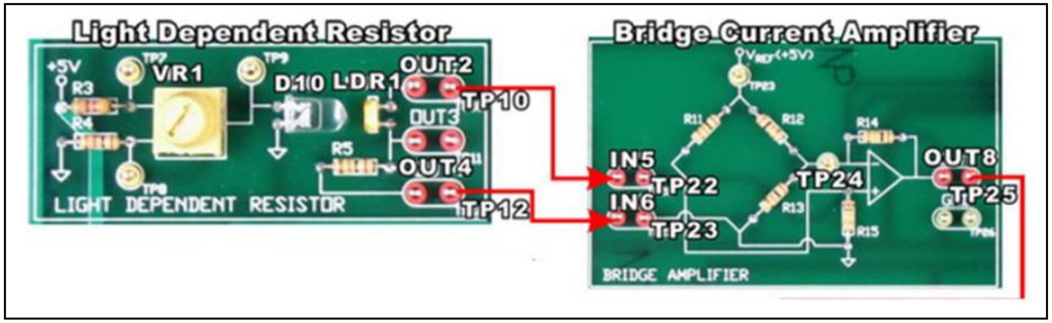
10. Complete **Erro! Fonte de referência não encontrada.**.

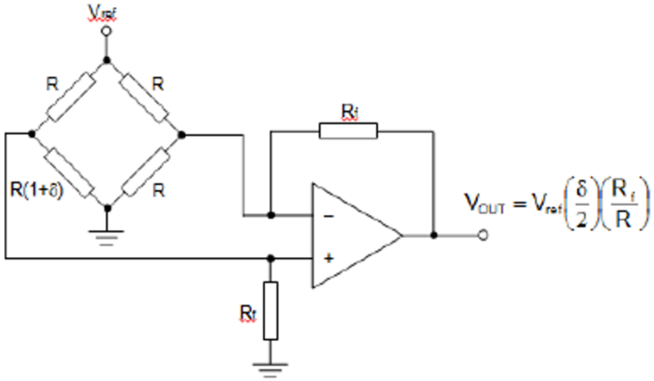
Table 2.1 – **Results of Measurements**

M^{th} Step	Converted Voltage, V_{ADC} (V) (Voltage Resolution × M^{th} Step)	Converted Voltage, V_{ADC} (V) measured In the output of the Function Generator (V)	Displayed Digital Signal on LEDs							
			D7	D6	D5	D4	D3	D2	D1	D0
0	0	0	0	0	0	0	0	0	0	0
1	0.0196		0	0	0	0	0	0	0	1
2	0,0392									
3	0.0588									
4	0.0784									
5	0.0980									
6	0.1176									
7	0,1372									
8	0.1568									
9	0,1764									
10	0.1960									
11	0.2156									
12	0.2352									
13	0.2548									
14	0.2744									
15	0.2940									
16	0.3136									
32	0.6272									
64	1.2544									
128	2.5098									
255	4.9980									

On (High) = 1   Off (Low) = 0

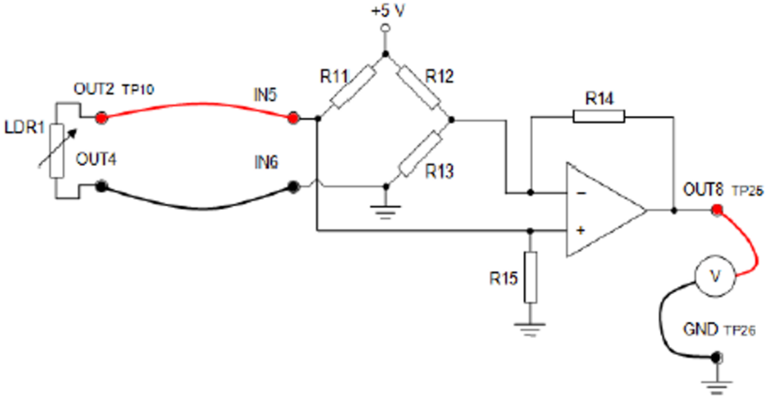
Light Sensor





$$V_{OUT} = V_{ref}\left(\frac{\delta}{2}\right)\left(\frac{R_f}{R}\right)$$

Fig. 2.8 – Wheatstone Bridge Amplifier



$$\boxed{V_{out} = V_{ref}\left(\frac{\delta}{2}\right)\left(\frac{R_f}{R}\right)}$$

$R = R_{11} = R_{12} = R_{13} = 10\text{k}\Omega$

$R_f = R_{14} = 100\text{k}\Omega$

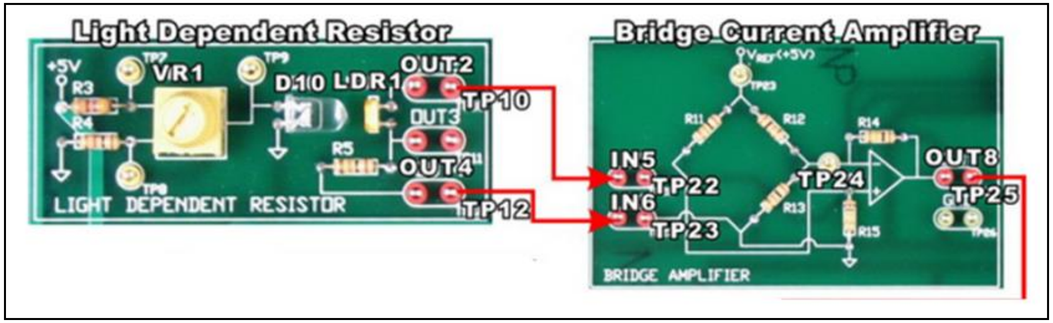
$R_5 = 10\text{k}\Omega$

$V_{ref} = 5\text{V}$

O ramo da ponte onde está o sensor tem uma resistência R(1+ δ). Um resistor R_5 = 10kΩ está em série com o LDR e deve ser considerado no cálculo de δ:

$$R_5 + R_{LDR} = R(1+\delta)$$

$$\rightarrow \boxed{\delta = \frac{R_{LDR}}{R}}$$



1 Slowly adjust the potentiometer **(VR1)** knob in the counter-clockwise direction until the voltage reading at test point **OUT8 (TP25)** increases to 0.5 V.

OBS: Os valores medidos nos kits são: 0.49 V, 0.5 V, 0,91 V, 0.44 V, 0.55 V, 0.491 V, 1 V, 0.64 V. (tolerância dos componentes utilizados na ponte de Wheatstone)

2 Remove both wire connections from test point **OUT2 (TP10)** to test point **IN5 (TP22)** and test point **OUT4 (TP12)** to test point **IN6 (TP23)**.

3 Measure and record the resistance across the photo-resistor **(LDR1)**.

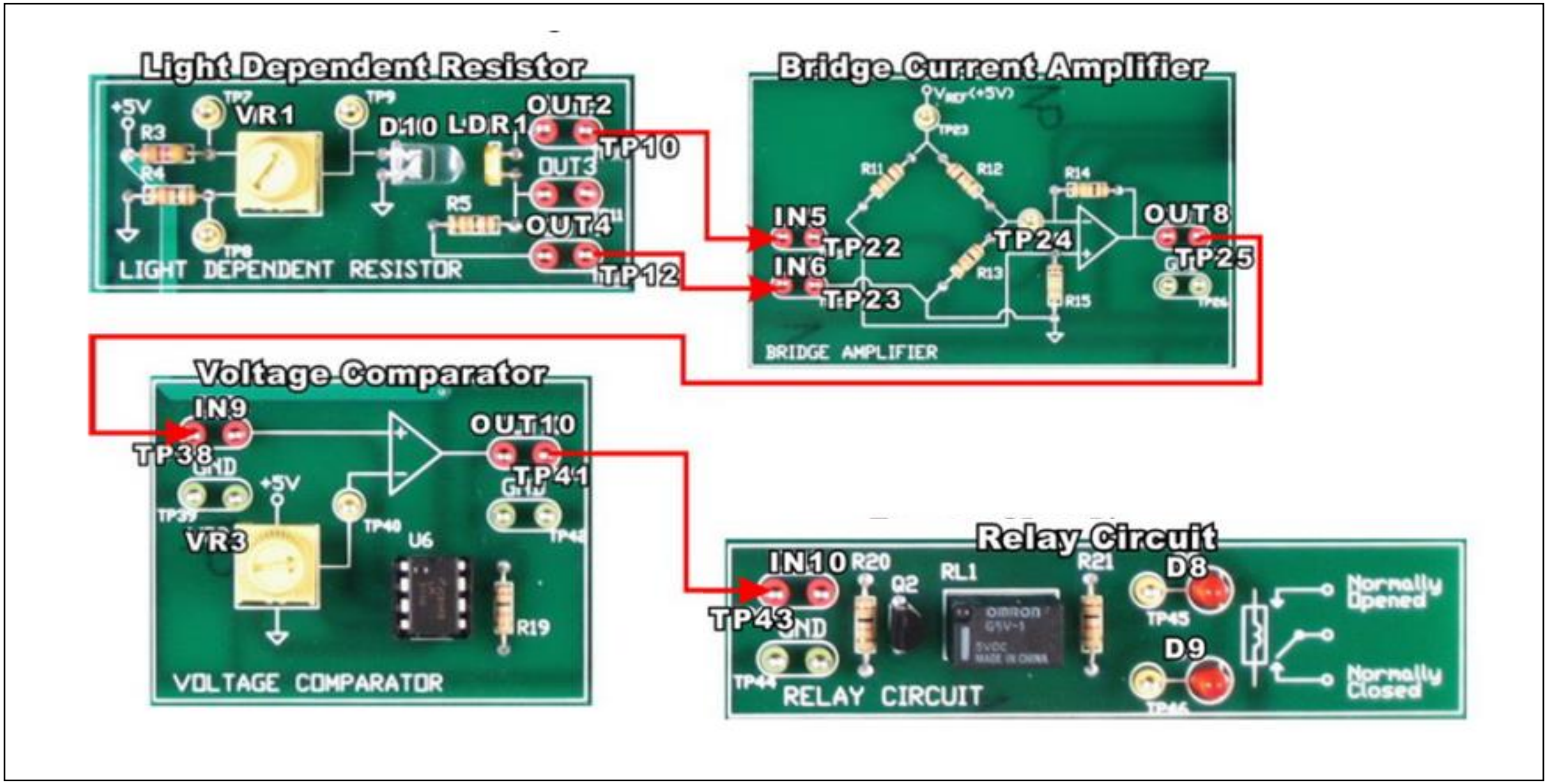
4 Calculate the output voltage (V_{OUT})

$$\boxed{\delta = \frac{R_{LDR}}{R}} \rightarrow \boxed{V_{out} = V_{ref}\left(\frac{\delta}{2}\right)\left(\frac{R_f}{R}\right)}$$

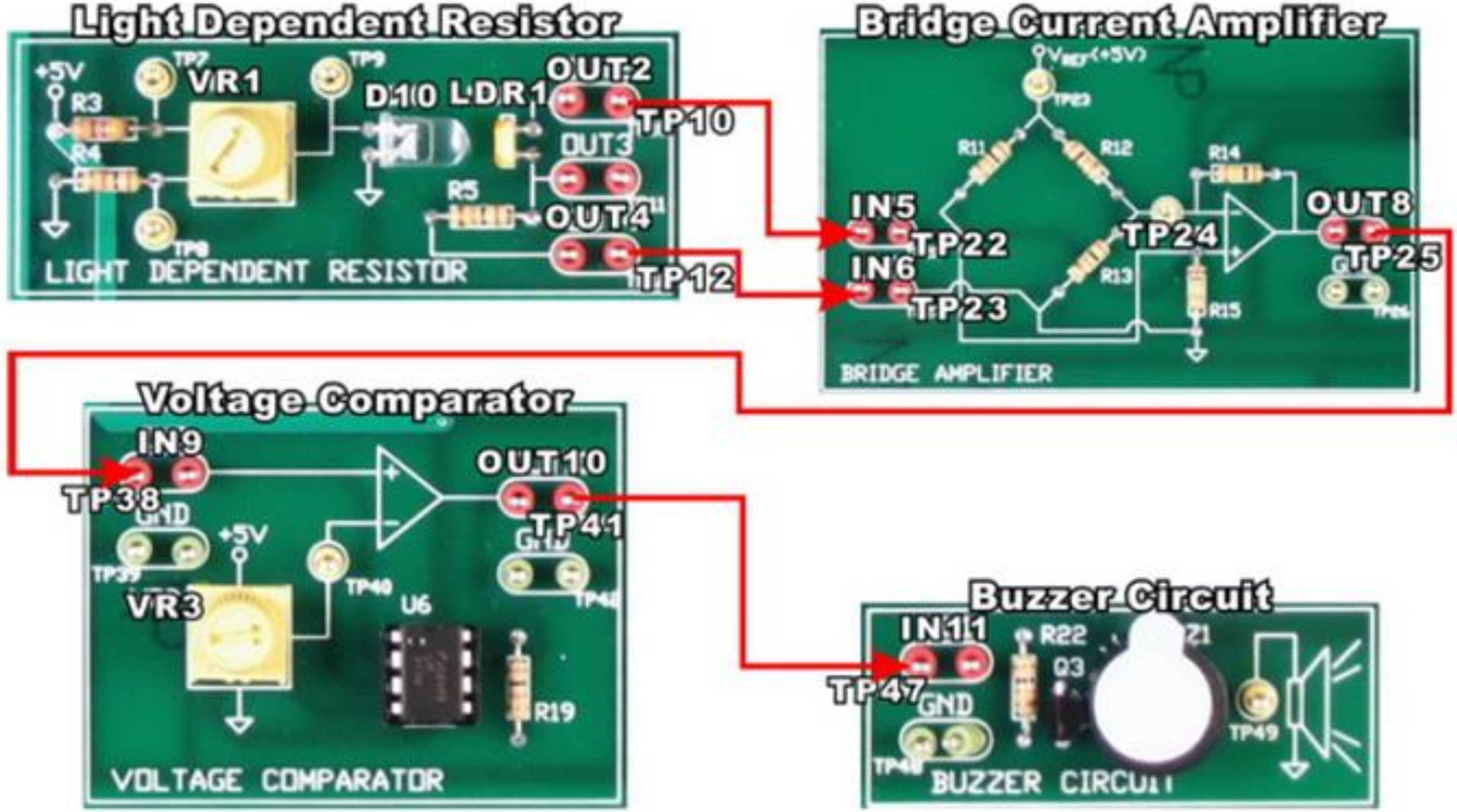
5 Compare the calculated output voltage V_{OUT} from the measured voltage reading in step 4.

6 Repeat the same procedures for **1.0 V**, **1.5 V**, **2.0 V**, **2.5 V**, and **3.0 V**.

Light Detection Circuit With a Relay Circuit



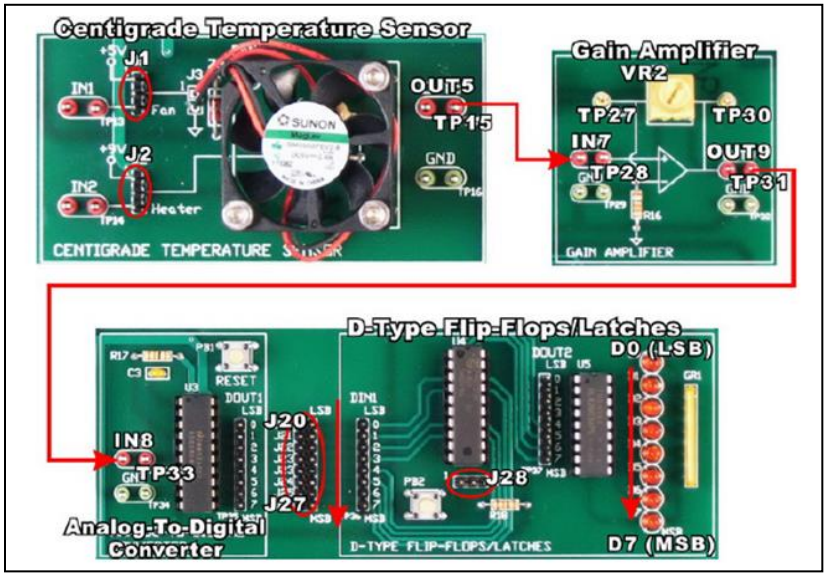
Light Detection Circuit with a Buzzer Circuit

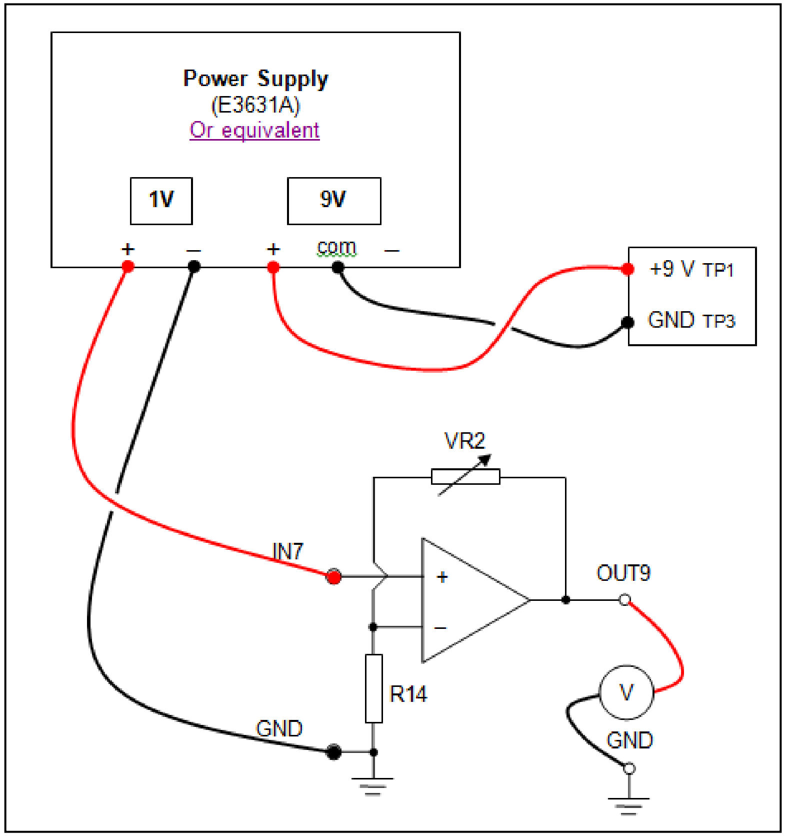


Temperature Sensor

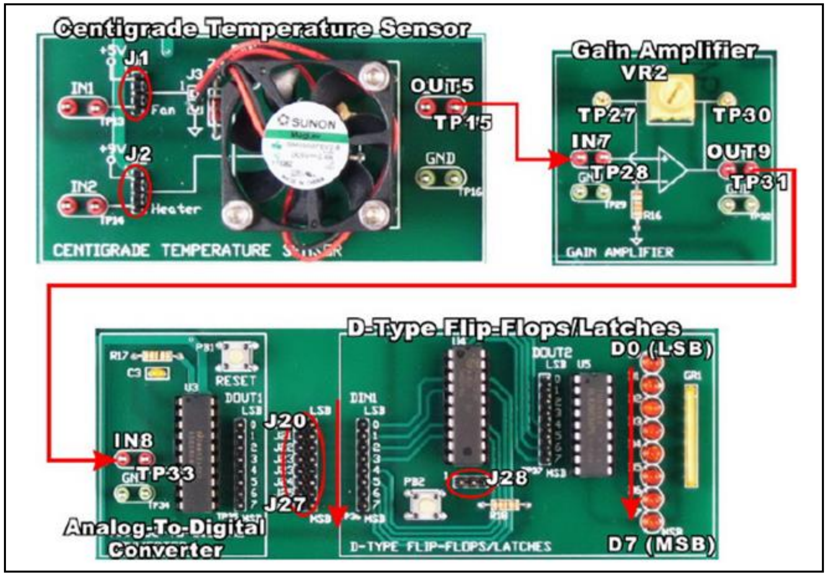
1

The temperature sensor **LM35** used in the ME3200 Electronic Instrumentation Kit has full-scale temperature sensitivity from **0** to **100° C** and a resolution of **10 mV per degree Celsius**. In other words, the analog output voltage ranges from **0** to **1 V** for temperatures between **0** and **100° C**.





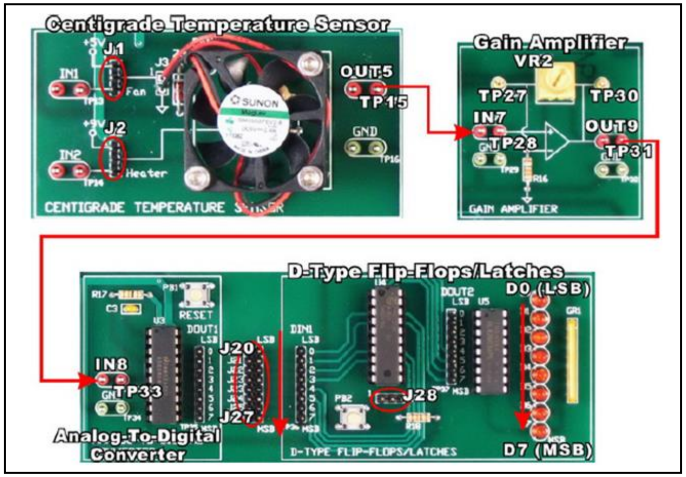
$$V_{out} = V_{in}\left(1 + \frac{V_{R2}}{R_{14}}\right)$$



2 Connect the **+1V** terminal of the power supply output to test points **IN7 (TP28).**

Adjust the potentiometer **(VR2)** knob to the fully clockwise position so that **VR2** becomes **0 Ω**, and hence, the gain factor of the amplifier becomes unity.

3 Slowly adjust the potentiometer **(VR2)** knob in counter-clockwise direction until the voltage reading at test point **OUT9 (TP31)** becomes **5 V**.



4 A máxima tensão de saída do amplificador é 5V (ou 11111111 em formato binário que corresponde à 256) o que corresponde a uma temperatura de $100^{o}C$. Se um valor digital da tensão for lida, por exemplo 10000000 (ou 128), qual é a temperatura correspondente ?

A temperatura é calculada usando a linearidade entre a tensão de saída do amplificador medida analogicamente ou digitalmente:

$5V \rightarrow 100^{o}C$
$V_{medida} \rightarrow T$

$256 \rightarrow 100^{o}C$
Valor digital da tensão medida → T

A temperatura também pode ser calculada pela divisão da tensão na entrada do amplificador pela sensibilidade do sensor. Exemplo, se $V_{medida} = 2{,}5V$, então

$$T = V_{entrada} / \text{sensibilidade} = (V_{medida}/5) / (10\ mV/^{o}C)$$

Temperature Alarme System