MEASUREMENTS AND SIGNAL CONDITIONING FOR POWER CONVERTERS

DESIGN OF SWITCH MODE CONVERTERS

DEZSO SERA (DES@ET.AAU.DK)

DEPARTMENT OF ENERGY TECHNOLOGY
AALBORG UNIVERSITY

OUTLINE

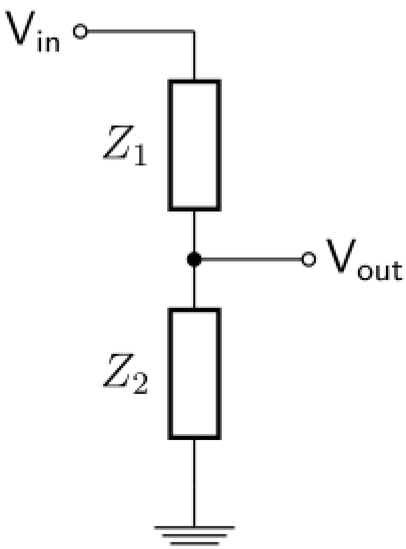
- VOLTAGE MEASUREMENT METHODS
- CURRENT MEASUREMENT METHODS
- GALVANIC ISOLATION
- PROTECTION
- ANALOGUE-TO-DIGITAL CONVERSION
- FILTERING (DIGITAL AND/OR ANALOGUE)

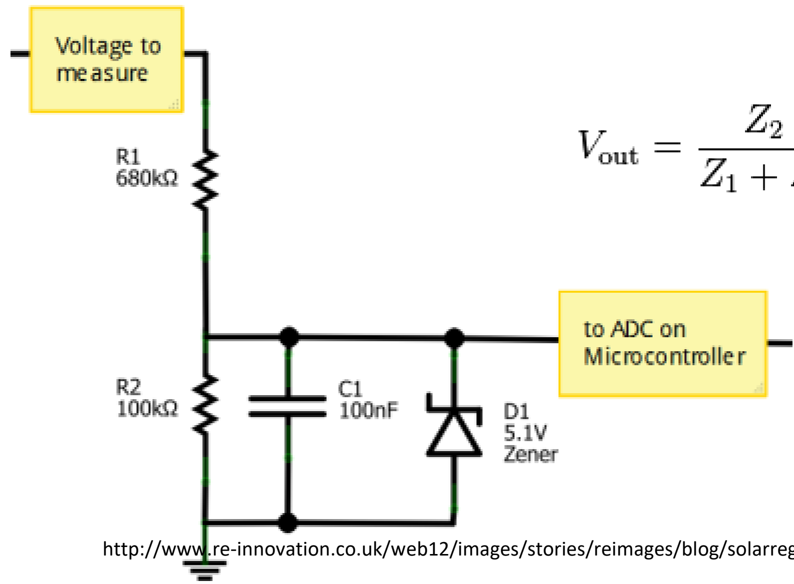
VOLTAGE MEASUREMENT

RESISTIVE VOLTAGE DIVIDER

- VOLTAGE IS A POTENTIAL DIFFERENCE BETWEEN TWO POINTS

- VOLTAGE DIVIDER:





$$V_{out} = \frac{Z_2}{Z_1 + Z_2} \cdot V_{in}$$

http://www.re-innovation.co.uk/web12/images/stories/reimages/blog/solarregulator/Voltage_divider.png

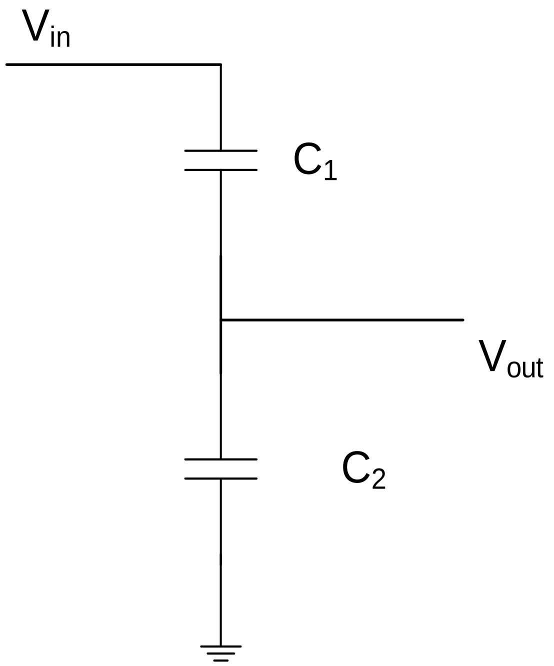
- ADVANTAGES:
  - Simple
  - Cheap
  - Both DC and AC

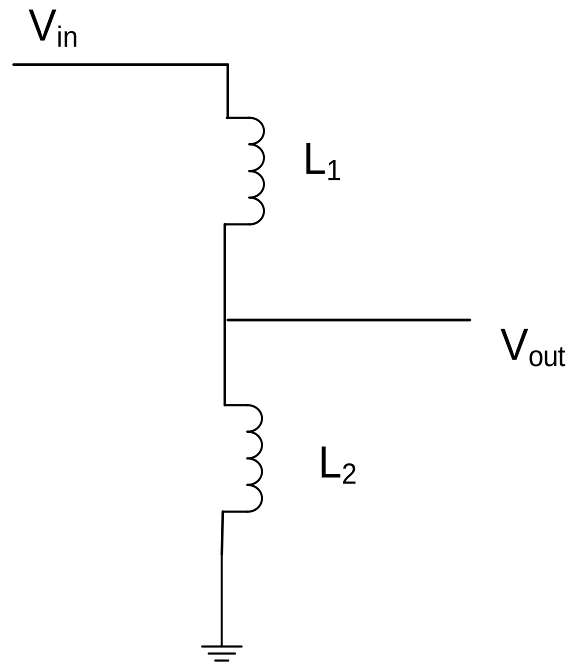
- DISADVANTAGES:
  - NO GALVANIC ISOLATION
  - RESISTOR VALUES CAN CHANGE WITH TEMPERATURE

VOLTAGE MEASUREMENT

CAPACITIVE AND INDUCTIVE VOLTAGE DIVIDER

- FOR AC ONLY



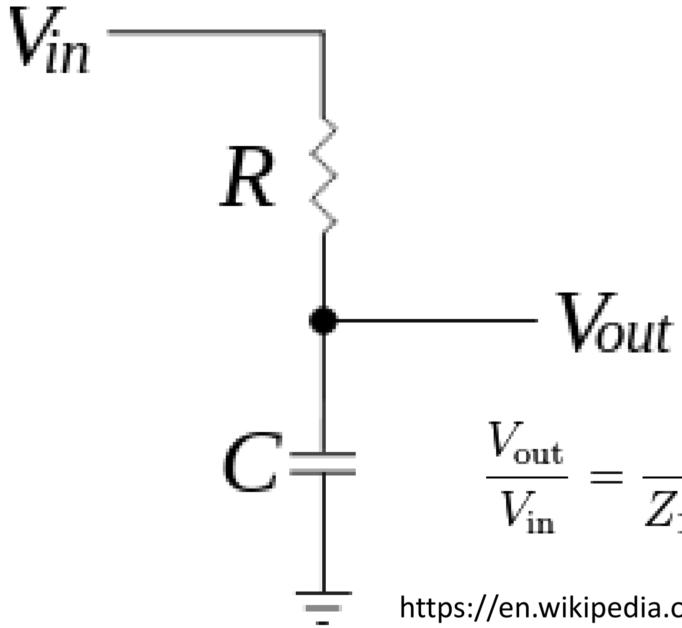


- $V_{out} = V_{in} \cdot \frac{C_1}{C_1+C_2}$ $\qquad V_{out} = V_{in} \cdot \frac{L_2}{L_1+L_2}$

VOLTAGE MEASUREMENT

VOLTAGE DIVIDER - RC

- LOW-PASS RC FILTER



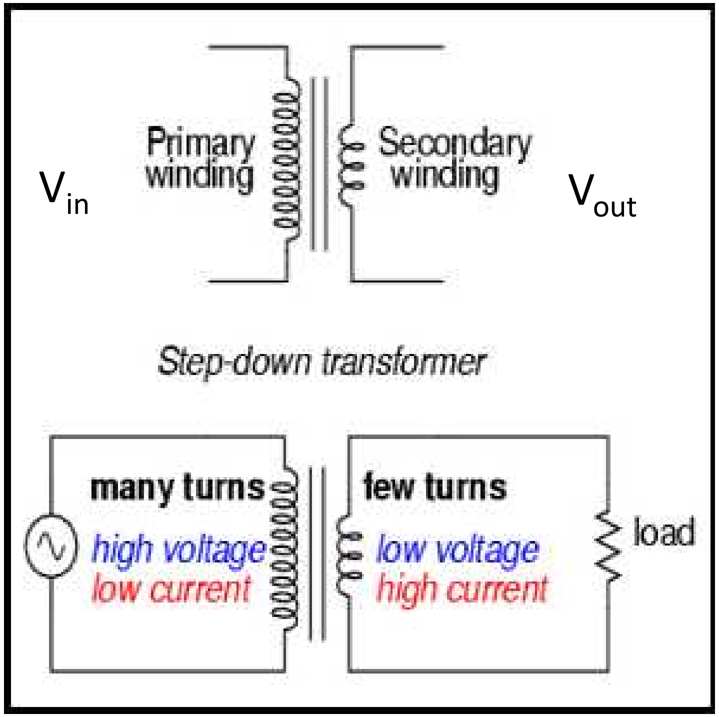
$$\frac{V_{\mathrm{out}}}{V_{\mathrm{in}}} = \frac{Z_2}{Z_1 + Z_2} = \frac{\frac{1}{\mathrm{j}\omega C}}{\frac{1}{\mathrm{j}\omega C} + R} = \frac{1}{1 + \mathrm{j}\omega RC} \; .$$

https://en.wikipedia.org/wiki/Voltage_divider

VOLTAGE MEASUREMENT

TRANSFORMER

- ❑ FOR AC ONLY



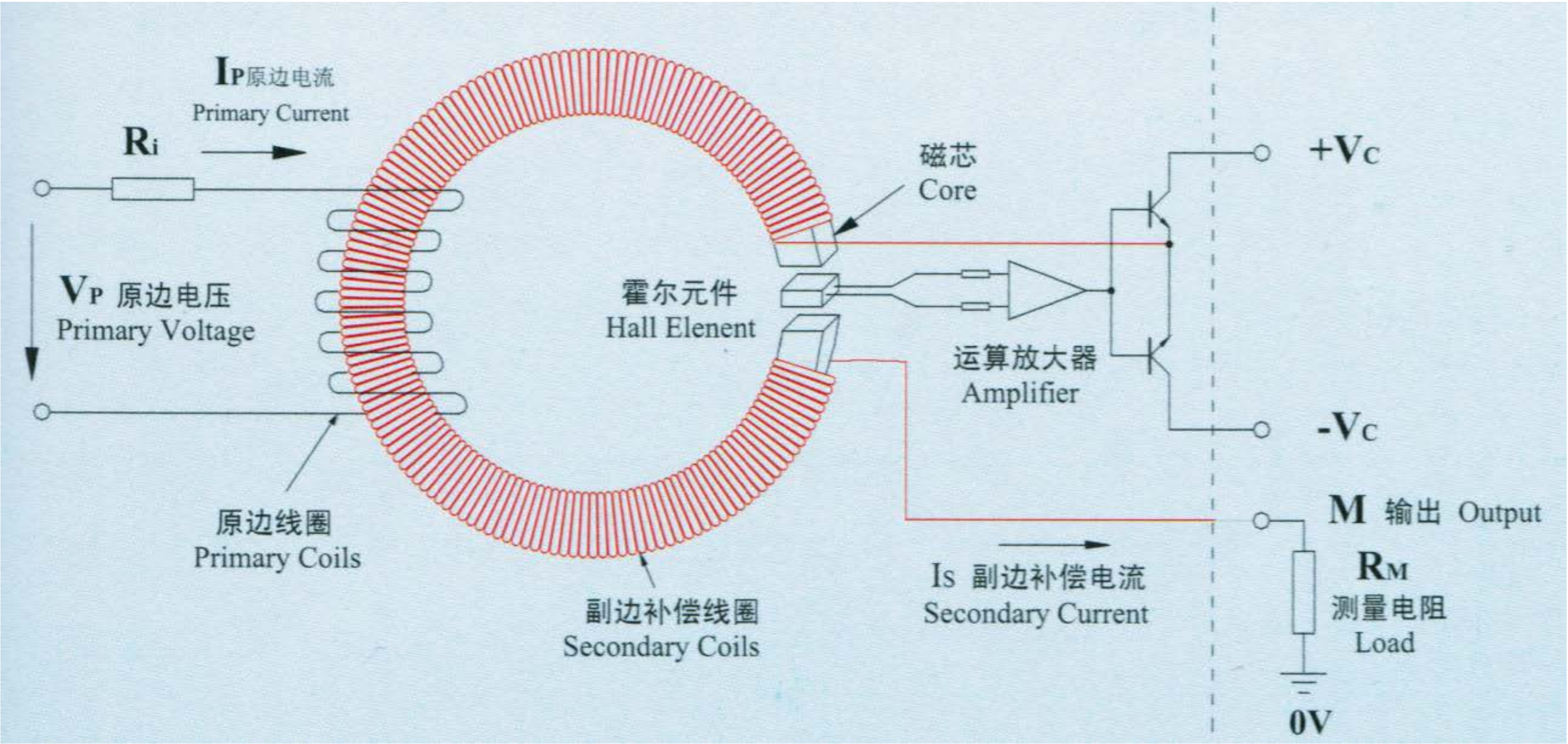
$$V_{out} = V_{in} \cdot \frac{N_2}{N_1}$$

❑ ADVANTAGES:
- SIMPLE
- GALVANIC ISOLATION

❑ DISADVANTAGES:
- TRANSFORMER NON-LINEARITIES
- LEAKAGE LOSSES
- MORE EXPENSIVE

VOLTAGE MEASUREMENT

HALL SENSOR



- ❑ SMALL CURRENT THROUGH PRIMARY BY MEASURED VOLTAGE
- ❑ BALANCING FLUX FROM SUPPLY CIRCUIT IN SECONDARY
- ❑ HALL DEVICE USED TO MEASURE FLUX - COMPENSATE

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- ❑ **CURRENT MEASUREMENT METHODS**
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- ❑ PROTECTION
- ❑ ANALOGUE-TO-DIGITAL CONVERSION
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CURRENT MEASUREMENT

MAIN TYPES

- ❑ TWO MAIN TYPES: DIRECT AND INDIRECT SENSING

- ❑ DIRECT SENSING IS BASED ON OHM'S LAW – SHUNT RESISTOR

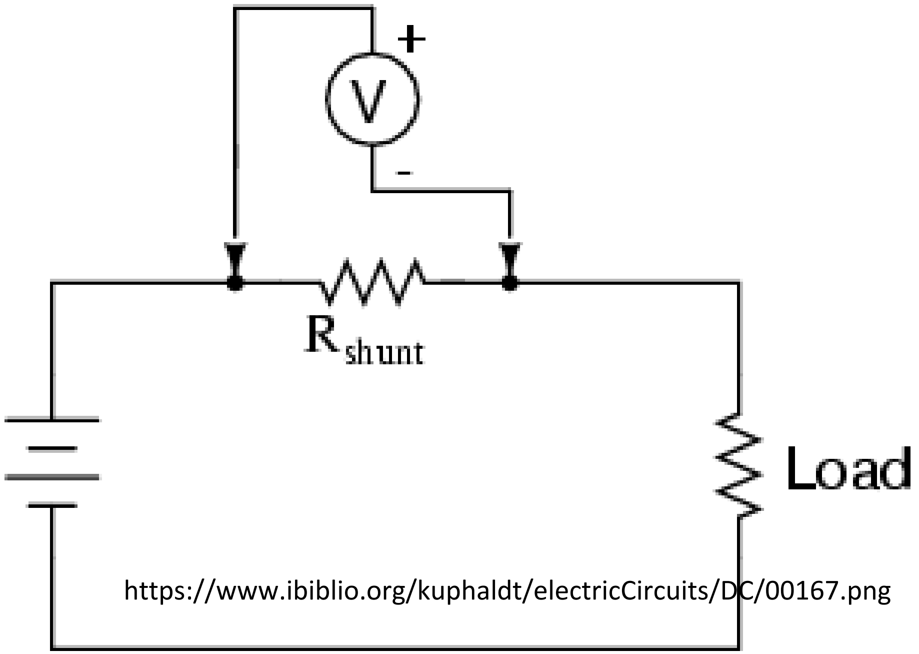
  Low R shunt → voltage drop is normally measured by differential amplifiers
  Invasive - the sensing circuit is part of the power circuit
  No galvanic isolation
  Usually for lower currents (<100A)
  Cost effective

- ❑ INDIRECT SENSING IS BASED ON AMPER'S AND FARADAY'S LAW

  Non-invasive – measures the field created by electric current
  Galvanic isolated
  Typically higher currents
  Typically more expensive sensors

CURRENT MEASUREMENT

SHUNT RESISTOR



https://www.ibiblio.org/kuphaldt/electricCircuits/DC/00167.png

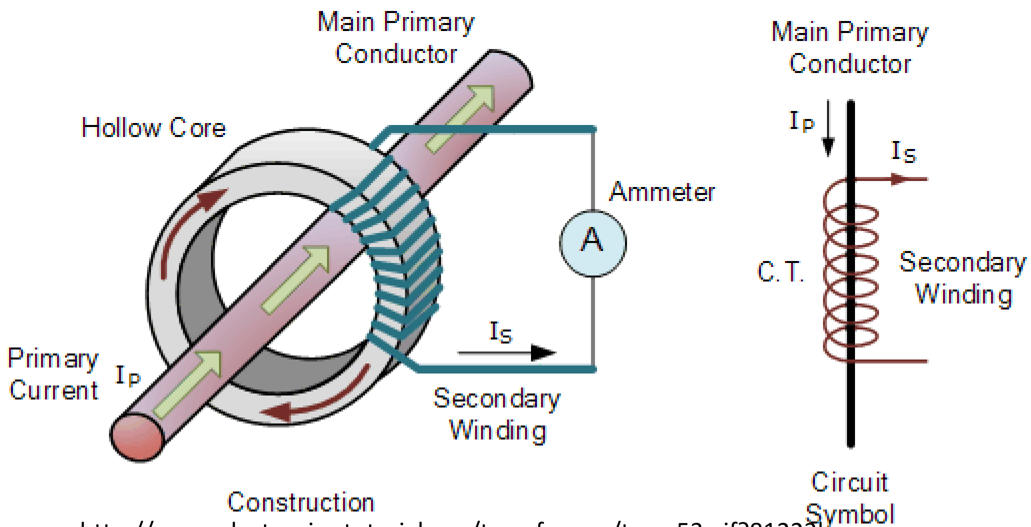
- ADVANTAGES:
  - Simple
  - Linear – Vout=I*R
  - Low-cost

- DISADVANTAGES:
  - NO GALVANIC ISOLATION
  - LOSSES ON R

CURRENT MEASUREMENT

CURRENT TRANSFORMER

- ❑ AC ONLY



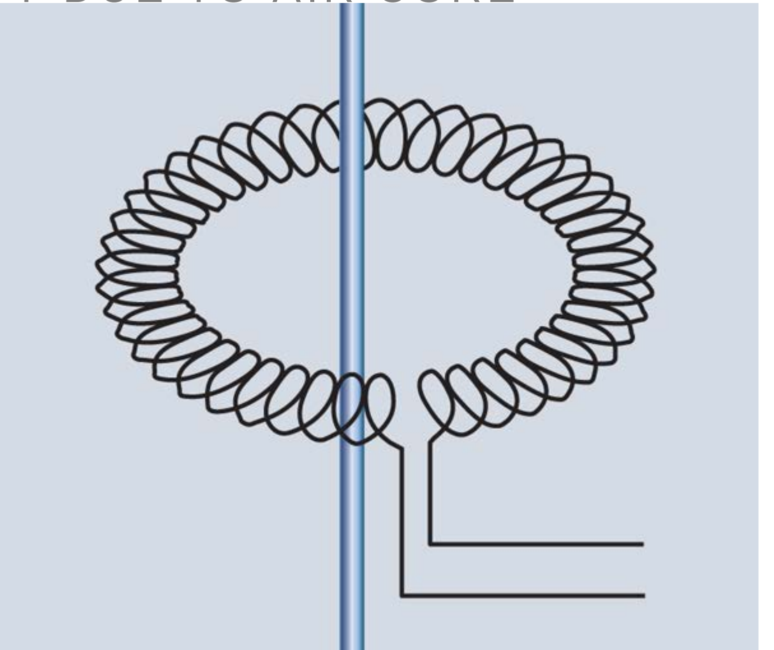
http://www.electronics-tutorials.ws/transformer/trans53.gif?81223b

- ❑ CAN MEASURE VERY HIGH CURRENTS
- ❑ GALVANIC ISOLATION
- ❑ SECONDARY SIDE CURRENT CAN BE TRANSFORMED TO V BY E.G. SHUNT

CURRENT MEASUREMENT

CURRENT TRANSFORMER – ROGOWSKI COIL

- SPECIAL DESIGNED WITH AIR CORE – LOWER INDUCTANCE AND FASTER RESPONSE
- VERY GOOD LINEARITY DUE TO AIR CORE

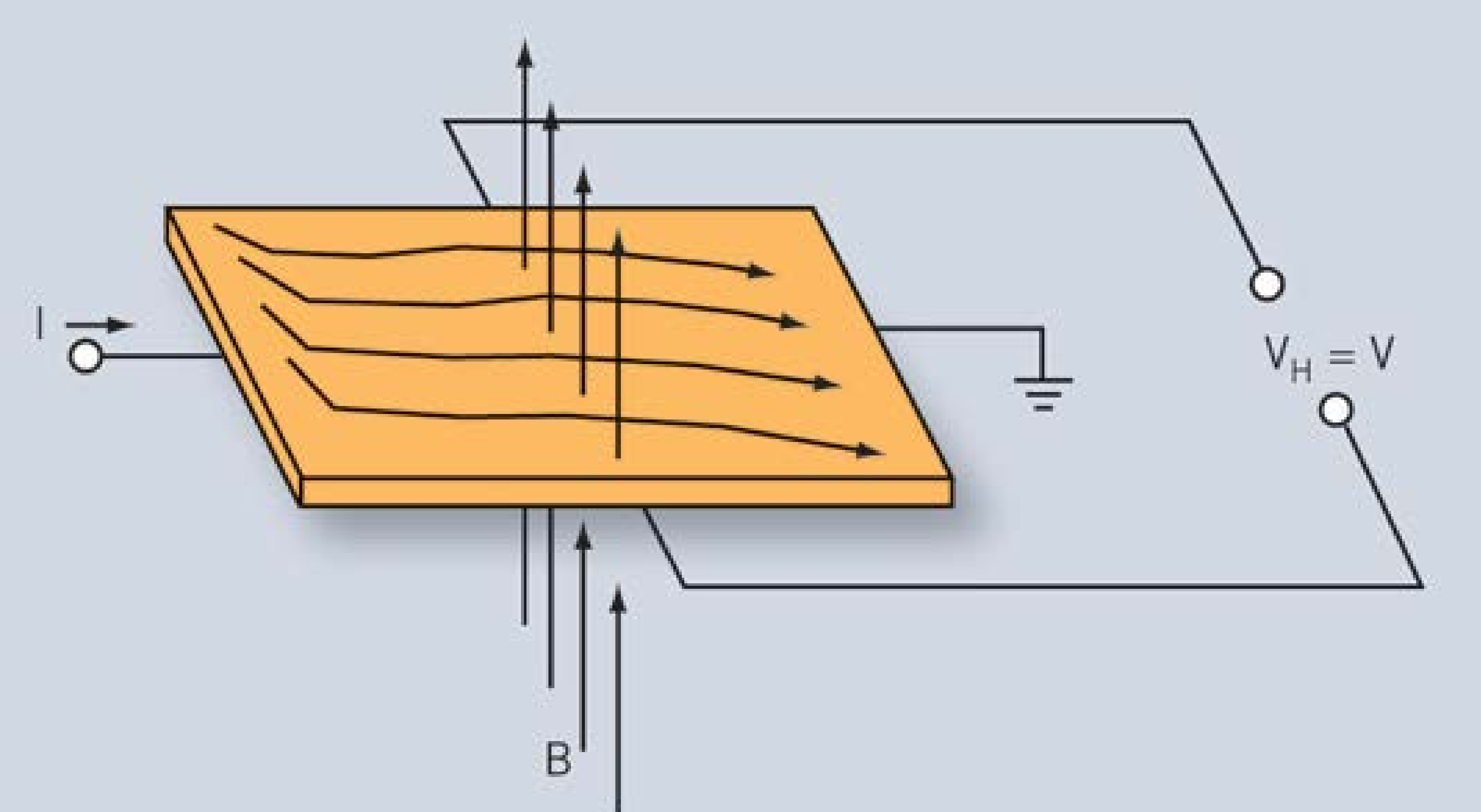


http://powerelectronics.com/power_conversion_system_design/circuit_analysis/current-measurements-fig2.jpg

- TYPICALLY USED FOR MEASURING IN HIGH BANDWIDTH APPLICATIONS >1MHZ, OR FAST TRANSIENT CURRENTS

CURRENT MEASUREMENT

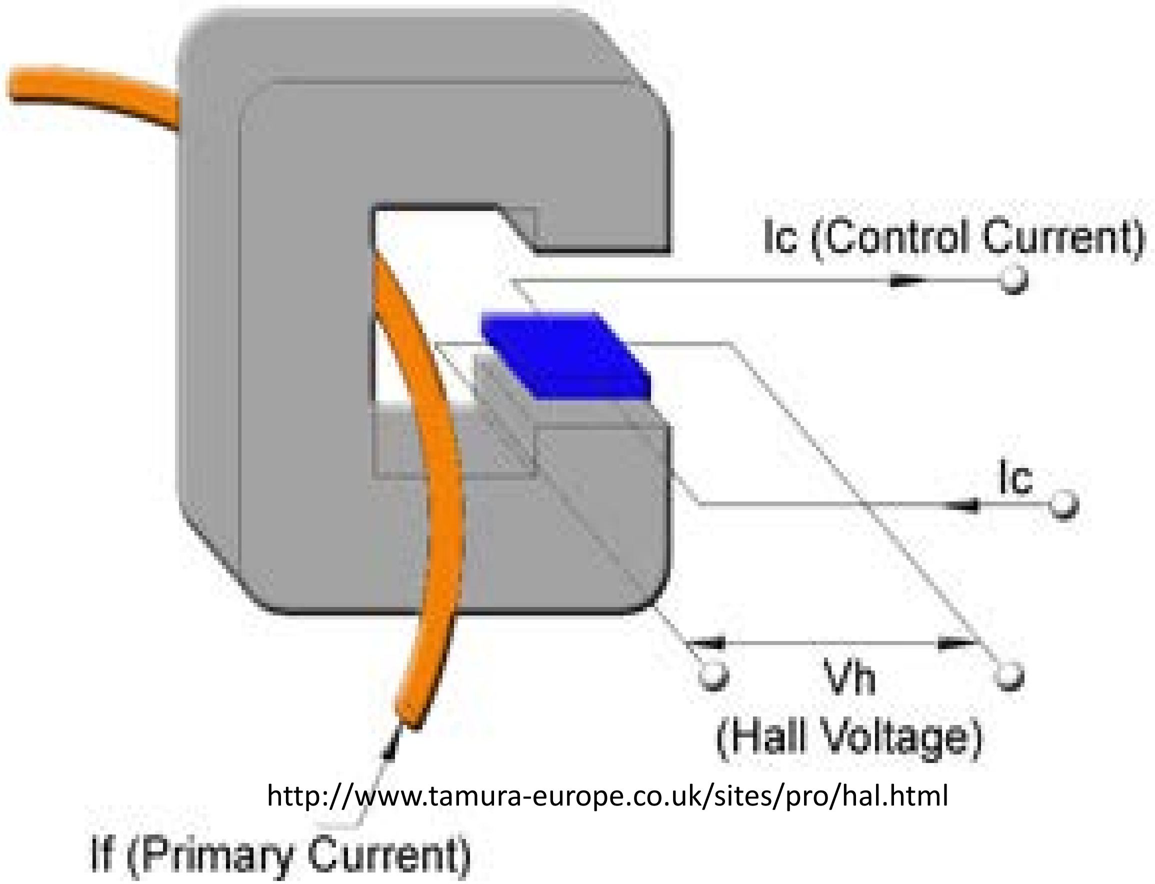
HALL-EFFECT SENSOR - PRINCIPLE



http://powerelectronics.com/power_conversion_system_design/circuit_analysis/current-measurements-fig3.jpg

CURRENT MEASUREMENT

OPEN-LOOP HALL-EFFECT SENSOR

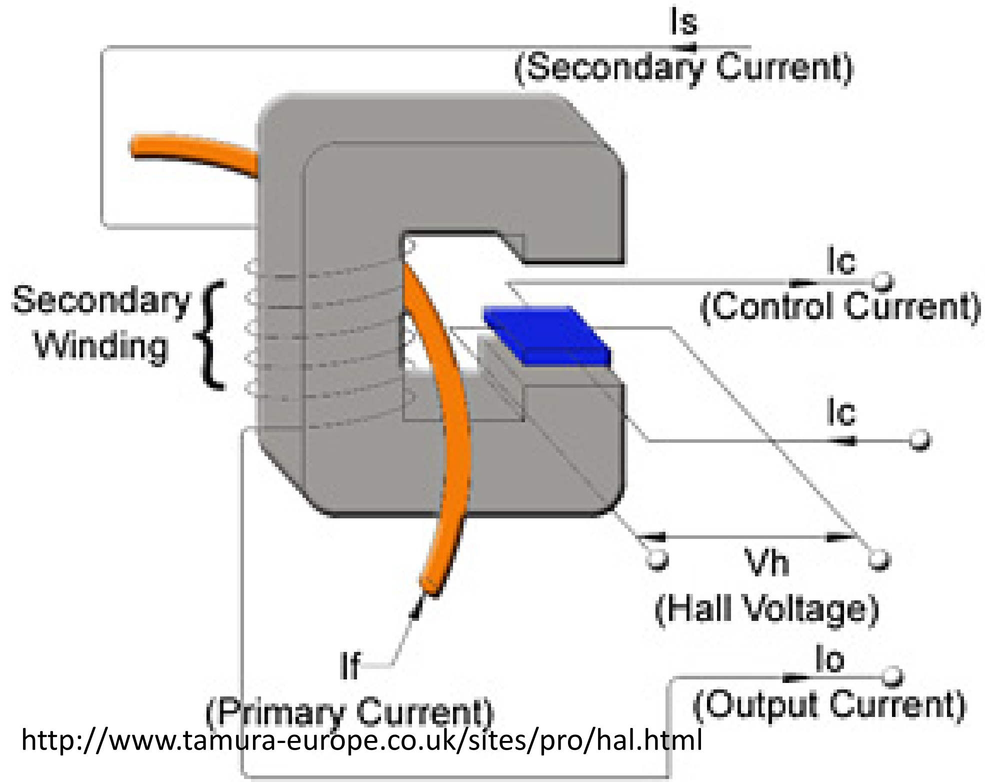


http://www.tamura-europe.co.uk/sites/pro/hal.html

CURRENT MEASUREMENT

CLOSED-LOOP HALL-EFFECT SENSOR

- ❑ ALSO CALLED COMPENSATED, OR ZERO-FLUX



http://www.tamura-europe.co.uk/sites/pro/hal.html

❑ COMPARED TO OPEN-LOOP VERSION:

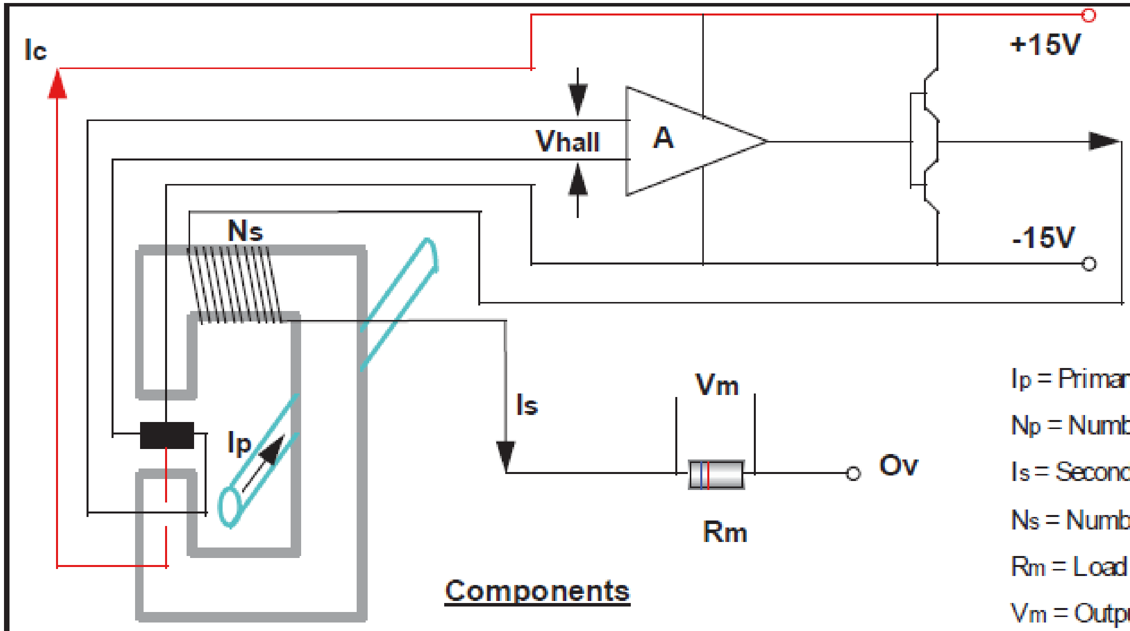
- Higher accuracy, no nonlinearity of Hall sensor
- Higher noise immunity
- No saturation, No temperature drift

❑ MORE EXPENSIVE

CURRENT MEASUREMENT

CLOSED-LOOP HALL-EFFECT SENSOR

❑ IMPLEMENTATION EXAMPLE



Fundamental Equation

Ip • Np = Is • Ns

Ip = Primary Current being Measured

Np = Number of Turns in Primary (usually equal to 1)

Is = Secondary Current (Output)

Ns = Number of Turns in Secondary Coil (1k-5k)

Rm = Load or Measuring Resistor

Vm = Output Voltage

Vhall = Error Signal Produced by Hall sensor

Components

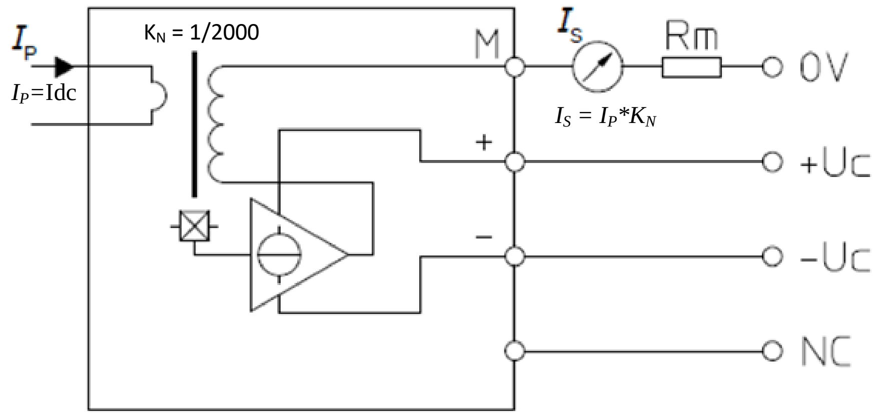
- **Laminated Steel Core**
- **Coil with Ns turns**
- **InSb Hall Effect IC**
- **Compensation Electronics**

Source: honeywell

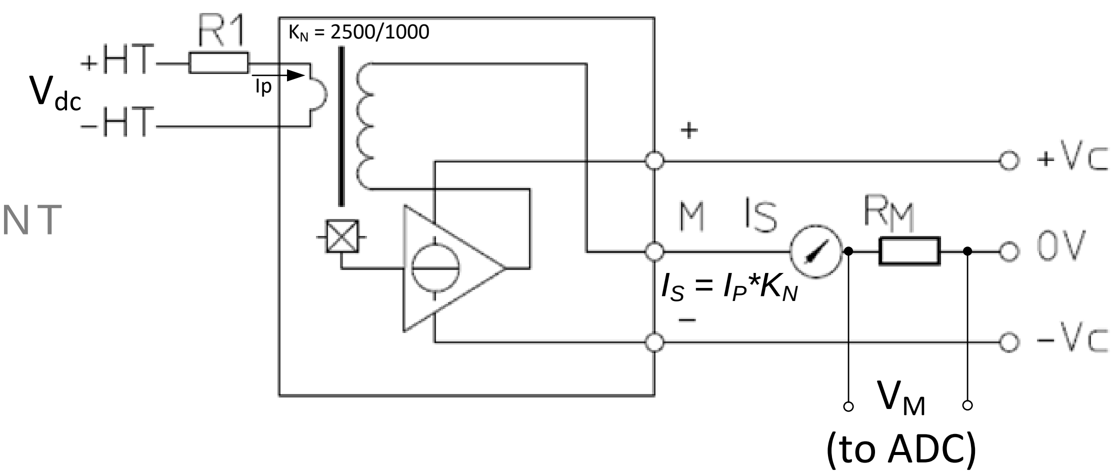
CURRENT MEASUREMENT

CLOSED-LOOP HALL-EFFECT SENSOR

- ❑ CURRENT MEASUREMENT



- ❑ VOLTAGE MEASUREMENT



Source: LEM

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GALVANIC ISOLATION

BLOCKS DC CURRENT FLOW BETWEEN THE ISOLATED CIRCUITS

- PURPOSE:

  To be able to pass signals between circuits with different ground potentials
  Safety - close ground loop through a person

- MAIN METHODS/PRINCIPLES:

  Transformer
  Opto-isolator
  Capacitor
  Hall effect

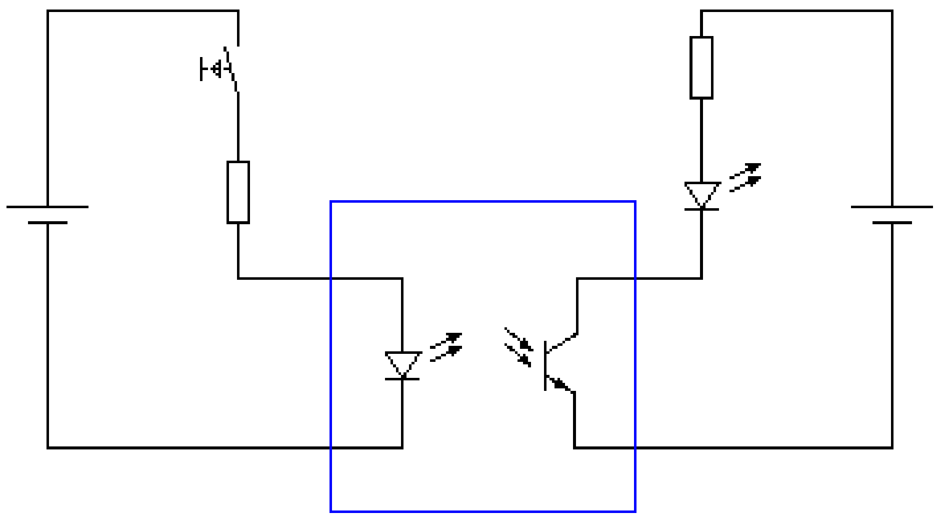
- CHARACTERISTICS

  Isolation impedance / leakage
  Blocking/isolation voltage
  Bandwidth

GALVANIC ISOLATION

OPTICAL ISOLATION - OPTO-COUPLER

- PRINCIPLE



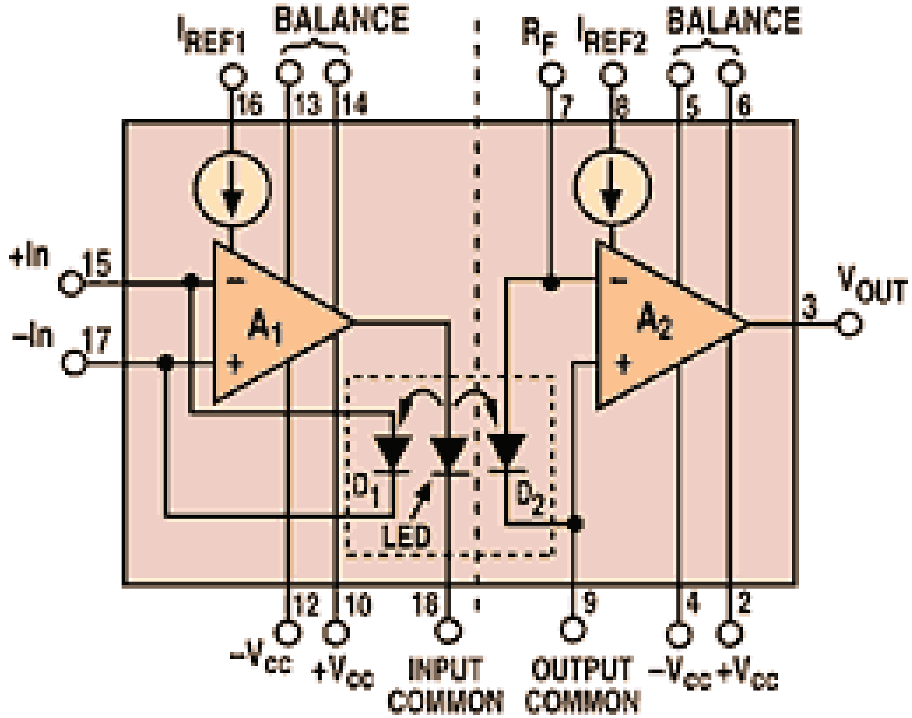
"Optokoppler" by Quark48 at the German language Wikipedia. Licensed under CC BY-SA 3.0 via Commons - https://commons.wikimedia.org/wiki/File:Optokoppler.gif#/media/File:Optokoppler.gif

- LED IS NON-LINEAR LIGHT SOURCE
- IN BASIC FORM IS ON/OFF (DIGITAL)
- OPTO-COUPLERS HAVE GENERALLY GOOD NOISE IMMUNITY

GALVANIC ISOLATION

OPTICAL ISOLATION

- IMPLEMENTATIONS – SIGNAL PASSED IN ANALOGUE FORM



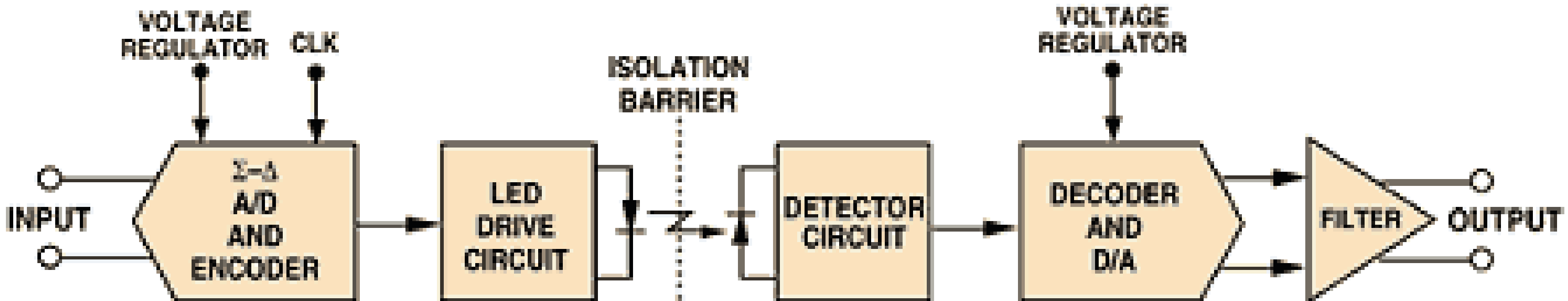
http://archives.sensorsmag.com/articles/0199/iso0199/iso0199_fig4.gif

- MATCHED PHOTODIODES

GALVANIC ISOLATION

OPTICAL ISOLATION

- IMPLEMENTATIONS – SIGNAL PASSED IN DIGITAL FORM



http://archives.sensorsmag.com/articles/0199/iso0199/iso0199_fig5.gif

- AVOIDS THE SECOND PHOTO-DIODE BUT ADDS TO THE COMPLEXITY

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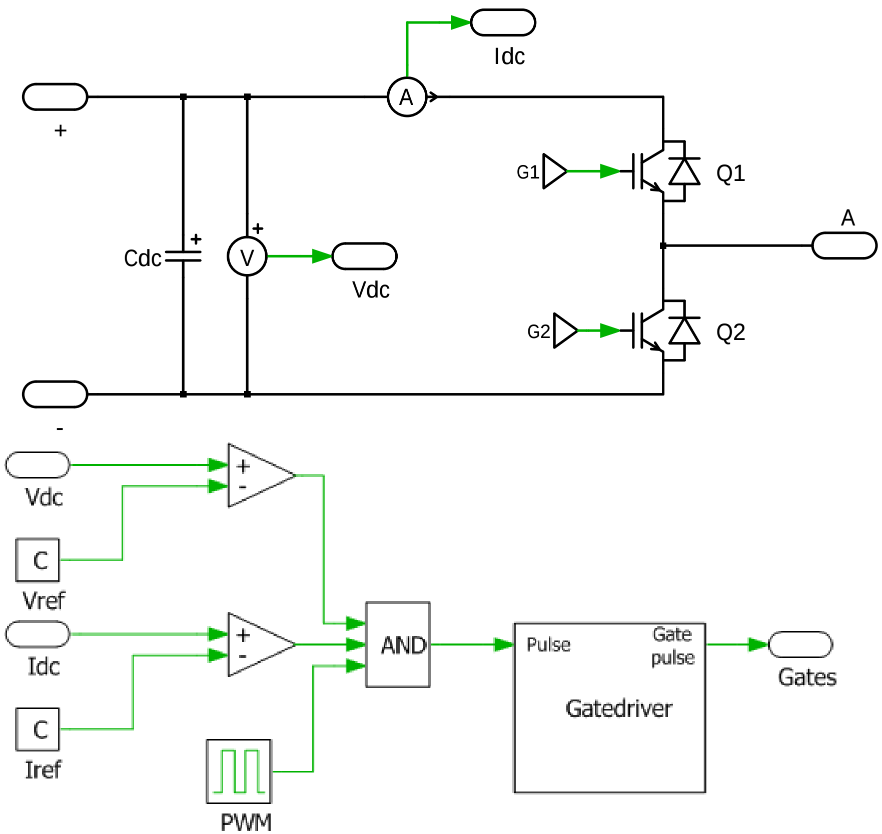
PROTECTION

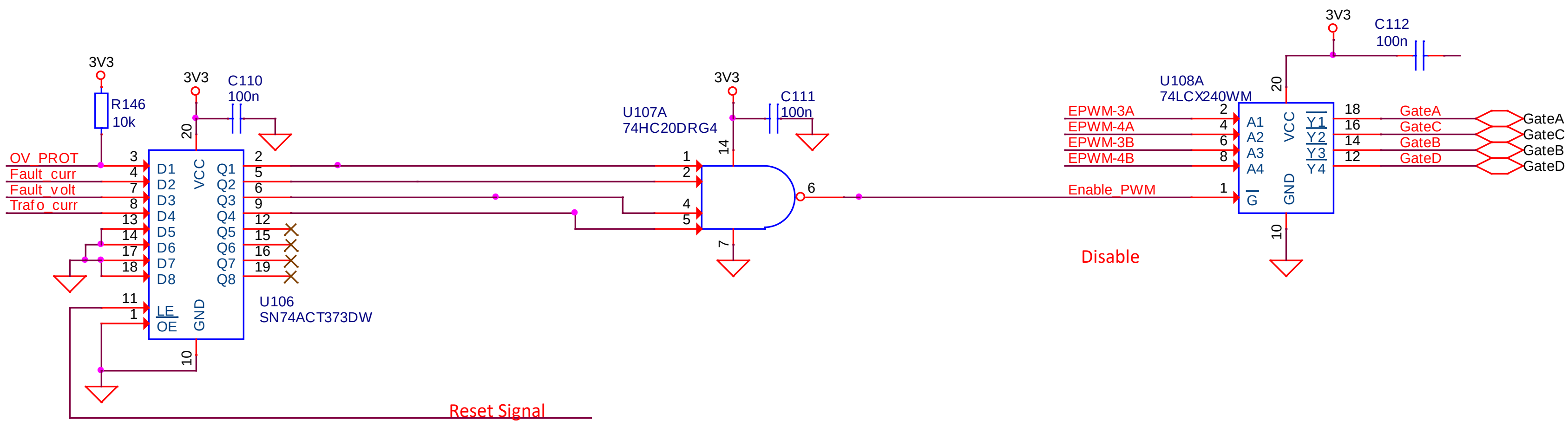
- Over voltage protection
- Over current protection



- What if it happens only once?

- What if it happens periodically?

LATCH AND BUFFER



- U106: **Latch** - x fault event makes Qx=1
- U107: NAND gate output = 1 (default 0)
- U108: **Buffer** – Disable = 1 -> gate pulses stopped
- Reset signal needed

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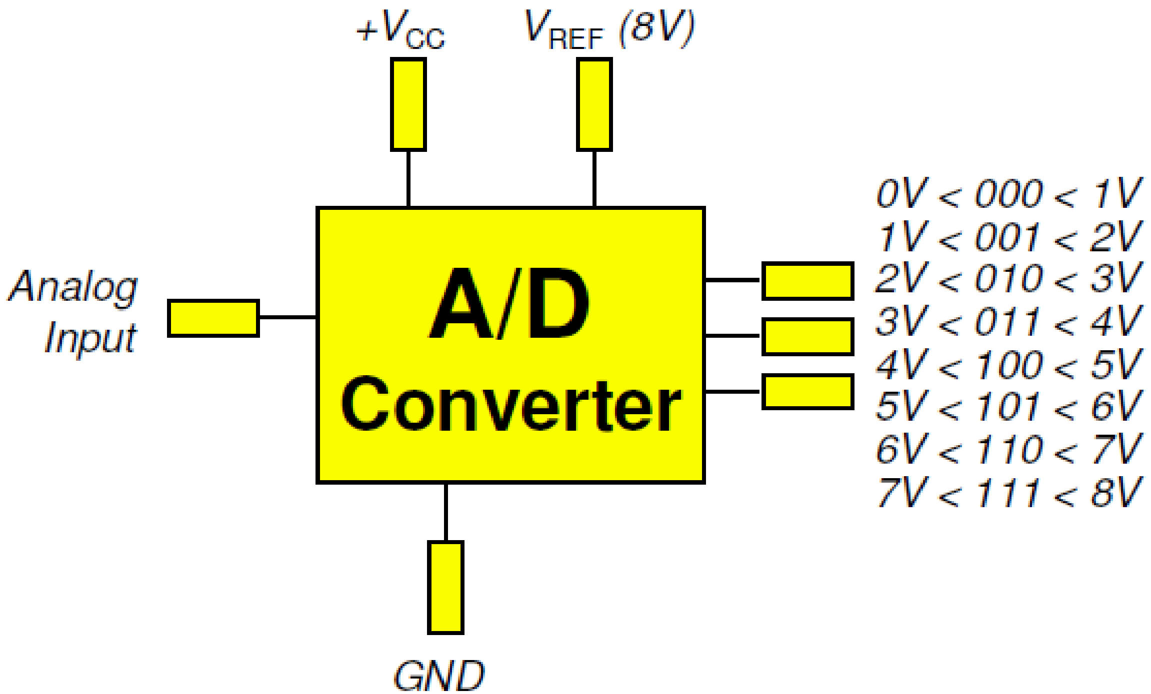
WHAT IS AN ADC

ANALOGUE-TO-DIGITAL CONVERTER

- CONVERTS AN ANALOGUE, CONTINUOUS SIGNAL AT ITS INPUT INTO A DIGITAL DISCRETE NUMBER AT ITS OUTPUT

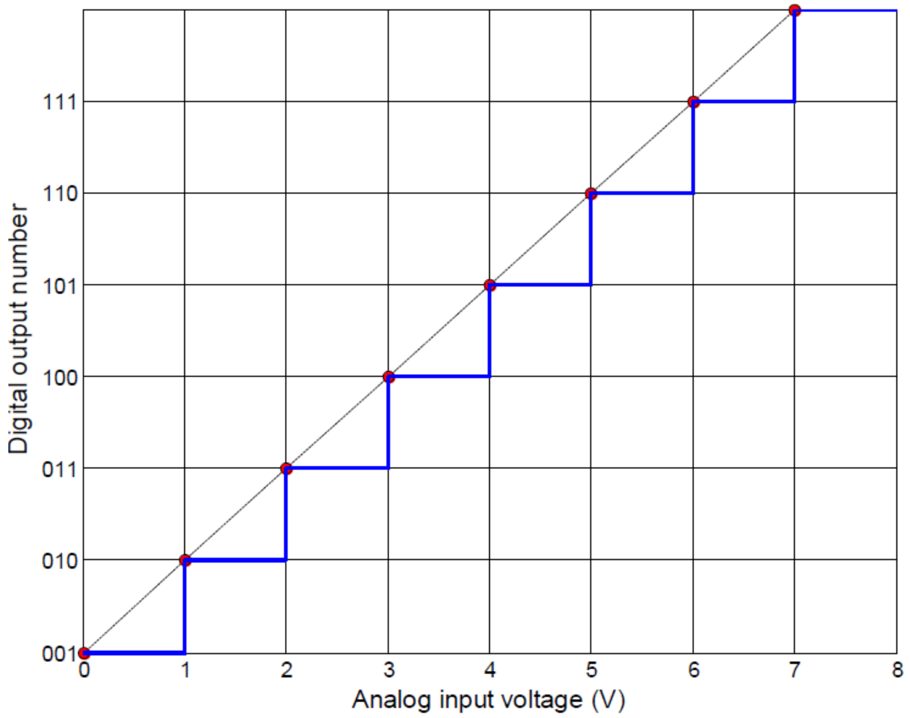
- FOR A 3-BIT ADC, THERE ARE 8 POSSIBLE OUTPUT CODES.



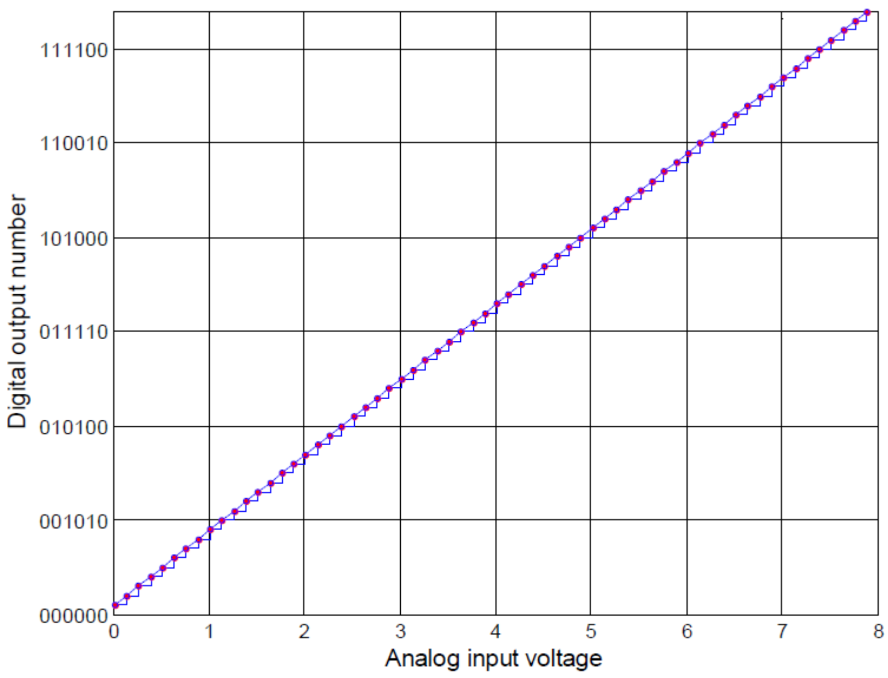
- IN THIS EXAMPLE, IF THE INPUT VOLTAGE IS 5.5V AND THE REFERENCE IS 8V, THEN THE OUTPUT WILL BE 101 (6V).

TRANSFER FUNCTION OF ADC AT DIFFERENT RESOLUTION

3-bit ADC



6-bit ADC



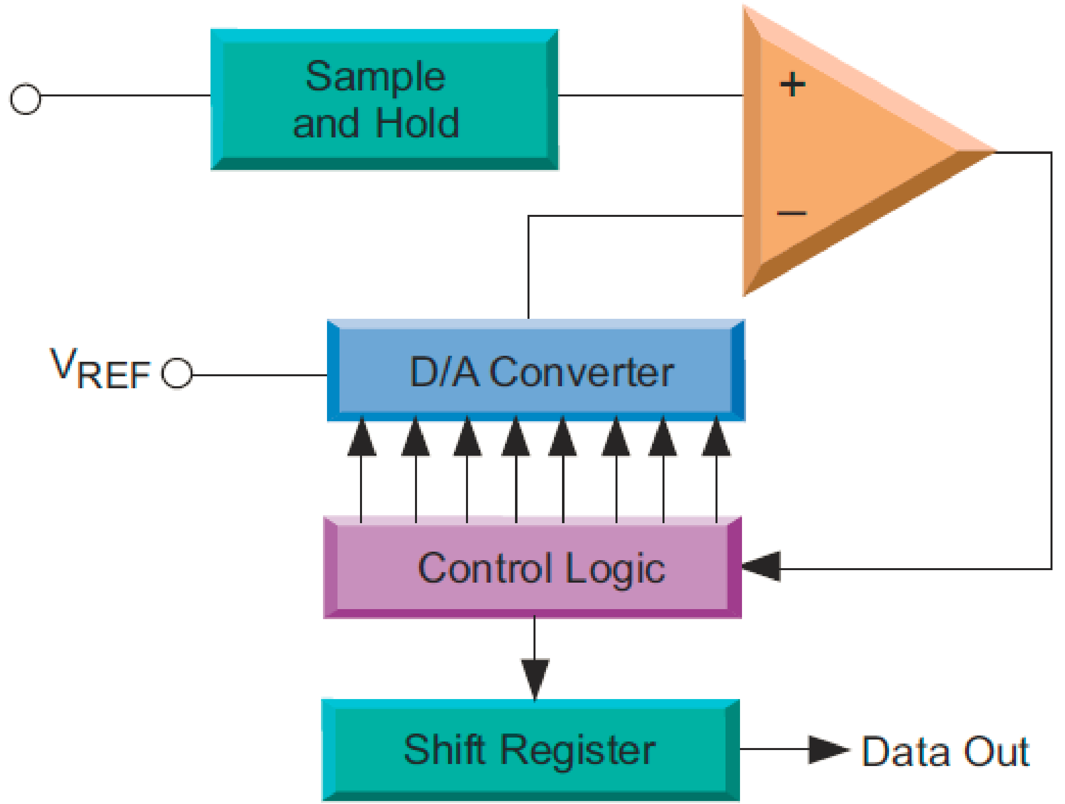
ADC RESOLUTION

- RESOLUTION: THE NUMBER OF DISCRETE VALUES IT CAN PRODUCE OVER THE RANGE OF ANALOGUE VALUES

- IT CAN BE GIVEN IN BITS: FOR EXAMPLE, A 12-BIT RESOLUTION ADC CAN PRODUCE 2^{12}= 4096 DISCRETE DIGITAL VALUES OF ITS FULL-SCALE ANALOGUE INPUT VOLTAGE

- IT CAN BE GIVEN IN VOLTS: FOR EXAMPLE, WITH A FULL-SCALE INPUT OF 0-3V, WILL HAVE A RESOLUTION OF 3/ 4096 =0.00073V

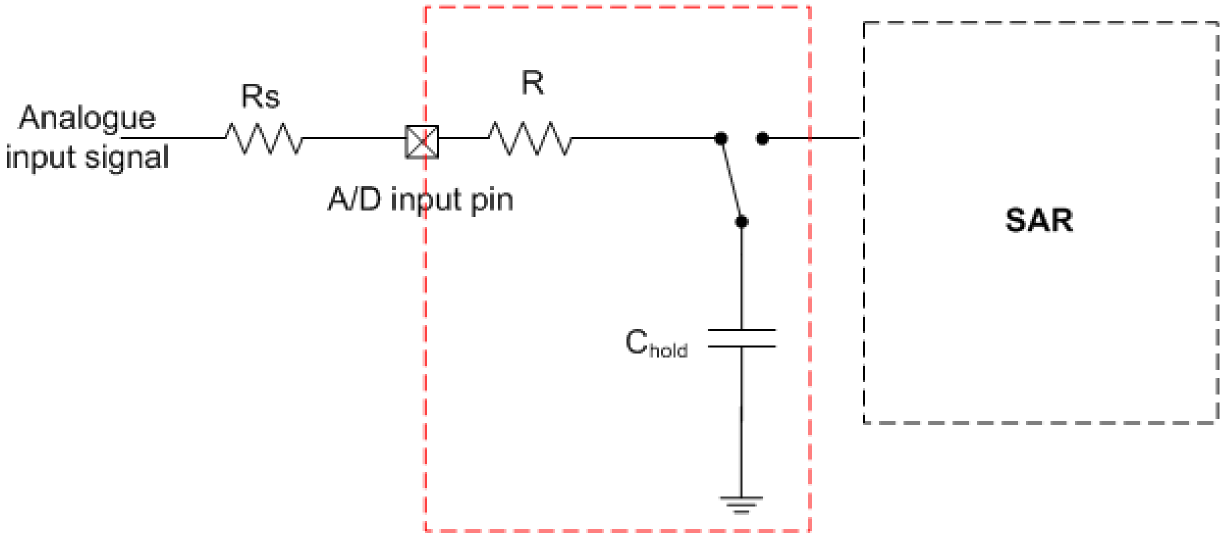
TYPICAL A/D CONVERSION SCHEME



SAMPLE AND HOLD CIRCUIT

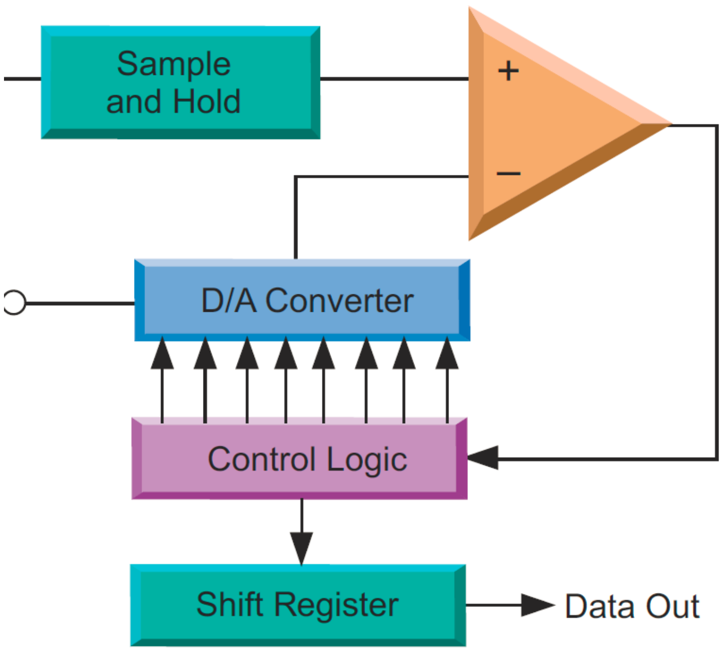
- THE PURPOSE THE S/H CIRCUIT IS TO KEEP THE VOLTAGE LEVEL CONSTANT DURING THE CONVERSION (MAINLY A CAPACITOR)

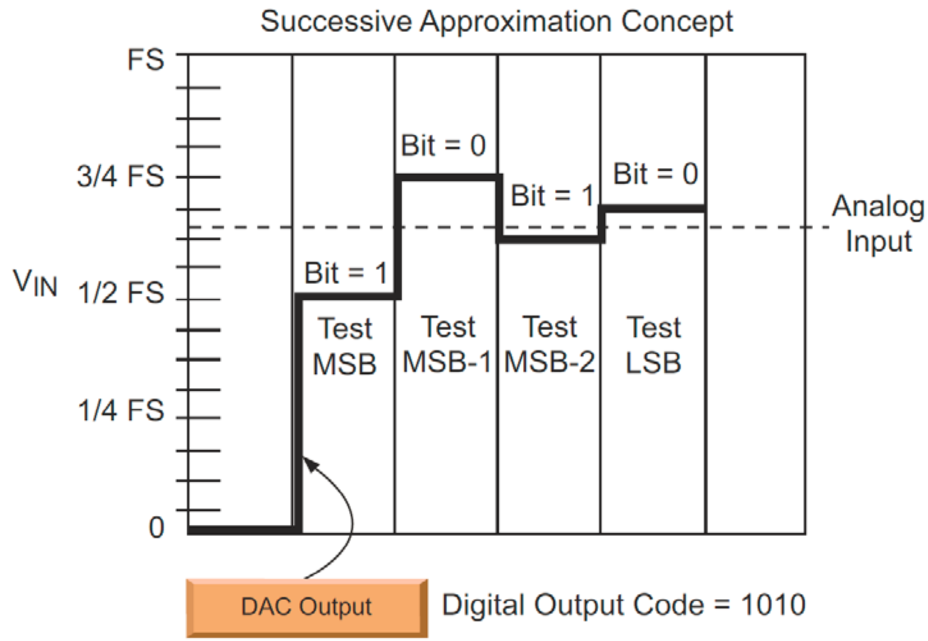
- THE SETTLING TIME (TIME NEEDED TO CHARGE UP THE S/H CAPACITOR) LIMITS THE MAXIMUM INPUT FREQUENCY



Simplified scheme of a Sample and Hold circuit

SUCCESSIVE APPROXIMATION





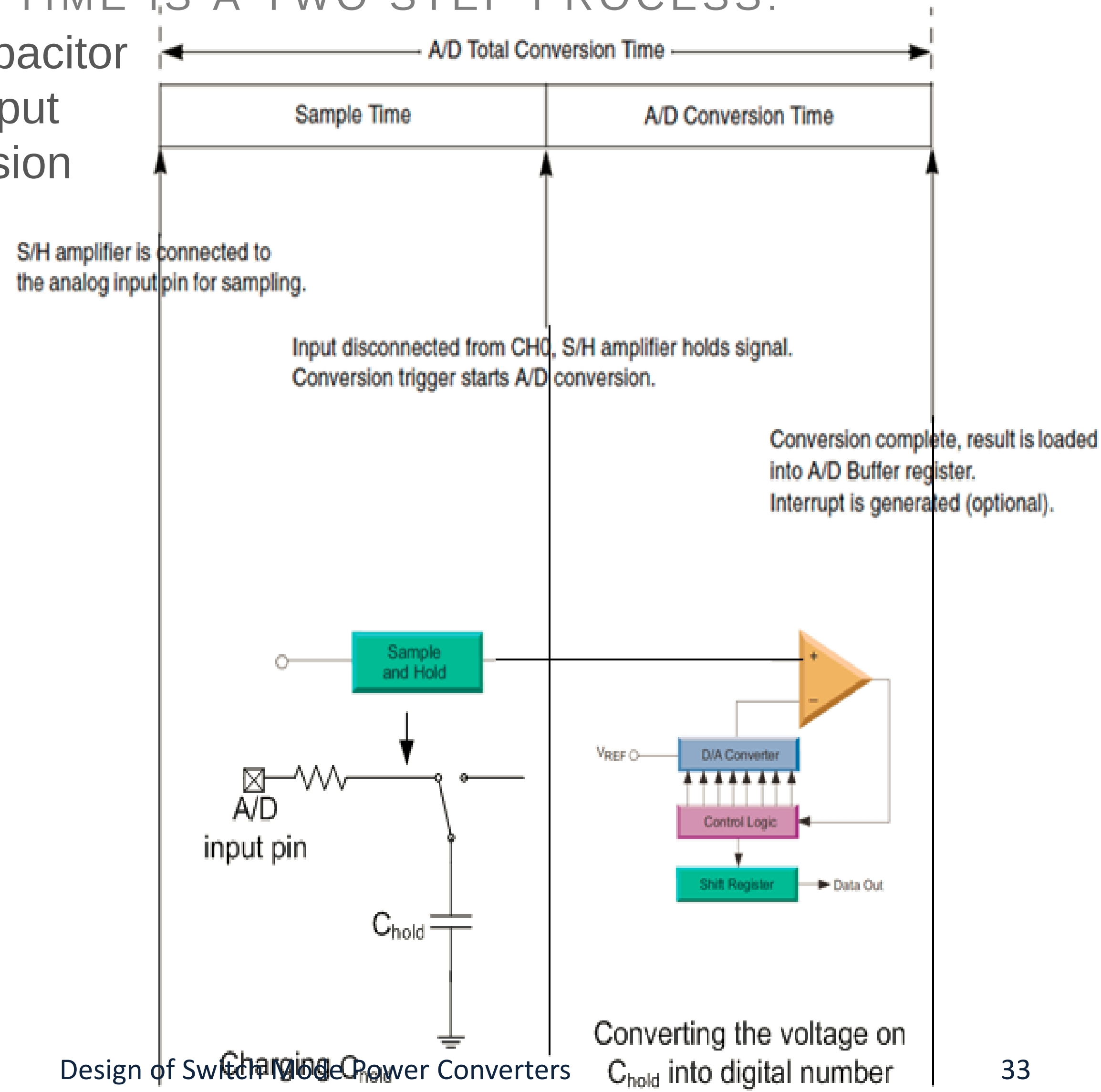
1 - MSB of DAC input is set to ’1’ (half of DAC output range)

2 - Test if DAC output is higher than analog input. If higher, MSB = 0, else MSB =1

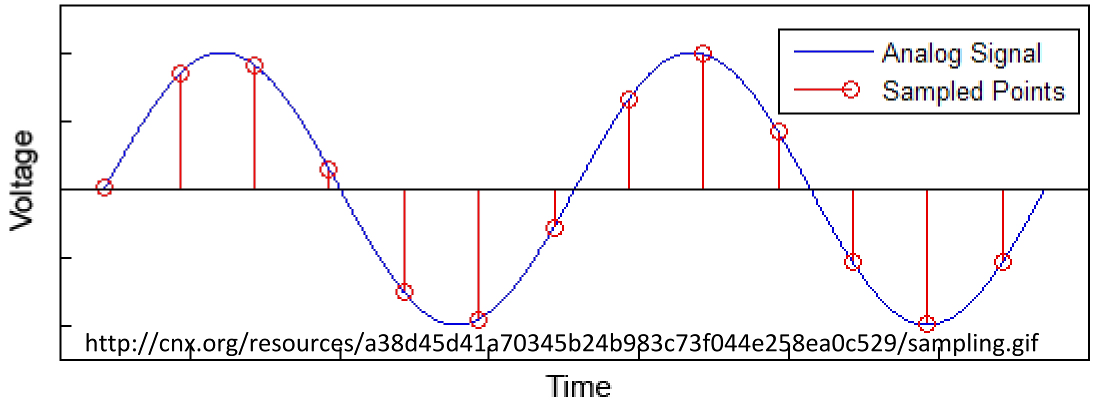
3 - Repeat 1 and 2 with MSB-1

SUMMARY OF THE CHARACTERISTICS OF THE ADC

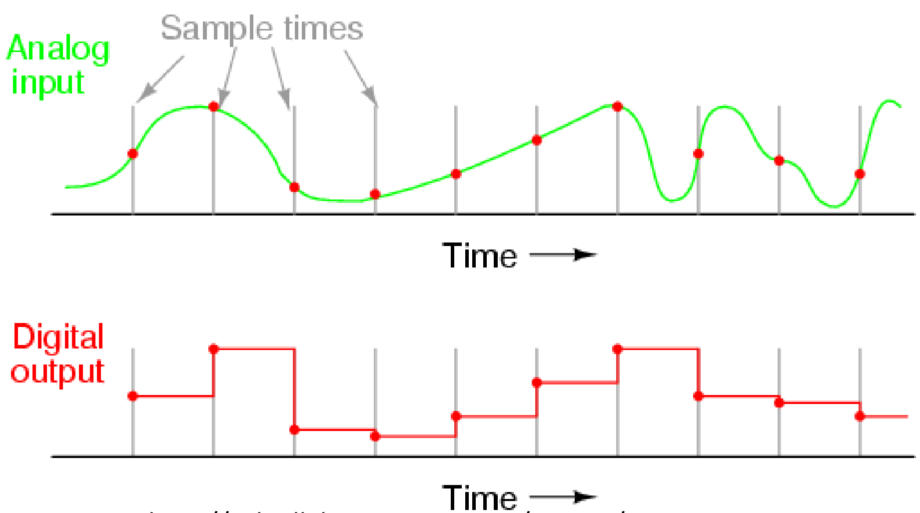
- THE FULL CONVERSION TIME IS A TWO STEP PROCESS:
  1. Charging the sampling capacitor
  2. Disconnect C hold from input pin and start the A/D conversion



PERIODIC SAMPLING



http://cnx.org/resources/a38d45d41a70345b24b983c73f044e258ea0c529/sampling.gif



http://sub.allaboutcircuits.com/images/04253.png

PERIODIC SAMPLING

NYQUIST'S RULE

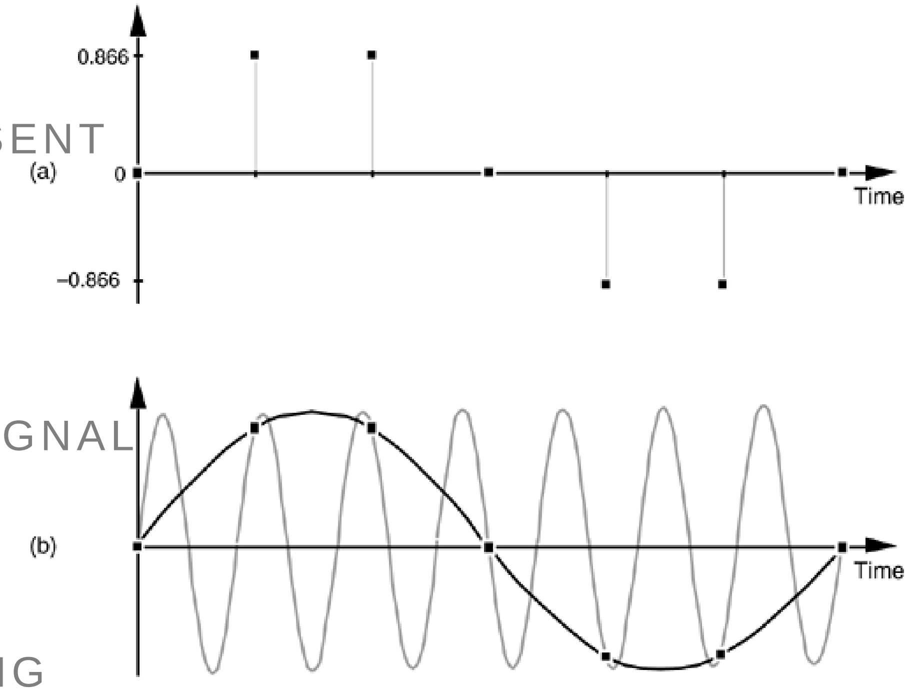
- SAMPLING OF CONTINUOUS SIGNAL WAVEFORM
- MEASURED SIGNALS WITH COMPLEX WAVEFORMS CAN BE REPRESENTED BY SUM OF SINUSOIDAL (FOURIER)

IN ORDER TO CORRECTLY REPRESENT THE MEASURED SIGNAL:

$F_{sampling} \geq 2 * F_{max}$

F_{max} –THE HIGHEST FREQUENCY COMPONENT IN THE MEASURED SIGNAL

IF THERE ARE (UNDESIRABLE) FREQUENCY COMPONENTS WITH $F > F_{sampling}$ →ANALOGUE FILTERING PRIOR TO ADC



Understanding Digital Signal Processing, 2nd Edition, Richard G. Lyons
Published Mar 15, 2004 by Prentice Hall.

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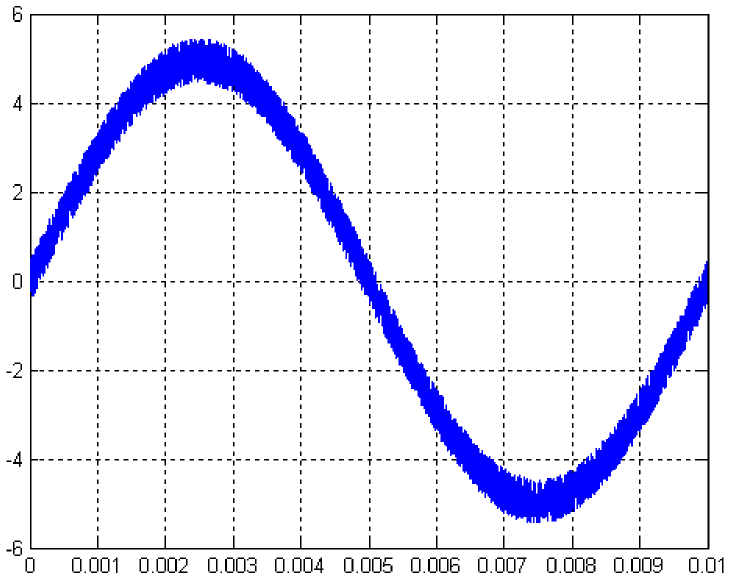
FILTERING

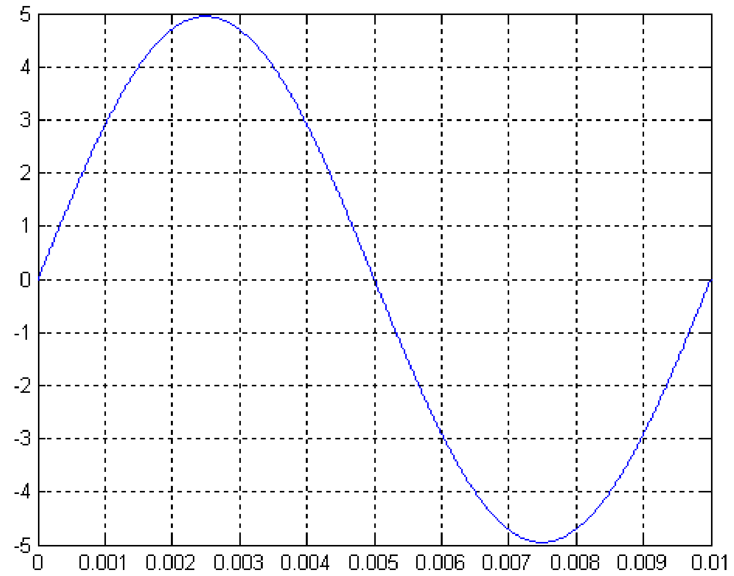
❑ WHY DO WE USE FILTERING?

Reduce the amplitude of the unwanted frequency components (usually called noise) from the input (measured) signal spectrum

Unfiltered signal



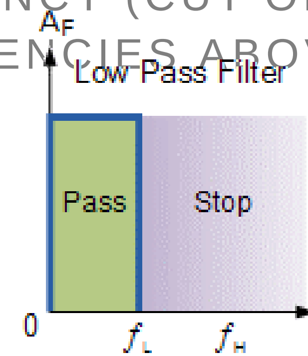
Filtered signal



TYPE OF FILTERS

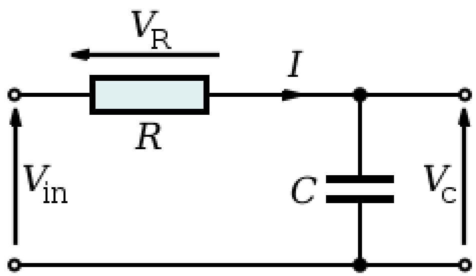
LOW PASS

- PASSES FREQUENCIES BELOW A CERTAIN FREQUENCY (CUT OFF FREQUENCY) AND REJECTS (ATTENUATES) FREQUENCIES ABOVE THE CUT OFF FREQUENCY

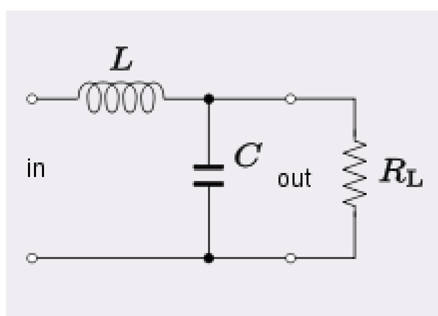


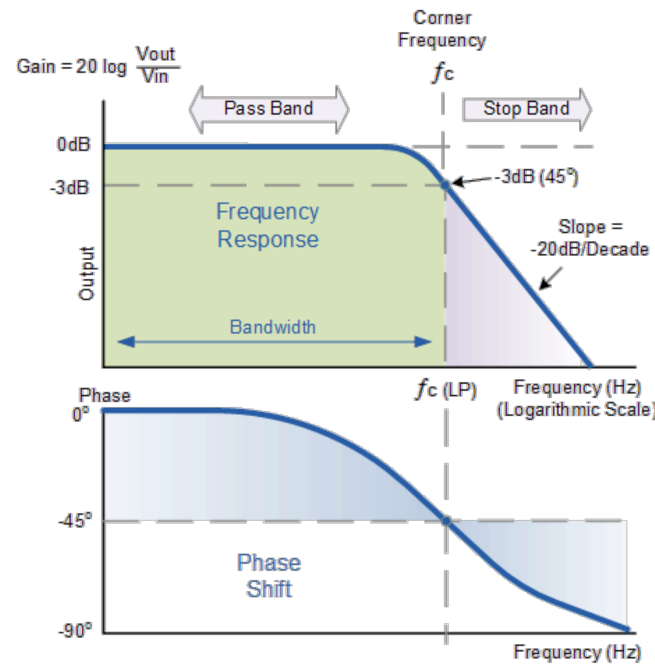
- EXAMPLES:

- FIRST ORDER



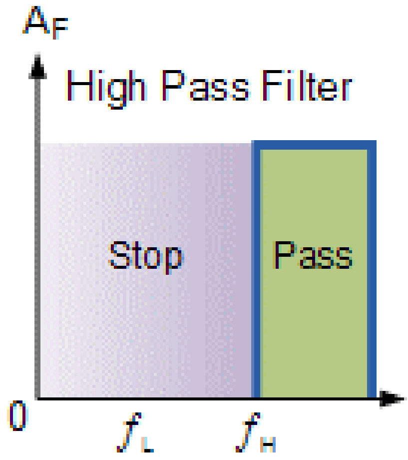
- SECOND ORDER





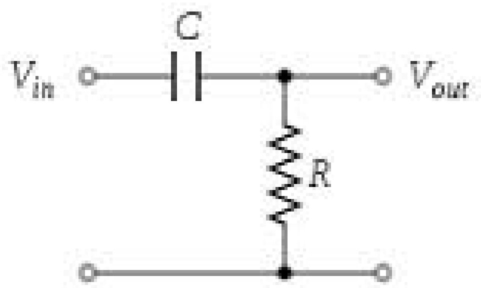
TYPE OF FILTERS - HIGH PASS

- PASSES FREQUENCIES ABOVE A CERTAIN FREQUENCY (CUT OFF FREQUENCY) AND REJECTS (ATTENUATES) FREQUENCIES BELOW THE CUT OFF FREQUENCY

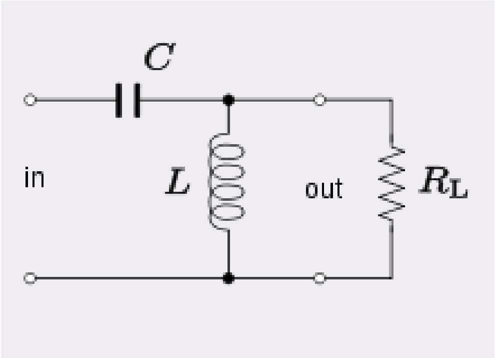


- EXAMPLE:

- FIRST ORDER

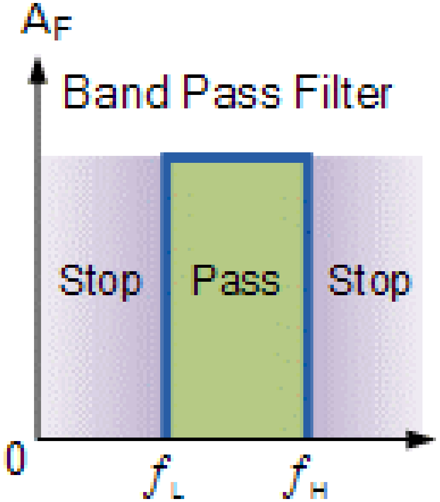


- SECOND ORDER

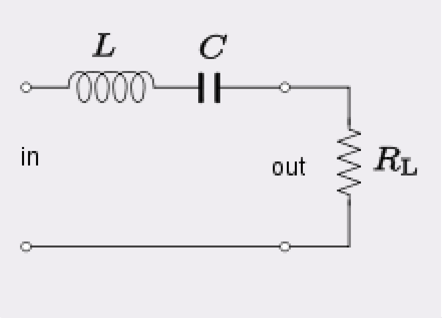


TYPE OF FILTERS - BAND PASS

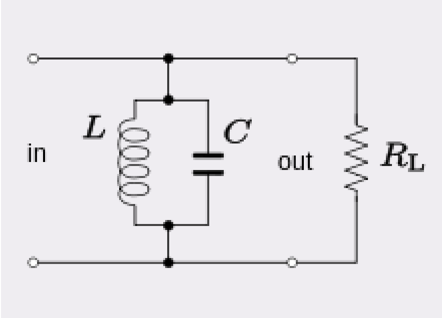
- PASSES FREQUENCIES WITHIN A CERTAIN RANGE AND REJECTS (ATTENUATES) FREQUENCIES OUTSIDE THAT RANGE



- EXAMPLE:



- SECOND ORDER

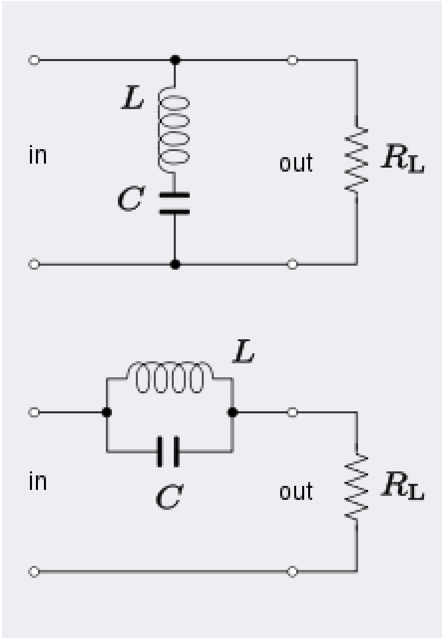


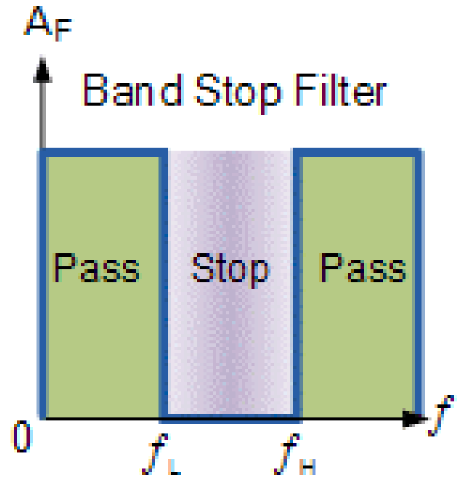
TYPE OF FILTERS - BAND STOP (NOTCH)

- PASSES FREQUENCIES OUTSIDE A CERTAIN RANGE AND REJECTS (ATTENUATES) FREQUENCIES OUTSIDE THAT RANGE

- EXAMPLE:

- SECOND ORDER





OUTLINE

- ❑ VOLTAGE MEASUREMENT METHODS
- ❑ CURRENT MEASUREMENT METHODS
- ❑ GALVANIC ISOLATION
- ❑ PROTECTION
- ❑ ANALOGUE-TO-DIGITAL CONVERSION
- ❑ FILTERING (DIGITAL AND/OR ANALOGUE)

EXERCISE

- ON MOODLE