Signal and error transmission in worst case situation

HW Ing. George A. MARK
Siemens VDO Automotive, Timişoara

ABSTRACT. The measurement of an analog value is used as control and feedback in many applications in automotive business. But how do we know that the value is the real value or is an unreal value due to errors? That's why the purpose of this paper is to describe the differences between ideal operation situation, with ideal components and real operation situation under real environmental conditions, especially in automotive industry. The circuit described is a part of an embedded system called ECU (Engine Control Unit).

1 Introduction

Automotive industry is in our day one of the most client oriented and the trends in the evolution of this branch shows there will be a steady increase of business market. There are many factors that characterize the products of automotive industry, like: safety, comfort, infotainment and utilities. This paper has the intention to concentrate on the safety factor. Safety means, measurement, anticipation, reaction and correction, all this in a proper time in such a way that the problem is removed or corrected.

The common sense of measurement is that a certain value is measured at the point where we want to find out the value. There are two types of measurements: *passive* with no reaction on the measured value, just a display gives the value to the user and the decision is to be made by the user and *active* measurement, which includes a reaction circuit (also called feedback) which gives in real time a value proportional with the measured value.

Nevertheless both methods are with errors, even if there is a control of the output value with a reaction circuit.

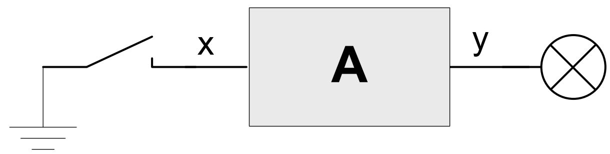

Figure 1. Simple measurement circuit

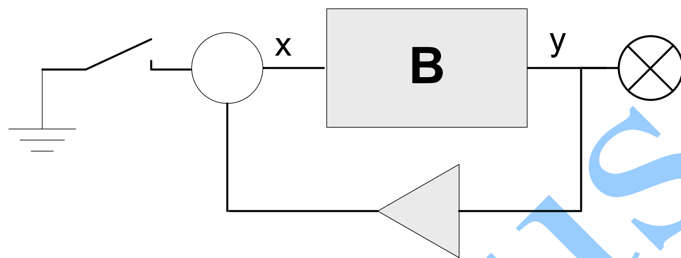

Figure 2. Measurement circuit with reaction

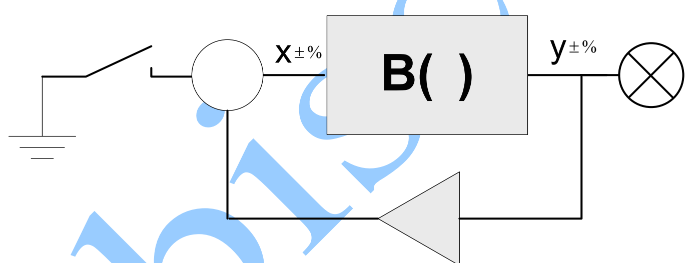

Figure 3. Real measurement circuit with reaction and tolerances

According to a simple analysis the ideal transfer functions of the circuits are:

$$y = A \cdot x$$

or

$$y = B \cdot x \pm \gamma$$

Input value x is measured and comes from a sensor, switch, resistor or some other device. The output value y is the converted value, probably a led, a display, a number or even a voltage for an intermediate circuit.

These equations are far from the reality, because in the real world each value is influenced by errors (tolerances, temperature, ageing and so on). And a more real representation of a system with reaction circuit could be, as presented in figure 3, (α includes all the other possible errors):

$$y(\%) = B(\varepsilon) \cdot x(\%,^{o}\mathrm{C}) \pm \gamma(\%,^{o}\mathrm{C}) \pm f(^{o}\mathrm{C}) \pm \alpha$$

Even if this equation is more close to reality there is one more thing to take in consideration and that is: the expectations. This means is it really necessary to have a real complex solution for a simple circuit like that or not?

The answer lies in the specifications of the product. The client is setting the limits and the expectations.

2 Errors and tolerances in a transmission path

Analyzing the errors transmission on a signal transmission shown in figure 4 will be done with each block.

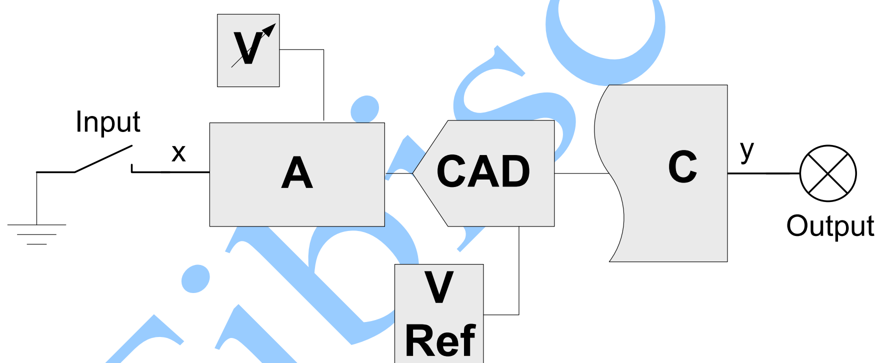

Figure 4. Signal flow

V – Voltage Regulator
A – Operational Amplifier
CAD – Analog to Digital Converter
µC – Micro Controller
Vref – Reference Voltage

3 Input errors

In the following chapter is described how errors and tolerances influence a simple circuit. For that is assumed that the voltage V_{in} and V_{out} are stable and do not vary in time or with temperature.

The *ideal* transfer function is done by the relation between input and output voltage:

$$V_{out} = \frac{R_2}{R_2 + R_1} \cdot V_{in}$$

As a common sense α factor includes other errors (due to ageing, temperature) that might appear during functionality of this divider and is used at this point for simplicity of equations.

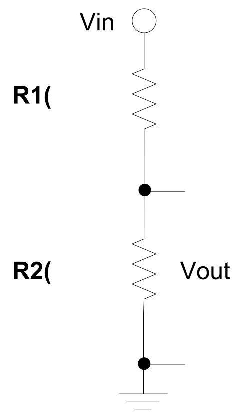

Figure 5. Voltage divider

Real equations of the V_{out} is given by:

$$V_{out} = \frac{R_2(1 \pm \varepsilon) \cdot (1 \pm \alpha)}{R_2(1 \pm \varepsilon)(1 \pm \alpha) + R_1(1 \pm \varepsilon)(1 \pm \alpha)} \cdot V_{in}$$

Still, the equation is noting new only that the answer that is given by it could be misinterpreted or not so obvious.

Suppose now that the ratio between the two resistors is given by the following equation:

$$R_1 = 0.1 \cdot R_2$$

It is easily seen from the table bellow that the error introduced by this divider is not so negligible and at bigger differences, like 10 times, the error is very important and must be taken in account.

Bellow is represented in a graphical manner how the errors are related to the ratio between the two resistor. Big errors is seen on bigger ratios, smaller errors on smaller ratios.

Table 1. Errors with a simple voltage divider

R1=R2	min	max	nominal	R2/R1
0.10	-16.67	19.57	0.10	9.00
0.20	-15.09	17.02	0.20	4.00
0.30	-13.46	14.58	0.30	2.33
0.40	-11.76	12.24	0.40	1.50
0.50	-10.00	10.00	0.50	1.00
0.60	-8.16	7.84	0.60	0.67
0.70	-6.25	5.77	0.70	0.43
0.80	-4.26	3.77	0.80	0.25
0.90	-2.17	1.85	0.90	0.11

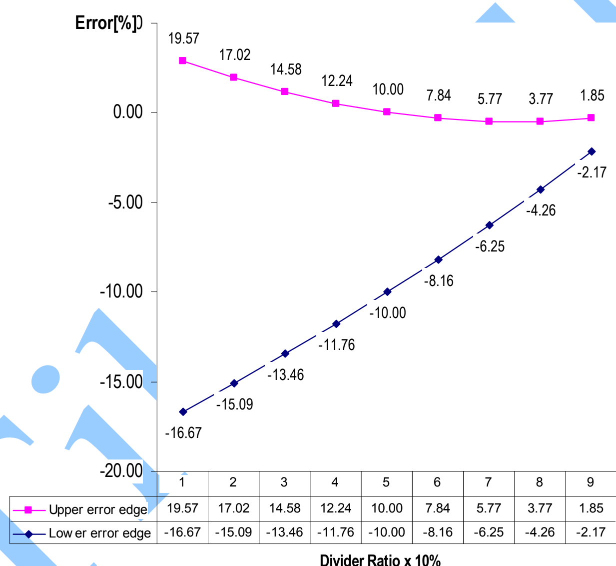

Figure 6. Divider ration as a function of error

The voltage at the output of the divider is so influenced by the divider behavior and ratio. This would be near the truth if the voltage at the input would be stable in time and with temperature as it is stated till now.

Important is one thing which simplifies the situation without drifting to much from the reality, is that resistor have different tolerances due to different factors, but according to practice and worst case situations this errors are not always added. Between these tolerances there is a relation and this relation is quite complex, so and approximation is still needed.

If all the tolerances are added the result for a 5% initial tolerance will be according to the datasheet bellow:

$$Totall\_Tolerance = \mathrm{E}_{soldering} + \mathrm{E}_{ageing} + \mathrm{E}_{endurance} + \mathrm{E}_{dampheat} + \mathrm{E}_{overload} + f(TC)$$

but according to practice this equation is not really necessary and the result can be rounded to these values:

Table 2. Tolerances equivalences

Initial Tolerances	Calculation tolerances
1%	3%
5%	8%
10%	13%

1.1 Electrical and reliability parameters:

5% and 1% initial tolerance

Case	0402		0603		0805		1206	
Tolerance	±5%	±1%	±5%	±1%	±5%	±1%	±5%	±1%
TC [ppm/K] 1Ω ≤ R < 5Ω 5Ω ≤ R < 10Ω 10Ω ≤ R < 100Ω 100Ω ≤ R < 1MΩ 1MΩ ≤ R < 10MΩ	±200 ±200 ±200 ±200 ±200	±100 ±100 ±100 ±100 NA	±200 ±200 ±200 ±200 ±200	±100 ±100 ±100 ±100 ±100	±200 ±200 ±200 ±200 ±200	±100 ±100 ±100 ±100 ±100	±200 ±200 ±200 ±200 ±200	±100 ±100 ±100 ±100 ±100
Standard values	E24	E96	E24	E96	E24	E96	E24	E96
Climatic category	55/125/56	55/125/56	55/155/56					
Rated dissipation P_{max} (T_{amb} = 70°C) [1]	0.063W		0.1W		0.125W		0.25W	
Max. rated voltage [2]	50V		50V		150V		200V	
Single pulse over voltage V^{i}_{max} (t_i < 1µs)	100V		150V		300V		400V	
Single pulse (t_i < 10µs) power P^{i}_{max}	3.5W		4W		6W		10W	
Continuous pulse (t_i < 10µs) power P^{i}_{max} (t_p / t_i = 1000)	1W		1W		1.3W		2W	
Resistance to soldering heat (unmounted, 10s, 260°C ± 5°C) ΔR / R_{max}	±(0.5% +0.05Ω)		±(0.5% +0.05Ω)		±(0.5% +0.05Ω)		±(0.5% +0.05Ω)	
Endurance (@ 70°C, 1000hours, loaded P_{max} or V_{max}, 1.5h on / 0.5h off) ΔR / R_{max}: R ≤ 1MΩ R > 1MΩ	±(1% +0.1Ω) ±(2% +0.1Ω)		±(1% +0.1Ω) ±(2% +0.1Ω)		±(0,5% +0.1Ω) ±(1% +0.1Ω)		±(0,5% +0.1Ω) ±(1% +0.1Ω)	
Damp heat test 1000hours, 85°C; 85% RH; loaded with 0.1P_{max} or V_{max}: ΔR / R_{max} for R ≤ 1MΩ R > 1MΩ	±(1% +0.1Ω) ±(2% +0.1Ω)		±(1% +0.1Ω) ±(2% +0.1Ω)		±(0,5% +0.1Ω) ±(1% +0.1Ω)		±(0,5% +0.1Ω) ±(1% +0.1Ω)	
Short time overload (T_{amb} = 20°C, P = 6.25P_{max}, 5s, V < 2V_{max}) ΔR / R_{max}	±(1% +0.05Ω)		±(1% +0.05Ω)		±(1% +0.05Ω)		±(1% +0.05Ω)	
ESD (2kV)	±(2% +0.1Ω)		±(1% +0.05Ω)		±(1% +0.05Ω)		±(1% +0.05Ω)	
Thermal resistance [K/W]	870		550		440		220	

Figure 7. Resistor datasheet

Usually automotive devices are supplied with +12.5V from the battery and this voltage can vary from 0V(battery discharged), to 9V(minimum operational voltage for the devices), to 16V(long time normal operation mode for the devices) and till 26V (short time operation for automotive devices).

The point of this paper is not to analyze the variation of the battery voltage with environmental conditions, but to describe how the circuits that are supplied with this voltage can influence the real life signals, over the whole range of voltage variation.

4 Voltage regulator errors

To continue with another simple circuit which is very used in automotive devices. This circuit is simple too, but does this circuit introduce errors? Due to the fact that all components have tolerances a simple analysis would show that errors appears in the transfer function.

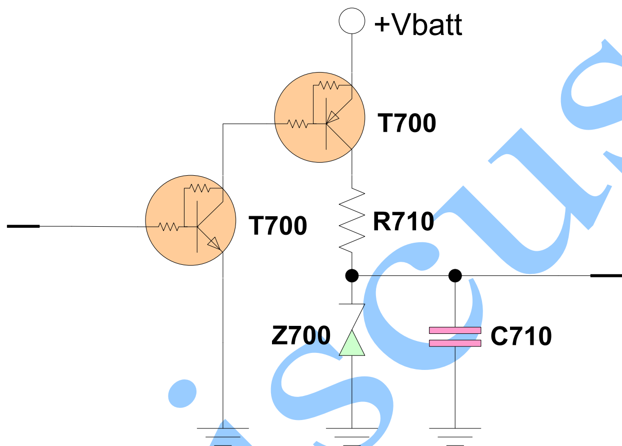

Figure 8. Simple voltage regulator

The simple transfer function of this circuit is presented by the simple equations:

$$V_{Z170} = V_{BATT} - V_{CEsat} - R_{710} \cdot (i_Z + i_S)$$

assuming off course that the functionality of Darlington transistors is guaranteed by the micro-controller.

Due to errors, temperature drift of the components the real equation of transfer is represented bellow(for maximum value only):

$$V_{Z170\max}(1 \pm \theta) = V_{BATT\max} - V_{CEsat\max} - R_{710}(1 \pm \varepsilon) \cdot (1 \pm \alpha) \cdot (i_{Z\max} + i_{S\max})$$

5 Operation amplifier signal conversion errors

In the path of signal conversion some times there is need of circuits that give a signal based on a

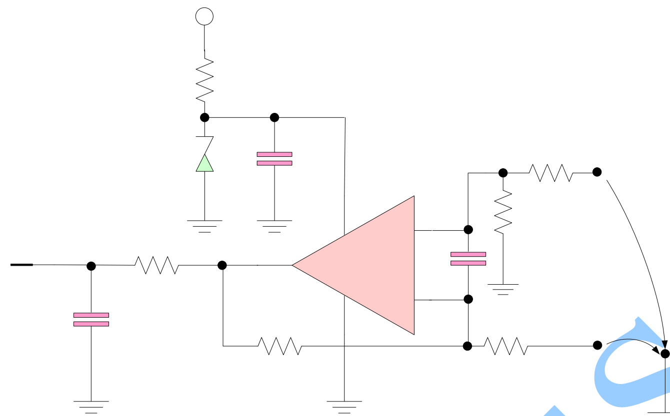

Figure 9. Differential circuit with OP-AMP

The transfer function for this circuit is described bellow, including this time all the errors:

$$V_{\mu C\_\max}(\varepsilon,\alpha,\theta)=\left(1+\frac{R_{700\_\max}}{R_{703\_\min}}\right)\cdot\left(\frac{R_{702\_\max}}{R_{702\_\min}+R_{701\_\min}}\right)\cdot V_{1\_\max}$$

the equations is valid only if $V_2 = V_{GND}$.

6 Analog to digital conversion

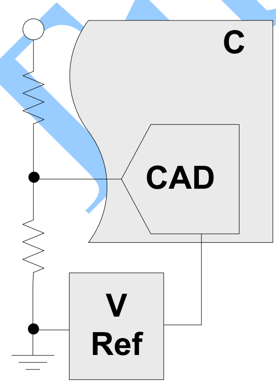

Figure 10. Voltage measuring

In the process of signal measurements often the display of the value is not done using a simple LED, LCD display or any other electronic device, but a value in a software tool that is used inside a complex algorithm to do what is was meant do.

Often hex codes and binary codes are used for the operation, still the device that converts the value in to a numerical value is a ADC (analog to digital converter).

There are two types(from the physical point of view) of ADC:

- specialized IC's
- micro-controller integrated

When measuring a voltage by means of an ADC the digital result of the conversion is given by the next formula, containing the integer function:

$$W = INT\left(\frac{V_{in}}{V_{ref}} \cdot W_{full} + 0.5\right)LSB$$

where: Vref is the A/D Converter's reference voltage, W_{full}=2N is the full-scale conversion result and W takes values in the interval 0 ÷ W_{full-1} ⇒ W = 0÷255 for 8-bit conversion and W = 0 ÷1023 for 10-bit conversion.

This formula includes the inherent quantification error of ±½ LSB. The expression of V_{in} is obtained by replacing the input leakage current "I" and resistor R_2 by an equivalent voltage source.

The influence of the voltage reference is given by:

$$Vref = Vrefnom \cdot (1 \pm vreftol) \cdot (1 \pm NLe)$$

So, the final equations is(∏ is a function of current):

$$W = INT\left[\left(V_{batt} \cdot \frac{R_{1\max}(\varepsilon,\theta,\alpha)}{R_{1\max}(\varepsilon,\theta,\alpha) + R_{2\max}(\varepsilon,\theta,\alpha)} + \Pi\right)\frac{W_{full}}{V_{ref \cdot nom}(1 \pm vreftol)\cdot(1 \pm NLe)}\right]$$

Conclusions

Error transmission in the simple circuit showed in the figure 4 is not to be neglected. Due to tolerances and due to temperature influence the initial signal is often altered in such a manner that the value obtained is much to different, up to 40%(if more then there is an error in the equations). In order to avoid such situations, a good worst case analysis and good quality components must be used.

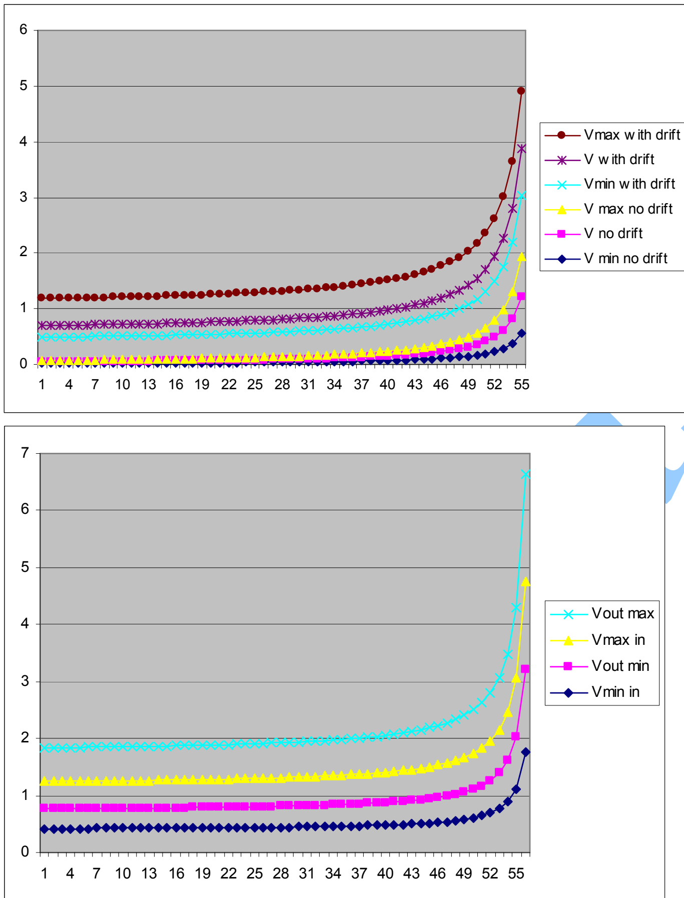

Figure 11. Influence on voltage measurements

References

[CH01] **Bruce Carter and L.P. Huelsman** - *Handbook Of Operational Amplifier Active RC Networks*, Texas Instruments, SBOA093a, 2001

[MA01] **Ron Manicini** – *OPAmps for everyone*, Texas Instruments, 2001

[Pla04a] **Dan Plavosin** – *Battery Voltage Measurement,* Siemens VDO Automotive, Timisoara, 2004

[Pla04b] **Dan Plavosin** – *Application Note for Battery Voltage Measurement*, Siemens VDO Automotive, Timisoara, 2004