Embedded system inputs and outputs disturbing sources and the linear optocoupler behavior mathematical description

Otáhal Jiří, Michal Brázdil, Hruška František

***Abstract*—** The paper reveals the possible sources of interference that can disrupt the function of inputs and outputs of embedded systems or interfere with correct interpretation of the input signals or the possibility of complete destruction of input and output circuits by these interferences. The issue of capping limits for analog signals with linear optocoupler and also use of designed limit voltage limiters are solved as well. In the last part the measured static and dynamic limiters characteristics are measured and linear optocoupler is described mathematically.The research work was performed to financial support of grant reg. No IGA/32/FAI/11/D and by the European Regional Development Fund under the project CEBIA-Tech No.CZ.1.05/2.1.00/03.0089.

***Keywords*—** electromagnetic compatibility, voltage surges sources inputs protections, linear optocoupler, protection of analog signals, Strejc identification method, embedded system

I. INTRODUCTION

Digital and analog inputs of embedded systems are very sensitive to power surges. The normal maximum repeatable value of the input voltage is 1.1 times the microprocessor supply voltage max. These inputs must be protected against higher voltage surge described above, a possibility of error when connecting, for example, affixing a higher level of voltage. This protection against electromagnetic disturbance must be realized in input / output embedded system circuits.

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J. Otáhal is with the Department of Electronics and Measurements, Faculty of Applied Informatics, Tomas Bata University in Zlín, Czech Republic (e-mail: otahal@fai.utb.cz)¨

M. Brázdil is with the Department of Process Control, Faculty of Applied Informatics, Tomas Bata University in Zlín, Czech Republic (e-mail: otahal@fai.utb.cz)

F. Hruška is with the Department of Electronics and Measurements, Faculty of Applied Informatics, Tomas Bata University in Zlín, Czech Republic (e-mail: hruska@fai.utb.cz)

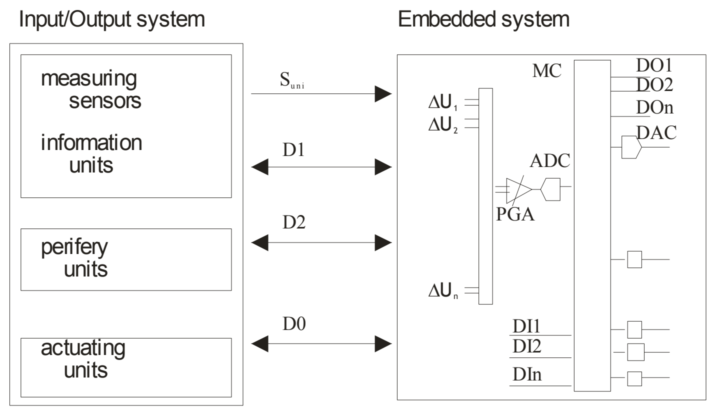

Fig. 1 The embedded system Structure

II. GOALS OF THIS PAPER

For precision input signal measurement, which are processed embedded systems is necessary to know the distortion which brings the circuit overvoltage Limiters, analog galvanic isolators.

This paper describes the results of finding the causes of static and dynamic nonlinearity overvoltage limiters, analog galvanic isolators and their mathematical description.

III. ELECTROMAGNETIC COMPATIBILITY

Electromagnetic compatibility (EMC) is the ability of a device, system or device to function properly in an environment in which operate other sources of electromagnetic signals (natural or artificial). At the same time its own electromagnetic activity does not influence its own surroundings impermissibly, neither it does not produce signals which could disrupt other devices (technical or biological.

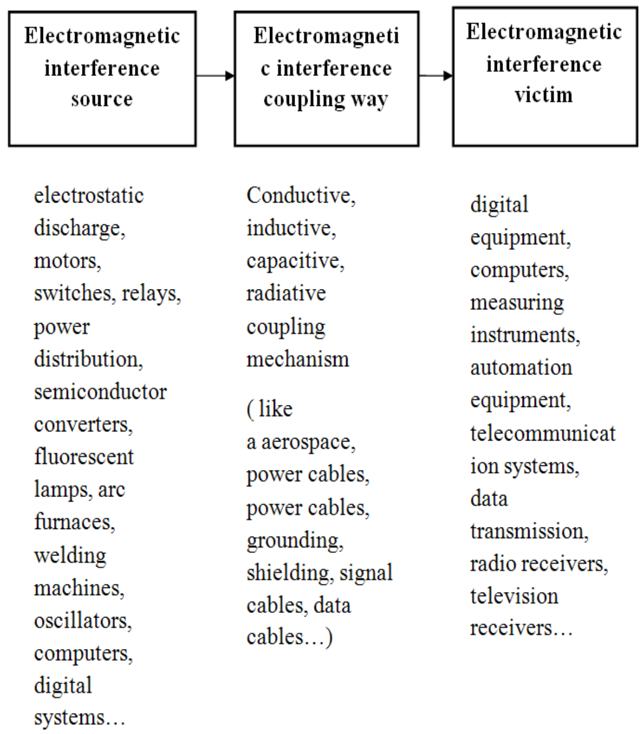

Fig. 2 The electromagnetic interference (EMI) coupling

Figure 1 shows basic coupling from source to electromagnetic interference victim. Electromagnetic interference can be broadcasted throw conductive, capacitive and radiative coupling.

EMC issue is very extensive, but it can be divided into two main areas biological systems EMC and technical systems EMC.

In the first phase of the coupling sources of electromagnetic interference are described.

It includes both natural sources of interference and artificial sources of interference. Natural sources of electromagnetic interference are electromagnetic processes in the atmosphere, sun, cosmos and other. Artificial sources of electromagnetic interference are resources created by human activity.

The second part deals with the coupling of transmission of electromagnetic interference environment. It describes the way that the energy of interference sources to get to disturbed object.

The third part includes the issue of the disturbed object. The issue deals with the classification of types of disturbing effects on the disturbed object. It is based on the structural and technological analysis of determined electromagnetic resistance.

In reality the interference is not realized between just two objects, but more interference is represented by each object. The procedure for the analysis is processed in a way that the former is taken into account only one source of interference, and disturbed for all other objects. In the next step of analysis is considered an object previously regarded as a source of interference in disturbed object, which removes the other objects that were previously considered to be the receiver noise. When seeking the best EMC system is to consider whether the disruptive effects of interference sources are its functional characteristics or functioning of the device parasitic products. Accordingly, resources are then directed to reduce interference, mainly on the source of interference, disturbed object or transmission coupling between these objects.

EMC can be divided into two basic groups: Electromagnetic interference and electromagnetic susceptibility.

A. *Electromagnetic interference*

Electromagnetic interference (EMI) is a process where the interference with the transmission path transmits the disturbed object. EMI is primarily concerned with identifying sources of interference, and noise transmission paths. EMC in this case achieves technical measures mainly on the source of interference and limiting their ties with the disturbed object.

B. *Electromagnetic susceptibility*

Electromagnetic susceptibility (EMS) device is the ability to operate without failures in the environment with electromagnetic interference, or precisely due to the permissible ambient electromagnetic interference. It deals with technical measures, thus increasing the immunity of the device leaders of the electromagnetic interference.

Each electrical object can be considered as a source and a receiver of electromagnetic interference. For obvious reasons, but specifically excludes a group of devices, which clearly prevails over the generation of disturbing signals above the reception ambient interference. These devices are called interference source.

The occupation of spectrum signal interference and physical activity signals can be divided into two groups.

• Low-frequency noise to the 10 kHz band

• Radio frequency interference in the band from 10 kHz to 400 GHz.

The time course of the interference signal is linked with the spectrum of this signal as well as the frequency of its most distinctive elements. These figures should be known mainly to the use technical means to suppress this interference. In particular, functional interference sources are representatives of the narrowband interference. Broadband interference will cause all natural disturbances and the most industrial noise.

Classifications commonly used artificial interference with disturbances are divided into three basic groups.

• Noise. These disturbances affect mainly the shape of the effective signal. The EMC has the name changed meaning, the context is not a random signal activity accompanying electrical equipment, but has a recurring character.

• Impulses. Disturbances are pulse shaped to a large proportion of the pulse heights to its duration. These impulses are transposing the useful signal in the form of positive and negative peaks.

• Transients. It is a single random interfering signal, the duration of these signal is from a few ms to several seconds.

IV. Voltage surges sources

A. Natural voltage surges sources

The largest natural voltage surge source is atmospheric electrostatic discharge, which originates as an atmospheric phenomenon. atmospheric electrostatic discharge strike actuate on a electrical equipment within a radius of about 4 km. Atmospheric electricity discharge creates electromagnetical steep pulse (Lemp - Lightning Electromagnetic Pulse). This impulse has affected to devices that are far more than 4km significant disruptive and often destructive effect. The value of the atmospheric electrostatic discharge current compensation amounts to 200 kA. In terms of the frequency interference, atmospheric electrostatic discharge produces a value of up to 140 dBmV in the 2-30 kHz band, as well as the interference level decreases with the slope 20 db / decade to frequencies around to 100 MHz. [1]

B. Electrostatic discharge

Manmade voltage surges sources in recent years growing increasingly in importance as a local electrostatic discharge (ESD - Electrostatic Discharge). Incidence of electrostatic discharge is possible wherever the friction movement of mechanical parts. Mechanical parts can be a metal and dielectric solid, liquid and gaseous. Although the local electrostatic discharge energy is small, usually less than 10mJ, the discharge voltage is order of units to tens of kV. This voltage level is very dangerous for electronic devices. Most modern equipment is working extremely small currents and especially with very high impedances such as CMOS. Electrostatic discharge voltage rise in people walking or rubbing parts like clothes. For modern electronic devices is this probably the biggest threat. A person can normally reach voltage to ground from 5kV to 15 kV. [1]

C. Industrial interference sources

The industrial sources of interference are the most important harmonic frequency power supply, which often generate longer alone generators to produce electricity. Higher harmonics will arise in the non-linear impedances in the electrical network. Large industrial sources of interference are high power semiconductor converters and outside the industry in households appliances are sources that have a power rectifier.

Energy networks contain switching and break elements that generate a series of transient phenomena. In the high voltage networks and very high voltage networks switching occurs when the influence of trunk line capacity and inductance of the oscillation frequency in the order of a few MHz. The oscillation duration is usually five to ten times its period and is spread easily through the capacitive coupling to the low voltage networks.

In the activities of mechanical relays, contactors, circuit breakers and low voltage power networks, it rise another type of noise when releasing the contacts under load. Once these elements distancing contact occurs a sharp decrease the current in circuit, and if the impedance of the circuit contains a significant inductive component arises influence interference of high voltage, which is practically across the contacts.

$$u = - L \cdot \frac{di}{dt} \qquad (1)$$

Between contacts starts up arc discharge and the voltage falls instantaneously to zero, the discharge goes out again and starts to increase tensions between the contacts. If this voltage exceeds the environment breakdown voltage, the arc lights again. This process can be several times depending on the size of inductive components disconecting circuit again. Between contacts generated pulses with steep saw impulses with very fast rising voltage and frequency in the order of several kV and frequency of several kHz. Similar interference occurs even when switching circuits with significant inductive impedance components . Within initial conditions is created the smaller pulse size.

Another interference type arises in high power thyristor systems management. In these devices are periodically switched high currents which can greatly distort the supply voltage course. Frequency spectrum of this type of interference extends to several tens of MHz. When these devices directly connected into the power network without the filter, they can cause power outages energy networks.

D. Galvanically separated signals

In many applications it is necessary protect devices or components, separate differences in ground potential and safety parts electrically circuit. The galvanic isolation can be use in several ways. The AC power circuits and in circuits of AC voltage measurements can be used to separate transformer. For DC voltage and current transformer for obvious reasons can not be used, however, may use sensors using Hall effect. The optical separation is the most often applied to isolate DC signals.

E. Optical Separation of Signal

Optical Separation of the signal is applied wherever low power signals separation is needed. Optical isolation is often also reach noise restrictions, which can be introduced into the circuit from the external environment such as long route in industrial distribution. The optocoupler is also a demand for components on the input side of the possibility of a major overload of the reasons the greatest resistance to voltage surges.

For galvanic separation this case is used optocouplers. Optocoupler consists of LEDs on one side and a photodiode, phototransistor, or triac photocathode on the other side. The alternative are called icoupler optocouplers that operate on the principle of electromagnetic induction.

- Optocoupler can be separated on analog and digital signals.

- In terms of nature of the signal to be electrically separated, optocouplers can be divided into three groups:
- Optocouplers for digital signals galvanic separation
- Optocouplers for analog signals galvanic separation
- Special optocouplers

F. Linear optocoupler

Optocouplers for analog signals galvanic isolation are formed on either side of the one LED and the other one photodiode. These optocouplers, however, are inherently less linear and for galvanic isolation of analog signals not very appropriate. Linearization is achieved by adding to the other LED photodiode, which is used to compensate optocoupler non-linearity. It should be noted that in order to signal the level of of such subsequently convert 12-bit converter with sufficient precision, linearity optocoupler transfer can have a maximum error of 0.01%. Providing that the photodiode on the other side of the photodiode and on the side of the photodiode has the same properties, nonlinearity is compensated through connecting external components with good stability. This connection also compensates for thermal semiconductor-based components instability. Thermal instability of this involvement varies is typically around ± 0.005% / ° C. This value is very important when deploying this type of components in real applications.

The picture below is typical performance optocoupler for electrical isolation of analog signals.

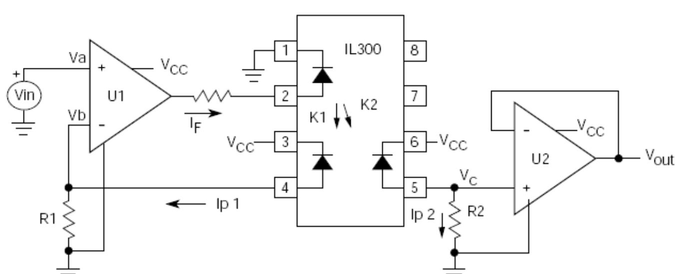

Fig. 3 The linear optocoupler typical connection[4]

The figure above shows a typical linear optocoupler connection. To achieve linearity optocoupler is needed to compensate for photodiodes nonlinearity and the photodiodes threshold voltage. Typical connection uses for the input the operational amplifier. Through photodiode and feedback resistor R1 flows the current IP1. This current is on resistor R1 which is connected to the inverting input of operational amplifier U1

$$I_{P1} = \frac{V_{IN}}{R_1} \tag{2}$$

As is evident from the picture above, the photodiode on the LED side is connected to the inverting operational amplifier input . Input voltage is given by

$$\frac{V_{IN}}{R_1} = K_1 \cdot I_F \tag{3}$$

The photodiode output on the other side is connected to the noninverting input of the output operational amplifier. When current flows through the photodiode, this current flows through resistor R2. The current in resistor R2 as is evident creates voltage. The output of the op amp output is:

$$V_0 = I_F \cdot K_2 \cdot R_2 \tag{4}$$

Therefore, the total transfer function (Vo / Vin) is the result of the ratio of the output operational amplifier U2 and the load resistance R2 and photodiode feedback circuit with a resistor R1. This circuit reduces the nonlinearity of LEDs and photodiodes to:

$$\frac{V_0}{V_{IN}} = \frac{K_2 \cdot R_2}{K_1 \cdot R_1} \tag{5}$$

The final transfer function is completely independent of the current through the LED. The entire circuit gain is given as the resistors R1 and R2 ratio:

$$\frac{V_0}{V_{IN}} = K_3 \cdot \frac{R_2}{R_1}; K_3 = \frac{K_2}{K_1} \tag{6}$$

G. The linear optocoupler history

S. Waaben in 1975 first announced creation of an optocoupler with one LED diode and two photodiodes in same optical space. The first photodiode is used as output and the second photodiode is used in the input circuit feedback. It was the first time and temperature stability linear optocoupler officially publicized. There are some companies in today's market that produced optocouplers with the same principle and function.

Problem of the protection of analog signals is in the maintaining of the linearity and stability of the surge when time-varying signals are used.

H. Selected circuits types

Problem of the protection of analog signals is maintaining the linearity and stability of the surge when time-varying signals are used. Three types of circuits were selected. Linear optocoupler IL300 is used in the first circuit; programmable voltage reference LM431 is used in the second circuit with behaving as an ideal zener diode. This circuit is used like a voltage limit limiter. The third circuit is using the typical Zener diode for comparison. For these purposes a test module was created on which all three above mentioned circuits were placed.

V. Methods

A. Static input / output characteristics measurement

Static input / output characteristics measurement is a helpful method for finding static characteristics like a gain and saturation voltage of these three circuits. The Next reason is a verification of the linearity and circuits behaviour. Measurements were carried out using the following equipment and software using VEE Pro 9.0, which established a program for this measurement. The input voltage was chosen in the range of 0 to 5.1V. Step input voltage was 10mV. The Waiting time between samples was chosen as 0.2 s which was sufficient to fully stabilize the input voltage. The Supply voltage of both the power supply circuits IL300 was 5.01 V. Measurements were repeated 10 times for each input voltage from 0 to 5V. The Circuit with the TL431 was set to limit voltage 2.95V. Zener diode was used according to the manufacturer for voltage 3V.

B. Static input / output characteristics measurement used equipment

Multimeters Agilent 34410A were connected to a computer via USB. Agilent E3632A Programmable source was connected to a computer via GPIB and GPIB converter / USB.

- Programmable input voltage source Agilent 3632E
- Voltmeter "D" Agilent 34410A to measure the input voltage
- Voltmeter "A" Agilent 34410A to measure the circuit with IL300 output voltage
- Voltmeter "B" Agilent 34410A to measure the circuit TL431 output voltage
- Voltmeter "C" Agilent 34410A voltmeter to measure the input circuit with Zener diode voltage circuit

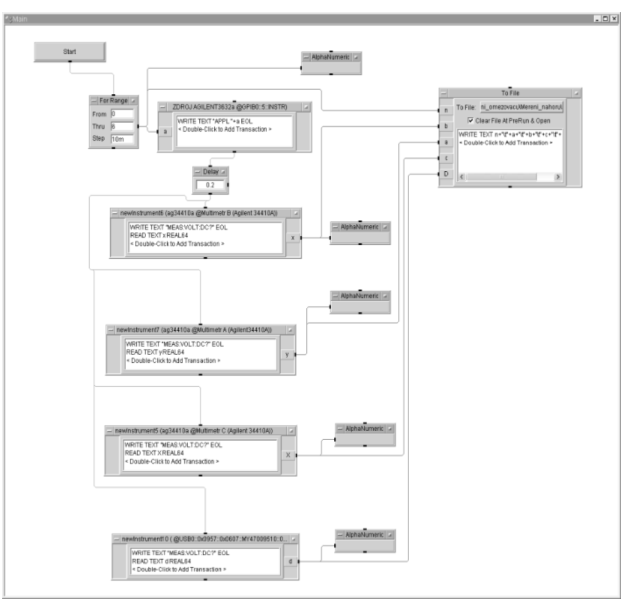

Fig. 4 Program in VEE Pro 9.0 for the automatic measurement

C. Dynamic input / output characteristics measurement

Dynamic input / output characteristics measurement is a method for finding dynamic characteristics. Circuit inputs are connected to a known time-varying DC signal. The Signal from the generator was plugged through shielded cable to one oscilloscope channel input and next three tested circuits outputs were connected to next three oscilloscope inputs and circuits outputs signals are compared with signal from generator. The maximum voltage was set lover than saturation voltages of these circuits. The testing signal was used the square wave signal. Measurements were carried out using the following equipment. The input voltage was chosen in the range of 0 to 5 V. The testing signal frequency was 10 kHz which is sufficient for this measurement.

D. Dynamic input / output characteristics measurement used equipment

- Agilent 33220A Function / Arbitrary Waveform Generator, 20 MHz as source of signal
- Agilent DSO6104A Oscilloscope: 1 GHz, 4 channels
- 3x N2862A Passive Probe, 10:1, 150 MHz, 1.2 m
- Probes were compared and set to the same gain.

E. Strejc identification method

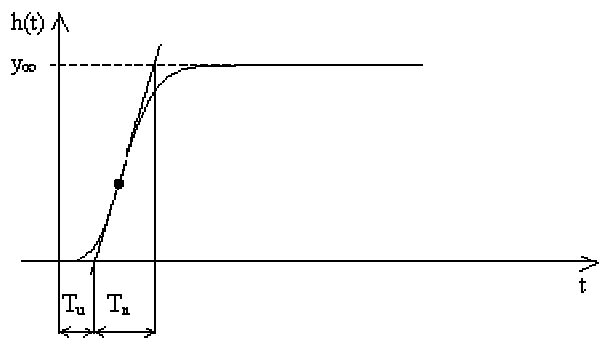

Fig. 5 The aperiodic step response with displayed a rise time and a delay time¨

If the step response of the controlled system has an aperiodic train, we can approach it by a second order proportional plant with a different time constants or by a n[th] order proportional plant with a same-time constants. The choice of the type of the model's plant is dependent on a

parameter τ, which is computed as:

$$\tau = \frac{T_u}{T_n} \tag{7}$$

where: T_u – delay time, T_n – rise time

If the parameter τ is smaller than 0.1, we choice the proportional plant with a different time constants, else we choice the proportional plant with same-time constants τ<0.1 ⇨ Will be approximation in form $$G(s) = \frac{K}{(T_1 s + 1) \cdot (T_2 s + 1)} \quad (8)$$

τ≥0.1 ⇨ Will be approximation in form $$G(s) = \frac{K}{(Ts + 1)^2} \quad (9)$$

VI. USED CIRCUITS

The test module was created on which all three above mentioned circuits were placed. For the circuit with the linear optocoupler IL300 connection was used the same schematic as in the datasheet for IL300. The circuit with programmable voltage reference LM431 was used in the second circuit with behaving as an ideal zener diode. Saturation voltage was set to 2.9V. Circuit with common zener diode was used only for comparison.

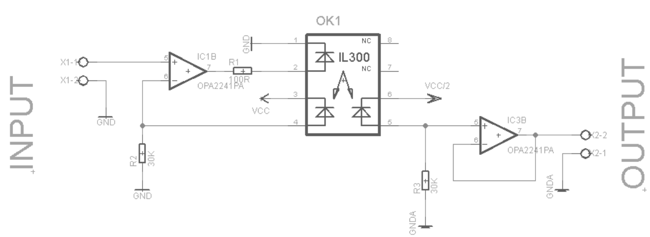

Fig. 6 The circuit schematic used: a) with IL300 linear optocoupler

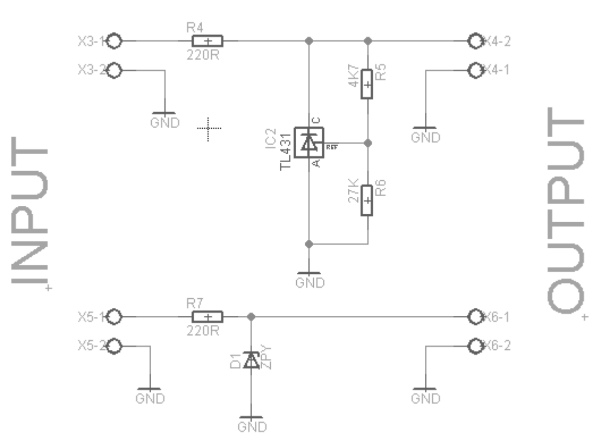

Fig. 7 Circuit schematics used: b) with the voltage reference LM431 circuit, c) with the common Zener diode

VII. CIRCUITS MEASUREMENTS AND IDENTIFICATION

A. *Static input / output characteristics measurement*

The first step was to measure input/output characteristic. 9 This characteristic shows figure 9. The DC voltage was used on all inputs of the three tested circuits. The input voltage was chosen in the range of 0 to 6 V. The step input voltage was 10mV and measurements were repeated tenfold.

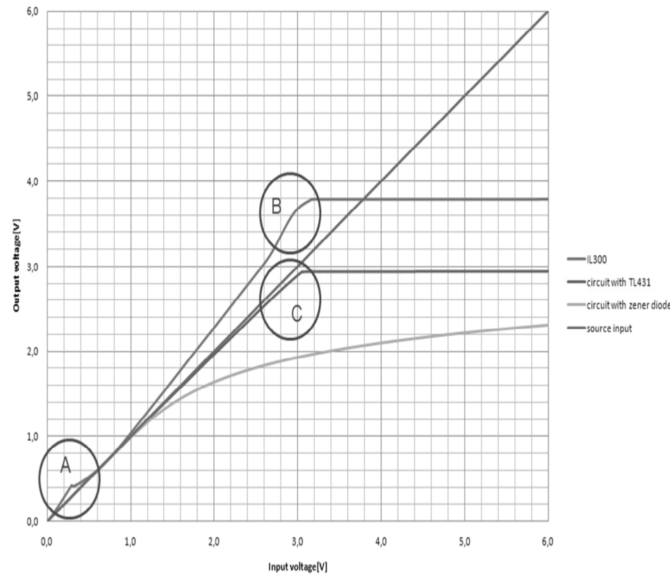

Fig.8 Static Input / Output characteristics of measured circuit

The circuit with a linear optocoupler IL300:

The resulting characteristics show several nonlinearities (area "A", "B") and the resulting deviation from the input voltage is determined by the increased gain of operational amplifiers, which can remove the appropriate circuit connection. R_3 was set from 30kΩ to 21.8kΩ

Circuit to circuit TL431:

The resulting highly linear characteristic and the resulting deviation from the input voltage

(Area 'C') are caused by from the circuit consumption and from the current through resistors R5 and R6.

Zener diode circuit:

As evident from the chart below, the Zener diode circuit has poor properties and it is listed here only for a comparison.

A. *Dynamic input / output characteristics measurement*

As the second step it was measured input / output dynamic characteristics. the square wave signal was used as The testing input signal. The testing signal frequency was 20 kHz and the duty cycle was 50%.

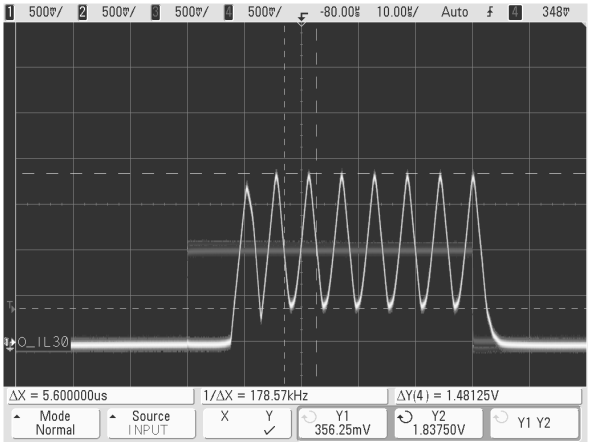

Fig. 9 The input / output dynamic characteristic

As can be seen in Figure 9, there was a very high output oscillation. Output is lighter trajectory and input is darker trajectory. It did not make any difference if the amplitude or the frequency of the input signal was changed. The same oscillation on the same amplitude and frequency is also when the DC invariable input was used. The oscillation frequency was 178.6 kHz and the amplitude was 1.49 V. When 1 nF capacitor was added to the input operational amplifier negative feedback and the ground, the oscillation was removed. In figure 11 output is lighter trajectory and input is darker trajectory.

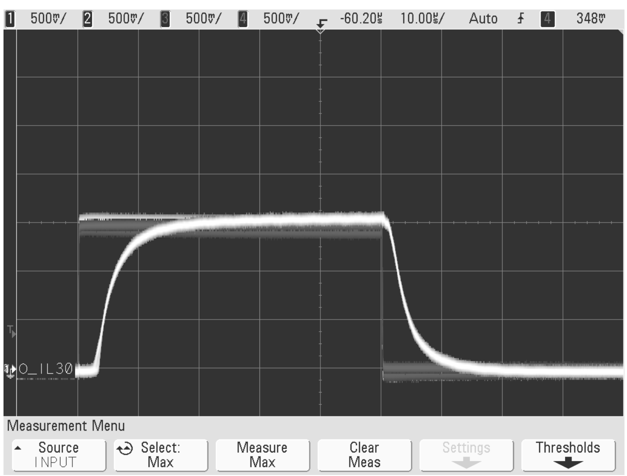

Fig. 10 The input / output dynamic characteristic after the intervention to circuit

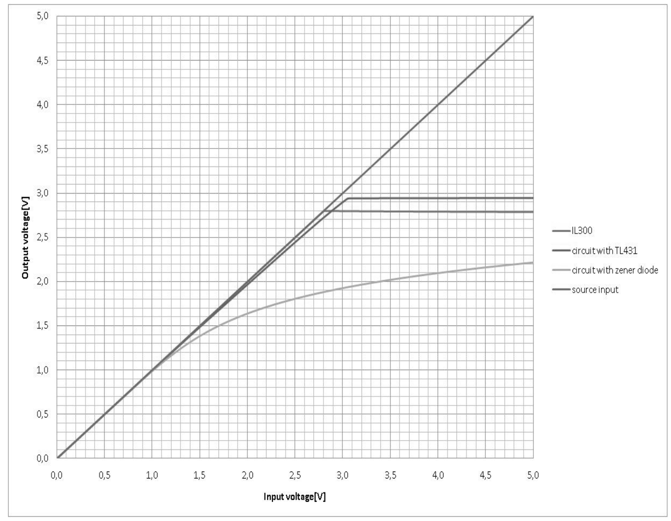

Fig. 11 The static input / output characteristic after the intervention to circuit

Figure 11 shows the static input / output characteristic after the intervention to circuit. It is evident from the figure hereinbefore the output signal from circuit with IL300 strictly imitates that of the input signal from generator.

B. Circuit with IL300 identification

As is evident on the figure 8 output from the circuit with I300 has the aperiodic train, therefore it would be used the Strejcs identification method. In this case after the step change of the signal follow a insensitivity zone which has a duration 2.35 µs. It stands to reason the insensitivity zone does not depend on the input frequency. It was used the Strejcs identification method for identification. $\tau<0.1$ thereby It was chosen the transfer function with the different time constants. Resulting transfer function of the circuit with IL300 is in the form

$$G(s)=\frac{1}{(0.8698s+1)\cdot(1.615s+1)} \qquad (10)$$

Next step was system simulation using software Matlab Simuling.

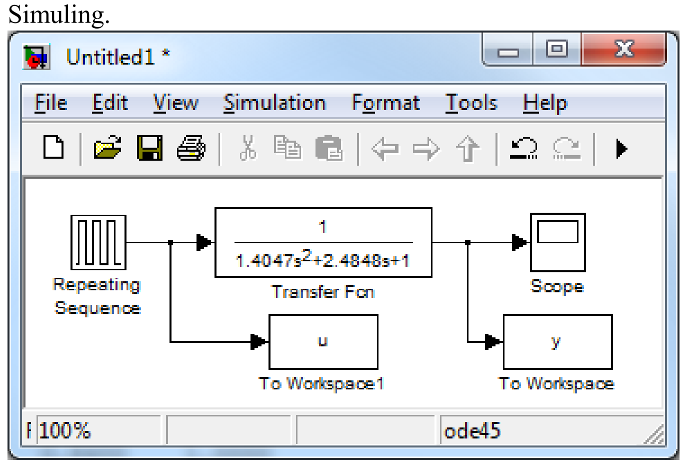

Fig. 12 The schematic in Matlab Simuling

Simulation in the Matlab was done and hereinbefore the curves strictly imitates the output signal from the circuit with the IL300 as can be seen in picture bellow.

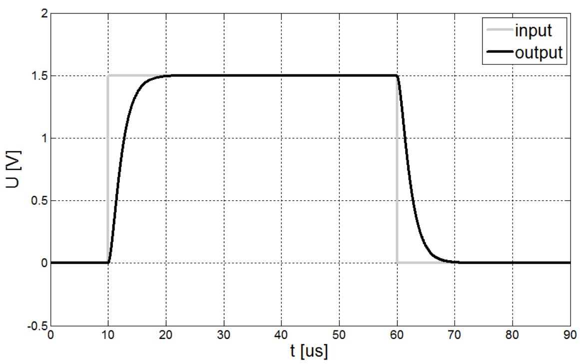

Fig. 13 The simulation in the Matlab Simuling

VIII. Discussion

For measure static input/ output characteristics was created the program in the VEE 9.0 PRO. Principles for find dynamic characteristics other protections of inputs and outputs were described and demonstrated on found circuit with IL300 behavior and mathematical description.

Another part of the work in the next period is a mathematical description of the behavior of another protections of inputs and outputs.

IX. ACKNOWLEDGMENT

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