FIBER OPTIC METHANE SENSOR USING DIODE LASER NEAR INFRARED RANGE

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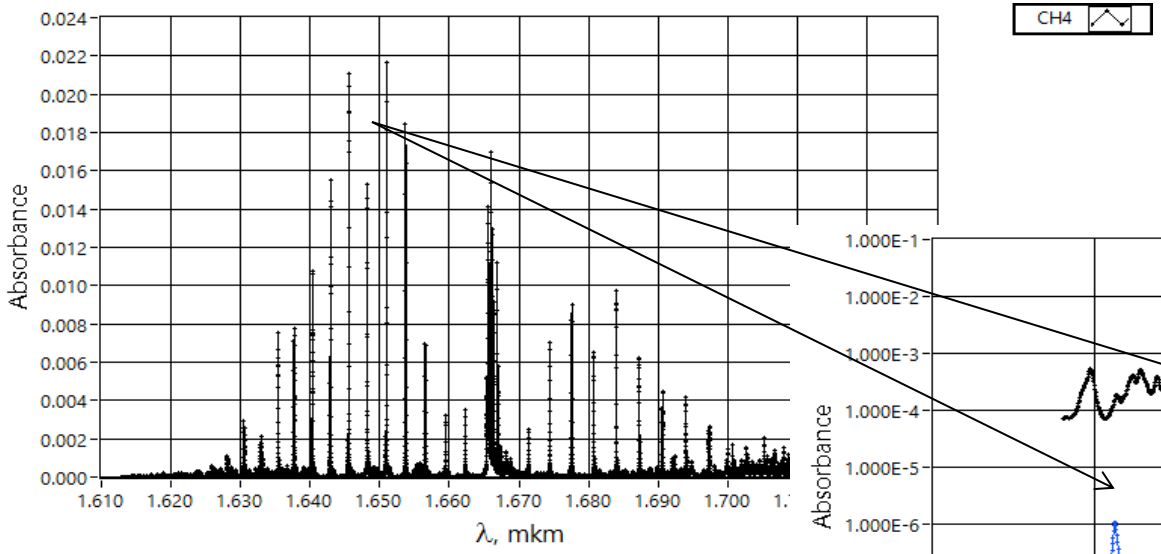
INTRODUCTION

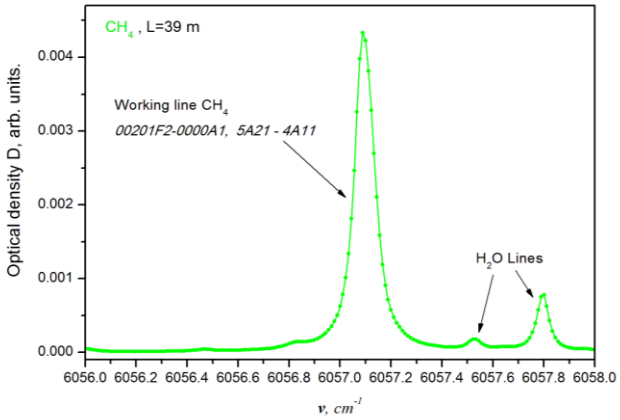
◆ Methane concentration monitoring in hazard areas is an important task for many applications (coal, oil, natural gas industries, etc.). Minimum CH4 concentration in the air when explosion is possible is 5 % and its measurement below 3 % is necessary. Additional requirement for some applications: no even low voltage electricity is allowed in hazard area. It means that all information transfer from control point to hazard area and back has to be done by light. Distance between control point and hazard area can be around 50 km. The sensor has to operate in hard environment conditions with high sensitivity and performance: temperature from -30 to 50 ^{o}C, high humidity and dust.

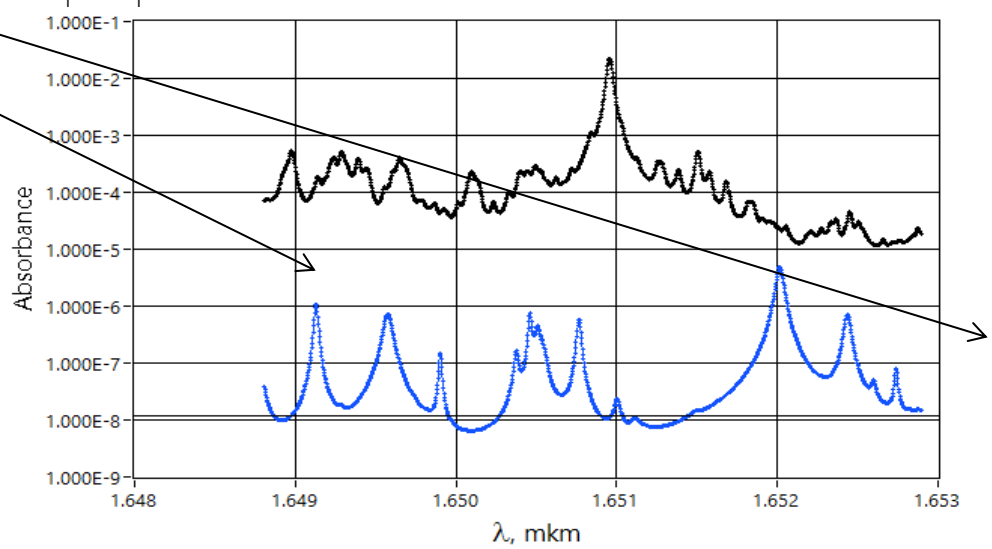
◆ NEL DL (1.651 μ) was used as a light source. Its radiation was transferred by 50 km single mode fiber cable to hazard area (dashed rectangular). To model it, a glass box (V = 8 liters) was used during tests. Analytical cell (L = 5 cm) was installed inside the box. After passing the analytical cell, DL radiation was focused in the other 50 km single mode fiber cable to transfer it to PD located at the control point.
During the tests carried out the glass box was filled with a known amounts of methane. Minimum detectable concentration (3σ) was 60 ppm at 50 ms response time. The results of experiments demonstrated a feasibility of CH4 remote sensing with the above mentioned requirements.

SPECTRAL RANGES

- We have selected spectral range: near 1,65 μm (CH_4).
- Experimental spectra:

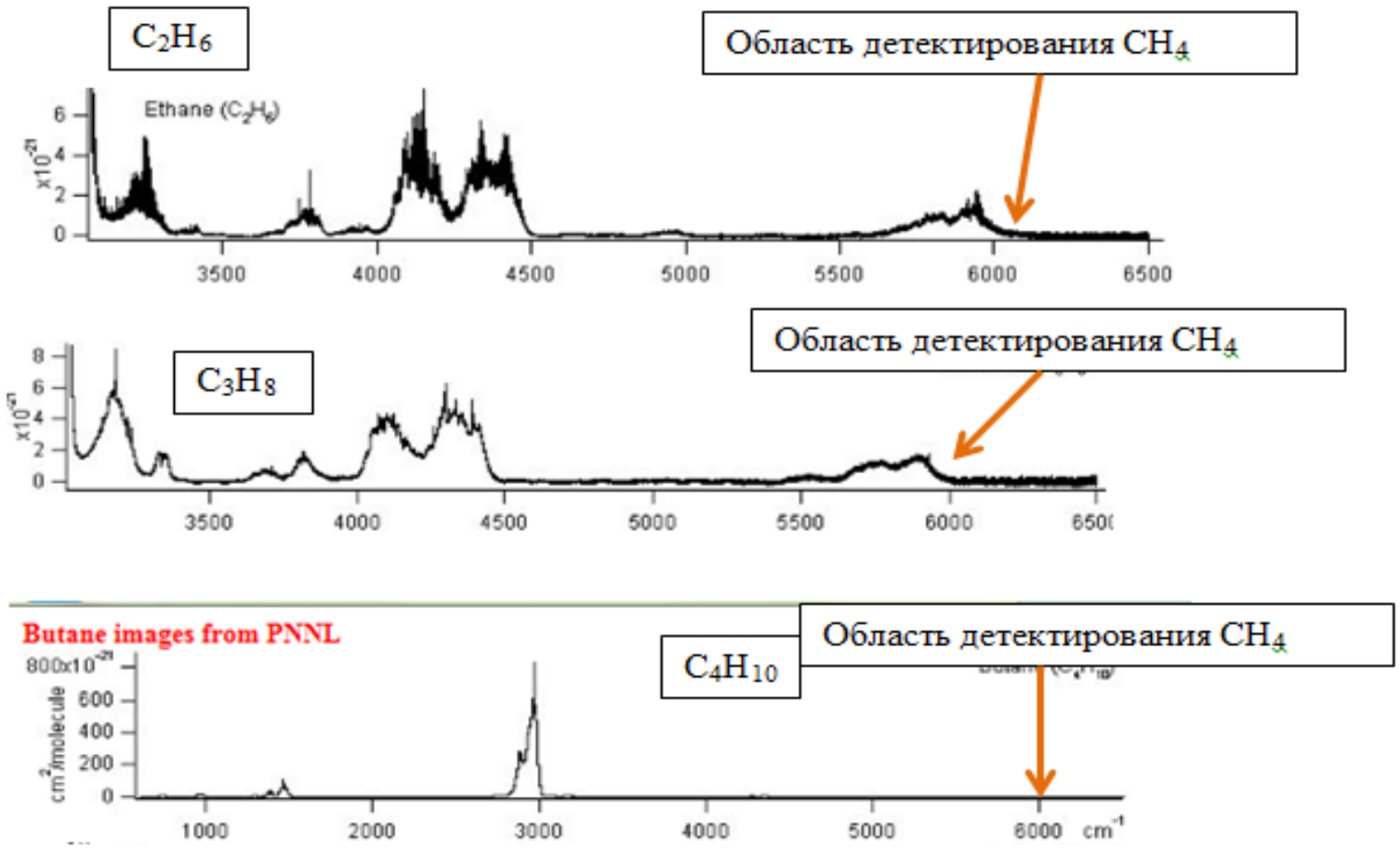






Analytical line of CH_4 in region of DL generation (black). Blue - water lines. Concentration H_2O and CH_4 is 1% in atm. Optical path 5 cm.

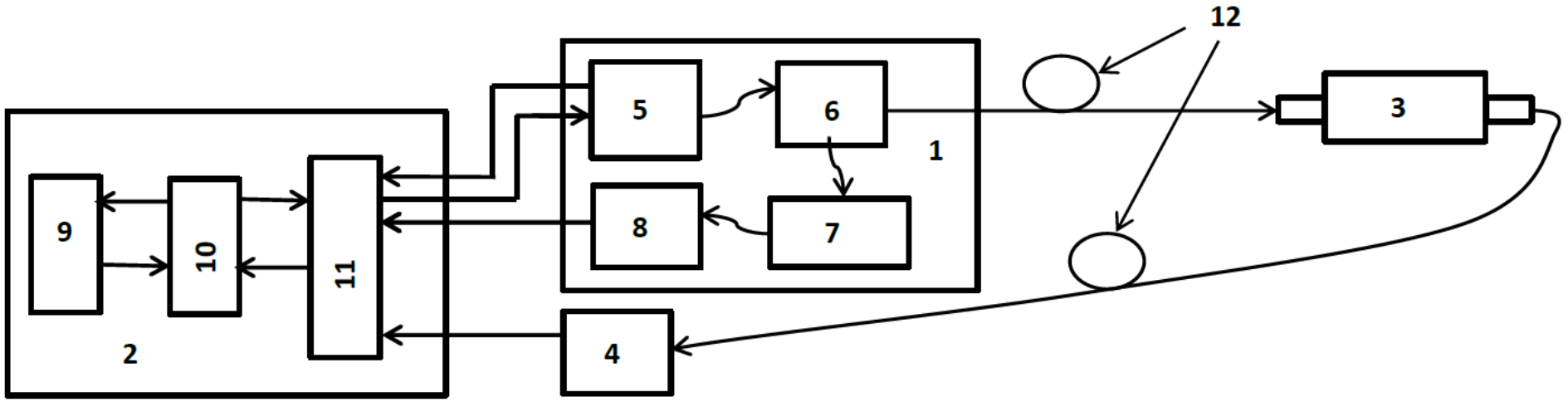
THE INFLUENCE OF LIGHT HYDROCARBONS FROM METHANE COLLECTION ON METHANE REGISTRATION



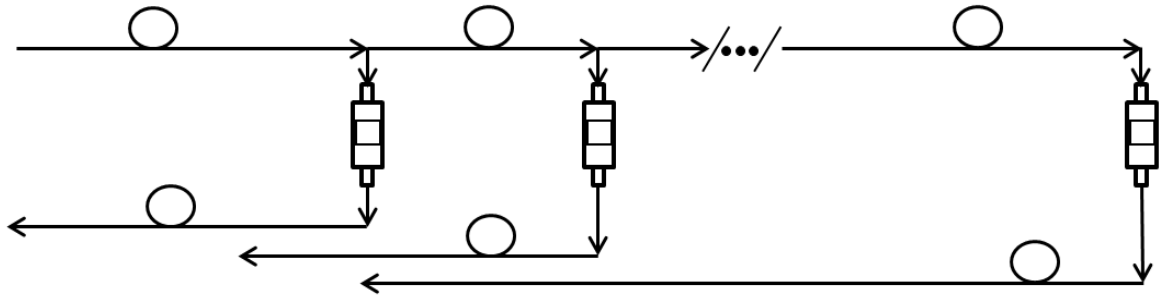
Absorption spectra of ethane, propane and butane in near IR region.

Analytical line of the methane has a high selectively and provides high sensitivity in the detection of CH_4 by use DLS method.

TDL SPECTROMETER BLOCK-SCHEME



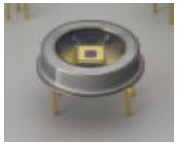
- 1-block laser radiation, 2 - control unit, for receiving and processing data 3 - analytical cell with fiber input and output, 4 - detector analytical signal, 5 - module diode laser, 6 - fiber splitter, 7 - cell comparison, 8 - signal detector comparison, 9 - programmable digital module, 10 - module DAC and ADC, 11 - module converters analog signals, 12 - fiber optical cable.



Increase analytical channels in parallel connection circuit

TDL SPECTROMETER

◆PD – Hamamatsu photonics InGaAs photodiodes, ø 1 mm, $D^* = 1.5 \cdot 10^{12}$ cm·Hz$^{1/2}$/W



◆DL – NTT Electronics diode lasers

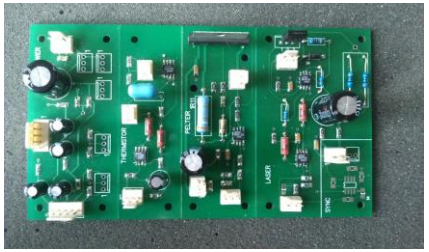
DFB, λ=1.65 μm and λ=1.60 μm

fiber single mode

P=15 mW. Pulse duration 1-2 ms

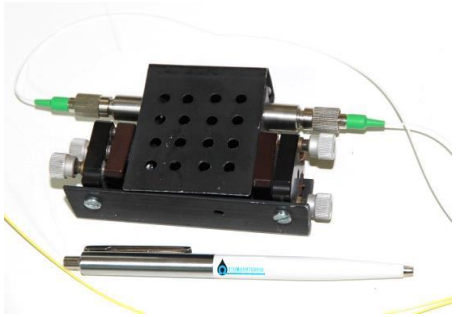
◆NI DAQ – National instruments multifunctional DAQ board NI USB 6289

◆Electronics – DL current and temperature control board, amplifiers

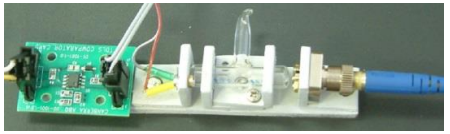


TDL SPECTROMETER

◆Analytical cell - Optical system, with single mode fiber input and output into cell. Optical length 5 cm, physical volume 60 ml.



◆Reference cells – glass cell with reference gas.
CH_4 L=4 cm, P_{CH4}=56 Torr in 1 Atm N_2

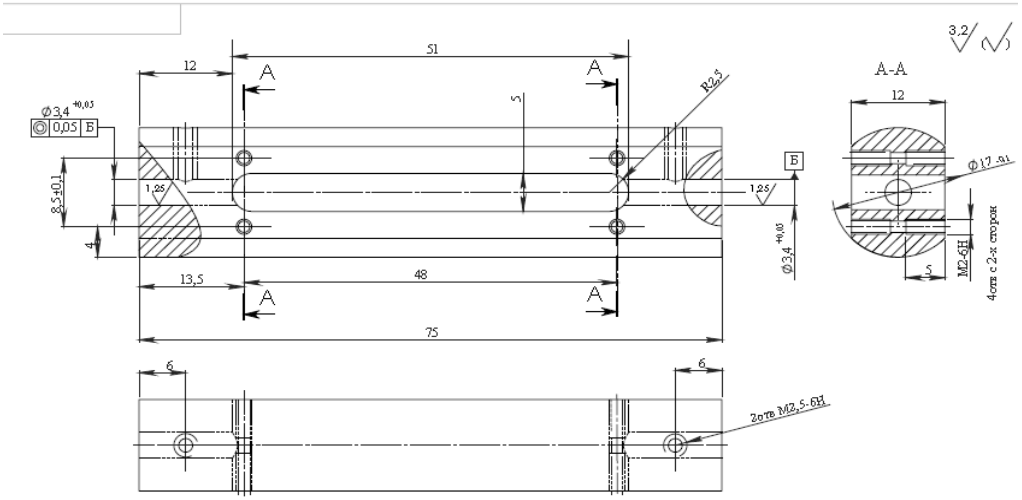


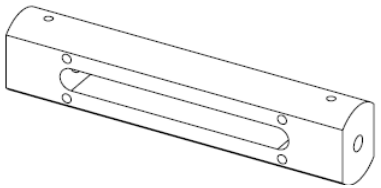
◆For ease of use all optoelectronic components TDLS placed in the system unit of a personal computer (PC)

◆GRIN Fiber optics collimators

THE NEW VERSION OF THE ANALYTICAL CELL

◆Analytical cell - ” stainless monolith” fiber optical cell. Length 5 cm , V= 20 ml. T regime +/- 40 ^{0}C.





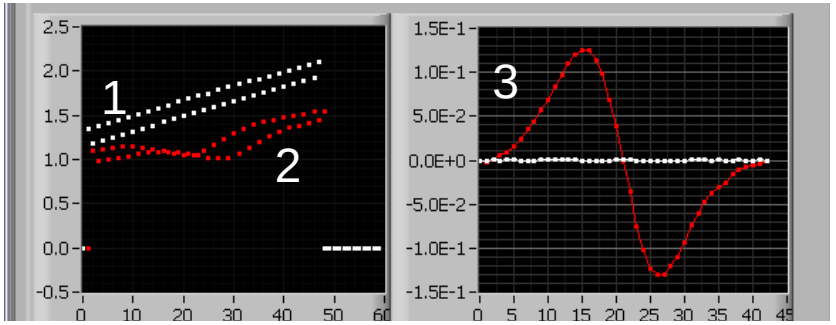
1.H12, h12, ±IT12/2.
2.Острые кромки притупить.
3.Остальные ТТ по ГОСТ 25069-81.

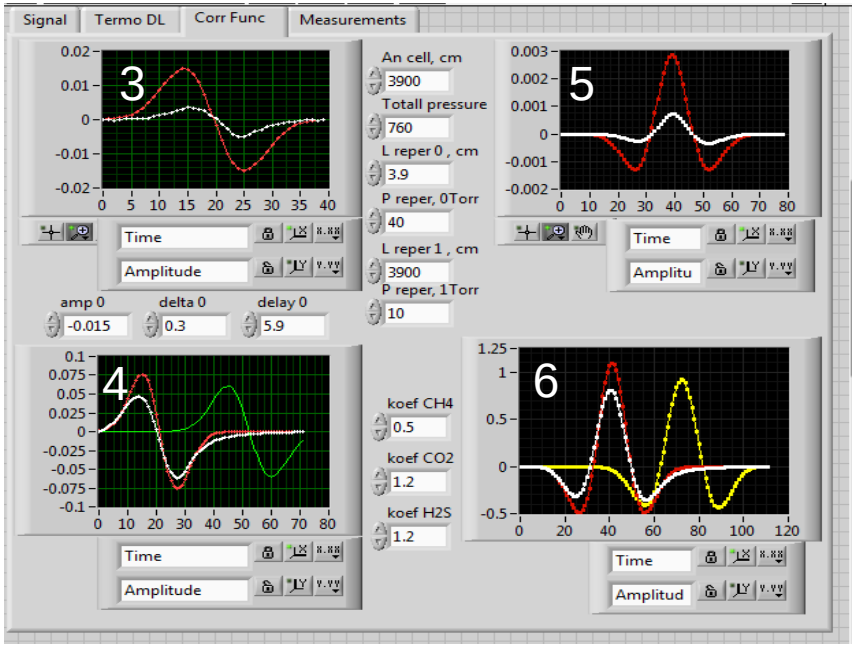
					ОПТЭ.201.015		
Изм.	Лист	№ докум.	Подп.	Дата	Кювета	Лит.	Масса / Масштаб
Разраб.							87г / 3:1
Пров.						Лист	Листов 1
Т.контр.							
Н.контр.					Сталь 12Х18Н10Т		

SOFTWARE

◆ Software for DL spectrometer is based on NI LabView 2014.

DL is excited by trapezoidal current pulse with modulation (1). In presence of molecular absorption two lines can be observed due to modulation (2). Using these data computer calculates signal looking like line first derivative (3) and filters it by correlation with model function (4). Reference signal used for DL frequency scan stabilization (5) and analytical – for concentration calculations (6).





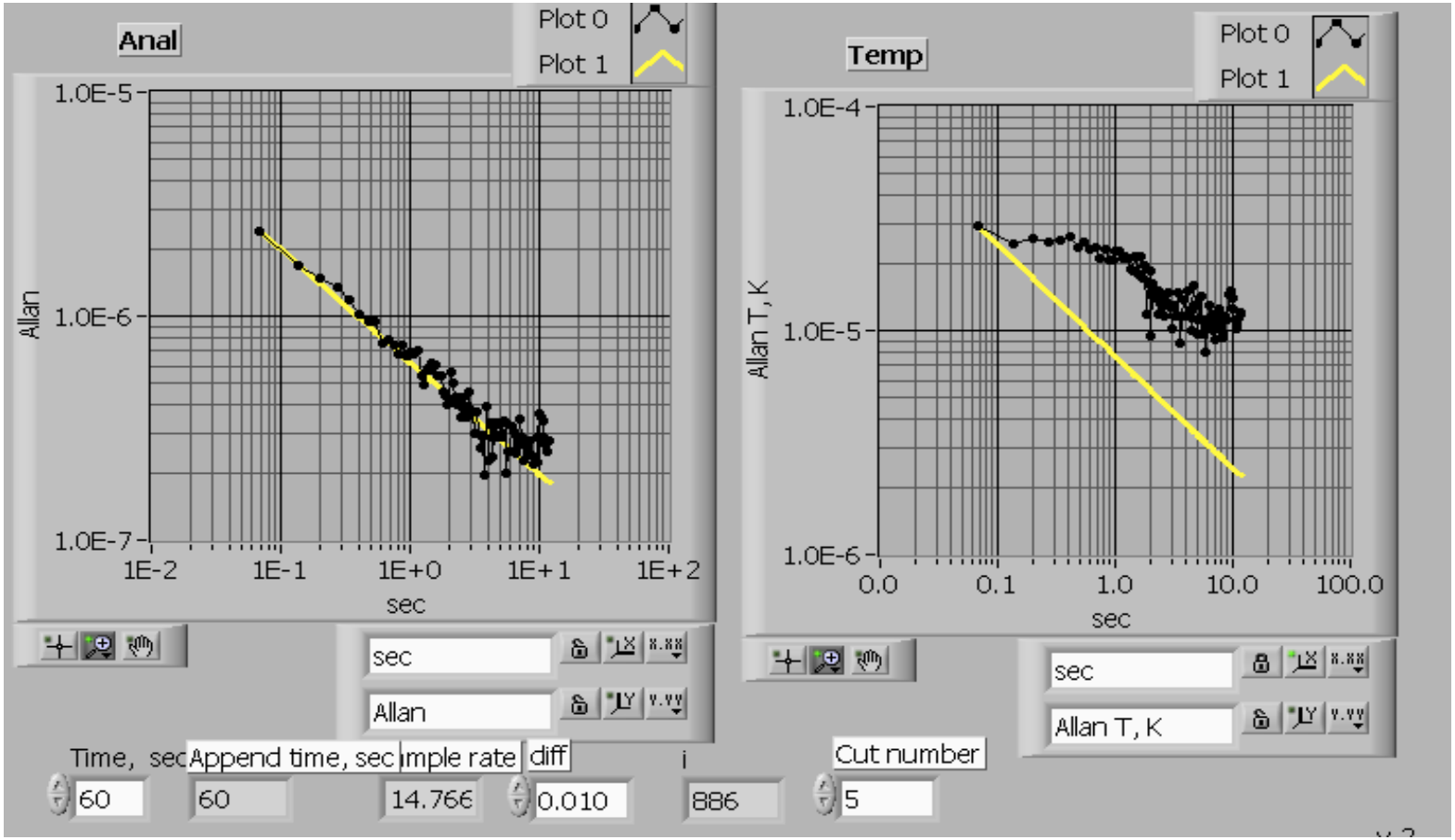
◆ Concentrations:

$$C = \frac{\alpha \cdot P_r \cdot L_r}{P_a \cdot L_a} \cdot 10^9, [ppb]$$

$$C_{xy} = \alpha \cdot C_{xx}$$

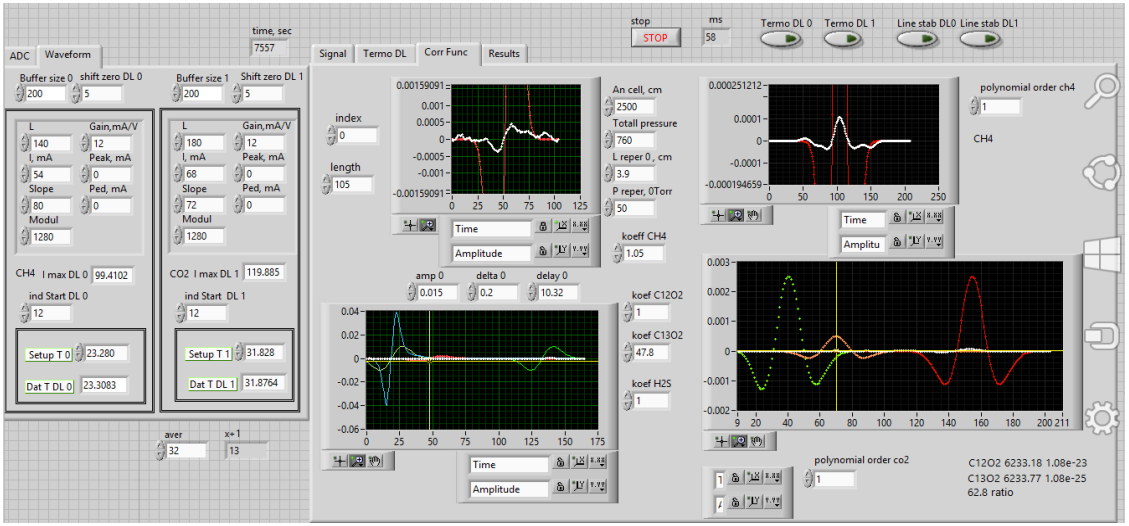
P_r – reference pressure, L_r – reference optical path, P_a - pressure in analytical cell, L_a – optical path in analytical cell. C_{xy} - cross correlation of model function and signal first derivative (white on 6), C_{xx} – autocorrelation of reference model function (red on 6).

Allan plots



To determine the minimal detectable absorption of impurities, the Allan procedure was used. In Fig.(left) the Allan variance of the absorption is plotted versus the averaging time. It is seen that the minimal detectable absorption at the path length 2 m
approaches 3 10^{-7} for the averaging time 3 s. Right- Allan variance instable Dl temperature. For these time averaging Allan T approaches 1.5 10^{-5} ^{0}C.

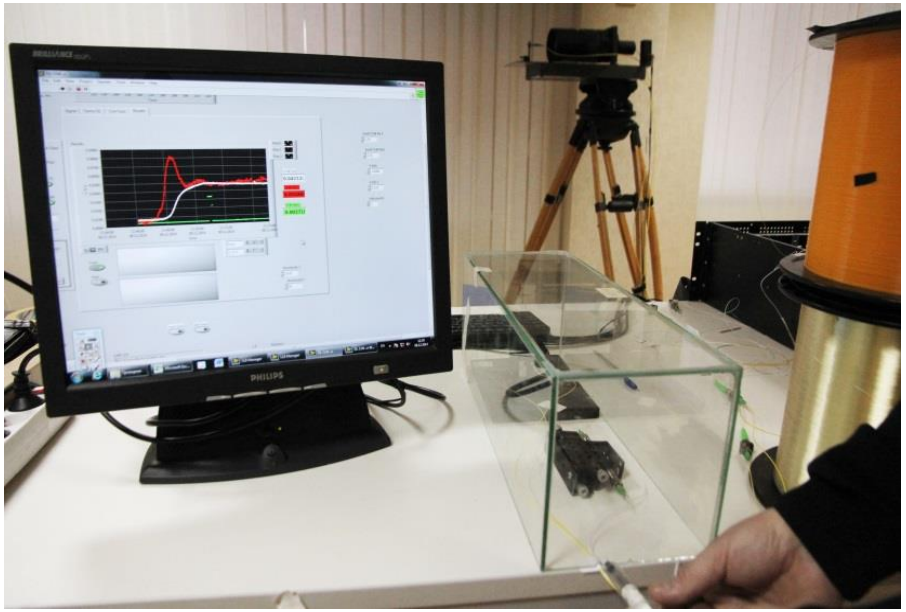
SOFTWARE CONTINUE



◆ Left working window - simultaneous correlation processing signal from DL. Linear regression for obtain concentration CH_4ю

◆ Right working window - Display visualization results of real time measurements concentration CH_4. Single time is 30 мс. Sensitivity is 0.02 Vol. %.

CALIBRATION TEST

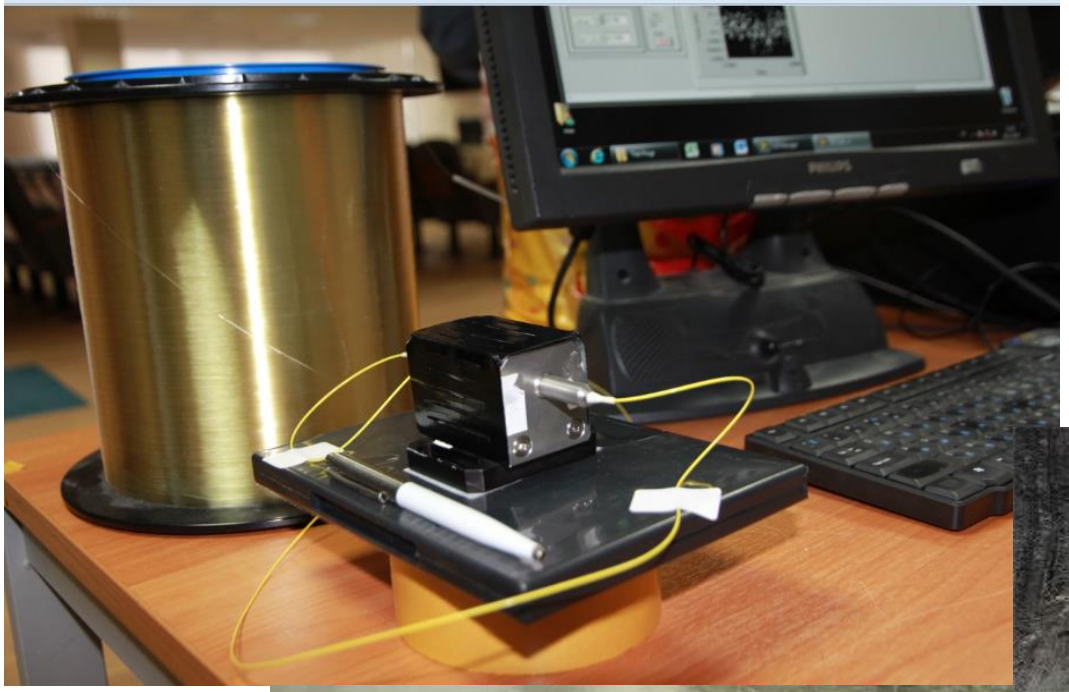


We used the glass cube for measure response time and calibration of methane concentration. The cube volume is 11 liters. By use the syringe in to cube was injected calibration gas mixture of methane and nitrogen in a ratio of 1/100.

Sensor Response Time (gas diffusion) is less then 30 c.

PRACTICAL APPLICATION

Distance between control point and hazard area can be around 50 km. The sensor has to operate in hard environment conditions with high sensitivity and performance: temperature from -30 to 50 ^{o}C, high humidity and dust.



TECHNICAL CHARACTERISTICS

• Measured component:	CH_4
• Frequency detection range	1,651 mkm
• Power of DL radiation	10 mW
• Detectivity	less then 0.02 % Vol
• Operating Temperature	-30 +50 ^{0}C
• Operating Humidity	0 to 95% RH, non-condensing
• Линейная зависимость измерения концентрация	до 10 % объема
• Sensor Optical Path	50 mm
• Sensor weight	200 g
• Maximum Link Distance	more then 50 km
• Number of Sensing Points	up to 5 points
• Operating Temperature of sensor	-45, + 55 ^{0}C
• Sensor Response Time (gas diffusion)	30 s
• Warm-up period	10 m, T=23 ^{0}C
• Control Unit Weight	8 kg
• Dimensions	480*560*360 mm
• Electrical Power Requirement	115/230V AC, 50/60Hz