Budker Institute of Nuclear Physics

(BINP)

Siberian Branch of
Russian Academy of Sciences

BINP Developments of Hydrostatic Level Measuring System for Slow Motion Studies

Authors of work:

B. Baklakov
M. Gladkov
A. Chupira
A. Erokhin
M. Kondaurov
A. Medvedko
V. Parkhomchuk
Sh. Singatulin

Presented by Anatoly S. Medvedko

Workshop on Ground Motion in Future Accelerators
SLAC
November, 6 to 9, 2000

Introduction

Investigations of seismic and slow ground motion influence on the particle accelerators are going for many years, but especially intensive work began approximately 15 years ago when projects of really Large machines are started seriously to develop. It means - SSC, LHC, NLC, VLEPP, etc.

First BINP publications concerning to this problem with some experimental results shows up at the beginning of 1991.

One of them is:

B. A. Baklakov, P. K. Lebedev, V. V. Parkhomchuk, A. A. Sery, A. I. Sleptcov and V. D. Shiltsev «Investigation of Seismic Vibrations and Relative displacement of Linear Collider VLEPP Elements», *Proc. of 1991 IEEE Particle Accelerator Conference,* San Francisco, USA, May 1991, p. 3273.

During some of the following years this team (slightly modified from time to time) had made a lot of measurements through all the World.

This our report will have for an object the equipment for providing of this kind of measurements.

So, the next plan of report we have:

1. Hydrostatic Leveling System of 1998 for FNAL
   Fogale Hydrostatic Level Sensor
   Configuration of Hydrostatic Leveling System
   The Slow Data Acquisition System Module
   Some results.

2. BINP Hydrostatic Level Sensor

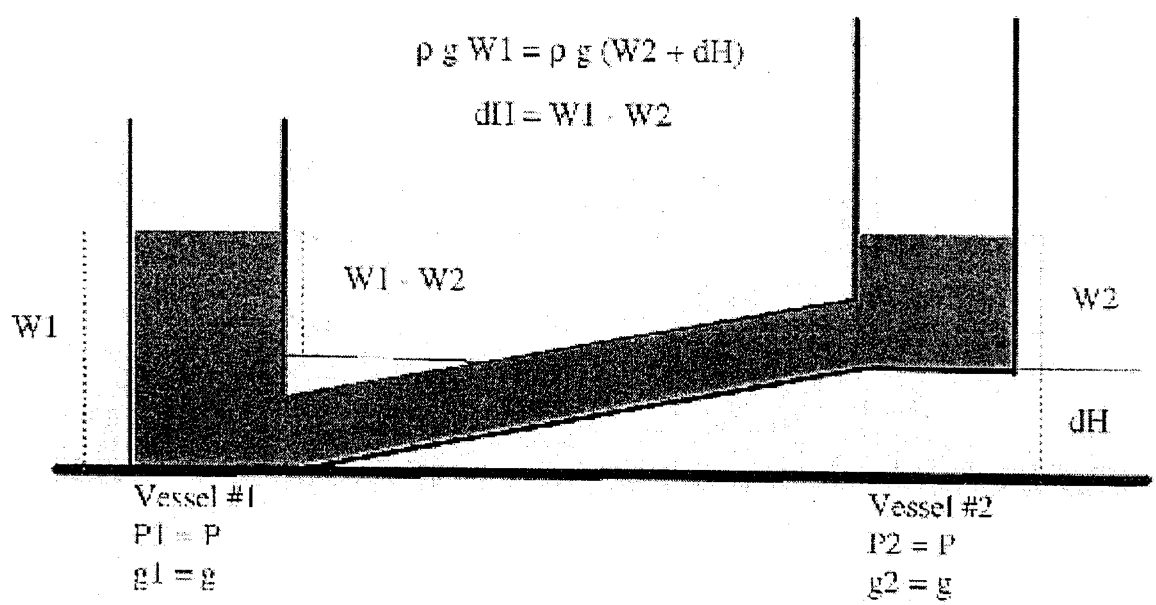
3. New configuration of Hydrostatic Leveling System

1. Hydrostatic Leveling System of 1998 for FNAL

For the Hydrostatic Leveling System that had been developed by BINP for FNAL during 1998 - 1999 years we had used the Hydrostatic Level Sensors developed and manufactured by Fogale Nanotech corporation. The Sensor is designed to measure the liquid (water) level with a very high sensitivity to variations of liquid level. Each Sensor vessel is linked to its neighbors by a system of pipes (Tubes).

Hydrostatic Leveling System (HLS) is based on principle of equilibrium of the pressure of liquid in communicating vessels.

Figure below shows a schematic of the principle. Assuming that the liquid used has a homogeneous density «ρ» and the gravitational force «g» and air pressure «P» are the same at both vessels, one can deduce the elevation difference between two vessels merely by subtracting the measured height of the liquid column at each vessel from the other. It can be assumed that the gravitational forces are almost identical at two vessel locations.



An air circuit between the vessels is usually used to maintain the system at the same atmospheric pressure. A small opening only at one air pipe usually enought. The pressure from that location is distributed to all other vessels.

Water, mixed with an anti-bacterial agent, is the reference fluid.

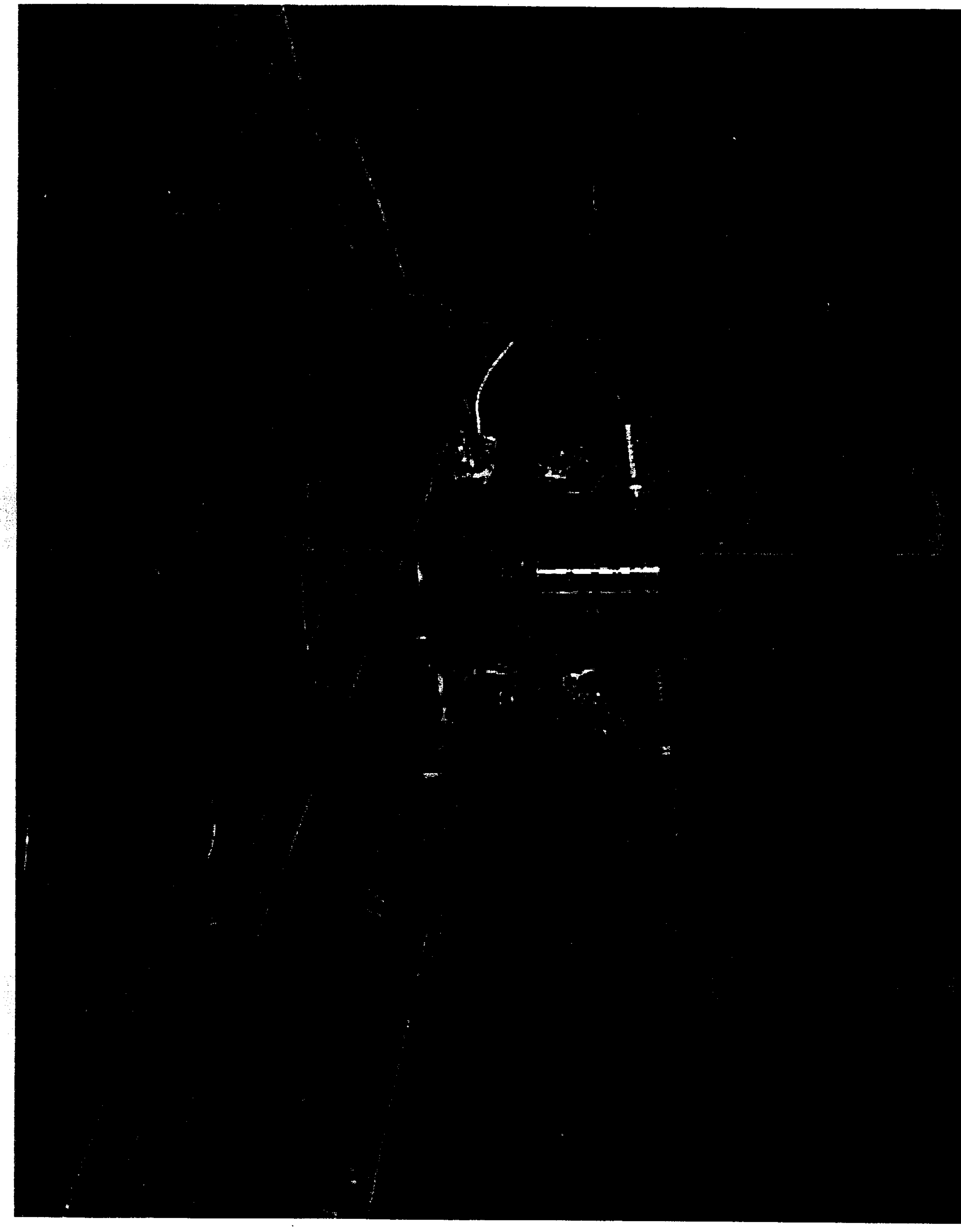
Fogale Hydrostatic Level Sensor

The Sensor (Probe) consists of vessel, capacitor sensor of liquid level displacement and temperature sensor. The vessel has a shape of barrel with four outlets for connecting with neighbor vessels by plastic pipes of air's and water's circuits. There is a special cavity in the vessel body for placement of a temperature sensor. The capacitor sensor also has a shape of barrel and usually is placed on top of the vessel. Both the vessel and the sensor body are made out of stainless steel.

Fogale Nanotech Sensor have the next parameters:

Parameter	Unit	Value
Measurement range	mm	2.5
Vertical distance between electrode and water surface	mm	6 to 8.5
Resolution in case of 16 bit ADC used	µm	+/-0.1

Each HLS is equipped with platinum PT100 thermal sensor inserted into own vessel. The uncertainty of temperature measurements is +/- 0.1 ^{0}C.
Internal electronics of HLS forms output voltage signals for displacement and temperature in range: 0-10 V. The signals linear with displacement and temperature. The HLS output signals have a small non-linearity, which typically approximated with third order polynomial function.



Configuration of Hydrostatic Leveling System.

The System developed for the FNAL was installed at PW6 - PW7 beam line at the September of 1999. It includes 6 Fogale - Type Sensors, positioned with the 30m - 30m - 60m - 30m - 30m intervals joined with system of Water Filled Tubes and Air Filled Pipes. Air Filled pipes have one small opening to atmospheric air.

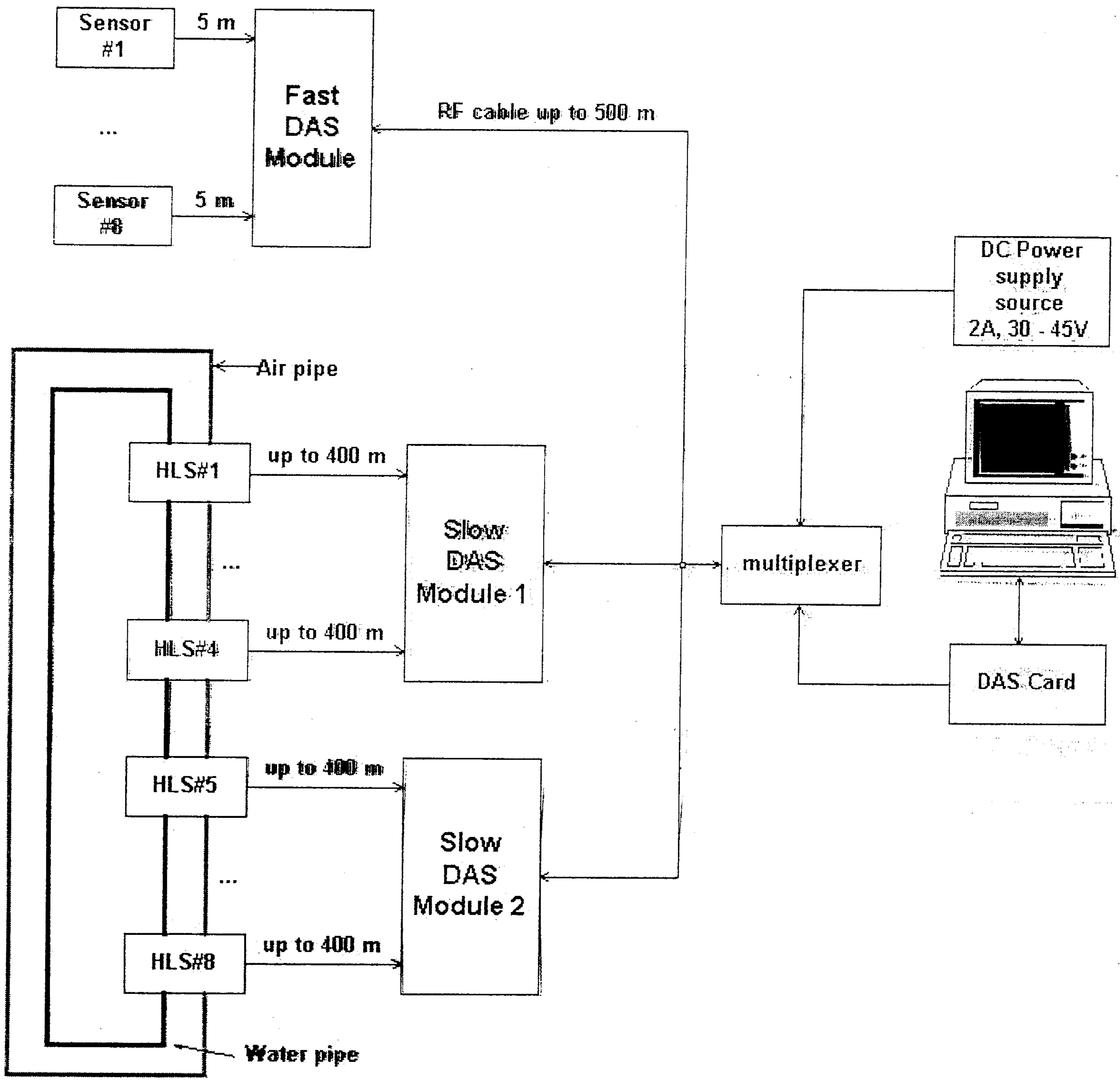
The configuration of the System is presented at the Function Diagram below. Besides the Sensors and water/air filled components the System includes two Slow Data Acquisition System Modules (DAS Module) placed inside the tunnel of beam line. The maximal distance between Sensor and DAS Module was about 300m. ***(They are Analogue Signal Lines.)***

The Power Supply and PC are installed outside tunnel; communication of PC with Modules in tunnel is in digital format.

As we pointed earlier, we use in the system

The Tubes Fully Filled with water.

As for all another systems, it is obvious that Hydrostatic Level Sensors of the system are mounted on special support plates fixed to ground.



Block Diagram of the Hydrostatic Leveling System for Slow Ground Motion Measurements at FNAL PW6-PW7 Tunnel.

The Slow Data Acquisition System Module.

Purpose of Slow DAS Module is to serve up to 4 Fogale Nanotech Type Hydrostatic Level Sensors with their temperature sensors, to digitize all input signals and to transmit the digitized values into the PC for data processing. Input signal bandwidth should be from DC up to 2 Hz.

Slow DAS Module has remote mode of control that can install quantity and serial number of the input channels for digitizing and determine the sequence of digitizing input signals.

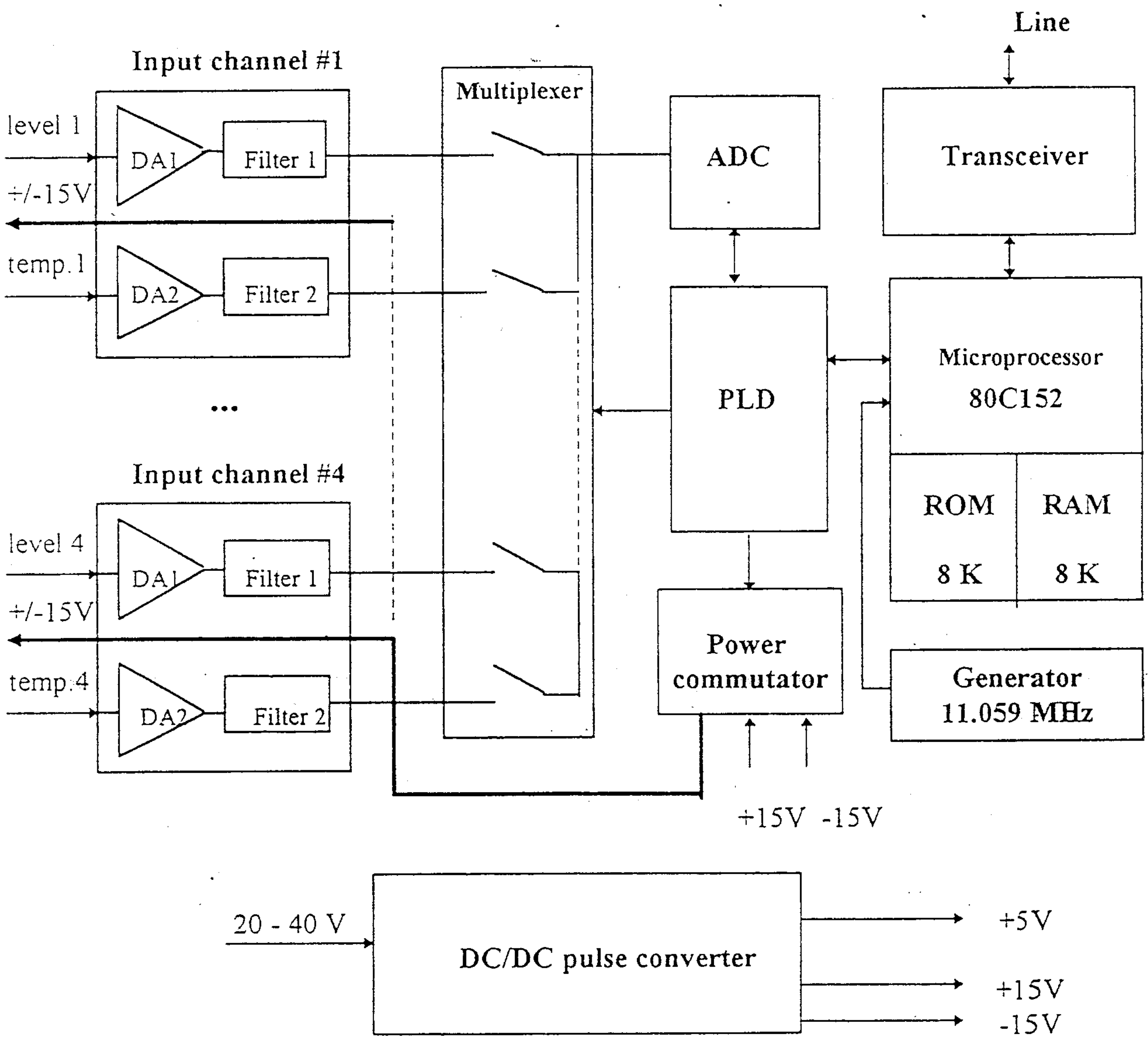
The Slow DAS Module includes 8-channel, 16-bit ADC, Programmable Logic Device of the Altera Manufactured (PLD), single-crystal 8-bit Microprocessor 80C152 type of the Intel Corporation with on-chip fast communication serial interface, buffer Transceiver for serial interface, two memory banks (8K ROM and 8K RAM), Power commutator and DC/DC Switch mode converter.

The electronic circuitry of the Slow DAS Module is similar to the electronic circuitry of the Fast DAS Module developed by BINP earlier. It has the same Multiplexer, ADC, Programmable Logic Device, Microprocessor 80C152, Transceiver, two memory banks and DC/DC pulse power converter.

Each of four Input Channel of the Slow DAS Module consists of two differential inputs: one is intended for level signal of the Hydrostatic Level Sensor and other for temperature signal of the Sensor. The Sensor's level signal goes through differential amplifier DA1 and active 4-order low pass filter (Filter 1) with constant cut-off frequency 2Hz. The temperature signal goes through the similar differential amplifier DA2 and active 1-order low pass filter (Filter 2) with cut-off frequency 2Hz also.

Power commutator serves as power switch for Sensors supply voltages. With help of the Power commutator one can switch on/off supply voltages for individual Sensors.

Operational principle of the Slow DAS Modules is the same as one of the Fast DAS Module.

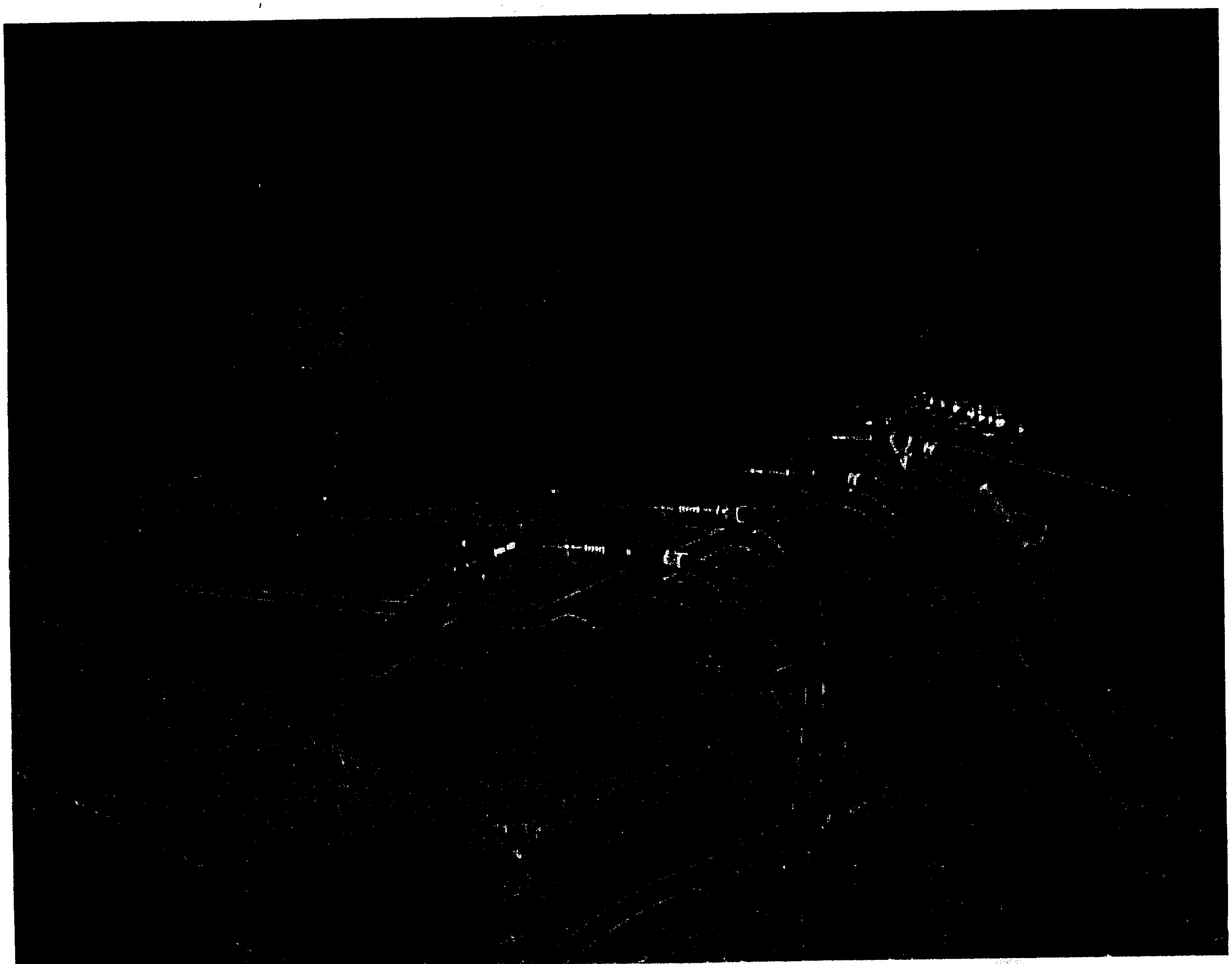


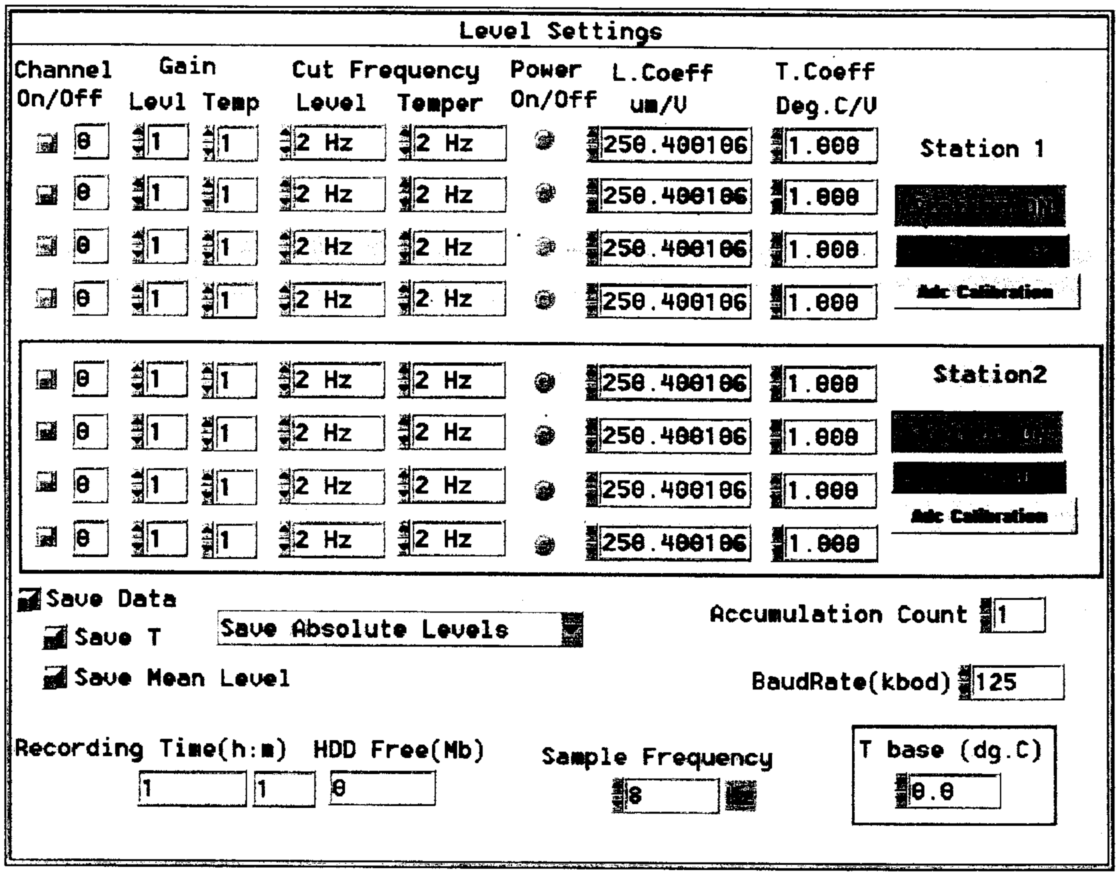
Block diagram of Slow DAS Module.

Slow DAS Module main parameters

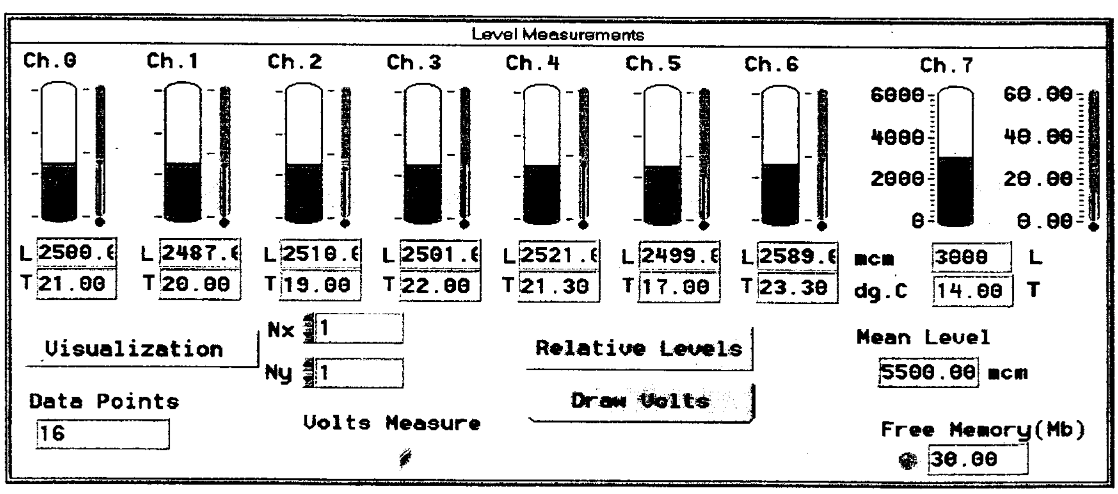
Input Parameters	Unit	Value
Number of Sensors Channels	--	4
Number of analog signals to be measured and digitized	--	8
Channel input voltage range	V	+/- 10
Resolution	bit	16
Channels filter cut-off frequency	Hz	2
Module supply the HLS with:		
a) Voltage	V	+/- 15
b) Current consumption of each Sensor Module less than	mA	+100; -60
Output parameters:		
Transmission rate of fast serial port	kBaud	690
Maximum fast port transmission distance up to	m	500
Supplying voltage	V	20 to 40
Power consumption for Module with 4 HLS - less than	W	15
Box dimension	mm^3	410x290x90
Box weight	kG	8

Slow DAS Module is to be controlled by the IBM PC or compatible computer via one coaxial cable.

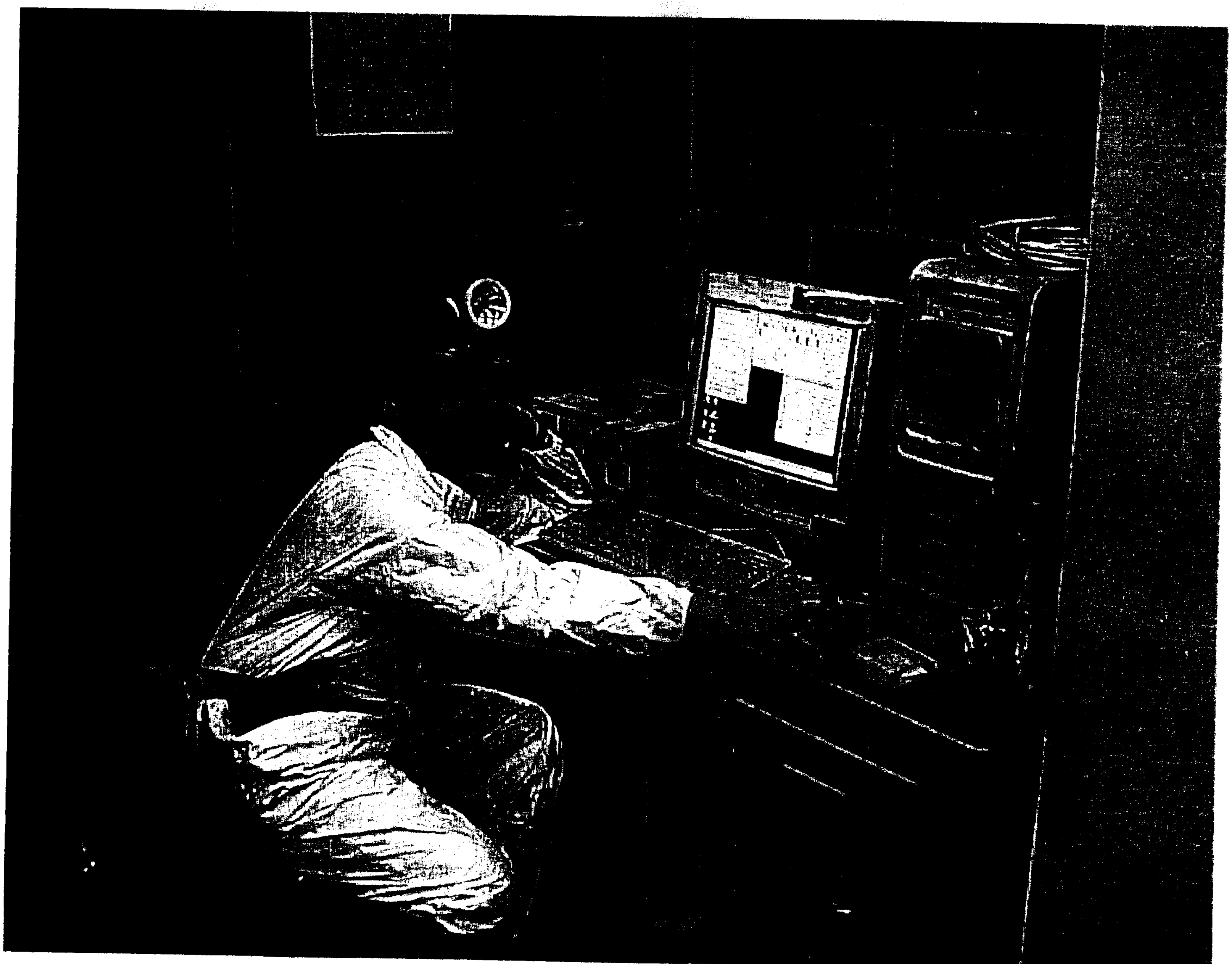




Level settings panel of DAS software.

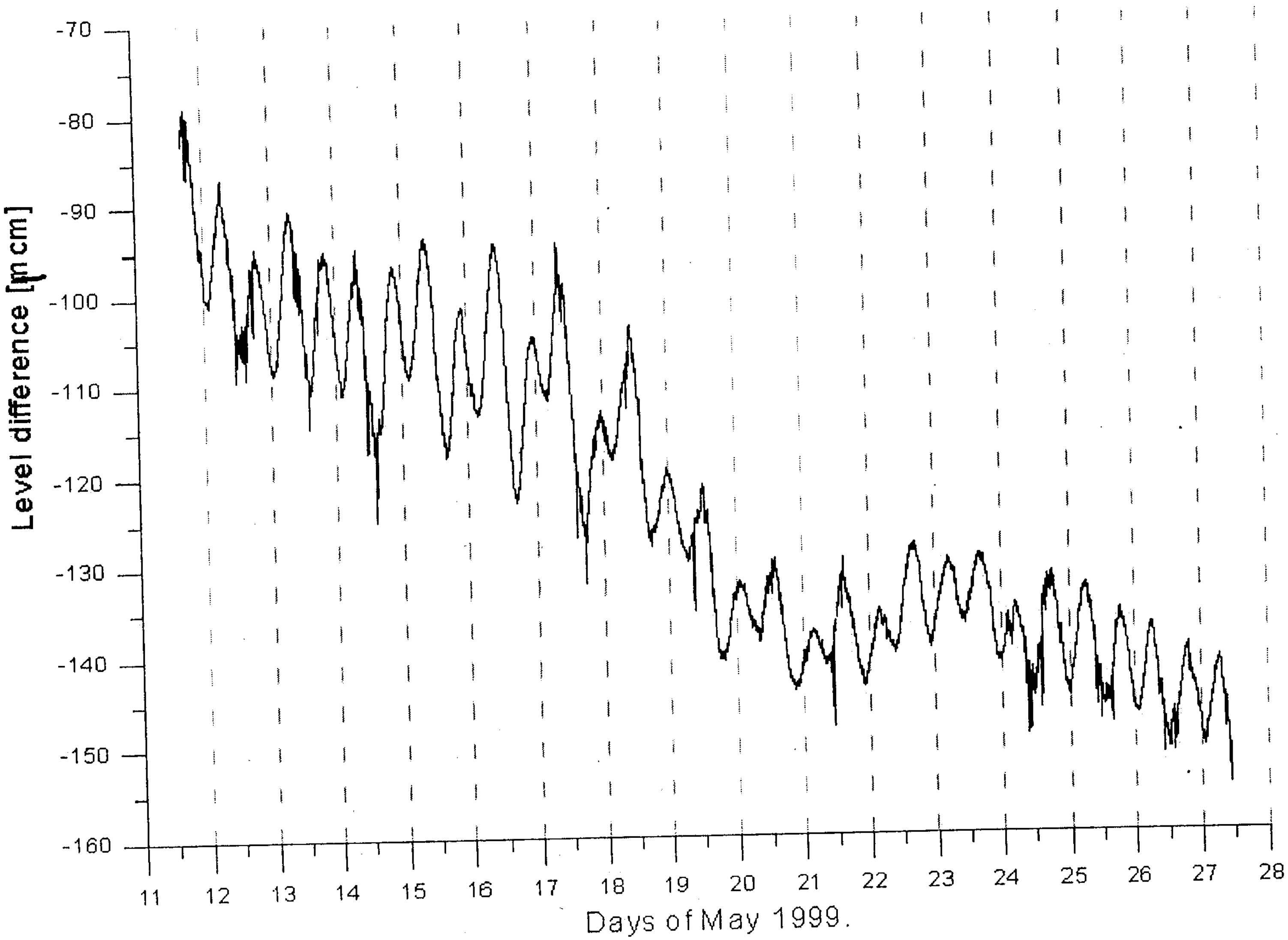


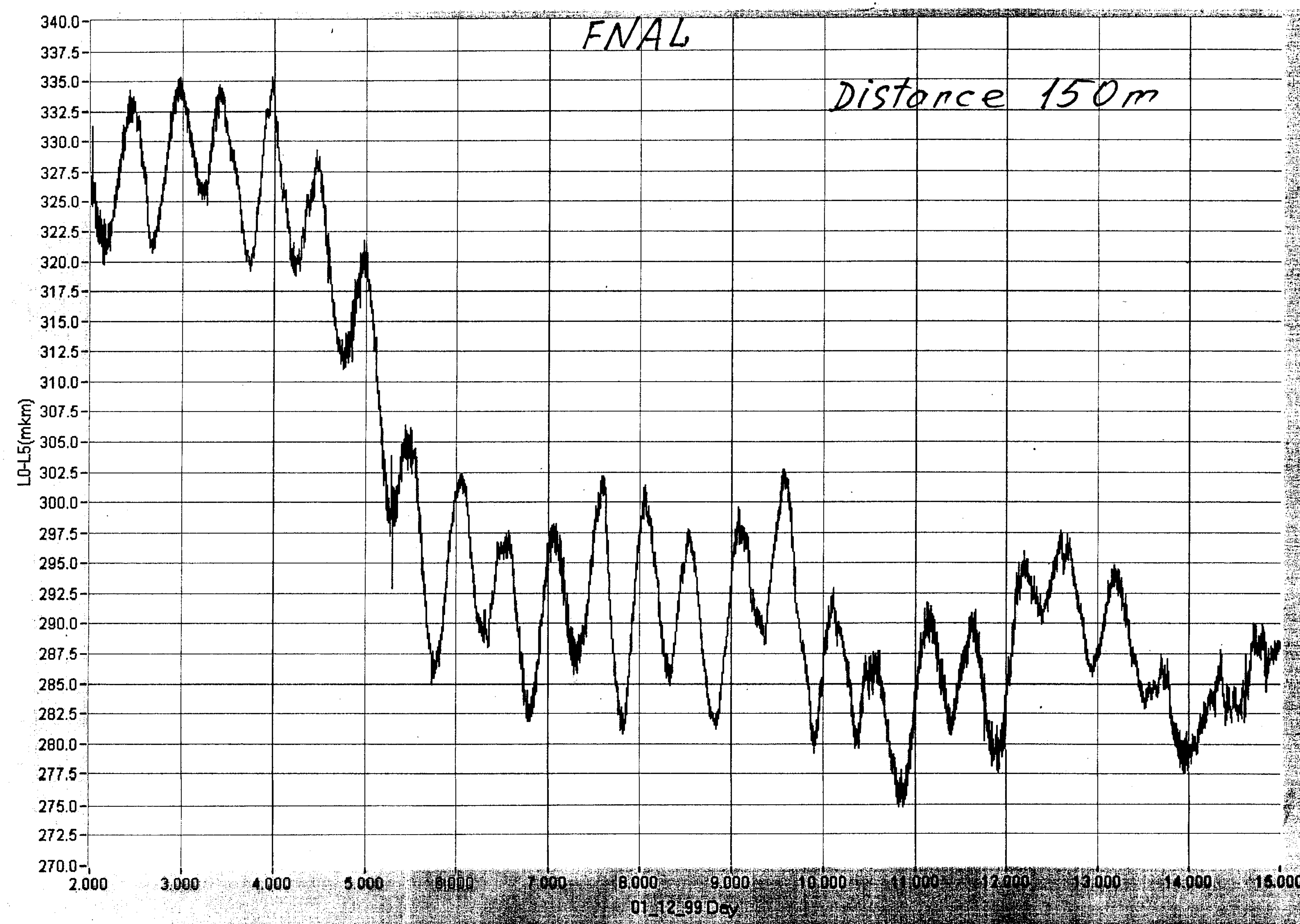
Level measurements panel of DAS software.



VEPP-5 Tunnel

Level difference of two HLS sensors at distance 230 meters.





FNAL
Distance 150m
L0-L5(mkm)
340.0
337.5
335.0
332.5
330.0
327.5
325.0
322.5
320.0
317.5
315.0
312.5
310.0
307.5
305.0
302.5
300.0
297.5
295.0
292.5
290.0
287.5
285.0
282.5
280.0
277.5
275.0
272.5
270.0
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.000
11.000
12.000
13.000
14.000
15.000
01_12_99 Day

Some results.

Hydrostatic Leveling System was used for measurements at the PW6 - PW7 beam line since September 1999 to February 2000.

One of typical examples of measurements is presented at the plot below. Plot covers two week time interval of measurements. Moon high and low tides oscillations with 12 hour period are observed very clear.

One can see that
the resolution of the System is approximately ± 1 μm.

2. BINP Hydrostatic Level Sensor

One of disadvantages of the Hydrostatic Level Sensor developed by Fogale Nanotech is the analogous (voltage) presentation of output signal.

As it is well known, this circumstances can create some difficulties in measurements when the system is installed not far from some electrical power systems or pulsed power systems like, for example, modulators, creating the electromagnetic noise and interference.

This was one of main arguments for us to begin developing of new Hydrostatic Level Sensor.

We accept the same general principles:

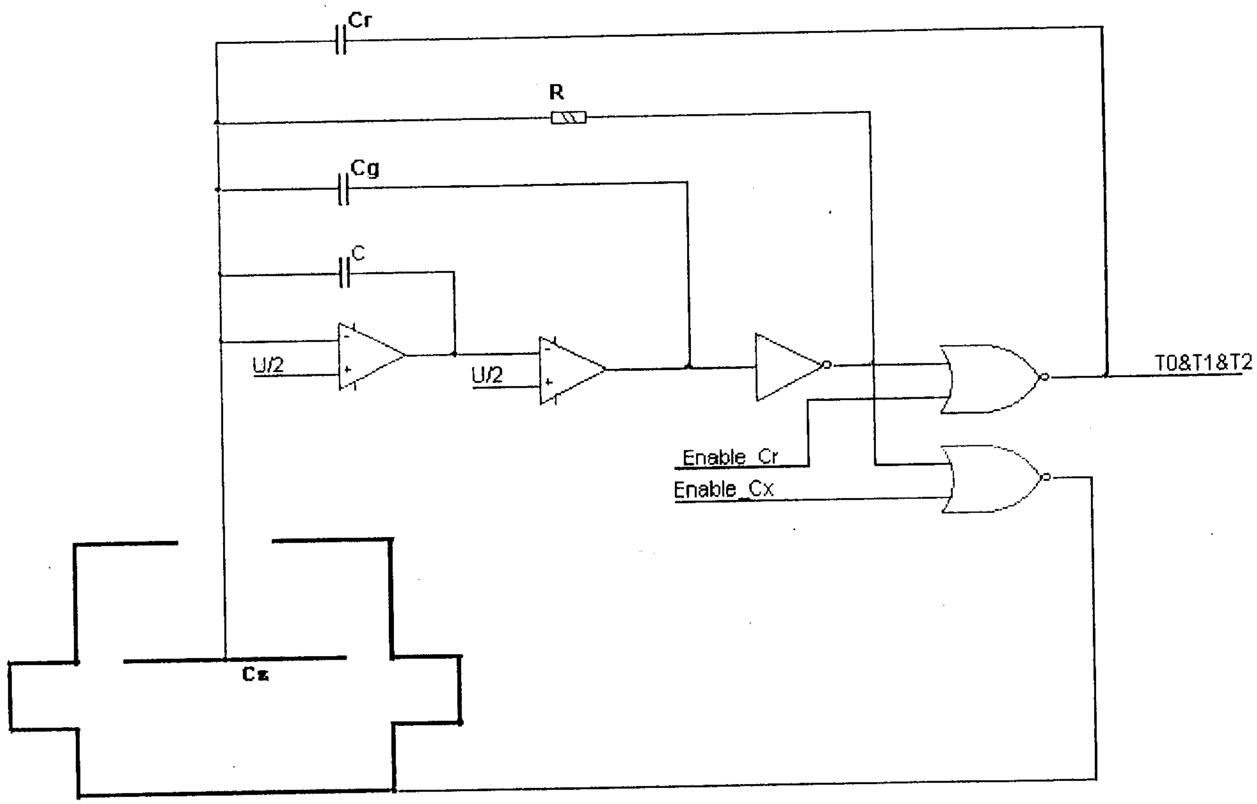
- To measure the Hydrostatic Level in vessel.
- To use the capacitance between sensing electrode and liquid surface as a variable parameter.
- To use the water as a liquid media inside the vessels.
- To use stainless steel body of the Sensor.

We had searched for:

- The suitable methods to convert variable capacitance into frequency; after that - to convert frequency into digital form.
- The suitable circuitry solution of «analogous» measurement of the variable capacitance and after that to convert voltage into digital form.

As a result, the idea to develop ***C => F converter*** became successful. We had developed the circuitry that use the idea presented at the work of *Ferry N. Toth and Gerard C.M. Meijer «A Low-Cost, Smart Capacitive Position Sensor»*, <<http://duteela.et.tudelft.nl/ferry/ieee.htm>>.

General idea of this converter is shown at the picture below.



T0=4*R*Cg

T1=4*R*Cg+4*R*Cr

T2=4*R*Cg+4*R*Cz

«C => F» converter is an RC-generator with oscillating frequency determined by it's internal parameters, including Capacitors C_g , C_r and C_z .

Oscillating period is T0 when both Gates are Switched OFF:

$$T_0 \cong 4RC_g$$

It became T1 when Gate pair is installed into the position «Enable C_r»

$$T_1 \cong 4RC_g + 4RC_r$$

For Gate pair installed into position «Enable C_Z»:

$$T_2 \cong 4RC_g + 4RC_z$$

Switching ON/OFF of Gates into all of three positions in turn, we will shift the oscillating frequency range of generator. And what is more, due to comparing of these periods (frequencies) we can take into account or eliminate influence of most of the circuitry elements instability on resulting measurements:

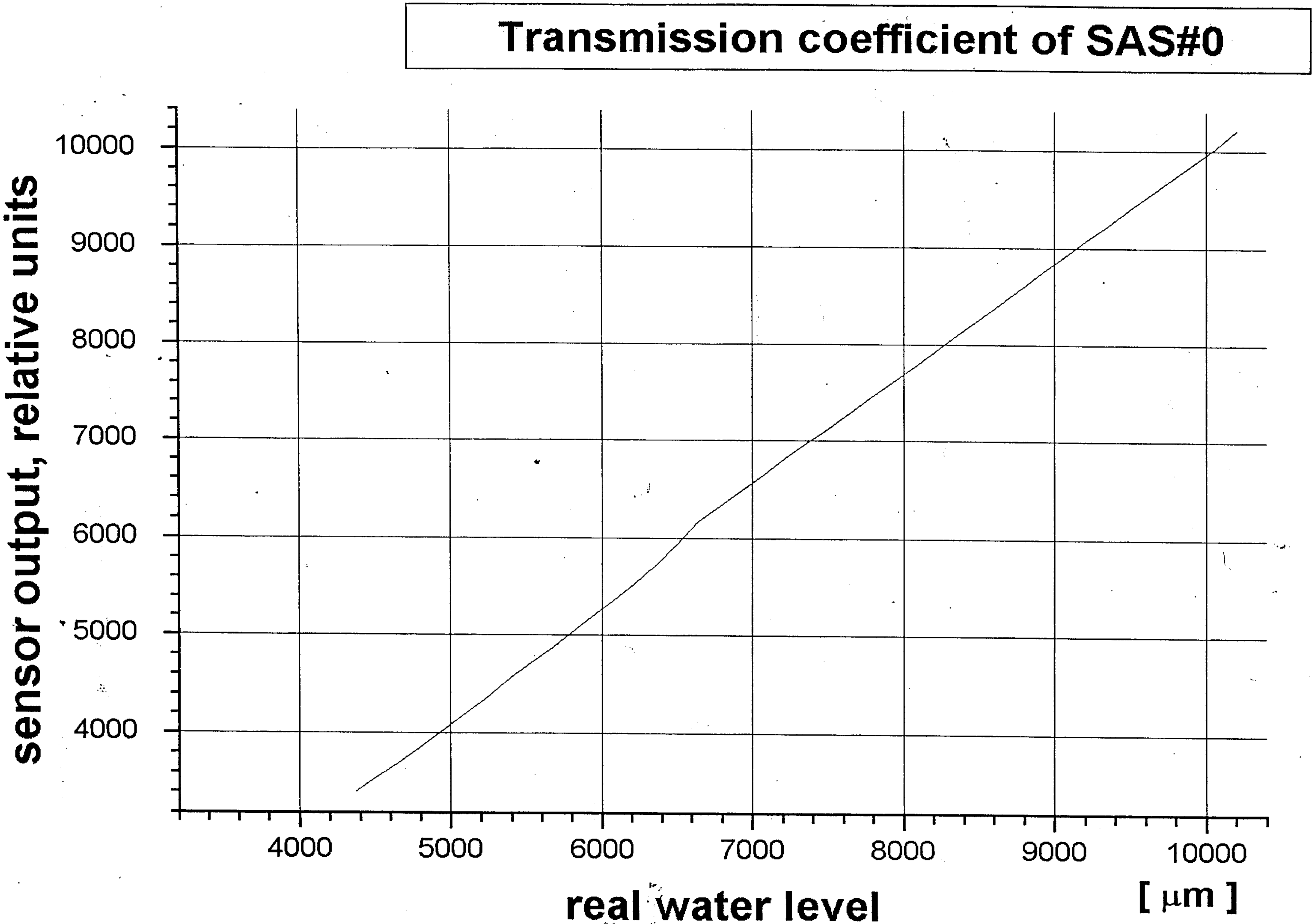
$$\frac{(T_1 - T_0)}{(T_2 - T_0)} = \frac{C_r}{C_z}$$

In our practical case period T_0 was chosen approximately as $T_0 \cong 20$ μsec, T_2 varies between 22 to 30 μsec depending on water level in vessel. The number of oscillation periods are counted during 72 milliseconds per each position of Switch. The electronics of Sensor measure also the temperature of it's body by using of PWM (Pulse Width Modulation) method, that also leads to proportional relation between temperature and number of pulses during the determined time interval. The resulting digital data are transmitted into the PC with the help of RS-485 Interface.

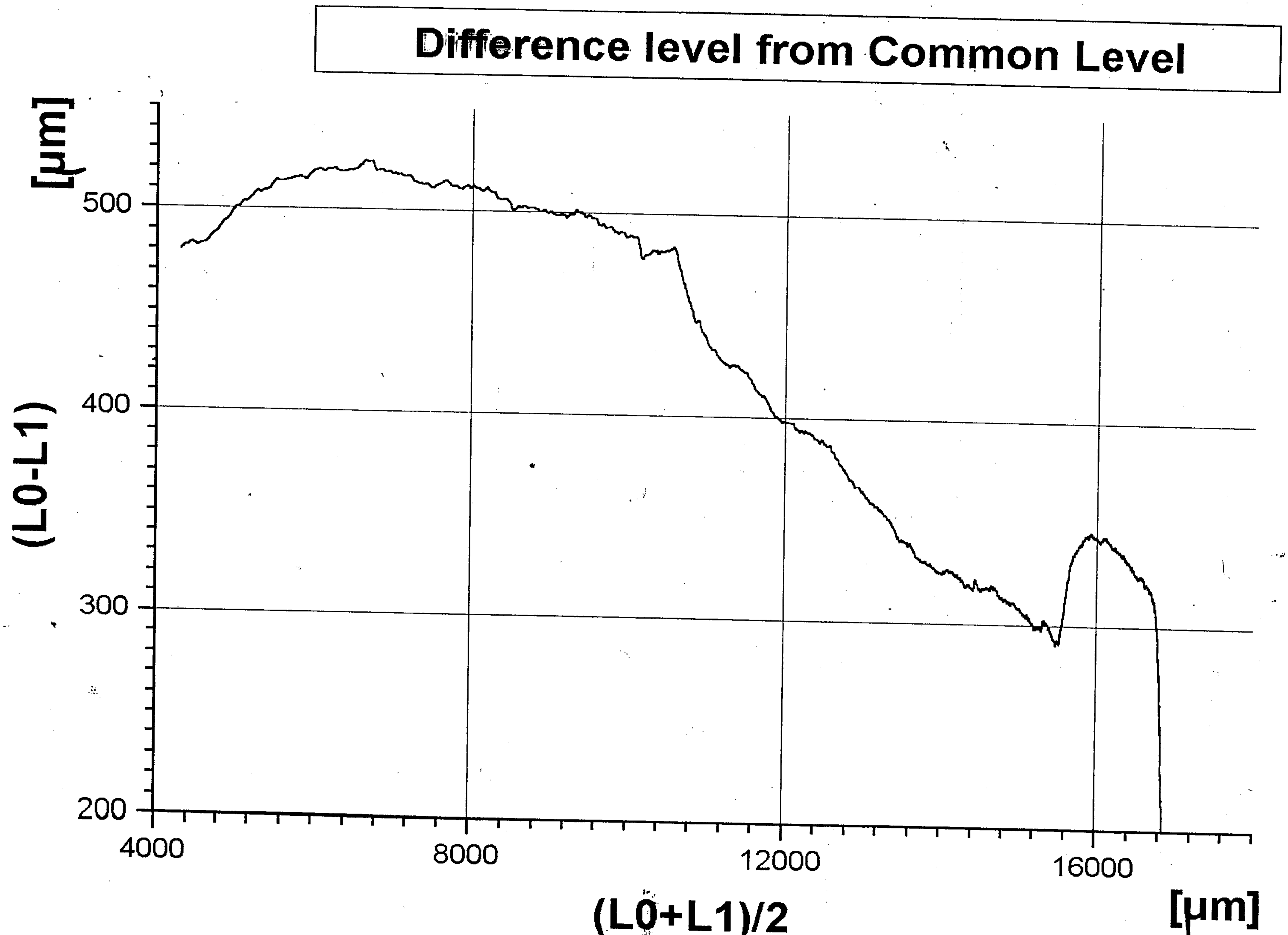
Some results.

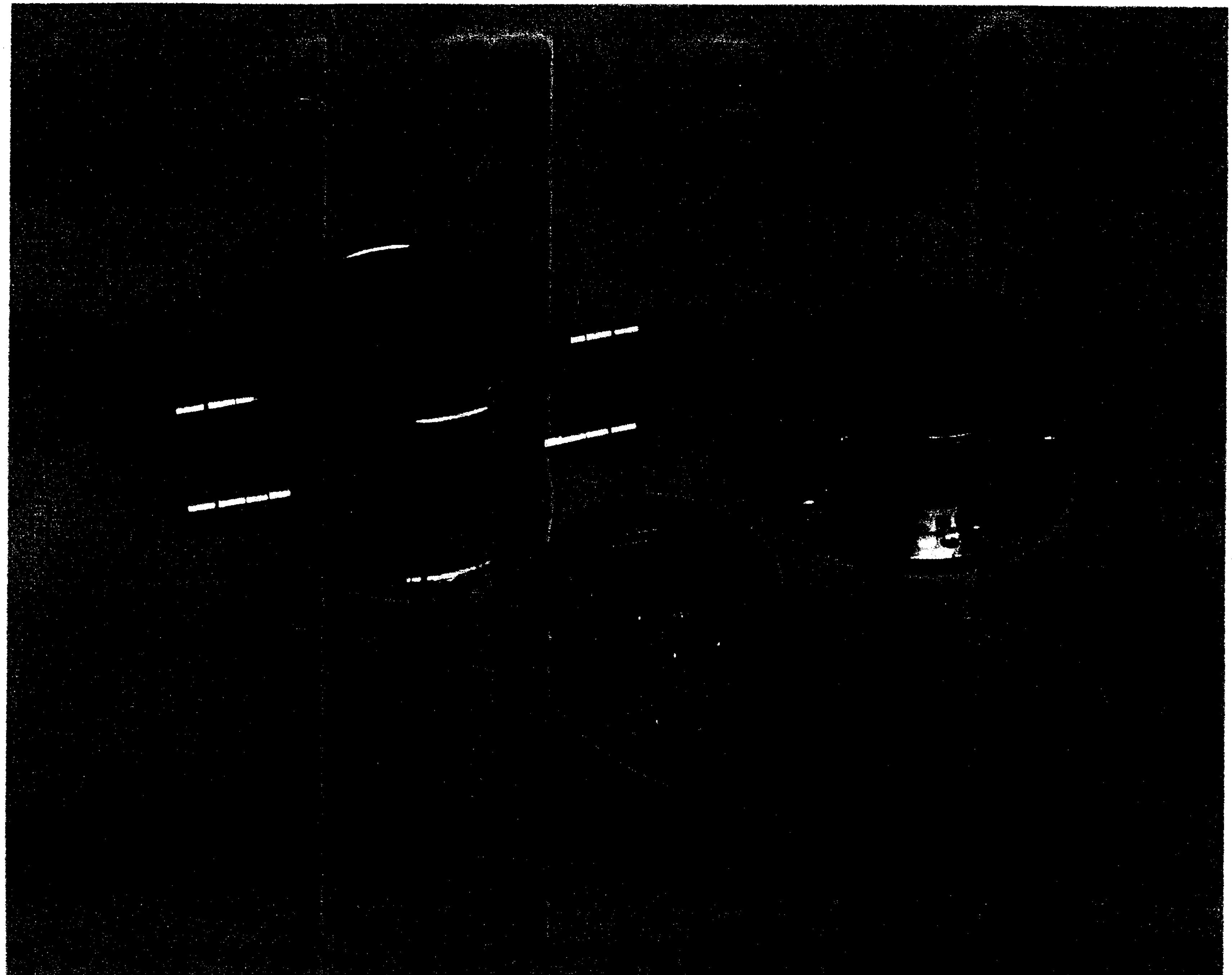
Work on the BINP Hydrostatic Level Sensor is not finished yet, but some preliminary results are presented below.

We can see that BINP Sensor (SAS Type) installed at the 80 m distance can observe the Moon influence on the ground with satisfactory signal - to - noise ratio. We can point out that two Sensor installed in one meter distance shows the sensitivity as well as 0.2 μm (noise has $\sigma \cong 0.1$ μm when averaging of 30 samples during one minute).



Transmission coefficient of SAS#0
sensor output, relative units
10000
9000
8000
7000
6000
5000
4000
4000
5000
6000
7000
8000
9000
10000
real water level
[μm]


Difference level from Common Level
[µm]
(L0-L1)
500
400
300
200
4000
8000
12000
16000
(L0+L1)/2
[µm]
31.10.



3. New configuration of Hydrostatic Leveling System

This announcement concerns to the Sensors and Data Acquisition system only. In case of successful tests of **BINP Sensor** (SAS - Type Sensor) we propose to organize the System configuration with digital signal transmitting with using of **RS-485 Interfaces** and Card into PC. System should be equipped with one atmospheric pressure Sensor with the same Interface.

The system can **accept the Fogale** Nanotech Sensors also. To incorporate them the ADC Card with RS-485 Interface should be added for these Sensors. This type of Cards is commercially available.

So, system will have direct connection between PC and Sensors. It has possibility to operate with **up to 20 Sensors**.

Powering of the Sensors should be also centralized and distributed via special cable.

In addition, to have a possibility of **on-line testing** and checking of all the System we propose to insert a relatively simple **calibration device**. It will look like an additional vessel with movable stainless steel cylinder that position inside vessel is controlled and measured.

The open problem to be considered is - what kind of water System to use:

- **Half Filled Tubes ??**

- **Classical Hydrostatic Leveling ??**

Some of Measurement errors.

a) Differential level error produced by water specific mass changing with temperature. This error is produced by all non-horizontal parts of water pipes, as a consequence of the difference of temperature ΔT between these parts. It means that the hydraulic circuit must be horizontal and fixed in vertical plane very near the free water surface inside communicating vessels.

Presented for **Hydrostatic Leveling,**
Not presented for **Half Filled Tubes**

b) Common Mode error due to simultaneous increasing or decreasing of water reference Level. This Common Mode signal can be produced by average water temperature variation or, for example, due to water evaporation. The Common Mode Level produce differential signal at the Sensors output, if Sensors have a different values of transmission coefficient.

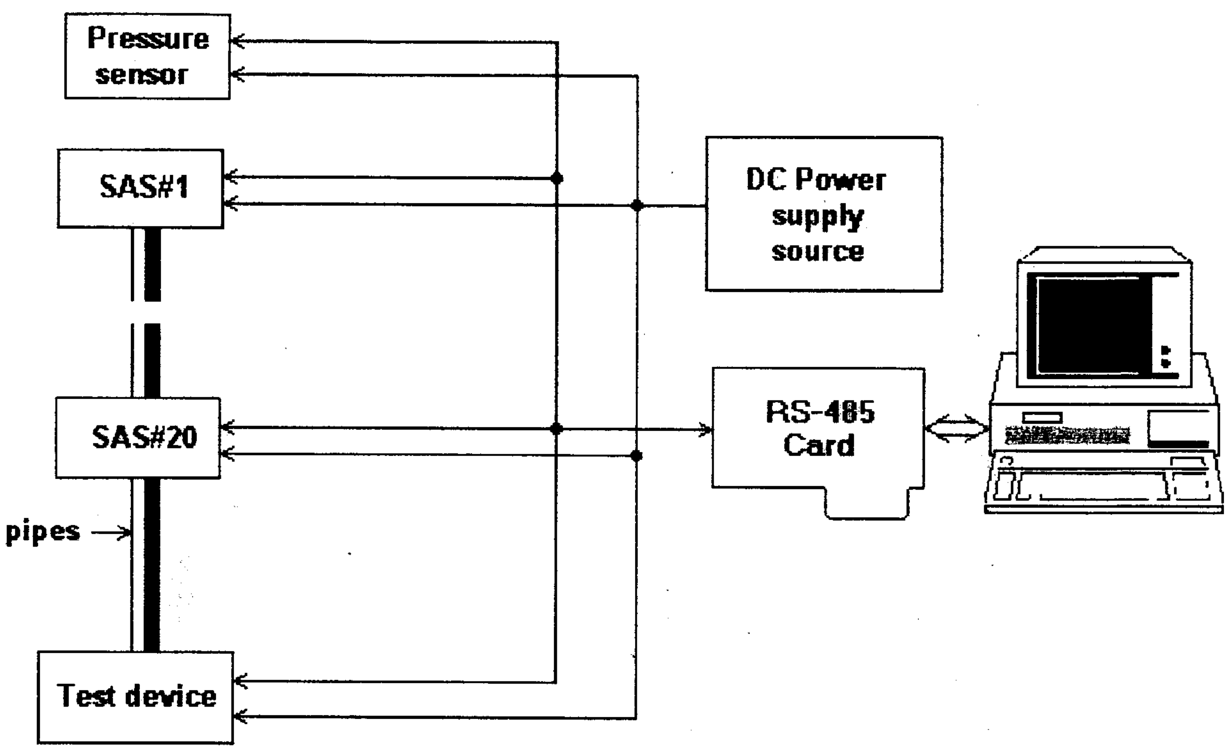
Increased for **Hydrostatic Leveling,**
in comparing with **Half Filled Tubes**

c) Different value of atmospheric pressure near different Sensors. This error is decreased due to Air Tubes connecting of all the Sensors. Tube has one small opening to outer air. System is equipped with continuous atmospheric pressure control device.

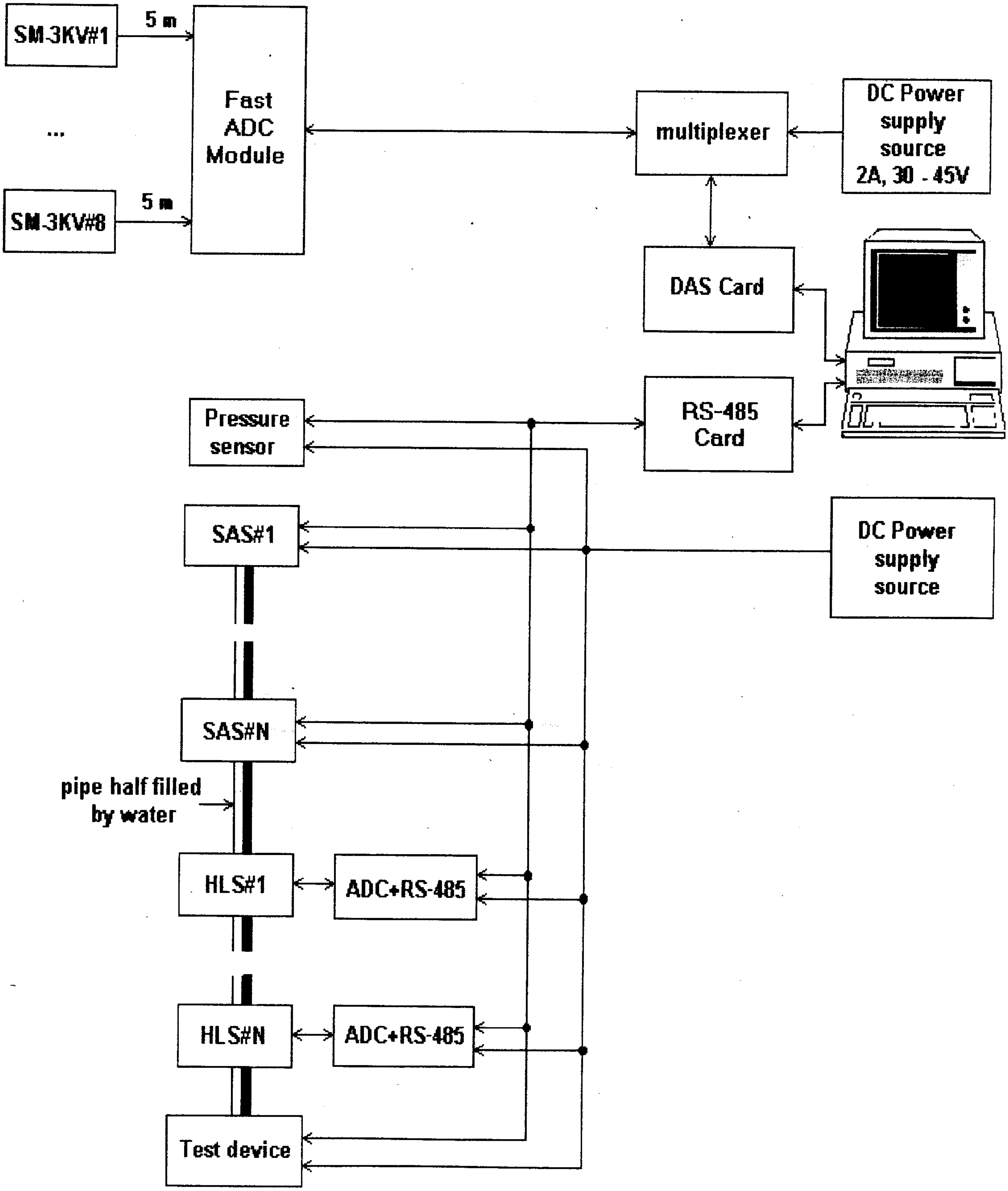
Increased for **Hydrostatic Leveling,**
in comparing with **Half Filled Tubes**

d) Long length of Analogous signal transmission line. It is well known that this method of signal transmitting is a more sensitive to external electromagnetic noises.

Comparing and analyzing of the different sources of measurement errors we came to conclusion that it should be more preferable to use the Half Filled Tubes, but the Sensors and Tubes assembly looks like more complicated and expensive in this case.

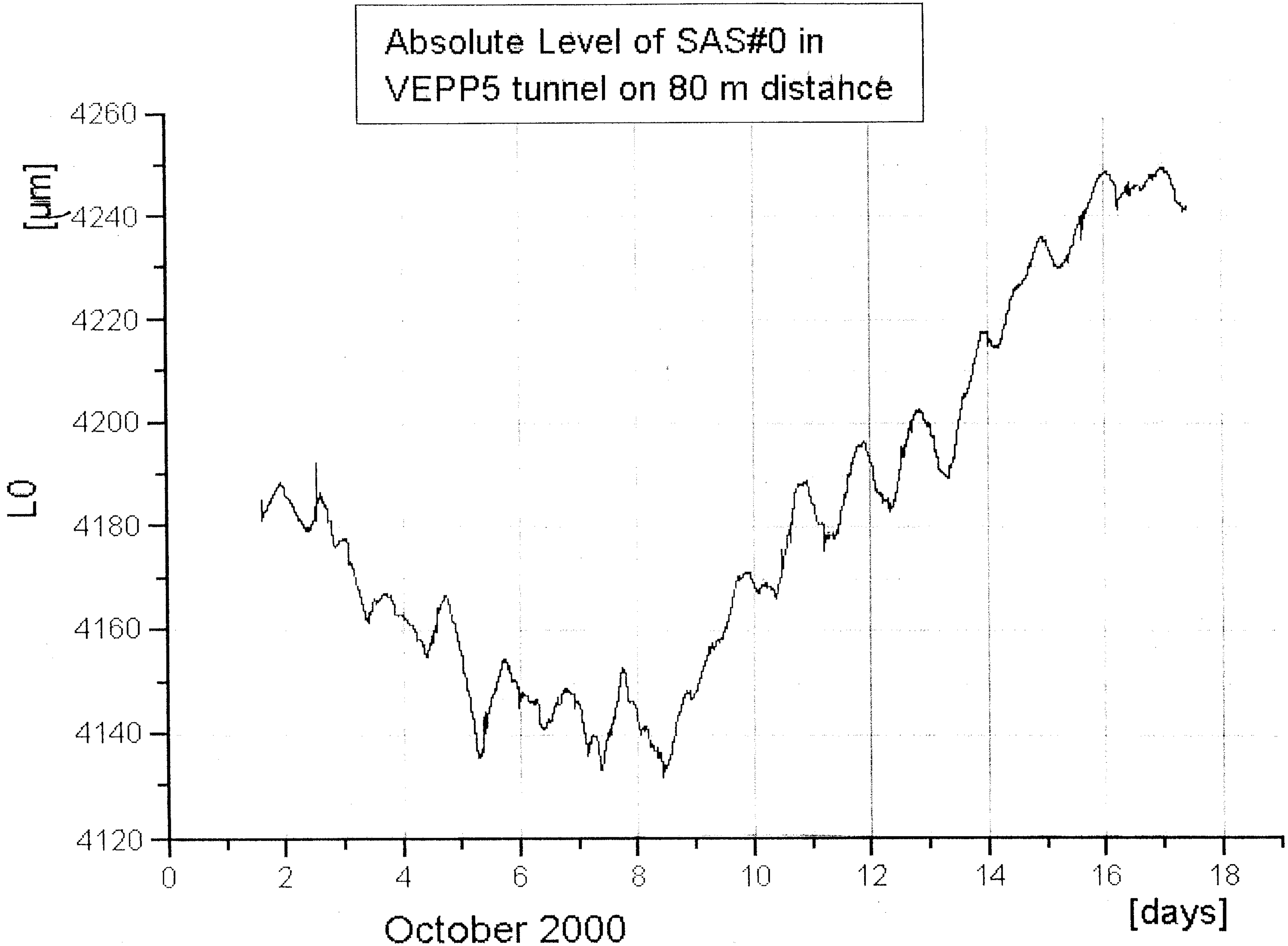


Block diagram of Data Acqusition System for slow tunnel drift measurements.

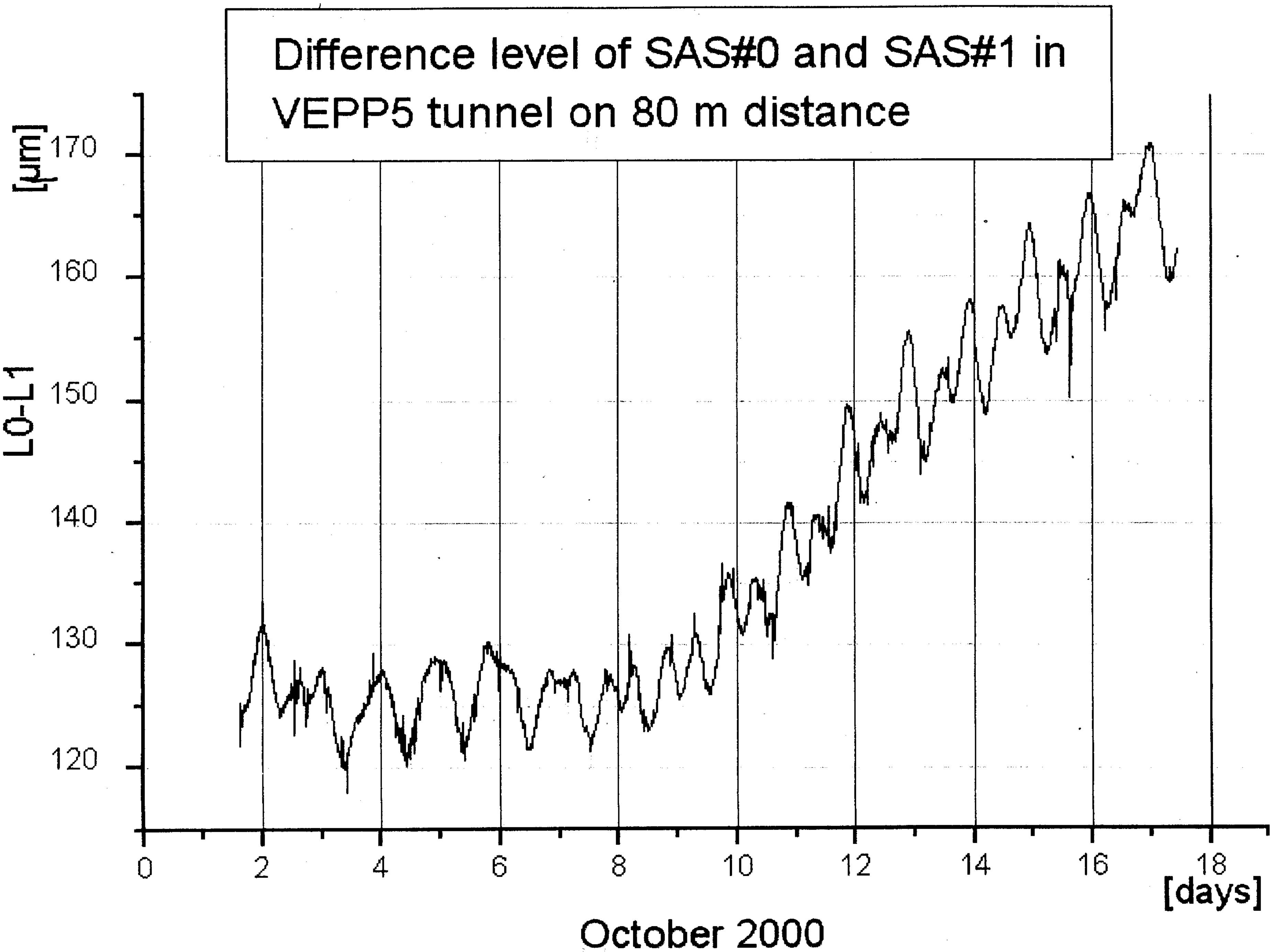


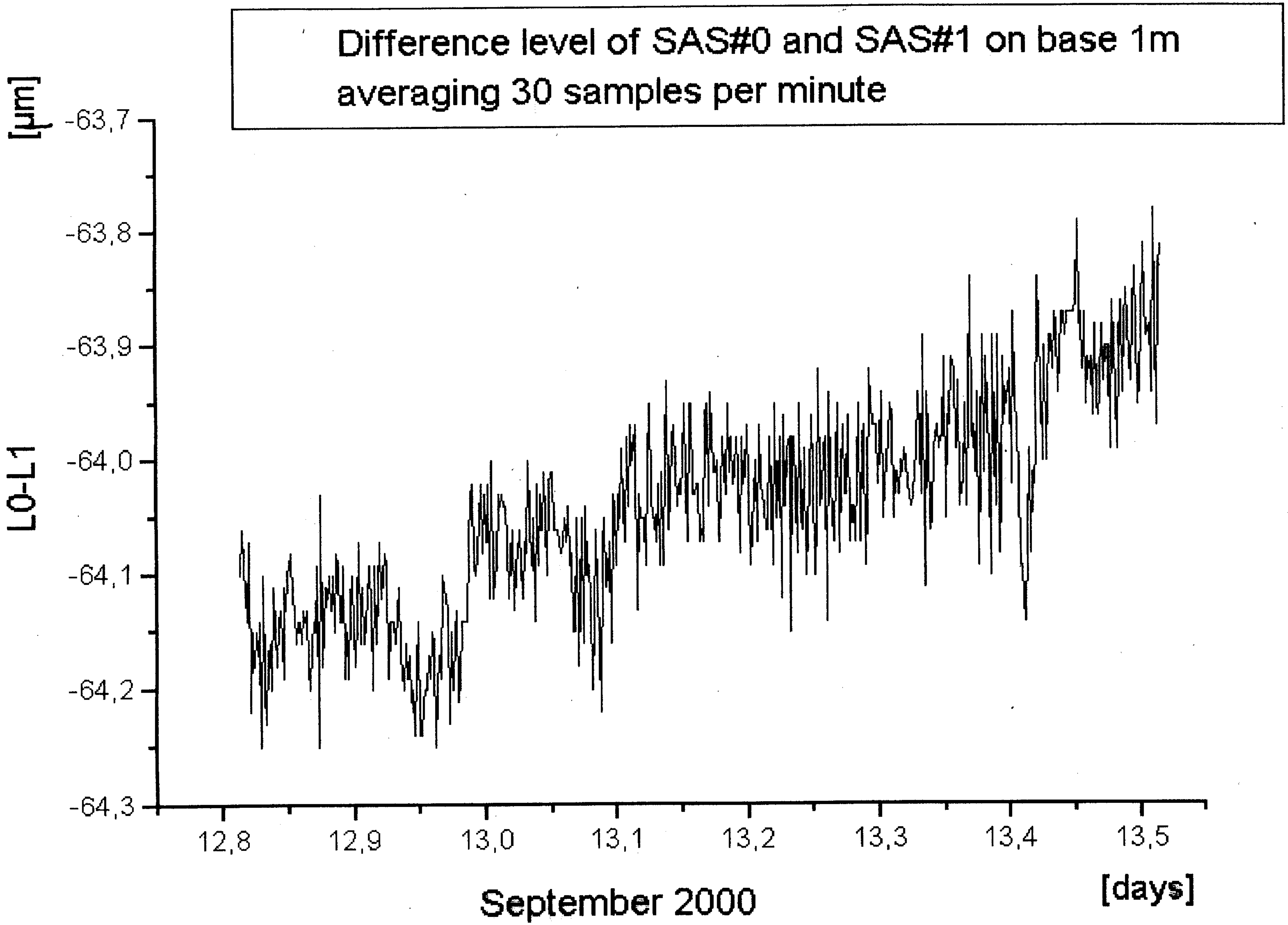
SAS - BINP level sensor, HLS - Fogale Nanotech sensor.

Number of hydrostatic level system sensors up to 20.



Absolute Level of SAS#0 in
VEPP5 tunnel on 80 m distahce
L0
[μm]
4260
4240
4220
4200
4180
4160
4140
4120
0
2
4
6
8
10
12
14
16
18
[days]
October 2000


Difference level of SAS#0 and SAS#1 in
VEPP5 tunnel on 80 m distance
L0-L1 [μm]
170
160
150
140
130
120
0
2
4
6
8
10
12
14
16
18
[days]
October 2000


Difference level of SAS#0 and SAS#1 on base 1m
averaging 30 samples per minute
L0-L1
[µm]
-63,7
-63,8
-63,9
-64,0
-64,1
-64,2
-64,3
12,8
12,9
13,0
13,1
13,2
13,3
13,4
13,5
[days]
September 2000