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Suitcase to Audit Solar Installations

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25 pp. 14 figs. 0 refs.

Abstract

The audit suitcase was proposed by BESEL to introduce in the solar energy market a new tool which can make an evaluation of solar installation efficiency. Non-invasive sensores and low poer components permit both easy installation of the devices and data storage for a period as long as ten days. This project was funded by the contract JOR3-CT98-7030 of the European Union JOULE III program.

Maletín de Auditoría para Instalaciones Solares

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Resumen

El maletín de auditoría para instalaciones solares es un proyecto propuesto por BESEL para introducir en el mercado una nueva herramienta que pueda hacer una evaluación de la eficiencia de una instalación solar. El uso de sensores no invasivos y componentes de bajo consumo permite una fácil instalación y almacenamiento de datos durante periodos superiores a 10 días. Este proyecto se realizó con la financiación del programa JOULE III de la UE bajo el contrato JOR3-CT98-7030.

Introduction

Solar installations for domestic hot water have made significant advances in the application of energy from natural sources. However the user of this type of installation frecuently cannot perceive the significant economy, in terms of traditional fuel savings, as he is not able to take account of the useful energy comming from the sun which is stored in his heat accumulator. Without this information he is not aware if his installation is working efficiently.

To address this situation, use has been made of remote monitoring systems which do not try to control the operation of the installation ,but to track its evolution to forecast its behaviour in energy terms and to determine the corrective measures which might be needed to handle any detected deviation.

Traditonal remote monitoring requires instruments and equipment to be fixed in place to collect the measurements of the installation variables (temperature,flow and solar radiation). The corresponding sensors are connected to a datalogger or control center where the provided information is stored. Subsequent transfer of the data and its treatment in a host computer gives an idea of the the energy balances which are the key to determine if the installation is working properly.

Although this system enables the user to perceive clearly the fuel savings, he has to face some very high additional costs related to the installation of the remote maesurement equipment (up to fifth of the total cost of the solar installation), and to make modifications in the pipes which can endanger the integrity of the system (e.i., the installation of an electromagnetic immersion flowmeter involves the shut-down and the emptying of a pipe section). Moreover he had to pay a permanent audit service which is not justified because the variations in the behaviour of solar installations have a large inertia and the greater part of the inefficiencies are detected progreessively after some time.

The project which was proposed by BESEL, intends to avoid the disadvantages of remote monitoring by creating an audit carrying case (the suitcase). The idea is to use a series of portable dataloggers with non-invasives sensors, (sensors which are installed without the need for tiresome stoppages), to take data during a prestablished relatively short period of time (i.e. 10 days). Subsequently the data stored in the probes will be transferred one at a time to a portable computer. A custom software program will automatically interpret the received information, generate the energy balances and even create the associated draft audit reports.

The consortium which has developped this project consists of two RTD performers (CIEMAT and UAM) and various associated SMEs. It is split in three groups:

- The CIEMAT electronic group together with a temperature sensor manufacturer, UTECO from Greece and an ultra-sound flowmeter manufacturer, MATELCO from Spain, have developped the stand-alone, non-invasive, compact probes which are light enough to be put into the audit suitcase.

- The UAM (Universidad Autonoma de Madrid) together with ASC from Italy have been in charge of the associated software development.
- BESEL from Spain, TALOS from Greece and HELIOSTAT from Greece advised on solar enegy and communication aspects. TALOS also advised on data adquisition systems, HELIOSTAT on solar diagrams and BESEL was the co-ordinator of the whole project supplying specific support tasks.

In addition a third RTD performer, the UMH (Universidad Miguel Hernandez) from Spain, has been involved in the development of certain tools that can make easier the installation of the non-invasives sensors.

1. C.I.E.M.A.T. objective

In this project the C.I.E.M.A.T. electronic group has provided all the probes to take data in the points of the solar installation fixed by the system manager.

Three probe types have been developped:

- Temperature
- flow
- solar radiation.

They have the following general technical characteristics:

- Autonomy: They measure in an autonomous way the physical magnitudes storing in memory the results during a 10 days period. Electronics circuits are battery powered in the temperature and solar radiation probes.
- Reduced size allows to place directly the probes on the measurement points.
- Non invasive sensors are used to avoid the need of introducing some modifications in the solar installation during the mounting probe process.
- All the probes are controlled by a host computer through a serial line. This control include:
  - programming of the sampling rate parameters;
  - surveillance of the good operation of the probes;
  - data transfer from the memory probes.

2 Technical description.

2.1. Non invasive sensors identification.

From the beginning of the project, contacts with two participating companies, UTECO and MATELCO , has been stablished in order to define what kind of sensors can be used in the temperature and flowmeter probes . In addition the solar energy division from C.I.E.M.A.T. proposed some devices to measure the solar radiation. A complete set of sensors has been tested to verify that its performances met our specifications.

The following conclusions were taken from the results of these tests:

- Platinum resistors (RTD) are a correct solution as non-invasive sensors to measure the water temperature inside the pipe. Thermal ribbons provided by MINCO are very easy to install.
- The transit time difference of an ultrasound wave is the only way to make a non-invasive measurement of the water flow. With Matelco collaboration a new electronic circuit has been developped.

. Pyranometers were disregarded to measure solar radiation, due to its very high price. Solar plate is the most suitable device despite its size that difficults to allocate it into the suitcase.

2.2. The electronic design of the probes.

The probes work in an autonomous way for a period of time not less than 10 days taking and storing the information supplied by the non-invasive sensors. Each probe controls a unique sensor, and consequently three types of probes has been designed: solar radiation meter, thermometer and flowmeter. The next general criteria have been followed in the design:

. the same microprocessor controls all the probes;
. the minimum RAM size to store all the taken data is 8 KBytes;
. each probe has an interface analog circuit which depends of the sensor type it uses;
. probes are activated only the time to take a datum;
. to reduce power consumption, a relay cuts the sensor power supply during the stanby periods;
. the thermometer and the solar radiation probes are fed by a battery;
. flow-meter is fed from the net because the ultrasound transmitter-receiver needs a high voltage supply of 24 V.

2.2.1. Temperature and radiation probes.

An electronic block diagram for both probes is shown in figure 1. The only difference between temperature and radiation probes is the analog interface which converts the sensor output into a 0-5V analog signal . The design is based on an HITACHI H8S/2357 microcontroller which has a 128 KBytes program memory, a 8 KBytes RAM memory for data storage, three serial ports, one 10 bit A/D and two D/A converters integrated in the same chip. The power consumption of the device in standby mode is less than 1 μA. An external real time clock is programmed to produce an interrupt signal each time the system must take and store a datum from the probe sensor. The probes are connected to the host computer through an RS-232 serial port.

The selection of the I.C. used in the design has been made according to :

. a very low power consumption in standby mode;
. a small board area;
. a single power supply (same supply voltage for all I.C.);
. and market availability.

Electronic Block Diagram

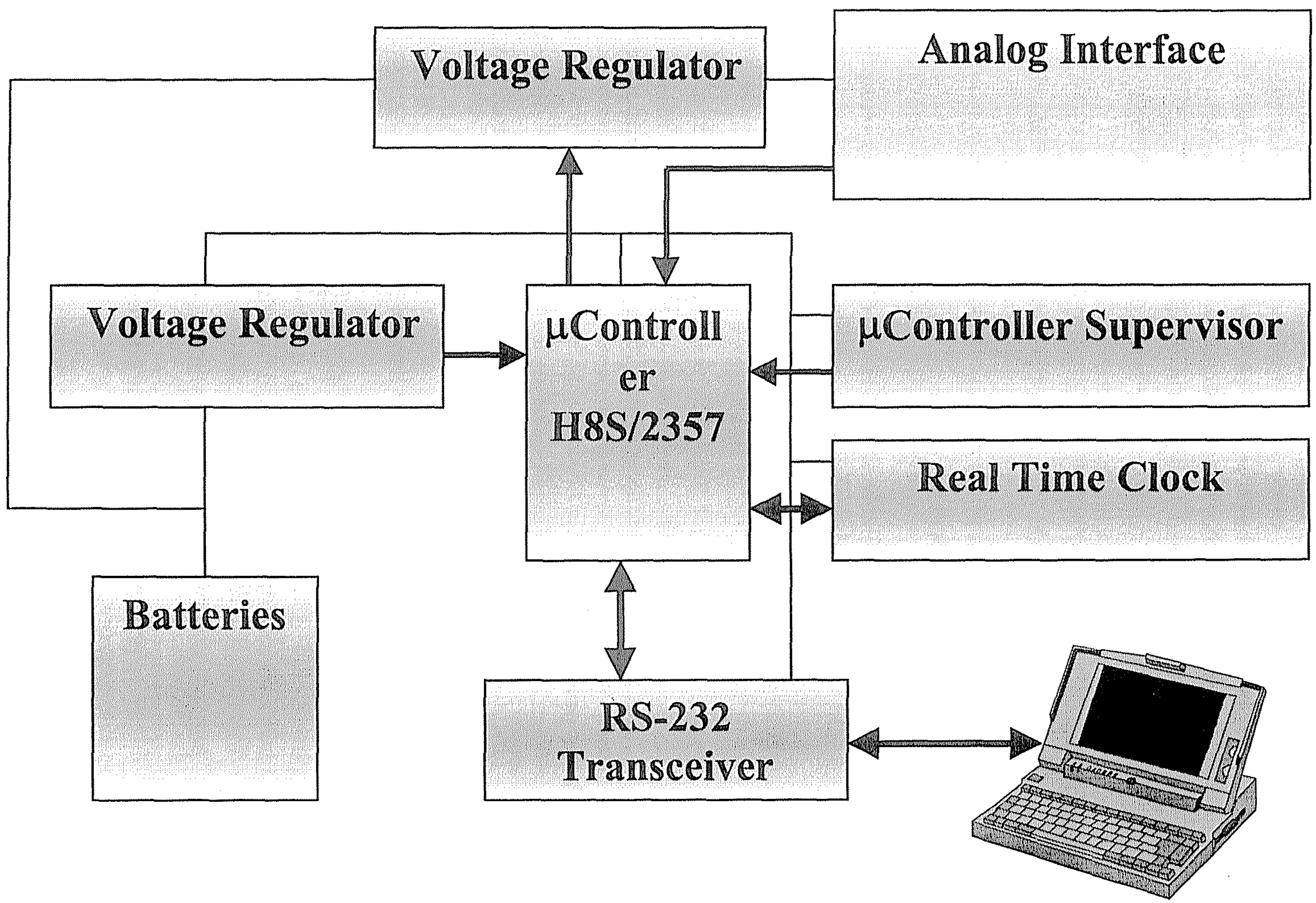


Figure 1. Electronic block diagram.

2.2.2. Flowmeter.

To measure flow speed from outside the pipe using the transit-time method, we have to calculate the difference between the transit time of an ultrasound wave which travels in the same sense than the liquid, and the time of the same wave travelling in the opposite sense. For example, if we assume that the pipe internal diameter is 20 mm, the distance between ultrasound transmitter and receiver 100 mm, the sound speed in water 1472 m/s and the flow 100 liters/hour , the difference of time transits Δt is close to 7.5 ns. The goal is to measure times with a resolution of a tenth of nanosecond.

A new digital method was developped to capture the echo signals.

Figure 4 represents a block diagram of the probe electronic circuit which is based on four main components:

-Gain programmable amplifier for echo detection. Amplifier gain is set by the microcontroller digital to analog converter.
- Flash analog to digital converter.
- FIFO memory.
- The Hitachi 8HS/2357microcontroller.
- The flowmeter must take a datum every five seconds and store all the measurements. To comply with this requirement, an external non volatile RAM memory has been added for storage purposes.

2.3- Probe program.

The probes microcontroller program has been written around two main elements:

. data acquisition routines,
. and communication with the host computer.

A very simple block diagram of the program is shown in the figure 5. To save power, the microcontroller stays in standby mode. When an external event occurs an interrupt is produced and microcontroller goes to the normal mode.

There are two possible external events:

. a character received from the host computer;
. an RTC periodic signal .

When the interrupt cames from the RS-232 serial port, the character is stored in an input buffer. When an "end of message" character is detected, the microprocessor executes the command sent by the host and returns to the standby mode.

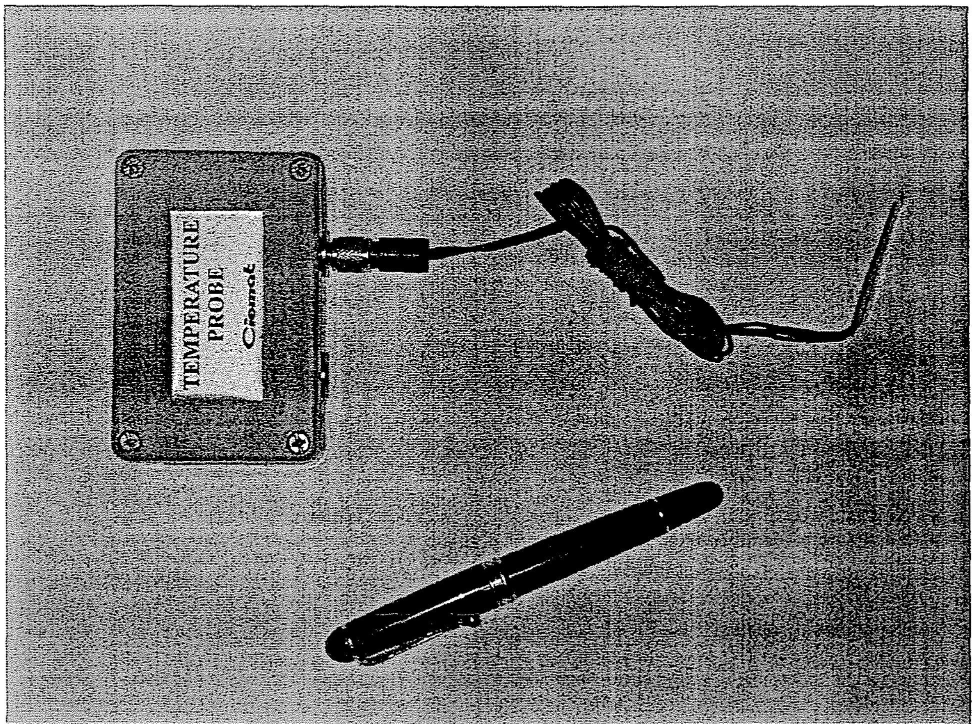


Figure 2. Tempearature probe

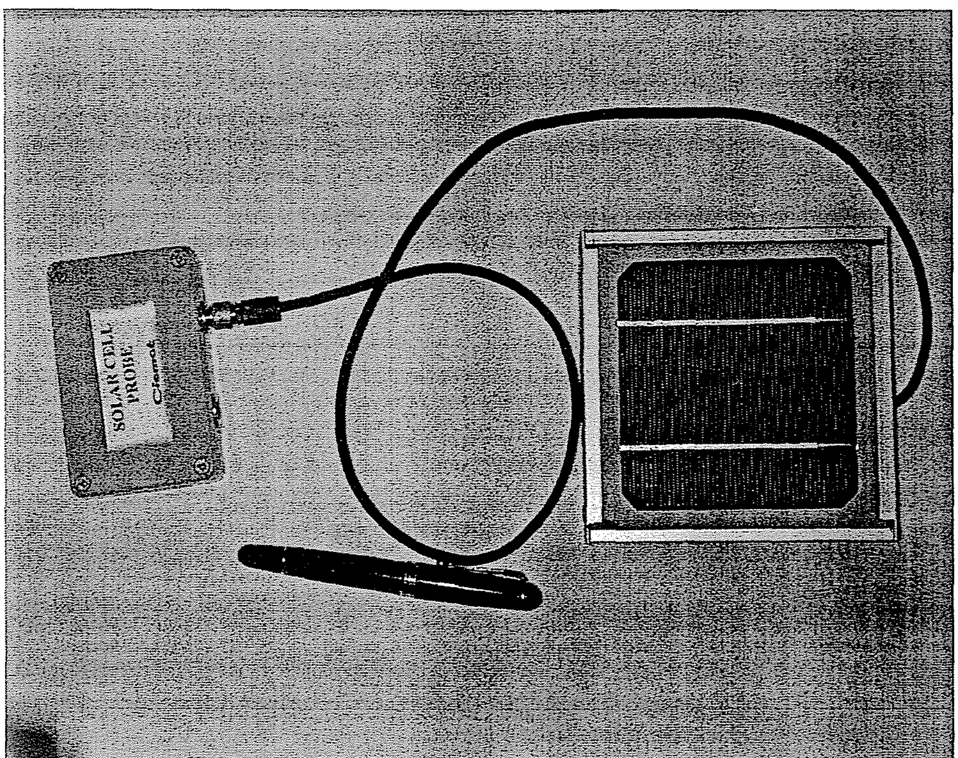


Figure 3. Solar cell probe.

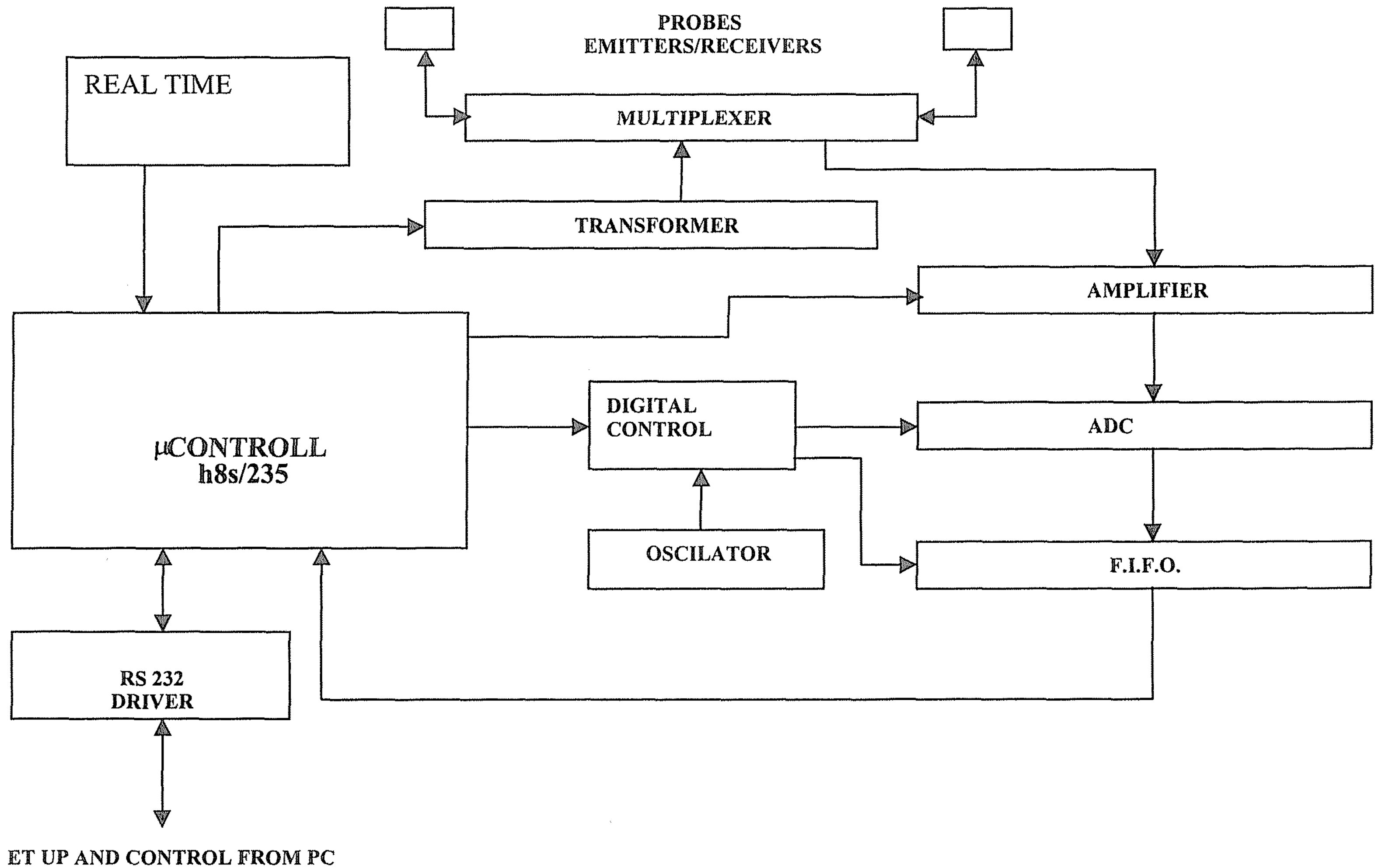


Figure 4. Flowmeter diagram.

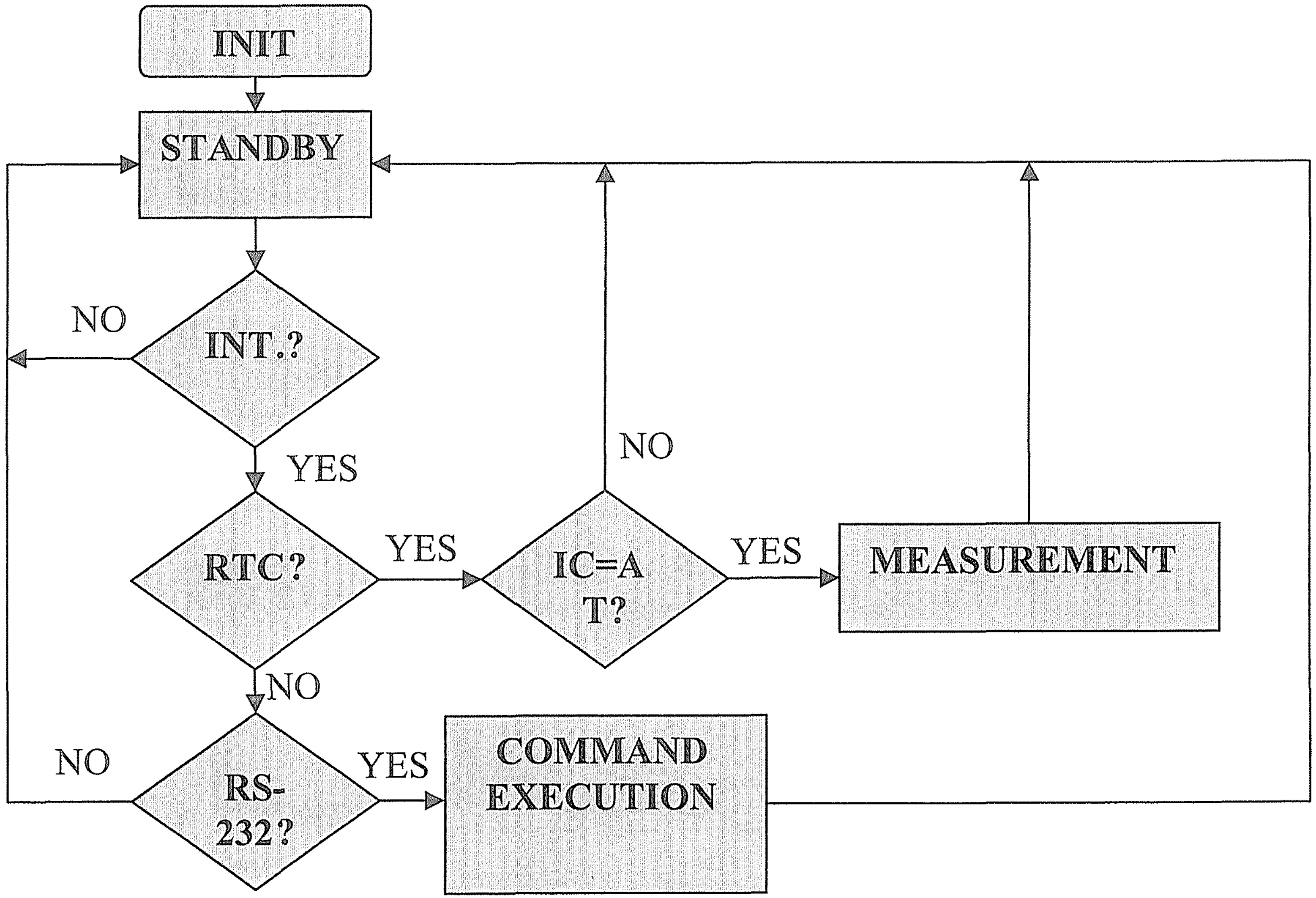


Figure 5. Basic program flow chart.

Similarly , the RTC interrupt forces the program to read the sensor output and to store the datum into the memory.

2.3.1. Communication protocol.

To connect the host computer with the probes , the C.I.E.M.A.T. and the U.A.M. groups have developed a communication protocol which is based on a command set. The probe microcontroller is always the slave of the host and transmits only when it receives a command. Each command is composed by a header, a letter which defines the operation type, and a set of parameters when necessary. The available commands are :

. **M** : begin to take data.
. **D** : trasmit all the data to the host.
. **T** : set the date and the hour on the real time clock.
. **C** : take a measurement. (only for maintenance purposes).
. **U** : trasmit the last measurement to the host.
. **E** : status request.
. **P** : stop the data taking.
. **E** : erase the data memory.
. **S** : set parameters needed for the operation

The header contents an identification character and the message number of bytes.

2.3.2. Temperature probe.

All probes are very easy to use. Before begining to take data, actual date and time must be sent to the probe. After that, a "take data" command will be accepted. Probe will stop to take data when happens one of the next three conditions :

- a "stop" command is received;
- memory data is full;
- the time period set by the "take data" command ends.

Any moment all stored data can be recovered with a "transmit data" message without interrupting the process.

When probe microprocessor receives a signal alarm from the real time clock the program jumps to the take-data routines. This happens once every ten minutes. After taking a data, the microprocessor prepares the real time clock for next measurement and comes back to the standby mode.

2.3.3. Solar radiation probe.

The solar radiation probe is similar to the temperature probe. Command set and operating modes are identical. But the probe has a measurement period of one minute. After ten minutes, the probe makes an average of a the ten previous measurements and stores it as the valid data. Moreover, by night, the probe only takes one datum every thirty minutes to save battery.

2.3.4. Flowmeter

Instead to go to standby mode during the non measurement period as the temperature and radiation probes do, the flowmeter is continuously calculating the transient time difference. To avoid deviations produced by local water turbulences, a stadistical method is used to get the flow value which is stored in RAM memory every five seconds.

2.4. Tests and calibrations.

2.4.1. The test bench.

An hydraulic circuit has been built to test flow and temperature probes.

Water circulation is done by means of a GRUNFOS pump model UPE 25-40. The maximum available flow with this device is 780 l/hour.

Flow is regulated by a SAMSON valve type 45-9

Water is heated up to 70 °C by the model CP1 AGUA 6KW electrical haeter from TOPE.

We have put in the circuit the necessary sensors to measure temperature and flow. So we can compare readings from these sensors with the measurements done by the probes.

UTECO has supplied two thermoresistences, which are put before and after the heater. These sensors have the same electric characteristics than the MINCO ribbons used by the probes.

A FISHER & PORTER mod. 10D 31XY flowmeter has been installed. This sensor gives a 4-20mA analog signal.

An ADAM module network permits to connect all the sensors to a personal computer via serial port.

To monitoring the test bench, a data acquisition program has been developped in Labview to take data from all the sensors.

2.4.2. Solar panel calibration.

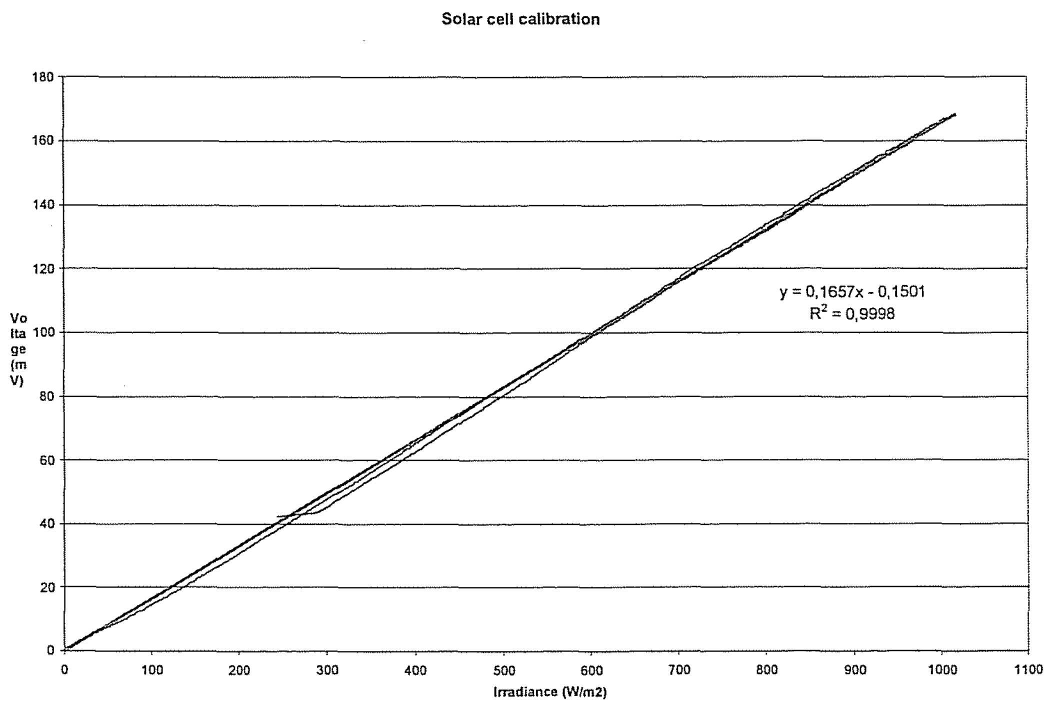


Figure 7. Solar cell calibration curve.

The photovoltaic cell of monocrystalline silicon provided by ISOFOTON, has been calibrated by the CIEMAT Solar Energy Department. The calibration curve is shown in fig 14. According to the report, the solar plate gives an electronic signal of 166 mV when irradiated at 1 kW/m^2 and loaded with a 0.05 Ω resistor.

2.4.3 Temperature probe.

2.4.3.1 Undertaken tests.

Tests have been undertaken in the hydraulic test bench to verify the behaviour of the MINCO thermoresistors that are used as temperature non invasive sensors. Thermoresistor measurements were compared with temperature references with satisfactory results.

2.4.3.2. Calibration of the probes.

To calibrate electronic interface we used a Fluke 5500A calibrator. This instrument simulates the sensor resistance for different temperatures. So, we obtain a curve that relates voltage output with RTD temperature.

Analog output voltage is converted to digital by the 10 bits analog to digital microcontroller converter.

Temperature range of the probes has been adjusted from 0°C to 100°C

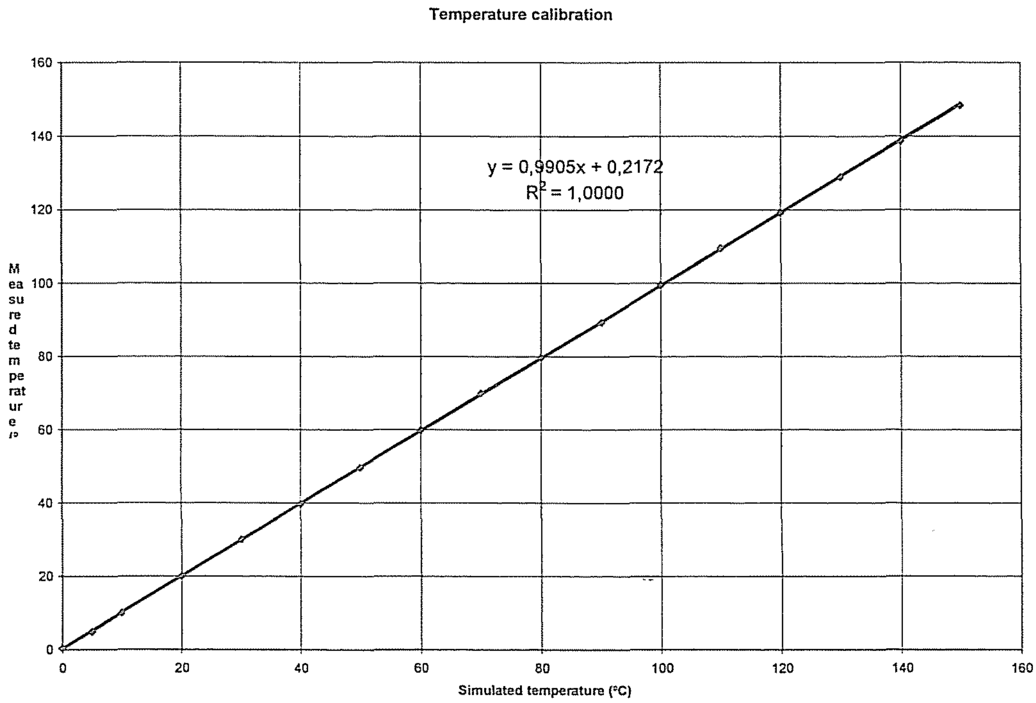


Figure 8. Temperature probe calibration curve.

2.4.4. Flowmeter.

2.4.4.1. Flow calculation.

There is two ways to install ultrasonic probes on the pipe: reflex and opposition. (see figure 11)

If we assume that:

probes are in reflex mode;
v is the speed of the water inside the pipe;
d in the internal diameter of the pipe;
c is the sound speed in the water;
and θ the angle that the propagation direction of the ultrasound wave forms

with pipe axis, we can put that

$$v = (\Delta T * c^2) / (4*d*\text{cotg}\theta)$$

where ΔT is the transient time difference. The flow can be get from the next expression:

$$flow = K* \Delta T *d$$

where

$$K = (\pi/16) * (c^2*\text{cotg } \theta)$$

In general we can write that

$$K = m*(\pi/8)*(c^2*\text{cotg}\theta)$$

Where m is a new constant that depends of the way the operator put the ultrasound probes. Its value is 1 in opposition mode or 0.5 in reflex mode.

θ is a parameter that depends of the construction of the ultrasound crystals. In our case cotgθ value is .43154. Therefore K=0.0070984 * m if we take 1472m/s as the water sound speed.

With ΔT in ns and d in mm the flow is given in cubic meters per hour.

2.4.4.3. Flowmeter calibration.

The calibration has been done in the test bench using Fisher and Porter flowmeter as reference. We started the test with the valve closed, and then we incremented the flow in 0.05 m^3/hour steps untill the valve was completelly open. In these contitions the pump provides a flow of roughly 0.78 m^3/ hour.

Figure 10 represents the the calibration process results.

2.5. The suitcase.

All the items are allocated in a suitcase of 47x35x19 cm which was provided by STOCKBOX. Pictures of fig. 23 and 24 show the suitcase with all the probes inside.

The suitcase contains:

- 1 solar radiation probe;
- 1 flowmeter;
- 8 temperature probes;

- 1 power supply to power the flowmeter;
- all the sensors needed for the ten probes;
- 1 RS 232 cable to connect probes with the host computer.

2.6. Technical Characteristics and Installation.

2.6.1. Power comsumption of the temperature and solar radiation probes.

The power comsumption of the temperature and solar radiation probes is:

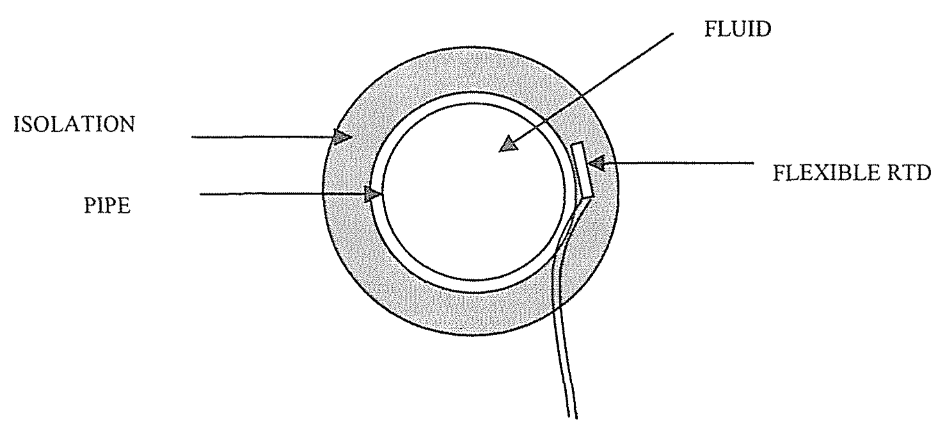
- In standby mode, 20 μA;
- During measurement period, 30 mA
- When communication with the host computer is stablished, 120mA

Probes are powered by a standard 9V battery. This kind of battery is very easy to found in the market. At C.I.E.M.A.T. we have done tests with a Procell Professional Alkaline Battery from DURACELL, in order to evaluate the autonomy of the probes. Measurements have been pursued for more than a mounth.

Warning ¡ The probes must be powered **before** connecting the RS232 wire to the host computer.

2.6.2. Installation of the temperature sensors.

To install the MINCO RTD the thermal isolation of the pipe must be first removed. When the ribbon is fixed to the pipe surface. (see next figure) the isolation has to be put on again.



Instalation of a flexible RTD (transversal view)

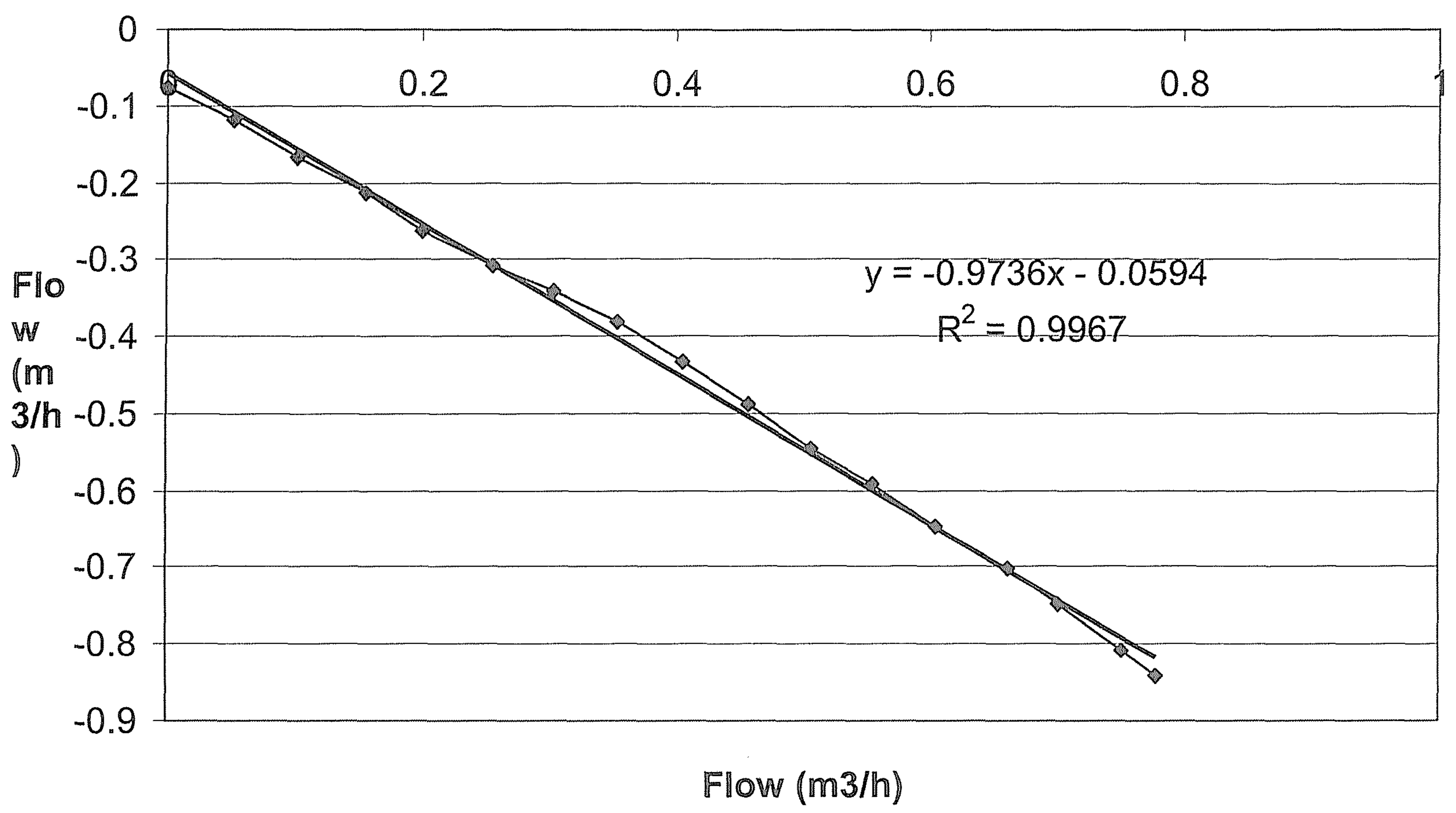


Figure 10. Flowmeter calibration.

2.6.3 Installation of the ultrasonic crystals.

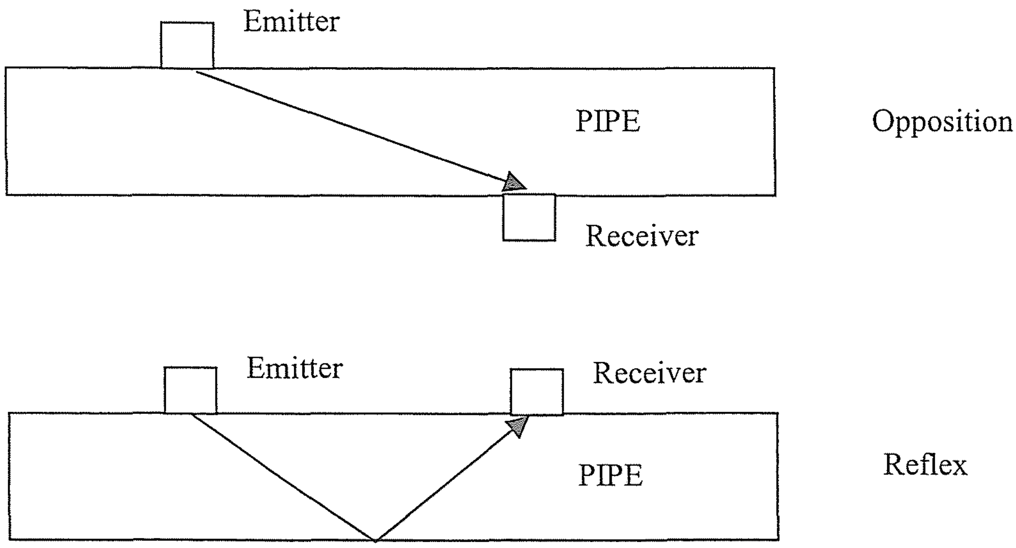


Figure 11. Ultrasound crystal installation.

First, the operator has to decide the installation mode of the ultrasonic crystals on the pipe. If pipe diameter is equal or less than 2 inches reflex mode must be used. For pipe diameters from two to four inches opposition mode is recommended. For diameters greater than four inches the probe does not work properly because the echo signal cannot be stored in the FIFO memory. Some modifications in the flowmeter-probe design are under study in order to measure flow in much greater pipes.

After the mode is stablished, the operator must calculate the distance between crystals. If we work in reflex mode, this distance is given by the next expression:

$$Distance = 2*(1.7692*e + 0.43154*d)$$

where e is the thickness pipe and d the internal diameter.

For opposition mode the expression is

$$Distance = 1.7692*e + 0.86208*d$$

As for the temperature ribbons the pipe thermal isolation must be removed before the installation of the ultrasound crystals.

To be sure that the probe is correctly installed, the operator must use the Parameter Command. When this command is received the probe searchs the echo signal and sends to the the host the time ellapsed between the emission and the reception of the echo signal. The operator can make a theoretical approach to this time by dividing the pipe diameter by the sound speed. If both values agree, probes are correctly installed and the measurement period can begin.

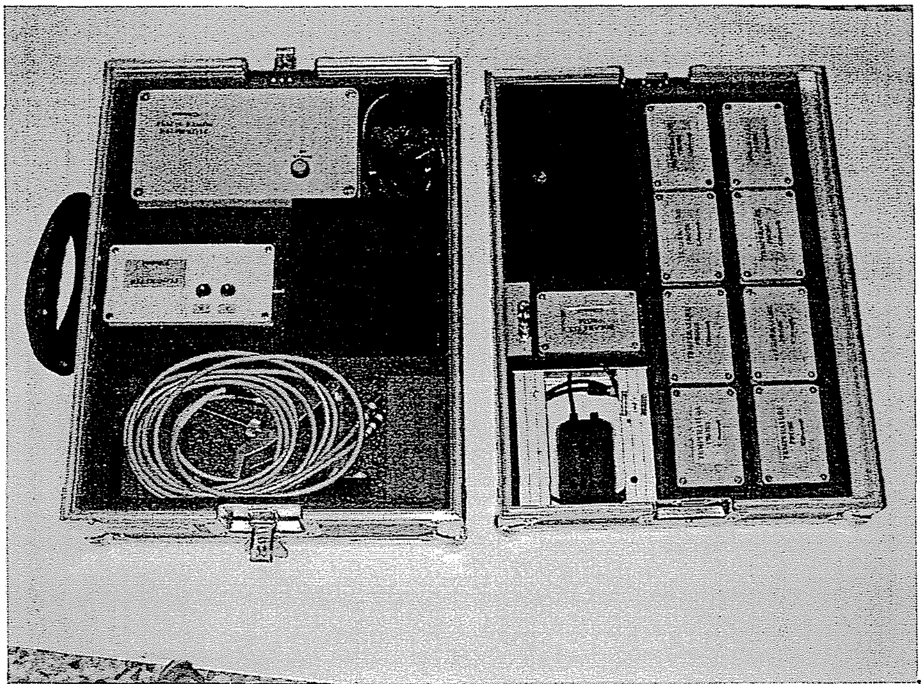


Figure 12. Internal view of the suitcase with all items inside.

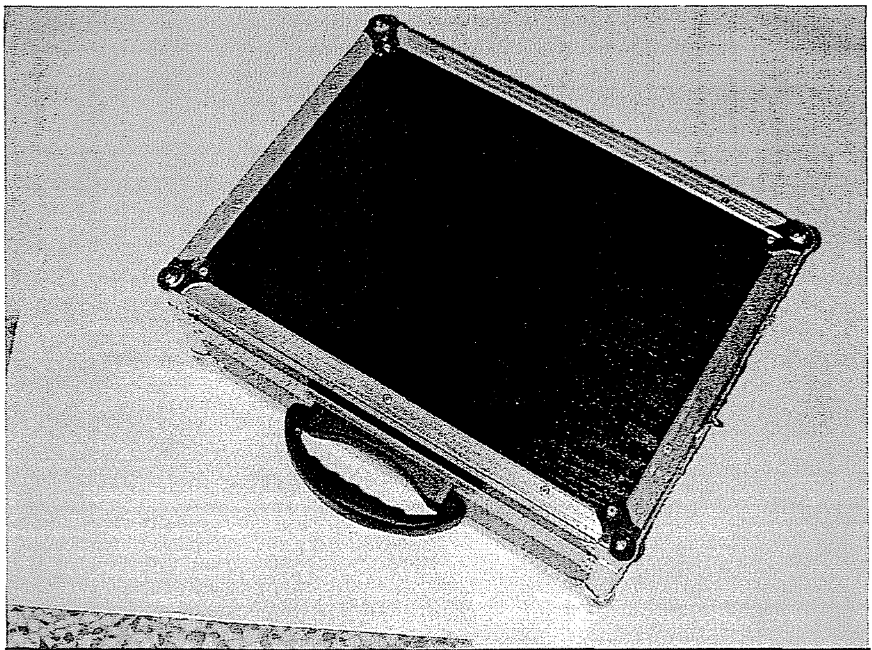


Figure 13. External view of the suitcase.