MELISSA

TECHNICAL NOTE 18.1

esa
estec

C. BINOIS

REGISTRE DES EDITIONS
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EDITION *(ISSUE)*	**Date**	**Observations**
00	07/92	ORIGINAL EDITION
01	02/93	PRESSURE LOOP and LEVEL CONTROL

REPERTOIRE DES PAGES
(PAGE ISSUE RECORD)

Ce document comprend les pages suivantes à l'édition indiquée
(Issue of this document comprises the following pages at the issue shown)

Document	Pages	EDITION *(ISSUE)*
TECHNICAL NOTE 18.1	ALL	00
TECHNICAL NOTE 18.1	ALL from page 22	01

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I. SCOPE

The main goals of this document is to describe the actual characteristics of the ESTEC control system as well as the mathematical models of the MELISSA compartments. In this point of view, it describes the structure and the main functionalities of the system. The user may find the complementary informations in the INDUSTAR user manuals (see References). This document describes also how the system is able to control a compartement (the application to the photosynthetic compartment is described). As this document intends to be also a working document for further use it may evolve in the futur, and It will be necessary to update it frequently. The second part of this document explains how a mathematical modelisation has be done and how it could be use to control on-line a MELISSA compartment. Finally, a first balance of the system and knowledge model characteristics and plans to comply with the goal of having a predictible control of whole the MELISSA loop, have been done.

II. CONTROL SYSTEM

The control system describes here after is based under MDC100 software from INDUSTAR and SENSYCON P100 controllers (with extensions and available options).

This system was chosen due to its many advantages :

-Modular and evolutive

-multi-users and multi-processes

-remote survey of processes

-separate control of each parameters

-safeguard of process with alarm management at controller level.

-low cost

-user friendly

-reliable and widely used in industry

II.1. HARDWARE ARCHITECTURE

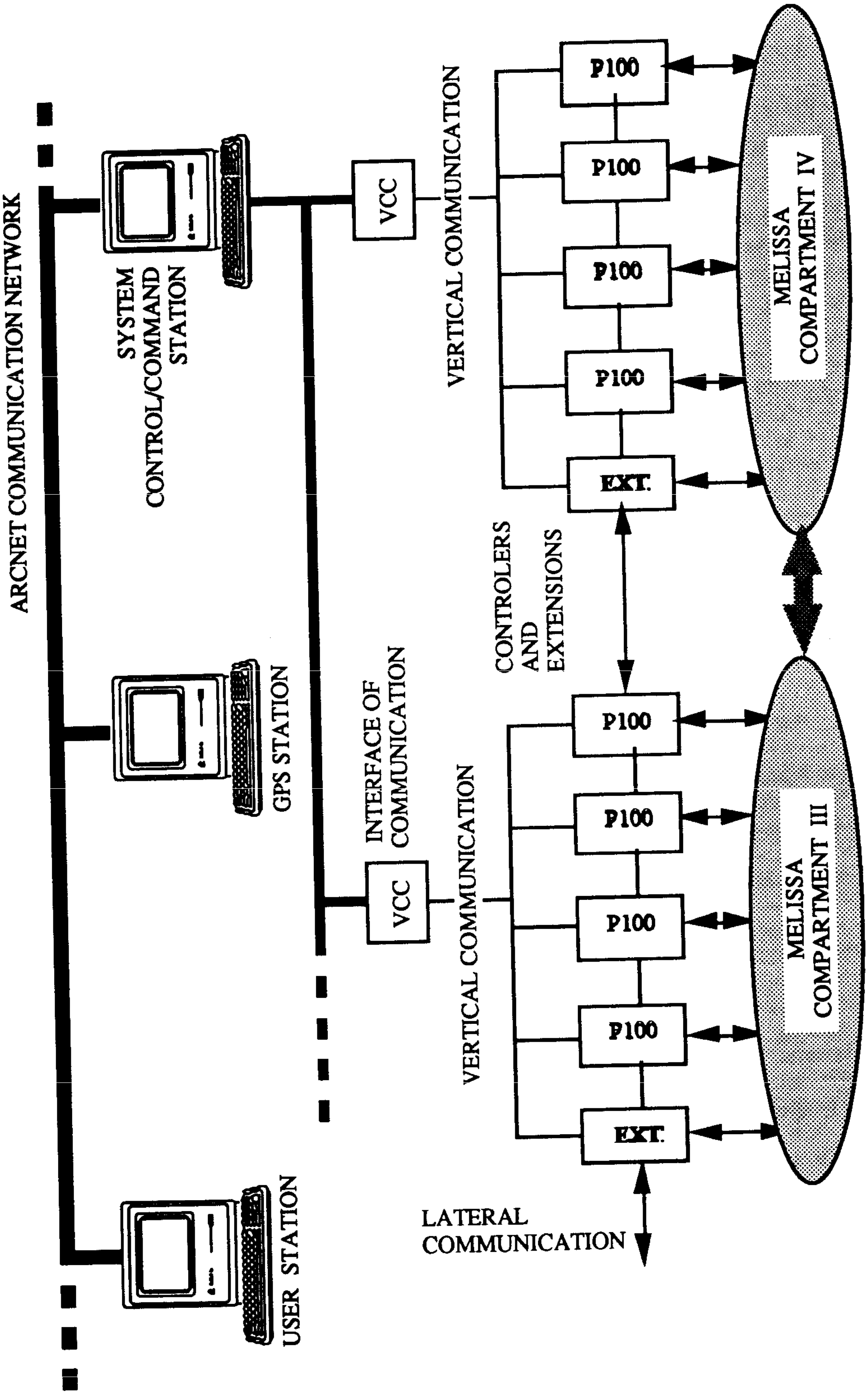

Figure 1 : hardware structure of the ESTEC control system.

II.1.1. GENERAL DESCRIPTION

The stations are interconnected via a token ring network : ARCNET

This network allows information transfer and remote control of processes. Stations are PC or PC compatibles machines such as COMPACQ-286 having MS-DOS as operating system. A specific communication board is installed in the PC extension port to allow the connection of the station.It exists three kinds of station, System, Control/command, and GPS station.

II.1.2. SYSTEM CONTROL/COMMAND STATION

This station supports two functions, System management and control/command.The System management function shall be installed on one station only to avoid problems coming from many different configurations. This function allows the manager to customise the system and is describe in the software description part.Control/command is the active part for process control, that means a direct link exists between the station and the controllers in charge of process. The station is connected to the P100 controllers through a vertical communication controller (VCC). A specific board installed in the PC extension port drive the VCC.

II.1.2.a P100 CONTROLLER

It is a fully autonomous programmable device able to manage up to 4 regulation loops. For MELISSA the P100s are all configured in 2 loops mode.

The P100 has 4 interfaces with its environment :

-A **user interface** constituted of front face and lateral dialogue keyboard. The front face allow user to have a global view of regulation loops. The loop states are thus well know by displaying of light bar graphs , numeric values and lights indicators. The lateral dialogue keyboard is used for configuration and utilisation of all the P100's capabilities, nevertheless a centralised system is more user friendly to manage more than one controller.

-A **lateral communication interface** to exchange data with others P100 or extensions when used. A maximum of 32 P100 (64 regulation loops) may be interconnected by this way.

-A **vertical communication interface** to allow connection of a supervising computer. This connection is made via a VCC100 which is able to drive up to 4 controllers. The serial link is an RS485 half duplex, asynchronous link with a rate of 315.5 kBauds.

-A **process interface** with analogue and digital input/output.

type	qty	description
Analogue Inputs	4	Voltage input 0-5V and 1-5V
AI		Current loop 0-20mA and 4-20mA
		Analogue / Digital conversion 12 bits
Analogue Outputs	2	Current loop 0-20mA and 4-20mA
AO		Analogue / Digital conversion 12 bits

Digital Inputs DI	4	This inputs may be activated by a relay contact or by an open collector connected to ground. The maximum current to drive is 5mA
Digital Outputs DO	2	This outputs provide when activated a 125mA output current under 24V through an unprotected open collector.

For MELISSA one VCC100 with four P100 and a logic extension set (24 inputs, 16 outputs) were affected to each compartment in order to have specific control electronic as closed as possible from the process. The analog links are all made using current loops 4-20mA, but for a low number of links the 0-20mA current loop is preferred to convert the current in a voltage.

The P100 also drive two regulation loops (LOOP).A regulation loop is a set of 20 lines maximum, each line containing one of the 100 internal functions of P100. The set of lines is scanned at an adjustable rate from the first line to the last one, this constitute the loop.

There is various internal functions :

-Input and output functions

-regulation functions

-mathematical functions

-sequence control functions

-logical and jump functions.

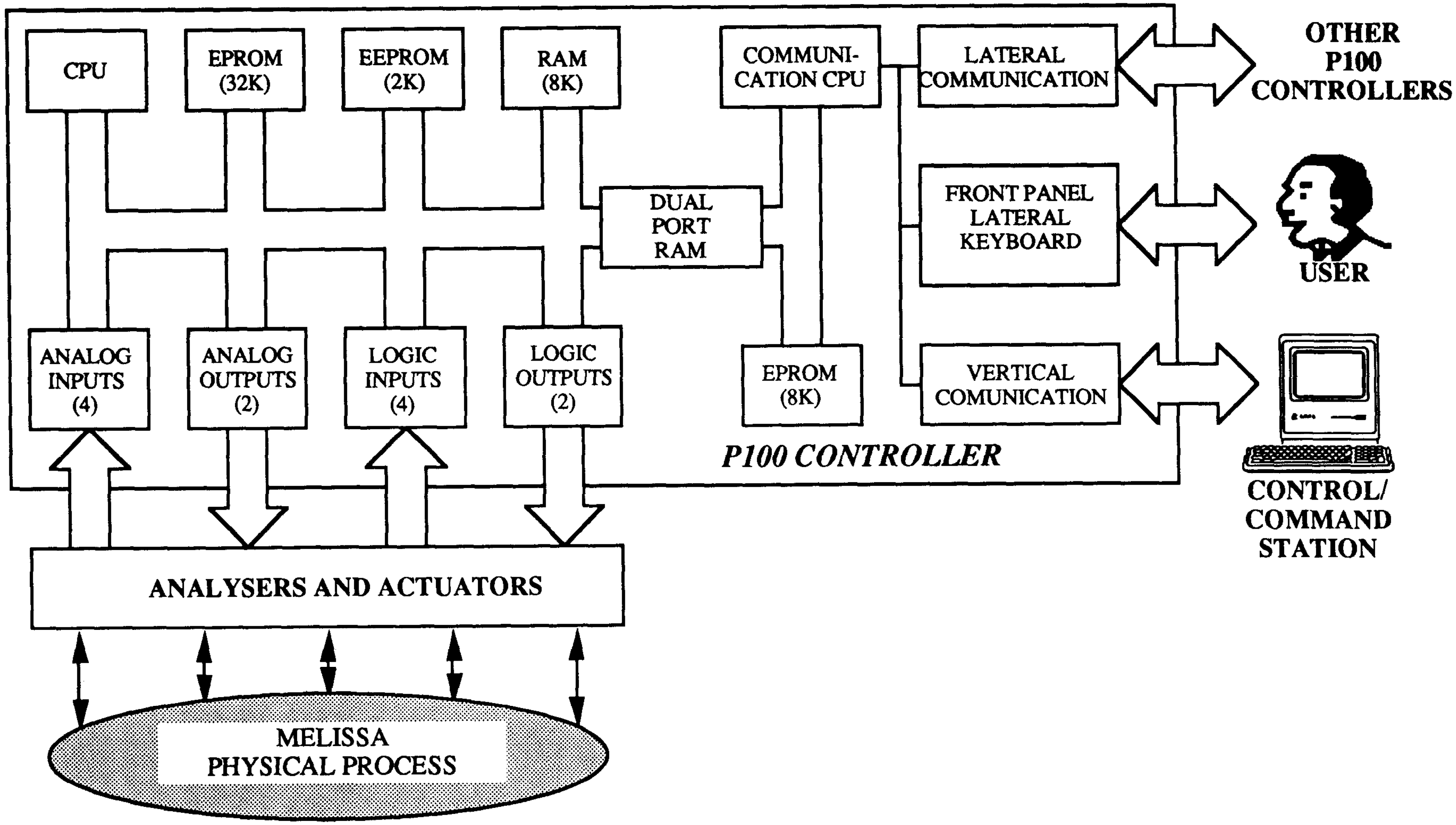

figure 2 : MICON P100 structure and environment.

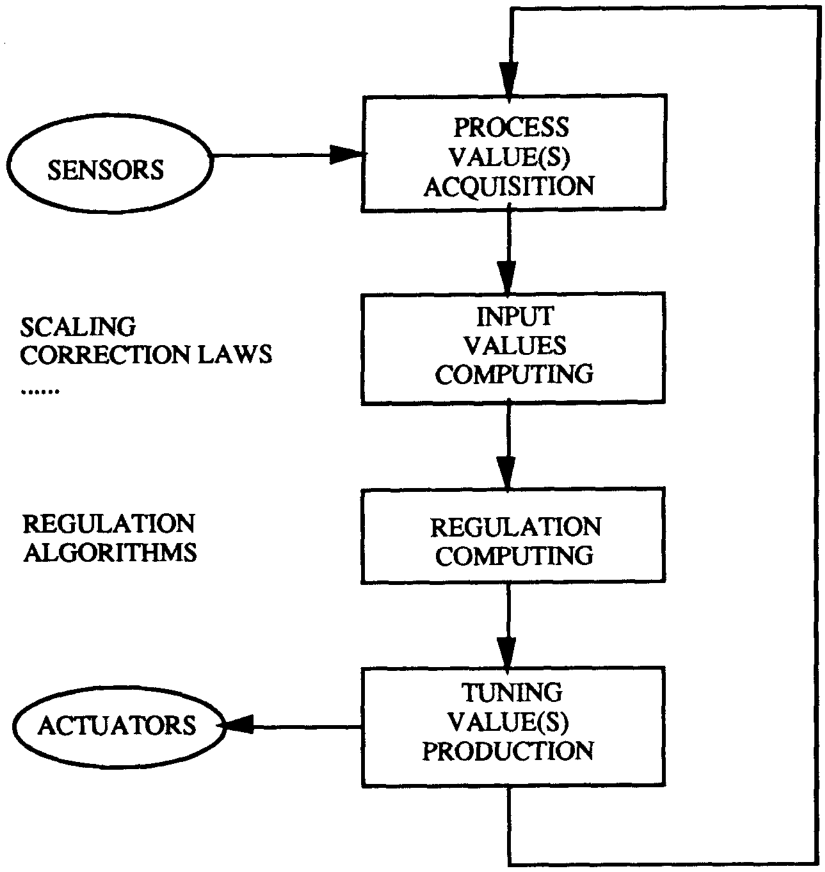

figure 3 : Principle of MICON regulation loop.

II.1.3. USER STATION

This station has only the control/command possibilities with eventually access limitations to data

II.1.4. -GPS- General Purpose Station

This station communicates with the control/command station connected to the process, using a set of predefined procedures (programmation interface GPS) to read or write data relative to controlled process.

It may access 2 types of data :

-TAG read only

-COMMAND read and write

The permission to access/modify data is configured by the system configuration software . Data are gathered by 40 in a group, only one may be active at a time.This station is intended to support user specific software such as a control model and allow a global view of many processes.

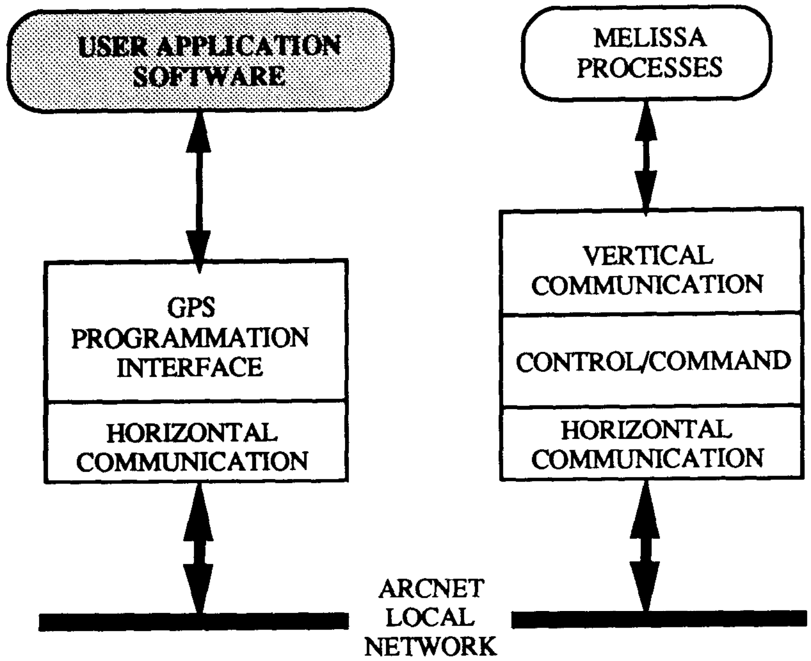

figure 4 : GPS link with the system.

II.2. SOFTWARE ARCHITECTURE

The system is composed of :

- a communication software using a mailbox to exchange data,
- five functional units :
    - -Control / command.
    - -Centralised alarm management.
    - -Curves display.
    - -Archiving and reports edition.
    - -Programmation interface

The installation is easy and simplified by a separate configuration of each unit. This allows the system to be personalised and yield a huge suppleness. The management is separate in two main parts whose are called ON LINE and OFF LINE according the system is running or stopped.

II.2.1. OFF LINE /SYSTEM CONFIGURATION

This configuration tool allows control system start-up updating and new applications development. The figure here after shows the different parts of this tool and the interaction between these parts.

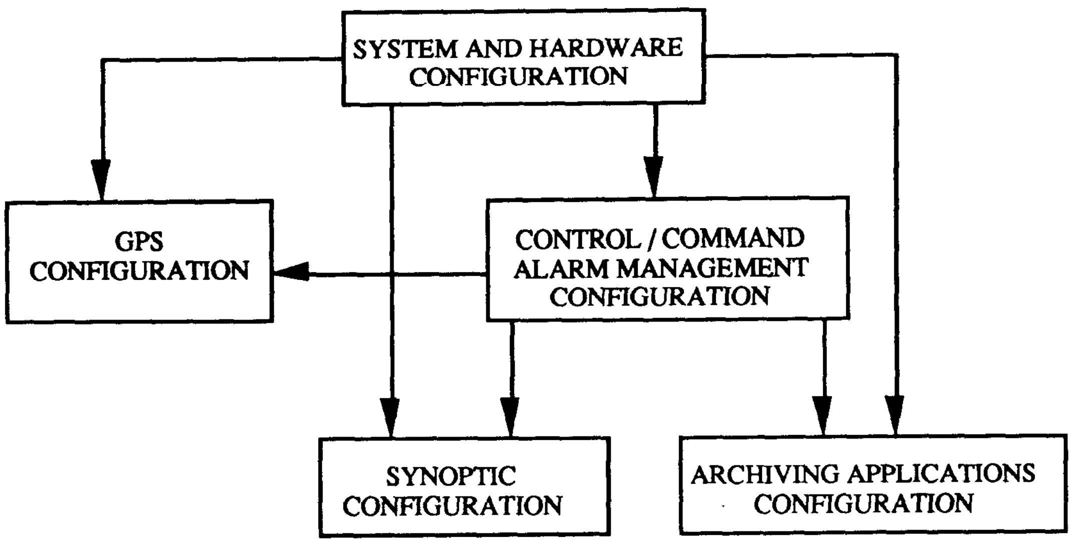

figure 5 : Interactions between the different configuration tools.

II.2.1.a SYSTEM AND HARDWARE CONFIGURATION

the following operations are available to the system manager :

-Network configuration, stations definition, allow the system to known each station and its attributed functions.

-Specification of the vertical link between stations and their associated equipments.

-Definition of the control equipments.

-Specification of the communication parameters for each installed station.

-Creation of configuration files to install and customise the control system.

-Definition of printers parameters to define informations printing.

II.2.1.b CONTROL/COMMAND AND ALARM CONFIGURATION

It is necessary to define, all input variables coming from the equipments, their associated alarm conditions, output variables and command sended to equipments, and computerised variables. Each of them will be associated with an identifier called TAG for input variables and COMMAND for output variables.

The operations to be completed are :

Digital tags definition characterised by :

-name i.e. DI--0106
-variable description for user
-equipment
-type alarm, state
-active state
-associated alarm

Analog tags definition characterised by :

-name i.e. AI--0106
-variable description for user
-equipment
-convertion of the binary input in intelligible unit ?
-unit of the variable
-controlled variable ?
-maximum and minimum value
-scale factor
-critical threshold high and low
-thresholds of the operating range
-associated alarm

Digital commands definition :

To define the commands disposable to the user and those calculated and sended by the control system.

-name i.e. DO--0106
-password ? to protect access
-variable description for user
-equipment
-displaying informations on synoptic
-associated alarm

analogic command definition

To define the commands disposable to the user or calculated by the control system. The system manages three different kinds of analogic commands :

-regulation	-->	LOOP
-virtual discrete	-->	VD
-memory location code	-->	LOC

Regulation command

-name i.e. LOOP0106
-loop description for user
-name of regulated variable
-equipment
-loop 1 to 8
-set point
-output value
-ratio
-bias
-loop state

The five last parameters may be analogic variables and have to be completed with their maximum and minimum values.

Virtual discretes

-name i.e. VD--0106
-variable description for user
-name of regulated variable
-number of the logical variable

memory location code

-name i.e. LOC-0106
-variable description for user
-name of regulated variable
-equipment
-number of the LOC variable
-maximun and minimum values with unit

All of these variables may be used to animates the synoptics and the control panels.

II.2.1.c ARCHIVING APPLICATIONS CONFIGURATION

The values of surveyed variables may be archived on disk for later analyses reports production or curves drawing. The report generation software uses two data bases, HISTO which contain raw samples of configured variables and, HISTO2 for computerised records. It uses also the data coming from the mail box.

The first step is to defined the station which will receive the configuration . The configuration may be different for each station.

It is then necessary to define the structure of each data base as follow:

-Duration of record is the time period we want to save on disk, data are gathered in a FIFO.

-Storage unit

--Number of scanning frequencies (5 maxi) from 1 second to 60 seconds for the first data base HISTO. For the second one HISTO2 data are scanned every minute and stored once an hour.

The system calculate the available disk space and ask the operator to confirm or not his choices.

First data base definition

The variables are first specified with their sampling rates, thus they are gathered in groups to allow exploitation. An archiving group contains up to ten variables among those defined. A group is characterised by :

-group name
-time scale
-display mode of data
-data order and characteristics

Second data base definition

The specification of variables to be treated is defined as follow :

-name
-description
-type of treatment to be done

The report generation software allows also the creation and printing of report issued with real time data, in this case we shall defined groups containing up to ten variables.

II.2.1.d SYNOPTIC AND USER INTERFACES CONFIGURATION

This tool allows a real customisation of the control system. The user can draw his own synoptics. These synoptics may be animate, thus the user has a schematic view of process with the dynamic informations coming from the sensors and the controlled equipments. The user may use pre defined symbols to draw his synoptics. It is also possible to define which one has to be displayed following the state of the controlled process.

II.2.1.e PROGRAMMATION INTERFACE CONFIGURATION

This tool allows the constitution of variable goups which will be manage by the programmation interface. Only the variables defined during the configuration sessions can be included in the groups. A group contains a maximum of 40 variables (tags and commands).

II.2.2. ON LINE

All the tools describes here after are the active part of the control system. The user may access to different working mode

II.2.2.a CONTROL / COMMAND AND ALARM MANAGEMENT

When this software is start up, it displays a window with the available choices (figure 6). The user may select the option he wants with a light pen by pointing the desired zone. The different possibilities are :

-view of the control system by displaying a part of all the configured variables i.e. LOOP on figure 7.

-view of the synoptic associated to a process i.e. compartment IV of Melissa on figure 8

The control panel displayed all the time in the lower part of the screen allows the user to view alarms or to modify the values displayed on the window. This function is a remote control tool for the process. It allows the user to follow and to pilot easily and efficiently the process. The system is thus completely transparent for the user. It exists a set of standard control panel for a quick start-up, nevertheless it is possible to create new ones.

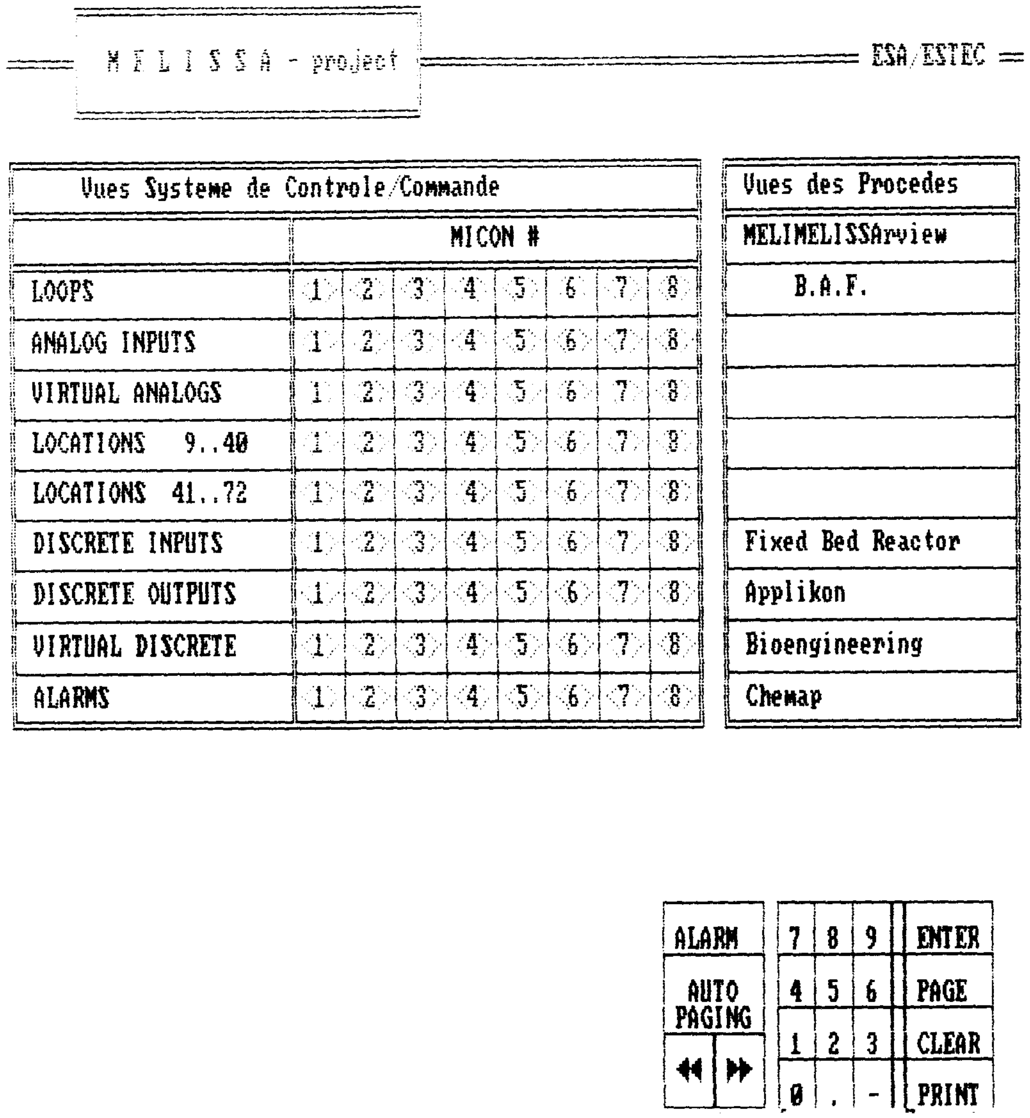

figure 6 startup window

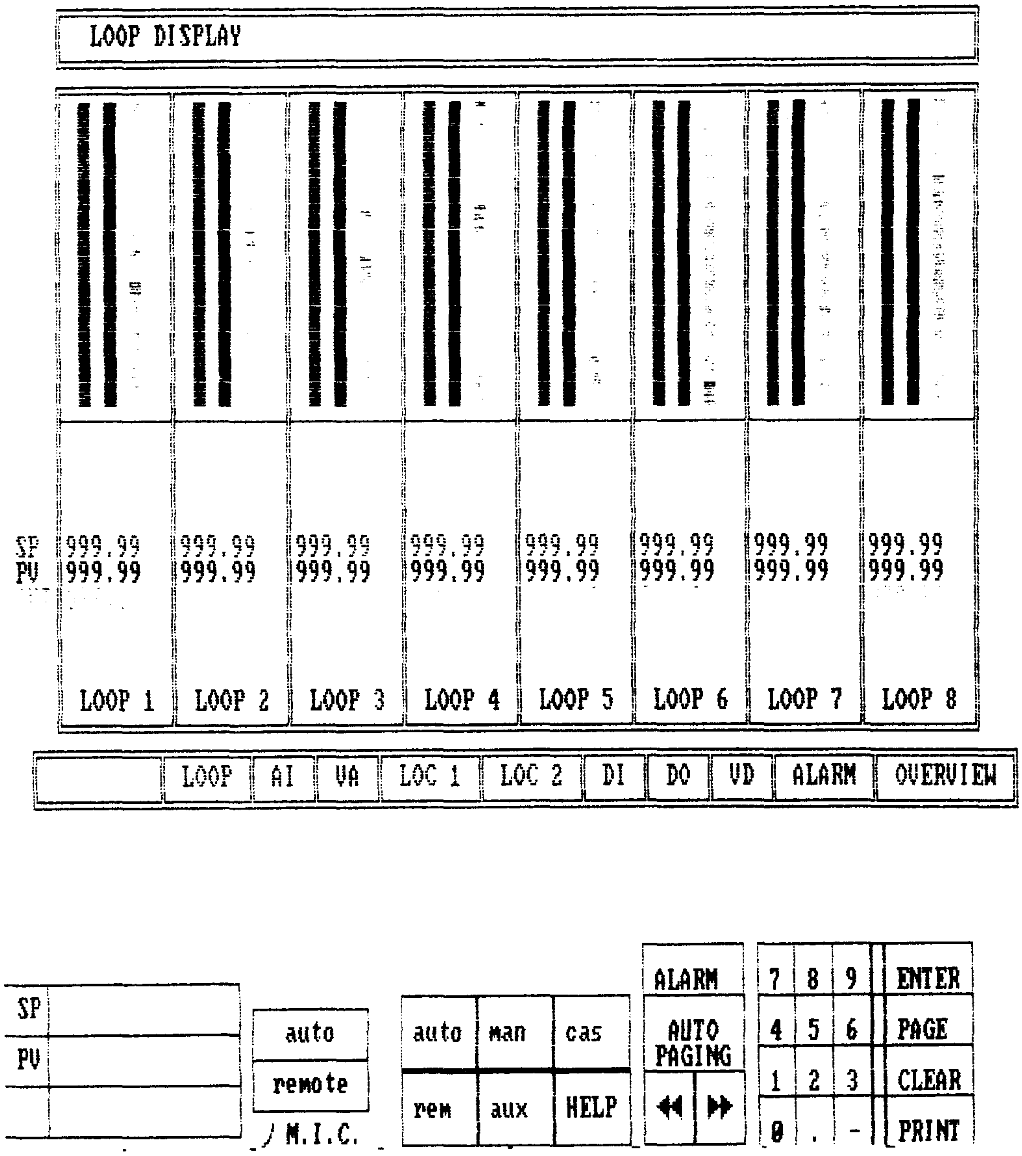

figure 7 view of the regulation loops

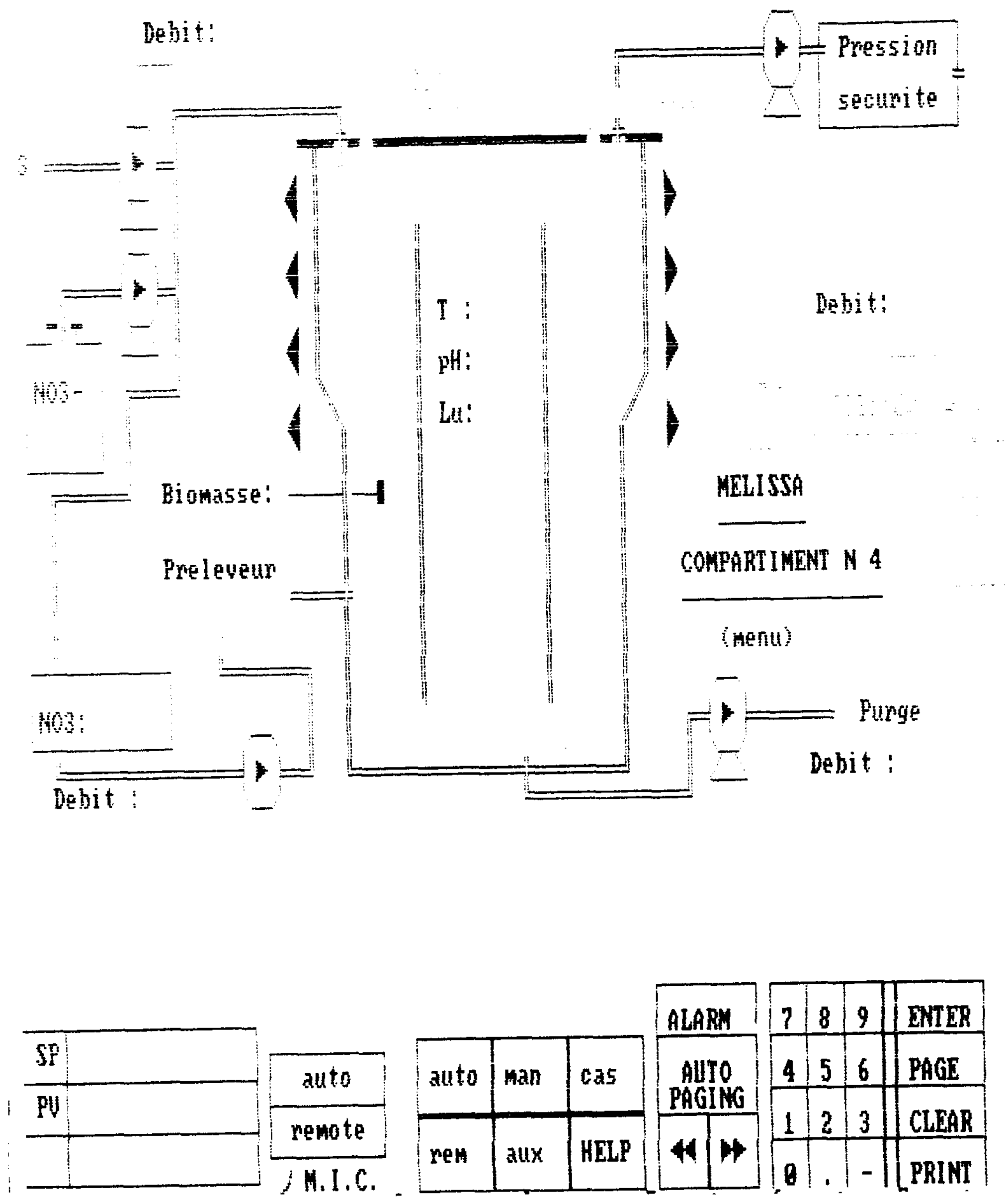

figure 8 view of the process synoptic

II.2.2.b ARCHIVING APPLICATIONS

There is two main functions : "curves" and "data processing".

CURVES

The graphic representation of the datas on a colour screen is useful to follow the behaviour of the process. The user may choice and modify the following items :

-the displayed group (ten variables maximum)

-the displayed variables

-the visualisation scale

-the time scale

-etc....

This function is like an ten channel oscilloscope.

DATA PROCESSING

This function allows printing of datas coming from the two data bases. The impression may be done automatically and in different ways.

FIRST DATA BASE HISTO

-table of values printing

-transfer of the report in an ASCII file for later exploitation

-graphic printing of values

SECOND DATA BASE HISTO2

-periodic report edition

-counters check

II.2.2.c MICON CONFIGURATION

This tool allows to configure (and modify) the MICON. The system associates one MICON with four P100 controllers configured in two loops mode. The user may perform the following operations : read, edit, send, or test a configuration.

A configuration is constituted of :

-loop configuration containing the P100 functions (20 maximum) to be executed

-loop auxiliary for the static parameters of the loop

-analog input configuration

-analog input auxiliary

-digital input configuration

After modification the configuration may be updated in the configuration files. It is possible to test a configuration by displaying of output values for each step of the eight loops of a MICON. It is also possible to display all discretes values.The on line configuration allows the user to work with the datas stored in the P100s. Once the modifications are done, there are only stored in the P100s, the configuration is not saved in files without the user operation.

II.2.3. PROGRAMMING INTERFACE GPS

This interface allows the user to develop his own applications. These applications shall be write in C language, the recommended version is Microsoft C 5,1. The userdef.h file contains all the declarations used by the GPS procedures. This file shall be included in the beginning of each source file by using the command #include <userdef.h>.

The available procedure are the followings :

open_gr to open a group file, the file may only be read. In order to have a quick access to the datas it is possible to open more than one file at a time.

activ_gr ,this function reads and transfers the contain of the file in the memory. The file shall be opened first and only one group can be activated at a time.

rd_gps , this function searches the specified TAG in the active group and reads the tag value in the mail box, the union IGPS is updated.

set_cmd , this function searches the specified COMMAND in the active group and reads the command value in the mail box, the union OGPS is updated.

wr_gps , this function writes the new value of a command in the mail box. The new value is then send to the equipment. The unions OGPS and S_USER shall be used.

close_gr ,this function closes the activated group and allows the user to activate another one.

gettags ,allows identification of a variable in an activated group.

garde ,checks during a specified time if the mail box is correctly updated.

II.3. APPLICATION TO THE PHOTOSYNTHETIC COMPARTMENT OF MELISSA

The system describes above was used to control in a first time the photosynthetic compartment of the MELISSA loop. It has been used for nitrifying compartment and it will be for all the others. The following pages shows how this system controls the compartment IV.For each loops, a synoptic describes the principle and two tables lists the operations done for the control, and the TAG and COMMAND associated to the controlled loop.

II.3.1. LOOP 1 - ALARMS and GENERAL MANAGEMENTS

LOOP	ALARMS and GENERAL MANAGEMENTS
GOAL	Provide a central management of alarms at controller level, counters reseting and transfert of intermediate results of control into memory location codes (LOC).
MEASUREMENTS	
ACTIONS	The P100 checks all the loops of the MICON 1 and setup a general alarm TAG if an alarm occurs on one loop. The alarms are enabled/disabled at controller level and at MICON level by user operations. A general alarm vector is provided in order to allow a quick identification of faults by the user control software The loop manages also the daily reseting of the totalisers using an external clock.
ALARMS	
INFORMATIONS	

	NAME	DESCRIPTION
ANALOG VALUES	LOC-0122 LOC-0121	Main alarm, active = 1. Alarm vector for MICON 1, sum of the following values if an alarm is set on the controller, zero if any. 1 -> controller 1 2 -> controller 2 4 -> controller 3 8 -> controller 4
DIGITAL VALUES	DO--0101	electric valve command for pressure regulation
ALARMS		

II.3.2. LOOP2 - PRESSURE REGULATION

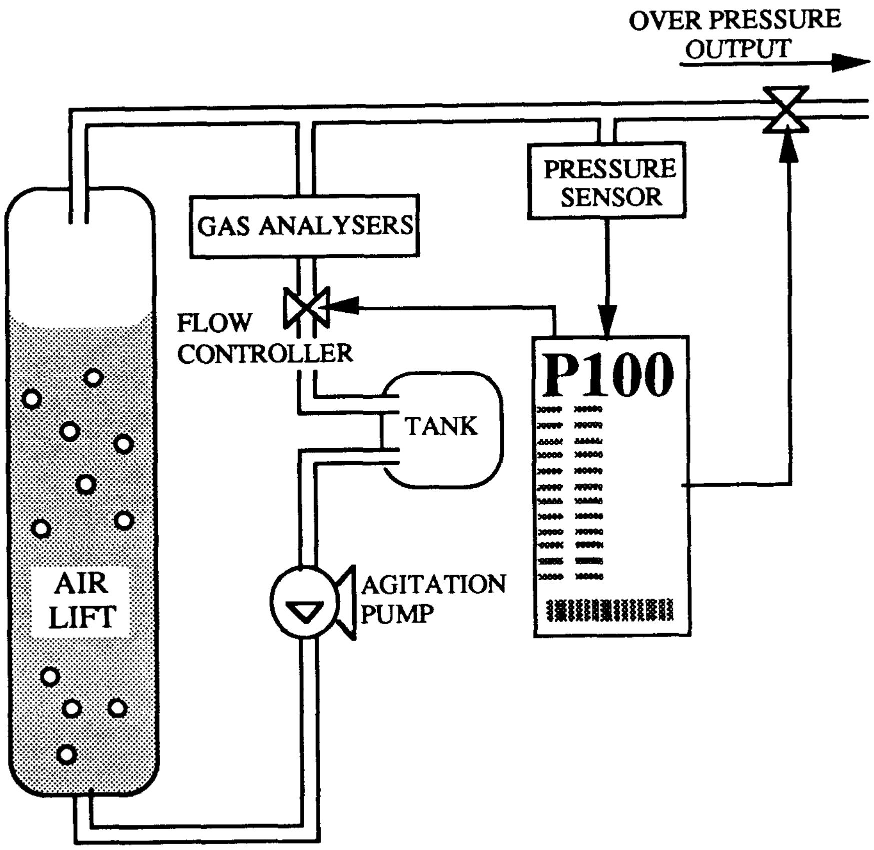

figure 9 : Pressure loop principle

LOOP	PRESSURE
GOAL	Maintain the pressure of the gaseous phase under a set point. Safety control of the bio-reactor.
MEASUREMENTS	Pressure sensor connected to the air lift Characteristics - Range 0 to 1000 mbar - Continuous measure - Calibration none - Direct value
ACTIONS	The P100 controls aperture of the valve during a fixed time when the pressure is upper the set point.
ALARMS	
INFORMATIONS	

	NAME	DESCRIPTION
ANALOG VALUES	AI--0101	CO2 analiser Maihak output
	AI--0102	O2 Servomex output
	AI--0103	gaseous pressure in air lift
	AO--0102	Flow controller command for pressure regulation
	LOOP0102	pressure regulation loop
	LOC-0114	Counter of the valve command actions
	LOC-0115	Totalisation of the pressure regulation command
DIGITAL VALUES	DI--0121	Range switch CO2 analiser
	DO--0121	electric valve command for pressure regulation
ALARMS		

II.3.3. LOOP3 - NITRATE REGULATION

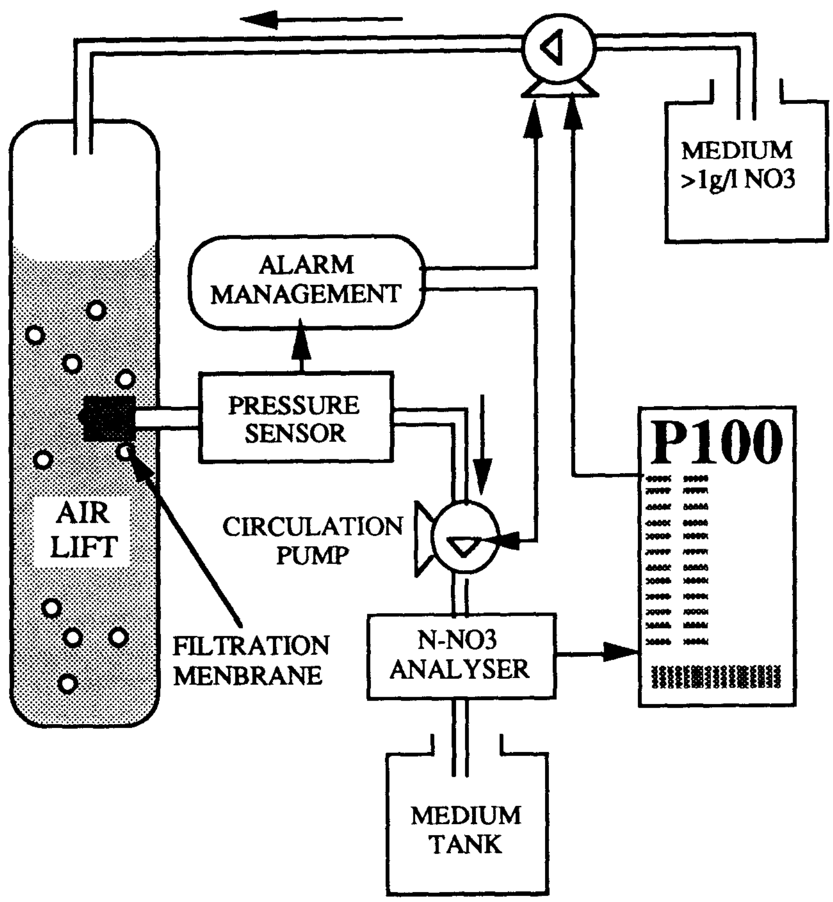

figure 10 : Nitrate regulation loop principle.

LOOP	NITRATE NO_3^-
GOAL	Maintain the nitrate concentration in culture medium around a fixed value to compensate nitrate consummations by spirulina.
MEASUREMENTS	The medium is extracted without biomass through a filtration membrane in rotation to avoid clogging, medium is then analysed and returned to the medium tank. The analyser measure nitrogen of nitrate concentration by ultra violet attenuation in medium. Characteristics - Range 0 to 25 mg N-NO3/l - Continuous measure - Calibration 20mn every day
ACTIONS	The P100 controls injection of medium with a high concentration of nitrates (> 2g/l). The volume of the culture is maintained constant by the liquid level regulation loop.
ALARMS	A pressure sensor provides information on membrane's state , in case of problems the pumps are stopped. deviation alarm alarm on the liquid level into the nitrate tank.
INFORMATIONS	Cumulating of actions allows nitrogen yields calculation

	NAME	DESCRIPTION
ANALOG VALUES	AI--0107	Nitrate measurement
	AO--0103	Nitrate injection pump command
	AI--0116	Pressure on filtration membrane
	LOOP0103	nitrate regulation loop
	LOC-0119	Totalisation of the nitrate regulation action
DIGITAL VALUES	DI--0105	indication of nitrate analyser calibration
	DO--0123	Enable the power supply of the nitrate circulation pump
ALARMS		

II.3.4. LOOP4 -pH REGULATION

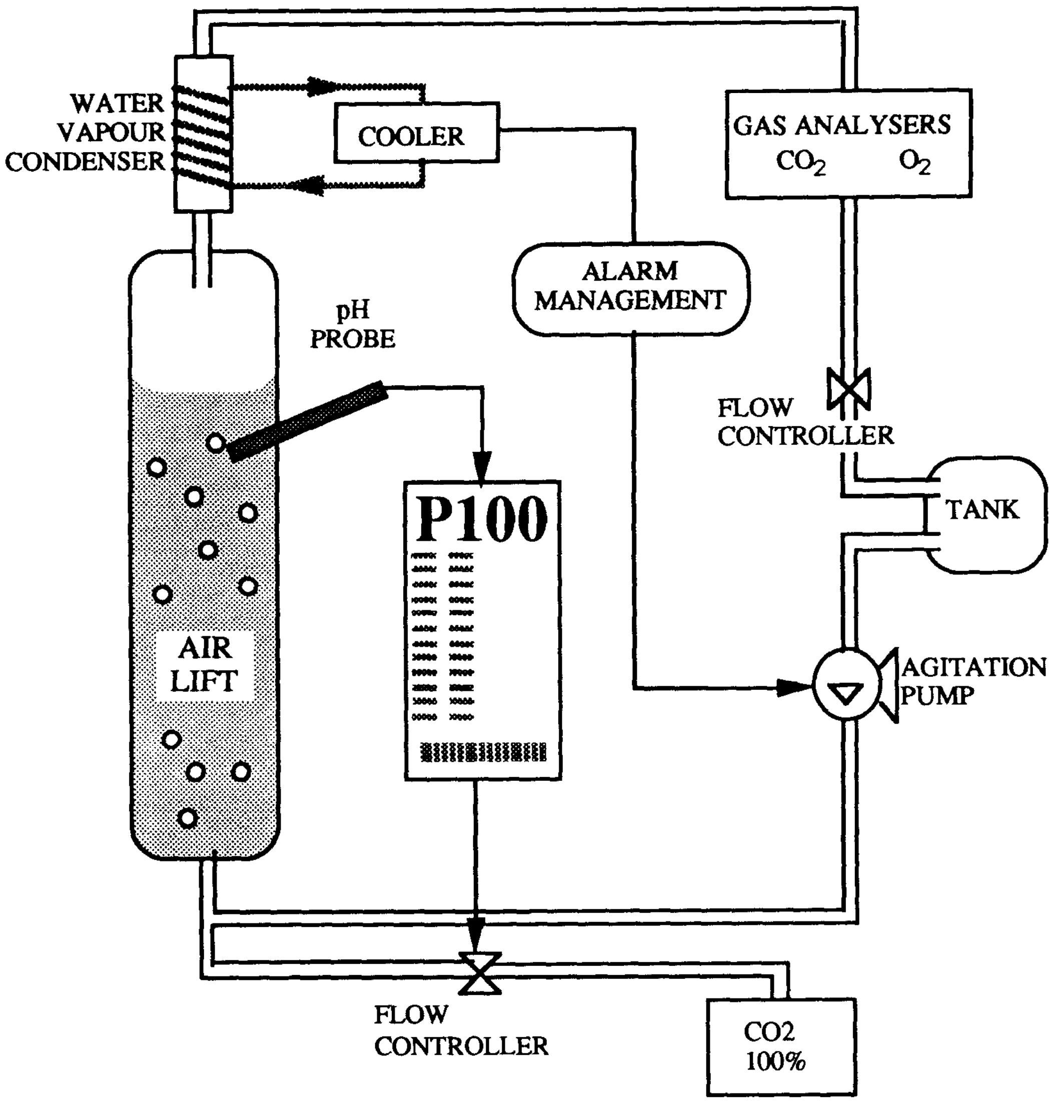

figure 11 : pH regulation loop principle and gaseous phase measurements

LOOP	pH
GOAL	Maintain the pH in culture medium around a fixed value to compensate pH augmentation due to spirulina growth.
MEASUREMENTS	The pH is measured with a pH probe in the bioreactor liquid phase. The gaseous phase is extracted through a vapour condenser then O2 and CO2 are analysed. An agitation pump blows in the bioreactor producing the agitation of culture. Characteristics
ACTIONS	The P100 controls injection of CO2 to reduce pH using a chemical reaction $CO_2 + OH^- \rightarrow HCO_3^-$ The speed of action is limited by CO_2 dilution time in medium.
ALARMS	A cooler defections stop the pH regulation and the air blowing/circulation pump to avoid liquid leaks in gaseous analysers. deviation alarm on pH possible if CO_2 tank is empty.
INFORMATIONS	Cumulation of actions allows calculation of CO_2 consumption, 100% equals to 100 ml/mn.

	NAME	DESCRIPTION
ANALOG VALUES	AI--0101	CO2measurement
	AI--0102	O2 measurement
	AI--0105	pH measurement
	AI--0113	pO2 measurement
	AO--0104	pH regulation command
	LOOP0104	pH regulation loop
	LOC-0113	Totalisation of pH regulation action
	LOC-0117	CO2 computed value
DIGITAL VALUES	DI--0121	CO2 range
	DI--0126	Alarm switch thermostatic bath for air lift condenser
	DO--0124	Enable power supply of agitation pump
ALARMS		

II.3.5. LOOP5 - LIGHT REGULATION

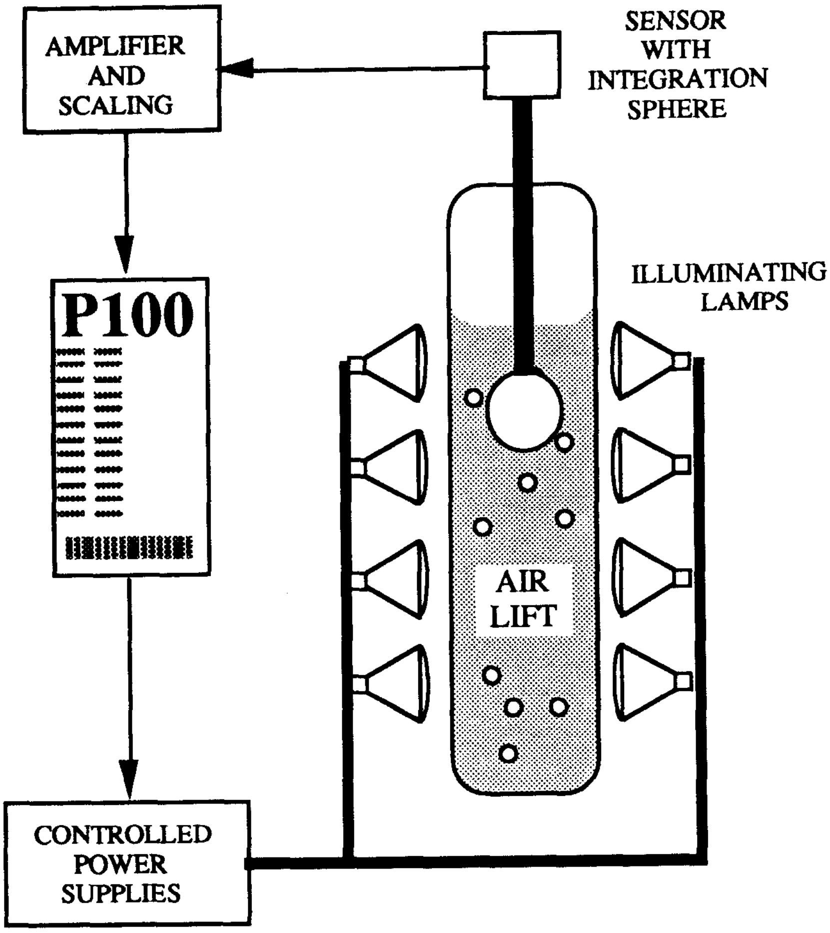

figure 12 : Light regulation loop principle.

LOOP	LIGHT
GOAL	Maintain the light intensity inside the bioreactor around a set point
MEASUREMENTS	The light is collected by an integration sphere in the middle of the bioreactor and lead to the sensor by an optical fiber. Characteristics -Range 0 to 850 W/m^2 by use of 4 scales -continuous measure -calibration done before starting the culture
ACTIONS	The P100 controls the power supplies to have the desired intensity inside the bioreactor.
ALARMS	
INFORMATIONS	

	NAME	DESCRIPTION
ANALOG VALUES	AI--0112	light measurement, raw value
	AO--0105	power supplies control
	LOOP0105	light regulation loop
	LOC-0119	Light measurement, computed value
	LOC-0110	Totalisation of the light regulation action.
DIGITAL VALUES	DI--0109	light range 0 to 850 W/m^2
	DI--0110	light range 0 to 85 W/m^2
	DO--0111	light range 0 to 8.5 W/m^2
	DO--0112	light range 0 to 0.85 W/m^2
ALARMS		

II.3.6. LOOP6 - TEMPERATURE REGULATION

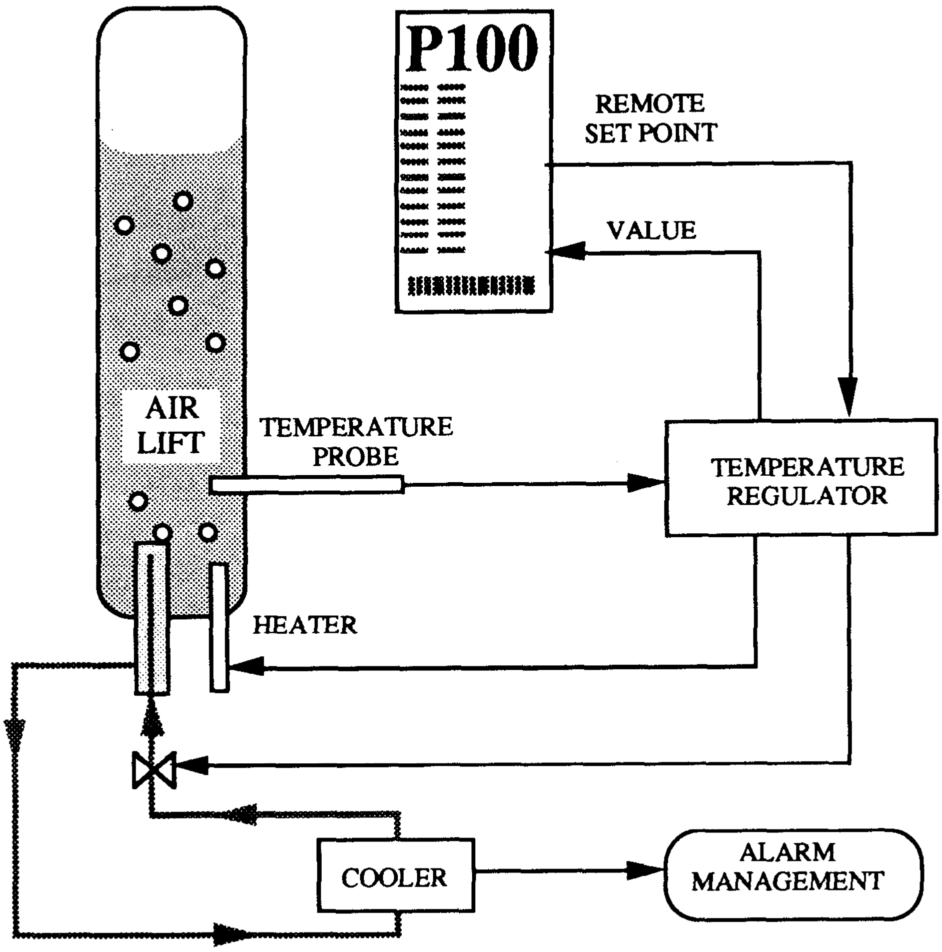

figure 13 : temperature regulation principle.

LOOP	TEMPERATURE
GOAL	Maintain the temperature of the culture around a set point.
MEASUREMENTS	A probe measure the temperature of the medium, the temperature controller provide the value to the P100 Characteristics - Range 0 to 150°C - Continuous measure - Calibration none
ACTIONS	all the regulation actions are performed by the temperature regulator. The P100 can only modify the value of the set point
ALARMS	In case of defect of the cooler, the light set point is reduce in order to limit the radiated energy coming from the lamps.
INFORMATIONS	

	NAME	DESCRIPTION
ANALOG VALUES	AI--0110 AO--0106	temperature measurement set point output for temperature
DIGITAL VALUES	DI--0107	Alarm switch thermostatic bath for temperature regulation
ALARMS		

II.3.7. LOOP7 - BIOMASS REGULATION

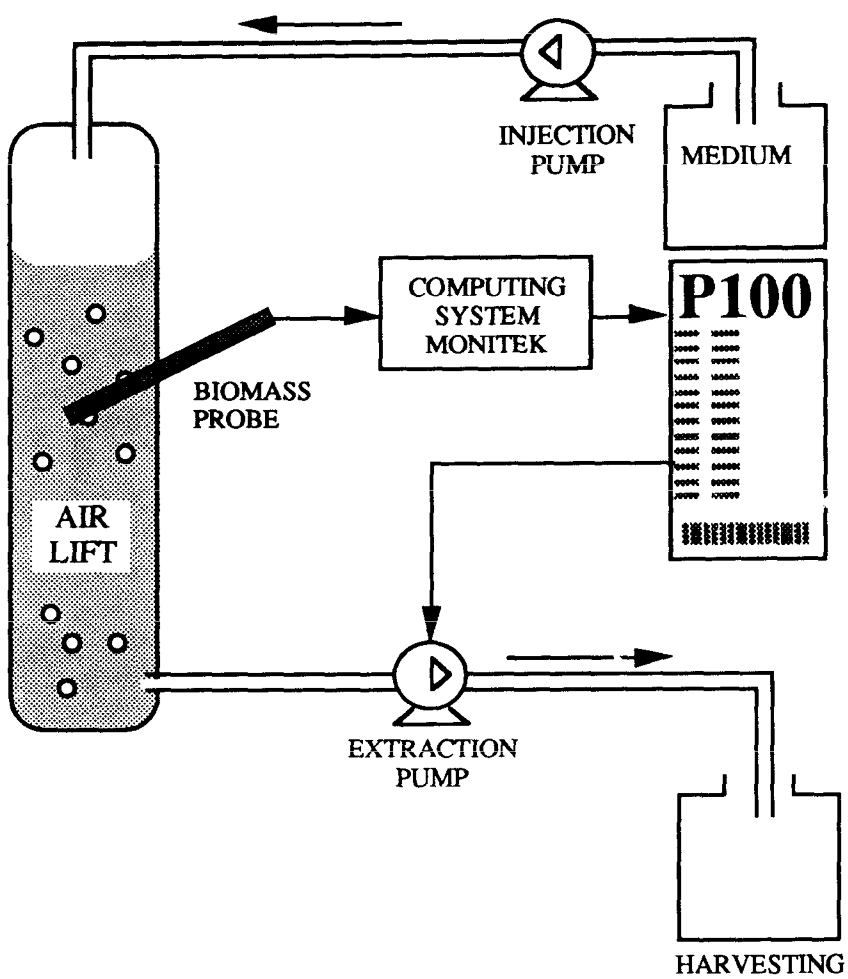

figure 14 : Biomass regulation principle.

LOOP	BIOMASS
GOAL	Maintain the biomass concentration in culture medium around a set point to compensate spirulina growth.
MEASUREMENTS	A biomass probe measure attenuation of a light beam through the culture. then a correction law is used by the controller to calculate the biomass concentration in the reactor Characteristics - Range 0 to 1 Attenuation - Continuous measure with two differents damping factors, one for small variations and one for huge variations. - Calibration before starting the culture for zero value, during the culture measurements on samples may be use to check and correct the biomass measurement.
ACTIONS	The P100 controls harvesting of medium with spirulina, the injection of Zarrouk medium (NO3 concentration around the NO3 set point) is managed by the liquid level regulation loop.
ALARMS	
INFORMATIONS	Totalisation of action allows volumetric growth speed calculation

	NAME	DESCRIPTION
ANALOG VALUES	AI--0114	Monitek attenuation (0-1)
	AO--0107	Biomass harvesting pump command
	LOOP0107	biomass regulation loop
	LOC-0118	Monitek attenuation
	LOC-0120	Computed value of biomass concentration
	LOC-0111	Totalisation of biomass regulation action
DIGITAL VALUES		
ALARMS		

II.3.8. LOOP8 - LIQUID LEVEL REGULATION

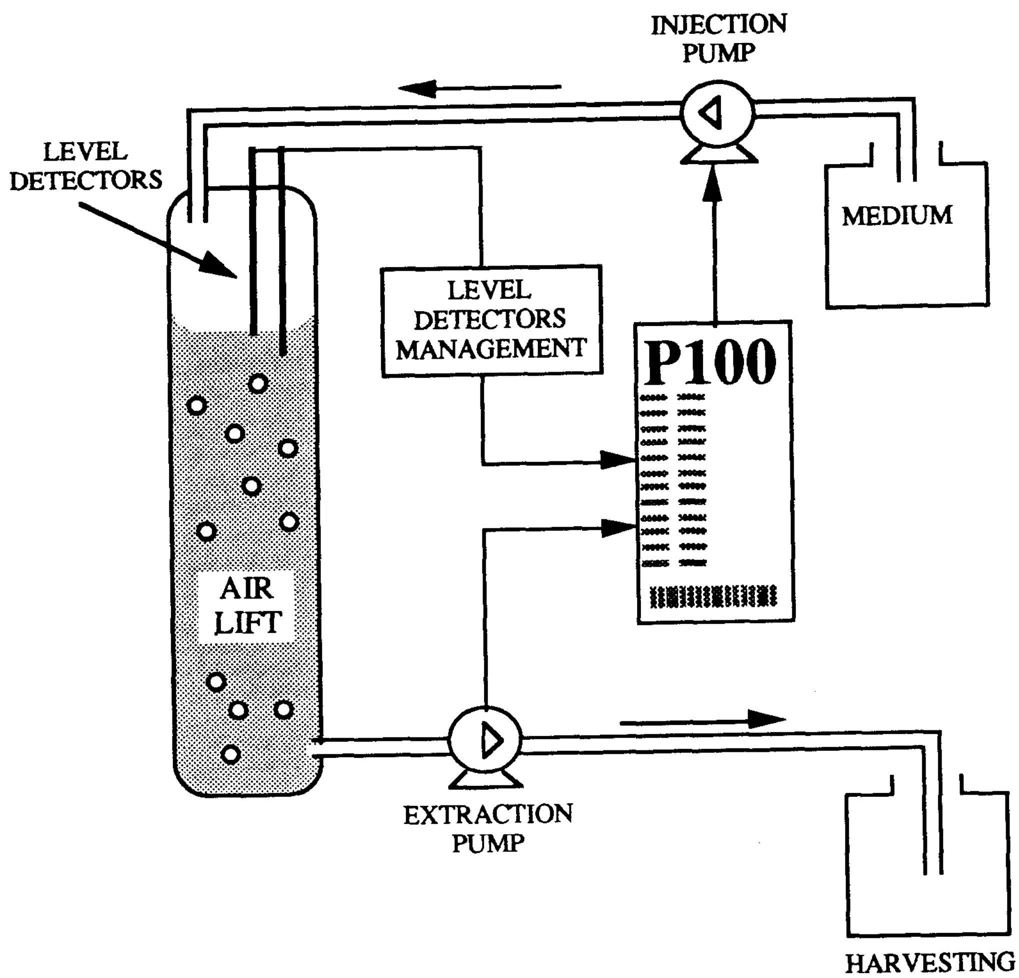

figure 14 : Liquid level regulation principle.

LOOP	LIQUID LEVEL
GOAL	Maintain the liquid level in the reactor within a range determined by two level dectectors, one for the high level and the other for the low level. This regulation loop was implemented to avoid emptying or filling of the reactor.
MEASUREMENTS	Two level detectors are (or not) in contact with the culture medium, thus two digital informations are available. Only one level measurement system is available, a relay was added to commute the input of this system either on the high level sensor either on the low level sensor.
ACTIONS	It exists three cases : - The liquid level is below the low level, the speed of the injection speed is 25% more than the speed of the extraction pump. - The liquid level is between the low and high level, the speed of the injection speed is the same than the speed of the extraction pump. - The liquid level is above the high level, the speed of the injection speed is 25% less than the speed of the extraction pump.
ALARMS	
INFORMATIONS	

	NAME	DESCRIPTION
ANALOG VALUES	AO--0108	Medium injection pump command
DIGITAL VALUES	DI--0136	Switch output of the liquid level detector system
	DO--0127	Relay command for the selection of the level detector
ALARMS		

III. MATHEMATICAL MODEL

This model was developed (JF CORNET et Al.) to describe the behaviour of Sprirulina Platensis in various culture conditions.This model is intended to be used by a control system in order to predict and control evolution of the culture.

III.1. CHARACTERISTICS

The state of the culture is describe by an overall chemical state vector C, which includes the concentrations of the compounds present in the biotic and abiotic phases.The different compounds of the biotic and abiotic phases that have been chosen for inclusion in the model are shown on figure 15. The state vector is :

$C = (C_{PC}, C_P, C_{CH}, C_{XA}, C_G, C_N, C_S)$

where C expresses a concentration in kilogramms per cubic meter , the subscipts N and S denotes the nitrate and sulfate concentration in culture medium. In addition the mass biotic fractions are defined by $z_i = C_i/C_{XA}$ for compound i and the total biomass concentration by $C_{XT} = C_{XA} + C_G$. When the culture is not in limitation condition by sulfur or nitrogen, experimental results indicate that the biotic mass fractions of proteins (z_P) , of phycocyanins (z_{PC}) , and of chlorophylls (z_{CH}) remain constant whatever the energy flux.

- $z_P = 0.57$
- $z_{PC} = 0.135$
- $z_{CH} = 0.0085$

BIOTIC PHASE

<table>
<tr><td colspan="4">Active biomass XA</td><td rowspan="3">Sulfated intra-cellular glycogen
G</td></tr>
<tr><td colspan="2">Total proteins P</td><td rowspan="2">Chlorophylls
CH
(PSI)</td><td rowspan="2">Biomass
B</td></tr>
<tr><td>Phycocyanins
PC
(PSII)</td><td>Others proteins
OP</td></tr>
<tr><td colspan="5">Total biomass XT</td></tr>
</table>

ABIOTIC PHASE

Nitrates N	Sulfates S

figure 15 stuctured model

The C,H,O,N,S, and P elemental composition of the active biomass XA is assumed to be constant whatever the culture conditions are. This assumption has been experimentaly confirmed and the measurements of the elemental composition of Spirulina afforded the following C-molar formula for the active biomass :

$$CH_{1.650}O_{0.531}N_{0.170}S_{0.007}P_{0.006}$$

This formula, which includes extracellular polysaccharide, gives the following stoichiometric equation for photosynthesis :

$$CO_2 + 0.724H_2O + 0.170HNO_3 + 0.007H_2SO_4 + 0.006H_3PO_4 \dashrightarrow CH_{1.650}O_{0.531}N_{0.170}S_{0.007}P_{0.006} + 1.378\ O_2$$

Tacking into account pH modifications during growth, this equation can be rewritten as :

$$HCO_3^- + 0.724\ H_2O + 0.170NO_3^- + 0.007SO_4^{2-} + 0.006HPO_4^{2-} + 0.196H^+ \dashrightarrow CH_{1.650}O_{0.531}N_{0.170}S_{0.007}P_{0.006} + 1.378\ O_2 + OH^-$$

With this equation the theoritical value of mass conversion yields of nitrates and sulfates in biomass can be calculated :

$Y_{N/XA} = 0.42$
$Y_{S/XA} = 0.028$

III.2. EXPRESSION OF THE MODEL

Considering that spirulina is a photosynthetic micro organism, it's not surprising that in the formulation of the mathematical model, light is the main parameter. The model take into account two effects on light transfer inside the bioreactor : absoption and scattering.

-The absorption depends on pigment concentrations, absorption is thus proportionnal to the phycocyanin and chlorophyll content of the cells, that is the sum $C_{PC} + C_{CH}$. The resultant biotic mass fraction of the light harvesting antenna is then expressed as $z_a = z_{PC} + z_{CH}$.

Scattering must be related to the size of cells suspended in the medium and is thus proportional to the mass concentration of the total biomass C_{XT}. Using the glycogen content of total biomass, $z_G = C_G/CXA$ the parameters α et δ are expressed as :

$$\alpha = \sqrt{\left[\frac{z_a E_a}{z_a E_a + (1+z_G) E_s}\right]}$$

$$\delta = [z_a E_a + (1+z_G) E_s]\ \alpha\ C_{XA}\ L$$

Where E_a and E_s are the overall absorption and scattering mass coefficients which have been experimentaly determined :

$E_a = 813\ m^2/kg$
$E_s = 175\ m^2/kg$

The radian energy available $4\pi Jz$ at the point z (for a rectangular reactor) is expressed as :

$$4\pi J_z = 2\, F_0 \left[\frac{(1+\alpha)e^{-\delta(Z-1)} - (1-\alpha)e^{\delta(Z-1)}}{(1+\alpha)^2 e^{\delta} - (1-\alpha)^2 e^{-\delta}} \right]$$

Fo is the incident flux and Z=z/L the dimensionless reduce lenght of the bioreactor.

The working illuminated lenght L_2 is defined as the portion of the reactor where growth occurs, and is calculated using :

$$(1+\alpha)^2 e^{\delta} - (1-\alpha)^2 - \frac{4\alpha}{T} = 0$$

$$T = F_L/F_0 \text{ and } F_L = 1\ W/m^2$$

Solving the above equation by replacing L by L_2 in the expression of ∂ give the value of L_2.

It is now possible to obtain growth kinetics of spirulina with the following equations. The mean growth rate $\langle\mu\rangle$ is expressed as :

$$\langle\mu\rangle = \frac{1}{L_2} \int_0^{L_2} \mu'_M \frac{4\pi Jz}{K_J + 4\pi Jz}\, dz$$

and the mean volumetric growth rate $\langle R\rangle$ for cultures not limited by minerals is given by :

$$\langle R\rangle = \langle\mu\rangle\, \gamma\, C_{PC}$$

γ expresses the working portion of the bioreactor L_2/L and $\langle\rangle$ mean volumetric integral $= \frac{1}{V}\iiint_V \ldots\, dV$

In addition the conpounds growth rates , tacking into account of culture conditions (mineral limitations) are expressed as :

$$\langle r_{XA}\rangle = \langle R\rangle \frac{C_N}{K_N + C_N} \frac{C_S}{K_S + C_S}$$

$$\langle r_{CH}\rangle = z_{CH} \langle r_{XA}\rangle$$

$$\langle r_{PC}\rangle = z_{PC} \langle R\rangle \left[\frac{C_N}{K_N + C_N} \frac{C_S}{K_S + C_S} - \left(\frac{K_N}{K_N + C_N} + \frac{K_S}{K_S + C_S} \right) \right]$$

$$\langle r_P\rangle = z_P \langle R\rangle \left[\frac{C_N}{K_N + C_N} \frac{C_S}{K_S + C_S} - q \left(\frac{K_S}{K_S + C_S} \right) \right]$$

$$\langle r_N\rangle = -\, Y_{N/XA} \langle r_{XA}\rangle$$

$$\langle r_S\rangle = -\, Y_{S/XA} \langle r_{XA}\rangle$$

$$\langle r_{XT} \rangle = \langle R \rangle \left[\frac{C_N}{K_N + C_N} \frac{C_S}{K_S + C_S} + \frac{C_{PC}}{K_{PC} + C_{PC}^2} \left(\frac{K_N}{K_N + C_N} + \frac{K_S}{K_S + C_S} \right) \right]$$

With the following numerical values

$\mu'_M = 0.52\ h^{-1}$
$K_J = 20\ W / m^2$
$K_N = 5.3\ mg/l$
$K_S = 0.25\ mg/l$
$K_{PC} = 0.15\ kg^2/m^6$
$q = 0.55$

The pH whitin 9 - 10 has no significant influence on the spirulina growth kinetics, in contrary the temperature modifies the behaviour of the culture, thus the kinetics values have to be corrected by multiplying with the factor corresponding to the medium temperature in the table below.

TEMPERATURE	FACTOR	TEMPERATURE	FACTOR
20	0.30	34	0.96
22	0.36	36	1.00
24	0.45	38	0.91
26	0.56	40	0.79
28	0.67	42	0.66
30	0.79	44	0.52
32	0.89		

Table 1 Temperature effect on spirulina growth speed

III.3. MODEL ADAPTATIONS

The model has to be modified to match the culture conditions in ESTEC, in addition it will be completed by new equations for exopolysaccharide.

III.3.1. ADAPTATION TO THE CYLINDRICAL STRUCTURE

A study is actually performed by JF CORNET to determine the light transfer equations in a cylindrical photobioreactor like the one in use at ESTEC. The concerned equations are the relations between $4\pi Jz$ and Fo with modifications on α and δ expressions and the equation leading to the working illuminated volume. The kinetic equation will remain unchanged.

III.3.2. INCLUDING OF EXOPOLYSACCHARIDE IN THE MODEL

It is planned for the future to include the production of extra cellular polysaccharide by the way of a specific stoichiometric equation and a kinetic equation.

IV. MODEL AND SYSTEM BALANCE

The model previously describe can be use to predict the behaviour of continuous cultures. At steady state (constant volume in the bio reactor) the mass balances are written as :

$$DC_{io} - DC_i + \langle r_i \rangle = 0$$

Cio is the mass concentration of subscript i in the influent, for biomass compounds it is obvious to write Cio = 0. D is the dilution rate and expresses the volume replaced in the bioreactor during a period of one hour.The following table lists all the measured and controlled parameters as well as the parameter used by the model. The annotations indicates the use of the parameter :

- Controlled

- Measured

- Used by the model

PARAMETER	CONTROL SYSTEM	MODEL	DESCRIPTION
CPC		U	phycocyanins concentration
CP		U	protein concentration
CCH		U	chlorophylls concentration
CXA		U	active biomass concentration
CG		U	glycogen concentration
Cxt	M,C	U	total biomass concentration
CN	M,C	U	nitrate concentration
CS		U	sulphate concentration
TEMP	M,C	U	temperature of the culture
F0	M	U	light incident flux
$4\pi J$	M,C	U	light flux inside the reactor
pH	M,C		pH of the culture
CO2	M		CO2 in gaseous phase
O2	M		O2 in gaseous phase
pO2	M		dissolved oxygen
Pressure	M,C		gaseous phase pressure

In order to order good results with the model, it will be necessary to measure biomass composition more precisely that it is actually. The mass concentration of some biomass compound may be evaluated by the use of a spectro photometer after correct calibration.

V. REFERENCES

JF CORNET, CG DUSSAP, G DUBERTRET A Structured model for simulation of cultures of the cyanobacterium I. coupling between light transfer and growth kinetics / biotechnology and bioengineering 1992, Vol.40, Pp 817-825

JF CORNET, CG DUSSAP, G DUBERTRET A Structured model for simulation of cultures of the cyanobacterium II. Identification of kinetic parameters under light and mineral limitations / biotechnology and bioengineering 1992, Vol.40, Pp 826-834

INDUSTAR MDC100 USER MANUAL

ANNEX A

CONTROL BAY OF SPIRULINA COMPARTMENT

All the control equipments are centralised in a control bay. This bay is described here-after and the wiring schematics follow.

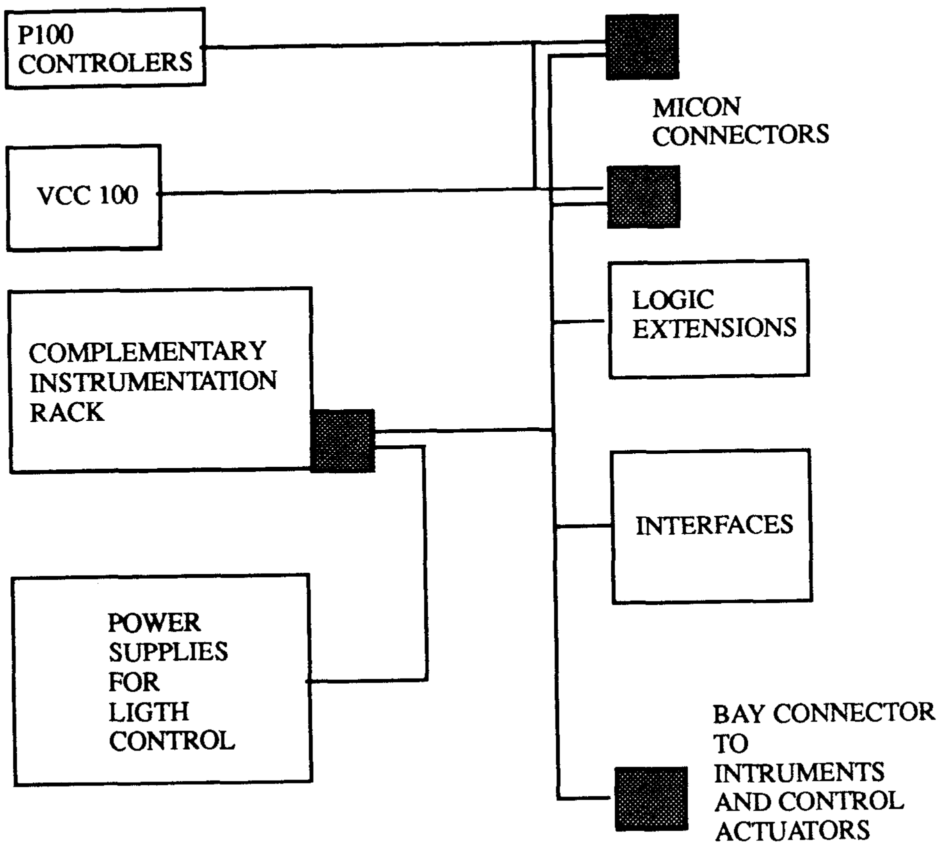

Figure A1 : Architecture of the 5th compartment control bay

The following pages contain the definition of each connector of the bay an the electrical schematics of the interfaces and the specific rack.

MICON 1

No	Pol	Tag Name	Description
1 2	+ -	AI--0101	CO_2 Analyser Maihak
3 4	+ -	AI--0102	O_2 Servomex
5 6	+ -	AI--0103	Gazeous Pressure Air-lift
7 8	+ -	AI--0104	
9 10	+ -	AO--0101	
11 12	+ -	AO--0102	Flowmeter for pressure regulation
13 14	+ -	DI--0121	Range Switch CO_2
15 16	+ -	DI--0122	RAZ by Main Clock
17 18	+ -	DI--0123	
19 20	+ -	DI--0124	
21 22	+ -	DO--0121	Pressure valve Air- lift
23 24	+ -	DO--0122	Main Alarm output , Red blinking light (220V)
26 27 28	D GND D/	Lateral Communication	
30 31 32	D GND D/	Vertical Communication	
33 34	+ -	24V power supply	

MICON 2

No	Pol	Tag Name	Description
1 2	+ -	AI--0105	pH Air lift
3 4	+ -	AI--0106	
5 6	+ -	AI--0107	NO_3^- Air-lift
7 8	+ -	AI--0108	
9 10	+ -	AO--0103	NO_3^- Regulation pump Air-lift
11 12	+ -	AO--0104	Flowmeter for pH regulation
13 14	+ -	DI--0125	Calibration Switch NO_3
15 16	+ -	DI--0126	Alarm switch thermostatic bath for Air lift condenser
17 18	+ -	DI--0127	Alarm switch thermostatic bath for temperature regulation
19 20	+ -	DI--0128	
21 22	+ -	DO--0123	Enable power supply of circulation pump NO3
23 24	+ -	DO--0124	Enable power supply of blowing pump
26 27 28	D GND D/	Lateral Communication	
30 31 32	D GND D/	Vertical Communication	
33 34	+ -	24V power supply	

MICON 3

No	Pol	Tag Name	Description
1 2	+ -	AI--0109	
3 4	+ -	AI--0110	Temperature measurement
5 6	+ -	AI--0111	
7 8	+ -	AI--0112	Ligth measurement
9 10	+ -	AO--0105	Ligth regulation, power supplies control
11 12	+ -	AO--0106	Temperature set point
13 14	+ -	DI--0129	Light range switch (lower)
15 16	+ -	DI--0130	Light range switch
17 18	+ -	DI--0131	Light range switch
19 20	+ -	DI--0132	Light range switch (higher)
21 22	+ -	DO--0125	
23 24	+ -	DO--0126	
26 27 28	D GND D/	Lateral Communication	
30 31 32	D GND D/	Vertical Communication	
33 34	+ -	24V power supply	

MICON 4

No	Pol	Tag Name	Description
1 2	+ -	AI--0113	pO_2 Air lift
3 4	+ -	AI--0114	Monitek measurement , biomass concentration
5 6	+ -	AI--0115	
7 8	+ -	AI--0116	Pressure on filtration membrane for NO_3 analyser
9 10	+ -	AO--0107	Biomass extraction pump
11 12	+ -	AO--0108	Medium injection pump
13 14	+ -	DI--0133	
15 16	+ -	DI--0134	
17 18	+ -	DI--0135	
19 20	+ -	DI--0136	Liquid level detector switch
21 22	+ -	DO--0127	Relay for selection of level detector
23 24	+ -	DO--0128	
26 27 28	D GND D/	Lateral Communication	
30 31 32	D GND D/	Vertical Communication	
33 34	+ -	24V power supply	

INTERFACES

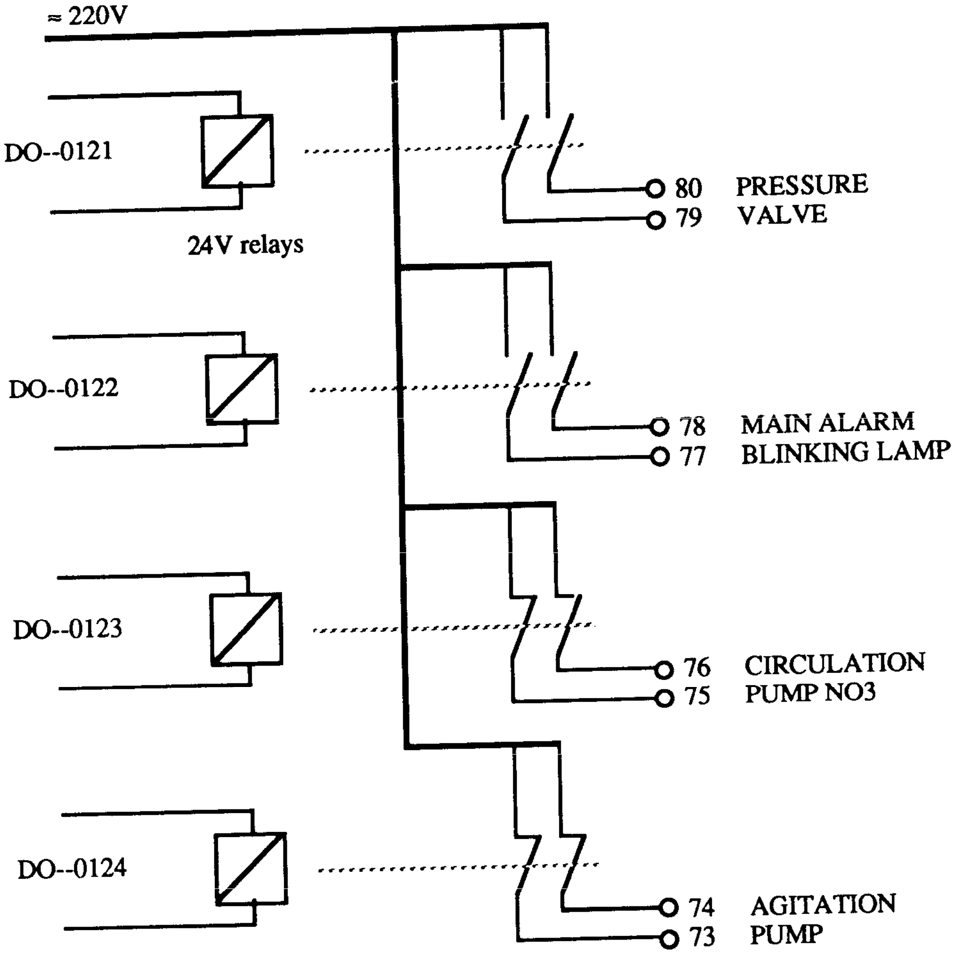

Figure A2 : 220v interface schematic

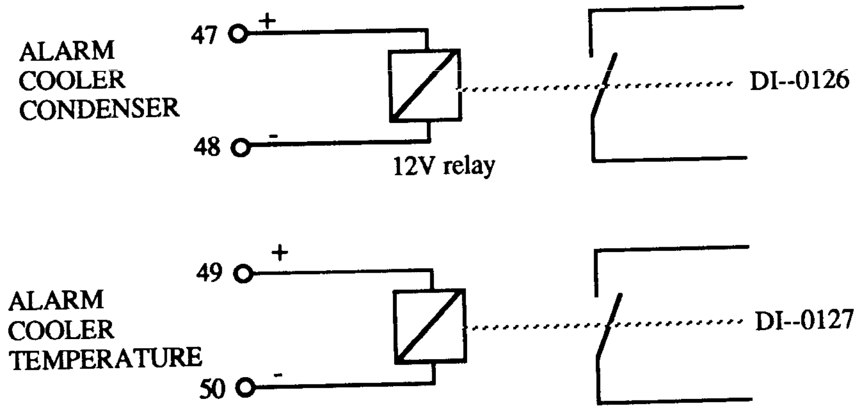

Figure A3 : 12V interface schematic

BAY CONNECTOR

No	Signal name	voltage/current	From	To
1 2 3	D GND D/	Vertical communication MICON 2		
4 5 6	D GND D/	Lateral communication	MICON 1 CONTROLER 4	MICON 2 CONTROLER 5
7 8 9	D GND D/	Vertical communication MICON 3		
10	N/A			
11 12	+ CO_2 - CO_2	4-20mA	CO2 analyser	AI--0101
13 14	CO_2 range	switch	CO2 analyser	DI--0121
15 16	+ O_2 - O_2	0-10V	O2 analyser	converter 4-20mA (AI--0102)
17 18	+ Biomass - Biomass	4-20mA	Monitek CT4 turbidimeter	AI--0114
19 20	+ pH - pH	4-20mA	pH indicator	AI--0105
21 22	+ set point Temperature - set point temperature	0-20mA to 4-20mA isolated	AO--0106	Temperature controler
23 24	+ temperature - temperature	4-20mA	Temperature controler	AI--0110
25 26	+ pO_2 - pO_2	4-20mA	pO_2 indicator	AI--0113
27 28	+ NO_3 - NO_3	4-20mA	NO_3 DR LANGE	AI--0107
29 30	Calibration switch NO_3	switch	NO_3 DR LANGE	DI--0125
31 32	+ Fitration membrane pressure - Filtration membrane pressure	4-20mA	TECH SEP Equipment	AI--0116
33 34	+ NO_3 injection pump - NO_3 injection pump	4-20mA	AO--0103	Peristaltic pump for NO_3 injection
35 36	+ pressure - pressure	4-20mA	pressure sensor gaseous phase	AI--0103
37 38	+24V 0V	sensor supply	BAY 24V power supply	pressure sensor

39 40 41 42 43	+ pH control - pH control +15V 0V -15V	0-20mA Flow controler supply	AO--0104 BAY ±15V power supply	CO_2 injection flow controller
44	N/A			
45 46	+ biomass control - biomass control	4-20mA	AO--0107	Peristaltic pump biomass extraction
47 48	+ alarm cooler condenser - alarm cooler condenser	+12V	thermostatic bath	relay 12V to DI--0126
49 50	+ alarm cooler temperature - alarm cooler temperature	+12V	thermostatic bath	relay 12V to DI--0127
51 52	liquid level relay	+24V	DO--0127	relay for selection of level detector
53 54	liquid level detector switch	switch	level detector	DI--0136
55 56	+ medium injection pump - medium injection pump	4-20mA	AO--0108	injection pump
57 58	+ pressure control - pressure control	0-20mA	AO--0102	pressure regulation flowmeter
59 60 61 62 63 64 65 66 67 68 69 70 71 72	N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A			
73 74	agitation pump	220V	DO--0124 via relay	pump power supply
75 76	NO_3 circulation pump	220V	DO--0123 via relay	pump power supply
77 78	Main alarm red blinking light	220V	DO--0122 via relay	lihgt
79 80	pressure valve	220V	DO--0121 via relay	valve

COMPLEMENTARY INSTRUMENTATION RACK

This rack contains specific equipments such as light amplifier, power supplies remote control, 4-20mA interfaces...etc...

RACK CONNECTOR

No	Signal name	voltage/current	From	To
1	+IN	N/A		converter10
2	-IN			
3	+OUT		converter10	
4	-OUT			
5	+IN	N/A		converter9
6	-IN			
7	+OUT		converter9	
8	-OUT			
9	+IN	N/A		converter8
10	-IN			
11	+OUT		converter8	
12	-OUT			
13	+IN	N/A		converter7
14	-IN			
15	+OUT		converter7	
16	-OUT			
17	+IN	N/A		converter6
18	-IN			
19	+OUT		converter6	
20	-OUT			
21	+IN	N/A		converter5
22	-IN			
23	+OUT		converter5	
24	-OUT			
25	+IN	N/A		converter4
26	-IN			
27	+OUT		converter4	
28	-OUT			
29	+IN	N/A		converter3
30	-IN			
31	+OUT		converter3	
32	-OUT			
33	+IN	N/A		converter2
34	-IN			
35	+OUT		converter2	
36	-OUT			

37 38 39 40	$+O_2$ $-O_2$ +out converter -out converter	0-10V 4-20mA	O_2 analyser converter1	converter1 AI--0102
41 42 43 44	Light regulation, power supplies control voltage	0-5V 0-5V	power supplies remote control box	power supply 6 remote control power supply 5 remote control
45 46 47 48	Light regulation, power supplies control voltage	0-5V 0-5V	power supplies remote control box	power supply 4 remote control power supply 3 remote control
+49 50 51 52	Light regulation, power supplies control voltage	0-5V 0-5V	power supplies remote control box	power supply 2 remote control power supply 1 remote control
53 54	Light regulation, power supplies control	0-20mA	AO--0105	power supplies remote control box
55 56 57 58 59 60 61 62	Range 4 Range 3 Range 2 Range 1 Common - Light +Light	switch switch switch switch 4-20mA	ligth amplifier	DI--0132 DI--0131 DI--0130 DI--0129 AI--0112

LIGHT AMPLIFIER

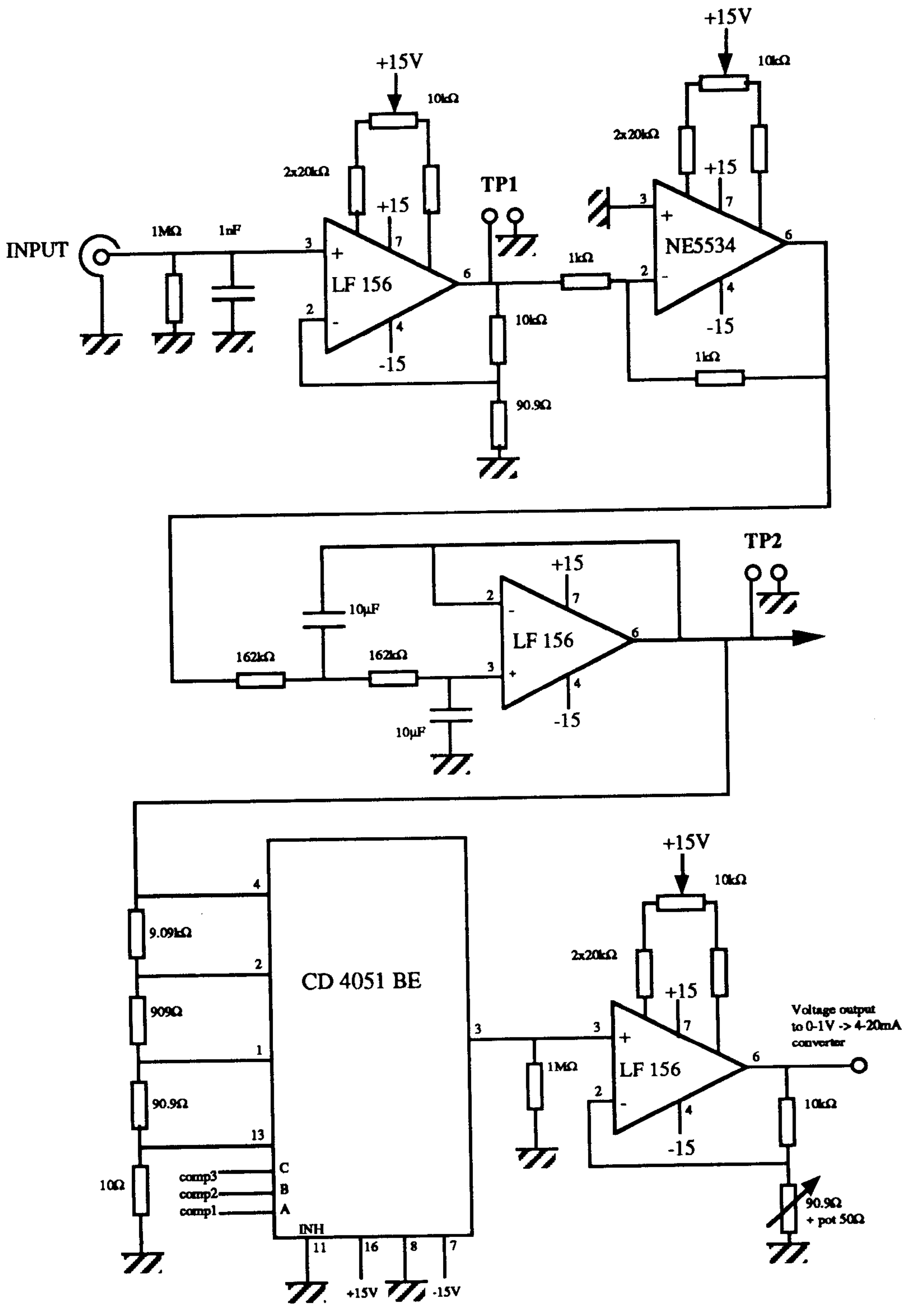

Figure A4 : Analogic chain

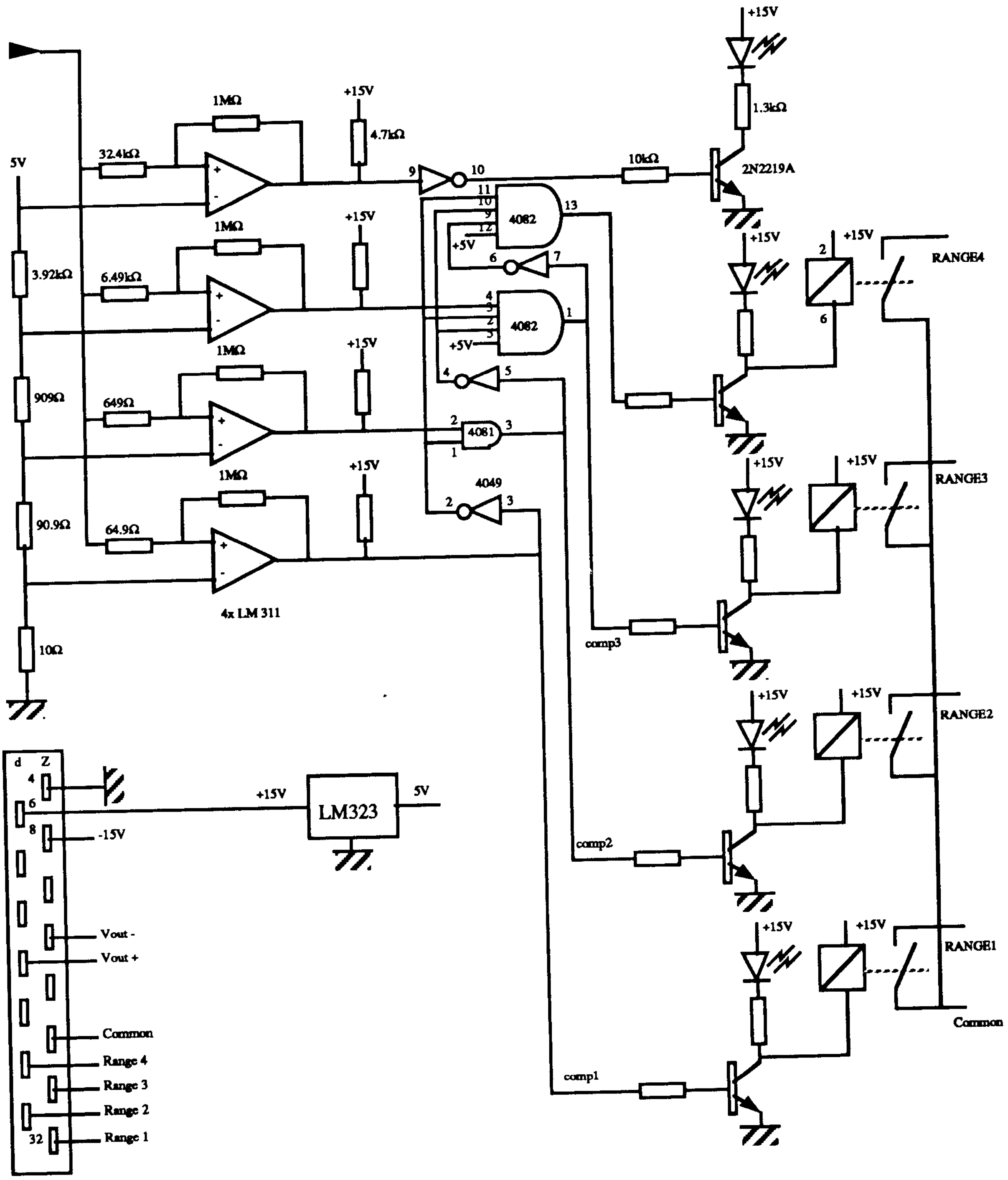

Figure A5 : Range selection circuit

REMOTE CONTROL BOX FOR POWER SUPPLIES

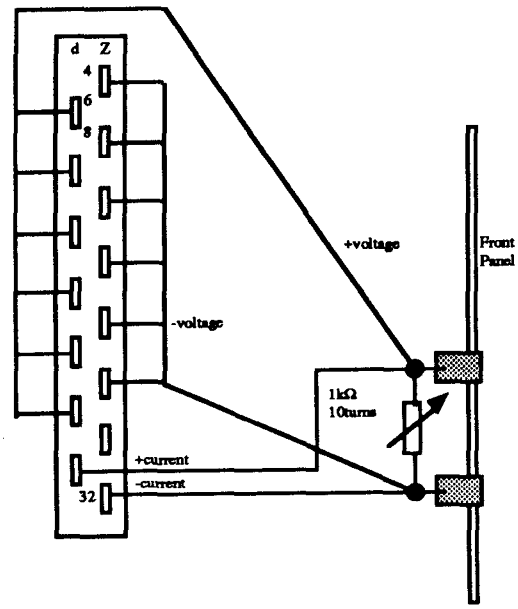

Figure A6 Power supplies remote control box