Note PS/HI 89-2
PS/CO 89-10

PROPOSAL FOR THE UPGRADING OF THE PSB RING TRANSFORMERS

(G.Benincasa, G.Gelato)

1. The needs

1.1 Historical background

The PSB was designed as a high-intensity proton accelerator. It was therefore equipped from the start with four beam transformers (one per ring), of the active feedback type, capable of accepting a maximum intensity of 5 E12 protons per ring, i.e. twice the design intensity of the machine.

When the performance of the PSB was improved, largely exceeding the design intensity, the transformers were upgraded to accept up to 2 E13 protons per ring (about twice the maximum intensity ever reached so far).

The digital interface included an 11 bits + sign ADC. No range switching was considered necessary; the digital resolution, about 1 E10 protons per ring, was accepted as adequate.

The acquisition and display software was designed accordingly, and the result of the measurements was (and still is) displayed in the MCR and elsewhere in units of 1 E10.

Within the multifarious evolution of the PS complex, the PSB was asked to accelerate a variety of beams of much lower intensity, from a few E10 to a few E8, with different particles and new RF gymnastics, involving change of harmonic number.

The system had therefore to be upgraded in various steps, to cover a dynamic range of more than six decades; the modifications had to be introduced without perturbing the operation of the machine, a limitation that, quite apart from other considerations, was determinant in the choice of the options for upgrading the system to its present configuration.

1.2 The present situation

The present layout can be best understood by referring to Fig. 1.

The original system was left essentially unchanged and used for protons as before; the only important element that was changed was the β-normalizer.

This change was required because the old normalizer derived the β information from the accelerating RF, a simple method, but legitimate only when the harmonic number is constant; with variable harmonic number, we have to derive the information from the magnetic field. Because the relationship between B and β is not a simple proportionality, as it is between RF and β, and because we need to use it in real time for analog observation, we introduced conversion tables, stored in EPROMs, one table per type of particle (the β vs. B relationship being particle dependent).

To cope with low intensity beams, we used the signals from a set of existing fast transformers. To obtain from a fast transformer the D.C. infomation required, we amplify through a radio-frequency amplifier the bunch signal, and detect the peak value in the gap between bunches, i.e. the bottom value.

For a fully bunched beam, this value is proportional to the D.C. beam current (during changes of harmonic number, as well as before capture, the beam is unbunched and the fast transformer provides no signal, a limitation that we have been forced to accept under the circumstances).

The RF amplifier consists of a 40 dB preamplifier in the PSB tunnel, to boost the signal above cable noise, and a 20 dB amplifier, located in the BOR. By proper switching, the gain can take the values 0 dB (by-pass), 20, 40 and 60 dB.
This provides us with 5 sensitivity ranges, in steps of a factor 10.
(The least sensitive one is obtained by switching to the slow transformer, and this is the normal choice with protons.)

The switching can be controlled in two ways:
a) Locally in the BOR; a control logic module receives information about the active user line from a dedicated PLS (*) decoder (which also tells the β computing circuitry what type of particle is present); to each user line a value of sensitivity is associated, by presetting it on a series of switches on the frontpanel of the control logic module.
b) Remotely through an I/O port; an external device (e.g. a standard CAMAC I/O register) can control the switching and read back the sensitivity in use.

Because no programming effort was available, the system has been operated so far only under local control, and with no read-back of the sensitivity factor.

This mode of operation has the following drawbacks:
a) Whenever the intensity for a given user line is changed by a significant factor (e.g. when changing over from a deuterons test beam to a sulphur beam), an operator has to go all the way from th MCR to the BOR to change the settings.
b) If, as it has often been the case, he forgets or neglects to do so, he may get confused in his analog observations, and interpret as an absence of beam what is simply a sensitivity setting that is too low. (We have tried to alleviate this problem by encoding in the analog signal, at the end of the cycle, the sensitivity in use and its corresponding saturation level: it helps, but it is not "operator friendly".)
c) The control system knows only one scale factor, and all displays will show the intensity always in units of E10, which may be wrong by a factor up to 10,000.
As a result, not only the displays are meaningless except for protons, but, if the data are automatically logged and used to produce statistics, the statistics may contain significant errors.

(*) For readers not familiar with PS operation: the Program Line Sequencer is a specific PS system generating, and distributing to all users every cycle, a serially coded message (the PLS "telegram") containing all the information about the present cycle (and the next) required for proper management of the Pulse to Pulse Modulation (PPM).

1.3 The operational improvements

From what has been said it appears clearly that, unless low-intensity operation of the PSB is abandoned, operational improvements are a serious need, the minimum requirement being that the control and/or display software be re-written to include remote setting of the sensitivity (in PPM, of course) and its acquisition, the latter no matter whether the control is local or remote.

This would not relieve the operator from the obligation to change the setting according to changes in beam intensity, but it would make his task a lot easier, and the displays meaningful.

A much more attractive operational improvement would be the introduction of autoranging, as it has been done for the D.C. beam transformer of the PS (limited, in the case of the PS, to the digital acquisition). The autoranging could be done entirely by the local intelligence, freeing completely the operators from any worry about scale factors and sensitivity setting, and reducing the data to be exchanged between instrument and control system to a very small amount indeed.

Although a number of trade-offs are possible between amount of hardware involved, complexity of software, and operational ease, autoranging is a rather expensive facility; now is the moment, before engaging in a major conversion effort, to decide whether we want it, and with what options. Introducing it later would increase the cost.

1.4 The operational protocol

A study, in which we participate, is being conducted by TEBOCO on the possibility of standardizing as far as possible the structure of the data to exchange between instrumentation and control/acquisition systems.

This data structure, or protocol, is now in a well advanced stage of definition. Before freezing this definition, however, we consider important to try out the concept in a real environment. The PSB transformers, given the fact that an entirely new software must be written, are very well suited as a test case for the new protocol, and we strongly recommend that they be selected for this purpose.

This is not without financial implications, and a few trade-offs are possible, as will become clear in the following chapters.

1.5 The obsolescence problem

The original electronics for the slow PSB transformers was designed in the late sixties and is showing clear signs of old age. It is built in a mechanical standard no longer in use at CERN, and the card connectors are causing faults with increasing frequency. Some of the transistors and operational amplifiers used are no longer on the market.

The proposed updating of the transformers must therefore include the reconstruction of the front end electronics along more modern lines.

1.6 Additional considerations

The present proposal does not consider replacing the transformer themselves, only electronics and software. The replacement of the transformers themselves (which would imply a different front end electronics) would in fact be highly desirable, for the following reasons:

- The system would be more homogeneous (the same analog signal treatment for all ranges, rather than the present different treatment for the least sensitive range on one hand and the other ranges on the other hand; one transformer for all ranges, rather than the present two-transformer system).
- The system could be largely standardized by using the same sensors as used in the D.C. transformers of AC, EPA, and (in future) LEAR, and many electronics modules as used in these machines as well as in the PS.
  This would facilitate the maintenance and reduce the spare parts inventory.
- The system would lose the blindness, that affects it on all but the least sensitive range, to unbunched beams. This blindness prevents beam intensity observation during capture and harmonic number manipulations.

These improvement are not discussed in this proposal because they are expensive and require major interventions in the machine tunnel for their installation: it seems therefore wiser to include their discussion in the plans for future acceleration of ions; if, for instance, the lead acceleration project is approved, a major overhaul of the PSB vacum system is likely to become necessary, and the installation work could be included in it, and scheduled accordingly.

We want to stress here that, if it will be decided at a later stage to implement these improvements, they will only affect the front-end electronics: from the input of the β-normalizers onwards, no modification of hardware, software or operation will be required.

2. The aims and the means

2.1 The aims

The considerations of the preceding chapter have led to the present proposal with the following aims:

a) Operational improvement. The minimum requirement is for remote control and acquisition of the sensitivity, but it is our conviction that autoranging must be introduced, and that the time to introduce it is **now**.

A related problem is that of the choice of range for analog observation; the options will be discussed in the following paraggrahs.

b) Testing the proposed operational protocol.

c) Rejuvenating those parts of the system that are likely to cause malfunctions because of aging components.

2.2 The means

The choice of the means to attain the proposed aims has an impact on the a log hardware, on the digital hardware, and on the software. We shall attempt to present the main options and to estimate their effect on the three parts of the system, and ultimately on the cost.

2.2.1 Operational improvement

2.2.1.1 Remote control and acquisition. No autoranging

2.2.1.1.1 Impact on analog hardware

This option has virtually no impact on the analog hardware, as it merely implies using the I/O port, unused at present.

2.2.1.1.2 Impact on digital hardware

The impact on the digital hardware is also very small: an I/O register is necessary to control the range switching and read back the status.

2.2.1.1.3 Impact on software

In the local intelligence, tables must be created, and modified by the operators according to the mode of operation, to store the setting required for each cycle; the intelligence will then use these tables to control the range switching in PPM. Before passing the results to the display driver, the intelligence must multiply the readings by the proper scale factors. As already observed, since the updating of the tables is not automatic, there is no real guarantee that the display and the data logger for the statistics will always receive the correct results. This option is therefore not a very attractive one.

2.2.1.2 Full autoranging (Digital and analog)

2.2.1.2.1 Impact on analog hardware

The impact of this option on the analog hardware can be best understood by referring to Fig. 2, where the configuration for one ring only is shown.

The autoranging in real time implies that the signal has to be available simultaneously with different values of sensitivity, on different amplifiers: all the amplifiers outputs will be acquired, but in general some of the amplifiers will be saturated. The local inteligence must be capable of recognizing the saturation, and will select for display, with the proper scale factor, the signal from the most sensitive among the non saturated channels.

The implication for the hardware is that, for each transformers, as many signal channels as there are ranges must operate in parallel: in the case of the PSB this means 5 channels per ring.

The signal should be split as far downstream along the signal handling chain as possible, as only the elments of the chain after the splitting point need to be replicated: unfortunatley, we are not free to choose, but must keep each element of the chain within the proper operating range: in our case the dertermining element is the detector, and that forces us to split the channels at the very beginning of the chain.

The elements of the chains that have to be added are shaded in Fig. 2 with diagonal lines; the ones that have to be rearranged and/or modified are shaded by dots (one of them is the amplifier of the slow transformer, located in the BAT: this is necessary for reasons of obsolescence, independently of the option chosen).

For purely digital acquisition, the β normalizers could in principle be eliminated, and the β correction be done by software. In fact, not only the β normalizers are essential for analog observation, but they also increase by a factor of almost 3 (the frequency swing in the PSB) the useful range of the ADC. Moreover, software correction would require storing the β tables in the local intelligence and acquiring, simultaneously with the current readings, the value of B; this in turn would require a counter for the B train, capable of being read without stopping. (The standard CAMAC counters used in other applications are capable of doing so, but only at the price of a non negligible software overhead.)
The advantages of software β-normalization are therefore extremely dubious.

The number of SOS channels required to implement this option goes up from one per ring to 5 per ring: if this number of channels can be afforded, the system becomes really operator friendly; all that the operator has to do to observe the analog signal is to select the proper SOS channel. Different operators can observe simultaneously with the same or different sensitivities.

The multiranging option requires also the addition of one cable per ring, of good quality, from the machine tunnel to the BOR.

If this option is adopted as described, the entire switching hardware, and of course its control, are eliminated. This constitutes a simplification, but no saving, because these elements already exist.

2.2.1.2.2 Impact on digital hardware

Because of the increase from 4 to 20 of the number of channels to be acquired the existing multiplexer (a standard 16-channel CAMAC module), which is shared with other instruments, will be no longer sufficient. A second multiplexer must be added.

2.2.1.2.3 Impact on software

The local intelligence must acquire 5 values per ring, corresponding to the 5 ranges: starting from the most sensitive range, it will decide, according to a simple criterion (e.g, reading above 95% of full range), whether the channel is saturated; if so, it will examine the next range, and so on, until one is found that is not saturated. The corresponding reading, with the proper scale factor, is sent over to the control computer for display.
This procedure insures that the signal will be always taken from the most sensitive non saturated range, and it has the advantage of being entirely automatic; no intervention from the operators is required at any time (unless he wants to change the instant(s) of reading: at present, they are fixed).
As a result, the software is considerably simpler than it is for the preceding option (2.2.1.1).

2.2.1.3 Digital autoranging only

2.2.1.3.1 Impact on analog hardware

In this option, the digital part would be exactly as described above, but instead of adding 16 extra SOS channels for analog observation, one would add an analog multiplexer under operator control. A multiplexer (from 20 inputs to 4 outputs) would probably cost less than 16 SOS channels; the operation, however would be less convenient, to a degree depending on which of the following variants is implemented:

a) Direct control of the range multiplexer by the operator.

In this case, the local intelligemce would be used simply as a communication link to pass over to the multiplexer the information about the range to select.

No PPM would be possible: once a range has been selected, it will remain until the operator changes the selection. The operational flexibility would be rather limited.

b) Range selection driven by tables in the local intelligence.

The local intelligence would contain a table of the range to be selected for each user line. The operator would need to change an entry only when the intensity for the corresponding user line has been changed significantly.

This method would be much more flexible than a); it would require less frequent intervention from the operator, and it would allow simultaneous analog monitoring of all beams, by the same or different operators.

The encoding of the range selection on the analog signal, obtained at present by appropriate markers, should be mantained. (It could be abandoned in the case of full autoranging, because the information would be implicit in the selection of the SOS channel).

2.2.1.3.2 Impact on digital hardware

An I/O register would be required to control the range multiplexer.

2.2.1.3.3 Impact on software

The additional software requirements, in comparison to option 2.2.1.2, are rather small for variant a), somewhat more significant for variant b), that requires the management of a PPM table.

2.2.1.4 Summary of 2.2.1

From the point of view of the operational improvement, we consider that solution 2.2.1.2 should be adopted. Only if 16 SOS channels cannot be made available solution 2.2.1.3, variant b) could be acceptable. The cost of the two solutions is not significantly different.

We do not recommend solution 2.2.1.1, the cheapest, because of the serious drawbacks already mentioned.

2.2.2 The operational protocol

We give below some additional background information necessary in order to understand the following paragraphs.

The digital interface of the PSB ring transformers is housed at present in a CAMAC crate and shares some of the CAMAC hardware with other equipment (transformers in the PSB ==> PS transfer line and in the PSB measurement line).

The shared hardware consists of:

a) An ACC, where the software for all the aforementioned transformers is installed.

b) An ADC for the acquisition of the transformers. Two MPX are connected to the ADC, but they are not shared, one being reserved for the PSB ring transformers only.

c) The basic CAMAC facilities (crate + power supply, U-port adaptor, serial crate controller, dataway display, PLS receiver).

How much of this hardware it is possible or advisable to reuse when re-writing the software to include the new protocol, depends on arguments that shall be developed in the following paragphs; in general, the savings that can be made by reusing hardware must be weighted against the cost of additional software effort and/or operational discomfort.

2.2.2.1 The communication link

The operational protocol is designed to be independent of the communication link used; when implementing it, however, a choice has to be made.

In the PS, the links between the control computers and the peripheral equipment consist of a number of serial CAMAC loops. It seems therefore natural to test the protocol using simply one of the existing loops. The equipment on which the protocol is implement should exchange messages on the loop only acording to the agreed protocol.

The loop would of course continue to carry other messages as it does now, but as long as they do not concern the equipment under test, they should not cause nor suffer any perturbation. This is not too difficult to achieve as long as all the equipment in a given crate use the same protocol; in this case the SCC can recognize messages not meant for that crate and pass them over along the loop.

2.2.2.2 The local intelligence

We propose that the new software will be written for a SMACC, not for the old ACC. This is part of a general policy in the PS for all new CAMAC-based intelligence, and we do not intend to depart from it.

2.2.2.3 The options for the new lay-out

We shall discuss the following two options:

a) A dedicated crate where only the hardware and software for the PSB ring transformers would be installed.

b) A crate where some hardware would be shared with other transformers as it is now.

2.2.2.3.1 Dedicated crate

2.2.2.3.1.1 Impact on hardware

This option would require the following CAMAC hardware:

1 CAMAC crate with power supply
1 SMACC
1 SCC
1 U-port adaptor
1 dataway display
1 ADC
1 analog MUX
1 PLS receiver

The rest of the required CAMAC hardware, i.e. 2 GPPC and 1 analog MUX could be recovered from the existing installation.

Depending on the options chosen concernig the SOS, an I/O register may be required (See 2.2.1.3.1).

The corresponding layout is shown in Fig. 3, while Fig. 4 shows the additional elements required if digital autoranging only is adopted.

2.2.2.3.1.2 Impact on software

The software already mentioned in 2.2.1, depending on the options chosen for the analog equipment, should be written, plus the software necessary for the implementation of the protocol.

2.2.2.3.1.3 Impact on operation

This option could be implemented and tested with virtually no perturbation of the operation. It could be tested and debugged on the transformer signal taken in parallel with the existing acquisition signal: the 2 GPPC and 1 analog MUX required are standard modules and could be borrowed from the spare parts pool for the duration of the tests; they would be returned once the new system is operational and the modules could be taken out of the old system.

The hardware and software for the other transformers sharing the CAMAC crate could be left unchanged; only the display driver for the PSB ring transformers should be replaced by a new one, communicating with the new crate according to the protocol. The display driver is in the control computer, so the ACC software would not be affected.

2.2.2.3.2 Sharing of hardware

2.2.2.3.2.1 Impact on hardware

To the existing CAMAC hardware should be added the following:

1 SMACC replacing the existing ACC)
1 analog MUX

Depending on the option chosen for the SOS, an I/O register may be also required.

2.2.2.3.2.2 Impact on software

In addition to the software for the PSB ring transformers, the software for the other transformer should be re-written as well, to be installed in the SMACC replacing the ACC. It should of course incorporate the new protocol, to avoid mixing, on the same communication port, messages using the new protocol and messages of different structure.

If we do not respect this condition, the detection and analysis of problems specifically related to the protocol that we want to test will become much more difficult and uncertain.

The problem of autoranging is much more difficult for the transformers in the transfer lines than for those in the ring. Even the problem of changing the sensitivity is not a trivial one.

During the past oxygen runs, a completely separate electronics with specialized software, running on the TEMPEX computer, has been used. The measurements required delicate manipulations and a substantial degree of human judgement, and were in fact performed by specialists on demand.

No satisfactory solution to this problem has been found so far: further thinking on the subject is necessary, but an (admittedly superficial) analysis seems to point towards very expensive electronics and possibly new transformers.

For the moment, therefore, all that one could do would be to re-write for the SMACC the program running in the ACC, and this would work on protons. Nothing would be gained from the point of view of the operation.

Later on, if a solution is found to incorporate low intensity measurements, the program should be re-written, and the software effort invested in the temporary version would be entirely wasted.

2.2.2.3.2.3 Impact on operation

The impact on operation depends on the availability of CAMAC crates and modules for a medium-term loan.

If there is no restriction, one can build a complete temporary system and work in parallel with the existing equipment, as mentioned in 2.2.3.1.3.

If that is not the case, substantial perturbation of the operation during the development and test phase is unavoidable.

2.2.3 The obsolescence problem

The modifications required because of obsolescence concern only a fraction of the analog electronics: they are necessary, and it seems appropriate to implement them in the frame of the global modifications to the system; they are independent of the options chosen, and are mentioned here only because their cost in terms of materials and manpower must be included in the global cost estimate.

3. Conclusion

3.1 Recommended solution

After considering the various options described above, we recommend that option 2.2.1.2 (Full autoranging) and 2.2.2.3.1 (Dedicated crate) be adopted.

They offer, in our view, the best operational improvement and they are the tidiest in terms of software and hardware, whith corresponding ease of maintenance.

They are expensive in terms of hardware, but they require less software effort than in the case of shared hardware (2.2.2.3.2).

Option 2.2.1.2, and the replacement of obsolete electronics, will benefit essentially operation and maintenance, and it seems logical that the associated costs be borne by the budget for operation and maintenance of the transformers of the PS complex.

Option 2.2.2.3.1, on the other hand, will essentially benefit the comfort and tidiness of the tests concerning the new protocol, and minimize the associated software effort: it seems therefore fair that TEBOCO, the originator and promotor of the whole protocol concept, act as a "sponsor" bearing the associated expenses.

It seems also opportune that the software effort be shared, although probably unevenly, between the instrumentation people and the control people.

3.2 Cost estimate

The equipment costs, including spares, and the manpower requirements can be roughly estimated as follows:

Option 2.2.1.2

15	20 dB wide-band amplifier for the fast transformers, with associated detectors	14,000 S.Fr.
15	β-normalizers	6,000 S.Fr.
16	low frequency SOS channels (*)	
5	calibration generators	5,000 S.Fr.
4	high quality cables from tunnel to BAT	4,000 S.Fr.

Manpower for development and construction	10 man*month

(*) Depends on number of channels available, if any.

Replacement of obsolete electronics

5 amplifiers for slow transformers	3,000 S.Fr.
5 calibration generators for slow transformers	3,000 S.Fr.
1 crate with power supply	3,000 S.Fr.
Manpower	2 man*month

Total costs to be borne by transformers budget:

38,000 S.Fr. + 12 man*month + cost of 16 SOS channels

Option 2.2.2.3.1

1 CAMAC crate	4,700 S.F
1 SCC	3,800 S.Fr.
1 U-port adaptor	1,950 S.Fr.
1 analog MUX	700 S.Fr.
1 ADC	2,460 S.Fr.
1 Dataway display	1,420 S.Fr.
1 SMACC	4,000 S.Fr.
1 PLS receiver	840 S.Fr.
Manpower for software development and testing	6 man*month

Total costs to be borne by TEBOCO:

~20,000 S.Fr.

Remark: The above proposal was discussed at the TBBI meeting # 15 (May, 19, 1988) and approved with the options recommended in section 3.1

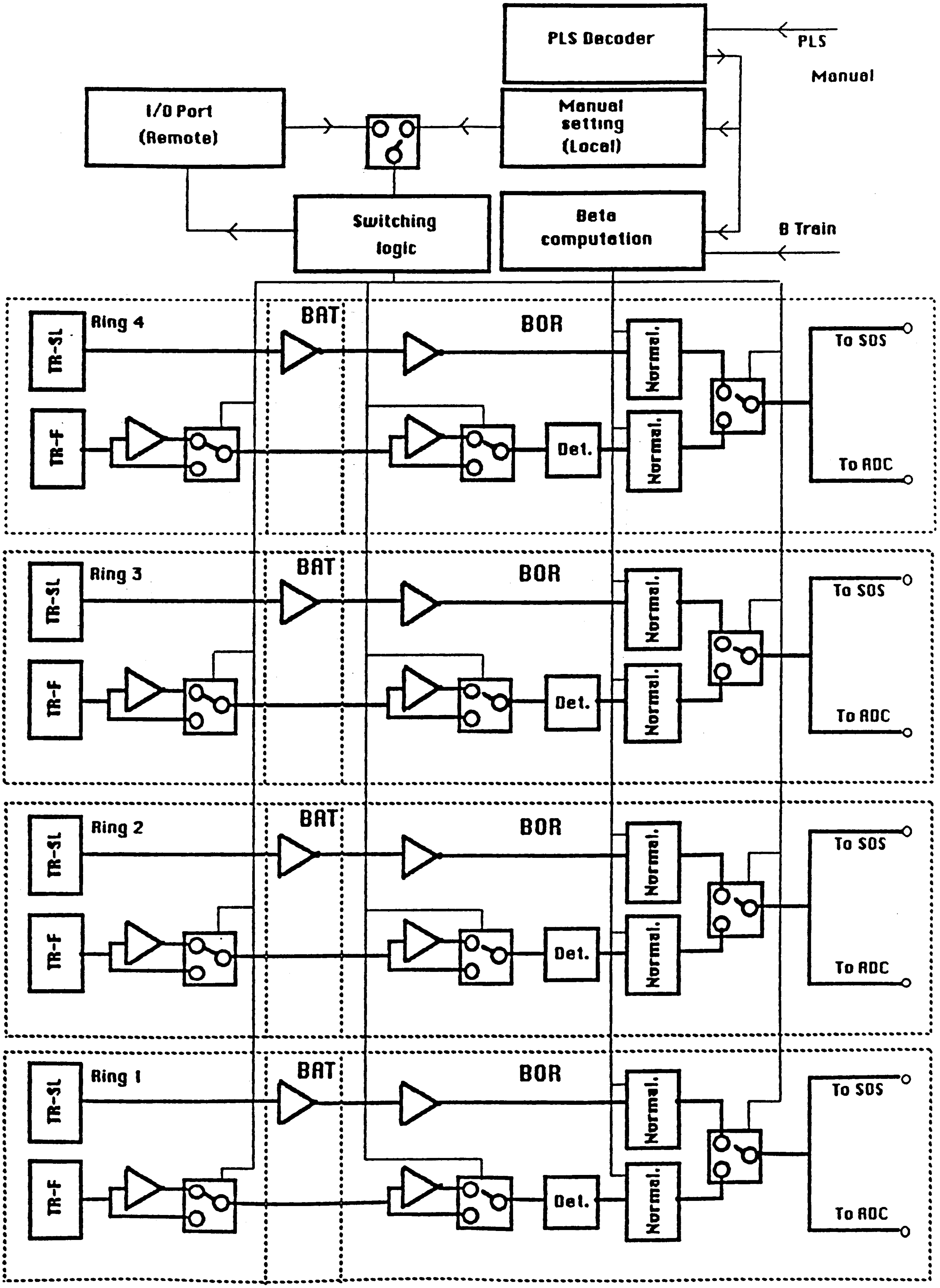
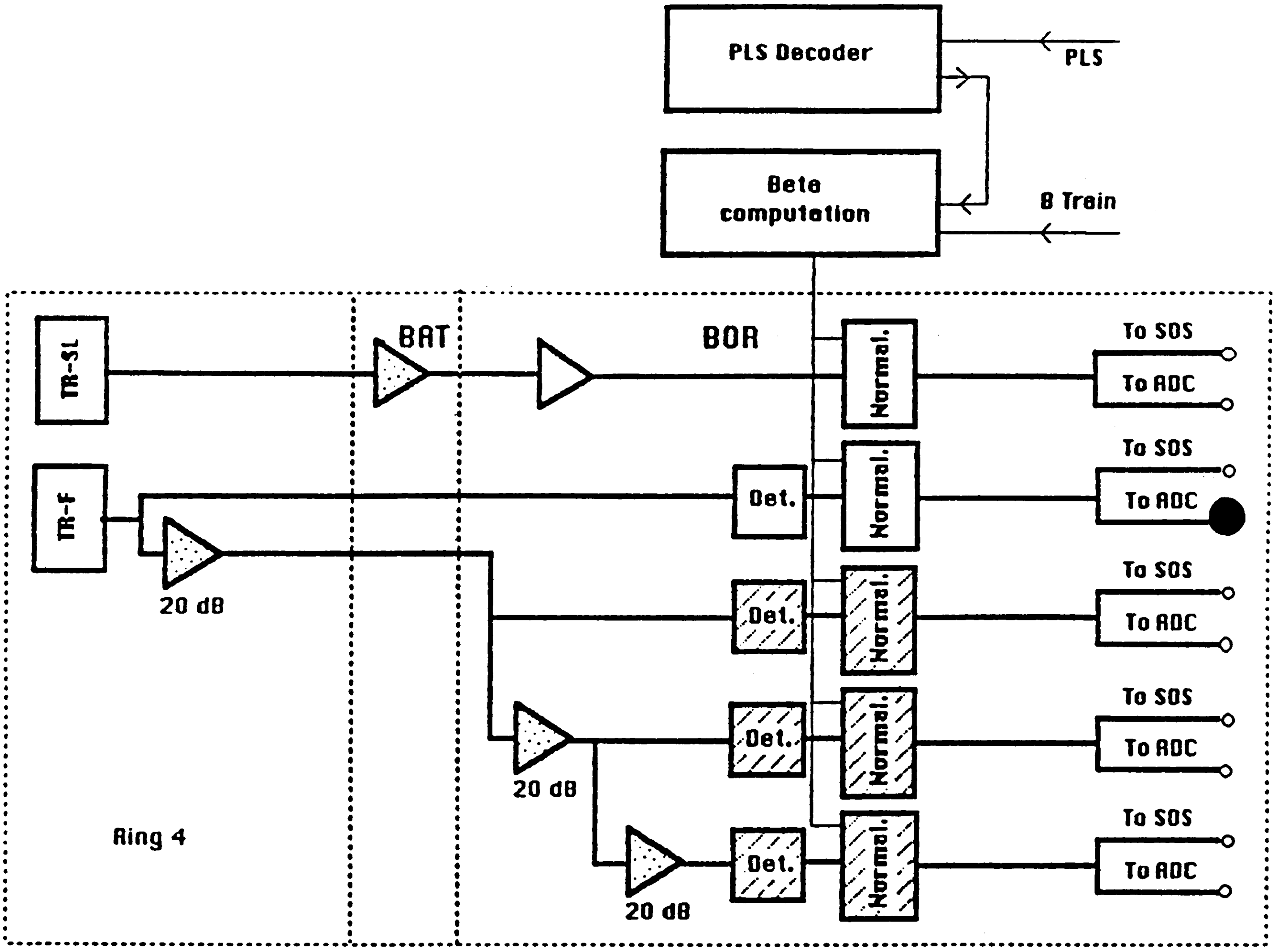

PLS Decoder
PLS
Manual
I/O Port
(Remote)
Manual
setting
(Local)
Switching
logic
Beta
computation
B Train
Ring 4
TR-SL
TR-F
BAT
BOR
Normal.
Normal.
Det.
To SOS
To ADC
Ring 3
TR-SL
TR-F
BAT
BOR
Normal.
Normal.
Det.
To SOS
To ADC
Ring 2
TR-SL
TR-F
BAT
BOR
Normal.
Normal.
Det.
To SOS
To ADC
Ring 1
TR-SL
TR-F
BAT
BOR
Normal.
Normal.
Det.
To SOS
To ADC

Fig.1



PLS Decoder
PLS
Beta computation
B Train
BAT
BOR
TR-SL
TR-F
Det.
Normal.
20 dB
Ring 4
To SOS
To ADC

Fig. 2

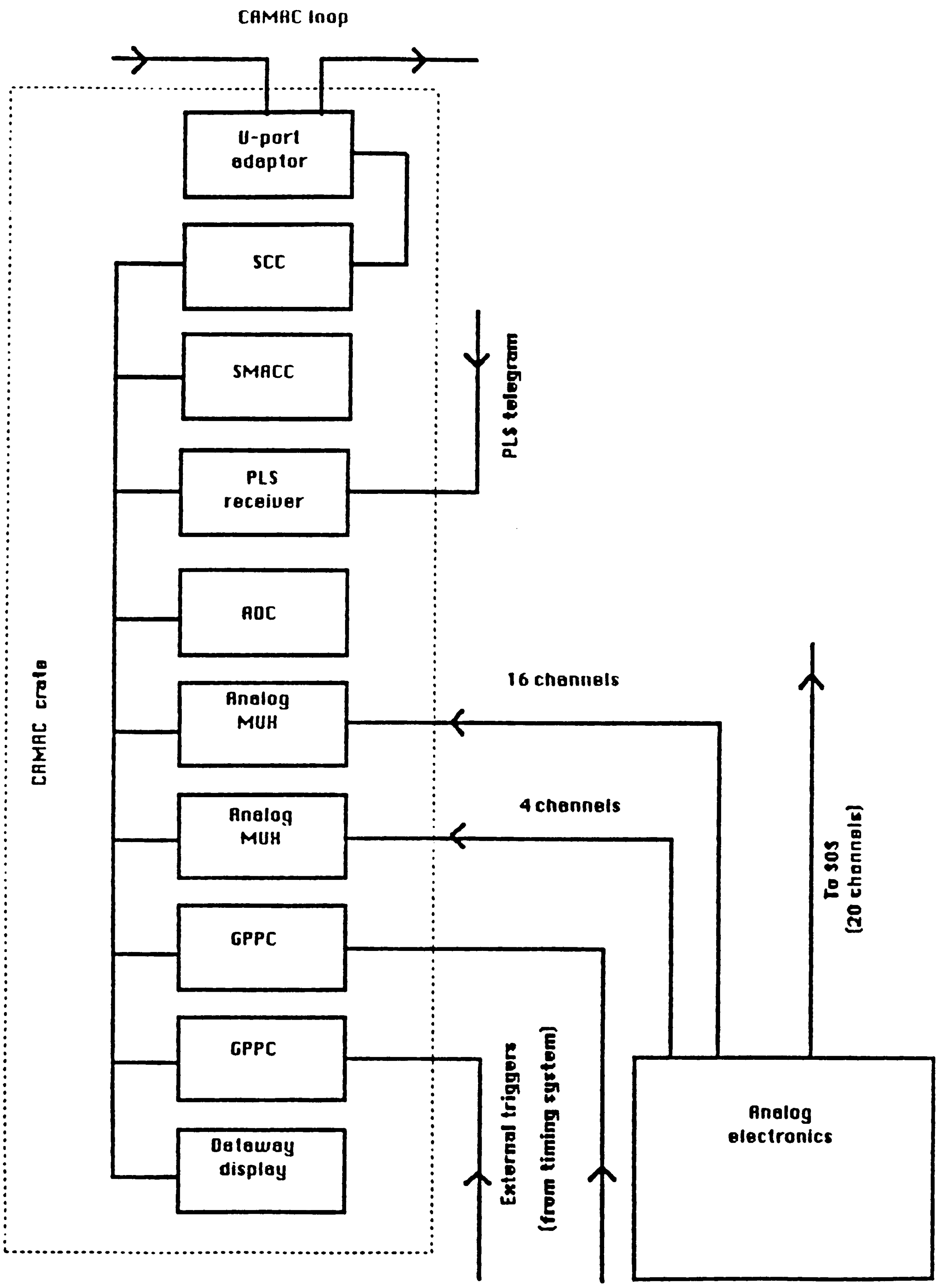

CAMAC loop
U-port adaptor
SCC
SMACC
PLS telegram
PLS receiver
ADC
CAMAC crate
16 channels
Analog MUX
4 channels
Analog MUX
To SOS (20 channels)
GPPC
GPPC
External triggers (from timing system)
Analog electronics
Dataway display

Fig. 3

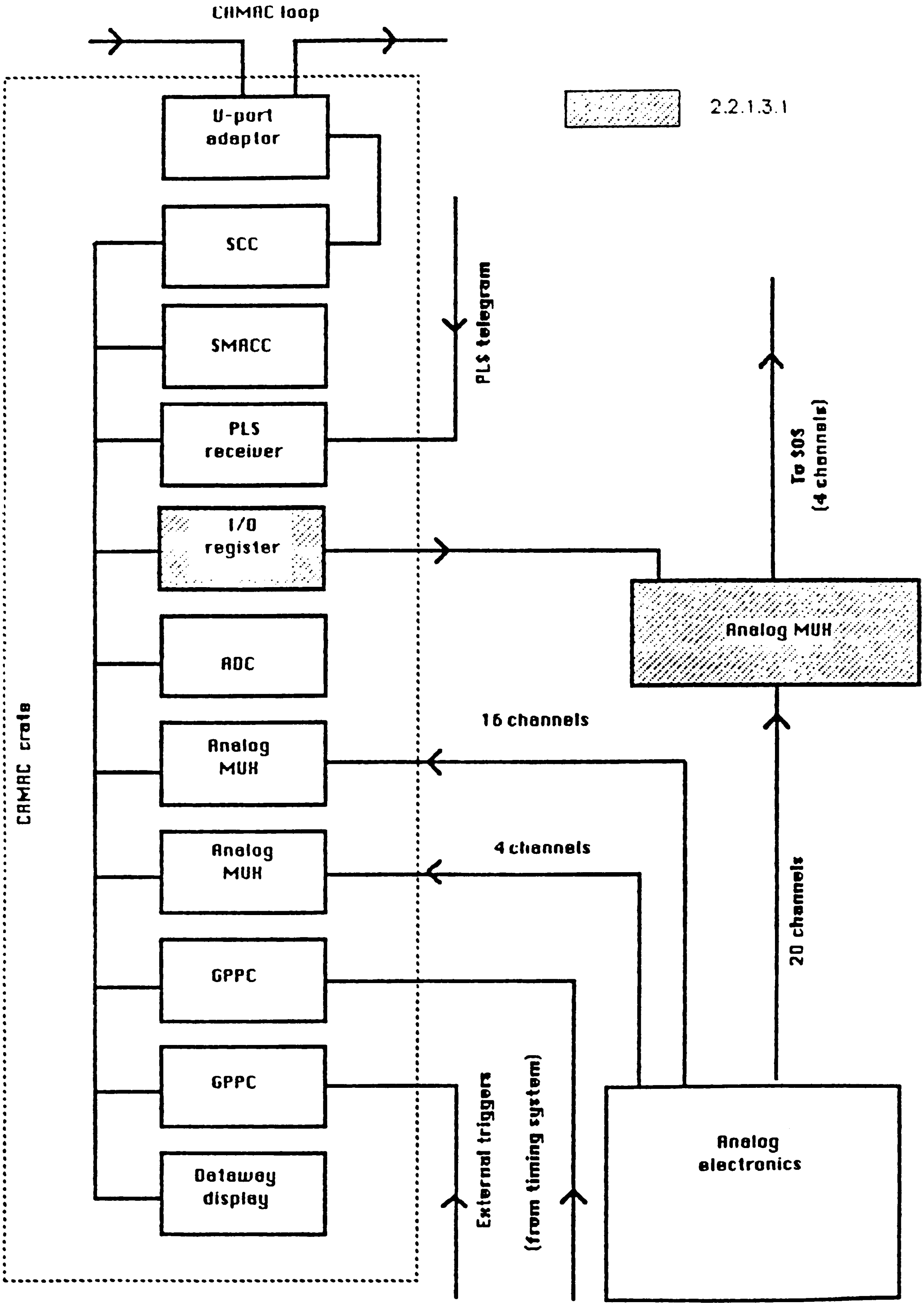

CAMAC loop
▨ 2.2.1.3.1
U-port adaptor
SCC
SMACC
PLS receiver
PLS telegram
I/O register
To SOS (4 channels)
Analog MUX
ADC
CAMAC crate
16 channels
Analog MUX
4 channels
Analog MUX
20 channels
GPPC
GPPC
Dataway display
External triggers
(from timing system)
Analog electronics

Fig. 4

Distribution Note H1-89-2 - CO-89-10 23.3.1989

PS

Carter C.

Daems G.

Heinze W.

Koziol H.

Kuiper B.

Odier P.

Perriollat F.

Schindl K.H.

+ 52
+ 10 (W.W.)