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THE NEW LINAC ANALOGUE WAVEFORM SELECTOR (AWS)

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1. INTRODUCTION

The new Linac control console [1], includes the facility to display and to observe on a scope, four analogue signals, remotely selected. The selection of these four signals out of a total of 400 Linac waveforms is made by the Analogue Waveform Selector [*] or AWS.

The operator selects the parameter he desires to display through the touch panel selector [2]. He first touches the word corresponding to the parameter and then allocates this parameter to one of the four output channels, each channel being permanently connected to one of the inputs of two double beam scopes. This selection is transferred to the computer and after proper software treatment, transmitted over the CAMAC bus to the specific data rack which contains the selected parameter.

The necessary switching arrangements are then executed locally and the signal is branched to the selected output bus.

This note gives a description of the system and its tentative specifications.

2. GENERALITIES

2.1 System properties

In spite of all digital information which will be provided for the new Linac, we feel that the Analogue Waveform Selector is the only valuable tool for observation of analogue pulse shapes.

It can be used for setting-up the machine, optimization, measurements, studies and fault diagnosis. The system becomes a vital instrument during critical operation moments and should satisfy a number of criteria, the most salient of them are given below.

a) Easy operation : the operator should be able to select the desired signal by the use of push buttons labelled with the name of the parameter.

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*) The device is not a fast multiplexer but a slow, remotely controlled selector. We prefer this term because it denotes the real function of the device and because it prevents confusion with the usually fast, continuously cycling analogue or digital multiplexers.

b) Reliable operation : the system could become of crucial importance as mentioned earlier, for quick diagnosis and cure. Therefore, it should be planned with a high degree of reliability. Partial power or equipment failure in a data rack should not affect the smooth operation of the rest of the system.

c) Easily expandable : if foreseen from the beginning, new controls locations (MCR, etc.) could easily be added later. New signals could also be added without any other modification than expansion of the existing hardware and software in such a manner so as to keep the initial installation in continuous uninterrupted operation (see also 7.).

d) Improvable : the initial design of the system is done so as to carefully match the transmission characteristics of the rest of the associated equipment (waveform quality, display oscilloscopes, etc.). This is important to keep the cost within specified values. However, experience has shown that after starting-up of a new installation, later requirements might ask for improvement of the initial performance. Frequency and pulse response, linearity and distortion, dynamic range and noise are figures adding heavily to the cost of such a selector. Therefore, provision should be made, to permit, if so required, later improvements of the initial installation.

2.2 System characteristics

The following, preliminary list, reflects the actual feelings of the Linac equipment designers as well as the present linac operation specialists.

Figures given below can easily be modified, if necessary, providing the resulting cost increase is justified (and available). The characteristics apply to overall system performance. They are compatible with usual linac noise conditions, oscilloscope precision and operational amplifier capabilities.

1.	Input parameters	∼ 400
2.	Output channels	4
3.	Selection time	0,1 sec
4.	Signal source level	± 2V, pk/pk
5.	Signal output level	± 1V, pk/pk at 50 Ohms

6.	Pulse response	better than 0,1 μs with 1% overshoot
7.	Pulse response droop	0 (DC response)
8.	Total noise (transients, DC offset, crosstalk, etc.)	less than 5 mV pk/pk
9.	Linearity and distortion	less than 1%

2.3 System components

In order to permit easy comparison of the different possible configurations, the system is split to the following parts :

1. Patch panels : these are the points where all signals are available with normalized level and impedance.
2. Video selectors : these are the remotely controlled switching matrixes, establishing the crossbar connections.
3. Line drivers : balanced output power amplifiers are used to drive the feeding end of the transmission lines.
4. Transmission lines : video, balanced (symmetric), transmission lines to transport the signals from the sources, through video selectors and line drivers to the Control Room.
5. Termination amplifiers : differential amplifiers at the end of the transmission lines to perform common mode noise rejection, eventually line compensation plus power boosting for multiple output distribution.
6. Selector panel : allows the operator to select the desired parameters. We use the touch panel identical to those used in other places of the Control Desk [2]. The device is coupled through the CAMAC to the computer and the Video selectors.
7. Control lines : these are the lines connecting video selectors to the selector panel. In our case the CAMAC buses are used for that purpose.
8. Software : this part of the system interprets the received commands, operates the switching by selecting the correct addresses, controls the execution and finally validates the requested action by displaying on an alphanumerical display panel the name of the selected parameter.

3. LAYOUT

3.1 Layout possibilities

The AWS can be designed with various configurations. Of the many possible for our application, we are going to analyze the three most promising (Fig. 1).

A. One separate line per parameter

This is a crude, rather primitive method where every signal is brought with a separate cable to the selector, located inside the Control Room.

B. One line per data rack

This is an improved variant of method A. Signals are pre-selected with the use of line concentrators installed in each data rack.

C. One single bus for the whole system

One cable per output channel runs throughout the Linac data racks to the control room. It is looped in the data racks where switches open the loop to branch the local signals.

3.2 Comparison study

Table 1 summarizes the properties of each solution. It is evident that layout A is not practical for our system dealing with 400 signals. It is very expensive with the multiple hardware and cabling required, contributing to the cabling chaos inside the racks.

Variant B, although considerably improving matters and with less hardware that A, suffers from lack of flexibility, a very important feature for any future modification and extension.

Variant C, showing marked technical and economical superiority over A and B, was preferred. It fulfils our requirements described in 2.1. As all the switching is carried inside the data racks, matching of signal levels and impedance is done inside the equipment where the signal originates with inexpensive additions to the existing hardware. The Patch Panel (see 2.3.1) then becomes obsolete and can be omitted.

The only weak point of variant C is its relatively low signal transmission quality. This is due to the fact that matching of the bus line can suffer from the multiple bridging and looping. In fact, cascading connectors and switches degrade the quality of the RF line. However, it has been found that, for our rather limited frequency requirements (5 MHz), this is not very important (see 4.2).

4. ANALOGUE BUS

4.1 Description

The principle of the operation of the system is shown in Fig. 2. Four cables, one per output channel, run through all Linac data racks. Each cable, forming the bus, enter each rack and after being looped there through the selection switch, leaves the rack to continue to the next one. When finally it leaves the last one (the one closest to the control room), it goes to the Termination Amplifiers, inside the control room.

When there is no local signal selection, and also when the rack is not powered, the line is looped passively, ensuring galvanic continuity, e.g., passive transmission only.

If a signal originating in a rack is selected, that line is interrupted at that rack and the local selected signal is then branched for transmission.

The command is received at the local CAMAC station and after being decoded, performs the above-mentioned switching as well as the necessary preselection of one out of the 16 parameters associated with that group. For reasons of economy, two groups of eight parameters each are dealt with, in the same module.

4.2 Transmission lines

A pulsed Linac is a very noisy electrical environment. Classic differential op amp techniques for common mode noise rejection are not always efficient nor sufficient [3].

A balanced (symmetric) transmission line offers considerable improvement of at least two orders of magnitude (40 db). Common mode rejection ratios up to 70 db can be easily achieved if multiple earth paths are reduced in an intelligent manner. The cable and the associated connectors are more expensive than single ended lines and become a non-negligible part of the total cost.

Table 2 shows the cost of some typical cable runs. The cost of two pairs of matching connectors and plugs is included (one connector and its matching chassis plug at either side of the run). Installation cost has not been included as it is substantially the same for all the cases.

Cables No. 4 and 5 are quite expensive, excellent for very long runs but not the most adequate for our application. Cables No. 1 and 2 have poor RF characteristics and in fact they are not true RF lines, thus being unsuitable for us. Cable No. 3 is a very convenient cable that fulfils all our requirements. It has excellent RF characteristics. It is flexible enough to permit bending with small radius, a very important aspect for our multiple looping through the data racks. The mechanically mating Lemo connector is a very satisfactory 100 ohm RF connector for the frequency range of our system. Cable No. 3 is, therefore, our choice.

4.3 Amplifiers

All amplifiers mentioned in the text are built using our standard amplifier video module (Fig. 4). It uses CERN stores standard parts and can be used in any differential, balanced or single-ended input or output configuration. The performance of this module exceeds the AWS specifications and the cost is very moderate.

5. SELECTORS

5.1 Selector description

The Linac standard analogue acquisition unit constitutes out of a NIM crate housing the necessary interface to the CAMAC. Up to 16 parameters can be connected to the input for signal processing and A/D conversion. Each input channel includes a front end amplifier for signal normalization (level and impedance) in front of the sample and hold, multiplexer and A/D converter. A FET switch selects under CAMAC control analogue signals from the output of the front end amplifier and sends them to the line drivers. This preselection is performed inside the input module at high impedance. The four preselected signals are then brought to the line drivers. These are power amplifiers able to drive the balanced, 2 47 ohm, load.

An analogue selector plug-in module, contains the line drivers and the command word decoders and associated logic. Any of the 16 inputs can be assigned to any of the four output channels. The command order is transmitted through the CAMAC. One 16-bit word is dedicated to one 8 input signal group. This word contains the required information of which input signal to branch to which output channel.

The final switching to the analogue bus is done in a separate box. A switching box is inserted in the bus (one box per bus), and can be interrupted to insert the locally selected parameter. As the bus should have low losses and reflections (long runs and multiple discontinuities are unavoidable), RF techniques are used here. Low capacity dry reed relays are put in strip line configuration making a very satisfactory circuit.

The command module is NIM, 3-unit wide plug-in unit. It requires two serial link channels and can be inserted at any place to the analogue bus to branch 8 input signals of ± 2V pk/pk, to any of the 4 analogue buses.

5.2 Switches

As one of the basic requirements of the system is operation continuity, even if one or several data racks are faulty, electronic switches are not suitable for this application. The dry reed relay is adequate for this purpose. The very long life of more than 10^6 operations and its moderate cost are attractive factors. The only weak point of this relay is the contact resistance. With 0,1 ohms per point and 50 or more contacts in series a serious attenuation problem may appear. Signals originating from the furthest end could be seriously attenuated.

An improvement would be the use of mercury wetted contacts. This could bring down the attenuation to only 1% which is within the specifications. But the high cost of this type of relay, its high sensitivity to vertical position errors (vertical to $\pm 30^\circ$) and its high contact capacity make it unsuitable for our case.

Life tests were carried out in our lab using standard CERN stores dry reed relays. A batch of 50 relays performed five million operations at 0 load and at 20% of the maximum permissible load. Except for some failures during the very beginning of the test, there was no cther failure and the contact resistance increase was less than 1%, at the end of the test. As the mismatch introduced by the contact resistance is purely ohmic, the reflection is not frequency dependent and can be easily compensated. The resulting level loss will be restored by using the adjustable gain of the line drivers.

The capacitive discontinuity introduced is too small to affect the rise time. At f = 10 MHz, a 100 pF capacity across a 95 Ohm line gives a reflection coefficient ρ

$$\rho = \frac{Z - R}{Z + R} = \frac{j\omega \frac{RC}{2}}{1 + j\omega \frac{RC}{2}} \quad \text{or} \quad |\rho| = 0{,}229$$

and the rise time

$$t_r = \frac{0{,}35}{f} |\rho| = 8\,\text{ns}$$

The low capacity between the open contacts permits at least 60 db isolation between any line configuration (any combination of open or closed lines).

5.3 Logic

As already mentioned, (see 5.1), one 16-bit word is necessary for the command of each group of 8 input signals. This word is transmitted from the computer over the CAMAC to the local crate. It comes from an "8-OUT" serial link module [4] in serial form and is decoded inside the local AWS command module. One output is sent to the front end amplifier to perform the preselection of the desired signal. Another output is sent to the analogue bus switch. The switch opens the incoming line and branches the already preselected parameter to the outgoing line.

The command module contains a store for the command word. This local register should be set to zero before any new selection. The decoder contains a safety logic which prevents execution of any illegal command word.

The bit allocation of the command word is as follows :

IV	III	II	I	Number of analogue bus
0000	0000	0000	0000	No local signal branched
0000	0000	0000	0001	Input 1 branched to bus I
0000	0000	0000	1000	Input 8 branched to bus I
1000	0100	0010	0001	Input 1 branched to bus I and " 2 " " II and " 4 " " III and " 8 " " IV.

In this last case all four buses have signals originating from the same group of 8 parameters and therefore all the other command registers of the system are set to 0.

Each group of four bits can only have values from 0000 to 1000 corresponding to binary numbers 0 to 8. Group patterns like 1111, 1110 or 1100 are therefore forbidden.

6. SELECTION CONTROL

6.1 Command Panel

The AWS command panel is located in the Linac Control Room Desk. It is composed of :

1) A touch panel selector, mentioned already in the introduction. It is essentially a CRT screen where up to 16 parameter names appear. Touching the screen surface at a parameter name, changes locally the capacity between transparent conductive fields on the screen. This triggers an interrupt in the computer and also notifies it of which of the 16 fields has been interrupted.

2) The hook buttons which permit after selection of the desired signal to branch it to one of the 4 buses.

3) An alphanumerical display panel showing the name of the parameter actually connected to each of the analogue buses.

4) Two double beam scopes to display the selected waveforms. Their inputs are connected to the outputs of the termination amplifiers of the four buses.

5) Timing delays for the above scopes. They are variable to permit to "move" the observed signal across the scope screen.

6.2 Selection software

The AWS command words are implemented as control command words in the new Linac Control System [5]. They are received from the computer through the CAMAC at the output of an 8 serial output CAMAC module [4]. This module has eight separate output channels, each one giving a 16-bit command word. One command word is necessary for the handling of a group of eight analogue signals. The CNAF necessary to produce this word is contained in a special software cell of five words. It contains all the necessary information for CAMAC station identification in the Linac serial CAMAC, as well as status test and command bit information. The necessary Dataway functions are the following :

A(I), F(28)	to all AWS channels resets the logic to zero
A(I), F(16)	writes command word 0 to all channels to cancel any previous selection.
A(I), F(27)	tests if previous transfer is complete
A(I), F(16)	writes actual command word
A(I), F(27)	tests if the transfer is complete.

7. COST

The following cost estimate of the basic equipment does not include computer hardware and software cost and CAMAC system cost (crate, module, cable, etc.). Termination amplifiers and display scopes are fixed expenses independent of the number of parameters. Extension of the system to more than four output channels, or more than one independently operated console will increase the total expenditure by as many times as the required group of channels (in sets of four) for the new operating position.

As a comparison we can mention that a commercial system built and installed entirely by an outside firm was offered at $ 60'000.- (1972 prices).

Distribution

Linac Group
EST
CCI Group

REFERENCES

1) U. Tallgren, New Linac Control Reports, MPS/LINP Note 73-4, MPS/LINP/Note 74-6 and MPS/LIN Note 74-31.

2) F. Beck and B. Stumpe, CERN 73-6, Lab. II Controls.

3) A. Cheretakis, A/D and D/A Conversion techniques of the new linac, (in preparation).

4) A. Chapman-Hatchett, 8 serial output CAMAC module, type MPS-5247, CERN CAMAC News No. 2.

5) P.F. Mead, The New Linac Control software (in preparation).

Cost estimate

1.	Plug-in modules with decoders, switchers, line drivers and line selectors	25 x	1'800.-	= 52'500	47,48
2.	Pre-selector cards, inside the sample-hold modules	50 x	320.-	= 16'000	14,47
3.	Connecting cables for above	200 x	15.-	= 3'000	2,71
4.	Connecting cables from CAMAC station to above equipment	50 x	75.-	= 3'750	3,39
5.	CAMAC modules, 8-out serial, including CAMAC crate and supply cost share	7 x	800.-	= 5'600	5,06
6.	Termination amplifiers	4 x	500.-	= 2'000	1,81
7.	Touch button selector panel	1 x	8'500.-	= 8'500	7,69
8.	Display scopes, timing delays, self-scan display	2 x	8'000.-	= 16'000	14,47
9.	Four balanced transmission line runs of 50 mtrs each	200 x	1,40	= 280	0,25
10.	Connectors for above, 25 sets x 4 = 100	100 x	19,44	= 1'944	1,75
11.	Manpower for cables, 50 man-hours	50 x	20	= 1'000	0,90
	Total cost			110'574	100.-

Average cost per parameter 110'574/400 = 276.- Frs.

	Cable cost	Cost of electronics			Signal quality		Relia-bility	Expanda-bility
		Selector	Line drivers	Termination amplifiers	Frequency response	Noise rejection		
A. One line per parameter	Very high One line per signal Low density (400 runs)	Moderate (1600 points)	High (400)	with 2-pole switching 4 If not,400	Excellent	Poor (bad earth paths)	Good	Poor
B. One line per data rack	Moderate (100 runs)	Moderate to high (1700 points)	Moderate (100)	with 2-pole switching 4 If not, 400	Moderate	Good	Poor	Poor
C. One single bus	Low (4 runs)	Moderate (1600 points) Incorporated in existing hardware	Moderate (100) Incorpor. in exist. hardware	4 only	low	Good	Good	Excellent

Table 1 : Comparative table of merits of different lay outs.

	Cable Type	Imped. (ohms)	Price (fr/mtr)	RF response at 10 MHz	Suitable connectors			Total cost of cable+connectors		Remarks
					Type	Price				
						Cable	Chassis	10 mtr	50 mtr	
1.	G-03939	320	0,92	-	Lemo-0	6,88	5,08	33,12	69,92	Low cost, non RF cable
2.	G-03930/1	320	0,97	-	Lemo-1	8,54	6,39	39,56	78,36	" " " "
3.	Suhner G-05730	95	1,40	100 mtr -6 db / 10 MHz	Lemo-2	11,59	7,85	52,88	108,88	
4.	AN RG-22	95	3,00	100 mtr - 3 db / 10 MHz	Burndy-4	23,44	8,65	94,18	214,18	High quality cable suitable for long runs (200 m)
	1xQUAD	110	1,40		Burndy-4	23,44	8,65	78,18	134,18	Bulky cable, difficult to handle

Table 2 Performance and cost of various symmetric video cable runs

Cable and connector prices are CERN prices for big quantities.

Each run cost includes two cable connectors and two mating chassis sockets.

Cable laying and connector fitting manpower is not given as it is substantially the same for all cases.

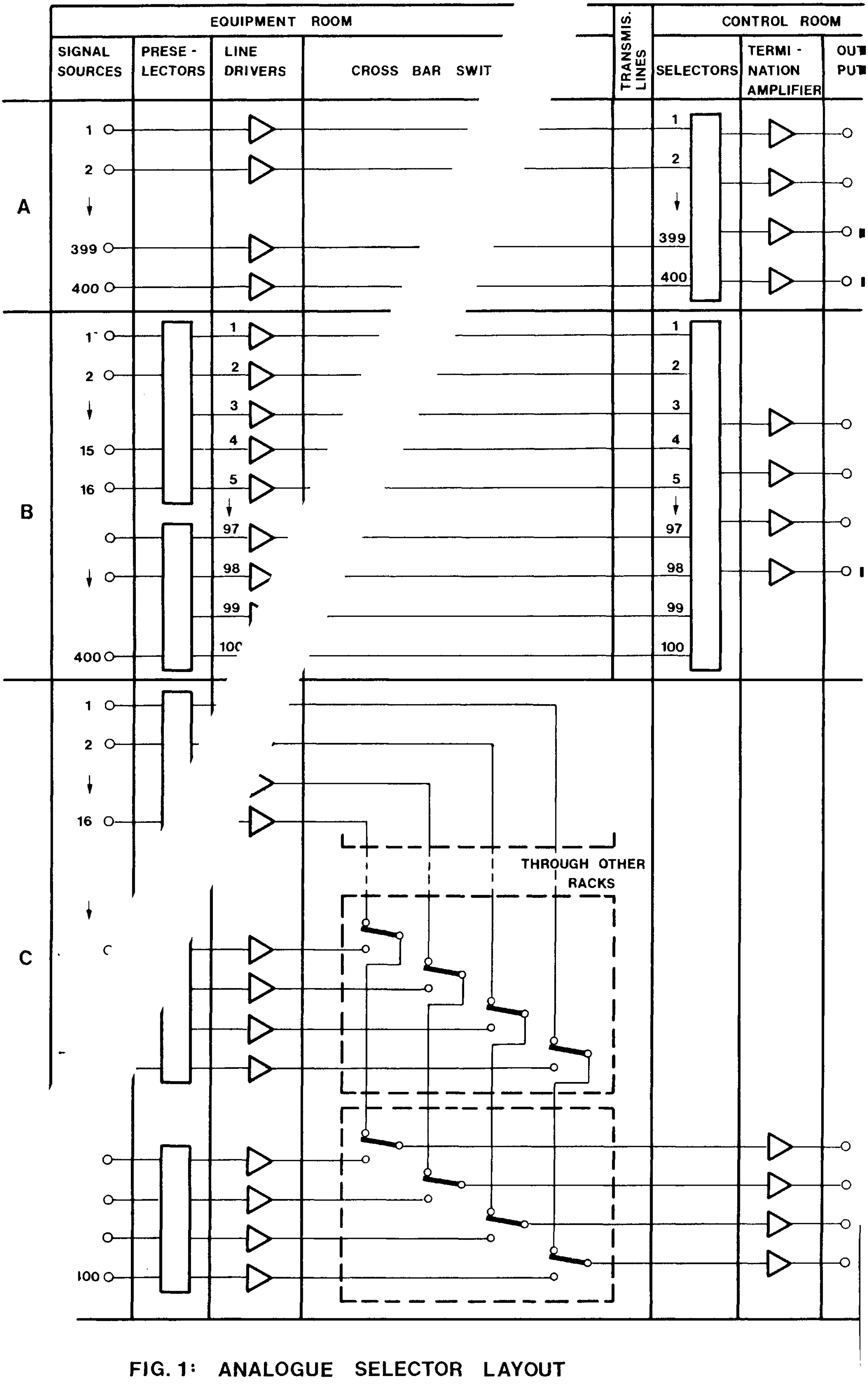

FIG. 1: ANALOGUE SELECTOR LAYOUT

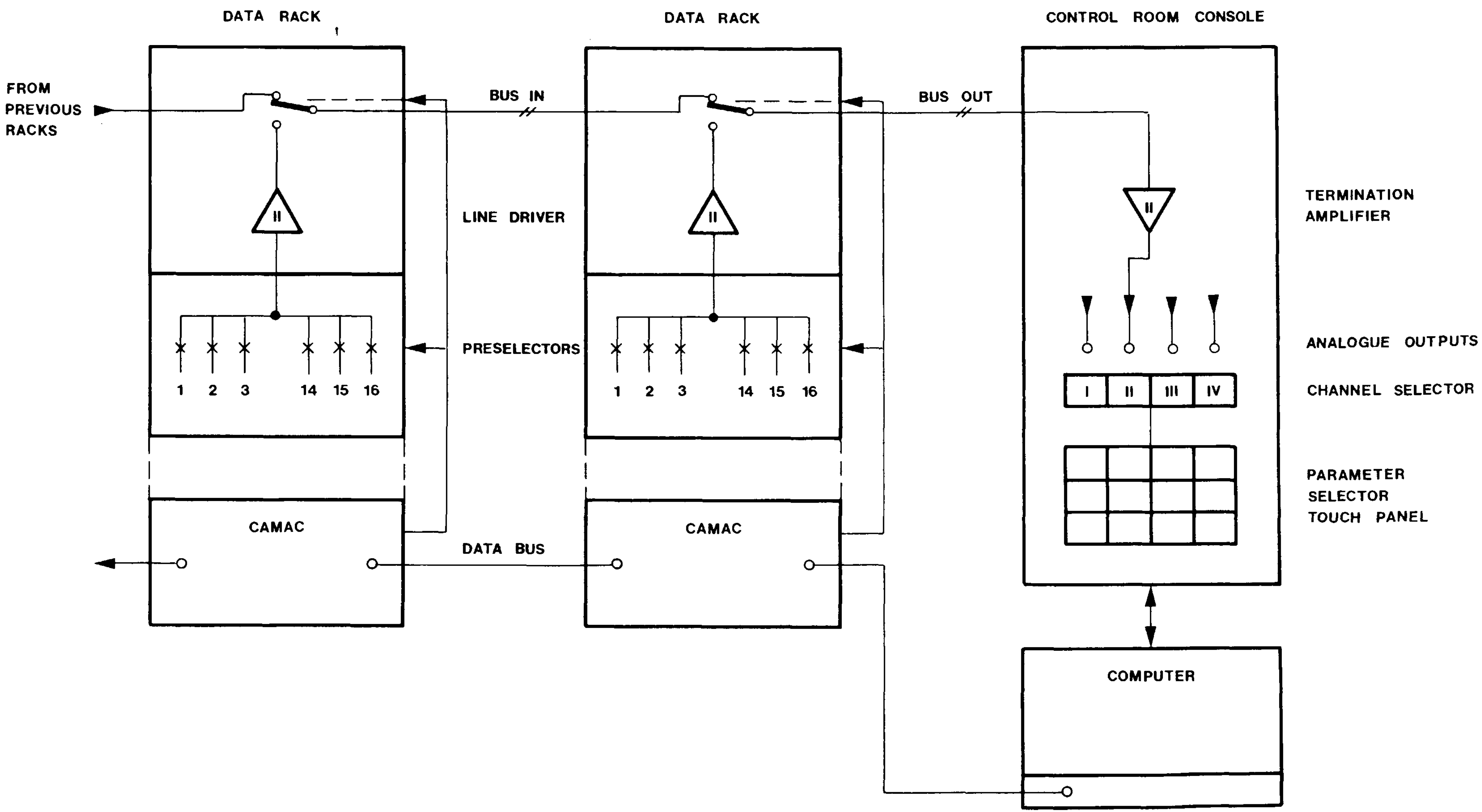

FIG. 2: ANALOGUE BUS (ONE OUT OF FOUR CHANNELS SHOWN)

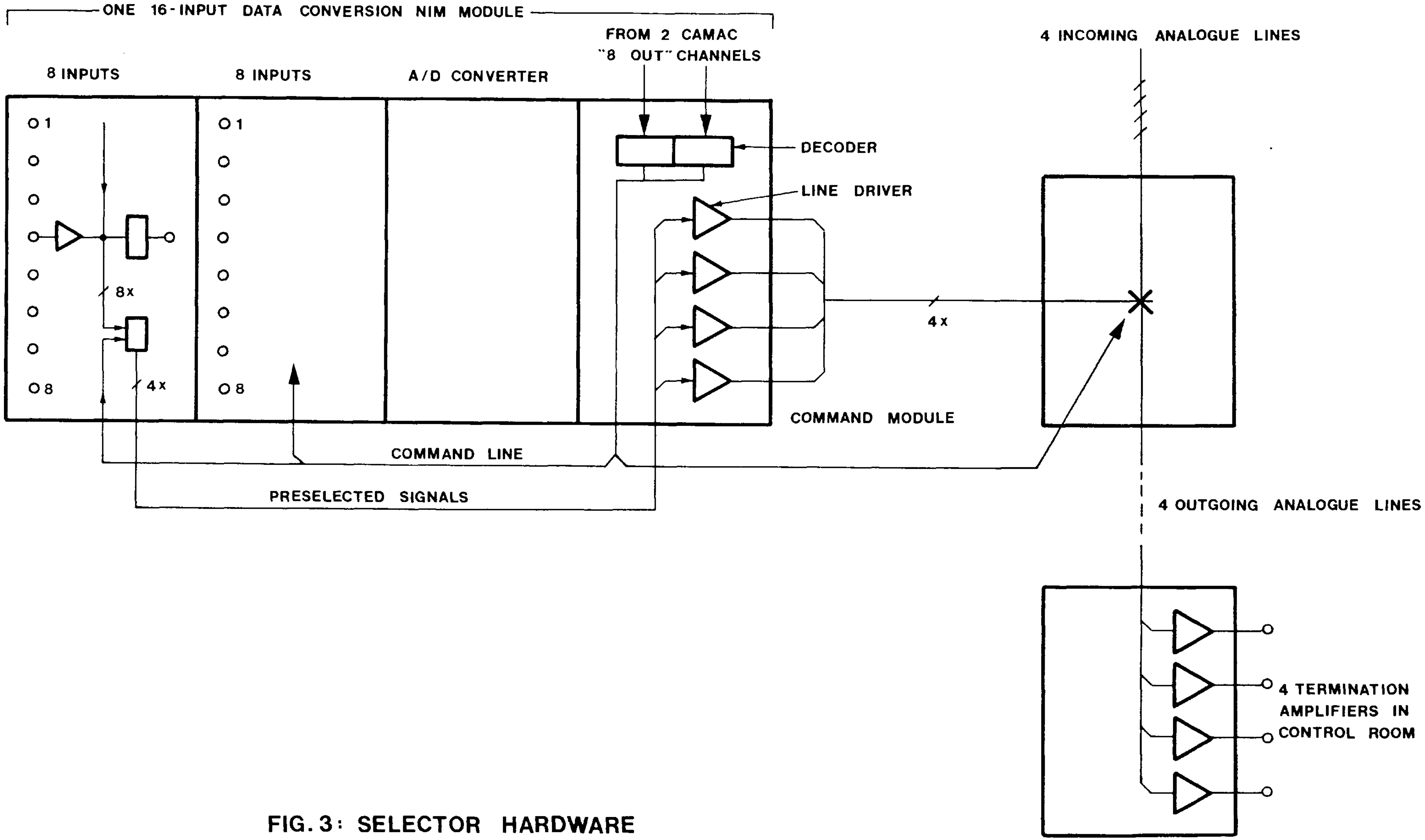

FIG. 3: SELECTOR HARDWARE

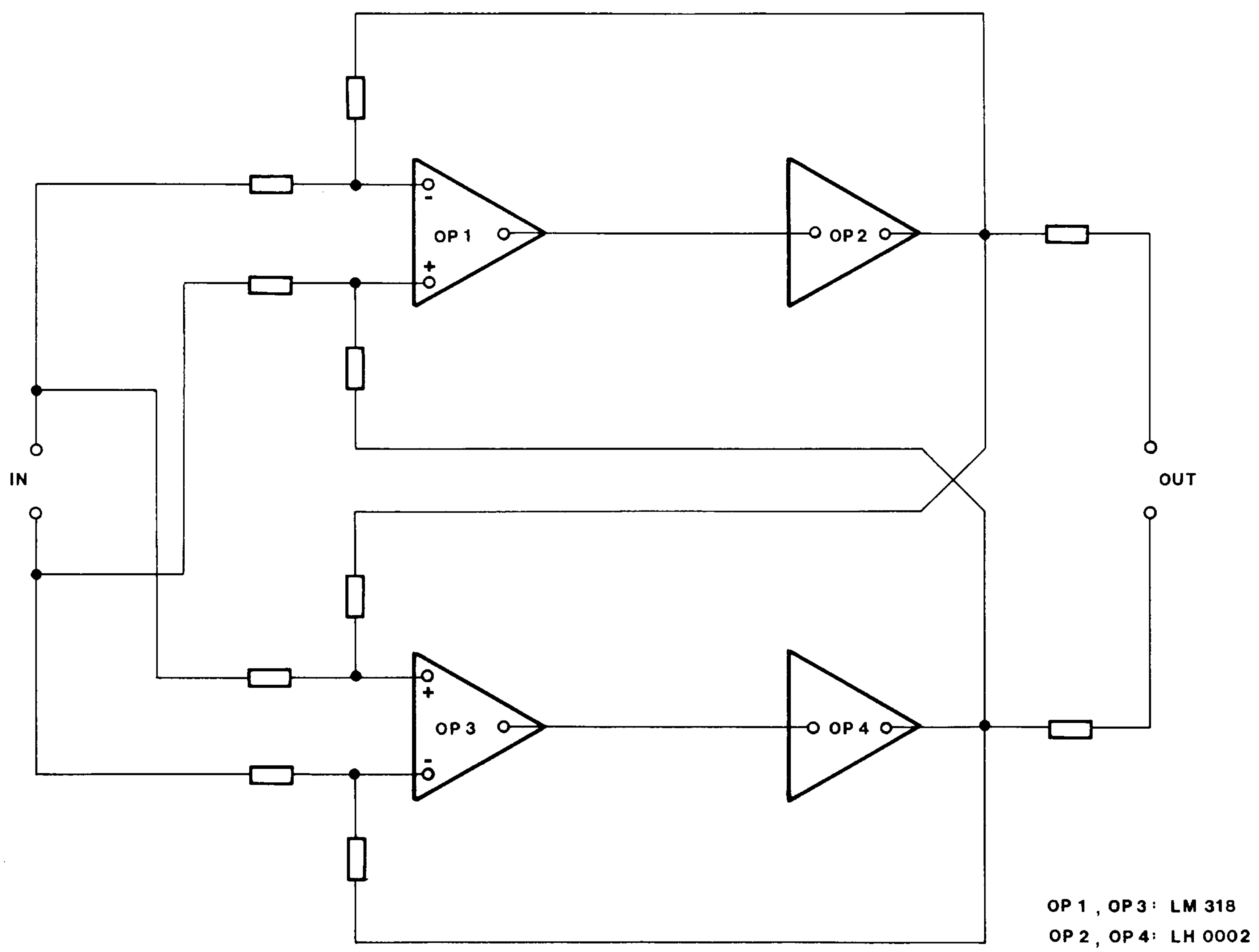

FIG. 4: BALANCED AMPLIFIER

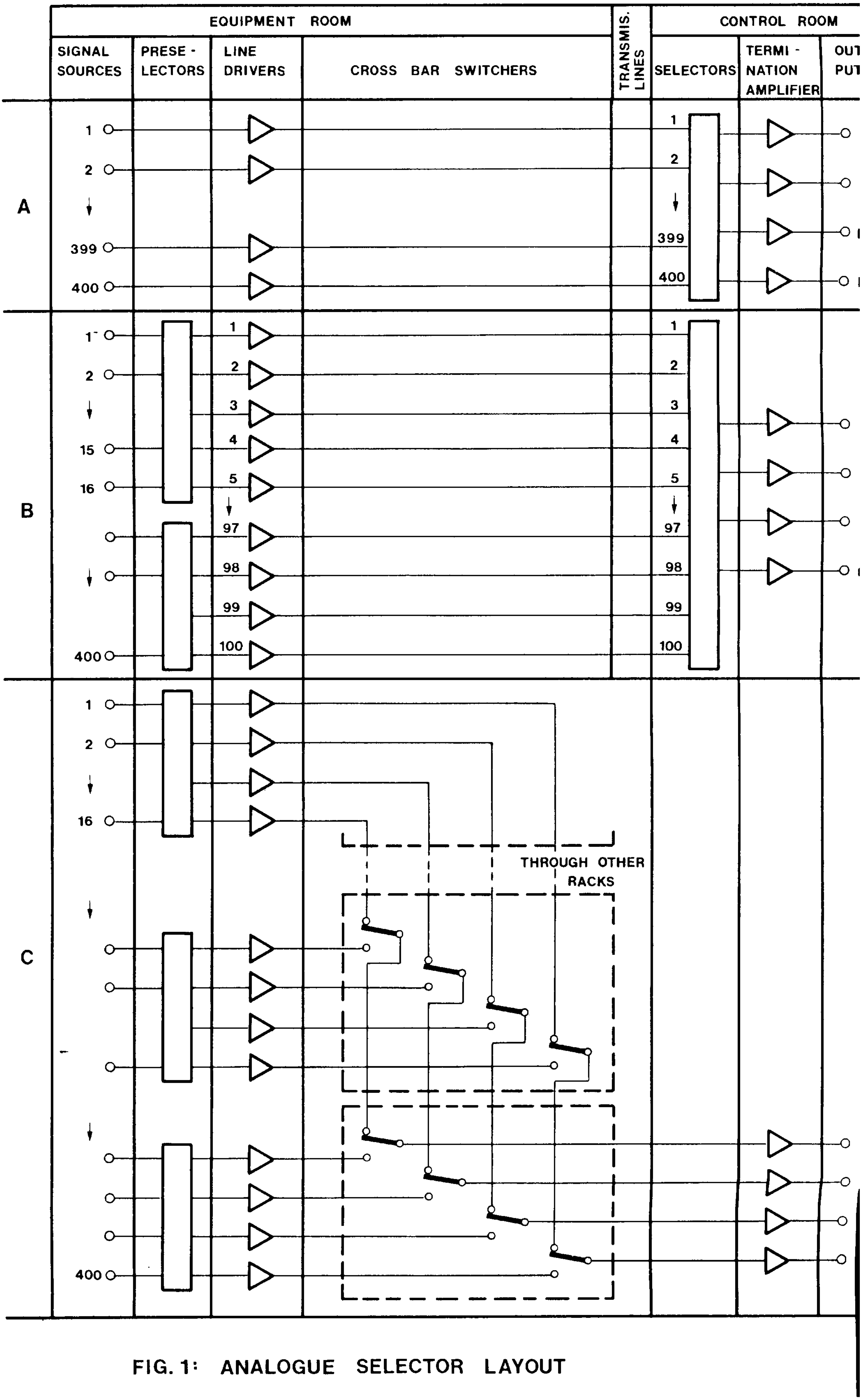

FIG. 1: ANALOGUE SELECTOR LAYOUT