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Data Communication at the CERN Computer Centre

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DD-jh

Abstract

The growing interest for on-line computer service and process control at CERN decentralises certain computer activities. Small process computers, remote batch stations and user terminals are to be backed by a powerful central computer. The present data network is principally star shaped. At the centre of it is a CDC 6600-6500 computer combination. It has a front end CDC 3100 computer with a Hewlett Packard 2116 as multiplexer.

In order to obtain a fairly efficient use of the Hewlett Packard I/O capacity, the slow terminals up to 300 bits/sec, are grouped together. In using a group number at the local exchange, I/O channel sharing is obtained. More permanent terminal users, however, may have a dedicated channel by using point to point lines. The corresponding line drivers and receivers are PTT approved equipment, such as acoustic couplers, modems and electronic switch relays. Medium and high speed transmission is used for buffered display terminals, remote batch stations and process control installations.

At data rates up to 48 kbit/sec, baseband transmission is permitted on leased lines. For higher bit rates, only privately installed transmission lines are used. With network branches of 3 km in mind, a special baseband modem has been developed. It operates at bit rates of 750 kbit/sec under all circumstances and may, dependent on line length and quality, operate at considerable higher bit rates. With a high quality twisted pair video line for example, a 4 Mbit/sec PSK modulated signal passed at a line length of up to 1 km with a bit error rate better than 10^{-9}. Line compensation is provided by R-C networks reducing the RC factor of the lines with factors of the order of 10 to 20. So far, only asynchronous transmission techniques have been applied. Some synchronous media will be implemented in the 2.4 kbit range. There will be an increase in the flexibility with the introduction of a buffered synchronous to asynchronous converter.

Cycle steal block transfers are initiated by synchronising status transfers.

Some details about the fast parallel connections between the CDC 3100 and the HP 2116B will be given in the paper, as well as descriptions of some computer simulation techniques used to test the present systems. Finally some plans on a future network will be given.

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Bibliography

1. Introduction

A muti-access data acquisition, file handling and remote job entry system called FOCUS* operates at CERN on a CDC 3100 computer which is connected to CDC 6600 and 6500 computers. The 3100 has a "front-end" communication processor to which a CERN built data network is connected. It consists of low speed connections to time-sharing consoles (mostly Teletypes); medium speed connections to Alpha-numeric and Graphic displays and high speed connections to Data-acquisition and Remote Batch Stations.

The present CERN site is of triangular shape with sides of 2000, 2000 and 600 meters (see Fig. 1). For a limited number of slow speed data connections the PTT** dial-up network is used but for most of our connections a special network was developed and installed as well as special digital transmission devices to replace the (expensive) modems. As we were not restricted to any particular transmission convention as far as our own network was concerned, we were able to choose the characteristics as a function of our particular needs.

Extensive use was made of Computer Channel Simulators to test the hardware and in particular the computer/computer connections. In this way on-line debugging time was reduced to a minimum.

FOCUS is now working at full capacity, 2 Remote Batch Stations, 4 Data acquisition computers, 4 Graphic displays and more than 30 consoles have been connected. (See Fig. 2).

2. On-line Computer Users

The very different character of on-line computer users at the CERN site, necessitates a great variety of data transmission systems. In order to facilitate switching and improve the general flexibility of the on-line computer service, in the most economical manner, serial instead of parallel data transmission techniques were used. Network branches are currently up to 3 kilometers in length and future branches of 5 or even 8 kilometers are likely.

At the moment, the following categories of on-line computer users are to be distinguished:

a) Users who want to edit or control their jobs by means of an inexpensive low speed terminal, with bit rates of 100 - 300 bit/sec. The average duration of a connection, "the call time" or "log in time" is in the order of one hour.

b) Users of terminals with graphic capabilities. The display

* Facility for On-line Computing and User Services.
** Post Téléphone Télégraphe (The Swiss Post Office).

terminals used for this purpose permit medium speed bit rates of 10 kbit - 50 kbit/sec. Their average log in time is about two hours.

c) Users of Remote Batch facilities. This is the most popular facility with users. With small computers equipped with a card reader and line printer as local concentrators, data is buffered and transferred as packages with bit rates of 750 kbit/sec.

d) Finally the numerous experimental physics groups in possesion of a small or medium sized computer. They need an additional on-line connection to the central computer system, because of the considerable amount of collected data and the complexity of their experimental set up. The computers at the experiments normally act as combined process control computer and data concentrators and are normally referred to as data acquisition stations.

3. The Communication Processor

The central multiplexor-concentrator of the on-line services is an extended Hewlett Packard HP 2116B computer. It consists of a CPU with 16 k of core (cycle time 1.6μsecs). The machine has an I/O capacity of 48 channels. There are 2 Direct Memory Accesses which are shared by 16 channels. Except for the console TTY all Interfaces were developed and built at CERN. Low speed connections are half duplex and occupy only one channel, which means only one card in the machine. All medium and high speed connections occupy two channels and are full duplex. Apart from the paper tape reader and punch and the link to the 3100, all connections are serial and asynchronous. We use ASCII codes (7 bits + parity) on low and medium speeds (50 kbits/sec). 5 low speed lines (200 Baud) are connected to the HP 2116 via the PTT dial-up network and 10 users are provided with a dial up capability via modems or acoustic couplers. A Hewlett Packard network channel interface consists of an interface board with buffered serialising-parallelising logic, bus drivers and bus logic, ordinary integrated twisted pair line drivers and receivers as well as CCITT* voltage drivers and receivers. For the low and medium speed devices (100 - 50.000 bits/sec) the buffer is eight bits, the clock is adjustable and lateral parity is checked and generated. Logic is provided for half duplex, clockless or clocked transmission and internal strapping permits two wire or four wire operation, with program selectable echoing of characters by hardware. Medium speed channel interfaces are programmable into two different modes. One mode corresponding to I/O rates of 1 kword/sec and the other corresponding to 5 kword/sec.

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* Comité Consultatif International Télégraphique et Téléphonique.

For the high speed Hewlett Packard serial interfaces a data word of 16 bits + parity was chosen instead of the ASCII format. Sixteen bit buffers were thus required and lateral as well as longitudinal parity were generated and checked hardware wise.

4. The Communications Controller

The actual data reception and transmission take place in a so-called communications controller. It communicates over twisted pairs with the Hewlett Packard but has various transmission methods at its disposal. A flexible patching system makes it possible to change from one transmission technique to the other. It contains a P.T.T. compartment for telephone line connections.

5. Communication Devices

5.1 Asynchronous 200 Baud Modems

Because of the fairly short average "call time" of the low speed terminals and because of the demand in this category within CERN and even from outside, the switching services of the local exchange have been used for this purpose. This exchange permits the use of group numbers. Every group consists of one main telephone number and up to five consecutive slave numbers. As soon as the main number has been dialed, the group scanner passes the line to the first free number out of the group. As soon as the five consecutive numbers are all occupied, the group is considered full and new callers will find the line engaged. With twice as many terminals as there are input-output channels available in this category, a satisfying efficiency has been obtained. The users of this dial-up, slot sharing system require of course an appropriate, approved modem or acoustic coupler in the 200 baud range. Accordingly 200 baud modems had to be installed inside the Communications Controller.

5.1.1 Modems Connected to the Central Multiplexor

The used modems are Philips STR 651, asynchronous 200 Baud modems (data sets). Every modem is directly connected to the CCITT driver and receiver on the HP channel interface board. In order to use the modems in "Automatic Answering" mode, some additional hardware had to be implemented. Called data sets are strapped at 1650 Hz for a logical "0" and at 1850 Hz for a logical "1". The caller data set acknowledges this carrier with the complementary carriers of 980 Hz for a "0" and 1180 Hz for a "1".

The modems are connected with the reception of the Ringing Indicator and stay connected as long as a Carrier is received. The interim period is overlapped by means of a 20 second lasting extension of the Ringing Indicator.

5.1.2 Modems Connected to the Terminals

The most commonly used terminal at CERN is the TTY 33 teletype with current interface. To connect this TTY to a standard modem, current to voltage translators for the data lines are implemented inside the modem. Modems can only be used in places where the telephone set plugs into a wall socket. In order to facilitate the use, telephone sockets have been mounted on the rear panel of the modems. It is intended for the telephone set when the modem is plugged into the wall socket. Relay contacts establish the appropriate connection.

5.2 Acoustic Couplers

In cases where telephone sets have a fixed connection with the telephone network, modems cannot be used. The introduction of acoustic couplers in these cases has been very useful. The applied coupler TC-101 is made by Moore Reed and has been approved by the P.T.T.

5.3 Baseband Transmission Sets

5.3.1 Electronic Switch Relays

For the low data rates up to 300 bit/sec privatly installed lines do not, of course, give any restrictions in the applied transmission techniques. For the sake of flexibility however, PTT regulations are practised whenever possible. For a low speed Teletype driver for instance, the PTT approved electronic switch relay, Telefunken ER04-06-08 was used, allowing for private, point to point, PTT lines on special occasions. Both half duplex and full duplex systems can be used on two or four wired connections.

5.3.2 Asynchronous Baseband Devices

In order to facilitate the use of our private twisted pair transmission techniques, baseband modems or "Codecs"* have been developed. As with modems, they operate in pairs, one on each side of the transmission line and interface following the CCITT specifications. (Fig. 3). The data rate and the permissible distance

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* Codec stands for Coding - Decoding Device. Coding in the most common sense of the work, without the necessity of modulation and demodulation.

between two codecs depends on the type of line drivers and receivers used. The concept of the codecs is fairly modular. Every codec has space for extensions. Most commonly used is the asynchronous codec with 200 Baud communication interface. Control signals like Clear to send and Carrier detected are returned on the Request to send and Data Terminal Ready signals respectively. The Modem Ready signal is generated as soon as the power is switched on. This kind of codec is used for the slow and medium speed communications, in particular for use with the four Tektronic T4002 display terminals.

For higher speed applications (bit rates up to 1 Mbit/sec) codecs have been developed too. The use of PTT lines at the CERN site in these bit rates is rather unattractive, mainly because of the high cost of approved communication devices. Besides, slot sharing is not very desirable, because of the average long call duration and the fairly fixed locations of the users in these categories. The transmission technique used is strictly asynchronous. Single opening bits and double stop bits frame each seventeen bit word and serve as clock synchronisers.

Data are transmitted with current balanced line drivers, voltage symmetrical around zero. Line compensation is done with RC networks reducing the RC effect of the lines by a factor of about twenty, reducing both amplitude attenuation and phase distortion. It reduces the sensitivity to common mode crosstalk voltages in the transmission lines, even in cases of asymmetries in the transmitter output impedances. It is noted that the components of the line compensation, the common mode reduction and the ground insolation at the receiver side, are selected carefully in order to avoid differential voltage components due to tolerance differences.

5.3.3 The Synchronous Codec

This codec (fig. 4) has a synchronous communication interface (CCITT-V24). In one version, the clock is generated, but not used to modulate the data. Consequently twice the amount of transmission lines are required. A useful application of this codec is the case where the two sets out of one pair are put together. That is, the situation in which the actual line length in between two codecs has gone to zero.

The obtained synchronous terminal to communication set interface is to be used in cases where synchronous terminals have to be connected directly onto a communication interface. On non private data channels (e.g. the PTT network) dissipation outside a certain frequency range is often restricted or even forbidden. Consequently data structures have to be analysed on higher harmonics outside the fundamental frequency band. With modulated data streams instead of unmodulated data one obtains a better defined and narrower bandwidth. This and the ineffiency of using four twisted pair lines for one full duplex communication channel made us decide to introduce a second version of the synchronous codec. Data are F.S.K.* modulated upon the baseband clock signal. The codec (Fig. 5) is to be used in half duplex and in full duplex mode.

5.3.4 The Synchronous to Asynchronous Converter

Due to the fact that at bit rates higher than 300 Baud, terminals often operate synchronously, a buffered synchronous to asynchronous transmission converter was introduced. This converter is to be used in combination with or without a modem and consequently has a data set interface as well as a terminal interface.

6. Transmission Lines

All privatly installed transmission lines have been, until recently, the twenty six pair, commonly shielded, I.K.O cables. With a resistance of 98Ω/km, a capacity of 110 nF/km, an inductance of 0.3 mH/km, a cross section of 0.5 mm^2 and group speed of $1.8.10^8$m/sec they offered an attenuation of about 0.7 Neper/km. They permitted us to go at 750 kbit/sec up to distances of 3 km, while using 60 mA balanced current drivers.

For future extensions as well as for the future data network, a twenty four pair video cable will be installed. The cable consists out of an equal number of video and audio pairs and has the following characteristics. For the video pairs, the resistance is 48 Ω/km, the capacity 49 nF/km, cross section 0.64 mm^2, group speed about $1.9.10^8$ m/sec and attenuation (100kHz) is 0.22 N/km. The audio pair has a resistance of 144 Ω/km, a capacity of 35 mF/km, inductance of 0.86 mH/km, a cross section of 0.21 mm^2, a group speed of about $1.9.10^8$ m/sec and an attenuation 0.46 N/km. The cable permits the transmission of F.S.K baseband signals up to 4 Mbit/sec (8 Mbaud) on the video pairs at distances up to 1 km and of 3 Mbit/sec on the audio parts at the same distance (Fig. 6).

These bit rates were again achieved with the 60 mA balanced drivers and appropriate RC-line compensation. Error rates were better than 10^{-9}. For the time being, however, only non-modulated, asynchronous bit rates of about 1 Mbit/sec are foreseen.

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* Frequency Shift Keying

7. Computer Interfaces

With the actual bit rates of 750 kbit/sec, the current H.P. central multiplexor is effectively used.

This transmission speed chosen, was

a) At a safe limit of what could confortably be obtained with our current transmission system and average cable qualities (error rates $< 10^{-10}$).

b) A higher transmission speed was not useful since the 3100 connection itself runs no faster than 600,000 bits per second.

c) This transmission speed was necessary to reduce the DMA load on the HP 2116. Only two simultaneous DMA channels are provided on the machine and as one DMA is dedicated to the 3100 connection, the other has to be shared in burst mode among the high speed links.

Interleaving of DMA transfers on the same DMA channel is not possible because once a block transfer has been indicated and started it has to be completed before another link takes DMA. The high speed block transfers were made possible because of the fact that all remote computers could work under DMA (Fig. 7).

Every computer interface is equipped with a hardware time out clock in order to avoid otherwise undetectable DMA hang up situations. In cases where DMA network request levels were common with those of other local peripherals, the risk existed that another local DMA operation was in progress and had to be completed first.

In asynchronous transmission techniques, staticised words have to be accessed during the presense of the stop bits only. In order to avoid input buffering in these cases, optional additional stop bits could be added by means of an easy hardware selection.

Interfacing to the IBM 1800 computer was done directly onto an I/O channel. The IBM 1130 was interfaced on the 1133 multiplexor, storage access channel. The Hewlett Packard 2100 interfaces with the same logic used in the Hewlett Packard 2116B multiplexor. In addition to the fast computer links a few slow computer connections are realised. A modem connection with a second Hewlett Packard 2100 works at ordinary 110 bit/sec rates and a spectrometer of the Health Physics department has been connected with electronic switch relays on a private PTT line.

8. Systems Synchronisation

Low and medium speed devices are synchronised in the following way. At regular intervals, an interrupt scan is performed within the HP multiplexor. Newly arrived, buffered characters are sensed in this way and checked on parity errors or character lost, two status bits, available on every buffered interface board. The HP traces Carriage Return characters as terminators of a message and transfers the data to the CDC 3100. Communication between individual terminals is possible with a special command. All messages, however, pass by the CDC 3100 computer except in cases where the CDC 3100 is down, when a general warning message is originated inside the HP multiplexor.

The high speed communication is synchronised in the following way:

Programmed single word message initiate DMA block transfers, acknowledge the completion of block transfer and the detection of parity errors and the abort of a current transfer. With the remote computers as "Masters", transfer requests arrive at regular intervals, from the remote computers only. A detected transmission error will cause the retransmission of the entire data block.

9. The HP 2116B - CDC 3000 Coupler

The HP 2116B - CDC 3000 Coupler comprises the necessary logic to interface a Hewlett-Packard 2116B computer to a CDC 3000 series channel (Fig. 8). It provides facilities to enable the two computers to initialise, synchronize and perform data transfers at high rates. The coupler is an entirely parallel device and includes special hardware to cope with word length differences of the two machines (24 bits in CDC 3100, 16 bits in HP 2116B). The connection to the HP 2116B is established via two I/O channels, one of which carries status and control information while the second one handles data input/output. The CDC side of the coupler is of single access type.

The initialisation and the synchronization of the two machines are performed via a status register, certain bits of which can be manipulated from each machine. These bits enable the two machines to initialise and synchronize data transfers. Other status register bits are peculiar to each machine and reflect hardware conditions of interest to the machines.

Data transfers are carried out blockwise. A 24-bit buffer is used as an intermediate store to allow the coupler to perform assembly/disassembly of the information bytes. There are two different modes selectable from the CDC side. The HP 2116B handles the data input/output under direct memory access. Lateral parity check is performed on CDC output data and a parity error causes a "TX PARITY ERROR" to the CDC 3000 channel. The coupler generates a parity bit on HP 2116B output data.

There are several possibilities of interrupting the two computers. The CDC side of the coupler provides a 10 bit interrupt mask register settable by a function code from the CDC channel.

This register is compared bit by bit with corresponding 10 bits of the status register and whenever two bits coincide an interrupt is generated to the CDC channel. Some special hardware conditions interrupt the same channel.

Since the HP 2116B side of the coupler is established via two I/O channels, there are consequently two different interrupts. The status and control channel is interrupted upon receipt of status from the CDC channel or on a HP 2116B request to read status. Interrupts on the data channel are set in the standard Hewlett-Packard manner.

10. Computer Channel Simulation

On-line hardware testing on computers which are used practically 24 hours a day had proved to be a difficult problem. It was decided to reduce it to an absolute minimum by developing computer channel simulators for use on a small HP 2115 computers. So far two simulators have been developed and have been used extensively and on-line testing was reduced to a few hours in some cases.

10.1 The CDC 3000 Channel Simulator

The simulator consists of an interface unit which contains the 3000 type drivers, receivers and connectors. The interface unit is entirely controlled by the Hewlett-Packard 2115A computer. All the channel control, status and data signals are represented by bits on different input/output channels. Software drivers in the 2115A take care of all the control. The hardware is relatively simple as only functions like level conversion and signal routing had to be provided as well as parity checking and generation. Connections to and from the 2115A are made via 3 interface cards on 3 different input/output channels. The software which was developed in assembly language includes drivers for all the channel functions such as: master clear, copy status, connect, function, input and output block transfers and interrupt.

10.2 The IBM 1800 Channel Simulator

The concept is the same as that for the 3000 channel simulator. However, the hardware is much more complex because of the nature of the 1800 channel. The channel uses computer time pulses which are simulated by hardware. Three channels are used for the communication with the 2115. Software drivers have been developed to generate all status and control functions as well as programmed and Cycle Steal Input/output transfers.

11. Experience and Future Plans

The FOCUS system in its present configuration has been running now for more than one year. It operates more than 20 hours a day and 7 days a week. The data communication hardware is one of the most reliable parts of the whole system, with MTBF's exceeding 30 days. The high speed data-links and especially the link to Remote Input/Output Stations are heavily used.

A new large central computing system has recently been installed at CERN. It is based on a CDC 7600 computer with a CDC 6400 computer acting as a "front-end" input/output processor. During the course of 1972 the CDC 6500, which is now at the current centre, will be connected to this system as well.

At the present time we are planning a communication control system which will be connected to both "front-ends" and which has to take care of the control of 4 remote links to the central facility. This system should be able to accommodate up to 100 time sharing consoles (110-2000b/s), 30-40 fast computer/computer serial links (50kb - 1Mb/s) and fast parallel connections to the front-end (12 Mbits/sec). In addition to this the CERN site will also grow to a size of about 5 × 3 kilometers over the next 4-5 years. With low and medium speed connections remotely concentrated, only high speed links have to be considered for the central multiplexor. In order to cope with the expected amount of high speed data, a series of fast multiport memories are foreseen controlled by small computers. We expect that the new communications control system will contain a lot of CERN built hardware, in particular the parallel connections to the front-ends and the high speed serial connections. Undoubtedly the experience with the present Data Communication system will be of great value.

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12.5 Datel, Transmission de données sur les réseaux de télécommunications de l'entreprise des PTT Suisse.

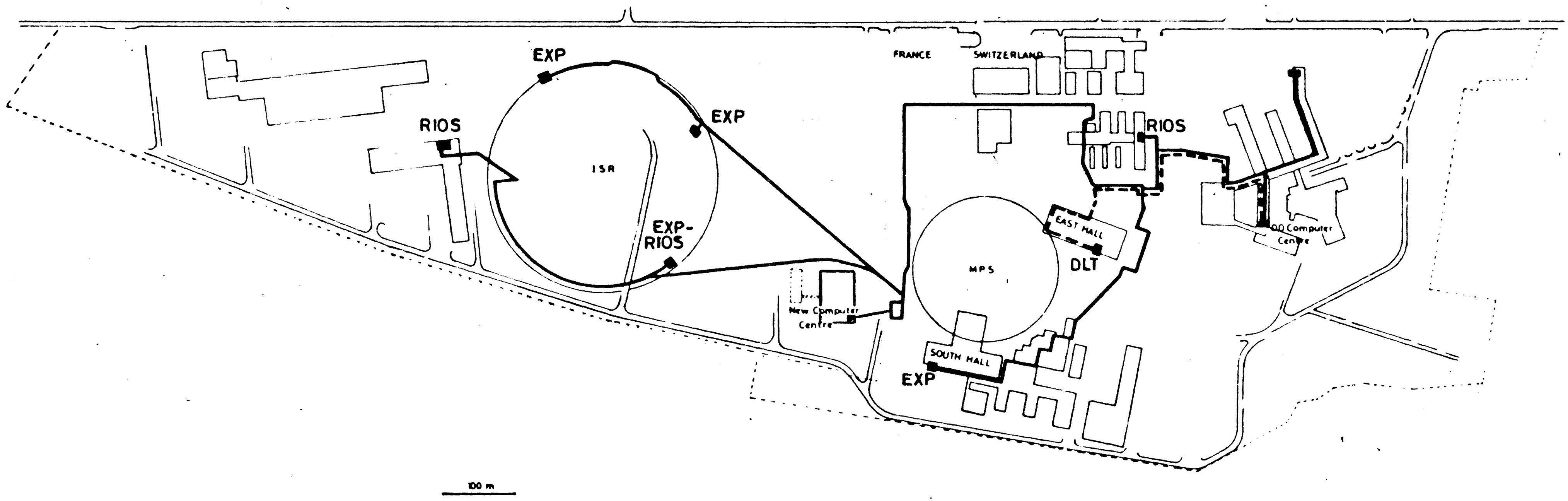

Fig. 1 The private high speed data network at the present CERN site.

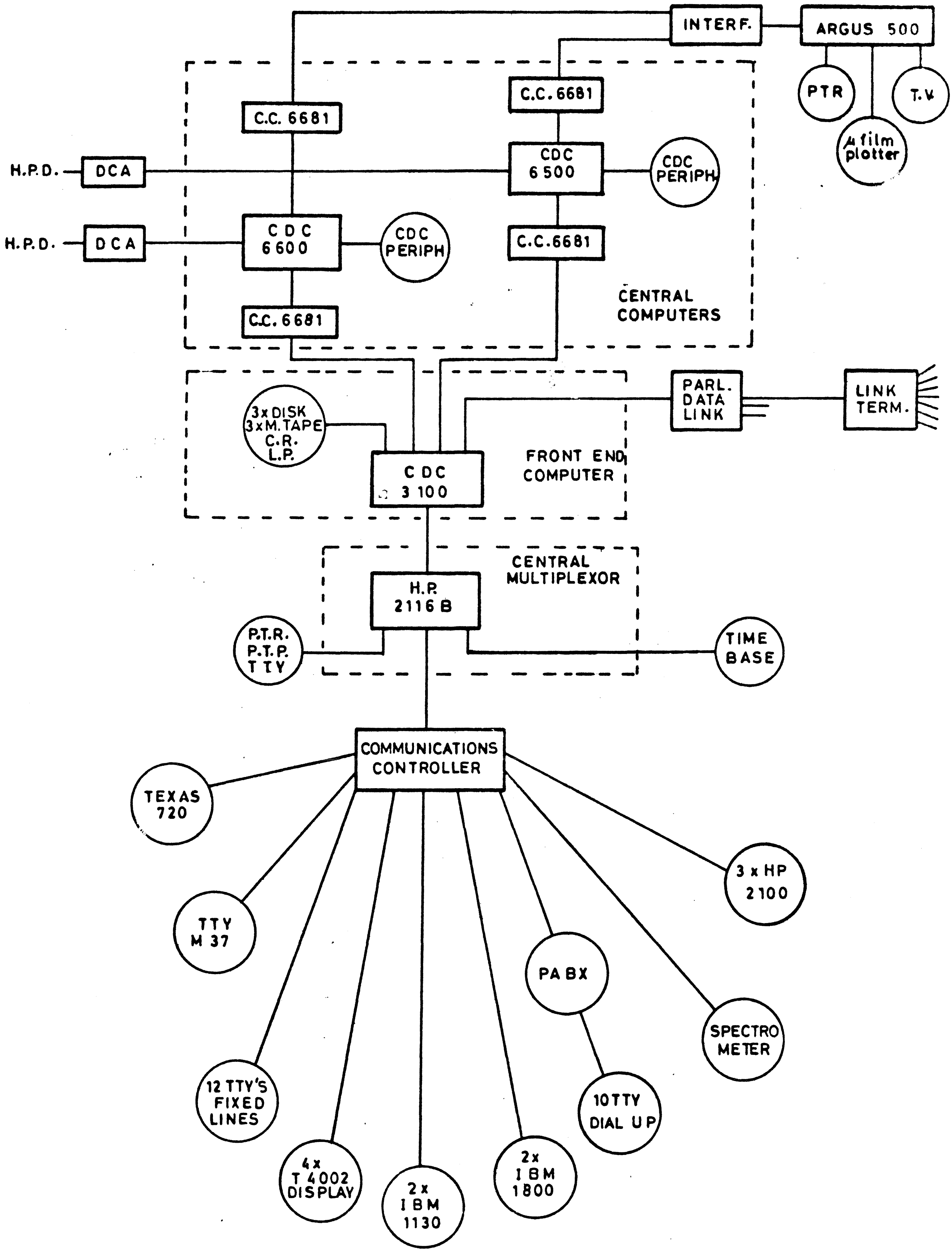

Fig. 2 FOCUS HARDWARE CONFIGURATION

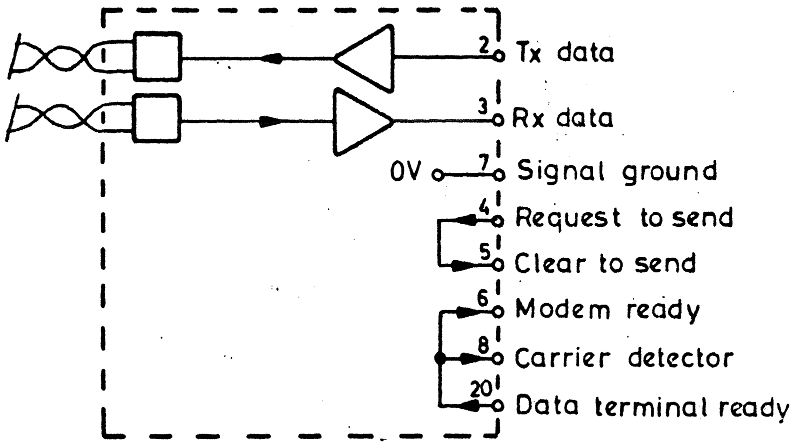

Fig. 3 ASYNCHRONOUS CODEC

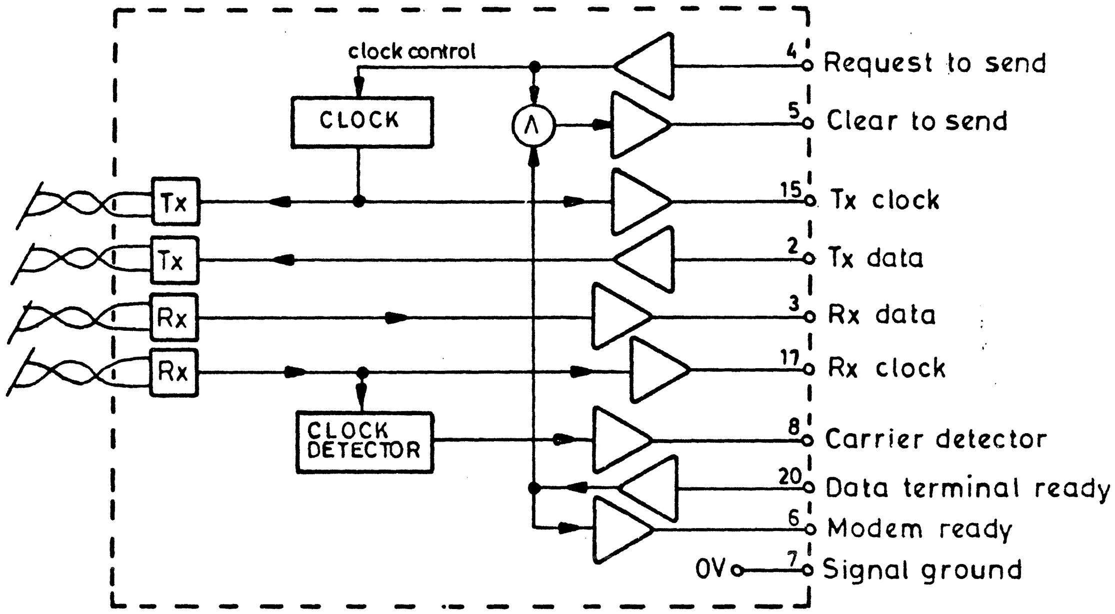

Fig. 4 - SYNCHRONOUS CODEC (without modulation)

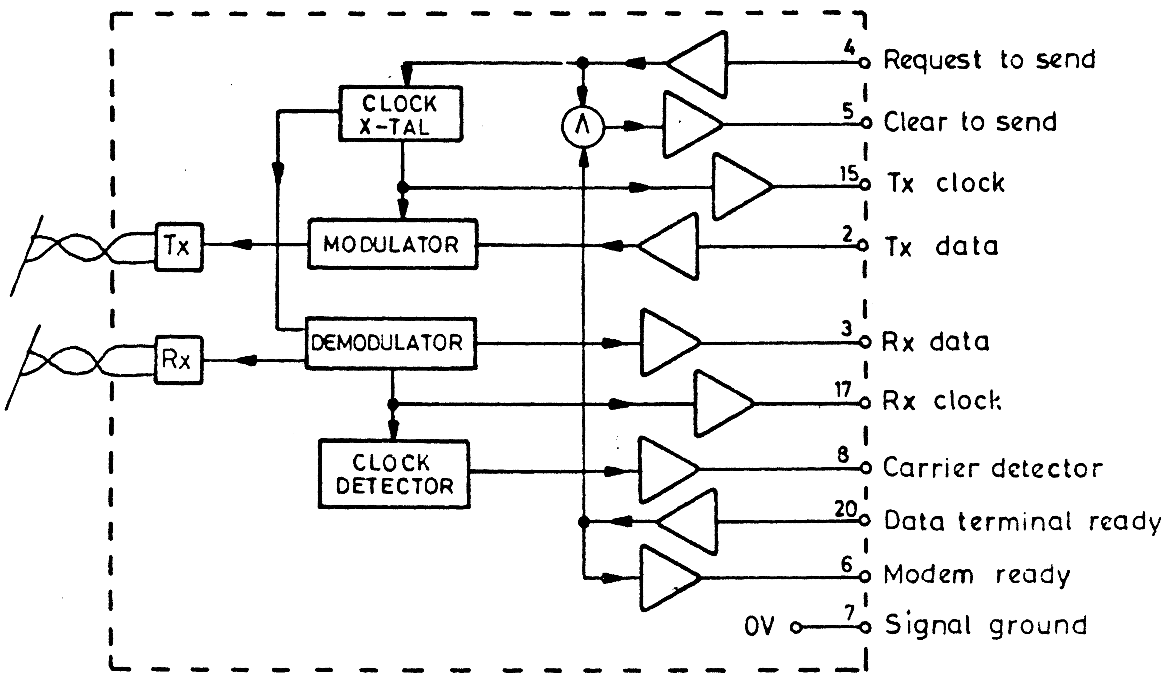

Fig. 5 - SYNCHRONOUS CODEC (with FSK modulation)

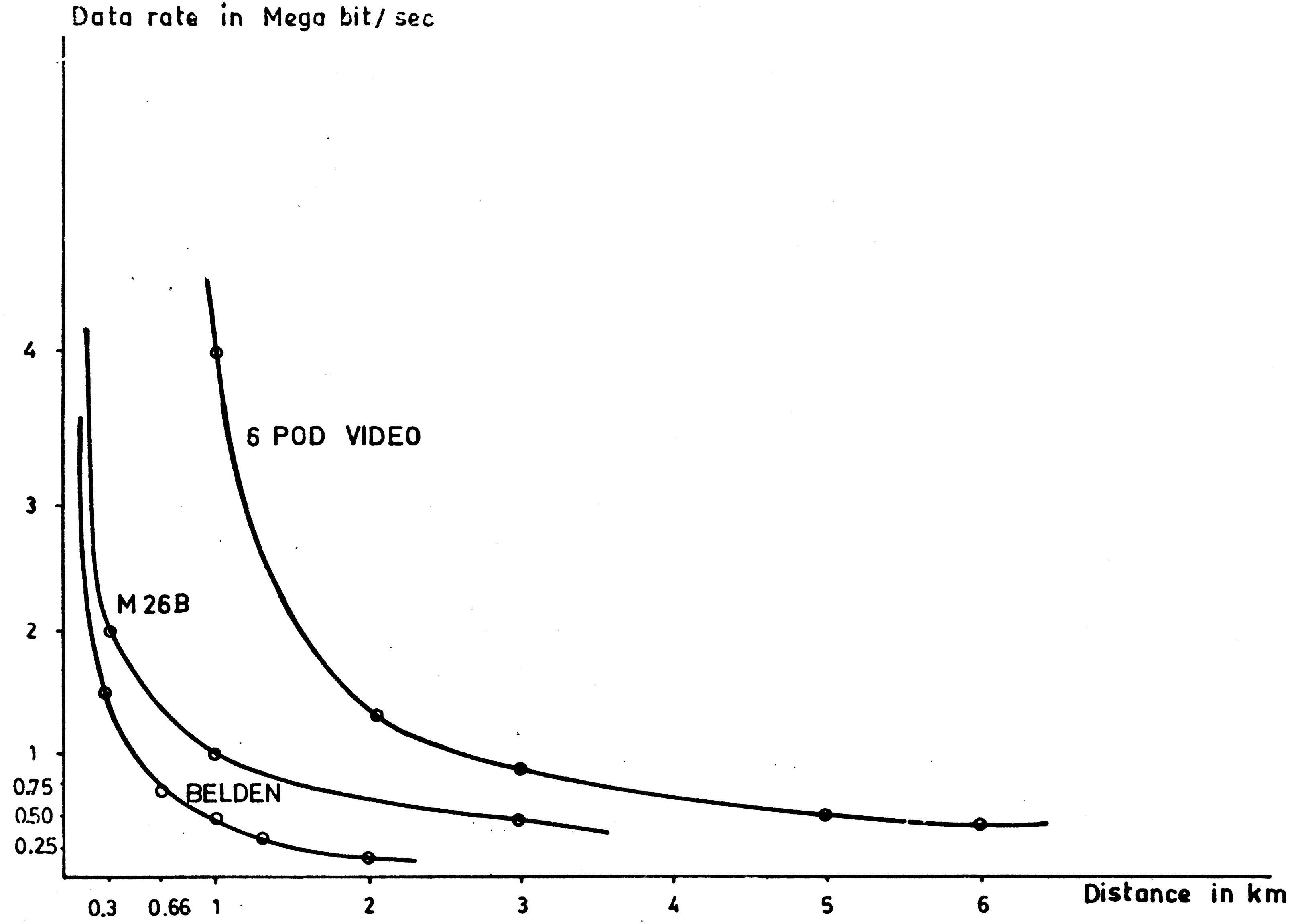

Fig. 6 SOME COMPARATIVE CABLE TESTS (error rate $<10^{-9}$)

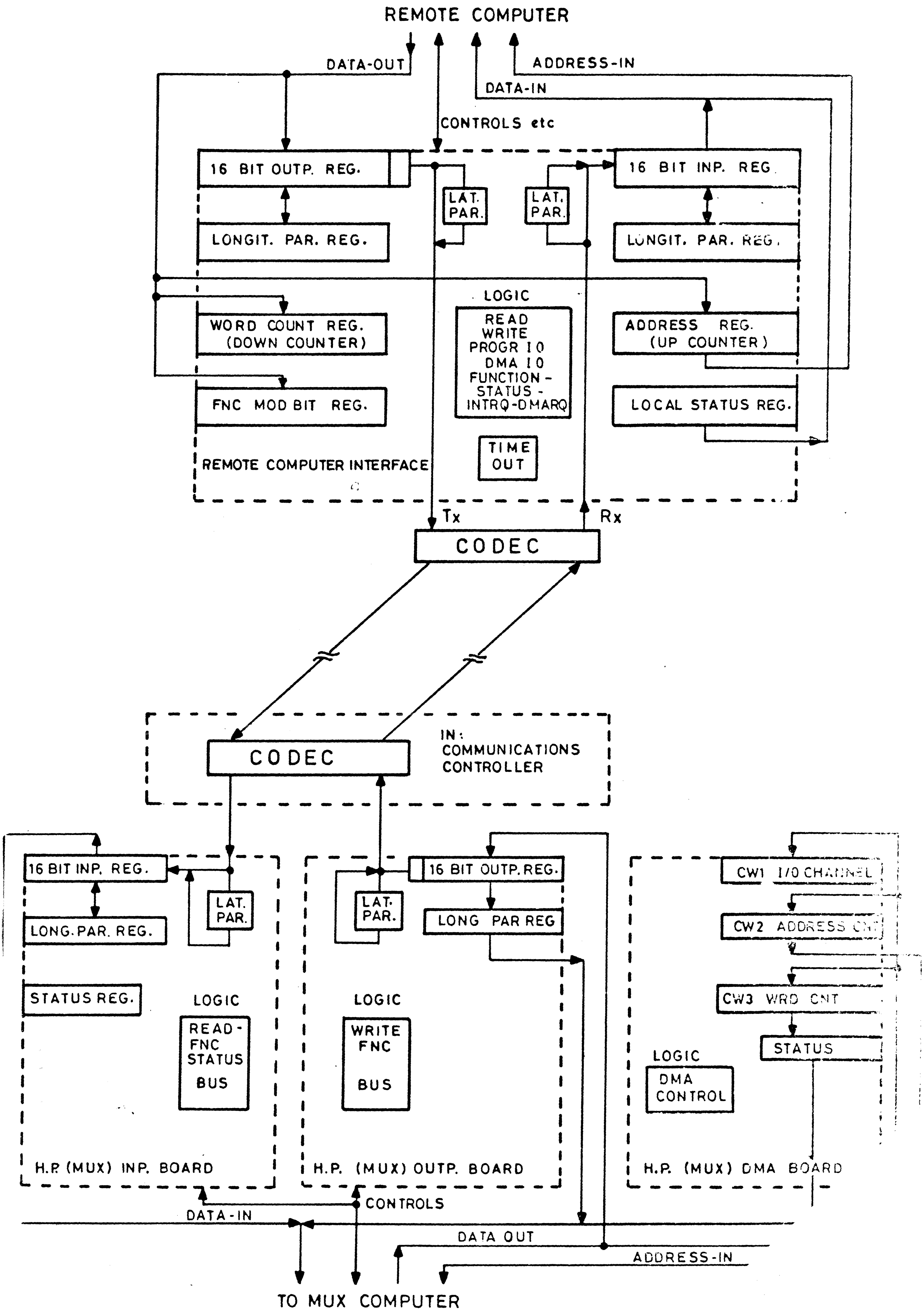

Fig. 7 – EXAMPLE OF A DMA CONTROLLED HIGH SPEED ...

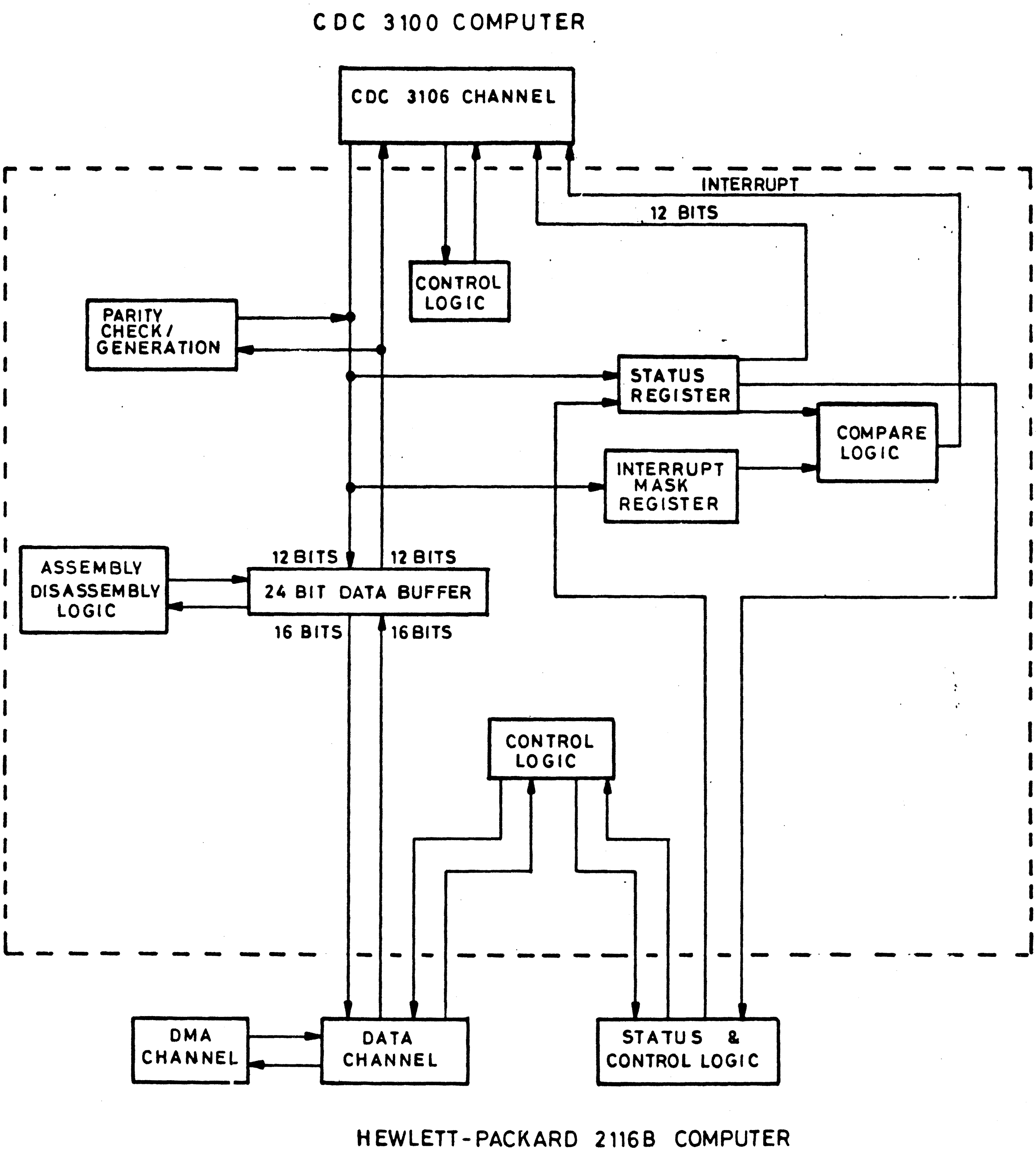

Fig. 8 - AN EXAMPLE OF A COMPUTER - COMPUTER COUPLER