

OPTICAL FIBRE DIGITAL BUS FOR AVIONICS DATA
SYSTEMS

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ABSTRACT

In this paper, an optical fibre data network on board of military a/c is considered. Over this network informations are to be communicated between computers, sensors, displays and other avionics systems in form of packetized message. Empty slots strategy protocol is considered over a loop configured network. Some aspects of this network are analyzed so as to clarify its traffic characteristics and design issues.

A complete experimental set-up is under development. A 3-station loop configuration is assumed and interface units for each station is implemented using the commercially available MSI digital circuits. CRT photos showing packetized signals, framing and synchronization signals are included. Implementation using microprocessors will be straight-forward from the implemented scheme.

1- INTRODUCTION

In modern a/c, the boundaries separating functional systems on-board are becoming increasingly difficult to define. The avionics systems move into areas such as autothrottle, energy management, power-plant and active control, ... ect. that were reserved as "forbidden zones" of aeronautical engineers. Moreover, with the large variety of missions **needing artificial** intelligence, reconnaissance, jamming, operations as message relaying centre... ect., proper avionics systems have to be added to those ones used for navigation and fire control. To cope with the problem of diversification of functions and places of effecting them on-board, a powerful tendency towards integration of on-board systems and securing intelligent as well as efficient intercommunication and coordination. Being physically separated, the functional units and subsystems are to be connected in a network. As the avionics systems are becoming more and more computer based and ever demanding modular advanced digital architecture (using VLSI/VH SIC), the aforementioned network should handle digital signals among its multiple processors and computer-like devices. This thrust has exploded key questions **about reliability/availability**, fault tolerance, testability, programmability and throughputs. The question of throughputs and capacities enabling to fully utilize the computational power of interconnected processors and to satisfy the need for very high processing rates in the abovementioned

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applications, has stimulated the research for wide-band transmission media on board of a/c. The considered media are: coaxial cables, optical fibres or the existing RF/IF cables and waveguides.

In this paper, we examine the problem of implementing an optical data "bus" on-board of an a/c . Optical links (both point-to-point or bus) are going to carry information between computers, sensors, displays and other systems to be seen later. This particular problem is to be solved with fibres of lengths 30-60 m. Use of integrated optics (couplers, modulators, ...) is considered for optical information processing and networking so as to minimize the number of opto-electronics interfaces and cut down the losses as well as sizes in the whole network. Reducing sizes and weights, such a system will make redundant avionics control systems attractive. Moreover, with decreased interface problems, the way is opened for modular avionics and integrated system with distributed processing.

One of the interesting aspects of the problem under investigation is that the laboratory "dimensions" are representing exactly those, in reality, on-board of an a/c . Therefore, with the reality transcribed in laboratory, measurements and consequently conclusions, problems, ... etc. are done on the real system. Thus, with this research project, we are able to test the feasibility of the concepts and explore the unforeseen areas of the problem.

In section 2, the optical data "bus" is introduced. Optical system components are outlined and essential parameters are considered.

In section 3, the performance consideration of the a/c network is considered. Discussion of access protocols and loop traffic characteristics is done. Packet length is chosen for implementation.

In section 4, the base band experimental set up is given and the possibility of centralized active bypass switch is considered. Finally, conclusions and the network extension issues are given.

2- THE OPTICAL SYSTEM CONSIDERATIONS

The multiplexed avionics systems using optical fibre can be broadly classified into: point-to-point types and multiterminal data networks. Point-to-point are now matured and primarily used for very high speed data transfer using either single optical source or wave-division multiplexing (WDM) technique. Ring networks are series connectors of point-to-point link and are going to be discussed later on. Multi-terminal "buses" are used to interconnect a number of terminals through star couplers or T-couplers (or in general directional couplers). The tapped bus architecture belongs to this category.

As to the basic building blocks for the optical fibre network shown in Fig.(1), they are : optical source (Tx), photo-detector (Rx), the optical fibre and the distribution components. These are discussed in the following and their influences on the network-performance are considered.

2.1. The Optical Link Components

2.1.1. The Optical Transmitters

The optical transmitter comprises : the optical source, power supply and driving circuit (in which the modulation signals is injected) and support

electronics.

As to the sources: the light-emitting diodes (LED) or laser diodes (LD) are to be used. They are available in the windows from (200 - 900 nm) and around (1300 nm). In the first region the sources are generally alloys of Ga As while in the second they are principally alloys of In GaAsP. LEDs are simpler sources capable of being directly modulated at data rates of about 20 Mb/sec. For higher data rate a WDM technique can be used or a laser sources have to be used, limitation on modulation rate is imposed by the recombination rate of source holes and electrons [4]. It should be noted that lasers require complicated support electronics in stabilization circuitry, and have lower life time, but capable of higher power delivery. For comparative study of optical sources see [2,3]. Any how the decision between LED, LD is usually done costwise and it is decided here to use LEDs.

2.1.2. Optical receivers (photo-detectors)

The optical receiver comprises mainly the photo-detector, low noise amplifiers (that are AGC controlled) and the processing circuits for the received digital waveform. Integrated packages, not including the photo diodes, are used to enable high data rates. As to the photo diodes, the commonly used ones are either silicon PIN or avalanche photodiodes (APD). The PIN diodes are preferred for application up-to 100 Mb/sec. rate, and they need low biasing supply but do not have gain as APD. The APD have also fast response times and are eligible for ultrahigh data rates and ultrasensitive reception. Discussion of the sensitivity limit or quantum limit is given in [4].

2.1.3. Optical fibres

The optical fibres are generally classified as single mode or multimode fibres that are characterized by their core size, core/cladding refractive indices, bandwidth, attenuation and numerical aperture. For the a/c applications, characterized by their short lengths, fibres with semigraded indices, large core diameters are acceptable. The attenuation over short distances is not very critical (cable of 2.4 dB/Km are quite good). As to the bandwidth, the dispersion. (material, modal) are the limiting factors. However, for a/c application, this doesn't seem to be a problem for short distance applications.

2.1.4. Optical distribution elements : (couplers, connectors,)

Connectors for single and multichannel applications are used. They may be lugged and sealed to exhibit minimum losses, easiness of maintainability and repair. Connector losses of about 0.7 dB are possible using mating plugs, sleeves and ball bearing arrays to solve the everlasting problem of mechanical alignment [5].

As to couplers, star couplers and T-couplers are used. Star couplers of fused biconical taper [5] are promising in a/c applications to divide one or more inputs into multiple outputs. The T-couplers are also used to tap the optical power onto and off the main cable. They are accompanied with splitting (tapping) losses. It is to be noted that the concept of "high impedance tap" is not yet present in the optical systems. Due to this, the number of taps (network nodes) is about 10 [6].

Integrated optics [7] (optoelectric circuits), having the optical and electronic components on a single substrate, are promising for minimizing losses, mismatch impedance and thus high data rate problems.

2.2. The optical network requirements and implications

To analyze the a/c optical network, the following key characteristics are to be considered:

(i) Data rate (channel bandwidth): This is affected by the rise times of transmitter, receiver, couplers and the fibre, The network configuration has its own influence on the system throughput and therefore ring and bus topologies are the only eligible for high speed applications |8| as these topologies do not require routing. WDM techniques are promising to lessen the data rate limitations whenever exist.

(ii) Bit error rates: To estimate this ultimate performance parameter, consideration of the system power budget (transmitted power, receiver sensitivity and power margin in-between) as well as the system rise time budget. Synchronization (or timing) requirements have to be secured. Discussion of such problems may be found in |9|.

3. PERFORMANCE CONSIDERATIONS IN THE A/C LOCAL AREA NETWORK

In the process of study of the a/c typical local area network we are led uptill now to the following issues: First, the required bandwidth for the military a/c on-board control processing functions and mission fulfillment functions is only met presently and in the future by optical fibres. Secondly, a/c constraints on size, weight, power consumption, ... etc. are met using the optical fibres. Third, trends towards computerizing, integrating, modularizing and increasing reliability of on-board function are trusted by networking using optical fibres.

In what follows we are going to consider some aspects of a/c network so as to realize the ultimate requirements of military a/c on-board performance.

Namely, the topology, access protocol, and measure of the network performance

3.1. Topological consideration (choice of the ring)

The most known configurations, star, loop (or ring) and bus topologies seem to be the natural alternatives of the a/c networks.

To cope with veryhigh data rate requirements (100 Mb/sec) ring and bus topologies win |7|. Moreover, both of these topologies, win from the point of view of reliability (star is critical), expandability and performance. As for as implementation with optical fibre is considered the ring topology is preferred as it is in reality a series of point-to-point connections which are mastered by the technologist and developers of optical transmission systems. Bus is a multipoint drop (multitap) with related losses.

Comparative studies of ring vs bus topologies can be found in |10|.

In this work, ring topology is chosen to be implemented with fibres. In practice, there are famous implemented rings as cambridge ring |11|, DCS, D-Net and others |12|.

3.2. Ring access protocols

The access problem encountered is : having meessages from multiplicity of sources attempting to use the same communication facility or entering the same concentration facility simultaneously. The set of rules governing the exchange of data over the comm. facility is known as the access protocol. The most common access techniques for the ring network are Token ring, slotted ring, Register insertion and contention |1| , |13|.

In this work, the slotted ring is chosen due to its simplicity, It is noteworthy that the cambridge ring has favoured this one for the register insertion which has superior performance as will be seen later.

3.3. The ring performance

The basic performance measures are:

- The delay D that occurs between the instant when a packet is ready for transmission from a source (or node), and the completion of successful transmission . Delay has different origins: propagation delay, processing delay and traffic delays, only the later is considered here
- The throughput S, i.e. the carried load (in bits/sec or packets/sec, sometimes normalized to channel capacity) between nodes
- The utilization U of the network medium, referenced to the total capacity being used.

The performance of the ring network is affected by the following factors:

- (i) The medium parameters being the bandwidth B, the propagation delay (=distance of comm. path d/propagation velocity v) and the channel error rate (typical 10^{-7} - 10^{-9} and can be neglected)
- (ii) The packet length L in bits.
- (iii) The ring access protocol.
- (iv) The offered load G (in bits/sec or packets /sec) to be communicated over the network. This includes information packets, control and collisions packets, (if exist).
- (v) The number of stations (or nodes) N

The first two points are considered as constants characterizing the network and used to find the propagation time-to-transmission time ratio a (where $a = \tau / (L/B)$) Typical values of a is 0.01 to 1 for high speed local networks under consideration. Both U and S decrease as a increases [14].

As to the access protocol, it will be seen that is the heart of the design problem.

The offered load G and number N are generally considered as the controlling (or independent) variables in the problem under consideration. The performance of the ring network is considered in the following paragraphs,

3.3.1. Bounds of performance :

A short-cut approach to explore the performance behaviour of the network is based on the work described in [15].

This approach gives the answers about the feasible operating regions where the offered load is within the handling capacity of the network under assumption of the same load-generating behaviour of N active stations, it can be shown that :

$$\frac{N}{T_{idle} + N \cdot T_{syst}} \leq S \leq \frac{N}{T_{idle} + T_{syst}} \tag{1}$$

as far as S channel capacity,

$$N \cdot T_{syst} - T_{idle} \leq D \leq N \cdot T_{syst} \tag{2}$$

and

$$D \geq T_{syst}$$

where T_{idle} : is the mean idle time for a station whenever it has no message waiting for transmission

T_{syst} : is the time elapse for transmitting a message once the medium access is gained . Over_head is included.

A bound for the utilization U is given by [14]

$$U \leq 1 / (1+a)$$

(3)

3.3.2. Analytic and simulation methods for slotted ring performance evaluation

An example of analytic and simulation approach to evaluate the performance of a ring network is due to Sherman [16], and Hayes [17]. The average delay included by traffic in the ring (queuing delay) is calculated for uniform traffic pattern in which all users are identical and communicate equally to all others . The bursty nature of data sources is taken into account and the smoothed version that may be adhered to concentration at each source node is also considered.

For bursty sources, being approximated to fit the model M/G/1, the following expression is derived for the average queuing delay $E |T_{\text{que}}|$

$$E |T_{\text{que}}| = E |T_{\text{syst}}| \frac{u}{1-u} + f_1(u, T_b, N, T_{\text{idle}}, \text{Queuing model}) \quad (4)$$

where T_b is the line busy period, the detailed expression of $f_1(.)$ can be found in [16].

For non-bursty sources, a constant rate data flow is assumed and the following expression is used:

$$E |T_{\text{que}}| = U \cdot E |T_b| \cdot F_2 (\text{Queuing model, Buffer length}) \quad (5)$$

The detailed expression for F_2 can be found in [16]. samples of these results are shown in Fig.2, from this the following conclusions are obtained:

- (i) For $U \leq 0.5$, the delay is of the order of the packet transmission time T_p (up to $4 T_p$). This is the case of light and moderate loading.
- (ii) For $u > 0.5$ the delay rises substantially to several order of magnitude, showing some sort of threshold behaviour.

3.3.3. Comparative performance of ring protocols:

Despite the parameters unique to each protocol upon which the performance is critically dependent , a comparison is done by Liu [18] and Bux [10]. Some of these results are given in Fig. 4 for 5 and 20 stations [18]. From these figures and from [10] the following conclusions are drawn:

(i) Slotted ring has the poorest delay performance, while register insertion has the best. Delay performance of slotted ring is impaired due to large overhead in small sized packets and the time to pass empty slot around the ring for traffic fairness.

(ii) Token ring has greater delay than CSMA/CD for light load and less for heavy load but both have better delay characteristics than the slotted ring .

(iii) The register-insertion seems to be advantageous as it has the highest utilization and permit multiple user stations.

Nevertheless, the slotted ring has the following advantages [10]:

(i) Expected delay for a message is proportional to its length (shorter packets have better service than longer ones)

(ii) The overall mean delay is independent of packet length distribution

A comparison among ring disciplines are given in table .1.

The contention ring operates as token ring in heavy loading conditions [11] and is not included for comparison.

3.3.4. Remarks to reliability/availability/survivability in ring network [6,13].

Over LANS, two types of problems can disrupt communication:

- Transmission errors.
- Component failure or malfunction: This can happen to :
 - (i) Headend connector to the medium.
 - (ii) Transmission medium.
 - (iii) Network interface unit
 - (iv) Network control unit.

Over the ring, the loss of single link of repeater can result in a loss-of the whole ring. This can be overcome by :

- use of active bypass switch to eliminate a faulty repeater,
- use of multiple ring connected by bridges [19].

Other means can be done to improve reliability of network interface unit and network control centres.

3.4. Selected parameters for implementation of slotted ring

Chosen for its simplicity, we have realized a 3-stations slotted ring. concerning the packet length (slot size) and overhead bits per slot, let us remember that on cambridge slotted ring [11] the packet length is 37 bits out of which 21 bits are used as overhead, whereas over the experimental network [20], the packet length is 512 out of which 26 bits are used as overhead, Being easy to alter, these parameters are selected to be 99 bits for packet length and 26 bits as overhead to simplify the experimental prototype implementation using available MSI TTL circuits.

4. BASE BAND EXPERIMENTAL SET-UP (IMPLEMENTATION)

In this section we present the implementation of a loop data networking comprising three stations as shown in Fig. 3.

Two of the stations have the interface units E1 & while the third is a control station -A.

4.1. Message format

The message to be transmitted is divided into constant length packets, each packet has a collection of words separated by guard bits which allow simple synchronization of the loop as described by Pierce [21]. The packet format is given in Fig. 4, the first three words form the control overhead and the rest is reserved for the data. We have chosen the word of the packet to be 8 bits separated by a guard bit. We only allow synchronous accessing on the loop by framing pulses.

4.2. Control functions description (table 2):

The control overhead has three words, the data block control word (DBCW), the destination address and the source address word-DBCW is divided into four 2-bits field that carry a coded representation of the packet status, The first field (TC) determines the type of message (Private or common), the second field (LC) determines the spare bits that can be used for external control functions, the fourth field (Hc) is used to secure the fairness among subscribers with the help of a lag-prevention flip-flop (HPFF) established in each "B" station, the possible states are shown in the table.

4.3. Realization of data loop network:

4.3.1. Packet framing and synchronization:

The proposed packet consists of a 9 words each of 8 bits as shown in Fig.5.

The used circuit contains two decade counters type 73190 with feedback elements to eliminate the clock after generation of the packet. The counter states will be decoded to form a proper shift/Load signals to all stations registers, so the obtained waveforms are shown in Fig. 6. to Fig.7.

4.3.2. The interface station -B

The main function of the interface B is described by krobfl |20|. It permits a user to read and write fixed-length packet under the supervision of DBCW. Input/output signals are shown in Fig.8 . the main functional operations are described in the flowchart given in Fig.9 . In the realized circuit, we have used 4-to-10 lines decoders type 7442 (BCD-to-Decimal) to perform the functions of reading and writing procedures. Also, we have used buffer registers of length 26 bits type 74199-8 bits, to encode and decode the contents of the packet's header. The local loop destination address is hardwired within the station in order to provide positive sender identification 00110100. The timing diagram of the input/output signals is shown in Fig.10, notice that the full packet has been acknowledged by resetting the LC field to zero. Fig. 11, and Fig.12 , are photographs of the obtained packet in cases of reading and writing.

4.3.3. The control station -A

Station A serves to close the loop and selectively repeating packets around the loop in a manner to prevent building of traffic in the ring due to undeliverable packets. Also, station -A provides clocking and synchronizing information for all messages, beside the generation of the packet framing signal, all these functions are summerized in the flowchart given in Fig.13. In the realized circuit we have used buffer registers of 26 bits to have the chance of encoding and decoding of the circulated packet's header. Also , redundant of source and destination address registers are used to have the possibility of interchange these addresses with each other without errors.

v- CONCLUSION AND WORK EXTENSION

In this work we have discussed the problems relevant to the selection and implementation of an on-board optical data network for avionics applications. The baseband assemblies of this typical local area network are implemented using discrete digital circuits. VLSI modules are considered for future extension of this work while connecting opto-electronic interfaces and optical fibres. Integrated optics are to be utilized on-board. The complete prototype (baseband and optical components) is investigated as a teaching aid in the laboratory of avionics' computer.

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Table 1 . Comparison of ring access methods

characteristic	register insertion	slotted ring	token ring
transmit opportunity	idle state/ empty buffer	empty slot	token
packet purging	receive/ transmite	transmitter	transmitter
no.packet	multiple	multiple	single
main adv.	max. utiliz.	simplicity	fairness
main disadv.	purge mecha.	BW. waste	token maintance

Table 2. Overhead description

Field	Description
<u>TC</u>	<u>Message-Type</u>
0 0	Private message
1 0	Common , , ,
0 1	Undeliverable foreign message
1 1	Special common message
<u>LC</u>	<u>Loop Vacant-Full</u>
0 0	Packet vacant (VCC)
1 0	,, full (FCC1)
0 1	,, ,, and passed an "A" station once (FCC2)
1 1	,, ,, ,, ,, ,, ,, twice (FCC3)
<u>HC</u>	<u>Hog Prevention</u>
0 0	No one wants to send a message
1 0	One wants to send a message , packet passed an "A" station before he aquires it
0 1	One wants to send a message
1 1	The same as (1 0) , but another one also wants to send a message
<u>HPFF</u>	<u>Hog Prevention Flip-Flop</u>
0	The subscriber has not sent a message
1	The subscriber has just sent a message

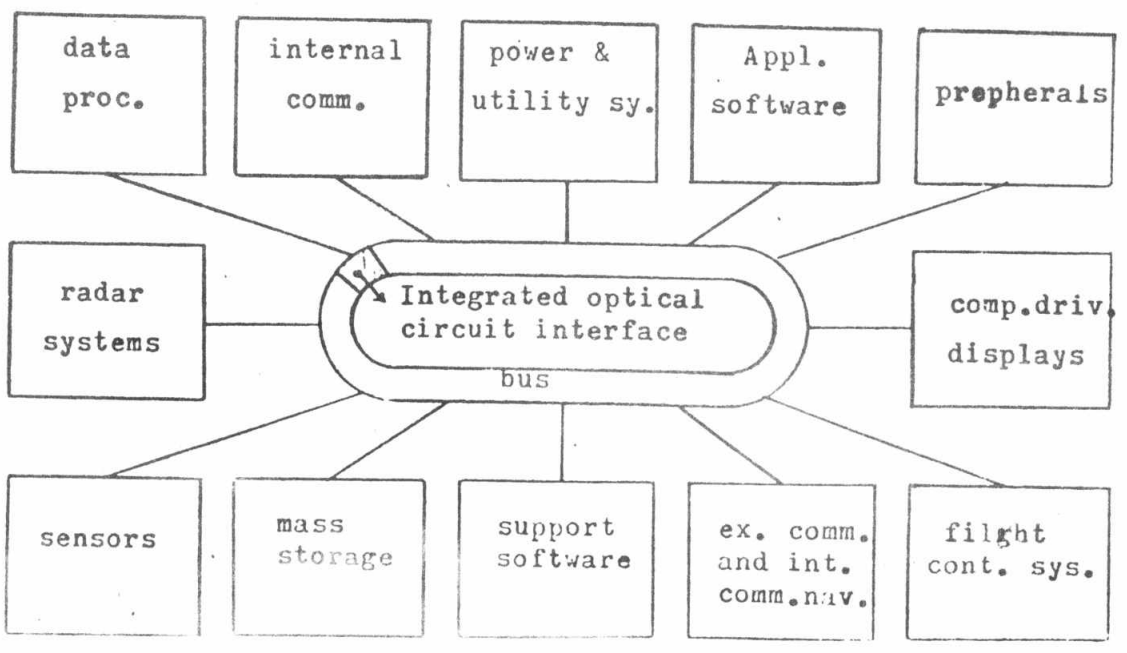


Fig. 1 Avionics optical fibre data network

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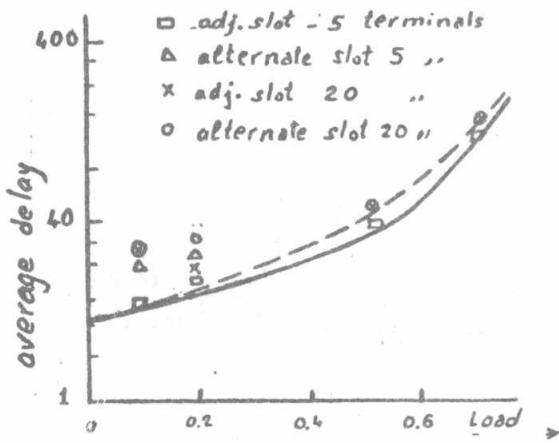


Fig. 2. Delay for slotted ring

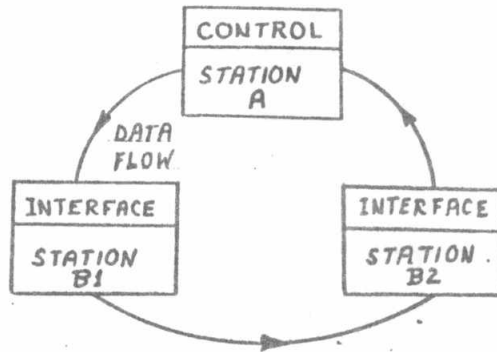


Fig. 3. Loop configuration

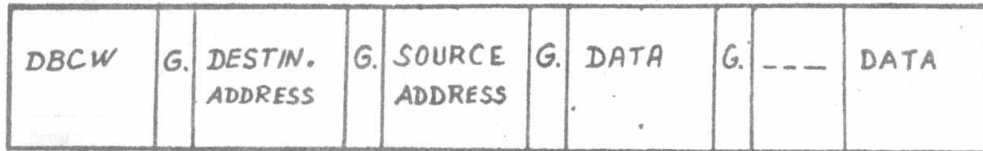


Fig. 4. Message format

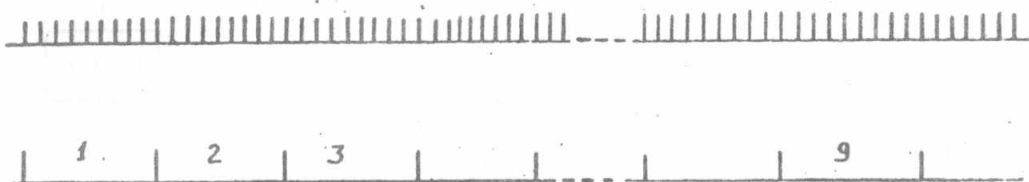


Fig. 5. Vacant packet waveform

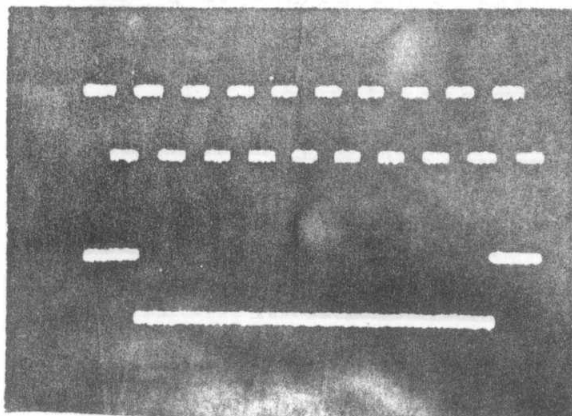


Fig. 6. The clock and 8-bits waveform

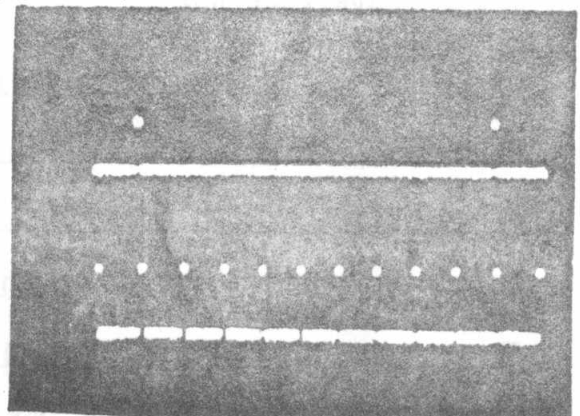
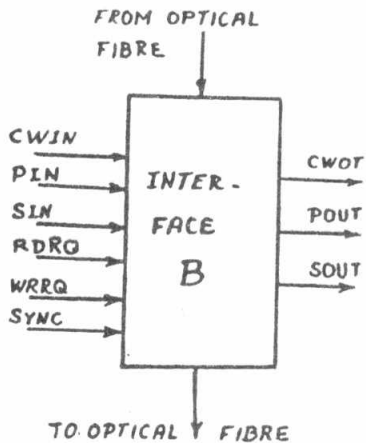


Fig. 7. Framing and packet signal

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- CWIN : Control word IN
- CWOT : ,, ,, OUT
- PIN : Parallel IN 8 bits
- POUT : ,, OUT ,,
- SIN : Serial IN
- SOUT : ,, OUT
- SYNC : Synch. signal
- RDRQ : Read request
- WRRQ : Write ,,
- TC1D : TC field/"1" bit detected
- TDAD : Terminal destination address detected.
- HCZD : HC field/"0" bit detected
- HC2 : HC field/ second bit

Remark; Other symbols on the flowchart can be found in Table 2.

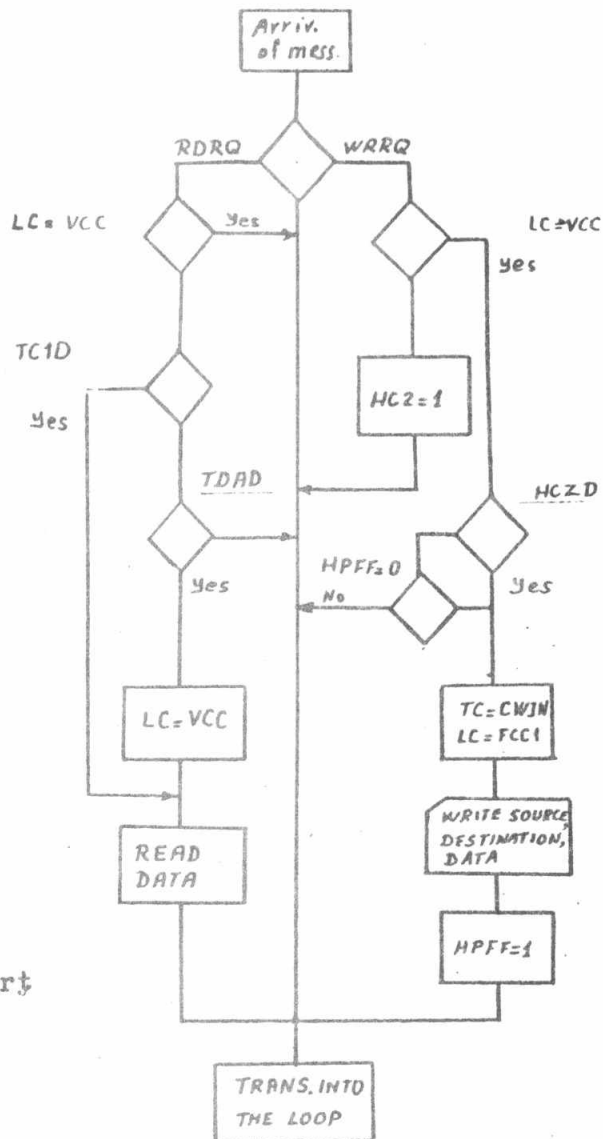


Fig. 8 . B- interface unit.

Fig. 9 .Flowchart of B-unit

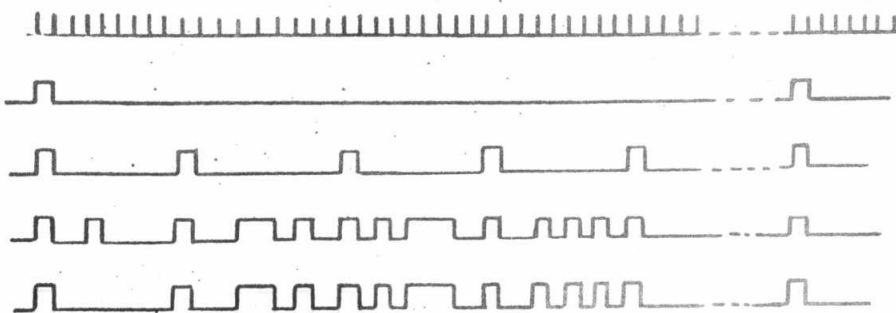
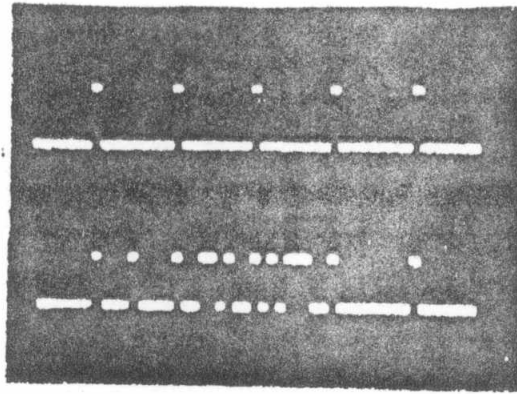


Fig. 10. Timing diagram of the B-interface unit



a) packet empty
b) header showing destin./surce addresses

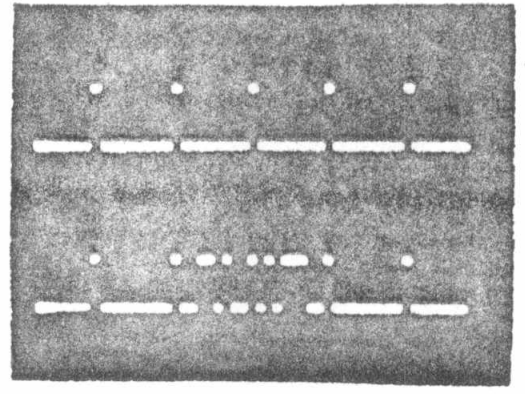


Fig. 12. Packet signal(reading)

Fig. 11. Packet signal(writing)

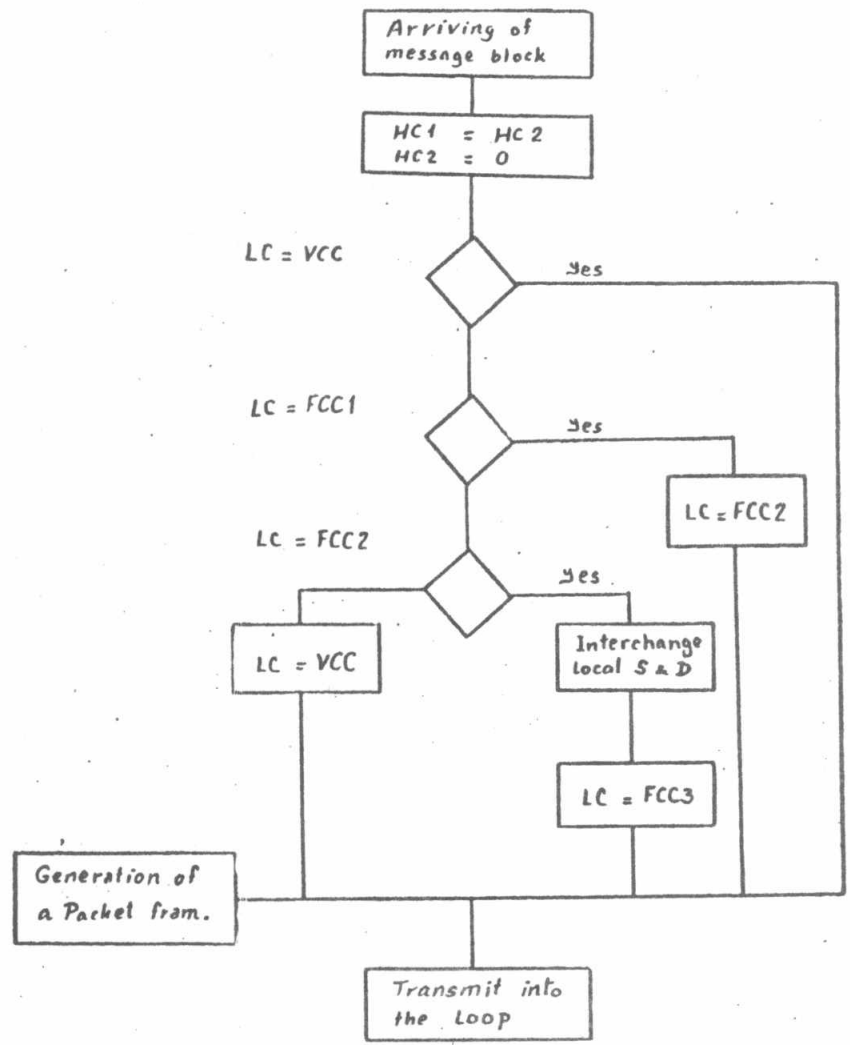


Fig.13. Flowchart of unit A