

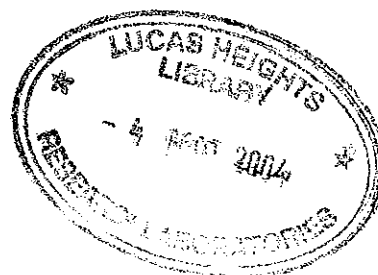


**AUSTRALIAN ATOMIC ENERGY COMMISSION
RESEARCH ESTABLISHMENT
LUCAS HEIGHTS**

A MULTIPLEXED COMPUTER-COMPUTER, COMPUTER-DEVICE DATA LINK

by

P.J. ELLIS



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ABSTRACT

A data link is described which provides an access path between many computer based stations so that the facilities of a central large computing system can be used. It is operated as a party line with each sending-receiving station capable of communicating with any other station; subsequent data transfers can be in burst or unit byte modes. The hardware format is a 24 bit parallel data bus with a parity bit per eight bit byte, and five pairs of symmetrical asynchronous control lines used to govern data flow, status retrieval, etc. on the data bus.

The link also allows remote peripheral devices to be attached to it and controlled by a particular computer.

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Figure 1 Block Diagram of Multiple User Dataway

Figure 2 Typical Block Transfer Sequence

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Figure 5 Write Sequence – Read Not Ready

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1. INTRODUCTION

This report describes a computer link designed to provide an access path or data way between many computer based stations at the A. A. E. C. Research Establishment, Lucas Heights. The main consideration is that the computer stations should be able to call on the computational facilities of the IBM 360 computer and its associated disc storage when their own computing power or storage is inadequate for the current task. The data way will connect directly to the PDP-9/L pilot computer which has already been linked to the IBM 360 computer and operates as a multiple address channel control unit (Richardson 1969).

The original concept was expanded so that any computer attached to the data way could call on any other computer similarly attached. This feature makes each station symmetrical in its operation. The concept was further extended to allow certain peripheral devices to be attached to a particular computer over the data way. The devices, such as teleprinters and typewriters, are relatively slow, requiring transfer of one data byte per call. Faster devices that can operate in burst mode if required may be attached to the data way.

2. IMPLEMENTATION OF THE DATA WAY

2.1 General (Refer to Figure 1)

The data way consists of one multiwire cable having various entry points at appropriate positions at the Research Establishment. Each entry point may be connected to as many stations as required or extended to cover intra-building networks. All stations consist of a control unit and the device or devices that it operates. The control unit buffers the data way from the device or devices by governing the control and data signals applied to the data way. Two types of control unit are provided for; one is able to handle the signals expected from the processor of a small computer while the other is restricted to handling signals sent from some simple peripheral device.

Each control unit has a particular set of addresses associated with it, each address being unique to a particular control unit function. These addresses are responded to by the control unit if requested by input control signals. The size of the set of addresses is determined by the type of device and its function. A control unit responds to many addresses if interfaced to a computer with many addressable peripherals that are not separately attached to the data way. These addresses, however, are still unique to a particular control unit.

Each device is interfaced with its control unit using the logic conventions and circuit techniques peculiar to the device. The control unit provides appropriate signals and responses which must be acknowledged by the device interface and appropriate action taken. This is more applicable when the device is a computer which has execution delays or inadequate programmed responses. For a unit device, the responses are relatively fixed and straightforward.

2.2 Linking Between Control Units

The cable between all units on the Research Establishment site is one complete length which is not broken when a unit is connected. This reduces the effect of contact impedances and generated noise due to bad connections. All connections to the cable are by tapping which enables a control unit to be disconnected without disturbing the line and eliminates the possibility of the line not being reconnected properly after a control unit is disconnected.

The linking cable is operated as a party line with one sending and one receiving station busy at any one time. Units wishing to transmit over the line have to wait for completion of the current data transmission. The use of carriers to enable many simultaneous transmissions was not considered because the expected data rates and requests will not unduly engage the line. If peak periods develop then responses at these times may suffer.

Since all stations are connected in parallel to the link, any signal transmitted by any control unit is received by every station that is currently operational. If two stations raise different signals at the same instant then both signals are transmitted. This feature may cause an invalid result when two stations raise Address Out simultaneously (see Section 8.2 Address Out Overlap) but overlap of the other control signals is not logically possible.

2.3 Open-Unit Operation

The data way is designed to cope with two types of control unit which operate in either the open or unit mode. The unit mode has been restricted to disallow certain sequences. The open mode is completely unrestricted as this type of control unit would usually be interfaced to a small digital computer. The digital computer has sufficient storage to hold return addresses, status information, etc. until they are required and is also able to transfer block data at rates over ten thousand words per second. An open control unit can handle as many data way addresses as would be expected of a computer and its peripherals.

The unit mode of control unit operation is used when mechanical devices such as typewriters, paper tape readers and paper tape perforators have to be attached to the data way. These devices are normally associated with only one other station on the data way and they transfer data in character form at rates below one thousand characters per second. They are restricted in that no buffering is available to transfer data blocks efficiently, and no storage is available for return addresses and status information. Thus the control unit associated with them is simplified and can handle one address for sending and one address for receiving only.

3. DATA WAY SIGNALS

The signals to be used in the data way control units have been selected to enable levels, etc. to be as standard as possible with those conventions used in the more recent integrated small digital computers. The signals to be used to drive the cable have been selected to minimise the dropout rate for transmission and subsequent retrieval. As errors cannot be completely eliminated, various error checking facilities have also been provided.

3.1 Logic Levels and Conventions

The logic used throughout the control units will be realised by using integrated circuits of the transistor transistor logic (TTL) families. These units operate from a nominal +5 V supply and have logic levels as follows:

Logical One - + 2.5 Volt - + 4.5 Volt

Logical Zero - 0 Volt - + 0.8 Volt

All signals in the control unit obey the convention with the exception of the line driving signals. Any unit that has to be interfaced to a control unit has to provide the appropriate conversion logic. This permits all control units to be identical, with the exception of the address selection logic which is unique to a particular unit.

Transmission signals that drive the cable lines operate in such a way that lines driven to earth are affirmative, that is, logical one. Lines that are logical zero are allowed to relax to the supply line using an appropriate load rather than be driven, in order to prevent overloading if two units try to drive a line at once. Driving the lines to ground should reduce the effects of noise during transmission but complete evaluation of noise effects has not yet been possible.

3.2 Maximum Data Rates

It is proposed to use a poly-quad telephone cable which has certain frequency limitations that must not be exceeded if correct data is to be sent and received. However, the main frequency limitation

for the data way is the overall transmission time between the two end devices; this is quite large compared with the switching speeds of the control unit circuitry. Transmission times up and down the 900 metre cable are of the order of several microseconds and the maximum possible data rates have been limited to approximately 50 kHz.

3.3 Responses

Owing to the above transmission times there will also be instances where responses are quite variable. This is to be expected when one control unit requests attention from another, and the granting of this request is indicated by some fixed response. Owing to cable delays etc. these expected responses vary with the distance between caller and receiver so further design delays have been introduced by control signals which drop the maximum data rates still further. If the control units are attached to small processors then computational delays as well as transmission delays will result, but for the purposes of the following descriptions the computer delays are neglected. However they must be allowed for when evaluating the data and control response capabilities of a particular send-receive pair. Extremely long response times are not allowed and are aborted to prevent the data way from being hung up.

3.4 Error Checking

Error checking is accomplished in three basic ways. These are certain delay periods which are used to detect incorrect responses, parity checking of data, word-count and checksum checks. The delay periods are applicable to the initial selection sequence to prevent two callers initiating selects together and to the ending or disconnect sequences to ensure that the data way is clear and not hung up. Parity checking applies to every eight bit byte that is transmitted over the data way and is used to reduce the effect of noise during register strobe periods. The word count and checksum errors are a function of the sending or receiving computers and are not handled by the link.

4. OPERATION OF THE DATA WAY

4.1 Intercommunication Sequences

A number of possible fixed sequences may occur between a sending and receiving pair. These sequences will vary depending upon particular responses but can be classified as follows:

1. Initial selection

When a control unit is required to communicate with another control unit, the first sequence performed must be to call the other control unit over the party line when the line is not busy. This initial selection sequence covers the expected responses from the two control units until the data way is locked in successfully, or becomes not busy after an unsuccessful selection, or becomes not busy after a sequence requiring no data transfer.

A control unit must go through the initial selection sequence to engage the line, this being the only method of calling any other control unit. The initial selection sequence is normally a prelude to a data transfer but may be used to request status or to perform a command that requires no further data, for example, rewind, backspace, etc. The initial selection sequence is terminated by Time-Out if correct responses are not forthcoming.

2. Data transfer

The data transfer sequence is used for the transfer of data only. It must follow an initial selection sequence and be terminated by an ending sequence for correct operation. Data is transferred on a call and answer basis and as such is asynchronous. Synchronous devices are not being considered but may be implemented at a later date.

3. Ending sequence

When a data transfer between two control units has been completed, certain information should be passed between the control units and the link should be disengaged. The ending sequence is used to complete this information exchange in the form of respective status information and also to drop the operational control lines in a fixed order to free the party line for the next user.

4. Miscellaneous sequences

There are some possible sequences that depend upon the device or peripheral attached to the control unit and also upon whether the receiving device is busy. These sequences are only modifications and combinations of the above three main sequence types and are described in more detail under specific headings. The only other sequence, Disconnect, occurs only when a possible malfunction has been detected. It is actually an external hardware precaution which cannot be implemented by a control unit.

4.2 Control Signals

The signals used to operate the data way fall into two categories, namely, control signals used to specify functions and data signals used to pass data, addresses, etc.

Control signals provide functional information such as requests, busy or hold signals and disconnect signals. Control signals affect logical operation as soon as they are received and have to be more precisely defined than data signals, which are strobed into a buffer when required.

Control signals operate in pairs, one provided by the 'sender' and one by the 'receiver', one only of each pair being able to remain set at one time. The pairs of control lines operate on a call-answer basis with the call line resetting when the correct answer is received and vice versa. Particular control signals are restricted in certain instances, the most obvious of these being the initial selection lines when the data way is busy. The restriction of these signals is generally controlled by gating within the control generation logic but other restrictions can apply depending upon software operations of particular computers or hardware limitations of particular peripheral devices.

1. Address In -- Address Out

This control pair is used to request a link operation. Address Out is raised by the sending station together with the device address, command, etc. on the data lines. Address In is raised by the receiving station which acknowledges the receipt of Address Out with address data pertinent to that station. Address In is usually a hardware acknowledgment and signifies that the requested device address is operational. Address In does not signify that the device is available, or that it is not busy with some other task.

2. Hold In -- Hold Out

This control pair is used to lock the line between two control units. The Hold In signal indicates that the receiving station is available to undertake the particular command required of it. Hold Out is the associated acknowledgment from the sending station.

3. Service In -- Service Out

This pair is used to control the transmission of data to and from the particular sending and receiving stations. The Service In signal is a request indicating that the data receiving station is ready for a word of data. The Service Out signal indicates that the data sending station has transferred the data word onto the line at the request of Service In.

4. End In – End Out

These control signals are used to terminate the use of the data way after an operation is complete or when either the sender or receiver wants it to be terminated. These signals can only be raised by control units currently operating as the sending or receiving station.

5. Disconnect

This signal is not generated in any control unit but when present causes all control units to drop any raised signals regardless of any operation that is proceeding. Disconnect is generated by a cable-end station when an apparent malfunction has been present on the data way for the time-out period (see Section 7).

4.3 Data Signals

Data signals are present on the data way at particular times depending on which control lines are present. The data signals represent address, status or actual data information. A data word is 24 bits long and is sent in parallel as three 8 bit bytes. Each byte has a parity bit associated with it such that the parity over the nine lines representing the byte is odd. The parity is generated by the sender before sending and the receiver regenerates and compares it with the parity line. If incorrect parity results, appropriate error indicators are set and transmitted during the ending sequence.

1. Address

The most significant byte of this data word specifies the address of the station to be called during Address In. The command or operation is specified in the next byte. The value of the least significant byte may be a return address or a data byte depending upon the type of device attached to the receiving station. If a control unit receives the correct address with incorrect parity then the address is ignored.

2. Status

At various stages throughout link operations, either station may require to know the condition of the other linked station and associated peripheral device. Status data is available on request and is presented whether requested or not during the initial selection and ending sequences. The status word consists of various indicators representing error, device busy, attention, etc.

3. Data

Data information on the line is treated as 24 bit words. There are no packing or unpacking facilities. If, for example, characters are required, they must be sent as 8 bits and 16 zeros or they must be prepacked by the computer or device.

5. DATA WAY SEQUENCES – OPEN OPERATION

The open method of operation of the data way is designed for communication between two computers which would normally be handling data on a block basis and be capable of a varied set of operations. Any open control unit can communicate with any other open control unit provided the software sequences allow the particular operation. The open mode of operation is characterized by the inclusion of the return address in the address word sent out during the initial selection sequence. The return address allows the receiving computer to reply to a request after the original communication has ended. A typical instance would be where a computer is commanded to read a data block but cannot do so until an intermediate job is finished. When the computer is ready to receive the data block, a ready status could be sent using the return address.

Although the open control unit is primarily intended for use with computers only, it can be used with any device, provided the device-control unit interface can handle the varied options that may occur. An open control unit may communicate with a closed control unit under certain restricted circumstances.

5.1 Initial Selection Sequence (Refer to Figure 2)

When a data transfer operation is required between two control units the data way must first be engaged. The form of this procedure depends upon the status of the control units, and the only sequence considered here is a successful engagement of the party line before a data transfer.

When the sending control unit senses a data way not-busy condition, Address Out is raised and the address word is strobed onto the data bus. These signals propagate along the link and are received by every control unit attached to it. Each control unit checks the address byte of the address word and compares it with its own fixed address block. When a control unit makes a valid comparison, it generates Address In to signify that the addressed device is present and operational. Address In does not signify that the device is not busy; this is determined by further responses. When received by the sending unit the Address In signal drops the Address Out signal which consequently removes the address word from the data bus. This procedure completes the address phase of the initial selection sequence.

Following Address In the receiving station is required to present its status to the sending station. This is done by raising Hold In if the station is ready to transfer data. This operation is acknowledged by the sender raising Hold Out which drops Hold In when present at the receiving control unit.

The Address In line being raised in conjunction with the raising of Hold Out indicates that the link has been successfully engaged and that data transmission may proceed. When these two lines are raised, all control units generate a data way not-operational signal which can only be overridden by those control units which themselves have generated the Address In and Hold Out signals, namely the receiving and sending stations respectively. During the initial selection sequence all control units are prevented from raising Address Out by the presence of Address In, there being no such restriction on any other control lines.

5.2 Data Transfer Sequence (Refer to Figure 2)

When data is ready to be transferred the data way has already been engaged and thus a valid read or write command must have been sent and accepted. The sending and receiving stations as mentioned during the initial selection sequence are now referred to as the reading and writing stations. Designation of the station as a reader or writer depends solely on the required operation word and not on whether the station initiated the link operation.

The successful engagement of the party line is used to generate a request to the reading station to indicate when it is ready to receive data. When ready, the reading station raises Service In which requests the writing station to send the first data word. Upon receipt of Service In the writer raises Service Out and strobes the data word onto the data bus. The Service Out signal cancels the Service In when received by the reading station and this station loads the data word in readiness for processing by the device attached to the control unit. When this data word has been processed, the reading control unit again raises Service In to indicate that it is ready for the next word. This Service In response drops Service Out when present at the writing station. Upon receipt of Service In, the writing station drops Service Out, the data bus, and subsequently raises Service Out to strobe the next data word onto the data way.

The Service In - Service Out responses alternate until either the reading station has had enough data or the writing station has sent all available data. When the data transfer is thus complete the only remaining operation is to disengage the link.

5.3 Ending Sequence

The ending sequence is a relatively simple operation but is controlled quite rigorously. This is because both control units, whether reader or writer, have to be able to terminate the link operation, but logically must be prevented from doing so together. Thus the writing station is only permitted to request the ending sequence when Service In has been raised and the reading station can only request the ending sequence when Service Out is raised.

The actual ending sequence depends upon which station terminates the link operation, although both possible sequences are quite symmetrical.

(a) Sender Termination (Refer to Figure 2)

The sender starts to disengage the line by raising End Out and strobing status and error information onto the data bus. End Out automatically lowers any Service requests present on the data way. When End Out is detected by the receiver and the status is recorded, Address In is lowered, End In is raised, and status and receiver control unit error information is strobed onto the data bus. When End In is detected by the sending station, End Out is cleared automatically, status is recorded and the sender completes decoupling the line by dropping Hold Out.

(b) Receiver Termination (Refer to Figure 3)

The receiving station starts to disengage the line by raising End In and strobing the status word onto the data bus. Raising End In clears any Service requests that have been raised and strobes any error indicators set by the receiver onto the data bus.

When the End In has been received by the sending station and status has been recorded, End Out is raised to acknowledge End In, Hold Out is lowered to start disengaging the line and sender status is strobed onto the data bus together with any errors detected by the sending control unit during the transmission. This action completes the end sequence as far as the sending station is concerned.

When End Out has been detected by the receiving station, End In is cleared automatically, the status information is recorded and the receiver completes decoupling the line by dropping Address In.

When both Address In and Hold Out are not raised all control units generate a link operational signal which is used to clear any control lines that are still raised.

5.4 Initial Selection Only (Refer to Figure 4)

Initial Selection Only is the default sequence when the receiving control unit is busy and is not ready to proceed with the command specified in the address word. This sequence is also used when the command can be satisfied without a data transfer.

The most important feature of Initial Selection Only is the transmission of status information which is used to determine if and why a data transfer has been delayed.

Initial Selection Only is exactly identical to the initial selection sequence during the Address Out - Address In phase of operation. When status has been compiled by the receiving station after receipt of Address Out, this information is strobed onto the data bus and End In is raised. The sending station on receipt of End In compiles the status information and acknowledges the operation by raising End Out. If status information has to be transmitted to the receiving station then this is strobed onto the data bus at End Out time.

End Out cancels End In when detected by the receiver, status information is loaded into the control unit and finally Address In is dropped. The line then becomes operational and clears the End Out signal being generated by the sending station.

This sequence can also be used as a test control unit operation which enables the sending control unit to examine the status of a particular control unit, possibly before embarking on a more complex operation.

6. DATA WAY SEQUENCES – UNIT OPERATION

This mode of operation is used when a computer or a buffer storage device operates a keyboard-printer or some type of remote terminal. The unit operation sequences are also capable of working with paper tape readers, paper tape perforators, etc. which operate normally as single character devices.

A unit device is classified as one which requires one byte or character of information per operation at a rate that is slow compared with the link capabilities. Blocking of information using the unit device control unit has purposely been restricted to prevent engaging the link for exceedingly long periods. This perhaps is not really necessary as Time-Out would disconnect the two control units in any case, but for efficient operation Time-Out should be the exception rather than the rule.

A unit device normally has no storage associated with it except that for the current data character. This means that queueing of calling stations when the device is busy is not feasible unless especially requested as a valid requirement for the device station. The unit device is thus tied to a particular calling station only, and its sequences have been modified so that the unit device can send to one address only. The station with this address would normally be operating a controlling computer or a buffer storage peripheral.

Since a unit device has been restricted to communicate with only one other station, the return address byte of the address word for the initial selection sequence is now redundant for its control unit. This byte has been replaced with the data byte or character, and so the required activity on the line is reduced because the initial selection sequence is now a pseudo data transfer sequence.

6.1 Unit Device Operation

The modes of operating a unit device are quite varied depending upon the philosophy of the programmer of the controlling computer. These modes can normally be broken into the following groups which have been restricted to an output device or writer for text convenience only.

1. When writing onto a unit device the write command and the data byte are sent to the device which replies busy or accepts the character. If the unit device is busy the procedure is tried repeatedly until it is finally accepted.
2. When writing onto a unit device the write command and data byte are issued and if the device is busy it replies a ready or attention status when it becomes available. The write command would then be re-issued.
3. If the status of the unit device is known at all times by the sending unit, a write command can be issued, depending upon this status being not busy, and is accepted without further sequences in all cases except when the device is non-operational. For this mode, the unit device must send status whenever it becomes ready and this must be stored by its controller.

The above three cases differ in that the onus for status presentation is on different devices although all modes are possibly quite acceptable. For link operation the number of actual operations per character per unit device should obviously be minimised. Status presentation by the unit device as used by case 3 above takes 2 sequences per character, case 2 takes 1 or 3 per character, and case 1 takes 1 or an indefinite number.

The most consistent mode of operation (case 3) is where the unit device is required to present a ready status whenever it has completed an operation which results in two sequences per character of data transmitted. In view of minimisation, if the ready status return is modified to include the possibility of the supervising computer writing another character before the sequence is terminated, then

only one sequence per character is necessary. This mode of operation can be achieved if the output device, instead of sending ready status, initiates a read command which can be interpreted by the computer as a ready condition if another character is not available for transmission. This particular mode of operation can be used to operate the device with an absolute minimum of link occupation without using device buffering of more than the current character. The other modes of operation are not excluded by the above response and may still be used where required but their use should be limited, to cut down link traffic.

6.2 Unit Selection

The sequence of calling a unit device from its control device or vice versa depends upon whether a read or write sequence is being performed. The write sequence has the data byte inherent in the address word whereas a read sequence needs to insert the data word somewhere within the sequence. The two sequences are therefore described separately.

6.3 Unit Write Sequence (Refer to Figure 5)

When a write operation is required the sending control unit raises Address Out and strobes the unit address word comprising address, command and data bytes onto the data bus. The receiver responds Address In automatically if connected and then replies End In after status has been determined, which is strobed onto the data bus at End In time. The sending control unit acknowledges with End Out (and status if necessary) which results in the receiver dropping Address In and thus clearing the line.

6.4 Unit Read Sequence (Refer to Figure 5)

When a read operation is required, the sending control unit raises Address Out and strobes the address word comprising address, command and dummy bytes onto the data bus. The receiver responds Address In automatically if connected. If the receiver is not ready, the normal End In – End Out sequence is followed as for the Write sequence above but if the receiver is ready with a data character it strobes this information onto the data bus and raises Service Out.

When Service Out is detected by the sending unit, it loads the data byte and raises End Out (with status if necessary). The receiving unit on receipt of End Out drops Address In and thus clears the line.

7. CONTROL UNIT INTERFACING

7.1 Computer Interfacing

Since the primary object of the data way is to enable computers to transmit and receive information, the open control unit has been designed to facilitate interfacing with most commonly used processors. In the simplest case the control unit can be used with an accumulator transfer under program interrupt for both address and data reading and writing whereas in more complex interfaces the control unit can be used with data-channel or direct memory access devices when data blocks are being transmitted.

The most efficient method of operating the data way is to attach it to a computer which has an automatic priority interrupt feature, although normal program interrupt is sufficient for control unit operation. For data transfer in blocks it is preferable to use a data channel or direct memory access option to operate the Service In – Service Out sequences because programmed data transfers will use excessive computer and data way time.

As stated previously all signals going into and coming from a control unit (with the exception of the link cables) are transistor transistor logic (TTL) compatible. Thus most dated computers require some form of level shifting and perhaps amplification, whereas the latest models are all TTL compatible owing to extensive use of integrated circuits within the computer itself.

7.2 Interface Signals

The computer-control unit interface is required to perform all those functions not carried out by the control unit, in addition to those that are peculiar to the particular computer. The control unit is arranged to provide all input gating into the data registers, etc. The output levels from the data and address registers have to be gated by the computer to give the required pulses, etc. for the computer registers.

Two data inputs to the control unit interface are available. Each is twenty-four bits wide and has a separate input strobe for each byte. This permits loading the control unit registers in blocks of eight, sixteen or twenty-four, depending on the computer used. The two data inputs above allow for the connection of a programmed register or a hardware register for data-break transfers.

Control signals to be raised from the computer require pulses from a device selector or similar device. These signals are inhibited by the control unit if they would cause incorrect sequence generation.

Most signalling from control unit to computer is in the form of program or priority interrupt. These lines can be amalgamated, if required, so that only one interrupt occurs and a table index word can be generated to differentiate between them. Interrupts to the computer should be caused by the following signals being received by the control unit:

1. Address Out – when the control unit receives a correct address during Address Out.
2. Hold In – when the sending control unit receives the Hold In reply.
3. Hold Out – when the receiving control unit receives the Hold Out reply.
4. End In – when the sending control unit receives End In.
5. End Out – when the receiving control unit receives End Out.
6. Service In – when the writing unit receives a request for data.
7. Service Out – when the reading unit receives a data word.
8. Link Busy – when a control unit is not permitted to raise Address Out owing to the link already being engaged.
9. Link Available – when the link becomes not busy after a link busy response.
10. Initial Selection No Reply – when a control unit has raised Address Out and not received the Address In response.
11. Address Out Overlap – when a control unit has been thrown off the link during Address Out, owing to incorrect data responses.
12. Active Disconnect – when a control unit has been active and the sequence has been aborted by Time Out.

Service In (6) and Service Out (7) would not be connected to the interrupt system if data channel or direct memory access was used.

7.3 Address Information

The most significant byte of the address word specifies the unique address of the device being called. The control unit may be assigned any required number of device addresses, for example, for a computer and its associated peripheral devices. These addresses however must be in specific blocks

and must start at appropriate block boundaries. These boundaries are established by any address containing zeros in that number of low order bit positions equal to the total number of bits required to decode the maximum number of addresses assigned to the control unit.

Command Information

The command byte occupies bits 8–15 of the Address word and specifies initiation and termination of particular operations to the appropriate device. Proposed bit assignments are as follows:

Bit P	Parity
Bit 0	Unassigned
Bit 1	Sense
Bits 2 and 3	Control
Bit 2	Write
Bit 3	Read
Bit 4	Variation
Bit 5	Variation
Bit 6	Variation
Bit 7	Variation .

A command byte consisting of all zeros should be interpreted as a Test I/O command which has a similar format to a Sense Command.

0. Unassigned This bit may be used to distinguish between open and closed operation commands.
1. Sense The sense operation is used to request loading of status during an initial selection only sequence. The sense command will not change the mode or status of the addressed device.
2. and 3. Control This operation is used to perform particular operations and normally proceeds without the transfer of data. A control command with all variation bits set to zero performs a No operation. The device should signal device end at the end of a control function.
2. Write The write command initiates the execution of a data transfer from the sending to the receiving control unit or station.
3. Read This command initiates the transfer of data from the receiving to the sending station.
- 4,5,6, and 7. Variation These bits are used to define particular variations of the above commands and may be used to modify particular transfers for particular devices. For example, if data is packed before being sent on the data way these bits are used to define the packing format.

7.4 Status Information

Status is signalled by the receiver under various circumstances such as in the initial selection sequence during Hold In or End In, in the terminating sequence during End In and during unit device

sequences. Status is presented by the sender during End Out for most sequences. Status need not be signalled at these points but failure to do so may be interpreted as meaning that no status conditions exist.

The status word of 24 bits is too large for present requirements so only the least significant byte is used. The proposed bit assignments are as follows:

Bit P	Parity
Bit 0	Attention
Bit 1	Status Modifier
Bit 2	Not Assigned
Bit 3	Busy
Bit 4	Not Assigned
Bit 5	Device End
Bit 6	Device Error
Bit 7	Data way Error .

These status conditions are detected by the peripheral device or by the station control unit and transmitted over the data way when status is required.

0. Attention This bit is generated when some asynchronous condition occurs in the peripheral device that is not associated with the normal operation of a data way sequence.
1. Status Modifier The Status Modifier is used by stations which cannot provide current status during a Test sequence. These stations present the status modifier bit alone during the initial selection sequence.
3. Busy This status bit is only transmitted during an initial selection or unit selection sequence and indicates that the specified command cannot be executed because of a previously initiated operation.
5. Device End Device End is caused by the completion of an input-output operation by the actual device. For buffered devices the Device End may occur on completion of a mechanical operation. For control operations, Device End is generated at the completion of the operation at the device. Device End should always be signalled at the completion of an operation which has caused a busy status to be transmitted during the operation.
6. Device Error Device Error is presented whenever a fault is detected by the operating device or an associated central processor. This bit would normally be set during the termination sequence following a data transfer and may have been caused by a word-count or checksum error.
7. Data way Error This status bit is presented whenever a control unit detects an error, and is strobed onto the data way whenever status is expected. This error is usually caused by a detected parity error during data transmission.

8. INVALID SEQUENCE CORRECTION

8.1 Time Out

When certain control lines are raised by a control unit the link becomes busy to all other users. This means that if a correct reply is not received, the link may be hung up. A correct reply may not be forthcoming owing to a number of conditions, the most common of these being when a computer is in a non-interruptable state or when a device is called during Address Out which has become non-operational or switched off. These hangups may not be permanent but will exclude all other prospective users for an indefinite time.

The problem of hangup is due to control lines, etc. being treated as d.c. levels. Owing to this d.c. treatment of the control signals the particular sequences have to be detected and timed for a period determined by worst case signal and computer responses on the line. At the end of this period the disconnect signal is propagated to all stations and has the effect of unconditionally clearing all raised control lines, thus freeing the data way for intending users.

Time-out depends on control lines and their sequences; it does not depend on the control unit which raises the signal and therefore needs to be generated once only for the complete link system. This is accomplished in a cable-end control unit which consists of the time-out counter, sequence gates and the disconnect generator. This control unit also contains line terminators for all signal lines.

The time-out period has been set initially to one millisecond. This period has been selected as a compromise between expected computer responses and down time on the party line. It has also been selected without any operating experience and as such is subject to review and change if necessary. The disconnect signal remains raised until all erroneous levels have been cleared.

One minor problem that may occur when a disconnect has cleared the line and more than one prospective sender is trying to engage the line is the high possibility that these senders will generate Address Out simultaneously and further hang up the line. This problem has been minimised by delaying control unit responses for several milliseconds after a disconnect. These delays are generated in each control unit and it is unlikely that two such delays will correspond to within the cable propagation time ($\sim 3 \mu\text{sec}$).

8.2 Address Out Overlap

Address Out Overlap is due to two control units raising Address Out together with the resultant 'OR'ing of the address bits on the data way. Operations which result from this condition can cause completely invalid operation for numerous reasons. Address Out overlap could normally occur if two control units raised Address Out simultaneously within the switching time for the address control lines. These times are of the order of tenths of microseconds and as such are quite small. However, when the delay or propagation time of the control signal down the data way cable is included, the overlap period can be of the order of two to three microseconds, which although small, can be quite significant when data way traffic is heavy.

The problem was rectified by modifying the Address Out phase of control unit operation without affecting any normal sequence responses. This modification to the Address Out phase is not apparent to the device-control unit interface and no changes to these are necessary.

The probability of Address Out overlapping is normally very low and will vary considerably with data way traffic. The three possibilities that may occur when two addresses overlap must be detected by each control unit when sending or receiving, and appropriate action taken.

1. The most common case of Address Out overlapping will result in the two address words 'OR'ing with a resultant parity error on the data way. This results in no Address In reply from any receiver, owing to the incorrect parity. This condition is detected by control unit gating and will result in an interrupt to the device indicating no reply to Address Out.

2. A case which should have low probability is that where the address words supplied by the two control units combine to form a valid parity word that differs from that of both control units. An Address In may result which may be an incorrect reply. This possibility is detected by the sending control unit by comparing the data way lines with those of the address register and if they are unequal then the control unit is reset. This results in an interrupt being signalled to the device indicating Address Out Overlap.

3. The least likely case of Address Out Overlap is where one address word is completely masked by the other. The masking address word is compared correctly but the masked unit compares incorrectly resulting in a valid initial selection for the masking unit and an Address Out Overlap interrupt for the other.

9. CONCLUSION

The link which will be called the Multiple User Dataway (MUD) will be constructed in three phases, namely, the logical implementation of the proposed sequences within a Dataway control unit, the dynamic checking of these sequences when transferring data, commands, etc., between two adjacent computers and finally, the dynamic checking of the complete system using the maximum intended cable lengths with its associated delays, noise problems, etc. Phase 1 is complete and phase 2 is proceeding.

When complete, the Dataway will greatly reduce the manual manipulation of data from experiments and will reduce the need for subsidiary data storage such as perforated paper tape, in addition to providing the basis for a remote batching facility for the main computer.

10. REFERENCE

Richardson, D.J. (1969). - A Generalised computer to computer link for an IBM 360 computer. Aust. Computer Journal 1 (5): 273. Also issued as AAEC/TM485.

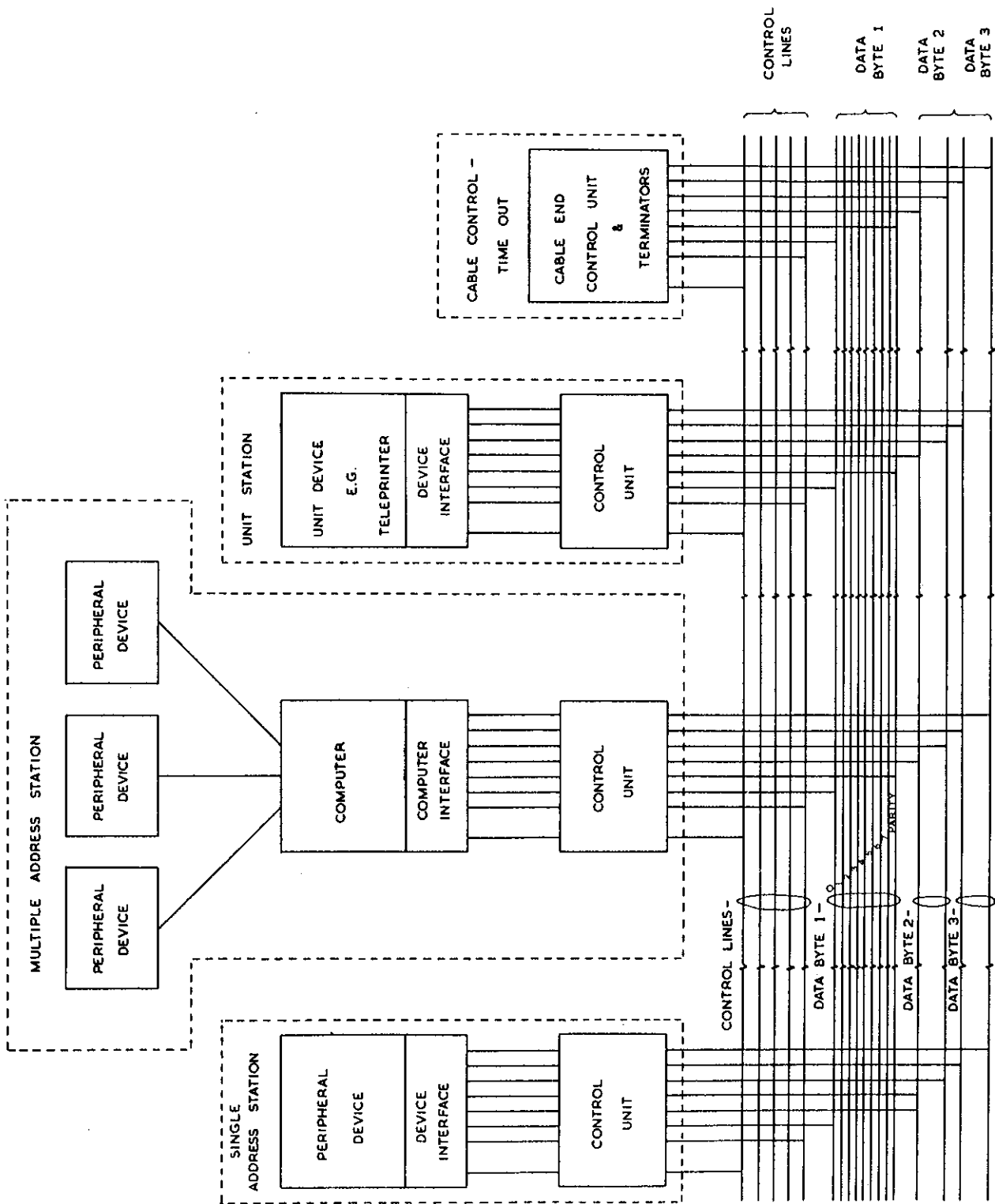


FIGURE 1. BLOCK DIAGRAM OF MULTIPLE USER DATAWAY

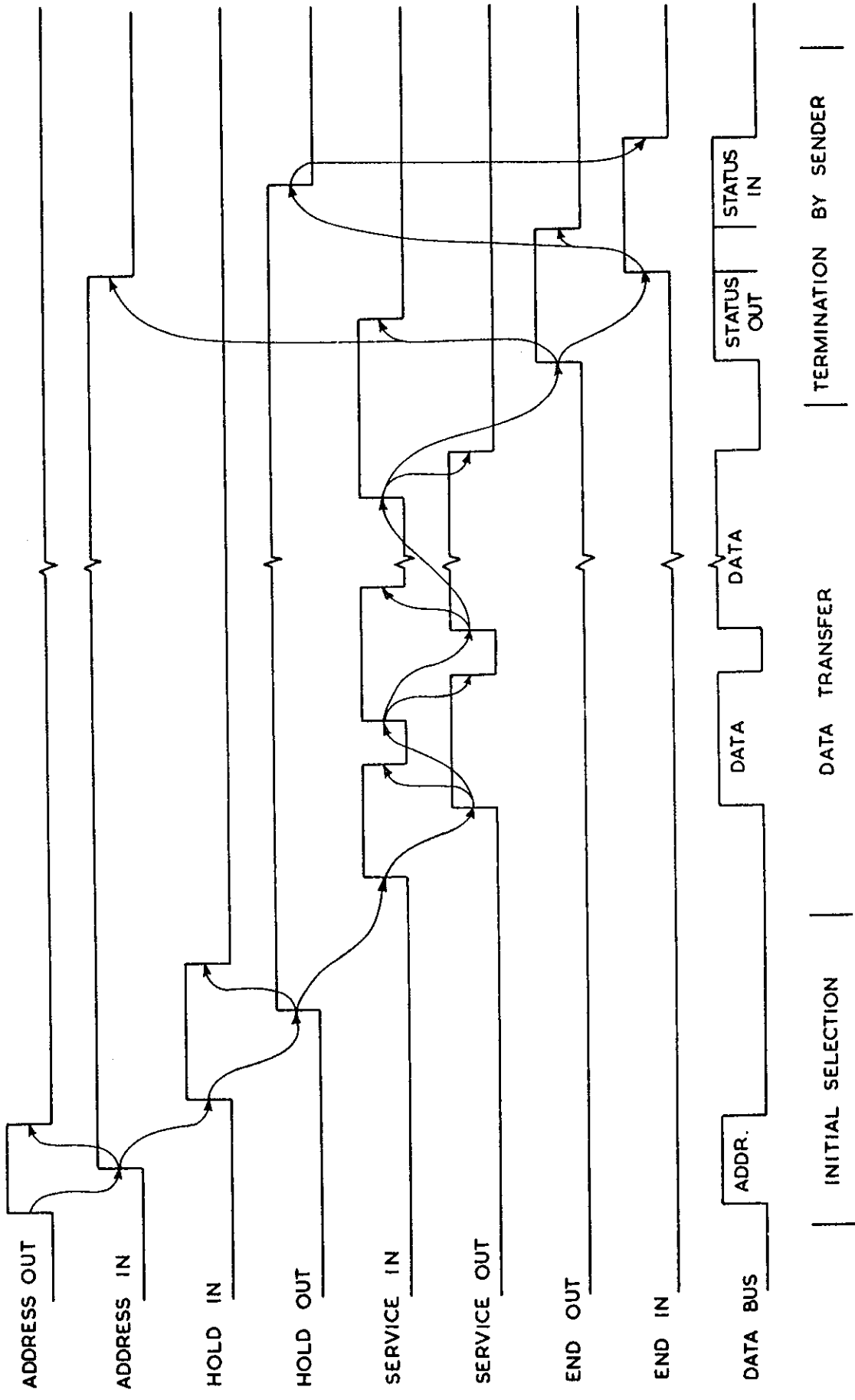


FIGURE 2. TYPICAL BLOCK TRANSFER SEQUENCE

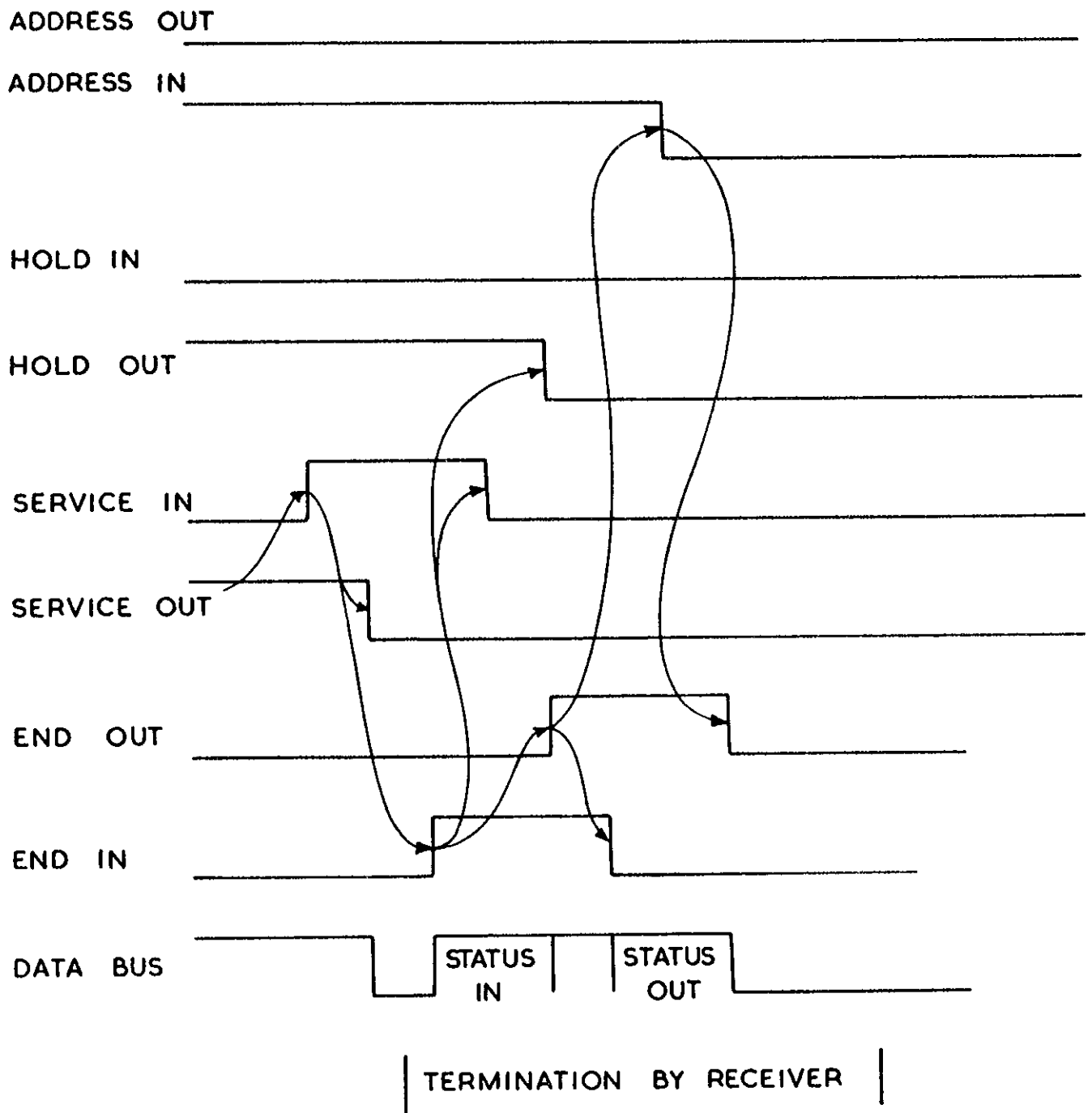


FIGURE 3. ENDING SEQUENCE BY END-IN

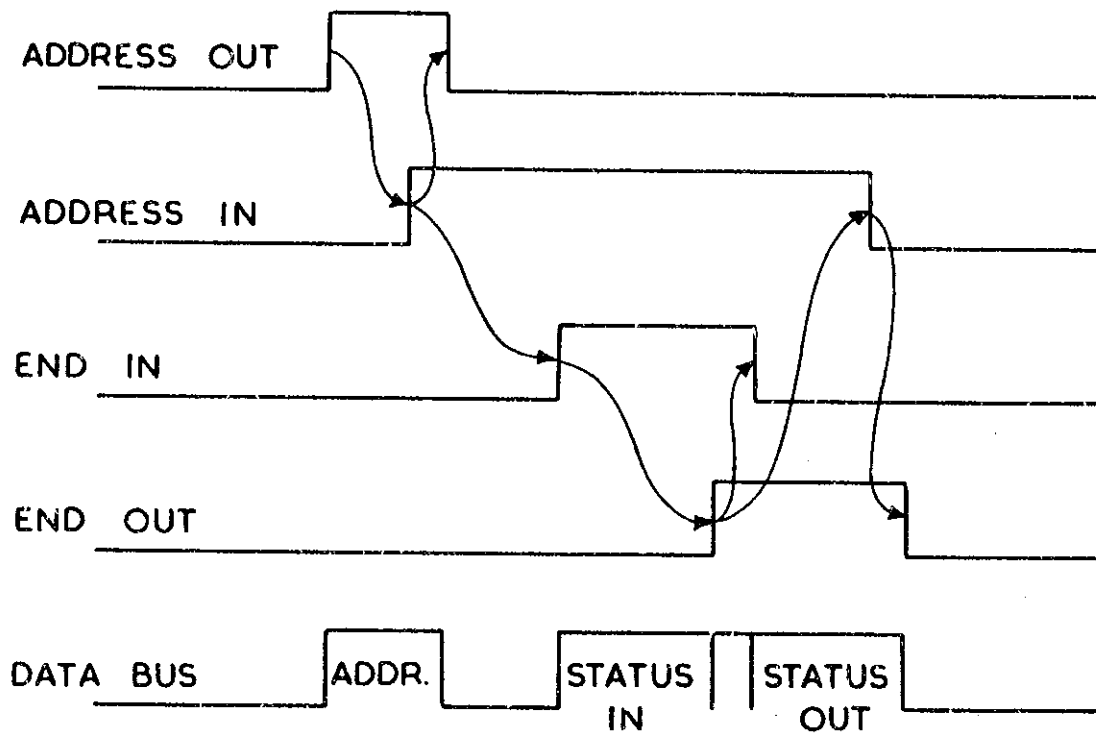


FIGURE 4. INITIAL SELECTION ONLY

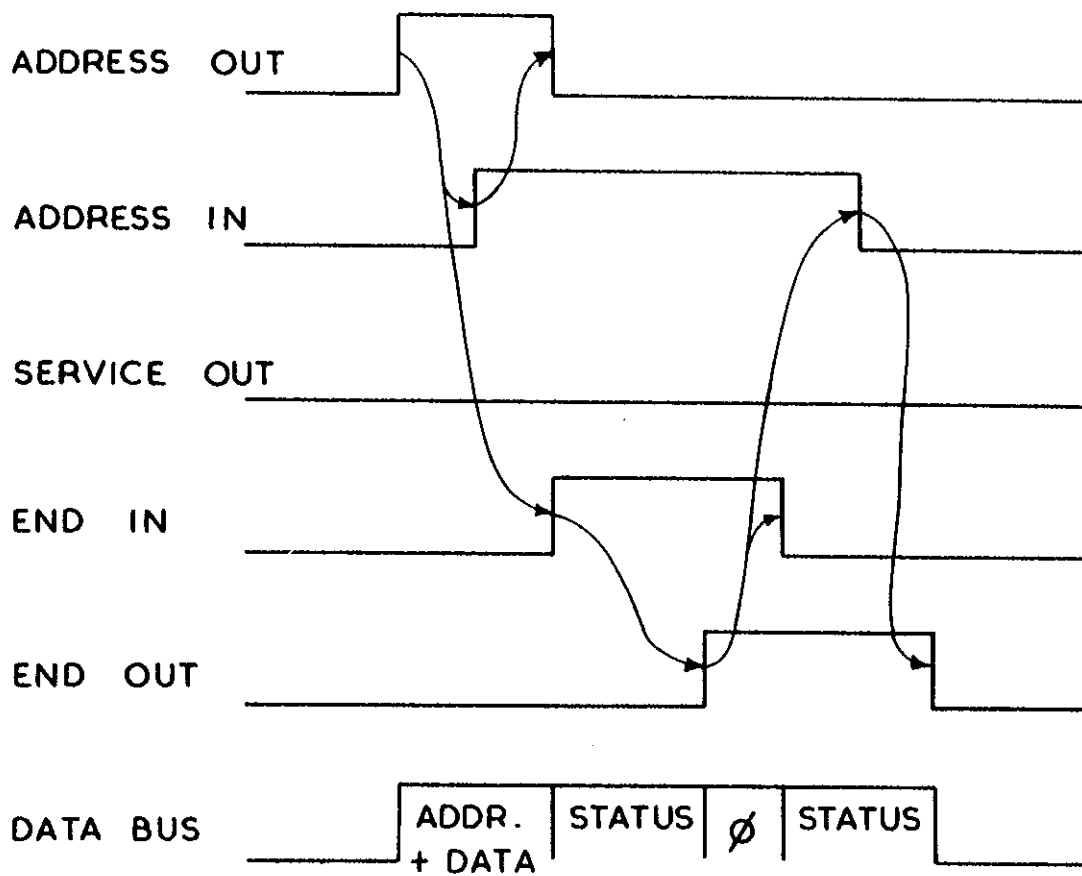


FIGURE 5. WRITE SEQUENCE - READ NOT READY

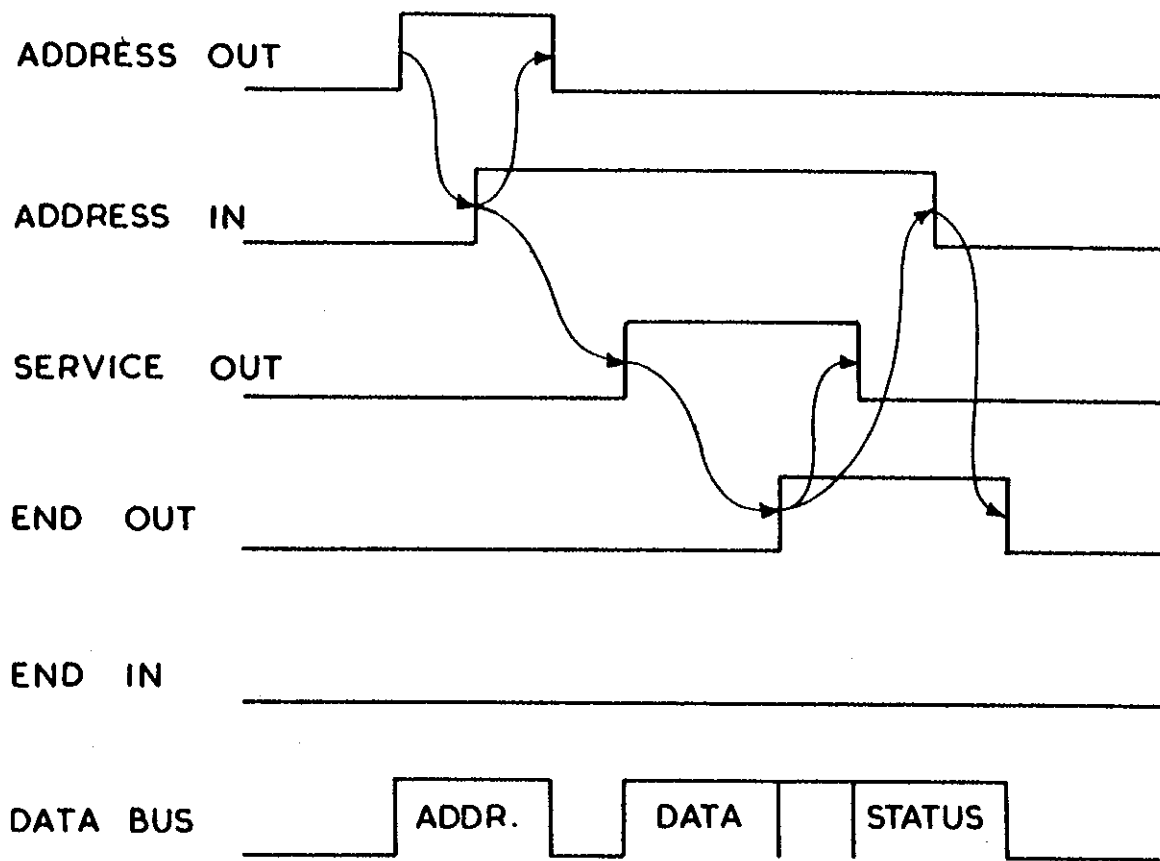


FIGURE 6. READ READY RESPONSE