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A SHORT DESCRIPTION OF THE CAM/VC BRANCH HIGHWAY

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ERRATUM

TO: All recipients of UCRL-20217

FROM: Technical Information Division

SUBJECT: UCRL-20217: "A Short Description of the CAMAC Branch Highway" Fredrick A. Kirsten, December 10, 1970

Please make the following correction on subject report:

Page 6, Fig. 6: The bar marked "BRW" should have arrow heads on both ends

8/24/71

A SHORT DESCRIPTION OF THE CAMAC BRANCH HIGHWAY

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December 10, 1970

Summary

This paper presents a short summary and description of the CAMAC Branch Highway. The purpose of the Branch and some of its characteristics are explained. Certain operational sequences are described in detail.

The paper is designed to supplement the CAMAC Branch Highway Specification,[3] and is one of a series of papers [4–7] on CAMAC topics.

Introduction

The standard CAMAC crate[1] contains 23 normal stations usable for modules other than Crate Controller (abbreviated as CC). The crate cannot be expanded. If a given system exceeds the capacity of a single crate, it can be accommodated by using more crates. This immediately raises the problem of intercrate communication, a problem which has been solved in at least two ways. One way might be called a radial configuration. In this configuration, the crates are individually interfaced to the system controller (e.g., computer). Each CC of this system is designed to interface with the computer IO structure, and any communication between crates is carried out at the computer level.

The second configuration is the CAMAC Branch Highway,[2] the subject of this paper. The Branch Highway specification[3] (EUR-4600e) was developed to provide a means for effecting the intercrate communication "in-house,"--i.e., within the CAMAC structure. A computer interfaces to the Branch at only one point. The computer therefore addresses the entire multicrate system as a single entity, rather than as separate, independent crates. Multicrate systems may, of course, be built with more than one Branch, in which case each Branch is independently interfaced.

Within the CAMAC world, there will be places for both types of configurations. We do not attempt to point out the relative merits of the two in this paper, but simply say that the Branch provides a consistent, convenient, and compatible means for interconnecting multicrate systems and that components for assembling branch-compatible systems are becoming readily available.

It was mentioned that multicrate systems can have more than one branch. In this paper, we simplify the problem by considering only single-branch systems. Let us also assume that the system controller is always a stored-program computer. This is not essential, but the inherent complexity of multicrate systems makes hardware controllers less practical.

The reader should be aware that the branch is clearly, though concisely, defined in EUR-4600e. Here, we supplement and (we hope) clarify the material in the specification.

What Does a Branch Look Like?

A Branch is most commonly described in terms of the chain configuration shown in Fig. 1, although other configurations are possible. The addressing structure of the Branch imposes an upper limit of seven crates per Branch.

Branch Driver

Control over the Branch is exercised by the Branch Driver. It performs a role analogous to that played by the Crate Controller within the crate. It issues commands, controls the timing of a Branch operation, and receives service requests originating in the modules in the crate. The Branch Highway specifications completely describe the interaction of the Branch Driver with the Highway. The other face of the Branch Driver, that which interacts with the computer,[7] is not specified. It is designed according to the demands of the specific computer.

Branch Highway

The Branch Highway is the set of wires that interconnects the Branch Driver and the Crate Controllers. In Fig. 1, it is shown as a heavy vertical line, interrupted by the Crate Controllers. Actually, it is not interrupted: all wires of the branch are bussed through the Crate Controllers. Each Crate Controller gains access to the Highway by tapping onto the wires. Each such set of taps is called a port.

The Branch Highway contains 66 pairs of signal and ground wires that carry all signals necessary for Branch operation. These include timing and control signals as well as a 24-bit bidirectional data bus. No provision is made for transmitting power.

Crate Controller

The interface between the Branch Highway and the Dataway of a crate is by means of a Crate Controller (CC). EUR-4600e describes certain properties that such a CC must have. These include:

1. Identification of crate number. Allowable numbers are 1-7 inclusive.

2. Certain N (pseudostation) numbers that may be used for internal CC operations.

3. Provision for off-line or on-line condition. An off-line crate does not respond to Branch commands, and does not interfere with Branch operations. In addition, provision is made for the Branch Driver to determine which crates are off-line.

4. Ability to carry out a graded-L request operation.

Appendix 1 of EUR-4600e contains the specifications for a standard CC that interfaces the Branch and a crate. A CC that satisfies the Appendix 1 specifications is called a Crate Controller Type A.[4]

Termination Unit

All signal sources connected to the Branch Highway must be of the wired-OR type. For their successful operation, a source of pull-up current must be provided on each signal wire. The termination unit provides these pull-up currents. It also electrically terminates the two-wire transmission lines of the Branch Highway. The recommended value for the terminating impedances is 100 ohms, a value reasonably close to the impedance of most multiwire cables.

Terminations may be provided in Branch Drivers, or as separate units. At least one set of terminations must be used on every Branch. Two terminations, one at each end of the Branch, may be necessary to absorb electrical reflections that might otherwise interfere with proper interpretation of the signals.

Connectors

EUR-4600e specifies the standard 132-pin connector for use with the Branch Highway.

Branch Highway Signals

Table I lists the signals that are carried on the 66 twisted-pair lines of the Branch Highway. Branch Highway signal designations all have B as the first letter. For example, the equivalents of the subaddress signal called A1, A2, etc., on the Dataway are designated as BA1, BA2, etc., on the Branch.

In contrasting the signals shown in Table I with the signals carried on the Dataway, the following observations can be made:

1. The Crate Address signals are unique to the Branch Highway.

2. The station number is carried as a binary-coded number on the five BN lines. These lines have a capacity of 32 station-number codes. Since the crate contains only 23 addressable, normal stations, some of the extra codes can be used for special functions.

3. The subaddress and function codes are carried in exactly the same binary-coded form as on the Dataway.

4. The Branch Highway has a single 24-bit bidirectional Read-Write bus (lines BRW1-BRW24) for transferring data. It is also used for transmitting the 24-bit graded L word. (The Dataway uses two 24-bit unidirectional data buses--one for each direction of data transmission.)

5. The Branch signal BQ is the OR'd sum of the Q lines of all crates addressed in a command. The BQ signal has the same significance on the Branch Highway as the Q signal has on the Dataway.

6. The timing signals, BTA and BTB are unique to the Branch Highway. These are used to effect a "hand-shaking," to synchronize Dataway cycles with Branch Driver cycles. Note that the Branch Driver issues a single BTA signal, whereas provision is made for seven individual BTB responses by the seven possible Crate Controllers. The details of the timing and its relationship to the Dataway cycle are given in another reference.[5]

7. The transmission of L-request signals is quite different from that on the Dataway. Two special signals, the Branch Demand (BD) and the Graded-L request command (BG), are provided in the Branch Highway to coordinate the transmission of graded-L information from the individual crate to the Branch Driver.

8. There is only one unaddressed command on the Branch Highway. This is Initialize, BZ. It has the same significance as Z on the Dataway.

To summarize very briefly, the Branch Highway set of signals permits the following operations:

(a) Commands can be addressed to specific modules in specific crates;

(b) data and Q responses can be transmitted to and from the addressed modules;

(c) L requests can be transmitted from individual modules to the source of system control.

Branch Operations

Unaddressed Commands

The Branch Highway structure contains only one unaddressed command--Initialize (BZ). Within the context of the Branch Highway, "unaddressed" means that the command is directed to all crates.

Initialize is also an unaddressed command on the Dataway. Therefore, if a Branch Driver issues an Initialize command, it is transmitted to all stations in all crates of the system. The purpose of Initialize is to place the entire system into a passive, quiescent condition such that it is able to accept any commands that follow. The command is usually given when the power is first turned on or following any condition that has made the system inoperative.

Initialize may cause erasure of data and the resetting of control bistables.

Addressed Commands

The addressed command of the Branch Highway is similar to that of the Crate Dataway but has an additional level of addressing--the Crate Address. The canonical form of addressed command is often written CNAF, where C represents the address of the selected crate, N is the address of the selected station within the crate, A is the selected subaddress within the module residing in the addressed station, and F is the function to be performed. The form CNAF is easy to write, and is pronounceable. (One might argue that BCR·BN·BA·BF is more nearly correct, but his arguments would be stated only in writing.) The two parts are CNA, the address (noun), and F, the function (verb). The parts are sometimes interchanged, and written FCNA.

The individual parts of the command are now considered.

Crate Address--C. The ordinal form of the Crate Address is carried on the seven BCR wires. A seven-position switch in the Crate Controller selects the address of that crate. No two crates may have the same address. This type of coding permits more than

TABLE I Signal Lines at Branch Highway Ports

Title		Designation	Generated by	Signal Line Pairs	Use
Command	Crate Address	BCR1 – BCR7	Branch Driver	7	Each line addresses one crate in the branch
	Station Number	BN1, 2, 4, 8, 16.	" "	5	Binary coded station number
	Sub-address	BA1, 2, 4, 8.	" "	4	As on Dataway A lines
	Function	BF1, 2, 4, 8, 16.	" "	5	As on Dataway F lines
Data	Read/Write	BRW1 – BRW24	Branch Driver (W) or Crate Controller (R,GL)	24	For Read data, Write data, and Graded-L
Status	Response	BQ	Crate Controller	1	As on Dataway Q line
Timing	Timing A	BTA	Branch Driver	1	Indicates presence of Command, etc.
	Timing B	BTB1 – BTB7	Crate Controller	7	Each line indicates presence of data, etc., from one crate controller
Demand Handling	Branch Demand	BD	Crate Controller	1	Indicates presence of demand
	Graded-L Request	BG	Branch Driver	1	Requests 'Graded-L' Operation
Common Controls	Initialise	BZ	Branch Driver	1	As on Dataway Z line
Spare	Reserved	BX1 -- BX9		9	For future requirements

TABLE II Station Number Codes used in Crate Controllers

N Code	Use	B, S1, and S2	Remarks
N(0)	Reserved		
N(1) -- (23)	Address the corresponding normal station	Yes	Normal stations occupied by the controller need not be addressed
N(24)	Address preselected normal stations	Yes	
N(26)	Address all normal stations	Yes	
N(28)	Address crate controller only	Yes	
N(30)	Address crate controller only	No	Does not suppress L signals No transfer via Dataway R and W lines
N(25, 27, 29, 31)	Reserved		

one crate to be addressed on a given command. During an addressed command operation, only the addressed crates respond to the command.

Station Number--N. The station number is carried as a five-bit binary coded number on the lines BN1 through BN16. In the Crate Controller these must be decoded into an ordinal (one-out-of-32) code, with elements N(0) through N(31). Since the normal stations in the crate are numbered 1 through 23, the Branch is capable of transmitting station numbers beyond the range required for addressing normal stations. Thus, codes N(0), and N(24) through N(31), are available for other uses. Table II shows how the station number codes are to be interpreted by the Crate Controller.

On the Dataway, it is permissible to address more than one station on a given command. However, since the Branch Highway carries a binary-coded station number, the multiple-station addressing feature would be lost if some other provision were not made. The other provision is N(24) and N(26). If a Branch Highway command with N(26) is transmitted, the Crate Controller translates this to mean "address all normal stations, 1 through 23." If a Branch Highway command with address N(24) is transmitted, the Crate Controller translates this to mean "address all normal stations that have been preselected." In this case, preselecting means setting the appropriate bits in a 23-bit register in the Crate Controller. This 23-bit register would have been loaded on a previous Branch Highway cycle that used one of the other "non-standard" N codes, N(30). Both N(28) and N(30) are used to address features residing in the Crate Controller--e.g., the preselected station register mentioned above.

Subaddress--A. A direct four-bit translation is made from the Branch Highway code carried on BA1 through BA8 into the Dataway bits A1 through A8.

Function Code--F. The five signals BF1 through BF16 are directly translated bit for bit into the five Dataway signals F1 through F16.

Transmission of Data.

The flow of data differs slightly depending on whether a Read or Write command is in progress. For a Read command, the addressed module in the addressed crate places its data on the unidirectional Dataway Read bus. The data are transferred to the bidirectional Branch Highway BRW bus and sent to the Branch Driver. During a Write command, the Branch Driver places the data on the BRW bus. The Crate Controller of the addressed crate retransmits the data on the W bus of its crate, where they are available to the addressed module in that crate.

Clear and Initialize Commands

The crate Dataway command repertoire includes two unaddressed commands, Clear (C), and Inhibit (I), which are not specifically accounted for on the list of Branch Highway signals. Figure 2 schematically shows a way in which the Inhibit line of a crate can be controlled with Branch addressed commands. In this figure, a flip-flop in the Crate Controller controls the Inhibit signal on the Dataway. Table II shows that N(30) is intended to be used to address functions within the Crate Controller where no transfer via Dataway R or W lines is involved. Thus two commands using an arbitrary subaddress (chosen when the CC was designed), function codes F(24) (Enable), and F(26)

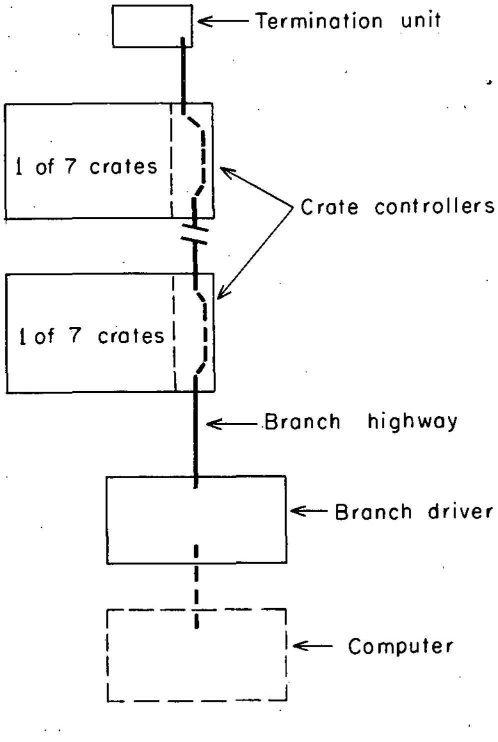

Fig. 1 A typical configuration of a Branch Highway system.

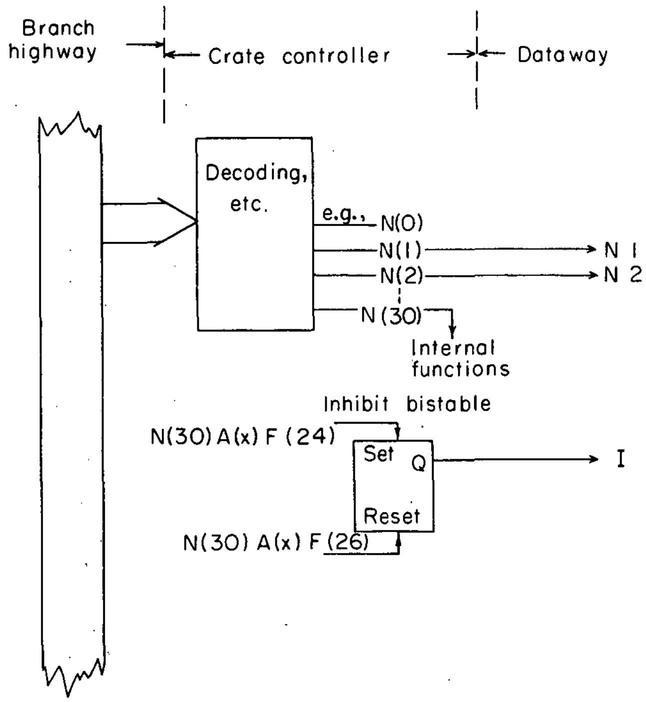

Fig. 2 This shows how the Inhibit signal in a crate may be controlled by Branch Highway commands.

(Disable) and station address N(30) are used respectively to set and reset the flip-flop.

The Clear command can be handled in a similar fashion as Inhibit. These two commands have the unique characteristic of being addressed commands in the Branch, and unaddressed commands on the Dataway.

BQ Response

As described elsewhere,[6] a CAMAC module may generate a logic 1 on the bussed Q line in response to a Dataway operation for two reasons:

(a) As an indication that a Read or Write command is being obeyed. (For example, Q = 0 is the proper response if the addressed register is nonexistent.)

(b) As a status response to a non Read/Write command--i.e., the command asks a question, and the module responds "Yes" or "No" by an appropriate Q response.

In a Branch Highway system, the commands are issued by the Branch Driver. In order to allow the Branch Driver to react to the Q responses that the modules make to these commands, the Q signals of the individual crates are OR'd onto the Branch BQ line as shown in Fig. 3. In this example, it is assumed that the command on the Branch is addressed to a module in the crate shown in the figure. The Crate Controller recognizes the C part of the CNAF command, and passes NAF onto the Dataway. The addressed module accepts the NAF command and generates a Q response. Note that Q is gated in such a way that only the addressed crate(s) are connected to BQ. The Q response of this crate and all Q responses from other crates are wire-OR'd onto the BQ line, where it becomes available to the Branch Driver.

The Q response in (a) is useful for block transfers involving a series of modules. A simple hardware-controlled algorithm in the Branch Driver can be used to sequentially access registers in physically adjacent modules. This is called "pseudo-sequential" addressing in the reference,[6] where its use in single-crate systems is discussed. It should be noted that this works equally well in Branch systems, with the added advantage that the crate boundaries become "transparent"--the series of accessed modules can extend over more than one crate.

L Requests

A CAMAC module may, in the course of time, need to request attention from the source of system control. For this purpose, the Dataway provides 23 L signals, one from each normal station to the control station. These enable the Crate Controller to know instantly not only that a module needs attention, but also which. There is a problem in giving the Branch Driver the same capability for instantly identifying the module generating an L request: to provide the same capability as in the crate would take 7 crates x 23 modules/crate = 161 wires. This is more than the 66 that exist on the Branch for all other purposes. One could reduce the number of wires by binary-coding the address of the module in question, but this would permit only one module's L request to be on the line at any instant. The Branch Highway provides a compromise solution, in which the 24-BRW data lines are given an extra task: to carry a 24-bit L request status word.

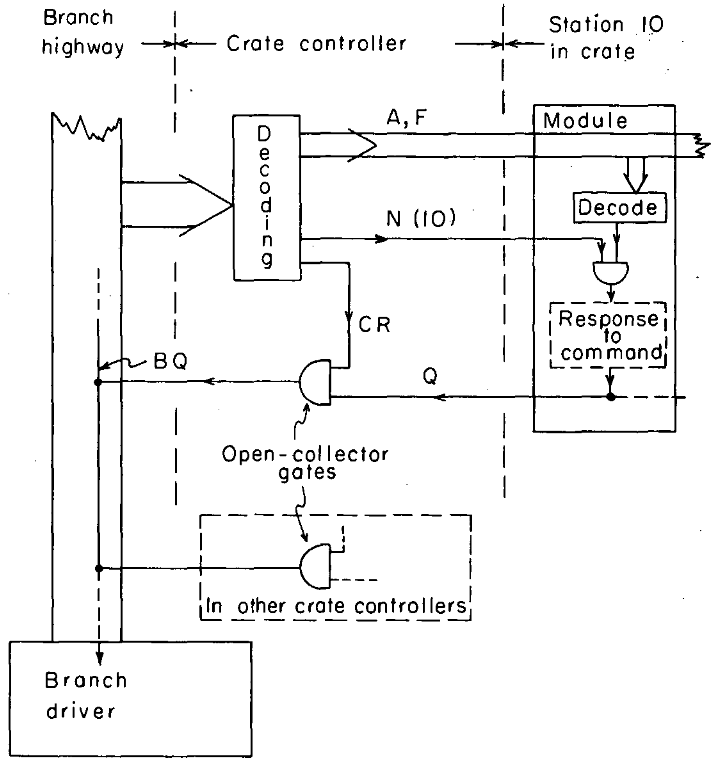

Fig. 3 The relationship between the BQ line of the Branch and the Q lines in individual crates.

The steps involved in an L request recognition are illustrated in Figures 4 and 5. Let us assume that the module in station 10 of Crate 1 in Fig. 4 sets its L line to logic 1. A 23-input OR gate in Crate Controller (1) generates a logic 1 output if any of its 23 L inputs is in the logic 1 state (this includes our L(10), of course). The output of the OR gate, along with all similar OR gates in all Crate Controllers of the Branch, are wire-OR'd onto the Branch Demand (BD) line in the Branch Highway. Thus BD = logic 1 signals the Branch Driver that, somewhere in its system, there lies a module in distress.

The next step, to identify the module, is illustrated in Fig. 5. There exists a special command, Graded-L Request (BG), by which the Branch Driver can demand further details. BG requires all on-line Crate Controllers to participate in the generation of a 24-bit Graded-L word (GL word), to be transmitted to the Driver via the BRW lines. Obviously, the BG command can be issued only when other addressed-command operations are not in progress. As part of the BG command cycle (also known as a Graded-L, or GL, operation), the Driver may strobe the 24-bit GL word into a register, shown as GL-reg. in Fig. 5. Then, by examining the contents of the GL register, it can learn more (perhaps enough) about the identify of the requester.

An immediate question is raised: What do the individual bits of the GL word mean? Actually, CAMAC does not specify. Or, to put it another way, it gives the system designer flexibility to design the GL word as he sees fit. For example, he may

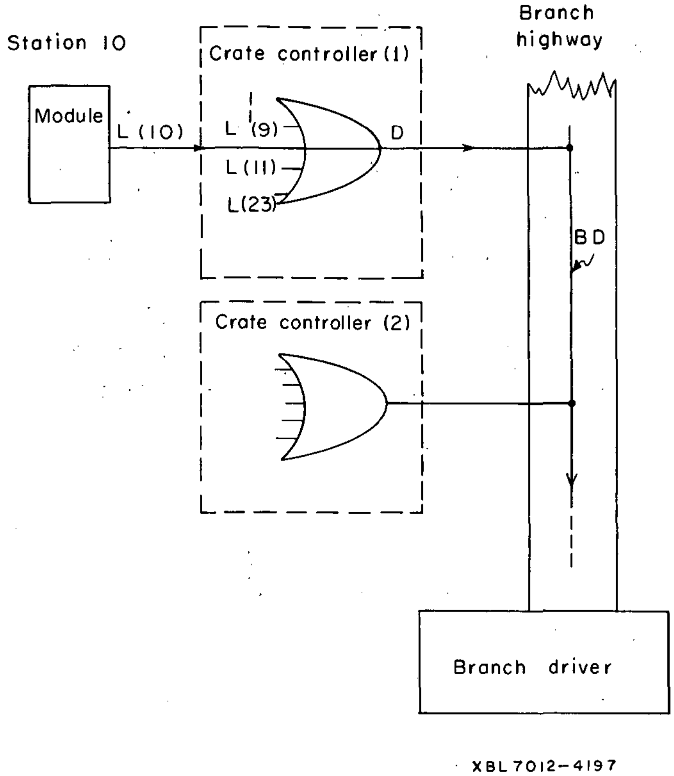

Fig. 4 The relationship between the BD line of the Branch and the L lines in the crates.

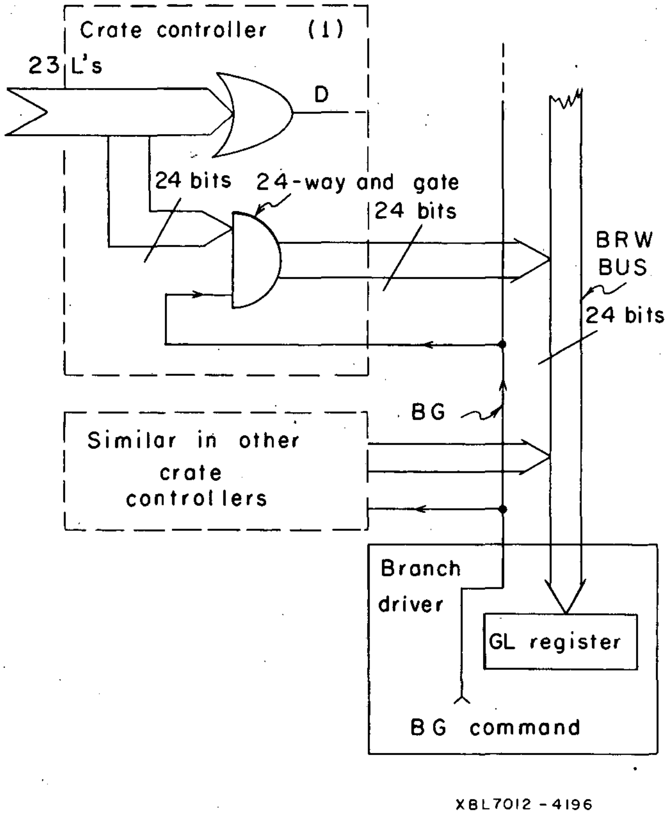

Fig. 5 This shows the use of the BRW bus of the Branch in collecting and transferring the Graded-L status word.

reserve seven bits (one for each crate) of the GL word to indicate which crates have active L requests. For another example, if there are no more than 24 modules in the entire system that will make L requests, he can assign one bit to each of them. The Crate Controller Type A contains a feature, called the LAM grader, that facilitates the assignment of bits. Further details are given in Reference 4.

A second question arises: what if the 24-bit GL word cannot carry enough information to completely identify the L source? Then additional questions must be asked, perhaps using the Test Look-at-Me function code, F(10). The area over which the F(10) questions are asked is presumably narrowed by the information in the GL word. It should be pointed out that this same form of questioning is necessary, in any case, if the module has more than one L source.

The two-step process described above can be accomplished by a very simple set of hardware. When a BD signal is received, the hardware waits for the current Branch operation to finish, then issues the BG command, and strobes the 24 bits into the GL register. The additional searching--via F(10), for example--may well be too complicated for simple hardware, and may be relegated to the software of the controlling computer.

Flow of Data and Control Signal

The capabilities of the Branch to transmit control and data are summarized in Fig. 6. Control flows predominantly from Branch Driver to Crates: only the BD signal flows oppositely. The flow of data is nearly symmetrical: 24 data bits in each direction, plus the BQ bit from Crate to Branch Driver.

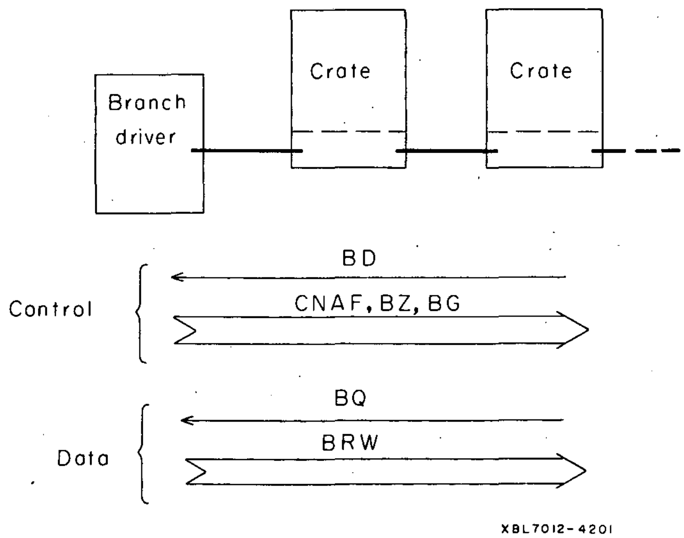

Fig. 6 A resumé of the command and data transferring capabilities of the Branch Highway.

Multiple Branch Drivers?

At present a Branch Highway is limited to only one Branch Driver (one source of control). If more than one Driver were to exist, a priority structure would be necessary, to determine positively which

Driver has control of the Branch at any instant. This priority structure is not now included in the specifications, but could possibly be added at a later date.

References

1. "CAMAC, A modular Instrumentation System for Data Handling, Description and Specification", EURATOM Report EUR 4100e, March 1969. Note that this has been reprinted in the U. S. (August 1970) with the NIM Committee comments and endorsement. Requests for information in the U. S. should be addressed to Louis Costrell, Chairman, AEC Committee on Nuclear Instrument Modules, Radiation Physics Building, National Bureau of Standards, Washington, D. C. 20234

2. R.C.M. Barnes, I. N. Hooton, and J. M. Richards, "Data Transfers and Demand Handling in Multi-crate CAMAC Systems", Proc. of the 1969 Nuclear Science Symposium, IEEE Transactions on Nuclear Science, Vol. NS-17, No. 1, February 1970, pp 463-466.

3. "CAMAC Organization of Multi-Crate Systems, specification of the Branch Highway and CAMAC Crate Controller Type A," to be published as EUR-4600e. Requests for information should be directed as shown under Ref. 1.

4. S. Dhawan, "The CAMAC Crate Controller Type A". (See Note)

5. R. S. Larsen, "CAMAC Dataway and Branch Highway Signal Standards". (See Note)

6. F. A. Kirsten, "Operational Characteristics of the CAMAC Dataway". (See Note)

7. F. A. Kirsten, "Characteristics of Interfaces Between CAMAC and the Branch Highway". (See Note)

NOTE: References 4-7 and this paper were presented in the CAMAC tutorial session of the 1970 Nuclear Science Symposium, New York, November 4-6, 1970. They are scheduled to be published in the IEEE Transactions on Nuclear Science, April 1971.

Reference 6 will also be printed as UCRL-20214; Reference 7 as UCRL-20232.

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