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A SHORT DESCRIPTION OF THE CAMAC BRANCH HIGHWAY*

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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 intended to serve as an introduction to the CAMAC Branch Highway Specification,[1] and is one of a series of papers[2-5] on CAMAC topics. It is a revised version of a paper previously published.[2] Since the first version was published, a revision of the branch highway specification has been issued. The present paper is based only on the revised specification.[1] Information on the differences between the original and revised specifications is available.[7,8]

Introduction

The standard CAMAC crate[4] contains up to 23 normal stations usable for modules other than the 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 question on how to organize multi-crate systems, a question which has been answered in at least two ways. In one way, the crates are individually interfaced to the system controller (e.g., computer). Each CC is designed to communicate directly with the computer I/O structure; any communication between crates is carried out at the computer level.

The second way uses the CAMAC Branch Highway, the subject of this paper. The Branch Highway specification[1] was developed to provide a standard organization for multi-crate systems. A computer interfaces to the branch at only one point. The computer therefore addresses the entire multi-crate system as a single entity, rather than as separate, independent crates. Multi-crate 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 inter-connecting multi-crate systems and that components for assembling branch-compatible systems are becoming readily available.

It was mentioned that multi-crate systems can have more than one branch. In this paper, we simplify the discussion 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 multi-crate systems makes hardware controllers less practical.

*Work performed under the auspices of the U. S. Atomic Energy Commission.

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 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 wires that carry all signals necessary for branch operation. This includes a 24-bit bidirectional data bus. No provision is made for transmitting power.

The capabilities of the branch to transmit control and data are summarized in Fig. 2. 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 and BX bits from crate to branch driver.

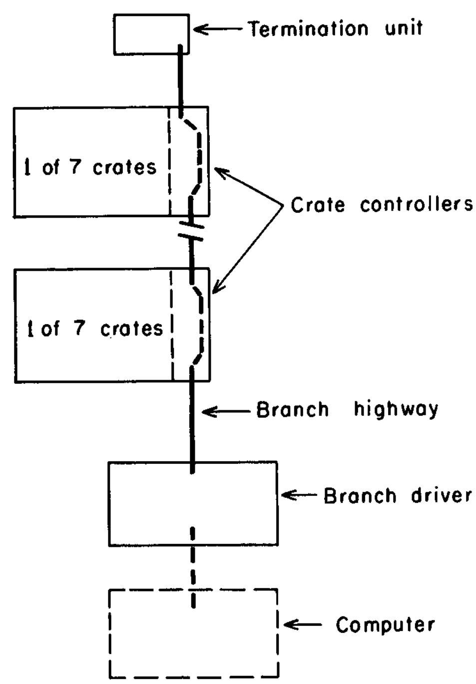

Fig. 1. A typical configuration of a branch highway system.

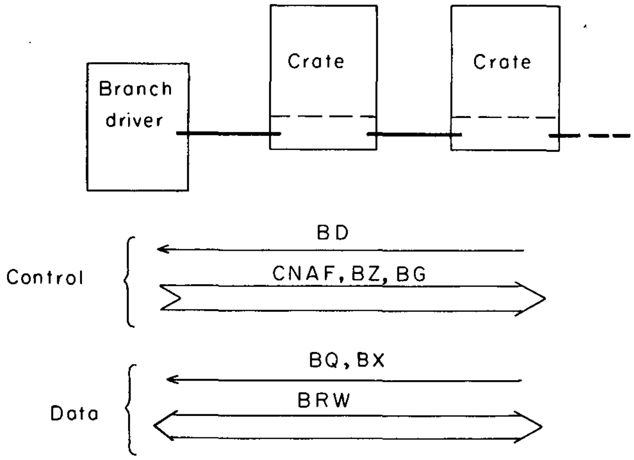

Fig. 2. A resume of the control and data signal facilities of the branch highway.

Branch Driver

Control over the branch is exercised through the branch driver. It performs a role analogous to that played by the crate controller within the crate. It is the master and the crates are slaves. Only the branch driver can issue commands. The crates can originate only one signal, the branch demand, which is the service request.

In its role as master, the branch driver issues commands, sends and receives data, controls the timing of branch operations, and receives service requests originating in the modules in the crates. 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,[5] is not specified. It is designed according to the characteristics of the specific computer, and according to the types and complexities of CAMAC operations to be carried out.

Crate Controller

The interface between the branch highway and the Dataway of a crate is by means of a crate controller (CC). The specification describes certain properties that such a CC must have. It also specifies in detail a specific CC, known as Crate Controller Type A (CCA). The use of a CCA to interface the branch and a Dataway is not mandatory. Neither is it the only way it can be done. However, since designs other than CCA are rarely, if ever, used for this purpose, only the CCA is referred to in this paper. Some properties of branch-compatible crate controllers include:

1. Selection of crate identifying number. Allowable numbers are 1-7 inclusive.

2. Certain N (pseudostation) numbers (e.g., N(28), N(30)) that may be used to address commands to perform operations internal to the CCA.

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.

4. Ability to carry out a Graded-L operation.

Termination Unit

All signal sources connected to the branch highway must be of the open-collector type, compatible with wired-OR operations. 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

A 132-pin connector is specified for connecting branch drivers and crate controllers to the highway.

Sources and Receivers

All branch lines are bussed--i.e., the signals they carry are available at all crates and at the branch driver. Consider a line carrying a signal generated by a source in the branch driver, and directed toward the crates (for example, one of the BF lines). Such a line has connected to it a single source (transmitter) in the branch driver; and a receiver in each of the crates. All crates receive the signal, but only the addressed crate(s) use it. The receivers each absorb only a small amount of the signal energy, so that the flow of the signal is not appreciably affected by the presence of the receiver.

Now consider the BQ line. It is an example of a line carrying a signal that is generated by the crates and directed toward the branch driver. Each crate has a signal called Q. The BQ signal on the branch is defined as the inclusive OR of all the Q signals--i.e., $BQ=Q(1)+Q(2)+---+Q(7)$, where: the symbol + stands for the logical OR; Q(1) is the Q signal at crate 1, etc., and, if crate X is absent, $Q(X) \equiv$ '0'. This relationship between BQ and the Q's is effected by using sources at each crate that are "wire-ORable." If all sources are "generating" logic '0', the line assumes the '0' state. If any <u>one</u> source generates a logic '1', the line assumes the '1' state. Thus, you see, the OR is accomplished along the wire, rather than by means of an OR gate made of discrete electronic devices.

A third example would be a BRW line on which signnals flow in either direction. The equivalent of a BRW line could be formed by connecting together the BF line in the first example and the BQ line in the second. In a full seven crate system, there would now be eight receivers and eight transmitters on this composite line. Since all branch highway transmitters are wire-ORable, and all receivers are light loads, the circuit still behaves nicely, and data can flow in the two directions depicted by the BRW bar in Fig. 2.

Details of the electrical characteristics of the sources and receivers are available elsewhere.[3]

TABLE I Signal Lines at Branch Highway Ports

Title		Designation	Generated by	Signal Lines	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
	Command Accepted	BX	Crate Controller	1	As on Dataway X 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 Control	Initialise	BZ	Branch Driver	1	As on Dataway Z line
Reserved		BV1 – BV7		7	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	No Dataway operation
N(25, 27, 29, 31)	Reserved		

Branch Highway Signals

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 signals 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. These constitute a higher level of address than is needed in the crate, and permit addressing of commands to a particular crate or crates.

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 within the CCA.

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 24-bit bidirectional Read-Write bus (lines BRW1-BRW24) for transferring data, either from branch drivers to crates, or vice versa. (The Dataway uses two 24-bit unidirectional data buses--one for each direction of data transmission.)

5. The branch signals BQ and BX are the OR'd sums of the Q and X lines of all crates addressed in a command. The BQ and BX signals have the same significance on the branch highway as the Q and X signals have 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 highway 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 other references.[2,3]

7. The transmission of service-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 Look-at-Me information from the individual crate to the branch driver.

8. There is only one unaddressed operation 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; and the Q and X responses of the modules returned to the branch driver;

(b) Data 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 Operations

The branch highway executes only one unaddressed operation--Initialize (BZ). Within the context of the branch highway, "unaddressed" means that the command is directed to all crates.

Initialize is also an unaddressed operation on the Dataway. Therefore, if a branch driver issues an Initialize instruction, it results in Initialize arriving at all stations of all on-line 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.

Command Operations

The command operations (addressed commands) of the branch highway are similar to those of the crate Dataway but have 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 that 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.

<u>Crate Address--C.</u> The ordinal form of the crate address is carried on the seven BCR wires. A seven-position switch in the crate controller is used to select the address for that crate. No two crates may have the same address. This type of coding permits more than one crate to be addressed on a given command. During an addressed command operation, only the addressed crates respond to the command.

<u>Station Number--N.</u> 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 a 25 station 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 interpreted by Crate Controllers Type A.

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 capability 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 the command to 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 the command to all normal stations that have been preselected." In this case, preselecting means setting the appropriate bits in a 23-bit register (Station Number 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 bit-to-bit translation is made from the branch highway subaddress code carried on the four lines, BA1 through BA8, onto the Dataway lines A1 through A8.

Function Code--E. 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 cycle, 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 Inhibit Operations.

The crate Dataway command repertoire includes two unaddressed operations, Clear (C), and Inhibit (I), which are not specifically accounted for on the list

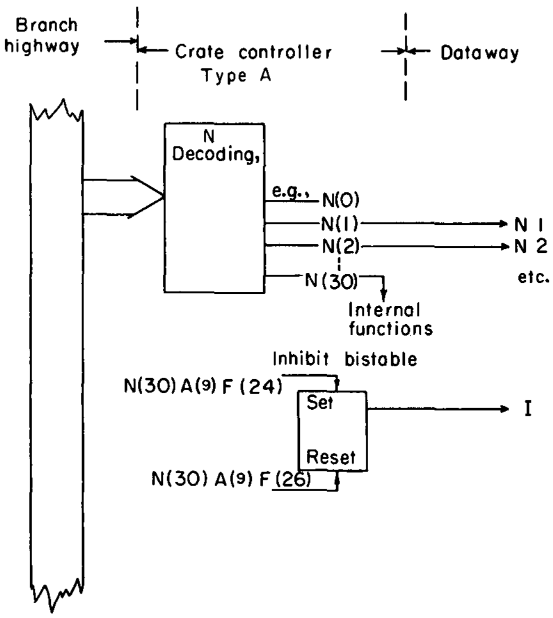

Fig. 3. This shows how the unaddressed Inhibit (I) signal in crate may be controlled by addressed branch highway commands. The N decoder is shown to illustrate that N(30) is directed toward some features in the crate controller itself.

of branch highway signals. These two operations have the unique characteristic of being carried as addressed commands in the branch, and unaddressed operations on the Dataway.

Figure 3 schematically shows a way in which the Inhibit line of a crate is controlled with branch 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 to be A(9) when the CCA was designed), function codes F(24) (Enable), and F(26) (Disable) and station address N(30) are used respectively to set and reset the bistable (flip-flop) that generates the crate I.

The Clear operation is handled in a similar fashion. The main difference is that commanding a Clear results in single cycle of Clear operation.

BQ Response

A CAMAC module may respond to certain Dataway operations with a Q-response. The Q responses fall generally into two categories.

(a) Certain commands issued by the branch driver ask a question regarding the status of some feature in the addressed module. The module answers by means of a Q response.

(b) The Dataway specifications define three modes of block transfer of data (Address Scan, Stop and Repeat modes) in which the Q-response plays an important part. These block transfers are effected by means of a series of Read or Write commands. In a branch system, the series of commands is issued by the branch driver. The Q responses can be interpreted so as to regulate the progression of the series either by branch driver hardware or by computer software. In a branch system, the array of modules accessed by a single Address Scan series can be contained in more than one crate. Some of the algorithms by which the series of commands can be generated are described elsewhere.[5]

In order to pass the Q responses to the branch driver, the Q signals of the individual crates are OR'd onto the branch BQ line as shown in Fig. 4. In the example of Fig. 4, it is assumed that the command on the branch is addressed to a module in crate 1. 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 only the Dataway Q from the addressed crate(s) is gated onto BQ. The Q response of this crate and all Q responses from any other addressed crates are wire-OR'd onto the BQ line, which is available to the branch driver.

L Requests

A CAMAC module may, in the course of time, need to request attention from the system controller. For this purpose, the Dataway provides the means for transporting an individual L(Look-at-Me) signal from each module to the crate controller. These enable the crate controller to know instantly not only that a module needs attention, but also which module. It would have been expensive to give the branch driver the same capability for instantly identifying the module generating an L request. This would have required 161 wires -- 7 crates/branch x 23 modules/crate = 161 modules/branch. This is more than the 66 wires that the branch uses for all other purposes. One could reduce

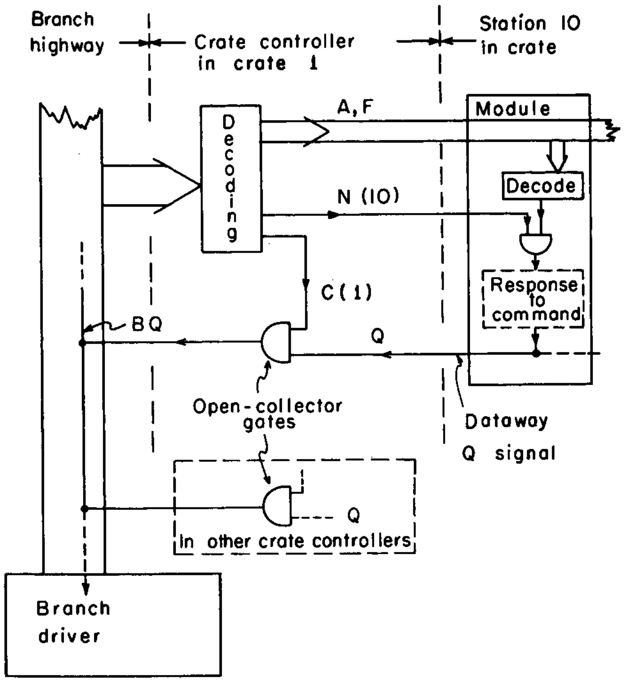

Fig. 4. The Q circuit. The branch driver issues a command directed to a module. The module gives response on the Dataway Q line. The Q signals are collected on BQ and thereon arrive at the branch driver.

the number of wires required by arranging to carry the binary code of the location of the Look-at-Me, 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 based on the following features.

a) A branch signal, Branch Demand (BD) is used to indicate the presence of a request for service anywhere in the branch.

b) The 24 BRW lines are given an extra task: to carry a 24-bit L-request status word. This word is known as the graded-L word (GL-word).

c) A signal generated by the branch driver, the Graded-L Request (BG) signal commands each crate to place its contribution to the GL-word onto the BRW lines.

Each crate controller Type A has a LAM-grader connector mounted on its rear panel. The 23 L lines of the Dataway are brought to 23 pins of this connector. Another 24 pins accept 24 binary signals which are, in fact, the contributions of that crate to the GL-word. The signals available at the LAM-grader connector permit an external device known as a LAM grader to create GL-bits from various logical combinations of the L-request signals. The Demand (D) signal in a CCA is the OR'd sum of the 24 GL bits, and the Branch Demand (BD) is the OR'd sum of all D signals. Note that a D can be generated only if there is a LAM grader connected to the LAM-grader connector.

Graded-L word

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 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.

In the simplest form, the LAM-grader consists only of some wires on a mating connector. For example, connecting pin 20* to pin 33 of the LAM-grader connector assigns L(10) to bit 16 of the GL word. Or, connecting pins 24 and 26 to pin 13 assigns the wire OR'd sum of L(12) and L(13) to GL bit 6. Keep in mind that this same bit assignment takes place in the other crate controllers of the branch. A given bit on the GL word may be used to carry information from modules in several crates, if desired.

Many systems have their LAM graders in the form of modules. These can contain as sophisticated an array of logic as the designer wishes to have (or can afford).

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.

An example

The steps involved in determining the source of an L request are illustrated in Figures 5 and 6. Let us assume that the module in station 10 of Crate 1 in Fig. 5 sets its L to logic 1. This sets L(10) of the Dataway to '1'. L(10) is directed by the LAM grader to a GL-bit, say GL(12). A 23 input OR gate in crate controller (1) generates a logic 1 output if any of its 23 GL inputs is in the logic 1 state (this includes the GL bit assigned to our L(10), of course). The output of the OR gate, along with all similar OR gates in all crate controllers of the branch is 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.

In Fig. 5, the branch driver has issued the BG signal. In response to this, the crate controllers place their contributions to the GL-word onto the BRW lines. This information is shown being saved in a GL register in the branch driver.

Command Accepted, BX

Each Dataway has a line called Command Accepted, X. It collects signals from addressed modules indicating the ability of the module to execute the command. As with the Q-BQ pair, the X signals from the crates are simply wire-OR'd onto the BX line of the Branch Highway. This makes the Command Accepted signal available to the Branch Driver.

*A complete list of pin assignments for the LAM-grader connector is in the specification.[1]

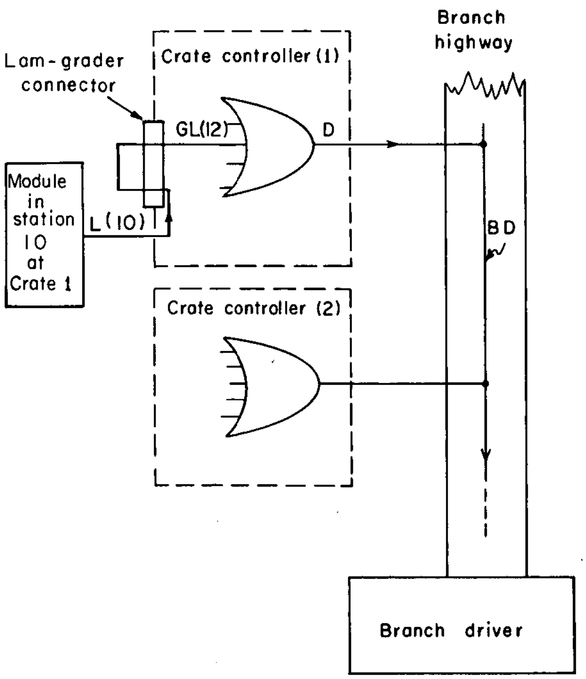

Fig. 5. In this illustration, the module in station 10 of crate 1 issues an L signal. Via the LAM-grader (just a piece of wire in this example) the L is assigned to a GL bit. The OR'd sum of the GL bits travels via the BD line to the branch driver. Wake up, branch driver!

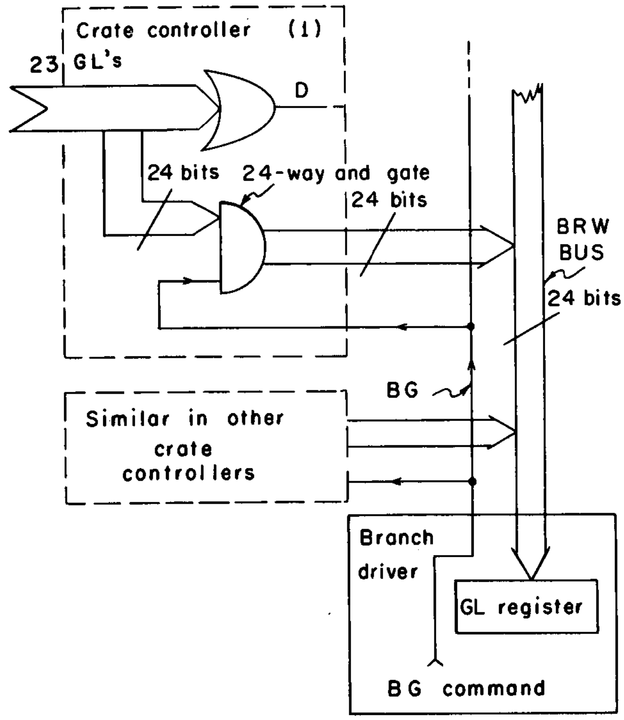

Fig. 6. This shows the use of the BRW lines in collecting contributions to the GL word.

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Note: References 2-5 will be published in the April 1973 issue of IEEE Transactions on Nuclear Science. This issue will be called "CAMAC Tutorial Issue."