THE CYCLOTRON CORPORATION BUS-ORIENTED COMPUTER CONTROL SYSTEM

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Abstract

A bus-oriented computer control system has been developed for manual and automatic operation of cyclotrons. The bus is a noise-immune, optically isolated extension of a DEC LSI-11 computer bus. This simplifies the software since each device register is addressed as if it were a computer memory location. Thus the full range of PDP-11 instructions can be used to operate directly upon any cyclotron data location. Standard modules have been designed to interface power supplies and other cyclotron subsystems to the bus. They perform the functions of ON/OFF control, monitoring of interlock status, control of analog variables, and analog data acquisition. All digital data output to a subsystem can be read back for verification.

Introduction

The Cyclotron Corporation has designed a series of small variable-energy cyclotrons which can be operated routinely by a non-technical person without the necessity for manual adjustments during operation. The start-up, tuning, and shut-down are performed automatically by a computer which controls all cyclotron parameters. Only the desired energy and intensity of the beam need be specified.

To facilitate automatic operation the cyclotrons have been designed with a smaller number of control variables than is usual for a variable energy cyclotron. This is accomplished by accelerating negative ions which are extracted by stripping. The energy of the extracted beam is varied by changing the position of the stripping foil and the current in an external combination magnet. With this arrangement the RF frequency and the cyclotron magnetic field are the same for all beam energies. No radial profile coils are needed. The negative ion source is located at the center of the cyclotron so there is no injection system.

In order to select a method of interfacing the computer to the various cyclotron power supplies and other cyclotron subsystems, an analysis was made of the requirements for reliable control of a small cyclotron. Then existing interface systems were examined before designing a new one for our application.

Requirements

The decision was made that the actual implementation of a digital interface would have the following characteristics:

1. All interlock circuitry for the protection of equipment or personnel must be hard-wired. The control computer is not depended upon to take any action necessary for safety.
2. The complete status of all interlocks must be available to the computer.
3. There must be a way of verifying all setpoints and ON/OFF commands.
4. Devices interfaced to the digital system must require no more attention from the computer than a conventional analog-only control system would require from a human operator. Power supplies are well regulated and analog data acquisition units have data available immediately whenever the computer requests it.
5. The control system must provide backup hardware capable of controlling individual subsystems either locally or remotely without the computer. The backup controller may be digital but must be simple in design and operation.
6. Cyclotron power supplies must be electrically isolated from the digital transmission system. This requirement is insurance against data loss or damage to logic components under conditions of high load transients and consequent excursions of the power supply ground.

Existing Standards

Two existing interface standards were considered before deciding to define a new one specifically for our use. One of those is CAMAC, used widely in accelerator control systems. Two possible CAMAC configurations would meet the requirement of electrical isolation between the power supplies. One would be to use a CAMAC crate and crate controller for each power supply. The crates would be connected to an isolated serial highway. This approach was deemed inefficient in the use of CAMAC module slots, and unnecessarily expensive. The other possibility is to use a smaller number of CAMAC crates and distribute control and status lines from each crate to several power supplies. In order to maintain isolation these lines would all have to be digital. That implies the design of our own D/A and A/D converter hardware and involves more cabling. Also the grouping of functions in a crate would depend on the physical locations of the power supplies and other subsystems, which are not the same in all installations of our cyclotrons.

The GPIB (General Purpose Interface Bus, IEEE Standard 488) was considered as another alternative. One problem with the GPIB is that the standard makes no provision for electrical isolation or even for long transmission line lengths. Adapters to overcome these deficiencies are available, although not according to a fixed standard. The devices presently available for the GPIB do not match well the requirements of cyclotron control.

Most seem to be better suited to a low-noise laboratory environment. Hence we would have had to build some of our own interfaces in this case also. Our examination of the standard and the little other literature available on GPIB did not encourage us as to the ease of such interfacing.

The decision was then made to design a digital interface specifically suited to electrically isolated control of randomly placed subsystems. Since the computer would be dedicated to cyclotron control functions, it was felt that the use of a non-standard interface would not hinder any potential application of the cyclotron. Users who need computer capability for their application provide their own computer and interface. Communication between an application system and the cyclotron control computer can be easily arranged as necessary.

The T.C.C. Bus

The analog variables to be controlled in a cyclotron require an accuracy of 12 bits in most cases, and 16 bits for the main magnet supply. 16-bits is also the most common word size for minicomputers. It seemed natural therefore to use a bus which transfers data as 16-bit words. The Cyclotron Corporation chose as a model the bus of a Digital Equipment Corporation LSI-11 computer. The LSI-11 bus is similar to the UNIBUS, used on other PDP-11 computers, the major differences being the shared use of the same lines for data and address, and the reduction of the number of priority levels for interrupts. The T.C.C. Differential Bus is logically a subset of the LSI-11 bus. Electrically it consists of differential-pair signal transmission lines, driven by tri-state drivers which are disabled in all devices except the one transferring data or address.

The 21 lines comprising the data transfer section of the LSI-11 bus are present in the T.C.C. bus. Both address and data are time-multiplexed over 16 data/address lines. To write or read the contents of a device register, the processor first asserts the device address on the bus for a fixed time. After the address time has been completed, the processor performs either an output or input data transfer to or from the device. The actual data transfer is asynchronous and requires a response from the addressed device. Of the 5 control lines, 3 are driven by the processor to specify whether the data/address lines are currently being used for address, input data, or output data. One is used to specify that a write operation is to alter only half of the device register (one 8-bit byte). The fifth control line is the reply line, used by the addressed register to indicate that it has placed its data on the data/address lines or that it has accepted output data from the lines. In addition to these 21 lines used for data transfer, the T.C.C. bus has 2 interrupt request lines, each generating a vector on the computer's bus if enabled by the program.

The logical similarity of the T.C.C. bus to the LSI-11 bus facilitates the control of the bus by an LSI-11 computer. The interface between the two buses can be a bus window, transparent to the computer. This is shown in figure 1. The T.C.C. bus occupies a 256-word portion of the computer's overall address space. Thus the program can access any device register with one assembly-language instruction, just as it would access a memory location.

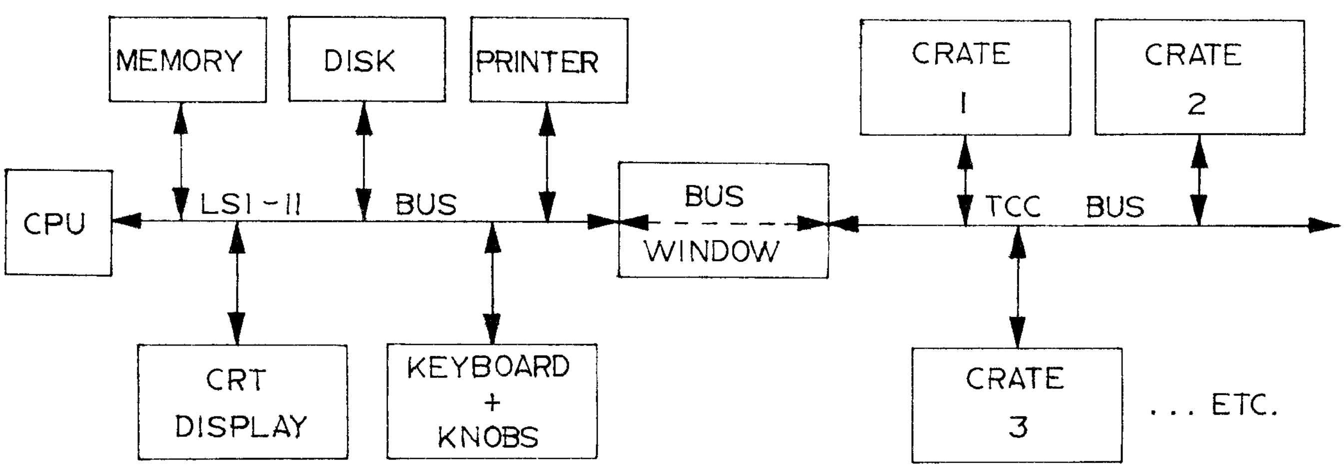

FIG. 1

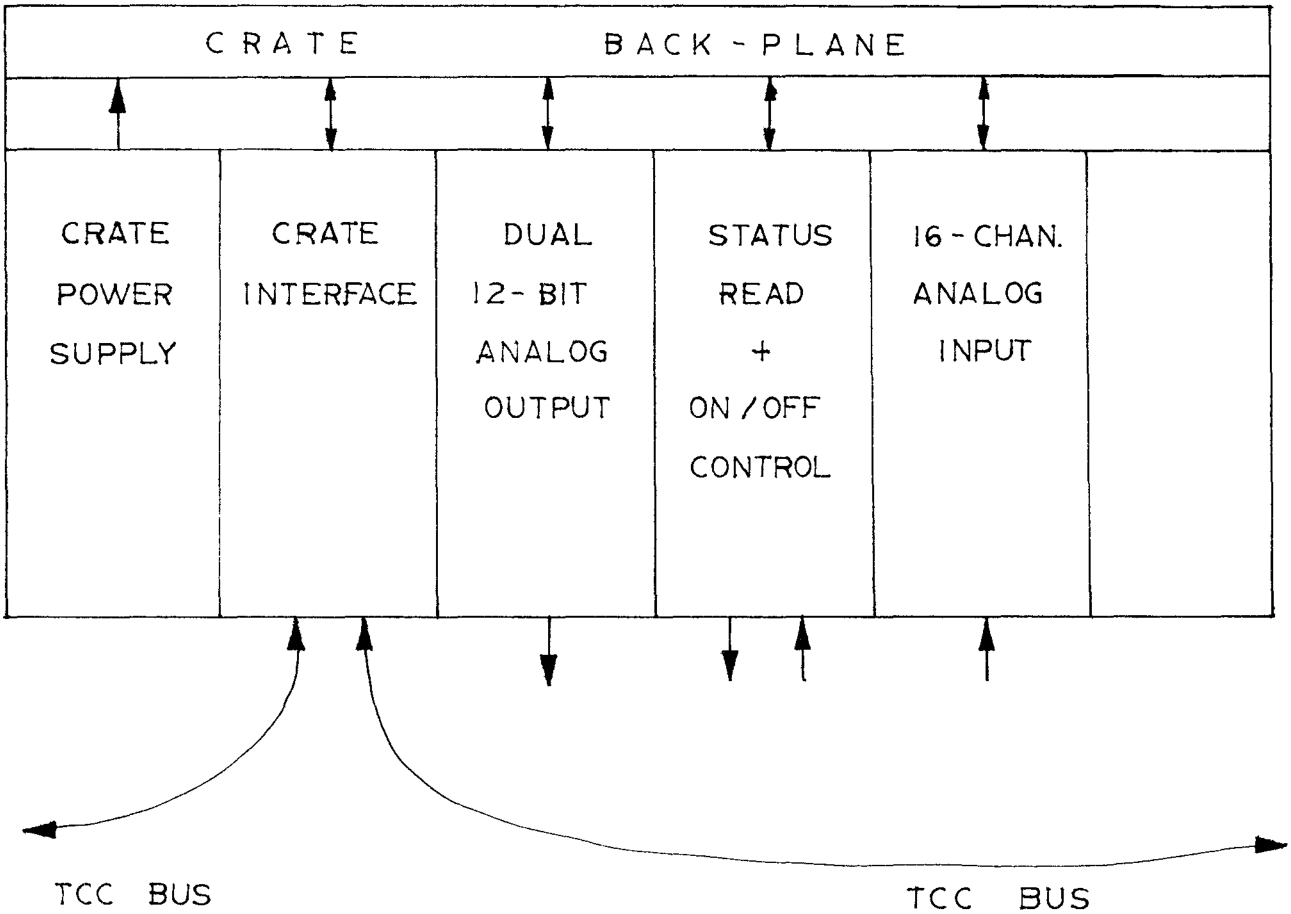

FIG. 2

The small number of lines and simple protocol of the T.C.C. bus allow economical interfacing to cyclotron power supplies and other equipment. Figure 2 shows a module crate which would be used in a typical power supply, and a crate interface which isolates the modules electrically from the bus. The crate interface also decodes addresses and performs timing functions.

Several modules have been designed to interface power supplies and other cyclotron subsystems to the crates. One module performs a dual channel 12-bit analog output function. Another has one 16- bit output which slews at a predetermined rate to whatever setting is written to its SET register. A 16-channel analog data acquisition module converts voltage levels to 12-bit binary numbers and stores them in a local memory. The contents of this memory can be read via the bus. One type of module contains a 16-bit status input register and 12 single-bit outputs, 6 of which are 0.5 second pulses.

In addition to the operating hardware, devices have been designed and built to test all modules, interfaces, and the bus. These are simple boxes containing switches and lights for the various lines of the bus, and a limited amount of logic.

Current Status

The hardware to control a cyclotron using the T.C.C. bus has been built in prototype form as of September, 1978. It is expected that a cyclotron will be operating using these controls in January of 1979.