

A MODULAR APPROACH TO DISTRIBUTED CONTROL IMPLEMENTATIONS

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Abstract. The implementation of two distinct low-cost distributed control schemes is discussed. Intended for projects on the fields of industrial automation and energy management, both systems were developed using a modular system conceived and executed previously. This modular system was designed for stand-alone control applications. The text discusses how additional hardware and software have been designed in order to allow its utilization as the standard outstation on the distributed environments implemented. The physical connections differ substantially from each other. One is a twisted pair where high data rates are possible. The second is the low-voltage power grid, where a power-line carrier technique is used to code information by means of FSK, where comparatively low data rates are imposed. The software enveloped to support communications through the network is designed in such way as to provide the user with similar facilities in both implementations.

Keywords. Controllers; control equipment; energy control; industrial control; communications control applications.

INTRODUCTION

Modular systems are nowadays widely used in the development of microcomputer-based instrumentation. Thus, emphasizing their advantages to design-to-cost approaches is likely to turn-out into a set of common-places. At the Department of Electrical Engineering (DEE) a decision to implement a modular system arose for two main reasons. On one hand, several research projects needed a flexible and easy to use controller to accomplish diverse tasks, each one with its specific needs and environment. On the other hand it was believed that student research projects would develop and produce results more quickly when the students involved in control applications would not need to build-up the whole hardware with which to work.

THE BASIC MODULE

The modular system has been named with the designation MIUC, that will henceforth be used.

The main module, henceforth designated FCMI, and shown by the diagram in Fig. 1, is the CPU card. It features: an 8031 microcontroller as CPU, driven by a 12Mhz crystal; 64 Kbytes of both external data and program memory; memory space may be selected at will to accept banks of

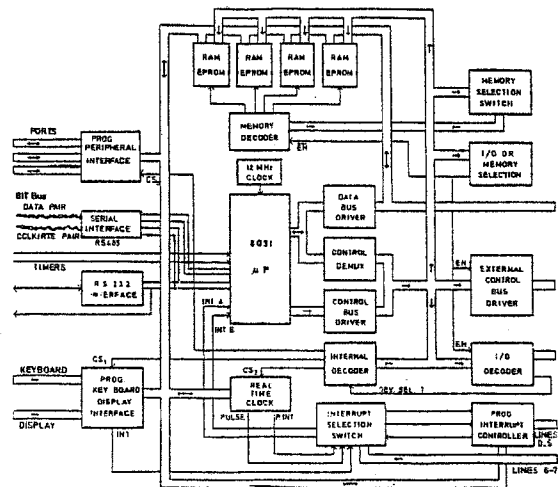


Fig. 1. Main module configuration

2K, 4K, 8K, 16K and 32Kbytes; 32 TTL level I/O lines, of which 8 are individually programmable for input or output; a serial channel both at TTL and RS232 levels, with programmable baud rate; real-time programmable clock-calendar with battery back-up, independent functions of clock, alarm, timer and interrupt generation capability; a priority interrupt

controller for 8 different lines, also providing an enable/disable function for each interrupt; optional keyboard and display interface circuit; interface arrangements for a communication channel implementing standard RS485; an I/O address decoder that enables the simultaneous use of seven other modules, each with an internal address space of 64 positions; various connectors to accomplish different tasks - a DIN41612 connector to the bus common to all modules (MIUC bus), a 24-way connector for keyboard and display access, a 42-way connector for the I/O lines and access to the 8031 internal 16 bit timers and a 10 way connector for the serial ports.

Software development aids are available for the 8051 family of microcontrollers that may be used with the MIUC. Namely, Basic52, a compiled PLM version known as PLM51, Macro assembler and a linker that allow the development of applications intermixing both levels of programming languages. Besides, a real-time executive is also available, with the help of which a multi-tasking working mode may be implemented in the MIUC system. Finally a monitor/debugger was developed, which implements the usual functions, and turns possible the communication with a external development system by the serial channel.

For applications requiring no further hardware but with need of direct user interface, a dedicated module has been developed that uses the keyboard/display interface provided plus some extra I/O lines. This board features: LED drives for a 7-segment 8 digit display, 2 opto-isolated lines for external pulse inputs, an interface to a mini-printer for hard-copy report/diagnostic production, interface for 2 rotary-switches and input lines for a 16 keyboard.

FURTHER MODULES

Analog I/O

A second module pluggable into the system common bus, provides analog I/O, featuring: 32 differential input channels multiplexed to a single A/D converter with a 12 bit resolution; 4 different ranges for the analog voltage input are possible through the use of an instrumentation amplifier provided with software programmable gain; the sampling period is less than 50 μ s in all cases. Digital to analog conversion is implemented through 2 output differential channels with 14 bits resolution, with conversion time less than 6 μ s and two ranges of voltage amplitude. Fig. 2. depicts the configuration just described.

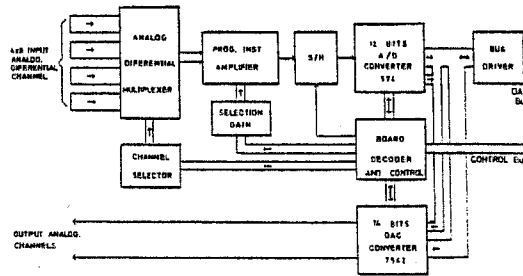


Fig. 2. Analog I/O module

Interface to the User

Module 3 is a general-purpose man-machine interface. It comprises interfaces to an LCD alphanumeric display with 32 characters, a keyboard with 16 or 32 keys, a rotary switch with 8 positions, 4 output SPDT miniature relays, a panel mountable mini-printer and also 4 opto-isolated input channels. It has been conceived to serve a wide range of applications.

Miscellaneous

Several other modules have been designed and implemented. A fast analog I/O board with two 12 bit DAC's and eight 8 bit DAC's, 32 analog input channels multiplexed to an ADC with 10 bit resolution or, alternatively, 16 analog inputs to be converted in 2 μ s with 8 bit resolution is intended for use in applications requiring high-speed data conversions and a considerable number of analog outputs.

Two supplementary serial channels (RS232) and a number cruncher have been accommodated into another module to increase both interaction capability with peripheral equipment and numerical computation ability.

Two actuator modules exist for power interface, one implemented with opto-isolated triacs with zero-crossing switching and the other with electromechanical relays, both with 8 outputs rated at 240 VAC. The former switches currents up to 8 Amp and the latter 10 Amp.

COMMUNICATION FACILITIES FOR DISTRIBUTED CONTROL

Modules 1 to 3, more extensively described, when used together implement a complete station. In fact, they provide processing capabilities, analog and digital I/O and a versatile user interface for local parameter programming, mode selection, display, etc. These features are adequate for most applications where a single controller is

enough to handle all the required tasks. However, some of the projects in course at the DEE have been specified based on distributed processing architectures. Low cost was a key design criterion. This led to the decision of implementing the necessary hardware and software interfaces to establish a network where the forementioned basic modular system would play the role of intelligent outstations, organized in a hierarchical structure. Differences exist between the master and the slave implementations both at hardware and software levels. Special concern has been put, however, in minimizing these differences, in order to achieve simultaneously low-cost and easy reproducibility implementation. Owing to different project environments, two physically different designs have been considered. One of them achieves fast data communications through a twisted-pair of wires, based on Intel's Bitbus specifications, and it is to be used in a manufacturing automation application. The other uses a power line carrier (PLC) technique to convey information through the electricity distribution grid. Having much slower data rates, it is to be used in an energy management system (EMS). This technique of communication is specially attractive in retrofit applications, where the cost of installing dedicated wire for control purposes may lead to very large EMS payback periods.

The use of two such different techniques imposes totally independent designs at both the physical and data link layers of the network. However, special concern has been put to achieve compatibility between the two implementations at the next layers. The objective is to allow the use of similar procedures to perform the communication tasks, avoiding the development of different software tools for each network implementation.

FAST COMMUNICATION MODULES (FCM's)

Typically, industrial control systems involve a large amount of I/O points, master-slave connections and short packets of information circulating at high speed. Recently, Intel introduced a serial-network architecture designated Bitbus, specified with the declared purpose of standardize and simplify the design of real-time distributed control systems. It configures a structure of the hierarchical type, corresponding to the forementioned characteristics, materially implemented in hardware through an enhanced version of the 8051 microcontroller referenced 8044, and in software through a real-time multi-tasking executive for the same family of devices in conjunction with some specific Bitbus utilities.

The FCM1, having already available the interface standard RS485, has been used as the basis to implement the Bitbus specifications at the modular system

already existent. Two types of node were considered: one being able to act as master or slave (FCM2), the other just as slave (FCM1). It is thus possible to explore the modular characteristics of the MIUC system at the slave level, assigning it the fundamental attributes of an intelligent outstation. The FCM2 has been built around a modified FCM1 version, basically to accommodate a parallel interface to a host computer acting as the network supervisor. This module may also be used to implement a multiple level hierarchical network when in communication with a FCM1 through the parallel interface establishing a node from where a ramification to a new hierarchical subnetwork may start. The last will work as a slave node upwards and FCM2 as a master node downwards. The block diagram in Fig. 3 illustrates a possible network configuration achievable with the FCM's.

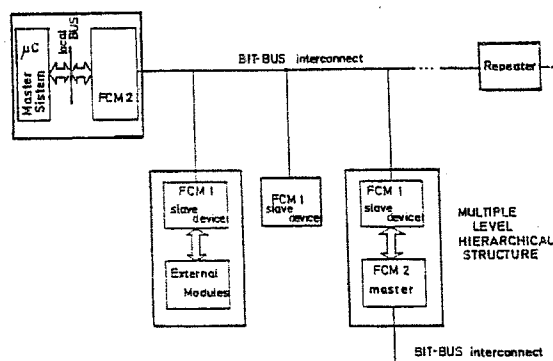
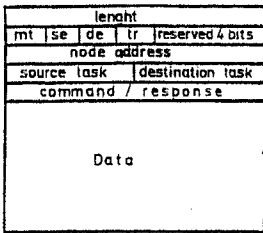


Fig. 3. Network configuration

The RS485 standard used in this implementation allows a multidrop support Fig. 3, here materialized with three different options for data transfer rates and maximum distances: 2.4 Mbaud over a 4 wire cable reaching 30 meters and 28 nodes (synchronous transmission mode); 375 Kbaud over a twisted-pair up to 300 meters and 62.5 kbaud up to 1200 meters (self-clocked mode), all of them selectable at the FCM's boards.

Both FCM's use the 8044 microcontroller taking profit of the RS485 interface to implement the network's physical layer. Message framing and the control of frame transfer over the data link is executed by specific software that Intel developed according to a subset of the IBM SDLC protocol. The use of the 8044 at the FCM's makes these tasks transparent to the user, provided that he respects the rule of connecting a single master to several slaves in a multidrop topology. A message protocol, Fig. 4, allows a task to task interface between the master and slaves, with an order/reply structure, in the multi-tasking environment provided at each node by the real-time executive software.



mi-message type
 se-source extension
 de- destination extension
 tr-track

FIG. 4. Message Format

As shown in Fig. 5, one essential part at the FCM2 module is the parallel interface. It is basically composed of two latches acting as a one-byte-FIFO, one being the transmit-register and the other the receive-register. Respectively Figures 5, and 6 illustrate the structure and hardware diagram of this interface.

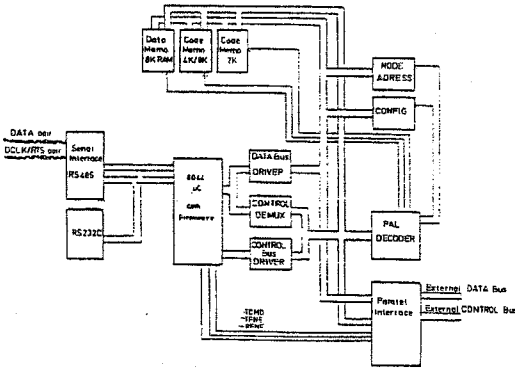


Fig. 5. FCM2 Module configuration

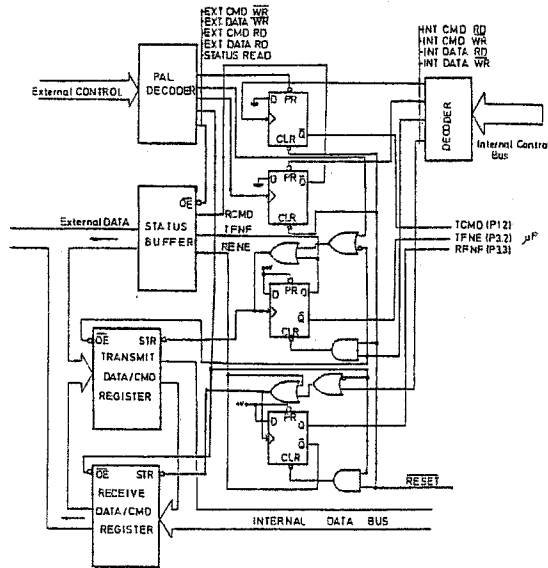


Fig. 6. Parallel Interface hardware

POWER LINE CARRIER MODULE (PLC)

The PLC module, consists of a MIUC based board to be connected to a parallel bus through a parallel interface similar to the one described for the FCM2 above. On the other hand it establishes the interface to the power grid in order to use it as a data transmission medium. In this particular implementation of a network for distributed control, the PLC module is an integral part of the MIUC based outstations. Fig. 7 depicts a PLC node block diagram.

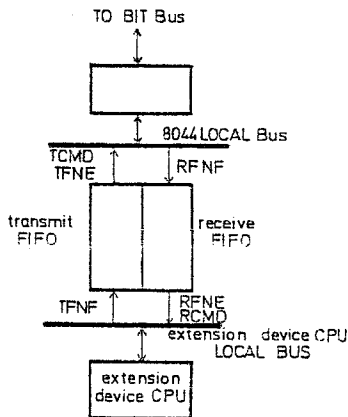


Fig. 6. Parallel Interface structure

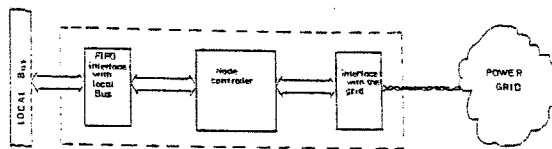


Fig. 7. PLC Node block diagram

Each byte of a message is formatted according to Fig. 8, based on the encoding scheme proposed in the Bi-Line BAT system by National Semiconductors. Four different fields compose the frame format: information field, containing one byte of the message to be transmitted, preceded by a preamble and a byte address field, and followed by 4 bit control field and checksum. The address

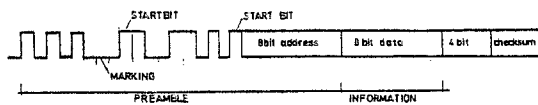


Fig. 8. Frame Format

involved in the transfer. In the hierarchical system implemented this implies that a master will never be able to address more than 255 slaves. As the power grid is an extremely noisy media each message to be transmitted is partitioned to conform to the one-byte information structure just presented. This forced to incorporate a means of controlling the message length. The 4 bits of the control field are used for this purpose, constantly indicating the remaining number of bytes to be sent for transmission completion. Two data link error conditions are considered, that we defined by time-out and protocol errors. The first occurs when the master device transmit a frame without receive the correspondent response within a programmable interval time. If three consecutive of this errors occurs, is indicated a time-out error. Any other type of errors are considered as a protocol error, that includes all type of frame format corruption. Also in this case it is taken an action similar to the described above, but with a different indication of error.

As it will be referred below, there are problems derived both from the noisy characteristics of the power grid and from the information encoding technique used - FSK, asynchronous mode. This implies that it is not possible to recover information using a standard UART device. In this situation, the 8051 microcontroller on the PLC module not only manages the frame formatting according to the protocol used, but also has to perform as a special UART device to solve the forementioned problems. The transmission speed achieved up now is 1200 Baud.

The message protocol used has an order/reply structure, analog to the one referred for the FCM's.

The physical interface with the power line is implemented with the LM1893 integrated circuit. It is a transmit/receive chip that converts both ways digital data and FSK coded information. The traditional problems encountered in the coupling to the AC line have been handled by following the manufacturer's specifications. Fig. 9 represents the typical coupling to the AC network and connections used between the microcontroller and the LM1893.

Thus latter circuit has two modes of operation (receive and transmit), selectable by the logic state of an input line. Its functional characteristics have had influence on the frame preamble

organization, Fig. 8. The first 3 cycles of alternating bits are justified by the need to perform the lock of the internal PLL on the incoming signal. The next three low bits are used by the reception algorithm to perform as a mark preceding the start bit that follows. A unique bit pattern, follows completing the preamble, with the specific function of reinforcing the ability to detect synchronization errors.

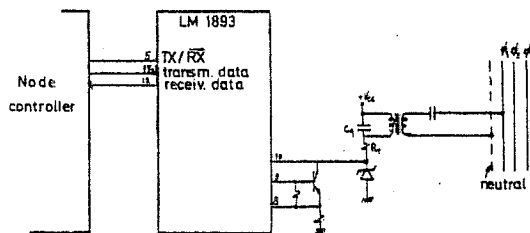


Fig. 9. Typical coupling and connection with the controller.

CONCLUSION

A versatile low-cost modular system, formally intended for stand-alone control applications, has been enhanced in order to allow its use on distributed control schemes. Both a high and a low-speed transmission channels have been implemented, for different applications such as industrial automation and energy management. Future objectives in this field of work include tests on adverse (noisy) environments to analyse performance.

REFERENCES

- Budzinski, M.C. (1984). Bitbus promises to standardize control. Systems Software, July.
- Williams, P.D.M. (1984). Serial bus simplifies distributed control. Control Engineering, June.
- Wolochow, P.I. (1984). Intel's bitbus microcontroller interconnect - a modern method of robot communication Robotics Age, June.
- Frederiksen, T.M. (1982). Silicon Technology for Energy Management Systems. IEEE Intersociety Energy Conversation Conference.
- Lee, Mitchell (1982). A new carrier current transceiver. IEEE Transactions on Consumer Electronics Vol CE-28, Num 3.
- National, Semiconductor Corporation. The Bi-Line Carrier Current Networking System. National Literature Department, Literature No. 570075.