THE APPLICABILITY OF APT TOWARDS MEETING CONTROL NEEDS IN DISCRETE PARTS MANUFACTURING

by

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(ABSTRACT)

For about ten years, Texas Instruments has been developing a software environment of integrated tools for designing, debugging and documenting process control solutions that run on programmable controllers. The product -- the Applications Productivity Tool (APT), allows process and control engineers to design and program in a graphical environment that compiles into machine code (relay ladder logic). APT is primarily targeted for the batch manufacturing industry in which engineers combine elements of both discrete and continuous control strategies.

The objective of this research was to determine the applicability of APT in discrete parts manufacturing, using two applications of discrete manufacturing. One of these applications was a Fischertechnik model of a manufacturing system, configured to simulate the production of three distinct parts. The other application was the flexible manufacturing system being assembled in the Computer Integrated Manufacturing Laboratory (CIM Laboratory), which is equipped to produce models of a robot and a CNC milling machine.

The integration of the various activities and signals was done using the TI 565 programmable controller. APT code was generated using the TI CVU 6000 computer workstation, and then downloaded to the controller. This APT code generated ladder logic, and the resulting control solution was then compared to the manually generated relay ladder logic. The effectiveness of these two methods is presented, as are some problems associated with programming in APT. The limitations and shortcomings encountered with APT with regards to the SFC language, the devices used, and the modules included, are also discussed. The generated codes were tested on these two applications, and on the basis of the results, the applicability of APT in these two applications of discrete parts manufacturing was established. This research was specifically aimed at identifying problems in applying APT to discrete parts manufacturing, and at identifying appropriate alternative ways to organise discrete parts manufacturing control with the APT structure.

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Chapter 1
Introduction

1.1 Introduction

A programmable controller (P/C) is a solid state, industrially hardened device designed to control machine or process operations in the industrial environment. It makes use of a memory resident program to take certain actions (outputs) in response to conditions which are being monitored continuously (inputs). These inputs and outputs interface with the P/C through modules or devices. The National Electrical Manufacturers Association (NEMA) defines a programmable controller as a digital electronic apparatus with a programmable memory for storing instructions to implement specific functions such as logic, sequencing, timing, counting and arithmetic to control machines and processes [5].

Programmable controllers have been described as the industrial revolution of the seventies. They have, in the short span of time since their introduction, provided extensive industrial control capabilities never considered possible in prior years. Industrial control systems incorporating P/C's are now able to operate machines or processes with an efficiency and accuracy never before achievable with conventional relay-based control systems, which were used prior to the birth of the P/C's.

P/C's are the electronic replacement for relay and switch control systems. They have traditionally been used for discrete, on/off logic in areas such as automobile manufacturing, storage and retrieval systems, spray painting, steel making, and in the chemical and petrochemical industry. P/C's provide the fast scan times for I/O required in that domain.

P/C's make use of a stored program to achieve control funtions. There are four types of languages normally used to create the P/C program [5]. These are:

* Boolean Mnemonics
* Ladder Diagrams
* Functional Blocks
* English Statements

These languages can be grouped into two major categories. The first category is comprised of Boolean mnemonics and ladder diagrams, which are considered basic P/C languages. The second category consists of the functional blocks and English statements, which are considered higher level languages. The basic P/C languages consist of a set of instructions that will perform the most primitive type of control functions: timing, counting, sequencing and logic, and are essentially aimed at discrete on / off control. However, depending on the controller model, the instruction set may be extended or enhanced to perform other basic functions. The high level languages have been brought about by a need to execute more powerful instructions that go beyond the simple timing, counting, and on / off control. These languages are suited for operations such as analog control, data manipulation, reporting, and other functions that are not possible with the basic instruction sets.

1.2 Problem Statement

Programming methodologies [4] typically found in industries such as petrochemical, food, pharmaceutical, and automotive have historically been very different. They range from an emphasis on configuration, for elements like PID (Proportional Integral Derivative) loops in petrochemical industries, to an emphasis on relay ladder logic in the automotive industry. Discrete control deals with simple on/off control of a process, with actions taking place at specific, distinct points in time. Discrete manufacturing typically concerns the manufacturing of a discrete number of products, with each product moving from one processing area to another in steps. Continuous manufacturing, on the other hand, involves a continuous monitoring and processing of the product at all times of production. Batch control comes as an interface between discrete and continuous manufacturing, and is discussed in Section 1.4 with the help of an example. However, it is important to note that even though industries may be "typified" by a particular control orientation, most industrial plants contain some elements of all types of control, be it discrete, continuous, or batch. The industries commonly referred to as batch industries have a high mix of discrete and continuous control.

Relay ladder logic (RLL) has traditionally been the language of choice for programming P/C's. Initially, RLL adequately performed simple Boolean functions, aimed at discrete control, but industry needed more functionality for finer control. Eventually, RLL capabilities were extended to include calculation blocks. Then, as total factory automation became desirable, and as the need arose for control strategies for both discrete and continuous processes, P/C vendors added hardware to perform some portion of the continuous control, such as PID loops, and provided rudimentary interfaces between RLL logic and the continuous calculation.

Relay ladder logic is an ideal user-oriented language for the electrician who maintains the system at the shopfloor, but it does not support well the growing complexity of control systems, especially the more "batch" type requirements such as recipes and interlocks in the food, pharmaceutical and chemical industries. RLL's awkwardness in handling the growing complexity of control requirements, the reluctance of new, more computer-literature engineers to use a Boolean language, and the need to better integrate, not just interface, support for the continuous and discrete portions of control, all conspired to create an opportunity for a better software engineering approach in the domain. The concept of Grafcets [6], Petrinets [13], and state transition techniques [12] are some of the software engineering efforts aimed at overall manufacturing control. Grafcet is a sequential function program that uses macro steps whereby the system designer follows a logical, top down approach beginning with a global representation of the system, and then successively developing each subsequence. If a problem or fault occurs during operation, this approach allows the user to zoom in on the problem area to focus on the causes [6]. Petrinet is one step beyond a Flexible Manufacturing System. It is the complete automation of a manufacturing system. All commands are given by a main controller including the assignment of jobs, inspection and rerouting if a breakdown or defect occurs. The Petrinet is a diagram of a system in the form of circles, lines and arrows. Petrinet itself can be viewed on a screen as the system is running so that the exact state of the system can be known by looking at the screen [13]. State transition techniques are discussed in detail in Section 2.6.

The Applications Productivity Tool (APT), recently announced by Texas Instruments, is an attempt at a software oriented control solution for continuous, discrete, and batch manufacturing. The APT control design system is not confined to the controls in just one area of the plant. It is aimed to handle continuous control, using packages (such as PID loops) for feedforward and decoupling of loops, for example, just as well as it handles sequencing logic required in batch processes. The objective of this research was to see if it is possible to apply APT as an alternative to relay ladder logic in the discrete manufacturing environment.

1.3 The Applications Productivity Tool (APT) : A Software Approach

APT is a self-documenting, graphical programming environment for process control design and implementation. The APT structure allows for a mapping of the physical process into the control strategy. APT encourages partitioning of the control problem so that the structure of the control system reflects the structure of the physical process. For instance, batch systems can be viewed as a collection of major pieces of processing equipment (units) that have associated with them temperature sensors, pressure switches and other secondary support equipment such as motors, pumps and valves. Two graphical languages within APT, the

Sequential Function Chart (SFC) language and the Continuous Function Chart (CFC) language, are provided for handling design problems ranging from discrete to batch to continuous manufacturing applications. When a design is complete, APT automatically translates the charts into ladder logic code for use on the TI 565 controller. This frees the engineer from this detailed task in order to allow him to concentrate on the "bigger picture", i.e. the overall control strategy. The Texas Instruments claim is that the ladders generated can be used directly by floor personnel for purposes of maintenance and debugging.

1.4 Research Objective

APT was created to allow the user to handle batch process control in an efficient manner. The ability to represent parallel processes easily allows APT to handle the unique problem that batch processes represent. Batch control essentially involves the integration of discrete control with continuous control. In batch control, some common equipment is used for different processes or products. A typical example of a batch control application is in the food processing industry, wherein certain ingredients are required to make a product. Measured quantities (by weight) of each ingredient have to be mixed. The mixing has to be stopped after a certain temperature is reached. In order to do this, the temperature has to be continuously monitored, and this constitutes the continuous process control. Once the mix is made, it is sent to another equipment for further processing. This is where discrete control steps in, and processes the transition from one state to the other. The previous equipment may now be used to produce some other product, and the ingredients required may be different. Thus, batches of different products are produced, and this application would be classified as batch control.

APT was specifically targetted for the batch processing industry, which involves a combination of discrete and continuous manufacturing. The specific objective of this research was to determine the applicability of APT in discrete parts manufacturing, using two physical applications of discrete manufacturing. One of these applications is a Fischerteknik model of a manufacturing system, which consists of a parts loader, a conveyor, a parts diverter, the machining stations, and a parts sorter. This is configured to simulate the production of three parts, which have undergone different machining operations at the machining stations. The second application is the computer integrated flexible manufacturing system being equipped with two robots, two numerical control machines, a material handling and delivery system (AS/RS), a TI 565 programmable controller, and a network of computers. The system will be configured to produce wax models of a robot and a CNC milling machine.

The integration of the various activities and signals was done using the TI 565 P/C. APT code was generated using the Sequential Function Chart (SFC) language on the TI personal computer, and this code was downloaded to the controller. The resulting control solution was then compared to the programs generated manually in relay ladder logic itself. The effectiveness of these two methods is discussed, as are any problems associated with programming in APT. The limitations and shortcomings encountered with APT with regard to the SFC language, the devices used, and the modules included, are also presented. The generated codes were tested on these two applications, and on the basis of these results, applicability of APT for the two applications of discrete parts manufacturing was established. This research was also aimed at identifying problems, such as length of ladders generated and the compilation times, in applying APT to discrete parts manufacturing, and at identifying appropriate alternative ways of programming to organise discrete parts manufacturing control, using the APT structure.

1.5 Outline of the Research

This thesis is divided into six chapters. The first chapter outlines the objectives of this research. The second chapter presents a literature review of programmable controllers, their programming languages, state transition techniques, and the APT structure. The third chapter describes the two discrete manufacturing applications, and discusses the methodology used in the research. Chapter four outlines the development of the test programs in APT and RLL, while the fifth chapter presents the results and then discusses the merits and demerits of APT as applied to the two applications. The last chapter presents the conclusions and makes recommendations for future research.

Chapter 2
Literature Review

2.1 Introduction

With the strong desire for competitive advantage, and the need for efficiency and quality, it has become not only fashionable, but also imperative for corporations to invest in automation. According to David C. Penning of Dataquest Inc., the major growth (area) for manufacturing automation vendors will be in the areas of software, networks, and decision support systems [2].

Programmable logic controllers have come a long way. Today's controllers are performing extremely complex tasks, at ever-higher levels of integration, with greater reliability coupled with continually better cost and performance levels. But for all the progress in hardware and software capabilities, actual programming remains a long and complex task. The flexibility desired in automation (which has led to smaller control software design lifecycles), and the reduced time from concept to commissioning are factors which have led to the critical need to provide a complete, flexible, intuitive and easy to use set of support tools in an automated environment.

This chapter examines the background of programmable controllers, their principles of operation, and the varied programming techniques used in P/C operations. A comparison is made between APT and the most widely used programming technique, relay ladder logic diagramming. Some of the advantages and disadvantages offered by APT are examined. The main programming language used by APT for discrete manufacturing is the SFC graphical language. The underlying concept behind the SFC language is then discussed.

2.2 Programmable Controller Background

Industrial control of machinery and processes prior to the birth of the P/C was performed using specially designed industrial control relays. Most control relays are mechanical devices subject to wear and fatigue. The contacts of a relay can arc and eventually weld together. Large cabinet relays are noisy and generate a great deal of heat when in full operation, and relay-controlled systems must be hardwired, making the installation, or even a simple change, both time consuming and expensive to perform.

With advances in technology, especially in the field of electronics, solid-state replacements for the relays were investigated. As transistors and simple integrated circuits became more cost effective to use, companies such as General Electric, Allen Bradley, and Westinghouse developed solid state control systems. These systems increased the reliability of a control system immensely, and decreased the cost of an installation [7]. These systems gradually gave way to the P/C's, owing to some primary requirements, listed below:

1) The control hardware and / or device must be easily and quickly programmed and reprogrammed at the user's facility with a minimum interruption of service.

2) All system components must be capable of operations in industrial plants with special support equipment, hardware or environments.

3) The system must be easily maintained and repaired. Status indicators and plug-in modularity must be designed with the system to facilitate trouble shooting and repair.

4) The P/C should be capable of communication with central data collection systems for the purpose of system status and operation monitoring.

5) The P/C should be capable of accepting 120 volts ac signals from standard existing control systems, push buttons and limit switches. Output signals from the P/C should be capable of driving motor starter and solenoid valve loads operating at 120 volts ac.

Today, every P/C manufactured not only meets the original criteria listed above, it exceeds these simple requirements many times over. The P/C is in essence a special purpose computer designed to provide a more flexible and reliable alternative to an industrially designed relay based control system. The P/C of today is a total control system in a small package capable of assuming a variety of control system functions.

2.3 Principles of Operation

A P/C is essentially composed of two units, the Central Processing Unit (CPU) and the Input / Output interface. The CPU provides the intelligence to the controller and has three major components; the Processor, the Memory and the Power Supply. The CPU continuously reads (scans) input data from various sensing devices, executes the stored user program from memory, and sends appropriate output commands to control devices. This process of reading inputs, executing the program, and controlling outputs is done on a continuous basis, and is called scanning. Typical scan times vary from 2 to as much as 200 milliseconds, depending on the particular controller, size and structure of program and number of inputs / outputs [5]. The power supply provides all the necessary voltages required for the proper operation of the other CPU sections.

The Input / Output section forms the interface by which field devices are connected to the controller. The purpose of the interface is to condition the various signals received from or sent to the external (field) devices. Incoming signals from sensors such as pushbuttons, limit switches, force sensors, thermocouples, selector switches, and thumbwheel switches are wired to terminals on the input interfaces. Devices that will be controlled, such as motor starters, solenoid valves, pilot lights and position valves are connected to the terminals of the output interfaces. An additional component, the programming device, is required to enter the control program into memory.

2.4 The P/C as Compared to a Computer

The architechture of the P/C is essentially the same as that of a general-purpose computer. Some P/C's are implemented with general purpose computer chips. There are however, some points which distinguish P/C's from computers.

One of the primary distinctions between the P/C and the computer is that, while a computer is a general-purpose computer capable of executing many different programs simultaneously or in any order, the P/C is a special purpose machine designed to execute only one program at a time, and continuously [7]. The execution time for a program on the computer may take from anywhere between a few seconds to some hours, while the P/C has very fast scan times (2-200 milliseconds), and is continuously scanning the inputs and changing the outputs, whenever needed.

Secondly, the P/C was specifically designed to survive the not always stable conditions of the industrial environment and is not a general purpose data processing machine. A well designed P/C can be placed in areas with substantial amounts of electrical noise, electromagnetic effects, mechanical vibration, or extreme temperatures and non-condensing humidity; areas which are not very conducive to the operation of personal computers.

A third major distinction between the P/C and the personal computer is based on the programming language used for coding. P/C's use four major programming languages [5]; Boolean equations, logic diagrams, mnemonic programming, and relay ladder logic programming. Relay ladder logic has been the language of choice so far. Computers, on the other hand, use structured languages for their programming, and are aimed at scientific and data processing functions.

2.5 P/C Programming Languages

As mentioned earlier, there are four types of languages normally encountered in P/C's, which are used to create the P/C program [5]. These are:

* Boolean Mnemonics
* Ladder Diagrams
* Functional Blocks
* English Statements

These languages can be grouped into two major categories. The first category is comprised of Boolean mnemonics and ladder diagrams, which are considered basic P/C languages, while the second category consists of the higher level languages, the functional blocks and English statements. The basic P/C languages consist of a set of instructions that will perform the most primitive type of control functions: timing, counting, sequencing and logic, and are essentially aimed at discrete manufacturing control, such as is needed for the Fischertechnik Manufacturing model and the CIM Laboratory discussed later in Chapter 3. However, depending on the controller model, the instruction set may be extended or enhanced to perform other basic functions. The high level languages have been brought about by a need to execute more powerful instructions that go beyond the simple timing, counting, and on/off control. These languages are aimed at continuous or batch control type of operations, and are suited for operations such as analog control, data manipulation, reporting, and other functions that are not possible with the basic instruction sets.

The Boolean language is a basic level P/C language that is based primarily on the Boolean operators AND, OR, and NOT. A complete Boolean instruction set consists of the Boolean operators, and other mnemonic instructions that will implement all the functions of the basic ladder diagram instruction set. A mnemonic instruction is written in an abbreviated form, using three or four letters that generally imply the operations of the instruction. An example of Boolean mnemonics is shown in Figure 1 (a). X9 and X10 represent input instructions, while Y1 represents the output instruction. "STR" represents the start of a string of instructions. "AND" is an example of a Boolean operator, while the "OUT" instruction refers to the output of that string.

The ladder diagram language is a symbolic instruction set that is used to create a P/C program. The ladder diagram for the Boolean language program discussed above is shown in Figure 1 (b). The ladder instruction symbols can be formatted to obtain the desired control logic that is to be entered into memory. The main function of the ladder diagram program is to control outputs based on the input conditions. This is achieved through the control of what is referred to as a ladder rung. In general, a rung consists of a set of input conditions, represented by contact instructions and the contact symbol (Parallel lines), and an output instruction at the end of the rung, represented by the coil symbol (circle). Each contact or coil is referenced with an address number (not shown), which in term references either an internal output (control relay), or a connected input (X9 or X10) or output (Y1).

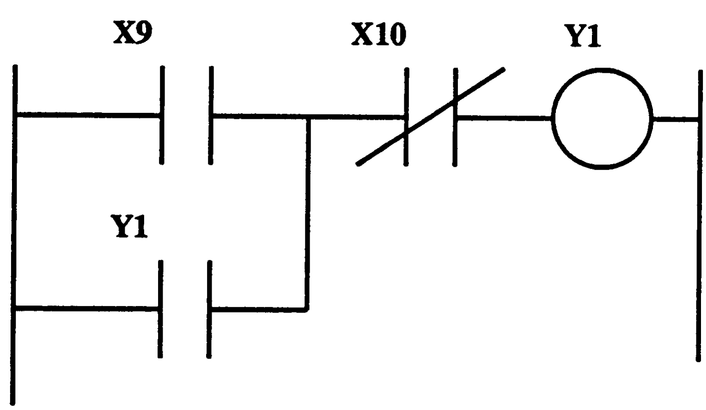
STR X9

OR Y1

AND NOT X10

OUT Y1

(a) Boolean Mnemonics



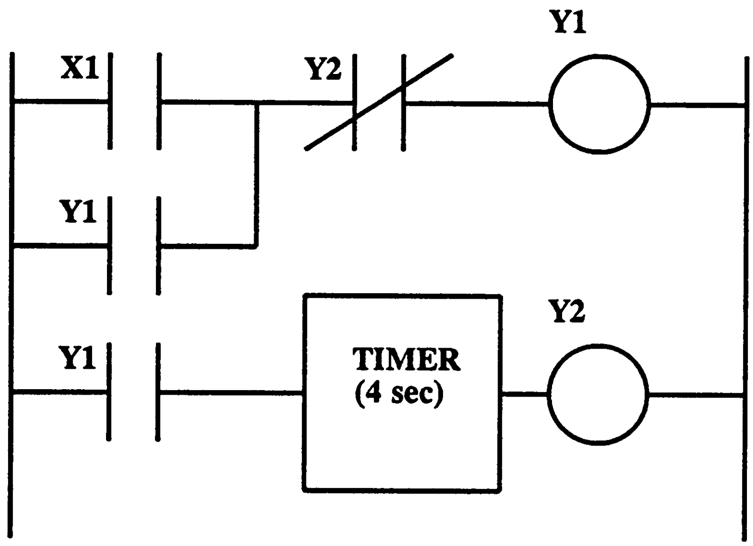
(b) Ladder Logic Diagrams

Figure 1: Programming Language Examples

For an output to be activated or energised, at least one closed path on that rung must exist.

Functional blocks are high level instructions that permit the user to program more complex functions using the ladder diagram format. The instruction set is composed of "blocks" that execute or perform a specific function. When using block instructions, input conditions are programmed using normally open (NO) and normally closed (NC) contacts that will enable the block operation. There are also some parameters associated with the block that must be programmed. These parameters normally include storage or holding registers used to store preset values, or I/O registers (variables) used to input or output numerical data (analog, BCD, etc.). Functional blocks are of four main types: timer and counter instructions in block form, arithmetic, data manipulation and data transfer blocks. Each of these classifications is formed by a group of instructions of similar operations. Depending on the block type, there will be one or more control lines and one or more data specifications within the block. An example of a functional block is shown in Figure 2 (a).

English statement languages for P/C's can be considered a derivative of computer languages. The English statements, or control statements, as they may also be called, have provided additional computing power to the controller. Advocates of control statements as a high level language give two main reasons for their support: the statements' simplicity facilitates the programming of a control task, and the ease with which other users can easily interpret the program once it has been read. Most high level languages mimic the English



(a) Functional Block

100 REM Begin OR Operation

150 Y1 = 0

200 IF X1 = 1 THEN 500

300 IF X2 = 1 THEN 500

400 GO TO 100

500 Y1 = 1

600 GO TO 200

(b) English Statements

Figure 2: Programming Language Examples

language or a common computer programming language such as BASIC or FORTRAN. An example is given in figure 2 (b).

2.6 State Transition Techniques

State transition techniques utilize the concept of function charts for the sequential description of controlled processes in which events appear as a result of a limited number of defined actions [12]. By changing the situation, these events will, in general, lead to other actions, which in their turn cause further events. Examination of an industrial control system shows that, although the overall control process is dependent on a great number of inputs, it can be split up into a limited number of functionally well defined situations, each situation being dependent only on a few inputs. The functioning of the automated system is facilitated by the fact that each evolution of the system from one situation to another is controlled by only considering the information that is available at the previous evolution state. This evolution is described by using a limited number of graphical symbols for the representation of steps and their associated actions, transitions and their associated transition conditions, and directed links.

The descriptive diagram achieved by this method is called a Function Chart, and can be used to obtain a "high level" implementation dependent description of the control system. The Function Chart can be used for a precise description of the relationship between the input (conditions) and the output (actions) of a process, as well as for an overall description. This is achieved by dividing the process into a number of well defined successive stages, called steps, separated by transitions. The end of a step is marked by the appearance of the process information satisfying the condition for the transition to the next step. Steps do not overlap. During a step, actions may be initiated, continued or finished.

In order to prepare a clear and unambiguous function chart of a system, it is of vital importance that the boundary of the system, and thus the scope of the chart, be clearly defined. As a pure functional description does not present any details regarding physical boundaries or the internal structure of the system, this information must be given by means of an adequate description of the inputs and outputs at the assumed boundary. The boundary here defines the limits of the physical control desired. A control system must be divided into two interdependent parts [12]:

* The controlled system, which comprises the operative equipment executing the physical process and
* The controlling system, which is the equipment receiving information from the supervisor, the process, etc., and issuing orders to the controlled system.

A Function Chart is defined by a set of symbols for the Steps, Transitions and the Directed links, interconnecting steps and transitions. Figure 3 shows the operating procedure for a motor which starts running when an input signal (INPUT1) is received and stops when input PH001 goes to a high state. In the figure, the rectangles represent the steps, while the dashes between steps represent the transition conditions. With each step, one or more commands or actions may be associated. The step commands statements would depend on the

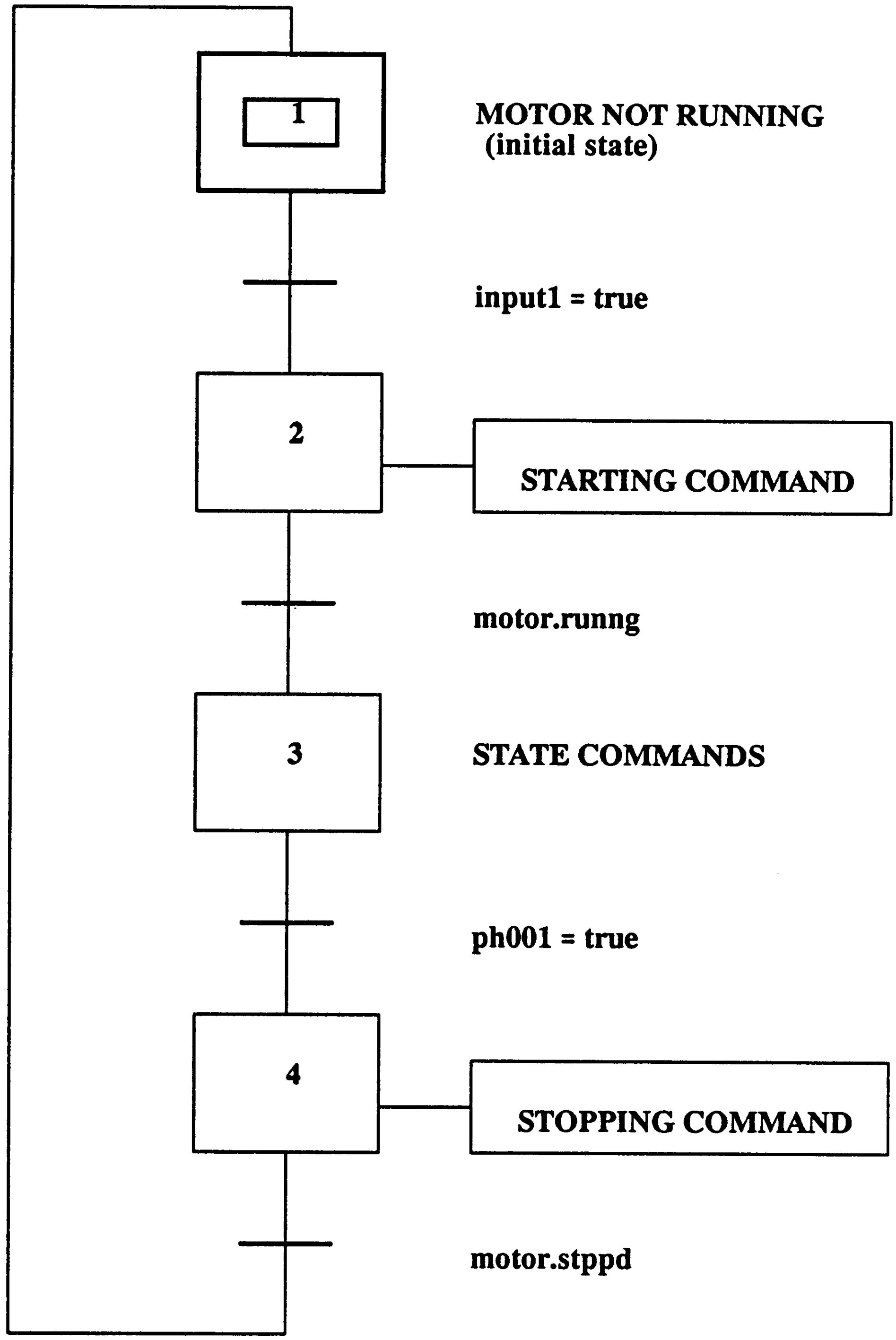


Figure 3: Function Chart for the Operating Procedure of a Slip-Ring Induction Motor

particular language (Function Chart based) used. At a given instant, a step may be either active or inactive. The set of active steps defines the state of the control process. The steps which are active at the beginning of the control process correspond to the initial situation and are represented by initial steps; they characterise the initial behaviour of the controlling system. An active step can cause one or more commands or actions. A command is specified by a written statement inside a rectangle connected to the step symbol with which it is associated. When the step is deactivated, the command may either return to the state it had before the step was activated, or maintain its present state. In Figure 3, the blocks 1, 2, 3 and 4 represent the steps.

In a function chart, evolution of the active states of steps takes place as a result of the clearing of one or more transitions, for instance, input1=true, and corresponds with the new state of the control process. A transition is enabled if all preceding steps, connected to its corresponding transition by directed links, are active. A transition is cleared when it is enabled, and the associated transition condition is satisfied. The clearing of a transition implies the activation of all the following steps, connected to its corresponding transition symbol by directed links and the deactivation of all the preceding steps connected to its corresponding transition symbol by directed links. A logic proposition, called a transition condition, which can either be true or false, is associated with each transition.

2.7 APT Structure

APT is a self-documenting, graphical programming environment for process control design and implementation. The structure of APT allows the user to map the physical process into the control strategy [2]. APT encourages partitioning of the control problem so that the structure of the control system reflects the structure of the physical process. Two graphical languages within APT, the Sequential Function Chart (SFC) language and the Continuous Function Chart (CFC) language, assist in handling design problems ranging from discrete to batch to continuous. This thesis uses the SFC language to apply APT exclusively to the discrete manufacturing applications. When a design is complete, APT automatically translates it into ladder logic code for use on the TI 565 controller.

2.7.1 Object Oriented Nature of APT

The control information of the actual devices of the manufacturing process (motors, valves, etc.) are maintained in an object-oriented database to allow the user to define specifications only once in a program. This frees the designer to focus on the control algorithm he wishes to use instead of the data entry process. For example, once a valve is defined, the command to open valvel is OPEN VALVE1. Therefore, every time that a valve is used, the user does not need to worry about the actual coding of how to open or close it; he is merely concerned with the desired control algorithm (i.e. when to open or close).

2.7.2 Sequential Function Chart

The Sequential Function Chart (SFC) language, is a graphical language for the discrete portion of control strategy, and defines the state oriented control of the process [4]. The SFC language provides the power to organise complex strategies and to represent parallel processes easily. Section 2.7.5 discusses an example of an SFC. The SFC language promotes a top down design approach by allowing the designer to break a large problem into manageable pieces, and to concentrate on the details within a small area of the overall control strategy. The major part of this thesis is centered around the SFC language. As mentioned earlier, an SFC consists of steps and transitions. Steps define actions to be completed in a process; transitions define the conditions under which the actions are completed, so that the process can proceed to the next stage.

2.7.3 Continuous Function Chart

The second graphical language, the Continuous Function Chart (CFC) language, is intended for the development of complex continuous control strategies [4]. Creating a CFC involves selecting, placing, and graphically connecting control blocks such as PID loops, time proportioning control blocks, and user defined algorithms. CFC's allow the user to document the flow of data from a signal input to the system, through processing, to a signal output to the external world, and help in analog control. SFC's, on the other hand, are used only for discrete control. Time proportioning blocks allow the programmer to add dynamic characteristics to the process, and include first and second order lag blocks, first and second order lead blocks, and a dead time compensator [10].

2.7.4 Batch Process Control

APT is aimed at allowing the user to handle batch-process control in an efficient manner. The ability to represent parallel processes allows APT to handle the problem that batch processes represent. When in a batch mode, a command in the SFC causes a continuous function block to execute simultaneously. The CFC task will continue execution until a step in the SFC halts its execution. This ability to execute both the SFC and the CFC in parallel allows APT to address the batch processing marketplace.

2.7.5 APT Program Example

Figure 4 illustrates the use of a Sequential Function Chart in an APT program. The steps, represented by the rectangles, contain all the commands for a specific state, while the dashes between steps represent the transition conditions. Step 1 is shown highlighted in order to represent the initial step of the SFC. The SFC activates from this step onwards.

The objective of this program is to eject a part onto a conveyor motor when a part request input (INPUT1) is activated. When INPUT1 goes high, the pneumatic ram VALVE1 opens, and pushes the block onto the conveyor. At this point, the conveyor motor starts running, and stops

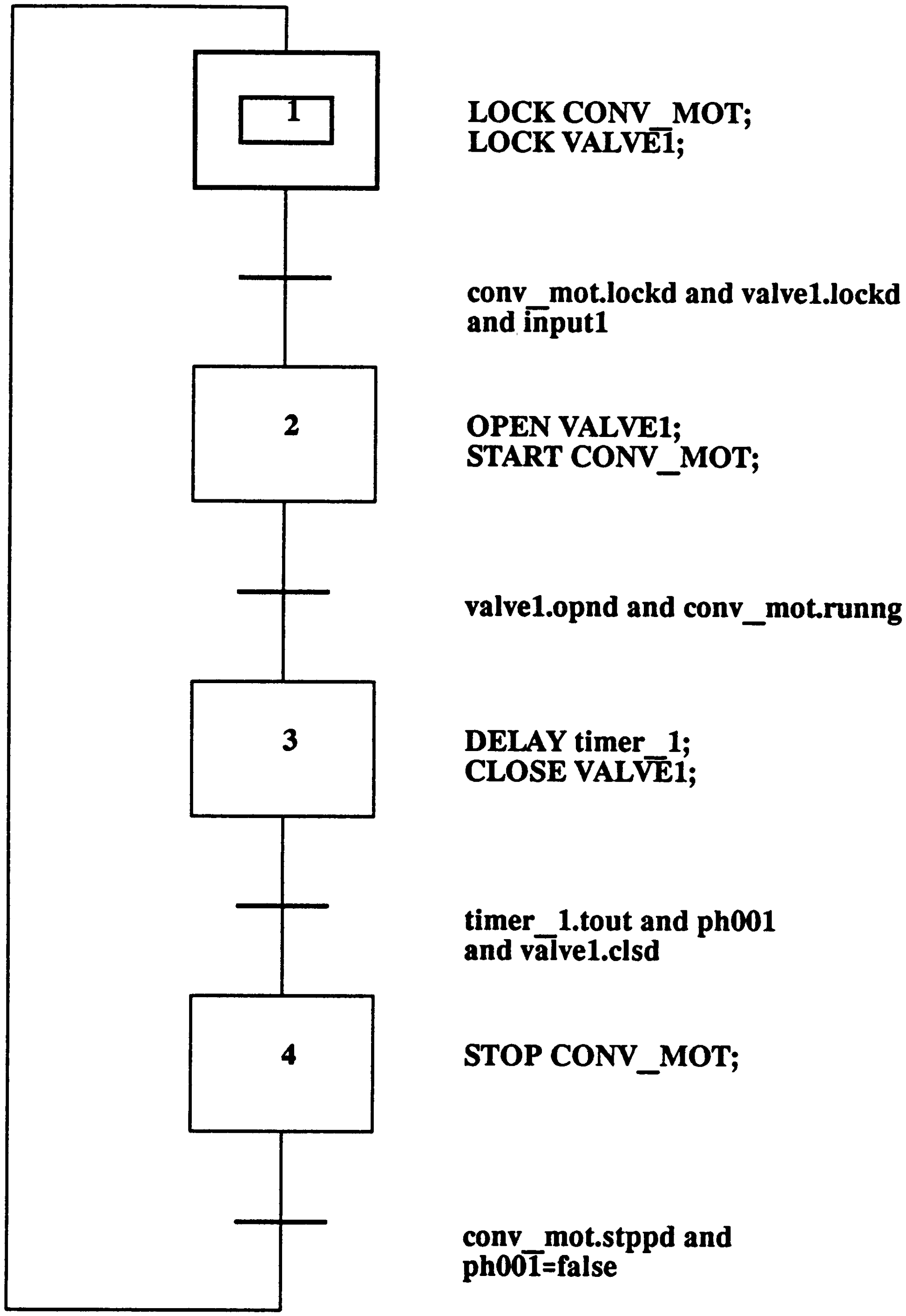


Figure 4: APT Program Example

only when a photocell input (PH001) is activated. When the block is removed, the input PH001 goes low, and the transition condition, PH001=false, is true; consequently, the SFC goes back to the initial state. The LOCK command is associated with placing the devices (CONV_MOT and VALVE1) in an auto mode, where they can be controlled from the program. OPEN and CLOSE are commands associated with the valves. START activates the motor, while STOP deactivates it. The suffixes like *.opnd*, *.clsd*, *.runng* are all feedback signals which are true or false. The condition CONV_MOT.RUNNG is true when the motor is running, and false otherwise. These suffixes are used in the transition condition to progress from one state to another.

Chapter 3
Methodology

3.1 Introduction

The objective of this research was to determine the applicability of APT in discrete parts manufacturing. Real time application of APT in this field was attempted using two applications, the Fischertechnik manufacturing system model, and the computer integrated flexible manufacturing system laboratory. Discussed in this section are the physical setup and configurations of the two systems and the various tasks that the P/C was to control. The breakdown of the particular physical system is then presented.

3.2 Fischertechnik Manufacturing System Model Description

The Fischertechnik manufacturing system model, as shown in Figure 5, is made of Fischertechnik components, and miniature air cylinders. All model wiring is connected to a control panel, and then to an electrical interface box before connecting to an appropriate control system. The input/output listing is given in Appendix A. Colored wooden blocks are advanced through the model to simulate the flow of

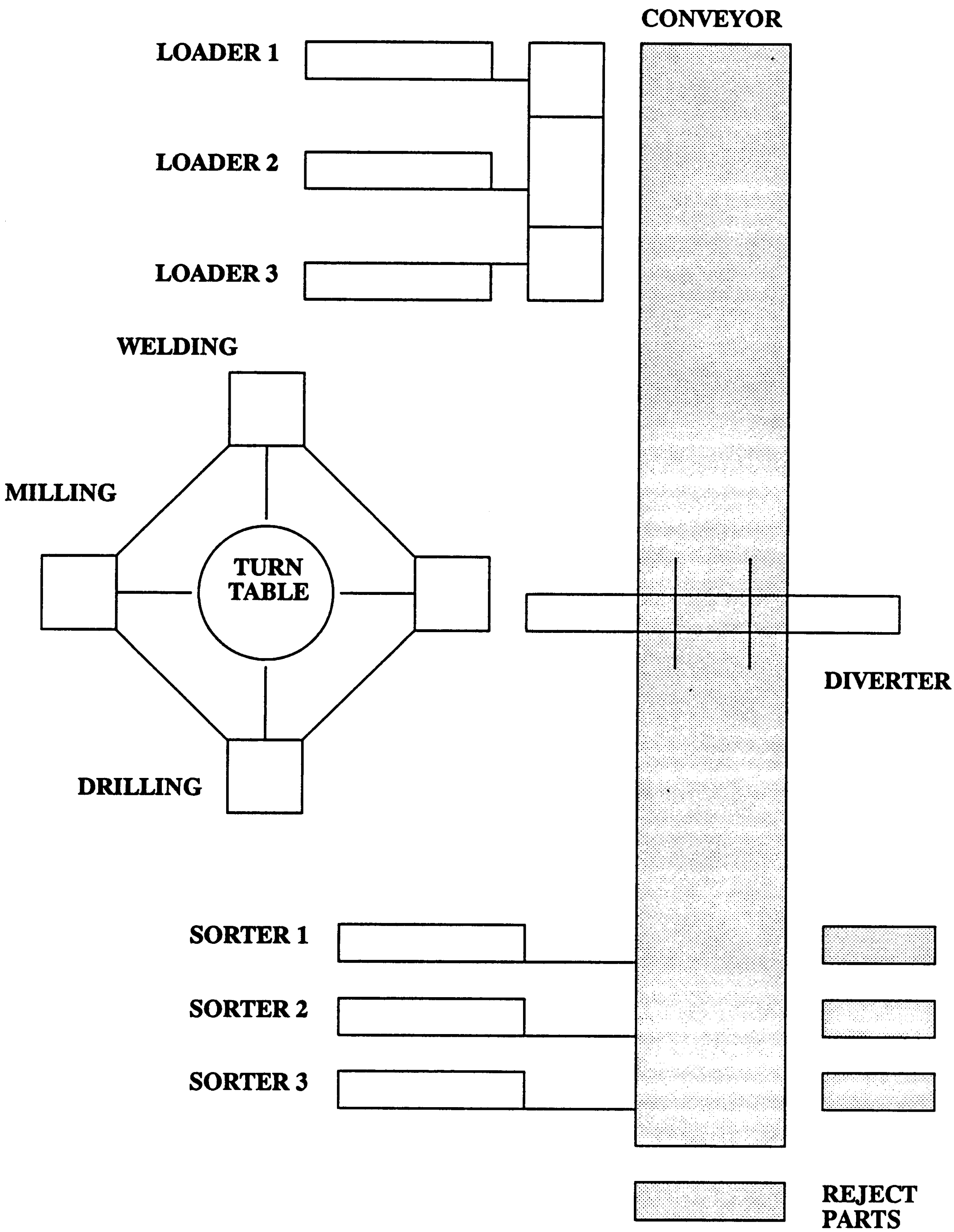


Figure 5: Fischertechnik FMS Model

different work pieces. Functionally, the model can be divided into four major subsystems [1]:

1) A parts loading station,

2) A machining subsection with three machining centers,

3) A parts sorting station, and

4) A material handling subsystem with a conveyor belt, a parts diverter and a turntable.

The first mechanism in the model is the parts loader. Three separate stacks of blocks are contained in the loader as "raw material". Each stack has a miniature pneumatic cylinder associated with it to push the bottom block onto the conveyor belt for movement to the machining centers. When the cylinder retracts, the next block falls into place to be dispensed when needed. An active signal from the control system causes a cylinder to extend and hence a part is pushed onto the belt. A spring return retracts the pushing mechanism when the active signal is dropped. Each air valve is wired through a diode to a horn or buzzer to provide a signal to indicate when it is active.

The conveyor belt runs the entire length of the model, and is controlled in an on/off manner. A belt speed sensor creates a pulse train as the belt drive gear rotates. This signal can be used to measure travel distances of items while they are on the belt.

A diverter is located over the conveyor belt to bring parts into the machining area. A bidirectional dc motor is provided to move parts to and from the machining areas. Limit switches are placed at the extreme ends of the diverter travel. These switches signal the controller that travel is complete and electronically disable further travel. A light beam and photoresistor combination is located across the conveyor in front of the diverter to sense approaching boxes. The conveyor belt must be stopped when diverting a box to or from the machining area.

A turntable is used to present the parts to the machines and is driven in an off/on manner. A reed switch is mounted in a fixed position on the model to sense when the turntable has rotated to the next machining position.

Three machining stations are represented in the model - a drilling station, a milling station, and a welding station. Each station has a drive head and two axes of motion that are under system control. The drive head, a turning axis or light, is driven in an off/on manner. The X and Y axes of each machine are driven by bidirectional dc motors. Limit switches are mounted on each motion axis to indicate travel limits and to disable further travel in that direction. While no contact is actually made with the wooden block, tool motion and turning can be simulated by timing axis travel in each direction.

The parts sorter is the final mechanism in the system, and consists of three pneumatic rams and their respective parts chutes. A fourth chute is provided for reject parts but has no associated active mechanism. The rams are identical to the loader cylinders and are activated by a signal from the controller. A light and photoresistor combination has been placed across the conveyor in front of each sorting station to sense approaching parts.

3.3 CIM Laboratory Layout and Description

The Computer Integrated Manufacturing Laboratory (see Figure 6) is being created to provide instruction and research facilities in the integration and control aspects of computer based manufacturing technologies. As planned, it has two IBM industrial robots, two 3-axis numerical control milling machines, a material handling and delivery system, a vision system, an AS/RS, a TI 565 programmable controller, and a network of personal computers. The control hierarchy has been based on the intended structure of the CIM Laboratory's control software. It will consist of three basic levels - System, Cell and Equipment levels.

The system level control facilities will be responsible for the overall performance of the system. The system controller will coordinate the production and support activities that are carried out by the cell controllers at the next lower level. The planning horizon for the system controller can be from a few hours to several days. The system level controller is above the cell controller in the control hierarchy. Two major modules have been identified within the system-level controller, i.e., a task manager and a resource manager. The task manager does capacity planning, identifies production resource requirements, summarises quality performance data, generates schedules, tracks individual orders to completion and tracks equipment utilization. The resource manager monitors and updates levels of all raw material stock and replacement parts inventory necessary to run the factory. Based on the availability of resources, and the tasks that need to be performed for the completion of each batch, the system controller sends its commands to the cell controller by posting it in a common area in

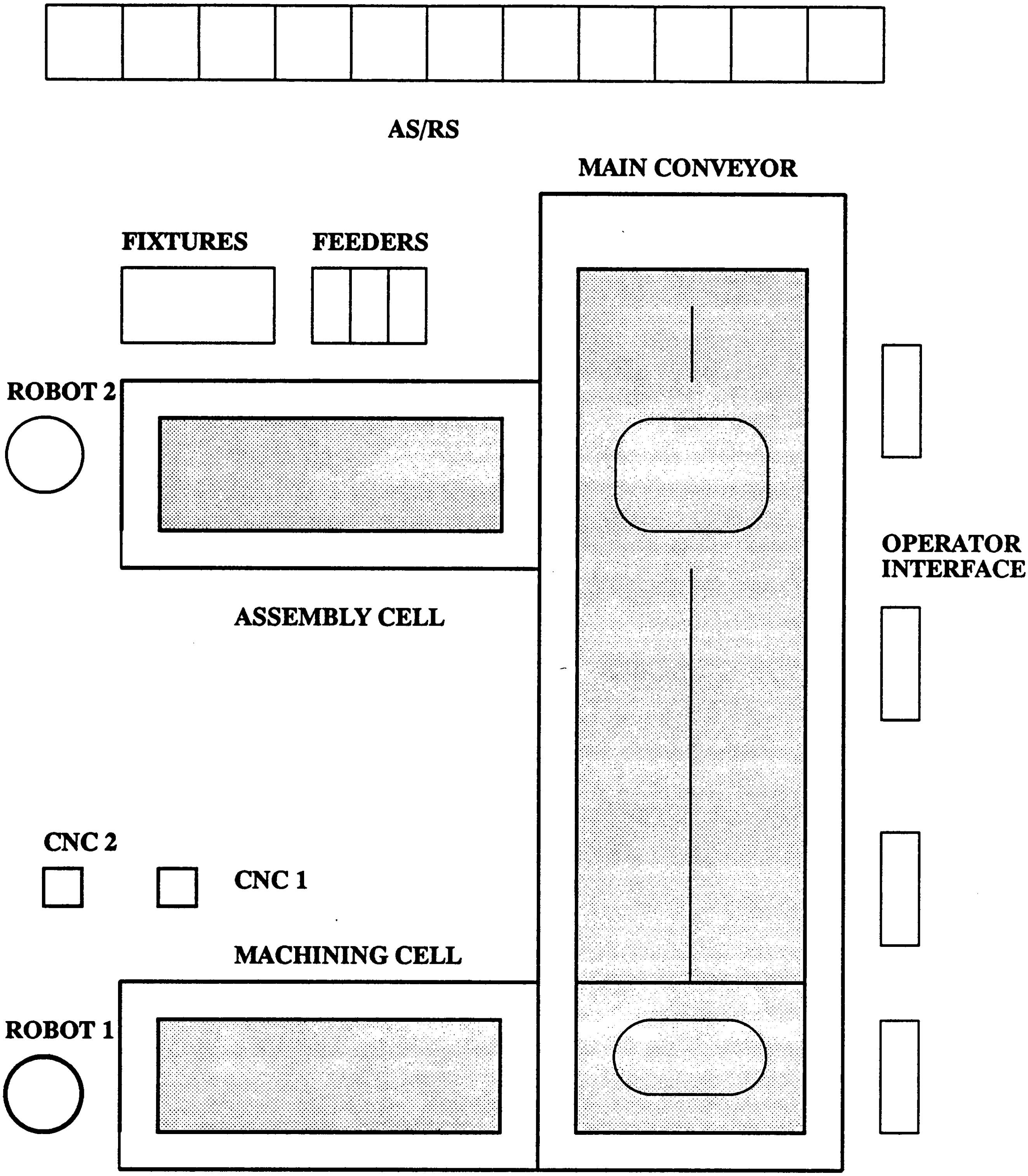


Figure 6: CIM Laboratory Layout

memory called a "mail box". Commands are passed down by the system controller to the cell controllers which send up status reports.

The cell level is responsible for directing and coordinating the actions of the machinery under its domain. The cell controller is responsible for getting directions from the system controller by reading them from the "mailbox", breaking the directions down into smaller modules and executing them on the machinery under the cell controllers domain. To do this, the cell controller references predefined functions and procedures [3] to accomplish desired subtasks. The cell controller also monitors the machinery for digital input and output (I/O) for error conditions. The input/output listing is given in Appendix B.

There are three cell level controllers in the system. The first, called the Assembly Cell Controller, handles all the communications and actions associated with the assembly operation, viz., assembly, kitting, or refilling feeders. The second, called the Machining Cell Controller, handles communications between the computer and its components, the robot and the CNC milling machines. Finally, the Material Handling Controller handles communication between the cell and the conveyor, AS/RS and vision system through the P/C. This workcell bears specific relevance to this research, as it communicates with the P/C, and sends the the task codes.

3.4 Workcell 3 - Material Handling Controller

The material handling workcell consists of an AT&T 6300 computer connected to a TI 565 programmable controller, and communicating with the conveyor and the AS/RS through discrete I/O lines wired up to the P/C. This workcell is responsible for all material handling and delivery functions, and is essentially concerned with the supply of pallets to the assembly and machining workcells, and with the removal of pallets from these workcells and other locations to the AS/RS. The AS/RS subsystem will be used for the storage and retrieval of pallets, and will be controlled by the P/C. The conveyor transports the pallet from the AS/RS dropoff point to the designated location, and from the cells (assembly and machining) to the AS/RS. The conveyor is equipped with photosensors, limit switches, and pallet stops, in order to achieve the above mentioned functions. These are controlled by the P/C through discrete I/O lines. The vision system is there to verify the type of pallet being sent to the assembly or machining workcells. If an error or mismatch is found, the vision system signals the controller, and the pallet is returned to its original storage location.

3.4.1 Material Handling and Storage System Task Specifications

Thirteen overall tasks have been defined for the material handling workcell controller. These are:

1) Move a pallet from the input conveyor to the output conveyor.
2) Move a pallet from the input conveyor to the assembly cell.
3) Move a pallet from the input conveyor to the machining cell.
4) Move a pallet from the assembly cell to the machining cell.
5) Move a pallet from the machining cell to the assembly cell.
6) Move a pallet from the assembly cell to the output conveyor.
7) Move a pallet from the machining cell to the output conveyor.
8) Move a pallet from the machining cell to the operator interface.

9) Move a pallet from the assembly cell to the operator interface.

10) Move a pallet from the input conveyor to the operator interface.

11) Move a pallet from the operator interface to the output conveyor.

12) Move a pallet from the operator interface to the assembly cell.

13) Move a pallet from the operator interface to the machining cell.

The reason for forming the tasks in this fashion was that the conveyor system here was required to perform only these tasks at the present stage of development of the CIM Laboratory. The APT and RLL codes were developed to accomplish each of these individual tasks. Each task was represented as a function chart, in the same unit. Depending on the task chosen, the corresponding APT function chart is activated. One of the objectives of this research was to determine different ways to organise discrete parts manufacturing using the APT structure. Based on these subtasks defined above for the Computer Integrated Manufacturing Laboratory, it was found possible to use the APT structure to represent the processes involved by means of one unit and Sequential Function Charts.

3.5 CIM Laboratory Functioning

The CIM Laboratory, as described earlier, is equipped to produce wax models of a robot and a Dyna milling machine. The AS/RS, when implemented, will contain one of the following pallet types:

* A pallet with unmachined wax blocks for one robot
* A pallet with unmachined wax blocks for one milling machine
* A pallet with a machined but unassembled robot

* A pallet with a machined but unassembled milling machine
* A pallet with only raw material blocks for the robot or the milling machine.

As visualised, the operator at the material handling controller will have a menu driven screen wherein the different tasks detailed above would be provided. Depending on the task code input by the operator, the P/C will perform the desired task. Once the task is completed, the assembly cell controller and the machining cell controller will take over the operation in their domain (local control, not under the P/C). For instance, if the operator desires a robot raw material pallet to be sent to the machining cell and machined, he would type in the number corresponding to that task. Once the pallet reaches the machining cell, the P/C sends a signal to the machining cell controller, and the cell controller now starts controlling the machining operations desired. When the machining is finished, a machining done signal is sent back to the P/C. A vision system is also envisioned at the start of the input conveyor, to check the pallet type.

3.6 Present Status of the CIM Laboratory

The CIM Laboratory layout, as envisaged, has been described earlier in Section 3.3. The functions of the system controller and the workcell controller have also been presented. The material handling controller is directly linked to this thesis. This controller is not fully functional as yet. The communication functions between the controller and the P/C have to be written. The AS/RS has yet to be implemented.

As a result, the programs presented in chapter 4 do not consider the AS/RS. The vision system has been developed, but not been integrated within the system. Thus, though the vision system related tasks have been considered, communication between the vision system and the P/C is not considered. All the inputs connected to the task specifications (X98-X101) have to be forced (turned on or off manually from the P/C), until the discrete I/O lines from the controller are connected. A strobe (X97) to signal the start of a task is also forced on at the start of the task.

3.7 Summary

The methodology used in this research was essentially aimed at identifying different approaches that can be used while applying APT to discrete parts manufacturing. If a top-down approach is taken towards the problem, the whole system can be broken up into smaller sections, based on either the desired function or the type of equipment used. Each of these subsections is called a unit. The size or range of this unit is variable, and this size is what determined the approach. Based on the unit, the sequential function charts were then constructed. Once the APT code was downloaded to the controller, and the resulting ladder logic employed in the control of the discrete application, the unit was examined to see whether the desired objective was obtained.

Chapter 4
Development of Programs

4.1 Introduction

The purpose of this research was to apply APT to control the two discrete manufacturing applications described earlier. The Fischertechnik model provided different levels of control complexity while the CIM Laboratory provided a second system with a more rigid control structure. Different programming approaches were developed to test the flexibility and range of applicability of APT, and the physical limit of control for each approach was determined. An attempt was made to determine the level of control achieved by each approach for the Fischertechnik model, and to establish where and at what stage each approach broke down.

4.2 Fischertechnik Manufacturing System APT Programs

The Fischertechnik manufacturing system model provides an effective test bed for development and testing. The complexity of the control structure can be adopted as desired. Three different APT programming techniques were developed as part of this research project.

RLL code was also developed manually to match the control results of one approach, and this RLL code was compared to that generated by the APT program.

As discussed earlier, the Fischertechnik model is configured to load three different parts onto a conveyor, for transport to the processing area. These parts are then diverted to a turntable for presentation to different machines, viz., drilling, milling and welding. They are processed, put back onto the conveyor, and then sorted to different unloading chutes depending on the part type. As studied earlier, different levels of control complexity can be incorporated into the system:

1) At the lowest level, there is only one part in the system at one time. A part is ejected onto the conveyor, taken to the processing stations, processed, and then sorted. After the part has left the system, the next part is ejected onto the system to begin processing.

2) A slightly more complex control strategy is to permit multiple parts on the conveyor, but only one part on the turntable. Only one part can be in the processing area at a time. Parts can be loaded onto the conveyor continuously until a part reaches the processing area. At this time the conveyor is stopped and the part processed. Once processing is complete, the conveyor is restarted and transportation continues until another part is ready for processing. Hence, it is possible for loading and sorting to be occuring at the same time and for multiple parts to be on the conveyor both before and after the processing area.

3) The next level of complexity differs from the previous level in that the conveyor may continue to operate while a part is being processed. The conveyor only stops when the presence of another part is indicated when the pre-diverter photocell input goes high. This part must then wait for the completion of all processing for the previous part.

4) A significant increase in the level of complexity is reached when multiple parts are permitted on both the conveyor and the turntable. Concurrent processing of different part types is envisaged, with the conveyor in the on state while the processing is in progress. The conveyor stops only when the presence of another part requiring processing is indicated.

5) The highest level of control complexity considers multiple parts on the conveyor, allows for more than one part on the turntable, and also considers machine breakdown. Machine breakdown leads to a situation where parts bypass machines leading to a loss in the initial sequencing of parts.

Three different approaches were used to program the Fischertechnik model. The part type and the machining equipment required formed the basis for the approaches. One approach was based on trying to control the model entirely on the part type. A second approach used the machining equipment required as the basis of the control code. The last approach integrated both the part type and the equipment used into a single combined control program. An attempt was made to examine how well each approach adapted to the level of control desired.

4.2.1 Approach One

In the first approach, the Fischertechnik model manufacturing system was divided into four main subsections; the input request section, the loader section, the diverting section and the sorting section. The input request section included the part request input queueing, while the loader section was concerned with the operation of the loading rams. The diverting section handled the diversion of the part from the conveyor to the turntable, and the subsequent processing operations and indexing of the turntable. The sorting section handled the sorting of the processed parts by the sorter chutes. Based on this partitioning, the APT program was subdivided into a main SFC (Figure 7) and four subordinate SFC's (LOADER, L_RAMS, DIVERTER and SORTER). The documentation for SFC L_RAMS can be found in Appendix C. The SFC's are discussed below:

1) **LOADER**: This SFC is concerned essentially with the part request inputs. Each part request input is loaded sequentially into a queue or array. Each array element has a specific integer value to characterise the part type. The system thus builds up a long queue of parts to be processed. These parts are picked out sequentially.

2) **L_RAMS**: This SFC controls the loading station, and handles the operation of the loader rams. Upon receiving the initial input to the system, the loader ram corresponding to that part type opens immediately, ejects a part onto the conveyor, and closes after a predetermined time interval. After the first part, each subsequent loading is based on the present position of the array

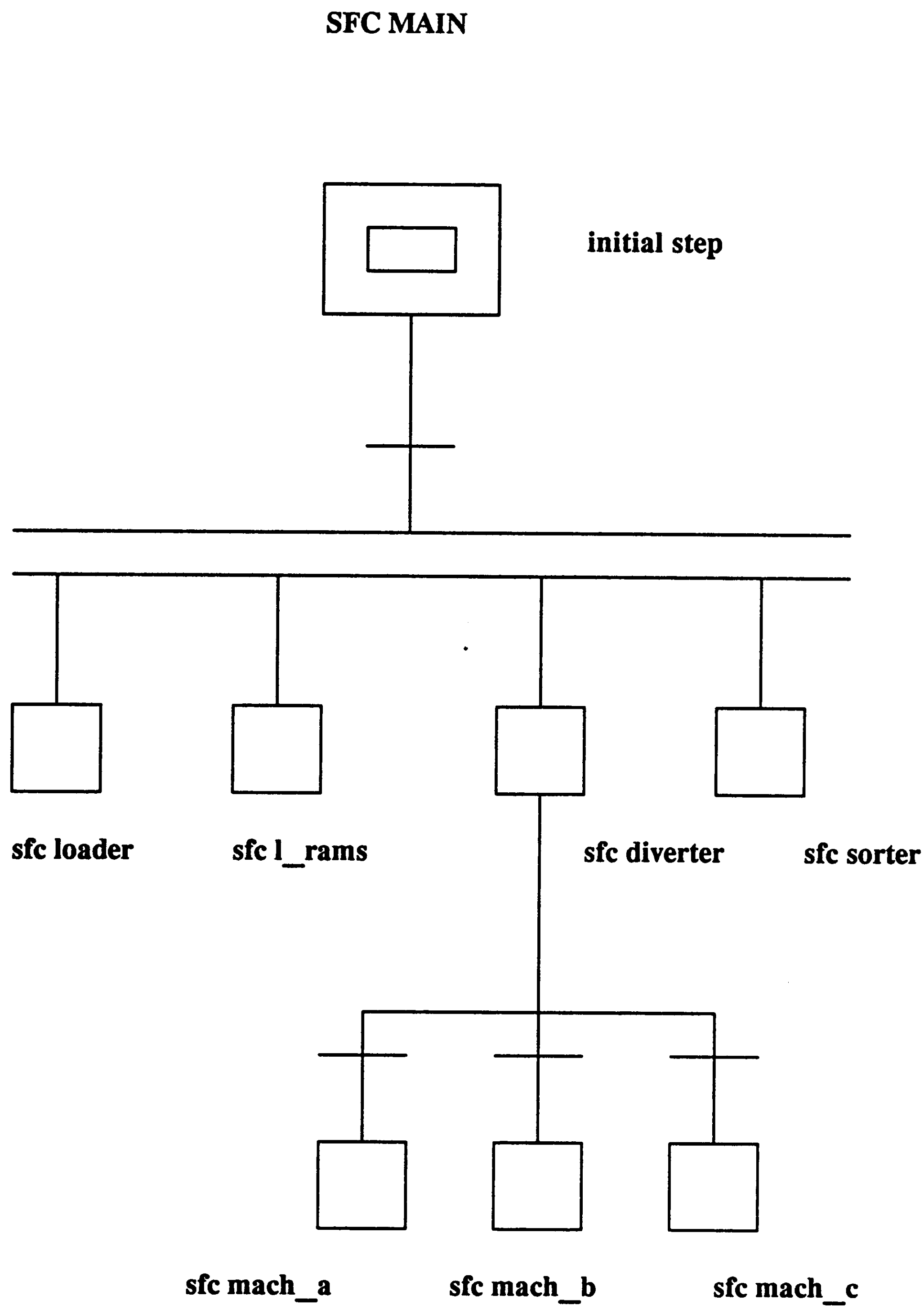


Figure 7: FMS Approach 1 APT Code

pointer; the loader station activates and opens the appropriate loader ram after the pre-diverter input (INP18) goes high. This particular constraint is imposed in order to maintain a suitable distance between consecutive parts on the conveyor.

3) **DIVERTER:** This SFC manages the sequence of operations required for the part to be taken from the conveyor, processed and then brought back to the conveyor. Based on the part type, one of three part type SFC's (MACH_A, MACH_B or MACH_C) is called from within the DIVERTER SFC. These three SFC's handle the processing operations for the three part types.

a) **MACH_A:** This SFC controls the indexing and processing operations for part type A. The part is first indexed to the drilling station and the drilling completed. The part is then indexed to the milling station, and the milling performed. The end of the milling operation signals the end of processing, and the part is indexed back to the diverter position, from where it is taken to the conveyor.

b) **MACH_B:** This SFC deals with the indexing and processing operations for part type B. The part is first indexed to the drilling station and the drilling completed. The part is then indexed to the welding station, and the welding performed. The completion of welding operations signals the end of processing, and the part is indexed to the diverter position, from where it is diverted back to the conveyor.

c) **MACH_C:** This SFC deals with the indexing and processing operations for part type C. The part is first indexed to the milling station and the milling completed. Next, the part is indexed to the welding station, and the welding performed. Completion of welding operations signals the end of operation, and the part is indexed to the diverter position, from where it is taken back to the conveyor.

4) **SORTER:** This SFC manages the sorting station and handles the operation of the sorter rams. Based on the current position of the array pointer, the appropriate loader ram is opened.

5) **MAIN:** This is the startup SFC, and is used to call all the other subordinate SFC's initially, with the help of a parallel structure.

4.2.2 Approach Two

In this approach, an attempt was made to make the program as modular as possible. The system was broken up into subsystems depending on the equipment type, and an SFC constructed for the operation of each subsystem. Variables were passed along from one SFC, sequentially activating another SFC. The advantage of using variables was to increase flexiblity in program development. It was now possible to have an SFC active at more than one point simultaneously. The SFC's constructed were called by the main SFC (Figure 8). Initially, all the SFC's were in an active state. Thus, all the initial steps in each of the subordinate SFC's were active. Within each subordinate SFC however, the transition to the next step was dependent on a transition condition (call_movdiv, for instance), which was a variable (either true or false). The next step was activated only after the variable was set to a true state from some other SFC (see Figure 9). The moment transition

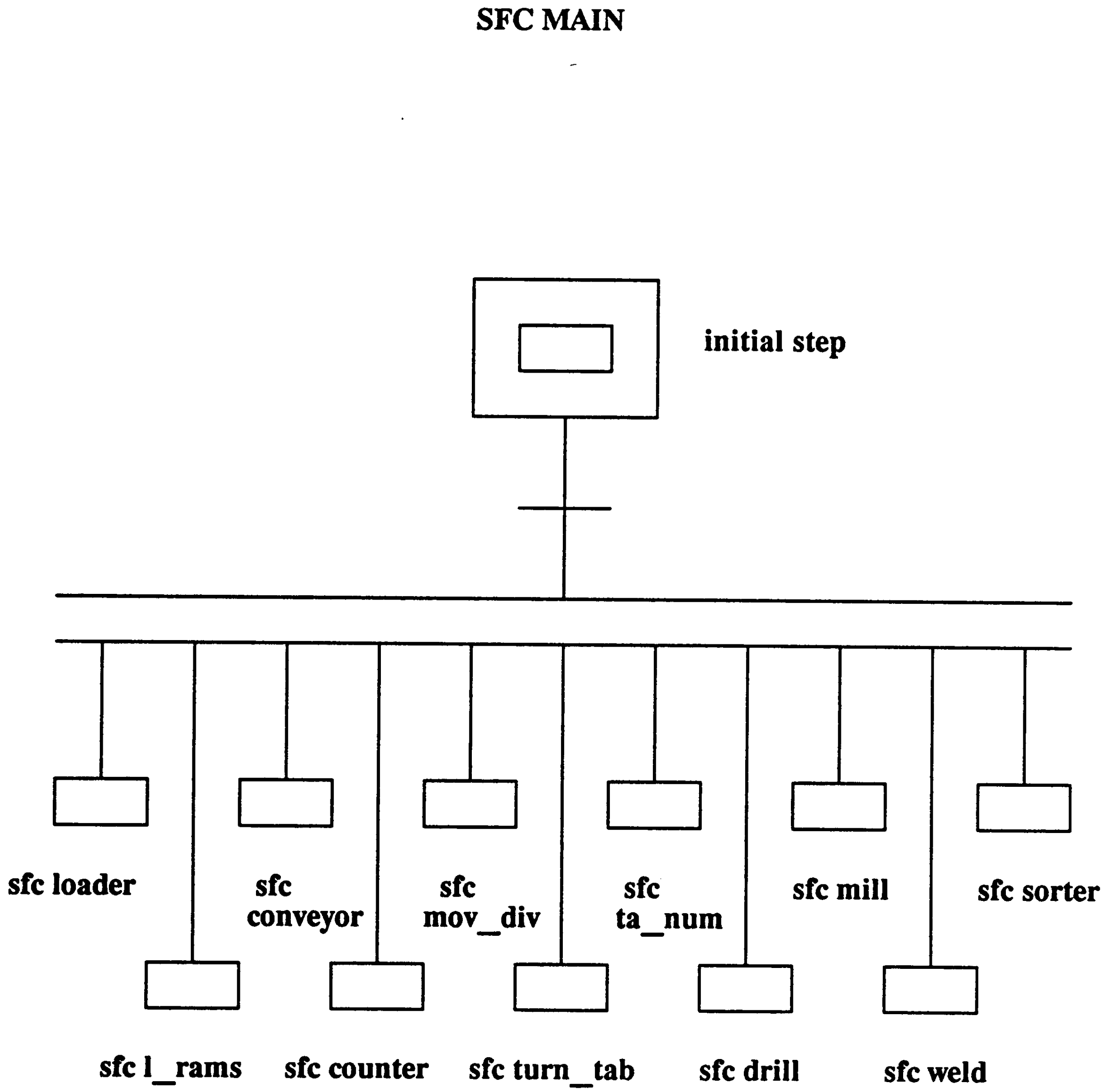


Figure 8: FMS Approach 2 APT Code

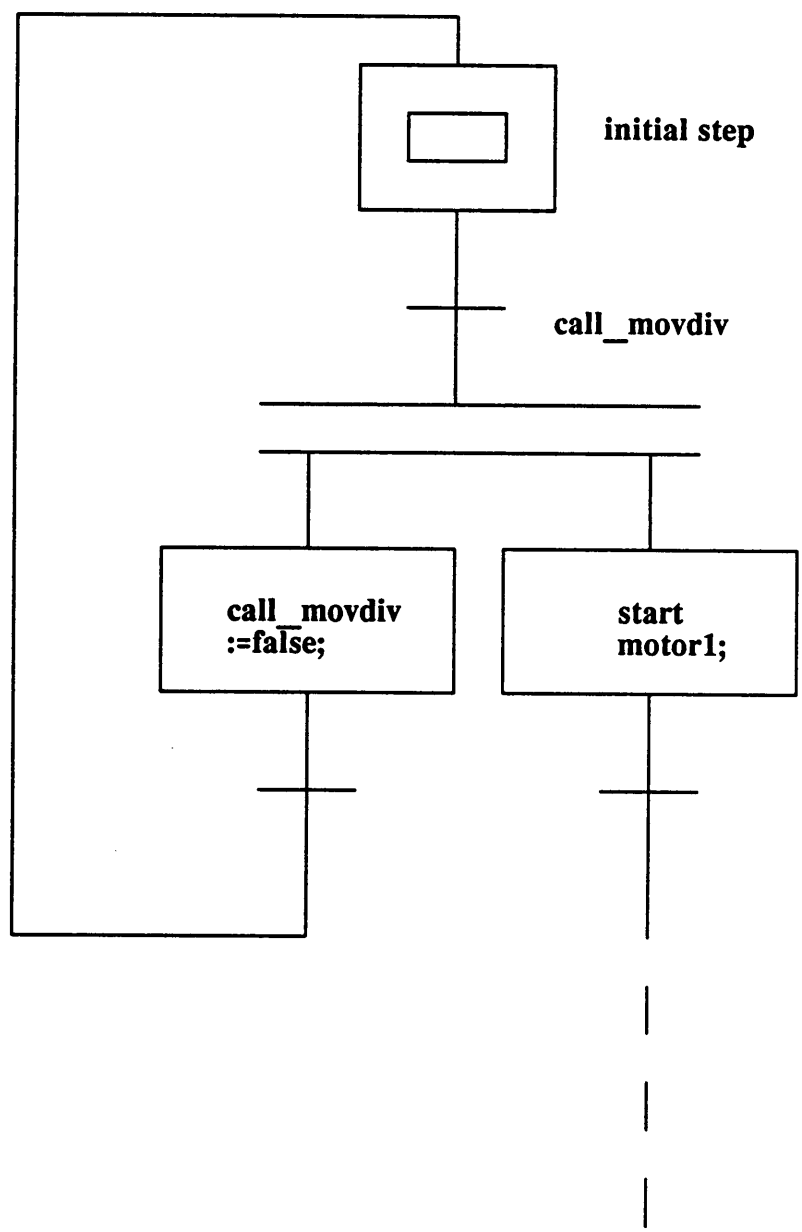


Figure 9: Example of use of variables

to the second step was achieved, the SFC split up into a parallel operation, wherein one phase returned operation to the initial state, while the second one continued processing the steps and transitions. The purpose of doing this was to reset the state of the variable to false in the step which returned operation to the initial stage. The SFC would now remain there till the transition following it was again set to true. The second parallel operation meanwhile continued uninterrupted. In this way, the SFC could be active at more than one step simultaneously. The SFC's used are discussed below.

1) **LOADER:** This SFC is concerned essentially with the part request inputs. Each part request input is loaded sequentially into a queue or array. Each array element has a specific integer value to characterise the part. The system thus builds up a long queue of parts to be processed. These parts are picked out sequentially.

2) **L_RAMS:** This SFC controls the loading station, and handles the operation of the loader rams. Upon receiving the initial input to the system, the loader ram corresponding to that part type opens immediately and closes after a predetermined time interval. After the first part, each subsequent loading is based on the present position of the array pointer; the loader station activates and opens the appropriate loader ram after the pre-diverter input (INP18) goes high. This particular constraint is imposed in order to maintain a suitable distance between consecutive parts on the conveyor.

3) **CONVEYOR:** This SFC handles the conveyor status and turns the conveyor on or off. This SFC is triggered by setting the value of

a specific variable (call_conv) to true. After reaching the end step, the SFC returns to the initial step. The call_conv variable is assigned a 'false' state, and the SFC is returned to its initial state, wherein it waits for a call_conv = true transition condition again.

4) **COUNTER:** This SFC is used to count the belt pulse input, which is used in a counter to activate the diverter. The SFC progresses beyond the initial active state when the *call_counter* variable is set to true from some other SFC. At the end of the counter SFC, the call_counter variable is assigned a false state, and the SFC is returned to the initial state.

5) **MOV_DIV:** This SFC controls the diverter, and is used to move it from the conveyor centered position to the table centered position and vice-versa. The state of the calling variable (*call_movdiv*) is set to true from some other SFC to activate it, and at the end of SFC execution, this value is set to false. The diverter direction is controlled by two other variables, *div_fwd* and *div_rev*, which are also set to a true state from some other SFC.

6) **TURN_TAB:** This SFC manages the indexing of the turntable from one station to another. Calling this SFC once results in the rotation of the turntable by 90 degrees. The variable (*call_ttable*) is used to activate it.

7) **TA_NUM and TAB_SORT:** These two SFC's are the core of the machining operation. They handle the processing sequence of the particular part type, and are used to call one of three other SFC's (DRILL, MILL and WELD) by setting the value of their

corresponding variables to true. The processing sequence for this approach was changed to increase control complexity. Part type A was required to undergo drilling, milling and welding, while part type B underwent milling and welding and part type C underwent drilling and welding.

8) **DRILL:** This SFC manages the processing operations at the drilling station, and is activated by calling it from the SFC TA_NUM. The *drill_done* variable was used to indicate whether the drilling station was busy or idle.

9) **MILL:** This SFC handles the processing operations at the milling station, and is activated by calling it from the TA_NUM SFC. The *mill_done* variable was used to indicate whether the milling station was busy or idle.

10) **WELD:** This SFC handles the processing operations at the welding station, and is activated by calling it from the TA_NUM SFC. The *weld_done* variable was used to indicate whether the welding station was busy or idle. The state of the *drill_done*, *mill_done* and *weld_done* variables was tested every time indexing was required. Indexing was started only when all the variables were in a false state. If any of the variables was true, indexing was done only after that operation was finished.

11) **SORTER:** This SFC manages the sorting station and handles the operation of the sorter rams. Based on the current position of the array pointer, the appropriate loader ram is opened.

12) **MAIN:** This is the startup SFC, and is used to call all the other subordinate SFC's initially, with the help of a parallel structure.

4.2.3 Approach Three

This approach is different from the other two approaches in that the subdivision is not done on the basis of the equipment, but rather on the basis of the part type. Three SFC's (PART_A, PART_B and PART_C) are used, and these govern the sequence of operations required for the three part types. One of these three SFC's is activated from SFC L_RAMS when the block is loaded onto the conveyor, and governs the activity of that block from that point on. This is done by setting the value of the corresponding variables, *call_a*, *call_b* or *call_c* to true. The other SFC's are used here for ease in programming. The SFC MAIN is shown in Figure 10. The SFC's are:

1) **LOADER**: This SFC is concerned essentially with the part request inputs. Each part request input is loaded sequentially into a queue or array. Each array element has a specific integer value to characterise the part. The system thus builds up a long queue of parts to be processed. These parts are picked out sequentially.

2) **L_RAMS**: This SFC controls the loading station, and handles the operation the loader rams. Based on the present position of the array pointer, the loader station activates and opens the appropriate loader ram, after the pre-diverter input (INP18) goes high. At the time the block is loaded onto the conveyor, one of the three SFC's (PART_A, PART_B or PART_C) is activated.

3) **MOV_DIV**: This SFC controls the diverter, and is used to move it from the conveyor centered position to the table centered position and vice-versa. The state of the calling variable (*call_movdiv*)

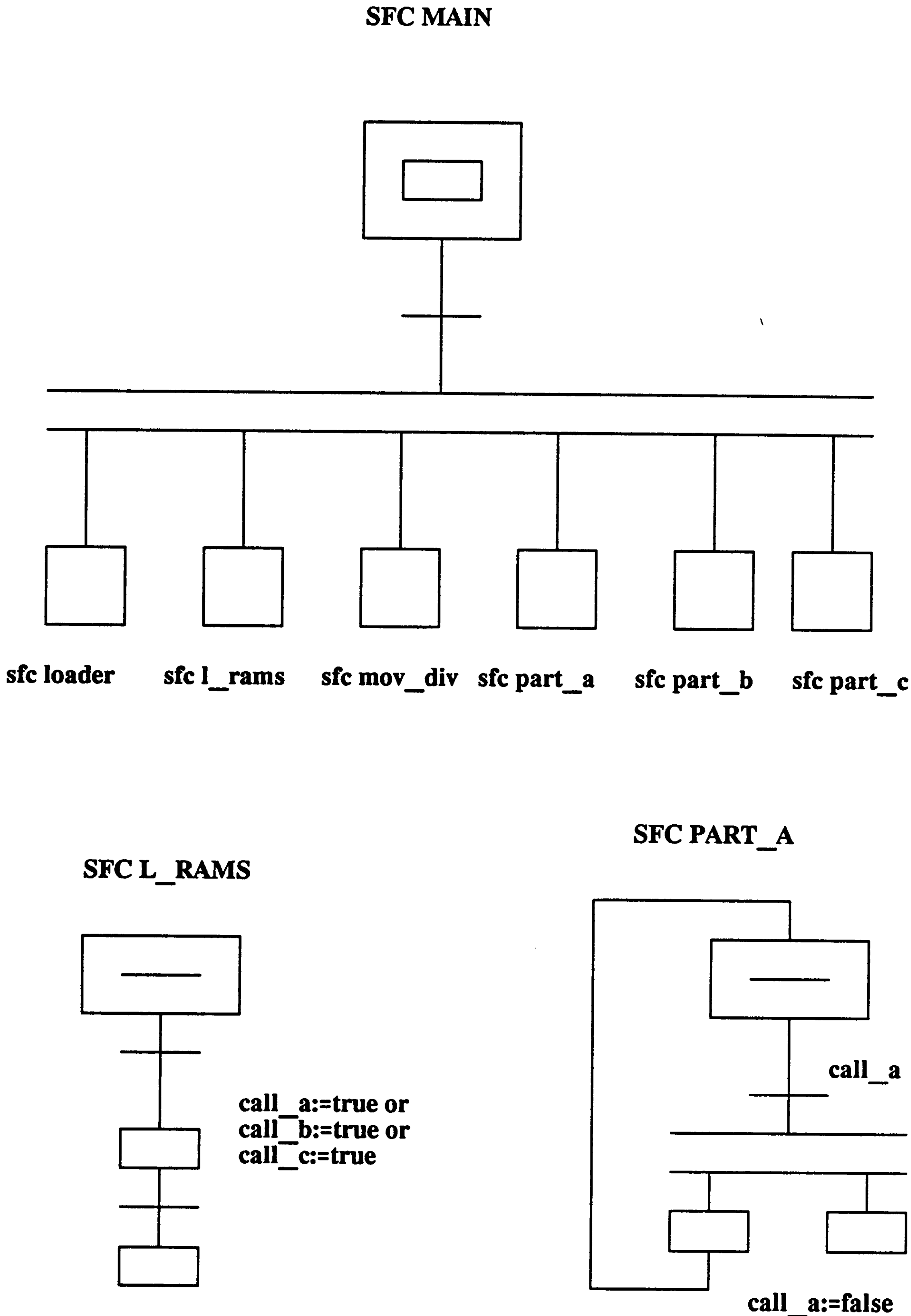


Figure 10: FMS Approach 3 APT Code

is set to true from some other SFC to activate it, and at the end of SFC execution, this value is set to false. The diverter direction is controlled by two other variables, *div_fwd* and *div_rev*, which are also set to a true state from some other SFC.

4) **PART_A**: This SFC is activated by setting variable *call_a* to true. It controls the entire sequence of operations for block type A, right from the point where the block is loaded onto the conveyor, to the point where it is sorted. Part type A undergoes drilling, milling and welding, and also uses variables *drill_done*, *mill_done* and *weld_done* to indicate whether the specific machining operation is finished.

5) **PART_B**: This SFC is activated by setting variable *call_b* to true. It deals with the entire sequence of operations for block type B, right from the point where the block is loaded onto the conveyor, to the point where it is sorted. Part type B undergoes milling and welding, and uses the same variables as above.

6) **PART_C**: This SFC is activated by setting variable *call_c* to true. It deals with the entire sequence of operations for block type C, right from the point where the block is loaded onto the conveyor, to the point where it is sorted. Part type C undergoes drilling and welding, and uses the same variables as above.

7) **MAIN**: This is the starting SFC, and calls the other SFC's. Initially, only the LOADER and L_RAMS SFC's are active, while the other SFC's are activated by passing variable values through SFC L_RAMS.

4.3 FMS Model RLL Program

The relay ladder logic (RLL) for the FMS model was developed on the TI565 programmable controller. Some of the special functions available on the TI565 were used in the development of the RLL program [11]. The objective of developing ladder logic to achieve control of the model was to compare the ladder generated using APT to that generated manually. Appendix D gives a listing of the RLL program.

At the start of the program, integer values 1, 2 and 4 were loaded into three register locations. Depending on the part type (A, B or C), integer values 1, 2 or 4 were respectively moved into a fourth register sequentially. This register was then used as the input memory location for the TI565 special function FTSR-IN (Fall Thru Shift Register - In). This function loaded values into an array of registers, in a sequential order. Another special function FTSR_OUT (Fall Thru Shift Register - Out) was then used to pick out the first element from the queue in a first-in-first-out (FIFO) basis.

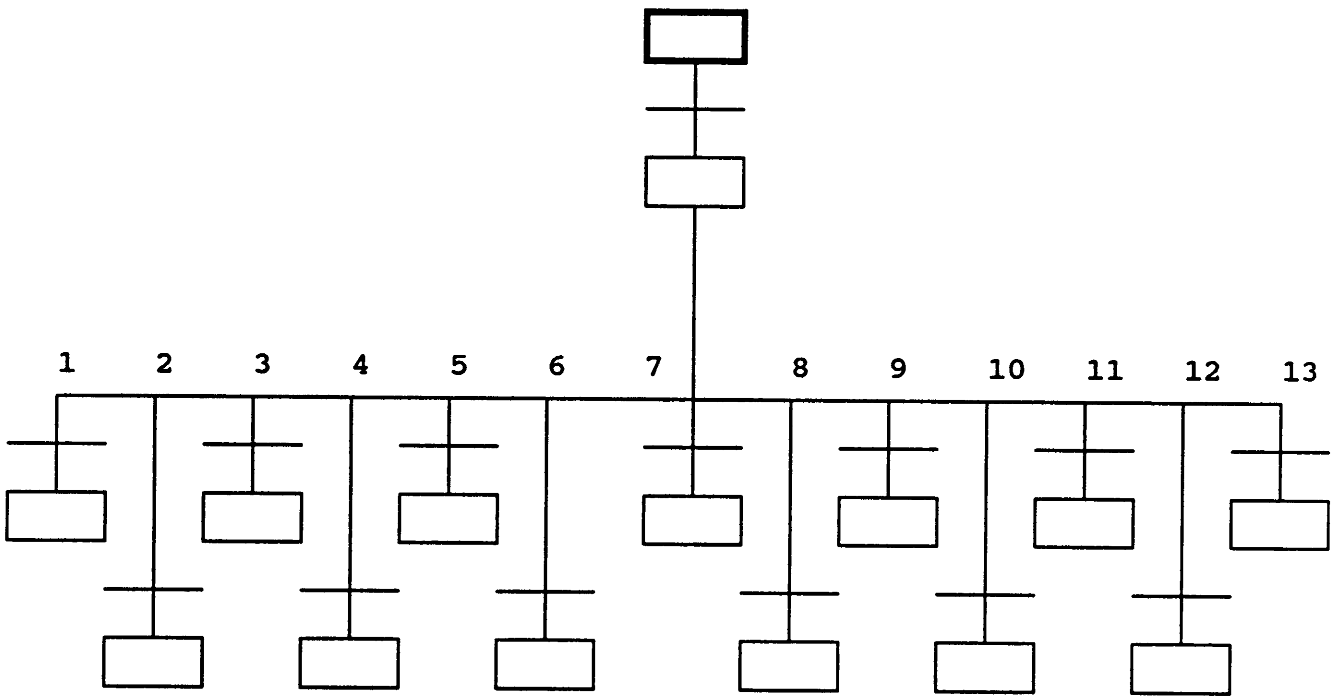
In essence, there were three divisions of ladder logic code. The first controlled the loader station, which queued up the requests using the FTSR-IN function and then ejected the appropriate part onto the conveyor once the pre-diverter photocell input (INP18) went high. These parts were ejected onto the conveyor on a FIFO basis. The diverter section then diverted the part from the conveyor to the turntable. The second section was at the turntable, where special function FTSR-OUT was used to determine the part type. Depending on a selection operation (BITP - BitPick), one of three GTS (Go To Subroutine) instructions was executed, and the indexing and processing were carried out. At the end of this operation, the product was then taken back to the conveyor, and the final section, the sorter section, handled the activation of the sorter rams. The FTSR-OUT special function was again used for the sorting function. Part type A was required to undergo drilling and milling, while type B was required to undergo milling and welding, and type C was required to undergo drilling and welding. This was the same sequence and type of operations as used in approach one using APT.

4.4 CIM Laboratory APT Program

As described earlier, the CIM Laboratory will be equipped to produce wax products of a toy robot and a CNC milling machine. Pallets will be moved between the AS/RS, the assembly cell and the machining cell. The function of the CIM Laboratory APT program was to control the material handling requirements of the lab. The material handling tasks for the system have been described earlier. Four discrete input lines are hooked to the P/C for carrying the task codes, and depending on the values entered, one of thirteen subtasks is executed, after the command strobe is set to a high state.

The APT program structure for the CIMlab consists of a main SFC (Figure 11) which starts the Shuttleworth conveyor, and then calls one of the thirteen SFC's, each corresponding to one of the subtasks required. Depending on the state (High/Low) of the four task code lines, one of the tasks is performed. Only after that task is completed can another one be started. The SFC's used are given below.

SFC MAIN



1 : sfc inc_outc

2 : sfc inc_ass

3 : sfc inc_mac

4 : sfc ass_mac

5 : sfc mac_ass

6 : sfc ass_outc

7 : sfc mac_outc

8 : sfc mac_opin

9 : sfc ass_opin

10 : sfc inc_opin

11 : sfc opi_outc

12 : sfc opin_ass

13 : sfc opin_mac

Figure 11: CIM Laboratory APT Program

1) **MAIN:** This SFC starts the conveyor, and calls one of the thirteen SFC's mentioned below, based on the task code input.

2) **INC_OUTC:** This SFC carries the pallet from the input conveyor to the output conveyor. This task was provided to carry the pallet back to the storage place in case the vision system check on the pallet reported a bad or faulty pallet. The task code corresponding to this task is 0001.

3) **INC_ASS:** This SFC carries the pallet from the input conveyor to the assembly cell. This task was provided in order to either kit an empty pallet, or carry out assembly of machined parts, or to help in the restocking of the feeders for the assembly station. The task code corresponding to this task is 0010.

4) **INC_MAC:** This SFC carries the pallet from the input conveyor to the machining cell. This task was provided to carry a kitted pallet from storage to the machining cell for machining of its components. The task code corresponding to this task is 0011.

5) **ASS_MAC:** This SFC carries the pallet from the assembly cell to the machining cell. This task was provided to carry a pallet kitted from the assembly cell to the machining cell for machining of its components. The task code corresponding to this task is 0100.

6) **MAC_ASS:** This SFC carries the pallet from the machining cell to the assembly cell. This task was provided to carry a machined pallet from the machining cell to the assembly cell for assembly of its components. The task code corresponding to this task was 0101.

7) **ASS_OUTC**: This SFC carries the pallet from the assembly cell to the output conveyor. This task was provided to carry an assembled product from the assembly cell to the output conveyor. The task code corresponding to this task is 0110.

8) **MAC_OUTC**: This SFC carries the pallet from the machining cell to the output conveyor. This task was provided to carry a machined but unassembled product from the machining cell to the output conveyor. The task code corresponding to this task is 0111.

9) **MAC_OPIN**: This SFC carries the pallet from the machining cell to the operator interface. This task was provided to carry a machined but unassembled product from the machining cell to the operator. The task code corresponding to this task is 1000.

10) **ASS_OPIN**: This SFC carries the pallet from the assembly cell to the operator interface. This task was provided to carry an assembled product from the assembly cell to the operator. The task code corresponding to this task is 1001.

11) **INC_OPIN**: This SFC carries the pallet from the input conveyor to the operator interface. This task was provided to carry a pallet from the input conveyor to the operator. The task code corresponding to this task is 1010.

12) **OPI_OUTC**: This SFC carries the pallet from the operator interface to the output conveyor. This task was provided to carry a pallet from the operator to the output conveyor to help with initialization. The task code corresponding to this task is 1011.

13) **OPIN-ASS**: This SFC carries the pallet from the operator interface to the assembly cell. This task was provided to carry a pallet from the operator to the assembly cell for restocking the feeders,

kitting a pallet or assembling a pallet with machined parts. The task code corresponding to this task is 1100.

14) OPIN_MAC: This SFC carries the pallet from the operator interface to the machining cell. This task was provided to carry a kitted pallet from the operator to the machining cell for machining to the operator. The task code corresponding to this task is 1101.

4.5 CIM Laboratory RLL Program

The CIM Laboratory ladder logic program was developed using the TI565 programmable controller. The program listing can be found in Appendix E. The objective of developing this code was to compare it with the code generated by the APT program. The functionality achieved by using both programs was the same.

The RLL program for the CIM Laboratory was developed with the GTS (Go To Subroutine) instruction as a primary feature. Depending on the task code input, the program skips to a particular section of logic, and executes it till the conditional input to the RTN (End of Subroutine) is satisfied. There are thirteen subroutines provided in the program to control all the subtasks desired in the material handling requirements.

Chapter 5
Results and Analysis

5.1 Introduction

In this Chapter, the resulting control solutions achieved with the programs described in chapter 4 are discussed. The extent of control achieved is examined for each program. An attempt is also made to determine at what stage a specific approach breaks down. For the Fischertechnik model manufacturing system, the program limitations are discussed with respect to the five levels of controls described earlier in Chapter 4, Section 4.2. For the CIM Laboratory, on the other hand, only one approach is used to achieve the desired purpose.

On the basis of the test programs and the control results, an effort is made to discuss the specific features of APT programming. Flexibility in programming methodology, debugging, memory considerations, ease of understanding programs, the RLL code generated by APT and the compilation time required are some of the aspects discussed.

5.2 Fischertechnik Manufacturing System Model

This section examines the physical control achieved using the different programming approaches for both the Fischertechnik Manufacturing model and the CIM Laboratory. Physical control using both, the APT approaches and the manually generated RLL codes, was examined. An analysis (numerical and descriptive) of APT with respect to some factors such as flexibility in program design, scan times and RLL length, is done in Section 5.5.

5.2.1 Physical Control Complexity Achieved Using Approach One

This approach essentially consisted of calling one SFC from a step in the DIVERTER SFC, depending on the part type and then stopping all other operations for that program until the machining SFC had completed execution. Limited control of the model was achieved. Control complexity was possible upto level two, where it was found possible to have multiple blocks on the conveyor at one time. However, it was only possible to have one block on the turntable at one time, and the conveyor had to be stopped while processing of the part was in progress. Processing of only one part type was carried out at one time, and the diverter stayed at the table-centered position until the machining operations for the part were completed, and the part brought back to the diverter position. Only then was the diverter moved back to the conveyor-centered position and the conveyor restarted.

The limitations to this approach arose from the fact that the machining SFC was a part of the DIVERTER SFC. The entire machining SFC had to be completed and the part taken back to the conveyor before it was possible to have the DIVERTER SFC active again. The DIVERTER SFC was already active while machining was in progress, and it was not possible to have it active at more than one point at the same time. This led to the next approach, wherein use was made of the concept of variables being passed along from one SFC to another, sequentially activating it.

5.2.2 Physical Control Complexity Achieved Using Approach Two

The purpose of this approach was to have the initial state in the SFC active at all times of program execution. The transition to the next step was governed by a calling variable. The moment the transition condition to the second step was true, the SFC branched in two parts; one part returned it to its initial state, and the second progressed. The initial step was again active until the transition condition was satisfied.

With the use of the variables described in Chapter 4, overall control of the FMS was achieved upto level 4. It was found possible to have multiple blocks on the conveyor at one time, and also to have more than one processing operation going on at the same time. In fact, it was found possible to have all the processing stations operating at the same time, and the conveyor on, as also the sorter and loader SFC's active. While the processing was in progress, processed parts were being sorted while unprocessed blocks were coming down the conveyor. The diverter remained at the table-centered position until the presence of a new part requiring processing was sensed. It then came back to the conveyor-centered position while the conveyor was moving. When the *drill_done*, *mill_done* and *weld_done* variables were set to false, and the preset belt pulse tick count reached, the diverter moved the unmachined part onto the turntable and indexing was carried out. Any order of parts on the conveyor was possible. The conveyor stops at the pre-diverter area in case processing is not complete, and waits for the *mill_done*, *drill_done* and *weld_done* signals before it starts moving again. The block then gets loaded onto the turntable and indexed. Overall control objective was achieved to a large extent.

5.2.3 Physical Control Complexity Achieved Using Approach Three

This approach used a less modular approach than the second approach. There was essentially one SFC for each part type, activated by a calling variable. The control achieved by this approach was the same as that of the previous one, for the same sequence of operations. Concurrent machining at all three stations was possible. The conveyor stopped only when the pre-diverter input went high and the *drill_done*, *mill_done* and *weld_done* input was true. Loading of the parts onto the conveyor and sorting at the appropriate sorter station went on uninterrupted.

5.2.4 Physical Control Complexity Achieved Using RLL for Fischertechnik Model

The RLL developed was intended to match the control aspect attained by the APT code generated for approach one. Multiple blocks on the conveyor were present, with only one part on the turntable at any one time, and the conveyor was stopped while the processing was in progress. The program was set up so that all the requests had to be loaded initially. The same physical control complexity was achieved as that using approach one of the APT program.

5.3 Physical Control for CIM Laboratory using APT

The APT program developed performed the desired functions effectively. All the tasks were given specific task codes, and the APT program took these inputs (X97 - X100) and performed that specific task. While the task was in progress, a *'sys_busy'* indicator was set to true, and this prevented any other task from being executed while this one was in progress. Any of the desired tasks could be performed by entering the right task code for the task, and then forcing the strobe bit to a high value. This code deals with only one pallet on the conveying system at one time, and only one task being performed at any one time. The AS/RS was not taken into consideration as it had not been installed as yet.

5.4 Physical Control for CIM Laboratory using RLL

The RLL developed for the CIMLAB was much shorter than the RLL generated by the APT code. The APT generated PLL code was lengthy and difficult to understand. The RLL developed performed the same tasks, and put the material handling system in an functional state. As compared to the APT program results, the reaction times to changes in the input conditions were smaller, owing to enhanced scan tines.

5.5 APT Characteristics - An Analysis

5.5.1 Flexibility in Program Development

APT offers good flexiblity in program development for control purposes. As demonstrated by the different approaches used for controlling the FMS model, it is possible to achieve various levels of control complexity using APT. The object oriented base of APT accomodates flexible operations without redesigning the control system. Once an object has been defined in the device declaration table, it can be easily manipulated without looking at any preceding connection to it, as is the case in ladder logic. The operation of a device is governed from the commands in a step, and is not dependent on other factors. Using variables as transition conditions also increases program flexibility, as demonstrated by the FMS program approaches two and three. The use of the variables *drill_done*, *mill_done* and *weld_done* in the Fischertechnik model program development helped in identifying a particular machining station as busy or idle. This state was in turn processed by another SFC (TURN_TAB) before indexing could be done. The use of these variables, as also the calling variables, greatly helped in program development.

Approach Two for the Fischertechnik model is particularly useful in demonstrating increased program flexibility. Suppose the drilling operations on one of the part types have to be changed i.e, the drilling instructions were now different. Using this approach, the programmer would only need to edit the 'DRILL" SFC , and the new program could now be used. On the other hand, if manually generated RLL was being used to control the application, the programmer would have to trace through rungs of ladder logic to isolate the drilling sequence, and then modify it. This becomes a major problem in case a lot of control relays are present, since these would also have to be examined to understand the entire program logic.

5.5.2 Ease in Understanding Programs

APT provides a graphical representation of the process control problem, and uses English languages statements for commands and transition statements. This makes it much easier for people other than the actual programmer to understand the program. The top-down approach also helps in defining the situation clearly. The system is more intelligible across all control disciplines, at any level of expertise. As opposed to ladder logic, where one is presented with a large output of rungs, it is easier to understand an APT program, wherein the actual process is itself laid out by virtue of the top down approach used in APT. The English language statements also make it more user friendly for more computer literate users. The design of a program becomes simpler with the help of English statements, where one can follow the logic in a better fashion as opposed to ladder logic.

5.5.3 Debugging

APT provides good debugging facilities. The process control solution is laid out graphically on the screen in a tops-down approach. Through the debug utility, it is possible to monitor the state of the steps while the program is in the run mode. When the step is active, it is highlighted. This capability in APT is very useful in debugging, as it can tell the programmer where the error in the program lies, and corrective action can be taken starting here. It also provides a single step run mode, wherein the program stops after every step, and the operator has to press a key on the keyboard to go to the next step. RLL, on the other hand, shows only which elements are activated. Debugging is difficult, since the program is usually long.

5.5.4 Memory and Compilation Time Considerations

The memory requirements for using APT were noticeably higher than those for TISOFT 565 [11]. APT requires about 12 MBytes of memory to load successfully, while TISOFT requires around 1.5 MBytes. For the Fischertechnik model, the ladder generated using APT for approach one occupied 97 KBytes memory, while the corresponding RLL generated manually occupied 66 KBytes (Table 1). For the CIM Laboratory, the APT generated ladder took up 85 KBytes memory, while the ladder generated manually took up 64 KBytes (Table 2).

Compilation times for the APT programs were in the 30 - 60 minute range, on an 80386 based machine (Tables 1 and 2). Any time the program was changed, it was necessary to recompile the program. Troubleshooting

TABLE 1

FMS Model Results

	APP 1	APP 2	APP 3	RLL
Comp Time (min) with Debug	58	67	62	0
Comp Time (min)	21	28	32	0
RLL Length (X-Y)	10470	12310	13280	1420
Scan Time (msec)	48	53	61	22
Ladder Mem (KB)	24	28	28	16
System Mem (KB)	97	109	109	66
* Thruput (pph)	27	57	58	26
Conv ontime %	24	72	74	23

* Order of parts was CBACBACBAC (C-M,W; B-D,W; A-D,M,W)

TABLE 2

CIM Laboratory Results

	APT Program	RLL Program
Comp time (min) with Debug	55	0
Comp Time (min) w/o Debug	24	0
RLL Code Length (X-Y)	9010	990
Scan Times (msec)	48	21
Ladder memory (KB)	20	16
System Memory (KB)	85	64

and debugging were thus hindered. TISOFT, on the other hand, did not need compilation.

5.5.5 RLL Code Generated

It was observed that the RLL code generated using the APT programs was very large and had a lot of control relays. One of the claims of APT is that it automatically compiles to relay ladder logic for ease in maintenance and troubleshooting. However, from the ladder logic obtained from the APT programs, it would appear to be very difficult to understand or debug the program, even with the cross-reference table. The large number of control relays make it extremely difficult to track the program through. The RLL program written for the FMS model (approach 1) had a total of 1420 elements, while the corresponding APT generated RLL code had 10470 lines of code (Table 1). For the CIM Laboratory the manually generated RLL had 990 elements, while the APT generated code had 9010 elements (Table 2).

5.5.6 Scan Times

It was observed that the scan times for the APT generated RLL code were higher than those for the RLL generated manually, owing to the larger program length. Though the ratio of RLL length (manually generated versus APT generated) was 1:10 (see Tables 1 and 2), the scan times ratio was 1:2, primarily because the APT generated RLL had a lot of JMP (Jump) instructions, which were skipped over.

Chapter 6
Conclusions and Recommendations

The use of different approaches in programming methodology for controlling the Fischertechnik FMS model demonstrated that APT could have definite applications in discrete manufacturing. The FMS model is a physical simulation of an industrial application, and it was demonstrated that APT could effectively be used to achieve the control objective. The CIM Laboratory was also programmed using APT, and the functions desired here were provided effectively.

It was observed that APT did indeed offer good flexibility in programming technique, and could be used effectively in different ways. It was definitely more user-friendly to the programmer than ladder logic, and easier to comprehend, due to the usage of English statements. The graphical layout also helped to depict the process control effectively. The debugging capabilities in APT were found to be good, and helped in pinpointing errors effectively.

The RLL code generated by the APT program was however, found to be very large and complicated, making it very difficult to follow the logic. This goes against the TI claim that the resulting solution can be used by maintenance and shopfloor personnel. As mentioned earlier, compilation times were in the 30 - 60 minute range, on an 80386 based machine. It is possible to shorten the compilation time using memory enhancement software [14].

Future research on this subject could be directed towards achieving the final control objective required for the Fischertechnik manufacturing system model, wherein machine breakdown is considered, and order is not maintained. The turntable could be fully loaded, and the conveyor moving. The conveyor would only stop when the pre-diverter photocell input signals another part for machining. In this situation, it is possible that one or more parts would bypass machining at one particular station, and be sent out to the reject chute instead of being sorted at the sorter stations. This control objective was not considered in the scope of this research, but would be a good and feasible objective.

The CIM Laboratory APT program at the moment only handles tasks till the conveyor. The AS/RS was not considered as it has not been installed as yet, and testing of the code would not have been possible. The AS/RS integration would test the APT applicability in discrete manufacturing further, and if control is achieved, could further strengthen the case for discrete manufacturing applicability. Flagging of error conditions using the safe state SFC's could be another way for using APT in the CIMLAB for higher control objectives. The APT code presented handles only the simple conveying functions from one part of the material handling system to another. It does not handle any communication messages between the P/C and the Dyna milling machines, or the robots. Thus, once the robot and Dyna communication code is written, the APT program could be extended to handle the communication messages. APT code could also be generated so that the situation of more than one pallet on the conveyor at any one time can be handled.

APT programming can be done only on the TI 565 programmable controller. APT does not run on the TI 520 or TI 530 or any other programmable controller models. The high cost of the TI 565 model would act as a factor in APT application. If an industrial environment requires a simple on/off process control solution, without much complexity, it would be preferable to use ladder logic on a small controller, as opposed to APT application on the TI565 model. APT is more suitable for a large scale industrial environment with a complex control structure. The benefits offered by APT are highlighted in a complex control structure. APT is also especially useful in a flexible manufacturing system, wherein factors such as machining parameters for parts and parts sequencing are changed often. Using the APT programming technique, it is possible to isolate each machine and include its operation sequence in an SFC. For instance, if the machining steps on a part have to be changed, the programmer could easily modify that SFC, and leave the rest of the control structure as it is. On the other hand, using ladder logic, the machining steps may be embedded in a large set of rungs, which may be related by other control relays. Tracing the logic here may be difficult.

As discussed earlier, one of the disadvantages of using APT is that the generated RLL is very large. If the system being controlled is big, the response time to changes in input conditions may be slower than the case where manually generated RLL is used to control the system. Thus, if a large system requires a very fast response time to changing input conditions, use of APT to control it may not be fully reliable.

In conclusion, APT code was used successfully to control the two discrete manufacturing applications described. The scope of this research was limited to the discrete manufacturing environment. On the basis of the control achieved, it would appear to be possible to apply APT to the discrete manufacturing environment.

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APPENDIX A

Fischertechnik Model Input / Output Listing

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I/O REPORT

FMS_APP1 fms program - 1 pt on ttab
IO I/O symbolic name table
Modified: 12/Apr/1989 18:22:20

Name	Type	Description	Address
OUT32	DO Digital output	Laser Y ax on/off signal	Y1088
OUT31	DO Digital output	Laser Y ax motor direction sig	Y1087
OUT30	DO Digital output	Laser X ax motor on/off signal	Y1086
OUT29	DO Digital output	Laser X ax motor direction sig	Y1085
OUT28	DO Digital output	Milling drive motor signal	Y1084
OUT27	DO Digital output	Milling stn alarm signal	Y1083
OUT26	DO Digital output	Sorter ram C signal	Y1082
OUT25	DO Digital output	Sorter ram B signal	Y1081
OUT24	DO Digital output	Laser drive motor signal	Y1080
OUT23	DO Digital output	Laser welding stn alarm signal	Y1079
OUT22	DO Digital output	Drilling Y ax motor on/off sig	Y1078
OUT21	DO Digital output	Drilling Y ax mot direction si	Y1077
OUT20	DO Digital output	Sorter ram A signal	Y1076

I/O REPORT

Name	Type	Description	Address
OUT19	DO Digital output	Dispenser ram C signal	Y1075
OUT18	DO Digital output	Dispenser ram B signal	Y1074
OUT17	DO Digital output	Dispenser ram A signal	Y1073
OUT16	DO Digital output	Drilling X ax motor on/off sig	Y1072
OUT15	DO Digital output	Drilling X ax mot direction si	Y1071
OUT14	DO Digital output	Drilling drive motor signal	Y1070
OUT13	DO Digital output	Drilling stn alarm signal	Y1069
OUT12	DO Digital output	Ram stn alarm sig	Y1068
OUT11	DO Digital output	Startup alarm signal, not inst	Y1067
OUT10	DO Digital output	System on/off light	Y1066
OUT9	DO Digital output	Turntable on/off signal	Y1065
OUT8	DO Digital output	Milling Y ax motor on/off sig	Y1064
OUT7	DO Digital output	Milling Y ax motor direction o	Y1063
OUT6	DO Digital output	Milling X ax motor on/off sig	Y1062
OUT5	DO Digital output	Milling X ax motor direction o	Y1061

I/O REPORT

Name	Type	Description	Address
OUT4	DO Digital output	Diverter on/off signal	Y1060
OUT3	DO Digital output	Diverter drive signal	Y1059
OUT2	DO Digital output	Conveyor drive signal	Y1058
OUT1	DO Digital output	Matl handling stn alarm	Y1057
INP32	DI Digital input	C request pushbutton inp	X1056
INP31	DI Digital input	Laser Y ax retracted swt inp	X1055
INP30	DI Digital input	Laser Y ax extended swt inp	X1054
INP29	DI Digital input	Laser X ax retracted swt inp	X1053
INP28	DI Digital input	Milling X ax extended swt inp	X1052
INP27	DI Digital input	Milling stn disable swt inp	X1051
INP26	DI Digital input	Reject chute photo resistor in	X1050
INP25	DI Digital input	Chute C photoresistor inp	X1049
INP24	DI Digital input	Laser X ax extended swt inp	X1048
INP23	DI Digital input	Laser welding stn disable swt	X1047
INP22	DI Digital input	B request pushbutton inp	X1046

I/O REPORT

Name	Type	Description	Address
INP21	DI Digital input	Drilling Y ax retracted swt in	X1045
INP20	DI Digital input	Chute B photo resistor inp	X1044
INP19	DI Digital input	Chute A photo resistor inp	X1043
INP18	DI Digital input	Pre diverter photo resistor in	X1042
INP17	DI Digital input	Post loader photo resistor inp	X1041
INP16	DI Digital input	Drilling Y ax extended swt inp	X1040
INP15	DI Digital input	Drilling X ax retracted swt in	X1039
INP14	DI Digital input	Drilling X ax extended swt inp	X1038
INP13	DI Digital input	Drilling stn disable swt inp	X1037
INP12	DI Digital input	Ram stn disable swt inp	X1036
INP11	DI Digital input	Emergency stop pushbutton inp	X1035
INP10	DI Digital input	Reset pushbutton inp	X1034
INP9	DI Digital input	Turn table reed swt inp	X1033
INP8	DI Digital input	A request pushbutton swt	X1032
INP7	DI Digital input	Milling Y ax retracted swt inp	X1031

I/O REPORT

Name: INP6	Type: DI Digital input Description: Milling Y ax extended swt inp	Address: X1030
Name: INP5	Type: DI Digital input Description: Milling X ax retracted swt inp	Address: X1029
Name: INP4	Type: DI Digital input Description: Diverter/table centered inp	Address: X1028
Name: INP3	Type: DI Digital input Description: Diverter/conveyor centered inp	Address: X1027
Name: INP2	Type: DI Digital input Description: Belt timing pulse input	Address: X1026
Name: INP1	Type: DI Digital input Description: Matl Handling stn disable swth	Address: X1025

I/O REPORT

I/O TABLE SUMMARY

Total I/O:	64
Analog Inputs(AI):	0
Analog Outputs(AO):	0
BCD Inputs(BI):	0
BCD Outputs(BO):	0
Digital Inputs(DI):	32
Digital Outputs(DO):	32
Digital Flags(DF):	0
Peerlink Reserved Words(PL):	0
Thermocouple(TC):	0
Resist Temp Detect(RT):	0
Word Inputs(WI):	0
Word Outputs(WO):	0

APPENDIX B

CIM Laboratory Input / Output Listing

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I/O REPORT

CIMLAB cimlab trial control program
IO I/O symbolic name table
Modified: 19/Jul/1989 17:52:56

Name	Type	Description	Address
OI016	DI Digital input	operator / test input	X0176
OI015	DI Digital input	operator / test input	X0175
OI014	DI Digital input	operator / test input	X0174
OI013	DI Digital input	operator / test input	X0173
OI012	DI Digital input	operator / test input	X0172
OI011	DI Digital input	operator / test input	X0171
OI010	DI Digital input	operator / test input	X0170
OI009	DI Digital input	operator / test input	X0169
OI008	DI Digital input	operator / test input	X0168
OI007	DI Digital input	operator / test input	X0167
OI006	DI Digital input	operator / test input	X0166
OI005	DI Digital input	operator / test input	X0165
OI004	DI Digital input	operator / test input	X0164

I/O REPORT

Name	Type	Address	Description
OI003	DI Digital input	X0163	operator / test input
OI002	DI Digital input	X0162	operator / test input
OI001	DI Digital input	X0161	operator / test input
PH016	DI Digital input	X0149	prt pres; conv to AS/RS sectio
PH015	DI Digital input	X0148	prt pres; AS/RS to conv sectio
PH014	DI Digital input	X0147	prt pres; mach shot pin mech
PH013	DI Digital input	X0146	prt pres; assy shot pin mech
PH012	DI Digital input	X0145	prt pres; out conv, out side
PH011	DI Digital input	X0144	prt pres; at assy l&t, out
PH010	DI Digital input	X0143	prt pres; assy l&t,out, rt-out
PH009	DI Digital input	X0142	prt pres; pre assy l&t, out si
PH008	DI Digital input	X0141	prt pres; mach l&t,out, rt-out
PH007	DI Digital input	X0140	prt pres; at mach l&t, in side
PH006	DI Digital input	X0139	prt pres; mach l&t,in, pl-n_sp
PH005	DI Digital input	X0138	prt pres; pre mach, in side

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I/O REPORT

Name	Type	Description	Address
PH004	DI Digital input	prt pres; at assy l&t, in side	X0137
PH003	DI Digital input	prt pres; assy l&t, in, rt-in	X0136
PH002	DI Digital input	prt pres; assy l&t,in, pl-n-sp	X0135
PH001	DI Digital input	prt pres; pre assy, in side	X0134
LS004	DI Digital input	mach shot pin; raised	X0133
LS003	DI Digital input	assy shot pin; raised	X0132
LS002	DI Digital input	mach l&t; raised	X0131
LS001	DI Digital input	assy l&t; raised	X0130
IS012	DI Digital input	shuttle position;conv post tal	X0129
IS011	DI Digital input	shuttle position;conv post tal	X0128
IS010	DI Digital input	shuttle position;rack post sho	X0127
IS009	DI Digital input	shuttle position;rack post tal	X0126
IS008	DI Digital input	prt pres; in AS/RS rack	X0125
IS007	DI Digital input	prt pres; on shuttle	X0124
IS006	DI Digital input	vertical position, mark	X0123

I/O REPORT

Name	Type	Description	Address
IS005	DI Digital input	vertical position, slow zone	X0122
IS004	DI Digital input	vertical position, home	X0121
IS003	DI Digital input	horizontal position, mark	X0120
IS002	DI Digital input	horizontal position, slow zone	X0119
IS001	DI Digital input	horizontal position, home	X0118
CL059	DI Digital input	dyna 2; m/c done ack, WCC-PLC	X0117
CL057	DI Digital input	dyna 2; m/c done strobe,DY-PLC	X0116
CL055	DI Digital input	dyna 2; go pulse, WCC-PLC	X0115
CL054	DI Digital input	dyna 1; m/c done ack, WCC-PLC	X0114
CL052	DI Digital input	dyna 1; m/c done strobe,DY_PLC	X0113
CL050	DI Digital input	dyna 1; go pulse, WCC-PLC	X0112
CL032	DI Digital input	AS/RS vertical address; bit 3	X0111
CL031	DI Digital input	AS/RS vertical address; bit 2	X0110
CL030	DI Digital input	AS/RS vertical address; bit 1	X0109
CL029	DI Digital input	AS/RS vertical address; bit 0	X0108

I/O REPORT

Name: CL028 Type: DI Digital input Address: X0107
Description: AS/RS horizontal addrs; bit 3

Name: CL027 Type: DI Digital input Address: X0106
Description: AS/RS horizontal addrs; bit 2

Name: CL026 Type: DI Digital input Address: X0105
Description: AS/RS horizontal addrs; bit 1

Name: CL025 Type: DI Digital input Address: X0104
Description: AS/RS horizontal addrs; bit 0

Name: CL024 Type: DI Digital input Address: X0103
Description: AS/RS command (store/retrieve)

Name: CL023 Type: DI Digital input Address: X0102
Description: AS/RS command strobe

Name: CL008 Type: DI Digital input Address: X0101
Description: conv task code; bit 3

Name: CL007 Type: DI Digital input Address: X0100
Description: conv task code; bit 2

Name: CL006 Type: DI Digital input Address: X0099
Description: conv task code; bit 1

Name: CL005 Type: DI Digital input Address: X0098
Description: conv task code; bit 0

Name: CL004 Type: DI Digital input Address: X0097
Description: conv command strobe

Name: SV017 Type: DO Digital output Address: Y0053
Description: mach shotpin; lower

Name: SV016 Type: DO Digital output Address: Y0052
Description: mach shotpin; lift

Name: SV015 Type: DO Digital output Address: Y0051
Description: assy shotpin; lower

Name: SV014 Type: DO Digital output Address: Y0050
Description: assy shotpin; lift

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I/O REPORT

Name	Type	Description	Address
SV013	DO Digital output	mach l&t; lower	Y0049
SV012	DO Digital output	mach l&t; lift	Y0048
SV011	DO Digital output	assy l&t; lower	Y0047
SV010	DO Digital output	assy l&t; lift	Y0046
SV008	DO Digital output	plt stop; AS/RS to conv sectio	Y0045
SV007	DO Digital output	plt stop; conv to AS/RS sectio	Y0044
SV006	DO Digital output	plt stop; out conv, out side	Y0043
SV005	DO Digital output	plt stop; post assy l&t, out s	Y0042
SV004	DO Digital output	plt stop; pre assy l&t, out si	Y0041
SV003	DO Digital output	plt stop; pre mach l&t, in sid	Y0040
SV002	DO Digital output	plt stop; post assy l&t, in si	Y0039
SV001	DO Digital output	plt stop; pre assy l&t, in sid	Y0038
MD027	DO Digital output	shuttle drive, direction	Y0037
MD026	DO Digital output	shuttle drive, on/off	Y0036
MD025	DO Digital output	vertical drive, direction	Y0035

I/O REPORT

Name	Type	Address	Description
MD024	DO Digital output	Y0034	vertical drive, slow/fast
MD023	DO Digital output	Y0033	vertical drive, on/off
MD022	DO Digital output	Y0032	horizontal drive, direction
MD021	DO Digital output	Y0031	horizontal drive, slow/fast
MD020	DO Digital output	Y0030	horizontal drive, on/off
MD011	DO Digital output	Y0029	mach l&t, direction
MD010	DO Digital output	Y0028	mach l&t, on/off
MD009	DO Digital output	Y0027	assy l&t, direction
MD008	DO Digital output	Y0026	assy l&t, on/off
MD007	DO Digital output	Y0025	conv-AS/RS; conv drive, on/off
MD006	DO Digital output	Y0024	AS/RS-conv; conv drive, on/off
MD005	DO Digital output	Y0023	mach conv drive, direction
MD004	DO Digital output	Y0022	mach conv drive, on/off
MD003	DO Digital output	Y0021	assy conv drive, direction
MD002	DO Digital output	Y0020	assy conv drive, on/off

I/O REPORT

Name: MD001	Type: DO Digital output Description: mainline conv drive, on/off	Address: Y0019
Name: CL058	Type: DO Digital output Description: dyna 2; m/c done sigl, PC-WCC	Address: Y0018
Name: CL056	Type: DO Digital output Description: dyna 2; wait for rdy, PC-Dyna	Address: Y0017
Name: CL053	Type: DO Digital output Description: dyna 1; m/c done sigl, PC-WCC	Address: Y0016
Name: CL051	Type: DO Digital output Description: dyna 1; wait for rdy, PC-Dyna	Address: Y0015
Name: CL036	Type: DO Digital output Description: AS/RS status code; bit 3	Address: Y0014
Name: CL035	Type: DO Digital output Description: AS/RS status code; bit 2	Address: Y0013
Name: CL034	Type: DO Digital output Description: AS/RS status code; bit 1	Address: Y0012
Name: CL033	Type: DO Digital output Description: AS/RS status code; bit 0	Address: Y0011
Name: CL022	Type: DO Digital output Description: ack AS/RS command	Address: Y0010
Name: CL021	Type: DO Digital output Description: AS/RS system done	Address: Y0009
Name: CL020	Type: DO Digital output Description: AS/RS system busy	Address: Y0008
Name: CL012	Type: DO Digital output Description: conv status code; bit 3	Address: Y0007
Name: CL011	Type: DO Digital output Description: conv status code; bit 2	Address: Y0006
Name: CL010	Type: DO Digital output Description: conv status code; bit 1	Address: Y0005

I/O REPORT

Name: CL009	Type: DO Digital output Description: conv status code; bit 0	Address: Y0004
Name: CL003	Type: DO Digital output Description: ack conv command	Address: Y0003
Name: CL002	Type: DF Digital Flag Description: conv sys done	Address: Y0002
Name: CL001	Type: DF Digital Flag Description: conv sys busy	Address: Y0001

I/O REPORT

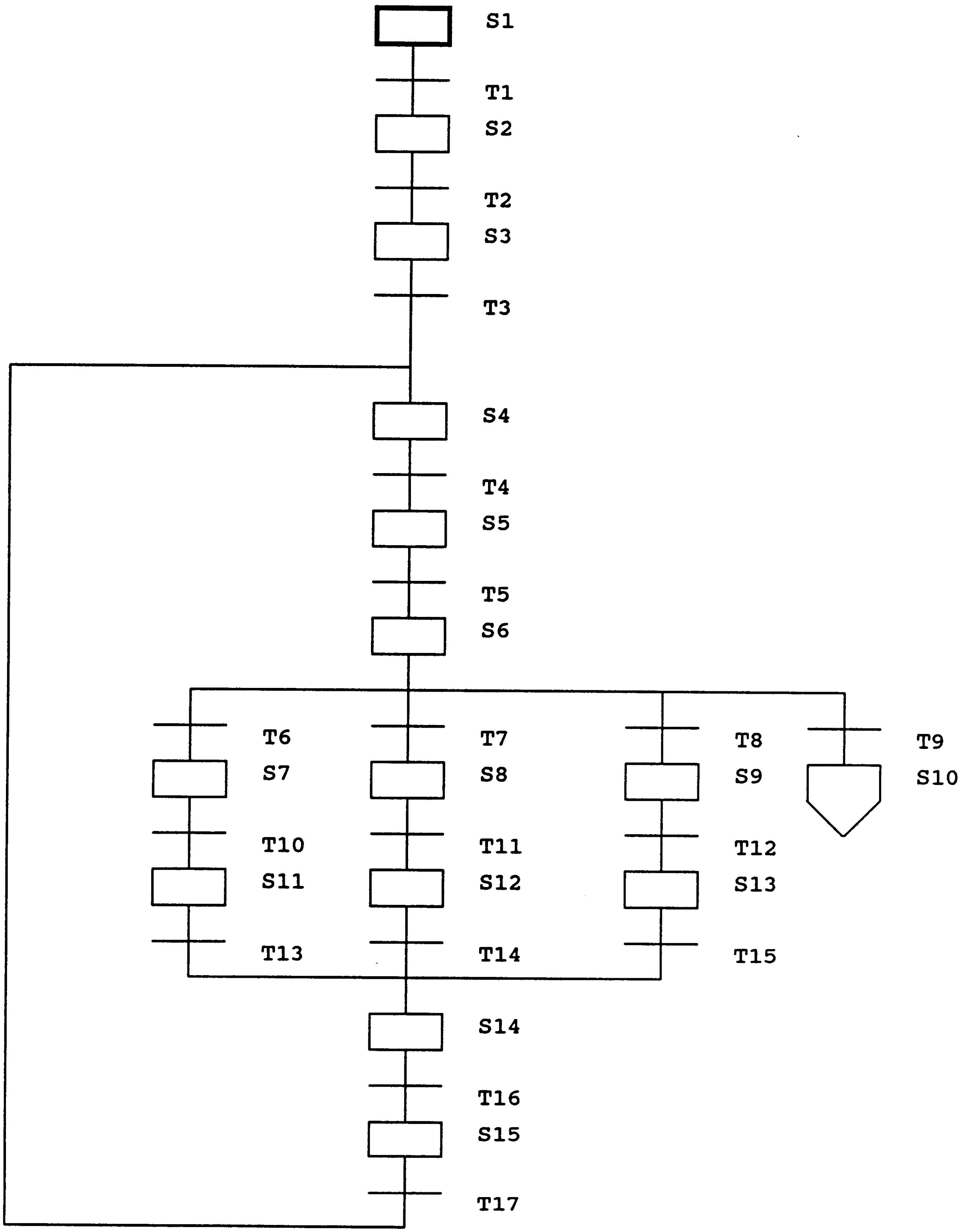
I/O TABLE SUMMARY

Total I/O:	122
Analog Inputs(AI):	0
Analog Outputs(AO):	0
BCD Inputs(BI):	0
BCD Outputs(BO):	0
Digital Inputs(DI):	69
Digital Outputs(DO):	51
Digital Flags(DF):	2
Peerlink Reserved Words(PL):	0
Thermocouple(TC):	0
Resist Temp Detect(RT):	0
Word Inputs(WI):	0
Word Outputs(WO):	0

APPENDIX C

FMS APT Approach 1 - SFC L_RAMS

SFC L_RAMS (Approach 1)



SFC L_RAMS (Approach 1)

Textual Information Chart

S1

```
lock motor1;
lock valve1;
lock valve2;
lock valve3;
```

T1

```
true
```

S2

```
block_num:=0;
```

T2

```
true
```

S3

```
index:=1;
```

T3

```
true
```

S4

T4

```
true
```

S5

```
end1:=0;
end2:=0;
end3:=0;
end4:=0;
lramdone:=0;
```

T5

```
true
```

S6

```
MATH
  BEGIN
```

```
IDUMB:=IARR_1[index];
if (IDUMB=1) then
   end1:=1;
elsif (IDUMB=2) then
   end2:=1;
elsif (IDUMB=3) then
   end3:=1;
else
   end4:=1;
endif;
lramdone:=1;
```

T6

end1=1 AND lramdone=1

T7

end2=1 AND lramdone=1

T8

end3=1 AND lramdone=1

T9

end4=1 AND lramdone=1

S7

open valve1;

S8

open valve2;

S9

open valve3;

S10

graphically connected to S5

T10

valve1.opnd

T11

valve2.opnd

T12

valve3.opnd

S11

close valve1;

S12

close valve2;

S13

close valve3;

T13

valve1.clsd

T14

valve2.clsd

T15

valve3.clsd

S14

increment index;

T16

inp18=true

S15

T17

inp18=false

Total number of steps : 14

Total number of transitions : 17

APPENDIX D

FMS Model Relay Ladder Logic Program

```
---------------------------------------------------------------------------------------
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                                   DATE= 00-00-00                          OFF LINE

     !X1034 X1035                                                           C1025 !
1    *-]/[-*-] [--------------------------------------------------------------( )--*
     !     !                                                                      !
     !C1025!                                                                      !
     *-] [-*                                                                      !
     !                                                                            !
     !C1025  *------------*   *------------*   *------------*              C1026 !
9    *-] [---!    LDC1    !---!    LDC2    !---!    LDC3    !------------------( )--*
     !       !            !   !            !   !            !                     !
     !       !            !   !            !   !            !                     !
     !       ! A:   V1    !   ! A:   V2    !   ! A:   V3    !                     !
     !       !            !   !            !   !            !                     !
     !       !            !   !            !   !            !                     !
     !       ! N=    1    !   ! N=    2    !   ! N=    4    !                     !
     !       *------------*   *------------*   *------------*                     !
     !C1025  *------------*                                                C1026 !
22   *-] [---!    LDC4    !-------------------------------------------------------( )--*
     !       !            !                                                       !
     !       !            !                                                       !
     !       ! A:   V5    !                                                       !
     !       !            !                                                       !
     !       !            !                                                       !
     !       ! N=    0    !                                                       !
     !       *------------*                                                       !
     !C1025 X1027 X1035                                                     Y1058 !
29   *-] [-*-]/[---] [------------------------------------------------------------( )--*
     !     !                                                                      !
     !Y1058!                                                                      !
     *-] [-*                                                                      !
     !                                                                            !
     !X1032 X1046 X1056  *------------*                                     C1040 !
39   *-]/[---] [---] [---!    O/S1    !-------------------------------------------( )--*
     !                   !            !                                           !
     !                   !            !                                           !
     !                   !            !                                           !
     !                   !            !                                           !
     !                   !            !                                           !
     !                   *------------*                                           !
     !C1040  *------------*                                                C1041 !
48   *-] [---!   MOVW1    !-------------------------------------------------------( )--*
     !       !            !                                                       !
     !       !            !                                                       !
     !       ! A:   V1    !                                                       !
     !       ! B:   V4    !                                                       !
     !       !            !                                                       !
     !       ! N=    1    !                                                       !
     !       *------------*                                                       !
     !X1032 X1046 X1056  *------------*                                     C1042 !
56   *-] [---]/[---] [---!    O/S2    !-------------------------------------------( )--*
     !                   !            !                                           !
     !                   !            !                                           !
     !                   !            !                                           !
     !                   !            !                                           !
     !                   !            !                                           !
```

```
--------------------------------------------------------------------------------------------
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                                 DATE= 00-00-00                          OFF LINE
       !C1042  *-------------*
65     *-] [---!  MOVW2       !                                     C1043 !
       !       !              !-------------------------------------( )--*
       !       !              !                                           !
       !       !  A:  V2      !                                           !
       !       !  B:  V4      !                                           !
       !       !              !                                           !
       !       !  N=   1      !                                           !
       !       *-------------*                                            !
       !X1032 X1046 X1056  *-------------*                          C1044 !
73     *-] [---] [---]/[---!   O/S3      !--------------------------( )--*
       !                   !             !                                !
       !                   !             !                                !
       !                   !             !                                !
       !                   !             !                                !
       !                   *-------------*                                !
       !C1044  *-------------*                                      C1045 !
82     *-] [---!  MOVW3       !-------------------------------------( )--*
       !       !              !                                           !
       !       !  A:  V3      !                                           !
       !       !  B:  V4      !                                           !
       !       !              !                                           !
       !       !  N=   1      !                                           !
       !       *-------------*                                            !
       !C1041  *-------------*                                      C1050 !
90     *-] [-*-!  SFPGM1      !-------------------------------------( )--*
       !     ! !              !                                           !
       !C1043! !              !                                           !
       *-] [-* !              !                                           !
       !     ! !              !                                           !
       !C1045! !              !                                           !
       *-] [-* !              !                                           !
       !       *-------------*                                            !
       !C1041  *-------------*                                      C1050 !
99     *-] [-*-!  SFPGM3      !-------------------------------------( )--*
       !     ! !              !                                           !
       !C1043! !              !                                           !
       *-] [-* !              !                                           !
       !     ! !              !                                           !
       !C1045! !              !                                           !
       *-] [-* !              !                                           !
       !       *-------------*                                            !
       !C1041  *-------------*                                      C1092 !
108    *-] [-*-!  SFPGM5      !-------------------------------------( )--*
       !     ! !              !                                           !
       !C1043! !              !                                           !
       *-] [-* !              !                                           !
       !     ! !              !                                           !
       !C1045! !              !                                           !
       *-] [-* !              !                                           !
       !       *-------------*                                            !
```

```
---------------------------------------------------------------------------------------------
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                                   DATE= 00-00-00                               OFF LINE

       !Y1058  *--------------*                                                  C1055 :
117    *-] [---!    CMP1      !-----------------------------------------------( )--*
       !       !              !                                                      :
       !       ! A:   V1      !                                                      :
       !       ! B:   V11     !                                                      :
       !       !              !                                                      :
       !       !LT=           !                                                      :
       !       !GT=           !                                                      :
       !       *--------------*                                                      :
       !C1055                                                                    C1056 :
126    *-] [-----------------------------------------------------------------------( )--*
       !                                                                             :
       !C1056          *--------------*                                          C1057 :
130    *-] [--------*-! SFPGM2        !-------------------------------------------( )--*
       !            ! !               !                                              :
       !X1042 C1058!  !               !                                              :
       *-] [---]/[-*  !               !                                              :
       !              !               !                                              :
       !              !               !                                              :
       !              !               !                                              :
       !              *---------------*                                              :
       !Y1058  *--------------*                                                  C1058 :
140    *-] [---!    CMP2      !-----------------------------------------------( )--*
       !       !              !                                                      :
       !       ! A:   V5      !                                                      :
       !       ! B:   V10     !                                                      :
       !       !              !                                                      :
       !       !LT=           !                                                      :
       !       !GT=           !                                                      :
       !       *--------------*                                                      :
       !C1057  *--------------*                                                  C1060 :
149    *-] [---!    O/S8      !-----------------------------------------------( )--*
       !       !              !                                                      :
       !       !              !                                                      :
       !       !              !                                                      :
       !       !              !                                                      :
       !       !              !                                                      :
       !       *--------------*                                                      :
       !C1060  *--------------*    *--------------*                              C1061 :
154    *-] [---!    CDB1      !---!    BITP1      !---------------------------( )--*
       !       !              !   !               !                                  :
       !       ! A:   V6      !   ! A:   V7       !                                  :
       !       ! B:   V7      !   !               !                                  :
       !       !              !   !               !                                  :
       !       ! N=    4      !   ! N=    16      !                                  :
       !       *--------------*   *---------------*                                  :
       !C1061 C1063                                                              Y1073 :
165    *-] [-*-]/[-------------------------------------------------------------( )--*
       !     !                                                                       :
       !Y1073!                                                                       :
       *-] [-*                                                                       :
       !                                                                             :
```

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--------------------------------------------------------------------------------------------
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                                   DATE= 00-00-00                        OFF LINE
         !C1061 C1063
 173     *-] [-*-]/[------------------------------------------------------------ C1062 !
         !     !                                                          ---( )--*
         !C1062!                                                                  !
         *-] [-*                                                                  !
         !                                                                        !
         !C1062          *--------------*                                         !
 181     *-] [----------!   TMR1       !------------------------------------- C1063 !
         !              ! PROTECTED    !                                  ---( )--*
         !              !              !                                          !
         !              ! P=    0001.0 !                                          !
         !              !              !                                          !
         !Y1073         !              !                                          !
         *-] [----------!              !                                          !
         !              *--------------*                                          !
         !C1060   *--------------*   *--------------*                             !
 189     *-] [---!     CDB2      !---!    BITP2     !-------------------- C1064 !
         !       !               !   !              !                     ---( )--*
         !       !               !   !              !                             !
         !       ! A:   V6       !   ! A:    V7     !                             !
         !       ! B:   V7       !   !              !                             !
         !       !               !   !              !                             !
         !       ! N=    4       !   ! N=     15    !                             !
         !       *---------------*   *--------------*                             !
         !C1064 C1065                                                             !
 200     *-] [-*-]/[------------------------------------------------------------ Y1074 !
         !     !                                                          ---( )--*
         !Y1074!                                                                  !
         *-] [-*                                                                  !
         !                                                                        !
         !C1064 C1065                                                             !
 208     *-] [-*-]/[------------------------------------------------------------ C1066 !
         !     !                                                          ---( )--*
         !C1066!                                                                  !
         *-] [-*                                                                  !
         !                                                                        !
         !C1066          *--------------*                                         !
 216     *-] [----------!   TMR2       !------------------------------------- C1065 !
         !              ! PROTECTED    !                                  ---( )--*
         !              !              !                                          !
         !              ! P=    0001.0 !                                          !
         !              !              !                                          !
         !Y1074         !              !                                          !
         *-] [----------!              !                                          !
         !              *--------------*                                          !
         !C1060   *--------------*   *--------------*                             !
 224     *-] [---!     CDB3      !---!    BITP3     !-------------------- C1067 !
         !       !               !   !              !                     ---( )--*
         !       !               !   !              !                             !
         !       ! A:   V6       !   ! A:    V7     !                             !
         !       ! B:   V7       !   !              !                             !
         !       !               !   !              !                             !
         !       ! N=    4       !   ! N=     14    !                             !
         !       *---------------*   *--------------*                             !
```

```
-----------------------------------------------------------------------------
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                              DATE= 00-00-00                         OFF LINE

       !C1067 C1069
235    *-] [-*-]/[-------------------------------------------------- Y1075 !
       :     !                                                    --( )--*
       !Y1075!                                                            :
       *-] [-*                                                            :
       !                                                                  :
       !C1067 C1069                                                       :
243    *-] [-*-]/[-------------------------------------------------- C1068 :
       :     !                                                    --( )--*
       !C1068!                                                            :
       *-] [-*                                                            :
       !                                                                  :
       !C1068         *-------------*                                     :
251    *-] [---------!   TMR3       !------------------------------- C1069 !
       !             ! PROTECTED    !                             --( )--*
       !             !              !                                     !
       !             ! P=   0001.0  !                                     !
       !             !              !                                     !
       !Y1075        !              !                                     !
       *-] [---------!              !                                     !
       !             *-------------*                                      !
       !X1043  *-------------*                                            !
259    *-] [---! SFPGM4      !------------------------------------- C1157 !
       !       !             !                                    --( )--*
       !       !             !                                            !
       !       *-------------*                                            !
       !C1157  *-------------*                                            !
264    *-] [---!   O/S30     !------------------------------------- C1160 :
       !       !             !                                    --( )--*
       !       !             !                                            !
       !       *-------------*                                            !
       !C1160  *-------------*     *-------------*                        !
269    *-] [---!   CDB10     !---!   BITP10    !--------------------- C1161 !
       !       !             !   !             !                  --( )--*
       !       ! A:  V39     !   ! A:  V38     !                          !
       !       ! B:  V38     !   !             !                          !
       !       !             !   !             !                          !
       !       ! N=   4      !   ! N=   16     !                          !
       !       *-------------*   *-------------*                          !
       !C1160  *-------------*   *-------------*                          !
280    *-] [---!   CDB11     !---!   BITP11    !--------------------- C1164 !
       !       !             !   !             !                  --( )--*
       !       ! A:  V39     !   ! A:  V38     !                          !
       !       ! B:  V38     !   !             !                          !
       !       !             !   !             !                          !
       !       ! N=   4      !   ! N=   15     !                          !
       !       *-------------*   *-------------*                          !
```

```
-----------------------------------------------------------------------------------
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                               DATE= 00-00-00                            OFF LINE
     !C1160  *--------------*   *--------------*
291  *-] [---!    CDB12     !---!    BITP12    !---------------------------C1167 !
     !       !              !   !              !                         --( )--*
     !       !              !   !              !                                !
     !       ! A:   V39     !   ! A:   V38     !                                !
     !       ! B:   V39     !   !              !                                !
     !       !              !   !              !                                !
     !       ! N=    4      !   ! N=    14     !                                !
     !       *--------------*   *--------------*                                !
     !C1161 C1655                                                        C1650 !
302  *-] [-*-]/[---------------------------------------------------------( )--*
     !     !                                                                    !
     !C1650!                                                                    !
     *-] [-*                                                                    !
     !                                                                          !
     !X1026          *--------------*                                           !
310  *-] [----------!    CTR10     !-----------------------------------C1655 !
     !               !  PROTECTED   !                                  --( )--*
     !               !              !                                           !
     !               !  P=    13    !                                           !
     !               !              !                                           !
     !C1650          !              !                                           !
     *-] [----------!              !                                           !
     !               *--------------*                                           !
     !C1655 C1665                                                        Y1076 !
318  *-] [-*-]/[---------------------------------------------------------( )--*
     !     !                                                                    !
     !Y1076!                                                                    !
     *-] [-*                                                                    !
     !                                                                          !
     !C1655 C1665                                                        C1666 !
326  *-] [-*-]/[---------------------------------------------------------( )--*
     !     !                                                                    !
     !C1666!                                                                    !
     *-] [-*                                                                    !
     !                                                                          !
     !C1666          *--------------*                                           !
334  *-] [----------!    TMR20     !-----------------------------------C1665 !
     !               !  PROTECTED   !                                  --( )--*
     !               !              !                                           !
     !               !  P=  0001.0  !                                           !
     !               !              !                                           !
     !Y1076          !              !                                           !
     *-] [----------!              !                                           !
     !               *--------------*                                           !
     !C1164 C1565                                                        C1540 !
342  *-] [-*-]/[---------------------------------------------------------( )--*
     !     !                                                                    !
     !C1540!                                                                    !
     *-] [-*                                                                    !
     !                                                                          !
     !C1540 X1044 C1555                                                  C1550 !
350  *-] [---] [-*-]/[---------------------------------------------------( )--*
     !           !                                                              !
     !C1550      !                                                              !
     *-] [-------*                                                              !
     !                                                                          !
```

```
------------------------------------------------------------------------------------
     TEXAS INSTRUMENTS PROGRAMMING AND DOCUMENTATION SOFTWARE       PAGE 0007

                                 DATE= 00-00-00                        OFF LINE
      :X1026           *--------------*
3..   *-] [----------: CTR11          :------------------------------------C1555 :
      .              . PROTECTED      :                                ---( )--*
      .              :                :                                        :
      .              : P=   15        :                                        :
      .              :                :                                        :
      :C1550         :                :                                        :
      *-] [----------:                :                                        :
      :              *----------------*                                        :
      :C1555 C1565                                                             :
368   *-] [-*-]/[--------------------------------------------------------Y1081 :
      :     :                                                          ---( )--*
      :Y1081:                                                                  :
      *-] [-*                                                                  :
      :                                                                        :
      :C1555 C1565                                                             :
376   *-] [-*-]/[--------------------------------------------------------C1566 :
      :     :                                                          ---( )--*
      :C1566:                                                                  :
      *-] [-*                                                                  :
      :                                                                        :
      :C1566          *---------------*                                        :
384   *-] [----------: TMR21          :------------------------------------C1565 :
      :              : PROTECTED      :                                ---( )--*
      :              :                :                                        :
      :              : P=    0001.0   :                                        :
      :              :                :                                        :
      :Y1081         :                :                                        :
      *-] [----------:                :                                        :
      :              *----------------*                                        :
      :C1167 C1765                                                             :
392   *-] [-*-]/[--------------------------------------------------------C1700 :
      :     :                                                          ---( )--*
      :C1700:                                                                  :
      *-] [-*                                                                  :
      :                                                                        :
      :C1700 X1049 C1755                                                       :
40.   *-] [---] [-*-]/[--------------------------------------------------C1750 :
      .           :                                                    ---( )--*
      .C1750      :                                                            :
      *-] [-------*                                                            :
      :                                                                        :
      :X1026          *---------------*                                        :
410   *-] [----------: CTR12          :------------------------------------C1755 :
      :              : PROTECTED      :                                ---( )--*
      :              :                :                                        :
      :              : P=   15        :                                        :
      :              :                :                                        :
      :C1750         :                :                                        :
      *-] [----------:                :                                        :
      :              *----------------*                                        :
      :C1755 C1765                                                             :
418   *-] [-*-]/[--------------------------------------------------------Y1082 :
      :     :                                                          ---( )--*
      :Y1082:                                                                  :
      *-] [-*                                                                  :
      :                                                                        :
```

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                                DATE= 00-00-00                     OFF LINE

      !C1755 C1765                                                C1766 !
426   *-] [-*-]/[------------------------------------------------( )--*
      !     !                                                         !
      !C1766!                                                         !
      *-] [-*                                                         !
      !                                                               !
      !C1766          *-------------*                             C1765 !
434   *-] [---------!   TMR22       !--------------------------------( )--*
      !             ! PROTECTED     !                                 !
      !             !               !                                 !
      !             ! P=    0001.0  !                                 !
      !             !               !                                 !
      !Y1082        !               !                                 !
      *-] [---------!               !                                 !
      !             *-------------*                                   !
      !X1042 C1210                                                C1205 !
442   *-] [-*-]/[------------------------------------------------( )--*
      !     !                                                         !
      !C1205!                                                         !
      *-] [-*                                                         !
      !                                                               !
      !X1026          *-------------*                             C1210 !
450   *-] [---------!   CTR5        !--------------------------------( )--*
      !             ! PROTECTED     !                                 !
      !             !               !                                 !
      !             ! P=    28      !                                 !
      !             !               !                                 !
      !C1205        !               !                                 !
      *-] [---------!               !                                 !
      !             *-------------*                                   !
      !C1210 Y1059 X1028                                          Y1060 !
458   *-] [-*-]/[---] [------------------------------------------( )--*
      !     !                                                         !
      !Y1060!                                                         !
      *-] [-*                                                         !
      !                                                               !
      !X1028                                                      C1220 !
466   *-]/[------------------------------------------------------( )--*
      !                                                               !
      !C1220  *-------------*                                     C1230 !
472   *-] [---! SFPGM6      !----------------------------------------( )--*
      !       !             !                                         !
      !       !             !                                         !
      !       !             !                                         !
      !       !             !                                         !
      !       !             !                                         !
      !       *-------------*                                         !
      !C1230  *-------------*                                     C1240 !
477   *-] [---!   O/S32     !----------------------------------------( )--*
      !       !             !                                         !
      !       !             !                                         !
      !       !             !                                         !
      !       !             !                                         !
      !       !             !                                         !
      !       *-------------*                                         !
```

```
     !C1240  *--------------*   *--------------*
482  *-] [---!    CDB21     !---!    BITP21    !-------------------------- C1515 !
     !       !              !   !              !                         --( )--*
     !       ! A:  V69      !   ! A:  V68      !                                 !
     !       ! B:  V68      !   !              !                                 !
     !       ! N=   4       !   ! N=   16      !                                 !
     !       *--------------*   *--------------*                                 !
     !C1240  *--------------*   *--------------*
493  *-] [---!    CDB22     !---!    BITP22    !-------------------------- C1516 !
     !       !              !   !              !                         --( )--*
     !       ! A:  V69      !   ! A:  V68      !                                 !
     !       ! B:  V68      !   !              !                                 !
     !       ! N=   4       !   ! N=   15      !                                 !
     !       *--------------*   *--------------*                                 !
     !C1240  *--------------*   *--------------*
504  *-] [---!    CDB23     !---!    BITP23    !-------------------------- C1517 !
     !       !              !   !              !                         --( )--*
     !       ! A:  V69      !   ! A:  V68      !                                 !
     !       ! B:  V68      !   !              !                                 !
     !       ! N=   4       !   ! N=   14      !                                 !
     !       *--------------*   *--------------*                                 !
     !C1515 C1691
515  *-] [-*-]/[------------------------------------------------------------ C1300 !
     !     !                                                            --( )--*
     !C1300!                                                                     !
     *-] [-*                                                                     !
     !C1516 C1691
523  *-] [-*-]/[------------------------------------------------------------ C1400 !
     !     !                                                            --( )--*
     !C1400!                                                                     !
     *-] [-*                                                                     !
     !C1517 C1691
531  *-] [-*-]/[------------------------------------------------------------ C1500 !
     !     !                                                            --( )--*
     !C1500!                                                                     !
     *-] [-*                                                                     !
     !X1027  *--------------*
539  *-]/[---!    O/S73     !------------------------------------------- C1691 !
     !       !              !                                          --( )--*
     !       !              !                                                  !
     !       *--------------*                                                  !
     !C1300
544  *-] [---------------------------------------------------------------- G731 !
                                                                        --( )--*
```

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                              DATE= 00-00-00                                  OFF LINE
      !C1400
548   *-] [--------------------------------------------------------------------GTS2 :
      !                                                                  --( )--*
      !C1500
552   *-] [--------------------------------------------------------------------GTS3 :
      !                                                                  --( )--*
      !
556   *------------------------------------------------------------------------END  :
      !                                                                  --( )--*
      !
557   *------------------------------------------------------------------------SBR1 :
      !                                                                  --( )--*
      !X1028   *------------*
559   *-]/[---!   O/S41    !-----------------------------------------------C1027 :
      !        !            !                                        --( )--*
      !        !            !                                               :
      !        !            !                                               :
      !        *------------*                                               :
      !C1027 C1049 C1305 C1610
564   *-] [-*-]/[---]/[---]/[----------------------------------------------Y1065 :
      !     !                                                        --( )--*
      !Y1065!                                                               :
      *-] [-*                                                               :
      !     !                                                               :
      !C1299!                                                               :
      *-] [-*                                                               :
      !     !                                                               :
      !C1399!                                                               :
      *-] [-*                                                               :
      !X1033 C1301 C1401 C1612   *------------*
580   *-]/[---]/[---]/[---]/[---!   O/S33    !-----------------------------C1049 :
      !                          !            !                      --( )--*
      !                          !            !                             :
      !                          !            !                             :
      !                          *------------*                             :
      !C1049 C1299
591   *-] [-*-]/[----------------------------------------------------------Y1070 :
      !     !                                                        --( )--*
      !Y1070!                                                               :
      *-] [-*                                                               :
      !Y1070   *------------*
599   *-] [---!   O/S34    !-----------------------------------------------C1075 :
      !        !            !                                        --( )--*
      !        !            !                                               :
      !        !            !                                               :
```

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     !C1375          C1380                                                    Y1071
604  *-] [--------*-]/[-------------------------------------------------------( )--*
     !            !
     !Y1071 X1038!
     *-] [---] [-*
     !
     !Y1071                                                                   Y1072
615  *-] [-*--------------------------------------------------------------------( )--*
     !     !
     !C1380!
     *-] [-*
     !
     !X1038 X1039                                                             C1380
621  *-]/[-*-] [-------------------------------------------------------------( )--*
     !     !
     !C1380!
     *-] [-*
     !
     !C1380 C1390                                                             C1385
629  *-] [-*-]/[-------------------------------------------------------------( )--*
     !     !
     !C1385!
     *-] [-*
     !
     !X1045 C1385 Y1072                                                       Y1078
637  *-]/[-*-] [-*-]/[-------------------------------------------------------( )--*
     !     !     !
     !Y1078!     !
     *-] [-*     !
     !           !
     !Y1077      !
     *-] [-------*
     !
     !X1040 X1045                                                             C1390
649  *-]/[-*-] [-------------------------------------------------------------( )--*
     !     !
     !C1390!
     *-] [-*
     !
     !C1390                                                                   Y1077
657  *-] [-------------------------------------------------------------------( )--*
     !
     !C1390 C1299                                                             C1396
661  *-] [-*-]/[-------------------------------------------------------------( )--*
     !     !
     !C1396!
     *-] [-*
     !
     !C1396 Y1078                                                             C1397
669  *-] [---]/[-------------------------------------------------------------( )--*
     !
```

```
     !C1397  *-------------*
675  *-] [---!   O/S36     !------------------------------------------------C1299 !
     !       !             !                                             --( )--*
     !       !             !                                                    !
     !       !             !                                                    !
     !       *-------------*                                                    !
     !C1299 C1612 C1610                                                   C1301 !
680  *-] [---]/[-*-]/[----------------------------------------------------( )--*
     !           !                                                              !
     !C1301      !                                                              !
     *-] [-------*                                                              !
     !                                                                          !
     !X1033 C1301 C1401  *-------------*                                        !
690  *-]/[---] [---]/[---!   O/S49     !------------------------------C1305 !
     !                   !             !                               --( )--*
     !                   !             !                                        !
     !                   !             !                                        !
     !                   *-------------*                                        !
     !C1305 C1399                                                         Y1084 !
699  *-] [-*-]/[------------------------------------------------------( )--*
     !     !                                                                    !
     !Y1084!                                                                    !
     *-] [-*                                                                    !
     !                                                                          !
     !Y1084  *-------------*                                                    !
707  *-] [---!   O/S38     !------------------------------------------------C1475 !
     !       !             !                                             --( )--*
     !       !             !                                                    !
     !       !             !                                                    !
     !       *-------------*                                                    !
     !C1475        C1480                                                  Y1061 !
712  *-] [--------*-]/[-------------------------------------------------( )--*
     !            !                                                             !
     !Y1061 X1052 !                                                             !
     *-] [---] [-*                                                              !
     !                                                                          !
     !Y1061                                                               Y1062 !
723  *-] [-*--------------------------------------------------------------( )--*
     !     !                                                                    !
     !C1480!                                                                    !
     *-] [-*                                                                    !
     !                                                                          !
     !X1052 X1029                                                         C1480 !
729  *-]/[-*-] [----------------------------------------------------------( )--*
     !     !                                                                    !
     !C1480!                                                                    !
     *-] [-*                                                                    !
```

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                                   DATE= 00-00-00                             OFF LINE
       !C1480 C1490
737    *-] [-*-]/[---------------------------------------------------------------C1485 .
       !     !                                                                ( )--*
       !C1485!                                                                      .
       *-] [-*                                                                      .
       !                                                                            .
       !X1031 C1485 Y1062                                                           .
745    *-]/[-*-] [-*-]/[---------------------------------------------------------Y1064 .
       !     !     !                                                          ( )--*
       !Y1064!     !                                                                .
       *-] [-*     !                                                                .
       !           !                                                                .
       !Y1063      !                                                                .
       *-] [-------*                                                                .
       !                                                                            .
       !X1030 X1031                                                                 .
757    *-]/[-*-] [---------------------------------------------------------------C1490 .
       !     !                                                                ( )--*
       !C1490!                                                                      .
       *-] [-*                                                                      .
       !                                                                            .
       !C1490                                                                       .
765    *-] [---------------------------------------------------------------------Y1063 .
       !                                                                      ( )--*
       !C1490 C1399                                                                 .
769    *-] [-*-]/[---------------------------------------------------------------C1496 .
       !     !                                                                ( )--*
       !C1496!                                                                      .
       *-] [-*                                                                      .
       !                                                                            .
       !C1496 Y1064                                                                 .
777    *-] [---]/[---------------------------------------------------------------C1497 .
       !                                                                      ( )--*
       !C1497  *--------------*                                                     .
783    *-] [---!    O/S39     !--------------------------------------------------C1399 .
       !       !              !                                       ( )--*
       !       !              !                                                     .
       !       !              !                                                     .
       !       !              !                                                     .
       !       !              !                                                     .
       !       *--------------*                                                     .
       !C1399 C1610                                                                 .
788    *-] [-*-]/[---------------------------------------------------------------C1401 .
       !     !                                                                ( )--*
       !C1401!                                                                      .
       *-] [-*                                                                      .
       !                                                                            .
       !X1033 C1301  *--------------*                                               .
796    *-]/[---] [---!    CTR7      !--------------------------------------------C1100 .
       !             !  PROTECTED   !                                         ( )--*
       !             !              !                                               .
       !             !  P=    2     !                                               .
       !             !              !                                               .
       !C1401        !              !                                               .
       *-] [---------!              !                                               .
```

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                                  DATE= 00-00-00                     OFF LINE
      !C1100  *--------------*
806   *-] [---!    O/S40     !------------------------------------------- C1610 :
      !       !              !                                         --( )--*
      !       !              !                                                :
      !       !              !                                                :
      !       !              !                                                :
      !       *--------------*                                                :
      !C1610 C1691                                                            :
811   *-] [-*-]/[-------------------------------------------------------- C1612 :
      !     !                                                          --( )--*
      !C1612!                                                                 :
      *-] [-*                                                                 :
      !                                                                       :
      !C1610 C1691                                                            :
819   *-] [-*-]/[-------------------------------------------------------- Y1059 :
      !     !                                                          --( )--*
      !Y1059!                                                                 :
      *-] [-*                                                                 :
      !                                                                       :
      !Y1059                                                                  :
827   *-] [------------------------------------------------------------- Y1060 :
      !                                                                --( )--*
      !C1691                                                                  :
831   *-]/[------------------------------------------------------------- END  :
      !                                                                --(C)--*
      !                                                                       :
834   *----------------------------------------------------------------- RTN  :
      !                                                                --( )--*
      !                                                                       :
836   *----------------------------------------------------------------- SBR2 :
      !                                                                --( )--*
      !X1028  *--------------*                                                :
838   *-]/[---!    O/S41     !------------------------------------------ C1027 :
      !       !              !                                         --( )--*
      !       !              !                                                :
      !       !              !                                                :
      !       !              !                                                :
      !       *--------------*                                                :
      !C1027 C1049                                                            :
843   *-] [-*-]/[-------------------------------------------------------- C1107 :
      !     !                                                          --( )--*
      !C1107!                                                                 :
      *-] [-*                                                                 :
      !                                                                       :
```

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     !C1027 C1049 C1305 C1610                                          Y1065 :
851  *-] [-*-]/[---]/[---]/[------------------------------------------( )--*
     !     !
     !Y1065!
     *-] [-*
     !     !
     !C1299!
     *-] [-*
     !     !
     !C1399!
     *-] [-*
     !
     !X1033 C1301 C1401 C1612  *-------------*                        C1109 :
867  *-]/[---]/[---]/[---]/[---!    O/S33    !------------------------( )--*
     !                         !             !
     !                         !             !
     !                         *-------------*
     !C1109         *-------------*                                   C1049 :
878  *-] [----------!    CTR29    !-----------------------------------( )--*
     !              ! PROTECTED   !
     !              !             !
     !              ! P=    2     !
     !C1107         !             !
     *-] [----------!             !
     !              *-------------*
     !C1049 C1299                                                      Y1084 :
886  *-] [-*-]/[------------------------------------------------------( )--*
     !     !
     !Y1084!
     *-] [-*
     !
     !Y1084  *-------------*                                           C1375 :
894  *-] [---!    O/S34    !------------------------------------------( )--*
     !       !             !
     !       !             !
     !       *-------------*
     !C1375          C1380                                              Y1061 :
899  *-] [---------*-]/[----------------------------------------------( )--*
     !             !
     !Y1061 X1052!
     *-] [---] [-*
     !
     !Y1061                                                             Y1062 :
910  *-] [-*----------------------------------------------------------( )--*
     !     !
     !C1380!
     *-] [-*
```

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                            DATE= 00-00-00                           OFF LINE

      !X1052 X1029                                                    C1380 !
916   *-]/[-*-] [-----------------------------------------------------( )--*
      !     !                                                               !
      !C1380!                                                               !
      *-] [-*                                                               !
      !                                                                     !
      !C1380 C1390                                                    C1385 !
924   *-] [-*-]/[-----------------------------------------------------( )--*
      !     !                                                               !
      !C1385!                                                               !
      *-] [-*                                                               !
      !                                                                     !
      !X1031 C1385 Y1062                                              Y1064 !
932   *-]/[-*-] [-*-]/[-----------------------------------------------( )--*
      !     !     !                                                         !
      !Y1064!     !                                                         !
      *-] [-*     !                                                         !
      !           !                                                         !
      !Y1063      !                                                         !
      *-] [-------*                                                         !
      !                                                                     !
      !X1030 X1031                                                    C1390 !
944   *-]/[-*-] [-----------------------------------------------------( )--*
      !     !                                                               !
      !C1390!                                                               !
      *-] [-*                                                               !
      !                                                                     !
      !C1390                                                          Y1063 !
952   *-] [-----------------------------------------------------------( )--*
      !                                                                     !
      !C1390 C1299                                                    C1396 !
956   *-] [-*-]/[-----------------------------------------------------( )--*
      !     !                                                               !
      !C1396!                                                               !
      *-] [-*                                                               !
      !                                                                     !
      !C1396 Y1064                                                    C1397 !
964   *-] [---]/[-----------------------------------------------------( )--*
      !                                                                     !
      !C1397 *-------------*                                          C1299 !
970   *-] [---!    O/S36    !-----------------------------------------( )--*
      !       !             !                                               !
      !       !             !                                               !
      !       !             !                                               !
      !       !             !                                               !
      !       *-------------*                                               !
      !C1299 C1612 C1610                                              C1301 !
975   *-] [---]/[-*-]/[-----------------------------------------------( )--*
      !           !                                                         !
      !C1301      !                                                         !
      *-] [-------*                                                         !
      !                                                                     !
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                                    DATE= 00-00-00                    OFF LINE

        !X1033 C1301 C1401  *-------------*                             C1305 !
985     *-]/[---] [---]/[---!   O/S49     !-----------------------------( )--*
        !                   !             !                                   !
        !                   !             !                                   !
        !                   !             !                                   !
        !                   !             !                                   !
        !                   !             !                                   !
        !                   *-------------*                                   !
        !C1305 C1399                                                    Y1080 !
994     *-] [-*-]/[-----------------------------------------------------( )--*
        !     !                                                               !
        !Y1080!                                                               !
        *-] [-*                                                               !
        !                                                                     !
        !Y1080  *-------------*                                         C1475 !
1002    *-] [---!   O/S38     !-----------------------------------------( )--*
        !       !             !                                               !
        !       !             !                                               !
        !       !             !                                               !
        !       !             !                                               !
        !       *-------------*                                               !
        !C1475        C1480                                             Y1085 !
1007    *-] [-------*-]/[-------------------------------------------------( )--*
        !           !                                                         !
        !Y1085 X1048!                                                         !
        *-] [---] [-*                                                         !
        !                                                                     !
        !Y1085                                                          Y1086 !
1018    *-] [-*---------------------------------------------------------( )--*
        !     !                                                               !
        !C1480!                                                               !
        *-] [-*                                                               !
        !                                                                     !
        !X1048 X1053                                                    C1480 !
1024    *-]/[-*-] [-----------------------------------------------------( )--*
        !     !                                                               !
        !C1480!                                                               !
        *-] [-*                                                               !
        !                                                                     !
        !C1480 C1490                                                    C1485 !
1032    *-] [-*-]/[-----------------------------------------------------( )--*
        !     !                                                               !
        !C1485!                                                               !
        *-] [-*                                                               !
        !                                                                     !
        !X1055 C1485 Y1086                                              Y1088 !
1040    *-]/[-*-] [-*-]/[-----------------------------------------------( )--*
        !     !     !                                                         !
        !Y1088!     !                                                         !
        *-] [-*     !                                                         !
        !           !                                                         !
        !Y1087      !                                                         !
        *-] [-------*
```

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                                  DATE= 00-00-00                        OFF LINE

      !X1054 X1055
1052  *-]/[-*-] [-------------------------------------------------------C1490 !
      !     !                                                     --( )--*
      !C1490!                                                              !
      *-] [-*                                                              !
      !                                                                    !
      !C1490                                                          Y1087 !
1060  *-] [-------------------------------------------------------------( )--*
      !                                                                    !
      !C1490 C1399                                                    C1496 !
1064  *-] [-*-]/[---------------------------------------------------------( )--*
      !     !                                                              !
      !C1496!                                                              !
      *-] [-*                                                              !
      !                                                                    !
      !C1496 Y1088                                                    C1497 !
1072  *-] [---]/[---------------------------------------------------------( )--*
      !                                                                    !
      !C1497  *--------------*                                        C1399 !
1078  *-] [---!    O/S39     !----------------------------------------( )--*
      !       !              !                                             !
      !       !              !                                             !
      !       !              !                                             !
      !       *--------------*                                             !
      !C1399 C1610                                                    C1401 !
1083  *-] [-*-]/[---------------------------------------------------------( )--*
      !     !                                                              !
      !C1401!                                                              !
      *-] [-*                                                              !
      !                                                                    !
      !X1033 C1301 C1401  *--------------*                            C1610 !
1091  *-]/[---] [---] [---!    O/S40     !----------------------------( )--*
      !                   !              !                                 !
      !                   !              !                                 !
      !                   !              !                                 !
      !                   *--------------*                                 !
      !C1610 X1027                                                    C1612 !
1100  *-] [-*-] [-------------------------------------------------------( )--*
      !     !                                                              !
      !C1612!                                                              !
      *-] [-*                                                              !
      !                                                                    !
      !C1610 X1027                                                    Y1059 !
1108  *-] [-*-] [-------------------------------------------------------( )--*
      !     !                                                              !
      !Y1059!                                                              !
      *-] [-*                                                              !
      !                                                                    !
      !Y1059                                                          Y1060 !
1116  *-] [-------------------------------------------------------------( )--*
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                              DATE= 00-00-00                       OFF LINE
     !X1027                                                           END  !
1120 *-] [--------------------------------------------------------------(C)--*
     !                                                                      !
     !                                                                RTN  !
1123 *--------------------------------------------------------------( )--*
     !                                                                      !
     !                                                               SBR3  !
1125 *--------------------------------------------------------------( )--*
     !
     !X1028   *-------------*                                       C1027 !
1127 *-]/[---!    O/S41     !---------------------------------------( )--*
     !        !              !                                             !
     !        !              !                                             !
     !        !              !                                             !
     !        *-------------*                                              !
     !C1027 C1049 C1305 C1610                                        Y1065 !
1132 *-] [-*-]/[---]/[---]/[----------------------------------------( )--*
     !      !                                                              !
     !Y1065!                                                               !
     *-] [-*                                                               !
     !      !                                                              !
     !C1299!                                                               !
     *-] [-*                                                               !
     !      !                                                              !
     !C1399!                                                               !
     *-] [-*                                                               !
     !                                                                     !
     !X1033 C1301 C1401 C1612 *-------------*                        C1049 !
1148 *-]/[---]/[---]/[---]/[---!    O/S33     !------------------------( )--*
     !                          !              !                           !
     !                          !              !                           !
     !                          !              !                           !
     !                          *-------------*                            !
     !C1049 C1299                                                    Y1070 !
1159 *-] [-*-]/[----------------------------------------------------( )--*
     !      !                                                              !
     !Y1070!                                                               !
     *-] [-*                                                               !
     !                                                                     !
     !Y1070   *-------------*                                        C1375 !
1167 *-] [---!    O/S34     !---------------------------------------( )--*
     !        !              !                                             !
     !        !              !                                             !
     !        !              !                                             !
     !        *-------------*                                              !
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       TEXAS INSTRUMENTS PROGRAMMING AND DOCUMENTATION SOFTWARE     PAGE 0020

                              DATE= 00-00-00                                 OFF LINE

       !C1375         C1380                                                   Y1071 !
1172   *-] [--------*-]/[--------------------------------------------------------( )--*
       !            !                                                               !
       !Y1071 X1038!                                                                !
       *-] [---] [-*                                                                !
       !                                                                            !
       !Y1071                                                                  Y1072 !
1183   *-] [-*-------------------------------------------------------------------( )--*
       !     !                                                                      !
       !C1380!                                                                      !
       *-] [-*                                                                      !
       !                                                                            !
       !X1038 X1039                                                           C1380 !
1189   *-]/[-*-] [---------------------------------------------------------------( )--*
       !     !                                                                      !
       !C1380!                                                                      !
       *-] [-*                                                                      !
       !                                                                            !
       !C1380 C1390                                                           C1385 !
1197   *-] [-*-]/[---------------------------------------------------------------( )--*
       !     !                                                                      !
       !C1385!                                                                      !
       *-] [-*                                                                      !
       !                                                                            !
       !X1045 C1385 Y1072                                                     Y1078 !
1205   *-]/[-*-] [-*-]/[---------------------------------------------------------( )--*
       !     !     !                                                                !
       !Y1078!     !                                                                !
       *-] [-*     !                                                                !
       !           !                                                                !
       !Y1077      !                                                                !
       *-] [-------*                                                                !
       !                                                                            !
       !X1040 X1045                                                           C1390 !
1217   *-]/[-*-] [---------------------------------------------------------------( )--*
       !     !                                                                      !
       !C1390!                                                                      !
       *-] [-*                                                                      !
       !                                                                            !
       !C1390                                                                 Y1077 !
1225   *-] [---------------------------------------------------------------------( )--*
       !                                                                            !
       !C1390 C1299                                                           C1396 !
1229   *-] [-*-]/[---------------------------------------------------------------( )--*
       !     !                                                                      !
       !C1396!                                                                      !
       *-] [-*                                                                      !
       !                                                                            !
       !C1396 Y1078                                                           C1397 !
1237   *-] [---]/[---------------------------------------------------------------( )--*
       !                                                                            !
```

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      !C1397  *--------------*
1243  *-] [---!    O/S36     !-----------------------------------------C1299
      !       !              !                                        --( )--!
      !       !              !                                               !
      !       !              !                                               !
      !       *--------------*                                               !
      !C1299 C1612 C1610                                                     !
1248  *-] [---]/[-*-]/[-------------------------------------------------C1301
      !           !                                                   --( )--!
      !C1301      !                                                          !
      *-] [-------*                                                          !
      !                                                                      !
      !C1299 C1305                                                           !
1258  *-] [-*-]/[---------------------------------------------------------C1112
      !     !                                                         --( )--!
      !C1112!                                                                !
      *-] [-*                                                                !
      !                                                                      !
      !X1033 C1301 C1401 C1612  *--------------*                             !
1266  *-]/[---] [---]/[---]/[---!    O/S49     !-------------------------C1111
      !                         !              !                      --( )--!
      !                         !              !                             !
      !                         !              !                             !
      !                         *--------------*                             !
      !C1111           *--------------*                                      !
1277  *-] [------------!    CTR39     !----------------------------------C1305
      !                !  PROTECTED   !                               --( )--!
      !                !              !                                      !
      !                !  P=    2     !                                      !
      !C1112           !              !                                      !
      *-] [------------!              !                                      !
      !                *--------------*                                      !
      !C1305 C1399                                                           !
1285  *-] [-*-]/[---------------------------------------------------------Y1080
      !     !                                                         --( )--!
      !Y1080!                                                                !
      *-] [-*                                                                !
      !                                                                      !
      !Y1080  *--------------*                                               !
1293  *-] [---!    O/S38     !-----------------------------------------C1475
      !       !              !                                        --( )--!
      !       !              !                                               !
      !       !              !                                               !
      !       *--------------*                                               !
```

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                                 DATE= 00-00-00
                                                                         OFF LINE
       !C1475        C1480
1298   *-] [--------*-]/[-----------------------------------------------  Y1085 .
       !            !                                                  -----( )--*
       !Y1085 X1048!                                                             :
       *-] [---] [-*                                                             :
       !                                                                         :
       !Y1085                                                                    :
1309   *-] [-*------------------------------------------------------------  Y1086 :
       !    !                                                         -----( )--*
       !C1480!                                                                   :
       *-] [-*                                                                   :
       !                                                                         :
       !X1048 X1053                                                              :
1315   *-]/[-*-] [--------------------------------------------------------  C1480 .
       !    !                                                         -----( )--*
       !C1480!                                                                   :
       *-] [-*                                                                   :
       !                                                                         :
       !C1480 C1490                                                              :
1323   *-] [-*-]/[--------------------------------------------------------  C1485 :
       !    !                                                         -----( )--*
       !C1485!                                                                   :
       *-] [-*                                                                   :
       !                                                                         :
       !X1055 C1485 Y1086                                                        :
1331   *-]/[-*-] [-*-]/[--------------------------------------------------  Y1088 :
       !    !       !                                                 -----( )--*
       !Y1088!       !                                                           :
       *-] [-*       !                                                           :
       !             !                                                           :
       !Y1087        !                                                           :
       *-] [--------*                                                            :
       !                                                                         :
       !X1054 X1055                                                              :
1343   *-]/[-*-] [--------------------------------------------------------  C1490 .
       !    !                                                         -----( )--*
       !C1490!                                                                   :
       *-] [-*                                                                   :
       !                                                                         :
       !C1490                                                                    :
1351   *-] [--------------------------------------------------------------  Y1087 .
       !                                                              -----( )--*
       !C1490 C1399                                                              :
1355   *-] [-*-]/[--------------------------------------------------------  C1496 .
       !    !                                                         -----( )--*
       !C1496!                                                                   :
       *-] [-*                                                                   :
       !                                                                         :
       !C1496 Y1088                                                              :
1363   *-] [---]/[--------------------------------------------------------  C1497 :
       !                                                              -----( )--*
                                                                                 :
```

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                                 DATE= 00-00-00                               OFF LINE
      !C1497  *-------------*                                                  C1399 .
1369  *-] [---!    O/S39    !-------------------------------------------------( )--.
      !       !             !                                                        .
      !       !             !                                                        .
      !       !             !                                                        .
      !       !             !                                                        .
      !       !             !                                                        .
      !       *-------------*                                                        .
      !C1399 C1610                                                             C1401 .
1374  *-] [-*-]/[-----------------------------------------------------------------( )--.
      !     !                                                                        .
      !C1401!                                                                        .
      *-] [-*                                                                        .
      !                                                                              .
      !X1033 C1301 C1401  *-------------*                                      C1610 .
1382  *-]/[---] [---] [---!    O/S40    !-------------------------------------( )--.
      !                   !             !                                            .
      !                   !             !                                            .
      !                   !             !                                            .
      !                   !             !                                            .
      !                   !             !                                            .
      !                   *-------------*                                            .
      !C1610 X1027                                                             C1612 .
1391  *-] [-*-] [-----------------------------------------------------------------( )--.
      !     !                                                                        .
      !C1612!                                                                        .
      *-] [-*                                                                        .
      !                                                                              .
      !C1610 X1027                                                             Y1059 .
1399  *-] [-*-] [-----------------------------------------------------------------( )--.
      !     !                                                                        .
      !Y1059!                                                                        .
      *-] [-*                                                                        .
      !                                                                              .
      !Y1059                                                                   Y1060 .
1407  *-] [-----------------------------------------------------------------------( )--.
      !                                                                              .
      !X1027                                                                    END  .
1411  *-] [-----------------------------------------------------------------------( )--.
      !                                                                              .
      !                                                                         RTN  .
1414  *---------------------------------------------------------------------------( )--.
      !                                                                              .
      !                                                                         NOP  .
1416  *---------------------------------------------------------------------------( )--.
      !                                                                              .
      !                                                                         NOP  .
1417  *---------------------------------------------------------------------------( )--.
      !                                                                              .
      !                                                                         NOP  .
1418  *---------------------------------------------------------------------------( )--.
      !                                                                              .
      !                                                                         NOP  .
1419  *---------------------------------------------------------------------------( )--
```

APPENDIX E

CIM Laboratory Relay Ladder Logic Program

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                            DATE= 00-00-00                          OFF LINE
     ! X97
1    *-] [-*-----------------------------------------------------------Y19 !
     !     !                                                        --( )--*
     ! Y19 !                                                               !
     *-] [-*                                                               !
     !                                                                     !
     !X101  X100   X99   X98   X97   Y1                                C10 !
4    *-]/[---]/[---]/[---] [---] [---]/[--------------------------------( )--*
     !                                                                     !
     !X101  X100   X99   X98   X97   Y1                                C11 !
11   *-]/[---]/[---] [---]/[---] [---]/[--------------------------------( )--*
     !                                                                     !
     !X101  X100   X99   X98   X97   Y1                                C12 !
18   *-]/[---]/[---] [---] [---] [---]/[--------------------------------( )--*
     !                                                                     !
     !X101  X100   X99   X98   X97   Y1                                C13 !
25   *-]/[---] [---]/[---]/[---] [---]/[--------------------------------( )--*
     !                                                                     !
     !X101  X100   X99   X98   X97   Y1                                C14 !
32   *-]/[---] [---]/[---] [---] [---]/[--------------------------------( )--*
     !                                                                     !
     !X101  X100   X99   X98   X97   Y1                                C15 !
39   *-]/[---] [---] [---]/[---] [---]/[--------------------------------( )--*
     !                                                                     !
     !X101  X100   X99   X98   X97   Y1                                C16 !
46   *-]/[---] [---] [---] [---] [---]/[--------------------------------( )--*
     !                                                                     !
     !X101  X100   X99   X98   X97   Y1                                C17 !
53   *-] [---]/[---]/[---]/[---] [---]/[--------------------------------( )--*
     !                                                                     !
     !X101  X100   X99   X98   X97   Y1                                C18 !
60   *-] [---]/[---]/[---] [---] [---]/[--------------------------------( )--*
     !                                                                     !
     !X101  X100   X99   X98   X97   Y1                                C19 !
67   *-] [---]/[---] [---]/[---] [---]/[--------------------------------( )--*
     !                                                                     !
     !X101  X100   X99   X98   X97   Y1                                C20 !
74   *-] [---]/[---] [---] [---] [---]/[--------------------------------( )--*
     !                                                                     !
     !X101  X100   X99   X98   X97   Y1                                C21 !
81   *-] [---] [---]/[---]/[---] [---]/[--------------------------------( )--*
     !                                                                     !
     !X101  X100   X99   X98   X97   Y1                                C22 !
88   *-] [---] [---]/[---] [---] [---]/[--------------------------------( )--*
     !                                                                     !
     ! C10   C45                                                       C30 !
95   *-] [-*-]/[-------------------------------------------------------( )--*
     !     !                                                               !
     ! C30 !                                                               !
     *-] [-*                                                               !
     !                                                                     !
     ! C11   C45                                                       C31 !
99   *-] [-*-]/[-------------------------------------------------------( )--*
     !     !                                                               !
     ! C31 !                                                               !
     *-] [-*                                                               !
     !                                                                     !
```

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        TEXAS INSTRUMENTS PROGRAMMING AND DOCUMENTATION SOFTWARE      PAGE 0002

                          DATE= 00-00-00                                 OFF LINE
     ! C12   C45
103  *-] [-*-]/[--------------------------------------------------------------C32 :
     !      !                                                         --( )--*
     ! C32  !                                                                  :
     *-] [-*                                                                   :
     !                                                                         :
     ! C13   C45
107  *-] [-*-]/[--------------------------------------------------------------C33 :
     !      !                                                         --( )--*
     ! C33  !                                                                  :
     *-] [-*                                                                   :
     !                                                                         :
     ! C14   C45
111  *-] [-*-]/[--------------------------------------------------------------C34 :
     !      !                                                         --( )--*
     ! C34  !                                                                  :
     *-] [-*                                                                   :
     !                                                                         :
     ! C15   C45
115  *-] [-*-]/[--------------------------------------------------------------C35 :
     !      !                                                         --( )--*
     ! C35  !                                                                  :
     *-] [-*                                                                   :
     !                                                                         :
     ! C16   C45
119  *-] [-*-]/[--------------------------------------------------------------C36 :
     !      !                                                         --( )--*
     ! C36  !                                                                  :
     *-] [-*                                                                   :
     !                                                                         :
     ! C17   C45
123  *-] [-*-]/[--------------------------------------------------------------C37 :
     !      !                                                         --( )--*
     ! C37  !                                                                  :
     *-] [-*                                                                   :
     !                                                                         :
     ! C18   C45
127  *-] [-*-]/[--------------------------------------------------------------C38 :
     !      !                                                         --( )--*
     ! C38  !                                                                  :
     *-] [-*                                                                   :
     !                                                                         :
     ! C19   C45
131  *-] [-*-]/[--------------------------------------------------------------C39 :
     !      !                                                         --( )--*
     ! C39  !                                                                  :
     *-] [-*                                                                   :
     !                                                                         :
     ! C20   C45
135  *-] [-*-]/[--------------------------------------------------------------C40 :
     !      !                                                         --( )--*
     ! C40  !                                                                  :
     *-] [-*                                                                   :
     !                                                                         :
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                              DATE= 00-00-00                        OFF LINE
        ! C21    C45
139     *-] [-*-]/[-------------------------------------------------C41     !
        !       !                                                   --( )--*
        ! C41   !                                                          !
        *-] [-*                                                            !
        !                                                                  !
        ! C22    C45                                                       !
143     *-] [-*-]/[-------------------------------------------------C42     !
        !       !                                                   --( )--*
        ! C42   !                                                          !
        *-] [-*                                                            !
        !                                                                  !
        ! Y2     *-----------*                                             !
147     *-] [---!   O/S1    !--------------------------------------C45     !
        !        !           !                                      --( )--*
        !        !           !                                             !
        !        !           !                                             !
        !        !           !                                             !
        !        *-----------*                                             !
        ! C30                                                              !
150     *-] [-------------------------------------------------------GTS1   !
        !                                                           --( )--*
        ! C31                                                              !
153     *-] [-------------------------------------------------------GTS2   !
        !                                                           --( )--*
        ! C32                                                              !
156     *-] [-------------------------------------------------------GTS3   !
        !                                                           --( )--*
        ! C33                                                              !
159     *-] [-------------------------------------------------------GTS4   !
        !                                                           --( )--*
        ! C34                                                              !
162     *-] [-------------------------------------------------------GTS5   !
        !                                                           --( )--*
        ! C35                                                              !
165     *-] [-------------------------------------------------------GTS6   !
        !                                                           --( )--*
        ! C36                                                              !
168     *-] [-------------------------------------------------------GTS7   !
        !                                                           --( )--*
        ! C37                                                              !
171     *-] [-------------------------------------------------------GTS8   !
        !                                                           --( )--*
        ! C38                                                              !
174     *-] [-------------------------------------------------------GTS9   !
        !                                                           --( )--*
        ! C39                                                              !
177     *-] [-------------------------------------------------------GTS10  !
        !                                                           --( )--*
        ! C40                                                              !
180     *-] [-------------------------------------------------------GTS11  !
        !                                                           --( )--*
        ! C41                                                              !
183     *-] [-------------------------------------------------------GTS12  !
        !                                                           --( )--*
                                                                           !
```

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                              DATE= 00-00-00                             OFF LINE
      ! C42
186   *-] [-------------------------------------------------------------GTS13 !
      !                                                          -----( )--*
      !                                                                     !
189   *-------------------------------------------------------------------END  !
      !                                                          -----( )--*
      !                                                                     !
190   *-------------------------------------------------------------------SBR1 !
      !                                                          -----( )--*
      ! C30   Y2                                                            !
192   *-] [-*-]/[---------------------------------------------------------Y1   !
      !     !                                                    -----( )--*
      ! Y1  !                                                               !
      *-] [-*                                                               !
      !                                                                     !
      !X134   C55                                                           !
196   *-] [-*-]/[---------------------------------------------------------C50  !
      !     !                                                    -----( )--*
      ! C50 !                                                               !
      *-] [-*                                                               !
      !                                                                     !
      ! C50                                                                 !
200   *-] [---------------------------------------------------------------Y27  !
      !                                                          -----( )--*
      ! C50                                                                 !
202   *-] [---------------------------------------------------------------Y39  !
      !                                                          -----( )--*
      !X137   Y47                                                           !
204   *-] [-*-]/[---------------------------------------------------------Y46  !
      !     !                                                    -----( )--*
      ! Y46 !                                                               !
      *-] [-*                                                               !
      !                                                                     !
      !X130                                                                 !
208   *-] [---------------------------------------------------------------Y26  !
      !                                                          -----( )--*
      !X144                                                                 !
210   *-] [---------------------------------------------------------------C55  !
      !                                                          -----( )--*
      ! C55   Y2                                                            !
212   *-] [-*-]/[---------------------------------------------------------Y47  !
      !     !                                                    -----( )--*
      ! Y47 !                                                               !
      *-] [-*                                                               !
      !                                                                     !
      ! C55   Y2                                                            !
216   *-] [-*-]/[---------------------------------------------------------Y43  !
      !     !                                                    -----( )--*
      ! Y43 !                                                               !
      *-] [-*                                                               !
      !                                                                     !
      !X145   Y2                                                            !
220   *-] [-*-]/[---------------------------------------------------------C60  !
      !     !                                                    -----( )--*
      ! C60 !                                                               !
      *-] [-*                                                               !
      !                                                                     !
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                                  DATE= 00-00-00
                                                                            OFF LINE
      : C60  X145   *-----------*
224   *-] [---]/[---:   O/S2    :---------------------------------------------Y2----:
      :             :           :                                            ( )---*
      :             :           :                                                  :
      :             *-----------*                                                  :
      : Y2                                                                         :
228   *-]/[----------------------------------------------------------------END-----:
      :                                                                    (C)---*
      :                                                                            :
230   *--------------------------------------------------------------------RTN-----:
      :                                                                    ( )---*
      :                                                                            :
232   *--------------------------------------------------------------------SBR2----:
      :                                                                    ( )---*
      : C31    Y2                                                                  :
234   *-] [-*-]/[----------------------------------------------------------Y1------:
      :     :                                                              ( )---*
      : Y1  :                                                                      :
      *-] [-*                                                                      :
      :                                                                            :
      :X134   C61                                                                  :
238   *-] [-*-]/[----------------------------------------------------------Y39-----:
      :     :                                                              ( )---*
      : Y39 :                                                                      :
      *-] [-*                                                                      :
      :                                                                            :
      :X137   Y47                                                                  :
242   *-] [-*-]/[----------------------------------------------------------Y46-----:
      :     :                                                              ( )---*
      : Y46 :                                                                      :
      *-] [-*                                                                      :
      :                                                                            :
      : C61   Y2                                                                   :
246   *-] [-*-]/[----------------------------------------------------------Y47-----:
      :     :                                                              ( )---*
      : Y47 :                                                                      :
      *-] [-*                                                                      :
      :                                                                            :
      :X130   C61                                                                  :
250   *-] [-*-]/[----------------------------------------------------------Y26-----:
      :     :                                                              ( )---*
      : Y26 :                                                                      :
      *-] [-*                                                                      :
      :                                                                            :
      : Y26  X135   C61                                                            :
254   *-] [---]/[-*-]/[----------------------------------------------------C60-----:
      :           :                                                        ( )---*
      : C60       :                                                                :
      *-] [-------*                                                                :
      :                                                                            :
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                              DATE= 00-00-00
                                                                         OFF LINE
       : C60        *-------------*
259    *-] [--------:   TMR1      :----------------------------------------C62   :
       :            : PROTECTED   :                                   --( )--*
       :            :             :                                          :
       :            : P=   0005.0 :                                          :
       :            :             :                                          :
       : Y26        :             :                                          :
       *-] [--------:             :                                          :
       :            *-------------*                                          :
       : C62   *-----------*                                                 :
264    *-] [---:   O/S3    :-------------------------------------------C61   :
       :       :           :                                      --( )--*
       :       :           :                                             :
       :       :           :                                             :
       :       *-----------*                                             :
       : Y26  X146                                                       :
267    *-] [-*-]/[---------------------------------------------------Y20  :
       :     :                                                    --( )--*
       : Y20 :                                                           :
       *-] [-*                                                           :
       :                                                                 :
       :X146  X132                                                       :
271    *-] [-*-]/[---------------------------------------------------Y50  :
       :     :                                                    --( )--*
       : Y50 :                                                           :
       *-] [-*                                                           :
       :                                                                 :
       :X132   *-----------*                                             :
275    *-] [---:   O/S4    :--------------------------------------------Y2   :
       :       :           :                                      --( )--*
       :       :           :                                             :
       :       :           :                                             :
       :       *-----------*                                             :
       : Y2                                                              :
278    *-]/[---------------------------------------------------------END  :
       :                                                          --(C)--*
       :                                                                 :
280    *-------------------------------------------------------------RTN  :
       :                                                          --( )--*
       :                                                                 :
282    *-------------------------------------------------------------SBR3 :
       :                                                          --( )--*
       :                                                                 :
       : C32   Y2                                                        :
284    *-] [-*-]/[----------------------------------------------------Y1  :
       :     :                                                    --( )--*
       : Y1  :                                                           :
       *-] [-*                                                           :
       :                                                                 :
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                               DATE= 00-00-00                          OFF LINE
     !X131   C61                                                        Y28  !
288  *-] [-*-]/[-------------------------------------------------------( )--*
     !     !                                                                 !
     ! Y28 !                                                                 !
     *-] [-*                                                                 !
     !                                                                       !
     !X140   Y49                                                        Y48  !
292  *-] [-*-]/[-------------------------------------------------------( )--*
     !     !                                                                 !
     ! Y48 !                                                                 !
     *-] [-*                                                                 !
     !                                                                       !
     ! C61   Y2                                                         Y49  !
296  *-] [-*-]/[-------------------------------------------------------( )--*
     !     !                                                                 !
     ! Y49 !                                                                 !
     *-] [-*                                                                 !
     !                                                                       !
     ! Y28  X139   C61                                                  C60  !
300  *-] [---]/[-*-]/[-------------------------------------------------( )--*
     !           !                                                           !
     ! C60       !                                                           !
     *-] [-------*                                                           !
     !                                                                       !
     ! C60          *------------*                                      C62  !
305  *-] [----------!    TMR1    !-------------------------------------( )--*
     !              ! PROTECTED  !                                           !
     !              !            !                                           !
     !              ! P=  0005.0 !                                           !
     !              !            !                                           !
     ! Y28          !            !                                           !
     *-] [----------!            !                                           !
     !              *------------*                                           !
     ! C62     *------------*                                           C61  !
310  *-] [---!    O/S3    !---------------------------------------------( )--*
     !         !            !                                                !
     !         !            !                                                !
     !         !            !                                                !
     !         !            !                                                !
     !         !            !                                                !
     !         *------------*                                                !
     ! Y28  X147                                                        Y22  !
313  *-] [-*-]/[-------------------------------------------------------( )--*
     !     !                                                                 !
     ! Y22 !                                                                 !
     *-] [-*                                                                 !
     !                                                                       !
     !X147  X133                                                        Y52  !
317  *-] [-*-]/[-------------------------------------------------------( )--*
     !     !                                                                 !
     ! Y52 !                                                                 !
     *-] [-*                                                                 !
     !                                                                       !
```

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         TEXAS INSTRUMENTS PROGRAMMING AND DOCUMENTATION SOFTWARE     PAGE 00[illegible]

                                  DATE= 00-00-00                              OFF LINE
      !X133    *-------------*                                                    
321   *-] [---!    O/S4     !----------------------------------------------Y2  !
      !       !             !                                            ( )---!
      !       !             !                                                  !
      !       !             !                                                  !
      !       !             !                                                  !
      !       *-------------*                                                  !
      ! Y2                                                                END  !
324   *-]/[-----------------------------------------------------------(C)---*
      !                                                                        !
      !                                                                   RTN  !
326   *-------------------------------------------------------------------( )---*
      !                                                                        !
      !                                                                  SBR4  !
328   *-------------------------------------------------------------------( )---*
      !                                                                        !
      ! C33   Y2                                                          Y1   !
330   *-] [-*-]/[---------------------------------------------------------( )---*
      !     !                                                                  !
      ! Y1  !                                                                  !
      *-] [-*                                                                  !
      !                                                                        !
      ! Y1    Y50   Y2                                                    Y51  !
334   *-] [-*-]/[---]/[---------------------------------------------------( )---*
      !     !                                                                  !
      ! Y51 !                                                                  !
      *-] [-*                                                                  !
      !                                                                        !
      !X132   C71                                                         Y21  !
339   *-]/[-*-]/[---------------------------------------------------------( )---*
      !     !                                                                  !
      ! Y21 !                                                                  !
      *-] [-*                                                                  !
      !                                                                        !
      ! Y21                                                               Y20  !
343   *-] [---------------------------------------------------------------( )---*
      !                                                                        !
      ! Y21   C71                                                         Y27  !
345   *-] [-*-]/[---------------------------------------------------------( )---*
      !     !                                                                  !
      ! Y27 !                                                                  !
      *-] [-*                                                                  !
      !                                                                        !
      ! Y27                                                               Y26  !
349   *-] [---------------------------------------------------------------( )---*
      !                                                                        !
      ! Y21   Y47                                                         Y46  !
351   *-] [-*-]/[---------------------------------------------------------( )---*
      !     !                                                                  !
      ! Y46 !                                                                  !
      *-] [-*                                                                  !
      !                                                                        !
```

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                                DATE= 00-00-00                         OFF LINE

       !X137    C71                                                    C70   !
355    *-] [-*-]/[-------------------------------------------------------( )--*
       !     !                                                               !
       ! C70 !                                                               !
       *-] [-*                                                               !
       !                                                                     !
       ! C70              *-------------*                                    !
359    *-] [-----------!   TMR3       !-----------------------------  C72   !
       !                ! PROTECTED    !                             ----( )--*
       !                !              !                                     !
       !                ! P=   0010.0  !                                     !
       !                !              !                                     !
       ! Y26            !              !                                     !
       *-] [-----------!              !                                     !
       !                *-------------*                                      !
       ! C72   *-------------*                                               !
364    *-] [---!    O/S6     !-------------------------------------  C71    !
       !       !             !                                   ----( )--*
       !       !             !                                               !
       !       !             !                                               !
       !       *-------------*                                               !
       ! C71    Y2                                                     Y47   !
367    *-] [-*-]/[-------------------------------------------------------( )--*
       !     !                                                               !
       ! Y47 !                                                               !
       *-] [-*                                                               !
       !                                                                     !
       !X131    C61                                                    Y28   !
371    *-] [-*-]/[-------------------------------------------------------( )--*
       !     !                                                               !
       ! Y28 !                                                               !
       *-] [-*                                                               !
       !                                                                     !
       !X140    Y49                                                    Y48   !
375    *-] [-*-]/[-------------------------------------------------------( )--*
       !     !                                                               !
       ! Y48 !                                                               !
       *-] [-*                                                               !
       !                                                                     !
       ! C61    Y2                                                     Y49   !
379    *-] [-*-]/[-------------------------------------------------------( )--*
       !     !                                                               !
       ! Y49 !                                                               !
       *-] [-*                                                               !
       !                                                                     !
       ! Y28  X139    C61                                              C60   !
383    *-] [---]/[-*-]/[-------------------------------------------------( )--*
       !           !                                                         !
       ! C60       !                                                         !
       *-] [-------*                                                         !
       !                                                                     !
```

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        TEXAS INSTRUMENTS PROGRAMMING AND DOCUMENTATION SOFTWARE .   PAGE 0010

                                   DATE= 00-00-00                          OFF LINE
      ! C60           *------------*                                         C62  :
388   *-] [---------!   TMR1       !-------------------------------------------( )--*
      !             ! PROTECTED    !                                              !
      !             !              !                                              :
      !             ! P=    0005.0 !                                              :
      !             !              !                                              :
      ! Y28         !              !                                              :
      *-] [---------!              !                                              :
      !             *--------------*                                              :
      ! C62    *------------*                                                C61  :
393   *-] [---!    O/S3     !----------------------------------------------------( )--*
      !        !            !                                                     :
      !        !            !                                                     :
      !        !            !                                                     :
      !        !            !                                                     :
      !        *------------*                                                     :
      ! Y28  X147                                                            Y22  :
396   *-] [-*-]/[------------------------------------------------------------( )--*
      !     !                                                                     :
      ! Y22 !                                                                     :
      *-] [-*                                                                     :
      !                                                                           :
      !X147  X133                                                            Y52  :
400   *-] [-*-]/[------------------------------------------------------------( )--*
      !     !                                                                     :
      ! Y52 !                                                                     :
      *-] [-*                                                                     :
      !                                                                           :
      !X133    *------------*                                                Y2   :
404   *-] [---!    O/S4     !----------------------------------------------------( )--*
      !        !            !                                                     :
      !        !            !                                                     :
      !        !            !                                                     :
      !        !            !                                                     :
      !        *------------*                                                     :
      : Y2                                                                   END  :
407   *-]/[------------------------------------------------------------------(C)--*
      :                                                                           :
      !                                                                      RTN  :
409   *----------------------------------------------------------------------( )--*
      !                                                                           :
      !                                                                      SBR5 :
411   *----------------------------------------------------------------------( )--*
      !                                                                           :
      : C34   Y2                                                             Y1   :
413   *-] [-*-]/[------------------------------------------------------------( )--*
      !     !                                                                     :
      : Y1  !                                                                     :
      *-] [-*                                                                     :
      !                                                                           :
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      ! Y1     Y52   Y2                                         Y53  !
417   *-] [-*-]/[---]/[-----------------------------------------( )--*
      !       !                                                      !
      ! Y53   !                                                      !
      *-] [-*                                                        !
      !                                                              !
      !X133   C71                                               Y23  !
422   *-]/[-*-]/[-----------------------------------------------( )--*
      !       !                                                      !
      ! Y23   !                                                      !
      *-] [-*                                                        !
      !                                                              !
      ! Y23                                                     Y22  !
426   *-] [-----------------------------------------------------( )--*
      !                                                              !
      ! Y23   C71                                               Y29  !
428   *-] [-*-]/[-----------------------------------------------( )--*
      !       !                                                      !
      ! Y29   !                                                      !
      *-] [-*                                                        !
      !                                                              !
      ! Y29                                                     Y28  !
432   *-] [-----------------------------------------------------( )--*
      !                                                              !
      ! Y23   Y49                                               Y48  !
434   *-] [-*-]/[-----------------------------------------------( )--*
      !       !                                                      !
      ! Y48   !                                                      !
      *-] [-*                                                        !
      !                                                              !
      !X141   Y2                                                Y49  !
438   *-] [-*-]/[-----------------------------------------------( )--*
      !       !                                                      !
      ! Y49   !                                                      !
      *-] [-*                                                        !
      !                                                              !
      !X141                                                     C71  !
442   *-] [-----------------------------------------------------( )--*
      !                                                              !
      !X130   C61                                               Y26  !
444   *-] [-*-]/[-----------------------------------------------( )--*
      !       !                                                      !
      ! Y26   !                                                      !
      *-] [-*                                                        !
      !                                                              !
      !X143   Y47                                               Y46  !
448   *-] [-*-]/[-----------------------------------------------( )--*
      !       !                                                      !
      ! Y46   !                                                      !
      *-] [-*                                                        !
      !                                                              !
      ! C61   Y2                                                Y47  !
452   *-] [-*-]/[-----------------------------------------------( )--*
      !       !                                                      !
      ! Y47   !                                                      !
      *-] [-*                                                        !
      !                                                              !
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                                    DATE= 00-00-00                     OFF LINE

      ! Y26  X135   C61                                                  C60  !
456   *-] [---]/[-*-]/[-----------------------------------------------------( )--*
      !             !                                                         !
      ! C60         !                                                         !
      *-] [---------*                                                         !
      !                                                                       !
      ! C60            *-------------*                                   C62  !
461   *-] [-----------!   TMR1       !-------------------------------------( )--*
      !                ! PROTECTED   !                                        !
      !                !             !                                        !
      !                ! P=   0005.0 !                                        !
      !                !             !                                        !
      ! Y26            !             !                                        !
      *-] [-----------!             !                                        !
      !                *-------------*                                        !
      ! C62    *-------------*                                           C61  !
466   *-] [---!    O/S3     !-------------------------------------------( )--*
      !        !             !                                                !
      !        !             !                                                !
      !        !             !                                                !
      !        *-------------*                                                !
      ! Y26  X146                                                        Y20  !
469   *-] [-*-]/[-------------------------------------------------------------( )--*
      !     !                                                                 !
      ! Y20 !                                                                 !
      *-] [-*                                                                 !
      !                                                                       !
      !X146  X132                                                        Y50  !
473   *-] [-*-]/[-------------------------------------------------------------( )--*
      !     !                                                                 !
      ! Y50 !                                                                 !
      *-] [-*                                                                 !
      !                                                                       !
      !X132    *-------------*                                           Y2   !
477   *-] [---!    O/S4     !-------------------------------------------( )--*
      !        !             !                                                !
      !        !             !                                                !
      !        !             !                                                !
      !        *-------------*                                                !
      ! Y2                                                               END  !
480   *-]/[---------------------------------------------------------------(C)--*
      !                                                                       !
      !                                                                  RTN  !
482   *-------------------------------------------------------------------( )--*
      !                                                                       !
      !                                                                  SBR6 !
484   *-------------------------------------------------------------------( )--*
      !                                                                       !
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      ! C35    Y2
486   *-] [-*-]/[----------------------------------------------------------Y1--!
                                                                         ( )--*
      !       !
      ! Y1    !
      *-] [-*
      !
      ! Y1     Y50    Y2
490   *-] [-*-]/[---]/[-----------------------------------------------------Y51--!
                                                                         ( )--*
      !       !
      ! Y51   !
      *-] [-*
      !
      !X132   C71
495   *-]/[-*-]/[----------------------------------------------------------Y21--!
                                                                         ( )--*
      !       !
      ! Y21   !
      *-] [-*
      !
      ! Y21
499   *-] [----------------------------------------------------------------Y20--!
                                                                         ( )--*
      !
      ! Y21   C71
501   *-] [-*-]/[----------------------------------------------------------Y27--!
                                                                         ( )--*
      !       !
      ! Y27   !
      *-] [-*
      !
      ! Y27
505   *-] [----------------------------------------------------------------Y26--!
                                                                         ( )--*
      !
      ! Y21   Y47
507   *-] [-*-]/[----------------------------------------------------------Y46--!
                                                                         ( )--*
      !       !
      ! Y46   !
      *-] [-*
      !
      !X144
511   *-] [----------------------------------------------------------------C71--!
                                                                         ( )--*
      !
      ! C71   Y2
513   *-] [-*-]/[----------------------------------------------------------Y47--!
                                                                         ( )--*
      !       !
      ! Y47   !
      *-] [-*
      !
      ! C71   Y2
517   *-] [-*-]/[----------------------------------------------------------Y43--!
                                                                         ( )--*
      !       !
      ! Y43   !
      *-] [-*
      !
      !X145   Y2
521   *-] [-*-]/[----------------------------------------------------------C60--!
                                                                         ( )--*
      !       !
      ! C60   !
      *-] [-*
      !                                                                        !
```

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         TEXAS INSTRUMENTS PROGRAMMING AND DOCUMENTATION SOFTWARE     PAGE 0014

                              DATE= 00-00-00                                    OFF LINE
      ! C60  X145   *--------------*
 525  *-] [---]/[---!    O/S9      !---------------------------------------Y2     !
      !             !              !                                       ( )---*
      !             !              !                                             !
      !             !              !                                             !
      !             *--------------*                                             !
      ! Y2                                                                       !
 529  *-]/[--------------------------------------------------------------END    !
      !                                                                  (C)---*
      !                                                                          !
 531  *-------------------------------------------------------------------RTN    !
      !                                                                   ( )---*
      !                                                                          !
-533  *-------------------------------------------------------------------SBR7   !
      !                                                                   ( )---*
      ! C36   Y2                                                                 !
 535  *-] [-*-]/[---------------------------------------------------------Y1     !
      !     !                                                             ( )---*
      ! Y1  !                                                                    !
      *-] [-*                                                                    !
      !                                                                          !
      ! Y1    Y52   Y2                                                           !
 539  *-] [-*-]/[---]/[---------------------------------------------------Y53    !
      !     !                                                             ( )---*
      ! Y53 !                                                                    !
      *-] [-*                                                                    !
      !                                                                          !
      !X133   C80                                                                !
 544  *-]/[-*-]/[---------------------------------------------------------Y23    !
      !     !                                                             ( )---*
      ! Y23 !                                                                    !
      *-] [-*                                                                    !
      !                                                                          !
      ! Y23                                                                      !
 548  *-] [---------------------------------------------------------------Y22    !
      !                                                                   ( )---*
      ! Y23   C80                                                                !
 550  *-] [-*-]/[---------------------------------------------------------Y29    !
      !     !                                                             ( )---*
      ! Y29 !                                                                    !
      *-] [-*                                                                    !
      !                                                                          !
      ! Y29                                                                      !
 554  *-] [---------------------------------------------------------------Y28    !
      !                                                                   ( )---*
      ! Y23   Y49                                                                !
 556  *-] [-*-]/[---------------------------------------------------------Y48    !
      !     !                                                             ( )---*
      ! Y48 !                                                                    !
      *-] [-*                                                                    !
      !                                                                          !
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        TEXAS INSTRUMENTS PROGRAMMING AND DOCUMENTATION SOFTWARE      PAGE 0015

                              DATE= 00-00-00                              OFF LINE
     !X141   Y2
560  *-] [-*-]/[---------------------------------------------------------------Y49  !
     !     !                                                              ( )--*
     ! Y49 !                                                                   !
     *-] [-*                                                                   !
     !                                                                         !
     !X141                                                                     !
564  *-] [--------------------------------------------------------------------C80  !
     !                                                                    ( )--*
     ! C80   Y2                                                                !
566  *-] [-*-]/[-------------------------------------------------------------Y43  !
     !     !                                                              ( )--*
     ! Y43 !                                                                   !
     *-] [-*                                                                   !
     !                                                                         !
     !X145   Y2                                                                !
570  *-] [-*-]/[-------------------------------------------------------------C75  !
     !     !                                                              ( )--*
     ! C75 !                                                                   !
     *-] [-*                                                                   !
     !                                                                         !
     ! C75  X145   *-------------*                                             !
574  *-] [---]/[---!    O/S10    !-----------------------------------------Y2   !
     !             !             !                                    ( )--*
     !             !             !                                         !
     !             !             !                                         !
     !             *-------------*                                         !
     ! Y2                                                                  !
578  *-]/[-------------------------------------------------------------------END  !
     !                                                                    (C)--*
     !                                                                         !
580  *-----------------------------------------------------------------------RTN  !
     !                                                                    ( )--*
     !                                                                         !
582  *-----------------------------------------------------------------------SBR8 !
     !                                                                    ( )--*
     ! C37   Y2                                                                !
584  *-] [-*-]/[-------------------------------------------------------------Y1   !
     !     !                                                              ( )--*
     ! Y1  !                                                                   !
     *-] [-*                                                                   !
     !                                                                         !
     ! Y1    Y52    Y2                                                         !
588  *-] [-*-]/[---]/[-------------------------------------------------------Y53  !
     !     !                                                              ( )--*
     ! Y53 !                                                                   !
     *-] [-*                                                                   !
     !                                                                         !
     !X133   C80                                                               !
593  *-]/[-*-]/[-------------------------------------------------------------Y23  !
     !     !                                                              ( )--*
     ! Y23 !                                                                   !
     *-] [-*                                                                   !
     !                                                                         !
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                  TEXAS INSTRUMENTS PROGRAMMING AND DOCUMENTATION SOFTWARE      PAGE 0016

                                      DATE= 00-00-00                                OFF LINE
         ! Y23
597      *-] [-------------------------------------------------------------------Y22    !
         !                                                                   ----( )--*
         ! Y23    C80                                                                   !
599      *-] [-*-]/[-------------------------------------------------------------Y29    !
         !     !                                                             ----( )--*
         ! Y29 !                                                                        !
         *-] [-*                                                                        !
         !                                                                              !
         ! Y29                                                                          !
603      *-] [-------------------------------------------------------------------Y28    !
         !                                                                   ----( )--*
         ! Y23    Y49                                                                   !
605      *-] [-*-]/[-------------------------------------------------------------Y48    !
         !     !                                                             ----( )--*
         ! Y48 !                                                                        !
         *-] [-*                                                                        !
         !                                                                              !
         !X141    Y2                                                                    !
609      *-] [-*-]/[-------------------------------------------------------------Y49    !
         !     !                                                             ----( )--*
         ! Y49 !                                                                        !
         *-] [-*                                                                        !
         !                                                                              !
         !X141                                                                          !
613      *-] [-------------------------------------------------------------------C80    !
         !                                                                   ----( )--*
         ! C80    Y2                                                                    !
615      *-] [-*-]/[-------------------------------------------------------------Y41    !
         !     !                                                             ----( )--*
         ! Y41 !                                                                        !
         *-] [-*                                                                        !
         !                                                                              !
         !X142    Y2                                                                    !
619      *-] [-*-]/[-------------------------------------------------------------C75    !
         !     !                                                             ----( )--*
         ! C75 !                                                                        !
         *-] [-*                                                                        !
         !                                                                              !
         ! C75   X142       *--------------*                                            !
623      *-] [---]/[---!    O/S10     !------------------------------------Y2     !
         !                  !              !                                 ----( )--*
         !                  !              !                                            !
         !                  !              !                                            !
         !                  *--------------*                                            !
         ! Y2                                                                           !
627      *-]/[-------------------------------------------------------------------END    !
         !                                                                   ----(C)--*
         !                                                                              !
629      *-----------------------------------------------------------------------RTN    !
         !                                                                   ----( )--*
         !                                                                              !
631      *-----------------------------------------------------------------------SBR9   !
         !                                                                   ----( )--*
                                                                                        !
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                               DATE= 00-00-00
                                                                        OFF LINE
      ! C38    Y2
633   *-] [-*-]/[-----------------------------------------------------------Y1 !
      !      !                                                          --( )--*
      ! Y1   !                                                                 !
      *-] [-*                                                                  !
      !                                                                        !
      ! Y1     Y50    Y2                                                       !
637   *-] [-*-]/[---]/[---------------------------------------------------Y51  !
      !      !                                                         --( )--*
      ! Y51  !                                                                 !
      *-] [-*                                                                  !
      !                                                                        !
      !X132    C71                                                             !
642   *-]/[-*-]/[---------------------------------------------------------Y21  !
      !      !                                                         --( )--*
      ! Y21  !                                                                 !
      *-] [-*                                                                  !
      !                                                                        !
      ! Y21                                                                    !
646   *-] [---------------------------------------------------------------Y20  !
      !                                                                --( )--*
      ! Y21    C71                                                             !
648   *-] [-*-]/[---------------------------------------------------------Y27  !
      !      !                                                         --( )--*
      ! Y27  !                                                                 !
      *-] [-*                                                                  !
      !                                                                        !
      ! Y27                                                                    !
652   *-] [---------------------------------------------------------------Y26  !
      !                                                                --( )--*
      ! Y21    Y47                                                             !
654   *-] [-*-]/[---------------------------------------------------------Y46  !
      !      !                                                         --( )--*
      ! Y46  !                                                                 !
      *-] [-*                                                                  !
      !                                                                        !
      !X137    C71                                                             !
658   *-] [-*-]/[---------------------------------------------------------C70  !
      !      !                                                         --( )--*
      ! C70  !                                                                 !
      *-] [-*                                                                  !
      !                                                                        !
      ! C70              *--------------*                                      !
662   *-] [----------!  TMR3          !-----------------------------------C72  !
      !                 !  PROTECTED     !                              --( )--*
      !                 !                !                                     !
      !                 !  P=    0010.0  !                                     !
      !                 !                !                                     !
      ! Y26             !                !                                     !
      *-] [----------!                !                                     !
      !                 *--------------*                                       !
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                         DATE= 00-00-00                       OFF LINE

      : C72    *-------------*
667   *-] [---:    C/S6      :--------------------------------------------- C71  :
      :       :              :                                            --( )--*
      :       :              :                                                    :
      :       :              :                                                    :
      :       *--------------*                                                    :
      ! C71    Y2                                                                 :
670   *-] [-*-]/[--------------------------------------------------------- Y47   :
      :       :                                                           --( )--*
      ! Y47   !                                                                   :
      *-] [-*                                                                     :
      :                                                                           :
      !X138    C80                                                                :
674   *-] [-*-]/[--------------------------------------------------------- Y29   :
      :       :                                                           --( )--*
      ! Y29   !                                                                   :
      *-] [-*                                                                     :
      :                                                                           :
      !X131                                                                       :
678   *-] [--------------------------------------------------------------- Y28   :
      :                                                                   --( )--*
      !X140    Y49                                                                :
680   *-] [-*-]/[--------------------------------------------------------- Y48   :
      :       :                                                           --( )--*
      ! Y48   !                                                                   :
      *-] [-*                                                                     :
      :                                                                           :
      !X141    Y2                                                                 :
684   *-] [-*-]/[--------------------------------------------------------- Y49   :
      :       :                                                           --( )--*
      ! Y49   !                                                                   :
      *-] [-*                                                                     :
      :                                                                           :
      !X141                                                                       :
688   *-] [--------------------------------------------------------------- C80   :
      :                                                                   --( )--*
      ! C80    Y2                                                                 :
690   *-] [-*-]/[--------------------------------------------------------- Y41   :
      :       :                                                           --( )--*
      ! Y41   !                                                                   :
      *-] [-*                                                                     :
      :                                                                           :
      !X142    Y2                                                                 :
694   *-] [-*-]/[--------------------------------------------------------- C75   :
      :       :                                                           --( )--*
      ! C75   !                                                                   :
      *-] [-*                                                                     :
      !                                                                           :
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       : C75  X142  *------------*                                   Y2   :
699    *-] [---]/[---:   O/S10    :-----------------------------------( )--*
       :             :            :                                       :
       :             :            :                                       :
       :             :            :                                       :
       :             *------------*                                       :
       : Y2                                                          END  :
702    *-]/[---------------------------------------------------------(C)--*
       :                                                                  :
       :                                                             RTN  :
704    *-------------------------------------------------------------( )--*
       :                                                                  :
       :                                                           SBR10  :
706    *-------------------------------------------------------------( )--*
       :                                                                  :
       : C39   Y2                                                    Y1   :
708    *-] [-*-]/[---------------------------------------------------( )--*
       :     :                                                            :
       : Y1  :                                                            :
       *-] [-*                                                            :
       :                                                                  :
       :X138   C80                                                   Y29  :
712    *-] [-*-]/[---------------------------------------------------( )--*
       :     :                                                            :
       : Y29 :                                                            :
       *-] [-*                                                            :
       :                                                                  :
       :X131                                                         Y28  :
716    *-] [---------------------------------------------------------( )--*
       :                                                                  :
       :X140   Y49                                                   Y48  :
718    *-] [-*-]/[---------------------------------------------------( )--*
       :     :                                                            :
       : Y48 :                                                            :
       *-] [-*                                                            :
       :                                                                  :
       :X141   Y2                                                    Y49  :
722    *-] [-*-]/[---------------------------------------------------( )--*
       :     :                                                            :
       : Y49 :                                                            :
       *-] [-*                                                            :
       :                                                                  :
       :X141                                                         C80  :
726    *-] [---------------------------------------------------------( )--*
       :                                                                  :
       : C80   Y2                                                    Y41  :
728    *-] [-*-]/[---------------------------------------------------( )--*
       :     :                                                            :
       : Y41 :                                                            :
       *-] [-*                                                            :
       :                                                                  :
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       TEXAS INSTRUMENTS PROGRAMMING AND DOCUMENTATION SOFTWARE     PAGE [illegible]

                              DATE= 00-00-00                              OFF LINE
      !X142   Y2                                                          C75   !
732   *-] [-*-]/[---------------------------------------------------------( )---*
      !      !                                                                  !
      ! C75  !                                                                  !
      *-] [-*                                                                   !
      !                                                                         !
      ! C75  X142   *--------------*                                      Y2    !
736   *-] [---]/[---!    O/S10     !--------------------------------------( )---*
      !             !              !                                            !
      !             !              !                                            !
      !             !              !                                            !
      !             !              !                                            !
      !             *--------------*                                            !
      ! Y2                                                                END   !
740   *-]/[-------------------------------------------------------------(C)---*
      !                                                                         !
      !                                                                   RTN   !
742   *-------------------------------------------------------------------( )---*
      !                                                                         !
      !                                                                   SBR11 !
744   *-------------------------------------------------------------------( )---*
      !                                                                         !
      ! C40   Y2                                                          Y1    !
746   *-] [-*-]/[---------------------------------------------------------( )---*
      !      !                                                                  !
      ! Y1   !                                                                  !
      *-] [-*                                                                   !
      !                                                                         !
      !X142   C70    Y2                                                   Y41   !
750   *-]/[-*-]/[---]/[---------------------------------------------------( )---*
      !      !                                                                  !
      ! Y41  !                                                                  !
      *-] [-*                                                                   !
      !                                                                         !
      !X142   Y2                                                          C70   !
755   *-] [-*-]/[---------------------------------------------------------( )---*
      !      !                                                                  !
      ! C70  !                                                                  !
      *-] [-*                                                                   !
      !                                                                         !
      ! C70   Y2                                                          Y43   !
759   *-] [-*-]/[---------------------------------------------------------( )---*
      !      !                                                                  !
      ! Y43  !                                                                  !
      *-] [-*                                                                   !
      !                                                                         !
      !X145   Y2                                                          C60   !
763   *-] [-*-]/[---------------------------------------------------------( )---*
      !      !                                                                  !
      ! C60  !                                                                  !
      *-] [-*                                                                   !
      !                                                                         !
```

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-----------------------------------------------------------------------------
        TEXAS INSTRUMENTS PROGRAMMING AND DOCUMENTATION SOFTWARE    PAGE 0021

                               DATE= 00-00-00                         OFF LINE
      ! C60  X145  *-------------*                                         Y2  !
 767  *-] [---]/[---!   O/S11     :--------------------------------------( )--*
      !             !             :                                           !
      !             !             :                                           !
      !             !             :                                           !
      !             *-------------*                                           !
      ! Y2                                                               END  !
 771  *-]/[------------------------------------------------------------(C)--*
      !                                                                       !
      !                                                                  RTN  !
 773  *--------------------------------------------------------------( )--*
      !                                                                       !
      !                                                                SBR12 !
 775  *--------------------------------------------------------------( )--*
      !                                                                       !
      ! C41    Y2                                                        Y1   !
 777  *-] [-*-]/[----------------------------------------------------( )--*
      !     !                                                                 !
      ! Y1  !                                                                 !
      *-] [-*                                                                 !
      !                                                                       !
      !X142   C81    Y2                                                  Y41  !
 781  *-]/[-*-]/[---]/[----------------------------------------------( )--*
      !     !                                                                 !
      ! Y41 !                                                                 !
      *-] [-*                                                                 !
      !                                                                       !
      !X142   Y2                                                         C81  !
 786  *-] [-*-]/[----------------------------------------------------( )--*
      !     !                                                                 !
      ! C81 !                                                                 !
      *-] [-*                                                                 !
      !                                                                       !
      !X130   C61                                                        Y26  !
 790  *-] [-*-]/[----------------------------------------------------( )--*
      !     !                                                                 !
      ! Y26 !                                                                 !
      *-] [-*                                                                 !
      !                                                                       !
      !X143   Y47                                                        Y46  !
 794  *-] [-*-]/[----------------------------------------------------( )--*
      !     !                                                                 !
      ! Y46 !                                                                 !
      *-] [-*                                                                 !
      !                                                                       !
      ! C61   Y2                                                         Y47  !
 798  *-] [-*-]/[----------------------------------------------------( )--*
      !     !                                                                 !
      ! Y47 !                                                                 !
      *-] [-*                                                                 !
      !                                                                       !
```

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        TEXAS INSTRUMENTS PROGRAMMING AND DOCUMENTATION SOFTWARE      PAGE 0022

                                     DATE= 00-00-00                            OFF LINE
         ! Y26   X135    C61
001      *-] [---]/[-*-]/[-------------------------------------------------------C60  !
         !             !                                                          ( )--*
         ! C60         !                                                              !
         *-] [-------*                                                               !
         !                                                                            !
         ! C60             *-------------*                                            !
007      *-] [----------!  TMR1         !-----------------------------------------C62  !
         !                 ! PROTECTED     !                                          ( )--*
         !                 !               !                                          !
         !                 ! P=    0005.0  !                                          !
         ! Y26             !               !                                          !
         *-] [----------!               !                                          !
         !                 *-------------*                                            !
         ! C62    *-------------*                                                     !
012      *-] [---!    O/S3      !----------------------------------------------C61  !
         !        !              !                                                    ( )--*
         !        !              !                                                    !
         !        *-------------*                                                     !
         ! Y26  X146                                                                  !
015      *-] [-*-]/[---------------------------------------------------------------Y20  !
         !     !                                                                      ( )--*
         ! Y20 !                                                                      !
         *-] [-*                                                                      !
         !X146  X132                                                                  !
019      *-] [-*-]/[---------------------------------------------------------------Y50  !
         !     !                                                                      ( )--*
         ! Y50 !                                                                      !
         *-] [-*                                                                      !
         !X132    *-------------*                                                     !
023      *-] [---!    O/S4      !----------------------------------------------Y2   !
         !        !              !                                                    ( )--*
         !        !              !                                                    !
         !        *-------------*                                                     !
         ! Y2                                                                         !
026      *-]/[------------------------------------------------------------------END  !
         !                                                                            (C)--*
         !                                                                            RTN  !
028      *----------------------------------------------------------------------( )--*
         !                                                                            !
         !                                                                          SBR13 !
030      *----------------------------------------------------------------------( )--*
         !                                                                            !
```

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       : C42    Y2
832    *-] [-*-]/[-------------------------------------------Y1----( )--*
       :      :
       : Y1   :
       *-] [-*
       :
       :X142   C81    Y2
836    *-]/[-*-]/[---]/[-------------------------------------Y41---( )--*
       :      :
       : Y41  :
       *-] [-*
       :
       :X142   Y2
841    *-] [-*-]/[-------------------------------------------C81---( )--*
       :      :
       : C81  :
       *-] [-*
       :
       :X143   Y47
845    *-] [-*-]/[-------------------------------------------Y46---( )--*
       :      :
       : Y46  :
       *-] [-*
       :
       :X130   C91
849    *-] [-*-]/[-------------------------------------------Y26---( )--*
       :      :
       : Y26  :
       *-] [-*
       :
       :X135   C2
853    *-] [-*-]/[-------------------------------------------C91---( )--*
       :      :
       : C91  :
       *-] [-*
       :
       : C91   Y2
857    *-] [---]/[-------------------------------------------Y47---( )--*
       :
       :X131   C61
860    *-] [-*-]/[-------------------------------------------Y28---( )--*
       :      :
       : Y28  :
       *-] [-*
       :
       :X140   Y49
864    *-] [-*-]/[-------------------------------------------Y48---( )--*
       :      :
       : Y48  :
       *-] [-*
       :
       : C61   Y2
868    *-] [-*-]/[-------------------------------------------Y49---( )--*
       :      :
       : Y49  :
       *-] [-*
       :
```

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     ! Y28  X139   C61                                                   C60  !
872  *-] [---]/[-*-]/[-------------------------------------------------( )--*
     !              !                                                          !
     ! C60          !                                                          !
     *-] [--------*                                                            !
     !                                                                         !
     ! C60            *-------------*                                          !
877  *-] [----------!    TMR1        !-------------------------------------C62  !
     !               !  PROTECTED    !                                 ( )--*
     !               !               !                                         !
     !               !  P=    0005.0 !                                         !
     !               !               !                                         !
     ! Y28           !               !                                         !
     *-] [----------!               !                                         !
     !               *--------------*                                          !
     ! C62     *--------------*                                          C61  !
882  *-] [---!     O/S3        !---------------------------------------( )--*
     !        !                !                                               !
     !        !                !                                               !
     !        *---------------*                                                !
     ! Y28  X147                                                         Y22  !
885  *-] [-*-]/[---------------------------------------------------------( )--*
     !      !                                                                  !
     ! Y22  !                                                                  !
     *-] [-*                                                                   !
     !                                                                         !
     !X147  X133                                                         Y52  !
889  *-] [-*-]/[---------------------------------------------------------( )--*
     !      !                                                                  !
     ! Y52  !                                                                  !
     *-] [-*                                                                   !
     !                                                                         !
     !X133     *--------------*                                          Y2   !
893  *-] [---!     O/S4        !---------------------------------------( )--*
     !        !                !                                               !
     !        !                !                                               !
     !        *---------------*                                                !
     ! Y2                                                                END  !
896  *-]/[---------------------------------------------------------------(C)--*
     !                                                                         !
     !                                                                   RTN  !
898  *-------------------------------------------------------------------( )--*
     !                                                                         !
     !                                                                   NOP  !
900  *-------------------------------------------------------------------( )--*
     !                                                                         !
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