A Microprocessor Based Weighing & Feed Control System

Thesis submitted for the Degree of Master of Science
(Engineering)

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ABSTRACT.

A MICRO-PROCESSOR BASED WEIGHING AND FEED CONTROL SYSTEM.

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This paper describes the development of a micro-processor based computer control system for the raw material weighing and feed system of a submerged arc ferro-alloy furnace.

The system is designed to replace the more conventional semi-automatic analogue controller at present in use in many installations. It may be used either as a stand-alone unit or as an out-station in a distributed control computer-based system. In the latter, the micro-processor unit forms an intelligent peripheral to the central control computer.

The control unit consists of an 8-bit micro-processor with 8 kilowords of storage. It can control, at present, 3 weighing hoppers fed from 12 raw material storage bins. It responds to service requests from any of the furnace feed hoppers by setting up the necessary conveyor belt and shuttle routing and then feeding the contents of the weighing hoppers onto the transport system.

In addition to the above functions, it is capable of compensating for weighing hopper overshoot, tarring errors, moisture content of raw materials, and can effect local changes in the raw material composition being fed to the furnace. Set points would typically be entered manually via an operator's console, but may be changed at any time, either by the operator or from information supplied by a central computer.

The system is equipped with a teleprinter. This may be used to make set-point alterations, print-out inventories at selected times, record any changes made, and so on. Any information typed out is accompanied by a time-of-day record.

The system described was developed in the Department of Electrical Engineering, University of Cape Town, for the National Institute of Metallurgy.

29th. September, 1975.

It has now been confirmed that "A Microprocessor Based Weighing and Feed Control System" has been accepted as a paper to be presented at the above Conference.

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SECTION 1.

OVERVIEW

CHAPTER 1

ARC FURNACES AND THE NEED TO IMPROVE THEIR CONTROL

"The weighing and charging system represents a most important group of control variables" - Elken Company, Norway {1}

1.0 INTRODUCTION

During the last few years, large submerged-arc furnaces have been commissioned in the South African ferro-alloy industry. It has been found that such furnaces, although more economical in operation than earlier, smaller furnaces, suffer considerably from problems relating to their design, operation, choice of raw materials, and composition of feed mixture. These problems result in inefficient operation of the furnaces.

In view of the economic importance of the ferro-alloy industry to South Africa, the National Institute of Metallurgy embarked on an investigation into the use of computers for the control of large, submerged-arc furnaces. {2, 3, 4, 5}

The furnace chosen for the investigation was a 48 MVA ferro-chromium furnace situated at Witbank.

As a result of this investigation it was decided to investigate the defects of, and improvements to, the existing conventional, semi-automatic analogue batch-weighing and feed-mix transport and furnace-charging systems used in these types of furnaces. As a specific example, the one used at Witbank (the Witbank system) was to be considered. This system is used as a typical example throughout this thesis.

1.1 DESCRIPTION OF THE WITBANK SYSTEM

Figure 1.1 shows a mimic panel of the raw-material batch-weighing and transport system.

H1 to H10 are a battery of holding bins containing the different raw materials, such as crushed metal ores, and suitable reductants, such as coke, fluxes, and so on.

From/

FIGURE 1.1 MIMIC PANEL OF A TYPICAL RAW MATERIAL BATCH WEIGHING AND DISTRIBUTION SYSTEM FOR AN ARC FURNACE.

(Chapter 1 - continued)

From these bins the raw materials are fed into one of the three weighing hoppers (WH1 - WH3) suspended on load cells. The actual feeding operation is achieved by means of two-speed vibration feeders (F1 - F10). The feeders operate in a "coarse mode" until the weight in a weighing hopper is within 90% of a desired setpoint (a value at which a particular feeder must be stopped). The system then changes over to a "fine mode" of feeding until the setpoint is reached. When the weighing hoppers have been filled with the desired proportions of raw materials they are emptied onto the transport system via three additional feeders (FF1 - FF3). These feeders are adjusted so that the materials from each of the weighing hoppers form three equidistant layers on top of one another on the conveyor belts. This procedure is to assist in the mixing of the materials. The feed-mix is then transported by means of a system of conveyor belts and shuttles to one of the furnace hoppers (FH1 - FH12), as required. Level indicators on the furnace hoppers determine which hopper is to be serviced. The charge mix is fed into the furnace by gravity through tubes which lead through the furnace hoppers through the furnace cover. At present, there are four feeding points round each electrode. (Figure 1.2)

For safety reasons, and to allow for maintenance and repair shut-down of the charging system, the furnace hoppers are large enough to hold sufficient material to feed for several hours.

1.2 DISADVANTAGES OF THE CONVENTIONAL SYSTEM

Before attempting to improve the existing, conventional system, the disadvantages of the system must be outlined.

- (a) Uncontrolled and varying overshoots of the weighing hopper input feeders give rise to weighing errors which may have a magnified effect on the weight ratio between the different raw materials. This is caused by the/

TOP VIEW

FIGURE 1.2 DIAGRAMMATICAL SKETCH SHOWING THE RELATIVE POSITIONS OF THE ELECTRODES, FURNACE HOPPERS AND FURNACE FEEDING POINTS IN AN ENCLOSED SUBMERGED ARC FURNACE.

the successive feeding of batches of several materials into the same hopper and using accumulated setpoints. The meaning of "accumulated setpoints" in this context may be illustrated by the following example: take the few feeders supplying WH1, and assume that the following recipe is required:

100 kg from H1
 50 kg from H2
 150 kg from H3
 120 kg from H4

The accumulated setpoints will then be:

SP1 = 100
 SP2 = 150
 SP3 = 300
 SP4 = 420

The weight ratio error will exist because raw materials of the same composition are normally fed from the same holding bin in the same order.

(b) When a weighing hopper is supposed to be empty, the load cell output may not show zero weight of material. This is caused by:

- (i) material sticking to the weighing hopper or to its output feeder
- (ii) drifts in the load cell amplifiers
- (iii) supply voltage variations

The fact that no automatic compensation for this "taring error" exists leads to a considerable percentage error.

(c) "Accumulated setpoints" imply that if the desired amount of any one setpoint is to be changed, all the succeeding setpoints have to be changed accordingly. This must be done at present by manual adjustments of the setpoint potentiometers.

(d) All the furnace hoppers are treated equally and receive a feed-mix of the same recipe, determined by one set of setpoints. The possibility of introducing changes to the feed-mix recipe locally in the furnace is not provided for. It is often desirable to change, for example, the coke addition to different furnace feeding points.

(e)/

(Chapter 1 - continued)

- (e) The setpoint representation by means of potentiometers is unsuitable for automatic setpoint control. This is a disadvantage, not only for sophisticated furnace control, but also for simple applications, such as moisture compensation, ash compensation, and so on.
- (f) No provision is made for moisture compensation. As the coke can sometimes contain up to 16% moisture, this is a serious disadvantage. Similar compensation could be provided for the ash content of the coke.
- (g) The only automatic aid in determining an inventory of raw materials consumed are electro-mechanical counters for the number of batches fed to the weighing hoppers of each material. This means that the inventory record relies on manual data-logging and calculation.
- (h) The whole system operates on a fixed cycle which is inflexible and time-consuming; for example, if the same furnace hopper is to be serviced twice consecutively, all the feeders, conveyors, shuttles, and so on, must be shut down completely before commencing the second cycle. The system's stable state, i.e. waiting for a furnace hopper to become empty, is achieved when the weighing hoppers are fully charged. This makes load correction difficult.
- (i) There is no provision for external management adjustment of the setpoints. All the adjustments have to be made manually by operators whose reliability may sometimes be questioned. Ideally one would like to be able to make adjustments from a central computer or a data terminal. It would also be desirable to have all adjustments properly logged.

1.3 THE NEED TO IMPROVE

As previously stated, the larger arc furnaces suffer from inherent difficulties which result in inefficient operation, but is it worth spending time and money on improving the weighing and charging systems?

Certainly; the Elkern Company in Norway think it well worthwhile:

"Proportioning of the feed mix and adjustments of the charge

/composition

composition - for the furnace as a whole, or locally. - are the only control means available besides altering the electrode positions or the transformer voltage. Therefore, it is essential that the weighing system is designed as a practical control tool, so that desired control actions can be effected quickly and accurately, whether they are decided by an operator or by an automatic controller. Secondly, as most of the disturbances causing process variations which require control actions are caused by the raw materials in the first place, an accurate weighing system may help to keep these disturbances as small as possible. Further, as far as the primary disturbances (e.g. varying coke moisture content) can be measured, they should be compensated for by a feed-forward control of the weighing setpoints before they reach the furnace. Poor and varying properties of the raw materials are common excuses for difficulties with furnace operation, and it is frequently assumed that better raw materials or expensive pre-treatment only can improve the situation. However, we believe that insufficient accuracy of the weighing system in many cases is more to blame than the raw material quality, and that variations in the raw materials could have been compensated for by a better control system for the weighing and charging." {1}

Local experience suggests that the above is probably accurate. This, along with the need for accurate inventory and information logging, makes the design of a new batch-weighing and raw-material distribution system desirable.

CHAPTER 2

APPROACHES TO IMPROVE THE CONTROL OF THE WEIGHING SYSTEM

In order to improve the control of a submerged arc furnace weighing system, a careful study of the shortcomings of the conventional system must be made. Chapter 1 revealed the following defects:

- (a) No error feedback. No provision is made to ascertain the overshoot or taring errors. The correction of these should be made in succeeding weighing batches.
- (b) No attempt is made to determine the effect of the feed-mix recipe on the furnace performance and to make suitable local or universal corrections of the recipe being fed to different zones in the furnace.
- (c) No error feedforward. No attempt is made to allow for the possible defects of the raw materials (e.g. the moisture or ash content of the coke).
- (d) Lack of accurate inventory and logging information.
- (e) Poor provision for external management adjustments.

2.1 CHOICE OF CONTROL SYSTEM

A full cycle of the weighing system takes approximately four minutes. There might be delays of hours between the servicing of specific furnace hoppers. If it is hoped to perform any of the feedback functions, the control system will have to store data for at least the duration of these periods.

The latter factor, together with the inventory requirements, implies that some form of data storage is required. Because of the large storage capacity needed, a digital store is indicated. The above, as well as the following factors, weighs heavily in favour of a digital control system

- (i) Signals will have to be transmitted to the controller over long distances, and digital transmission offers a high degree of noise immunity.
- (ii) A digital system does not suffer from any long-term stability problems

such/

such as drifts in amplifiers, and so on.

(iii) A digital system offers the ability to achieve any desired degree of accuracy, once the signals have been digitized. Thus the storage of the setpoints and the error correction calculations can easily be carried out to an exact, specified degree of accuracy.

(iv) A digital control system favours the use of thumbwheel switches as setpoint inputs to the system. This means that these inputs can be specified exactly.

(v) Apart from the load cell amplifier outputs, all the other signals are digital (relay contacts, etc.)

2.2 THE NEED FOR A DIGITAL COMPUTER

When a designer is confronted with the task of developing a large digital controller which must have large data storage ability and be able to perform arithmetical operations, the suitability of a minicomputer must be thoroughly investigated. The advantages of incorporating a computer into a digital controller for this system were found to be:

- (i) Flexibility. By software (programming) changes, the system can be adapted to incorporate any possible modifications. It can also be updated, if necessary.
- (ii) Reliability. Extensive use of modern components, such as integrated circuits, together with many years of experience in their use, has given minicomputers a well-deserved reputation for reliability.
- (iii) The fact that, despite vastly different applications, the basic hardware of a certain make of computer remains the same, means that the computer is much easier to maintain.
- (iv) A computer can be used for more than one set task and will readily perform the function of co-ordinating such tasks.

(v)/.....

(v) The computer can continuously keep track of variables over a long period of time. In many cases, it can detect process trends and slowly developing deterioration. {3}

2.3 WHY A MICRO-COMPUTER?

Paragraph 2.2 justifies the use of a computer as the control element of this system. The next problem is the question of what type of computer is to be used. Investigation showed that the micro-processor would be a suitable choice, based on the following reasons:

(a) The functions of the weighing and feeder control system are relatively simple. It was unlikely that any software would be available for the chosen micro-processor so that any complex programming would count against the use of a micro-processor based system.

(b) Cost. It was estimated that the cost would be far less than that of any mini-computer based system available.

(c) The process is slow and has many dead-time periods. Most commercial micro-processors are considerably slower than the average mini-computer.

(d) Distributed control. The micro-processor is suitable for use in a distributed control system. This might consist of various micro-processor based controllers, controlling smaller processes within a plant. All these controllers could be linked to a central station, possibly mini-computer based, from where they would receive management information calculated on a global scale. Each micro-processor controlled "outstation" should be able to operate independently of the global input parameters. The central controller would also be used for all inventory functions and external control and/or access to the system. The advantages of such a system would be:

- (i) The breakdown of any part of the system need not affect the successful operation of other portions.
- (ii) The cabling to each local outstation would be minimized to possibly only one transmission channel. As the outstation is capable of independent operation, a break in this channel would not have catastrophic effects.

(iii).....

- (iii) The cabling from the process to the nearest local outstation would be minimized.
- (iv) Only software changes would need to be made to adapt the basic micro-processor based hardware to any local function it might be required to perform.
- (e) Because of the use of large-scale integration, a micro-processor based system is likely to have fewer components, fewer connections and a much lower power dissipation. It will be more reliable and easier to maintain.

2.4 THE MICRO-COMPUTER BASED SYSTEM

It was decided to design and build a micro-processor based control system of which the basic "computer" hardware and software must be suitable to control a batch-weighing and raw material distribution system of the type used in arc furnaces.

A simulator was to be designed and built which would simulate the Witbank system. The processor was to be interfaced to it in order to demonstrate and assess the processor's capabilities.

The above system is known as the "prototype system", throughout this thesis.

CHAPTER 3

THE MICROPROCESSOR

3.1 HISTORY

When the first two microprocessors were announced in 1971, an industry which had been predicted for at least a decade came into being. The major effect that this was to have on the electronics industry may be illustrated by some of the following quotes:

- (i) "The microprocessors recently introduced by various semi-conductor companies foreshadow wide changes in the design of many electronic products and systems". { 7 }
- (ii) "Microprocessors, to some degree, are causing computer history to repeat itself. The new areas in which microprocessors are being applied are as surprising and as imaginative as were the first minicomputer applications". { 8 }
- (iii) "The advent of the microprocessor is the beginning of a new computer revolution in our technological society". { 9 }
- (iv) "The microprocessor has been designed as a sub-system into a startling variety of products and applications. The dollar volume growth from one year to the next appears to be about five-to-one in microprocessor and related component sales. Clearly, it has become a popular tool. Well over 100,000 will be shipped, this year (1974)... Commercially available microprocessors aren't yet five years old (1974) and there are already more than two dozen that the designer can choose from". { 6 }

The term "microprocessor" is usually given to a central processing unit (CPU) which consists of a control and arithmetic and logic unit (ALU) implemented in one or a few large-scale integration (LSI) packages.

A/...

(Chapter 3 - continued)

A microcomputer is a microprocessor which has been interconnected to a memory and generally also to a control unit by which it can "communicate" with the outside world.

A microcomputer is distinguished from a minicomputer by:

- (i) Much greater use of large-scale integration techniques
- (ii) Lower cost
- (iii) Lower power
- (iv) Generally, but not necessarily, lower speed.

3.2 ARCHITECTURE

In considering the different microprocessor architectures there appear to be three major areas for investigation. { 6 }

- (i) Software Design - covers the features of the microprocessor as seen by the programmer
- (ii) Hardware Design - includes the requirements of the environment in which the microprocessor must operate
- (iii) Systems Design - affects the use of, and the interaction between, the software and hardware to achieve the required result.

(a) System Design

Some major features of microprocessors are:

Interrupt Structure
One-chip CPU Packaging
Direct Memory Access Ability, and
Arithmetic Modes

- (i) Interrupts may or may not be important, depending upon two factors:
 - (1) does the application require real-time quick response to external events, and
 - (2) does the software design strategy encourage the use of interrupts?

Many/...

(Chapter 3 - continued)

Many applications don't require interrupts - even real-time applications. Instead of allowing main-line processing programs to be interrupted, software organization may assure the testing of some external status signal frequently enough to guarantee service.

(ii) One-chip CPU packaging has a substantial effect on assembly and repair costs as well as affecting the size of the finished product. Even among one-chip CPUs there are tremendous varieties on the number of ICs which must be added before achieving a working computer. A CPU that multiplexes^{addresses} through the same pins as data requires several external packages to catch and hold a memory address. Most of the larger packages avoid this multiplexing. Other areas which frequently require substantial amounts of supporting logic are state decoding and I/O control. The signals required to enable interrupts, enable and address input/output ports, write into storage and interrupt or reset the system, may be available at CPU pins or they may require as many as ten or twenty packages of decoding, storage and timing logic. While the parts costs of these extra chips is relatively small, they can double or treble the manufacturing costs of the computer.

(iii) Microprogrammability allows the fine structure of the microprocessor to be changed, while the gross structure remains. In particular, the number of registers the programmer sees and the suite of instructions can be modified, within limited realms, but gross changes are not possible. Microprograms are usually stored in read-only memories, either on the computer's control chip or externally. Microprogramming is important when a microcomputer is being designed that will emulate some other (more popular) computer, or when some specialised applications-oriented instructions need to be implemented to augment existing instructions set. Common but time-consuming software routines (such as multiply) can be implemented as microprogrammed instructions to speed up program execution.

Virtually/....

Virtually any program can be reduced to a microprogram. Relatively complicated processing tasks (like Fast Fourier Transforms) will be executed much faster if implemented as a microprogram.

(vi) Direct Memory Access: this has been a popular option on minicomputers for a long time. DMA allows high-speed peripheral devices ^{to} gain direct access to main storage without bothering the CPU: the alternative requires the software to read/write each and every word between main storage and the peripheral equipment. In order for DMA to work, the CPU must be prevented from interfering with main storage at the same time as the data transfer is taking place. Some microprocessors have special controls that suspend the CPU cycles (and, in fact, remove the device from the data/address bus by disabling three-state output drivers) whenever DMA is in progress. Processors that do not have an inherent DMA ability can be used in DMA applications, but the additional hardware is often complicated.

(v) Arithmetic: is almost always performed in two's-complement form on microprocessors. In addition, some processors have special instructions designed for handling BCD numbers. Whether these instructions are important or not depends upon whether the input/output data must be in BCD form.

(vi) Vendor Commitment. Whether or not the vendor will continue making the microprocessor long enough to be of use during the life of the application is important. Furthermore, the manufacturer's commitment to the support of the product line can make life easy or difficult for the system-designer. Because of the complexity of these products, there are nearly always idiosyncracies that are uncovered only after several applications of the product have been completed.

(b) HARDWARE DESIGN

Microprocessors require other ancillary parts to make entire application systems work. As an absolute minimum, a microprocessor needs a program store

(although/.....

(Chapter 3 - continued)

(although the Burroughs Mini-D has it on the CPU chip). Some microprocessors are easy to interface to storage, and others are hard. To the extent that the vendor has put all the necessary interfacing circuitry on the CPU, memory and input/output parts, a family exists.

(i) Completeness:

Completeness of the parts-family is important. Some vendors seem to feel that if the processor can be connected to a RAM, regardless of the number of additional chips involved, then their RAM is a member of the parts-family. Other semiconductor manufacturers have taken special pains to be sure that storage and processor input/output parts can all fit together without intervening logic; such systems are considered to have complete parts sets.

(ii) Master Clocks:

Clocks are required for microprocessors, although some of the newer processors only require a frequency-controlling two-terminal device (crystal or R-C net). Some of the vendors offer clock or clock-driver chips. In many designs, the DIP socket-sized crystal oscillators such as those from Motorola or Vectron are used. In others, crystal-controlled stability is not important. Generally, the clock frequencies do not have a direct relationship to the data manipulation speed of the processor. Note, however, that some processors require multi-phased clocks with critically inter-related timing relationships and awkward logic levels.

(iii) Power

Voltage and power dissipation are considerations in many systems. Many of the MOS processors require two supplies excluding ground (usually +5 and -9 or -10 volts). Power dissipation is most often a function of the intended operating speed range.

(iv)/.....

(iv) Compatibility

Most of the microprocessors offer some degree of TTL compatibility, but numerous variations in the input/output logic levels are common - even on one chip. Some of the processors require an output buffer stage (sometimes low power TTL) in order to be TTL compatible.

(v) Packaging

Package-size generally varies from 16 to 48 dual-in-line (d.i.l.) pinned packages. In general, packages with fewer pins would be easier to interconnect, while packages with a large number of pins would be easier to interface to.

(c) SOFTWARE DESIGN CONSIDERATIONS

After the system is designed, and the hardware has taken shape, someone has to program the microprocessor. What the programmer sees is largely determined by the architecture of the computer and the environment in which that native architecture operates.

(i) Word Size

Word size affects the microscopic efficiency of some common kinds of software operations but it seldom affects the overall throughput of the design. In many applications, four-bit processors out-perform similar designs on eight-bit processors, although the opposite is also true.

In general, ease of programming is inversely proportional to:

- (1) Word size, because smaller data word sizes require multi-word operations on practical data quantities, and
- (2) The number of different register sizes in a computer, because simple register-to-register data transfers are limited.

Computers with small word-sizes (four-bit) and to a lesser extent eight-bit) always require a different register size for storing some addresses. For example, the program location counter is often made an integral number of native words in size. When the word size is small, the manipulation of storage

addresses/.....

(Chapter 3 - continued)

addresses and program addresses is complicated. Hence, ease of programming and not necessarily the overall application efficiency is what is influenced by word size.

(ii) Addressing Capacity

How large a program can be written without resorting to special external hardware and internal software techniques is defined by the program-addressing range. The ideal processor for an application has neither too small nor too large a capacity. A too small range means that extra hardware will be required to extend the addressing. On the other hand, excessive capacity means that extraneous address bits will be carried in every instruction that refers to storage.

(iii) Addition Time

Register-to-register^{addition/} time is a popular estimate for the computing speed of a computer. This instruction is chosen as a selection factor because nearly every computer has an add instruction. Microprocessors with more than one programmer-accessible register for data manipulation on the CPU chip can perform a fast register-addition in a minimum instruction execution time. Some processors, however, are organised as one-accumulator computers so that register-to-register additions are not provided; in this case, the addition of the contents of an arbitrary storage location to the accumulator is often scored as the minimum addition time.

(iv) Register Complement

The number of registers in the microprocessor is probably the most important feature of its architecture. Different registers in a computer have different uses; the ways that they may be used are embodied in the instruction set. The most precious resource that the programmer can allocate in software is the set of CPU registers. The more registers there are, the less likelihood there is of main storage references. Generally, references to main storage are more expensive in time than the references to on-chip registers.

Arithmetic/....

Arithmetic (or ALU) registers are those on which ALU functions can be performed, the register can be a source or destination of operands for the operation. Registers that can supply but not receive operands for the ALU are not considered arithmetic registers. An index register is a programmer-accessible register that is implicitly included in certain references to main storage. Unless the contents of the register can be added to another value (from, say, the instruction itself) during the storage addressing cycle, it is not an index register.

All other programmer-accessible data registers to a microprocessor (excluding the ALU and index registers) are called general purpose or scratch-pad registers. (In some large-scale computers a general-purpose register can be used in any of these three modes; this practice is not popular in microprocessors).

(v) Return Stack

Return addresses are usually handled through the medium of a push-down stack in microprocessors. Except for the Intersil 6100, which emulates the DEC PDP-8, microprocessors put subroutine return addresses into a push-down stack in a read-write memory; this memory may be on the CPU chip or external main storage. Return addresses are not saved within the program storage areas as in many minicomputers because most programs for microprocessors are stored in read-only memory.

When the return addresses are stored in an on-chip push-down stack, there is some natural limit to the number of dynamic subroutine calls. If there are eight stack positions, then generally only seven subroutine calls may be active at one time; if interrupts are anticipated, the real stack size must be kept smaller to allow some stack depth for the interrupt service routine. When return addresses are stored in RAM, an on-chip stack pointer is maintained in the CPU, when a subroutine is called, the return address is pushed into the RAM stack, and the pointer is updated.

The/.....

The on-chip stack allows faster subroutine calls because RAM does not have to be accessed. Stacks in RAM are of potentially huge depth, and this allows certain kinds of algorithms to be easily programmed. If the on-chip stack is accessible to the programmer, the depth of that stack can be extended by software. Most on-chip stacks are not accessible, and this imposes a rigid limit on the allowed depth of subroutine calling.

(vi) Addressing Modes

The addressing of data and program segments is an area that presents enormous variations from computer to computer. The problem is to allow references to be made to any arbitrary word in the addressing space, yet eliminate the need for a full set of address bits in each and every instruction. If the full address is required, program sizes tend to grow. Most microprocessors take advantage of the fact that most data program references are local in scope; that is, references are most often close to the address of the current instruction being executed or close to the last datum reference in main storage.

Any of the following addressing modes may be found in different microprocessors: direct, abbreviated (only part of the address is carried in the ⁱⁿstruction), immediate, relatively, indexed and indirect.

3.3 APPLICATIONS

The applications area of the microprocessors may be broken up into three major categories { 10 }

- (i) To replace hard-wired random logic
- (ii) To replace minicomputers in certain applications
- (iii) Totally new applications

(a) Replace Some Minicomputers

Microprocessors were originally not intended to replace minicomputers. They were meant to provide an alternative to hardwired logic design. However,
microprocessors/.....

(Chapter 3 - continued)

microprocessors now form a viable alternative to minicomputers when only limited computation and control are required.

(b) Replace Hard-wired Random Logic

The experience gained by Tektronics { 10 } shows that a microprocessor may profitably be used when the number of medium-scale integration (MSI) and single-scale integration (SSI) packages necessary to implement the controller with random logic amount to more than 30 - 40. In the United States { 11 }, a microprocessor and one kiloword of memory ^{may} replace about 50-100 IC's, and this reflects a cost saving of about 75%. Microprocessors may replace hard-wired random logic in existing products as well as in products still in the design phase. In some cases, the advantages of microprocessors compensate for the trouble of designing the extra software cycle.

(c) New Applications

The microprocessor has brought with it a whole new era of products. We now hear of "intelligent" instruments, "intelligent" interfaces, and "intelligent terminals. The concept of adding "intelligence" to traditionally "dumb" products is a very exciting one, since it provides possibilities remote in the past.

Examples of the fields in which microprocessors are used today:

- (1) Point of sale terminals
- (2) Graphic terminals
- (3) Remote data entry terminals
- (4) Industrial systems:

Capacitance bridges
DVM's
Synthesizers
Waveform-processing instruments

- (5) Process and numerical control systems
- (6) Aircraft control systems
- (7) Traffic controllers
- (8) Peripheral controllers

(Chapter 3 - continued)

- (9) Inventory systems
- (10) Credit card verification systems
- (11) Medical instrumentation

CHAPTER 4

PROPOSED SYSTEM

Extensive investigation showed that the following system would have the characteristics desired of a microprocessor-based, batch-weighing and raw-material distribution system of the type used in arc furnaces.

The processor should be able to control a system having the following maximum specifications:

- (1) No. of weighing hoppers (with feeders) : 3
- (2) No. of holding bins (with feeders) : 12
- (3) No. of electrodes : 3
- (4) No. of furnace hoppers per electrode : 5
- (5) The destination of the raw material feed-mix should be any selected furnace hopper.
- (6) The routing control should be capable of being adapted to any system similar to that of the Witbank system.
- (7) Moisture compensation for one material.
- (8) Load cell input to processor is 13-bit BCD with a resolution of 1 in 1999.
- (9) Each furnace hopper can be considered as a different zone and can have a special raw-material recipe.
- (10) Taring error compensation.
- (11) Overshoot error compensation.
- (12) The whole system should not be shut down after each weighing cycle when unnecessary.
- (13) A terminal device (such as a teletype) should be used for inventory control Input/Output with the system.
- (14) An operator control panel should be used for simplified control of the system.
- (15) The existing conventional type of system must be modified as little as possible and, in particular, it should be possible to switch over to the existing emergency, normal-feed and weighing standby.

A more detailed description of some of the desired characteristics follows:

4.1 THE WEIGHING HOPPERS AND THEIR FEEDERS

The analogue outputs from the weighing load cells will have to be digitized to supply digital readout panel meters as well as the 13-bit BCD (binary coded decimal) inputs to the processor. The feeders which empty the weighing hoppers are thyristor-controlled vibration feeders. They will be turned on and off from the processor, but as the ratios of the materials, particularly weighing hoppers, vary very little for a specific

set-up/.....

set-up, their feeding rates will remain manually adjustable.

4.2 THE HOLDING BINS AND THEIR FEEDERS

The system as such will not check the levels of the raw materials in the holding bins, but this can be incorporated via an alarm port which will be discussed later. The feeders feeding out of the holding bins into the weighing hoppers will, except for their feeding rates, be completely controlled from the processor in their fine and coarse feeding modes.

4.3 THE FURNACE HOPPERS

In conventional systems there are four furnace hoppers around each electrode. It was decided to incorporate facilities in the processor to allow for the addition of an extra furnace hopper at each electrode. This could then be used to make quick local corrections within the furnace. These furnace hoppers would be especially designed so that they could always be empty (or nearly empty), thus minimizing the time before the corrective batch reached the active region in the furnace.

4.4 THE ROUTING

The processor will output a signal, selecting one of the furnace hoppers. The conventional control system (such as exists at Witbank) will then be used to control the belts and shuttles so that the route is set up to the selected furnace hopper. The processor can assess this route via the data input bus to check if the route is correct and working (i.e. all the belts up to speed) before releasing the feed-mix from the weighing hoppers on a specific occasion or at any time thereafter.

4.5 MOISTURE COMPENSATION

One of the raw materials used, coke, has an average moisture content of 5%, but this can rise as high as 16%. It is therefore necessary, when weighing the coke, to compensate for this discrepancy, in order to ensure an alloy of the desired quality. Typically every 100 kg of feed-mix contains about 22 kg of coke. ∴ 16% moisture in the coke equals

(Chapter 4 - continued)

$$\frac{16}{100} \times 22 = 3,52 \text{ kg in 100 kg ore}$$

∴ the relationship between weighing accuracy and percentage moisture is (for a weighing accuracy of 0,5%):

$$\frac{0,5 \times 22}{100} \times \frac{100}{3,52} = 3,1\%$$

With this accuracy required of the moisture analysis, an input of 8 bit BCD number for the % moisture content to the processor was chosen. This gives a resolution of 1 in 99 or 1%.

4.6 TARING ERROR

Before a weighing hopper is filled, the processor checks the "zero weight" and makes a taring error correction.

4.7 OVERSHOOT ERROR

Overshoot errors exist because after the feeders feeding the weighing hoppers have been switched off, more material might fall into the weighing hopper. After switching off a particular feeder, the processor therefore waits for a suitable settling-down time and checks the weight in the weighing hopper. It uses this weight to make corrections in a similar way as for taring error correction.

4.8 SHUT-DOWN SYSTEM AFTER EACH CYCLE?

In a conventional systems of this type, the whole system (including conveyors, and so on) shuts down after each cycle, even if the same furnace hopper is due to be serviced again. Such a process is very time-consuming, since the controller must wait for all the conveyors to come up to speed. The processor does not shut down the system but merely changes the required conditions, therefore no time is wasted if the same furnace hopper is to be serviced again.

4.9/.....

(Chapter 4 - continued)

4.9 EXTERNAL COMMUNICATION

The external control elements to and from the system are to be as follows:

- (i) An operator-controlled panel to start, stop, set initial setpoints, and so on.
- (ii) A teletypewriter to print and/or punch onto paper tape the inventory and management information, as required. The teletypewriter will also be used as a more sophisticated input device of some control parameters.

Setpoint input to the processor: the operator will specify the initial and "average" required setpoints (recipe applicable to all the furnace hoppers) on thumbwheel switches. These are input into the processor on request from the control panel. Any special recipes for a particular furnace hopper or group of furnace hoppers and the number of changes for which they are required can be entered from the teletypewriter. This entry takes priority over the thumbwheel settings.

Inventory information will be as follows:

- (i) An automatic 8-hourly shift report will be made which will consist of the following:

Original setpoints and any alterations;

Time of any report or alteration;

Sum of the weight of materials used for each holding bin;

Sum of the weight of materials (total mixture) fed into each furnace hopper.

- (ii) Any of the above can be requested from the teletypewriter at any time.
- (iii) Provision for any of the above to be punched onto paper tape for processing elsewhere.

4.10 INTERFERENCE WITH EXISTING CONVENTIONAL SYSTEMS

Interference with, and interconnection to, typical conventional systems will then be as follows. The outputs of the load cell amplifiers have to be conditioned, digitized and multiplexed onto the processor's input/....

(Chapter 4 - continued)

input bus. The signals from the processor, selecting which furnace hopper is to be serviced, are to be converted and connected to the existing routing control. The signals from the process, i.e. "shuttle position", "belt up to speed", "furnace hopper empty", and so on, have to be conditioned and multiplexed onto the processor's input bus.

SECTION 2.

SYSTEM HARDWARE.

CHAPTER 5

AN INTRODUCTION TO THE HARDWARE

5.1 GENERAL

The prototype microprocessor-based system was designed to meet the following requirements:

- (i) Be capable of establishing the feasibility of the project.
- (ii) Be capable of evaluating the ultimate requirements of such a system. In other words, it should establish the specification for a final production model.
- (iii) It should not necessarily be considered as a pre-production model and therefore need not be in an industrial form.

The prototype which was developed consists of the following sections (see Figure 5.1):

- (i) A processor. This consists mainly of:
 - (1) An Intel 8008 microprocessor (the 8008)
 - (2) Eight kilowords of eight-bit memory
 - (3) A front panel
 - (4) An interface to a minicomputer
 - (5) Process interfacing
 - (6) A teletype interface
- (ii) Software development aids. This consists of:
 - (1) A direct memory access channel through which the processor's memory can be loaded from a minicomputer - a Varian 620/L-100.
 - (2) A peripheral device from which any memory location can be changed or displayed. This device also uses direct memory access techniques.
- (iii) A simulator (see Chapter 9). This is a digital system designed to simulate, as closely as possible, the operation of the Witbank system. This was designed to enable the programmer to test process-control software and to evaluate whether the chosen microprocessor is fast enough to cope with the demands of the system.

(iv)/.....

FIGURE 5.1 PROTOTYPE WITH DEVELOPMENT AIDS :
SYSTEM INTERCONNECTION.

FIGURE 5.2 PROPOSED LAYOUT OF THE SYSTEM WHEN INSTALLED
ON THE PLANT.

(Chapter 5 - continued)

- (iv) An operator control panel. For the prototype, this was combined in one cabinet with the simulator.

5.2 INTEGRATING THE PROTOTYPE WITH THE REAL PROCESS

In order to use the prototype as the control element in the actual system, the following aspects were considered. (See Figure 5.2).

- (i) Replacement of the simulator by the real process. The system was designed so that the cable connecting the processor with the simulator/operator's control panel would be used to connect to a converter cabinet. From this point, the system would be inter-connected to the operator's control panel and to the process. The inter-connecting cable can be kept short so that no special transmission techniques would be required. All the necessary signal conversions to obtain the signal and noise immunity would be done in the converter cabinet.
- (ii) Replacement of the software development aids. The memory is structured in such a way that the control program can be replaced by read-only (ROM) memory which is non-destructible. The control variables and inventory information will remain stored in random-access (RAM) memory. In this way, the DMA channel to a minicomputer and to the peripheral device would no longer be required. Note that the processor is designed to incorporate the facility of obtaining the management information directly from a minicomputer.

5.3 SELECTION OF ELECTRONIC COMPONENTS

The choice of logic family for the prototype was transistor-transistor-logic, TTL. This decision was based on the following points:

- Relatively inexpensive
- Fast enough to be compatible with the rest of the system
- Readily available
- Available with a range of logic functions
- Most current microprocessors are designed to be TTL compatible.
- Suitable memory components exist which are TTL compatible.

TTL/.....

TTL, and more specifically the 54/74 series, has many compatible logic families to which the prototype could easily be changed if this were found to be necessary.

The choice of microprocessor to be used was made during the first quarter of 1974. The choice of microprocessors at that time (especially on the local market) was reasonably limited. (See Appendix 1)

The Intel 8008 was chosen because:

- (i) Lack of ROM programming facilities and of a thorough knowledge of microprogramming techniques weighed heavily against the use of micro-programmable microprocessors.
- (ii) The application favoured the use of interrupts which are readily handled with an 8008.
- (iii) It was estimated that the 8008 was fast enough for the current system. The Intel 8080, which is ten times faster than the 8008, was not readily available. It was therefore decided that if the 8008 proved too slow the system could always be upgraded to an 8080. The 8080 is compatible with the software required for the 8008.
- (iv) The 8008 input lines are TTL-compatible and its output lines only require low-power TTL - buffers for TTL compatibility.
- (v) The 8008 is widely used in industry in the United States of America and has therefore proved its reliability. In fact, it is one of the few standard microprocessors in industry.

5.4 THE INTEL 8008 MICROPROCESSOR { 6 }

The following brief summary of the Intel 8008 microprocessor delineates some of its characteristics. (Appendix 2 gives the manufacturers' full description and specifications).

The 8008 is an eight-bit microprocessor available in an eighteen-pin dual-in-line package.

It can add two eight-bit numbers in 20 microseconds.

Internally/.....

Internally, the Control Processor is arranged around seven registers, one of which is the accumulator. The accumulator is used in the arithmetic operations and with input/output instructions. Two of the registers are used for all references in main storage. In order to address a specific word in memory, the program must load these two registers individually. This implies that at least three instructions must be used to refer to a single location in memory.

The 8008 has a relatively simple interrupt mechanism. When the interrupt signal is used, the processor inhibits incrementing the program counter, issues an acknowledgement, and proceeds through the normal instruction fetch. The external interrupt hardware "jams" in a substituted instruction, usually a sub-routine call that simultaneously saves the program counter and invokes the interrupt service routine.

In most computers, when an external event causes an interrupt, the contents of the processor registers ^{can be/} saved in main storage. These registers can then be used by the interrupt service sub-routine. In the 8008, the register pair used for storage addressing may already contain values established before the interrupt occurred, so that they cannot be disturbed. The system designer can choose to reserve two of the general purpose registers as interrupt registers (into which the storage addressing registers can be placed during interrupt servicing). This implies the reservation of two of the seven registers available. In the case of the prototype, it was decided to use two external hardware registers (loaded and read via input/output instructions) for this purpose. (See 6.7).

Thus it can be seen that a major disadvantage of the 8008 is the addressing scheme which requires programming addresses directed into a specific register pair.

5.5 A FUNCTIONAL DESCRIPTION OF THE PROCESSOR

Figure 5.3 is a block schematic showing the relationships between the different sections of the prototype. All circuitry inside the dotted line is built inside the processor cabinet. The blocks in the schematic are referred to....

FIGURE 5.3
A BLOCK SCHEMATIC OF
THE PROTOTYPE.

referred to numerically.

The 8008 (1) is the heart of the processor. It has an eight-bit input/output data bus (shown shaded). The 8008 is driven from a two-phase clock (8) and its two control inputs are an interrupt line ($\overline{\text{int}}$) and a ready line ($\overline{\text{rdy}}$). The ready line can be used to cause the 8008 to "wait" for any desired period between the address and data phases of its normal operational cycle. The 8008 has three status output lines which display the internal processor state, and a synchronisation line (sync).

On output, the data bus is buffered by, and fed to, the address registers (3) and (4) and to the data output register (5). The six higher order bits (HOB's) of address register (3) can be decoded by the input/output controller (12) to select the appropriate external device. The two highest order bits are decoded by the logic unit (7) to indicate the current machine cycle, i.e. memory read, I/O, memory write.

On input, the correct byte of data is selected and fed to the input buffer (6) via input multiplex (18) circuits which are controlled from the logic unit (7). The data on the input buffer is selected at the correct time by the logic unit and placed on the 8008 data bus.

The "ready control" (10) causes the 8008 to enter a "wait-state" whenever any external device has not completed its required function in time to meet the requirements of the 8008's timing cycle. The uses of the front panel (11) are:

- (i) To stop program execution
- (ii) To start program execution at a specific location
- (iii) To "step" through a program one cycle at a time
- (iv) To display the current processor condition

The timer (20) enables the programmer to estimate short periods of time without having to use "marking time" sub-routines.

The interface (19) to an external minicomputer is divided into two sections (19(a) and 19 (b)). 19 (b) is built into the processor and is

designed/.....

(Chapter 5 - continued)

designed so that it can interconnect to any type of minicomputer using an appropriate interface (19 (a)).

(a)

(b)

(c)

(d)

(e)

(a) VARIAN 620/L-100

(b) SIMULATOR & CONTROL PANEL

(c) PROCESSOR

(d) DMA LOADER/DISPLAY

(e) TELETYPE

THE PROCESSOR

(a) MIMIC PANEL

(b) LOAD CELL OUTPUTS

(c) SETPOINTS

(d) TIME-OF-DAY CLOCK

(e) MOISTURE & TARE

(f) START & RESTART

A TYPICAL CIRCUIT CARD

CHAPTER 6

THE PROCESSOR

16.6.1 THE 8008 AND ITS CONTROL CIRCUITS

The 8008 and its control circuits are constructed on one card occupying slot number one in the main processor rack. The circuit of this card is shown on Figure 6.1. Familiarity with the 8008 (Appendix 2) will facilitate understanding of the descriptions which follow.

External control over the 8008 is via the RDY and $\overline{\text{INT}}$ lines. In turn, the 8008 exercises control the entire system, using its state lines (S0, S1, S2) and two control bits (CB0, CB1) which are output on its data bus during every T2-state.

The state lines are continuously decoded by D1 into one of the processors states (T11, T1, T2, W, T3, S, T4 or T5).

The control bits are stored in register Reg1 using the signal $T2 \cdot \phi_{22}$ (gate A1). They are then decoded by D2 to reveal the current machine cycle being executed.

The four possible machine cycles are:

- 1) PCI Designates the address is for a memory read (first byte of instruction)
- 2) PCR Designates the address is for a memory read (additional bytes of instruction)
- 3) PCC Designates the data as an input/output operation command.
- 4) PCW Designates the address is for a memory write data.

The SYNC output from the 8008 and the signals from the two-phase dock (ϕ_1, ϕ_2) are decoded by D3 as follows:

$$\phi_{11} = \text{SYNC} \cdot \phi_1 ; \phi_{12} = \text{SYNC} \cdot \phi_1 ; \phi_{21} = \text{SYNC} \cdot \phi_2 \text{ and } \phi_{22} = \text{SYNC} \cdot \phi_2$$

These signals and the SYNC signal are used to obtain the correct timing relationships in the microcomputer system.

During the T1 (or T11) state, the data appearing on the 8008's data bus is stored in the LOB address register REG 2. The signal $(T1 + T11) \cdot \phi_{22}$ is used as the clock signal (gates O1 and A4).

During/...

FIGURE 6.1
THE 8008 AND ITS CONTROL
CIRCUITS

During the T2 state, the data is stored in the HOB address register, REG 3, using the signal $T2 \cdot \phi_{22}$. Note that the two highest order bits are stored in a separate register REG 1 to supply the control bits as previously described.

Data output from the 8008 is via REG 4. The data can be loaded into this register during two of the machine-states (T1 (or T1I) and T3). When the 8008 requires to output data to its memory (PCW-cycle), the data is made available during a T3-state. Register REG 4 is latched to receive this data during the period when the signal $T3 \cdot PCW \cdot \phi_{12}$ (gate A2) first appears until the end of the next ϕ_{22} signal (flip-flop F1). When the 8008 outputs data via an instruction (PCC-cycle) the data is made available during the T1 (or T1I) state. Register REG 4 is latched to receive this information using the signal $(T1 + T1I) \cdot \phi_{22}$.

Data input to the 8008 is via buffer B1. The state-output lines can have a delay of up to 1.1 microseconds before indicating the T3-state. The data input to the 8008 must appear on its data lines before or with the falling edge of ϕ_{11} , during the T3-state. This means that the system is required to anticipate an imminent T3-state when data input is required. Therefore, the rising edge of the signal $\phi_{22} \cdot T2$ is detected (flip-flop F2) and then "and-ed" with SYNC and PCW to achieve this (gate A5). The signal $T3 \cdot \phi_{12}$ (gate A3) is used to clear flip-flop F2.

Flip-flops F3 and F4 are used to synchronize an incoming interrupt with the 8008's clock signals. The 8008 recognizes the interrupt during its next instruction fetch cycle by the output of a T1I-state in place of a T1-state. This is recognized by flip-flop F5. The outputs of F5 are used to indicate to the peripherals that an interrupt is being acknowledged (INTA) and to clear the flip-flop F3 and F4 via gate A6. The pull-up resist^{or}, R1, is included so that interrupt requests ($\overline{INT}$) may be "dot-ored" together, using open-collector techniques.

The/...

The signal, $\overline{T3 \cdot \phi_{22}}$, indicates to the peripheral controllers that one cycle in which they may be required is finished. $\overline{T3 \cdot \phi_{22}}$ is thus used as a reset signal for these controllers.

The signal, $\overline{MARY}$, indicates to the memory circuits that a valid memory address has been placed on the address bus, $A_0 - A_{13}$.

The signal, $\overline{MDRY}$, indicates to the memory circuits that valid data which must be stored exists on the data output bus, $O_0 - O_7$.

Note that in the design of these circuits an effort was made to facilitate a changeover to an 8080 microprocessor if this was found to be necessary for reasons previously discussed. (See Chapter 5.3).

6.2 THE FRONT PANEL AND ITS ASSOCIATED CIRCUITRY

The light-emitting diodes (l.e.d.s.), their drivers, and the switches are located on the front panel; the associated circuitry is built on card two (slot two). Figure 6.2 shows these circuits.

The switches in the top left-hand corner are shown for the processor in the "RUN" mode, i.e. its normal functional mode.

With the toggle switch, S1, in the "RUN" position, ready pulses, $\overline{(RDY)}$, are supplied to the 8008 (via gate A1) using the signal, $\overline{PCC \cdot \phi_{22}}$.

From this it can be seen that except during input/output operations ready pulses are automatically supplied; hence

(i) The memory used is fast enough to ensure that the 8008 will never be retarded by memory transfers.

(ii) As the ready signal (RDY) is inhibited during input/output (PCC-cycle) operations, all peripheral controllers have to supply the 8008 with a suitable ready signal when data transfers are taking place.

With S1 in the "STEP" position, the ready pulses are supplied via a spring-loaded switch, S2, and monostable M1, thus providing a single-step facility.

The/....

FIGURE 6.2
THE FRONT PANEL
CIRCUITRY

(Chapter 6 - continued)

The toggle switch, S4, performs the following functions:

- (i) In the normal mode, it holds the Q output of flip-flop F1 in a high state, and disables the "INSTRUCTION" input switches from the I-bus. The I-bus is now free to receive signals from memory when required because the signal EMOP (enable memory output) will be in the true state.
- (ii) If S4 is now switched to the panel mode, the following sequence of events takes place.
 - (1) The "CLEAR" is removed from F1.
 - (2) An interrupt is generated and sent to the 8008 via buffer B2.
 - (3) When the 8008 acknowledges this interrupt (INTA), the flip-flop, F1, is preset via gate A1.
 - (4) EMOP is disabled (gates O1, B2 and A2).
 - (5) The 8008 will now receive its next instruction from the switches S5 - S12.

As the output of buffer B1 remains in a low state, all further interrupts are inhibited while S4 remains in the panel mode.

RST is a signal which can disable EMOP if an interrupt occurs during normal program execution while S4 is in the normal mode. This is in order to "jam in" an alternate interrupt instruction, (see Chapter 6.8), during normal program execution.

The switch, S4, can also be used to start the processor after power on, or to re-start the processor after it has entered a "stopped-state".

The processor can be made to begin program execution from any desired memory location, as follows:

- (i) Start with the switch positions as in Figure 6.2.
- (ii) Switch S1 to position "STEP".
- (iii) Press reset button (switch S3)
- (iv) Switch S4 to position "PANEL".

(v)/.....

- (v) Enter a jump instruction via the "INSTRUCTION" switches (01000100)
- (vi) Press "STEP" (switch 32)
- (vii) Enter first byte of execution address via "INSTRUCTION" switches (A0 - A7)
- (viii) Press "STEP"
- (ix) Enter second byte of execution address via "INSTRUCTION" switches (A8 - A14).
- (x) Press "STEP".
- (xi) The desired execution address should now be displayed on the "ADDRESS" light-emitting diode displays. Switch S4 to "NORMAL" and S1 to RUN: the processor will then execute the desired program.

S1 to RUN will cause the processor to execute the desired program.

By switching S4 to "NORMAL", and alternately pressing the "STEP" switch, the operator can execute the program, one byte at a time.

By switching S4 to "PANEL" and S1 to "RUN", the processor will repeatedly attempt to execute the instruction set on the "INSTRUCTION" switches. If a one-byte instruction is used, the processor will continuously output all the possible memory addresses on its Address bus, $A_0 - A_{13}$.

The two flip-flops, F2 and F3, are used to supply the timing relationships required to interface the 8008 with its memory.

(See Chapter 6.3).

6.3 THE MEMORY

Slots three and four of the processor rack are reserved for memory. In the prototype, only slot four is used and contains eight kilowords of eight-bit semi-conductor memory. This memory module consists entirely of 1024 x 1 bit Static MOS random access memory chips, along with the relevant decoding circuitry. The Intel 2102 memory element is used and full manufacturer's data for this component appears

in/....

in Appendix 3.

The decoding circuits and memory organization have been chosen to ensure easy interleaving of one kiloword pages of random access or read-only memory as required.

Figure 6.3 shows the decoding circuits and the memory organization. Note that the ten low-order bits of the address are connected in parallel to the ten address-selection inputs of all the 2101's. The four high-order bits ($A_{10} - A_{13}$) are fed to a four-to-sixteen line decoder, D1, which selects any one of sixteen possible memory pages of one kiloword each. By interchanging the outputs of D1, different types of memory can be interleaved in one kiloword page increments. Note that each selected output of D1 goes to the chip select (CE) inputs of eight 2102's making up a memory page.

The read/write (R/W) inputs of all the memory chips are connected together. When this signal is held in a low state, the memory is prepared for a write cycle. With the R/W signal in a high state, a read cycle is implemented.

The internal arrangement of one memory page using eight 2102's is shown in figure 6.4. Note that all the data-out and data-in pin connections for each bit position (i.e. lowest order bit) of each page are connected together.

6.4 INPUT-OUTPUT DEVICE ADDRESS DECODING:

There are two decoders in the processor which determine the address of the device to which the programmer requires access. The one decoder is located on card two and serves that particular card. The other decoder is on card five and similarly serves the devices specified on card five.

The two I/O instructions of the 8008 are:

- (1) For input : 0100MMM1
- (2) For output : 01RRMMM1 (RR $\neq$ 00)

It can be seen that different combinations of MMM and RR will permit a maximum of 8 input ports and 24 output ports. During input/output operations
(PCC-cycle)/...

FIGURE 6.3
MEMORY ORGANISATION
AND DECODING.

FIGURE 6.4
 THE ARRANGEMENT OF A
 SINGLE MEMORY PAGE.

(Chapter 6 - continued)

the lower order six bits of these instructions are made available during the T2-state on the address lines $A_8 - A_{13}$.

Figure 6.5 shows the circuitry of the decoders. I/O DECODER 1 serves card two and I/O DECODER 2 serves card five. Table 6.1 shows all possible combinations of the input/output instructions, along with their octal equivalents and how they are utilized. All further references to these instructions will be in octal form.

(a) I/O DECODER 1:

From Table 6.1 it can be seen that this decoder detects four input (111, 113, 115, 117) and four output (131, 133, 135, 137) instructions.

These eight instructions can be uniquely distinguished from the others by the fact that the signal, A_{13} , is always low and the signal, A_{11} , is always high. Therefore the signal $\overline{PCC} \cdot W \cdot A_{11} \cdot \overline{SYNC} \cdot \overline{A_{13}}$ (gates A1 and A2) is used to enable the decoder D1 which selects one of these eight I/O instructions according to the state of the signals A_{12} , A_{10} , and A_9 .

When any of the instructions, 135, 133, 131 or 111, have been decoded for the 8008, it is not necessary to "wait" for the $\overline{RDY}$ signal to be generated (Gates O1 and A3).

(b) I/O DECODER 2:

This decoder detects four input (101, 103, 105, 107) and twelve output (121, 123, 125, 127, 141, 143, 145, 147, 161, 163, 165, 167) instructions.

These sixteen instructions can be distinguished from the others by the fact that the signal A_{11} is always low when such instructions occur. Therefore the signal $\overline{PCC} \cdot W \cdot \overline{A_{11}} \cdot \overline{SYNC}$ (gate A4) is used to enable the decoder which selects one of these sixteen I/O instructions.

As none of these instructions requires the 8008 to enter a "wait" state, $\overline{RDY}$ signals are generated by gate A5 when they are used.

FIGURE 6.5
INPUT/OUTPUT DECODING

TABLE 6.1

Number	Binary Bit												I/O instr. (Octal)	I/O Decoder	Input or Output	Function
	PCC	A13	A12	A11	A10	A9	A8									
1	0	1	0	0	0	0	0	0	0	1		101	2	INP	Select lob's of process input data	
2	0	1	0	0	0	0	0	0	1	1		103	2	INP	Select hob's of process input data	
3	0	1	0	0	0	0	1	0	1			105	2	INP	Select timer	
4	0	1	0	0	0	0	1	1	1	1		107	2	INP	Input from data terminal (TTY)	
5	0	1	0	1	0	0	0	0	1			121	2	OUT	Spare	
6	0	1	0	1	0	0	0	1	1	1		123	2	OUT	Output to data terminal (TTY)	
7	0	1	0	1	0	1	0	1	0	1		125	2	OUT	Spare	
8	0	1	0	1	0	1	0	1	1	1		127	2	OUT	Spare	
9	0	1	1	0	0	0	0	0	0	1		141	2	OUT	Spare	
10	0	1	1	0	0	0	0	1	1	1		143	2	OUT	Spare	
11	0	1	1	0	0	0	1	0	1	1		145	2	OUT	Select data for input	
12	0	1	1	0	0	0	1	1	1	1		147	2	OUT	Control the feeders,	
13	0	1	1	1	0	0	0	0	0	1		161	2	OUT	Filling and emptying	
14	0	1	1	1	0	0	0	1	1	1		163	2	OUT	the weighing hoppers	
15	0	1	1	1	0	1	0	1	0	1		165	2	OUT	Spare	
16	0	1	1	1	0	1	1	1	1	1		167	2	OUT	Select furnace hopper to be serviced	
17	0	1	1	1	1	1	0	0	1			171		OUT	Not decoded	
18	0	1	1	1	1	1	0	1	1	1		173		OUT	Not decoded	
19	0	1	1	1	1	1	1	0	1			175		OUT	Not decoded	
20	0	1	1	1	1	1	1	1	1	1		177		OUT	Not decoded	
21	0	1	0	0	1	1	0	0	0	1		111	1	INP	Read external reg.	
22	0	1	0	0	1	1	0	0	1			113	1	INP	Spare	
23	0	1	0	0	1	1	0	1	0	1		115	1	INP	Spare	
24	0	1	0	0	1	1	1	1	1	1		117	1	INP	Input from minicomputer	
25	0	1	0	1	1	1	0	0	1			131	1	OUT	Load external reg.	
26	0	1	0	1	1	1	0	1	1	1		133	1	OUT	Enable interrupts	
27	0	1	0	1	1	1	1	0	1	1		135	1	OUT	Disable interrupts	
28	0	1	0	1	1	1	1	1	1	1		137	1	OUT	Output to minicomputer	
29	0	1	1	0	1	1	0	0	1			151		OUT	Not decoded	
30	0	1	1	0	1	1	0	1	1	1		153		OUT	Not decoded	
31	0	1	1	0	1	1	1	0	1	1		155		OUT	Not decoded	
32	0	1	1	0	1	1	1	1	1	1		157		OUT	Not decoded	

6.5 INTERFACING TO A MINICOMPUTER

As previously mentioned, interfacing to a minicomputer is implemented using two interfaces. An interface on board two is designed to accept signals from, and send signals to, a minicomputer. These signals are fully decoded, and it was ensured that they could easily be interfaced. A further interface is required to adapt these signals to the particular minicomputer being used - in this case a VARIAN 620/L - 100.

These interfaces serve two functions:

- (i) During program development: the programmer can use a minicomputer directly to load the microcomputer memory. A Direct Memory Access channel is used for this operation.
- (ii) In a distributed control system: this link has been provided so that the two computer systems can pass data between each other under program control.

Figure 6.6 shows the interfacing associated with the processor. Similarly Figure 6.7 shows the circuitry needed to interface the processor to a VARIAN 620/L - 100.

Note: As the VARIAN was used only for program development on the prototype, no attempt was made to interlace the prototype into the VARIAN'S priority interrupt chain.

(a) To exchange data under program control

This sequence is normally initiated by the minicomputer executing an external control command, an 'EXC' instruction for the VARIAN. If the processor needs to initiate such a data exchange, it must issue an interrupt signal to the minicomputer. The resulting interrupt service routine causes the minicomputer to input a status word supplied by the processor, thus obtaining information about the processor's requirements.

(i) To/...

FIGURE 6.6
MINICOMPUTER
INTERFACE

FIGURE 6.7
PROCESSOR TO VARIAN
INTERFACE

(Chapter 6 - continued)

- (i) To send data from the VARIAN to the processor:

An EXC command (100427_8) is decoded and sent to the processor ($\overline{\text{ROTP}}$). The VARIAN then enters into a "sense loop", waiting to output data to device number 27, which is the processor. In the meantime, the signal $\overline{\text{ROTP}}$ causes the processor to be interrupted. The processor's interrupt service subroutine then initiates data input using input instruction 117. This instruction is decoded by I/O DECODER 1, and a "sense true" signal is sent back to the VARIAN. In receipt of this "sense true" signal, the VARIAN outputs the required data during the signal $\overline{\text{DIOX}}.\overline{\text{DIOY}}$ (data transfer out and data phase of computer cycle). This signal also produces the necessary "ready" pulse to return the processor from its "wait" state.

- (ii) To send data from the Processor to the VARIAN:

A similar process to (i) above is used, except for the following points:

- . EXC instruction = 100227_8
- . Decoded signal to processor = $\overline{\text{RIFP}}$
- . Processor output instruction = 137_8
- . VARIAN data input signal = $\overline{\text{DIOX}}.\overline{\text{DIOY}}$

- (b) Loading the Processor Memory using Direct Memory Access from a Minicomputer:

This sequence is entirely controlled from the VARIAN. The VARIAN expects the processor to be in a "wait" state, with its memory address register containing the address of the lowest memory location to be loaded. The processor's front panel switches must be set for "step" and "panel" modes. The instruction switches must contain a "no-operation" instruction code, i.e. 300_8 .

The sequence is initiated by the execution of an external control command, EXC 100127_8 , by the VARIAN. This sets a flip-flop which, via signals DDO and OBIN, disables the microprocessor's data output register.

Any/....

Any data sent from the VARIAN is loaded into the chosen processor memory location and a "ready" pulse is supplied to the processor. The processor then executes the "no-operation" instruction and increments its address register. This will then hold the address of the next memory location.

Thus the processor's program counter is used to generate the memory addresses to be loaded. Consecutive memory locations of the processor are loaded by repeatedly sending the required data from the VARIAN.

6.6 THE DIRECT MEMORY ACCESS LOADER AND DISPLAY

This device was designed as a software development aid. It consists of the following (see Figure 6.8):

- . Eight light-emitting diodes (led 1-8)
- . Eight Octal push-button switches (S0-S7)
- . A toggle switch which can be in either the "examine" or "load" modes.
- . A push-button switch to clear the current entry displayed on the led's 1 - 8.
- . A push-button switch to load the current entry into the current memory location.
- . The necessary control circuits for the above.

The memory loader has the following functions:

- . To display the contents of the current memory location while "stepping" through a program (examine mode).
- . To load the current memory location with the data displayed while the processor is in the "panel-mode".

Note: The address register is automatically incremented in a similar way as for a Direct Memory Access load from a minicomputer.

The data is entered in OCTAL (3 digits) and decoded into binary by a diode Read Only Memory. The binary information is shifted along a shift register consisting of D-type flip-flops, and is loaded into the current memory location when the "load" button is pressed.

At present, the Direct Memory Access loader is contained in a separate box but could, with value, be included on the front panel.

(Chapter 6 - continued)

6.7 EXTERNAL HARDWARE REGISTERS

As discussed in Chapter 5.4, a major disadvantage of the 8008 microprocessor is the addressing scheme employed which requires memory addresses to be held in a specific register pair. Therefore, two external hardware registers have been added into which the programmer can deposit the contents of the A-register and any other register. This will then leave two registers free into which the current address can be temporarily stored during an interrupt servicing routine.

The circuitry of these two registers is built on board 2, and is shown in Figure 6.9. They consist essentially of two Intel integrated circuits which are 8-bit latches. (See Appendix 4)

Output instruction 131_8 causes the current contents of the A-register to be sent to one of these registers. Input instruction 111_8 causes the A-register to be loaded from one of these registers.

After each communication with any one of the registers, flip-flop F1 toggles, causing a pointer to select the other register for the next input or output operation.

Chapter 11.9 gives an example of how the programmer may use these registers during an interrupt sequence.

6.8 THE INTERRUPT CONTROLLER

The interrupt controller is also built onto card two. Its circuitry is shown on figure 6.10. The interrupt controller features

- . a software enable/disable facility
- . an interrupt priority scheme
- . the ability to interrupt ^{to/} anyone of eight addresses by using the RST instruction (00AAA101)
- . the ability to store all interrupt requests until they are serviced.

An/.....

FIGURE 6.10
THE INTERRUPT
CONTROLLER

(Chapter 6 - continued)

An interrupt request will cause one of the flip-flops F1 - F8 to be pre-set, thus causing the flip-flop complement output to go to a low state. C1, a synchronous three-bit counter feeds a 3-8 line decoder, which alternately tests each one of the F1-F8 flip-flop's outputs. When any of these outputs is in a low state, this condition will be detected by one of gates A1-A8. The outputs of A1-A8 are dot-ored together, thus generating an interrupt to the 8008 microprocessor, and stopping the counter C1 with the address of the interrupting device on its output. These three bits then form part (AAA) of the RST instruction which is placed onto the processor's input via Register 1 at the time when the processor acknowledges $\overline{\text{INTA}}$, the interrupt. This signal, $\overline{\text{INTA}}$, is also used to clear the appropriate flip-flop, using REG. 2. The counter is also reset via monostable, M1.

The interrupts are assigned as follows:

($\overline{\text{INRQ0}}$ = highest priority)

<u>INTERRUPT VECTOR</u>	<u>RST (OCTAL)</u>	<u>INTERRUPT ADDRESS (OCTAL)</u>	<u>FUNCTION</u>
$\overline{\text{INRQ0}}$	005	00000	To start the processor
$\overline{\text{INRQ1}}$	015	00010	} For use by the process
$\overline{\text{INRQ2}}$	025	00020	
$\overline{\text{INRQ3}}$	035	00030	
$\overline{\text{INRQ4}}$	045	00040	
$\overline{\text{INRQ5}}$	055	00050	Data to Teletype
$\overline{\text{INRQ6}}$	065	00060	Data from Teletype
$\overline{\text{INRQ7}}$	075	00070	Data from minicomputer
			Data to minicomputer

Note: For power failure re-start, a different interrupt mechanism is to be used, as discussed in Chapter 7.

6.9 INTERFACE TO A TELETYPE

Figure 6.11 shows circuitry of the teletype interface. The output (parallel to serial) and input (serial to parallel) shifts registers are shown in Figure 6.12. All these circuits are located on board 5.

The interface is designed for a teletype having a twenty milliamp signalling current and a forty volt battery. After each input or output operation is completed, the interface interrupts the processor indicating that the teletype is ready for the next operation.

6.10 THE TIMER AND COMMUNICATION WITH THE PROCESS

Figure 6.13 shows these circuits.

(a) The Timer: This consists of a 1 Hz clock fed into a $\div 256$ counter. Input instruction 105 causes the output of the counter to be placed on the microprocessor's data input bus via register REG. 1.

(b) Data Input to the Processor: This is a sixteen-bit bus (DIB0 to DIB15) which can be placed onto the microprocessor's data input bus in one of two eight-bit bytes (REG. 2 and REG. 3). Input instruction 101 is used for the low-order bits and instruction 103 is used for the high-order bits.

(c) Data Output to the Process: As shown in Chapter 6.4, eight output instructions are decoded by I/O DECODER 2 and are available to the process. The microprocessor's data-output (O-BUS) is buffered by B1 and is available to the process.

These output signals may be used as follows:

- (i) To send an eight-bit byte to any one of eight destinations.
- (ii) To select one of eight sixteen-bit data words which are to be placed on the data input bus (DIB0-DIB15).
- (iii) Each eight-bit data output bus can be decoded into one of two hundred and fifty-six output control pulses.
- (iv) Each eight-bit data bus can be decoded to select any one of two hundred and fifty-six, sixteen-bit words of data to be placed on DIB0-DIB15.

(v)/.....

FIGURE 6.12
TELETYPE INTERFACE

NUMERICAL REFERENCES
TO FIG. 6-11

FIGURE 6.13
PROCESS COMMUNICATION
AND TIMER

(Chapter 6 - continued)

(v) Combinations of the above are possible.

Note: That whenever the processor inputs from D1B0-D1B15, a signal $\overline{\text{ENIN}}$ is made available to the process. $\overline{\text{ENIN}}$ enables the designer to multiplex inter-process signal onto D1B0-D1B15. Whenever the signal, $\overline{\text{ENIN}}$, is in a true state, the bus should be freed for use by the processor.

CHAPTER 7

POWER AND POWER FAILURE

An investigation was undertaken into the power standby requirements of intelligent controllers during a power failure. This, along with the specific needs of the processor, revealed the following points:

- . The semi-conductor random access memory which will be used for variable and inventory storage is destructible during a power failure.

- . It is desirable that the inventory information is protected for at least one shift period (eight hours). Any power failure longer than this is regarded as being so catastrophic that the loss of inventory information is of relatively minor importance.

- . The processor's power failure software will require approximately ten milliseconds in order to effect a program-controlled shut-down after the power failure is first detected.

- . The processor will need to know the extent of the power failure, i.e. which parts of the process are affected, and so on.

- . The process has an under-voltage trip mechanism which shuts off the motors driving the feeders, belts, and so on. This trip mechanism has to be reset when the power supply is restored.

Experiments were carried out to determine a suitable power supply system. As a result of this, the power system shown in Figure 7.1 was devised.

Note: The processor is first notified of the power failure by a special interrupt which cannot be disabled (Figure 7.1). The processor can also monitor the state of the power supply system via ^{an/}input port.

Suggested circuits for a power failure interrupt generation are shown in Figure 7.2. This interrupter "jams" in three successive bytes of a jump instruction, thus causing the program to transfer control directly to the power failure routine.

When/....

FIGURE 7.2 SUGGESTED POWER FAILURE INTERRUPTER

FIGURE 7.1 SUGGESTED POWER SUPPLY SYSTEM

(Chapter 7 - continued)

When a power failure occurs, the line PWRF goes to a low state, causing the processor to enter its power failure routine. The current contents of all the registers are stored and the processor "reads" the power failure monitoring port. If the power failure is only momentary, none of these lines will be in a low state and the processor can return to its previous task: otherwise, suitable action can be taken. During a power failure program, a flag in memory should be set so that a normal "power-on" can be distinguished from a "power-on" after a power failure. In each case, the processor will start from address 0000.

CHAPTER 8

THE PROCESS INTERFACE

8.1 INTRODUCTION

Chapter 6.10 discusses hardware facilities which are provided by the processor for process control functions. This chapter will deal with how these facilities have been utilized to control the batch weighing and transport system simulator.

On the prototype the process interface is situated in the simulator cabinet and directly inter-connected to the simulator. On a real plant this interface would be built into the converter cabinet where the necessary signal conditioning would also take place. The systems designer would also have to ensure that the necessary signal levels are obtained and also the necessary degree of isolation between the processor and the process is maintained.

8.2 THE INTERFACE

Refer to Figure 8.1. An appropriate output instruction causes the contents of the A-register to be output on the O-bus ($O_0 - O_7$) and stored in one of six registers (REG 1 - REG 6). The first four bits of REG 1 are decoded by D1 into one of sixteen signals which will be used to control the conveyor and shuttle system so that a route is established to the selected furnace hopper.

REG 3 sets the weighing hopper mode, i.e. whether it is being filled in the coarse or fine feed mode, or whether it is being emptied.

REG 4 and 5 control the vibration feeders. The feeders are either in the stopped or running modes according to the contents of REG 4 and 5

REG 6 selects one byte of data (maximum 16-bits) which is to be placed on the processor's data input bus (DIB). Decoder, D2, selects general input ports which enable the processor to monitor the process. Decoder, D3, selects

which/...

(Chapter 8..... continued)

which setpoint (on thumbwheel switches) is to be put on the DIB. The signal ENIN frees the DIB when the processor does not require it and this enables the system's designer to multiplex other (inter-process) signals onto the DIB.

Table 8.1 gives all the software codes which are used to control the process.

8.3 PROCESS INITIATED COMMUNICATION

One interrupt vector, INRQ2, is reserved for use whenever the process wants to initiate communication with the processor. This will normally be during an emergency. The software routine initiated by INRQ2 would load the A register with 004_8 and output it using instruction 145_8 . (See Table 8.2). This would select a sixteen-bit data byte which the system designer could utilize to send the required information to the processor.

The interrupt vector, INRQ3, is used to inform the processor when all three weighing hoppers are empty.

8.4 START-UP AND RESTART

The initial start-up of the processor is via the interrupt vector, INRQ0, from the operator's control panel.

Whenever the operator wishes the processor to re-read the setpoints from the thumbwheel switch bank, he can do so via the control panel. This action is communicated to the processor by INRQ1. The processor will cancel all previously determined setpoints and revert to the setpoints currently displayed on the thumbwheel switches.

OUTPUT INSTRUCTION FUNCTION

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TABLE 8.2

FUNCTION OF THE SELECTED DATA BYTE

THE CONTENTS OF THE FIRST FIVE-BITS SEND VIA OUTPUT PORT 145, IN OCTAL.	FUNCTION
00	Weighing hopper 1's load cell output
01	Weighing hopper 2's load cell output
02	Weighing hopper 3's load cell output
03	The conveyer belt 'up to speed' signals
04	Process interrupt (See Chapter 8.3)
05	The shuttle position signals.
12	Furnace hopper level indicators
13	Moisture content of setpoint 1.
14	Time-of-day <u>clock</u>
20	Setpoint 1
21	Setpoint 2
22	Setpoint 3
23	Setpoint 4
24	Setpoint 5
25	Setpoint 6
26	Setpoint 7
27	Setpoint 8
30	Setpoint 9
31	Setpoint 10
32	Setpoint 11
33	Setpoint 12

CHAPTER 9

THE SIMULATOR

9.1 INTRODUCTION

The simulator was designed to ensure an accurate assessment of the processor's capabilities as a control unit for the weighing and transport system of an arc furnace. In particular, it was feared that the micro-processor system would not be fast enough to control the filling of the weighing hoppers.

While the weighing hoppers are being filled, the three load cell outputs have to be continually monitored in order to control the feeders, F1 - F10, correctly. It was therefore important to simulate accurately the time dependant variables of the system.

In order to test the software developed on the prototype, the simulator should display on a mimic panel how the real process would react to the processor's signals.

Attention, however, was concentrated on the need to assess the suitability and capacity of the processor and the software, rather than on simulating all the possible fault conditions which might occur.

As a simulator with a suitable mimic panel would be needed to facilitate industry acceptance and operator training, it was decided not to attempt the simulation on a computer. To ensure easy input/output interfacing between the simulator and the processor, the simulator was designed and built using TTL-logic; therefore analogue simulation was discounted.

9.2 THE WEIGHING SYSTEM SIMULATOR

Refer to Figure 9.1 for the block diagram of the system. The three weighing hoppers are simulated identically as is shown for "HOPPER 3".

An up/down counter is used to simulate the effect of the increase or decrease of the load cell voltage. The controller selects the appropriate clock frequency to represent the different feeding rates.

Flashing/....

FIGURE 9.1
THE WEIGHING SYSTEM
SIMULATOR

Flashing light-emitting diode displays on the mimic panel are used to indicate whether any feeder is 'on' or 'off', and also the passage of feed mix onto the conveyor system. Seven-segmented displays are used to indicate the current counter outputs - the quantity of feed mix in any of the weighing hoppers.

Taring errors are simulated by using a bank of thumbwheel switches. When the counter is in the counting down mode (weighing hopper being emptied), the comparator's output indicates when the counter's output equals the taring error and the controller turns the counter off. (For further details of the weighing system simulator, see "DIGITAL SIMULATION OF A WEIGHING SYSTEM. 1974 B.SC. THESIS No. 21" by G. Bloch).

9.3 SIMULATING THE TRANSPORT SYSTEM

Conveyor belts were simulated using serial shift registers. The clocking frequency of each shift register corresponds to the length of the conveyor belt which it simulates. The different routes and shuttle positions are set up using combinational logic to 'steer' the route to the selected furnace hopper.

Light-emitting diodes on the mimic panel indicate:

- (i) which belts are moving
- (ii) in which directions the belts are moving
- (iii) the presence of feed mix at the source and destination of each belt.

The present 'state' of the transport system is coded with combinational logic and made available so that the processor can have access to it via the Data Input Bus (DIB). The processor can therefore input signals from the simulator representing:

- (i) the belt 'up to speed' signals
- (ii) in which directions the belts are moving
- (iii) the positions of the shuttles

(Chapter 9 - continued)

9.4 FURNACE HOPPER LEVEL INDICATORS

The furnace hopper level indicators are simulated using toggle switches which are set by the simulator operator. The state of these two-position toggle switches are read by the processor to determine which furnace hoppers are 'empty'.

9.5 MOISTURE CONTENT

A bank of thumbwheel switches represent the percentage (0-99%) moisture content of the material fed from holding Bin 1. The outputs of the thumbwheel switches can be placed onto the DIB and thus read by the processor.

SECTION 3.**SYSTEM SOFTWARE.**

CHAPTER 10

SOFTWARE PHILOSOPHY

The heart and soul of any computer control system is the software - the collection of programs which marshalls together the hardware resources and controls their interaction in a predetermined fashion.

10.1 OBJECTIVES OF SOFTWARE FOR THE PROTOTYPE SYSTEM

It must be appreciated that the programs written for the prototype are not intended to create fully operational control systems. The programs are to be used in conjunction with a simulator, not a real system. As such, they must perform the following functions:

(i) Evaluate the Hardware:

Are there enough input and output ports and are they of the correct types?

Has sufficient provision been made for interrupt vectors?

Is there provision for enough peripheral devices?

What type of peripherals is suitable?

Is the operator's control panel functional?

Is the mimic panel suitable?

(ii) Evaluate the Programming Aids:

Is it feasible to tackle a programming task of this magnitude in pure machine code?

If not, will an Assembler be sufficient, or should the system's designer have to start thinking in terms of higher-level languages?

Are the hardware programming aids provided suitable for program development?

(iii) Develop Control Strategy:

Computer control systems can be re-programmed: the system designer is not necessarily committed to follow the control strategy used on the prototype. Every effort, however, was made to develop the prototype into a practical control tool. The existing software was written so that additions or alterations can be done without disturbing the overall memory structure.

(Chapter 10 - continued)

All the fault conditions which might occur on a real plant have not been provided for. It is proposed to use the prototype with its simulator in conjunction with users of this type of batch weighing and transport system. This will enable the systems designer to gain knowledge of the type of fault conditions likely to occur and the best corrective measures to be taken. Throughout the software description, suggestions for possible fault detection and correction measures will be given where they are appropriate.

10.2 SYSTEM FLOW DIAGRAM

The software consists of a set of sub-routines which are utilized by a main control program. Each sub-routine may make use of other sub-routines. All the sub-routines which perform a general function, such as multiplication, BCD to binary conversions, and so on, are termed utility sub-routines and are not included in the flow diagram description.

The system flow diagram is shown in Figure 10.1. The alphabetically referenced blocks are contained within the main control program. The numerically referenced blocks are implemented by subroutines. The blocks within dotted lines have not been included in the prototype software but would be required in a fully operational system.

(a) The main program is entered after the operator presses a button on the control panel, causing an interrupt to the main program which initiates the following sequence of events:

- (1) Further interrupts are disabled. (A)
- (2) The RAM memory is initialized. (B)
- (3) The time of day is recorded on the teletype. (1)
- (4) The "general" setpoints are read from thumbwheel switches, stored (2), and recorded by the teletype. (3).
- (5) The interrupts are then enabled (C)

(b)/....

FIGURE 10.1 SYSTEMS FLOW DIAGRAM

(Chapter 10 - continued)

(b) A check is made to see if any of the furnace hoppers requires servicing.

If no furnace hoppers are empty, the following events take place:

- (1) The transport system is switched off after enough time has elapsed to ensure that the previous weighing batch has reached its destination (N)
 - (2) A shift report is created if due and the shift report parameters are re-set after the information has been typed out (M)
 - (3) The "EXTERNAL CONDITIONS" flags are checked, to see if any device (or the process) has requested attention. Typical external conditions checked for are:
 - (i) The operator's requiring input control parameters to be entered from the teletype.
 - (ii) The interrupt indicating that a new set of setpoints has been entered on the thumbwheel switches has taken place.
 - (iii) The central computer requiring attention.
 - (iv) The process wishing to indicate a certain condition to the processor via the alarm port.
 - (4) The control is then transferred to (b) above.
- (c) If one furnace hopper (or more) is empty the following events take place:
- (1) In block E a check is made to see how many furnace hoppers are empty, and which furnace hoppers are empty. This information, together with the previous furnace hopper servicing history, is used to set flags indicating the present servicing state.
 - (2) The information processed in (C)(1) above, is used to select which furnace hopper is to be serviced next (say, F.H.(X)). (F)
 - (3) F.H.(X)'s previous filling history is checked to determine the total recipe errors which were made in the mix previously fed to it. The error, plus the current moisture and taring error, is used to determine the desired feed-mix recipe for F.H.X. (4)

(4)/.....

- (4) The interrupts are disabled. The weighing hoppers are filled (5) with the desired recipe. After each feeder is turned off, the overshoot error is determined after a suitable settling-down time. All the overshoot errors are then stored. The interrupts are enabled after the weighing hoppers have been filled.
- (5) Next, conveyers and shuttles, which make up the route to F.H.(X) are started (G); a check is made to see when the route is set up and if this is achieved within a certain period.
- (6) The feeders which empty the weighing hoppers on to the conveyer system are now started.
- (7) While the weighing hoppers are being emptied, the errors in the desired recipe are used to calculate the total recipe error for F.H.(X) and stored (6). Also the inventory record is updated (7).
- (8) A check of the "FURNACE HOPPER SERVICE" flags is made to see if a special recipe was used. If so, the old recipe is re-stored (8).
- (9) The processor then waits for an interrupt which will indicate that the weighing hoppers are empty (J). It also checks to see that this happens during a specified period. (9).
- (10) The feeders which emptied the weighing hoppers are turned off (K).
- (11) The "FURNACE HOPPER SERVICE" flags are then interrogated to see if a "fast cycle mode" is required when many (more than six) furnace hoppers were empty (L).
- (12) The control is transferred to point (b) (3) above.

10.3/.....

10.3 SOFTWARE NOTATION

In order to streamline the software documentation, it was decided to establish certain conventions.

(a) The following notation is used in the program descriptions:

- (1) $A_R, B_R, C_R, D_R, E_R, H_R, L_R$: internal processor registers
- (2) LOC. 10-16: memory locations from address 10_8 to address 16_8
- (3) C, Z, S, P : internal processor flags, carry zero, sign and parity
- (4) M_R : current memory location being addressed by H_R (HOB) and L_R
- (5) HOB : highest order byte in a multi-byte reference
- (6) LOB : lowest order byte
- (7) hob : highest order bit
- (8) lob : lowest order bit
- (9) Unless otherwise indicated, octal numbers are used.

(b) There are 24 different input or output instructions which can be used.

These are listed in Table 6.1. Refer to Table 10.1 for the mnemonics which, for convenience, have been assigned to certain of these input/output instructions.

(c) Detailed program listings can be found in Appendix 6 which is bound separately.

Note: These listings have been produced by a pseudo-dissembler program from the original machine-code.

(d) Memory usage has been assigned as follows:

loc 0-3777	ROM	(Read Only Memory)
loc 4000-7777	RAM	(Random Access Memory)
loc 10000-17777	ROM	(Read Only Memory)

Note:

- (i) In order to provide flexibility in the prototype, only random access memory was used. However, the software is structured so that the above memory structure may be adopted.

(ii)/.....

TABLE 10.1INPUT/OUTPUT INSTRUCTION MNEMONICS

INSTR.	MNEMONIC	FUNCTION
101	ILB	Input lob's of process data
103	IHB	Input hob's of process data
105	PPZ	Input from timer
107	ITY	Input from the teletype
123	OTY	Output to the teletype
145	OSD	Select the next byte of input data
147	OFF	Select feeders F9 to F12 and FF1 to FF3
161	OSF	Select feeders, F1 to F8
163	OWH	Weighing hopper control
167	ODC	Select furnace hopper
111	WAR	Read external register
117	IP7	Input from minicomputer
131	WRA	Load external register
133	ENI	Enable interrupts
135	DSI	Disable interrupts
137	OT7	Output to minicomputer

- (ii) During program development on the prototype it was found convenient not to use the top kiloword (loc 16000-17777) of available ROM space and to use loc 6600-7777 as ROM memory. This could easily be altered.
- (iii) As the program was written in machine code, all references to any of loc 4000-6577 (RAM) should be read as if a variable name is implied.

CHAPTER 11THE UTILITY ROUTINES

In this chapter are discussed the utility routines used by the control program. Such routines are necessary for successful system operation but have no specific relation to the batch-weighing and raw material distribution system.

11.1 DOUBLE WORD ADDITION

Sub-routine ADDM

(a) Purpose

To add the contents of E_R and D_R (HOB) to memory locations 4000 and 4001 (HOB).

(b) Limitations

No check is made to see if the maximum negative number possible is exceeded.

(c) Error Checks

If overflow occurs loc. 4002 is set to some non-zero number.

(d) Program Location

Address 143-216.

(e) Entrance

Via a sub-routine call to address 143.

(f) Descriptions

The lower order bytes are first added together. The carry bit is added to the higher order bytes when they are added.

11.2 INCREMENT THE MEMORY REGISTERS

Sub-routine INCM

(a) Purpose

To increment the contents of the H(HOB) and L registers.

(b) Program Location

Address 220-230

(c)/.....

(Chapter 11 - continued)

(c) Entrance

Via a sub-routine call to address 220

11.3 DECREMENT THE MEMORY REGISTERS

Sub-routine DECM

(a) Purpose

To decrement the contents of the H(HOB) and L registers.

(b) Program location

Address 231-241

(c) Entrance

Via a sub-routine call to address 231

11.4 OBTAIN 2'S COMPLEMENT

Sub-routine COMP.

(a) PurposeTo obtain the 2's complement of E_R and D_R (HOB)(b) Program location

Address 242-260

(c) Entrance

Via a sub-routine call to address 242

11.5 DOUBLE WORD SUBTRACTION

Sub-routine SUBR

(a) Purpose :To subtract the contents of E_R and D_R (HOB) from loc 4000 and 4001 (HOB)(b) Limitations

Similar to 11.1

(c) Error Checks

Similar to 11.1

(d) Program location

Address 261-267

(e)/.....

(Chapter 11 - continued)

(e) Entrance :

Via a sub-routine call to address 261.

(f) Other routines used:

(i) Sub-routine ADDM (11.1)

(ii) Sub-routine COMP (11.4)

(g) Description : The 2's complement of E_R and D_R is obtained and added to
loc 4000 and 400111.6 INTEGER DIVISION

Sub-routine DIVD

(a) PurposeTo divide E_R and D_R (HOB) into loc 4003-4006 (HOB). The quotient is placed in loc 4000-4001 (HOB), and the remainder in loc 4003-4006.(b) Limitations:The program is written to divide a 2-byte divisor into a 4-byte dividend and the user is required to ensure that these limits are not exceeded.(c) Error Checks:

See (f) below.

(d) Program Location:(e) Entrance:

Via a sub-routine call to loc 300.

(f) Other Routines Used:

(i) Sub-routine COMP (11.4)

(g) Description:

The program follows "the pencil-and-paper" method, i.e. it follows the same method as a mathematician would use to do a binary division on paper.

11.7/.....

(Chapter 11 - continued)

11.7 INTEGER MULTIPLICATION

sub-routine MULT

(a) Purpose:

To multiply E_R and D_R (HOB) by loc 4000-4001 (HOB). The product is placed in loc 4003-4006 (HOB).

(b) Limitations:

The program is written to multiply 2, 2-byte numbers to obtain a 4-byte product. This sub-routine was written in conjunction with sub-routine DIVD. They are structured so that the intermediate total of a mixed calculation can be 4 bytes (32 bits) long.

(c) Error Checks:

None.

(d) Program Location:

Loc 520-706

(e) Entrance:

Via a sub-routine call to loc 520.

(f) Other Routines Needed:

None

(g) Description:

Similar to 11.6 (g).

11.8 NUMBER OUTPUT TO THE TELETYPE

Sub-routine OCHA

(a) Purpose:

To output E_R , D_R and C_R (HOB) to a teletype in the form of a six-digit number plus a sign digit. If loc 4030 is non-zero the lower order 4 digits only are output.

(b) Limitations:

The number must be within the range -32, 769 - 327, 680. The user must ensure that $C_R = 377$ (all 1's) when he wishes to output a negative number.

(c)/....

(c) Error Checks

See (f) below.

(d) Program Location:

loc. 720-1057

loc. 120-141

(e) Entrance:

Via a sub-routine call to loc. 720. If the user wants to output a negative number or more than 4 digits, loc. 4030 must be zero, otherwise loc. 4030 must be non-zero.

(f) Other Routines Used:

(i) Sub-routine COMP (11.4)

(ii) Sub-routine DIVD (11.6)

(iii) Interrupt vector INRQ4 (11.9)

(iv) Sub-routine OUTF (11.9)

(g) Description:

Before being processed the -ve numbers are complemented. The decimal digits are extracted from the binary word by repeated divisions by 10_{10} . They are then converted to ASCII and stored. If the number was -ve, a -ve sign (in ASCII) is stored with it. These words are then outputted in series.

11.9 INTERRUPTS WHEN OUTPUTTING TO A TELETYPE

Sub-routine OUTF.

(a) Purpose

Whenever the peripheral controller has completed an output operation to the teletype, an interrupt to loc. 40 is generated. This routine sets a flag in memory to indicate that the teletype is ready to receive data.

(b)/.....

(Chapter 11 - continued)

(b) Program Location

Loc. 40-44 (interrupt vector)

Loc. 1060-1103 (set flag)

(c) Entrance(i) Via interrupt vector $\overline{INRQ4}$ or,

(ii) Via a sub-routine call to the loc. 1060.

(d) Description

This routine can be entered as the result of an external interrupt; thus all the internal processor register contents must be saved.

A_R and B_R are stored in the external hardware registers so that these registers can be used to save H_R and L_R , the memory address registers.

The memory loc. 4026 is set and all the registers are restored.

11.10 NUMBER INPUT FROM THE TELETYPE

Sub-routine INPN

(a) Purpose

To input a positive or negative number from the teletype and convert it into a 16-bit binary number.

(b) Limitations

The numbers must be within the range +32, 768 to -32, 767.

(c) Error Checks

If the number entered is beyond the above range or if an illegal character is entered, a question mark is printed. If the operator types a "/" character, the number which has been entered is deleted and the required number may be re-entered. The use of INPN must be completed within five minutes; otherwise, the operator must re-negotiate the input transaction.

(d) Program Location

loc. 1110 - 1427

(e) Entrance

Via a sub-routine call to loc. 1110.

(f)/.....

(f) Other Routines Used

- (i) Sub-routine WAIT 2 (proposed for the 5-minute period)
- (ii) Sub-routine MULT (11.7)
- (iii) Sub-routine OUTF (11.5)
- (iv) Sub-routine COMP (11.4)
- (v) Sub-routine INF (11.11)

(g) Description

The binary word is formed by extracting the decimal digits from the ASCII code words and multiplying by 10. If the first ASCII code is a -ve sign, the 2's complement of the binary word is taken.

11.11 INTERRUPTS WHEN INPUTTING FROM THE TELETYPE

Sub-routine INF

(a) Purpose

Whenever the peripheral controller has completed an input operation using the teletype, an interrupt to loc. 50 is generated. This routine sets a flag in memory to indicate that a character has been entered.

(b) Program Location

loc. 50-54 (interrupt vector)

loc. 1430-1461 (set flag)

(c) Entrance

- (i) Via interrupt vector INRQ5, or
- (ii) A sub-routine call to loc. 1430

(d) Description

See Chapter 11.9 (d)

11.12/.....

11.12 BCD TO BINARY CONVERSION

Sub-routine BCDTB

(a) Purpose

To convert the BCD coded contents of the C_R and B_R (HOB) into binary information. The binary number is placed in loc. 4000 and 4001 (HOB).

(b) Limitation

The highest order BCD bit (the sign bit) is ignored and a positive number is always produced.

(c) Program Location

loc. 2040-2106

(d) Entrance

Via a sub-routine call to loc. 2040

(e) Other Routines used

(i) Sub-routine CALC (11.13)

(f) Description

The BCD digits (groups of four bits) are separated, multiplied by the corresponding order of 10_{10} and added together.

11.13 SUB-ROUTINE CALC.(a) Purpose

To be used with sub-routine BCDTB

(b) Program location

Loc. 2110-2150

(c) Entrance

Via a sub-routine call to loc. 2110

11.14 BINARY TO BCD CONVERSION

Sub-routine BTBCD

(a) Purpose

To convert the binary number in loc. 4003 and loc. 4004 (HOB) into four BCD numbers. The four-bit binary (BCD) numbers are placed in loc. 4045 and 4046 with the units bit-string occupying the 4 lower-order bit

positions/...

(Chapter 11 - continued)

positions of loc. 4045.

(b) Limitations

The binary number may not be -ve.

(c) Program location

loc. 2155-2221

(d) Entrance

Via a sub-routine call to loc. 2155

(e) Description

The BCD digits are extracted by repeatedly dividing by 10 and using the resulting remainders.

11.15 TO OUTPUT ALPHA NUMERIC DATA VIA THE TELETYPE

Sub-routine OUTF.

(a) Purpose

To print the contents (ASCII characters) of all memory loc. between two specified addresses. The first address is specified by H_R (HOB) and C_R . The last address is specified by H_R (HOB) and B_R .

(b) Limitations

The sub-routine can only output a string of memory locations of which the higher order byte (H_R) is the same.

(c) Program Location

loc. 2011 - 2037

(d) Entrance

Via a sub-routine call to loc. 2011.

11.16 CONTROL INPUT VIA THE TELETYPE

Sub-routine CINP

(a) Purpose

To examine a character received from the teletype and to branch to the routine which executes the required action as indicated by that character.

(b)/.....

(Chapter 11 - continued)

(b) Limitations

Due to periods during which the interrupts may have been disabled, the operator has to wait for a response from the processor after he has depressed a key indicating that a specific control action is required. CINP caters for a maximum of 5 different input control characters.

(c) Error Checks

When any character is entered which "CINP" does not recognise or expect, the following is printed : "?", "RETURN", "LINE FEED"

(d) Program Location

loc. 10477-10562

loc. 3540 -3547

(e) Entrance

via a sub-routine call to loc. 10477

(f) Other Routines Used

(i) Sub-routine OUTP (11.15)

NOTE: "CINP" jumps to one of several different routines according to which control action is desired as specified by the input-fed character.

(g) Description

When the main program examines the "EXTERNAL CONDITION" flags and determines that the operator has entered a character from the teletype, a call to CINP is made. The character is examined and a branch is made to the appropriate routine.

11.17 RECORD TIME OF DAY

Sub-routine TIME 1.

(a) Purpose

To read the time from a digital clock (in BCD code) and store it in loc. 4045 (minutes and tens of minutes) and Loc. 4046 (hours and tens/...

(Chapter 11 - continued)

tens of hours)(b) Program Location

loc. 11730 - 11775

(c) Entrance

Via a sub-routine call to loc. 11730

11.18 PRINT TIME OF DAY

Sub-routine TIMP

(a) Purpose

To convert the BCD coded contents of loc. 4045 and 4046 into ASCII coded characters and to print them onto the teletype. (See Chapter 11.17)

(b) Program Location

Loc. 12000 - 12134

(c) Entrance

Via a sub-routine call to loc. 12000

(d) Other Routines Used

(i) Sub-routine OUTP (11.15)

11.19 TO TIME A SHORT DELAY

Sub-routine TIMD

(a) Purpose

To enable a program to estimate any period from 1 to 127 seconds without having to use "marking-time" routines. The period to be timed corresponds to the contents of D_R .

(b) Limitations

Timing to within 1 second is only possible if TIMD is used at least once every second.

(c) Program Location

loc. 13300 - 13340

(d) Entrance

Via a sub-routine call to loc. 13300.

(e)/.....

(e) Description

Input instruction code 105 causes the output of an eight-bit counter running at one hertz to be read. When the programmer wants to program a short time delay into a routine, he is required to read the timer and store the count in a specific memory location. When the programmer wishes to use TIMD, M_R must point to the memory location, where the count is stored and D_R must contain the desired timing period. TIMD sets the carry flip-flop as follows:

C = 0: when the timed period is not over

C = 1: when the timed period is over

CHAPTER 12

THE CONTROL PROGRAMS

12.1 LOADING THE WEIGHING HOPPERS

Sub-routine CONW, Sub-routine WEIGH

These two sub-routines together control the proportioning of the ingredients which are fed into the weighing hoppers. The inputs to these routines are:

- (i) The desired setpoints which will have been converted into the BCD code and stored in specific memory locations, and
- (ii) The BCD coded outputs of the three load cells which are located underneath the weighing hoppers.

These routines control the feeders which feed contents of the holding bins into the weighing hoppers.

Sub-routine CONW is the main controlling program and sub-routine WEIGH is its main sub-routine.

12.1.1 SUB-ROUTINE WEIGH

(a) Purpose

Every time this sub-routine is entered, one of the following actions can take place. The specific action is controlled by "flags" in memory which are continually interrogated and updated by WEIGH and CONW.

- (i) Return to CONW if the selected weighing hopper has been loaded.
- (ii) Start the selected feeder.
- (iii) Stop the selected feeder if its setpoint has been reached.
- (iv) Switch the selected feeder from the coarse feed to the fine feed mode if the weight is within 90% of the setpoint.
- (v) Return to CONW if not enough time has elapsed for the selected load cell output to stabilize after a feeder has been stopped.
- (vi) Record the actual setpoint used (including overshoot error) after the selected load cell's output has settled down.

(vii)/...

- (vii) If the current feeder has completed its task, then select the next feeder and its setpoint.

(b) Limitations

WEIGH is controlled from CONW; CONW decides which feeder (and weighing hopper) is to be serviced. As WEIGH can only "look" at the one load cell output at a time but material may be feeding into all three weighing hoppers, there will be a certain feeding rate (mass per unit time) beyond which the feeders may not be turned off quickly enough, resulting in excessive overshoot errors.

(c) Program Location

loc. 2260 - 2574

loc. 2705 - 2767

loc. 3000 - 3010

(d) Entrance

Via a sub-routine call to loc. 2260.

(e) Other Routines Used.

- (i) Sub-routines CUFE (12.1.3)
- (ii) Sub-routine FLAG (12.1.4.)
- (iii) Sub-routine NESP (12.1.5.)
- (iv) Sub-routine FEED (12.1.6.)
- (v) Sub-routine TIMD (11.1.9.)
- (vi) Sub-routine COMS (12.1.7.)

(f) Description

Refer to the flow chart, Figure 12.1.

12.1.2 SUB-ROUTINE CONW

(a) Purpose

To perform the function of a main controlling routine for the loading of the weighing hoppers. CONW controls the initiating, sequencing, ending, and error checks for the loading process.

(b)/...

FIGURE 12.1 LOADING THE WEIGHING HOPPERS.

(b) Limitations

See sub-routine WEIGH

(c) Error Checks

Recommended error checks are that a check should be made that each feeder performs its function and that the weighing hoppers are loaded within a specified maximum period.

(d) Program Location

loc. 13420 - 13543

(e) Entrance

Via a sub-routine call to loc. 13420.

(f) Other Routines Used

- (i) Sub-routine COSP (12.1.8)
- (ii) Sub-routine WEIGH (12.1.1)
- (iii) Sub-routine ERR (Proposed)

(g) Description

Refer to flow chart, figure 12.2.

ERR is a sub-routine whose function will be to perform the error checks recommended in (c) above.

12.1.3 TO HAVE ACCESS TO THE CURRENTLY SELECTED FEEDER

Sub-routine CUFE

(a) Purpose

CUFE places the pointer (loc. 4771) to the currently selected weighing hopper in C_R . It also places the pointer (loc. 4730, 4733, or 4736) selecting the current feeder in B_R . Upon exit from CUFE, M_R contains this memory location.

(b) Program Location

Loc. 2600 - 2614.

(c) Entrance

Via a sub-routine call to loc. 2600.

SUBROUTINE CONW

FIGURE 12.2 TO CONTROL THE WEIGHING HOPPER LOADING

12.1.4. TO HAVE ACCESS TO THE CURRENTLY RELEVANT FLAGS

Sub-routine FLAG.

(a) Purpose

To make M_R point to the relevant address in memory which contains the desired program flag and is used by WEIGH.

(b) Program Location

Loc. 2615 - 2630.

(c) Entrance.

Via a sub-routine call to loc. 2613.

(d) Description

There are four flags relevant to each weighing hopper: NEXT FEEDER, WAIT, STOPPED and FINE FEED. These are numbered 0, 1, 2 and 3, respectively. This number must be loaded into A_R before entrance to FLAG. Upon exit from FLAG, M_R will point to the memory location containing information relevant to the flag.

12.1.5 TO LOAD THE NEXT SETPOINT

Sub-routine NESP

(a) Purpose

After the previous setpoint has been reached, NESP is used to select the next appropriate setpoint for a particular weighing hopper.

(b) Program Location

Loc. 2635 - 2702.

(c) Entrance

Via a sub-routine call to loc. 2635.

(d) Other Routines Used

Sub-routine CUFE (12.1.3)

(e) Description

For each weighing hopper there are specific memory locations which store the current setpoint for a particular feeder to that hopper. NESP loads these locations as required.

(Chapter 12 - continued)

12.1.6 TO CONTROL THE FEEDERS WHICH LOAD THE WEIGHING HOPPERS

Sub-routine FEED

(a) Purpose

To turn the currently selected feeder on or off.

(b) Program Location

Loc. 13150 - 13275.

Loc. 2730-2767

(c) Entrance

Via a sub-routine call to loc. 13150.

(d) Description

If E_R is non-zero the currently selected feeder is turned on.

If E_R is zero the currently selected feeder is turned off.

12.1.7 TO CHECK IF THE CURRENTLY SELECTED SETPOINT HAS BEEN REACHED

Sub-routine COMS

(a) Purpose

To read the relevant load cell output to see if the current setpoint has been reached.

(b) Program Selection

Loc. 1770 - 2010

(c) Entrance

Via a sub-routine call to loc. 1770

(d) Description

COMS sets the carry-flag if the setpoint has been reached.

12.2 TO PERFORM ERROR CORRECTIONS ON THE CURRENTLY SELECTED SETPOINTS

Sub-routine COSP

(a) Purpose

COSP does the following manipulations on the setpoints of the currently selected furnace hopper:

(i) Reads/.....

(Chapter 12 - continued)

- (i) Reads the percentage moisture content of the ingredients in holding bin one and adds the required amount to setpoints 1, 2, 3 and 4, (remembering that they are accumulative).
- (ii) Reads the load cell outputs when the weighing hoppers are supposedly empty and adjusts the setpoints according to these taring errors. All the setpoints corresponding to each of the weighing hoppers are adjusted for the taring error.
- (iii) Corrects the setpoints according to the overshoot errors from the previous occasion when the currently selected furnace hopper was serviced.
- (iv) Calculates 90% of the setpoints as determined by i), ii) and iii) above.
- (v) Converts the corrected setpoints and their 90% equivalents into the BCD code and stores these ready for use by the weighing hopper loading routines.

(b) Limitations

Moisture correction is only done to the first order of accuracy. For example, if the recipe requires 100 kg of the ingredient which contains, say, 10% moisture, then COSF will correct setpoint according to the formulae:

$$\begin{aligned}\text{Corrected setpoint} &= 100 + \frac{100}{1} \times \frac{10}{100} \\ &= 110 \text{ kg}\end{aligned}$$

Remember that the 10% of the ingredient added also contains 10% or 1 KG of moisture, etc. In this case, therefore, too little will have been added to the setpoint.

(c) Error Checks

Provision has been made for an alarm indication if a taring error of more than 256 kg is detected.

(d) Program Location

Loc. 3020 - 3533

(e)/.....

(Chapter 12 - continued)

(e) Entrance

Via a sub-routine call to loc. 3020.

(f) Other Routines Used

- i) Sub-routine BCDTB (11.12)
- ii) Sub-routine FISP (12.3)
- iii) Sub-routine MULT (11.7)
- iv) Sub-routine DIVD (11.6)
- v) Sub-routine COMP (11.4)
- vi) Sub-routine ADDM (11.1)
- vii) Sub-routine BTBCD (11.14)

(g) Description

Refer to the flow chart, Figure 12.3.

12.3 TO ADDRESS THE CURRENT SETPOINT

Sub-routine FISP

(a) Purpose

FISP sets M_R to the memory location address in which the first byte of the desired setpoint is stored.

(b) Progress Location

Loc. 12614 - 12701.

(c) Entrance

Via a sub-routine call to loc. 12614.

(d) Other Routines Used.

- i) Sub-routine MULT (11.7)
- ii) Sub-routine ADDM (11.1)

(e) Description

Throughout the control porcess a pointer selecting which furnace hopper is to be serviced is stored in loc. 4063. Similarly, loc. 4064 is/....

FIGURE 12.3

TO PERFORM ERROR CORRECTIONS ON THE CURRENTLY
SELECTED SETPOINTS.

(Chapter 12 - continued)

is used for a setpoint pointer. FISP makes use of these two pointers to set up M_R (H_R & L_R). The overshoot error for each setpoint is stored ^{in/} exactly 1000 memory locations away from the setpoint, and the programmer can therefore increment H_R twice in order to set up M_R to the memory location address containing the first byte of the overshoot error.

12.4 TO DETERMINE THE GENERAL SETPOINTS

Sub-routine RESP.

(a) Purpose

To read the thumbwheel switch outputs which specify the "general" setpoints for each furnace hopper, convert these values into 2-byte binary numbers and store them as the current setpoints.

(b) Error Checks

If any succeeding setpoint is smaller than the preceding setpoint and both these setpoints apply to feeders feeding into the same weighing hopper, then that setpoint is made equal to the preceding one. Because the setpoints are accumulative, this will imply that nothing will be fed from the corresponding holding bin. Therefore, if the plant hardware or the desired recipe dictates that a certain holding bin should not be used, a zero indication on the corresponding setpoint will be the only change necessary.

(c) Program Location

Loc. 12135 - 12332.

(d) Entrance

Via a sub-routine call to loc. 12135.

(e) Other Routines Used

- i) Sub-routine BCDTB (11.12)
- ii) Sub-routine FISP (12.3)

(f) Description/.....

(Chapter 12 - continued)

(f) Description

Refer to Flow Chart, Figure 12.4.

12.5 TO PRINT THE SETPOINTS ONTO THE TELETYPE

Sub-routine ROSP : Sub-routine ROGP.

Together these two sub-routines list the setpoints. ROSP is used during a shift report to list the setpoints which currently apply to each furnace hopper (see Figure 12.5). ROGP is used to list the general setpoints which apply to all the furnace hoppers after the system has just been started up or re-started upon the operator's request. (See Figure 12.6).

12.5.1 SUB-ROUTINE ROSP(a) Purpose

As discussed above.

(b) Program Location

Loc. 12340 - 12520

Loc. 12710 - 12760	} The output literal lists coded in ASCII
Loc. 13000 - 13125	

(c) Entrance

Via a sub-routine call to loc. 12340.

(d) Other Routines Used

- i) Sub-routine OUTP (11.15)
- ii) Sub-routine OCHA (11.8)
- iii) Sub-routine FISP (12.3)

12.5.2. SUB-ROUTINE ROGP(a) Purpose

As discussed above.

(b) Program Location

Loc. 14410 - 14431

Loc. 14432 - 14467 The output literal list coded in ASCII

(c) Entrance/.....

SUBROUTINE RESP

FIGURE 12.4 TO DETERMINE THE GENERAL SETPOINTS

THE CURRENT SETPOINTS ARE:

SETPOINTS:

F.H.	1	2	3	4	5	6	7	8	9	10	11	12
0001	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0002	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0003	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0004	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0005	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0006	0120	0300	0375	0405	0100	0150	0150	0150	0250	0700	1000	1050
0007	0120	0300	0375	0405	0100	0150	0150	0150	0250	0700	1000	1050
0008	0120	0300	0375	0405	0100	0150	0150	0150	0250	0700	1000	1050
0009	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0010	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0011	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0012	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0013	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0014	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0015	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050

FIGURE 12.5 A SETPOINT REPORT

TIME: 1100 HOURS

THE GENERAL SETPOINTS ARE:

SETPOINTS:

F.H.	1	2	3	4	5	6	7	8	9	10	11	12
0015	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050

FIGURE 12.6 A GENERAL SETPOINT REPORT

(c) Entrance

Via a sub-routine call to loc. 14410.

(d) Other Routines Used

Sub-routine OUTP (11.15)

Note: ROGP does not exist in the normal manner but performs a jump into ROSP (Chapter 12.4.1).

(e) Description

ROGP prints the "general setpoints" heading. It then sets pointers in memory to indicate that only the last furnace hopper's setpoints are still to be outputted. ROSP is then entered at loc. 12357 so that only the last furnace hopper's setpoints are printed as normal. Note that it is only intended to use ROGP immediately after RESP (Chapter 12.4) when the setpoints for all the furnace hoppers will be equal.

12.6 TO CHANGE THE CONTROL PARAMETERS FROM THE TELETYPE

Routine PERC. Routine LOCO.

These routines are used to make adjustments to the setpoints from the teletype. They are entered via jump instructions from sub-routine CINP (11.16). They are terminated by a "return" and will therefore return directly to the calling program. Refer to the flow chart, figure 12.9.

12.6.1. ROUTINE LOCO(a) Purpose

To enable the operator to effect changes on the recipe of the feed mix to be fed to certain specified furnace hoppers. The operator can specify for how many batches per furnace hopper the altered recipe is to be used before reverting to the 'old' recipe. An example of the printout produced during such a communication between the operator and processor is shown in Figure 12.7. Note that the underlined printing is
is/.....

C
LOCAL CORRECTION

CHANGE S.P.: 6 BY: 20
 CHANGE S.P.: 7 BY: -10
 CHANGE S.P.: 8 BY: 15
 CHANGE S.P.: 99
 BATCHES: 4
 FOR F.H'S.: 4; 5; 6; 7; 99
 TIME: 1130 HOURS
 CORRECTION ACCEPTED

FIGURE 12.7 TEMPORARY ADJUSTMENT TO AFFECT A LOCAL CORRECTION

A
SETPOINT ADJUST

CHANGE S.P.: 1 BY: 10
 CHANGE S.P.: 2 BY: 15
 CHANGE S.P.: 4 BY: 30
 CHANGE S.P.: 99
 FOR F.H'S.: 6; 7; 8; 9; 99
 TIME: 1130 HOURS
 CORRECTION ACCEPTED

FIGURE 12.8 A PERMANENT SETPOINT ADJUSTMENT

FIGURE 12.9 CHANGE THE CONTROL PARAMETERS FROM THE TELETYPE

(Chapter 12 - continued)

done by the operator from the teletype keyboard.

(b) Limitations

A maximum of 256 batches per furnace hopper can be specified.

(c) Error Checks

See Section (f) below.

(d) Program Location

Loc. 14647 - 15250

Loc. 6600 - 6750 : the literal list for output coded in ASCII

(e) Entrance

Via a jump to loc. 14647.

(f) Other Routines Used

(i) Sub-routine OUTP (11.15)

(ii) Sub-routine TIREC (proposed)

(iii) Sub-routine INPN (11.10)

(iv) Sub-routine SPAD (12.6.3)

(v) Sub-routine Time 1 (11.17)

(vi) Sub-routine (11.18)

(g) Description

Refer to the flow chart, figure 12.9.

12.6.2 SUB-ROUTINE PERC.

(a) Purpose

To enable the operator to effect changes in the recipe to the feed mix to be supplied to specified furnace hoppers. These changes will be used for all the succeeding batches. (See Figure 12.8).

(b) Program Location

Loc. 14470 - 114646

Loc. 14400 - 14404

Loc. 6600 - 6750 : the literal list of characters for output coded in ASCII

(c) Program/.....

(Chapter 12 - continued)

(c) Program Entrance

- (i) Via a jump to loc. 14625.
- (ii) The program is re-entered from LOCO via a jump to loc. 14470.

(d) Description

Refer to the flow chart, figure 12.9.

12.6.3. TO ADJUST THE SETPOINTS ACCORDING TO OPERATOR SPECIFICATIONS

Sub-routine SPAD

(a) Purpose

During a setpoint adjustment the operator specifies the change in the setpoint required according to this change.

(b) Program location

loc. 1620 - 1710

(c) Entrance

Via a sub-routine call to loc. 1620.

12.7 TO PRODUCE A SHIFT REPORT

Sub-routine INVEN

(a) Purpose

To print onto the teletype an inventory of:

- (i) The raw materials used from each holding bin, (loc. 5650 - 5677);
- (ii) The feed mix fed to each furnace hopper (loc. 5014 - 5051);
- (iii) The total mass of raw material used (loc. 5060 - 5062).

INVEN also lists the current setpoints required for each furnace hopper.

See Figure 12.10 for an example of such a shift report.

(b) Program Location

loc. 3540 - 3766

loc. 10570 - 10746

loc. 6747 - 7127 : literal list of the output characters coded in ASCII.

(c) Entrance/.....

INVENTORY REPORT
TIME: 0800 HOURS

THE CURRENT SETPOINTS ARE:

SETPOINTS:												
F.H.	1	2	3	4	5	6	7	8	9	10	11	12
0001	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0002	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0003	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0004	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0005	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0006	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0007	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0008	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0009	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0010	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0011	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0012	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0013	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0014	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050
0015	0110	0275	0350	0350	0100	0150	0150	0150	0250	0700	1000	1050

TOTALS-MATERIALS USED.[IN KG.]

HOLDING BINS:

000001 003460
000002 005059
000003 002260
000004 000733
000005 003071
000006 001505
000007 000000
000008 000000
000009 007748
000010 013317
000011 009003
000012 001494

BY F.H.S.:

000001 006296
000002 006299
000003 003150
000004 003134
000005 015878
000006 003226
000007 006446
000008 003221
000009 000000
000010 000000
000011 000000
000012 000000
000013 000000
000014 000000
000015 000000

TOTAL MOISTURE: 000338

TOTAL ORE: 047650

TIME: 0800 HOURS

FIGURE 12.10 AN INVENTORY REPORT

(Chapter 12 - continued)

(c) Entrance

Via a sub-routine call to loc. 3540.

(d) Description

INVEN can be used either for a shift report in which case the programmer should set loc. 5063 to zero causing the inventory parameters to reset. If loc. 5063 is non-zero, the inventory parameters will not be reset. Note that the word sizes chosen to store the parameters are such that they can hold any number expected to accumulate within an eight-hour shift period. The programmer should therefore ensure that INVEN is used with the loc. 5063 equal to zero at least once every shift.

12.8 TO UPDATE THE INVENTORY RECORD

Sub-routine UPIN

(a) Purpose

To accumulate and store the inventory of raw materials used each time a furnace hopper has been serviced. UPIN therefore prepares the data which is used by INVEN (Chapter 12.7) to make up the data for inventory or shift reports.

(b) Limitations

- (i) The quantity of feed mix fed to each furnace hopper and the quantity of raw material fed from each holding bin is accumulated in 16-bit positive words. This gives a maximum of 65,536 kg. of material per shift per accumulator.
- (ii) The grand total of all the feed mix consumed is accumulated in a 3-byte word. The routine which outputs numbers is 6 decimal digits long. Therefore a maximum of 999,999 kg per shift is allowed for.

(c) Program/....

(Chapter 12 - continued)

(c) Program Location

loc. 13720 - 14230

(d) Entrance

Via a sub-routine call to loc. 13720.

(e) Other Routines Used

(i) Sub-routine SUBR (11.5)

(ii) Sub-routine ADDM (11.1)

(f) Description

Refer to the flow chart, figure 12.11. The quantity of raw material used from each holding bin is calculated as follows:

Let Hx and Hx-1 be holding bins feeding into the same weighing hopper.

Let SPx and ESPx be the desired setpoint and the error in the desired setpoint.

Then the quantity of raw material fed from Hx will be:

Quantity from Hx = SPx - ESPx - (quantity from Hx-1)

SPx - ESPx is stored as an intermediate total called ITx.

The intermediate totals corresponding to the highest setpoint of each weighing hopper is added together to obtain the total feed mix fed to the currently selected furnace hopper.

12.9 TO DETERMINE WHETHER A FURNACE HOPPER REQUIRES ATTENTION

Sub-routine FEMP

(a) Purpose

To determine whether the furnace hopper indicated by B_R requires service by examining loc. 6000-6004 (Chapter 12.10). FEMP sets the carry flag to 1 if the selected furnace hopper's feed mix level is low. FEMP sets D_R to indicate to which 'filling group' (see Chapter 12.10) the selected furnace hopper belongs.

(b) Program Location

loc. 14240 - 14320

(c) Entrance/.....

SUBROUTINE UPIN

FIGURE 12.11 TO UPDATE THE INVENTORY RECORD

(Chapter 12 - continued)

(c) Entrance

Via a sub-routine call to loc. 14240.

12.10 TO SELECT THE NEXT FURNACE HOPPER TO BE SERVICED

Sub-routine NEFH

(a) Purpose

To minimise mechanical wear and tear on the conveyor system, it was decided that the furnace hoppers should be grouped into 'filling groups' fed from a common shuttle. NEFH examines B_R to see which is the last furnace hopper to have been serviced and uses the value of D_R (Chapter 12.9) to see if any furnace hoppers in the same filling group require service. This is used as a first priority selection of which furnace is to be serviced next. The second priority selection is based purely on a numerical cycle. Note that an emergency priority selection mode is used when many (more than six) furnace hoppers become empty.

(Chapter 12. 11. (e) ii)

(b) Program Location

loc. 144330 - 14370

(c) Entrance

Via a sub-routine call to loc. 144330.

12.11 TO SELECT WHICH FURNACE HOPPER IS TO BE SERVICED

Routine HOPR.

(a) Purpose

- (i) To determine if any furnace hoppers require service.
- (ii) To arrange the furnace hoppers which require service into their filling groups and to store these as follows:
 - loc. 6000 furnace hoppers 1, 2, 3 and/or 4.
 - loc. 6001 furnace hoppers 5, 6, 7, and/or 8.
 - loc. 6002 furnace hoppers 9, 10, 11 and/or 12
 - loc. 6003 furnace hoppers 13, 14 and/or 15.

(iii) To/...

(Chapter 12 - continued)

- (iii) To examine and set the 'FURNACE HOPPER SERVICE' flags, thus determining the filling mode which is applicable.
- (iv) As a result of (i), (ii) and (iii) above, to select which furnace hopper must then be actually serviced.

(b) Program Location

loc. 11000 - 11337

loc. 11456 - 11574

loc. 13345 - 13370

(c) Entrance

Via a jump to loc. 11000 from the main program. Note that as HOPR is entered via a jump instruction and as HOPR also returns to the main program via a jump instruction, it is really part of the main program. It is, however, convenient to consider it separately as a sub-routine.

(d) Other Routines Needed

- (i) Sub-routine FEMP (12.9)
- (ii) Sub-routine NEFH (12.10)
- (iii) Sub-routine SWOP (12.12)

(e) Description

Loc. 6000 - 6003 is examined to determine how many furnace hoppers require service. The furnace filling mode is chosen (see the flow chart, Figure 12.12), according to this quantity and the 'FURNACE HOPPER SERVICE FLAGS' adjusted for:

(i) Filling Mode 1.

Chosen when less than 7 furnace hoppers require service. This is the normal mode (see flow chart, figure 12.12).

(ii) Filling Mode 2.

More than six furnace hoppers require service (see the flow chart, figure 12.13). Mode 2 is a quick filling mode. Whenever it is entered, 2 loads are dumped into each furnace hopper which requires service.

Control/...

FIGURE 12.12 FILLING MODE 1.

FIGURE 12.13 FILLING MODE 2

FIGURE 12.14 FILLING MODE 3.

(Chapter 12 - continued)

Control is then passed back to mode 1 and mode 2 cannot be re-entered unless a state has been reached when only two or less furnace hoppers require service. Mode 2 is primarily included so that some buffer capacity of feed mix can be placed into each furnace hopper after the furnace has been tapped. Note the default condition when re-starting the processor will always be with the flag set indicating that two or less furnace hoppers have been emptied.

(iii) Filling Mode 3

This mode is entered when a flag is set indicating that the operator requires a special set of setpoints for a limited number of batches (12.6.1). (See the flow chart, Figure 12.14).

12.12 TO LOAD A "SPECIAL RECIPE" FOR A SELECTED FURNACE HOPPER

Sub-routine SWOP

(a) Purpose

This routine is used to add the differences between the actual recipe and the special recipe to the error factors used for correcting the setpoints before they are used. After the weighing hoppers have been loaded the same routine is used to reverse the above process.

(b) Program Location

loc. 11341 - 11454

(c) Entrance

Via a sub-routine call to loc. 11341.

(d) Other Routines Used

(i) Sub-routine FISP (12.3)

(ii) Sub-routine COMP (11.4)

(e) Description

If the flag stored in loc. 6113 is not set, this indicates that SWOP has been used before loading the weighing hoppers and the 'special requirements' are added to the errors in the setpoints. Otherwise,

the/...

the errors are restored to their previous values.

12.13 COORDINATION OF THE DIFFERENT ROUTINES INTO A CONTROL PROGRAM

THE MAIN PROGRAM

(a) Purpose

To produce a flexible controlling program. Any major changes in the control philosophy could be accommodated by partly or completely changing the main program. All the sub-programs are designed in such a way that they can fit into any new control philosophy.

(b) Limitations

The main program must operate within the restrictions imposed by the sub-programs and hardware configuration provided.

(c) Error Checks

Many error checks are described in Chapter 12. As discussed in Chapter 10.1, many more possible fault conditions must still be evaluated and, if necessary, included. Some suggestions for possible corrective measures which may be important are given in Section 4.

(d) Program Location

loc. 10000 - 10470

Note: Provision has been made in this main program to insert new routines and instructions.

(e) Other Routines Used

All the other routines in Chapters 11 and 12 are used directly or indirectly by the main program.

(f) Description

Refer to all previous descriptions and to the flow chart. Figure 10.1.

SECTION 4.

FROM PROTOTYPE TO PROCESS.

CHAPTER 13

EQUIPMENT FAILURE

13.1 INTRODUCTION

As discussed in Chapter 10.1, it is proposed to evaluate likely equipment failures and develop corrective measures, using the prototype system. This chapter contains a preliminary survey of possible fault conditions and the necessary corrective measures.

It should be noted that at the expense of (1) memory capacity, (2) processor operating speed, (3) software simplicity, and (4) system simplicity, the system designer can specify elaborate and very sophisticated fault detection and correction measures. The prototype only occupies approximately seven kilowords of memory out of a maximum of sixteen, so that the memory capacity is not likely to be exceeded. Although the system contains considerable 'dead-time' periods during which the processor will be idle, faults are most likely to occur during 'active' periods when operating speed might be critical.

In view of operator and industry inexperience with microprocessor systems, it is desirable to sacrifice as little as possible of the software and systems simplicity. The above factors and also the fact that the furnace hoppers have a large buffer capacity - even when they require service - indicate that fault detection and correction should be as simple and as direct as possible.

13.2 PROCESSOR FAILURE

To limit possible equipment damage and plant breakdown when the processor fails, it is recommended that the following process interlocks and/or fault detection should exist. (This is excluding the normal over/under voltage trips, etc.)

(i) None/.....

- (i) None of the feeders loading the weighing hoppers should be allowed to operate when any of the feeders emptying them are operating, and vice versa.
- (ii) Only one feeder loading a particular weighing hopper must operate at a time.
- (iii) None of the feeders loading a weighing hopper must operate when its load cell output has exceeded a maximum value.
- (iv) A break in the load cell system must cause the load cell output to indicate its maximum value.
- (v) The feeders emptying the weighing hoppers must not operate when the conveyor belt onto which they feed is not running.
- (vi) No conveyor should operate unless signals are present, indicating that a specific furnace hopper has been selected and that the plant is therefore in the transportation mode.

13.3 PROCESS FAILURE

By using the processor the system designer could utilize the following methods to detect a plant failure.

(a) TIME:

Using the hardware timer (Chapter 6.10) or a time-of-day digital clock, certain events can be timed to ensure that they occur within certain time limits. Areas where this approach can be fruitfully applied are, for instance,

- (i) To check that the weighing hoppers are emptied within a certain period. This could indicate the malfunctioning of any of the feeders which empty the weighing hoppers.
- (ii) To ensure that the weighing hoppers are loaded within a certain period. This could indicate the malfunctioning of any of the feeders which fill the weighing hoppers.
- (iii) To check that the signals indicating that the route to a furnace hopper is working are all present within a certain period. This

would/.....

This would indicate if:

- any belt has slipped off;
- any belt has 'jammed';
- any motor has failed to start;
- any motor is rotating too slowly;
- a malfunctioning of the shuttle system;
- a malfunctioning of a transducer.

- (iv) If the operator initiates a communication routine and for some reason abandons the data terminal, control should automatically be returned to the processor after a certain period.

(b) ALARM PORT

As explained in Chapter 8.3, an interrupt vector can be used by the plant to initiate a data transfer to the processor. This facility can be used by the process to inform the processor of fault conditions which do not immediately affect the essential operation of the plant and therefore cannot readily be detected. An example of such conditions might be a signal that a motor is overheating or that a holding bin is nearly empty.

(c) CONTINUOUS PROCESS MONITORING

The processor can, whenever it has any idle time, be continuously monitoring the signals from the process. This method could be used while the feed-mix is being transported to a furnace hopper to ensure that the route remains working correctly.

13.4 CORRECTIVE MEASURES

(a) During a processor failure, the operator will have to switch over to the manual control system until the processor fault has been corrected.

(b) There are two types of plant failure which should be considered separately:

- 1) Failures which prevent the system from operating at all and which require immediate attention.
- 2) Failures which do not affect the operation of the whole

process/.....

process.

Typical corrective measures which can be employed would then be as follows:

- (i) When any fault is first detected:
 - do the necessary operation to prevent any further mishap;
 - inform the operator of the fault;
 - wait for a response from the operator to confirm the error.
- (ii) If the fault is of category (1) above, output an inventory of the materials used since the last shift report and perform an ordered shutdown of the system.
- (iii) If the fault is of category (2) above, wait for a further communication from the operator to indicate how to continue.

The above scheme enables the operator to investigate the error and perhaps by some simple action - like removing a lump of ore sticking into a feeder - enable the process to continue normally. The operator can also detect that the error is not due to the plant malfunctioning, but that a transducer is not operating; he can therefore instruct the processor to ignore, for example, a specific 'belt up to speed' signal not being present.

CHAPTER 14

SYSTEM EVALUATION

14.1 INTRODUCTION

It was found convenient to evaluate the prototype system from the following viewpoints:

Hardware

Software

System.

14.2 HARDWARE EVALUATION

(a) General

The hardware facilities provided proved to be adequate and there is ample buffer capacity except in the case of the interrupt controller.

(b) The Microprocessor

Doubts had been raised as to whether a micro-computer would prove fast enough to control the proper loading of the weighing hoppers. The controlling factor is, of course, the operating speed of the 8008 micro-processor. The simulator was operated at speeds in excess of those in a typical plant (see Appendix 5), and the processor was always able successfully to control the weighing hopper loading. No overshoot errors occurred which would indicate that a setpoint, having been reached, had not been detected in time. In (5.3) the possibility of upgrading the system to an 8080 micro-processor was raised. It may still prove attractive to change to a faster micro-processor, for reasons discussed in (14.4).

(c) The Interrupt Controller

All eight interrupt vectors provided for have been utilized. See (14.4) for an alternative suggestion as to how the processor should determine that the weighing hoppers are empty. This will free one of the interrupt vectors providing some additional buffer capacity.

Experience/.....

(Chapter 14 - continued)

Experience gained during development of the prototype system suggests that not much is to be accrued in the use of interrupts as a direct means of process control in this type of application. Generally, the processor knows when it expects some process action to happen and can therefore continually monitor the appropriate input port to determine this. Indications are that the areas where interrupt vectors can be put to good use are:

- (1) To introduce major branches in the program flow:
 - (i) To start up the processor;
 - (ii) To detect a power failure;
 - (iii) To inform the processor of 'unexpected' operator-initiated communication;
 - (iv) To inform the processor of 'unexpected' failures or alarm conditions which have occurred.
- (2) During Peripheral Communication:

If all the peripheral controllers are designed so that an interrupt is generated for every communication action, then the programmer would be able to write control software without having to include any peripheral 'sense loops'. This implies that disabling of the interrupts for long, continuous periods is undesirable.

(d) The Mimic Panel

The mimic panel proved to be of great value. A possible improvement would be to have l.e.d. displays indicating which furnace hopper is to be serviced, i.e. the position of the shuttle above that furnace hopper. At present, this can only be determined when the l.e.d., indicating that it is being charged with feed mix, operates.

(e) The Operator's Control Panel

The facilities provided seem to be adequate but this, as with point (d) above, can only be determined by introducing the prototype system to operators of a real plant.

(f) Current/....

(f) Current Processing Phase

If the present control strategy is adhered to, namely, that long periods of time exist during which the interrupts are disabled and no peripherals will respond to external communications requests, then it is strongly recommended that an external hardware flag register, under program control, exist to indicate to other devices, i.e. a controlling computer or to the operator (via l.e.d. displays), which processing phase is being executed.

14.3 SOFTWARE

In Chapter 10.1, the objectives of the software for the prototype were stated. These were to:

- Evaluate the hardware;
- Evaluate the programming aids;
- Develop control strategy.

The hardware evaluation was done in Chapter 14.2. The control strategy will be discussed in Chapter 14.4.

An Evaluation of the Programming Aids

The hardware programming aids proved to be useful and functional. The system which loads the processor from the VARIAN minicomputer proved to be particularly useful. The programmer could use the facilities provided by the VARIAN to:

- . Store programs on paper tape;
- . Change programs using VARIAN's debug techniques;
- . Load and re-load the RAM memory of the processor easily and quickly;

The Direct Memory access loader and display was invaluable once the memory was loaded for the following applications:

. Checking/....

(Chapter 14 - continued)

- . Checking programs;
- . Changing locations in memory;
- . Checking memory locations when stepping through a program to debug it.

A device which would most probably be needed for debugging the system when it is being installed on the plant and after its control program has been committed to ROM would be a hardware 'program breakpoint'. This is a device which would inhibit the 'ready' signal whenever the address bus compares with an address specified via front panel switches. This would enable the field engineer to insert breakpoints in the control flow of the program during the system checkout phase. Although a similar function was implemented using software on the prototype - remember that random excess memory was used - it would have been useful during program development also.

All the software was developed using the 8008's machine coded instructions. No complex calculations were required and the control functions are relatively simple. A process control orientated macro-assembler with the utility routines mentioned in Chapter 11 plus some general control routines available as some of its functions within the instruction set, would considerably reduce the programming time and complexity in this type of application.

It is doubtful if any conventional compilers or translators would have provided the programmer with the same degree of input/output control and freedom of memory allocation which were considered invaluable during the machine-coded program development.

14.4 SYSTEMS EVALUATION

The problem of whether the system would be fast enough to execute certain control functions led to the development of initial control strategy in which interrupts are disabled for long continuous periods. External devices required to initiate communication with the processor therefore have to 'wait' for considerable periods during certain processing phases. The software techniques to implement

this/.....

this type of strategy is simpler than those for a conventional, "time-shared" system which will, for instance, give the operator the impression that he has continual access to the processor. If the present system is adhered to, the hardware flag register mentioned in Chapter 14.2 (f) will become a necessity. It will 'tell' the operator when the teletype will 'respond' to his 'requests' and will inform other devices (like a controlling computer) when access to the processor is possible.

Initial investigation suggests, however, that the 8008 micro-processor is so fast that the interrupts need never be disabled after the system is initialized. This would enable the programmer to change, for example, the routines communicating with the teletype so that interrupts from the teletype interface would cause immediate control actions rather than just setting a flag in memory.

At present, an interrupt is generated to the processor when all three weighing hoppers are empty. This system has the following disadvantages:

- (i) It will be difficult for external hardware to tell when a weighing hopper is empty because of possible taring errors.
- (ii) It will be difficult to pinpoint an error while the hoppers are being emptied.

A preferable scheme is to let the processor periodically monitor the load cell outputs when the feeders emptying the feeding hoppers are operating. This would enable the individual monitoring of the discharge rates, and thereby facilitate error detection. This also releases one of the interrupt vectors.

14.5 CONCLUSION

The microprocessor provides the control systems designer with an exciting alternative in applications where computer control is desirable. In many such applications, however, conventional mini-computer based systems would be too expensive or too elaborate - like cracking a nut with a sledge hammer. In view of its low price, flexibility and miniature size, the microprocessor is opening up new application areas which previously were not considered.

The features comprising the micro-processor based controller described in this thesis were designed with a specific application in mind. However, only the timing range of the 'timer' and the software developed have any specific characteristics relating to the batch-weighing and feed-mix transportation system of an arc furnace. The fact that such a low cost system (no higher than R1000 in hardware costs) would easily adapt to many entirely different systems underlines the great flexibility of micro-processor based systems.

A flexible, intelligent controller has been developed. The practicability of applying a micro-processor in such an original application as this has been established. Furthermore, the micro-processor based system produces a practical control tool, with a degree of accuracy and with inventory logging facilities which are far cheaper than any offered by competitive analog or digital systems.

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APPENDICES

MICROPROCESSOR SCORECARD

MICROPROCESSOR SCORECARD	CLASSIFICATION	TECHNOLOGY			PARTS FAMILY			FEATURES			ADDRESS CAPACITY			CLOCK (MHz)	REGISTER SIZE (bits)	NUMBER OF CPU REGISTERS			RETURN STACK SIZE (bits)	VOLTAGES REQUIRED	POWER DISSIPATION	TEMPERATURE RANGE (°C)	PACKAGE SIZE (mm)	PRICE RANGE (\$)	STATUS	REMARKS																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																										
		CISC	VLSI	BIOS	RAM	ROM	I/O	DMA	Microprogrammed	Data Memory	BCD Arithmetic	Word Size (bits)	Program Memory			Program Memory	ALU	X									Y	Z	W	V	U	T	S	R	Q	P	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A	9	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-13	-14	-15	-16	-17	-18	-19	-20	-21	-22	-23	-24	-25	-26	-27	-28	-29	-30	-31	-32	-33	-34	-35	-36	-37	-38	-39	-40	-41	-42	-43	-44	-45	-46	-47	-48	-49	-50	-51	-52	-53	-54	-55	-56	-57	-58	-59	-60	-61	-62	-63	-64	-65	-66	-67	-68	-69	-70	-71	-72	-73	-74	-75	-76	-77	-78	-79	-80	-81	-82	-83	-84	-85	-86	-87	-88	-89	-90	-91	-92	-93	-94	-95	-96	-97	-98	-99	-100	-101	-102	-103	-104	-105	-106	-107	-108	-109	-110	-111	-112	-113	-114	-115	-116	-117	-118	-119	-120	-121	-122	-123	-124	-125	-126	-127	-128	-129	-130	-131	-132	-133	-134	-135	-136	-137	-138	-139	-140	-141	-142	-143	-144	-145	-146	-147	-148	-149	-150	-151	-152	-153	-154	-155	-156	-157	-158	-159	-160	-161	-162	-163	-164	-165	-166	-167	-168	-169	-170	-171	-172	-173	-174	-175	-176	-177	-178	-179	-180	-181	-182	-183	-184	-185	-186	-187	-188	-189	-190	-191	-192	-193	-194	-195	-196	-197	-198	-199	-200	-201	-202	-203	-204	-205	-206	-207	-208	-209	-210	-211	-212	-213	-214	-215	-216	-217	-218	-219	-220	-221	-222	-223	-224	-225	-226	-227	-228	-229	-230	-231	-232	-233	-234	-235	-236	-237	-238	-239	-240	-241	-242	-243	-244	-245	-246	-247	-248	-249	-250	-251	-252	-253	-254	-255	-256	-257	-258	-259	-260	-261	-262	-263	-264	-265	-266	-267	-268	-269	-270	-271	-272	-273	-274	-275	-276	-277	-278	-279	-280	-281	-282	-283	-284	-285	-286	-287	-288	-289	-290	-291	-292	-293	-294	-295	-296	-297	-298	-299	-300	-301	-302	-303	-304	-305	-306	-307	-308	-309	-310	-311	-312	-313	-314	-315	-316	-317	-318	-319	-320	-321	-322	-323	-324	-325	-326	-327	-328	-329	-330	-331	-332	-333	-334	-335	-336	-337	-338	-339	-340	-341	-342	-343	-344	-345	-346	-347	-348	-349	-350	-351	-352	-353	-354	-355	-356	-357	-358	-359	-360	-361	-362	-363	-364	-365	-366	-367	-368	-369	-370	-371	-372	-373	-374	-375	-376	-377	-378	-379	-380	-381	-382	-383	-384	-385	-386	-387	-388	-389	-390	-391	-392	-393	-394	-395	-396	-397	-398	-399	-400	-401	-402	-403	-404	-405	-406	-407	-408	-409	-410	-411	-412	-413	-414	-415	-416	-417	-418	-419	-420	-421	-422	-423	-424	-425	-426	-427	-428	-429	-430	-431	-432	-433	-434	-435	-436	-437	-438	-439	-440	-441	-442	-443	-444	-445	-446	-447	-448	-449	-450	-451	-452	-453	-454	-455	-456	-457	-458	-459	-460	-461	-462	-463	-464	-465	-466	-467	-468	-469	-470	-471	-472	-473	-474	-475	-476	-477	-478	-479	-480	-481	-482	-483	-484	-485	-486	-487	-488	-489	-490	-491	-492	-493	-494	-495	-496	-497	-498	-499	-500	-501	-502	-503	-504	-505	-506	-507	-508	-509	-510	-511	-512	-513	-514	-515	-516	-517	-518	-519	-520	-521	-522	-523	-524	-525	-526	-527	-528	-529	-530	-531	-532	-533	-534	-535	-536	-537	-538	-539	-540	-541	-542	-543	-544	-545	-546	-547	-548	-549	-550	-551	-552	-553	-554	-555	-556	-557	-558	-559	-560	-561	-562	-563	-564	-565	-566	-567	-568	-569	-570	-571	-572	-573	-574	-575	-576	-577	-578	-579	-580	-581	-582	-583	-584	-585	-586	-587	-588	-589	-590	-591	-592	-593	-594	-595	-596	-597	-598	-599	-600	-601	-602	-603	-604	-605	-606	-607	-608	-609	-610	-611	-612	-613	-614	-615	-616	-617	-618	-619	-620	-621	-622	-623	-624	-625	-626	-627	-628	-629	-630	-631	-632	-633	-634	-635	-636	-637	-638	-639	-640	-641	-642	-643	-644	-645	-646	-647	-648	-649	-650	-651	-652	-653	-654	-655	-656	-657	-658	-659	-660	-661	-662	-663	-664	-665	-666	-667	-668	-669	-670	-671	-672	-673	-674	-675	-676	-677	-678	-679	-680	-681	-682	-683	-684	-685	-686	-687	-688	-689	-690	-691	-692	-693	-694	-695	-696	-697	-698	-699	-700	-701	-702	-703	-704	-705	-706	-707	-708	-709	-710	-711	-712	-713	-714	-715	-716	-717	-718	-719	-720	-721	-722	-723	-724	-725	-726	-727	-728	-729	-730	-731	-732	-733	-734	-735	-736	-737	-738	-739	-740	-741	-742	-743	-744	-745	-746	-747	-748	-749	-750	-751	-752	-753	-754	-755	-756	-757	-758	-759	-760	-761	-762	-763	-764	-765	-766	-767	-768	-769	-770	-771	-772	-773	-774	-775	-776	-777	-778	-779	-780	-781	-782	-783	-784	-785	-786	-787	-788	-789	-790	-791	-792	-793	-794	-795	-796	-797	-798	-799	-800	-801	-802	-803	-804	-805	-806	-807	-808	-809	-810	-811	-812	-813	-814	-815	-816	-817	-818	-819	-820	-821	-822	-823	-824	-825	-826	-827	-828	-829	-830	-831	-832	-833	-834	-835	-836	-837	-838	-839	-840	-841	-842	-843	-844	-845	-846	-847	-848	-849	-850	-851	-852	-853	-854	-855	-856	-857	-858	-859	-860	-861	-862	-863	-864	-865	-866	-867	-868	-869	-870	-871	-872	-873	-874	-875	-876	-877	-878	-879	-880	-881	-882	-883	-884	-885	-886	-887	-888	-889	-890	-891	-892	-893	-894	-895	-896	-897	-898	-899	-900	-901	-902	-903	-904	-905	-906	-907	-908	-909	-910	-911	-912	-913	-914	-915	-916	-917	-918	-919	-920	-921	-922	-923	-924	-925	-926	-927	-928	-929	-930	-931	-932	-933	-934	-935	-936	-937	-938	-939	-940	-941	-942	-943	-944	-945	-946	-947	-948	-949	-950	-951	-952	-953	-954	-955	-956	-957	-958	-959	-960	-961	-962	-963	-964	-965	-966	-967	-968	-969	-970	-971	-972	-973	-974	-975	-976	-977	-978	-979	-980	-981	-982	-983

APPENDIX 2 - 8008 DATA

I. INTRODUCTION

The 8008 is a single chip MOS 8-bit parallel central processor unit for the MCS-8 micro computer system. A micro computer system is formed when the 8008 is interfaced with any type or speed standard semiconductor memory up to 16K 8-bit words. Examples are INTEL's 1101, 1103, 2102 (RAMs), 1302, 1602A, 1702A (ROMs), 1404, 2405 (Shift Registers).

The processor communicates over an 8-bit data and address bus (D_0 through D_7) and uses two input leads (READY and INTERRUPT) and four output leads (S_0 , S_1 , S_2 and Sync) for control. Time multiplexing of the data bus allows control information, 14 bit addresses, and data to be transmitted between the CPU and external memory.

This CPU contains six 8-bit data registers, an 8-bit accumulator, two 8-bit temporary registers, four flag bits, and an 8-bit parallel binary arithmetic unit which implements addition, subtraction, and logical operations. A memory stack containing a 14-bit program counter and seven 14-bit words is used internally to store program and subroutine addresses. The 14-bit address permits the direct addressing of 16K words of memory (any mix of RAM, ROM or S.R.).

The control portion of the chip contains logic to implement a variety of register transfer, arithmetic control, and logical instructions. Most instructions are coded in one byte (8 bits); data immediate instructions use two bytes; jump instructions utilize three bytes. Operating with a 500kHz clock, the 8008 CPU executes non-memory referencing instructions in 20 microseconds. A selected device, the 8008-1, executes non-memory referencing instructions in 12.5 microseconds when operating from an 800kHz clock.

All inputs (including clocks) are TTL compatible and all outputs are low-power TTL compatible.

The instruction set of the 8008 consists of 48 instructions including data manipulation, binary arithmetic, and jump to subroutine.

The normal program flow of the 8008 may be interrupted through the use of the "INTERRUPT" control line. This allows the servicing of slow I/O peripheral devices while also executing the main program.

The "READY" command line synchronizes the 8008 to the memory cycle allowing any type or speed of semiconductor memory to be used.

STATE and SYNC outputs indicate the state of the processor at any time in the instruction cycle.

II. PROCESSOR TIMING

The 8008 is a complete central processing unit intended for use in any arithmetic, control, or decision-making system. The internal organization is centered around an 8-bit internal data bus. All communication within the processor and with external components occurs on this bus in the form of 8-bit bytes of address, instruction or data. (Refer to the accompanying block diagram for the relationship of all of the internal elements of the processor to each other and to the data bus.) For the MCS-8 a logic "1" is defined as a high level and a logic "0" is defined as a low level.

A. State Control Coding

The processor controls the use of the data bus and determines whether it will be sending or receiving data. State signals S₀, S₁, and S₂, along with SYNC inform the peripheral circuitry of the state of the processor. A table of the binary state codes and the designated state names is shown below.

S ₀	S ₁	S ₂	STATE
0	1	0	T1
0	1	1	T1I
0	0	1	T2
0	0	0	WAIT
1	0	0	T3
1	1	0	STOPPED
1	1	1	T4
1	0	1	T5

B. Timing

Typically, a machine cycle consists of five states, two states in which an address is sent to memory (T1 and T2), one for the instruction or data fetch (T3), and two states for the execution of the instruction (T4 and T5). If the processor is used with slow memories, the READY line synchronizes the processor with the memories. When the memories are not available for either sending or receiving data, the processor goes into the WAIT state. The accompanying diagram illustrates the processor activity during a single cycle.

Figure 1. Basic 8008 Instruction Cycle

The receipt of an INTERRUPT is acknowledged by the T11. When the processor has been interrupted, this state replaces T1. A READY is acknowledged by T3. The STOPPED state acknowledges the receipt of a HALT instruction.

Many of the instructions for the 8008 are multi-cycle and do not require the two execution states, T4 and T5. As a result, these states are omitted when they are not needed and the 8008 operates asynchronously with respect to the cycle length. The external state transition is shown below. Note that the WAIT state and the STOPPED may be indefinite in length (each of these states will be 2n clock periods). The use of READY and INTERRUPT with regard to these states will be explained later.

Figure 2. CPU State Transition Diagram

C. Cycle Control Coding

As previously noted, instructions for the 8008 require one, two, or three machine cycles for complete execution. The first cycle is always an instruction fetch cycle (PCI). The second and third cycles are for data reading (PCR), data writing (PCW), or I/O operations (PCC).

The cycle types are coded with two bits, D₆ and D₇, and are only present on the data bus during T2.

D ₆	D ₇	CYCLE	FUNCTION
0	0	PCI	Designates the address is for a memory read (first byte of instruction).
0	1	PCR	Designates the address is for a memory read data (additional bytes of instruction or data).
1	0	PCC	Designates the data as a command I/O operation.
1	1	PCW	Designates the address is for a memory write data.

Figure 3. 8008 Block Diagram

III. BASIC FUNCTIONAL BLOCKS

The four basic functional blocks of this Intel processor are the instruction register, memory, arithmetic logic unit, and I/O buffers. They communicate with each other over the internal 8-bit data bus.

A. Instruction Register and Control

The instruction register is the heart of all processor control. Instructions are fetched from memory, stored in the instruction register, and decoded for control of both the memories and the ALU. Since instruction executions do not all require the same number of states, the instruction decoder also controls the state transitions.

B. Memory

Two separate dynamic memories are used in the 8008, the pushdown address stack and a scratch pad. These internal memories are automatically refreshed by each WAIT, T3, and STOPPED state. In the worst case the memories are completely refreshed every eighty clock periods.

1. Address Stack

The address stack contains eight 14-bit registers providing storage for eight lower and six higher order address bits in each register. One register is used as the program counter (storing the effective address) and the other seven permit address storage for nesting of subroutines up to seven levels. The stack automatically stores the content of the program counter upon the execution of a CALL instruction and automatically restores the program counter upon the execution of a RETURN. The CALLs may be nested and the registers of the stack are used as last in/first out pushdown stack. A three-bit address pointer is used to designate the present location of the program counter. When the capacity of the stack is exceeded the address pointer recycles and the content of the lowest level register is destroyed. The program counter is incremented immediately after the lower order address bits are sent out. The higher order address bits are sent out at T2 and then incremented if a carry resulted from T1. The 14-bit program counter provides direct addressing of 16K bytes of memory. Through the use of an I/O instruction for bank switching, memory may be indefinitely expanded.

2. Scratch Pad Memory or Index Registers

The scratch pad contains the accumulator (A register) and six additional 8-bit registers (B, C, D, E, H, L). All arithmetic operations use the accumulator as one of the operands. All registers are independent and may be used for temporary storage. In the case of instructions which require operations with a register in external memory, scratch pad registers H & L provide indirect addressing capability; register L contains the eight lower order bits of address and register H contains the six higher order bits of address (in this case bit 6 and bit 7 are "don't cares").

C. Arithmetic/Logic Unit (ALU)

All arithmetic and logical operations (ADD, ADD with carry, SUBTRACT, SUBTRACT with borrow, AND, EXCLUSIVE OR, OR, COMPARE, INCREMENT, DECREMENT) are carried out in the 8-bit parallel arithmetic unit which includes carry-look-ahead logic. Two temporary registers, register "a" and register "b", are used to store the accumulator and operand for ALU operations. In addition, they are used for temporary address and data storage during intra-processor transfers. Four control bits, carry flip-flop (c), zero flip-flop (z), sign flip-flop (s), and parity flip-flop (p), are set as the result of each arithmetic and logical operation. These bits provide conditional branching capability through CALL, JUMP, or RETURN on condition instructions. In addition, the carry bit provides the ability to do multiple precision binary arithmetic.

D. I/O Buffer

This buffer is the only link between the processor and the rest of the system. Each of the eight buffers is bi-directional and is under control of the instruction register and state timing. Each of the buffers is low power TTL compatible on the output and TTL compatible on the input.

IV. BASIC INSTRUCTION SET

The following section presents the basic instruction set of the 8008.

A. Data and Instruction Formats

Data in the 8008 is stored in the form of 8-bit binary integers. All data transfers to the system data bus will be in the same format.

D ₇	D ₆	D ₅	D ₄	D ₃	D ₂	D ₁	D ₀
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DATA WORD

The program instructions may be one, two, or three bytes in length. Multiple byte instructions must be stored in successive words in program memory. The instruction formats then depend on the particular operation executed.

One Byte Instructions

D ₇	D ₆	D ₅	D ₄	D ₃	D ₂	D ₁	D ₀
----------------	----------------	----------------	----------------	----------------	----------------	----------------	----------------

OP CODE

Two Byte Instructions

D ₇	D ₆	D ₅	D ₄	D ₃	D ₂	D ₁	D ₀
----------------	----------------	----------------	----------------	----------------	----------------	----------------	----------------

OP CODE

D ₇	D ₆	D ₅	D ₄	D ₃	D ₂	D ₁	D ₀
----------------	----------------	----------------	----------------	----------------	----------------	----------------	----------------

OPERAND

Three Byte Instructions

D ₇	D ₆	D ₅	D ₄	D ₃	D ₂	D ₁	D ₀
----------------	----------------	----------------	----------------	----------------	----------------	----------------	----------------

OP CODE

D ₇	D ₆	D ₅	D ₄	D ₃	D ₂	D ₁	D ₀
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LOW ADDRESS

X	X	D ₅	D ₄	D ₃	D ₂	D ₁	D ₀
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HIGH ADDRESS*

TYPICAL INSTRUCTIONS

Register to register, memory reference, I/O arithmetic or logical, rotate or return instructions

Immediate mode instructions

JUMP or CALL instructions

*For the third byte of this instruction, D₆ and D₇ are "don't care" bits.

For the MCS-8 a logic "1" is defined as a high level and a logic "0" is defined as a low level.

B. Summary of Processor Instructions

Index Register Instructions

The load instructions do not affect the flag flip-flops. The increment and decrement instructions affect all flip-flops except the carry.

MNEMONIC	MINIMUM STATES REQUIRED	INSTRUCTION CODE D ₇ D ₆ D ₅ D ₄ D ₃ D ₂ D ₁ D ₀	DESCRIPTION OF OPERATION
(1) Lr ₁ r ₂	(5)	1 1 D D D S S S	Load index register r ₁ with the content of index register r ₂ .
(2) LrM	(8)	1 1 D D D 1 1 1	Load index register r with the content of memory register M.
LMr	(7)	1 1 1 1 1 S S S	Load memory register M with the content of index register r.
(3) LrI	(8)	0 0 D D D 1 1 0 B B B B B B B	Load index register r with data B . . . B.
LMI	(9)	0 0 1 1 1 1 1 0 B B B B B B B	Load memory register M with data B . . . B.
INr	(5)	0 0 D D D 0 0 0	Increment the content of index register r (r ≠ A).
DCr	(5)	0 0 D D D 0 0 1	Decrement the content of index register r (r ≠ A).

Accumulator Group Instructions

The result of the ALU instructions affect all of the flag flip-flops. The rotate instructions affect only the carry flip-flop.

ADr	(5)	1 0 0 0 0 S S S	Add the content of index register r, memory register M, or data B . . . B to the accumulator. An overflow (carry) sets the carry flip-flop.
ADM	(8)	1 0 0 0 0 1 1 1	
ADI	(8)	0 0 0 0 0 1 0 0 B B B B B B B	
ACr	(5)	1 0 0 0 1 S S S	Add the content of index register r, memory register M, or data B . . . B to the accumulator with carry. An overflow (carry) sets the carry flip-flop.
ACM	(8)	1 0 0 0 1 1 1 1	
ACI	(8)	0 0 0 0 1 1 0 0 B B B B B B B	
SUr	(5)	1 0 0 1 0 S S S	Subtract the content of index register r, memory register M, or data B . . . B from the accumulator. An underflow (borrow) sets the carry flip-flop.
SUM	(8)	1 0 0 1 0 1 1 1	
SUI	(8)	0 0 0 1 0 1 0 0 B B B B B B B	
SBr	(5)	1 0 0 1 1 S S S	Subtract the content of index register r, memory register M, or data B . . . B from the accumulator with borrow. An underflow (borrow) sets the carry flip-flop.
\$BM	(8)	1 0 0 1 1 1 1 1	
\$BI	(8)	0 0 0 1 1 1 0 0 B B B B B B B	

MNEMONIC	MINIMUM STATES REQUIRED	INSTRUCTION CODE						DESCRIPTION OF OPERATION
		D ₇ D ₆	D ₅ D ₄ D ₃	D ₂ D ₁ D ₀				
NDr	(5)	1 0	1 0 0	S S S	Compute the logical AND of the content of index register r, memory register M, or data B . . . B with the accumulator.			
NDM	(8)	1 0	1 0 0	1 1 1				
NDI	(8)	0 0	1 0 0	1 0 0				
		B B	B B B	B B B				
XRr	(5)	1 0	1 0 1	S S S	Compute the EXCLUSIVE OR of the content of index register r, memory register M, or data B . . . B with the accumulator.			
XRM	(8)	1 0	1 0 1	1 1 1				
XRI	(8)	0 0	1 0 1	1 0 0				
		B B	B B B	B B B				
ORr	(5)	1 0	1 1 0	S S S	Compute the INCLUSIVE OR of the content of index register r, memory register m, or data B . . . B with the accumulator.			
ORM	(8)	1 0	1 1 0	1 1 1				
ORI	(8)	0 0	1 1 0	1 0 0				
		B B	B B B	B B B				
CPr	(5)	1 0	1 1 1	S S S	Compare the content of index register r, memory register M, or data B . . . B with the accumulator. The content of the accumulator is unchanged.			
CPM	(8)	1 0	1 1 1	1 1 1				
CPI	(8)	0 0	1 1 1	1 0 0				
		B B	B B B	B B B				
RLC	(5)	0 0	0 0 0	0 1 0	Rotate the content of the accumulator left.			
RRC	(5)	0 0	0 0 1	0 1 0	Rotate the content of the accumulator right.			
RAL	(5)	0 0	0 1 0	0 1 0	Rotate the content of the accumulator left through the carry.			
RAR	(5)	0 0	0 1 1	0 1 0	Rotate the content of the accumulator right through the carry.			

Program Counter and Stack Control Instructions

(4) JMP	(11)	0 1	X X X	1 0 0				Unconditionally jump to memory address B ₃ . . . B ₃ B ₂ . . . B ₂ .
		B ₂ B ₂	B ₂ B ₂ B ₂	B ₂ B ₂ B ₂				
		X X	B ₃ B ₃ B ₃	B ₃ B ₃ B ₃				
(5) JFc	(9 or 11)	0 1	0 C ₄ C ₃	0 0 0				Jump to memory address B ₃ . . . B ₃ B ₂ . . . B ₂ if the condition flip-flop c is false. Otherwise, execute the next instruction in sequence.
		B ₂ B ₂	B ₂ B ₂ B ₂	B ₂ B ₂ B ₂				
		X X	B ₃ B ₃ B ₃	B ₃ B ₃ B ₃				
JTc	(9 or 11)	0 1	1 C ₄ C ₃	0 0 0				Jump to memory address B ₃ . . . B ₃ B ₂ . . . B ₂ if the condition flip-flop c is true. Otherwise, execute the next instruction in sequence.
		B ₂ B ₂	B ₂ B ₂ B ₂	B ₂ B ₂ B ₂				
		X X	B ₃ B ₃ B ₃	B ₃ B ₃ B ₃				
CAL	(11)	0 1	X X X	1 1 0				Unconditionally call the subroutine at memory address B ₃ . . . B ₃ B ₂ . . . B ₂ . Save the current address (up one level in the stack).
		B ₂ B ₂	B ₂ B ₂ B ₂	B ₂ B ₂ B ₂				
		X X	B ₃ B ₃ B ₃	B ₃ B ₃ B ₃				
CFc	(9 or 11)	0 1	0 C ₄ C ₃	0 1 0				Call the subroutine at memory address B ₃ . . . B ₃ B ₂ . . . B ₂ if the condition flip-flop c is false, and save the current address (up one level in the stack.) Otherwise, execute the next instruction in sequence.
		B ₂ B ₂	B ₂ B ₂ B ₂	B ₂ B ₂ B ₂				
		X X	B ₃ B ₃ B ₃	B ₃ B ₃ B ₃				
CTc	(9 or 11)	0 1	1 C ₄ C ₃	0 1 0				Call the subroutine at memory address B ₃ . . . B ₃ B ₂ . . . B ₂ if the condition flip-flop c is true, and save the current address (up one level in the stack). Otherwise, execute the next instruction in sequence.
		B ₂ B ₂	B ₂ B ₂ B ₂	B ₂ B ₂ B ₂				
		X X	B ₃ B ₃ B ₃	B ₃ B ₃ B ₃				
RET	(5)	0 0	X X X	1 1 1				Unconditionally return (down one level in the stack).
RFc	(3 or 5)	0 0	0 C ₄ C ₃	0 1 1				Return (down one level in the stack) if the condition flip-flop c is false. Otherwise, execute the next instruction in sequence.
RTc	(3 or 5)	0 0	1 C ₄ C ₃	0 1 1				Return (down one level in the stack) if the condition flip-flop c is true. Otherwise, execute the next instruction in sequence.
RST	(5)	0 0	A A A	1 0 1				Call the subroutine at memory address AAA000 (up one level in the stack).

Input/Output Instructions

INP	(8)	0 1	0 0 M	M M 1				Read the content of the selected input port (MMM) into the accumulator.
OUT	(6)	0 1	R R M	M M 1				Write the content of the accumulator into the selected output port (RRMMM, RR ≠ 00).

Machine Instruction

HLT	(4)	0 0	0 0 0	0 0 X				Enter the STOPPED state and remain there until interrupted.
HLT	(4)	1 1	1 1 1	1 1 1				Enter the STOPPED state and remain there until interrupted.

NOTES:

- (1) SSS = Source Index Register
DDD = Destination Index Register } These registers, r, are designated A(accumulator-000), B(001), C(010), D(011), E(100), H(101), L(110).
- (2) Memory registers are addressed by the contents of registers H & L.
- (3) Additional bytes of instruction are designated by BBBBBBBB.
- (4) X = "Don't Care".
- (5) Flag flip-flops are defined by C₄C₃: carry (00=overflow or underflow), zero (01=result is zero), sign (10=MSB of result is "1"), parity (11=parity is even).

C. Complete Functional Definition

The following pages present a detailed description of the complete 8008 Instruction Set.

Symbols	Meaning	
<B2>	Second byte of the instruction	
<B3>	Third byte of the instruction	
r	One of the scratch pad register references: A, B, C, D, E, H, L	
c	One of the following flag flip-flop references: C, Z, S, P	
C ₄ C ₃	Flag flip-flop codes	
	Condition for True	
00	carry	Overflow, underflow
01	zero	Result is zero
10	sign	MSB of result is "1"
11	parity	Parity of result is even
M	Memory location indicated by the contents of registers H and L	
()	Contents of location or register	
Λ	Logical product	
⊕	Exclusive "or"	
∨	Inclusive "or"	
A _m	Bit m of the A-register	
STACK	Instruction counter (P) pushdown register	
P	Program Counter	
←	Is transferred to	
XXX	A "don't care"	
SSS	Source register for data	
DDD	Destination register for data	
	Register #	Register Name
	(SSS or DDD)	
	000	A
	001	B
	010	C
	011	D
	100	E
	101	H
	110	L

INDEX REGISTER INSTRUCTIONS

LOAD DATA TO INDEX REGISTERS – One Byte

Data may be loaded into or moved between any of the index registers, or memory registers.

Lr_1r_2 (one cycle – PCI)	11	DDD	SSS	$(r_1) \leftarrow (r_2)$ Load register r_1 with the content of r_2 . The content of r_2 remains unchanged. If $SSS=DDD$, the instruction is a NOP (no operation).
LrM (two cycles – PCI/PCR)	11	DDD	111	$(r) \leftarrow (M)$ Load register r with the content of the memory location addressed by the contents of registers H and L. ($DDD \neq 111$ – HALT instr.)
LMr (two cycles – PCI/PCW)	11	111	SSS	$(M) \leftarrow (r)$ Load the memory location addressed by the contents of registers H and L with the content of register r . ($SSS \neq 111$ – HALT instr.)

LOAD DATA IMMEDIATE – Two Bytes

A byte of data immediately following the instruction may be loaded into the processor or into the memory

LrI (two cycles – PCI/PCR)	00	DDD	110	$(r) \leftarrow \langle B_2 \rangle$ Load byte two of the instruction into register r .
LMI (three cycles – PCI/PCR/PCW)	00	111	110	$(M) \leftarrow \langle B_2 \rangle$ Load byte two of the instruction into the memory location addressed by the contents of registers H and L.

INCREMENT INDEX REGISTER – One Byte

INr (one cycle – PCI)	00	DDD	000	$(r) \leftarrow (r)+1$. The content of register r is incremented by one. All of the condition flip-flops except carry are affected by the result. Note that $DDD \neq 000$ (HALT instr.) and $DDD \neq 111$ (content of memory may not be incremented).
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DECREMENT INDEX REGISTER – One Byte

DCr (one cycle – PCI)	00	DDD	001	$(r) \leftarrow (r)-1$. The content of register r is decremented by one. All of the condition flip-flops except carry are affected by the result. Note that $DDD \neq 000$ (HALT instr.) and $DDD \neq 111$ (content of memory may not be decremented).
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ACCUMULATOR GROUP INSTRUCTIONS

Operations are performed and the status flip-flops, C, Z, S, P, are set based on the result of the operation. Logical operations (NDR, XRR, ORR) set the carry flip-flop to zero. Rotate operations affect only the carry flip-flop. Two's complement subtraction is used.

ALU INDEX REGISTER INSTRUCTIONS – One Byte

(one cycle – PCI)

Index Register operations are carried out between the accumulator and the content of one of the index registers ($SSS=000$ thru $SSS=110$). The previous content of register SSS is unchanged by the operation.

ADr	10	000	SSS	$(A) \leftarrow (A)+(r)$ Add the content of register r to the content of register A and place the result into register A.
ACr	10	001	SSS	$(A) \leftarrow (A)+(r)+(\text{carry})$ Add the content of register r and the contents of the carry flip-flop to the content of the A register and place the result into Register A.
SUr	10	010	SSS	$(A) \leftarrow (A)-(r)$ Subtract the content of register r from the content of register A and place the result into register A. Two's complement subtraction is used.

ACCUMULATOR GROUP INSTRUCTIONS - Cont'd.

SBr	10	011	SSS	$(A) \leftarrow (A) - (r) - (\text{borrow})$ Subtract the content of register r and the content of the carry flip-flop from the content of register A and place the result into register A.
NDr	10	100	SSS	$(A) \leftarrow (A) \wedge (r)$ Place the logical product of the register A and register r into register A.
XRr	10	101	SSS	$(A) \leftarrow (A) \vee (r)$ Place the "exclusive - or" of the content of register A and register r into register A.
ORr	10	110	SSS	$(A) \leftarrow (A) \vee (r)$ Place the "inclusive - or" of the content of register A and register r into register A.
CPr	10	111	SSS	$(A) - (r)$ Compare the content of register A with the content of register r. The content of register A remains unchanged. The flag flip-flops are set by the result of the subtraction. Equality ($A=r$) is indicated by the zero flip-flop set to "1". Less than ($A < r$) is indicated by the carry flip-flop, set to "1".

ALU OPERATIONS WITH MEMORY - One Byte

(two cycles - PCI/PCR)

Arithmetic and logical operations are carried out between the accumulator and the byte of data addressed by the contents of registers H and L.

ADM	10	000	111	$(A) \leftarrow (A) + (M)$ ADD
ACM	10	001	111	$(A) \leftarrow (A) + (M) + (\text{carry})$ ADD with carry
SUM	10	010	111	$(A) \leftarrow (A) - (M)$ SUBTRACT
SBM	10	011	111	$(A) \leftarrow (A) - (M) - (\text{borrow})$ SUBTRACT with borrow
NDM	10	100	111	$(A) \leftarrow (A) \wedge (M)$ Logical AND
XRM	10	101	111	$(A) \leftarrow (A) \vee (M)$ Exclusive OR
ORM	10	110	111	$(A) \leftarrow (A) \vee (M)$ Inclusive OR
CPM	10	111	111	$(A) - (M)$ COMPARE

ALU IMMEDIATE INSTRUCTIONS - Two Bytes

(two cycles - PCI/PCR)

Arithmetic and logical operations are carried out between the accumulator and the byte of data immediately following the instruction.

ADI	00	000	100	$(A) \leftarrow (A) + \langle B_2 \rangle$ ADD
ACI	00	001	100	$(A) \leftarrow (A) + \langle B_2 \rangle + (\text{carry})$ ADD with carry
SUI	00	010	100	$(A) \leftarrow (A) - \langle B_2 \rangle$ SUBTRACT
SBI	00	011	100	$(A) \leftarrow (A) - \langle B_2 \rangle - (\text{borrow})$ SUBTRACT with borrow
NDI	00	100	100	$(A) \leftarrow (A) \wedge \langle B_2 \rangle$ Logical AND
XRI	00	101	100	$(A) \leftarrow (A) \vee \langle B_2 \rangle$ Exclusive OR
ORI	00	110	100	$(A) \leftarrow (A) \vee \langle B_2 \rangle$ Inclusive OR
CPI	00	111	100	$(A) - \langle B_2 \rangle$ COMPARE

ROTATE INSTRUCTIONS – One Byte

(one cycle – PCI)

The accumulator content (register A) may be rotated either right or left, around the carry bit or through the carry bit. Only the carry flip-flop is affected by these instructions; the other flags are unchanged.

RLC	00 000 010	$A_{m+1} \leftarrow A_m, A_0 \leftarrow A_7, (\text{carry}) \leftarrow A_7$ Rotate the content of register A left one bit. Rotate A_7 into A_0 and into the carry flip-flop.
RRC	00 001 010	$A_m \leftarrow A_{m+1}, A_7 \leftarrow A_0, (\text{carry}) \leftarrow A_0$ Rotate the content of register A right one bit. Rotate A_0 into A_7 and into the carry flip-flop.
RAL	00 010 010	$A_{m+1} \leftarrow A_m, A_0 \leftarrow (\text{carry}), (\text{carry}) \leftarrow A_7$ Rotate the content of Register A left one bit. Rotate the content of the carry flip-flop into A_0 . Rotate A_7 into the carry flip-flop.
RAR	00 011 010	$A_m \leftarrow A_{m+1}, A_7 \leftarrow (\text{carry}), (\text{carry}) \leftarrow A_0$ Rotate the content of register A right one bit. Rotate the content of the carry flip-flop into A_7 . Rotate A_0 into the carry flip-flop.

PROGRAM COUNTER AND STACK CONTROL INSTRUCTIONS

JUMP INSTRUCTIONS – Three Bytes

(three cycles – PCI/PCR/PCR)

Normal flow of the microprogram may be altered by jumping to an address specified by bytes two and three of an instruction.

JMP (Jump Unconditionally)	01 XXX 100 < B_2 > < B_3 >	$(P) \leftarrow \langle B_3 \rangle \langle B_2 \rangle$ Jump unconditionally to the instruction located in memory location addressed by byte two and byte three.
JFc (Jump if Condition False)	01 0C ₄ C ₃ 000 < B_2 > < B_3 >	If (c) = 0, $(P) \leftarrow \langle B_3 \rangle \langle B_2 \rangle$. Otherwise, $(P) = (P)+3$. If the content of flip-flop c is zero, then jump to the instruction located in memory location $\langle B_3 \rangle \langle B_2 \rangle$; otherwise, execute the next instruction in sequence.
JTc (Jump if Condition True)	01 1C ₄ C ₃ 000 < B_2 > < B_3 >	If (c) = 1, $(P) \leftarrow \langle B_3 \rangle \langle B_2 \rangle$. Otherwise, $(P) = (P)+3$. If the content of flip-flop c is one, then jump to the instruction located in memory location $\langle B_3 \rangle \langle B_2 \rangle$; otherwise, execute the next instruction in sequence.

CALL INSTRUCTIONS – Three Bytes

(three cycles – PCI/PCR/PCR)

Subroutines may be called and nested up to seven levels.

CAL (Call subroutine Unconditionally)	01 XXX 110 < B_2 > < B_3 >	$(\text{Stack}) \leftarrow (P), (P) \leftarrow \langle B_3 \rangle \langle B_2 \rangle$. Shift the content of P to the pushdown stack. Jump unconditionally to the instruction located in memory location addressed by byte two and byte three.
CFc (Call subroutine if Condition False)	01 0C ₄ C ₃ 010 < B_2 > < B_3 >	If (c) = 0, $(\text{Stack}) \leftarrow (P), (P) \leftarrow \langle B_3 \rangle \langle B_2 \rangle$. Otherwise, $(P) = (P)+3$. If the content of flip-flop c is zero, then shift contents of P to the pushdown stack and jump to the instruction located in memory location $\langle B_3 \rangle \langle B_2 \rangle$; otherwise, execute the next instruction in sequence.
CTc (Call subroutine if Condition True)	01 1C ₄ C ₃ 010 < B_2 > < B_3 >	If (c) = 1, $(\text{Stack}) \leftarrow (P), (P) \leftarrow \langle B_3 \rangle \langle B_2 \rangle$. Otherwise, $(P) = (P)+3$. If the content of flip-flop c is one, then shift contents of P to the pushdown stack and jump to the instruction located in memory location $\langle B_3 \rangle \langle B_2 \rangle$; otherwise, execute the next instruction in sequence.

In the above JUMP and CALL instructions $\langle B_2 \rangle$ contains the least significant half of the address and $\langle B_3 \rangle$ contains the most significant half of the address. Note that D_6 and D_7 of $\langle B_3 \rangle$ are "don't care" bits since the CPU uses fourteen bits of address.

RETURN INSTRUCTIONS.— One Byte

(one cycle – PCI)

A return instruction may be used to exit from a subroutine; the stack is popped-up one level at a time.

RET 00 XXX 111

(P) $\leftarrow$ (Stack). Return to the instruction in the memory location addressed by the last value shifted into the pushdown stack. The stack pops up one level.

Rfc 00 0C₄C₃ 011
(Return Condition
False)

(Return Condition
False)

If $(c) = 0$, $(P) \leftarrow (\text{Stack})$; otherwise, $(P) = (P) + 1$.

If the content of flip-flop c is zero, then return to the instruction in the memory location addressed by the last value inserted in the pushdown stack. The stack pops up one level. Otherwise, execute the next instruction in sequence.

RTc 00 1C₄C₃ 011
(Return Condition True)

(Return Condition True)

If $(c) = 1$, $(P) \leftarrow (\text{Stack})$; otherwise, $(P) = (P) + 1$.

If the content of flip-flop c is one, then return to the instruction in the memory location addressed by the last value inserted in the pushdown stack. The stack pops up one level. Otherwise, execute the next instruction in sequence.

RESTART INSTRUCTION – One Byte

(one cycle – PCI)

The restart instruction acts as a one byte call on eight specified locations of page 0, the first 256 instruction words.

RST 00 AAA 101

(Stack) ← (P), (P) ← (000000 00AA000)

Shift the contents of P to the pushdown stack.

The content, AAA, of the instruction register is shifted into bits 3 through 5 of the P-counter. All other bits of the P-counter are set to zero. As a one-word "call", eight eight-byte subroutines may be accessed in the lower 64 words of memory.

INPUT/OUTPUT INSTRUCTIONS

One Byte

(two cycles – PCI/PCC)

Eight input devices may be referenced by the input instruction

INP **01** **OOM** **MM1**

(A)→(input data lines). The content of register A is made available to external equipment at state T1 of the PCC cycle. The content of the instruction register is made available to external equipment at state T2 of the PCC cycle. New data for the accumulator is loaded at T3 of the PCC cycle.

MMM denotes input device number. The content of the condition flip-flops, S,Z,P,C, is output on D₀, D₁, D₂, D₃ respectively at T4 on the PCC cycle.

Twenty-four output devices may be referenced by the output instruction.

OUT 01 RRM MM1

(Output data lines)→(A). The content of register A is made available to external equipment at state T1 and the content of the instruction register is made available to external equipment at state T2 of the PCC cycle. RRRMM denotes output device number (RR ≠ 00).

MACHINE INSTRUCTION

HALT INSTRUCTION – One Byte

(one cycle – PCI)

```

HLT          00  000  00X
              or
              11  111  111

```

or
11 111 111

On receipt of the Halt Instruction, the activity of the processor is immediately suspended in the STOPPED state. The content of all registers and memory is unchanged. The P-counter has been updated and the internal dynamic memories continue to be refreshed.

D. Internal Processor Operation

Internally the processor operates through five different states:

	Internal State	Typical Function
T1	NORMAL	Send out lower eight bits of address and increment program counter.
	INTERRUPT	Send out lower eight bits of address and suppress incrementing of program counter and acknowledge interrupt.
T2		Send out six higher order bits of address and two control bits, D ₆ and D ₇ . Increment program counter if there has been a carry from T1.
	WAIT	Wait for READY signal to come true. Refresh internal dynamic memories while waiting.
T3	NORMAL	Fetch and decode instruction; fetch data from memory; output data to memory. Refresh internal memories.
	STOPPED	Remain stopped until INTERRUPT occurs. Refresh internal memories.
T4 and T5		Execute instruction and appropriately transfer data within processor. Content of data bus transfer is available at I/O bus for convenience in testing. Some cycles do not require these states. In those cases, the states are skipped and the processor goes directly to T1.

The 8008 is driven by two non-overlapping clocks. Two clock periods are required for each state of the processor. ϕ_1 is generally used to precharge all data lines and memories and ϕ_2 controls all data transfers within the processor. A SYNC signal (divide by two of ϕ_2) is sent out by the 8008. This signal distinguishes between the two clock periods of each state.

Processor Clocks

The figure below shows state transitions relative to the internal operation of the processor. As noted in the previous table, the processor skips unnecessary execution steps during any cycle. The state counter within the 8008 operates as a five bit feedback shift register with the feedback path controlled by the instruction being executed. When the processor is either waiting or stopped, it is internally cycling through the T3 state. This state is the only time in the cycle when the internal dynamic memories can be refreshed.

Transition State Diagram (Internal)

The following pages show the processor activity during each state of the execution of each instruction.

INTERNAL PROCESSOR OPERATION

INDEX REGISTER INSTRUCTIONS

INSTRUCTION CODING D ₇ D ₆ D ₅ D ₄ D ₃ D ₂ D ₁ D ₀	OPERATION	# OF STATES TO EXECUTE INSTRUCTION	MEMORY CYCLE ONE (1)				
			T1(2)	T2	T3	T4(3)	T5
1 1 D D D S S S	Lr _{1/2}	(5)	PC _L OUT (4)	PC _H OUT	FETCH INSTR. (5) TO IR & REG. b	SSS TO REG. b (6)	REG. b TO DDD
1 1 D D D 1 1 1	LrM	(8)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b	(7)	
1 1 1 1 1 S S S	LMr	(7)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b	SSS TO REG. b	
0 0 D D D 1 1 0	Lrl	(8)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b		
0 0 1 1 1 1 1 0	LMI	(9)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b		
0 0 D D D 0 0 0	INr	(5)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b	X	ADD OP - FLAGS AFFECTED
0 0 D D D 0 0 1	DCr	(5)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b	X	SUB OP - FLAGS AFFECTED

ACCUMULATOR GROUP INSTRUCTIONS

1 0 P P P S S S	ALU OP r	(5)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b	SSS TO REG. b	ALU OP - FLAGS AFFECTED
1 0 P P P 1 1 1	ALU OP M	(8)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b		
0 0 P P P 1 0 0	ALU OP I	(8)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b		
0 0 0 0 0 0 1 0	RLC	(5)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b	X	ROTATE REG. A CARRY AFFECTED
0 0 0 0 1 0 1 0	RRC	(5)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b	X	ROTATE REG. A CARRY AFFECTED
0 0 0 1 0 0 1 0	RAL	(5)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b	X	ROTATE REG. A CARRY AFFECTED
0 0 0 1 1 0 1 0	RAR	(5)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b	X	ROTATE REG. A CARRY AFFECTED

PROGRAM COUNTER AND STACK CONTROL INSTRUCTIONS

0 1 X X X 1 0 0	JMP	(11)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b		
0 1 0 C C 0 0 0	JFc	(9 or 11)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b		
0 1 1 C C 0 0 0	JTc	(9 or 11)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b		
0 1 X X X 1 1 0	CAL	(11)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b		
0 1 0 C C 0 1 0	CFc	(9 or 11)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b		
0 1 1 C C 0 1 0	CTc	(9 or 11)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b		
0 0 X X X 1 1 1	RET	(5)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b	POP STACK	X
0 0 0 C C 0 1 1	RFc	(3 or 5)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b	POP STACK (13)	X
0 0 1 C C 0 1 1	RTc	(3 or 5)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b	POP STACK (13)	X
0 0 A A A 1 0 1	RST	(5)	PC _L OUT	PC _H OUT	FETCH INSTR. TO REG. b AND PUSH STACK (0 → REG. a)	REG. a TO PC _H	REG. b TO PC _L (14)

I/O INSTRUCTIONS

0 1 0 0 M M M 1	INP	(8)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b		
0 1 R R M M M 1	OUT	(6)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b		

MACHINE INSTRUCTIONS

0 0 0 0 0 0 X	HLT	(4)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b & HALT (18)		
1 1 1 1 1 1 1	HLT	(4)	PC _L OUT	PC _H OUT	FETCH INSTR. TO IR & REG. b & HALT (18)		

NOTES:

- The first memory cycle is always a PC_L (instruction) cycle.
- Internally, states are defined as T1 through T5. In some cases more than one memory cycle is required to execute an instruction.
- Content of the internal data bus at T4 and T5 is available at the data bus. This is designed for testing purposes only.
- Lower order address bits in the program counter are denoted by PC_L and higher order bits are designated by PC_H.
- During an instruction fetch the instruction comes from memory to the instruction register and is decoded.
- Temporary registers are used internally for arithmetic operations and data transfers (Register a and Register b.)
- These states are skipped.
- PCR cycle (Memory Read Cycle).
- "X" denotes an idle state.
- PCW cycle (Memory Write Cycle).
- When the JUMP is conditional and the condition fails, states T4 and T5 are skipped and the state counter advances to the next memory cycle.

MEMORY CYCLE TWO					MEMORY CYCLE THREE				
T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
REG. L OUT (8)	REG. H OUT	DATA TO REG. b	X (9)	REG. b TO DDD					
REG. L OUT (10)	REG. H OUT	REG. b TO OUT							
PC _L OUT (8)	PC _H OUT	DATA TO REG. b	X	REG. b TO DDD					
PC _L OUT (8)	PC _H OUT	DATA TO REG. b			REG. L OUT (10)	REG. H OUT	REG. b TO OUT		
REG. L OUT (8)	REG. H OUT	DATA TO REG. b	X	ALU OP - FLAGS AFFECTED					
PC _L OUT (8)	PC _H OUT	DATA TO REG. b	X	ARITH OP - FLAGS AFFECTED					
PC _L OUT (8)	PC _H OUT	LOWER ADD. TO REG. b			PC _L OUT (8)	PC _H OUT	HIGHER ADD. REG. a	REG. a TO PC _H	REG. b TO PC _L
PC _L OUT (8)	PC _H OUT	LOWER ADD. TO REG. b			PC _L OUT (8)	PC _H OUT	HIGHER ADD. REG. a (11)	REG. a TO PC _H	REG. b TO PC _L
PC _L OUT (8)	PC _H OUT	LOWER ADD. TO REG. b			PC _L OUT (8)	PC _H OUT	HIGHER ADD. REG. a (11)	REG. a TO PC _H	REG. b TO PC _L
PC _L OUT (8)	PC _H OUT	LOWER ADD. TO REG. b			PC _L OUT (8)	PC _H OUT	HIGHER ADD. REG. a	REG. a TO PC _H	REG. b TO PC _L
PC _L OUT (8)	PC _H OUT	LOWER ADD. TO REG. b			PC _L OUT (8)	PC _H OUT	HIGHER ADD. REG. a (12)	REG. a TO PC _H	REG. b TO PC _L
PC _L OUT (8)	PC _H OUT	LOWER ADD. TO REG. b			PC _L OUT (8)	PC _H OUT	HIGHER ADD. REG. a (12)	REG. a TO PC _H	REG. b TO PC _L
REG. A TO OUT (15)	REG. b TO OUT	DATA TO REG. b	COND ff OUT (16)	REG. b TO REG. A					
REG. A TO OUT (15)	REG. b TO OUT	X (17)							

12. When the CALL is conditional and the condition fails, states T4 and T5 are skipped and the state counter advances to the next memory cycle. If the condition is true, the stack is pushed at T4, and the lower and higher order address bytes are loaded into the program counter.

13. When the RETURN condition is true, pop up the stack; otherwise, advance to next memory cycle skipping T4 and T5.

14. Bits D₃ through D₅ are loaded into PC_L and all other bits are set to zero; zeros are loaded into PC_H.
15. PCC cycle (I/O Cycle).

16. The content of the condition flip-flops is available at the data bus: S at D₀, Z at D₁, P at D₂, C at D₃.

17. A READY command must be supplied for the OUT operation to be completed. An idle T3 state is used and then the state counter advances to the next memory cycle.

18. When a HALT command occurs, the CPU internally remains in the T3 state until an INTERRUPT is recognized. Externally, the STOPPED state is indicated.

V. PROCESSOR CONTROL SIGNALS

A. Interrupt Signal (INT)

1) INTERRUPT REQUEST

If the interrupt line is enabled (Logic "1"), the CPU recognizes an interrupt request at the next instruction fetch (PCI) cycle by outputting $S_0 S_1 S_2 = 011$ at T11 time. The lower and higher order address bytes of the program counter are sent out, but the program counter is not advanced. A successive instruction fetch cycle can be used to insert an arbitrary instruction into the instruction register in the CPU. (If a multi-cycle or multi-byte instruction is inserted, an interrupt need only be inserted for the first cycle.)

When the processor is interrupted, the system INTERRUPT signal must be synchronized with the leading edge of the ϕ_1 or ϕ_2 clock. To assure proper operation of the system, the interrupt line to the CPU must not be allowed to change within 200ns of the falling edge of ϕ_1 . An example of a synchronizing circuit is shown on the schematic for the SIM8-01 (Section VII).

Figure 4. Recognition of Interrupt

If a HALT is inserted, the CPU enters a STOPPED state; if a NOP is inserted, the CPU continues; if a "JUMP to 0" is inserted, the processor executes program from location 0, etc. The RESTART instruction is particularly useful for handling interrupt routines since it is a one byte call.

Figure 5. 8008 Interrupt

2) START-UP OF THE 8008

When power (V_{DD}) and clocks (ϕ_1 , ϕ_2) are first turned on, a flip-flop internal to the 8008 is set by sensing the rise of V_{DD} . This internal signal forces a HALT (00000000) into the instruction register and the 8008 is then in the STOPPED state. The following sixteen clock periods after entering the STOPPED state are required to clear (logic "0") memories (accumulator, scratch pad, program counter, and stack). During this time the interrupt line has been at logic "0". Any time after the memories are cleared, the 8008 is ready for normal operation.

To reset the flip-flop and also escape from the stopped state, the interrupt line must go to a logic "1"; It should be returned to logic "0" by decoding the state T11 at some time later than ϕ_{11} . Note that whenever the 8008 is in a T11 state, the program counter is not incremented. As a result, the same address is sent out on two successive cycles.

Three possible sequences for starting the 8008 are shown on the following page. The RESTART instruction is effectively a one cycle call instruction, and it is convenient to use this instruction to call an initiation subroutine. Note that it is not necessary to start the 8008 with a RESTART instruction.

The selection of initiation technique to use depends on the sophistication of the system using the 8008. If the interrupt feature is used only for the start-up of the 8008 use the ROM directly, no additional external logic associated with instructions from source other than the ROM program need be considered. If the interrupt feature is used to jam instructions into the 8008, it would then be consistent to use it to jam the initial instruction.

The timing for the interrupt with the start-up timing is shown on an accompanying sheet. The jamming of an instruction and the suppression of the program counter update are handled the same for all interrupts.

EXAMPLE 1:

Shown below are two start-up alternatives where an instruction is not forced into the 8008 during the interrupt cycle. The normal program flow starts the 8008.

a.	8008 ADDRESS OUT	INSTRUCTION IN ROM	
	0 0 0 0 0 0 0 0 0 0 0 0 0 0	NOP (LAA 11 000 000)	} Entry Directly To Main Program
	0 0 0 0 0 0 0 0 0 0 0 0 0 0	NOP	
	0 0 0 0 0 0 0 0 0 0 0 0 0 1	INSTR ₁	
	0 0 0 0 0 0 0 0 0 0 0 0 1 0	INSTR ₂	
b.	8008 ADDRESS OUT	INSTRUCTION IN ROM	
	0 0 0 0 0 0 0 0 0 0 0 0 0 0	RST (RST = 00 XYZ 101)	} A Jump To The Main Program
	0 0 0 0 0 0 0 0 X Y Z 0 0 0	INSTR ₁	
	0 0 0 0 0 0 0 0 X Y Z 0 0 1	INSTR ₂	

EXAMPLE 2:

A RESTART instruction is jammed in and first instruction in ROM initially ignored.

	8008 ADDRESS OUT	INSTRUCTION IN ROM	
	0 0 0 0 0 0 0 0 0 0 0 0 0 0	INSTR ₁ (RST = 00 XYZ 101)	} Start-up Routine
	0 0 0 0 0 0 0 0 X Y Z 0 0 0	INSTR ₂	
	0 0 0 0 0 0 0 0 X Y Z 0 0 1	INSTR ₃	
	0 0 0 0 0 0 0 0 n n n n n n	RETURN	} Main Program
	0 0 0 0 0 0 0 0 0 0 0 0 0 0	INSTR ₁ (INSTR ₁ executed now)	
	0 0 0 0 0 0 0 0 0 0 0 0 0 1	INSTR ₂	

Note that during the interrupt cycle the flow of the instruction to the 8008 either from ROM or another source must be controlled by hardware external to 8008.

START-UP OF THE 8008

B. Ready (RDY)

The 8008 is designed to operate with any type or speed of semiconductor memory. This flexibility is provided by the READY command line. A high-speed memory will always be ready with data (tie READY line to V_{CC}) almost immediately after the second byte of the address has been sent out. As a result the 8008 will never be required to wait for the memory. On the other hand, with slow ROMs, RAMs or shift registers, the data will not be immediately available; the 8008 must wait until the READY command indicates that the valid memory data is available. As a result any type or any combination of memory types may be used. The READY command line synchronizes the 8008 to the memory cycle. When a program is being developed, the READY signal provides a means of stepping through the program, one cycle at a time.

VI. ELECTRICAL SPECIFICATION

The following pages provide the electrical characteristics for the 8008. All of the inputs are TTL compatible, but input pull-up resistors are recommended to insure proper V_{IH} levels. All outputs are low-power TTL compatible. The transfer of data to and from the data bus is controlled by the CPU. During both the WAIT and STOPPED states the data bus output buffers are disabled and the data bus is floating.

Figure 6. Data Bus I/O Buffer

Figure 7. I/O Circuitry

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias	0°C to +70°C
Storage Temperature	-55°C to +150°C
Input Voltages and Supply Voltage With Respect to V _{CC}	+0.5 to -20V
Power Dissipation	1.0 W @ 25°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other condition above those indicated in the operational sections of this specification is not implied.

D.C. AND OPERATING CHARACTERISTICS

T_A = 0°C to 70°C, V_{CC} = +5V ± 5%, V_{DD} = -9V ± 5% unless otherwise specified. Logic "1" is defined as the more positive level (V_{IH}, V_{OH}). Logic "0" is defined as the more negative level (V_{IL}, V_{OL}).

SYMBOL	PARAMETER	LIMITS			UNIT	TEST CONDITIONS
		MIN.	TYP.	MAX.		
I _{DD}	AVERAGE SUPPLY CURRENT- OUTPUTS LOADED*		30	60	mA	T _A = 25°C
I _{LI}	INPUT LEAKAGE CURRENT			10	μA	V _{IN} = 0V
V _{IL}	INPUT LOW VOLTAGE (INCLUDING CLOCKS)	V _{DD}		V _{CC} -4.2	V	
V _{IH}	INPUT HIGH VOLTAGE (INCLUDING CLOCKS)	V _{CC} -1.5		V _{CC} +0.3	V	
V _{OL}	OUTPUT LOW VOLTAGE			0.4	V	I _{OL} = 0.44mA C _L = 200 pF
V _{OH}	OUTPUT HIGH VOLTAGE	V _{CC} -1.5			V	I _{OH} = 0.2mA

*Measurements are made while the 8008 is executing a typical sequence of instructions. The test load is selected such that at V_{OL} = 0.4V, I_{OL} = 0.44mA on each output.

A.C. CHARACTERISTICS

T_A = 0°C to 70°C; V_{CC} = +5V ± 5%, V_{DD} = -9V ± 5%. All measurements are referenced to 1.5V levels.

SYMBOL	PARAMETER	8008		8008-1		UNIT	TEST CONDITIONS
		LIMITS		LIMITS			
		MIN.	MAX.	MIN.	MAX.		
t _{CY}	CLOCK PERIOD	2	3	1.25	3	μs	t _R , t _F = 50ns
t _R , t _F	CLOCK RISE AND FALL TIMES		50		50	ns	
t _{φ1}	PULSE WIDTH OF φ ₁	.70		.35		μs	
t _{φ2}	PULSE WIDTH OF φ ₂	.55		.35		μs	
t _{D1}	CLOCK DELAY FROM FALLING EDGE OF φ ₁ TO FALLING EDGE OF φ ₂	.90	1.1		1.1	μs	
t _{D2}	CLOCK DELAY FROM φ ₂ TO φ ₁	.40		.35		μs	
t _{D3}	CLOCK DELAY FROM φ ₁ TO φ ₂	.20		.20		μs	
t _{DD}	DATA OUT DELAY		1.0		1.0	μs	C _L = 100pF
t _{OH}	HOLD TIME FOR DATA BUS OUT	.10		.10		μs	
t _{IH}	HOLD TIME FOR DATA IN	[1]		[1]		μs	
t _{SD}	SYNC OUT DELAY		.70		.70	μs	C _L = 100pF
t _{S1}	STATE OUT DELAY (ALL STATES EXCEPT T1 AND T11) [2]		1.1		1.1	μs	C _L = 100pF
t _{S2}	STATE OUT DELAY (STATES T1 AND T11)		1.0		1.0	μs	C _L = 100pF
t _{RW}	PULSE WIDTH OF READY DURING φ ₂₂ TO ENTER T3 STATE	.35		.35		μs	
t _{RD}	READY DELAY TO ENTER WAIT STATE	.20		.20		μs	

[1] t_{IH} MIN ≥ t_{SD}

[2] If the INTERRUPT is not used, all states have the same output delay, t_{S1}.

TIMING DIAGRAM

[1] READY line must be at "0" prior to ϕ_{22} of T_2 to guarantee entry into the WAIT state.

TYPICAL D.C. CHARACTERISTICS

TYPICAL A.C. CHARACTERISTICS

CAPACITANCE $f = 1MHz$; $T_A = 25^\circ C$; Unmeasured Pins Grounded

SYMBOL	TEST	LIMIT (pF)	
		TYP.	MAX.
C_{IN}	INPUT CAPACITANCE	5	10
C_{DB}	DATA BUS I/O CAPACITANCE	5	10
C_{OUT}	OUTPUT CAPACITANCE	5	10

Silicon Gate MOS 2102

1024 BIT FULLY DECODED STATIC MOS
RANDOM ACCESS MEMORY

- Single +5 Volts Supply Voltage
- Directly TTL Compatible — All Inputs and Output
- Static MOS — No Clocks or Refreshing Required
- Low Power — Typically 150 mW
- Access Time — Typically 500 nsec
- Three-State Output — OR-Tie Capability
- Simple Memory Expansion — Chip Enable Input
- Fully Decoded — On Chip Address Decode
- Inputs Protected — All Inputs Have Protection Against Static Charge
- Low Cost Packaging — 16 Pin Plastic Dual-In-Line Configuration

The Intel® 2102 is a 1024 word by one bit static random access memory element using normally off N-channel MOS devices integrated on a monolithic array. It uses fully DC stable (static) circuitry and therefore requires no clocks or refreshing to operate. The data is read out nondestructively and has the same polarity as the input data.

The 2102 is designed for memory applications where high performance, low cost, large bit storage, and simple interfacing are important design objectives.

It is directly TTL compatible in all respects: inputs, output, and a single +5 volt supply. A separate chip enable (CE) lead allows easy selection of an individual package when outputs are OR-tied.

The Intel 2102 is fabricated with N-channel silicon gate technology. This technology allows the design and production of high performance easy to use MOS circuits and provides a higher functional density on a monolithic chip than either conventional MOS technology or P-channel silicon gate technology.

Intel's silicon gate technology also provides excellent protection against contamination. This permits the use of low cost silicone packaging.

SILICON GATE MOS 2102

Absolute Maximum Ratings*

Ambient Temperature Under Bias	0°C to 70°C
Storage Temperature	-65°C to +150°C
Voltage On Any Pin With Respect To Ground	-0.5V to +7V
Power Dissipation	1 Watt

*COMMENT:

Stresses above those listed under "Absolute Maximum Rating" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or at any other condition above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D. C. and Operating Characteristics

T_A = 0°C to +70°C, V_{CC} = 5V ±5% unless otherwise specified

SYMBOL	PARAMETER	LIMITS			UNIT	TEST CONDITIONS
		MIN.	TYP.(1)	MAX.		
I _{LI}	INPUT LOAD CURRENT (ALL INPUT PINS)			10	μA	V _{IN} = 0 to 5.25V
I _{LOH}	OUTPUT LEAKAGE CURRENT			10	μA	$\overline{CE}$ = 2.2V, V _{OUT} = 4.0V
I _{LOL}	OUTPUT LEAKAGE CURRENT			-100	μA	$\overline{CE}$ = 2.2V, V _{OUT} = 0.45V
I _{CC1}	POWER SUPPLY CURRENT		30	60	mA	ALL INPUTS = 5.25V DATA OUT OPEN T _A = 25°C
I _{CC2}	POWER SUPPLY CURRENT			70	mA	ALL INPUTS = 5.25V DATA OUT OPEN T _A = 0°C
V _{IL}	INPUT "LOW" VOLTAGE	-0.5		+0.65	V	
V _{IH}	INPUT "HIGH" VOLTAGE	2.2		V _{CC}	V	
V _{OL}	OUTPUT "LOW" VOLTAGE			+0.45	V	I _{OL} = 1.9mA
V _{OH}	OUTPUT "HIGH" VOLTAGE	2.2			V	I _{OH} = -100μA

Typical D.C. Characteristics

NOTE: 1. Typical values are for T_A = 25°C and nominal supply voltage.

SILICON GATE MOS 2102

A. C. Characteristics $T_A = 0^\circ\text{C}$ to 70°C , $V_{CC} = 5\text{V} \pm 5\%$ unless otherwise specified

SYMBOL	PARAMETER	LIMITS			UNIT
		MIN.	TYP. (1)	MAX.	
READ CYCLE					
t _{RC}	READ CYCLE	1000			ns
t _A	ACCESS TIME		500	1000	ns
t _{CO}	CHIP ENABLE TO OUTPUT TIME			500	ns
t _{OH1}	PREVIOUS READ DATA VALID WITH RESPECT TO ADDRESS	50			ns
t _{OH2}	PREVIOUS READ DATA VALID WITH RESPECT TO CHIP ENABLE	0			ns
WRITE CYCLE					
t _{WC}	WRITE CYCLE	1000			ns
t _{AW}	ADDRESS TO WRITE SETUP TIME	200			ns
t _{WP}	WRITE PULSE WIDTH	750			ns
t _{WR}	WRITE RECOVERY TIME	50			ns
t _{DW}	DATA SETUP TIME	800			ns
t _{DH}	DATA HOLD TIME	100			ns
t _{CW}	CHIP ENABLE TO WRITE SETUP TIME	900			ns

A. C. CONDITIONS OF TEST

Input Pulse Levels: $+0.65$ Volt to 2.2 Volt
 Input Pulse Rise and Fall Times: 20nsec
 Timing Measurement Reference Level: 1.5 Volt
 Output Load: 1 TTL Gate and $C_L = 100$ pF

Capacitance ⁽²⁾ $T_A = 25^\circ\text{C}$, $f = 1\text{MHz}$

SYMBOL	TEST	LIMITS (pF)	
		TYP. (1)	MAX.
C_{IN}	INPUT CAPACITANCE (ALL INPUT PINS) $V_{IN} = 0\text{V}$	3	5
C_{OUT}	OUTPUT CAPACITANCE $V_{OUT} = 0\text{V}$	7	10

Waveforms

READ CYCLE

WRITE CYCLE

NOTES: 1. Typical values are for $T_A = 25^\circ\text{C}$ and nominal supply voltage.
 2. This parameter is periodically sampled and is not 100% tested.

Microcomputer Peripherals-- Schottky Bipolar

8212 EIGHT-BIT INPUT/OUTPUT PORT

The 8212 input/output port consists of an 8-bit latch with tri-state output buffers along with control and device selection logic. Also included is a service request flip-flop for the generation and control of interrupts to the microprocessor.

The device is multimode in nature. It can be used to implement latches, gated buffers or multiplexers. Thus, all of the principal peripheral and input/output functions of a microcomputer system can be implemented with this device.

- Fully Parallel 8-Bit Data Register and Buffer
- Service Request Flip-Flop for Interrupt Generation
- Low Input Load Current — .25 mA Max.
- Three State Outputs
- Outputs Sink 15 mA

- 3.65V Output High Voltage for Direct Interface to 8080 CPU or 8003 CPU
- Asynchronous Register Clear
- Replaces Buffers, Latches and Multiplexers in Microcomputer Systems
- Reduces System Package Count

PIN CONFIGURATION

PIN NAMES

DI ₁ - DI ₈	DATA IN
DO ₁ - DO ₈	DATA OUT
DS ₁ - DS ₂	DEVICE SELECT
MD	MODE
STB	STROBE
INT	INTERRUPT (ACTIVE LOW)
CLR	CLEAR (ACTIVE LOW)

LOGIC DIAGRAM

APPENDIX 5 - WITBANK SYSTEM PARAMETERS

Shown below is a table giving the relevant constants of the weighing system used at present at Witbank.

Speed of belts	1,33 m/s
Length of belt	8
Separation between weighing hoppers	6,4 m

Filling of Weighing Hoppers			
<u>W H 1</u>			
Bin No.	Discharge Time (Secs)	Amount (Kg)	Rate (Kg/sec)
H1	20	110	5,5
H2	14	165	11,8
H3	10	75	7,5
H4	<u>0</u>	<u>0</u>	<u>0</u>
Total	44	Total 350	Ave. 8
<u>W H 2</u>			
H5	20	100	5
H6	<u>10</u>	<u>50</u>	<u>5</u>
Total	30	Total 150	Ave. 5
<u>W H 3</u>			
H7	12	250	21
H8	12	450	37
H9	16	380	24
H10	<u>16</u>	<u>420</u>	<u>26</u>
Total	56	Total 1500	Ave. 27

Discharge of Weighing Hoppers.			
WH1	60	350	5,8
WH2	60	150	2,5
WH3	60	1500	25