## XII AUXILIARY ARITHMETIC UNIT

## GENERAL DESCRIPTION

The auxiliary arithmetic unit (AAU), illustrated in Figure XII-1, extends the arithmetic capability of the GE-225 System. Although it has a controller and is connected to the central processor through the controller selector, the AAU is not merely another peripheral device; it is an extension of the basic arithmetic unit. It can be thought of as an enlarged central processor with larger registers which permit the complicated calculations needed in scientific work.

Three modes of calculations can be performed: normalized floating point, unnormalized floating point, and fixed point. Addition, subtraction, multiplication, and division can be done in any of the three modes.

The AAU and its controller occupy two cabinets (often called racks). Neither is designated as the controller, but they are identified as cabinet \#1 and cabinet \#2. The cabinet with the control and indicator panel is \#1. The AAU has its own power supply which is similar to that of the central processor. It also generates its


Figure XII-1. Auxiliary Arithmetic Unit
GE-225
own timing pulses for controlling data flow within the AAU. It contains the hardware facilities for double word-length binary arithmetic operations.

Only one AAU may be connected to a single GE-225 System, and it must always be connected to plug number seven (which has the lowest priority). The AAU operates only on line. Central processor operations can continue while arithmetic operations are in progress in the AAU.

## Floating Point Modes

An important reason for using a floating point mode is that it permits using a much larger range of numbers. The largest number which can be used in the fixed point mode is $\pm 2^{38}-1$. In floating point format, the largest number which can be used is approximately 2255 and the smallest is approximately 2-256. Another advantage in floating point mode is found in the way it handles decimal points and fractions. In business data processing, the presence of a decimal point causes little difficulty in computation because it is usually in a fixed position such as separating dollars from cents. As such, it is always two places from the right of the number. In scientific calculations, the decimal point can be any place in a number. For example, a whole number may need to be added to a number which has all fractional digits (to the right of the decimal point). As you know, the way one aligns these two numbers makes a great deal of difference in the answer. It is possible for the program to be written so as to align each and every decimal point for each and every calculation, but this is a tedious and cumbersome procedure. The AAU provides the hardware to simplify the programming of whole and fractional number calculations, and also save time in the process.

Because the computer and AAU operate in binary rather than in decimal digits, the term decimal point should be replaced by the term binary point. In a binary number system, the binary point separates the whole number from its fractional part.

The method which the AAU uses in keeping track of the binary point in calculations is called floating point arithmetic. In this, each number is represented as a fraction called a mantissa times a power of two. The exponent of the power of two and the mantissa are seen on the control and indicator panel of the AAU.

An explanation follows of how the mantissa and exponent of a decimal number can be represented in binary in the computer.

## Example

This example illustrates how the decimal number 256 can be represented in binary in the computer in the form of a mantissa and exponent. Appendix $B$ can be used to obtain numbers to various powers of 2 and appendix $C$ can be used to convert decimal and octal numbers.

The number to be represented is: ${ }^{(256)} 10$
The same number in binary is: $(100,000,000) 2$
The fractional part (mantissa) in normalized position for the number 256 in each number system is:
.256 for the decimal number
.1 for the binary number
We need now to find the exponents to which the bases of each of these numbers must be raised to produce the number which can be multiplied by the fractional mantissa to produce the original number. This is illustrated as follows:

## Decimal Number System

The base is 10 . The mantissa is (.256) 10 $10^{3}=(1000)_{10}$
The exponent is 3
Check: ${ }^{(1000)_{10}} \times(.256)_{10}=256$ which is the original number.

## Binary Number System

The base is 2. The mantissa is (.1) 2
$(2)^{1001}=(512)_{10}=(1000)_{8}=(1,000,000,000)_{2}$
The exponent is (1001) 2
Check: $\quad(1,000,000,000)_{2} \times(.1)_{2}=(100,000,000)_{2}$
which is the original number.
The binary number with a mantissa of .1 and an exponent of 1001 would be represented on the control and indicator panel of the AAU as follows: (all numbers not shown at the right are zeros).


There are two more qualifications to floating point representation. The fraction must be less than one and greater than or equal to a half, and both the mantissa and exponent must have a sign. In the representation just described, the number is said to be normalized, and it is a unique number.

A normalized number is one in which the most significant non-zero digit of the mantissa is next to the decimal point. For example, in an unnormalized mode, the number 6786 could be represented as $.006786 \times 10^{6}$. In the normalized form, the leading zeros are removed and the number would be $.6786 \times 10^{4}$. Normalized

floating point numbers are represented in the computer in the following binary configuration (Figure XII-2) which allows eight bits for the exponent and thirty bits for the mantissa. If either the exponent or mantissa is negative, the appropriate sign is set to minus and the exponent or mantissa is represented in two's complement form. The two signs need not be the same.


Figure XII-2. Format of Floating Point Number in Memory

Like other double words in memory, both words must be in successive locations, the first of which is even numbered.

The use of double words is often referred to as doubleprecision arithmetic. When data in the 2 -word floating format enters the AAU, it is converted to one word 40 bits long. The word, illustrated in Figure XII-3, consists of an 8 -bit exponent with a sign and a 30 -bit mantissa with a sign. The binary point is considered to be to the left of the most significant bit of the 30 -bit mantissa.


* Bit 21 is between bits 9 and 10 in the register displays
Figure XII-3. Format of Floating Point Word in the AAU

In floating point addition and subtraction, the numbers involved must have identical exponents. The AAU automatically adjusts the exponents to make them the same.

## Fixed Point Mode

In the fixed point mode, arithmetic operation in the AAU is the same as it is in the central processor with the exception that the AAU registers are twice as large. The terms mantissa and exponent have no meaning in the fixed point mode.

The AAU word is originally two 20 -bit words in memory, as illustrated in Figure XII-4. The sign of the first word is the sign of the entire 40 -bit word. The
sign of the second word (bit position 21 in the AAU word) should agree with the sign of the first word. When the words are transferred 'to the AX register, the least significant bit goes to position 40 as is illustrated in Figure XII-5.


Figure XII-4. Format of Fixed Point Word in Memory

| 1 | 2 | -Thru $\longrightarrow 20$ | $21{ }^{*}$ | 22 | $\longrightarrow$ Thru $\longrightarrow$ | 40 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| S | Most Significant Bits (2's Complement if Negative) (Corresponds to Y) |  | $\begin{array}{\|l\|} \hline \mathbf{S} \\ \mathrm{I} \\ \mathrm{G} \\ \mathrm{~N} \end{array}$ | Least Significant Bit (2's Complement if Negative (Corresponds to $\mathrm{Y}+1$ ) |  |  |

*Bit 21 is between bits 9 and 10 in the display register.
Figure XII-5. Format of Fixed Point Word in the AAU

## AAU OPERATION

Because the AAU controller is always connected to plug number seven of the controller selector, no SEL instruction is necessary to select the plug number. However, a SET instruction is required to select the mode for unnormalized floating point, floating point, or fixed point operation. The operator can see which mode is in use by observing which MODE indicator is lit on the control and indicator panel.

All AAU data words are first placed in the memory of the central processor as two 20 -bit words, with bit meaning dependent upon the mode of operation selected. When the AAU is granted access to memory, two data words are brought from memory through the central processor $M$ register and checked for parity. Each data word then enters a 20 -bit buffer register in the AAU and then into a 40 -bit conversion register where the 40 -bit double word format of the AAU is formed.

The AAU has a 40 -bit AX register and a 40 -bit QX register. In arithmetic operations these two registers are used in the same way the $A$ and $Q$ registers of the central processor are used. A Load AAU (FLD)
instruction loads data from memory into the AX register. The AAU also has a 40 -bit adder which performs the same type of arithmetic operations as the arithmetic unit of the central processor. (The list of instructions which apply to AAU operations follows, with octal codes.) The value calculated may be stored by use of an FST instruction, in which case, the AAU again gains access to the central processor. It transfers the results of calculation back through the controller selector to memory.

## CONTROLS AND INDICATORS

The functions of controls and indicators are summarized in Table XVI.

AX and QX Registers. The operator can see the contents of the AX and QX registers on the AAU control and indicator panel (illustrated in Figure XII-6). On the panel, the indicator light for the sign of the mantissa in both the AX and QX registers is labeled $\mathrm{S}_{\mathrm{m}}$ and is placed before the mantissa group rather than
in bit position 21. This is done to present a more meaningful picture of the floating point word and to expedite reading the contents of the registers in floating point modes. In the fixed point mode, where the grouping of bits into mantissa and exponent has no meaning, the sign of the mantissa, bit 21, becomes the sign of bits 22 through 40.

The AX and QX registers can only be read during a pause or a halt in the program. The contents of the registers may be of help to the programmer or service engineer in diagnosing trouble in either the program or the equipment, so the operator should make a note of all information on the panel at the time of an unprogrammed halt. As is true of all sign indicators, the sign is negative when the light is on and positive when the light is off. Line divisions between the register lights assist in reading the register contents in octal numbers. The following example illustrates how one of these registers may be read. The binary indicators can be mentally converted to octal and written in octal.


This information would then be written as $(-235+6105710143) 8$


Figure XII-6. AAU Control and Indicator Panel
(6)5 - 2 25

MODE Indicators and Switches, There are three mode indicators and switches on the control and indicator panel. When the program specifies the mode, the applicable mode indicator is lit (FLOATING NORMAL, FLOATING UN-NORMAL, or FIXED). These three indicators are also switches, and can establish the mode, when depressed. However, their use as switches is for maintenance personnel only. When the program makes an unscheduled halt, the operator should make a note of which of the three mode indicators is lit.

Instruction Register. The AAU has an instruction register (IX), which holds the instruction sent to the AAU. Since only bits positions $2,3,4,16,17,18,19$, and 20 are required by the AAU, only these bits are transferred. The AAU uses the I register of the central processor for memory reference any time an operand transfer is needed, so it is not necessary that bits 5 through 15 be in the AAU itself. Only the seven IX register positions which are used in the AAU are indicated on the control and indicator panel. These lights must also be noted by the operator at the time of an unprogrammed halt.

ALERT Indicators and Switches. The AAU is not in a 'ready' status when it is busy doing an internal instruction, but it becomes ready when the instruction is completed. The AAU READY indicator is lit when the AAU is in a 'Ready' status. The AAU can be tested by the program for 'ready' or 'not ready'. The two conditions of overflow and underflow have indicators on the panel and can be tested by the program. The OVER FLOW indicator is lit as a result of an illegal carry when two positive registers are being added, or as a result of an illegal divide. The indicator is reset (turned off) when the AAU accepts the next instruction which accesses memory or when the operator depresses the CLEAR ALERT switch. The UNDER FLOW indicator is turned on when a carry is missing as a result of the addition of two negative registers. The indicator is turned off by the next instruction accepted by the AAU or by the depression of the CLEAR ALERTS switch. When the CLEAR ALERTS switch is depressed, it clears the circuitry and turns off the OVER FLOW and UNDER FLOW indicators. The CLEAR ALERTS switch remains illuminated whenever the AAU DC power is on.

Power Switches. The switches for direct current power are located above the maintenance panel, inside the front panel door of cabinet \#1 (Figure XII-7). The operator must depress the switch D.C. ON to turn power on, and depress the switch D.C. OFF to turn power off. To the right of these switches is an A.C. ON indicator which glows green to indicate when AC power is on. The AC power is normally turned on by the service engineer and left on. The AC POWER ON-OFF toggle switch is beside the indicator.

Maintenance Panel Switches. The maintenance panel (Figure XII-7) is inside the front panel door of cabinet \#1. Only two switches on this panel are of concern to
the operator, so the others will not be described. The SINGLE STEP switch, at the left of the panel, is used to clear the circuitry before AAU operations commence. The NORMAL/TEST switch must always be in the NORMAL position (only service engineering personnel use it in the TEST position).

## AAU INSTRUCTIONS

Instructions which apply to the $A$ and $Q$ registers of the central processor such as LAQ, MAQ, LQA, and $X A Q$, can be made to apply to the AAU by a 'Tag A' in the coding. The instruction ' $B A R$ ' allows interrogation of the AAU for various conditions, permitting the program to test and branch. The following is a list of the instructions which apply to the AAU. The operator should learn to recognize the octal codes for these instructions.

| Instructions | Mnemonic Code | Octal Code |
| :---: | :---: | :---: |
| Set Unnormalized Floating |  |  |
| Point | SET | 3200010 |
| Set Normalized Floating Point | t SET | 3100010 |
| Set Fixed Point | SET | 3500010 |
| Load AAU | FLD | 3000000 |
| Store AAU | FST | 3300000 |
| Load AX from QX (Tag A) | LAQ | 3600002 |
| Move AX to QX (Tag A) | MAQ | 3100002 |
| Load QX from AX (Tag A) | LQA | 3200002 |
| Exchange AX and QX (Tag A) | XAQ | 3500002 |
| AAU Add | FAD | $31 \mathrm{YYYYY*}$ |
| AAU Multiply | FMP | 35YYYYY* |
| AAU Divide | FDV | 36YYYYY* |
| AAU Subtract | FSU | 32YYYYY* |
| Branch on AAU Not Ready | BAR BAN | 2516720 |
| Branch on AAU Ready | BAR BAR | 2514720 |
| Branch on AAU Plus | BAR BPL | 2516721 |
| Branch on AAU Minus | BAR BMI | 2514721 |
| Branch on AAU Zero | BAR BZE | 2514722 |
| Branch on AAU Not Zero | BAR BNZ | 2516722 |
| Branch on Overflow | BAR BOV | 2514723 |
| Branch on No Overflow | BAR BNO | 2516723 |
| Branch on Underflow | BAR BUF | 2514724 |
| Branch on No Underflow | BAR BNU | 2516724 |
| Branch on Error | BAR BER | 2514727 |
| Branch on No Error | BAR BNE | 2516727 |

## SETUP PROCEDURE

The steps in preparing the AAU for operation are as follows. (See Table XVI for a summary of controls and indicators.) It is assumed that the PWR ON switch on the control console has been depressed to turn on power to the central processor.

1. Depress the D.C. ON switch inside the front panel of cabinet \#1.
2. Depress the SINGLE STEP switch on the maintenance panel inside of cabinet \#1.

[^0]

Figure XII-7. Power Switches and Maintenance Panel
3. Check to make sure the TEST/NORMAL switch is in the NORMAL position.
4. If a red ALERT light is on, depress the CLEAR ALERTS switch on the control and indicator panel.

The AAU is now ready to be called upon by the program.

The AAU is turned off by depressing the D.C. OFF switch inside the front panel of cabinet \#1.

TABLE XVI
FUNCTIONS |OF CONTROLS AND INDICATORS FOR THE AAU

| Location | Control or Indicator | Function |
| :---: | :--- | :--- |
| AAU Control and Indicator <br> panel (Figure XII-6) | A register display <br> lights | Display contents of AAU's AX register. |
|  | Q register display <br> lights | Display contents of AAU's QX <br> register. |

© ⿷匚 2225

TABLE XVI (CONT.)

| Location | Control or Indicator | Function |
| :---: | :---: | :---: |
| AAU Control and Indicator panel (cont) | FLOATING NORMAL indicating MODE switch (white) | Establishes and indicates normalized floating point mode of operation. |
|  | FLOATING UN-NORM indicating MODE switch (white) | Establishes and indicates unnormalized floating point mode of operation. |
|  | FIXED indicating MODE switch (white) | Establishes and indicates fixed point mode of operation. |
|  | I register display lights | Display contents of AAU's I register. |
|  | AAU READY indicator light (green) | Indicates, when lit, that the AAU is ready to process another instruction. Is not lit when the AAU is busy processing the previous instruction. |
|  | OVER FLOW indicator light (red) | Indicates when capacity of AAU has been exceeded in the positive direction. (Is reset by next instruction or reset manually by CLEAR ALERTS switch.) |
|  | UNDER FLOW indicator light (red) | Indicates when capacity of AAU has been exceeded in the negative direction. (Is reset by next instruction or reset manually by CLEAR ALERTS switch.) |
|  | CLEAR ALERTS illuminated switch (white) | Resets OVER FLOW or UNDER FLOW indicators under manual control. (Normally illuminated while power is on.) |
| Inside front panel door of AAU cabinet \#1, above maintenance panel (Figure XII-7) | D.C. ON switch | Turns D.C. power on. |
|  | D.C. OFF switch | Turns D.C. power off. |
| AAU maintenance panel (Figure XII-7) | SINGLE step switch | Clears AAU circuitry. |
|  | Test/Normal switch | Must be in the NORMAL position for on-line operation. |



## ERRORS AND OPERATOR CORRECTIVE ACTION

## Operator Errors

Most program halts while using the AAU result from either machine errors or program errors. The principal duties of the operator are to help the programmer debug a program by noting and clearing overflow and underflow conditions.

An operator error sometimes results when the control console AUTO/MANUAL switch is moved to the MANUAL position during AAU operations. This is apt to give an AAU alert. To prevent this, the operator should use a program loop under option switch control. Such a loop is described in Section XI entitled 'Inter rupt' in the manual GE-225 Programming Conventions, CPB 178.

If the operator neglects to depress the D.C. ON switch inside of cabinet \#1 when the program requires the AAU to be used, he may never know of his error until a distressed programmer notifies him that all AAU arithmetic operations were written as zeros. Aside from providing wrong answers, the program appears to be operating correctly when the operator neglects to turn on AAU power. Because of this, the operator must make doubly sure he has the AAU power on whenever a program might call for AAU operations.

In programming debugging, it is possible to step through the AAU program by placing the central processor in MANUAL and depressing the START switch on the control console for each execution. The operator should know, however, that this can only be done with the INST/WORD switch in the INST position. If the operator should accidentally step the program with the switch in the WORD position, it will impair the operation of the program and require that the operator restart the program either at the beginning or at some designated restart point.

The operator will find that the AAU may, at times, execute more than one instruction when the STEP switch is depressed. This is due to a peculiarity of the AAU design which causes two instructions to be executed when the second of a pair of instructions
does not require memory access. (This design feature permits faster AAU operation.) For example, the instruction Move AX to QX does not require memory access. So, when it follows an instruction which is executed by depressing the START switch, both instructions are executed.

The operator should be aware of the fact that the AAU is permanently wired to the controller selector with address number seven, and no controller selector plug is needed. Because of this, plug 7 should be stored away where it could not be used inadvertently with some other peripheral. A duplication of the address could result in damage to equipment.

## Program Errors

Three types of program errors cause the same results and require the same operator action:

1. When the program contains a legal 37XXXXX instruction for use of the mass random access data storage unit, but does not first have a SEL instruction, the 37 XXXXX instruction could reach the IX register of the AAU by mistake.
2. The illegal instruction 34 XXXXX can also enter the IX register by mistake.
3. If the program tries to perform an unindexed arithmetic operation using an address less than 16, this too will enter the IX register.

All of the above errors cause all computer operations to stop and cause the PRIORITY alarm light on the control console of the central processor to come on. The instruction which caused the difficulty is visible in the I register of the AAU. When this happens, the operator must return the program to the programmer with notification of the difficulty. Before continuing operations, the operator must clear the circuitry by depressing the SINGLE STEP switch on the AAU maintenance panel.

Table XVII summarizes some of the error conditions which the operator might encounter in AAU operation. Possible causes for the errors and corrective action are included.

TABLE XVII

## AUXILIARY ARITHMETIC UNIT ERROR CONDITIONS

| Error Condition | Possible Cause | Corrective Action |
| :--- | :--- | :--- |
| The program hangs up and <br> central processor oper- <br> ation halts. The computer <br> is in the AUTO mode and <br> the red PRIORITY alarm <br> light on the control con- <br> sole is lit. | A 34XXXXX instruction <br> was given to the AAU <br> or a 37XXXXX instruc- <br> tion got into the I <br> register of the AAU in <br> error. | Return the program with notification <br> to the programmer. Depress the <br> SINGLE STEP switch on the AAU <br> maintenance panel to clear the <br> circuitry. |
| The program hangs up and <br> central processor oper- <br> ation halts. The computer <br> is in AUTO and the red <br> PRIORITY light may or <br> may not come on. | A system which had an <br> AAU used plug \#7 for <br> another peripheral and <br> a SEL instruction <br> called for \#7. | Stop all operation and notify the <br> service engineer so that he can check <br> to see if any damage was done to the <br> equipment. |
| The programmer notifies <br> the operator that the pro- <br> gram produced all zeros <br> in place of AAU arithmetic <br> operations. | AAU power was not <br> turned on. | Rerun the program, making sure that <br> the D.C. ON switch inside of cabinet <br> \#1 is turned on. |


[^0]:    * Y represents the modified address of the instruction, and must be larger than 15.

