15. LADDER LOGIC FUNCTIONS

Topics:

- Functions for data handling, mathematics, conversions, array operations, statistics, comparison and Boolean operations.
- Design examples

Objectives:

- To understand basic functions that allow calculations and comparisons
- To understand array functions using memory files

15.1 INTRODUCTION

Ladder logic input contacts and output coils allow simple logical decisions. Functions extend basic ladder logic to allow other types of control. For example, the addition of timers and counters allowed event based control. A longer list of functions is shown in Figure 201. Combinatorial Logic and Event functions have already been covered. This chapter will discuss Data Handling and Numerical Logic. The next chapter will cover Lists and Program Control and some of the Input and Output functions. Remaining functions will be discussed in later chapters.

- Combinatorial Logic
    - relay contacts and coils
- Events
    - timer instructions
    - counter instructions
- Data Handling
    - moves
    - mathematics
    - conversions
- Numerical Logic
    - boolean operations
    - comparisons
- Lists
    - shift registers/stacks
    - sequencers
- Program Control
    - branching/looping
    - immediate inputs/outputs
    - fault/interrupt detection
- Input and Output
    - PID
    - communications
    - high speed counters
    - ASCII string functions

Figure 201 Basic PLC Function Categories

Most of the functions will use PLC memory locations to get values, store values and track function status. Most function will normally become active when the input is true. But, some functions, such as TOF timers, can remain active when the input is off. Other functions will only operate when the input goes from false to true, this is known as positive edge triggered. Consider a counter that only counts when the input goes from false to true, the length of time the input is true does not change the function behavior. A negative edge triggered function would be triggered when the input goes from true to false. Most functions are not edge triggered: unless stated assume functions are not edge triggered.

NOTE: I do not draw functions exactly as they appear in manuals and programming software. This helps save space and makes the instructions somewhat easier to read. All of the necessary information is given.

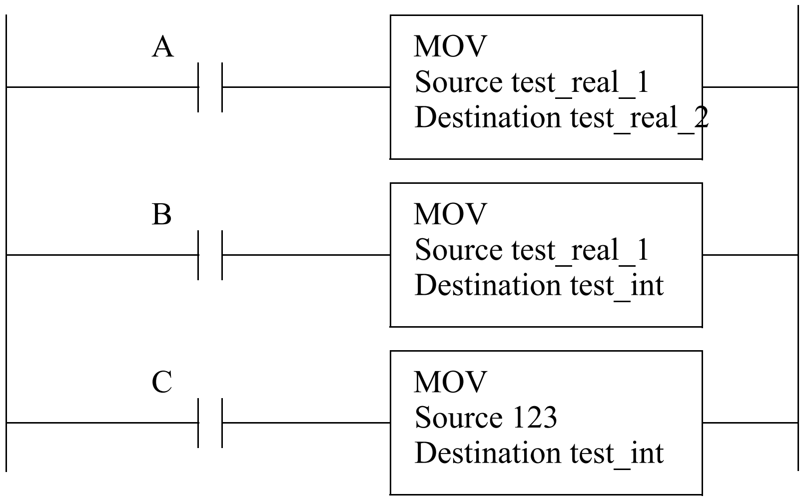
15.2 DATA HANDLING

15.2.1 Move Functions

There are two basic types of move functions;

MOV(value,destination) - moves a value to a memory location
MVM(value,mask,destination) - moves a value to a memory location, but with a mask to select specific bits.

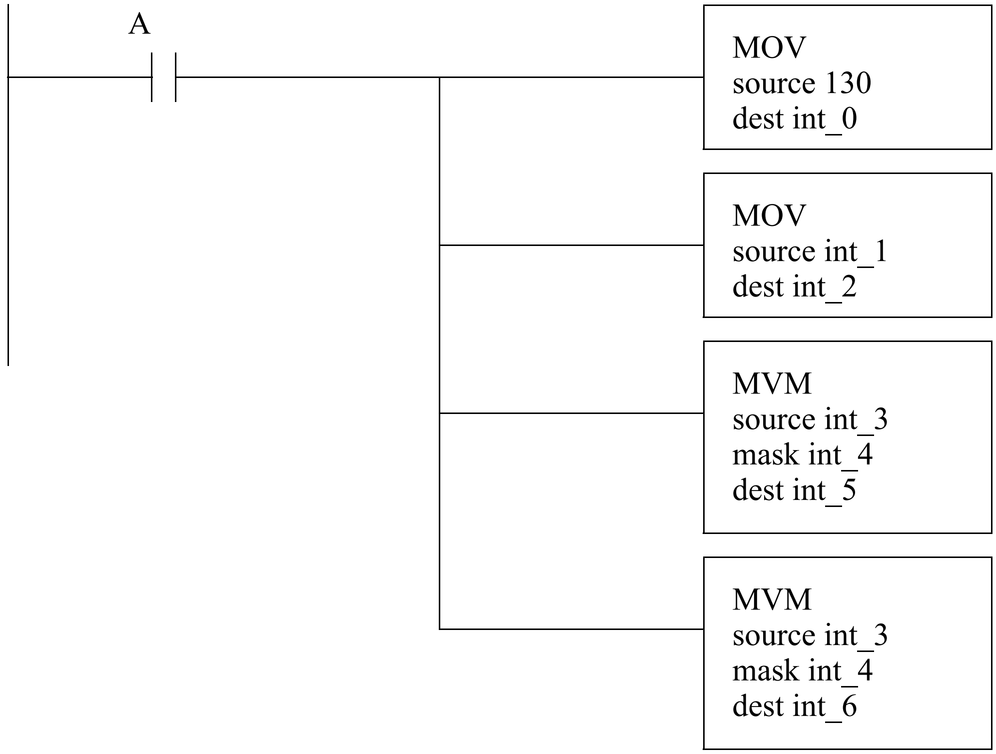
The simple MOV will take a value from one location in memory and place it in another memory location. Examples of the basic MOV are given in Figure 202. When *A* is true the MOV function moves a floating point number from the source to the destination address. The data in the source address is left unchanged. When *B* is true the floating point number in the source will be converted to an integer and stored in the destination address in integer memory. The floating point number will be rounded up or down to the nearest integer. When *C* is true the integer value of 123 will be placed in the integer file *test_int*.



NOTE: when a function changes a value, except for inputs and outputs, the value is changed immediately. Consider Figure 202, if *A*, *B* and *C* are all true, then the value in *test_real_2* will change before the next instruction starts. This is different than the input and output scans that only happen before and after the logic scan.

Figure 202 Examples of the MOV Function

A more complex example of move functions is given in Figure 203. When *A* becomes true the first move statement will move the value of 130 into *int_0*. And, the second move statement will move the value of -9385 from *int_1* to *int_2*. (Note: The number is shown as negative because we are using 2s compliment.) For the simple MOVs the binary values are not needed, but for the MVM statement the binary values are essential. The statement moves the binary bits from *int_3* to *int_5*, but only those bits that are also on in the mask *int_4*, other bits in the destination will be left untouched. Notice that the first bit *int_5.0* is true in the destination address before and after, but it is not true in the mask. The MVM function is very useful for applications where individual binary bits are to be manipulated, but they are less useful when dealing with actual number values.



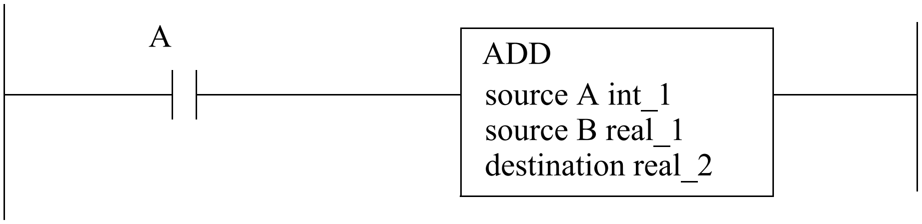
	before			after	
	binary	decimal		binary	decimal
int_0	0000000000000000	0		0000000010000010	130
int_1	1101101101010111	-9385		1101101101010111	-9385
int_2	1000000000000000	-32768	→	1101101101010111	-9385
int_3	0101100010111011	22715	becomes	0101100010111011	22715
int_4	0010101010101010	10922		0010101010101010	10922
int_5	0000000000000001	1		0000100010101011	2219
int_6	1101110111111111			1101110111111111	

NOTE: the concept of a mask is very useful, and it will be used in other functions. Masks allow instructions to change a couple of bits in a binary number without having to change the entire number. You might want to do this when you are using bits in a number to represent states, modes, status, etc.

Figure 203 Example of the MOV and MVM Statement with Binary Values

15.2.2 Mathematical Functions

Mathematical functions will retrieve one or more values, perform an operation and store the result in memory. Figure 204 shows an *ADD* function that will retrieve values from *int_1* and *real_1*, convert them both to the type of the destination address, add the floating point numbers, and store the result in *real_2*. The function has two sources labelled *source A* and *source B*. In the case of ADD functions the sequence can change, but this is not true for other operations such as subtraction and division. A list of other simple arithmetic function follows. Some of the functions, such as the negative function are unary, so there is only one source.

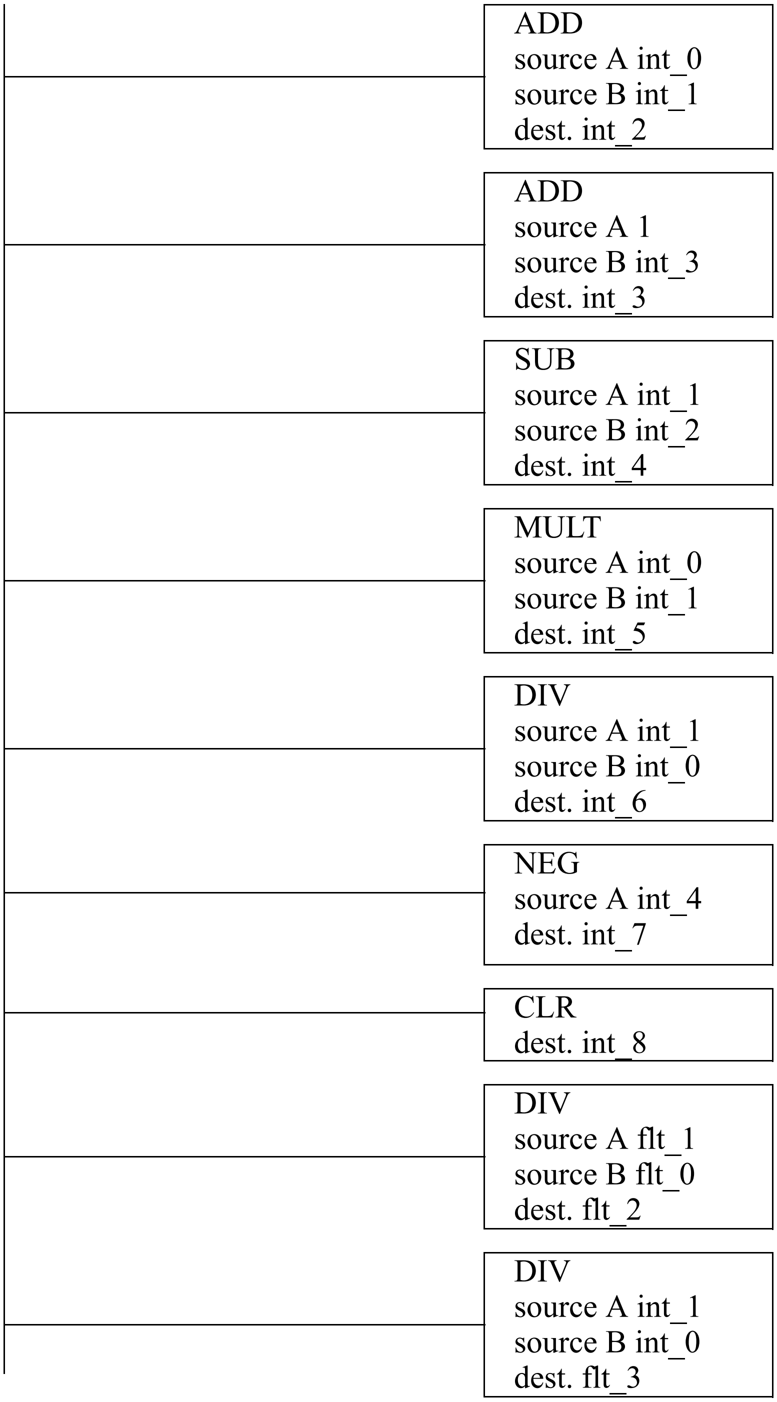


ADD(value,value,destination) - add two values
SUB(value,value,destination) - subtract
MUL(value,value,destination) - multiply
DIV(value,value,destination) - divide
NEG(value,destination) - reverse sign from positive/negative
CLR(value) - clear the memory location

NOTE: To save space the function types are shown in the shortened notation above. For example the function *ADD(value, value, destination)* requires two source values and will store it in a destination. It will use this notation in a few places to reduce the bulk of the function descriptions.

Figure 204 Arithmetic Functions

An application of the arithmetic function is shown in Figure 205. Most of the operations provide the results we would expect. The second ADD function retrieves a value from *int_3*, adds 1 and overwrites the source - this is normally known as an increment operation. The first DIV statement divides the integer 25 by 10, the result is rounded to the nearest integer, in this case 3, and the result is stored in *int_6*. The *NEG* instruction takes the new value of *-10*, not the original value of *0*, from *int_4* inverts the sign and stores it in *int_7*.



addr.	before	after
int_0	10	10
int_1	25	25
int_2	0	35
int_3	0	1
int_4	0	-10
int_5	0	250
int_6	0	3
int_7	0	10
int_8	100	0
flt_0	10.0	10.0
flt_1	25.0	25.0
flt_2	0	2.5
flt_3	0	2.5

Note: recall, integer values are limited to ranges between -32768 and 32767, and there are no fractions.

Figure 205 Arithmetic Function Example

A list of more advanced functions are given in Figure 206. This list includes basic trigonometry functions, exponents, logarithms and a square root function. The last function *CPT* will accept an expression and perform a complex calculation.

ACS(value,destination) - inverse cosine
COS(value,destination) - cosine
ASN(value,destination) - inverse sine
SIN(value,destination) - sine
ATN(value,destination) - inverse tangent
TAN(value,destination) - tangent
XPY(value,value,destination) - X to the power of Y
LN(value,destination) - natural log
LOG(value,destination) - base 10 log
SQR(value,destination) - square root
CPT(destination,expression) - does a calculation

Figure 206 Advanced Mathematical Functions

Figure 207 shows an example where an equation has been converted to ladder logic. The first step in the conversion is to convert the variables in the equation to unused memory locations in the PLC. The equation can then be converted using the most nested calculations in the equation, such as the *LN* function. In this case the results of the *LN* function are stored in another memory location, to be recalled later. The other operations are implemented in a similar manner. (Note: This equation could have been implemented in other forms, using fewer memory locations.)

given

$$A = \sqrt{\ln B + e^{C}\operatorname{acos}(D)}$$

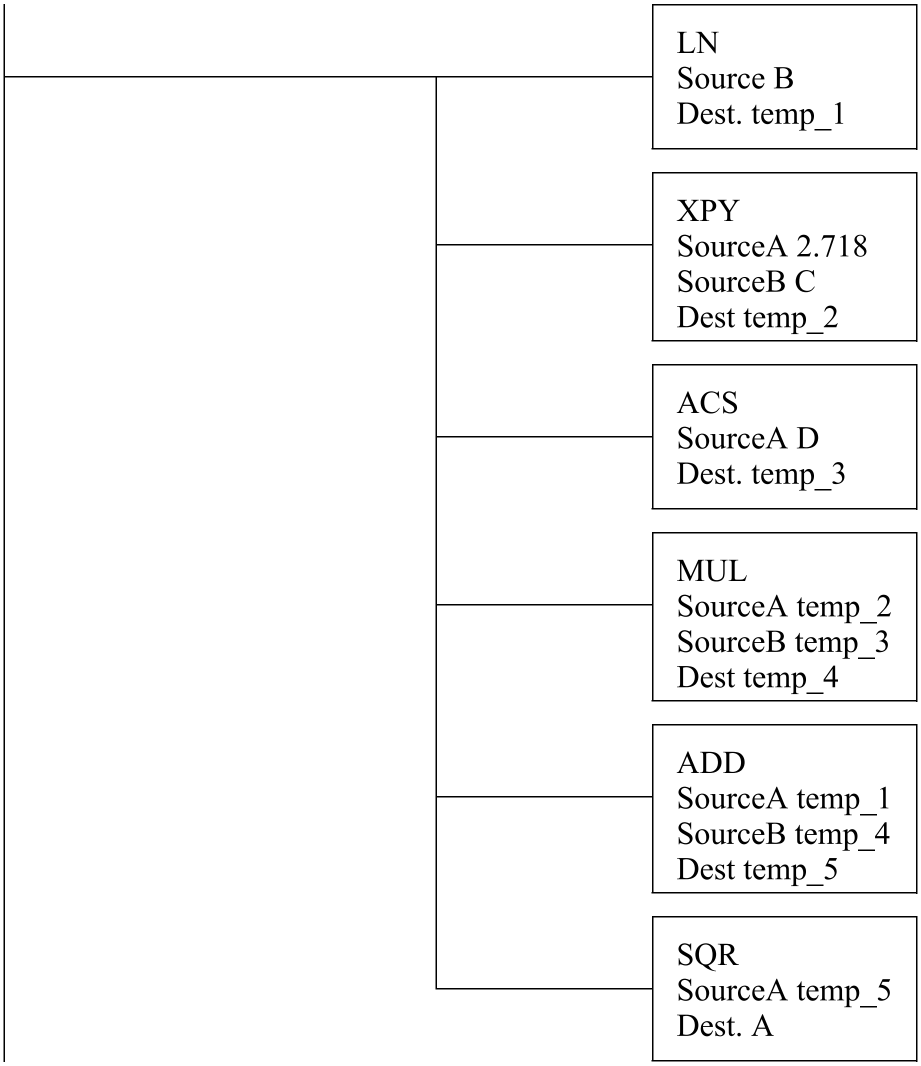


Figure 207 An Equation in Ladder Logic

The same equation in Figure 207 could have been implemented with a CPT function as shown in Figure 208. The equation uses the same memory locations chosen in Figure 207. The expression is typed directly into the PLC programming software.

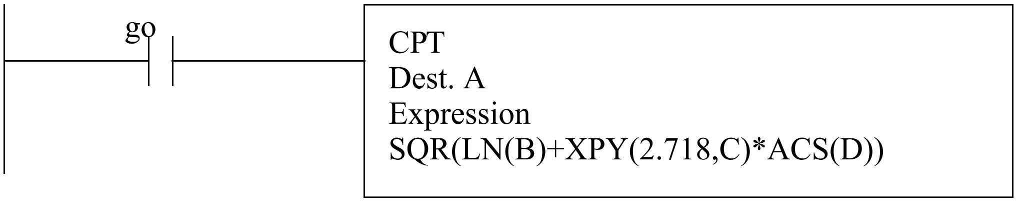
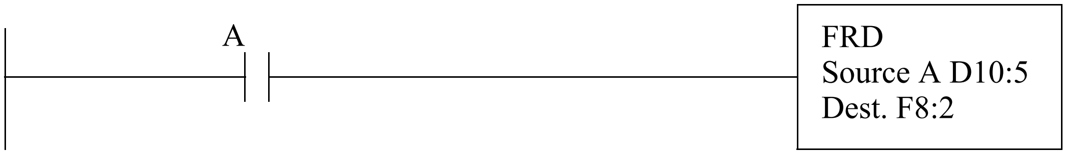


Figure 208 Calculations with a Compute Function

Math functions can result in status flags such as overflow, carry, etc. care must be taken to avoid problems such as overflows. These problems are less common when using floating point numbers. Integers are more prone to these problems because they are limited to the range.

15.2.3 Conversions

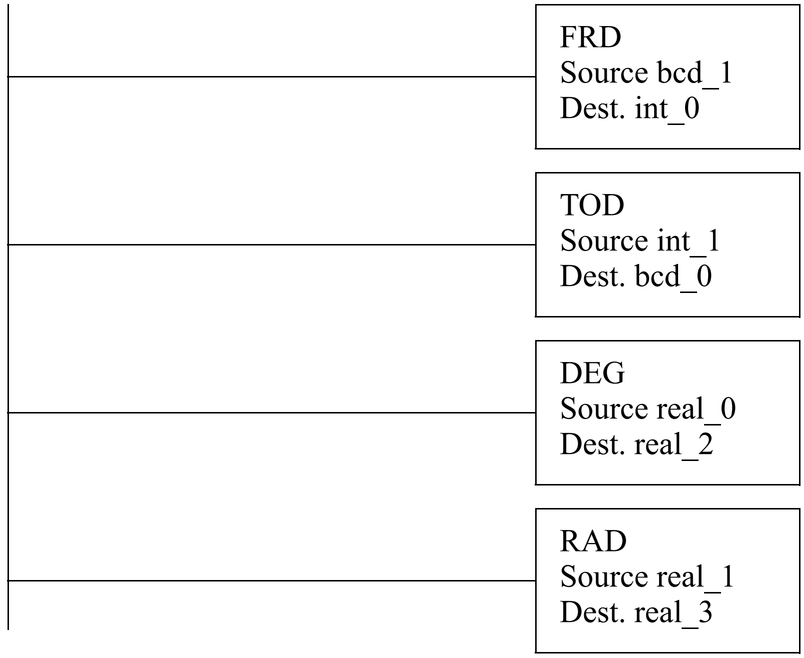
Ladder logic conversion functions are listed in Figure 209. The example function will retrieve a BCD number from the *D* type (BCD) memory and convert it to a floating point number that will be stored in *F8:2*. The other function will convert from 2s compliment binary to BCD, and between radians and degrees.



TOD(value,destination) - convert from BCD to 2s compliment
FRD(value,destination) - convert from 2s compliment to BCD
DEG(value,destination) - convert from radians to degrees
RAD(value,destination) - convert from degrees to radians

Figure 209 Conversion Functions

Examples of the conversion functions are given in Figure 210. The functions load in a source value, do the conversion, and store the results. The TOD conversion to BCD could result in an overflow error.



Addr.	Before	after
int_0	0	1793
int_1	548	548
real_0	3.141	3.141
real_1	45	45
real_2	0	180
real_3	0	0.785
bcd_0	0000 0000 0000 0000	0000 0101 0100 1000
bcd_1	0001 0111 1001 0011	0001 0111 1001 0011

these are shown in binary BCD form

Figure 210 Conversion Example

15.2.4 Array Data Functions

Arrays allow us to store multiple data values. In a PLC this will be a sequential series of numbers in integer, floating point, or other memory. For example, assume we are measuring and storing the weight of a bag of chips in floating point memory starting at *weight[0]*. We could read a weight value every 10 minutes, and once every hour find the average of the six weights. This section will focus on techniques that manipulate groups of data organized in arrays, also called blocks in the manuals.

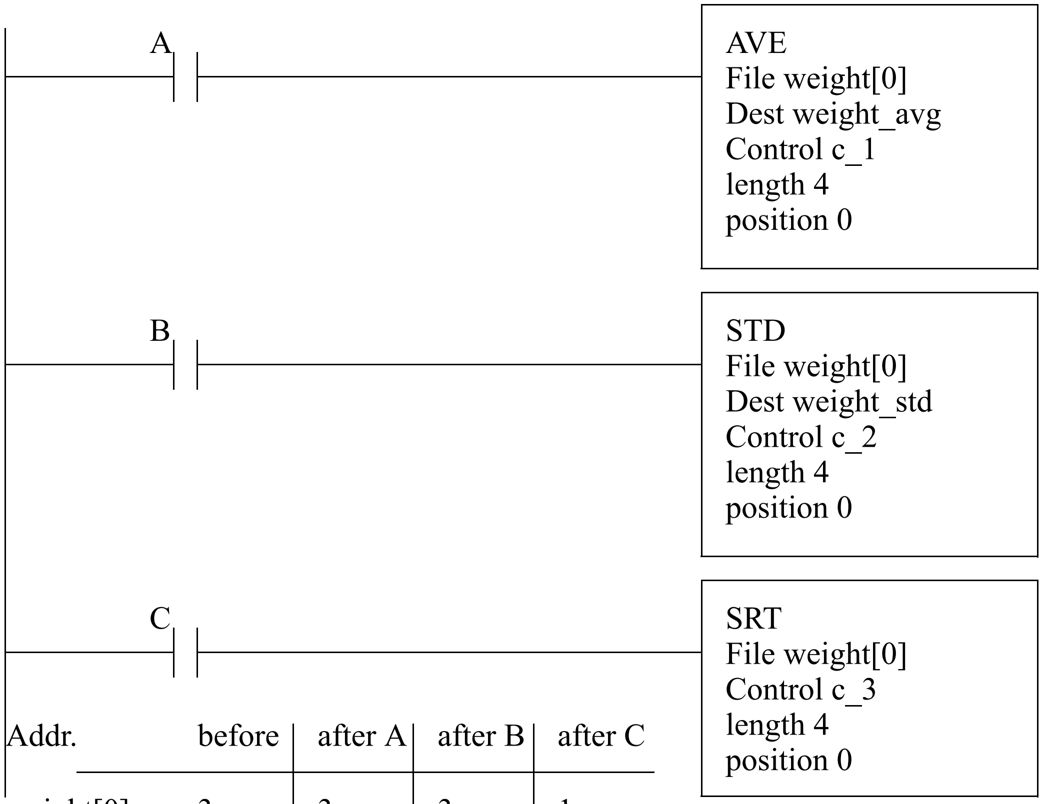
15.2.4.1 - Statistics

Functions are available that allow statistical calculations. These functions are listed in Figure 211. When *A* becomes true the average (AVE) conversion will start at memory location *weight[0]* and average a total of *4* values. The control word *weight_control* is used to keep track of the progress of the operation, and to determine when the operation is complete. This operation, and the others, are edge triggered. The operation may require multiple scans to be completed. When the operation is done the average will be stored in *weight_avg* and the *weight_control.DN* bit will be turned on.

AVE(start value,destination,control,length) - average of values
STD(start value,destination,control,length) - standard deviation of values
SRT(start value,control,length) - sort a list of values

Figure 211 Statistic Functions

Examples of the statistical functions are given in Figure 212 for an array of data that starts at *weight[0]* and is 4 values long. When done the average will be stored in *weight_avg*, and the standard deviation will be stored in *weight_std*. The set of values will also be sorted in ascending order from weight[0] to weight[3]. Each of the function should have their own control memory to prevent overlap. It is not a good idea to activate the sort and the other calculations at the same time, as the sort may move values during the calculation, resulting in incorrect calculations.



Addr.	before	after A	after B	after C
weight[0]	3	3	3	1
weight[1]	1	1	1	2
weight[2]	2	2	2	3
weight[3]	4	4	4	4
weight_avg	0	2.5	2.5	2.5
weight_std	0	0	1.29	1.29

Figure 212 Statistical Calculations

> ASIDE: These function will allow a real-time calculation of SPC data for control limits, etc. The only PLC function missing is a random function that would allow random sample times.

15.2.4.2 - Block Operations

A basic block function is shown in Figure 213. This COP (copy) function will copy an array of 10 values starting at *n[50]* to *n[40]*. The *FAL* function will perform mathematical operations using an expression string, and the FSC function will allow two arrays to be compared using an expression. The *FLL* function will fill a block of memory with a single value.

COP(start value,destination,length) - copies a block of values
FAL(control,length,mode,destination,expression) - will perform basic math operations to multiple values.
FSC(control,length,mode,expression) - will do a comparison to multiple values
FLL(value,destination,length) - copies a single value to a block of memory

Figure 213 Block Operation Functions

Figure 214 shows an example of the *FAL* function with different addressing modes. The first FAL function will do the following calculations *n[5]=n[0]+5, n[6]=n[1]+5, n[7]=n[2]+5, n[7]=n[3]+5, n[9]=n[4]+5*. The second FAL statement will be *n[5]=n[0]+5, n[6]=n[0]+5, n[7]=n[0]+5, n[7]=n[0]+5, n[9]=n[0]+5*. With a mode of *2* the instruction will do two of the calculations when there is a positive edge from B (i.e., a transition from false to true). The result of the last FAL statement will be *n[5]=n[0]+5, n[5]=n[1]+5, n[5]=n[2]+5, n[5]=n[3]+5, n[5]=n[4]+5*. The last operation would seem to be useless, but notice that the mode is *incremental*. This mode will do one calculation for each positive transition of *C*. The *all* mode will perform all five calculations in a single scan whenever there is a positive edge on the input. It is also possible to put in a number that will indicate the number of calculations per scan. The calculation time can be long for large arrays and trying to do all of the calculations in one scan may lead to a watchdog time-out fault.

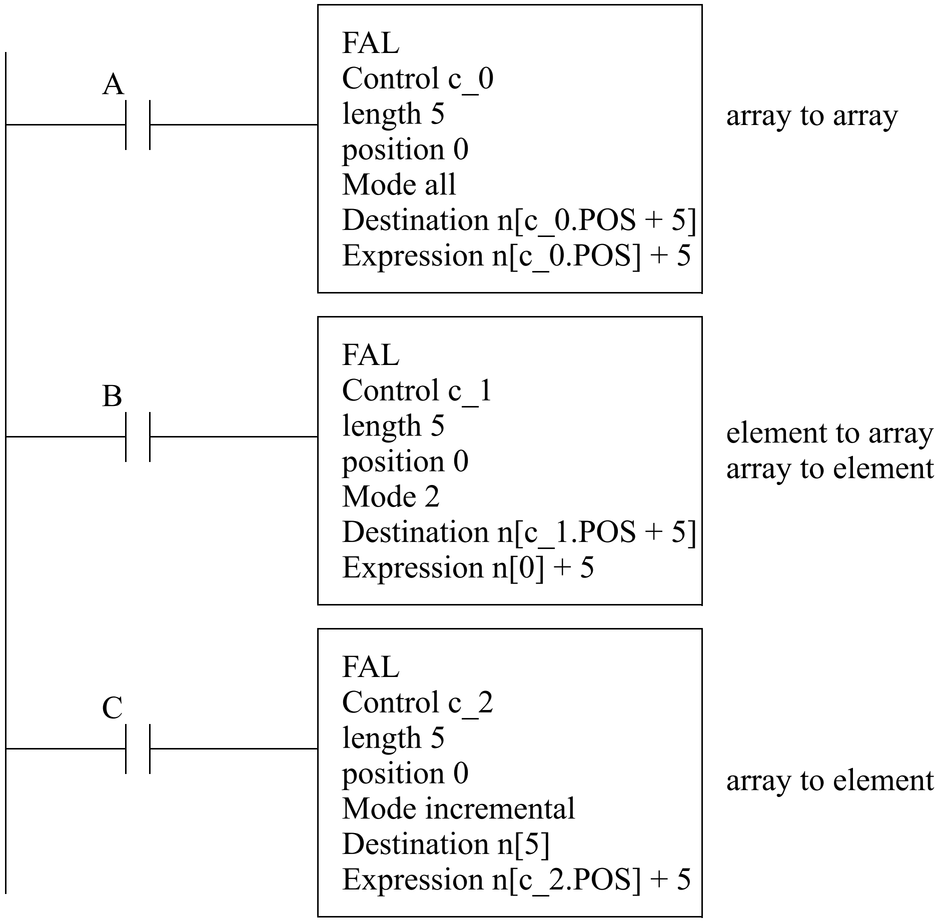
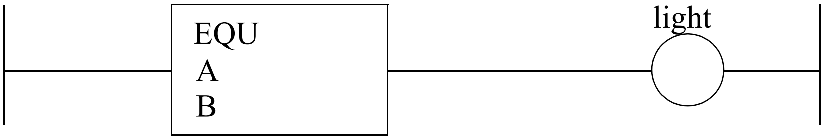


Figure 214 File Algebra Example

15.3 LOGICAL FUNCTIONS

15.3.1 Comparison of Values

Comparison functions are shown in Figure 215. Previous function blocks were outputs, these replace input contacts. The example shows an EQU (equal) function that compares two floating point numbers. If the numbers are equal, the output bit *light* is true, otherwise it is false. Other types of equality functions are also listed.



EQU(value,value) - equal
NEQ(value,value) - not equal
LES(value,value) - less than
LEQ(value,value) - less than or equal
GRT(value,value) - greater than
GEQ(value,value) - greater than or equal
CMP(expression) - compares two values for equality
MEQ(value,mask,threshold) - compare for equality using a mask
LIM(low limit,value,high limit) - check for a value between limits

Figure 215 Comparison Functions

The example in Figure 216 shows the six basic comparison functions. To the right of the figure are examples of the comparison operations.

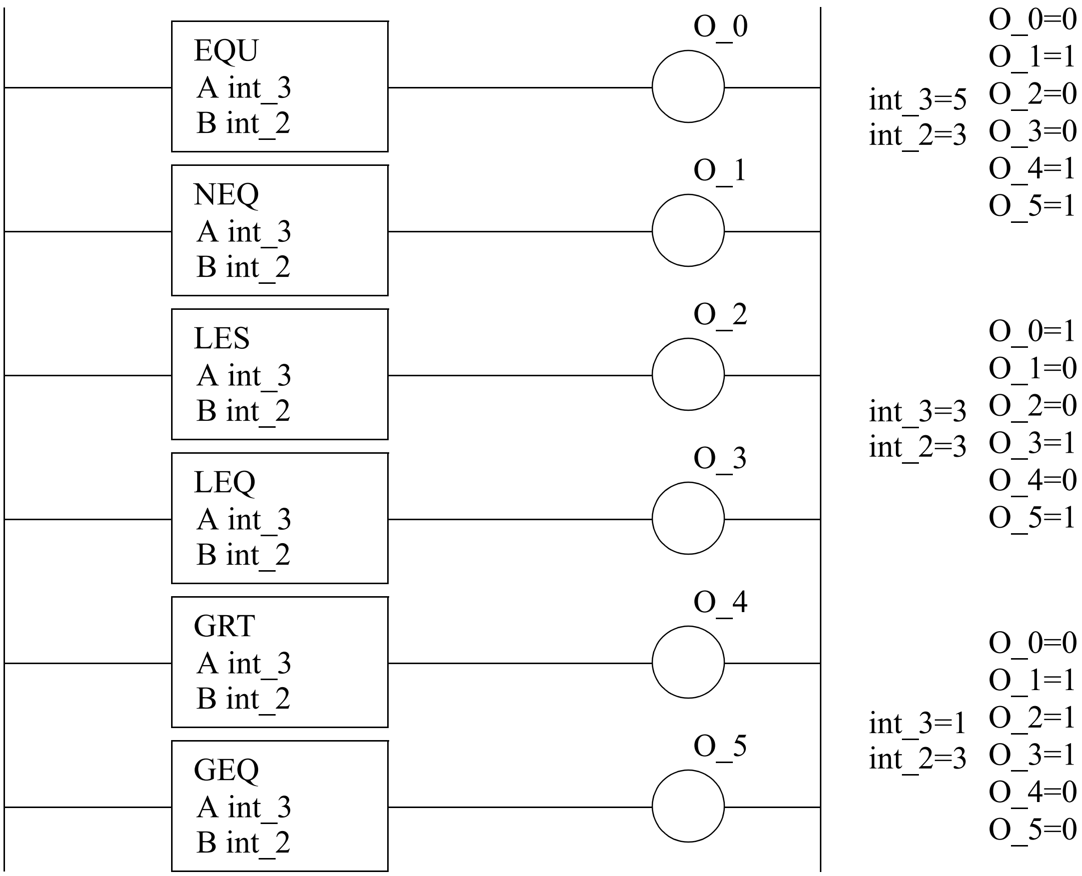


Figure 216 Comparison Function Examples

The ladder logic in Figure 216 is recreated in Figure 217 with the CMP function that allows text expressions.

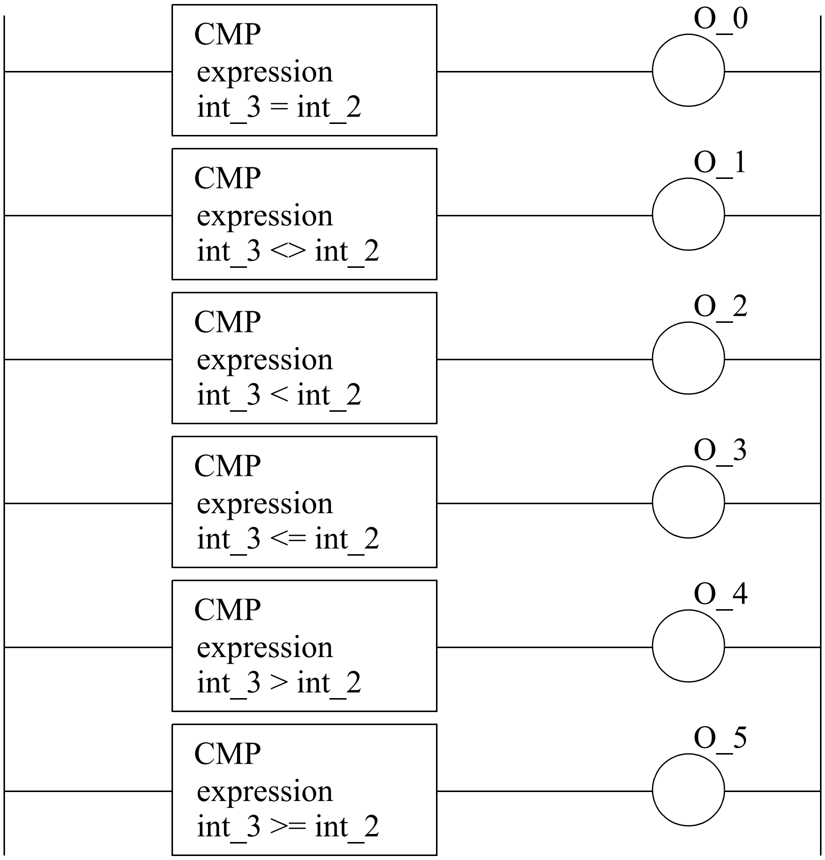


Figure 217 Equivalent Statements Using CMP Statements

Expressions can also be used to do more complex comparisons, as shown in Figure 218. The expression will determine if *B* is between *A* and *C*.

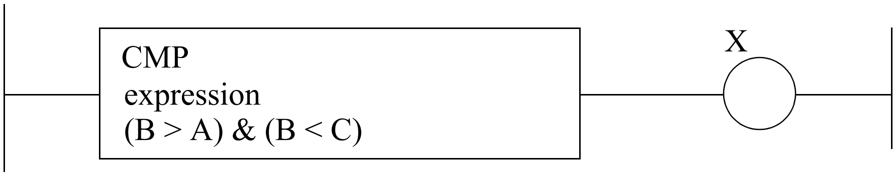
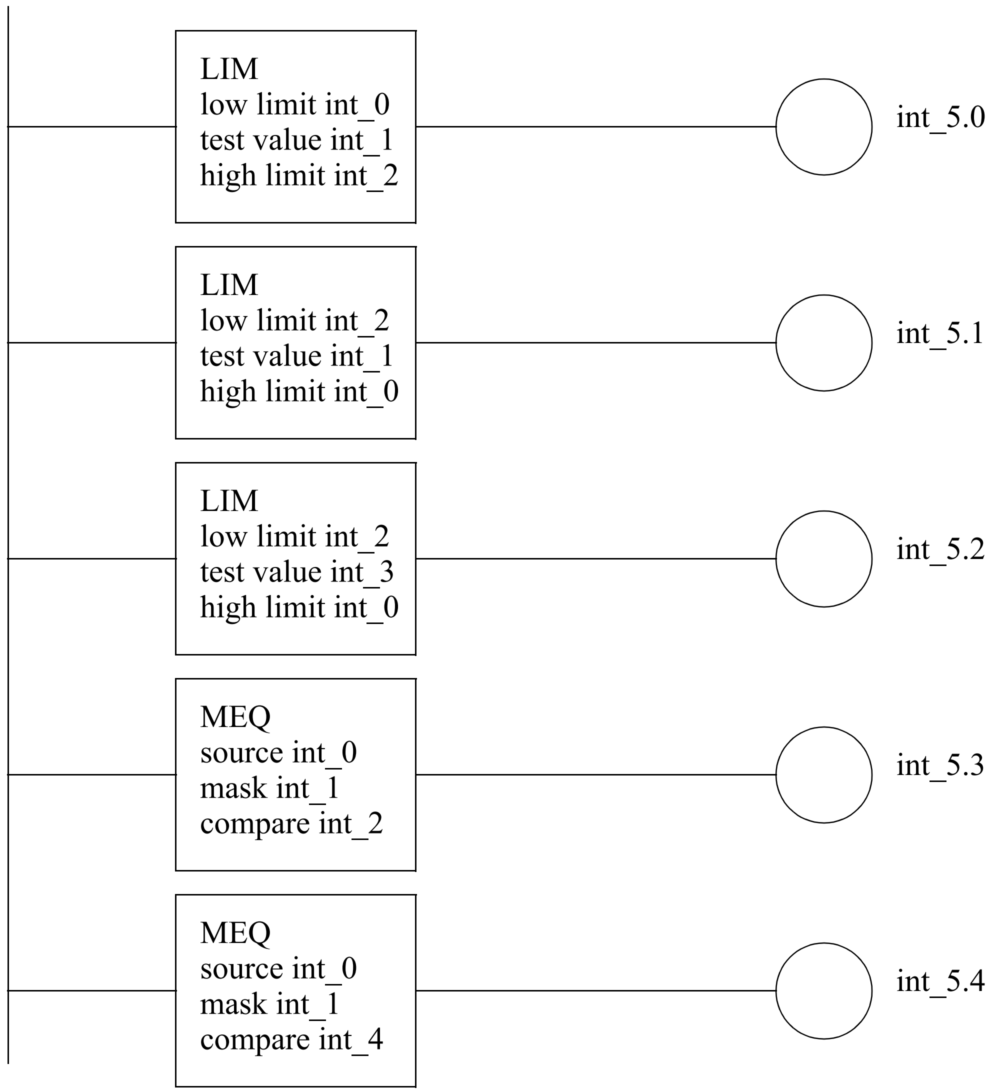


Figure 218 A More Complex Comparison Expression

The LIM and MEQ functions are shown in Figure 219. The first three functions will compare a test value to high and low limits. If the high limit is above the low limit and the test value is between or equal to one limit, then it will be true. If the low limit is above the high limit then the function is only true for test values outside the range. The masked equal will compare the bits of two numbers, but only those bits that are true in the mask.



Addr.	before (decimal)	before (binary)	after (binary)
int_0	1	0000000000000001	0000000000000001
int_1	5	0000000000000101	0000000000000101
int_2	11	0000000000001011	0000000000001011
int_3	15	0000000000001111	0000000000001111
int_4		0000000000001000	0000000000001000
int_5	0	0000000000000000	0000000000001101

Figure 219 Complex Comparison Functions

Figure 220 shows a numberline that helps determine when the LIM function will be true.

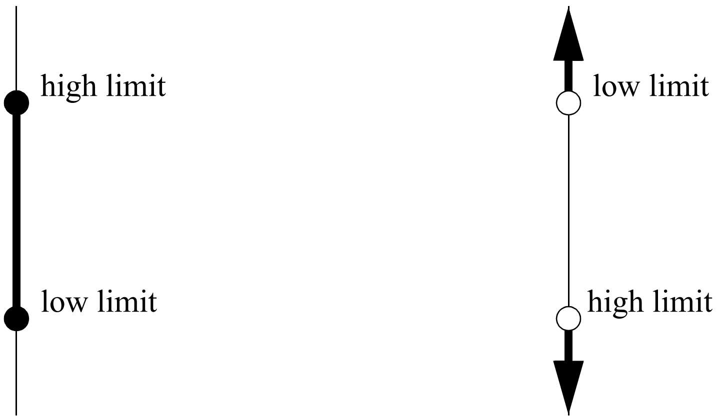


Figure 220 A Number Line for the LIM Function

File to file comparisons are also permitted using the FSC instruction shown in Figure 221. The instruction uses the control word *c_0*. It will interpret the expression 10 times, doing two comparisons per logic scan (the Mode is *2*). The comparisons will be *f[10]<f[0], f[11]<f[0]* then *f[12]<f[0], f[13]<f[0]* then *f[14]<f[0], f[15]<f[0]* then *f[16]<f[0], f[17]<f[0]* then *f[18]<f[0], f[19]<f[0]*. The function will continue until a false statement is found, or the comparison completes. If the comparison completes with no false statements the output *A* will then be true. The mode could have also been *All* to execute all the comparisons in one scan, or *Increment* to update when the input to the function is true - in this case the input is a plain wire, so it will always be true.

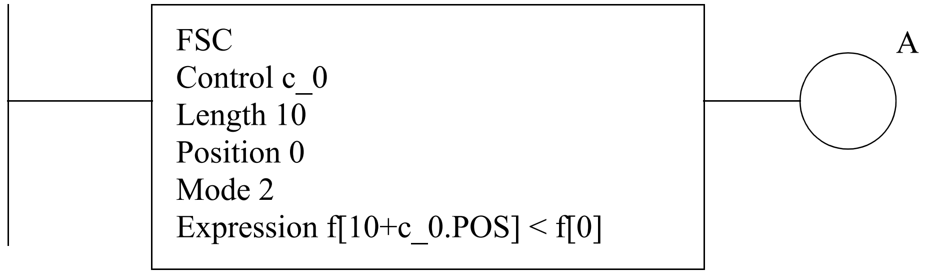
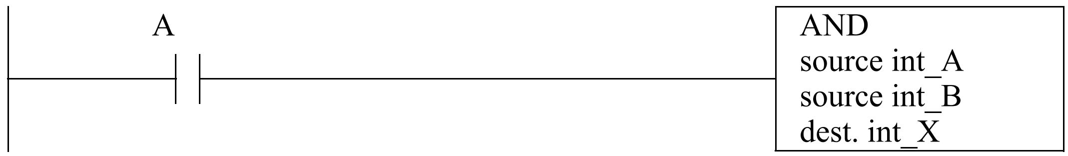


Figure 221 File Comparison Using Expressions

15.3.2 Boolean Functions

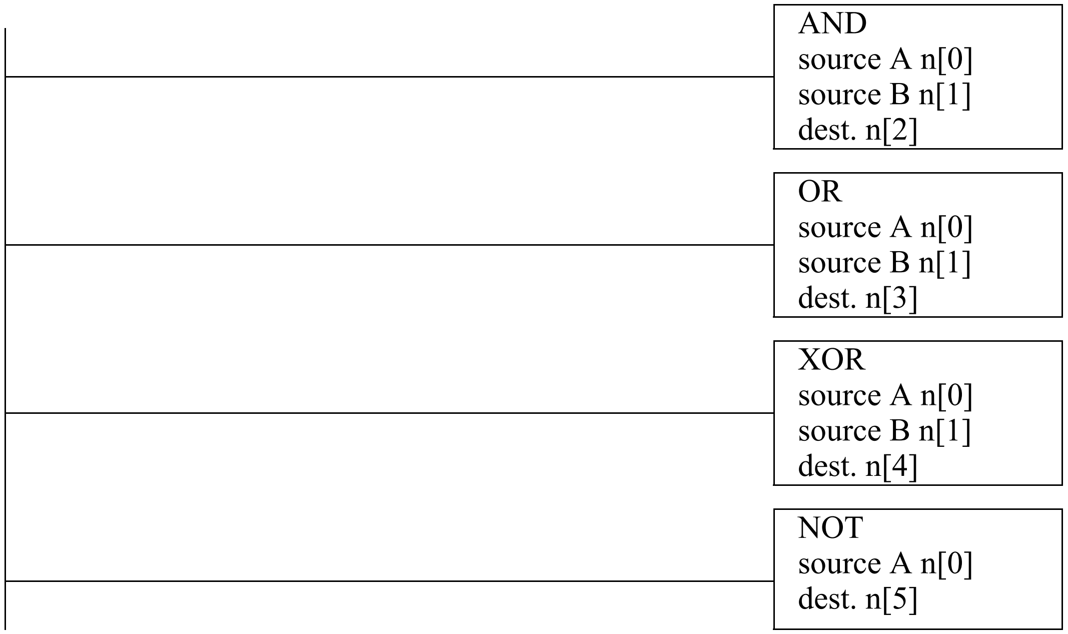
Figure 222 shows Boolean algebra functions. The function shown will obtain data words from bit memory, perform an and operation, and store the results in a new location in bit memory. These functions are all oriented to word level operations. The ability to perform Boolean operations allows logical operations on more than a single bit.



AND(value,value,destination) - Binary and function
OR(value,value,destination) - Binary or function
XOR(value,value,destination) - Binary exclusive or function
NOT(value,destination) - Binary not function

Figure 222 Boolean Functions

The use of the Boolean functions is shown in Figure 223. The first three functions require two arguments, while the last function only requires one. The AND function will only turn on bits in the result that are true in both of the source words. The OR function will turn on a bit in the result word if either of the source word bits is on. The XOR function will only turn on a bit in the result word if the bit is on in only one of the source words. The NOT function reverses all of the bits in the source word.



	addr.	data (binary)
	n[0]	0011010111011011
	n[1]	1010010011101010
after	n[2]	0010010011001010
	n[3]	1011010111111011
	n[4]	1001000100110001
	n[5]	1100101000100100

Figure 223 Boolean Function Example

15.4 DESIGN CASES

15.4.1 Simple Calculation

Problem: A switch will increment a counter on when engaged. This counter can be reset by a second switch. The value in the counter should be multiplied by 2, and then displayed as a BCD output using (O:0.0/0 - O:0.0/7)

Solution:

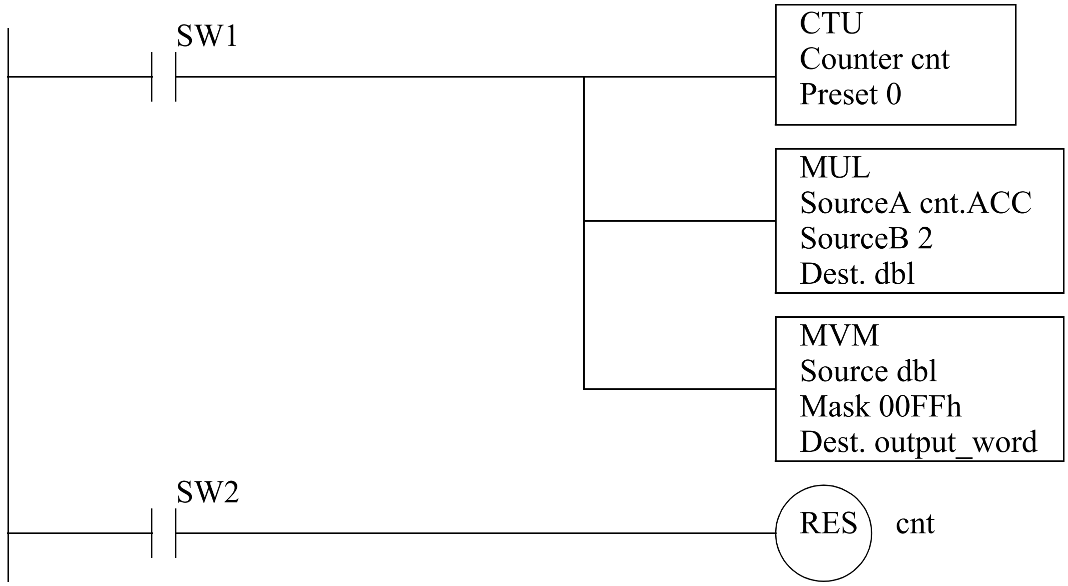


Figure 224 A Simple Calculation Example

15.4.2 For-Next

Problem: Design a for-next loop that is similar to ones found in traditional programming languages. When *A* is true the ladder logic should be active for 10 scans, and the scan number from 1 to 10 should be stored in n0.

Solution:

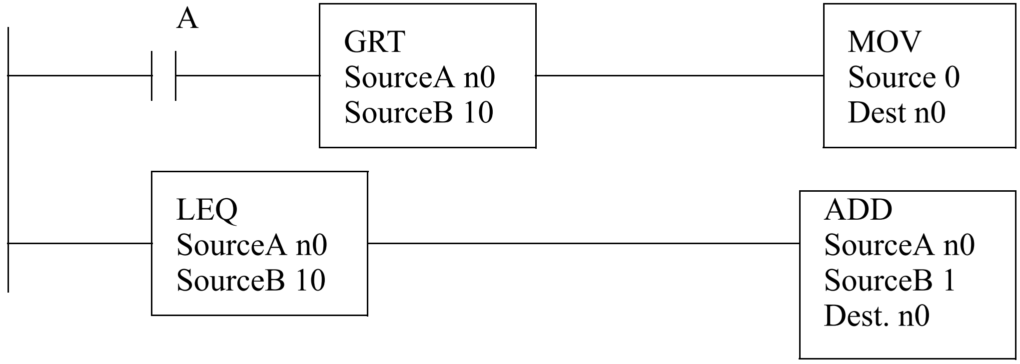


Figure 225 A Simple Comparison Example

As designed the program differs from traditional loops because it will only complete one ’loop’ each time the logic is scanned.

15.4.3 Series Calculation

Problem: Create a ladder logic program that will start when input *A* is turned on and calculate the series below. The value of *n* will start at 1 and with each scan of the ladder logic *n* will increase until n=100. While the sequence is being incremented, any change in *A* will be ignored.

$$x = 2(n-1)$$

Solution:

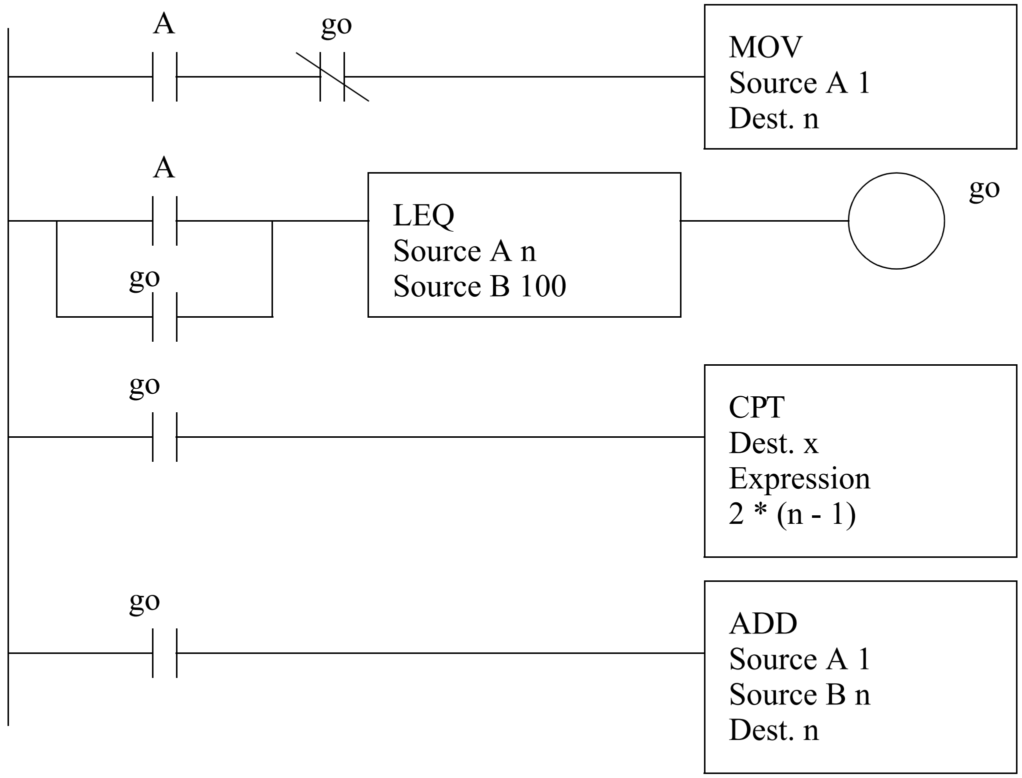
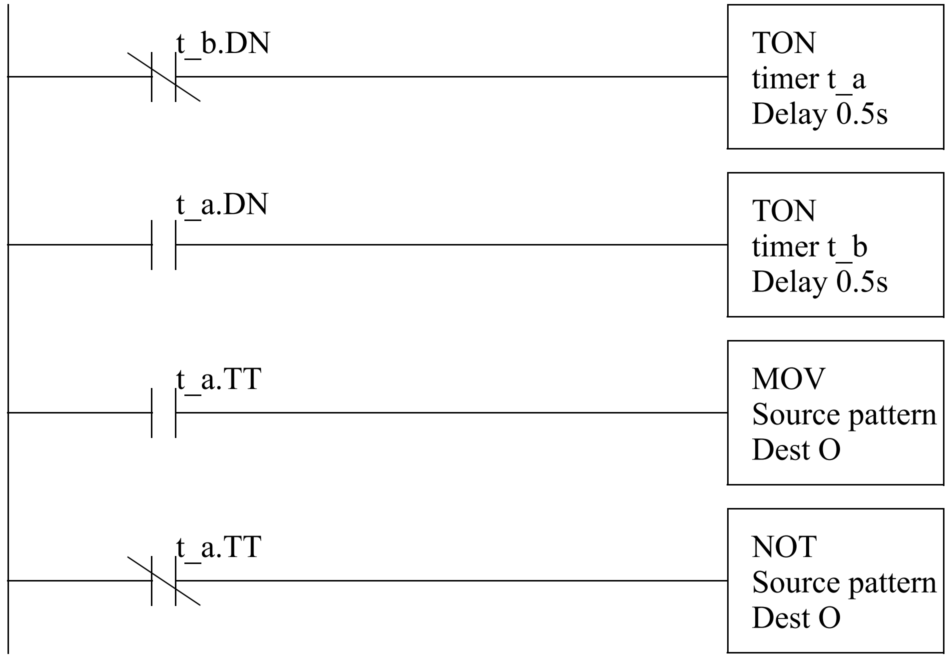


Figure 226 A Series Calculation Example

15.4.4 Flashing Lights

Problem: We are designing a movie theater marquee, and they want the traditional flashing lights. The lights have been connected to the outputs of the PLC from O[0] to O[17] - an INT. When the PLC is turned, every second light should be on. Every half second the lights should reverse. The result will be that in one second two lights side-by-side will be on half a second each.

Solution:



pattern = 0101 0101 0101 0101

Figure 227 A Flashing Light Example

15.5 SUMMARY

- Functions can get values from memory, do simple operations, and return the results to memory.
- Scientific and statistics math functions are available.
- Masked function allow operations that only change a few bits.
- Expressions can be used to perform more complex operations.
- Conversions are available for angles and BCD numbers.
- Array oriented file commands allow multiple operations in one scan.
- Values can be compared to make decisions.
- Boolean functions allow bit level operations.
- Function change value in data memory immediately.

15.6 PRACTICE PROBLEMS

1. Do the calculation below with ladder logic,

n_2 = -(5 - n_0 / n_1)

2. Implement the following function,

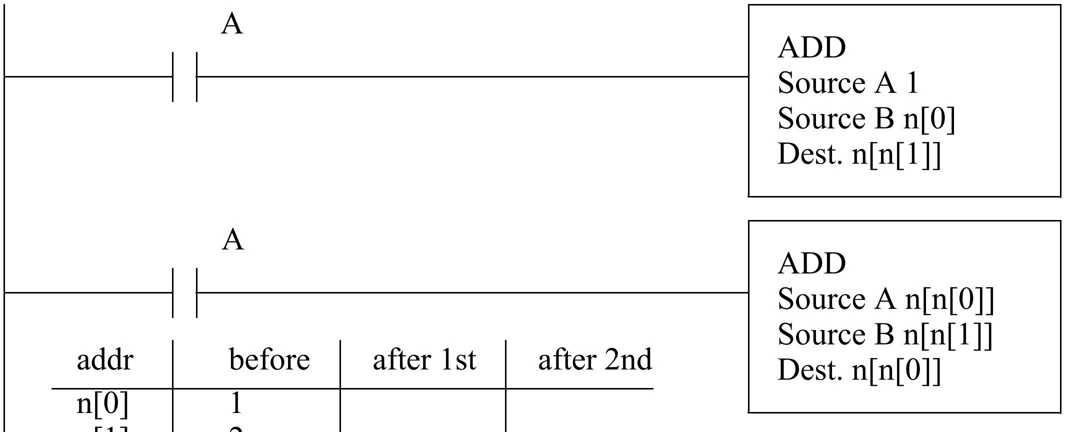
$$x = \operatorname{atan}\left(y\left(\frac{y + \log(y)}{y + 1}\right)\right)$$

3. A switch will increment a counter on when engaged. This counter can be reset by a second switch. The value in the counter should be multiplied by 5, and then displayed as a binary output using output integer 'O_lights'.

4. Create a ladder logic program that will start when input *A* is turned on and calculate the series below. The value of *n* will start at 0 and with each scan of the ladder logic *n* will increase by 2 until n=20. While the sequence is being incremented, any change in *A* will be ignored.

$$x = 2(\log(n) - 1)$$

5. The following program uses indirect addressing. Indicate what the new values in memory will be when button A is pushed after the first and second instructions.



addr	before	after 1st	after 2nd
n[0]	1		
n[1]	2		
n[2]	3		

6. A thumbwheel input card acquires a four digit BCD count. A sensor detects parts dropping down a chute. When the count matches the BCD value the chute is closed, and a light is turned on until a reset button is pushed. A start button must be pushed to start the part feeding. Develop the ladder logic for this controller. Use a structured design technique such as a state diagram.

Inputs	Outputs
bcd_in - BCD input card	chute_open
part_detect	light
start_button	
reset_button	

7. Describe the difference between incremental, all and a number for file oriented instruction, such as *FAL*.

8. What is the maximum number of elements that moved with a file instruction? What might happen if too many are transferred in one scan?

9. Write a ladder logic program to do the following calculation. If the result is greater than 20.0, then the output

’solenoid’ will be turned on.

$$A = D - Be^{-\frac{T}{C}}$$

10. Write ladder logic to reset an RTO counter (timer) without using the RES instruction.

11. Write a program that will use Boolean operations and comparison functions to determine if bits 9, 4 and 2 are set in the input word *input_card*. If they are set, turn on output bit *match*.

12. Explain how the mask works in the following MVM function. Develop a Boolean equation.

13. A machine is being designed for a foreign parts supplier. As part of the contractual agreement the logic will run until February 26, 2008. However, after that date the machine will enable a ‘contract_expired’ value and no longer run. Write the ladder logic.

14. Use an FAL instruction to average the values in n[0] to n[20] and store them in ’n_avg’.

15. The input bits from ’input_card_A’ are to be read and XORed with the inputs from ’input_card_B’. The result is to be written to the output card ’output_card’. If the binary pattern of the least 16 output bits is 1010 0101 0111 0110 then the output ’match_bell’ will be set. Write the ladder logic.

16. Write some simple ladder logic to change the preset value of a counter ’cnt’. When the input ‘A’ is active the preset should be 13, otherwise it will be 9.

17. A machine ejects parts into three chutes. Three optical sensors (A, B and C) are positioned in each of the slots to count the parts. The count should start when the reset (R) button is pushed. The count will stop, and an indicator light (L) turned on when the average number of parts counted is 100 or greater.

18. a) Write ladder logic to calculate and store the binary (geometric) sequence in 32 bit integer (DINT) memory starting at n[0] up to n[200] so that n[0] = 1, n[1] = 2, n[2] = 4, n[3] = 16, n[4] = 64, etc. b) Will the program operate as expected?

15.7 ASSIGNMENT PROBLEMS

1. Write a ladder logic program that will implement the function below, and if the result is greater than 100.5 then the output ’too_hot’ will be turned on.

$$X = 6 + Ae^{B}\cos(C + 5)$$

2. Write ladder logic to calculate the average of the values from thickness[0] to thickness[99]. The operation should start after a momentary contact push button *A* is pushed. The result should be stored in ’thickness_avg’. If button *B* is pushed, all operations should be complete in a single scan. Otherwise, only ten values will be calculated each scan. (Note: this means that it will take 10 scans to complete the calcula-

tion if A is pushed.)

3. Write a ladder logic program that will calculate the standard deviation of numbers in the locations f[0] to f[29] without using the STD function.

4. A program is to perform the following actions for a self-service security check. The device will allow bags to be inserted to the test chamber through an entrance door. If the bag passes the check it can be removed through an exit door, otherwise an alarm is sounded. Create a state diagram using the steps below.
    1. The machine starts in an ‘idle’ state. The ‘open_entry’ output is activated to open the input door. The ‘open_exit’ output is deactivated to close the output door.
    2. When a bag is inserted the ‘bag_detected’ input goes high. The ‘open_entry’ input should be deactivated to close the door.
    3. When the ‘entry_door_closed’ and ‘exit_door_closed’ inputs are active then a ‘test’ output will be set high to start a scan of the bags.
    4. When the scan of the bags is complete a ‘scan_done’ input is set. The ‘test’ output should be turned off.
    5. The scan results in two real values ‘nitrates’ and ‘mass’. The calculation below is performed. If the ‘risk’ is below 0.3, or above 23.5, then the machine enters an alarm state (step 8), otherwise it continues to step 6.

    $$risk = 4^{nitrates} + sqrt(mass)nitrates$$

    6. The ‘open_exit’ output is activated to open the exit door. The machine waits until the ‘bag_detected’ input goes low.
    7. The ‘open_exit’ output is deactivated to close the door. The machine waits until the ‘exit_door_closed’ input is high before returning to the ‘idle state.
    8. In the alarm state an operator input ‘key’ must be active to open the exit door. After this input is released the door will close and return to the ‘idle’ state.