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THESIS APPROVAL

The abstract and thesis of Nee-Hua Cho for the Master of Science in Electrical and Computer Engineering were presented November 8, 1995, and accepted by the thesis committee and the department

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AN ABSTRACT OF THE THESIS OF Nee-Hua Cho for the Master of Science in Electrical and Computer Engineering presented November 8, 1995.

Title: Equivalent Relationship of Function-level Representation and Implementation of Unified Indexing of FFT Algorithms.

With the advance of the VLSI technology, the FFT algorithm has been pushed further in solving the multidimensional array signal processing in real time. Many DSP chip users have tried to find ways to improve addressing huge data in multidimension systems with minimum cost and maximum performance. However, there is no efficient method to address data for 1-D to M-D FFTs.

A methodology has been defined to conquer the addressing problem of M-D FFT. It is well known that the twiddle factor matrix of Discrete Fourier Transform (DFT) can be recursively factored into basic butterfly stage matrices. The matrix can be factored into three matrices practically specifying the input data, twiddle factor, and output data sequence of the Fast Fourier Transform (FFT). The equivalent relationship of these matrices will be introduced. The equivalent relationship for a variety of the FFT algorithms can be obtained by equivalent transformations. Furthermore, the multidimensional (M-D) FFT can be represented by the same vector-matrix form as the one-dimensional (1-D) FFT. In addition, the addressing sequences of the 1-D FFT is a subset of the M-D FFT. Therefore, the signal flow graph of the 1-D FFT can be used to describe that of the M-D FFT and all M-D indexing can be implemented by 1-D indexing.

Finally, this unified indexing approach was implemented into the WinDSP software simulator. Examples of M-D FFTs implemented with the unified indexing method are simulated on the WinDSP and the computation performance were analyzed. From the benchmark analysis, the 2-D FFT applications implemented with unified methodology use less instructions and the execution time is almost two times faster than the traditional method.

WinDSP is a software simulator that simulates the functional characteristics of Sharp LH9124/LH9320 DSP chip set. It intended to manage the complete development of DSP applications, from conceptualization and experimentation, to verification of unified indexing for 1-D to M-D FFT. It is also intended for system development, where hardware can be implemented for the design.

**EQUIVALENT RELATIONSHIP OF FUNCTION-LEVEL
REPRESENTATION AND IMPLEMENTATION OF
UNIFIED INDEXING OF FFT ALGORITHMS**

by

NEE-HUA CHO

A thesis submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE
in
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Portland State University

1995

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Vancouver, Washington

Nee-Hua Cho

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CHAPTER I

INTRODUCTION

With advances in today's digital signal processing (DSP) algorithms and very large scale integration (VLSI) technologies, array signal processors (ASP) with highly parallel computing structures have become increasingly important in recent years [Haykin, 1985]. By definition, parallel computing structures imply a basic computational element repeated perhaps hundreds or thousands of times [Hwang and Briggs, 1984]. Array signal processing deals with propagating signals received by an array of sensors (or a multichannel of sensors). Array signal processors handle large volumes of data from multi-channel arrays. Traditional analog signal processing can provide the required speed. However, strict stability (i.e. requiring fine adjustment) and resolution requirements (mathematics finess) are difficult to obtain. Therefore, the design of an array digital signal processor chip architecture, the development of DSP algorithms and the implementation of the system are solutions to analog problems. The digital system is usually constrained by processing speed and the I/O bottleneck of array processing. Limited sampling rate and complexity of algorithms adopted in the processor are classic examples that degrade system speed and performance.

The increasing performance demands in modern signal and image processing applications necessitate a revolution in DSP algorithms and super-computing technology. The Fast Fourier Transform (FFT) is usually a fundamental driving force for real-time

digital signal processing in array processor systems such as radar, sonar, seismic, medical image, telecommunication, etc. Array signal processing must handle multi-dimension and multi-channel problems. Array processing performance is usually offset by the steps required for multi-dimension indexing or addressing. With the availability of low-cost, high density and high-speed VLSI devices, the FFT algorithm has pushed multidimensional array signal processing into real-time. However, there is no efficient addressing method for one dimensional (1-D) to multi-dimensional (M-D) FFTs. A unified indexing technique developed and defined by C. J. Ju [Ju, 1993] solved the problems of addressing method for 1-D to M-D FFTs. This technique has simplified all multidimensional indexing. But the question remains: How well is the unified indexing technique mapped to the DSP architecture of the commercial chip set? What advantages does the unified addressing technique have over the traditional method? To be feasible, the DSP chip set must be implemented within reasonable bounds of hardware requirements and constraints, yet perform with real-time efficacy. The Sharp LH9124/LH9320 chip set is of particular interest, relative to the contemporary FFT processors because of its highly parallel and pipeline architecture and its by-pass form execution unit.

This thesis involves the implementation of unified indexing of FFT algorithms and shows the equivalent relationship between function-level representation of the LH9124 FFT instructions and the vector matrices transformed using the unified indexing approach. These led to the development of WinDSP software simulator which implements the unified indexing concepts and simulates the functional characteristics of the LH9124/LH9320 chip set. An overview of fundamental digital signals, a brief description of

LH9124/LH9320 architecture and a derivation of the unified addressing FFT algorithm are given to show constraints and conditions imposed on the design of the WinDSP software simulator.

ALGORITHM ANALYSIS, DERIVATION AND MAPPING

Most array signal processors are special-purpose DSP chips. Therefore, the architecture design is application-driven or algorithm-driven. The algorithm development and algorithm-to-chip architecture mapping are essential to the overall system performance. The algorithm is analyzed to get special features and to find efficient solutions for a specific set of problems. Our applications are in array signal processing. Some features are specific to those applications. First, they are compute-intensive applications. Second, they usually have to handle multi-dimension and multi-channel problems. Third, they encounter scaling problems due to the block floating-point arithmetic. Finally, the applications must be configured into parallel or pipeline architectures to meet real time speed requirements such as latency and throughput.

To conquer compute-intensive and highly (or mostly) parallel applications, FFT-based block-oriented DSP algorithms will be adopted. The multi-dimensional (M-D) Fast Fourier Transform is an essential algorithm for most applications. In M-D FFT computations, the performance of enhanced array processor architecture structures is greatly degraded by the M-D indexing calculations. Moreover, the signal reference level adjustments (scaling) required in M-D FFT computations also make array processors quite inefficient compared to the one-dimensional case. These two problems must be

solved to design efficient array systems.

To support efficient computations of the M-D FFT, a novel unified indexing FFT algorithm was developed [Ju, 1993]. Unified indexing means that the general M-D FFT algorithm indexing can be mapped to 1-D FFT indexing and can be computed by 1-D FFT method. These including data, twiddle factors, and digit-reverse addressing. The algorithm derivation can be described in the following.

1-D FFT Derivation and Analysis

It is well-known that the computing efficiency of the FFT comes from recursive factorization of the twiddle factor matrix in the Discrete Fourier Transform (DFT) [Oppenheim and Schafer, 1989]. The matrix can be recursively partitioned and factored into butterfly stage matrices. Each butterfly stage matrix can be further factored into three matrices: A right permutation matrix, a central butterfly computation matrix, and left permutation matrix. The three-matrix representation of the butterfly stage matrix has essential meaning in the physical FFT algorithm implementation [Ju, 1993]. The right permutation matrix can represent the input interconnection and define the input data address sequence of the stage. Similarly, the left permutation matrix can denote the output interconnection and also define the output data address sequence of the stage. The data address sequence including the digit-reverse address sequence can be directly obtained from the locations of ones from top to bottom of the permutation matrix. The central butterfly computation matrix is a block diagonal matrix which performs the butterfly operations of the stage. This matrix can also be used to derive the twiddle factor address sequence.

Unified Indexing for M-D FFTs

As in the 1-D case, the twiddle factor matrix of the M-D Discrete Fourier Transform (DFT) can be decomposed into the multiplications of the butterfly stage matrices, see “Fundamental Computing Structures: Butterflies” on page 18. It can be derived through equivalent matrix transformations since the M-D FFT has the same matrix structure as the 1-D FFT when both have the same number of data, see “Unified Signal Flow Graph Structure for 1-D to M-D FFT” on page 42. In addition, the permutation matrices for both 1-D and M-D FFTs in each stage are the same. This implies that the signal flow graph structure of the M-D FFT can be mapped to that of the 1-D FFT. Thus, the data and digit-reverse indexing of the 1-D FFT can be universally applied to those of the M-D FFTs. It can also be shown that the twiddle factor matrices of the 1-D FFT are the subset of those of the M-D FFT. This means the twiddle factor sequence of the 1-D FFT can also be used for that of the M-D FFT.

PROBLEM STATEMENT

The array processor LH9124 and address generator LH9320 developed by Sharp Microelectronics Technology [LH9124 and LH9320 User’s Guide] are high speed chips and at the time of their introduction were innovative designs for real-time applications. When it’s used for processing large data set in complex system applications, they still ran into system architecture problems. Systems with large number of data mostly want to process multidimension and multi-channel FFTs. Thus, to implement a M-D FFT algorithm, the traditional method required many instructions and excessive pipeline

overhead to compute the data. For example, in the traditional method for 2-D FFT, each individual row vector is computed and the scaling factor extracted. Then each individual row is scaled with the maximum scaling factor extracted. This same process is applied for each column vector. Thus, the whole process will take excessive hardware and software to accomplish the FFT computation. There is no efficient addressing method for 1-D to M-D FFTs. Hence, the unified indexing for 1-D to M-D approach was proposed to address these problems.

There are several advantages for implementing the unified indexing technique. First, the number of FFT instructions required is greatly reduced. Less physical memory is used and the performance can be improved by reducing instruction pipelined overhead. For example, the unified approach requires only 3 instructions to implement 16 by 16 by 16 3-D FFT, while the traditional approach requires 768 instructions. Second, no data matrix transposition is required because the transposition is already covered in the M-D to 1-D Signal Flow Graph structure mapping. Thus it is much easier for users to implement the M-D FFT without considering the time-consuming complex matrix transposition. Third, the unified approach automatically solves the scaling problems that occur in the block floating-point arithmetic. The traditional approach requires extra hardware or software to solve the problem. Fourth, the simplified and unified 1-D addressing not only speeds up the M-D FFT algorithms but also makes the chip function definition easier. Finally, the function instructions of LH9124 reduce effort in program coding and debugging.

GOALS AND DESIGN DEVELOPMENT METHODOLOGY

Starting from the vector-matrix representation, the equivalent relationship between 1-D and M-D FFTs employing the equivalent transformation of the matrices has been defined in this thesis. Particularly, it will be shown that the signal flow graph (SFG) structure of the 1-D FFT can be used to represent that of the M-D FFT regardless of the dimension if the total number of elements is the same. The radix-2 FFT is the basis of all these implementations. The novel unified indexing for 1-D to M-D FFT algorithms can be implemented in the LH9124/LH9320 FFT architecture. Not all FFT chip set architectures can implement the unified indexing technique.

The primary goal of the thesis is to implement the unified indexing methodology in WinDSP software simulator for 1-D to M-D FFT algorithm. The window-based software simulator not only simulates the functional characteristics of the LH9124/LH9320 chip set, but also presents the function block diagram equivalent of function-level representation and the unified indexing matrix. WinDSP software simulator can be used to verify the correctness and performance of M-D FFT applications that using the concept of novel unified indexing vector matrix compared with the traditional method. WinDSP was developed solely by the author and has been evaluated by commercial companies like G. E. Medical, Catalina Research, Baka Corporation and etc. WinDSP software tool can be used to verify the unified indexing implementation for 1-D to M-D FFT in near real-time computation. With the implementation of the LH9124/LH9320 DSP chip set, it can be shown that the unified approach for M-D FFT has tremendous advantage over the traditional M-D FFT approach in performance. Another advantage

expected is there will be a cost saving in hardware and software development. This approach can be extended to the fast cosine transform adopted by image processing systems that require fast high-end real-time computations.

ORGANIZATION OF THIS THESIS

In Chapter I, a brief introduction to system requirements and specification for fast array processors is given. FFT algorithm analysis, derivation and mapping are also briefly outlined. The important aspect of this thesis is to implement the unified indexing approach for 1-D to M-D FFT using WinDSP simulator as a tool. The function-level representation mapping between the unified indexing of the FFT algorithm and the LH9124 FFT instruction set will also be presented in this thesis by the author.

WinDSP simulates the function and the data flow characteristics of the LH9124. Each function block diagram of the WinDSP is also the function-level representation of an instruction in the LH9124. The mapping relationship of WinDSP and unified indexing approach of the FFT will be introduced. The function block diagram is object-oriented, has clear visualization, allows conceptualization and prototyping, and is easy for real-time hardware implementation.

In Chapter II, a brief overview of the Fast Fourier Transform (FFT) and Fast Cosine Transform (FCT) algorithm is given. The derivation of FFT from DFT will be discussed, the derivation of FCT and three ways of implementing the FCT on the LH9124 will also be introduced, together with applications, using the concept of Unified Index Addressing.

Chapter III briefly introduces the LH9124 chip architecture and design considerations. Again some mathematical derivations, analysis and mappings will be presented.

Chapter IV presents the concept of the Unified Index Addressing of FFT. The detailed algorithms analysis, mathematical derivations and data-flow-graph mappings of the FFT indexing will be presented. Following that, the concept of mapping 1-D FFT to M-D addressing will be explained and its simplicity will be emphasized. The architectural and operational description of the FFT data I/O design will also be provided.

Chapter V is devoted to the software WinDSP, a function block and system block level simulation. The description of designing the software environment that manages a complete application development from the conceptualization stage will be given. The mapping relationship between the unified indexing matrix and the function block diagram of the WinDSP will be presented. The importance of this tool is that it helps to understand the mapping relationships between the algorithmic flow graph structure and its index addressing. Some examples will show the direct relationship of the flow-graph indexing using the user-friendly simulator for designing applications at the fundamental level.

In Chapter VI, the evaluation and performance of the FFT examples are analyzed and compared to competing approaches. The benchmark for implementing unified indexing approach and the traditional approach will be analyzed.

Chapter VII closes the thesis with concluding remarks and summarizes the achievements of the thesis.

Appendix A contains the detailed examples of 1-D 16-point implementations of

the unified indexing algorithm. Appendix B shows the example of using unified indexing on 4 by 4 2-D FFT algorithms. Appendix C presents the address sequence in a table from examples in Appendix A and B. Finally, Appendix D lists all the source code of the WinDSP simulation program.

CHAPTER II

FUNDAMENTALS OF DIGITAL SIGNALS

A signal can be defined as a function that conveys information. Generally, a signal is about the state or behavior of a physical system. Signal can be represented in many different ways, but in most cases, the information contained in the signal can be mathematically analyzed. Signals can be represented as functions of one or more independent variables. For example, an image signal is represented mathematically on brightness of two spatial variables, whereas the speech signal is represented as a function of one independent variable. The independent variables in the mathematical representation of a signal may be continuous or discrete. Continuous-time signals are often referred to as analog signals, and are defined along a continuum of time. Discrete-time signals are represented as sequences of numbers and are defined at discrete times. In DSP applications, a sequence of numbers x , in which the n -th number in the sequence is denoted $x[n]$, is formally written as

$$x = \{x[n]\}, \quad n = \{\dots, -4, -3, -2, -1, 0, 1, 2, 3, 4, \dots\} \quad (2.1)$$

where n is an integer. In a practical setting, such sequences can often arise from periodic sampling of an analog signal. In this case, the numeric value of the n -th number in the sequence is equal to the value of the analog signal $x_a(t)$ at time nT ; i.e.

$$x[n] = x_a(nT), \quad n = \{\dots, -4, -3, -2, -1, 0, 1, 2, 4, \dots\} \quad (2.2)$$

where T is the uniform interval (typically a time interval) between input samples. $x_a(nT)$ can represent a sequence of numbers generated on a computer, data taken from an experiment or numbers from some natural phenomena that have been sampled. For simplicity, the sequence is denoted as $x(nT)$ or $x(n)$, where the uniform sampling period is implied. A discrete sequence is shown in Figure 1.

Figure 1. Discrete signal x with independent variable nT

In many applications, the class of signals of interest is periodic. The periodic class of signals has an efficient method of analyzing the signal. The Fourier transform is commonly used to obtain the frequency spectrum of the signal. The frequency spectrum of a signal shows its periodic character.

Signal conveys specific information that the DSP system is attempting to interpret. One goal of a DSP system is to provide the best approach to analyzing or estimating the information content of the signal.

Overview of Fast Fourier Transform

The Discrete Fourier Transform (DFT) plays an important role in the analysis, design, and implementation of discrete-time signal processing algorithms and systems. The DFT is the link between the time representation $x(n)$ and the frequency representation $X(k)$. The DFT is a sequence rather than a function of a continuous variable, and it corresponds to the equally-spaced frequency-sampled Fourier transform signal. The Fourier transform has been a powerful and principal analysis tool in diverse fields such as linear systems, probability theory, boundary-valued problems, communications theory, signal processing and many other. For instance, general applications for Fourier transform algorithm include; magnetic resonance imaging (MRI), computer-assisted tomography (CAT) scanners, radar system, telecommunications and etc.

Figure 2. The unit circle in the complex z -plane

The definition of the DFT is given by the expression:

$$X(k) = \sum_{n=0}^{N-1} x(n) W_N^{kn} \text{ for } k=0, 1, \dots, N-1 \quad (2.3)$$

and the inverse of DFT, IDFT, is expressed as:

$$x(n) = \frac{1}{N} \sum_{k=0}^{N-1} X(k) W_N^{-kn} \text{ for } n = 0, 1, \dots, N-1 \quad (2.4)$$

where $W_N^k = e^{-j2\pi(k/N)}$ is a sequence of twiddle factors of the DFT and is equally spaced around the unit circle in the complex plane. The unit circle is defined as the contour of a circle, in z -plane, correspond to $|z| = 1$ unit radius, as illustrated in Figure 2. In these equations $x(n)$ is the sample value in the time domain and $X(k)$ is the sample value in the frequency domain. If the sampling rate of a signal is F , the sequence of time-domain sampling locations becomes

$$0, 1/F, 2/F, 3/F, \dots, (N-1)/F \quad (2.5)$$

Thus, corresponding to these time-domain samples, the sequence of frequency-domain sampling locations will be

$$0, F/N, 2F/N, 3F/N, \dots, (N-1)F/N \quad (2.6)$$

The computation of the DFT and IDFT is basically a vector dot operation. The DFT and IDFT both produce periodic results with period N [Oppenheim and Schaffer, 1989]. It can be seen from Equations (2.3) and (2.4) that some symmetric properties also exist. A direct computation of the DFT or IDFT requires N^2 complex multiplications and $N(N-1)$ complex additions. The FFT is an efficient algorithm for computing the DFT and can be derived from the DFT. The discrete Fourier transform can be computed in $O(N \log_2 N)$ complex multiplication operations by using the FFT algorithm.

Formation of the FFT

The Fast Fourier Transform (FFT) algorithm achieves its computational efficiency through a divide and conquer strategy. The essential idea is a grouping of the time and frequency samples such that the DFT summation over N values can be expressed as a combination of DFT summations over $N/2$ samples. When N is a power of two, this process of grouping can be repeatedly applied until the DFT summation has been reduced to a combination of DFT summation over only two samples. For example, Equation (2.3) can be divided as follows when N is a power of two.

$$\begin{aligned} X(k) &= \sum_{n=0}^{N/2-1} X(2n)W_N^{2nk} + \sum_{n=0}^{N/2-1} x(2n+1)W_N^{(2n+1)k} \\ &= \sum_{n=0}^{N/2-1} x(2n)W_N^{2nk} + W_N^k \sum_{n=0}^{N/2-1} x(2n+1)W_N^{2nk} \end{aligned} \quad (2.7)$$

Define two $(N/2)$ -point sequences $\{h(n)\}$ and $\{g(n)\}$ as the even and odd elements of $\{x(n)\}$ respectively. Then,

$$h(n) = x(2n) \quad (2.8)$$

$$g(n) = x(2n+1) \quad (2.9)$$

The discrete Fourier transform of the two $(N/2)$ -point sequences can be defined as follows

$$H(k) = \sum_{n=0}^{N/2-1} h(n)W_{N/2}^{kn} \quad (2.10)$$

$$G(k) = \sum_{n=0}^{N/2-1} g(n)W_{N/2}^{kn} \quad (2.11)$$

Thus, the discrete Fourier transform $\{x(n)\}$ can be expressed in terms of even and odd

elements as

$$X(k) = \sum_{n=0}^{N/2-1} h(n)W_{N/2}^{2nk} + \sum_{n=0}^{N/2-1} g(n)W_{N/2}^{2nk} \quad (2.12)$$

In terms of $H(k)$ and $G(k)$, we have

$$X(k) = H(k) + W_N^k G(k) \quad (2.13)$$

For the coefficient at $(k+N/2)$, we obtain

$$X(k + N/2) = H(k) - W_N^k G(k) \quad (2.14)$$

Figure 3. A 8-point DFT decomposed into 8-point 3-stage Radix-2 FFT

Therefore, N-Point discrete Fourier transform can be represented by two $(N/2)$ -

point discrete Fourier transforms. Since N is a power of two, the above partitioning scheme can be iteratively applied to the sequences $\{h(n)\}$ and $\{g(n)\}$ by $N/4$ elements. These partitions can be carried out until the two-point DFT is reached. The process is depicted in Figure 3 for $N = 8$. Figure 4 shows the flow graph of an 8-point FFT that denotes the results of the 8-point decomposed DFT.

Figure 4. A flow graph of 8-point FFT with 3-stage DIT Radix-2 Structure

Figure 5. Radix-2 Butterfly Structure

Fundamental Computing Structures: Butterflies

The structure shown in Figure 4 is called decimation-in-time (DIT). Its basic module is a radix-2 butterfly shown in Figure 5 in which two points $x_k(a)$ and $x_k(b)$ are computed to give two output points $x_{k+1}(a)$ and $x_{k+1}(b)$ via the operations represented by Equations (2.13) and (2.14). Because of the shape of the flow graph, this elementary computation is called a *butterfly*. Each radix-2 butterfly requires one complex multiplication and two complex additions, as illustrated in Figure 5 and where the twiddle factors (coefficients) are always powers of W_N and the exponents are separated by $N/2$. Observing Figure 4, it can be seen that there are $\log_2 N$ radix-2 butterflies. Therefore, there are a total of $(N/2)\log_2 N$ radix-2 butterflies in an N -point FFT. In addition, the input is in the bit-reverse order and the output is in the linear order. Further explanation of the

terms “bit-reverse order” and “linear order” can be seen under the section: “1-D Data Sequence: Linear and Digit-reverse” on page 21.

From the flow graph shown in Figure 4, some other structures of FFT can be derived by exchanging the indexing of the flow graph. One of these structures is shown in Figure 6, where the input indexing (or addressing) is in the linear order and the output indexing is in the bit-reverse order. Both structures employ the in-place algorithm. In-place means the computed outputs can be placed in the same memory location (storage) as the inputs. Moreover, the addressing for the input and output data can be shared. This is important because the addressing for that stage data is generated only once. One more structure equivalent to the structure from Figure 4 is depicted in Figure 7. The four radix-2 butterflies enclosed in the dashed box can be replaced with a radix-4 butterfly. The structure has inputs in digit-reversed order and outputs in linear order. It is not an in-place algorithm for radix-2 but it is an in-place algorithm for radix-4.

The N-point FFT can be implemented by the mixed radix operation as long as the following relation exists

$$N = r_0 \times r_1 \times r_2 \times \dots \times r_{k-1} \quad (2.15)$$

where r_i is 2 for a radix-2 stage, 4 for a radix-4 stage and 16 for a radix-16 stage. The r_0 is the first stage and r_{k-1} is the last stage of the FFT. The order of the stages can be arbitrarily selected when implemented by the chip set. If $N = 2^M$, there are M stages by the radix-2 structure. Then the FFT can be defined to have M columns. For an arbitrary j-th column, there are three ways to implement the column. First, it may be directly implemented as a radix-2 stage. Second, it and its next column may be implemented by a radix-4 stage.

Third, it and its next three columns may be implemented by a radix-16 stage.

Figure 6. A Flow graph of 8-point FFT with Linear Input and Bit-Reverse Output

Figure 7. A flow graph of Digit-Reverse Input and Linear Output for 4x2 Stage FFT

1-D Data Sequence: Linear and Digit-reverse

The decimation-in-time FFT algorithm with inputs in digit-reverse order and

outputs in linear order is implemented in Sharp chip set. Set a digit number $n = n_{N-1}n_{N-2} \dots n_1n_0$ and assume the radix of n_i is r_i . For example, a 16-point FFT using radices (r_i) of $2 \times 2 \times 4$, the digit number $n = 013$ (of mixed radix) starting from right to left translates to $(2^1 4^1) * 0 + (2^0 4^1) * 1 + (4^0) * 3 = (8 * 0) + (4 * 1) + (1 * 3) = 7_{10}$ (decimal number). A binary number is a special case of a digit number with the radius of all the n_i being 2. The digit number implemented by the Sharp chip set for the FFT has the constraint that the radix of an arbitrary n_i is 2 or 4. A digit number used by the radix-16 is actually represented by two digits $n_i n_{i-1}$ with radix of each digit being 4. The weighting factor of n_i is obtained by

$$W_i = r_{i-1} \times r_{i-2} \times \dots \times r_1 \times r_0 \quad (2.16)$$

The function of digit-reverse is then defined as follows

$$dr(n) = dr(n_{N-1}n_{N-2} \dots n_1n_0) = n_0n_1 \dots n_{N-2}n_{N-1} \quad (2.17)$$

In this case, from the example above where $n = 013$, the digit reverse $dr(n) = 310$. If the pattern of its associated radius $r_{N-1}r_{N-2} \dots r_1r_0$ is symmetric, the function of digit-reverse is reversible. Thus,

$$dr(dr(n)) = n \quad (2.18)$$

The function of bit-reverse is always reversible because its radius pattern is symmetric.

The digit-reverse sequence can be generated in the same way as the linear sequence. Both the sequences can be recursively generated by adding a fixed addend as follows

$$S_{n+1} = S_n + addend \quad (2.19)$$

There are two differences in interpreting the Equation (2.19). First, the carry digit is propagated from right to left for the linear sequence and from left to right for the digit-

reverse sequence. Second, the addends for the two are different. The addend of the linear sequence is 1 for the least significant digit and 0 for all the other digits. The carry over digit is left propagated. For example in 2x2x2 structure, $011 + 1 = 100$ and in 4x2 structure, $03 + 1 = 10$. The addend of the digit-reverse sequence is 1 for the most significant digit and 0 for all the other digits. The carry over digit is right propagated. For example in 2x2x2 structure, $110 + 1 = 001$ and in 4x2 structure, $30 + 1 = 01$.

Table I: Relation between Linear and Digit-Reverse Order

2x2x2 Structure				2x4 Structure			
Linear		Digit-reverse		Linear		Digit-Reverse	
Decimal	Digit	Digit	Decimal	Decimal	Digit	Digit	Decimal
0	000	000	0	0	00	00	0
1	001	100	4	1	01	10	2
2	010	010	2	2	02	20	4
3	011	110	6	3	03	30	6
4	100	001	1	4	10	01	1
5	101	101	5	5	11	11	3
6	110	011	3	6	12	21	5
7	111	111	7	7	13	31	7

Both the linear and digit-reverse sequences of 8-points with the radices pattern of 2x2x2 and 2x4 are shown in Table I. For the 2x2x2 radices pattern, the addend is 001 for the linear sequence and 100 for the digit-reverse sequence. For the 2x4 radices pattern, the addend is 01 for the linear sequence and 10 for the digit-reverse sequence. It can be seen from Table I that the digit-reverse sequence can also be obtained by reflecting the digits according to the center digit. For example, the digit-reverse of 1234 and 12345 are 4321 and 54321, respectively.

Inverse Fast Fourier Transform

The inverse FFT (IFFT) can employ the same address patterns as the forward FFT.

The equation shown in Equation (2.4) can be expressed by the following form

$$x(n) = \frac{1}{N} \left[\sum_{k=0}^{N-1} X^*(k) W_N^{kn} \right]^* \quad \text{for } n = 0, 1, \dots, N-1 \quad (2.20)$$

where the notation of the superscript * denotes the conjugated data. If the input frequency samples are conjugated, the bracketed term in Equation (2.20) is exactly an FFT operation. Thus, the computation of the IFFT can share all the instructions of the FFT. It can be seen from Equation (2.20) that the final computed results have to be conjugated also and scaled by the weight of $1/N$.

Two-Dimensional Fast Fourier Transform

Considering a complex function defined over a two-dimensional region $0 \leq n_1 \leq N_1 - 1$ and $0 \leq n_2 \leq N_2 - 1$, we can define a two-dimensional discrete transform over the same region as follows

$$X(k_1, k_2) = \sum_{n_1=0}^{N_1-1} \sum_{n_2=0}^{N_2-1} x(n_1, n_2) W_{N_1}^{n_1 k_1} W_{N_2}^{n_2 k_2} \quad (2.21)$$

$$\text{for } 0 \leq k_1 \leq N_1 - 1 \quad \text{and} \quad 0 \leq k_2 \leq N_2 - 1$$

Equation (2.21) can be reordered into the column-row expression

$$X(k_1, k_2) = \sum_{n_2=0}^{N_2-1} \left[\sum_{n_1=0}^{N_1-1} x(n_1, n_2) W_{N_1}^{n_1 k_1} \right] W_{N_2}^{n_2 k_2} \quad (2.22)$$

or into the row-column expression

$$X(k_1, k_2) = \sum_{n_1=0}^{N_1-1} \left[\sum_{n_2=0}^{N_2-1} x(n_1, n_2) W_{N_2}^{n_2 k_2} \right] W_{N_1}^{n_1 k_1} \quad (2.23)$$

If the item in the bracket of Equation (2.22) is expressed by a 2-D function $F(k_1, n_2)$, then the 2-D FFT can be computed by two phases of 1-D FFT as follows

$$F(k_1, n_2) = \sum_{n_1=0}^{N_1-1} x(n_1, n_2) W_{N_1}^{n_1 k_1} \quad \text{for } 0 \leq k_1 \leq N_1 - 1 \quad (2.24)$$

$$X(k_1, k_2) = \sum_{n_2=0}^{N_2-1} F(k_1, n_2) W_{N_2}^{n_2 k_2} \quad \text{for } 0 \leq k_2 \leq N_2 - 1 \quad (2.25)$$

Thus, the 2-D FFT can be obtained by computing 1-D FFT for each row of $x(n_1, n_2)$, putting the result into an intermediate array, and then computing 1-D FFT for each column of the intermediate array.

2-D Data Sequence: Linear and Digit Reverse

In the 1-D case, if the input sequence is in the linear order, the output sequence after FFT operations will be in the digit-reverse order, and vice-versa, according to the FFT Signal Flow Graph operation (refer to Figure 2.4). The 2-D FFT can be obtained by doing two phases of the 1-D FFT for each vector. Therefore, the indices k_1 and k_2 of the output array after 2-D FFT are both in digit-reverse order with respect to the indices n_1 and n_2 , respectively. For example, Table II shows the pattern of a (8, 8) 2-D input array. Assume that the 8-point column and row are implemented by the 1-D FFT with a radix-4

stage followed by a radix-2 stage. The function $F(k_1, n_2)$ of the intermediate stage 2-D array after row operations is shown in Table III. It can be seen that the index k_1 is in digit-reverse order and n_2 is in linear order. Table IV shows the function $X(k_1, k_2)$ of the final 2-D array after two phases of the 1-D FFT operations. Both indices k_1 and k_2 are in the digit-reverse order. Conversely, if the indices of $x(n_1, n_2)$ are in the digit-reverse order, the indices of the output array $X(k_1, k_2)$ will be in the linear order.

Table II: Pattern of an 8x8 2-D Linear Array

x(0,0)	x(1,0)	x(2,0)	x(3,0)	x(4,0)	x(5,0)	x(6,0)	x(7,0)
x(0,1)	x(1,1)	x(2,1)	x(3,1)	x(4,1)	x(5,1)	x(6,1)	x(7,1)
x(0,2)	x(1,2)	x(2,2)	x(3,2)	x(4,2)	x(5,2)	x(6,2)	x(7,2)
x(0,3)	x(1,3)	x(2,3)	x(3,3)	x(4,3)	x(5,3)	x(6,3)	x(7,3)
x(0,4)	x(1,4)	x(2,4)	x(3,4)	x(4,4)	x(5,4)	x(6,4)	x(7,4)
x(0,5)	x(1,5)	x(2,5)	x(3,5)	x(4,5)	x(5,5)	x(6,5)	x(7,5)
x(0,6)	x(1,6)	x(2,6)	x(3,6)	x(4,6)	x(5,6)	x(6,6)	x(7,6)
x(0,7)	x(1,7)	x(2,7)	x(3,7)	x(4,7)	x(5,7)	x(6,7)	x(7,7)

Table III: Pattern of 2-D Array After 1-D FFT for Each Row

F(0,0)	F(2,0)	F(4,0)	F(6,0)	F(1,0)	F(3,0)	F(5,0)	F(7,0)
F(0,1)	F(2,1)	F(4,1)	F(6,1)	F(1,1)	F(3,1)	F(5,1)	F(7,1)
F(0,2)	F(2,2)	F(4,2)	F(6,2)	F(1,2)	F(3,2)	F(5,2)	F(7,2)
F(0,3)	F(2,3)	F(4,3)	F(6,3)	F(1,3)	F(3,3)	F(5,3)	F(7,3)
F(0,4)	F(2,4)	F(4,4)	F(6,4)	F(1,4)	F(3,4)	F(5,4)	F(7,4)
F(0,5)	F(2,5)	F(4,5)	F(6,5)	F(1,5)	F(3,5)	F(5,5)	F(7,5)
F(0,6)	F(2,6)	F(4,6)	F(6,6)	F(1,6)	F(3,6)	F(5,6)	F(7,6)
F(0,7)	F(2,7)	F(4,7)	F(6,7)	F(1,7)	F(3,7)	F(5,7)	F(7,7)

Table IV: Pattern of 2-D Array After 2-D FFT

X(0,0)	X(2,0)	X(4,0)	X(6,0)	X(1,0)	X(3,0)	X(5,0)	X(7,0)
X(0,4)	X(2,4)	X(4,4)	X(6,4)	X(1,4)	X(3,4)	X(5,4)	X(7,4)
X(0,1)	X(2,1)	X(4,1)	X(6,1)	X(1,1)	X(3,1)	X(5,1)	X(7,1)
X(0,5)	X(2,5)	X(4,5)	X(6,5)	X(1,5)	X(3,5)	X(5,5)	X(7,5)
X(0,2)	X(2,2)	X(4,2)	X(6,2)	X(1,2)	X(3,2)	X(5,2)	X(7,2)
X(0,6)	X(2,6)	X(4,6)	X(6,6)	X(1,6)	X(3,6)	X(5,6)	X(7,6)
X(0,3)	X(2,3)	X(4,3)	X(6,3)	X(1,3)	X(3,3)	X(5,3)	X(7,3)
X(0,7)	X(2,7)	X(4,7)	X(6,7)	X(1,7)	X(3,7)	X(5,7)	X(7,7)

Comparing Table II and Table IV, the function of the 2-D digit reverse has the following relation:

$$dr(n_1, n_2) = (dr(n_1), dr(n_2)) = (k_1, k_2) \quad (2.26)$$

The memory device is generally a 1-D array. In appendix A, a discussion on how to use the 1-D $N_1 * N_2$ point FFT to realize the 2-D FFT for the 2-D array implementation will be presented. N_1 and N_2 denote the dimensions of the vectors.

Multi-Dimensional Fast Fourier Transform

The column-row or row-column approach for the 2-D FFT can be extended to the Multi-Dimensional (M-D) FFT case. The three-dimensional FFT discussed here can be extended to multi-dimensional FFT. A three-dimensional (3-D) Discrete Fourier Transform is represented by

$$X(k_1, k_2, k_3) = \sum_{n_1=0}^{N_1-1} \sum_{n_2=0}^{N_2-1} \sum_{n_3=0}^{N_3-1} x(n_1, n_2, n_3) W_{N_1}^{n_1 k_1} W_{N_2}^{n_2 k_2} W_{N_3}^{n_3 k_3} \quad (2.27)$$

$$\text{for } n = 0 \leq k_i \leq N_i - 1$$

It can be reordered into the 1-D DFT expression as follows

$$X(k_1, k_2, k_3) = \sum_{n_3=0}^{N_3-1} \left\{ \sum_{n_2=0}^{N_2-1} \left[\sum_{n_1=0}^{N_1-1} x(n_1, n_2, n_3) W_{N_1}^{n_1 k_1} \right] W_{N_2}^{n_2 k_2} \right\} W_{N_3}^{n_3 k_3} \quad (2.28)$$

Thus, the 3-D FFT can be calculated by employing the following steps:

- (1) 1-D N_1 -point FFT $N_2 * N_3$ times first,
- (2) 1-D N_2 -point FFT $N_1 * N_3$ next, and
- (3) finally, 1-D N_3 -point FFT $N_1 * N_2$ times.

After the 3-D FFT calculation, the indices n_i and k_i will be in digit-reverse order in each vector as follows:

$$dr(n_1, n_2, n_3) = (dr(n_1), dr(n_2), dr(n_3)) = (k_1, k_2, k_3) \quad (2.29)$$

The basic execution modules are unchanged for 1-D to M-D FFT if the column-row or row-column approach is implemented.

Discrete Cosine Transform by FFT

The Discrete Cosine Transform (DCT) is a fundamental image processing algorithm for many image and video compression systems because of its fast computation and easy implementation. This section will discuss three methods of employing the chip set to implement the DCT. The DCT is defined as follows:

$$X(0) = \left(\frac{1}{N}\right)^{1/2} \sum_{n=0}^{N-1} x(n) \quad (2.30)$$

$$X(k) = \left(\frac{2}{N}\right)^{1/2} \sum_{n=0}^{N-1} x(n) \cos\left[\frac{\pi(2n+1)k}{2N}\right] \quad \text{for } k = 1, 2, \dots, N-1 \quad (2.31)$$

and the Inverse Discrete Cosine Transform (IDCT) is defined as follows:

$$x(n) = \left(\frac{1}{N}\right)^{1/2} X(0) + \left(\frac{2}{N}\right)^{1/2} \sum_{k=1}^{N-1} X(k) \cos\left[\frac{\pi(2n+1)k}{2N}\right] \quad (2.32)$$

for $n = 0, 1, \dots, N-1$

Method 1: N-Point DCT by Zero Extended 2N-Point FFT

The first method of computing N-point DCT extends the sequence from N points to 2N points by padding zeros to the last N points of data. The DCT from Equations (2.30) and (2.31) can be expressed as

$$X(k) = \text{Re} \left[c(k) e^{-j\pi k/(2N)} \sum_{n=0}^{2N-1} x(n) W_{2N}^{kn} \right] \quad \text{for } k = 0, 1, \dots, N-1 \quad (2.33)$$

where

$$c(k) = \begin{cases} \left(\frac{1}{N}\right)^{1/2} & k = 0 \\ \left(\frac{2}{N}\right)^{1/2} & \text{otherwise} \end{cases} \quad (2.34)$$

Equation (2.33) means that the N-point DCT can be obtained by executing the 2N-point real FFT first and then taking the real part of complex multiplications as shown in Figure 8. Thus, the DCT can be implemented by the LH9124 in three phases. The first computes the N-point FFT. The second computes the recombining process. The final

phase computes complex vector multiplications.

Figure 8. N-Point DCT by Zero Extended 2N-Point FFT

Method 2: N-point DCT by Symmetric Extended 2N-Point FFT

The second method of computing N-point DCT also extends the sequence from N points to 2N points. However, the extended 2N-point sequence is symmetric and defined as follows:

$$\hat{x}(n) = \begin{cases} x(n) & n = 0, 1, \dots, N-1 \\ x(2N-1-n) & n = N, N+1, \dots, 2N-1 \end{cases} \quad (2.35)$$

Then, the DFT of $\hat{x}(n)$ is given by

$$\hat{X}(k) = \sum_{n=0}^{2N-1} \hat{x}(n) W_{2N}^{nk} = 2e^{j\pi \frac{k}{2N}} \sum_{n=0}^{N-1} x(n) \cos \frac{\pi(2n+1)k}{2N} \quad (2.36)$$

Comparing Equation (2.36) with Equation (2.31), the DCT can be expressed as

$$X(k) = \frac{c(k)}{2} e^{-j\pi k/2N} \hat{X}(k) \quad \text{for } k = 0, 1, \dots, N-1 \quad (2.37)$$

Thus, the N-point DCT can be obtained by executing the 2N-point real FFT first and then adjusting the results by complex multiplications as shown in Figure 9. As in the first method, the DCT can also be implemented in the same three phases.

Figure 9. N-Point DCT by Symmetric Extended 2N-Point FFT

Method 3: N-Point DCT by N-Point FFT

The first two methods introduce inefficiency in computation by extending the data

sequence. In method 1, the sequence is extended to the length of $2N$ by zero padding. In method 2, the sequence is extended to a $2N$ symmetry. Method 3 directly computes the rearranged N -sequence data instead of extending the data sequence. The last method is obviously better than the first two because Sharp chip set can compute two sequences of data with this method at the same time and improve the speed performance. Here, the new data sequence $y(n)$ derived from the original sequence $x(n)$ is represented by

$$y(n) = \begin{cases} x(2n) & n = 0, 1, \dots, N/2 - 1 \\ x(2N - 2n - 1) & n = N/2, N/2 + 1, \dots, N - 1 \end{cases} \quad (2.38)$$

Thus, the N -point DCT is obtained from the N -point FFT instead of the $2N$ -point FFT.

$$\begin{aligned} \hat{X}(k) &= \sum_{n=0}^{N-1} x(n) \cos \frac{(2n+1)k\pi}{2N} \\ &= \sum_{n=0}^{N/2-1} x(2n) \cos \frac{(4n+1)k\pi}{2N} + \sum_{n=0}^{N/2-1} x(2n+1) \cos \frac{(4n+3)k\pi}{2N} \end{aligned} \quad (2.39)$$

Setting $n = N - n - 1$ in the second term of Equation (2.39), we may get

$$\begin{aligned} \hat{X}(k) &= \sum_{n=0}^{N/2-1} y(n) \cos \frac{(4n+1)k\pi}{2N} + \sum_{n=N/2}^{N-1} y(n) \cos \frac{(4n+1)k\pi}{2N} \\ &= \sum_{n=0}^{N-1} y(n) \cos \frac{(4n+1)k\pi}{2N} \end{aligned} \quad (2.40)$$

Thus, the DCT can be computed from the following equation:

$$X(k) = Re \left[c(k) e^{-j\pi(k/2N)} \sum_{n=0}^{N-1} y(n) W_N^{nk} \right] \quad (2.41)$$

It can also be derived that

$$X(N-k) = \text{Im} \left[c(k) e^{-j\pi(k/(2N))} \sum_{n=0}^{N-1} y(n) W_N^{nk} \right] \quad (2.42)$$

for $k = 0, 1, \dots, N/2$

This means that only the first $(N/2 + 1)$ points of the complex sequence can be computed. The first half of the DCT sequence can be obtained from the real part of the complex sequence and the second half of the DCT sequence can be obtained from the imaginary part of the complex sequence. The N-point DCT can be obtained by computing N-point real FFT first and then adjusting the results by complex multiplications as shown in Figure 10.

Figure 10. N-Point DCT of the N Real Data

CHAPTER III

BRIEF DESCRIPTIONS OF SHARP LH9124 AND LH9320

Array digital signal processing has become increasingly important because of the advancement of DSP algorithms and VLSI technologies [Haykin, 1985]. DSP deals with processing of propagating signals received by an array of sensors. The computing speed of an array processor usually constrains system performance. Therefore, sampling rate and number of the array sensors must be confined or the system modeling adaptability must be simplified. To overcome the speed bottleneck of array processing and to obtain the flexibility in system design, an array chip set (LH9124 and LH9320) has been developed by Sharp Microelectronics Technology.

The LH9124 is a high-performance block floating-point digital signal processor. The computation process is a procedure in which the original array is normalized to the far left of the computer word, with the restriction that $|x[n]| < 1$. This is a fixed-point procedure, except that after every addition there is an overflow test. The LH9124 unit consists of four I/O ports for flexible data flow control. The instruction set is defined in a function-level representation and consists of five instruction categories: Digital Signal Processing (DSP), Complex Arithmetic Instructions (CAI), Vector Arithmetic Instructions (VAI), Vector Logic Instructions (VLI) and General Purpose Instructions (GPI) [LH9124 User's Guide]. FFT instructions provided by the LH9124 are listed in Table V. These instructions can be found under DSP categories. DSP functions are

optimized for highly parallel and pipelined forms which built into the data path. Therefore, the Sharp LH9124 can obtain up to 680 million operations per second. For detailed information about the instructions, see the Sharp LH9124 User Guide manual.

Table V: The LH9124 Instruction Set

FUNCTIONS	DESCRIPTION
DSP INSTRUCTIONS	
BFLY2	Performs Radix-2 butterfly operation.
BFLY4	Performs Radix-4 butterfly operation.
BFLY16	Performs Radix-16 operation.
BWND2	Performs Radix-2 with complex window function.
BWND4	Performs Radix-4 with complex window function.
BFCT	Performs Fast cosine transform/double length operation.
B[C/D/R]FIR	Performs Complex or Double or Real finite impulse response filter operation.
COMPLEX ARITHMETIC INSTRUCTIONS	
CADD	Performs complex addition operation.
CMAG	Performs complex magnitude squared operation.
CMUL	Performs complex multiplication operation.
CSUB	Performs complex subtraction operation.
VECTOR ARITHMETIC INSTRUCTIONS	
VABS	Performs vector absolute operation.
VADD/VSUB	Performs vector addition or subtraction operation.
VMUL	Performs vector multiplication operation.
VMXM	Performs vector maximum and minimum operation.
VECTOR LOGICAL INSTRUCTIONS	
VNAND	Performs vector logical NAND operation.
VNOR	Performs vector logical NOR operation.
VPAS	Performs vector logical PASS operation.
VXNOR	Performs vector logical NOR operation.
GENERAL PURPOSE INSTRUCTIONS	
MOVC	Move coefficient data from C port to another (A,B,Q) port.
MOVD	Move data from (A,B,Q) to another port (A,B,C,Q) port.

Table VI: The LH9320 Address Generator Instruction Set for FFT

INSTRUCTION	DESCRIPTION
BF2i	Data address sequence for i-th column radix-2
BF4i	Data address sequence for $(2 * i)$ -th column radix-4
MXB24i	Data address sequence for $(2 * i + 1)$ -th column radix-4
BF16i	Data address sequence for $(4 * i)$ -th column radix-16
MXB216i	Data address sequence for $(4 * i + 1)$ -th column radix-16
MXB416i	Data address sequence for $(4 * i + 2)$ -th column radix-16
MXB2416i	Data address sequence for $(4 * i + 3)$ -th column radix-16
TF2i	Twiddle factor address sequence for i-th column radix-2
TF4i	Twiddle factor address sequence for i-th $(2 * i)$ -th radix-4
MXT24i	Twiddle factor address sequence for $(2 * i + 1)$ -th column radix-4
TF16i	Twiddle factor address sequence for $(4 * i)$ -th column radix-16
MXT216i	Twiddle factor address sequence for $(4 * i + 1)$ -th column radix-16
MXT416i	Twiddle factor address sequence for $(4 * i + 2)$ -th column radix-16
MXT2416i	Twiddle factor address sequence for $(4 * i + 3)$ -th column radix-16
RBF0	Linear Sequence to Digit-reverse sequence conversion

The LH9320 is a programmable address generator that provides the address patterns required by the LH9124. It can generate one 24-bit address per cycle for input, output or coefficient sequence to the LH9124 DSP chip. It possesses not only the general features such as linear, modulo, and bit-reverse addressing contained by the general purpose DSP chips but also special features for the LH9124 to optimize the performance of some DSP functions [LH9320 User's Guide]. The FFT addressing instructions for the LH9320 are listed in Table VI. If the j -th column is implemented by a radix-2 stage, the instructions BF2j and TF2j are used to generate the required data and address patterns. If the j -th column is the beginning column of a radix-4 stage, the instructions BF4i and TF4i will be implemented when $j = 2 * i$ or the instructions MXB24i and MXT24i will be implemented when $j = 2 * i + 1$. Similarly, we can select instructions for a radix-16 stage. Based on the novel algorithms of defining 1-D indexing for M-D mixed radix FFT

implementations [Ju, 1993], some instructions of the LH9320 can be universally employed to the array with an arbitrary numbers of dimensions.

Design Considerations of LH9124

The design goal of the chip set is that the strict real-time requirement of short computing latency or fast data throughput of array digital signal processing can be obtained at a reasonable cost. The design considerations for chip users to achieve this goal are discussed below based on the following five categories: (1) algorithm, (2) arithmetic, (3) data path structure, (4) instructions, and (5) system configuration.

Algorithm:

Block implementation is adopted since it allows for efficient use of parallel processors and fast block algorithms such as Fast Fourier Transform (FFT) to achieve speed gains. The term “block” refers to *radix-n* (where n can be either 2, 4 or 16) FFT decomposed from an N -point DFT with complex arithmetic operations (see Figure 3). The chip set emphasizes implementing block oriented DSP algorithms to solve problems through frequency-domain. In addition, array processing usually has to handle multi-dimensional data. The performance of the FFT algorithms regardless of the dimension is then the main concern of the design.

The Multi-Dimension (M-D) indexing for the M-D FFT is usually the performance killer of M-D array processing. In order to solve it, a novel FFT SFG implementation has been developed by C. J. Ju [Ju, 1993] to compute the M-D FFT as the 1-D FFT. There are many advantages to this approach. First, the unified 1-D addressing

for the 1-D to M-D FFT can be constructed. This unified addressing simplifies the design of the LH9320 to support M-D problems. In addition, the optimized instruction can be directly extracted from the vector-matrix representation of the algorithm. Second, the structure optimization for the FFT is reduced to the 1-D problem. Third, the concept of M-D to 1-D FFT mapping can be extended to solve other block oriented DSP algorithms, such as FIR and IIR [Ju and Alexander, 1987].

Arithmetic:

The block floating-point arithmetic (see “Block Floating-point Arithmetic and Implementation” on page 46) has been adopted by the LH9124 for the following reasons. First, block implementation is adopted and the FFT structure is inherently suitable for the block floating-point arithmetic. Second, it has the advantages of both floating-point and integer arithmetic. One exponent register can be used for all the block data to extend the dynamic range of the signal as done by the floating-point arithmetic. Thus, addition and multiplication operations can be implemented as easily as the corresponding fixed-point arithmetic operations. Third, the A/D and D/A devices have integer format. Therefore, both time and cost of performing the data conversion can be saved. It should be noted that there is one drawback of block arithmetic, i.e. the scaling for the block floating-point arithmetic.

Data Path Structure:

The LH9124 is a pass-based processor where each opcode and related data flow opcode is valid for one pass. By pass-based, we mean that for a single instruction

operation, the data from the input port is passed directly to the transform engine and to the output port without going through the holding registers and execution unit (see Figure 11). Data must be arranged according to the address sequences required before it is passed to the LH9124. The basic computing modules such as radix-2, radix-4, and radix-16 butterflies are built in the data path with the optimized parallel and pipelined structures. There are two reasons for the pass-based form design. First, a cascaded or parallel architecture can be built to meet the strict latency and throughput requirements. Second, instructions can be efficiently performed regardless of number of data and the array dimension.

Instructions:

The instructions from the instruction set of LH9124 are compact and are carried out at a macro level. These instructions are hardwired in the chip architecture. No complex programming for the instructions is required. The instructions are defined in a function-level representation. By function-level representation, we mean that the instructions are a set of complex arithmetic operations. For example, the instruction BFLY2 consists of a set of complex multiplications and additions to perform the radix-2 operation. Generally, the DSP application can be partitioned into several function block diagrams. The function-level representation of instructions can be directly mapped from the function block diagram. In another word, one can assume the function block diagram is function-level representation in graphical environment. Thus, no time-consuming software coding and debugging process are necessary. Users consider applications only at the function block diagram level. A window-based function simulator is provided to help

users develop DSP applications.

Another reason for the function block instruction is that the efficiency of parallel processing comes mainly from partitioning data and function. The function is already built in the data path with an optimized parallel and pipelined structure. Users need only to consider the data partition in constructing parallel systems. When the data is well-partitioned, speed improvements are usually proportional to the number of execution units employed.

System:

The address generating instruction set of the LH9320 is well-defined for the FFT to support both unit-processor and multi-processor systems. Moreover, the LH9124 includes 4-bidirectional 48-pin I/O ports. The four I/O port design provides users flexibility in system configuration. Users can use this flexibility either to optimize the system performance or to reduce the system cost. In addition, a parallel or cascaded system architecture can be developed with little or no extra hardware.

Figure 11. LH9124 Detailed Block Diagram and Execution Unit.

Unified Signal Flow Graph Structure for 1-D to M-D FFT

The architecture of LH9124 suitably and conveniently matches the concept of the unified addressing for the 1-D to M-D FFT algorithm. This section will show that a unified Signal Flow Graph (SFG) structure representing the 1-D to M-D FFT can be constructed. Conceptually, the M-D FFT algorithm can be easily understood and realized. Practically, the unified SFG structure implies the unified 1-D indexing, of data, coefficient factor, and bit-reverse for 1-D to M-D FFT implementation and simplifies the M-D FFT addressing.

A novel vector-matrix representation of FFT is proposed in Chapter IV. From the Discrete Fourier Transform (DFT) to FFT decomposition, each stage of the FFT can be described by three matrices: the right permutation matrix indicating the input interconnection, the center matrix indicating the butterfly operation, and the left permutation matrix indicating the output interconnection. It can be derived from the results obtained in Chapter IV that all the FFTs with the same number of elements regardless of dimensions have the same permutation matrices. This means that they share the same SFG structure. In addition, the butterfly operation matrices for the K-th vector of 1-D to M-D FFTs are the same. These results imply that the indexing for the 1-D FFT can be employed for that of the M-D FFT.

By the well-known DFT to Decimation-In-Time (DIT) FFT decomposition [Ju, 1993], the vector-matrix form of 1-D FFT with length $N = 2^s$ can be derived as

$$\underline{X} = FG_s(BI(s)) \times FG_{s-1}(BI(s-1)) \times \dots \times FG_1(BI(1)) \times \underline{x_b} \quad (3.1)$$

where $\underline{X}$ and $\underline{x_b}$, respectively, denote the N-point linear output vector and N-point bit

reverse input vector. $FG_k(BS(j))$ represents the k -th stage of the FFT and can be expressed as

$$FG_k(BS(j)) = P_{lk} \times BS(j) \times P_{rk} \quad (3.2)$$

$BS(j)$ is the butterfly operation matrix with radix-2 modules along the diagonal as

$$BS(j) = \begin{bmatrix} B_j(0) & 0 & \dots & 0 \\ 0 & B_j(1) & 0 & \dots \\ \dots & 0 & \dots & \dots \\ \dots & \dots & \dots & \dots \\ 0 & \dots & \dots & B_j(N/2 - 1) \end{bmatrix} \quad (3.3)$$

where “0” is a 2 by 2 zero matrix and the radix-2 butterfly (see “Fundamental Computing Structures: Butterflies” on page 18) module $B_j(n)$ can be represented by

$$B_j(n) = BF_N^i = \begin{bmatrix} W_N^0 & W_N^i \\ W_N^0 & W_N^{i+N/2} \end{bmatrix} \quad (3.4)$$

with

$$i = \frac{N}{2^j} \times \text{Int}\left(\frac{n}{2^{s-1}}\right) \quad (3.5)$$

$\text{Int}(x)$ denotes the integer part of x . P_{rk} specifies the interconnection between inputs and butterfly modules and is a permutation matrix with its element defined as

$$P_{rk}(n, m) = \begin{cases} 1 & \text{for } m=f_{rk}(n) \\ 0 & \text{otherwise} \end{cases} \quad (3.6)$$

where

$$f_{rk}(n) = \frac{N}{2^{k-1}} \times \text{Mod}(n)_{2^{k-1}} + \text{Int}\left(\frac{n}{2^{k-1}}\right) \quad (3.7)$$

$Mod(x)_y$ denotes the modulo operation on the number x with modulo length y . Since the in-place algorithm is employed, the left permutation matrix P_{lk} is the transpose of the right permutation matrix.

The parallel vector-matrix form for the traditional 2-D FFT implementation with the row length $N_1 = 2^{s_1}$, the column length $N_2 = 2^{s_2}$, and the total number of the 2-D array elements $N = N_1 \times N_2$ can be derived and represented by the following form

$$\begin{aligned} \underline{X}_c = & FG_{s_2}(BS(s_2)) \times \dots \times FG_1(BS(1)) \times P_N \\ & \times FG_{s_1}(BS(s_1)) \times \dots \times FG_1(BS(1)) \times \underline{x}_{br}^T \end{aligned} \quad (3.8)$$

Where $\underline{X}_c$ is the N -point vector in the column-major order of the linear output array and $\underline{x}_{br}^T$ is the N -point vector in the row-major order of the bit-reversed input array. P_N is a transpose matrix to the transform data from the row-major order to column-major order. Combining the permutation matrices of Equation (3.6) with the transpose matrix P_N from Equation (3.8), a new form of the 2-D FFT structure is created:

$$\begin{aligned} \underline{X}_r^T = & FG_{s_1+s_2}(BS(s_2)) \times \dots \times FG_{s_1+1}(BS(1)) \\ & \times FG_{s_1}(BS(s_1)) \times \dots \times FG_1(BS(1)) \times \underline{x}_{br}^T \end{aligned} \quad (3.9)$$

where $\underline{X}_r^T$ is an N -point vector in the row-major order of the linear output array. A detailed derivation of Equation (3.1) through Equation (3.9) will be discussed further in chapter IV.

Comparing Equation (3.9) with Equation (3.1) and setting $s=s_1+s_2$, it can be seen that the N_1 by N_2 2-D FFT has the same interconnection structure as the N -point 1-D FFT. It implies that both the equations can have the same SFG structure. Moreover, the butterfly matrices are the same for the k -th stage of the row FFT, column FFT, and 1-D

FFT.

Figure 12 shows the SFG structure for the 4 by 4 2-D FFT and 16-point 1-D FFT. The upper (or the top) value shows the inputs, outputs, and twiddle factors for the 2-D case and the lower (or the bottom) value is for the 1-D case.

Figure 12. Signal Flow Graph for 4 by 4 2-D FFT and 16-point 1-D FFT

Figure 13. Signal Flow Graph for Traditional Implementation of 4 by 4 2-D FFT

Block Floating-point Arithmetic and Implementation

The LH9124 implements block floating-point arithmetic to improve the precision of computations for a fixed-point processor. The FFT algorithm for its inherent block processing structure is suited to block floating-point arithmetic. The block processing structure means that the FFT algorithm is decomposed into a pipeline of computing stages and that the block output data of the current stage is the block input data of the next stage as shown in Figure 3 in page 16. The processor with block floating-point arithmetic can

have the advantages of both fixed-point and floating-point. First, the architecture is simple because both multiplications and additions are fixed-point. Second, the block floating-point can obtain even higher precision than the floating-point with the same word length. However, these advantages will be offset by the overhead in computations if the scaling problem in block floating-point arithmetic is not well handled. Therefore, it is important to know how the M-D FFT is implemented to avoid the scaling problem of block floating-point arithmetic and it will be discussed below.

From Equation (3.8), the 4 by 4 2-D FFT implementation by the traditional approach is expressed as

$$\begin{aligned} \underline{X}_c = & FG_2(BI(s_2)) \times \dots \times FG_1(BI(1)) \times P_N \\ & \times FG_2(BI(2)) \times \dots \times FG_1(BI(1)) \times \underline{x}_r^T \end{aligned} \quad (3.10)$$

and its SFG structure is shown in Figure 13. The traditional 2-D FFT implementation computes the 1-D FFT for each row, transfers the data from the row-major into the column-major order, and then computes 1-D FFT for each column. The order of computations is from one rectangular block (represented by dotted box) to the other rectangular block shown in Figure 13. After the row FFTs, the number of scaling for each row vector may be different. The difference in scaling is due to the different bit growth in each row. Therefore, the overhead has occurred because the column FFTs cannot be directly computed from these data.

The overhead can be solved by either software or hardware. However, the computing time will be increased by the software approach and the hardware complexity will be increased by the hardware approach. For example, a vector processor solves this

problem by employing extra hardware to keep tracking the scale factor for each block and the maximum scale factor. The solution by the LH9124/LH9320 is to implement the novel approach of implementing the M-D FFT algorithm. The new approach can eliminate the scaling overhead by considering the whole array as a data block as shown in Figure 12. Only the maximum scale factor has to be kept for each stage.

Fundamentally, the block floating-point mechanism of the LH9124 consists of two parts, the input and the output. The output part is to calculate the maximum magnitude of the output data for the current stage of radix operations. Then, a scaling factor is derived as a reference value for the input scaling of the next stage. The input part receives the scaling factor generated by the previous stage. The number of bits to be shifted right for the current input data will be based on the scaling factor and the instruction to be executed. Therefore, the data overflow and the precision of integer operations are automatically controlled by the block floating-point mechanism.

CHAPTER IV

UNIFIED INDEXING OF FFT ALGORITHMS

It is well-known that the computing efficiency of the FFT comes from the recursive factorization of the twiddle factor matrix of the discrete Fourier transform. To derive the unified addressing for the one dimensional (1-D) to multidimensional (M-D) FFT algorithm, a novel matrix form of factorizing and representing twiddle factor matrix will be presented. Then, it will be also presented that all the matrices have their physical meaning in the practical implementation. Each stage of the FFT is represented by three cascaded matrices. The right permutation matrix specifies the input interconnections and defines the input data sequence. The left permutation matrix specifies the output interconnections and defines the output data sequence. The middle diagonal block matrix performs the butterfly operation and defines the twiddle factor sequence.

Equivalent relationships of these matrices will be introduced in this chapter. It will be shown that one kind of the FFT algorithms can be derived from the other kind of the FFT algorithm through the equivalent transform of the matrices. For example, the in-place bit-reverse inputs and linear outputs (BI/LO) FFT can be derived from the in-place linear inputs and bit-reverse outputs (LI/BO) FFT and vice versa. For definiteness, this chapter discusses the decimation-in-time (DIT) FFT only. Essentially, all the results can be extended to the decimation-in-frequency (DIF) FFT in a straightforward manner.

From the novel vector-matrix representation, an equivalent relationship between

1-D and M-D FFTs by employing the equivalent transformation of the matrices can be also derived. Therefore, it can be obtained that the signal flow graph (SFG) structure of the 1-D FFT can be used to represent that of the M-D FFT regardless of the dimension, if the total number of elements is the same. The radix-2 FFT is used as an illustration in the discussion, although the implemented approach can be extended to an arbitrary mixed radix FFT.

The unified indexing for 1-D to M-D FFT algorithm has been implemented in the array processor chip set, namely the LH9124/LH9320 developed by Sharp Microelectronics Technology. It can be seen from the chip set implementation that the computing time of the FFT is independent on the dimension of the FFT. Thus, both the 256 by 256 point 2-D complex FFT and the 64K 1-D complex FFT have the same computation time.

1-D Bit-reverse Inputs And Linear Outputs FFT

The DFT of an N-point sequence $\{x(n)\}$ is defined by

$$X(k) = \sum_{n=0}^{N-1} x(n) W_N^{nk} \quad \text{for } 0 \leq k < N-1 \quad \text{and} \quad W_N^j = e^{-2\pi j/N} \quad (4.1)$$

and its parallel form can be represented by the vector-matrix equation as

$$\begin{bmatrix} X(0) \\ X(1) \\ \dots \\ X(N-1) \end{bmatrix} = \begin{bmatrix} W_N^0 & W_N^1 & \dots & W_N^{N-1} \\ W_N^0 & W_N^2 & \dots & W_N^{2(N-1)} \\ \dots & \dots & \dots & \dots \\ W_N^0 & W_N^3 & \dots & W_N^{(N-1)(N-1)} \end{bmatrix} \begin{bmatrix} x(0) \\ x(1) \\ \dots \\ x(N-1) \end{bmatrix} \quad (4.2a)$$

or

$$\underline{X} = W_N \times \underline{x} \quad (4.2b)$$

The structure of the FFT will be based on factorization of the twiddle factor matrix W_N .

For the BI/LO FFT, W_N is factorized from the right first by the bit-reverse matrix P_{br} as

$$W_N = W'_N \times P_{br} \quad (4.3a)$$

For the LI/BO FFT, W_N is factorized from the left, first as

$$W_N = P_{br} \times W''_N \quad (4.3b)$$

By recursively decomposing the twiddle factor matrix W'_N , the vector-matrix form of the 1-D BI/LO FFT with the length $N=2^s$ can be derived as follows

$$\begin{aligned} \underline{X} &= FG_s(BI(s)) \times FG_{s-1}(BI(s-1)) \times \dots \times FG_1(BI(1)) \times P_{br} \times \underline{x} \\ &= \underline{fft}' \times \underline{x}_b \end{aligned} \quad (4.4)$$

where $\underline{X}$ and $\underline{x}_b$, respectively, denote the N-point linear output vector and N-point bit-reverse input vector (see “1-D Data Sequence: Linear and Digit-reverse” on page 21).

The matrix $FG_k(BI(k))$ denotes the k-th radix-2 butterfly stage of the BI/LO FFT. The chapter will show the further partition of the butterfly stage matrix into three matrices as

$$FG_k(BI(k)) = P_{lk} \times BI(k) \times P_{rk} \quad (4.5)$$

Some essential physical meaning in FFT algorithm implementation can be found through the three-matrix representation of the butterfly stage. The right permutation matrix P_{rk} and the left permutation matrix P_{lk} can specify the input data sequence and the output data sequence of the stage, respectively. The center block diagonal matrix $BI(k)$ performs the radix-2 butterfly operations of the k-th stage and specifies the twiddle

factor sequence. It is defined as

$$BI(k) = \begin{bmatrix} bi_k(0) & 0 & \dots & 0 \\ 0 & bi_k(1) & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & bi_k(N/2 - 1) \end{bmatrix} \quad (4.6)$$

where “0” is a 2 by 2 zero matrix and the radix-2 butterfly module $bi_k(n)$ along the diagonal of $BI(k)$ is defined as

$$bi_k(n) = \begin{bmatrix} W_N^0 & W_N^i \\ W_N^0 & -W_N^i \end{bmatrix} \quad \text{with } i = \frac{N}{2^k} \times \text{Int}\left(\frac{n}{2^{s-k}}\right) \quad (4.7)$$

The function $\text{Int}(x)$ denotes the integer part of the real number x . P_{rk} specifies the interconnection between inputs and butterfly modules and is an N by N permutation matrix with its elements defined as

$$P_{rk}(n, m) = \begin{cases} 1 & \text{for } n = \frac{N}{2^{s+1-k}} \times \text{Mod}(m)_{2^{s+1-k}} + \text{Int}\left(\frac{m}{2^{s+1-k}}\right) \\ 0 & \text{otherwise} \end{cases} \quad (4.8)$$

where $\text{Mod}(x)_y$ denotes the modulo operation on the number x with modulo length y and is defined as

$$\text{Mod}(x)_y = x - \text{Int}\left(\frac{x}{y}\right) \times y \quad (4.9)$$

Similarly, P_{lk} specifies the interconnection between outputs and butterfly modules with its elements defined as

$$P_{lk}(n, m) = \begin{cases} 1 & \text{for } m = \frac{N}{2^{s+l-k}} \times \text{Mod}(n)_{2^{s+l-k}} + \text{Int}\left(\frac{n}{2^{s+l-k}}\right) \\ 0 & \text{otherwise} \end{cases} \quad (4.10)$$

The bit-reverse matrix is also an N by N permutation matrix with its elements defined as

$$P_{bk}(n, m) = \begin{cases} 1 & \text{for } n = br(m) \\ 0 & \text{otherwise} \end{cases} \quad (4.11)$$

where $br(m)$ denotes the bit-reverse operation on the index m with the number of bits s as follows:

$$br(m)_s = br(m_{s-1}m_{s-2} \dots m_1m_0)_s = m_0m_1 \dots m_{s-2}m_{s-1} \quad (4.12)$$

1-D Linear Inputs And Bit-reverse Outputs FFT

The vector-matrix form of the 1-D LI/BO FFT with the length $N=2^s$ can be obtained by further factoring the twiddle factor matrix W_N'' in Equation (4.3b) as follows:

$$\underline{X} = P_{br} \times FG_1(BL(s)) \times FG_2(BL(s-1)) \times \dots \times FG_s(BL(1)) \times \underline{x} \quad (4.13)$$

Multiplying P_{br} to both sides of Equation (4.13), we have

$$\underline{X}_b = P_{br} \times \underline{X} = \text{fft}'' \times \underline{x} \quad (4.14)$$

As the BI/LO FFT case, the k -th butterfly stage of the LI/BO FFT can be further decomposed into three cascaded matrices

$$FG_{(s+l-k)}(BL(k)) = P_{l(s+l-k)} \times BL(k) \times P_{r(s+l-k)} \quad (4.15)$$

$BL(k)$ is the butterfly operation matrix of the k -th stage. Its input interconnection matrix is represented by $P_{r(s+l-k)}$ and its output interconnection matrix is $P_{l(s+l-k)}$. The fundamental difference between the BI/LO and LI/BO structures is the definition of the butterfly

operation matrix. The butterfly operation matrix for the LI/BO FFT is defined as

$$BL(k) = \begin{bmatrix} bl_k(0) & 0 & \dots & 0 \\ 0 & bl_k(1) & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & bl_k(N/2 - 1) \end{bmatrix} \quad (4.16)$$

The radix-2 butterfly module $bl_k(n)$ of $BL(k)$ is defined as

$$bl_k(n) = \begin{bmatrix} W_N^0 & W_N^i \\ W_N^0 & -W_N^i \end{bmatrix} \quad \text{with } i = br(mod(n)_{2^{k-1}})_{s-1} \quad (4.17)$$

Equivalence of FFT Algorithms by Matrix Transformation

The previous two sections have shown that each stage of BI/LO and LI/BO FFT algorithms can be represented by three cascaded matrices. In software or hardware realization of the FFT, these matrices can represent input, output and twiddle factor addressing sequences. In this section, some equivalent relationship of these matrices will be shown. Through these equivalent algorithms, it can be seen that one kind of FFT structure can be derived from the other kind of the FFT structure. After transformation, the new three cascaded matrices also denote the three addressing sequences for the FFT stage. The last two sections employ these equivalent relationships to M-D FFT. Some salient results can be obtained such as the unified 1-D FFT addressing sequence to implement the M-D FFT.

The following will list the theorems that describe the equivalent relationship of the input data, output data, bit-reverse and the twiddle factor matrices [Ju, 1993].

Theorem 1: (Input Interconnection Operation)

$$P_{r(Mmod(i+j-1)_s)} = P_{ri} \times P_{rj} \quad \text{for } 1 \leq i \leq s \text{ and } 1 \leq j \leq s \quad (4.18)$$

where $Mmod(x)$ is a modified modulo operation function defined as

$$Mmod(x)_y = x - Int\left(\frac{x-1}{y}\right) \times y \quad (4.19)$$

Theorem 2: (Output Interconnection Operation)

$$P_{l(Mmod(i+j-1)_s)} = P_{li} \times P_{lj} \quad \text{for } 1 \leq i \leq s \text{ and } 1 \leq j \leq s \quad (4.20)$$

Theorem 3: (Input and Output Interconnection Equivalent)

$$P_{rk} = P_{l(s+2-k)} \text{ and } P_{lk} = P_{r(s+2-k)} \quad (4.21)$$

Theorem 4: (Bit-Reverse Equivalent)

$$P_{lk} = P_{br} \times P_{rk} \times P_{br} \text{ and } P_{rk} = P_{br} \times P_{lk} \times P_{br} \quad (4.22)$$

Theorem 5: (Equivalence between BI/LO and LI/BO Butterfly Matrices)

$$BI(k) = P_{rs} \times P_{br} \times BL(k) \times P_{br} \times P_{ls} \quad (4.23a)$$

and

$$BL(k) = P_{rs} \times P_{br} \times BI(k) \times P_{br} \times P_{ls} \quad (4.23b)$$

A variety of FFT algorithms can be obtained by changing the order of the input and the output data sequences or by changing the order of butterfly matrix computations. Two examples are given in the following.

A. Example of Deriving Constant Geometry FFT from In-Place FFT.

The vector-matrix form of a 16-point in-place LI/BO FFT can be obtained from Equation (4.13) and (4.15) and expressed as

$$P_{br} \times \underline{X} = P_{l1} \times BL(4) \times P_{r1} \times P_{l2} \times BL(3) \times P_{r2} \times P_{l3} \\ \times BL(2) \times P_{r3} \times P_{l4} \times BL(1) \times P_{r4} \times \underline{x} \quad (4.24)$$

It can be derived from Theorem 1, 2 and 3 that

$$P_{r1} \times P_{l2} = P_{r2} \times P_{l3} = P_{r3} \times P_{l4} = P_{r4} \times P_{l1} = P_{r4} \quad (4.25)$$

Thus, Equation (4.24) becomes

$$P_{br} \times \underline{X} = P_{l1} \times BL(4) \times P_{r4} \times P_{l1} \times BL(3) \times P_{r4} \times P_{l1} \times BL(2) \times P_{r4} \times P_{l1} \times BL(1) \times P_{r4} \times \underline{x} \quad (4.26)$$

Equation (4.26) represents constant geometry 16-point LI/BO FFT. Similarly, constant geometry BI/LO FFTs can be derived from in-place BI/LO FFTs.

B. Example of Deriving In-Place LI/BO FFT from In-Place BI/LO FFT

The vector-matrix form of a 16-point in-place BI/LO FFT can be obtained from Equations (4.4) and (4.5) and represented by

$$\underline{X} = P_{l4} \times BI(4) \times P_{r4} \times P_{l3} \times BI(3) \times P_{r3} \times P_{l2} \times BI(2) \times P_{r2} \times P_{l1} \times BI(1) \times P_{r1} \times P_{br} \times \underline{x} \quad (4.27)$$

Using $BL(i)$ to replace $BI(i)$ by Equation (4.23a) and using Equations (4.19)-(4.22) to reduce the number of matrices, we can transform Equation (4.27) into

$$\underline{X} = P_{br} \times BL(4) \times P_{r4} \times BL(3) \times P_{r4} \times BL(2) \times P_{r4} \times BL(1) \times P_{r4} \times \underline{x} \quad (4.28)$$

Multiplying P_{br} to both sides of Equation (4.28) and using the equivalent relationship of Equation (4.25), the equation of the 16-point in-place LI/BO FFT can be obtained as shown in Equation (4.24).

Formulation of Vector Matrix Form of 2-D DFT

For a 2-D array (N_1, N_2) , the 2-D DFT by the row-column approach over the region is defined as

$$X(k_1, k_2) = \sum_{n_2=0}^{N_2-1} \left[\sum_{n_1=0}^{N_1-1} x(n_1, n_2) W_{N_1}^{n_1 k_1} \right] W_{N_2}^{n_2 k_2} \quad (4.29)$$

for $0 \leq k_1 \leq N_1$ and $0 \leq k_2 \leq N_2$

The parallel vector-matrix form of the 2-D DFT can be expressed as

$$\begin{bmatrix} X_{c0} \\ X_{c1} \\ \dots \\ X_{c(N_1-1)} \end{bmatrix} = \begin{bmatrix} TW_c & 0 & \dots & \dots & 0 \\ 0 & TW_c & \dots & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & \dots & TW_c \end{bmatrix} P_T \begin{bmatrix} TW_r & 0 & \dots & \dots & 0 \\ 0 & TW_r & \dots & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & \dots & TW_r \end{bmatrix} \begin{bmatrix} x_{r0}^T \\ x_{r1}^T \\ \dots \\ \dots \\ x_{r(N_2-1)}^T \end{bmatrix} \quad (4.30)$$

where TW_r and TW_c denote the twiddle factor matrices for the row DFT and column DFT, respectively. x_{ri} is the i -th row of the input array and X_{cj} is the j -th column of the output array. Set the row length $N_1 = 2^{s_1}$, column length $N_2 = 2^{s_2}$, and total elements $N = N_1 \times N_2$. The transpose matrix P_T is employed to transform the 2-D array from row-major order to column-major order and is also a permutation matrix expressed as

$$P_T = P_{r(s_1+1)} \quad \text{and} \quad P_T^{-1} = P_{l(s_1+1)} \quad (4.31)$$

2-D Linear Inputs And Bit-reverse Outputs FFT

The vector-matrix form for the 2-D LI/BO FFT implementation of Equation (4.30) can be represented by

$$\begin{bmatrix} X_{bc0} \\ X_{bc1} \\ \dots \\ \dots \\ X_{bc(N_1-1)} \end{bmatrix} = \begin{bmatrix} cfft & 0 & \dots & \dots & 0 \\ 0 & cfft & \dots & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & \dots & cfft \end{bmatrix} P_T \begin{bmatrix} rfft & 0 & \dots & \dots & 0 \\ 0 & rfft & \dots & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & \dots & rfft \end{bmatrix} \begin{bmatrix} x_{r0}^T \\ x_{r1}^T \\ \dots \\ \dots \\ x_{r(N_2-1)}^T \end{bmatrix} \quad (4.32)$$

where X_{bci} is the i -th column of the 2-D bit-reverse output array. $rfft$ and $cfft$ can be represented by Equation (4.13) with length N_1 and N_2 , respectively. It can be derived that the N_2 $rffts$ can be implemented by the first s_1 stages of the N -point 1-D FFT and the N_1 $cffts$ by the first s_2 stages of the N -point 1-D FFT. Thus, Equation (4.32) yields

$$\begin{aligned} \underline{X}_{bc} = & FG_1(BL(s_2)) \times FG_2(BL(s_2-1)) \times \dots \times FG_{s_2}(BL(1)) \times P_T \\ & \times FG_1(BL(s_1)) \times FG_2(BL(s_1-1)) \times \dots \times FG_{s_1}(BL(1)) \times \underline{x}_r^T \end{aligned} \quad (4.33)$$

Where $\underline{X}_{bc}$ is the N -point output vector and $\underline{x}_r^T$ is the N -point input vector shown in Equation (4.32). Combining the transpose matrix P_T with the row FFTs and using Theorem 1, 2 and 3, Equation (4.33) can be transformed into a new form of the 2-D FFT structure

$$\begin{aligned} \underline{X}_{bc} = & FG_1(BL(s_2)) \times FG_2(BL(s_2-1)) \times \dots \times FG_{s_2}(BL(1)) \\ & \times FG_{s_2+1}(BL(s_1)) \times FG_{s_2+2}(BL(s_1-1)) \\ & \times \dots \times FG_{s_1+s_2}(BL(1)) \times \underline{x}_c \end{aligned} \quad (4.34)$$

where $\underline{x}_c$ is an N -point vector in the linear column-major order of the input array.

Comparing Equation (4.34) with Equation (4.13) and setting $s = s_1 + s_2$, we can see that the N_1 by N_2 2-D FFT has the same interconnection (butterfly) structure as the N -point 1-D FFT. In another word, they can have the same Signal Flow Graph structure. Figure 14 shows the SFG structure of the traditional row-column 4 by 4 2-D LI/BO FFT implementation. Figure 15 shows the LI/BO SFG structure of the 4 by 4 mapped 2-D FFT

and 16-point 1-D FFT. The top indexing represents the inputs, outputs and twiddle factors for the 2-D case and the bottom indexing is for the 1-D case. The index “i” shown in the figure denotes the twiddle factor W_{16}^i . It can be seen that the twiddle factor matrices are the same for the k-th stage of the row FFT, column FFT and 1-D FFT. The twiddle factor addressing sequence can be obtained from Equation (4.17). The input and the output interconnections (butterfly) are the same for the 1-D and 2-D FFTs with the same number of points and the addressing sequences can be obtained from Equations (4.8) and (4.10).

2-D Bit-reverse Inputs And Linear Outputs FFT

The vector-matrix form of the BI/LO 2-D FFT can be derived in a similar way to that of the LI/BO 2-D FFT. If the TW_r and TW_c of Equation (4.30) are implemented by Equation (4.4), then Equation (4.30) can be transformed into the following form

$$\begin{aligned} \underline{X}_c = & FG_{s_2}(BI(s_2)) \times FG_{s_2-1}(BI(s_2-1)) \times \dots \times FG_1(BL(1)) \times P_T \\ & \times FG_{s_1}(BL(s_1)) \times FG_{s_1-1}(BL(s_1-1)) \times \dots \times FG_1(BL(1)) \times \underline{x}_{br}^T \end{aligned} \quad (4.35)$$

where $\underline{X}_c$ is an N-point vector in the column-major order of the linear output array and $\underline{x}_{br}^T$ is an N-point vector in the row-major order of the bit-reverse input array. Combining the transpose matrix P_T with the column FFTs and using Theorem 1, 2 and 3, Equation (4.35) can become

$$\begin{aligned} \underline{X}_r^T = & FG_{s_1+s_2}(BI(s_2)) \times FG_{s_1+s_2-1}(BI(s_2-1)) \times \dots \times FG_{s_1+1}(BL(1)) \\ & \times FG_{s_1}(BL(s_1)) \times FG_{s_1-1}(BL(s_1-1)) \times \dots \times FG_1(BL(1)) \times \underline{x}_{br}^T \end{aligned} \quad (4.36)$$

where $\underline{X}_r^T$ is an N-point vector in the row-major order of the linear output array. As the LI/BO case by comparing Equation (4.36) with Equation (4.4), the N_1 by N_2 2-D FFT has

the same interconnection structure as the N-point 1-D FFT. Moreover, the butterfly operation matrices are the same for the k-th stage of the row FFT, column FFT and 1-D FFT. Figure 16 shows the SFG structure of the traditional row-column 4 by 4 2-D BI/LO FFT implementation. Figure 17 shows the LI/BO SFG structure of the 4 by 4 mapped 2-D FFT and 16-point FFT.

Figure 14. Signal Flow Graph of Traditional LI/BO 4 by 4 2-D FFT

Figure 15. Signal Flow Graph of LI/BO 4 by 4 2-D Mapped & 16-point 1-D FFTs

Figure 16. Signal Flow Graph of Traditional BI/LO 4 by 4 2-D FFT

Figure 17. Signal Flow Graph of BI/LO 4 by 4 2-D Mapped & 16-point 1-D FFTs

CHAPTER V

WINDSP: A BLOCK ORIENTED WINDOW-BASED DSP ENVIRONMENT

WinDSP is a comprehensive software development system which was developed by the author for Sharp LH9124/LH9320 DSP chips. WinDSP is an integrated software development environment for information processing and data visualization executing under Microsoft Windows. It is also intended to manage the complete development of real-time DSP applications, from conceptualization and prototyping, to implementation in real-time hardware. WinDSP components include visual function-level representation of LH9124 instruction set, an interactive user application development editor (see Figure 18), an external LH9320 address generator package (see Figure 20), and a text/graphics data display window. Although the software is not able to perform real-time simulations, the user can still analyze data for real-time algorithms in real-time environment and in nearly real-time mode. It is also intended to ease code development for architectures that are not easy targets for conventional compilers. WinDSP supports users with varying levels of sophistication. The algorithm designer with little knowledge (or interest) in real-time DSP architectures can quickly and easily produce a simulation or real-time prototype using function blocks from the simulator. The program is also intended to minimize the system design turn-around time and eliminate the time-consuming software coding and debugging. This software is designed to be targetable in two ways. First, it can

synthesize FFT algorithms for a variety of array signal architectures, where the user specifies the function block diagram of the architecture. Second, it can target custom system configuration development in which the function block features are next inherited by the system application design. At the highest level, an algorithm is described using a hierarchical block diagram. Once the application is partitioned into the components of the function block diagram, the function-level representation of instructions will be directly mapped from the function block diagram to the system application. At the lowest level, the user can either simulate the algorithm, simulate the target architecture or download the instruction code and parameters from the simulator to the hardware system for real-time simulation.

A number of other block-diagram systems for DSP have appeared in recent years. Four commercially available programs are BOSS [Shanmugan, 1987] from the University of Kansas, DSPlay from Burr-Brown, Signal Processing Worksystem (SPW) from Comdisco and the Hypersignal-DSP from Hyperception. Hypersignal-DSP supports both real-time and non-real-time types of DSP. Hypersignal-DSP provides virtually limitless simulation, analysis, design, and support for a number of optional plug-in DSP/acquisition hardware cards to what is referred to as “associated Real-Time Signal Processing.” BOSS and SPW, on the other hand, were both strictly simulation systems, not aimed at real-time implementations. BOSS is particularly distinguished for its project management facilities. DSPlay is a PC-based system for both simulation and code generation (for the AT&T DSP32). All the systems could benefit from using the Unified Indexing of FFT Algorithms technique presented in Chapter IV.

Function block diagrams for simulation actually have a long and distinguished history, testifying to their attractiveness to the DSP community. A number of systems were proposed or built in the 1960's [Dertouzous, 1969], [Gold and Rader, 1969] and 1970's [Crystal and Kulsrud, 1974], [Korn, 1977]. The object-oriented approach applied in them makes these systems easy to simulate finite register-length effects; WinDSP relies on a simulation of the target hardware to accomplish the same objective. All of the systems are aimed at simulation, not real-time implementation, and most perform the scheduling at run-time, which is usually not practical in real-time implementations. The discrete Fourier transform is widely used for digital filtering and spectrum analysis, the effects of finite register length in DFT calculations are important. In the case of digital filters, however, a precise analysis is useful for estimates of the effect of arithmetic roundoff. Often a simplified analysis based on modifying the results by truncation is sufficient for the purpose of choosing the required register length for computing the Fourier transform.

The WinDSP Model

Graphical representation of computer program is a controversial topic. For general-purpose programming, many experimental systems have been disappointing. An example is *Pict* [Glinert and Tanimoto, 1984], a visual programming system in which entire programs are built graphically. However, many such systems go to the extreme in an attempt to express everything graphically, resulting in complexity limitations, cryptic and cumbersome representations for user and an arbitrary selection of symbols to

represent concepts that have no natural visualization. WinDSP software, depicted in Figure 18, uses graphical icons to represent the high-level structure of the program, leaving many details to programming of salient features. These features allow easy setup of the built-in instruction set and data flow configurations. The graphical representation of the data flow organization is simply a line linking two graphical icons on the screen of the program. The author makes no claim that a graphical representation of this type is suitable for all applications, however, the author is deeply convinced that this approach is suitable for applications that use the entire LH9124/LH9320 chip set functions.

Figure 18. Graphical Icons of WinDSP Software.

There are 27 graphical icons in WinDSP software shown in Figure 18. Each graphical icons represents the function-level representation of LH9124 instruction set. There are five categories of LH9124 instructions set (see “The LH9124 Instruction Set”

on page 35). The first fly-out menu, starting at the top, consists of function-level representation of LH9124 instruction set for DSP categories. The second fly-out menu consists of function-level representation for the CAI categories. The third fly-out menu consists of function-level representation for VLI categories. The fourth fly-out menu shows the GPI categories function-level representation. The last fly-out menu consists of the signal generator function and text/graphics display function. The signal generator function allows the user to create sample data for the application algorithms and the text/graphics display function displays the input and output data either in spectrum graphics or hexadecimal value.

Figure 19. The WinDSP Software Architecture

The WinDSP software architecture is depicted schematically in Figure 19, was developed primarily to implement unified indexing technique and help demonstrate the

equivalent relationship of function-level representation and the Unified Indexing of FFT algorithms (see CHAPTER IV on page 49). On the other hand, the WinDSP is used to improve productivity, promote software reuse in a wide variety of application domains and facilitate multidisciplinary problem solving.

In Figure 19, the function instructions of the LH9124 DSP are the core of the WinDSP simulation. These function instructions are coded as Dynamic Link Libraries (DLL) or WinDSP function libraries. When WinDSP calls for an instruction, the function library of that instruction is loaded into the program and released immediately when the instruction is no longer required by the main program (i.e the WinDSP Graphical User Interface module). This frees up the computer memory. The WinDSP Graphical User Interface module (see Figure 18), acts as a program manager to handle communication with all the other modules. The LH9124 simulator module and the LH9320 address generator simulator module were first developed running under Disk Operating System (DOS) environment. The LH9124 DOS simulator software simulates the functional behavior of LH9124 Digital Signal Processor's entire instruction set. The LH9320 DOS simulator is a menu-driven software that is used in conjunction with the LH9124 simulator. It generates address patterns and displays or prints the resulting addressing sequence values. The WinDSP software uses the LH9320 DOS simulator to generate the addresses for its simulation. The setup and configuration of the LH9124's signal parameters from the WinDSP can be ported to the Evaluation Module Board (EVM). Lastly, users upload and download module allows users to upload external sample data for analysis and evaluation, as well as download simulated data to their hardware system.

WinDSP also simulates the LH9124 DSP chip's characteristics and have functionality similar to the LH9124 DOS simulator, except WinDSP is Windows-based Graphics User Interface and easy to use. Figure 20 shows the initial start-up menu of the LH9320 DOS simulator when executed. There are seven selections in that start-up menu: (1) Edit program memory, (2) Edit channel length/overlap memory, (3) Edit configuration memory, (4) Execute the setup memory, (5) Display/print the address memory, (6) Save/load setup memory, and (7) Return to DOS (Exit the program). Since the LH9320 is not the main focus of the thesis, the author makes no attempt to discuss in detail the function of each selection. Further discussion of LH9320 DOS simulator software can be found in SHARP LH9320 RTS User's Guide.

Figure 20. LH9320 Simulator Memory Map Menu

WinDSP software provides two levels of simulation which are Block-Level

simulation and System-Level simulation. The Block-Level simulation, known as low-level simulation, is used mostly for algorithmic applications analysis, whereas the System-Level simulation (high-level) allows the user to map simulated block diagrams to a system application. Thus, WinDSP can be used for both system application development and algorithm development.

Equivalent Relationship of the Function-Level Representation

The instructions of the LH9124 are defined with a function-level representation. There are two salient features for the function-level representation of instructions. First, the instructions can be obtained directly from the algorithm to instruction mapping. Second, the instructions are optimized in the function-level representation. Therefore, users can easily use the chip set to obtain the optimum performance for their applications.

From the previous chapter, the FFT algorithm is represented by the general vector-matrix form. The 1-D FFT with length $N = 2^s$ is derived as

$$\underline{X} = FG_s(BS(s)) \times FG_{s-1}(BS(s-1)) \times \dots \times FG_1(BS(1)) \times \underline{x}_b \quad (5.1)$$

and the 2-D FFT with length N_1 by N_2 is derived as

$$\begin{aligned} \underline{X}_r^T = & FG_{s_1+s_2}(BS(s_2)) \times \dots \times FG_{s_1+1}(BS(1)) \\ & \times FG_{s_1}(BS(s_1)) \times \dots \times FG_1(BS(1)) \times \underline{x}_{br}^T \end{aligned} \quad (5.2)$$

The mapping relationship of Equation (5.1) and Equation (5.2) to the function-level representation of LH9124 instructions for the FFT algorithm can be further discussed and is best illustrated with 1-D 16 point FFT and 2-D 4 by 4 FFT examples. Using the Equation (5.1), the vector-matrix form for the 1-D 16-point FFT can be represented by

$$\underline{X} = FG_4[BI(4)] \times FG_3[BI(3)] \times FG_2[BI(2)] \times FG_1[BI(1)] \times \underline{x}_b \quad (5.3)$$

and using Equation (5.2) the vector-matrix for 4 by 4 2-D FFT can be represented by

$$\underline{X}_r^T = FG_4[BI(2)] \times FG_3[BI(1)] \times FG_2[BI(2)] \times FG_1[BI(1)] \times \underline{x}_r^T \quad (5.4)$$

Further expansion each terms of Equation (5.3), it becomes

$$\begin{aligned} \underline{X} = & P_{l4} \times BI(4) \times P_{r4} \times P_{l3} \times BI(3) \times P_{r3} \times P_{l2} \\ & \times BI(2) \times P_{r2} \times P_{l1} \times BI(1) \times P_{r1} \times P_{br} \times \underline{x} \end{aligned} \quad (5.5)$$

and Equation (5.4) becomes

$$\begin{aligned} \underline{X}_r^T = & P_{l4} \times BI(2) \times P_{r4} \times P_{l3} \times BI(1) \times P_{r3} \times P_{l2} \\ & \times BI(2) \times P_{r2} \times P_{l1} \times BI(1) \times P_{r1} \times P_{br} \times \underline{x}_r^T \end{aligned} \quad (5.6)$$

Notice that the permutation matrix, P_{lk} and P_{rk} (where $k = 1, 2, 3, 4$) of Equations (5.5) and (5.6), will have the same indexing sequence (see CHAPTER IV on page 49). Appendices A and B, showed the how the unified indexing is computed for 16-point 1-D FFT and 4 by 4 2-D FFT vector matrix respectively. The computed unified indexing sequences are listed Table XVII shown in Appendix C. In Appendix B, it shows that the indexing sequences of left and right permutation matrices for 4 by 4 2-D FFT vector matrix are equivalent to 1-D FFT for the same number of point. Thus, the example has proof that all the M-D FFT indexing can be simplified and implemented by 1-D indexing.

The Signal Flow Graph of 16-point 1-D FFT and 4 by 4 2-D FFT is illustrated in Figure 17. Equations (5.3) and (5.4) show that the 16-point FFT can be factored into four cascaded stages with radix-2 butterfly (see Figure 21). Table VII lists the LH9124/LH9320 instructions associated with computing the 16-point 1-D FFT and 4 by 4 2-D FFT. These instructions are also correspond directly to the Equations (5.5) and Equation

(5.6). The execution instructions are BFLY2 because of radix-2 FFT algorithm is implemented. The instruction BF2k (where $k = 0, \dots, \log_2[N]-1$) generates the address sequences for each $(j + 1)$ stage, and the indexing sequences of permutation matrices $P_{r(k+1)}$ or $P_{l(k+1)}$. The instruction TF2j (where $j = 0, \dots, \log_2[N]-1$) generates the twiddle factor sequences for each $(j + 1)$ stage corresponding to the diagonal sequence of the butterfly operation matrices $BS(j+1)$.

Table VII: Two FFT Examples using Radix-2 with LH9124/LH9320 Instructions

16-point 1-D FFT					4 by 4 2-D FFT			
Stage	Instr.	Input	Twiddle	Output	Instr.	Input	Twiddle	Output
1	BFLY2	RBF0	TF20	BF20	BFLY2	RBF0	TF20	BF20
2	BFLY2	BF21	TF21	BF21	BFLY2	BF21	TF21	BF21
3	BFLY2	BF22	TF22	BF22	BFLY2	BF22	TF20	BF22
4	BFLY2	BF23	TF23	BF23	BFLY2	BF23	TF21	BF23

The address patterns for each instruction in Table VII is shown in Table VIII. Compare the address pattern generated by the LH9320 in Table VIII and the address pattern in Table XVII (see APPENDIX C on page 109), you will find that both address sequences are same. Thus, from Equations (5.5) and (5.6), the permutation matrix P_{l4} and P_{r4} correspond to *BF23*. The permutation matrix P_{l3} and P_{r3} correspond to *BF22*. The permutation matrix P_{l2} and P_{r2} correspond to *BF21*. The permutation matrix P_{l1} and P_{r1} correspond to *BF20* and finally the permutation matrix P_{br} corresponds to *RBF0*. Likewise, the vector matrix $BI(4)$ has the same pattern as *TF23*. The vector matrix $BI(3)$, $BI(2)$, $BI(1)$ corresponds to *TF22*, *TF21* and *TF20*, respectively. The vector matrix $\mathbf{x}$ of Equation 5.5 is the input vector. Table IX shows the direct mapped relationship between

the LH9320 instruction and permutation matrix of unified indexing.

Table VIII: Address Patterns for LH9320 Instructions

Stage	1			2		3		4	
Index	RBF0	TF20	BF20	BF21	TF21	BF22	TF22	BF23	TF23
0	0	0	0	0	0	0	0	0	0
1	8	0	1	2	0	4	0	8	0
2	4	0	2	4	0	8	0	1	0
3	12	0	3	6	4	12	0	9	4
4	2	0	4	8	0	1	0	2	0
5	10	0	5	10	0	5	4	10	2
6	6	0	6	12	0	9	0	3	0
7	14	0	7	14	4	13	4	11	6
8	1	0	8	1	0	2	0	4	0
9	9	0	9	3	0	6	2	12	1
10	5	0	10	5	0	10	0	5	0
11	13	0	11	7	4	14	2	13	5
12	3	0	12	9	0	3	0	6	0
13	11	0	13	11	0	7	6	14	3
14	7	0	14	13	0	11	0	7	0
15	15	0	15	15	4	15	6	15	7

Table IX: Equivalent Relationship of Unified Indexing and LH9320 Instruction Set

Stage	16-point 1-D FFT				4 by 4 2-D FFT			
(k)	Inst.	P_{lk}	BI(k)	P_{rk}	Inst.	P_{lk}	BI(k)	P_{rk}
1	BFLY2	BF20	TF20	RBF0	BFLY2	BF20	TF20	RBF0
2	BFLY2	BF21	TF21	BF21	BFLY2	BF21	TF21	BF21
3	BFLY2	BF22	TF22	BF22	BFLY2	BF22	TF20	BF22
4	BFLY2	BF23	TF23	BF23	BFLY2	BF23	TF21	BF23

Figure 21. Function Block Diagram of 1-D 16-point & 2-D 4 by 4 FFT Computation

WinDSP Function-Level Representation Mapping

The WinDSP has two levels for user to develop DSP applications. They are the block and system level. Once the application algorithm has been built in the block level, the system level will inherit all the configurations, parameters and setup of the LH9124 chip set. On the start-up of WinDSP, the block level working environment is default. The user starts building algorithm application at this stage. After finishing building the algorithm, the user can simulate the application and goes on to the system level working environment to build the system related application. To illustrate how WinDSP works, the 16-point 1-D FFT example showed in Table VII will be presented. As shown in Figure 21, the radix-2 icons, signal generator icon and the display icons were selected from the DSP and SPEC fly-out menu (see Figure 18). Each icon is arranged in the block

level working environment as shown in Figure 21. A line between two icons indicates data path connection. This can be done by selecting the line menu button and drawing the line between two icons. The signal generator window is called when the left mouse button is double clicked on the signal generator icon (see Figure 22). The input sample data can be generated by selecting the signal generator menu and the external data can be loaded by selecting the load data button. An arbitrary value can be entered for the input data frequency range. The value for magnitude range, which must be less than 1 and greater or equal to -1. In the FFT algorithm, two types of input data are needed in order to compute the algorithm. The next input data must be the coefficient data and which can be generated by using the signal generator program. The default screen of Figure 22 shows generating real data screen. The imaginary data screen can be called by clicking on the Generate Imaginary button.

Figure 22. WinDSP Signal Generator Program Window

The next step of block level design is to set up the signal configuration of LH9124 and generate the address pattern from LH9320 DOS simulator. By double clicking on the radix-2 icon, a configuration setup window will appeared as shown in Figure 23.

Figure 23. WinDSP Signal Configuration Window

In Figure 23, the input, coefficient and output port are data files in WinDSP. But in the hardware design, these ports are connected to the physical memory. The address ports consist of the address sequence for the FFT operation. The read address, coefficient address and write address ports are used for reading the input address file, coefficient address file and output address file. This is done according to Table VII and these files are indexing the data for the LH9124 instruction. In this case, its indexed for radix-2 operation. Figure 23 shows the signal configuration setup of the first stage of 16-point radix-2 operation. The signal setup for the subsequent stage will have the same window menu but the data file and the address file will be different. The output data file is always

used by the input port of the next stage.

Once the signal configuration and parameters are setup, the program is ready for execution. Click on the Start button and the software will compute the example application, in this case the 16-point FFT algorithm using radix-2 butterfly. Finally, the user can examine the computed data by clicking at the Display/Print icon. A window will appear as shown in Figure 24, and display the result (in spectrum graphic) of that stage where display icon is connected. The top menu bar of the window will show to which stage it is connected. The port display window can also display the result in hexadecimal value if the Data button is clicked.

Figure 24. WinDSP Port Display Window

WinDSP is a very useful tool that has been used by major companies, like G.E. Medical, Catalina Research, Scientific Atlanta, Baka Corporation and Signal Science.

Example of 2-D FFT Application

The function block diagram for spectrum sharpening (it is also known as frequency domain filtering) of a 1K by 1K 2-D image is shown in the left column of Figure 25. Assume that the row and column FFTs are implemented represented by 4@16@16. The notation “@” represents the cascaded operation. The SFG structure of the 2-D FFT (see Figure 17) is represented by 4@16@16@4@16@16 with 1 Mega elements. It can be seen from Figure 25 that once the function block diagram of the desired application is defined, the required instructions can be directly obtained from the function block diagram to function-level representation of instruction mapping.

Figure 25. Block Diagram of 1K by 1K Image Spectrum Sharpening

The problem of the 2-D 1K by 1K image spectrum sharpening can be implemented by the chip set with 13 instructions as listed in Table X. Each function block is executed by one LH9124 instruction and three associated LH9320 instructions to control the input, output and coefficient data transfers. The 13-instruction implementation can be optimized into a 12 instruction implementation because the complex multiply and radix-4 column IFFT stages can be combined into one stage executed by the BWND4 instruction. The BWND4 is one of the LH9124 chip set instructions. It performs both the windowing operation as well as the radix-4 algorithm. Windowing can be considered as a complex multiply operation.

Table X: Spectrum Sharpening of a 1K by 1K 2-D Image

	LH9124	LH9320		
Stage	Execution Instructions	Inputs	Coefficients	Outputs
1	BFLY4	RBF0	TF40	BF20
2	BFLY16	BF22	MXT4160	BF22
3	BFLY16	BF26	MXT4161	BF26
4	BFLY4	BF210	TF40	BF210
5	BFLY16	BF212	MXT4160	BF212
6	BFLY16	BF216	MXT4161	BF216
7	CMUL	BF20	BF20	BF20
8	BFLY4	RBF0	TF40	RBF0
9	BFLY16	BF22	MXT4160	BF22
10	BFLY16	BF26	MXT4161	BF26
11	BFLY4	BF210	TF40	BF210
12	BFLY16	BF212	MXT4160	BF212
13	BFLY16	BF216	MXT4161	BF216

It should be noted from Figure 25 that the 2-D FFT is implemented in the row-

column order and the 2-D IFFT in the column-row order. The reason for this is that the row and column indices are swapped when the 2-D bit-reverse addressing is applied. Therefore, if the inputs are in the column-major order, the outputs after the 2-D FFT will be in the row-major order. Similarly, the row-major order inputs will imply the column-major order outputs after the 2-D IFFT. Thus, the column-major order inputs imply the column-major order outputs after FFT and IFFT operations. A similar comment can be extended to the M-D case.

CHAPTER VI

EVALUATION OF RESULTS AND PERFORMANCE COMPARISON

The novel FFT algorithms with unified indexing have been implemented in the Sharp LH9124 array processing chip set. The Sharp LH9124 is an execution unit with radix-2, radix-4 and radix-16 butterflies built in the highly pipelined data path. The radix-2, radix-4 and radix-16 butterflies can be implemented within 2, 4, and 16 cycles, respectively. The Sharp LH9320 is a programmable address generator to provide the address patterns required by the LH9124. The unified indexing equations defined in Chapter IV for the input/output data, twiddle factor and bit-reverse sequences are built in the instruction set of the LH9320. Each set of data from the input port to the output port in LH9124 is delayed by a latency of 8, 18, 20 or 68 system clocks depending on the function in process as described in Table XI.

Table XI: Latency of the LH9124 Instructions

Instructions	Latency
BWND2, BWND4	20 cycles
BFLY16	68 cycles
MOVD	8 cycles
All Other Instructions	18 cycles

The number of data to be processed by the FFT can be structured to use different combination of radices. Table XII shows the example of 1024-point FFT structured in

four different ways and its performance is compared. It can be seen that the performance is inversely proportional to the number of stages of the structure. The higher the performance, the shorter the stages. Thus, the three stage $4 \times 16 \times 16$ mixed mode structure has the best computing efficiency for the 1024-point FFT. The computing efficiency for the non-mixed mode radix-2 structure is 1. The computing efficiency of other structures will be compared with that of the radix-2 structure.

Table XII: Performance Comparison of 1024-point FFT Structures

Structure	$2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2$	$4 \times 4 \times 4 \times 4 \times 4$	$4 \times 16 \times 16$
Cycles	10420	5210	3276
No. of stages	10	5	3
Efficiency	1	2	3.18

The execution cycles in each stage depend on the data length only and are independent of the instruction applied. To improve the computing efficiency of the chip set, some functions can be combined together and replaced by one more powerful function. Thus, the speed for the functions can be doubled or quadrupled. For example, one radix-4 stage can be replaced with two radix-2 stages and one radix-16 stage can either be replaced with four radix-2 stages or two radix-4 stages. Both the LH9124 and LH9320 provide efficient instructions for these functions. Table XIII lists the instructions to implement the 16-point 1-D FFT and 4 by 4 2-D FFT by the radix-4 (BFLY4) FFT algorithm. The radix-2 algorithm shown in Table VII (on page 73) requires 136 cycles on the LH9124 chip. The radix-4 algorithm shown in Table XIII requires only 68 cycles on the LH9124 chip to finish 16-point FFT for either 1-D or 2-D case. Thus, the computing efficiency improvement is twice by using radix-4 algorithm.

Table XIII: Two FFT Examples using Radix-4 with LH9124/LH9320 Instructions

	16-point 1-D FFT				4 by 4 2-D FFT			
Stage	Function	Input	Twiddle	Output	Function	Input	Twiddle	Output
1	BFLY4	RBF0	TF40	BF40	BFLY4	RBF0	TF40	BF40
2	BFLY4	BF41	TF41	BF41	BFLY4	BF41	TF40	BF41

Table XIV compares the performance of the 64K-point 1-D FFT with 256 by 256 2-D FFT. It can be seen that both have the same performance because the data block size, the number of instructions, and the instruction pipeline overhead are all the same. It should be noted by using radix-2 instruction for the 2-D FFT, only 16 instructions (or stages) are required for the unified 2-D FFT implementation instead of 4096 instructions required by the traditional 2-D FFT implementation. Therefore, the instruction pipeline latency can be greatly reduced. With 25 nanoseconds machine cycle time, the 256 by 256 2-D complex FFT using radix-16 can be finished with 6.56 milliseconds.

Table XIV: Benchmark of Unified Indexing FFT Algorithms of Different Radix

	64K-point 1-D FFT			256 by 256 2-D FFT		
Butterfly	stages	cycles	msec	stages	cycles	msecs
Radix-2	16	1048864	26.22	16	1048864	26.22
Radix-4	8	524432	13.11	8	524432	13.11
Radix-16	4	262416	6.56	4	262416	6.56

Computational Complexity Model

The efficiency of the unified FFT algorithm is most often measured by the rate of growth of time and hardware required to solve problems of larger and larger size. In association with each instance of problem is a number n , in this case, the number of data to be processed. The other related measure is the number of computational stages.

Therefore, the total number of machine cycles for an FFT implementation is calculated as

$$Cycles = \sum_{i=1}^s (N_i + PO_i) \quad (6.1)$$

where N_i and PO_i denote the data block size and the pipelined overhead of the i -th instruction, respectively. s is the number of instructions or butterfly stages. Equation (6.1) models the unified indexing FFT algorithm complexity of LH9124/LH9320 chip set. It can be used for non-mixed and mixed radix mode structure. The number of cycles computed by Equation (6.1) is also the actual machine cycle for the hardware chip set. In the real world applications of the LH9124/LH9320 chip set, the external hardware parameters can affect the performance of the unified FFT algorithm. These parameters can be: slow I/O bus speed, slow memory speed, and other delays. The parameters can also be considered as overheads to the instructions and should be included with the calculation of the machine cycles.

Table XV on page 86 shows the benchmark of the unified FFT algorithm based on radix-2 instruction. The LH9124 DSP processor is running at 40MHz clock speed. Calculation of the computation time (in msec) in Table XV is derived by

$$Computation\ time\ (in\ msec) = (Cycles * Clock\ Speed) \quad (6.2)$$

The number of FFT used for the specific data size is computed as such:

$$No.\ of\ FFT\ per\ seconds = (Cycles / Clock\ speed) \quad (6.3)$$

In the real world, the number of data used the FFT algorithms applications are at least 256 and at most 2M bytes.

Table XV: Benchmark of Unified Indexing Algorithm using Radix-2

Unified (1-D) FFT Algorithm using Radix-2 only				
Data Size	Stages	Cycles	msecs	FFT/second
256	8	2192	0.0548	8.77e+10
512	9	4770	0.1192	1.91e+11
1024	10	10420	0.2605	4.17e+11
2048	11	22726	0.5681	9.09e+11
4096	12	49368	1.2342	1.97e+12
8192	13	106730	2.6682	4.27e+12
16384	14	229628	5.7407	9.19e+12
32768	15	491790	12.295	1.97e+13
65536	16	1048864	26.222	4.20e+13
131072	17	2228530	55.713	8.91e+13
262144	18	4718916	117.97	1.89e+14
524288	19	9961814	249.04	3.98e+14
1048576	20	20971880	524.29	8.39e+14
2097152	21	44040570	1101.0	1.76e+15

Three sets of graphs (see pages 87 and 88) have been plotted from Table XV. Figure 26 shows the graph of number of cycles versus the number of data. Figure 27 shows computation time in milliseconds versus the data size and Figure 28 shows the number of FFT per second against the data size. The shapes of all three graphs are proportional to $N \log_2 N$. From the three graphs, the unified indexing FFT algorithm satisfied Knuth's definition [Knuth, 1981] for Omicron (O) asymptotic order. Thus, the unified indexing algorithm is an $O(N \log_2 N)$ complex FFT computation. It should be noted that the larger the data size (i.e the number of data), the less significant the pipeline latency. Moreover, the external hardware overheads are also becoming negligible. The

data for the LH9124 instructions are usually implemented in block fashion manner. The computation overheads occur when data transfers from one block to other block, but not from one element of data to the other. In order to reduce the proportion of overhead in computations, the length of the block data should be as large as possible. The 2-D to 1-D FFT mapping has implicitly included the concept of extending the block length because the length of the FFT is the whole 2-D array of elements instead of one row or one column of elements.

Figure 26. Graph of Actual Computation Cycles vs. Data Size on LH9124/LH9320

Figure 27. Graph of Actual Computation Time vs. Data Size on LH9124/LH9320

Figure 28. Graph of Number of FFT per second vs. Data Size on LH9124/LH9320

Multi-Dimension FFT Applications

There are two meanings for the instructions optimized in the function-representation level. For chip designers, each function instruction is optimized in a parallel and pipelined form and built in the data path. For users, the optimum performance for their applications is to select one implementation that requires the minimum number of stages.

Table XVI: Benchmark of M-D FFT Applications on LH9124/LH9320

FFT Applications (Based on 25nsec per cycle)	Stages	Execution Cycles	Time (msec)
64K-Point 1-D FFT	4	262416	6.56
256 by 256 2-D FFT (Unified)	4	262416	6.56
256 by 256 2-D FFT (Traditional)	(1024+256)*	401920*	10.05
4K-Point 1-D FFT	3	12492	0.312
64 by 64 by 64 3-D FFT (Unified)	6	1573122	39.328
64 by 64 by 64 3-D FFT (Traditional)	24576	2629632	65.741
1K by 64-Channel Array Beamforming (U)	7	265542	6.639
1K by 1K 2-D Spectrum Filtering (U)	12	12583530	314.59
256 by 64-Channel DFT Filter Bank (U)	7	115064	2.877
* denotes there is an extra term added to the calculation. (U) denotes Unified			

Table XVI shows the benchmarking of M-D FFT applications on LH9124/LH9320 chip set. The computing time of the FFT depends on the total number of data in the array, and is independent on the dimension of FFT. For example, both the 256 by 256 points two-dimension (2-D) FFT and the 64K-point one-dimension (1-D) FFT can use the same 1-D indexing, and execute very fast within the execution unit. The traditional way of computing the 256 by 256 points two-dimensional (2-D) FFT is procedures intensive.

For example, to be consistent with the benchmark shown in Table XVI, first, compute each row of vectors matrix with two radix-16. There are 256 rows to compute. Second, search the maximum block-floating point scale factor on each row for 256 times. Then each of the 256 rows is scaled with the maximum scaling factor to prevent overflow. Repeat the steps for the column vectors matrix. Next, do a transposition on the scaled vectors from the row side. Finally, multiply the transposed vectors with the scaled vectors from the column side. Thus, the final result is the matrix vectors in frequency domain after the FFT. As it can be seen, there are many steps which the traditional 2-D FFTs have to go through. The overall overheads from each of these procedures can be, therefore, significant as compared with the unified indexing method. Thus, to compute the number of machine cycles for 256 by 256 2-D FFT in a traditional method, the formula is used:

$$Cycles = \sum_{i=1}^s 2(N_i + PO_i) + \sum_{i=1}^s (T_i + PO_i) + k_i \quad (6.4)$$

where N_i and PO_i denote the data block size for row/column operation and the pipelined overhead of the i -th instruction, respectively. T_i denotes the data block size for transposition operation. s is the number of instructions or butterfly stages. k is the number of cycles required for searching the block-floating scaling factor.

The unified indexing of FFT algorithm has provided significant improvement to 2-D FFT computation, as well as to the performance of the system.

CHAPTER VII

CONCLUSIONS AND FUTURE WORK

From the vector-matrix representation of the FFT algorithms, this thesis shows that the unified indexing methodology for the 2-D to 1-D FFTs has provided significant improvements to the performance of 2-D FFT architectures. The unified indexing approach, essentially, can be extended to more general multidimensional FFTs in a straightforward manner. The development of the WinDSP simulator tool with unified indexing helps the users to evaluate and design the multi-dimension FFT applications as 1-D FFT applications. To illustrate the simplest implementation for the unified indexing method, this thesis presented examples of 16-point 1-D FFT and 4 by 4 2-D FFT. The equivalent relationships between the 1-D FFT and M-D FFT were defined, and the mappings of function-level representation of instructions to the unified indexing structure were explained and illustrated. From Table XVI, the unified method used less instructions (stages) and obtained better performance than the traditional method.

There are a lot of advantages of using the Unified Indexing Approach [Ju, 1993]. First, only 1-D indexing is required for all the M-D FFT implementations. Second, the data matrix transpose is not required for the M-D FFT. Third, the definition and design of the address generator can be simplified. Fourth, the scaling problems of block floating-point arithmetic are automatically solved. Fifth, the program length can be greatly reduced. Finally, the unified indexing concept can be extended to solve scaling problems

of block floating-point arithmetic for the general DSP applications.

The FFT algorithm is computing-intensive and its architecture has some form of regularity. Therefore, it is a good candidate to be implemented by cascaded or parallel architectures. The LH9124 is suitable for cascaded or parallel architecture because of its by-pass form structure. The four data ports of the LH9124 have fast data transfer rates. The data from these ports do not go through holding registers. Thus, the throughput is improved by the cascaded architecture, and the latency by the parallel architecture. This implementation of cascaded and parallel architectures can be the future work.

The decomposition process of the DFT shows that the FFT inherently has the cascaded form. Each stage of the FFT can be implemented by one radix instruction of the LH9124. Hence, the N -stage FFT can be implemented by N cascaded LH9124 processors. The block output data of the i -th stage will be the block input data of the $(i+1)$ -th stage. The computation of the $(i + 1)$ -th stage will wait for the completion of the i -th stage because of data dependency.

The alternative way to improve the throughput for the FFT is obtained by parallel processing. The advantage of the parallel architecture is that each processor can run an independent job or algorithm. For an N -point FFT with M stages, the time required for a single LH9124 to finish the operation is about $N \cdot M$ cycles. Thus, by multiplexing, the $N \cdot M$ points of data can be loaded to M processors with each processor having N points.

The unified indexing method can also be extended to many other block transforms algorithm. Examples of these transforms are fast cosine transform, Reed-Muller, Walsh and etc.

REFERENCES

- M. Burnett, A. Goldberg, and T. Lewis, eds., "Visual Object-Oriented Programming: Concepts and Environments", Prentice-Hall, New York, 1995.
- W.H. Chen and C.H. Smith, "A Fast Computation Algorithm for the Discrete Cosine Transform," IEEE Trans. Comm., vol. COM-25, no. 9, pp. 1004-1009, Sep. 1977.
- J.W. Cooley and J.W. Tukey, "An Algorithm for the Machine Calculation of Complex Fourier Series," Math. of Comput., vol. 19, pp. 297-301, 1965.
- T. Crystal and L. Kulsrud, "Circus," CRD Working Paper, Inst. Def. Analysis, Princeton, NJ, Dec. 1974.
- M. Dertouzous, M. Kaliske and K. Polzen, "On line simulation of block-diagram systems," IEEE Trans. Comput., Vol. C-18, Apr. 1969.
- D.E. Dudgeon and R.M. Mersereau, "Multidimensional Digital Signal Processing," Prentice-Hall, Englewood Cliffs, New Jersey, 1984.
- D.F. Elliot and K.R. Rao, "Fast Transform, Algorithms, Analyses, Applications," Academic Press, 1982.
- E.P. Glinert and S. L. Tanimoto, "Pict: An interactive graphical programming environment," Computer, vol. 17, 1984.
- B. Gold and C. Rader, "Digital Processing of Signals," McGraw-Hill, New York, 1969.
- S. Haykin, ed., "Array Signal Processing," Englewood Cliffs, New Jersey, 1985.
- D. D. Hils, "Visual Languages and Computing Survey: Data Flow Visual Programming Languages," J. Visual Languages and Computing, Vol. 3, No. 1, pp. 69-101, 1992.
- W. H. Ho, E. A. Lee and d. G. Messerschmitt, "High level data flow programming for digital signal processing," presented at the VLSI DSP Workshop, IEEE ASSP Soc., Monterey, CA, Nov 1988.

K. Hwang and F.A. Briggs, "Computer Architecture and Parallel Processing," McGraw-Hill, New York, 1984.

Hypersignal-Window Analysis/Design Software, Hyperception Inc, Dallas, Texas.

D. H. Johnson and R. E. Vaughan, "A Software environment for digital signal processing simulations," *Circuits, Syst., Signal Processing*, vol. 6, pp. 31-44, Jan 1987.

R. Jordan and The Khoros Group, "Khoros: A Software Development Environment for Data Processing," *DSP applications*, pp 16-23, March 1993.

C-J. Ju and M. Fleming, "Design concept of real-time array signal processors." *Proceeding of the International Conference on Signal Processing Applications and Technology*, Boston, pp. 188-197, Nov 1992.

C-J. Ju, "Algorithms of defining 1-D indexing for M-D mixed radix FFT implementation," *Proceeding of IEEE Pacific Rim Conference on Communications, Computers and Signal Processing*, Victoria, Canada, May 1993.

C-J. Ju and W. Alexander, "Block Realization of Multidimensional IIR Digital Filters and its Finite Word Effects," *IEEE Trans. on Circuits and Systems*, pp. 1030-1044, Sept. 1987.

D.E. Knuth, "The Art of Computer Programming, Seminumerical Algorithms," 2nd ed., Addison-Wesley Publishing Co., Reading, MA, 1981.

G. Korn, "High-speed block-diagram languages for microprocessors and min-computers in instrumentation, control and simulation," *Comput. Elec. Eng.*, vol. 4, pp. 143-159, 1977.

S.Y. Kung, "VLSI Array Processors," Prentice Hall, Englewood Cliffs, New Jersey, 1988.

E.A. Lee, W.H. Ho, E.E. Goei, J.C. Bier and S. Bhattacharyya, "Gabriel: A Design Environment for DSP," *IEEE Trans. on ASSP*, vol. 37, no. 11, pp. 1751-1762, Nov 1989.

E.A. Lee, and D.G. Messerschmitt, "Static scheduling of synchronous data flow programs for digital signal processing," *IEEE Trans. Comput.*, vol. C-36, Jan 1987.

LH9124 Digital Signal Processor User's Guide, Sharp Electronics Corp, 1992.

LH9320 Address Generator User's Guide, Sharp Electronics Corp, 1992.

J. Makhoul, "A Fast Cosine Transform in One and Two Dimension," IEEE Trans Acoust., Speech and Signal Proc. vol. ASSP-28, no. 1, pp. 27-34, Feb 1980.

C. Myers, "Signal representation for symbolic and numerical processing," Ph.D. dissertation, Res. Lab. Electron., Cambridge, MA, M.I.T. Tech. Rep. 521, Aug. 1986.

K.N. Ngan, "Image Display Techniques Using the Cosine Transform," IEEE Trans. Acoust., Speech and Signal Processing, vol. ASSP-32, no. 1, pp. 173-177, Feb 1984.

A.V. Oppenheim and R.W. Schaffer, "Discrete-Time Signal Processing," Prentice-Hall, Englewood Cliffs, New Jersey, 1989.

F. Penz, "Visual Programming in the Object World," J. Visual Languages and Computing, Vol. 2, No. 1, pp. 17-41. 1991.

W.K. Pratt, "Digital Image Processing," John Wiley & Sons, New York, 1978.

J. Rasure, C. Williams, "An Integrated Data Flow Visual Language and Software Development Environment," Journal of Visual Languages and Computing, pp 217-246, Feb 1991.

J. Rasure, D. Koechner, R. Jordan, C. Williams, "A Design Environment for Multidimensional Signal Processing," Informatica y Automatica Journal, Vol 24, Number 1, pp. 18-23. 1992.

R.C. Reininger and J.D. Gibson, "Distribution of the Two-Dimensional DCT Coefficients for Images," IEEE Trans. Comm. vol. COM-31, no. 6, pp. 835-839, June 1983.

K. S. Shanmugan, G. J. Minden, E. Komp, T. C. Manning, and E. R. Wiswell, "Block-oriented system simulator (BOSS)," Telecommunication Lab., University of Kansas, Int. Memo., 1987.

N. C. Shu, "Visual Programming," Van Nostrand Reinhold, 1988.

M. A. Zissman, G. C. O'Leary and D. H. Johnson, "A block diagram compiler for a digital signal processing MIMD computer," DSP Workshop Presentation, Chatham, MA, Oct. 1986.

APPENDIX A

ANALYSIS OF UNIFIED INDEXING FOR 1-D TO M-D FFT

In chapter IV, a novel vector-matrix form to represent the unified indexing of FFT algorithm and the relationship of 1-D and M-D FFT were presented. The implementation structures for both the Bit-reverse-Input/Linear-Output (BI/LO) and Linear-Input/Bit-reverse-Output (LI/BO) for computing the FFT were shown. In this appendix, a vector matrix representation of 16-point FFT is used as the example. The example here is the analysis and expansion of the Bit-reverse Input and Linear Output (BI/LO) 16-point 1-D FFT using unified indexing definition. Appendix B will illustrate the expansion for the BI/LO 4 by 4 2-D FFT. The results of the two examples will be listed in Table XVII and compared with the address generated by Sharp LH9320 chip set. The implementation method for the LI/BO structure is similar to the one from the examples below.

The vector-matrix form of the 1-D BI/LO FFT with the length $N=2^s$ can be obtained as follows:

$$\underline{X} = FG_s(BI(s)) \times FG_{s-1}(BI(s-1)) \times \dots \times FG_1(BI(1)) \times P_{br} \times \underline{x} \quad (A.1)$$

The k -th butterfly stage of the BI/LO FFT can be further decomposed into three cascaded matrices:

$$FG_k(BI(k)) = P_{lk} \times BI(k) \times P_{rk} \quad (A.2)$$

where

$$P_{rk}(n, m) = \begin{cases} 1 & \text{for } n = \frac{N}{2^{s+1-k}} \times \text{Mod}(m)_{2^{s+1-k}} + \text{Int}\left(\frac{m}{2^{s+1-k}}\right) \\ 0 & \text{otherwise} \end{cases} \quad (\text{A.3})$$

and

$$P_{lk}(n, m) = \begin{cases} 1 & \text{for } m = \frac{N}{2^{s+1-k}} \times \text{Mod}(n)_{2^{s+1-k}} + \text{Int}\left(\frac{n}{2^{s+1-k}}\right) \\ 0 & \text{otherwise} \end{cases} \quad (\text{A.4})$$

The bit-reverse matrix is as follows:

$$P_{bk}(n, m) = \begin{cases} 1 & \text{for } n = \text{br}(m) \\ 0 & \text{otherwise} \end{cases} \quad (\text{A.5})$$

where $\text{br}(m)$ denotes the bit-reverse operation on the index m with the number of bits s as follows:

$$\text{br}(m)_s = \text{br}(m_{s-1}m_{s-2} \dots m_1m_0)_s = m_0m_1 \dots m_{s-2}m_{s-1} \quad (\text{A.6})$$

The butterfly operation matrix for the BI/LO FFT is defined as

$$BI(k) = \begin{bmatrix} bi_k(0) & 0 & \dots & 0 \\ 0 & bi_k(1) & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & bi_k(N/2 - 1) \end{bmatrix} \quad (\text{A.7})$$

The radix-2 butterfly module $bi_k(n)$ of located the diagonal of $BI(k)$ is defined as

$$bi_k(n) = \begin{bmatrix} W_N^0 & W_N^i \\ W_N^0 & -W_N^i \end{bmatrix} \quad \text{with } i = \frac{N}{2^k} \times \text{Int}\left(\frac{n}{2^{s-k}}\right) \quad (\text{A.8})$$

APPENDIX B

IMPLEMENTATION OF UNIFIED INDEXING TECHNIQUE ON A 2-D 4 BY 4 BI/LO FFT VECTOR MATRIX

Computation of 2-D 4 by 4 BI/LO FFT Vector Matrix

The vector-matrix form of unified indexing for the 2-D 4 by 4 BI/LO FFT implementation can be represented by

$$\underline{X}_c = FG_{s_2}(BI(s_2)) \times FG_{s_2-1}(BI(s_2-1)) \times \dots \times FG_1(BL(1)) \times P_T \quad (B.1)$$

$$\times FG_{s_1}(BL(s_1)) \times FG_{s_1-1}(BL(s_1-1)) \times \dots \times FG_1(BL(1)) \times \underline{x}_{br}^T$$

where $\underline{x}_{br}^T$ is an N-point vector in the row-major order of the bit-reverse input array and

$$P_T = P_{r(s_1+1)} \quad \text{and} \quad P_T^{-1} = P_{l(s_1+1)} \quad (B.2)$$

By substituting Equation (A.2) into Equation (B.1) to compute the bit-reverse input and linear output (BI/LO) of 4 by 4 2-D FFT, it becomes

$$\underline{X}_c = P_{l2} \times BI(2) \times P_{r2} \times P_{l1} \times BI(1) \times P_{r1} \times P_T \times P_{l2} \quad (B.3)$$

$$\times BI(2) \times P_{r2} \times P_{l1} \times BI(1) \times P_{r1} \times P_{br} \times \underline{x}_c$$

and

$$P_T = P_{r3} \quad \text{and} \quad P_T^{-1} = P_{l3} \quad (B.4)$$

Substituting P_T and P_T^{-1} into Equation (B.3),

$$\underline{X}_c = P_T^{-1} \times P_{l2} \times BI(2) \times P_{r2} \times P_T \times P_T^{-1} \times P_{l1} \times BI(1) \times P_{r1} \times P_T \quad (B.5)$$

$$\times P_{l2} \times BI(2) \times P_{r2} \times P_{l1} \times BI(1) \times P_{r1} \times P_{br} \times \underline{x}_c$$

which becomes

$$\underline{X}_r = P_{l4} \times BI(2) \times P_{r4} \times P_{l3} \times BI(1) \times P_{r3} \times P_{l2} \quad (B.6)$$

$$\times BI(2) \times P_{r2} \times P_{l1} \times BI(1) \times P_{r1} \times P_{br} \times \underline{x}_c$$

Thus Equation (B.6) is exactly the same as the Equation (A.9) and this shows that the address sequence for 2-D FFT can be transformed into address sequence of 1-D FFT.

For Stage 3 = $P_T^{-1} \times P_{ll} \times BI(l) \times P_{rl} \times P_T = P_{l3} \times BI(3) \times P_{r3}$

(i.e. set $k = 3$, $s = 4$, $N = 16$)

[illegible]

APPENDIX C

TABLE OF UNIFIED INDEXING SEQUENCES FOR PERMUTATION MATRICES

The indexing sequence for each stage of the permutation matrices from Appendices A and B is listed in Table XVII. To obtain the indexing sequence, the value for left permutation matrix is read row as reference and column as indexing sequence. To read the value for right permutation matrix, it is vice-versa from the left matrix. The left permutation matrix is the transpose of the right permutation matrix. The sequences listed in the table are in decimal value.

Table XVII: Addressing Sequences of 4 by 4 & 16-points 1-D BI/LO FFTs

	16-Point 1-D FFT									4 by 4 2-D FFT								
Stage	S1			S2		S3		S4		R1			R2		C1		C2	
Index	I	T	O	D	T	D	T	D	T	I	T	O	D	T	D	T	D	T
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	8	0	1	2	0	4	0	8	0	8	0	1	2	0	4	0	8	0
2	4	0	2	4	0	8	0	1	0	4	0	2	4	0	8	0	1	0
3	12	0	3	6	4	12	0	9	4	12	0	3	6	4	12	0	9	4
4	2	0	4	8	0	1	0	2	0	2	0	4	8	0	1	0	2	0
5	10	0	5	10	0	5	4	10	2	10	0	5	10	0	5	0	10	0
6	6	0	6	12	0	9	0	3	0	6	0	6	12	0	9	0	3	0
7	14	0	7	14	4	13	4	11	6	14	0	7	14	4	13	0	11	4
8	1	0	8	1	0	2	0	4	0	1	0	8	1	0	2	0	4	0
9	9	0	9	3	0	6	2	12	1	9	0	9	3	0	6	0	12	0
10	5	0	10	5	0	10	0	5	0	5	0	10	5	0	10	0	5	0
11	13	0	11	7	4	14	2	13	5	13	0	11	7	4	14	0	13	4
12	3	0	12	9	0	3	0	6	0	3	0	12	9	0	3	0	6	0
13	11	0	13	11	0	7	6	14	3	11	0	13	11	0	7	0	14	0
14	7	0	14	13	0	11	0	7	0	7	0	14	13	0	11	0	7	0
15	15	0	15	15	4	15	6	15	7	15	0	15	15	4	15	0	15	4

Legends:

I: Data Input O: Data Output T: Twiddle factor sequence
D: Data input or output sequence Si: Stage of 1-D FFT
Ri: Stage of 2-D row FFT Ci: Stage of 2-D column FFT

APPENDIX D

THE PROGRAM SOURCE CODE OF WINDSP

GRAPHICS USER INTERFACE

AND FUNCTIONAL BEHAVIORS OF LH9124 INSTRUCTION SET

```
#####
'# WinDSP.frm
'# This module is the main program of the WinDSP. It is called the workspace module
'# where user setup and development application in this module environment. The
'# modules provide icons of the LH9124 function sets and editor tools that enable user to
'# link each block together. This module also derive the functional characteristics of each
'# events when the instruction icon is depressed. As for the LH9124 instruction icons, each
'# icon will execute the datapath of the LH9124 DSP algorithm and then called the
'# dynamic link libraries function to execute the complex arithmetic of the DSP function.
'# Author: Nee-Hua Cho
'# Revision: 2.0.1
'# Module is called by starting of the WinDSP program
#####
```

DefInt A-Z

```
Dim RFlag As Integer
Dim NeedToSave As Integer
Dim MaxVal As Long
Dim MinVal As Long
Dim TxtEnable As Integer
Dim STxtEnable As Integer
Dim TextRect As RECT
```

```
Sub Blk_InstHScroll_Changing ()
    If ToolPalette_BlkExt.Visible Then ToolPalette_BlkExt.Visible = False
    Blk_WorkSpace.Left = -Blk_InstHScroll.Value
End Sub
```

```
Sub Blk_InstHScroll_GotFocus ()
    If Pic_Work.Visible Then
        'If Not BlkToolFlag Then Prepare_New_Icon XArr(ArraySiz), YArr(ArraySiz)
        'Tool_Select.Value = False
        'CurrentTool = &HEE
        'BlkToolFlag = True
    End If
End Sub
```

```
Sub Blk_InstVScroll_Changing ()
    If ToolPalette_BlkExt.Visible Then ToolPalette_BlkExt.Visible = False
    Blk_WorkSpace.Top = -Blk_InstVScroll.Value
End Sub
```

```
Sub Blk_InstVScroll_GotFocus ()
    If Pic_Work.Visible Then
        'If Not BlkToolFlag Then Prepare_New_Icon XArr(ArraySiz), YArr(ArraySiz)
        'Tool_Select.Value = False
        'CurrentTool = &HEE
    End If
End Sub
```

```

    'BlkToolFlag = True
End If
End Sub

Sub Blk_WorkSpace_DragDrop (Source As Control, X As Single, Y As Single)
Dim Movable As Integer
XTArr = X - DragX: YTArr = Y - DragY
If TypeOf Source Is TextBox Then
    TxtUnFocus TxtSelected
    Source.Move XTArr, YTArr
    TxtFocus TxtSelected
ElseIf TypeOf Source Is PictureBox Then
    If ArraySiz < 0 Then ArraySiz = 0: ArrayCount = 0
    Movable = True
    SavedMode = Blk_WorkSpace.DrawMode
    'Check to see there is line between the icon to be moved and if it does, erase it
    'and update the current line position of the move icon.
    For I = 0 To LineCount - 1
        If Hpts(I, 0) = XArr(ArraySiz) - 2 And Vpts(I, 0) = YArr(ArraySiz) + 16 Then
            If XTArr - 2 <= Hpts(I, 1) Then
                Msg = "Do not drag active icon beyond the left icon"
                MsgBox Msg, 16, "Dragging Icon Error"
                Movable = False
                Exit For
            End If
        ElseIf Hpts(I, 1) = XArr(ArraySiz) + 32 And Vpts(I, 1) = YArr(ArraySiz) + 24 Then
            If XTArr + 32 >= Hpts(I, 0) Then
                Msg = "Do not drag active icon beyond the right icon"
                MsgBox Msg, 16, "Dragging Icon Error"
                Movable = False
                Exit For
            End If
        ElseIf Hpts(I, 1) = XArr(ArraySiz) + 32 And Vpts(I, 1) = YArr(ArraySiz) + 8 Then
            'Erase the old Line
            XFinish = Hpts(I, 0): YFinish = Vpts(I, 0)
            XStart = Hpts(I, 1): YStart = Vpts(I, 1)
            If XTArr + 32 >= Hpts(I, 0) Then
                Msg = "Do not drag active icon beyond the right icon"
                MsgBox Msg, 16, "Dragging Icon Error"
                Movable = False
                Exit For
            End If
        End If
    End If
Next I
If Movable Then
    For I = 0 To LineCount - 1
        If Hpts(I, 0) = XArr(ArraySiz) - 2 And Vpts(I, 0) = YArr(ArraySiz) + 16 Then
            'Erase the old Line

```

```

XFinish = Hpts(I, 0): YFinish = Vpts(I, 0)
XStart = Hpts(I, 1): YStart = Vpts(I, 1)
Blk_WorkSpace.DrawMode = NOT_COPY_PEN
Draw_Icon_Line XStart, YStart, XFinish, YFinish
Blk_WorkSpace.DrawMode = SavedMode
'Update the line position
Hpts(I, 0) = XTArr - 2: Vpts(I, 0) = YTArr + 16
XFinish = XTArr - 2: YFinish = YTArr + 16
Draw_Icon_Line XStart, YStart, XFinish, YFinish
ElseIf Hpts(I, 1) = XArr(ArraySiz) + 32 And Vpts(I, 1) = YArr(ArraySiz) + 24

```

Then

```

'Erase the old Line
XFinish = Hpts(I, 0): YFinish = Vpts(I, 0)
XStart = Hpts(I, 1): YStart = Vpts(I, 1)
Blk_WorkSpace.DrawMode = NOT_COPY_PEN
Draw_Icon_Line XStart, YStart, XFinish, YFinish
Blk_WorkSpace.DrawMode = SavedMode
'Update the line position
Hpts(I, 1) = XTArr + 32: Vpts(I, 1) = YTArr + 24
XStart = XTArr + 32: YStart = YTArr + 24
Draw_Icon_Line XStart, YStart, XFinish, YFinish
ElseIf Hpts(I, 1) = XArr(ArraySiz) + 32 And Vpts(I, 1) = YArr(ArraySiz) + 8 Then
'Erase the old Line
XFinish = Hpts(I, 0): YFinish = Vpts(I, 0)
XStart = Hpts(I, 1): YStart = Vpts(I, 1)
Blk_WorkSpace.DrawMode = NOT_COPY_PEN
Draw_Icon_Line XStart, YStart, XFinish, YFinish
Blk_WorkSpace.DrawMode = SavedMode
'Update the line position
Hpts(I, 1) = XTArr + 32: Vpts(I, 1) = YTArr + 8
XStart = XTArr + 32: YStart = YTArr + 8
Draw_Icon_Line XStart, YStart, XFinish, YFinish
End If

```

Next I

```

XArr(ArraySiz) = XTArr
YArr(ArraySiz) = YTArr
Source.Move XTArr, YTArr

```

End If

End If

End Sub

Sub Blk_WorkSpace_Load ()

```

Blk_WorkSpace.Top = 0
Blk_WorkSpace.Left = 0
Blk_WorkSpace.BorderStyle = NONE
XArr(0) = 0: YArr(0) = 0
PicClip_Icons.ClipY = 0
PicClip_Icons.ClipX = 160

```



```

Tool_Bl6.Picture = PicClip_Icons.Clip
PicClip_Icons.ClipX = 192
Tool_Bl7.Picture = PicClip_Icons.Clip
PicClip_Icons.ClipX = 224
Tool_Bl8.Picture = PicClip_Icons.Clip
PicClip_Icons.ClipY = 32
PicClip_Icons.ClipX = 0
Tool_Bl9.Picture = PicClip_Icons.Clip
PicClip_Icons.ClipX = 32
Tool_Bl10.Picture = PicClip_Icons.Clip
PicClip_Icons.ClipX = 64
Tool_Bl11.Picture = PicClip_Icons.Clip
Pic_Work.BorderStyle = NONE
Pic_Work.Move 0, 0, 34, 54
End Sub

```

'This routine consist of three different function, the first does is to transfer the picture from
'the Pic_Work to the Workspace and then move Pic_Work to the location where the mouse
have previously
'click on.

```

Sub Blk_WorkSpace_MouseDown (Button As Integer, Shift As Integer, X As Single, Y As
Single)

```

```

If Button = LEFT_BUTTON And TP_TID = TP_BLK Then
  XOld = XArr(ArraySiz): YOld = YArr(ArraySiz)
  Select Case CurrentTool
    Case TP_TEXT
      Debug.Print TxtEnable, TxtNum
      If TxtNum > 0 Then
        If TxtEnable And TxtEdit(TxtNum - 1).Text = "" Then
          TxtUnFocus TxtNum - 1
          TxtEdit(TxtNum - 1).Move X, Y
          TxtEdit(TxtNum - 1).SetFocus
        End If
      End If
      If Not TxtEnable Then
        If TxtNum > 1 Then Load TxtEdit(TxtNum)
        TxtEdit(TxtNum).Top = Y
        TxtEdit(TxtNum).Left = X
        TxtEdit(TxtNum).Visible = True
        TxtEdit(TxtNum).Text = ""
        TxtEdit(TxtNum).SetFocus
        TxtNum = TxtNum + 1
        TxtEnable = True
      End If
    Case TP_SELECT
      TxtUnFocus TxtSelected
      For I = 1 To ArrayCount

```

```

    If (XArr(I) <= X And (XArr(I) + 34) >= X) And (YArr(I) <= Y And (YArr(I)
+ 54) >= Y) Then
        UnRFocus_Control MainEditor.Pic_Work
        R = BitBlt(Blk_WorkSpace.hDC, XOld, YOld, 34, 54, Pic_Work.hDC, 0,
0, SRCCOPY)
        Pic_Work.Picture = LoadPicture()
        Pic_Work.Move XArr(I), YArr(I)
        Get_Function_Pic Pic_Work, FuncCode(I, 0)
        R = PatBlt(Blk_WorkSpace.hDC, XArr(I), YArr(I), 34, 54, WHITENESS)
        Pic_Box_Paint Pic_Work, Stage(I), FuncCode(I, 0)
        ArraySiz = I
        Exit Sub
    End If
Next I
Case TP_LINE
    For I = 1 To ArrayCount
        If (XArr(I) <= X And (XArr(I) + 34) >= X) And (YArr(I) <= Y And (YArr(I)
+ 54) >= Y) Then
            'Check to see which icons is selected so that icon's ID can be properly set
            Select Case StartEvent
                Case False
                    IniDraw = True
                    StartEvent = True
                    'Store the initial start of the line to draw
                    StartX = XArr(I) + 16
                    StartY = YArr(I) + 16
                    'Make the last location equal the starting location
                    OldX = StartX
                    OldY = StartY
                    DsplyFlg1 = FuncCode(I, 0)
                    ArrayFlg1 = I
                    Hpts(LineCount, 1) = XArr(I) + 32: Vpts(LineCount, 1) = YArr(I) + 16
                Case True
                    StartEvent = False
                    FinDraw = True
                    DsplyFlg2 = FuncCode(I, 0)
                    ArrayFlg2 = I
                    Hpts(LineCount, 0) = XArr(I) - 2: Vpts(LineCount, 0) = YArr(I) + 16
            End Select
            Exit Sub
        End If
    Next I
    Msg = "Invalid -- No Icon selected"
    MsgBox Msg, 16, "UnLine Editor"
    FinDraw = False: StartEvent = False
    Hpts(LineCount, 0) = 0: Vpts(LineCount, 0) = 0
    Hpts(LineCount, 1) = 0: Vpts(LineCount, 1) = 0
    If IniDraw Then

```

```

        DrawLine Blk_WorkSpace, StartX, StartY, OldX, OldY
        IniDraw = False
    End If
    Case TP_UNLINE
        For I = 1 To ArrayCount
            If (XArr(I) <= X And (XArr(I) + 34) >= X) And (YArr(I) <= Y And (YArr(I)
+ 54) >= Y) Then
                Select Case StartEvent
                    Case False
                        IniDraw = True
                        StartEvent = True
                        'Store the initial start of the line to draw
                        StartX = XArr(I) + 16
                        StartY = YArr(I) + 16
                        'Make the last location equal the starting location
                        OldX = StartX
                        OldY = StartY
                        DsplyFlg1 = FuncCode(I, 0)
                        DisLineX1 = XArr(I) + 32: DisLineY1 = YArr(I) + 16
                        Blk_WorkSpace.DrawStyle = DASH
                    Case True
                        StartEvent = False
                        FinDraw = True
                        DsplyFlg2 = FuncCode(I, 0)
                        DisLineX2 = XArr(I) - 2: DisLineY2 = YArr(I) + 16
                End Select
            Exit Sub
        End If
    Next I
    Msg = "Invalid -- No Icon selected"
    MsgBox Msg, 16, "Line Editor"
    FinDraw = False: StartEvent = False
    DisLineX1 = 0: DisLineY1 = 0
    DisLineX2 = 0: DisLineY2 = 0
    If IniDraw Then
        DrawLine Blk_WorkSpace, StartX, StartY, OldX, OldY
        IniDraw = False
    End If
End Select
End If
End Sub

Sub Blk_WorkSpace_MouseMove (Button As Integer, Shift As Integer, X As Single, Y As
Single)
    Xpix = X
    YPix = Y
    Display_Mouse_Coordinates Xpix, YPix
    If StartEvent Then

```

```

    DrawLine Blk_WorkSpace, StartX, StartY, OldX, OldY
    DrawLine Blk_WorkSpace, StartX, StartY, Xpix, Ypix
    OldX = X
    OldY = Y
End If
End Sub

Sub Blk_WorkSpace_MouseUp (Button As Integer, Shift As Integer, X As Single, Y As Single)
    If Button = LEFT_BUTTON And TP_TID = TP_BLK Then
        Select Case CurrentTool
            Case TP_LINE
                If Not StartEvent And FinDraw Then
                    'Erase the previous line
                    DrawLine Blk_WorkSpace, StartX, StartY, OldX, OldY
                    OldX1 = Hpts(LineCount, 0)
                    OldY1 = Vpts(LineCount, 0)
                    StartX = StartX + 16
                    'Check for invalid operation
                    If StartX > OldX1 Then
                        Msg = "Click data line from left to right Or" & CRLF & "Icons are too close
to each other"
                        GoTo BlkLine_Err
                    ElseIf DsplyFlg1 = TP_DISPLAY And StartX < OldX Then
                        Msg = "Invalid Operation -- Display icon should be clicked last"
                        GoTo BlkLine_Err
                    ElseIf DsplyFlg1 = TP_SIGNAL And DsplyFlg2 = TP_DISPLAY Then
                        Msg = "Invalid Operation -- No data line should be drawn between" & CRLF
& "Signal icon and display icon"
                        GoTo BlkLine_Err
                    ElseIf DsplyFlg2 = TP_SIGNAL Then
                        Msg = "Invalid Operation -- Input to Signal icon is unavailable"
                        GoTo BlkLine_Err
                    End If
                    'Swap_Values Hpts(LineCount, 0), Hpts(LineCount, 1), Vpts(LineCount, 0),
Vpts(LineCount, 1)
                    'StartX = Hpts(LineCount, 1)
                    'StartY = Vpts(LineCount, 1)
                    'OldX1 = Hpts(LineCount, 0)
                    'OldY1 = Vpts(LineCount, 0)
                    If DsplyFlg2 = TP_DISPLAY Then
                        Vpts(LineCount, 1) = Vpts(LineCount, 1) - 8
                    Else
                        Vpts(LineCount, 1) = Vpts(LineCount, 1) + 8
                    End If
                    'Draw new final line
                    StartY = Vpts(LineCount, 1)
                    Draw_Icon_Line StartX, StartY, OldX1, OldY1
                End If
            End Select
        End If
    End Sub

```

```

OldX = OldX1
OldY = OldY1
If DsplyFlg2 = TP_DISPLAY Then
    DpyPort(ArrayFlg2) = ArrayFlg1
End If
FinDraw = False: IniDraw = False
LineCount = LineCount + 1
End If
Case TP_UNLINE
    If Not StartEvent And FinDraw Then
        'Erase the previous line
        DrawLine Blk_WorkSpace, StartX, StartY, OldX, OldY
        Blk_WorkSpace.DrawStyle = SOLID
        ChangePosition = False
        For I = 0 To LineCount - 1
            If Hpts(I, 0) = DisLineX2 And Hpts(I, 1) = DisLineX1 Then ChangePosition
= True
                If ChangePosition Then
                    Hpts(I, 0) = Hpts(I + 1, 0): Vpts(I, 0) = Vpts(I + 1, 0)
                    Hpts(I, 1) = Hpts(I + 1, 1): Vpts(I, 1) = Vpts(I + 1, 1)
                End If
            Next I
            If ChangePosition Then
                If DsplyFlg1 = TP_DISPLAY Or DsplyFlg2 = TP_DISPLAY Then
                    DisLineY1 = DisLineY1 - 8
                Else
                    DisLineY1 = DisLineY1 + 8
                End If
                Blk_WorkSpace.DrawMode = WHITENESS_PEN
                Draw Icon_Line DisLineX1, DisLineY1, DisLineX2, DisLineY2
                Blk_WorkSpace.DrawMode = COPY_PEN
                If LineCount > 0 Then LineCount = LineCount - 1 Else LineCount = 0
                ChangePosition = False
            Else
                Msg = "Invalid Operation Or No Line to delete" & CRLF & "Select icon
from left to right"
                MsgBox Msg, 16, "UnLine Editor"
                DisLineX1 = 0: DisLineY1 = 0
                DisLineX2 = 0: DisLineY2 = 0
            End If
        End If
        FinDraw = False: IniDraw = False
    End Select
End If
Exit Sub

BlkLine_Err:
MsgBox Msg, 16, "Line Editor Error"

```

```

Hpts(LineCount, 0) = 0: Vpts(LineCount, 0) = 0
Hpts(LineCount, 1) = 0: Vpts(LineCount, 1) = 0
FinDraw = False: IniDraw = False
End Sub

```

```

Sub Block_Delete_Selection ()

```

```

    Dim Selecting As Integer

```

```

    Dim PresentTool As Integer

```

```

    Select Case TP_TID

```

```

        Case TP_SYS

```

```

            PresentTool = FuncCode(SICount, 1)

```

```

            Selecting = False

```

```

            If SISiz <= 0 Then

```

```

                SISiz = 0: SICount = 0

```

```

                Clipboard.Clear

```

```

                Exit Sub

```

```

            End If

```

```

            I = 0

```

```

            Do While I < LCount

```

```

                If YPts(I, 0) = YSI(SICount) + 16 And XPts(I, 0) = XSI(SICount) - 2 Then

```

```

                    'Erase the Old Line

```

```

                    XFinish = XPts(I, 0): YFinish = YPts(I, 0)

```

```

                    XStart = XPts(I, 1): YStart = YPts(I, 1)

```

```

                    Sys_WorkSpace.DrawMode = NOT_COPY_PEN

```

```

                    Draw_Icon_Line XStart, YStart, XFinish, YFinish

```

```

                    Sys_WorkSpace.DrawMode = COPY_PEN

```

```

                    Selecting = True

```

```

                ElseIf YPts(I, 1) = YSI(SICount) + 8 And XPts(I, 1) = XSI(SICount) + 32 Then

```

```

                    'Erase the Old Line

```

```

                    XFinish = XPts(I, 0): YFinish = YPts(I, 0)

```

```

                    XStart = XPts(I, 1): YStart = YPts(I, 1)

```

```

                    Sys_WorkSpace.DrawMode = NOT_COPY_PEN

```

```

                    Draw_Icon_Line XStart, YStart, XFinish, YFinish

```

```

                    Sys_WorkSpace.DrawMode = COPY_PEN

```

```

                    Selecting = True

```

```

                ElseIf YPts(I, 1) = YSI(SICount) + 24 And XPts(I, 1) = XSI(SICount) + 32 Then

```

```

                    'Erase the Old Line

```

```

                    XFinish = XPts(I, 0): YFinish = YPts(I, 0)

```

```

                    XStart = XPts(I, 1): YStart = YPts(I, 1)

```

```

                    Sys_WorkSpace.DrawMode = NOT_COPY_PEN

```

```

                    Draw_Icon_Line XStart, YStart, XFinish, YFinish

```

```

                    Sys_WorkSpace.DrawMode = COPY_PEN

```

```

                    Selecting = True

```

```

                ElseIf YPts(I, 1) = YSI(SICount) + 16 And XPts(I, 1) = XSI(SICount) + 32 Then

```

```

                    'Erase the Old Line

```

```

                    XFinish = XPts(I, 0): YFinish = YPts(I, 0)

```

```

                    XStart = XPts(I, 1): YStart = YPts(I, 1)

```

```

                    Sys_WorkSpace.DrawMode = NOT_COPY_PEN

```

```

    Draw_Icon_Line XStart, YStart, XFinish, YFinish
    Sys_WorkSpace.DrawMode = COPY_PEN
    Selecting = True
Else
    I = I + 1
End If
If Selecting Then
    If LCount > 0 Then LCount = LCount - 1 Else LCount = 0
    J = I
    Do While J < LCount
        XPts(J, 0) = XPts(J + 1, 0): YPts(J, 0) = YPts(J + 1, 0)
        XPts(J, 1) = XPts(J + 1, 1): YPts(J, 1) = YPts(J + 1, 1)
        J = J + 1
    Loop
    Selecting = False
End If
Loop
'Remove icon, replace and update the erase icon with the next in the queue
For J = SICount To SISiz - 1
    XSI(J) = XSI(J + 1): YSI(J) = YSI(J + 1)
    FuncCode(J, 1) = FuncCode(J + 1, 1)
    Pass(J) = Pass(J + 1)
    If PresentTool = TP_DISPLAY And FuncCode(J, 1) = TP_DISPLAY Then
        Pass(J) = Pass(J) - 1
    ElseIf PresentTool = TP_SIGNAL And FuncCode(J, 1) = TP_SIGNAL Then
        Pass(J) = Pass(J) - 1
    ElseIf PresentTool = TP_AIME And FuncCode(J, 1) = TP_AIME Then
        Pass(J) = Pass(J) - 1
    ElseIf PresentTool = TP_AGMEM And FuncCode(J, 1) = TP_AGMEM Then
        Pass(J) = Pass(J) - 1
    End If
Next J
If SISiz > 0 Then
    If PresentTool = TP_AIME Then
        Aime_Flag = Aime_Flag - 1
        If Aime_Flag < 0 Then Aime_Flag = 0
    ElseIf PresentTool = TP_AGMEM Then
        AG_Flag = AG_Flag - 1
        If AG_Flag < 0 Then AG_Flag = 0
    ElseIf PresentTool = TP_DISPLAY Then
        Disply_Flag = Disply_Flag - 1
        If Disply_Flag < 0 Then Disply_Flag = 0
    ElseIf PresentTool = TP_SIGNAL Then
        Signal_Flag = Signal_Flag - 1
        If Signal_Flag < 0 Then Signal_Flag = 0
    End If
    SICount = SICount - 1
    SISiz = SISiz - 1

```

```

End If
If SICount >= 0 Then
    UnRFocus_Control MainEditor.Pic_SysWork
    Pic_SysWork.Picture = LoadPicture()
    If SICount = 0 Then SICount = SISiz
    Pic_SysWork.Move XSI(SICount), YSI(SICount)
    If SISiz = 0 Then
        Pic_SysWork.Visible = False
        ScreenInfo(ScrnStage).Changed = False
    Else
        Get_Function_Pic Pic_SysWork, FuncCode(SICount, 1)
        Pic_Box_Paint Pic_SysWork, Pass(SICount), FuncCode(SICount, 1)
        RFocus_Control MainEditor.Pic_SysWork
        R = PatBlt(Sys_WorkSpace.hDC, XSI(SICount), YSI(SICount), 34, 54, WHITE-
NESS)
    End If
End If
Case TP_BLK
    PresentTool = FuncCode(ArraySiz, 0)
    Selecting = False
    If ArrayCount <= 0 Then
        Stage_Flag = 0: Dpy_Flag = 0
        Sign_Flag = 0: ArraySiz = 0
        ArrayCount = 0
        Clipboard.Clear
        Exit Sub
    End If
    'Remove the line on the right of the selected icon and update the Hpts[] & Vpts[]
arrays
    I = 0
    Do While I < LineCount
        If Hpts(I, 0) = XArr(ArraySiz) - 2 And Vpts(I, 0) = YArr(ArraySiz) + 16 Then
            XFinish = Hpts(I, 0): YFinish = Vpts(I, 0)
            XStart = Hpts(I, 1): YStart = Vpts(I, 1)
            Blk_WorkSpace.DrawMode = WHITENESS_PEN
            Draw_Icon_Line XStart, YStart, XFinish, YFinish
            Blk_WorkSpace.DrawMode = COPY_PEN
            Selecting = True
        ElseIf Hpts(I, 1) = XArr(ArraySiz) + 32 And Vpts(I, 1) = YArr(ArraySiz) + 24
Then
            'Erase the old Line
            XFinish = Hpts(I, 0): YFinish = Vpts(I, 0)
            XStart = Hpts(I, 1): YStart = Vpts(I, 1)
            Blk_WorkSpace.DrawMode = WHITENESS_PEN
            Draw_Icon_Line XStart, YStart, XFinish, YFinish
            Blk_WorkSpace.DrawMode = COPY_PEN
            Selecting = True
        ElseIf Hpts(I, 1) = XArr(ArraySiz) + 32 And Vpts(I, 1) = YArr(ArraySiz) + 8 Then

```



```

'Erase the old Line
XFinish = Hpts(I, 0): YFinish = Vpts(I, 0)
XStart = Hpts(I, 1): YStart = Vpts(I, 1)
Blk_WorkSpace.DrawMode = WHITENESS_PEN
Draw_Icon_Line XStart, YStart, XFinish, YFinish
Blk_WorkSpace.DrawMode = COPY_PEN
Selecting = True
Else
  I = I + 1
End If
If Selecting Then
  If LineCount > 0 Then LineCount = LineCount - 1 Else LineCount = 0
  J = I
  Do While J < LineCount
    Hpts(J, 0) = Hpts(J + 1, 0): Vpts(J, 0) = Vpts(J + 1, 0)
    Hpts(J, 1) = Hpts(J + 1, 1): Vpts(J, 1) = Vpts(J + 1, 1)
    J = J + 1
  Loop
  Selecting = False
End If
Loop
'Remove icon, replace and update the erase icon with the next in the queue
For J = ArraySiz To ArrayCount - 1
  XArr(J) = XArr(J + 1): YArr(J) = YArr(J + 1)
  FuncCode(J, 0) = FuncCode(J + 1, 0)
  Stage(J) = Stage(J + 1)
  If PresentTool = TP_DISPLAY And FuncCode(J, 0) = TP_DISPLAY Then
    Stage(J) = Stage(J) - 1
    If DpyPort(J) Then DpyPort(J) = DpyPort(J + 1)
  ElseIf PresentTool = TP_SIGNAL And FuncCode(J, 0) = TP_SIGNAL Then
    Stage(J) = Stage(J) - 1
  ElseIf PresentTool >= &H0 And PresentTool <= &H1E Then
    If FuncCode(J, 0) <> TP_DISPLAY And FuncCode(J, 0) <> TP_SIGNAL Then
      Stage(J) = Stage(J) - 1
    End If
  End If
End If
Next J
If ArrayCount > 0 Then
  If PresentTool >= 0 And PresentTool <= &H1E Then
    Stage_Flag = Stage_Flag - 1
    If Stage_Flag < 0 Then Stage_Flag = 0
  ElseIf PresentTool = TP_DISPLAY Then
    Dpy_Flag = Dpy_Flag - 1
    If Dpy_Flag < 0 Then Dpy_Flag = 0
  ElseIf PresentTool = TP_SIGNAL Then
    Sign_Flag = Sign_Flag - 1
    If Sign_Flag < 0 Then Sign_Flag = 0
  End If
End If

```

```

    ArraySiz = ArraySiz - 1
    ArrayCount = ArrayCount - 1
End If
If ArraySiz >= 0 Then
    UnRFocus_Control MainEditor.Pic_Work
    Pic_Work.Picture = LoadPicture()
    If ArraySiz = 0 Then ArraySiz = ArrayCount
    Pic_Work.Move XArr(ArraySiz), YArr(ArraySiz)
    If ArrayCount = 0 Then
        Pic_Work.Visible = False
        ScreenInfo(ScrnStage).Changed = False
    Else
        Get_Function_Pic Pic_Work, FuncCode(ArraySiz, 0)
        Pic_Box_Paint Pic_Work, Stage(ArraySiz), FuncCode(ArraySiz, 0)
        RFocus_Control MainEditor.Pic_Work
        R = PatBlt(Blk_WorkSpace.hDC, XArr(ArraySiz), YArr(ArraySiz), 34, 54,
WHITENESS)
    End If
End If
End Select
End Sub

Sub BlockEditor_Close ()
    BlockEditor.Visible = False
End Sub

Sub BlockEditor_Resize ()
    If LastBlkWinState = MAXIMIZED Then
        TP_TID = TP_MAIN
        ScrnStage = 0
        If Pic_Work.Visible Then Prepare_New_Icon XArr(ArraySiz), YArr(ArraySiz)
        If ToolPalette_BlExt.Visible Then ToolPalette_BlExt.Visible = False
        ToolPalette_Icons_Initialize
    ElseIf BlockEditor.WindowState = MAXIMIZED Then
        Blk_Root_WkSpace.Move 0, 0, BlockEditor.ClientWidth - Blk_InstVScroll.Width,
BlockEditor.ClientHeight - Blk_InstHScroll.Height
        TP_TID = TP_BLK
        ScrnStage = 1
        ToolPalette_Icons_Initialize
        Sys_System.Caption = "System"
        ScrollBar_Positioning Blk_InstVScroll, Blk_InstHScroll, Blk_WorkSpace,
Blk_Root_WkSpace
        Pan_NSys.Visible = False
        Pan_NSysTxt.Visible = False
        If Not Tool_Select.Value Then Tool_Select.Value = True Else Initiate_SignEdit
        'If NeedToSave Then Menu_FileSelection_Click MID_SAVE_AS
        'If TxtEdit(TxtSelected).Visible Then TxtFocus TxtSelected
    End If

```

```

    LastBlkWinState = BlockEditor.WindowState
End Sub

```

```

Sub Com_MBLK_Click ()
    If Not BlockEditor.Visible Then BlockEditor.Visible = True
    BlockEditor.WindowState = MAXIMIZED
End Sub

```

```

Sub Com_MSYS_Click ()
    If Not SystemEditor.Visible Then SystemEditor.Visible = True
    SystemEditor.WindowState = MAXIMIZED
End Sub

```

```

Sub Cut_Copy_Or_Delete_Selection (Index As Integer)
'This routine check to see which icons to delete in the workspace
    Select Case Index
        Case MID_CUT, MID_COPY
            If TP_TID = TP_SYS Then
                DelCutTag = Pic_SysWork.Tag
                UnRFocus_Control MainEditor.Pic_SysWork
                Clipboard.Clear
                Clipboard.SetData Pic_SysWork.Picture, CF_BITMAP
                If Index = MID_COPY Then RFocus_Control MainEditor.Pic_SysWork
            End If
            If TP_TID = TP_BLK Then
                DelCutTag = Pic_Work.Tag
                UnRFocus_Control MainEditor.Pic_Work
                Clipboard.Clear
                Clipboard.SetData Pic_Work.Picture, CF_BITMAP
                If Index = MID_COPY Then RFocus_Control MainEditor.Pic_Work
            End If
            If Index = MID_CUT Then Block_Delete_Selection
        Case MID_DELETE
            If TP_TID = TP_BLK Or TP_TID = TP_SYS Then Block_Delete_Selection
    End Select
End Sub

```

'As the MousePointer is moved over any portion of the Editing area,
'this routine is called to display the mouse coordinates. The coordinates
'are that of the Work_Space, not the screen coordinates. This routine is
'called by the Work_Space MouseMove.

```

Sub Display_Mouse_Coordinates (Xpix, YPix)
    Pic_StatusArea.CurrentY = Pic_StatusArea.ScaleHeight * .3
    'Display X pixel coordinates only if within range of 0-770
    ,
    If (Xpix >= 0) And (Xpix <= Main_Width) Then
        Pan_XPts.Caption = Format$(Xpix)
    End If
End Sub

```

```

'Pic_StatusArea.CurrentX = Pic_StatusArea.ScaleWidth * .07
'Pic_StatusArea.Print Space$(Abs(Xpix < 10) + Abs(Xpix < 100)) + Format$(Xpix);
End If
'Display Y pixel coordinates only if within range of 0-460
,
If (YPix >= 0) And (YPix <= Main_Height) Then
    Pan_YPts.Caption = Format$(YPix)
    'Pic_StatusArea.CurrentX = Pic_StatusArea.ScaleWidth * .195
    'Pic_StatusArea.Print Space$(Abs(Ypix < 10) + Abs(Ypix < 100)) + Format$(Ypix);
End If
End Sub

```

```

Sub Display_Sys_Icon (SysTNam As Integer)
    SISiz = SISiz + 1
    Select Case SysTNam
        Case TP_COM1 'AIME
            Xipos = 0 + Abs(Sys_WorkSpace.Left)
            Yipos = 170 + Abs(Sys_WorkSpace.Top)
            FuncCode(SISiz, 1) = TP_AIME
        Case TP_COM2 'AGMEM
            Xipos = 0 + Abs(Sys_WorkSpace.Left)
            Yipos = 204 + Abs(Sys_WorkSpace.Top)
            FuncCode(SISiz, 1) = TP_AGMEM
        Case TP_COM3 'SIGNAL
            Xipos = 0 + Abs(Sys_WorkSpace.Left)
            Yipos = 236 + Abs(Sys_WorkSpace.Top)
            FuncCode(SISiz, 1) = TP_SIGNAL
        Case TP_COM4 'DISPLAY
            Xipos = 0 + Abs(Sys_WorkSpace.Left)
            Yipos = 270 + Abs(Sys_WorkSpace.Top)
            FuncCode(SISiz, 1) = TP_DISPLAY
    End Select
    Get_Function_Pic Pic_SysWork, FuncCode(SISiz, 1)
    Initial_PicContrl Pic_SysWork, Xipos, Yipos
End Sub

```

'This routine is to draw the line between the icons, if the icons is in the same level
'vertically a direct line is drawn, else the path of line is divided into half, depending
'on the position of the icons
,

```

Sub Draw_Icon_Line (ByVal X1 As Integer, ByVal Y1 As Integer, ByVal X2 As Integer,
ByVal Y2 As Integer)
    Select Case TP_TID
        Case TP_SYS
            Sys_WorkSpace.Line (X1, Y1)-(X1 + (X2 - X1) / 2, Y1)
            Sys_WorkSpace.Line -(X1 + (X2 - X1) / 2, Y2)
            Sys_WorkSpace.Line -(X2 - 4, Y2)
            Line_Arrow Sys_WorkSpace, X2, Y2
    End Select
End Sub

```

```

        'Sys_WorkSpace.DrawMode = SavedMode
    Case TP_BLK
        Blk_WorkSpace.Line (X1, Y1)-(X1 + (X2 - X1) / 2, Y1)
        Blk_WorkSpace.Line -(X1 + (X2 - X1) / 2, Y2)
        Blk_WorkSpace.Line -(X2 - 4, Y2)
        Line_Arrow Blk_WorkSpace, X2, Y2
    End Select
End Sub

Sub DrawLine (Source1 As Control, X1 As Integer, Y1 As Integer, X2 As Integer, Y2 As Integer)
    SavedMode = Source1.DrawMode
    Source1.DrawMode = INVERSE
    Source1.Line (X1, Y1)-(X2, Y2)
    Source1.DrawMode = SavedMode
End Sub

Sub Exit_System_Click ()
    Unload MainEditor
End Sub

Sub Form_Load ()
    'Position the ToolPalette and position the tool icons.
    If WindowState = NOMAL Then WindowState = MAXIMIZED
    Com_MBLK.Move 0, 0, 34, 34
    Com_MSYS.Move 0, 34, 34, 34
    ToolPalette_Icons_Selection.Move 0, 0, 35, 409
    Tool_Select.Move 0, 0, 34, 34
    Tool_Line.Move 0, 34, 34, 34
    Tool_UnLine.Move 0, 68, 34, 34
    Tool_Reset.Move 0, 102, 34, 34
    Tool_Text.Move 0, 136, 34, 34
    Tool_Com1.Move 0, 170, 34, 34
    Tool_Com2.Move 0, 204, 34, 34
    Tool_Com3.Move 0, 238, 34, 34
    Tool_Com4.Move 0, 272, 34, 34
    Tool_Com5.Move 0, 306, 34, 34
    Tool_Com6.Move 0, 340, 34, 34
    PicClip_Icons.ClipHeight = 32
    PicClip_Icons.ClipWidth = 32
    PicClip_Icons.ClipY = 192
    'Insert Select icon
    PicClip_Icons.ClipX = 0
    Tool_Select.PictureUp = PicClip_Icons.Clip
    'Insert Line icon
    PicClip_Icons.ClipX = 32
    Tool_Line.PictureUp = PicClip_Icons.Clip
    'Insert UnLine icon

```

```

PicClip_Icons.ClipY = 96
PicClip_Icons.ClipX = 128
Tool_UnLine.PictureUp = PicClip_Icons.Clip
'Insert Reset/Clear icon
PicClip_Icons.ClipX = 160
Tool_Reset.PictureUp = PicClip_Icons.Clip
'Insert Text icon
PicClip_Icons.ClipX = 192
Tool_Text.PictureUp = PicClip_Icons.Clip
'Arranging the drag Icons & ToolPalette for Sys_level in the Sys_WorkSpace
Sys_WorkSpace_Load
'Arrange the drag Icons & ToolPalette for Blk_level in the blk_WorkSpace
Blk_WorkSpace_Load
' Initialize the block-level and system-level screen filename to UNTITLED, so a
File.Save operation
' will react just like a File.Save As, the first time.
,

For I = 0 To 2
    ScreenInfo(I).Filename = Untitled
    ScreenInfo(I).Changed = False
Next I
Script_FName = ""
BF_Stage = 0
'DSPLY_INI_FileName = "BLOCKDSP.INI"
Old_Name = INI_FileName
SFCcount = 0
LineCount = 0
LCount = 0: Stage_Flag = 0
Aime_Flag = 0: AG_Flag = 0
Disply_Flag = 0: Signal_Flag = 0
Dpy_Flag = 0: Sign_Flag = 0
ArraySiz = 0: ArrayCount = 0
SISiz = 0: SICount = 0
TxtNum = 0: TxtSelected = 0
STxtNum = 0: STxtSelected = 0
NeedToSave = False
CurrentTool = TP_SELECT
MainEditorLoaded = True
End Sub

Sub Form_Resize ()
Dim Buffers As String * 20
Dim TStrg As String
Dim FPos As Integer
If LastWindowState = NOMAL Then
    'Update the Width and the Height of the main screen size
    Main_Width = ScaleWidth
    Main_Height = ScaleHeight

```

```

'Position the initial selection icons
Work_Space.Move 0, 0, Main_Width, Main_Height
R = GetWindowsDirectory Buffers, 20
FPos = InStr(1, Buffers, "\")
TStrg = Mid$(Buffers, 1, FPos - 1)
ChDrive TStrg
TStrg = Mid$(Buffers, FPos, R)
ChDir TStrg
If Screen.Height = 7200 Then
    Work_Space.Picture = LoadPicture("3DFiltr1.bmp")
Else
    Work_Space.Picture = LoadPicture("3DFiltr2.bmp")
End If
Frm_BlkJdg.Move Main_Width * .35, Main_Height * .8, 94, 52
Frm_Exit.Move Main_Width * .5, Main_Height * .8, 94, 52
Frm_BlkJdg.Visible = True
Frm_Exit.Visible = True
Frm_BlkJdg.SetFocus
ElseIf LastWindowState = MAXIMIZED Then
    If SystemEditor.WindowState = MAXIMIZED Then SystemEditor.WindowState =
NOMAL
        If BlockEditor.WindowState = MAXIMIZED Then BlockEditor.WindowState =
NOMAL
            End If
        LastWindowState = WindowState
End Sub

Sub Form_Unload (Cancel As Integer)
    Pic_Work.Picture = LoadPicture()
    Pic_SysWork.Picture = LoadPicture()
End
End Sub

Sub Frm_BlkJdg_Click ()
    TP_TID = TP_BLK
    MainEditor.Caption = "SHARP WinDSP: [Untitled]"
    Frm_Continue
    Menu_FileSelection(MID_NEW).Enabled = True
    Menu_FileSelection(MID_OPEN).Enabled = True
    BlockEditor.Visible = True
    BlockEditor.WindowState = MAXIMIZED
End Sub

Sub Frm_Continue ()
    Work_Space.Picture = LoadPicture()
    Menu_File.Visible = True
    Menu_Edit.Visible = True
    Menu_Run.Visible = True

```

```

Menu_Window.Visible = True
Menu_Help.Visible = True
Frm_Blkdsg.Visible = False
Frm_Exit.Visible = False
Work_Space.Move 34, 0, Main_Width - 34, Main_Height - 56
Pic_StatusArea.Move 0, Main_Height - 56, Main_Width, 36
ToolPalette_Icons_Selection.Visible = True
Pic_StatusArea.Visible = True
End Sub

Sub Frm_Exit_Click ()
    Unload MainEditor
End Sub

Sub Initial_PicCtrl (Source1 As Control, XIni As Integer, YIni As Integer)
    If TP_TID = TP_SYS Then
        XSI(SISiz) = XIni
        YSI(SISiz) = YIni
        SICount = SISiz
        Select Case FuncCode(SICount, 1)
            Case TP_AIME
                Aime_Flag = Aime_Flag + 1
                Pass(SICount) = Aime_Flag
            Case TP_AGMEM
                AG_Flag = AG_Flag + 1
                Pass(SICount) = AG_Flag
            Case TP_DISPLAY
                Disply_Flag = Disply_Flag + 1
                Pass(SICount) = Disply_Flag
            Case TP_SIGNAL
                Signal_Flag = Signal_Flag + 1
                Pass(SICount) = Signal_Flag
            Case Else
                Pass(SICount) = 0
        End Select
        SysToolFlag = False
    ElseIf TP_TID = TP_BLK Then
        XArr(ArrayCount) = XIni
        YArr(ArrayCount) = YIni
        ArraySiz = ArrayCount
        Select Case FuncCode(ArraySiz, 0)
            Case 0 To &H1E
                Stage_Flag = Stage_Flag + 1
                Stage(ArraySiz) = Stage_Flag
            Case TP_DISPLAY
                Dpy_Flag = Dpy_Flag + 1
                Stage(ArraySiz) = Dpy_Flag
            Case TP_SIGNAL

```



```

        Sign_Flag = Sign_Flag + 1
        Stage(ArraySiz) = Sign_Flag
    Case Else
        Stage(ArraySiz) = 0
    End Select
    If FuncCode(ArraySiz, 0) < TD_VMXM Then SFCcount = SFCcount + 1
End If
ScreenInfo(ScrStage).Changed = True
Tool_Select.Value = True      'Trigger the Select button click event and show depress
End Sub

```

```

Sub Line_Arrow (Source1 As Control, XCorner As Integer, YCorner As Integer)
    Source1.Line (XCorner, YCorner)-(XCorner - 4, YCorner - 4) 'Draw upper slant
    Source1.Line -(XCorner - 4, YCorner + 4)
    Source1.Line -(XCorner, YCorner)
End Sub

```

```

Sub MaxMinFun (NSTem As Long, Maxi As Long, Mini As Long)
    If Inpdatt.Rel0 >= Maxi Then
        Maxi = Inpdatt.Rel0
    ElseIf Inpdatt.Rel0 <= Mini Then
        Mini = Inpdatt.Rel0
    End If
    If Inpdatt.Iml0 >= Maxi Then
        Maxi = Inpdatt.Iml0
    ElseIf Inpdatt.Iml0 <= Mini Then
        Mini = Inpdatt.Iml0
    End If
    If Inpdatt.Rel1 >= Maxi Then
        Maxi = Inpdatt.Rel1
    ElseIf Inpdatt.Rel1 <= Mini Then
        Mini = Inpdatt.Rel1
    End If
    If Inpdatt.Iml1 >= Maxi Then
        Maxi = Inpdatt.Iml1
    ElseIf Inpdatt.Iml1 <= Mini Then
        Mini = Inpdatt.Iml1
    End If
    If NSTem = 0 Then
        Outdat.R0T = Inpdatt.Rel0: Outdat.I0T = Inpdatt.Iml0
        Outdat.R1T = 0: Outdat.I0T = 0
    Else
        Outdat.R0T = Maxi: Outdat.I0T = Mini
        Outdat.R1T = 0: Outdat.I1T = 0
    End If
    If Inpdatt.Rel2 >= Maxi Then
        Maxi = Inpdatt.Rel2
    ElseIf Inpdatt.Rel2 <= Mini Then

```

```

    Mini = Inpdat.Rel2
End If
If Inpdat.Iml2 >= Maxi Then
    Maxi = Inpdat.Iml2
ElseIf Inpdat.Iml2 <= Mini Then
    Mini = Inpdat.Iml2
End If
If Inpdat.Rel3 >= Maxi Then
    Maxi = Inpdat.Rel3
ElseIf Inpdat.Rel3 <= Mini Then
    Mini = Inpdat.Rel3
End If
If Inpdat.Iml3 >= Maxi Then
    Maxi = Inpdat.Iml3
ElseIf Inpdat.Iml3 <= Mini Then
    Mini = Inpdat.Iml3
End If
Outdat.R2T = Maxi: Outdat.I2T = Mini
Outdat.R3T = 0: Outdat.I3T = 0
End Sub

```

```

Sub Menu_Edit_Click ()
    If Not Tool_Select.Value Then Tool_Select.Value = True
    Menu_EditSelection(MID_CUT).Enabled = Pic_Work.Visible Or Pic_SysWork.Visible
    Menu_EditSelection(MID_COPY).Enabled = Pic_Work.Visible Or Pic_SysWork.Visible
    Menu_EditSelection(MID_PASTE).Enabled = Clipboard.GetFormat(CF_BITMAP)
    And (Pic_Work.Visible Or Pic_SysWork.Visible)
    Menu_EditSelection(MID_DELETE).Enabled = Pic_Work.Visible Or
    Pic_SysWork.Visible
    Menu_EditSelection(MID_CLSALL).Enabled = (ArrayCount > 0 Or SISiz > 0) And
    (TP_TID <> TP_MAIN)
End Sub

```

```

Sub Menu_EditSelection_Click (Index As Integer)
'Comments are to be taken out when necessary
    Select Case Index
        Case MID_CUT, MID_COPY, MID_DELETE
            Cut_Copy_Or_Delete_Selection Index
        Case MID_PASTE
            Paste_ClipBoard_Contents Index
        Case MID_EDIT_TXT
            Tool_Text.Value = True
            TxtEdit(TxtSelected).SetFocus
        Case MID_CLSALL
            'Clear all items and icons in the workspace
            Tool_Reset.Value = True
    End Select

```

End Sub

Sub Menu_File_Click ()

Menu_FileSelection(MID_NEW).Enabled = (TP_TID <> TP_MAIN)

Menu_FileSelection(MID_OPEN).Enabled = (TP_TID <> TP_MAIN)

Menu_FileSelection(MID_SAVE).Enabled = (TP_TID <> TP_MAIN)

Menu_FileSelection(MID_SAVE_AS).Enabled = (TP_TID <> TP_MAIN)

Menu_FileSelection(MID_WRITE_SCRIPT).Enabled = Scriptitnow

Select Case TP_TID

Case TP_BLK

'If the Block ToolPalette Extension is visible, hide it

If ToolPalette_BlExt.Visible Then ToolPalette_BlExt.Visible = False

'Prepare for draw line. Turn off the Pic_Work Container

If Pic_Work.Visible Then Prepare_New_Icon XArr(ArraySiz), YArr(ArraySiz)

'turn pic_work icon OFF

Case TP_SYS

'Prepare for draw line. Turn off the Pic_SysWork Container

If Pic_SysWork.Visible Then Prepare_New_Sys_Icon XSI(SICount), YSI(SICount)

'turn pic_work icon OFF

End Select

End Sub

Sub Menu_FileSelection_Click (Index As Integer)

Dim TemOK As Integer

Dim OrgLeft As Integer

Dim PicFlag As Integer

Script_Path = CurDir

Select Case Index

Case MID_NEW

Scriptitnow = False

Prepare_For_New_Scrn

Case MID_OPEN

Txt1 = ""

'Check if the Screen has changed since it was last saved.

If ScreenInfo(ScrnStage).Changed Then

'Inform user screen has been modified.

Txt1 = Txt1 + ScreenInfo(ScrnStage).Filename + CRLF

Txt1 = Txt1 + "The project has changed" + CRLF

Txt1 = Txt1 + "Current Path: " + CurDir\$ + CRLF + CRLF

Txt1 = Txt1 + "Do you want to save current changes?"

TemOK = MsgBox(Txt1, 51, "PROJECT HAS CHANGED")

If TemOK = MB_YES Then

Save_Screen MID_SAVE

Elseif TemOK = MB_CANCEL Then

If Not Tool_Select.Value Then Tool_Select.Value = True Else Initiate_SignEdit

Exit Sub

End If

End If

```

Open_Screen Index
'TxtEnable = False
If Not Tool_Select.Value Then Tool_Select.Value = True Else Initiate_SignEdit
Case MID_SAVE, MID_SAVE_AS
    Save_Screen Index
    If TP_TID = TP_BLK Then
        If ScreenInfo(2).Changed Then
            NeedToSave = True
            Sys_System_Click
        End If
    ElseIf TP_TID = TP_SYS Then
        If ScreenInfo(1).Changed Then
            NeedToSave = True
            Sys_System_Click
        End If
    End If
    If Not Tool_Select.Value Then Tool_Select.Value = True Else Initiate_SignEdit
Case MID_PRINT
    If TP_TID = TP_BLK Then
        If SystemEditor.Visible Then SystemEditor.Visible = False
        MainEditor.PrintForm
        If Not SystemEditor.Visible Then SystemEditor.Visible = True
    ElseIf TP_TID = TP_SYS Then
        If BlockEditor.Visible Then BlockEditor.Visible = False
        MainEditor.PrintForm
        If Not BlockEditor.Visible Then BlockEditor.Visible = True
    End If
    If Not Tool_Select.Value Then Tool_Select.Value = True Else Initiate_SignEdit
Case MID_WRITE_SCRIPT
    Write_Script Index
Case MID_EXIT
    Unload MainEditor
End Select
End Sub

Sub Menu_HlpSelection_Click (Index As Integer)
    If Index = MID_ABOUT Then
        AboutBox.Show Modal
    Else
        Get_Help Index
    End If
End Sub

Sub Menu_WinSelection_Click (Index As Integer)
    Select Case Index
    Case 1
        If TP_TID = TP_MAIN Then
            SystemEditor.Top = 0

```

```

        SystemEditor.Left = 0
        BlockEditor.Top = 21
        BlockEditor.Left = 21
    End If
Case 3
    If TP_TID = TP_SYS Then
        Sys_WorkSpace.Refresh
        'Draw_Icon_Line
    ElseIf TP_TID = TP_BLK Then
        Blk_WorkSpace.Refresh
        For I = 0 To LineCount - 1
            XFinish = Hpts(I, 0): YFinish = Vpts(I, 0)
            XStart = Hpts(I, 1): YStart = Vpts(I, 1)
            Draw_Icon_Line XStart, YStart, XFinish, YFinish
        Next I
    End If
End Select
End Sub

Sub Multiply_Routine_Selection (ByVal NumS As Long, FunTool As Integer, Stages As Integer)
    On Error Resume Next
    Select Case FunTool
        Case TP_BFLY16
            R = Bfly4(Inpdat, Outdat, 0)
            If RFlag Then
                AutoDSFI = Mag_Factor(Outdat.R0T, Outdat.I0T, AutoDSFI)
                AutoDSFI = Mag_Factor(Outdat.R1T, Outdat.I1T, AutoDSFI)
                AutoDSFI = Mag_Factor(Outdat.R2T, Outdat.I2T, AutoDSFI)
                AutoDSFI = Mag_Factor(Outdat.R3T, Outdat.I3T, AutoDSFI)
            End If
        Case TP_BFLY4
            R = Bfly4(Inpdat, Outdat, 0)
            AutoDSFI = Mag_Factor(Outdat.R0T, Outdat.I0T, AutoDSFI)
            AutoDSFI = Mag_Factor(Outdat.R1T, Outdat.I1T, AutoDSFI)
            AutoDSFI = Mag_Factor(Outdat.R2T, Outdat.I2T, AutoDSFI)
            AutoDSFI = Mag_Factor(Outdat.R3T, Outdat.I3T, AutoDSFI)
        Case TP_BFLY2
            R = Bfly2(Inpdat, Outdat, 0)
            If R Then
                MsgBox "Data Overflow or Underflow Error" & CRLF & "At stage " & Format$(Stages), 16, "Data Computation Error"
            End If
            AutoDSFI = Mag_Factor(Outdat.R0T, Outdat.I0T, AutoDSFI)
            AutoDSFI = Mag_Factor(Outdat.R1T, Outdat.I1T, AutoDSFI)
            AutoDSFI = Mag_Factor(Outdat.R2T, Outdat.I2T, AutoDSFI)
            AutoDSFI = Mag_Factor(Outdat.R3T, Outdat.I3T, AutoDSFI)
        Case TP_BWND4

```

```

R = Bfly4(Inpdat, Outdat, 1)
AutoDSFI = Mag_Factor(Outdat.R0T, Outdat.I0T, AutoDSFI)
AutoDSFI = Mag_Factor(Outdat.R1T, Outdat.I1T, AutoDSFI)
AutoDSFI = Mag_Factor(Outdat.R2T, Outdat.I2T, AutoDSFI)
AutoDSFI = Mag_Factor(Outdat.R3T, Outdat.I3T, AutoDSFI)
Case TP_BWND2
R = Bfly2(Inpdat, Outdat, 1)
AutoDSFI = Mag_Factor(Outdat.R0T, Outdat.I0T, AutoDSFI)
AutoDSFI = Mag_Factor(Outdat.R1T, Outdat.I1T, AutoDSFI)
AutoDSFI = Mag_Factor(Outdat.R2T, Outdat.I2T, AutoDSFI)
AutoDSFI = Mag_Factor(Outdat.R3T, Outdat.I3T, AutoDSFI)
Case TP_BFCT
R = Bfct(Inpdat, Outdat, 0)
AutoDSFI = Mag_Factor(Outdat.R0T, Outdat.I0T, AutoDSFI)
AutoDSFI = Mag_Factor(Outdat.R1T, Outdat.I1T, AutoDSFI)
AutoDSFI = Mag_Factor(Outdat.R2T, Outdat.I2T, AutoDSFI)
AutoDSFI = Mag_Factor(Outdat.R3T, Outdat.I3T, AutoDSFI)
Case TP_BRFT
R = Brft(Inpdat, Outdat)
Case TP_BCFIR
R = Bcfir(Inpdat, Outdat, rndFlag)
Case TP_BDFIR
R = Bdfir(Inpdat, Outdat, rndFlag)
Case TP_BRFIR
R = Brfir(Inpdat, Outdat, rndFlag)
Case TP_BFCT2
R = Bfct(Inpdat, Outdat, 1)
AutoDSFI = Mag_Factor(Outdat.R0T, Outdat.I0T, AutoDSFI)
AutoDSFI = Mag_Factor(Outdat.R1T, Outdat.I1T, AutoDSFI)
AutoDSFI = Mag_Factor(Outdat.R2T, Outdat.I2T, AutoDSFI)
AutoDSFI = Mag_Factor(Outdat.R3T, Outdat.I3T, AutoDSFI)
Case TP_CADD, TP_VADD
R = Vadd(Inpdat, Outdat)
Case TP_CMAG
R = Cmag(Inpdat, Outdat)
Case TP_CMUL
R = Cmul(Inpdat, Outdat)
Case TP_CSUB, TP_VSUB
R = Vsub(Inpdat, Outdat)
Case TP_VABS
Outdat.R0T = Abs(Inpdat.Rel0): Outdat.I0T = Abs(Inpdat.Iml0)
Outdat.R1T = Abs(Inpdat.Rel1): Outdat.I1T = Abs(Inpdat.Iml1)
Outdat.R2T = Abs(Inpdat.Rel2): Outdat.I2T = Abs(Inpdat.Iml2)
Outdat.R3T = Abs(Inpdat.Rel3): Outdat.I3T = Abs(Inpdat.Iml3)
Case TP_VMUL
R = Vmul(Inpdat, Outdat)
Case TP_VMXM
MaxMinFun NumS, MaxVal, MinVal

```

Case TP_VNAND

```

    Outdat.R0T = Not (Inpdat.Rel0 And Inpdat.Cox0)
    Outdat.I0T = Not (Inpdat.Iml0 And Inpdat.Snx0)
    Outdat.R1T = Not (Inpdat.Rel1 And Inpdat.Cox1)
    Outdat.I1T = Not (Inpdat.Iml1 And Inpdat.Snx1)
    Outdat.R2T = Not (Inpdat.Rel2 And Inpdat.Cox2)
    Outdat.I2T = Not (Inpdat.Iml2 And Inpdat.Snx2)
    Outdat.R3T = Not (Inpdat.Rel3 And Inpdat.Cox3)
    Outdat.I3T = Not (Inpdat.Iml3 And Inpdat.Snx3)

```

Case TP_VNOR

```

    Outdat.R0T = Not (Inpdat.Rel0 Or Inpdat.Cox0)
    Outdat.I0T = Not (Inpdat.Iml0 Or Inpdat.Snx0)
    Outdat.R1T = Not (Inpdat.Rel1 Or Inpdat.Cox1)
    Outdat.I1T = Not (Inpdat.Iml1 Or Inpdat.Snx1)
    Outdat.R2T = Not (Inpdat.Rel2 Or Inpdat.Cox2)
    Outdat.I2T = Not (Inpdat.Iml2 Or Inpdat.Snx2)
    Outdat.R3T = Not (Inpdat.Rel3 Or Inpdat.Cox3)
    Outdat.I3T = Not (Inpdat.Iml3 Or Inpdat.Snx3)

```

Case TP_VPAS, TP_MOVC, TP_MOVD

```

    Outdat.R0T = Inpdat.Rel0: Outdat.I0T = Inpdat.Iml0
    Outdat.R1T = Inpdat.Rel1: Outdat.I1T = Inpdat.Iml1
    Outdat.R2T = Inpdat.Rel2: Outdat.I2T = Inpdat.Iml2
    Outdat.R3T = Inpdat.Rel3: Outdat.I3T = Inpdat.Iml3

```

Case TP_VXNOR

```

    Outdat.R0T = Not (Inpdat.Rel0 Xor Inpdat.Cox0)
    Outdat.I0T = Not (Inpdat.Iml0 Xor Inpdat.Snx0)
    Outdat.R1T = Not (Inpdat.Rel1 Xor Inpdat.Cox1)
    Outdat.I1T = Not (Inpdat.Iml1 Xor Inpdat.Snx1)
    Outdat.R2T = Not (Inpdat.Rel2 Xor Inpdat.Cox2)
    Outdat.I2T = Not (Inpdat.Iml2 Xor Inpdat.Snx2)
    Outdat.R3T = Not (Inpdat.Rel3 Xor Inpdat.Cox3)
    Outdat.I3T = Not (Inpdat.Iml3 Xor Inpdat.Snx3)

```

End Select

End Sub

Sub Open_Screen (Index1 As Integer)

On Error Resume Next

Dim LongName As String

Dim Title As String

Dim CDPATH As String

If Index1 = MID_OPEN Then

 ' Set default filter.

 If TP_TID = TP_BLK Then

 MainEditor.CMDialog_Edit.Filter = "BDB Files (*.bdb)|*.BDB"

 MainEditor.CMDialog_Edit.DefaultExt = "BDB"

 ElseIf TP_TID = TP_SYS Then

 MainEditor.CMDialog_Edit.Filter = "SDB Files (*.sdb)|*.SDB"

 MainEditor.CMDialog_Edit.DefaultExt = "SDB"

```

End If
' Display Save As dialog.
MainEditor.CMDialog_Edit.FilterIndex = 1
If Right(ScreenInfo(ScrnStage).FullPath, 1) <> "\" Then
    MainEditor.CMDialog_Edit.Filename = ScreenInfo(ScrnStage).FullPath & "\" &
ScreenInfo(ScrnStage).Filename
End If
' If file has not been saved yet, set common dialog's
' default file name to *.dsp
If ScreenInfo(ScrnStage).Filename = "[Untitled]" Then
    MainEditor.CMDialog_Edit.Filename = IIf(TP_TID = TP_BLK, "*.bdb", "*.sdb")
End If
MainEditor.CMDialog_Edit.Action = 1
' Exit if user cancels the dialog.
If Err = 32755 Then Exit Sub
Title = MainEditor.CMDialog_Edit.Filetitle
LongName = MainEditor.CMDialog_Edit.Filename
ScreenInfo(ScrnStage).FullPath = Left(LongName, Len(LongName) - Len(Title))
ScreenInfo(ScrnStage).Filename = MainEditor.CMDialog_Edit.Filetitle
' Adjust for root directory.
If Len(ScreenInfo(ScrnStage).FullPath) = 3 Then
    CDPPath = ScreenInfo(ScrnStage).FullPath
Else
    CDPPath = Left(LongName, Len(LongName) - Len(Title) - 1)
End If
' Change directories for the editor and the viewer.
ChDir CDPPath
End If
MainEditor.MousePointer = HOURGLASS
Write_File_To_Screen ScreenInfo(ScrnStage).FullPath, ScreenInfo(ScrnStage).Filename
MainEditor.MousePointer = DEFAULT
End Sub

Sub Paste_ClipBoard_Contents (Index As Integer)
    If Index = MID_PASTE Then
        If TP_TID = TP_BLK Then
            ArrayCount = ArrayCount + 1
            UnRFocus_Control MainEditor.Pic_Work
            R = BitBlt(Blk_WorkSpace.hDC, XArr(ArraySiz), YArr(ArraySiz), 34, 54,
Pic_Work.hDC, 0, 0, SRCCOPY)
            Pic_Work.Picture = LoadPicture()
            Pic_Work.Tag = DelCutTag
            Pic_Work.Move XArr(ArraySiz) + 15, YArr(ArraySiz) - 15
            Pic_Work.Picture = Clipboard.GetData(CF_BITMAP)
            If FuncCode(ArraySiz, 0) >= 0 And FuncCode(ArraySiz, 0) <= &H1E Then
                Stage_Flag = Stage_Flag + 1
                Stage(ArrayCount) = Stage_Flag
            End If
        End If
    End If
End Sub

```



```

ElseIf FuncCode(ArraySiz, 0) = TP_DISPLAY Then
    Dpy_Flag = Dpy_Flag + 1
    Stage(ArrayCount) = Dpy_Flag
ElseIf FuncCode(ArraySiz, 0) = TP_SIGNAL Then
    Sign_Flag = Sign_Flag + 1
    Stage(ArrayCount) = Sign_Flag
Else
    Stage(ArrayCount) = 0
End If
ArraySiz = ArrayCount
Pic_Box_Paint Pic_Work, Stage(ArraySiz), FuncCode(ArraySiz, 0)
RFocus_Control MainEditor.Pic_Work
End If
End If
End Sub

```

'This routine is to draw a grey line around the Pic_Work or the Pic_SysWork Container
'and draw the blue box around the upper grey box of the DSP function.

```

Sub Pic_Box_Paint (PicSource1 As Control, BoxNum As Integer, IconID As Integer)
    LookUp_Func_ID PicSource1, IconID
    R = PatBlt(PicSource1.hDC, 2, 33, 28, 18, WHITENESS)
    PicSource1.CurrentX = 0
    PicSource1.CurrentY = 31
    If Len(PicSource1.Tag) < 5 Then
        PicSource1.Print " " & PicSource1.Tag
    Else
        PicSource1.Print PicSource1.Tag
    End If
    PicSource1.CurrentX = 5
    PicSource1.CurrentY = 40
    PicSource1.Print "["; BoxNum; "]"
End Sub

```

```

Sub Pic_IconTool_Highlight (Source2 As Control)
    'note this to unhighlight the Picture Icon Tools. These controls
    'must get their outline drawn on the picture box they are inside
    UnWide = Source2.Width
    UnHigh = Source2.Height
    Source2.Line (0, 0)-(UnWide, 1), &HFFFFFF, BF
    Source2.Line (0, 0)-(1, UnHigh), &HFFFFFF, BF
    Source2.Line (UnWide, UnHigh)-(0, UnHigh - 3), &H808080, BF
    Source2.Line (UnWide, UnHigh - 3)-(1, UnHigh - 4), &H808080, BF
    Source2.Line (UnWide, UnHigh)-(UnWide - 3, 0), &H808080, BF
    Source2.Line (UnWide - 3, UnHigh)-(UnWide - 4, 1), &H808080, BF
End Sub

```

```

Sub Pic_StatusArea_Paint ()

```

```

'Highlighting the StatusArea
Pic_IconTool_Highlight Pic_StatusArea
'Positioning the command Button
Sys_System.Move Main_Width - 290, 4, 60, 26
Start_System.Move Main_Width - 220, 4, 60, 26
Stop_System.Move Main_Width - 150, 4, 60, 26
Exit_System.Move Main_Width - 80, 4, 60, 26
Pic_StatusArea.FontBold = True
'Display X & Y mouse coordinates labels, "X=" and "Y="
Pic_StatusArea.CurrentY = Main_Height * .02
Pic_StatusArea.CurrentX = Main_Width * .01
Pic_StatusArea.Print "X=";
Pic_StatusArea.CurrentX = Main_Width * .115
Pic_StatusArea.Print "Y=";
'Position the Panel for X & Y coordinates
Pan_XPts.Top = Main_Height * .015
Pan_XPts.Left = Main_Width * .034
Pan_YPts.Top = Main_Height * .015
Pan_YPts.Left = Main_Width * .14
Pan_NSysTxt.Top = Main_Height * .015
Pan_NSysTxt.Left = Main_Width * .23
Pan_NSys.Top = Main_Height * .015
Pan_NSys.Left = Main_Width * .49
End Sub

Sub Pic_SysWork_DblClick ()
  If TP_TID = TP_SYS Then
    XInit = XSI(SICount): YInit = YSI(SICount)
    If Pic_SysWork.Visible Then Prepare_New_Sys_Icon XInit, YInit
    Select Case FuncCode(SICount, 1)
      Case TP_AIME
        CenterForm SignalEditor
        SignalEditor.Show Modeless
      Case TP_AGMEM
        CenterForm AGMEM_Editor
        AGMEM_Editor.Show Modal
      Case TP_DISPLAY
        CenterForm BGraph
        BGraph.Show Modeless
    End Select
  End If
End Sub

Sub Pic_SysWork_MouseDown (Button As Integer, Shift As Integer, X As Single, Y As Single)
  If TP_TID = TP_SYS Then
    Pic_SysWork.Drag 1
    DragX = X
  End If
End Sub

```

```

        DragY = Y
    End If
End Sub

Sub Pic_SysWork_MouseUp (Button As Integer, Shift As Integer, X As Single, Y As Single)
    If TP_TID = TP_SYS Then Pic_SysWork.Drag 2
End Sub

Sub Pic_SysWork_Paint ()
    Pic_SysWork.Line (1, 1)-(30, 31), QBColor(1), B
    Pic_SysWork.Line (1, 31)-(30, 52), QBColor(8), B
    Pic_Box_Paint Pic_SysWork, Pass(SICount), FuncCode(SICount, 1)
    RFocus_Control MainEditor.Pic_SysWork
End Sub

Sub Pic_Work_DblClick ()
    If TP_TID = TP_BLK Then
        XInit = XArr(ArraySiz): YInit = YArr(ArraySiz)
        If Pic_Work.Visible Then Prepare_New_Icon XInit, YInit
        Select Case FuncCode(ArraySiz, 0)
            Case TP_SIGNAL
                CenterForm XGen
                XGen.Show Modal
            Case TP_DISPLAY
                CenterForm BGraph
                BGraph.Show Modal
            Case Else
                CenterForm SignalEditor
                SignalEditor.Show Modal
        End Select
    End If
End Sub

Sub Pic_Work_MouseDown (Button As Integer, Shift As Integer, X As Single, Y As Single)
    If TP_TID = TP_BLK Then
        Pic_Work.Drag 1
        DragX = X
        DragY = Y
    End If
End Sub

Sub Pic_Work_MouseUp (Button As Integer, Shift As Integer, X As Single, Y As Single)
    If TP_TID = TP_BLK Then Pic_Work.Drag 2
End Sub

Sub Pic_Work_Paint ()

```

```

'Paint the Top square with blue color
Pic_Work.Line (1, 1)-(30, 31), QBColor(1), B
'Paint the Bottom square with gray color
Pic_Work.Line (1, 31)-(30, 52), QBColor(8), B
'Update the icon information
Pic_Box_Paint Pic_Work, Stage(ArraySiz), FuncCode(ArraySiz, 0)
'Highlight the icon
RFocus_Control MainEditor.Pic_Work
End Sub

Sub Prepare_For_New_Scrn ()
    Dim TemOK As Integer
    Txt1 = ""
    'Check if the Screen has changed since it was last saved.
    If ScreenInfo(ScrnStage).Changed Then
        'Inform user screen has been modified.
        Txt1 = Txt1 + ScreenInfo(ScrnStage).Filename + CRLF
        Txt1 = Txt1 + "The project has changed" + CRLF
        Txt1 = Txt1 + "Current Path:" + A_TAB + CurDir$ + CRLF + CRLF
        Txt1 = Txt1 + "Do you want to save current changes?"
        TemOK = MsgBox(Txt1, 51, "PROJECT HAS CHANGED")
        If TemOK = MB_YES Then
            Save_Screen MID_SAVE
        ElseIf TemOK = MB_CANCEL Then
            Exit Sub
        End If
    End If
    'Clear the screen and delete all variables
    Initialize_All_Variables TP_TID
    'Initialize the variables to default value
    ScreenInfo(ScrnStage).Filename = Untitled
    ScreenInfo(ScrnStage).Changed = False
    'Reset the title on the editors titlebar
    Caption = "SHARP WinDSP: [Untitled] "
    If Not Tool_Select.Value Then Tool_Select.Value = True Else Initiate_SignEdit
End Sub

'Prepare the new function icon for the pic_work and copy the existing image of the
pic_work
'to the blk_workspace and clear the picture in pic_work.

Sub Prepare_New_Icon (X As Integer, Y As Integer)
    UnRFocus_Control MainEditor.Pic_Work
    R = BitBlt(Blk_WorkSpace.hDC, X, Y, 34, 54, Pic_Work.hDC, 0, 0, SRCCOPY)
    MainEditor!Pic_Work.Visible = False
    MainEditor!Pic_Work.Picture = LoadPicture()
End Sub

```

'Prepare the new function icon for the pic_SysWork and copy the existing image of the pic_SysWork
'to the Sys_workspace and clear the picture in pic_SysWork.
,

```
Sub Prepare_New_Sys_Icon (X As Integer, Y As Integer)
    UnRFocus_Control MainEditor.Pic_SysWork
    R = BitBlt(Sys_WorkSpace.hDC, X, Y, 34, 54, Pic_SysWork.hDC, 0, 0, SRCCOPY)
    MainEditor!Pic_SysWork.Visible = False
    MainEditor!Pic_SysWork.Picture = LoadPicture()
End Sub
```

```
Sub Process_IO_Data (FunInProgress As Integer, Passes As Integer)
    Dim EData As Integer
    Dim FNumA As Integer
    Dim FNumB As Integer
    Dim FNumC As Integer
    Dim FileNum1 As Integer
    Dim FileNum2 As Integer
    Dim FileNum3 As Integer
    Dim CoFlag As Integer
    Dim MX1 As Integer
    Dim MY1 As Integer
    Dim MX2 As Integer
    Dim MY2 As Integer
    Dim Var1 As Integer
    Dim Var2 As Integer
    Dim Var3 As Integer
    Dim J0 As Integer
    Dim Datem As Long
    Dim Cotem As Long
    Dim MemPos As Long
    Dim VarTemp As String * 1
    Dim RAstrg As String
    Dim CAstrg As String
    Dim WAstrg As String
    On Error Resume Next
    Get_Ini_WorkDirEnv
    NS = 0
    'Opening the address pattern files
    RAstrg = RTrim$(RA_Txt) & ".AG2"
    CAstrg = RTrim$(CA_Txt) & ".AG2"
    WAstrg = RTrim$(WA_Txt) & ".AG2"
    If FunInProgress = TP_BFLY16 Then
        EData = 16
        ReDim RRMX(16): ReDim RYMX(16)
        ReDim CRTem(16): ReDim CYTem(16)
        ReDim RTem(16): ReDim RTem(16)
    Else
```

```

EData = 4
ReDim RRMX(4): ReDim RYMX(4)
ReDim CRTem(4): ReDim CYTem(4)
ReDim RTem(4): ReDim YTem(4)
End If
FileNum1 = FreeFile
Open RAStrg For Binary Access Read As #FileNum1
FileNum2 = FreeFile
Open WAStrg For Binary Access Read As #FileNum2
If Not AutoMan Then
    IPStrg = RTrim$(IP_Txt) & ".Dat"
    OPStrg = RTrim$(OP_Txt) & ".Dat"
    CPStrg = RTrim$(CP_Txt) & ".Dat"
    FNumA = FreeFile
    Open IPStrg For Random Access Read As #FNumA Len = 4
    FNumB = FreeFile
    Open OPStrg For Random Access Write As #FNumB Len = 4
End If
Select Case FunInProgress
    Case TP_BRFT, TP_CMAG, TP_VABS, TP_VMXM, TP_VPAS
        CoFlag = True
    Case Else
        CoFlag = False
        FileNum3 = FreeFile
        Open CAStrg For Binary Access Read As #FileNum3
        If Not AutoMan Then
            FNumC = FreeFile
            Open CPStrg For Random Access Read As #FNumC Len = 4
        End If
    End Select
While NS < NS_Dat
    For J = 1 To EData
        Get #FileNum1, , VarTemp
        Var1 = CVI(VarTemp)
        Get #FileNum1, , VarTemp
        Var2 = CVI(VarTemp)
        Get #FileNum1, , VarTemp
        Var3 = CVI(VarTemp)
        Datem = Var3 * 2 ^ 16 + Var2 * 2 ^ 8 + Var1
        If Datem <= 1024 Then
            MX1 = Datem: MY1 = 0
        Else
            MX1 = Datem Mod 1024
            MY1 = CInt(Datem \ 1024)
        End If
        If Not CoFlag Then
            Get #FileNum3, , VarTemp
            Var1 = CVI(VarTemp)

```

```

Get #FileNum3, , VarTemp
Var2 = CVI(VarTemp)
Get #FileNum3, , VarTemp
Var3 = CVI(VarTemp)
Cotem = Var3 * 2 ^ 16 + Var2 * 2 ^ 8 + Var1
If Cotem <= 1024 Then
    MX2 = Cotem: MY2 = 0
Else
    MX2 = Cotem Mod 1024
    MY2 = CInt(Cotem \ 1024)
End If
End If
If AutoMan Then
    If Not CoFlag Then
        CRTem(J) = CRMX(MX2, MY2)
        CYTem(J) = CYMX(MX2, MY2)
        If CSFI = 1 Then
            CRTem(J) = Dat_Shift(CRTem(J), 1)
            CYTem(J) = Dat_Shift(CYTem(J), 1)
        End If
    End If
Else
    MemPos = Cotem * 2 + 1
    If Not CoFlag Then
        Get #FNumC, MemPos, CRTem(J)
        Get #FNumC, MemPos + 1, CYTem(J)
        If CSFI = 1 Then
            CRTem(J) = Dat_Shift(CRTem(J), 1)
            CYTem(J) = Dat_Shift(CYTem(J), 1)
        End If
    End If
End If
If AutoMan Then
    Select Case DF_Dat
        Case &H1, &H2, &H3    'RQWA RQWC RQWB
            RTem(J) = QRMX(MX1, MY1)
            YTem(J) = QYMX(MX1, MY1)
        Case &H5, &H6, &H7    'RAWQ RAWC RAWB
            RTem(J) = ARMX(MX1, MY1)
            YTem(J) = AYMx(MX1, MY1)
        Case &H0, &H4        'RBWA RBWQ
            RTem(J) = BRMX(MX1, MY1)
            YTem(J) = BYMX(MX1, MY1)
        Case &H8, &H9, &HA    'RCWA RCWB RCWQ
            RTem(J) = CRTem(J)
            YTem(J) = CYTem(J)
    End Select
Else

```

```

    MemPos = Datem * 2 + 1
    'Write the Data to the input file
    Get #FNumA, MemPos, RTem(J)
    Get #FNumA, MemPos + 1, YTem(J)
End If
If DSFI_Tem > 0 Then
    RTem(J) = Dat_Shift(RTem(J), DSFI_Tem)
    YTem(J) = Dat_Shift(YTem(J), DSFI_Tem)
End If
Next J
J0 = 1: RFlag = False
For J = 1 To (EData \ 4)
    Inpdatt.Rel0 = RTem(J0): Inpdatt.Iml0 = YTem(J0)
    Inpdatt.Rel1 = RTem(J0 + 1): Inpdatt.Iml1 = YTem(J0 + 1)
    Inpdatt.Rel2 = RTem(J0 + 2): Inpdatt.Iml2 = YTem(J0 + 2)
    Inpdatt.Rel3 = RTem(J0 + 3): Inpdatt.Iml3 = YTem(J0 + 3)
    If Not CoFlag Then
        Inpdatt.Cox0 = CRTem(1): Inpdatt.Snx0 = CYTem(1)
        Inpdatt.Cox1 = CRTem(2): Inpdatt.Snx1 = CYTem(2)
        Inpdatt.Cox2 = CRTem(3): Inpdatt.Snx2 = CYTem(3)
        Inpdatt.Cox3 = CRTem(4): Inpdatt.Snx3 = CYTem(4)
    End If
    'Debug.Print Right$("000000" & Hex$(Inpdatt.Rel0), 6) & " " & Right$("000000"
    & Hex$(Inpdatt.Iml0), 6) & " " & Right$("000000" & Hex$(Inpdatt.Rel1), 6) & " " &
    Right$("000000" & Hex$(Inpdatt.Iml1), 6) & " " & Right$("000000" & Hex$(Inpdatt.Rel2),
    6) & " " & Right$("000000" & Hex$(Inpdatt.Iml2), 6) & " " & Right$("000000" & Hex$(In-
    pdatt.Rel3), 6) & " " & Right$("000000" & Hex$(Inpdatt.Iml3), 6)
    'Debug.Print Right$("000000" & Hex$(Inpdatt.Cox0), 6) & " " & Right$("000000"
    & Hex$(Inpdatt.Snx0), 6) & " " & Right$("000000" & Hex$(Inpdatt.Cox1), 6) & " " &
    Right$("000000" & Hex$(Inpdatt.Snx1), 6) & " " & Right$("000000" & Hex$(Inpdatt.Cox2),
    6) & " " & Right$("000000" & Hex$(Inpdatt.Snx2), 6) & " " & Right$("000000"
    & Hex$(Inpdatt.Cox3), 6) & " " & Right$("000000" & Hex$(Inpdatt.Snx3), 6)
    Multiply_Routine_Selection NS, FunInProgress, Passes
    RRMX(J0) = Outdat.R0T: RYMX(J0) = Outdat.I0T
    RRMX(J0 + 1) = Outdat.R1T: RYMX(J0 + 1) = Outdat.I1T
    RRMX(J0 + 2) = Outdat.R2T: RYMX(J0 + 2) = Outdat.I2T
    RRMX(J0 + 3) = Outdat.R3T: RYMX(J0 + 3) = Outdat.I3T
    'Debug.Print Right$("000000" & Hex$(Outdat.R0T), 6) & " " & Right$("000000"
    & Hex$(Outdat.I0T), 6) & " " & Right$("000000" & Hex$(Outdat.R1T), 6) & " " &
    Right$("000000" & Hex$(Outdat.I1T), 6) & " " & Right$("000000" & Hex$(Outdat.R2T),
    6) & " " & Right$("000000" & Hex$(Outdat.I2T), 6) & " " & Right$("000000" &
    Hex$(Outdat.R3T), 6) & " " & Right$("000000" & Hex$(Outdat.I3T), 6)
    J0 = J0 + 4
Next J
If FunInProgress = TP_BFLY16 Then
    J0 = 4: RFlag = True
    For J = 1 To 4
        Inpdatt.Rel0 = RRMX(J): Inpdatt.Iml0 = RYMX(J)

```



```

Inpdat.Rel1 = RRMX(J + 4): Inpdat.Iml1 = RYMX(J + 4)
Inpdat.Rel2 = RRMX(J + 8): Inpdat.Iml2 = RYMX(J + 8)
Inpdat.Rel3 = RRMX(J + 12): Inpdat.Iml3 = RYMX(J + 12)
Inpdat.Cox0 = CRTem(1): Inpdat.Snx0 = CYTem(1)
Inpdat.Cox1 = CRTem(J0 + 1): Inpdat.Snx1 = CYTem(J0 + 1)
Inpdat.Cox2 = CRTem(J0 + 2): Inpdat.Snx2 = CYTem(J0 + 2)
Inpdat.Cox3 = CRTem(J0 + 3): Inpdat.Snx3 = CYTem(J0 + 3)
J0 = J0 + 3
Multiply_Routine_Selection NS, FunInProgress, Passes
RRMX(J) = Outdat.R0T: RYMX(J) = Outdat.I0T
RRMX(J + 4) = Outdat.R1T: RYMX(J + 4) = Outdat.I1T
RRMX(J + 8) = Outdat.R2T: RYMX(J + 8) = Outdat.I2T
RRMX(J + 12) = Outdat.R3T: RYMX(J + 12) = Outdat.I3T
Next J
End If
For J = 1 To EData
  Get #FileNum2, , VarTemp
  Var1 = CVI(VarTemp)
  Get #FileNum2, , VarTemp
  Var2 = CVI(VarTemp)
  Get #FileNum2, , VarTemp
  Var3 = CVI(VarTemp)
  Datem = Var3 * 2 ^ 16 + Var2 * 2 ^ 8 + Var1
  If Datem <= 1024 Then
    MX1 = Datem: MY1 = 0
  Else
    MX1 = Datem Mod 1024
    MY1 = CInt(Datem \ 1024)
  End If
  If AutoMan Then
    Select Case DF_Dat
      Case &H4, &H5, &HA 'RBWQ RAWQ RCWQ
        QRMX(MX1, MY1) = RRMX(J): QYMX(MX1, MY1) = RYMX(J)
      Case &H0, &H1, &H8 'RBWA RQWA RCWA
        ARMX(MX1, MY1) = RRMX(J): AYMX(MX1, MY1) = RYMX(J)
      Case &H3, &H7, &H9 'RQWB RAWB RCWB
        BRMX(MX1, MY1) = RRMX(J): BYMX(MX1, MY1) = RYMX(J)
      Case &H2, &H6 'RAWC RQWC
        CRMX(MX1, MY1) = RRMX(J): CYMX(MX1, MY1) = RYMX(J)
    End Select
  Else
    MemPos = Datem * 2 + 1
    Put #FNumB, MemPos, RRMX(J)
    Put #FNumB, MemPos + 1, RYMX(J)
  End If
Next J
NS = NS + EData
If NS = NS_Dat - 4 Then

```

```

    If FunInProgress = TP_BCFIR Or FunInProgress = TP_BDFIR Or FunInProgress
= TP_BRFIR Then rndFlag = 1
    End If
Wend
Close
End Sub

```

```

Sub Save_Screen (Index1 As Integer)
    On Error Resume Next
    Dim LongName As String
    Dim Title As String
    Dim CDPATH As String
    If (Index1 = MID_SAVE_AS) Or (ScreenInfo(ScrnStage).Filename = Untitled) Then
        NeedToSave = False
        ' Set default filter.
        If TP_TID = TP_BLK Then
            MainEditor.CMDialog_Edit.Filter = "BDB Files (*.bdb)|*.BDB"
            MainEditor.CMDialog_Edit.DefaultExt = "BDB"
        ElseIf TP_TID = TP_SYS Then
            MainEditor.CMDialog_Edit.Filter = "SDB Files (*.sdb)|*.SDB"
            MainEditor.CMDialog_Edit.DefaultExt = "SDB"
        End If
        ' Display Save As dialog.
        MainEditor.CMDialog_Edit.FilterIndex = 1
        If Right(ScreenInfo(ScrnStage).FullPath, 1) <> "\" Then
            MainEditor.CMDialog_Edit.Filename = ScreenInfo(ScrnStage).FullPath & "\" &
ScreenInfo(ScrnStage).Filename
        End If
        ' If file has not been saved yet, set common dialog's
        ' default file name to *.dsp
        If ScreenInfo(ScrnStage).Filename = "[Untitled]" Then
            MainEditor.CMDialog_Edit.Filename = IIf(TP_TID = TP_BLK, "*.bdb", "*.sdb")
        End If
        MainEditor.CMDialog_Edit.Action = 2
        ' Exit if user cancels the dialog.
        If Err = 32755 Then Exit Sub
        Title = MainEditor.CMDialog_Edit.Filetitle
        LongName = MainEditor.CMDialog_Edit.Filename
        ScreenInfo(ScrnStage).FullPath = Left(LongName, Len(LongName) - Len(Title))
        ScreenInfo(ScrnStage).Filename = MainEditor.CMDialog_Edit.Filetitle
        ' Adjust for root directory.
        If Len(ScreenInfo(ScrnStage).FullPath) = 3 Then
            CDPATH = ScreenInfo(ScrnStage).FullPath
        Else
            CDPATH = Left(LongName, Len(LongName) - Len(Title) - 1)
        End If
        ' Change directories for the editor and the viewer.
        ChDir CDPATH
    End Sub

```

```

End If
MainEditor.MousePointer = HOURGLASS
Write_Screen_To_File ScreenInfo(ScrnlStage).FullPath, ScreenInfo(ScrnlStage).Filena-
me
MainEditor.MousePointer = DEFAULT
End Sub

```

```

Sub Scale_Data_Amount (DatSEL As Integer, IconID As Integer)
If DatSEL Then
  BFPI_Tem = BFPI_Dat
  If IconID = TP_MOVC Then DSFI_Tem = 0 Else DSFI_Tem = DSFI_Dat
Else
  Select Case IconID
    Case TP_BFLY16
      DSFI_Tem = AutoDSFI
    Case TP_BFLY4, TP_BWND4
      DSFI_Tem = AutoDSFI - 2
    Case TP_BFLY2, TP_BWND2, TP_BFCT, TP_BFCT2
      DSFI_Tem = AutoDSFI - 3
    Case TP_CMAG
      DSFI_Tem = AutoDSFI - 4
    Case Else
      DSFI_Tem = 0
  End Select
  If DSFI_Tem < 0 Then DSFI_Tem = 0
  BFPI_Tem = BFPO_Dat
End If
End Sub

```

```

Sub ScrollBar_Positioning (InstVS As Control, InstHS As Control, Wks As Control, Root-
Wks As Control)
  InstHS.Top = RootWks.Height
  InstHS.Left = 0
  InstHS.Width = RootWks.Width
  InstHS.Max = Wks.ScaleWidth - RootWks.ScaleWidth
  If (RootWks.ScaleWidth < Wks.ScaleWidth) Then
    InstHS.Enabled = True
    Diff = Wks.ScaleWidth \ RootWks.ScaleWidth
    InstHS.LargeChange = InstHS.Max \ Diff
  Else
    InstHS.Enabled = False
  End If
  InstHS.Refresh
  InstVS.Top = 0
  InstVS.Left = RootWks.Width
  InstVS.Height = RootWks.Height
  InstVS.Max = Wks.ScaleHeight - RootWks.ScaleHeight
  If (RootWks.ScaleHeight < Wks.ScaleHeight) Then

```

```

    InstVS.Enabled = True
    Diff = Wks.ScaleHeight \ RootWks.ScaleHeight
    InstVS.LargeChange = InstVS.Max \ Diff
Else
    InstVS.Enabled = False
End If
InstVS.Refresh
If TP_TID = TP_BLK Then
    Blk_Com_Box.Left = InstHS.Width
    Blk_Com_Box.Top = InstVS.Height
    Blk_Com_Box.Width = InstVS.Width
    Blk_Com_Box.Height = InstHS.Height
ElseIf TP_TID = TP_SYS Then
    Sys_Com_Box.Left = InstHS.Width
    Sys_Com_Box.Top = InstVS.Height
    Sys_Com_Box.Width = InstVS.Width
    Sys_Com_Box.Height = InstHS.Height
End If
End Sub

'When the MousePointer is within the Editing area, the MousePointer
'is changed depending on the Tool being used. This routine is called
'from the MouseMove event for the Sys and Block Work_Space to change the
'MousePointer.
'
Sub Set_MousePointer ()
    Select Case CurrentTool
        Case TP_SELECT
            Sys_WorkSpace.MousePointer = ARROW
        Case TP_LINE
            Sys_WorkSpace.MousePointer = ARROW
        Case TP_TEXT
            Sys_WorkSpace.MousePointer = I_BEAM
        Case Else
            Sys_WorkSpace.MousePointer = DEFAULT
    End Select
End Sub

Sub Start_System_Click ()
    Dim DSPDrive As String, DSPDir As String
    Dim TemVal As Integer
    CurPath$ = CurDir$
    Stop_System.Enabled = True
    Start_System.Enabled = False
    Select Case TP_TID
        Case TP_SYS
            If Pic_SysWork.Visible Then Prepare_New_Sys_Icon XSI(SICount), YSI(SICount)
            If SISiz > 0 And LCount > 0 Then

```

```

AutoDSFI = 0: I = 1
Screen.MousePointer = 11
While I <= ArrayCount
    If FuncCode(I, 0) >= &H0 And FuncCode(I, 0) <= &H1E Then
        LookUp_Func_ID Pic_Work, FuncCode(I, 0)
        THISFN_SECT = Pic_Work.Tag & " Pass" & Format$(Stage(I))
        Get_Ini_File_Settings
        Create_Port_Array NS_Dat, DF_Dat
        Scale_Data_Amount DSFISEL, FuncCode(I, 0)
        Process_IO_Data FuncCode(I, 0), Stage(I)
        DSFO_Dat = AutoDSFI
        BFPO_Dat = DSFI_Tem + BFPI_Tem
        KEY_STR = Format$(DSFO_Dat) & "," & Format$(BFPO_Dat)
        R = WritePrivateProfileString(THISFN_SECT, "DSFO BFPO", KEY_STR,
THISFN_INI)
    End If
    I = I + 1
Wend
Screen.MousePointer = 0
'Unload StatusDlg
Else
    MsgBox "No function icons selected or No Line path connection", 16, "Error in
execution"
    Start_System.Enabled = True
    Stop_System.Enabled = False
End If
Initiate_SignEdit
Case TP_BLK
    If Pic_Work.Visible Then Prepare_New_Icon XArr(ArraySiz), YArr(ArraySiz)
    If ArrayCount > 0 And LineCount > 0 Then
        'StatusDlg.Show Modeless
        AutoDSFI = 0: I = 1
        Screen.MousePointer = 11
        While I <= ArrayCount
            If FuncCode(I, 0) >= &H0 And FuncCode(I, 0) <= &H1E Then
                LookUp_Func_ID Pic_Work, FuncCode(I, 0)
                THISFN_SECT = Pic_Work.Tag & " Pass" & Format$(Stage(I))
                Get_Ini_File_Settings
                Create_Port_Array NS_Dat, DF_Dat
                Scale_Data_Amount DSFISEL, FuncCode(I, 0)
                Process_IO_Data FuncCode(I, 0), Stage(I)
                DSFO_Dat = AutoDSFI
                BFPO_Dat = DSFI_Tem + BFPI_Tem
                KEY_STR = Format$(DSFO_Dat) & "," & Format$(BFPO_Dat)
                R = WritePrivateProfileString(THISFN_SECT, "DSFO BFPO", KEY_STR,
THISFN_INI)
            End If
            I = I + 1

```

```

        Wend
        Screen.MousePointer = 0
        Scriptitnow = True
        'Unload StatusDlg
    Else
        MsgBox "No function icons selected or No Line path connection", 16, "Error in
execution"
        Start_System.Enabled = True
        Stop_System.Enabled = False
    End If
    Initiate_SignEdit
End Select
Start_System.Enabled = True
End Sub

```

```

Sub Stop_System_Click ()
    Start_System.Enabled = True
    Stop_System.Enabled = False
End Sub

```

```

Sub STxtEdit_Change (Index As Integer)
    TxtUnFocus Index
    STxtEdit(Index).Height = TextHeight(STxtEdit(Index)) + 4
    STxtEdit(Index).Width = TextWidth(STxtEdit(Index)) * 1.4 + 20
    If STxtEdit(Index).Text <> "" Then TxtFocus Index
    STxtEnable = False
End Sub

```

```

Sub STxtEdit_GotFocus (Index As Integer)
    TxtUnFocus STxtSelected
    If STxtEdit(STxtSelected).Text = "" Then
        If Index < STxtNum - 1 Then STxtEnable = False
        If Not STxtEnable Then STxtEdit(STxtSelected).Visible = False
    End If
    STxtSelected = Index
    TxtFocus Index
End Sub

```

```

Sub STxtEdit_MouseDown (Index As Integer, Button As Integer, Shift As Integer, X As
Single, Y As Single)
    If CurrentTool <> TP_TEXT Then
        STxtEdit(Index).Drag 1
        DragX = X / 15
        DragY = Y / 15
        Sys_WorkSpace.SetFocus
    End If
    'TxtUnFocus STxtSelected
End Sub

```

```
Sub STxtEdit_MouseMove (Index As Integer, Button As Integer, Shift As Integer, X As Single, Y As Single)
```

```
    STxtEdit(Index).MousePointer = IIf(CurrentTool = TP_SELECT, ARROW, DEFAULT)
End Sub
```

```
Sub STxtEdit_MouseUp (Index As Integer, Button As Integer, Shift As Integer, X As Single, Y As Single)
```

```
    If CurrentTool <> TP_TEXT Then STxtEdit(Index).Drag 2
End Sub
```

```
Sub Sys_InstHScroll_Changing ()
```

```
    Sys_WorkSpace.Left = -Sys_InstHScroll.Value
End Sub
```

```
Sub Sys_InstHScroll_GotFocus ()
```

```
    If Pic_SysWork.Visible Then
        'If Not SysToolFlag Then Prepare_New_Sys_Icon XSI(SICount), YSI(SICount)
        'Tool_Select.Value = False
        'CurrentTool = &HEE
        'SysToolFlag = True
    End If
End Sub
```

```
Sub Sys_InstVScroll_Changing ()
```

```
    Sys_WorkSpace.Top = -Sys_InstVScroll.Value
End Sub
```

```
Sub Sys_InstVScroll_GotFocus ()
```

```
    If Pic_SysWork.Visible Then
        'If Not SysToolFlag Then Prepare_New_Sys_Icon XSI(SICount), YSI(SICount)
        'Tool_Select.Value = False
        'CurrentTool = &HEE
        'SysToolFlag = False
    End If
End Sub
```

```
Sub Sys_System_Click ()
```

```
    'If Not Tool_Select.Value Then Tool_Select.Value = True
    If TP_TID = TP_BLK Then
        'If the Block ToolPalette Extension is visible, hide it
        If ToolPalette_BlExt.Visible Then ToolPalette_BlExt.Visible = False
        If Not SystemEditor.Visible Then SystemEditor.Visible = True
        SystemEditor.WindowState = MAXIMIZED
    ElseIf TP_TID = TP_SYS Then
        If Not BlockEditor.Visible Then BlockEditor.Visible = True
        BlockEditor.WindowState = MAXIMIZED
    End If
End Sub
```

End If
End Sub

```
Sub Sys_WorkSpace_DragDrop (Source As Control, X As Single, Y As Single)
Dim Movable As Integer
XTArr = X - DragX: YTArr = Y - DragY
If TypeOf Source Is TextBox Then
    TxtUnFocus STxtSelected
    Source.Move XTArr, YTArr
    TxtFocus STxtSelected
ElseIf TypeOf Source Is PictureBox Then
    Movable = True
    SavedMode = Sys_WorkSpace.DrawMode
    'Check to see there is line between the icon to be moved and if it does, erase it
    'and update the current line position of the move icon.
    For I = 0 To LCount - 1
        If YPts(I, 0) = YSI(SICount) + 16 And XPts(I, 0) = XSI(SICount) - 2 Then
            If XTArr - 2 <= XPts(I, 1) Then
                Msg = "Do not drag active icon beyond the left icon"
                MsgBox Msg, 16, "Dragging Icon Error"
                Movable = False
                Exit For
            End If
        ElseIf YPts(I, 1) = YSI(SICount) + 8 And XPts(I, 1) = XSI(SICount) + 32 Then
            If XTArr + 32 >= XPts(I, 0) Then
                Msg = "Do not drag active icon beyond the left icon"
                MsgBox Msg, 16, "Dragging Icon Error"
                Movable = False
                Exit For
            End If
        ElseIf YPts(I, 1) = YSI(SICount) + 24 And XPts(I, 1) = XSI(SICount) + 32 Then
            If XTArr + 32 >= XPts(I, 0) Then
                Msg = "Do not drag active icon beyond the left icon"
                MsgBox Msg, 16, "Dragging Icon Error"
                Movable = False
                Exit For
            End If
        ElseIf YPts(I, 1) = YSI(SICount) + 16 And XPts(I, 1) = XSI(SICount) + 32 Then
            If XTArr + 32 >= XPts(I, 0) Then
                Msg = "Do not drag active icon beyond the left icon"
                MsgBox Msg, 16, "Dragging Icon Error"
                Movable = False
                Exit For
            End If
        End If
    Next I
    If Movable Then
        For I = 0 To LCount - 1
```



```

If YPts(I, 0) = YSI(SICount) + 16 And XPts(I, 0) = XSI(SICount) - 2 Then
'Erase the Old Line
XFinish = XPts(I, 0): YFinish = YPts(I, 0)
XStart = XPts(I, 1): YStart = YPts(I, 1)
Sys_WorkSpace.DrawMode = NOT_COPY_PEN
Draw_Icon_Line XStart, YStart, XFinish, YFinish
Sys_WorkSpace.DrawMode = SavedMode
'Update the new position line
XPts(I, 0) = XTArr - 2: YPts(I, 0) = YTArr + 16
XFinish = XTArr - 2: YFinish = YTArr + 16
Draw_Icon_Line XStart, YStart, XFinish, YFinish
ElseIf YPts(I, 1) = YSI(SICount) + 8 And XPts(I, 1) = XSI(SICount) + 32 Then
'Erase the Old Line
XFinish = XPts(I, 0): YFinish = YPts(I, 0)
XStart = XPts(I, 1): YStart = YPts(I, 1)
Sys_WorkSpace.DrawMode = NOT_COPY_PEN
Draw_Icon_Line XStart, YStart, XFinish, YFinish
Sys_WorkSpace.DrawMode = SavedMode
'Update the new position line
XPts(I, 1) = XTArr + 32: YPts(I, 1) = YTArr + 8
XStart = XTArr + 32: YStart = YTArr + 8
Draw_Icon_Line XStart, YStart, XFinish, YFinish
ElseIf YPts(I, 1) = YSI(SICount) + 24 And XPts(I, 1) = XSI(SICount) + 32 Then
'Erase the Old Line
XFinish = XPts(I, 0): YFinish = YPts(I, 0)
XStart = XPts(I, 1): YStart = YPts(I, 1)
Sys_WorkSpace.DrawMode = NOT_COPY_PEN
Draw_Icon_Line XStart, YStart, XFinish, YFinish
Sys_WorkSpace.DrawMode = SavedMode
'Update the new position line
XPts(I, 1) = XTArr + 32: YPts(I, 1) = YTArr + 24
XStart = XTArr + 32: YStart = YTArr + 24
Draw_Icon_Line XStart, YStart, XFinish, YFinish
ElseIf YPts(I, 1) = YSI(SICount) + 16 And XPts(I, 1) = XSI(SICount) + 32 Then
'Erase the Old Line
XFinish = XPts(I, 0): YFinish = YPts(I, 0)
XStart = XPts(I, 1): YStart = YPts(I, 1)
Sys_WorkSpace.DrawMode = NOT_COPY_PEN
Draw_Icon_Line XStart, YStart, XFinish, YFinish
Sys_WorkSpace.DrawMode = SavedMode
'Update the new position line
XPts(I, 1) = XTArr + 32: YPts(I, 1) = YTArr + 16
XStart = XTArr + 32: YStart = YTArr + 16
Draw_Icon_Line XStart, YStart, XFinish, YFinish
End If
Next I
XSI(SICount) = XTArr
YSI(SICount) = YTArr

```

```

        Source.Move XTArr, YTArr
    End If
End If
End Sub

```

```

Sub Sys_WorkSpace_Load ()
    Sys_WorkSpace.Top = 0
    Sys_WorkSpace.Left = 0
    Sys_WorkSpace.BorderStyle = NONE
    Pic_SysWork.BorderStyle = NONE
    Pic_SysWork.Move 0, 0, 34, 54
End Sub

```

```

Sub Sys_WorkSpace_MouseDown (Button As Integer, Shift As Integer, X As Single, Y As Single)

```

```

    If Button = LEFT_BUTTON And TP_TID = TP_SYS Then
        XOld = XSI(SICount): YOld = YSI(SICount)
        Select Case CurrentTool
            Case TP_TEXT
                If STxtNum > 0 Then
                    If STxtEnable And STxtEdit(STxtNum - 1).Text = "" Then
                        TxtUnFocus STxtNum - 1
                        STxtEdit(STxtNum - 1).Move X, Y
                        STxtEdit(STxtNum - 1).SetFocus
                    End If
                End If
                If Not STxtEnable Then
                    If STxtNum > 1 Then Load STxtEdit(STxtNum)
                    STxtEdit(STxtNum).Top = Y
                    STxtEdit(STxtNum).Left = X
                    STxtEdit(STxtNum).Visible = True
                    STxtEdit(STxtNum).Text = ""
                    STxtEdit(STxtNum).SetFocus
                    STxtNum = STxtNum + 1
                    STxtEnable = True
                End If
            Case TP_SELECT
                TxtUnFocus STxtSelected
                For I = 1 To SISiz
                    If (XSI(I) <= X And (XSI(I) + 34) >= X) And (YSI(I) <= Y And (YSI(I) + 54)
>= Y) Then
                        UnRFocus_Control MainEditor.Pic_SysWork
                        R = BitBlt(Sys_WorkSpace.hDC, XOld, YOld, 34, 54, Pic_SysWork.hDC,
0, 0, SRCCOPY)
                        Pic_SysWork.Picture = LoadPicture()
                        Pic_SysWork.Move XSI(I), YSI(I)
                        Get_Function_Pic Pic_SysWork, FuncCode(I, 1)
                        R = PatBlt(Sys_WorkSpace.hDC, XSI(I), YSI(I), 34, 54, WHITENESS)

```

```

        Pic_Box_Paint Pic_SysWork, Pass(I), FuncCode(I, 1)
        SICount = I
        Exit Sub
    End If
Next I
Case TP_LINE
    For I = 1 To SISiz
        If (XSI(I) <= X And (XSI(I) + 34) >= X) And (YSI(I) <= Y And (YSI(I) + 54)
>= Y) Then
            'Check to see which icons is selected so that Icon's ID can be properly set
            Select Case StartEvent
                Case False
                    IniDraw = True
                    StartEvent = True
                    'Store the initial start of the line to draw
                    StartX = XSI(I) + 16
                    StartY = YSI(I) + 16
                    'Make the last location equal the starting location
                    OldX = StartX
                    OldY = StartY
                    DsplyFlg1 = FuncCode(I, 1)
                    ArrayFlg1 = I
                    XPts(LCount, 1) = XSI(I) + 32: YPts(LCount, 1) = YSI(I) + 16
                Case True
                    StartEvent = False
                    FinDraw = True
                    DsplyFlg2 = FuncCode(I, 1)
                    ArrayFlg2 = I
                    XPts(LCount, 0) = XSI(I) - 2: YPts(LCount, 0) = YSI(I) + 16
            End Select
            Exit Sub
        End If
    Next I
    Msg = "Invalid -- No Icon selected"
    MsgBox Msg, 16, "Line Editor"
    FinDraw = False: StartEvent = False
    XPts(LCount, 0) = 0: YPts(LCount, 0) = 0
    XPts(LCount, 1) = 0: YPts(LCount, 1) = 0
    If IniDraw Then
        DrawLine Sys_WorkSpace, StartX, StartY, OldX, OldY
        IniDraw = False
    End If
Case TP_UNLINE
    For I = 1 To SISiz
        If (XSI(I) <= X And (XSI(I) + 34) >= X) And (YSI(I) <= Y And (YSI(I) + 54)
>= Y) Then
            Select Case StartEvent
                Case False

```

```

        IniDraw = True
        StartEvent = True
        StartX = XSI(I) + 16
        StartY = YSI(I) + 16
        OldX = StartX
        OldY = StartY
        DsplyFlg1 = FuncCode(I, 1)
        ArrayFlg1 = I
        DisLineX1 = XSI(I) + 32: DisLineY1 = YSI(I) + 16
        Sys_WorkSpace.DrawStyle = DASH
    Case True
        StartEvent = False
        FinDraw = True
        DsplyFlg2 = FuncCode(I, 1)
        ArrayFlg2 = I
        DisLineX2 = XSI(I) - 2: DisLineY2 = YSI(I) + 16
    End Select
Exit Sub
End If
Next I
Msg = "Invalid -- No Icon selected"
MsgBox Msg, 16, "UnLine Editor"
IniDraw = False: FinDraw = False
DisLineX1 = 0: DisLineY1 = 0
DisLineX2 = 0: DisLineY2 = 0
If IniDraw Then
    DrawLine Sys_WorkSpace, StartX, StartY, OldX, OldY
    IniDraw = False
End If
End Select
End If
End Sub

Sub Sys_WorkSpace_MouseMove (Button As Integer, Shift As Integer, X As Single, Y As Single)
    'Caculate pixel mouse is currently over
    Xpix = X
    YPix = Y
    'The Mouse coordinates are always displayed within the StatusArea
    Display_Mouse_Coordinates Xpix, YPix
    'Depending on the Current tool, and in the case of the select tool,
    'the state of the selection, the MousePointer may change
    If StartEvent Then
        DrawLine Sys_WorkSpace, StartX, StartY, OldX, OldY
        DrawLine Sys_WorkSpace, StartX, StartY, Xpix, YPix
        OldX = X
        OldY = Y
    End If

```

End Sub

Sub Sys_WorkSpace_MouseUp (Button As Integer, Shift As Integer, X As Single, Y As Single)

 If Button = LEFT_BUTTON And TP_TID = TP_SYS Then

 Select Case CurrentTool

 Case TP_LINE

 If Not StartEvent And FinDraw Then

 'Erase the previous line

 DrawLine Sys_WorkSpace, StartX, StartY, OldX, OldY

 OldX1 = XPts(LCount, 0)

 OldY1 = YPts(LCount, 0)

 StartX = StartX + 16

 'Check for invalid operation

 If StartX > OldX1 Then

 Msg = "Click data line from left to right Or" & CRLF & "Icons are too close to each other"

 GoTo SysLine_Err

 ElseIf DsplyFlg1 = TP_DISPLAY And StartX < OldX Then

 Msg = "Invalid Operation -- Display icon should be clicked last"

 GoTo SysLine_Err

 ElseIf DsplyFlg1 = TP_SIGNAL Or DsplyFlg1 = TP_DISPLAY Or DsplyFlg1 = TP_AIME Then

 If DsplyFlg2 = TP_DISPLAY Or DsplyFlg2 = TP_SIGNAL Or DsplyFlg2 = TP_AIME Then

 Msg = "Invalid Operation"

 GoTo SysLine_Err

 End If

 ElseIf DsplyFlg2 = TP_SIGNAL Then

 Msg = "Invalid Operation -- Input to Signal icon is unavailable"

 GoTo SysLine_Err

 End If

 'Swap_Values Xpts(LCount, 0), Xpts(LCount, 1), Ypts(LCount, 0), Ypts(LCount, 1)

 'StartX = Xpts(LCount, 1)

 'StartY = Ypts(LCount, 1)

 'OldX1 = Xpts(LCount, 0)

 'OldY1 = Ypts(LCount, 0)

 If DsplyFlg2 = TP_DISPLAY Then

 YPts(LCount, 1) = YPts(LCount, 1) - 8

 ElseIf DsplyFlg1 = TP_AGMEM Then

 YPts(LCount, 1) = YPts(LCount, 1) + 8

 End If

 'Draw new final line

 StartY = YPts(LCount, 1)

 Draw_Icon_Line StartX, StartY, OldX1, OldY1

 OldX = OldX1

 OldY = OldY1

```

'The left side is AG and the right side is AIME, then the array of AG
'contained the general index of AIME, not the identify index of AIME
If DsplyFlg1 = TP_AGMEM And DsplyFlg2 = TP_AIME Then
    AGMPort(ArrayFlg1, 1) = ArrayFlg2 'input value of
ElseIf DsplyFlg1 = TP_AIME And DsplyFlg2 = TP_AGMEM Then
    AGMPort(ArrayFlg2, 0) = ArrayFlg1
ElseIf DsplyFlg1 = TP_AGMEM And DsplyFlg2 = TP_DISPLAY Then
    DisplayPort(ArrayFlg2) = ArrayFlg1
End If
FinDraw = False: IniDraw = False
LCount = LCount + 1
End If
Case TP_UNLINE
If Not StartEvent And FinDraw Then
    'Erase the previous line
    DrawLine Sys_WorkSpace, StartX, StartY, OldX, OldY
    Sys_WorkSpace.DrawStyle = SOLID
    ChangePosition = False
    For I = 0 To LCount - 1
        If XPts(I, 0) = DisLineX2 And XPts(I, 1) = DisLineX1 Then ChangePosition
= True
        If ChangePosition Then
            XPts(I, 0) = XPts(I + 1, 0): YPts(I, 0) = YPts(I + 1, 0)
            XPts(I, 1) = XPts(I + 1, 1): YPts(I, 1) = YPts(I + 1, 1)
        End If
    Next I
    If ChangePosition Then
        If DsplyFlg1 = TP_DISPLAY Or DsplyFlg2 = TP_DISPLAY Then
            DisLineY1 = DisLineY1 - 8
        ElseIf DsplyFlg1 = TP_AGMEM Then
            DisLineY1 = DisLineY1 + 8
        End If
        Sys_WorkSpace.DrawMode = WHITENESS_PEN
        Draw_Icon_Line DisLineX1, DisLineY1, DisLineX2, DisLineY2
        Sys_WorkSpace.DrawMode = COPY_PEN
        If LCount > 0 Then LCount = LCount - 1 Else LCount = 0
        ChangePosition = False
        If DsplyFlg1 = TP_AGMEM And DsplyFlg2 = TP_AIME Then
            AGMPort(ArrayFlg1, 1) = 0
        ElseIf DsplyFlg1 = TP_AIME And DsplyFlg2 = TP_AGMEM Then
            AGMPort(ArrayFlg2, 0) = 0
        End If
    Else
        Msg = "Invalid Operation Or No Line TO delete" & CRLF & "Select icon
from left to right"
        MsgBox Msg, 16, "UnLine Editor"
        DisLineX1 = 0: DisLineY1 = 0
        DisLineX2 = 0: DisLineY2 = 0
    End If
End Case

```

```

        End If
    End If
    FinDraw = False: IniDraw = False
End Select
End If
Exit Sub

```

```

SysLine_Err:
MsgBox Msg, 16, "Line Editor Error"
XPts(LCount, 0) = 0: YPts(LCount, 0) = 0
XPts(LCount, 1) = 0: YPts(LCount, 1) = 0
FinDraw = False: IniDraw = False
End Sub

```

```

Sub SystemEditor_Close ()
    SystemEditor.Visible = False
End Sub

```

```

Sub SystemEditor_Resize ()
    If LastSysWinState = MAXIMIZED Then
        TP_TID = TP_MAIN
        ScrnStage = 0
        If Pic_SysWork.Visible Then Prepare_New_Sys_Icon XSI(SICount), YSI(SICount)
        If ToolPalette_BlkExt.Visible Then ToolPalette_BlkExt.Visible = False
        ToolPalette_Icons_Initialize
    ElseIf SystemEditor.WindowState = MAXIMIZED Then
        Sys_Root_WkSpace.Move 0, 0, SystemEditor.ClientWidth - Sys_InstVScroll.Width,
        SystemEditor.ClientHeight - Sys_InstHScroll.Height
        TP_TID = TP_SYS
        ScrnStage = 2
        ToolPalette_Icons_Initialize
        Sys_System.Caption = "Block"
        ScrollBar_Positioning Sys_InstVScroll, Sys_InstHScroll, Sys_WorkSpace,
        Sys_Root_WkSpace
        PFlag = Stage_Flag
        Pan_NSys.Caption = Format$(PFlag)
        Pan_NSys.Visible = True
        Pan_NSysTxt.Visible = True
        If Not Tool_Select.Value Then Tool_Select.Value = True Else Initiate_SignEdit
        If NeedToSave Then Menu_FileSelection_Click MID_SAVE_AS
    End If
    LastSysWinState = SystemEditor.WindowState
End Sub

```

'If the button is depressed the pic_work contained the selected picture

```

Sub Tool_Blkl_Click ()
    ArrayCount = ArrayCount + 1
    Xipos = 0 + Abs(Blk_WorkSpace.Left)

```

```

Select Case CurrentTool
Case TP_COM1 'DSP
    FuncCode(ArrayCount, 0) = TP_BFLY2
    Yipos = 170 + Abs(Blk_WorkSpace.Top)
Case TP_COM2 'CAI
    FuncCode(ArrayCount, 0) = TP_CADD
    Yipos = 204 + Abs(Blk_WorkSpace.Top)
Case TP_COM3 'VAI
    FuncCode(ArrayCount, 0) = TP_VADD
    Yipos = 238 + Abs(Blk_WorkSpace.Top)
Case TP_COM4 'VLI
    FuncCode(ArrayCount, 0) = TP_VNAND
    Yipos = 272 + Abs(Blk_WorkSpace.Top)
Case TP_COM5 'GPI
    FuncCode(ArrayCount, 0) = TP_MOVD
    Yipos = 306 + Abs(Blk_WorkSpace.Top)
Case TP_COM6 'MISC
    FuncCode(ArrayCount, 0) = TP_SIGNAL
    Yipos = 338 + Abs(Blk_WorkSpace.Top)
End Select
Get_Function_Pic Pic_Work, FuncCode(ArrayCount, 0)
Initial_PicContrl Pic_Work, Xipos, Yipos
End Sub

```

```

Sub Tool_Blkl0_Click ()
    ArrayCount = ArrayCount + 1
    Xipos = 342 + Abs(Blk_WorkSpace.Left)
    Yipos = 170 + Abs(Blk_WorkSpace.Top)
    FuncCode(ArrayCount, 0) = TP_BFCT2
    Get_Function_Pic Pic_Work, FuncCode(ArrayCount, 0)
    Initial_PicContrl Pic_Work, Xipos, Yipos
End Sub

```

```

Sub Tool_Blkl1_Click ()
    ArrayCount = ArrayCount + 1
    Xipos = 380 + Abs(Blk_WorkSpace.Left)
    Yipos = 170 + Abs(Blk_WorkSpace.Top)
    FuncCode(ArrayCount, 0) = TP_BRFT
    Get_Function_Pic Pic_Work, FuncCode(ArrayCount, 0)
    Initial_PicContrl Pic_Work, Xipos, Yipos
End Sub

```

```

Sub Tool_Blkl2_Click ()
    ArrayCount = ArrayCount + 1
    Xipos = 38 + Abs(Blk_WorkSpace.Left)
    Select Case CurrentTool
    Case TP_COM1 'DSP
        FuncCode(ArrayCount, 0) = TP_BFLY4

```



```

        Yipos = 170 + Abs(Blk_WorkSpace.Top)
    Case TP_COM2 'CAI
        FuncCode(ArrayCount, 0) = TP_CSUB
        Yipos = 204 + Abs(Blk_WorkSpace.Top)
    Case TP_COM3 'VAI
        FuncCode(ArrayCount, 0) = TP_VSUB
        Yipos = 238 + Abs(Blk_WorkSpace.Top)
    Case TP_COM4 'VLI
        FuncCode(ArrayCount, 0) = TP_VNOR
        Yipos = 272 + Abs(Blk_WorkSpace.Top)
    Case TP_COM5 'GPI
        FuncCode(ArrayCount, 0) = TP_MOVC
        Yipos = 306 + Abs(Blk_WorkSpace.Top)
    Case TP_COM6 'MISC
        FuncCode(ArrayCount, 0) = TP_DISPLAY
        Yipos = 338 + Abs(Blk_WorkSpace.Top)
End Select
Get_Function_Pic Pic_Work, FuncCode(ArrayCount, 0)
Initial_PicContrl Pic_Work, Xipos, Yipos
End Sub

```

```

Sub Tool_Bl3_Click ()
    ArrayCount = ArrayCount + 1
    Xipos = 76 + Abs(Blk_WorkSpace.Left)
    Select Case CurrentTool
        Case TP_COM1 'DSP
            FuncCode(ArrayCount, 0) = TP_BFLY16
            Yipos = 170 + Abs(Blk_WorkSpace.Top)
        Case TP_COM2 'CAI
            FuncCode(ArrayCount, 0) = TP_CMUL
            Yipos = 204 + Abs(Blk_WorkSpace.Top)
        Case TP_COM3 'VAI
            FuncCode(ArrayCount, 0) = TP_VMUL
            Yipos = 238 + Abs(Blk_WorkSpace.Top)
        Case TP_COM4 'VLI
            FuncCode(ArrayCount, 0) = TP_VXNOR
            Yipos = 272 + Abs(Blk_WorkSpace.Top)
    End Select
    Get_Function_Pic Pic_Work, FuncCode(ArrayCount, 0)
    Initial_PicContrl Pic_Work, Xipos, Yipos
End Sub

```

```

Sub Tool_Bl4_Click ()
    ArrayCount = ArrayCount + 1
    Xipos = 114 + Abs(Blk_WorkSpace.Left)
    Select Case CurrentTool
        Case TP_COM1 'DSP
            FuncCode(ArrayCount, 0) = TP_BWND2

```

```

    Yipos = 170 + Abs(Blk_WorkSpace.Top)
Case TP_COM2 'CAI
    FuncCode(ArrayCount, 0) = TP_CMAG
    Yipos = 204 + Abs(Blk_WorkSpace.Top)
Case TP_COM3 'VAI
    FuncCode(ArrayCount, 0) = TP_VABS
    Yipos = 238 + Abs(Blk_WorkSpace.Top)
Case TP_COM4 'VLI
    FuncCode(ArrayCount, 0) = TP_VPAS
    Yipos = 272 + Abs(Blk_WorkSpace.Top)
End Select
Get_Function_Pic Pic_Work, FuncCode(ArrayCount, 0)
Initial_PicContrl Pic_Work, Xipos, Yipos
End Sub

```

```

Sub Tool_Bl5_Click ()
    ArrayCount = ArrayCount + 1
    Xipos = 152 + Abs(Blk_WorkSpace.Left)
    Select Case CurrentTool
        Case TP_COM1 'DSP
            FuncCode(ArrayCount, 0) = TP_BWND4
            Yipos = 170 + Abs(Blk_WorkSpace.Top)
        Case TP_COM3 'VAI
            FuncCode(ArrayCount, 0) = TP_VMXM
            Yipos = 238 + Abs(Blk_WorkSpace.Top)
    End Select
    Get_Function_Pic Pic_Work, FuncCode(ArrayCount, 0)
    Initial_PicContrl Pic_Work, Xipos, Yipos
End Sub

```

```

Sub Tool_Bl6_Click ()
    ArrayCount = ArrayCount + 1
    Xipos = 190 + Abs(Blk_WorkSpace.Left)
    Yipos = 170 + Abs(Blk_WorkSpace.Top)
    FuncCode(ArrayCount, 0) = TP_BCFIR
    Get_Function_Pic Pic_Work, FuncCode(ArrayCount, 0)
    Initial_PicContrl Pic_Work, Xipos, Yipos
End Sub

```

```

Sub Tool_Bl7_Click ()
    ArrayCount = ArrayCount + 1
    Xipos = 228 + Abs(Blk_WorkSpace.Left)
    Yipos = 170 + Abs(Blk_WorkSpace.Top)
    FuncCode(ArrayCount, 0) = TP_BDFIR
    Get_Function_Pic Pic_Work, FuncCode(ArrayCount, 0)
    Initial_PicContrl Pic_Work, Xipos, Yipos
End Sub

```

```

Sub Tool_Bl8_Click ()
    ArrayCount = ArrayCount + 1
    Xipos = 266 + Abs(Blk_WorkSpace.Left)
    Yipos = 170 + Abs(Blk_WorkSpace.Top)
    FuncCode(ArrayCount, 0) = TP_BRFR
    Get_Function_Pic Pic_Work, FuncCode(ArrayCount, 0)
    Initial_PicContrl Pic_Work, Xipos, Yipos
End Sub

Sub Tool_Bl9_Click ()
    ArrayCount = ArrayCount + 1
    Xipos = 304 + Abs(Blk_WorkSpace.Left)
    Yipos = 170 + Abs(Blk_WorkSpace.Top)
    FuncCode(ArrayCount, 0) = TP_BFCT
    Get_Function_Pic Pic_Work, FuncCode(ArrayCount, 0)
    Initial_PicContrl Pic_Work, Xipos, Yipos
End Sub

Sub Tool_Com1_Click (Value As Integer)
    If Value Then
        MainEditor.MousePointer = DEFAULT
        CurrentTool = TP_COM1
        ToolInProcess = True
        Select Case TP_TID
            Case TP_SYS
                PFlag = PFlag - 1
                If PFlag < 0 Then
                    Exit Sub
                Else
                    Pan_NSys.Caption = Format$(PFlag)
                End If
            If Pic_SysWork.Visible Then Prepare_New_Sys_Icon XSI(SICount), YSI(SI-
Count)
                Display_Sys_Icon CurrentTool
            Case TP_BLK
                'Wrong instruction or no extension icon selected. Turn extension off
                If ToolPalette_BlExt.Visible Then ToolPalette_BlExt.Visible = False
                If Pic_Work.Visible Then Prepare_New_Icon XArr(ArraySiz), YArr(ArraySiz)
                ToolPalette_BlExt.Move Abs(Blk_WorkSpace.Left), 170 +
Abs(Blk_WorkSpace.Top), 419, 52 'Set the toolpalette at the DSP icon position
                ToolPalette_Block_Initialize 'Redraw the first few blocks of
toolpalette icons
                ToolPalette_BlExt.Visible = True
            End Select
        End If
    End Sub

Sub Tool_Com2_Click (Value As Integer)

```

```

If Value Then
    MainEditor.MousePointer = DEFAULT
    CurrentTool = TP_COM2
    ToolInProgress = True
    Select Case TP_TID
        Case TP_SYS
            If Pic_SysWork.Visible Then Prepare_New_Sys_Icon XSI(SICount), YSI(SI-
Count)
                Display_Sys_Icon CurrentTool
            Case TP_BLK
                'Wrong instruction or no extension icon selected. Turn extension off
                If ToolPalette_BlExt.Visible Then ToolPalette_BlExt.Visible = False
                If Pic_Work.Visible Then Prepare_New_Icon XArr(ArraySiz), YArr(ArraySiz)
                ToolPalette_BlExt.Move Abs(Blk_WorkSpace.Left), 204 +
Abs(Blk_WorkSpace.Top), 153, 52
                ToolPalette_Block_Initialize
                ToolPalette_BlExt.Visible = True
            End Select
        End If
    End Sub

```

```

Sub Tool_Com3_Click (Value As Integer)
    If Value Then
        MainEditor.MousePointer = DEFAULT
        CurrentTool = TP_COM3
        ToolInProgress = True
        Select Case TP_TID
            Case TP_SYS
                If Pic_SysWork.Visible Then Prepare_New_Sys_Icon XSI(SICount), YSI(SI-
Count)
                    Display_Sys_Icon CurrentTool
            Case TP_BLK
                If ToolPalette_BlExt.Visible Then ToolPalette_BlExt.Visible = False
                If Pic_Work.Visible Then Prepare_New_Icon XArr(ArraySiz), YArr(ArraySiz)
                ToolPalette_BlExt.Move Abs(Blk_WorkSpace.Left), 238 +
Abs(Blk_WorkSpace.Top), 191, 52
                ToolPalette_Block_Initialize
                ToolPalette_BlExt.Visible = True
            End Select
        End If
    End Sub

```

```

Sub Tool_Com4_Click (Value As Integer)
    If Value Then
        MainEditor.MousePointer = DEFAULT
        CurrentTool = TP_COM4
        ToolInProgress = True
        Select Case TP_TID

```

```

Case TP_SYS
  If Pic_SysWork.Visible Then Prepare_New_Sys_Icon XSI(SICount), YSI(SI-
Count)
    Display_Sys_Icon CurrentTool
Case TP_BLK
  If ToolPalette_BlExt.Visible Then ToolPalette_BlExt.Visible = False
  If Pic_Work.Visible Then Prepare_New_Icon XArr(ArraySiz), YArr(ArraySiz)
  ToolPalette_BlExt.Move Abs(Blk_WorkSpace.Left), 272 +
Abs(Blk_WorkSpace.Top), 153, 52
  ToolPalette_Block_Initialize
  ToolPalette_BlExt.Visible = True
End Select
End If
End Sub

```

```

Sub Tool_Com5_Click (Value As Integer)
  If Value Then
    MainEditor.MousePointer = DEFAULT
    CurrentTool = TP_COM5
    ToolInProgress = True
    Select Case TP_TID
      Case TP_SYS
        'No icon is to be displayed
      Case TP_BLK
        If ToolPalette_BlExt.Visible Then ToolPalette_BlExt.Visible = False
        If Pic_Work.Visible Then Prepare_New_Icon XArr(ArraySiz), YArr(ArraySiz)
        ToolPalette_BlExt.Move Abs(Blk_WorkSpace.Left), 306 +
Abs(Blk_WorkSpace.Top), 77, 52
        ToolPalette_Block_Initialize
        ToolPalette_BlExt.Visible = True
    End Select
  End If
End Sub

```

```

Sub Tool_Com6_Click (Value As Integer)
  If Value Then
    MainEditor.MousePointer = DEFAULT
    CurrentTool = TP_COM6
    ToolInProgress = True
    Select Case TP_TID
      Case TP_SYS
        'Not icon is to be displayed
      Case TP_BLK
        If ToolPalette_BlExt.Visible Then ToolPalette_BlExt.Visible = False
        If Pic_Work.Visible Then Prepare_New_Icon XArr(ArraySiz), YArr(ArraySiz)
        ToolPalette_BlExt.Move Abs(Blk_WorkSpace.Left), 340 +
Abs(Blk_WorkSpace.Top), 77, 52
        ToolPalette_Block_Initialize
    End Select
  End If
End Sub

```

```

        ToolPalette_BlExt.Visible = True
    End Select
Else
    End If
End Sub

Sub Tool_Line_Click (Value As Integer)
    If IniDraw And (CurrentTool = TP_LINE Or CurrentTool = TP_UNLINE) Then
        If CurrentTool = TP_LINE Then
            If TP_TID = TP_BLK Then
                DrawLine Blk_WorkSpace, StartX, StartY, OldX, OldY
                Hpts(LineCount, 1) = 0
                Vpts(LineCount, 1) = 0
            ElseIf TP_TID = TP_SYS Then
                DrawLine Sys_WorkSpace, StartX, StartY, OldX, OldY
                XPts(LCount, 1) = 0
                YPts(LCount, 1) = 0
            End If
        End If
        IniDraw = False: FinDraw = False
        DisLineX1 = 0: DisLineY1 = 0
        StartEvent = False
    End If
    If Value Then
        MainEditor.MousePointer = DEFAULT
        CurrentTool = TP_LINE
        Select Case TP_TID
            Case TP_BLK
                'If the Block ToolPalette Extension is visible, hide it
                If ToolPalette_BlExt.Visible Then ToolPalette_BlExt.Visible = False
                'Prepare for draw line. Turn off the Pic_Work Container
                If Pic_Work.Visible Then Prepare_New_Icon XArr(ArraySiz), YArr(ArraySiz)
                'turn pic_work icon OFF
            Case TP_SYS
                'Prepare for draw line. Turn off the Pic_SysWork Container
                If Pic_SysWork.Visible Then Prepare_New_Sys_Icon XSI(SICount), YSI(SI-
Count) 'turn pic_work icon OFF
        End Select
        ScreenInfo(ScrnStage).Changed = True
        ToolInProcess = True
    End If
End Sub

Sub Tool_Reset_Click (Value As Integer)
    'Wrong instruction or no extension icon selected. Turn extension off
    If ToolPalette_BlExt.Visible Then ToolPalette_BlExt.Visible = False
    If IniDraw And (CurrentTool = TP_LINE Or CurrentTool = TP_UNLINE) Then
        If CurrentTool = TP_LINE Then

```

```

If TP_TID = TP_BLK Then
    DrawLine Blk_WorkSpace, StartX, StartY, OldX, OldY
    Hpts(LineCount, 1) = 0
    Vpts(LineCount, 1) = 0
ElseIf TP_TID = TP_SYS Then
    DrawLine Sys_WorkSpace, StartX, StartY, OldX, OldY
    Xpts(LCount, 1) = 0
    Ypts(LCount, 1) = 0
End If
End If
IniDraw = False: FinDraw = False
DisLineX1 = 0: DisLineY1 = 0
StartEvent = False
End If

```

```

If Value Then
    MainEditor.MousePointer = DEFAULT
    CurrentTool = TP_RESET
    Msg = "Are you sure that all icons & lines are to be erased?"
    If MsgBox(Msg, 49, "ERASE ALL") = 1 Then
        Initialize_All_Variables TP_TID
    End If
    Tool_Select.Value = True
End If
End Sub

```

'The Select button is always depress when the other tool button is not depress.

'The select button allows the icon to drag and edit the Pic_Work.

```

Sub Tool_Select_Click (Value As Integer)
    If IniDraw And (CurrentTool = TP_LINE Or CurrentTool = TP_UNLINE) Then
        If CurrentTool = TP_LINE Then
            If TP_TID = TP_BLK Then
                DrawLine Blk_WorkSpace, StartX, StartY, OldX, OldY
                Hpts(LineCount, 1) = 0
                Vpts(LineCount, 1) = 0
            ElseIf TP_TID = TP_SYS Then
                DrawLine Sys_WorkSpace, StartX, StartY, OldX, OldY
                Xpts(LCount, 1) = 0
                Ypts(LCount, 1) = 0
            End If
        End If
        IniDraw = False: FinDraw = False
        DisLineX1 = 0: DisLineY1 = 0
        StartEvent = False
    End If
    If Value Then
        MainEditor.MousePointer = DEFAULT
    End If
End Sub

```

```

Select Case TP_TID
Case TP_SYS
    If CurrentTool = TP_TEXT Then
        TxtUnFocus STxtSelected
        If STxtEdit(STxtSelected).Text = "" Then
            If STxtSelected = STxtNum - 1 Then
                STxtNum = STxtNum - 1
                If STxtNum < 0 Then STxtNum = 0
                If STxtNum - 1 < 0 Then STxtSelected = 0 Else STxtSelected = STxtNum - 1
                If STxtNum > 1 Then Unload STxtEdit(STxtNum) Else STxtEdit(STxt-
Num).Visible = False
                STxtEnable = False
            Else
                If Not STxtEnable Then STxtEdit(STxtSelected).Visible = False
            End If
        End If
        Sys_WorkSpace.SetFocus
    End If
    If Not Pic_SysWork.Visible And SISiz > 0 Then
        Pic_SysWork.Move XSI(SICount), YSI(SICount)
        Get_Function_Pic Pic_SysWork, FuncCode(SICount, 1)
        Pic_SysWork.Visible = True
        R = PatBlt(Sys_WorkSpace.hDC, XSI(SICount), YSI(SICount), 34, 54, WHITE-
NESS)
    End If
Case TP_BLK
    If CurrentTool = TP_TEXT Then
        TxtUnFocus TxtSelected
        If TxtEdit(TxtSelected).Text = "" Then
            If TxtSelected = TxtNum - 1 Then
                If TxtSelected > 1 Then Unload TxtEdit(TxtSelected) Else TxtEdit(Txt-
Selected).Visible = False
                TxtEnable = False
                TxtNum = TxtNum - 1
                If TxtNum <= 0 Then
                    TxtNum = 0
                    TxtSelected = 0
                Else
                    TxtSelected = TxtNum - 1
                End If
            Else
                If Not TxtEnable Then TxtEdit(TxtSelected).Visible = False
            End If
        End If
        'Blk_WorkSpace.SetFocus
    End If
    'If the Block ToolPalette Extension is visible, hide it
    If ToolPalette_BlExt.Visible Then ToolPalette_BlExt.Visible = False

```



```

'Move the picture container to the new icon location.
If Not Pic_Work.Visible And ArrayCount > 0 Then
    Pic_Work.Move XArr(ArraySiz), YArr(ArraySiz)
    Get_Function_Pic Pic_Work, FuncCode(ArraySiz, 0)
    Pic_Work.Visible = True
    R = PatBlt(Blk_WorkSpace.hDC, XArr(ArraySiz), YArr(ArraySiz), 34, 54,
WHITENESS)
    Pic_Work_Paint
End If
End Select
CurrentTool = TP_SELECT
ToolInProgress = False
End If
End Sub

Sub Tool_Text_Click (Value As Integer)
    If IniDraw And (CurrentTool = TP_LINE Or CurrentTool = TP_UNLINE) Then
        If CurrentTool = TP_LINE Then
            If TP_TID = TP_BLK Then
                DrawLine Blk_WorkSpace, StartX, StartY, OldX, OldY
                Hpts(LineCount, 1) = 0
                Vpts(LineCount, 1) = 0
            ElseIf TP_TID = TP_SYS Then
                DrawLine Sys_WorkSpace, StartX, StartY, OldX, OldY
                XPts(LCount, 1) = 0
                YPts(LCount, 1) = 0
            End If
        End If
        IniDraw = False: FinDraw = False
        DisLineX1 = 0: DisLineY1 = 0
        StartEvent = False
    End If
    If Value Then
        Select Case TP_TID
            Case TP_BLK
                'If the Block ToolPalette Extension is visible, hide it
                If ToolPalette_BlExt.Visible Then ToolPalette_BlExt.Visible = False
                'Prepare for erase of line. Turn off the Pic_Work Container
                If Pic_Work.Visible Then Prepare_New_Icon XArr(ArraySiz), YArr(ArraySiz)
            Case TP_SYS
                'Prepare for erase of line. Turn off the Pic_Work Container
                If Pic_SysWork.Visible Then Prepare_New_Sys_Icon XSI(SICount), YSI(SI-
Count)
        End Select
        CurrentTool = TP_TEXT
        MainEditor.MousePointer = I_BEAM
    End If
End Sub

```

```

Sub Tool_UnLine_Click (Value As Integer)
  If IniDraw And (CurrentTool = TP_LINE Or CurrentTool = TP_UNLINE) Then
    If CurrentTool = TP_LINE Then
      If TP_TID = TP_BLK Then
        DrawLine Blk_WorkSpace, StartX, StartY, OldX, OldY
        Hpts(LineCount, 1) = 0
        Vpts(LineCount, 1) = 0
      ElseIf TP_TID = TP_SYS Then
        DrawLine Sys_WorkSpace, StartX, StartY, OldX, OldY
        XPts(LCount, 1) = 0
        YPts(LCount, 1) = 0
      End If
    End If
    IniDraw = False: FinDraw = False
    DisLineX1 = 0: DisLineY1 = 0
    StartEvent = False
  End If
  If Value Then
    CurrentTool = TP_UNLINE
    Select Case TP_TID
      Case TP_BLK
        'If the Block ToolPalette Extension is visible, hide it
        If ToolPalette_BlExt.Visible Then ToolPalette_BlExt.Visible = False
        'Prepare for erase of line. Turn off the Pic_Work Container
        If Pic_Work.Visible Then Prepare_New_Icon XArr(ArraySiz), YArr(ArraySiz)
      Case TP_SYS
        'Prepare for erase of line. Turn off the Pic_Work Container
        If Pic_SysWork.Visible Then Prepare_New_Sys_Icon XSI(SICount), YSI(SI-
Count)
    End Select
    ScreenInfo(ScrStage).Changed = True
    ToolInProcess = True
  End If
End Sub

```

```

Sub ToolPalette_BlExt_Paint ()
  Tool_Blkl.Move 0, 0, 38, 38
  Tool_Blkl2.Move 38, 0, 38, 38
  Tool_Blkl3.Move 76, 0, 38, 38
  Tool_Blkl4.Move 114, 0, 38, 38
  Tool_Blkl5.Move 152, 0, 38, 38
  Tool_Blkl6.Move 190, 0, 38, 38
  Tool_Blkl7.Move 228, 0, 38, 38
  Tool_Blkl8.Move 266, 0, 38, 38
  Tool_Blkl9.Move 304, 0, 38, 38
  Tool_Blkl10.Move 342, 0, 38, 38
  Tool_Blkl11.Move 380, 0, 38, 38

```

```

ToolPalette_BlkExt.CurrentX = 0
ToolPalette_BlkExt.CurrentY = ToolPalette_BlkExt.ScaleTop + 38
Select Case CurrentTool
    Case TP_COM1 'DSP
        ToolPalette_BlkExt.Print " BFLY2"; " BFLY4"; " BFLY16";
        ToolPalette_BlkExt.Print " BWND2"; " BWND4"; " BCFIR";
        ToolPalette_BlkExt.Print " BDFIR"; " BRFR"; " BFCT";
        ToolPalette_BlkExt.Print " BFCT2"; " BRFT"
    Case TP_COM2 'CAI
        ToolPalette_BlkExt.Print " CADD"; " CSUB"; " CMUL"; " CMAG"
    Case TP_COM3 'VAI
        ToolPalette_BlkExt.Print " VADD"; " VSUB"; " VMUL";
        ToolPalette_BlkExt.Print " VABS"; " VMXM"
    Case TP_COM4 'VLI
        ToolPalette_BlkExt.Print "VNAND"; " VNOR"; " VXNOR";
        ToolPalette_BlkExt.Print " VPAS"
    Case TP_COM5 'GPI
        ToolPalette_BlkExt.Print " MOVD"; " MOVC"
    Case TP_COM6 'MISC
        ToolPalette_BlkExt.Print " Signal"; " Display"
End Select
End Sub

```

'This routine is to select the icon picture from the PicClip and assign
'it to each individual tool_com icons when user click on it.
,

```

Sub ToolPalette_Block_Initialize ()
    MainEditor.PicClip_Icons.ClipWidth = 32
    Select Case CurrentTool
        Case TP_COM1 'DSP
            PicClip_Icons.ClipY = 0
            PicClip_Icons.ClipX = 0
            Tool_Blkl.Picture = PicClip_Icons.Clip
            PicClip_Icons.ClipX = 32
            Tool_Blkl2.Picture = PicClip_Icons.Clip
            PicClip_Icons.ClipX = 64
            Tool_Blkl3.Picture = PicClip_Icons.Clip
            PicClip_Icons.ClipX = 96
            Tool_Blkl4.Picture = PicClip_Icons.Clip
            PicClip_Icons.ClipX = 128
            Tool_Blkl5.Picture = PicClip_Icons.Clip
        Case TP_COM2 'CAI
            PicClip_Icons.ClipY = 32
            PicClip_Icons.ClipX = 96
            Tool_Blkl.Picture = PicClip_Icons.Clip
            PicClip_Icons.ClipX = 128
            Tool_Blkl2.Picture = PicClip_Icons.Clip
            PicClip_Icons.ClipX = 160

```

```

    Tool_Bl3.Picture = PicClip_Icons.Clip
    PicClip_Icons.ClipX = 192
    Tool_Bl4.Picture = PicClip_Icons.Clip
Case TP_COM3 'VAI
    PicClip_Icons.ClipY = 32
    PicClip_Icons.ClipX = 224
    Tool_Bl1.Picture = PicClip_Icons.Clip
    PicClip_Icons.ClipY = 64
    PicClip_Icons.ClipX = 0
    Tool_Bl2.Picture = PicClip_Icons.Clip
    PicClip_Icons.ClipX = 32
    Tool_Bl3.Picture = PicClip_Icons.Clip
    PicClip_Icons.ClipX = 64
    Tool_Bl4.Picture = PicClip_Icons.Clip
    PicClip_Icons.ClipX = 96
    Tool_Bl5.Picture = PicClip_Icons.Clip
Case TP_COM4 'VLI
    PicClip_Icons.ClipY = 64
    PicClip_Icons.ClipX = 128
    Tool_Bl1.Picture = PicClip_Icons.Clip
    PicClip_Icons.ClipX = 160
    Tool_Bl2.Picture = PicClip_Icons.Clip
    PicClip_Icons.ClipX = 192
    Tool_Bl3.Picture = PicClip_Icons.Clip
    PicClip_Icons.ClipX = 224
    Tool_Bl4.Picture = PicClip_Icons.Clip
Case TP_COM5 'GPI
    PicClip_Icons.ClipY = 96
    PicClip_Icons.ClipX = 0
    Tool_Bl1.Picture = PicClip_Icons.Clip
    PicClip_Icons.ClipX = 32
    Tool_Bl2.Picture = PicClip_Icons.Clip
Case TP_COM6 'MISC
    PicClip_Icons.ClipY = 128
    PicClip_Icons.ClipX = 192
    Tool_Bl1.Picture = PicClip_Icons.Clip
    PicClip_Icons.ClipY = 160
    PicClip_Icons.ClipX = 0
    Tool_Bl2.Picture = PicClip_Icons.Clip
End Select
End Sub

Sub ToolPalette_Icons_Initialize ()
    'ToolPalette_Icons_Selection.Visible = True
    PicClip_Icons.ClipHeight = 32
    PicClip_Icons.ClipWidth = 32
    Tool_Select.PictureUp = LoadPicture()
    Tool_Line.PictureUp = LoadPicture()

```

```

Tool_Com1.PictureUp = LoadPicture()
Tool_Com2.PictureUp = LoadPicture()
Tool_Com3.PictureUp = LoadPicture()
Tool_Com4.PictureUp = LoadPicture()
Tool_Com5.PictureUp = LoadPicture()
Tool_Com6.PictureUp = LoadPicture()
Select Case TP_TID
Case TP_MAIN
    ToolPalette_Icons_Selection.Visible = False
    Com_MBLK.Visible = True
    Com_MSYS.Visible = True
    Start_System.Visible = False
    Stop_System.Visible = False
    Sys_System.Visible = False
Case TP_BLK
    Com_MBLK.Visible = False
    Com_MSYS.Visible = False
    Start_System.Visible = True
    Stop_System.Visible = True
    Sys_System.Visible = True
    ToolPalette_Icons_Selection.Visible = True
    'Tool_Palette_OnOff TP_BLK
    PicClip_Icons.ClipY = 96
    'Insert Select icon
    PicClip_Icons.ClipX = 64
    Tool_Select.PictureUp = PicClip_Icons.Clip
    'Insert Line icon
    PicClip_Icons.ClipX = 96
    Tool_Line.PictureUp = PicClip_Icons.Clip
    PicClip_Icons.ClipY = 160
    PicClip_Icons.ClipX = 32
    Tool_Com1.PictureUp = PicClip_Icons.Clip
    PicClip_Icons.ClipX = 64
    Tool_Com2.PictureUp = PicClip_Icons.Clip
    PicClip_Icons.ClipX = 96
    Tool_Com3.PictureUp = PicClip_Icons.Clip
    PicClip_Icons.ClipX = 128
    Tool_Com4.PictureUp = PicClip_Icons.Clip
    If Not Tool_Com5.Visible Then Tool_Com5.Visible = True
    If Not Tool_Com6.Visible Then Tool_Com6.Visible = True
    PicClip_Icons.ClipX = 160
    Tool_Com5.PictureUp = PicClip_Icons.Clip
    PicClip_Icons.ClipX = 192
    Tool_Com6.PictureUp = PicClip_Icons.Clip
Case TP_SYS
    Com_MSYS.Visible = False
    Com_MBLK.Visible = False
    Start_System.Visible = True

```

```

Stop_System.Visible = True
Sys_System.Visible = True
ToolPalette_Icons_Selection.Visible = True
'Tool_Palette_OnOff TP_SYS
PicClip_Icons.ClipY = 96
'Insert Select icon
PicClip_Icons.ClipX = 64
Tool_Select.PictureUp = PicClip_Icons.Clip
'Insert Line icon
PicClip_Icons.ClipX = 96
Tool_Line.PictureUp = PicClip_Icons.Clip
'Insert the LH9124 icon
PicClip_Icons.ClipY = 128
PicClip_Icons.ClipX = 160
Tool_Com1.PictureUp = PicClip_Icons.Clip
'Insert the LH9320 & memory icon
PicClip_Icons.ClipY = 192
PicClip_Icons.ClipX = 64
Tool_Com2.PictureUp = PicClip_Icons.Clip
'Insert the Signal icon
PicClip_Icons.ClipY = 128
PicClip_Icons.ClipX = 192
Tool_Com3.PictureUp = PicClip_Icons.Clip
'Insert the Display icon
PicClip_Icons.ClipY = 160
PicClip_Icons.ClipX = 192
Tool_Com4.PictureUp = PicClip_Icons.Clip
'Turn off the last two icons
If Tool_Com5.Visible Then Tool_Com5.Visible = False
If Tool_Com6.Visible Then Tool_Com6.Visible = False
End Select
End Sub

Sub TxtEdit_Change (Index As Integer)
    TxtUnFocus Index
    TxtEdit(Index).Height = TextHeight(TxtEdit(Index)) + 4
    TxtEdit(Index).Width = TextWidth(TxtEdit(Index)) * 1.4 + 20
    If TxtEdit(Index).Text <> "" Then TxtFocus Index
    TxtEnable = False
End Sub

Sub TxtEdit_GotFocus (Index As Integer)
    TxtUnFocus TxtSelected
    If TxtEdit(TxtSelected).Text = "" Then
        If Not TxtEnable Then TxtEdit(TxtSelected).Visible = False
    End If
    Blk_WorkSpace.Print Err,
    TxtFocus Index

```

```

    TxtSelected = Index
End Sub

```

```

Sub TxtEdit_MouseDown (Index As Integer, Button As Integer, Shift As Integer, X As Single, Y As Single)
    If Button = LEFT_BUTTON And CurrentTool = TP_SELECT Then
        TxtEdit(Index).Drag 1
        DragX = X / 15
        DragY = Y / 15
        Blk_WorkSpace.SetFocus
    End If
End Sub

```

```

Sub TxtEdit_MouseMove (Index As Integer, Button As Integer, Shift As Integer, X As Single, Y As Single)
    TxtEdit(Index).MousePointer = IIf(CurrentTool = TP_SELECT, ARROW, DEFAULT)
End Sub

```

```

Sub TxtEdit_MouseUp (Index As Integer, Button As Integer, Shift As Integer, X As Single, Y As Single)
    If Button = LEFT_BUTTON And CurrentTool = TP_SELECT Then TxtEdit(Index).Drag 2
End Sub

```

```

Sub Write_Script (XID As Integer)
    On Error Resume Next
    Dim LongName As String
    Dim Title As String
    Dim CDPATH As String
    If TP_TID = TP_BLK And SavFlag Then
        XInit = XArr(ArraySiz): YInit = YArr(ArraySiz)
        If Pic_Work.Visible Then Prepare_New_Icon XInit, YInit
    ElseIf TP_TID = TP_SYS And SavFlag Then
        XInit = XSI(SICount): YInit = YSI(SICount)
        If Pic_SysWork.Visible Then Prepare_New_Sys_Icon XInit, YInit
    End If
    If XID = MID_WRITE_SCRIPT Then
        ' Set default filter.
        MainEditor.CMDialog_Edit.Filter = "System Schedule Files (*.ssf)|*.SSF"
        ' Display Save As dialog.
        MainEditor.CMDialog_Edit.FilterIndex = 1
        MainEditor.CMDialog_Edit.DefaultExt = ".SSF"
        If Right(Script_Path, 1) <> "\" Then
            MainEditor.CMDialog_Edit.FileName = Script_Path & "\" & Script_FName
        End If
        ' If file has not been saved yet, set common dialog's
        ' default file name to *.ssf
        If Script_FName = "" Then

```

```

    MainEditor.CMDialog_Edit.Filename = "*.ssf"
End If
MainEditor.CMDialog_Edit.Action = 2
' Exit if user cancels the dialog.
If Err = 32755 Then Exit Sub
Title = MainEditor.CMDialog_Edit.Filetitle
LongName = MainEditor.CMDialog_Edit.Filename
Script_Path = Left(LongName, Len(LongName) - Len(Title))
Script_FName = MainEditor.CMDialog_Edit.Filetitle
' Adjust for root directory.
If Len(Script_Path) = 3 Then
    CDPPath = Script_Path
Else
    CDPPath = Left(LongName, Len(LongName) - Len(Title) - 1)
End If
' Change directories for the editor and the viewer.
ChDir CDPPath
End If
MainEditor.MousePointer = HOURGLASS
Extract_AG_File Script_Path, Script_FName, I
For I = 1 To ArrayCount
    System_Scheduler_File Script_Path, Script_FName, I
Next I
MainEditor.MousePointer = DEFAULT
End Sub

```