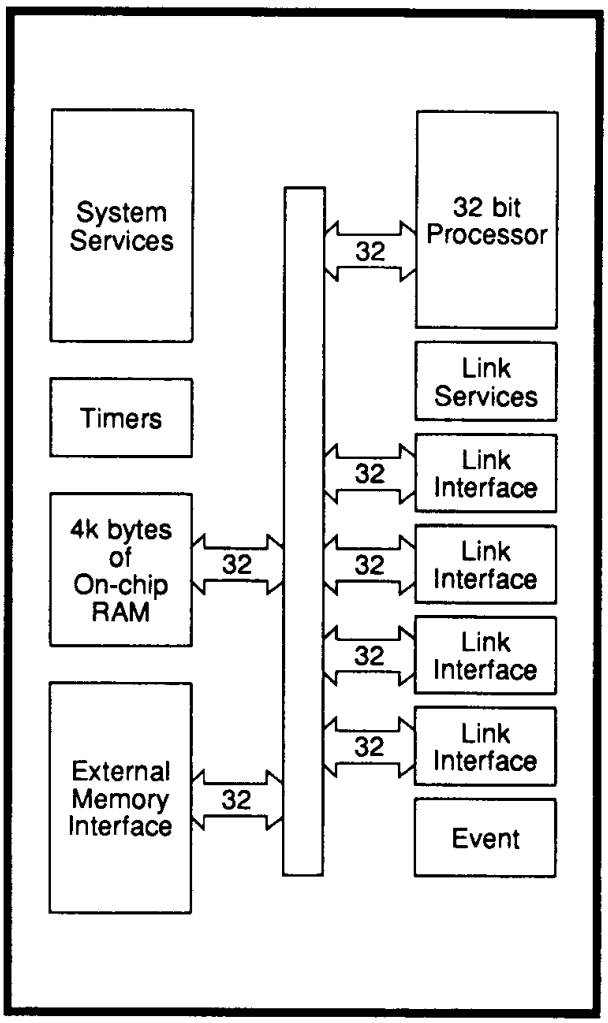
IMS T425
transputer

Advance Data

FEATURES

32 bit architecture
33 ns internal cycle time
30 MIPS (peak) instruction rate
Pin compatible with IMS T805, IMS T800 and IMS T414
Debugging support
4 Kbytes on-chip static RAM
120 Mbytes/sec sustained data rate to internal memory
4 Gbytes directly addressable external memory
40 Mbytes/sec sustained data rate to external memory
630 ns response to interrupts
Four INMOS serial links 5/10/20 Mbits/sec
High performance graphics support with block move instructions
Boot from ROM or communication links
Single 5 MHz clock input
Single +5V ±5% power supply
MIL-STD-883C processing will be available



APPLICATIONS

High speed multi processor systems
High performance graphics processing
Supercomputers
Workstations and workstation clusters
Digital signal processing
Accelerator processors
Distributed databases
System simulation
Telecommunications
Robotics
Fault tolerant systems
Image processing
Pattern recognition
Artificial intelligence

1 Introduction

The IMS T425 transputer is a 32 bit CMOS microcomputer with graphics support. It has 4 Kbytes on-chip RAM for high speed processing, a configurable memory interface and four standard INMOS communication links. The instruction set achieves efficient implementation of high level languages and provides direct support for the occam model of concurrency when using either a single transputer or a network. Procedure calls, process switching and typical interrupt latency are sub-microsecond.

For convenience of description, the IMS T425 operation is split into the basic blocks shown in figure 1.1.

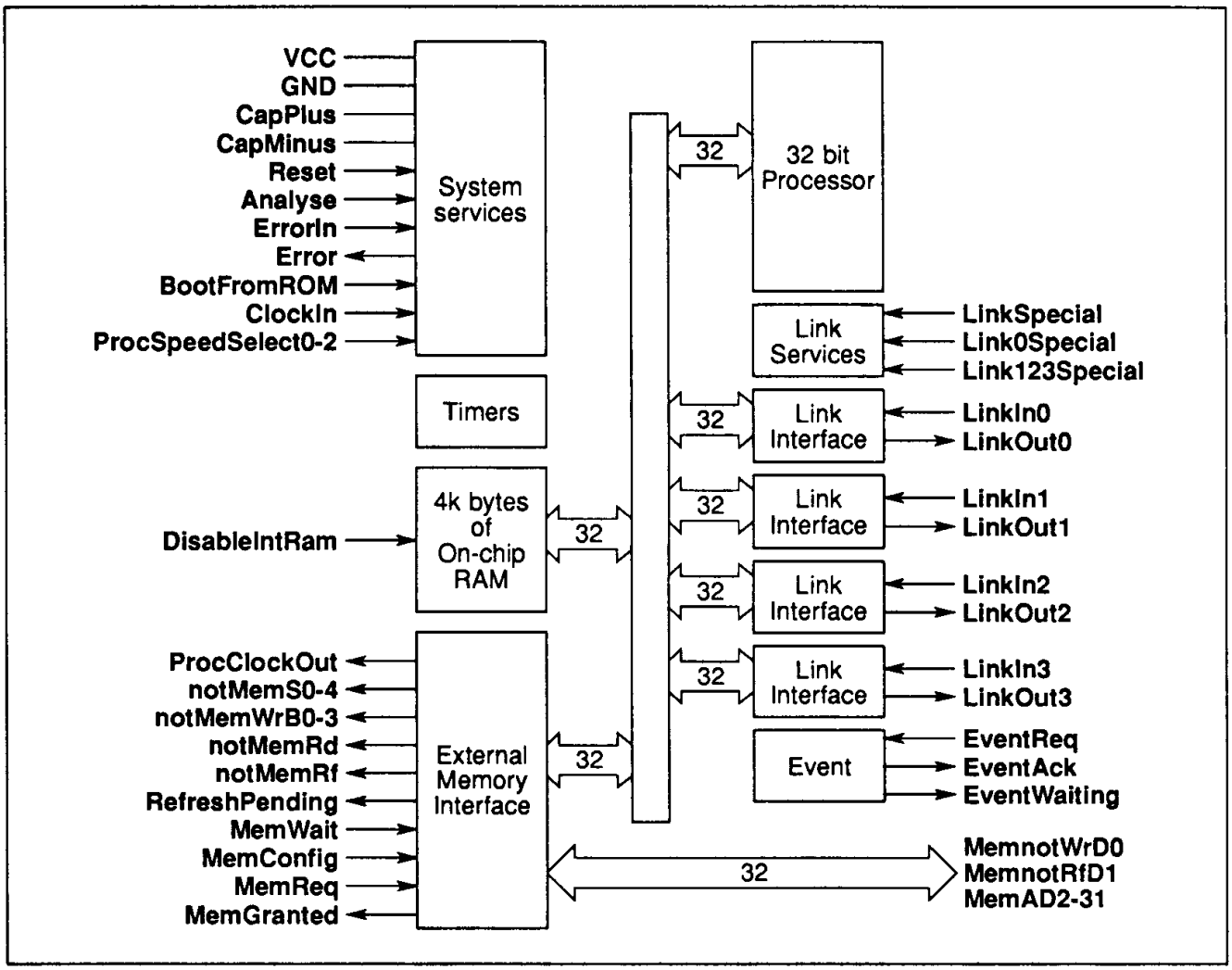


Figure 1.1 IMS T425 block diagram

The processor speed of a device can be pin-selected in stages from 17.5 MHz up to the maximum allowed for the part. A device running at 30 MHz achieves an instruction throughput of 30 MIPS peak and 15 MIPS sustained. The extended temperature version of the device complies with MIL-STD-883C.

High performance graphics support is provided by microcoded block move instructions which operate at the speed of memory. The two-dimensional block move instructions provide for contiguous block moves as well as block copying of either non-zero bytes of data only or zero bytes only. Block move instructions can be used to provide graphics operations such as text manipulation, windowing, panning, scrolling and screen updating.

Cyclic redundancy checking (CRC) instructions are available for use on arbitrary length serial data streams, to provide error detection where data integrity is critical. Another feature of the IMS T425, useful for pattern recognition, is the facility to count bits set in a word.

The IMS T425 can directly access a linear address space of 4 Gbytes. The 32 bit wide memory interface uses multiplexed data and address lines and provides a data rate of up to 4 bytes every 100 nanoseconds (40 Mbytes/sec) for a 30 MHz device. A configurable memory controller provides all timing, control and DRAM refresh signals for a wide variety of mixed memory systems.

System Services include processor reset and bootstrap control, together with facilities for error analysis. Error signals may be daisy-chained in multi-transputer systems.

The standard INMOS communication links allow networks of transputer family products to be constructed by direct point to point connections with no external logic. The IMS T425 links support the standard operating speed of 10 Mbits/sec, but also operate at 5 or 20 Mbits/sec. Each link can transfer data bi-directionally at up to 2.35 Mbytes/sec.

The IMS T425 is pin compatible with the IMS T800 and can be plugged directly into a circuit designed for that device. It has a number of additions to improve hardware interfacing and to facilitate software initialising and debugging. The improvements have been made in an upwards-compatible manner. Software should be recompiled, although no changes to the source code are necessary.

The IMS T425-20 is also pin compatible with the IMS T414-20, as the extra inputs used are all held to ground on the IMS T414. The IMS T425-20 can thus be plugged directly into a circuit designed for a 20 MHz version of the IMS T414.

The transputer is designed to implement the occam language, detailed in the occam Reference Manual, but also efficiently supports other languages such as C, Pascal and Fortran. Access to the transputer at machine level is seldom required, but if necessary refer to the *Transputer Instruction Set - A Compiler Writers' Guide*. The instruction set of the IMS T425 is the same as that of the IMS T800, except that the IMS T800 floating point instructions are replaced by the IMS T414 floating point support instructions.

This data sheet supplies hardware implementation and characterisation details for the IMS T425. It is intended to be read in conjunction with the Transputer Architecture chapter, which details the architecture of the transputer and gives an overview of occam.

2 Pin designations

Table 2.1 IMS T425 system services

Pin	In/Out	Function
VCC, GND		Power supply and return
CapPlus, CapMinus		External capacitor for internal clock power supply
ClockIn	in	Input clock
ProcSpeedSelect0-2	in	Processor speed selectors
Reset	in	System reset
Error	out	Error indicator
ErrorIn	in	Error daisychain input
Analyse	in	Error analysis
BootFromRom	in	Boot from external ROM or from link
DisableIntRAM	in	Disable internal RAM

Table 2.2 IMS T425 external memory interface

Pin	In/Out	Function
ProcClockOut	out	Processor clock
MemnotWrD0	in/out	Multiplexed data bit 0 and write cycle warning
MemnotRfD1	in/out	Multiplexed data bit 1 and refresh warning
MemAD2-31	in/out	Multiplexed data and address bus
notMemRd	out	Read strobe
notMemWrB0-3	out	Four byte-addressing write strobes
notMemS0-4	out	Five general purpose strobes
notMemRf	out	Dynamic memory refresh indicator
RefreshPending	out	Dynamic refresh is pending
MemWait	in	Memory cycle extender
MemReq	in	Direct memory access request
MemGranted	out	Direct memory access granted
MemConfig	in	Memory configuration data input

Table 2.3 IMS T425 event

Pin	In/Out	Function
EventReq	in	Event request
EventAck	out	Event request acknowledge
EventWaiting	out	Event input requested by software

Table 2.4 IMS T425 link

Pin	In/Out	Function
LinkIn0-3	in	Four serial data input channels
LinkOut0-3	out	Four serial data output channels
LinkSpecial	in	Select non-standard speed as 5 or 20 Mbits/sec
Link0Special	in	Select special speed for Link 0
Link123Special	in	Select special speed for Links 1,2,3

Signal names are prefixed by **not** if they are active low, otherwise they are active high.
Pinout details for various packages are given on page 326.

3 Processor

The 32 bit processor contains instruction processing logic, instruction and work pointers, and an operand register. It directly accesses the high speed 4 Kbyte on-chip memory, which can store data or program. Where larger amounts of memory or programs in ROM are required, the processor has access to 4 Gbytes of memory via the External Memory Interface (EMI).

3.1 Registers

The design of the transputer processor exploits the availability of fast on-chip memory by having only a small number of registers; six registers are used in the execution of a sequential process. The small number of registers, together with the simplicity of the instruction set, enables the processor to have relatively simple (and fast) data-paths and control logic. The six registers are:

The workspace pointer which points to an area of store where local variables are kept.

The instruction pointer which points to the next instruction to be executed.

The operand register which is used in the formation of instruction operands.

The *A*, *B* and *C* registers which form an evaluation stack.

A, *B* and *C* are sources and destinations for most arithmetic and logical operations. Loading a value into the stack pushes *B* into *C*, and *A* into *B*, before loading *A*. Storing a value from *A*, pops *B* into *A* and *C* into *B*.

Expressions are evaluated on the evaluation stack, and instructions refer to the stack implicitly. For example, the *add* instruction adds the top two values in the stack and places the result on the top of the stack. The use of a stack removes the need for instructions to respecify the location of their operands. Statistics gathered from a large number of programs show that three registers provide an effective balance between code compactness and implementation complexity.

No hardware mechanism is provided to detect that more than three values have been loaded onto the stack. It is easy for the compiler to ensure that this never happens.

Any location in memory can be accessed relative to the workpointer register, enabling the workspace to be of any size.

Further register details are given in *Transputer Instruction Set - A Compiler Writers' Guide*.

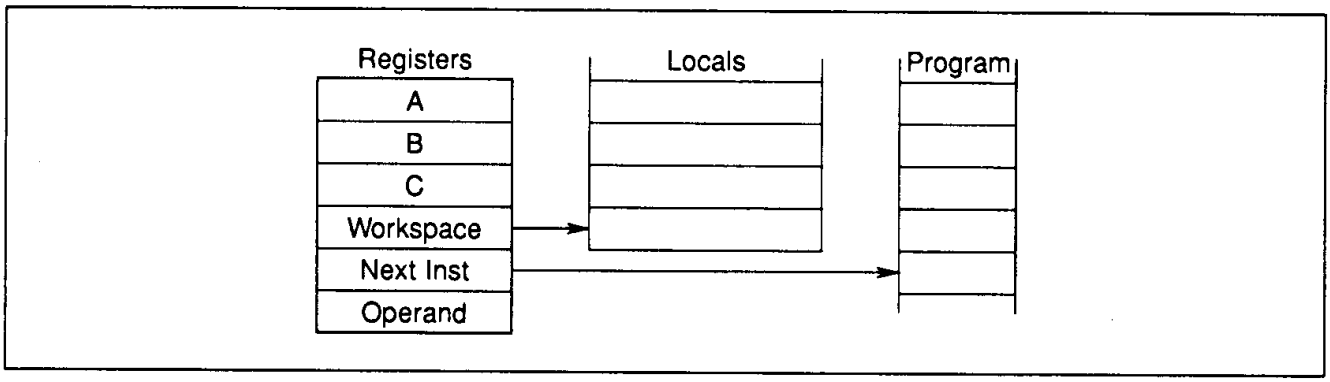


Figure 3.1 Registers

3.2 Instructions

The instruction set has been designed for simple and efficient compilation of high-level languages. All instructions have the same format, designed to give a compact representation of the operations occurring most frequently in programs.

Each instruction consists of a single byte divided into two 4-bit parts. The four most significant bits of the byte are a function code and the four least significant bits are a data value.

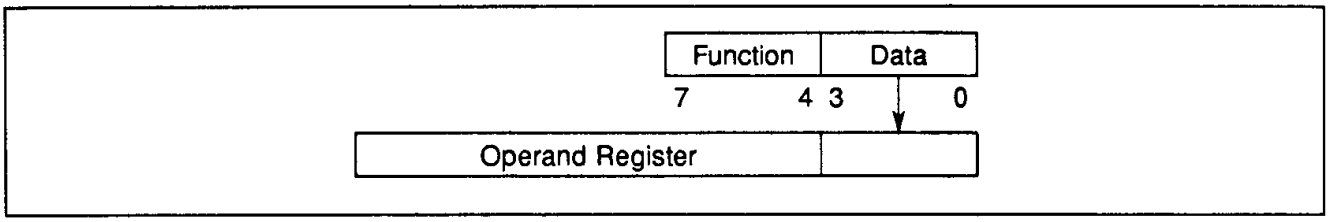


Figure 3.2 Instruction format

3.2.1 Direct functions

The representation provides for sixteen functions, each with a data value ranging from 0 to 15. Ten of these, shown in table 3.1, are used to encode the most important functions.

Table 3.1 Direct functions

load constant	*add constant*	
load local	*store local*	*load local pointer*
load non-local	*store non-local*	
jump	*conditional jump*	*call*

The most common operations in a program are the loading of small literal values and the loading and storing of one of a small number of variables. The *load constant* instruction enables values between 0 and 15 to be loaded with a single byte instruction. The *load local* and *store local* instructions access locations in memory relative to the workspace pointer. The first 16 locations can be accessed using a single byte instruction.

The *load non-local* and *store non-local* instructions behave similarly, except that they access locations in memory relative to the *A* register. Compact sequences of these instructions allow efficient access to data structures, and provide for simple implementations of the static links or displays used in the implementation of high level programming languages such as occam, C, Fortran, Pascal or ADA.

3.2.2 Prefix functions

Two more function codes allow the operand of any instruction to be extended in length; *prefix* and *negative prefix*.

All instructions are executed by loading the four data bits into the least significant four bits of the operand register, which is then used as the instruction's operand. All instructions except the prefix instructions end by clearing the operand register, ready for the next instruction.

The *prefix* instruction loads its four data bits into the operand register and then shifts the operand register up four places. The *negative prefix* instruction is similar, except that it complements the operand register before shifting it up. Consequently operands can be extended to any length up to the length of the operand register by a sequence of prefix instructions. In particular, operands in the range -256 to 255 can be represented using one prefix instruction.

The use of prefix instructions has certain beneficial consequences. Firstly, they are decoded and executed in the same way as every other instruction, which simplifies and speeds instruction decoding. Secondly, they simplify language compilation by providing a completely uniform way of allowing any instruction to take an operand of any size. Thirdly, they allow operands to be represented in a form independent of the processor wordlength.

3.2.3 Indirect functions

The remaining function code, *operate*, causes its operand to be interpreted as an operation on the values held in the evaluation stack. This allows up to 16 such operations to be encoded in a single byte instruction. However, the prefix instructions can be used to extend the operand of an *operate* instruction just like any other. The instruction representation therefore provides for an indefinite number of operations.

Encoding of the indirect functions is chosen so that the most frequently occurring operations are represented without the use of a prefix instruction. These include arithmetic, logical and comparison operations such as *add*, *exclusive or* and *greater than*. Less frequently occurring operations have encodings which require a single prefix operation.

3.2.4 Expression evaluation

Evaluation of expressions sometimes requires use of temporary variables in the workspace, but the number of these can be minimised by careful choice of the evaluation order.

Table 3.2 Expression evaluation

Program	Mnemonic	
x := 0	*ldc*	*0*
	stl	*x*
x := #24	*pfix*	*2*
	ldc	*4*
	stl	*x*
x := y + z	*ldl*	*y*
	ldl	*z*
	add	
	stl	*x*

3.2.5 Efficiency of encoding

Measurements show that about 70% of executed instructions are encoded in a single byte; that is, without the use of prefix instructions. Many of these instructions, such as *load constant* and *add* require just one processor cycle.

The instruction representation gives a more compact representation of high level language programs than more conventional instruction sets. Since a program requires less store to represent it, less of the memory bandwidth is taken up with fetching instructions. Furthermore, as memory is word accessed the processor will receive four instructions for every fetch.

Short instructions also improve the effectiveness of instruction pre-fetch, which in turn improves processor performance. There is an extra word of pre-fetch buffer, so the processor rarely has to wait for an instruction fetch before proceeding. Since the buffer is short, there is little time penalty when a jump instruction causes the buffer contents to be discarded.

3.3 Processes and concurrency

A process starts, performs a number of actions, and then either stops without completing or terminates complete. Typically, a process is a sequence of instructions. A transputer can run several processes in parallel (concurrently). Processes may be assigned either high or low priority, and there may be any number of each (page 269).

The processor has a microcoded scheduler which enables any number of concurrent processes to be executed together, sharing the processor time. This removes the need for a software kernel.

At any time, a concurrent process may be

Active
- Being executed.
- On a list waiting to be executed.

Inactive
- Ready to input.
- Ready to output.
- Waiting until a specified time.

The scheduler operates in such a way that inactive processes do not consume any processor time. It allocates a portion of the processor's time to each process in turn. Active processes waiting to be executed are held in two linked lists of process workspaces, one of high priority processes and one of low priority processes (page 269). Each list is implemented using two registers, one of which points to the first process in the list, the other to the last. In the Linked Process List figure 3.3, process *S* is executing and *P*, *Q* and *R* are active, awaiting execution. Only the low priority process queue registers are shown; the high priority process ones perform in a similar manner.

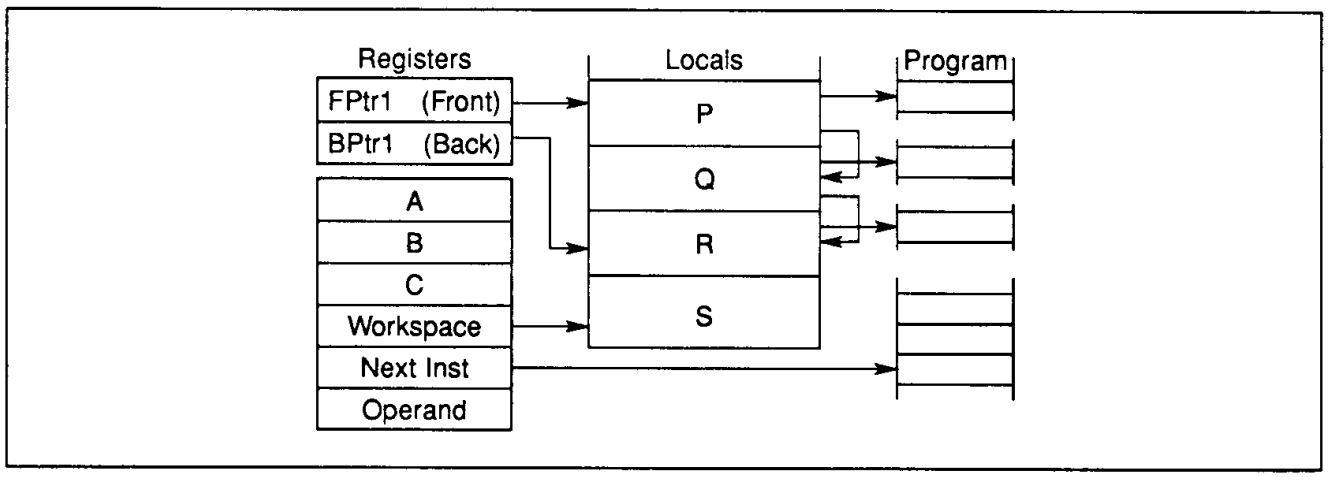


Figure 3.3 Linked process list

Table 3.3 Priority queue control registers

Function	High Priority	Low Priority
Pointer to front of active process list	*Fptr0*	*Fptr1*
Pointer to back of active process list	*Bptr0*	*Bptr1*

Each process runs until it has completed its action, but is descheduled whilst waiting for communication from another process or transputer, or for a time delay to complete. In order for several processes to operate in parallel, a low priority process is only permitted to run for a maximum of two time slices before it is forcibly descheduled at the next descheduling point (page 273). The time slice period is 5120 cycles of the external 5 MHz clock, giving ticks approximately 1 ms apart.

A process can only be descheduled on certain instructions, known as descheduling points (page 273). As a result, an expression evaluation can be guaranteed to execute without the process being timesliced part way through.

Whenever a process is unable to proceed, its instruction pointer is saved in the process workspace and the next process taken from the list. Process scheduling pointers are updated by instructions which cause scheduling operations, and should not be altered directly. Actual process switch times are less than 1 μs, as little state needs to be saved and it is not necessary to save the evaluation stack on rescheduling.

The processor provides a number of special operations to support the process model, including *start process* and *end process*. When a main process executes a parallel construct, *start process* instructions are used to create the necessary additional concurrent processes. A *start process* instruction creates a new process by adding a new workspace to the end of the scheduling list, enabling the new concurrent process to be executed together with the ones already being executed. When a process is made active it is always added to the end of the list, and thus cannot pre-empt processes already on the same list.

The correct termination of a parallel construct is assured by use of the *end process* instruction. This uses a workspace location as a counter of the parallel construct components which have still to terminate. The counter is initialised to the number of components before the processes are *started*. Each component ends with an *end process* instruction which decrements and tests the counter. For all but the last component, the counter is non zero and the component is descheduled. For the last component, the counter is zero and the main process continues.

3.4 Priority

The IMS T425 supports two levels of priority. Priority 1 (low priority) processes are executed whenever there are no active priority 0 (high priority) processes.

High priority processes are expected to execute for a short time. If one or more high priority processes are able to proceed, then one is selected and runs until it has to wait for a communication, a timer input, or until it completes processing.

If no process at high priority is able to proceed, but one or more processes at low priority are able to proceed, then one is selected.

Low priority processes are periodically timesliced to provide an even distribution of processor time between computationally intensive tasks.

If there are **n** low priority processes, then the maximum latency from the time at which a low priority process becomes active to the time when it starts processing is 2**n**-2 timeslice periods. It is then able to execute for between one and two timeslice periods, less any time taken by high priority processes. This assumes that no process monopolises the transputer's time; i.e. it has a distribution of descheduling points (page 273).

Each timeslice period lasts for 5120 cycles of the external 5 MHz input clock (approximately 1 ms at the standard frequency of 5 MHz).

If a high priority process is waiting for an external channel to become ready, and if no other high priority process is active, then the interrupt latency (from when the channel becomes ready to when the process starts executing) is typically 19 processor cycles, a maximum of 58 cycles (assuming use of on-chip RAM).

3.5 Communications

Communication between processes is achieved by means of channels. Process communication is point-to-point, synchronised and unbuffered. As a result, a channel needs no process queue, no message queue and no message buffer.

A channel between two processes executing on the same transputer is implemented by a single word in memory; a channel between processes executing on different transputers is implemented by point-to-point

links. The processor provides a number of operations to support message passing, the most important being *input message* and *output message*.

The *input message* and *output message* instructions use the address of the channel to determine whether the channel is internal or external. Thus the same instruction sequence can be used for both, allowing a process to be written and compiled without knowledge of where its channels are connected.

The process which first becomes ready must wait until the second one is also ready. A process performs an input or output by loading the evaluation stack with a pointer to a message, the address of a channel, and a count of the number of bytes to be transferred, and then executing an *input message* or *output message* instruction. Data is transferred if the other process is ready. If the channel is not ready or is an external one the process will deschedule.

3.6 Block move

The block move on the transputer moves any number of bytes from any byte boundary in memory, to any other byte boundary, using the smallest possible number of word read, and word or part-word writes.

A block move instruction can be interrupted by a high priority process. On interrupt, block move is completed to a word boundary, independent of start position. When restarting after interrupt, the last word written is written again. This appears as an unnecessary read and write in the simplest case of word aligned block moves, and may cause problems with FIFOs. This problem can be overcome by incrementing the saved destination (BregIntSaveLoc) and source pointer (CregIntSaveLoc) values by BytesPerWord during the high priority process.

3.7 Timers

The transputer has two 32 bit timer clocks which 'tick' periodically. The timers provide accurate process timing, allowing processes to deschedule themselves until a specific time.

One timer is accessible only to high priority processes and is incremented every microsecond, cycling completely in approximately 4295 seconds. The other is accessible only to low priority processes and is incremented every 64 microseconds, giving exactly 15625 ticks in one second. It has a full period of approximately 76 hours.

Table 3.4 Timer registers

Clock0	Current value of high priority (level 0) process clock
Clock1	Current value of low priority (level 1) process clock
TNextReg0	Indicates time of earliest event on high priority (level 0) timer queue
TNextReg1	Indicates time of earliest event on low priority (level 1) timer queue

The current value of the processor clock can be read by executing a *load timer* instruction. A process can arrange to perform a *timer input*, in which case it will become ready to execute after a specified time has been reached. The *timer input* instruction requires a time to be specified. If this time is in the 'past' then the instruction has no effect. If the time is in the 'future' then the process is descheduled. When the specified time is reached the process is scheduled again.

Figure 3.4 shows two processes waiting on the timer queue, one waiting for time 21, the other for time 31.

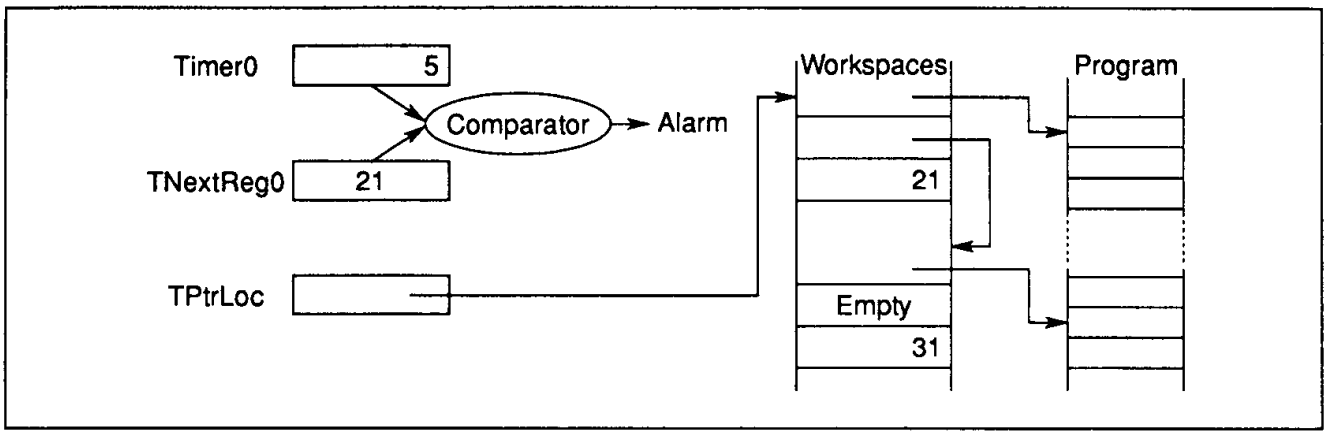


Figure 3.4 Timer registers

4 Instruction set summary

The Function Codes table 4.7. gives the basic function code set (page 266). Where the operand is less than 16, a single byte encodes the complete instruction. If the operand is greater than 15, one prefix instruction (*pfix*) is required for each additional four bits of the operand. If the operand is negative the first prefix instruction will be *nfix*.

Table 4.1 *prefix* coding

Mnemonic		Function code	Memory code
ldc	#3	#4	#43
ldc	#35		
is coded as			
pfix	#3	#2	#23
ldc	#5	#4	#45
ldc	#987		
is coded as			
pfix	#9	#2	#29
pfix	#8	#2	#28
ldc	#7	#4	#47
ldc	-31 (*ldc* #FFFFFFE1)		
is coded as			
nfix	#1	#6	#61
ldc	#1	#4	#41

Tables 4.8 to 4.21 give details of the operation codes. Where an operation code is less than 16 (e.g. *add*: operation code **05**), the operation can be stored as a single byte comprising the *operate* function code **F** and the operand (**5** in the example). Where an operation code is greater than 15 (e.g. *ladd*: operation code **16**), the *prefix* function code **2** is used to extend the instruction.

Table 4.2 *operate* coding

Mnemonic		Function code	Memory code
add	(op. code #5)		#F5
is coded as			
opr	*add*	#F	#F5
ladd	(op. code #16)		#21F6
is coded as			
pfix	#1	#2	#21
opr	#6	#F	#F6

The load device identity (*lddevid*) instruction (table 4.20) pushes the device type identity into the A register. Each product is allocated a unique group of numbers for use with the *lddevid* instruction. The product identity numbers for the IMS T425 are 0 to 9 inclusive.

The Processor Cycles column refers to the number of periods **TPCLPCL** taken by an instruction executing in internal memory. The number of cycles is given for the basic operation only; where the memory code for an instruction is two bytes, the time for the *prefix* function (one cycle) should be added. For a 20 MHz transputer one cycle is 50 ns. Some instruction times vary. Where a letter is included in the cycles column it is interpreted from table 4.3.

Table 4.3 Instruction set interpretation

Ident	Interpretation
b	Bit number of the highest bit set in register *A*. Bit 0 is the least significant bit.
m	Bit number of the highest bit set in the absolute value of register *A*. Bit 0 is the least significant bit.
n	Number of places shifted.
w	Number of words in the message. Part words are counted as full words. If the message is not word aligned the number of words is increased to include the part words at either end of the message.
p	Number of words per row.
r	Number of rows.

The **DE** column of the tables indicates the descheduling/error features of an instruction as described in table 4.4.

Table 4.4 Instruction features

Ident	Feature	See page:
D	The instruction is a descheduling point	273
E	The instruction will affect the *Error* flag	274, 285

4.1 Descheduling points

The instructions in table 4.5 are the only ones at which a process may be descheduled (page 268). They are also the ones at which the processor will halt if the **Analyse** pin is asserted (page 284).

Table 4.5 Descheduling point instructions

input message	*output message*	*output byte*	*output word*
timer alt wait	*timer input*	*stop on error*	*alt wait*
jump	*loop end*	*end process*	*stop process*

4.2 Error instructions

The instructions in table 4.6 are the only ones which can affect the *Error* flag (page 285) directly.

Table 4.6 Error setting instructions

add	*add constant*	*subtract*	
multiply	*fractional multiply*	*divide*	*remainder*
long add	*long subtract*	*long divide*	
set error	*testerr*		*cflerr*
check word	*check subscript from 0*	*check single*	*check count from 1*

4.3 Debugging support

Table 4.21 contains a number of instructions to facilitate the implementation of breakpoints. These instructions overload the operation of *j0*. Normally *j0* is a no-op which might cause descheduling. *Setj0break* enables the breakpointing facilities and causes *j0* to act as a breakpointing instruction. When breakpointing is enabled, *j0* swaps the current **Iptr** and **Wptr** with an **Iptr** and **Wptr** stored above MemStart. The breakpoint instruction does not cause descheduling, and preserves the state of the registers. It is possible to single step the processor at machine level using these instructions. Refer to *Support for debugging/breakpointing in transputers* (technical note 61) for more detailed information regarding debugger support.

Table 4.7 IMS T425 function codes

Function Code	Memory Code	Mnemonic	Processor Cycles	Name	D E
0	0X	j	3	jump	D
1	1X	ldlp	1	load local pointer	
2	2X	pfix	1	prefix	
3	3X	ldnl	2	load non-local	
4	4X	ldc	1	load constant	
5	5X	ldnlp	1	load non-local pointer	
6	6X	nfix	1	negative prefix	
7	7X	ldl	2	load local	
8	8X	adc	1	add constant	E
9	9X	call	7	call	
A	AX	cj	2	conditional jump (not taken)	
			4	conditional jump (taken)	
B	BX	ajw	1	adjust workspace	
C	CX	eqc	2	equals constant	
D	DX	stl	1	store local	
E	EX	stnl	2	store non-local	
F	FX	opr	-	operate	

Table 4.8 IMS T425 arithmetic/logical operation codes

Operation Code	Memory Code	Mnemonic	Processor Cycles	Name	D E
46	24F6	and	1	and	
4B	24FB	or	1	or	
33	23F3	xor	1	exclusive or	
32	23F2	not	1	bitwise not	
41	24F1	shl	**n**+2	shift left	
40	24F0	shr	**n**+2	shift right	
05	F5	add	1	add	E
0C	FC	sub	1	subtract	E
53	25F3	mul	38	multiply	E
72	27F2	fmul	35	fractional multiply (no rounding)	E
			40	fractional multiply (rounding)	E
2C	22FC	div	39	divide	E
1F	21FF	rem	37	remainder	E
09	F9	gt	2	greater than	
04	F4	diff	1	difference	
52	25F2	sum	1	sum	
08	F8	prod	**b**+4	product for positive register *A*	
			m+5	product for negative register *A*	

Table 4.9 IMS T425 long arithmetic operation codes

Operation Code	Memory Code	Mnemonic	Processor Cycles	Name	D E
16	21F6	ladd	2	long add	E
38	23F8	lsub	2	long subtract	E
37	23F7	lsum	3	long sum	
4F	24FF	ldiff	3	long diff	
31	23F1	lmul	33	long multiply	
1A	21FA	ldiv	35	long divide	E
36	23F6	lshl	**n**+3	long shift left (**n**<32)	
			n-28	long shift left(**n**≥32)	
35	23F5	lshr	**n**+3	long shift right (**n**<32)	
			n-28	long shift right (**n**≥32)	
19	21F9	norm	**n**+5	normalise (**n**<32)	
			n-26	normalise (**n**≥32)	
			3	normalise (**n**=64)	

Table 4.10 IMS T425 general operation codes

Operation Code	Memory Code	Mnemonic	Processor Cycles	Name	D E
00	F0	rev	1	reverse	
3A	23FA	xword	4	extend to word	
56	25F6	cword	5	check word	E
1D	21FD	xdble	2	extend to double	
4C	24FC	csngl	3	check single	E
42	24F2	mint	1	minimum integer	
5A	25FA	dup	1	duplicate top of stack	
79	27F9	pop	1	pop processor stack	

Table 4.11 IMS T425 floating point support operation codes

Operation Code	Memory Code	Mnemonic	Processor Cycles	Name	D E
73	27F3	cflerr	3	check floating point error	E
9C	29FC	fptesterr	1	load value true (FPU not present)	
63	26F3	unpacksn	15	unpack single length fp number	
6D	26FD	roundsn	12/15	round single length fp number	
6C	26FC	postnormsn	5/30	post-normalise correction of single length fp number	
71	27F1	ldinf	1	load single length infinity	

Processor cycles are shown as **Typical/Maximum** cycles.

Table 4.12 IMS T425 2D block move operation codes

Operation Code	Memory Code	Mnemonic	Processor Cycles	Name	D E
5B	25FB	move2dinit	8	initialise data for 2D block move	
5C	25FC	move2dall	(2p+23)*r	2D block copy	
5D	25FD	move2dnonzero	(2p+23)*r	2D block copy non-zero bytes	
5E	25FE	move2dzero	(2p+23)*r	2D block copy zero bytes	

Table 4.13 IMS T425 CRC and bit operation codes

Operation Code	Memory Code	Mnemonic	Processor Cycles	Name	D E
74	27F4	crcword	35	calculate crc on word	
75	27F5	crcbyte	11	calculate crc on byte	
76	27F6	bitcnt	b+2	count bits set in word	
77	27F7	bitrevword	36	reverse bits in word	
78	27F8	bitrevnbits	n+4	reverse bottom n bits in word	

Table 4.14 IMS T425 indexing/array operation codes

Operation Code	Memory Code	Mnemonic	Processor Cycles	Name	D E
02	F2	bsub	1	byte subscript	
0A	FA	wsub	2	word subscript	
81	28F1	wsubdb	3	form double word subscript	
34	23F4	bcnt	2	byte count	
3F	23FF	wcnt	5	word count	
01	F1	lb	5	load byte	
3B	23FB	sb	4	store byte	
4A	24FA	move	2w+8	move message	

Table 4.15 IMS T425 timer handling operation codes

Operation Code	Memory Code	Mnemonic	Processor Cycles	Name	D E
22	22F2	ldtimer	2	load timer	
2B	22FB	tin	30	timer input (time future)	D
			4	timer input (time past)	D
4E	24FE	talt	4	timer alt start	
51	25F1	taltwt	15	timer alt wait (time past)	D
			48	timer alt wait (time future)	D
47	24F7	enbt	8	enable timer	
2E	22FE	dist	23	disable timer	

Table 4.16 IMS T425 input/output operation codes

Operation Code	Memory Code	Mnemonic	Processor Cycles	Name	D E
07	F7	in	2w+19	input message	D
0B	FB	out	2w+19	output message	D
0F	FF	outword	23	output word	D
0E	FE	outbyte	23	output byte	D
43	24F3	alt	2	alt start	
44	24F4	altwt	5	alt wait (channel ready)	D
			17	alt wait (channel not ready)	D
45	24F5	altend	4	alt end	
49	24F9	enbs	3	enable skip	
30	23F0	diss	4	disable skip	
12	21F2	resetch	3	reset channel	
48	24F8	enbc	7	enable channel (ready)	
			5	enable channel (not ready)	
2F	22FF	disc	8	disable channel	

Table 4.17 IMS T425 control operation codes

Operation Code	Memory Code	Mnemonic	Processor Cycles	Name	D E
20	22F0	ret	5	return	
1B	21FB	ldpi	2	load pointer to instruction	
3C	23FC	gajw	2	general adjust workspace	
06	F6	gcall	4	general call	
21	22F1	lend	10	loop end (loop)	D
			5	loop end (exit)	D

Table 4.18 IMS T425 scheduling operation codes

Operation Code	Memory Code	Mnemonic	Processor Cycles	Name	D E
0D	FD	startp	12	start process	D
03	F3	endp	13	end process	D
39	23F9	runp	10	run process	
15	21F5	stopp	11	stop process	
1E	21FE	ldpri	1	load current priority	

Table 4.19 IMS T425 error handling operation codes

Operation Code	Memory Code	Mnemonic	Processor Cycles	Name	D E
13	21F3	csub0	2	check subscript from 0	E
4D	24FD	ccnt1	3	check count from 1	E
29	22F9	testerr	2	test error false and clear (no error)	
			3	test error false and clear (error)	
10	21F0	seterr	1	set error	E
55	25F5	stoperr	2	stop on error (no error)	D
57	25F7	clrhalterr	1	clear halt-on-error	
58	25F8	sethalterr	1	set halt-on-error	
59	25F9	testhalterr	2	test halt-on-error	

Table 4.20 IMS T425 processor initialisation operation codes

Operation Code	Memory Code	Mnemonic	Processor Cycles	Name	D E
2A	22FA	testpranal	2	test processor analysing	
3E	23FE	saveh	4	save high priority queue registers	
3D	23FD	savel	4	save low priority queue registers	
18	21F8	sthf	1	store high priority front pointer	
50	25F0	sthb	1	store high priority back pointer	
1C	21FC	stlf	1	store low priority front pointer	
17	21F7	stlb	1	store low priority back pointer	
54	25F4	sttimer	1	store timer	
17C	2127FC	lddevid	1	load device identity	
7E	27FE	ldmemstartval	1	load value of memstart address	

Table 4.21 IMS T425 debugger support codes

Operation Code	Memory Code	Mnemonic	Processor Cycles	Name	D E
0	00	jump 0	3	jump 0 (break not enabled)	D
			11	jump 0 (break enabled, high priority)	
			13	jump 0 (break enabled, low priority)	
B1	2BF1	break	9	break (high priority)	
			11	break (low priority)	
B2	2BF2	clrj0break	1	clear jump 0 break enable flag	
B3	2BF3	setj0break	1	set jump 0 break enable flag	
B4	2BF4	testj0break	2	test jump 0 break enable flag set	
7A	27FA	timerdisableh	1	disable high priority timer interrupt	
7B	27FB	timerdisablel	1	disable low priority timer interrupt	
7C	27FC	timerenableh	6	enable high priority timer interrupt	
7D	27FD	timerenablel	6	enable low priority timer interrupt	

5 System services

System services include all the necessary logic to initialise and sustain operation of the device. They also include error handling and analysis facilities.

5.1 Power

Power is supplied to the device via the **VCC** and **GND** pins. Several of each are provided to minimise inductance within the package. All supply pins must be connected. The supply must be decoupled close to the chip by at least one 100 nF low inductance (e.g. ceramic) capacitor between **VCC** and **GND**. Four layer boards are recommended; if two layer boards are used, extra care should be taken in decoupling.

Input voltages must not exceed specification with respect to **VCC** and **GND**, even during power-up and power-down ramping, otherwise *latchup* can occur. CMOS devices can be permanently damaged by excessive periods of latchup.

5.2 CapPlus, CapMinus

The internally derived power supply for internal clocks requires an external low leakage, low inductance 1μF capacitor to be connected between **CapPlus** and **CapMinus**. A ceramic capacitor is preferred, with an impedance less than 3 Ohms between 100 KHz and 10 MHz. If a polarised capacitor is used the negative terminal should be connected to **CapMinus**. Total PCB track length should be less than 50 mm. The connections must not touch power supplies or other noise sources.

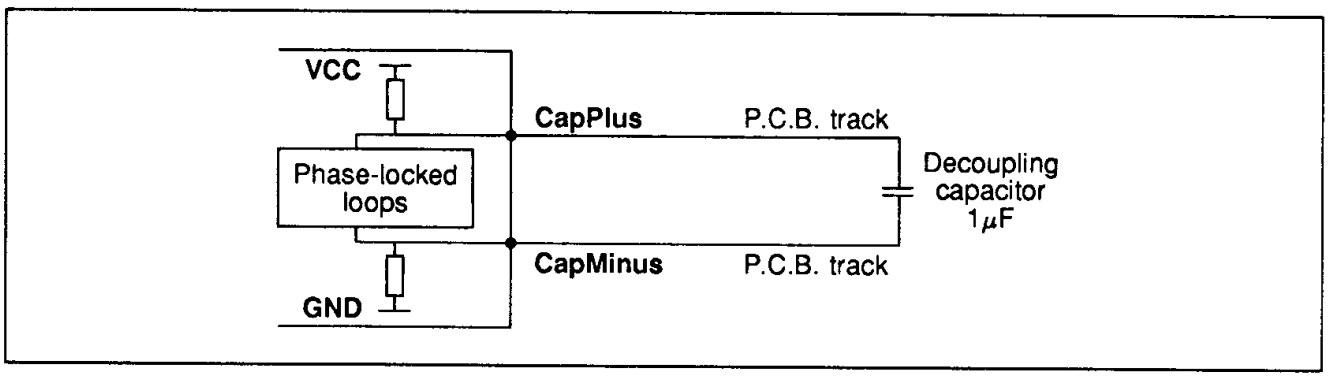


Figure 5.1 Recommended PLL decoupling

5.3 ClockIn

Transputer family components use a standard clock frequency, supplied by the user on the **ClockIn** input. The nominal frequency of this clock for all transputer family components is 5 MHz, regardless of device type, transputer word length or processor cycle time. High frequency internal clocks are derived from **ClockIn**, simplifying system design and avoiding problems of distributing high speed clocks externally.

A number of transputer devices may be connected to a common clock, or may have individual clocks providing each one meets the specified stability criteria. In a multi-clock system the relative phasing of **ClockIn** clocks is not important, due to the asynchronous nature of the links. Mark/space ratio is unimportant provided the specified limits of **ClockIn** pulse widths are met.

Oscillator stability is important. **ClockIn** must be derived from a crystal oscillator; RC oscillators are not sufficiently stable. **ClockIn** must not be distributed through a long chain of buffers. Clock edges must be monotonic and remain within the specified voltage and time limits.

Table 5.1 Input clock

SYMBOL	PARAMETER	MIN	NOM	MAX	UNITS	NOTE
TDCLDCH	ClockIn pulse width low	40			ns	1
TDCHDCL	ClockIn pulse width high	40			ns	1
TDCLDCL	ClockIn period		200		ns	1,2,4
TDCerror	ClockIn timing error			±0.5	ns	1,3
TDC1DC2	Difference in ClockIn for 2 linked devices			400	ppm	1,4
TDCr	ClockIn rise time			10	ns	1,5
TDCf	ClockIn fall time			8	ns	1,5

Notes

1 These paramters are not tested.

2 Measured between corresponding points on consecutive falling edges.

3 Variation of individual falling edges from their nominal times.

4 This value allows the use of 200ppm crystal oscillators for two devices connected together by a link.

5 Clock transitions must be monotonic within the range **VIH** to **VIL** (table 10.3).

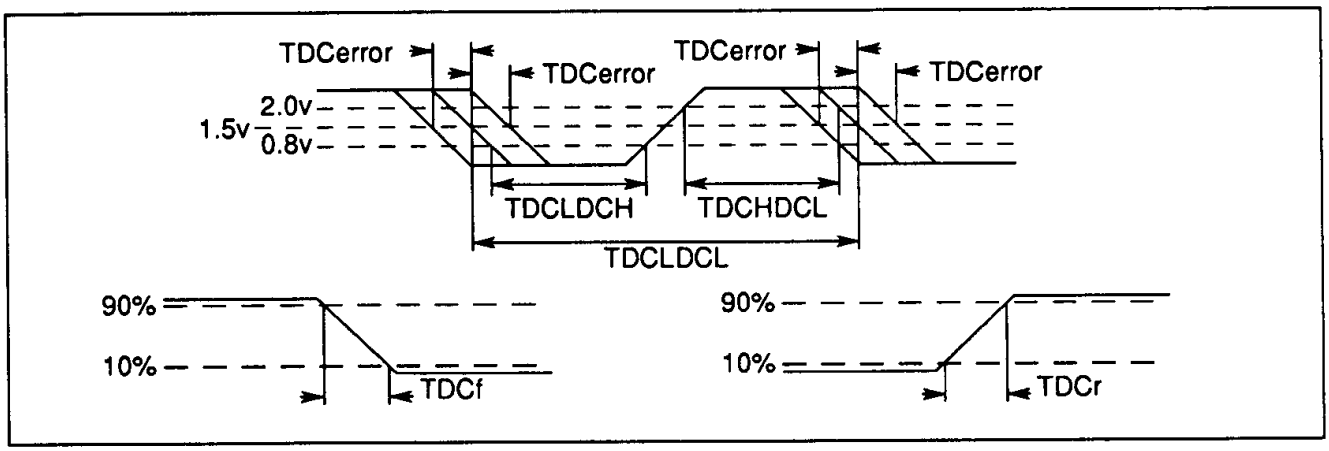


Figure 5.2 ClockIn timing

5.4 ProcSpeedSelect0-2

Processor speed of the IMS T425 is variable in discrete steps. The desired speed can be selected, up to the maximum rated for a particular component, by the three speed select lines **ProcSpeedSelect0-2**. The pins are tied high or low, according to the table below, for the various speeds. The pins are arranged so that the IMS T425 can be plugged directly into a board designed for a IMS T800.

Only six of the possible speed select combinations are currently used; the other two are not valid speed selectors. The frequency of **ClockIn** for the speeds given in the table is 5 MHz.

Table 5.2 Processor speed selection

Proc Speed Select2	Proc Speed Select1	Proc Speed Select0	Processor Clock Speed MHz	Processor Cycle Time ns	Notes
0	0	0	20.0	50.0	
0	0	1	22.5	44.4	
0	1	0	25.0	40.0	
0	1	1	30.0	33.3	
1	0	0	35.0	28.6	
1	0	1			Invalid
1	1	0	17.5	57.1	
1	1	1			Invalid

Note: Inclusion of a speed selection in this table does not imply immediate availability.

5.5 Reset

Reset can go high with **VCC**, but must at no time exceed the maximum specified voltage for **VIH**. After **VCC** is valid **ClockIn** should be running for a minimum period **TDCVRL** before the end of **Reset**. The falling edge of **Reset** initialises the transputer, triggers the memory configuration sequence and starts the bootstrap routine. Link outputs are forced low during reset; link inputs and **EventReq** should be held low. Memory request (DMA) must not occur whilst **Reset** is high but can occur before bootstrap (page 308).

After the end of **Reset** there will be a delay of 144 periods of **ClockIn** (figure 5.3). Following this, the **MemWrD0**, **MemRfD1** and **MemAD2-31** pins will be scanned to check for the existence of a pre-programmed memory interface configuration (page 297). This lasts for a further 144 periods of **ClockIn**. Regardless of whether a configuration was found, 36 configuration read cycles will then be performed on external memory using the default memory configuration (page 299), in an attempt to access the external configuration ROM. A delay will then occur, its period depending on the actual configuration. Finally eight complete and consecutive refresh cycles will initialise any dynamic RAM, using the new memory configuration. If the memory configuration does not enable refresh of dynamic RAM the refresh cycles will be replaced by an equivalent delay with no external memory activity.

If **BootFromRom** is high bootstrapping will then take place immediately, using data from external memory; otherwise the transputer will await an input from any link. The processor will be in the low priority state.

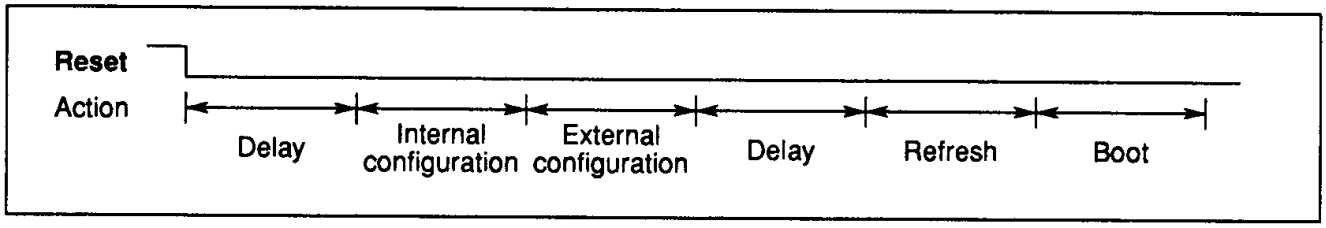


Figure 5.3 IMS T425 post-reset sequence

5.6 Bootstrap

The transputer can be bootstrapped either from a link or from external ROM. To facilitate debugging, **BootFromRom** may be dynamically changed but must obey the specified timing restrictions. It is sampled once only by the transputer, before the first instruction is executed after **Reset** is taken low.

If **BootFromRom** is connected high (e.g. to **VCC**) the transputer starts to execute code from the top two bytes in external memory, at address #7FFFFFFE. This location should contain a backward jump to a program in ROM. Following this access, **BootFromRom** may be taken low if required. The processor is in the low priority

state, and the *W* register points to *MemStart* (page 286).

Table 5.3 Reset and Analyse

SYMBOL	PARAMETER	MIN	NOM	MAX	UNITS	NOTE
TPVRH	Power valid before Reset	10			ms	
TRHRL	Reset pulse width high	8			ClockIn	1
TDCVRL	ClockIn running before Reset end	10			ms	2
TAHRH	Analyse setup before Reset	3			ms	
TRLAL	Analyse hold after Reset end	1			ClockIn	1
TBRVRL	BootFromRom setup	0			ms	
TRLBRX	BootFromRom hold after Reset	0			ms	3
TALBRX	BootFromRom hold after Analyse					3

Notes

1 Full periods of **ClockIn TDCLDCL** required.

2 At power-on reset.

3 Must be stable until after end of bootstrap period. See Bootstrap section.

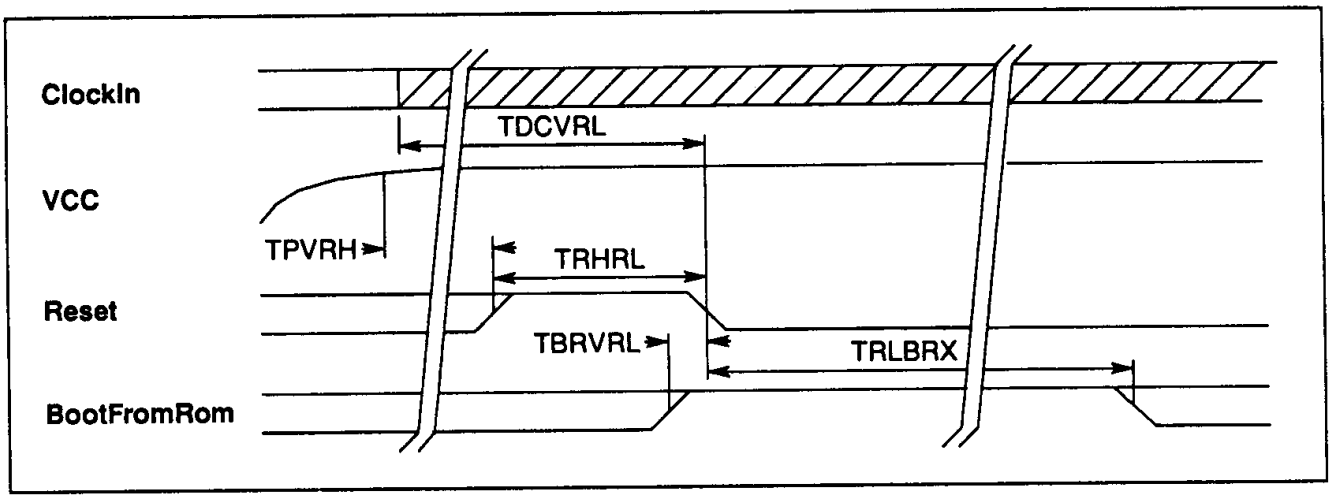


Figure 5.4 Transputer reset timing with Analyse low

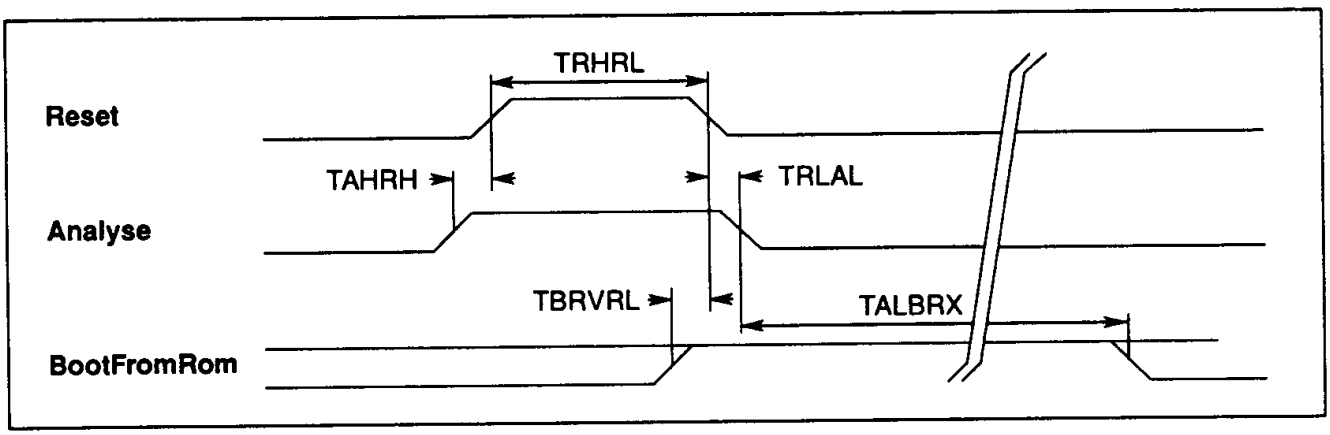


Figure 5.5 Transputer reset and analyse timing

If **BootFromRom** is connected low (e.g. to **GND**) the transputer will wait for the first bootstrap message to arrive on any one of its links. The transputer is ready to receive the first byte on a link within two processor cycles **TPCLPCL** after **Reset** goes low.

If the first byte received (the control byte) is greater than 1 it is taken as the quantity of bytes to be input. The following bytes, to that quantity, are then placed in internal memory starting at location *MemStart*. Following reception of the last byte the transputer will start executing code at *MemStart* as a low priority process. **BootFromRom** may be taken high after reception of the last byte, if required. The memory space immediately above the loaded code is used as work space. Messages arriving on other links after the control byte has been received and on the bootstrapping link after the last bootstrap byte will be retained until a process inputs from them.

5.7 Peek and poke

Any location in internal or external memory can be interrogated and altered when the transputer is waiting for a bootstrap from link. If the control byte is 0 then eight more bytes are expected on the same link. The first four byte word is taken as an internal or external memory address at which to poke (write) the second four byte word. If the control byte is 1 the next four bytes are used as the address from which to peek (read) a word of data; the word is sent down the output channel of the same link.

Following such a peek or poke, the transputer returns to its previously held state. Any number of accesses may be made in this way until the control byte is greater than 1, when the transputer will commence reading its bootstrap program. Any link can be used, but addresses and data must be transmitted via the same link as the control byte.

5.8 Analyse

If **Analyse** is taken high when the transputer is running, the transputer will halt at the next descheduling point (page 273). From **Analyse** being asserted, the processor will halt within three time slice periods plus the time taken for any high priority process to complete. As much of the transputer status is maintained as is necessary to permit analysis of the halted machine. Processor flags **Error**, **HaltOnError** and **EnableJ0Break** are normally cleared at reset on the IMS T425; however, if **Analyse** is asserted the flags are not altered. Memory refresh continues.

Input links will continue with outstanding transfers. Output links will not make another access to memory for data but will transmit only those bytes already in the link buffer. Providing there is no delay in link acknowledgement, the links should be inactive within a few microseconds of the transputer halting.

Reset should not be asserted before the transputer has halted and link transfers have ceased. When **Reset** is taken low whilst **Analyse** is high, neither the memory configuration sequence nor the block of eight refresh cycles will occur; the previous memory configuration will be used for any external memory accesses. If **BootFromRom** is high the transputer will bootstrap as soon as **Analyse** is taken low, otherwise it will await a control byte on any link. If **Analyse** is taken low without **Reset** going high the transputer state and operation are undefined. After the end of a valid **Analyse** sequence the registers have the values given in table 5.4.

Table 5.4 Register values after Analyse

I	*MemStart* if bootstrapping from a link, or the external memory bootstrap address if bootstrapping from ROM.
W	*MemStart* if bootstrapping from ROM, or the address of the first free word after the bootstrap program if bootstrapping from link.
A	The value of *I* when the processor halted.
B	The value of *W* when the processor halted, together with the priority of the process when the transputer was halted (i.e. the *W* descriptor).
C	The ID of the bootstrapping link if bootstrapping from link.

5.9 Error, ErrorIn

The **Error** pin carries the OR'ed output of the internal *Error* flag and the **ErrorIn** input. If **Error** is high it indicates either that **ErrorIn** is high or that an error was detected in one of the processes. An internal error can be caused, for example, by arithmetic overflow, divide by zero, array bounds violation or software setting the flag directly (page 274). Once set, the *Error* flag is only cleared by executing the instruction *testerr*. The error is not cleared by processor reset, in order that analysis can identify any errant transputer (page 284).

A process can be programmed to stop if the *Error* flag is set; it cannot then transmit erroneous data to other processes, but processes which do not require that data can still be scheduled. Eventually all processes which rely, directly or indirectly, on data from the process in error will stop through lack of data. **ErrorIn** does not directly affect the status of a processor in any way.

By setting the *HaltOnError* flag the transputer itself can be programmed to halt if *Error* becomes set. If *Error* becomes set after *HaltOnError* has been set, all processes on that transputer will cease but will not necessarily cause other transputers in a network to halt. Setting *HaltOnError* after *Error* will not cause the transputer to halt; this allows the processor reset and analyse facilities to function with the flags in indeterminate states.

An alternative method of error handling is to have the errant process or transputer cause all transputers to halt. This can be done by 'daisy-chaining' the **ErrorIn** and **Error** pins of a number of processors and applying the final **Error** output signal to the **EventReq** pin of a suitably programmed master transputer. Since the process state is preserved when stopped by an error, the master transputer can then use the analyse function to debug the fault. When using such a circuit, note that the *Error* flag is in an indeterminate state on power up; the circuit and software should be designed with this in mind.

Error checks can be removed completely to optimise the performance of a proven program; any unexpected error then occurring will have an arbitrary undefined effect.

If a high priority process pre-empts a low priority one, status of the *Error* and *HaltOnError* flags is saved for the duration of the high priority process and restored at the conclusion of it. Status of both flags is transmitted to the high priority process. Either flag can be altered in the process without upsetting the error status of any complex operation being carried out by the pre-empted low priority process.

In the event of a transputer halting because of *HaltOnError*, the links will finish outstanding transfers before shutting down. If **Analyse** is asserted then all inputs continue but outputs will not make another access to memory for data. Memory refresh will continue to take place.

After halting due to the *Error* flag changing from 0 to 1 whilst *HaltOnError* is set, register *I* points two bytes past the instruction which set *Error*. After halting due to the **Analyse** pin being taken high, register *I* points one byte past the instruction being executed. In both cases *I* will be copied to register *A*.

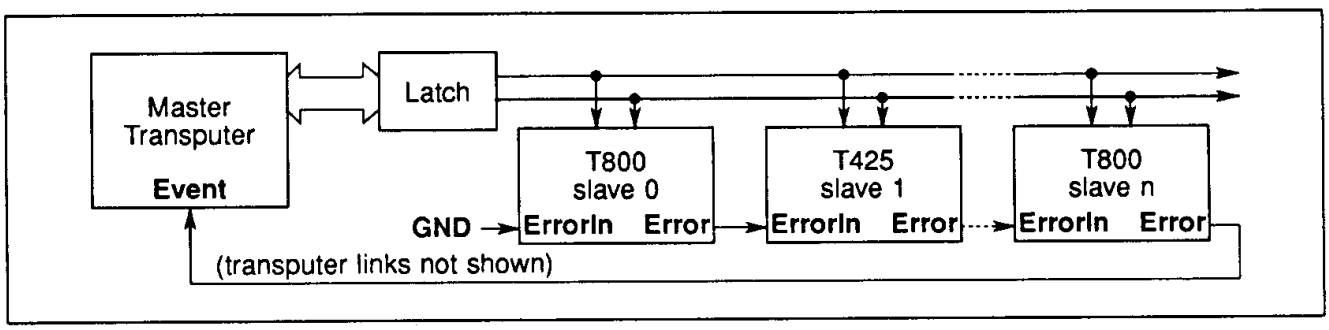


Figure 5.6 Error handling in a multi-transputer system

6 Memory

The IMS T425 has 4 Kbytes of fast internal static memory for high rates of data throughput. Each internal memory access takes one processor cycle **ProcClockOut** (page 288). The transputer can also access 4 Gbytes of external memory space. Internal and external memory are part of the same linear address space. Internal RAM can be disabled by holding **DisableIntRAM** high. All internal addresses are then mapped to external RAM. This pin should not be altered after **Reset** has been taken low.

IMS T425 memory is byte addressed, with words aligned on four-byte boundaries. The least significant byte of a word is the lowest addressed byte.

The bits in a byte are numbered 0 to 7, with bit 0 the least significant. The bytes are numbered from 0, with byte 0 the least significant. In general, wherever a value is treated as a number of component values, the components are numbered in order of increasing numerical significance, with the least significant component numbered 0. Where values are stored in memory, the least significant component value is stored at the lowest (most negative) address.

Internal memory starts at the most negative address #80000000 and extends to #80000FFF. User memory begins at #80000070; this location is given the name *MemStart*. An instruction *ldmemstartval* is provided to obtain the value of **MemStart**.

The context of a process in the transputer model involves a workspace descriptor (**WPtr**) and an instruction pointer (**IPtr**). **WPtr** is a word address pointer to a workspace in memory. **IPtr** points to the next instruction to be executed for the process which is the currently executing process. The context switch performed by the breakpoint instruction swaps the **WPtr** and **IPtr** of the currently executing process with the **WPtr** and **IPtr** held above **MemStart**. Two contexts are held above **MemStart**, one for high priority and one for low priority; this allows processes at both levels to have breakpoints. Note that on bootstrapping from a link, these contexts are overwritten by the loaded code. If this is not acceptable, the values should be peeked from memory before bootstrapping from a link.

The reserved area of internal memory below *MemStart* is used to implement link and event channels.

Two words of memory are reserved for timer use, *TPtrLoc0* for high priority processes and *TPtrLoc1* for low priority processes. They either indicate the relevant priority timer is not in use or point to the first process on the timer queue at that priority level.

Values of certain processor registers for the current low priority process are saved in the reserved *IntSaveLoc* locations when a high priority process pre-empts a low priority one. Other locations are reserved for extended features such as block moves.

External memory space starts at #80001000 and extends up through #00000000 to #7FFFFFFF. Memory configuration data and ROM bootstrapping code must be in the most positive address space, starting at #7FFFFF6C and #7FFFFFFE respectively. Address space immediately below this is conventionally used for ROM based code.

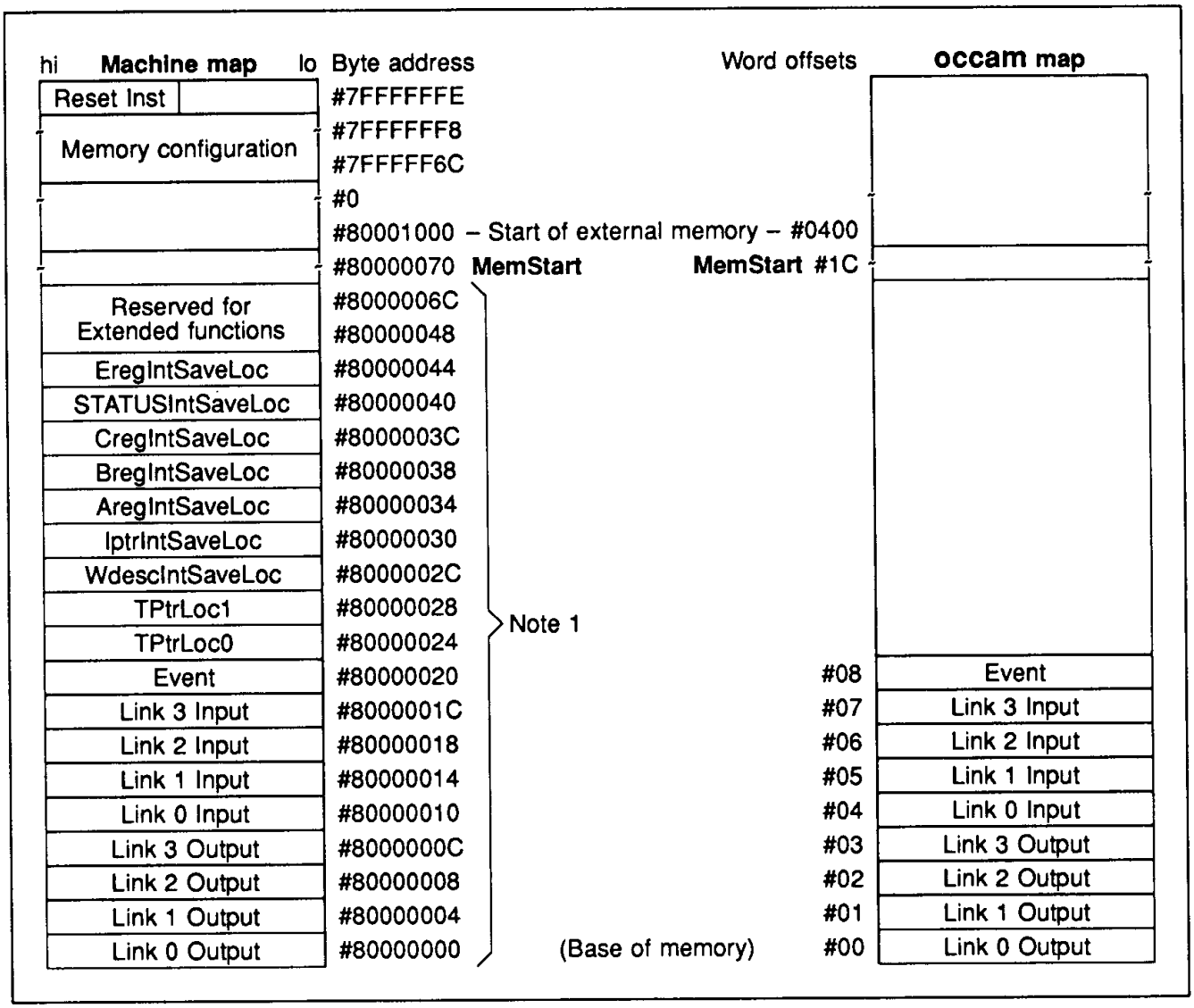


Figure 6.1 IMS T425 memory map

Notes

1 These locations are used as auxiliary processor registers and should not be manipulated by the user. Like processor registers, their contents may be useful for implementing debugging tools (**Analyse**, page 284). For details see *Transputer Instruction Set - A Compiler Writers' Guide.*

7 External memory interface

The External Memory Interface (EMI) allows access to a 32 bit address space, supporting dynamic and static RAM as well as ROM and EPROM. EMI timing can be configured at **Reset** to cater for most memory types and speeds, and a program is supplied with the Transputer Development System to aid in this configuration.

There are 17 internal configurations which can be selected by a single pin connection (page 297). If none are suitable the user can configure the interface to specific requirements, as shown in page 299.

7.1 ProcClockOut

This clock is derived from the internal processor clock, which is in turn derived from **ClockIn**. Its period is equal to one internal microcode cycle time, and can be derived from the formula

TPCLPCL = TDCLDCL / PLLx

where **TPCLPCL** is the **ProcClockOut Period**, **TDCLDCL** is the **ClockIn Period** and **PLLx** is the phase lock loop factor for the relevant speed part, obtained from the ordering details (Ordering section).

The time value **Tm** is used to define the duration of **Tstates** and, hence, the length of external memory cycles; its value is exactly half the period of one **ProcClockOut** cycle (0.5*TPCLPCL), regardless of mark/space ratio of **ProcClockOut**.

Edges of the various external memory strobes coincide with rising or falling edges of **ProcClockOut**. It should be noted, however, that there is a skew associated with each coincidence. The value of skew depends on whether coincidence occurs when the **ProcClockOut** edge and strobe edge are both rising, when both are falling or if either is rising when the other is falling. Timing values given in the strobe tables show the best and worst cases. If a more accurate timing relationship is required, the exact **Tstate** timing and strobe edge to **ProcClockOut** relationships should be calculated and the correct skew factors applied from the edge skew timing table 7.4.

The timing parameters in the following tables are based on 17 MHz and 20 MHz parts. Data for higher speeds is based on tests on a limited number of samples and may change when full characterisation is completed.

7.2 Tstates

The external memory cycle is divided into six **Tstates** with the following functions:

- **T1** Address setup time before address valid strobe.
- **T2** Address hold time after address valid strobe.
- **T3** Read cycle tristate or write cycle data setup.
- **T4** Extendable data setup time.
- **T5** Read or write data.
- **T6** Data hold.

Under normal conditions each **Tstate** may be from one to four periods **Tm** long, the duration being set during memory configuration. The default condition on **Reset** is that all **Tstates** are the maximum four periods **Tm** long to allow external initialisation cycles to read slow ROM.

Period **T4** can be extended indefinitely by adding externally generated wait states.

An external memory cycle is always an even number of periods **Tm** in length and the start of **T1** always coincides with a rising edge of **ProcClockOut**. If the total configured quantity of periods **Tm** is an odd number, one extra period **Tm** will be added at the end of **T6** to force the start of the next **T1** to coincide with a rising edge of **ProcClockOut**. This period is designated **E** in configuration diagrams (figure 7.11).

Table 7.1 ProcClockOut

SYMBOL	PARAMETER	MIN	NOM	MAX	UNITS	NOTE
TPCLPCL	ProcClockOut period	**a**-2	**a**	**a**+2	ns	1,5
TPCHPCL	ProcClockOut pulse width high	**b**-11.5	**b**	**b**+3.5	ns	2,5
TPCLPCH	ProcClockOut pulse width low		**c**		ns	3,5
Tm	ProcClockOut half cycle	**b**-1	**b**	**b**+1	ns	2,5
TPCstab	ProcClockOut stability			8	%	4,5

Notes

1 **a** is **TDCLDCL/PLLx**.

2 **b** is 0.5*__TPCLPCL__ (half the processor clock period).

3 **c** is **TPCLPCL-TPCHPCL**.

4 Stability is the variation of cycle periods between two consecutive cycles, measured at corresponding points on the cycles.

5 This parameter is sampled and not 100% tested.

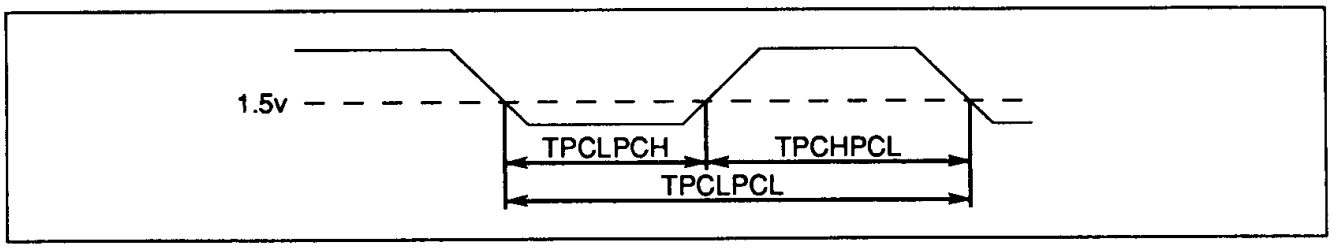


Figure 7.1 IMS T425 ProcClockOut timing

7.3 Internal access

During an internal memory access cycle the external memory interface bus **MemAD2-31** reflects the word address used to access internal RAM, **MemnotWrD0** reflects the read/write operation and **MemnotRfD1** is high; all control strobes are inactive. This is true unless and until a memory refresh cycle or DMA (memory request) activity takes place, when the bus will carry the appropriate external address or data.

The bus activity is not adequate to trace the internal operation of the transputer in full, but may be used for hardware debugging in conjuction with peek and poke (page 284).

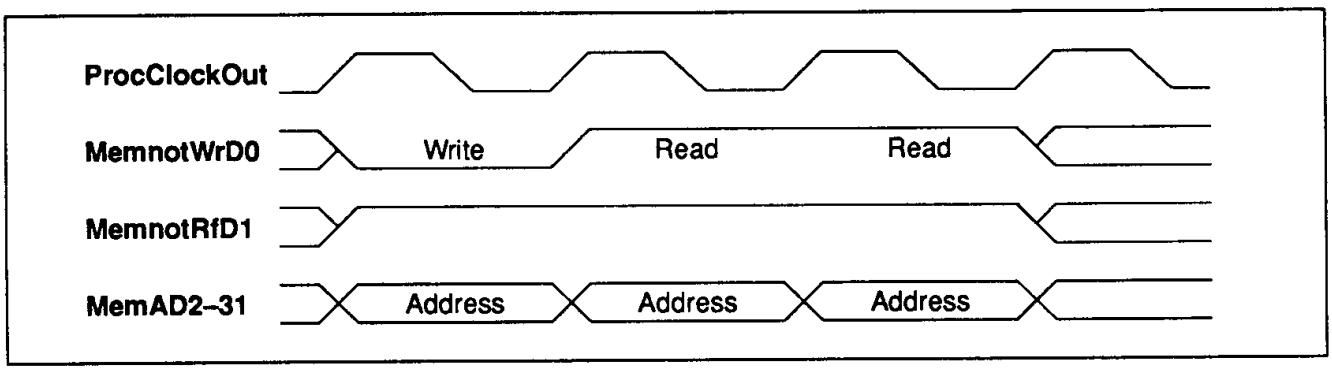


Figure 7.2 IMS T425 bus activity for internal memory cycle

7.4 MemAD2-31

External memory addresses and data are multiplexed on one bus. Only the top 30 bits of address are output on the external memory interface, using pins **MemAD2-31**. They are normally output only during **Tstates T1** and **T2**, and should be latched during this time. Byte addressing is carried out internally by the transputer for read cycles. For write cycles the relevant bytes in memory are addressed by the write strobes **notMemWrB0-3**.

The data bus is 32 bits wide. It uses **MemAD2-31** for the top 30 bits and **MemnotRfD1** and **MemnotWrD0** for the lower two bits. Read cycle data may be set up on the bus at any time after the start of **T3**, but must be valid when the transputer reads it at the end of **T5**. Data may be removed any time during **T6**, but must be off the bus no later than the end of that period.

Write data is placed on the bus at the start of **T3** and removed at the end of **T6**. If **T6** is extended to force the next cycle **Tmx** (page 290) to start on a rising edge of **ProcClockOut**, data will be valid during this time also.

7.5 MemnotWrD0

During **T1** and **T2** this pin will be low if the cycle is a write cycle, otherwise it will be high. During **Tstates T3** to **T6** it becomes bit 0 of the data bus. In both cases it follows the general timing of **MemAD2-31**.

7.6 MemnotRfD1

During **T1** and **T2**, this pin is low if the address on **MemAD2-31** is a refresh address, otherwise it is high. During **Tstates T3** to **T6** it becomes bit 1 of the data bus. In both cases it follows the general timing of **MemAD2-31**.

7.7 notMemRd

For a read cycle the read strobe **notMemRd** is low during **T4** and **T5**. Data is read by the transputer on the rising edge of this strobe, and may be removed immediately afterward. If the strobe duration is insufficient it may be extended by adding extra periods **Tm** to either or both of the **Tstates T4** and **T5**. Further extension may be obtained by inserting wait states at the end of **T4**.

In the read cycle timing diagrams **ProcClockOut** is included as a guide only; it is shown with each **Tstate** configured to one period **Tm**.

7.8 notMemS0-4

To facilitate control of different types of memory and devices, the EMI is provided with five strobe outputs, four of which can be configured by the user. The strobes are conventionally assigned the functions shown in the read and write cycle diagrams, although there is no compulsion to retain these designations.

notMemS0 is a fixed format strobe. Its leading edge is always coincident with the start of **T2** and its trailing edge always coincident with the end of **T5**.

The leading edge of **notMemS1** is always coincident with the start of **T2**, but its duration may be configured to be from zero to 31 periods **Tm**. Regardless of the configured duration, the strobe will terminate no later than the end of **T6**. The strobe is sometimes programmed to extend beyond the normal end of **Tmx**. When wait states are inserted into an EMI cycle the end of **Tmx** is delayed, but the potential active duration of the strobe is not altered. Thus the strobe can be configured to terminate relatively early under certain conditions (page 306). If **notMemS1** is configured to be zero it will never go low.

notMemS2, **notMemS3** and **notMemS4** are identical in operation. They all terminate at the end of **T5**, but the start of each can be delayed from one to 31 periods **Tm** beyond the start of **T2**. If the duration of one of these strobes would take it past the end of **T5** it will stay high. This can be used to cause a strobe to become active only when wait states are inserted. If one of these strobes is configured to zero it will never go low. Figure 7.5 shows the effect of **Wait** on strobes in more detail; each division on the scale is one period **Tm**.

Table 7.2 Read

SYMBOL	PARAMETER	MIN	NOM	MAX	UNITS	NOTE
TaZdV	Address tristate to data valid	0			ns	
TdVRdH	Data setup before read	25			ns	
TRdHdX	Data hold after read	0			ns	
TS0LRdL	notMemS0 before start of read	**a**-4	**a**	**a**+4	ns	1
TS0HRdH	End of read from end of notMemS0	-4		4	ns	
TRdLRdH	Read period	**b**-3		**b**+5	ns	2

Notes

1 **a** is total of **T2**+**T3** where **T2**, **T3** can be from one to four periods **Tm** each in length.

2 **b** is total of **T4**+**Twait**+**T5** where **T4**, **T5** can be from one to four periods **Tm** each in length and **Twait** may be any number of periods **Tm** in length.

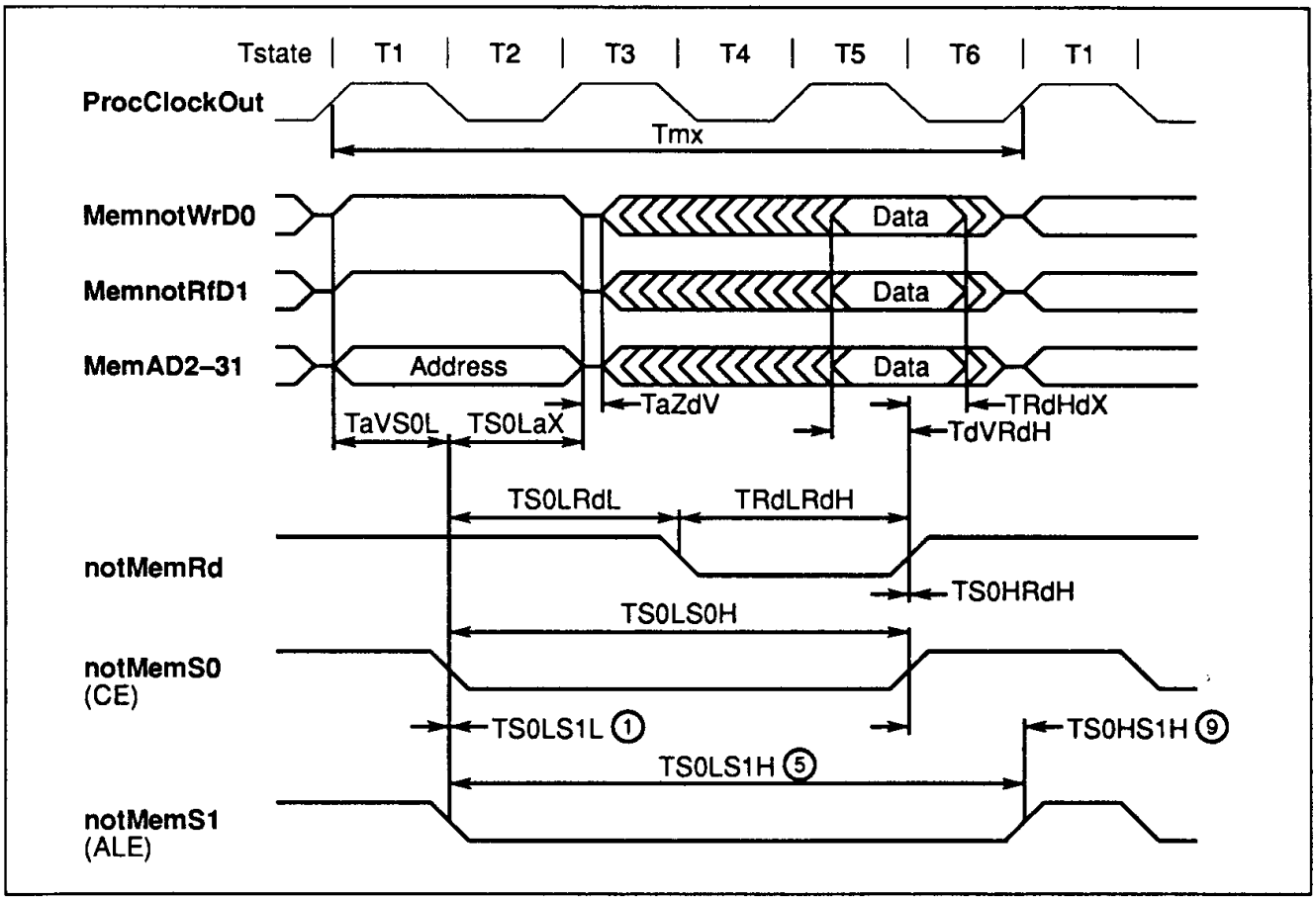


Figure 7.3 IMS T425 external read cycle: static memory

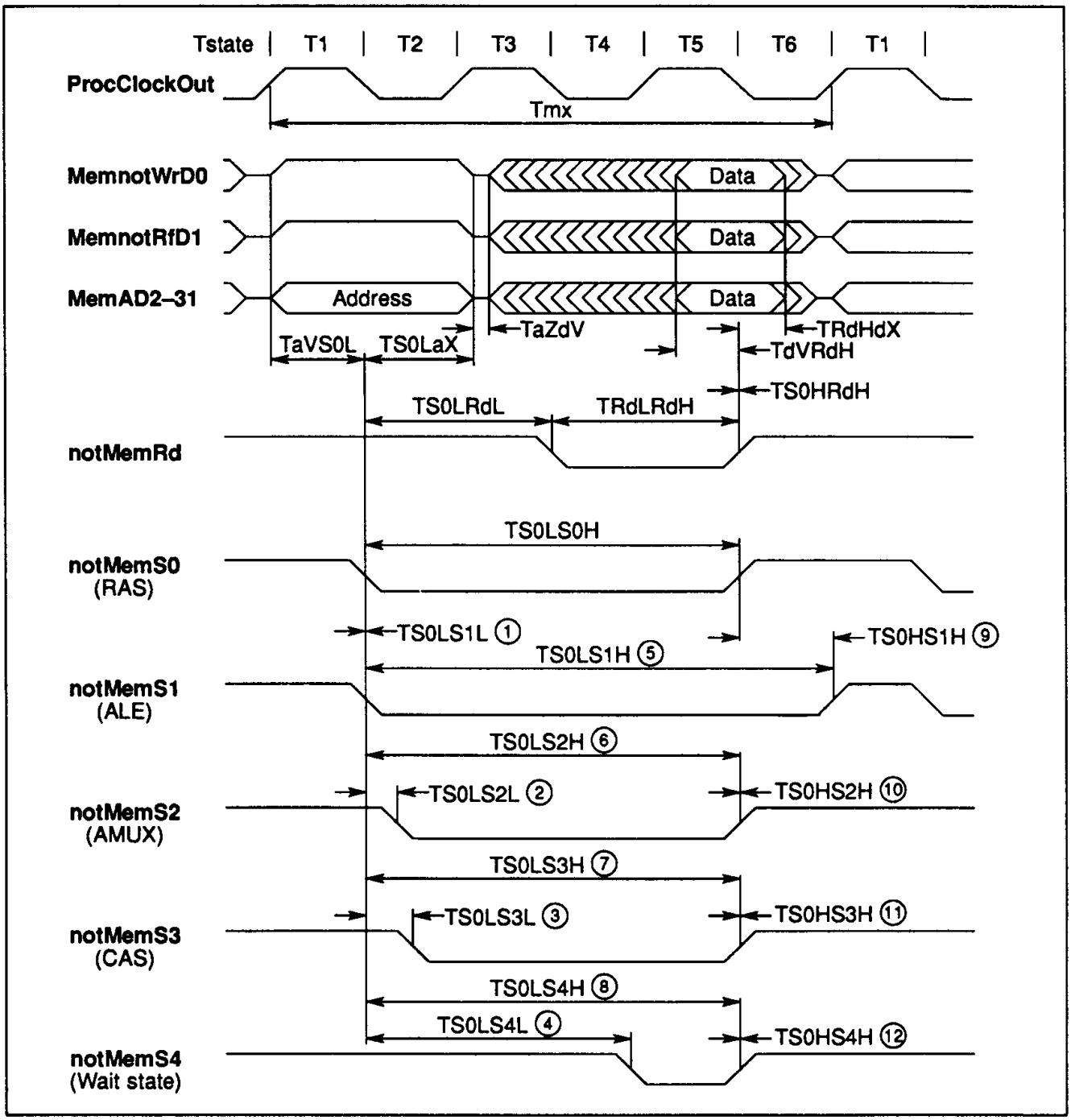


Figure 7.4 IMS T425 external read cycle: dynamic memory

Table 7.3 IMS T425 strobe timing

SYMBOL	(n)	PARAMETER	MIN	NOM	MAX	UNITS	NOTE
TaVS0L		Address setup before notMemS0	**a**-8			ns	1
TS0LaX		Address hold after notMemS0	**b**-8	**b**	**b**+8	ns	2
TS0LS0H		notMemS0 pulse width low	**c**-5		**c**+6	ns	3
TS0LS1L	1	notMemS1 from notMemS0	-4		4	ns	
TS0LS1H	5	notMemS1 end from notMemS0	**d**-1		**d**+9	ns	4,6
TS0HS1H	9	notMemS1 end from notMemS0 end	**e**-8		**e**+4	ns	5,6
TS0LS2L	2	notMemS2 delayed after notMemS0	**f**-6		**f**+5	ns	7
TS0LS2H	6	notMemS2 end from notMemS0	**c**-5		**c**+7	ns	3
TS0HS2H	10	notMemS2 end from notMemS0 end	-4		7	ns	
TS0LS3L	3	notMemS3 delayed after notMemS0	**f**-6		**f**+5	ns	7
TS0LS3H	7	notMemS3 end from notMemS0	**c**-5		**c**+7	ns	3
TS0HS3H	11	notMemS3 end from notMemS0 end	-4		7	ns	
TS0LS4L	4	notMemS4 delayed after notMemS0	**f**-6		**f**+5	ns	7
TS0LS4H	8	notMemS4 end from notMemS0	**c**-5		**c**+7	ns	3
TS0HS4H	12	notMemS4 end from notMemS0 end	-4		7	ns	
Tmx		Complete external memory cycle		**g**			8

Notes

1 **a** is **T1** where **T1** can be from one to four periods **Tm** in length.

2 **b** is **T2** where **T2** can be from one to four periods **Tm** in length.

3 **c** is total of **T2+T3+T4+Twait+T5** where **T2**, **T3**, **T4**, **T5** can be from one to four periods **Tm** each in length and **Twait** may be any number of periods **Tm** in length.

4 **d** can be from zero to 31 periods **Tm** in length.

5 **e** can be from -27 to +4 periods **Tm** in length.

6 If the configuration would cause the strobe to remain active past the end of **T6** it will go high at the end of **T6**. If the strobe is configured to zero periods **Tm** it will remain high throughout the complete cycle **Tmx**.

7 **f** can be from zero to 31 periods **Tm** in length. If this length would cause the strobe to remain active past the end of **T5** it will go high at the end of **T5**. If the strobe value is zero periods **Tm** it will remain low throughout the complete cycle **Tmx**.

8 **g** is one complete external memory cycle comprising the total of **T1+T2+T3+T4+Twait+T5+T6** where **T1**, **T2**, **T3**, **T4**, **T5** can be from one to four periods **Tm** each in length, **T6** can be from one to five periods **Tm** in length and **Twait** may be zero or any number of periods **Tm** in length.

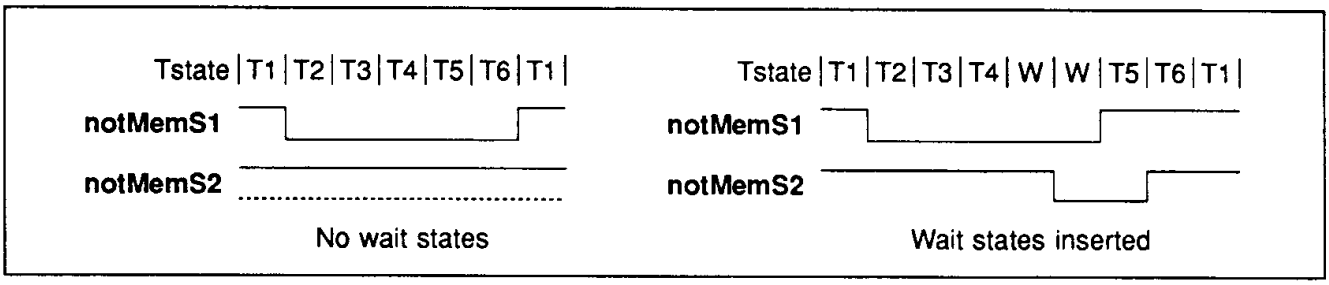


Figure 7.5 IMS T425 effect of wait states on strobes

Table 7.4 Strobe S0 to ProcClockOut skew

SYMBOL	PARAMETER	MIN	NOM	MAX	UNITS	NOTE
TPCHS0H	notMemS0 rising from ProcClockOut rising	-6		4	ns	
TPCLS0H	notMemS0 rising from ProcClockOut falling	-5		10	ns	
TPCHS0L	notMemS0 falling from ProcClockOut rising	-8		3	ns	
TPCLS0L	notMemS0 falling from ProcClockOut falling	-5		7	ns	

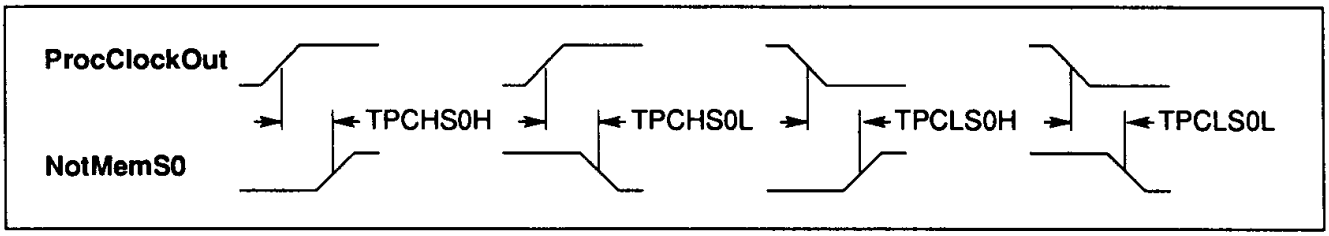


Figure 7.6 IMS T425 skew of notMemS0 to ProcClockOut

7.9 notMemWrB0-3

Because the transputer uses word addressing, four write strobes are provided; one to write each byte of the word. If a particular byte is not to be written, then the corresponding data outputs are tristated. **notMemWrB0** addresses the least significant byte.

The transputer has both early and late write cycle modes. For a late write cycle the relevant write strobes **notMemWrB0-3** are low during **T4** and **T5**; for an early write they are also low during **T3**. Data should be latched into memory on the rising edge of the strobes in both cases, although it is valid until the end of **T6**. If the strobe duration is insufficient, it may be extended at configuration time by adding extra periods **Tm** to either or both of **Tstates T4** and **T5** for both early and late modes. For an early cycle they may also be added to **T3**. Further extension may be obtained by inserting wait states at the end of **T4**. If the data hold time is insufficient, extra periods **Tm** may be added to **T6** to extend it.

Table 7.5 Write

SYMBOL	PARAMETER	MIN	NOM	MAX	UNITS	NOTE
TdVWrH	Data setup before write	**d**-7		**d**+10	ns	1,5
TWrHdX	Data hold after write	**a**-10		**a**+5	ns	1,2
TS0LWrL	notMemS0 before start of early write	**b**-5		**b**+5	ns	1,3
	notMemS0 before start of late write	**c**-5		**c**+5	ns	1,4
TS0HWrH	End of write from end of notMemS0	-5		4	ns	1
TWrLWrH	Early write pulse width	**d**-4		**d**+7	ns	1,5
	Late write pulse width	**e**-4		**e**+7	ns	1,6

Notes

1 Timing is for all write strobes **notMemWrB0-3**.

2 **a** is **T6** where **T6** can be from one to five periods **Tm** in length.

3 **b** is **T2** where **T2** can be from one to four periods **Tm** in length.

4 **c** is total of **T2+T3** where **T2, T3** can be from one to four periods **Tm** each in length.

5 **d** is total of **T3+T4+Twait+T5** where **T3, T4, T5** can be from one to four periods **Tm** each in length and **Twait** may be zero or any number of periods **Tm** in length.

6 **e** is total of **T4+Twait+T5** where **T4, T5** can be from one to four periods **Tm** each in length and **Twait** may be zero or any number of periods **Tm** in length.

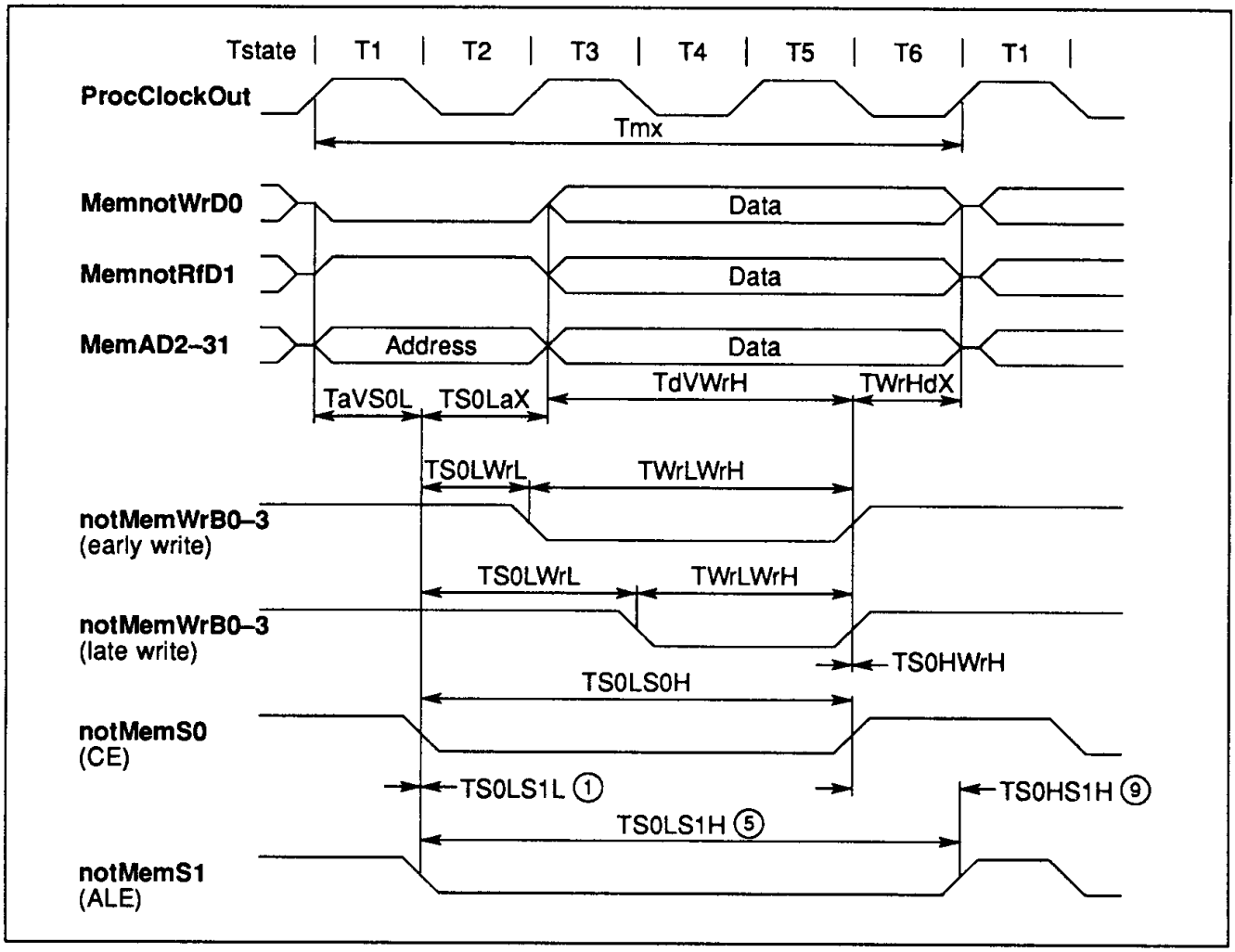


Figure 7.7 IMS T425 external write cycle

In the write cycle timing diagram **ProcClockOut** is included as a guide only; it is shown with each **Tstate** configured to one period **Tm**. The strobe is inactive during internal memory cycles.

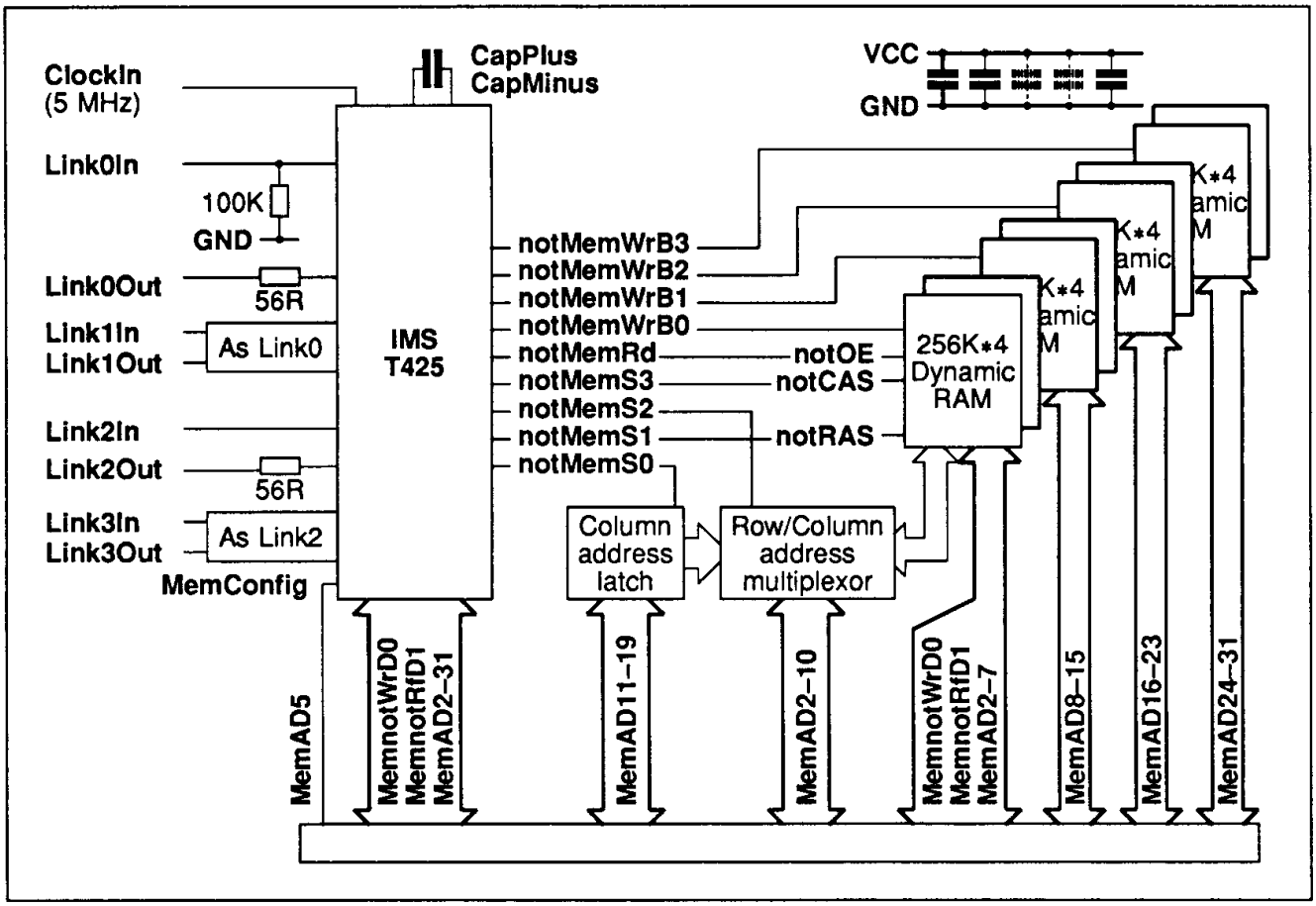


Figure 7.8 IMS T425 dynamic RAM application

7.10 MemConfig

MemConfig is an input pin used to read configuration data when setting external memory interface (EMI) characteristics. It is read by the processor on two occasions after **Reset** goes low; first to check if one of the preset internal configurations is required, then to determine a possible external configuration.

7.10.1 Internal configuration

The internal configuration scan comprises 64 periods **TDCLDCL** of **ClockIn** during the internal scan period of 144 **ClockIn** periods. **MemnotWrD0**, **MemnotRfD1** and **MemAD2-32** are all high at the beginning of the scan. Starting with **MemnotWrD0**, each of these lines goes low successively at intervals of two **ClockIn** periods and stays low until the end of the scan. If one of these lines is connected to **MemConfig** the preset internal configuration mode associated with that line will be used as the EMI configuration. The default configuration is that defined in the table for **MemAD31**; connecting **MemConfig** to **VCC** will also produce this default configuration. Note that only 17 of the possible configurations are valid, all others remain at the default configuration.

Table 7.6 IMS T425 internal configuration coding

	Duration of each Tstate periods Tm						Strobe coefficient				Write cycle	Refresh interval	Cycle time
Pin	T1	T2	T3	T4	T5	T6	s1	s2	s3	s4	type	ClockIn cycles	Proc cycles
MemnotWrD0	1	1	1	1	1	1	30	1	3	5	late	72	3
MemnotRfD1	1	2	1	1	1	2	30	1	2	7	late	72	4
MemAD2	1	2	1	1	2	3	30	1	2	7	late	72	5
MemAD3	2	3	1	1	2	3	30	1	3	8	late	72	6
MemAD4	1	1	1	1	1	1	3	1	2	3	early	72	3
MemAD5	1	1	2	1	2	1	5	1	2	3	early	72	4
MemAD6	2	1	2	1	3	1	6	1	2	3	early	72	5
MemAD7	2	2	2	1	3	2	7	1	3	4	early	72	6
MemAD8	1	1	1	1	1	1	30	1	2	3	early	†	3
MemAD9	1	1	2	1	2	1	30	2	5	9	early	†	4
MemAD10	2	2	2	2	4	2	30	2	3	8	late	72	7
MemAD11	3	3	3	3	3	3	30	2	4	13	late	72	9
MemAD12	1	1	2	1	2	1	4	1	2	3	early	72	4
MemAD13	2	1	2	1	2	2	5	1	2	3	early	72	5
MemAD14	2	2	2	1	3	2	6	1	3	4	early	72	6
MemAD15	2	1	2	3	3	3	8	1	2	3	early	72	7
MemAD31	4	4	4	4	4	4	31	30	30	18	late	72	12

† Provided for static RAM only.

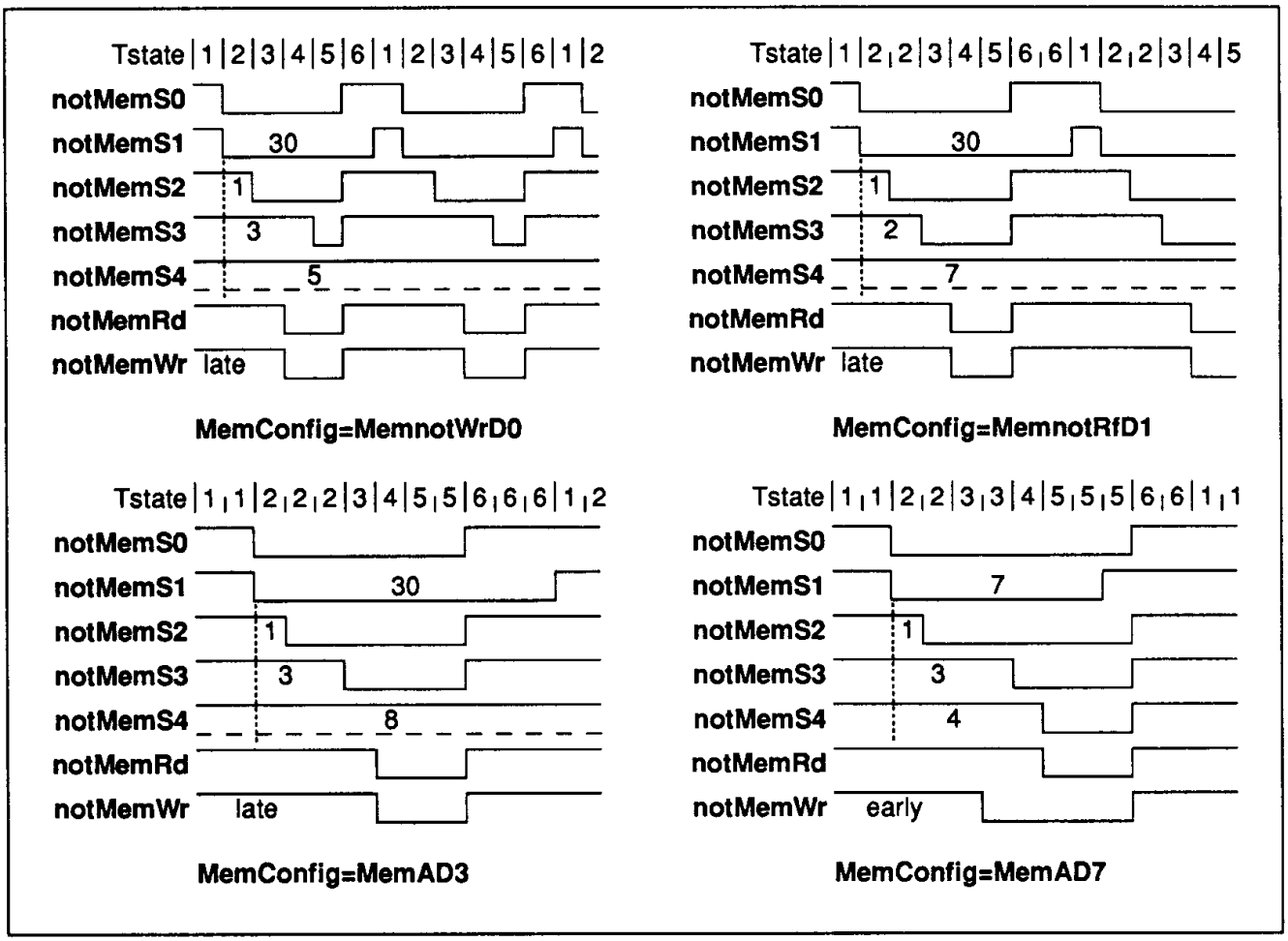


Figure 7.9 IMS T425 internal configuration

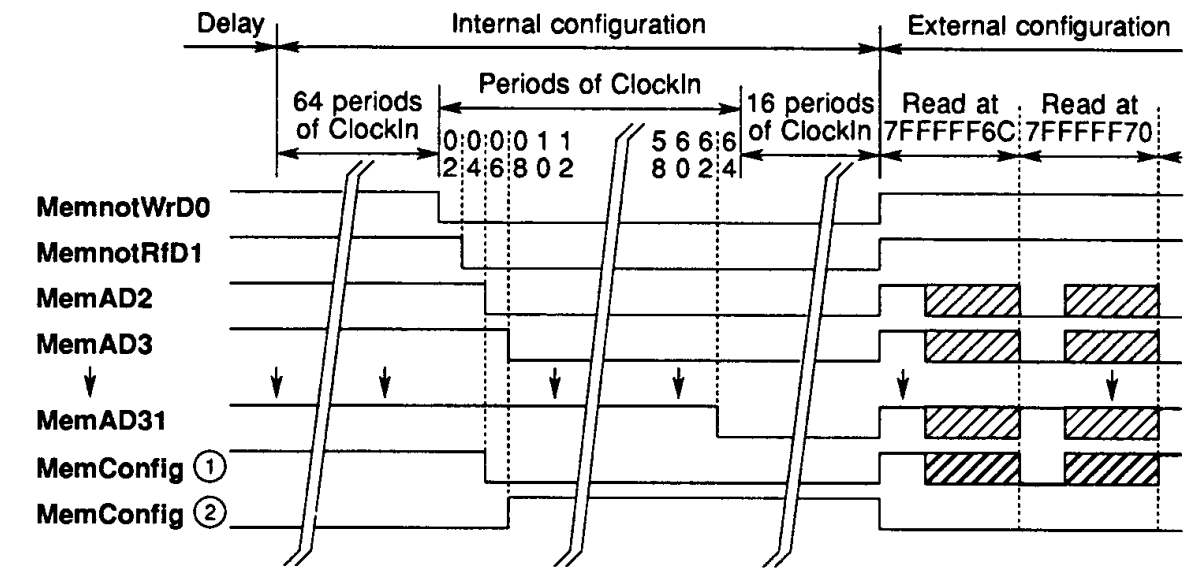


Figure 7.10 IMS T425 internal configuration scan

7.10.2 External configuration

If **MemConfig** is held low until **MemnotWrD0** goes low the internal configuration is ignored and an external configuration will be loaded instead. An external configuration scan always follows an internal one, but if an internal configuration occurs any external configuration is ignored.

The external configuration scan comprises 36 successive external read cycles, using the default EMI configuration preset by **MemAD31**. However, instead of data being read on the data bus as for a normal read cycle, only a single bit of data is read on **MemConfig** at each cycle. Addresses put out on the bus for each read cycle are shown in table 7.7, and are designed to address ROM at the top of the memory map. The table shows the data to be held in ROM; data required at the **MemConfig** pin is the inverse of this.

MemConfig is typically connected via an inverter to **MemnotWrD0**. Data bit zero of the least significant byte of each ROM word then provides the configuration data stream. By switching **MemConfig** between various data bus lines up to 32 configurations can be stored in ROM, one per bit of the data bus. **MemConfig** can be permanently connected to a data line or to **GND**. Connecting **MemConfig** to **GND** gives all **Tstates** configured to four periods; **notMemS1** pulse of maximum duration; **notMemS2-4** delayed by maximum; refresh interval 72 periods of **ClockIn**; refresh enabled; late write.

The external memory configuration table 7.7 shows the contribution of each memory address to the 13 configuration fields. The lowest 12 words (#7FFFFF6C to #7FFFFF98, fields 1 to 6) define the number of extra periods **Tm** to be added to each **Tstate**. If field 2 is 3 then three extra periods will be added to **T2** to extend it to the maximum of four periods.

The next five addresses (field 7) define the duration of **notMemS1** and the following fifteen (fields 8 to 10) define the delays before strobes **notMemS2-4** become active. The five bits allocated to each strobe allow durations of from 0 to 31 periods **Tm**, as described in strobes page 290.

Addresses #7FFFFFEC to #7FFFFFF4 (fields 11 and 12) define the refresh interval and whether refresh is to be used, whilst the final address (field 13) supplies a high bit to **MemConfig** if a late write cycle is required.

The columns to the right of the coding table show the values of each configuration bit for the four sample

external configuration diagrams. Note the inclusion of period **E** at the end of **T6** in some diagrams. This is inserted to bring the start of the next **Tstate T1** to coincide with a rising edge of **ProcClockOut** (page 288).

Wait states **W** have been added to show the effect of them on strobe timing; they are not part of a configuration. In each case which includes wait states, two wait periods are defined. This shows that if a wait state would cause the start of **T5** to coincide with a falling edge of **ProcClockOut**, another period **Tm** is generated by the EMI to force it to coincide with a rising edge of **ProcClockOut**. This coincidence is only necessary if wait states are added, otherwise coincidence with a falling edge is permitted. Any configuration memory access is only permitted to be extended using wait, up to a total of 14 **ClockIn** periods.

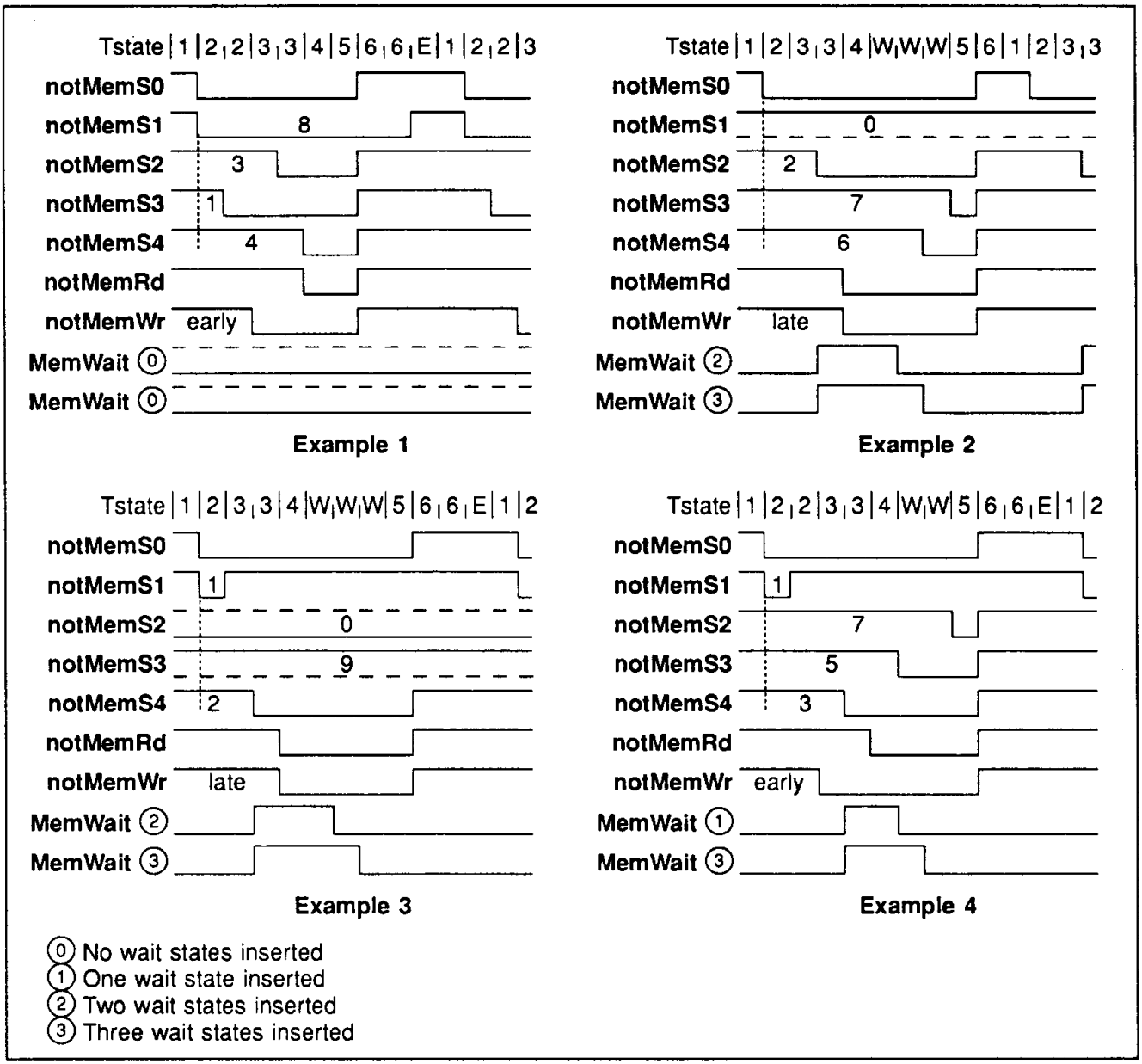
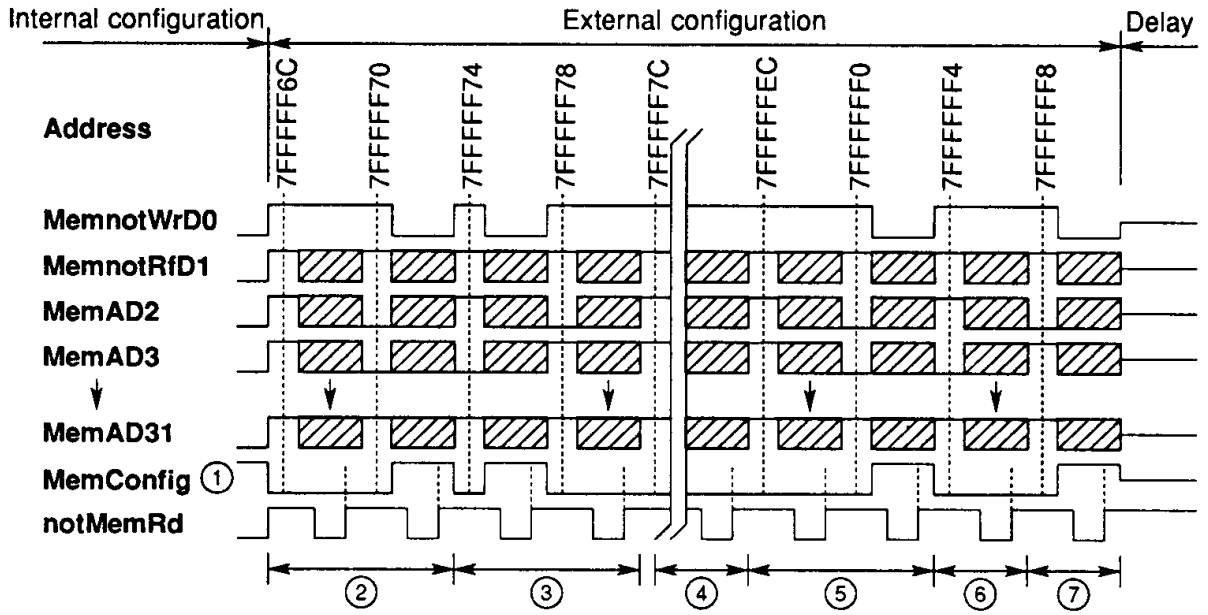


Figure 7.11 IMS T425 external configuration



① **MemConfig** connected to inverse of **MemnotWrD0**
② Configuration field 1; **T1** configured for 2 periods **Tm**
③ Configuration field 2; **T2** configured for 3 periods **Tm**
④ Configuration field 10; most significant bit of **notMemS4** configured high
⑤ Configuration field 11; refresh interval configured for 36 periods **ClockIn**
⑥ Configuration field 12; refresh enabled
⑦ Configuration field 13; early write cycle

Figure 7.12 IMS T425 external configuration scan

Table 7.7 IMS T425 external configuration coding

Scan cycle	MemAD address	Field	Function	Example diagram 1	2	3	4
1	7FFFFF6C	1	T1 least significant bit	0	0	0	0
2	7FFFFF70	1	T1 most significant bit	0	0	0	0
3	7FFFFF74	2	T2 least significant bit	1	0	0	1
4	7FFFFF78	2	T2 most significant bit	0	0	0	0
5	7FFFFF7C	3	T3 least significant bit	1	1	1	1
6	7FFFFF80	3	T3 most significant bit	0	0	0	0
7	7FFFFF84	4	T4 least significant bit	0	0	0	0
8	7FFFFF88	4	T4 most significant bit	0	0	0	0
9	7FFFFF8C	5	T5 least significant bit	0	0	0	0
10	7FFFFF90	5	T5 most significant bit	0	0	0	0
11	7FFFFF94	6	T6 least significant bit	1	0	1	1
12	7FFFFF98	6	T6 most significant bit	0	0	0	0
13	7FFFFF9C	7	notMemS1 least significant bit	0	0	1	1
14	7FFFFFA0	7		0	0	0	0
15	7FFFFFA4	7	⇓ ⇓	0	0	0	0
16	7FFFFFA8	7		1	0	0	0
17	7FFFFFAC	7	notMemS1 most significant bit	0	0	0	0
18	7FFFFFB0	8	notMemS2 least significant bit	1	0	0	1
19	7FFFFFB4	8		1	1	0	1
20	7FFFFFB8	8	⇓ ⇓	0	0	0	1
21	7FFFFFBC	8		0	0	0	0
22	7FFFFFC0	8	notMemS2 most significant bit	0	0	0	0
23	7FFFFFC4	9	notMemS3 least significant bit	1	1	1	1
24	7FFFFFC8	9		0	1	0	0
25	7FFFFFCC	9	⇓ ⇓	0	1	0	1
26	7FFFFFD0	9		0	0	1	0
27	7FFFFFD4	9	notMemS3 most significant bit	0	0	0	0
28	7FFFFFD8	10	notMemS4 least significant bit	0	0	0	1
29	7FFFFFDC	10		0	1	1	1
30	7FFFFFE0	10	⇓ ⇓	1	1	0	0
31	7FFFFFE4	10		0	0	0	0
32	7FFFFFE8	10	notMemS4 most significant bit	0	0	0	0
33	7FFFFFEC	11	Refresh Interval least significant bit	-	-	-	-
34	7FFFFFF0	11	Refresh Interval most significant bit	-	-	-	-
35	7FFFFFF4	12	Refresh Enable	-	-	-	-
36	7FFFFFF8	13	Late Write	0	1	1	0

Table 7.8 IMS T425 memory refresh configuration coding

Refresh interval	Interval in μs	Field 11 encoding	Complete cycle (mS)
18	3.6	00	0.922
36	7.2	01	1.843
54	10.8	10	2.765
72	14.4	11	3.686

Refresh intervals are in periods of **ClockIn** and **ClockIn** frequency is 5 MHz:

Interval = 18 * 200 = 3600 ns

Refresh interval is between successive incremental refresh addresses.
Complete cycles are shown for 256 row DRAMS.

Table 7.9 Memory configuration

SYMBOL	PARAMETER	MIN	NOM	MAX	UNITS	NOTE
TMCVRdH	Memory configuration data setup	25			ns	
TRdHMCX	Memory configuration data hold	0			ns	
TS0LRdH	notMemS0 to configuration data read	**a**-12		**a**+12	ns	1

Notes

1 **a** is 16 periods **Tm**.

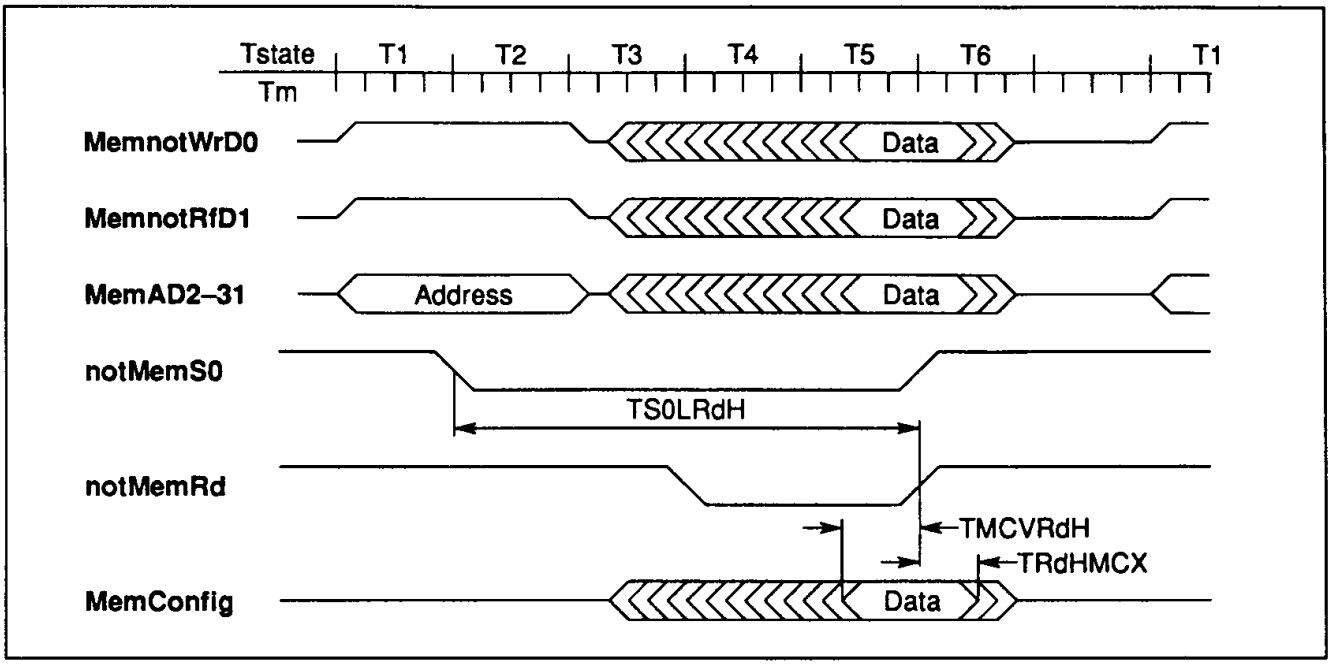


Figure 7.13 IMS T425 external configuration read cycle timing

7.11 RefreshPending

When high, this pin signals that a refresh cycle is pending. It remains high until the refresh cycle is started by the transputer. The minimum time for the **RefreshPending** pin to be high is for one cycle of **ProcClockOut** (two periods **Tm**), when the EMI was not about to perform a memory read or write. If the EMI was held in the tristate condition with **MemGranted** asserted, then **RefreshPending** will be asserted when the refresh controller in the EMI is ready to perform a refresh. **MemReq** may be re-asserted any time after the commencement of the refresh cycle. **RefreshPending** changes state near the rising edge of **ProcClockOut** and can therefore be sampled by the falling edge of **ProcClockOut**.

If no DMA is active then refresh will be performed following the end of the current internal or external memory cycle. If DMA is active the transputer will wait for DMA to terminate before commencing the refresh cycle. Unlike **MemnotRfD1**, **RefreshPending** is never tristated and can thus be interrogated by the DMA device; the DMA cycle can then be suspended, at the discretion of the DMA device, to allow refresh to take place.

The simple circuit of Figure 7.14 will suspend DMA requests from the external logic when **RefreshPending** is asserted, so that a memory refresh cycle can be performed. DMA is restored on completion of the refresh cycle. The transputer will not perform an external memory cycle other than a refresh cycle, using this method, until the requesting device removes its DMA request.

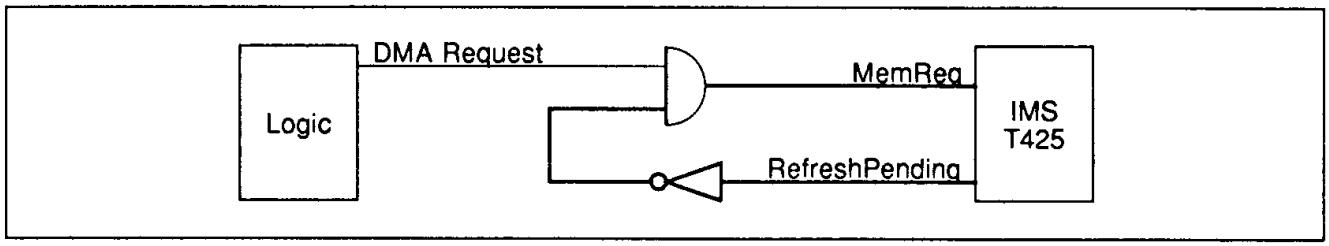


Figure 7.14 IMS T425 refresh with DMA

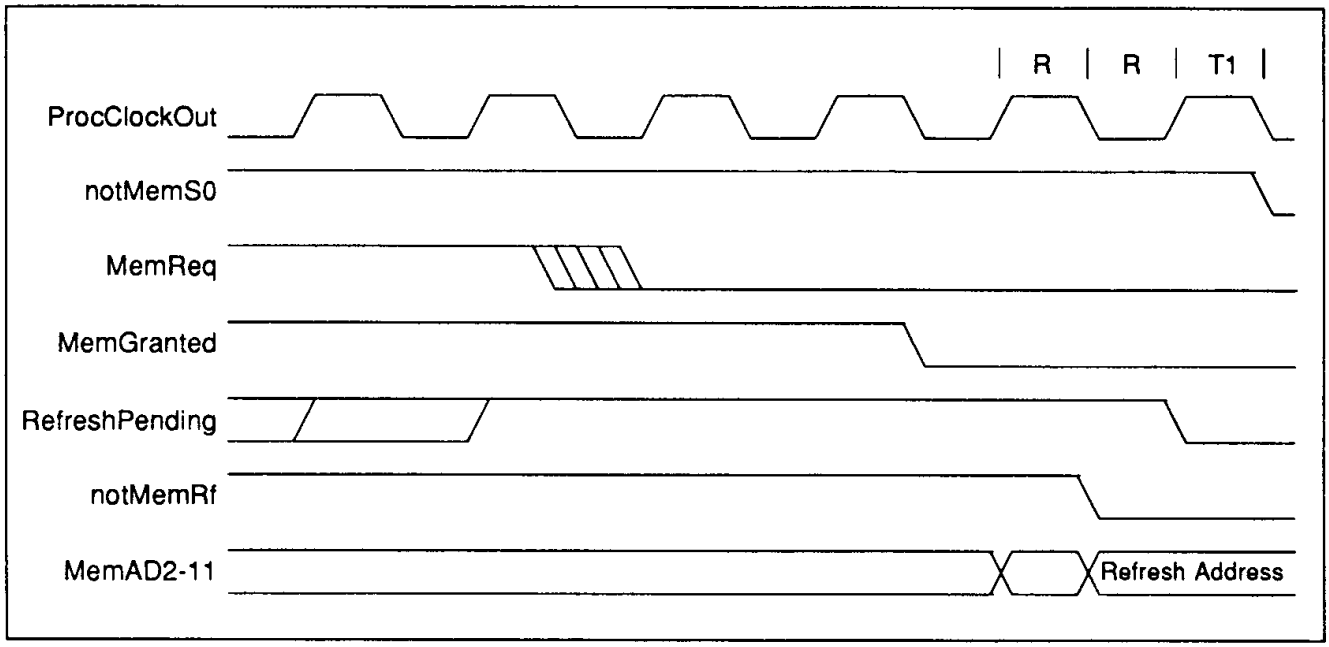


Figure 7.15 IMS T425 RefreshPending timing

7.12 notMemRf

The IMS T425 can be operated with memory refresh enabled or disabled. The selection is made during memory configuration, when the refresh interval is also determined. Refresh cycles do not interrupt internal memory accesses, although the internal addresses cannot be reflected on the external bus during refresh.

When refresh is disabled no refresh cycles occur. During the post-**Reset** period eight dummy refresh cycles will occur with the appropriate timing but with no bus or strobe activity.

A refresh cycle uses the same basic external memory timing as a normal external memory cycle, except that it starts two periods **Tm** before the start of **T1**. If a refresh cycle is due during an external memory access, it will be delayed until the end of that external cycle. Two extra periods **Tm** (periods **R** in the diagram) will then be inserted between the end of **T6** of the external memory cycle and the start of **T1** of the refresh cycle itself. The refresh address and various external strobes become active approximately one period **Tm** before **T1**. Bus signals are active until the end of **T2**, whilst **notMemRf** remains active until the end of **T6**.

For a refresh cycle, **MemnotRfD1** goes low before **notMemRf** goes low and **MemnotWrD0** goes high with the same timing as **MemnotRfD1**. All the address lines share the same timing, but only **MemAD2-11** give the refresh address. **MemAD12-30** stay high during the address period, whilst **MemAD31** remains low. Refresh cycles generate strobes **notMemS0-4** with timing as for a normal external cycle, but **notMemRd** and **notMemWrB0-3** remain high. **MemWait** operates normally during refresh cycles.

Table 7.10 Memory refresh

SYMBOL	PARAMETER	MIN	NOM	MAX	UNITS	NOTE
TRfLRfH	Refresh pulse width low	**a**-2		**a**+9	ns	1
TRaVS0L	Refresh address setup before notMemS0	**b**-12			ns	
TRfLS0L	Refresh indicator setup before notMemS0	**b**-4	**b**	**b**+6	ns	2

Notes

1 **a** is total **Tmx+Tm**.

2 **b** is total **T1+Tm** where **T1** can be from one to four periods **Tm** in length.

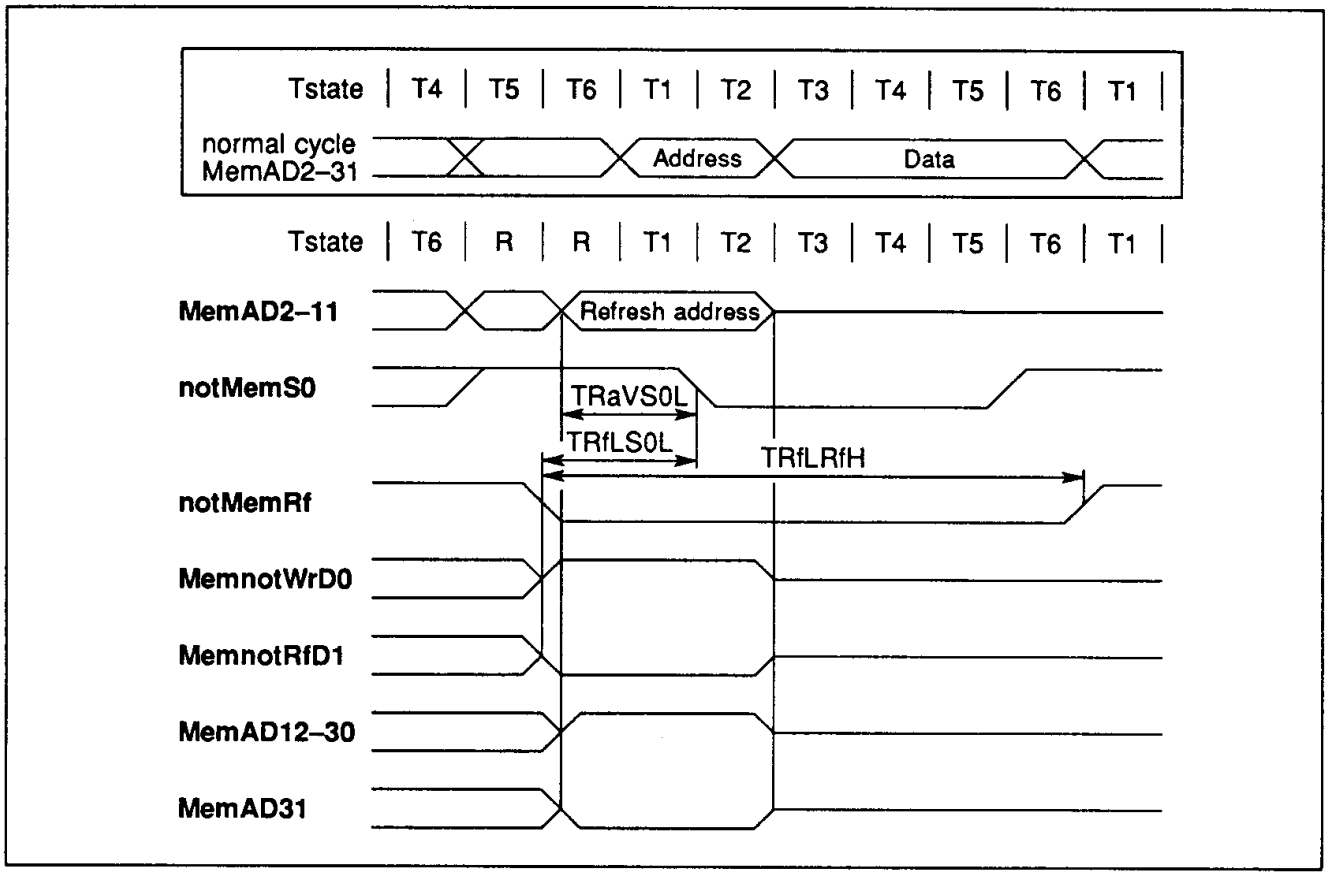


Figure 7.16 IMS T425 refresh cycle timing

7.13 MemWait

Taking **MemWait** high with the timing shown will extend the duration of **T4**. **MemWait** is sampled relative to the falling edge of **ProcClockOut** during a **T3** period, and should not change state in this region. By convention, **notMemS4** is used to synchronize wait state insertion. If this or another strobe is used, its delay should be such as to take the strobe low an even number of periods **Tm** after the start of **T1**, to coincide with a rising edge of **ProcClockOut**.

MemWait may be kept high indefinitely, although if dynamic memory refresh is used it should not be kept high long enough to interfere with refresh timing. **MemWait** operates normally during all cycles, including refresh and configuration cycles. It does not affect internal memory access in any way.

If the start of **T5** would coincide with a falling edge of **ProcClockOut** an extra wait period **Tm** (**EW**) is generated by the EMI to force coincidence with a rising edge. Rising edge coincidence is only forced if wait states are added, otherwise coincidence with a falling edge is permitted.

Table 7.11 Memory wait

SYMBOL	PARAMETER	MIN	NOM	MAX	UNITS	NOTE
TPCLWtH	Wait setup	-(0.5Tm+9)			ns	1,2
TPCLWtL	Wait hold	0.5Tm+10			ns	1,2
TWtLWtH	Delay before re-assertion of Wait	2Tm				

Notes

1 **ProcClockOut** load should not exceed 50pf.

2 If wait period exceeds refresh interval, refresh cycles will be lost.

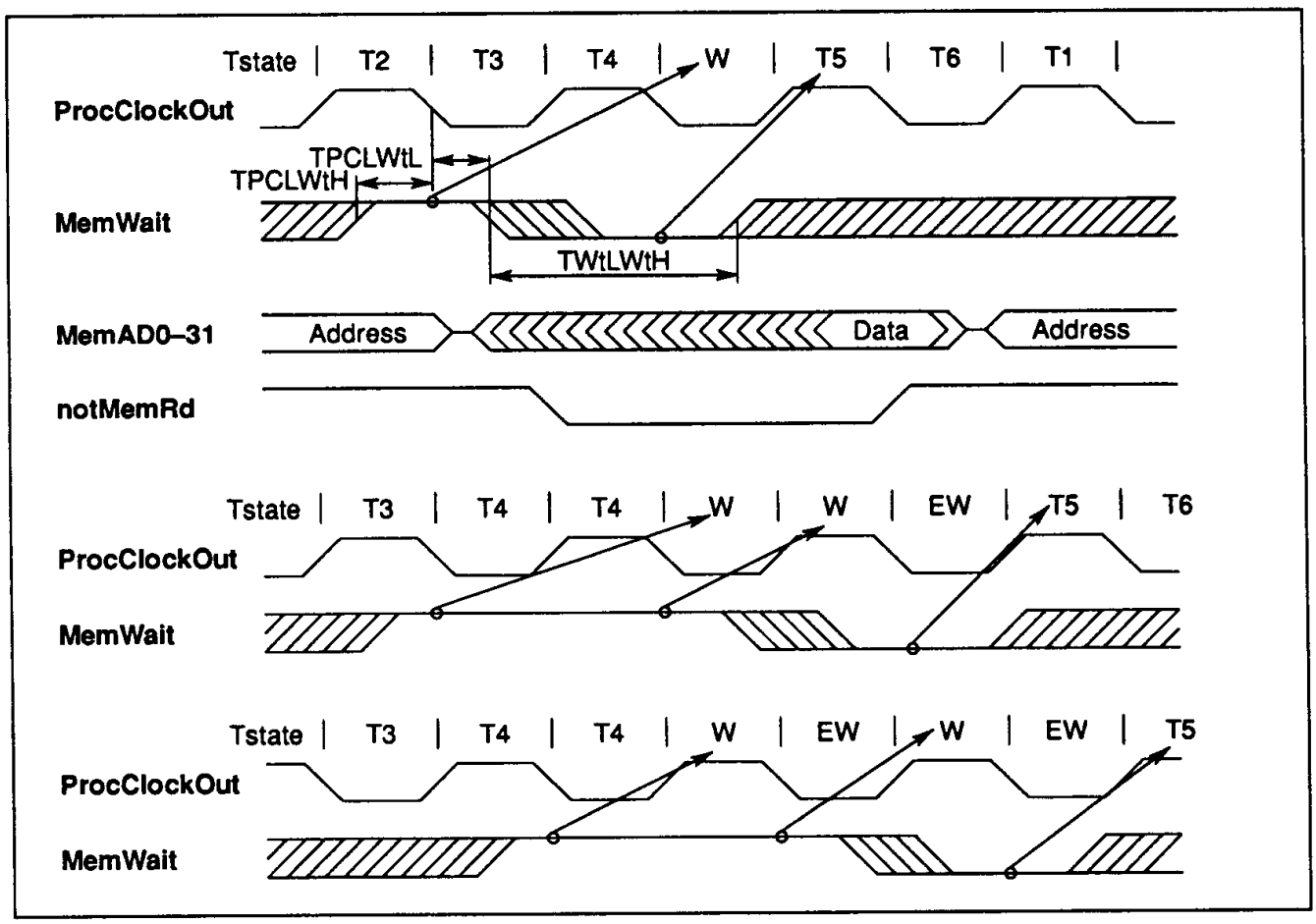


Figure 7.17 IMS T425 memory wait timing

7.14 MemReq, MemGranted

Direct memory access (DMA) can be requested at any time by taking the asynchronous **MemReq** input high. The transputer samples **MemReq** during the final period **Tm** of **T6** of both refresh and external memory cycles. To guarantee taking over the bus immediately following either, **MemReq** must be set up at least two periods **Tm** before the end of **T6**. In the absence of an external memory cycle, **MemReq** is sampled during every low period of **ProcClockOut**. The address bus is tristated two periods **Tm** after the **ProcClockOut** rising edge which follows the sample. **MemGranted** is asserted one period **Tm** after that.

Removal of **MemReq** is sampled during each low period of **ProcClockOut** and **MemGranted** is removed synchronously with the next falling edge of **ProcClockOut**. If accurate timing of DMA is required, **MemReq** should be set low coincident with a falling edge of **ProcClockOut**. Further external bus activity, either refresh, external cycles or reflection of internal cycles, will commence at the next rising edge of **ProcClockOut**.

Strobes are left in their inactive states during DMA. DMA cannot interrupt a refresh or external memory cycle, and outstanding refresh cycles will occur before the bus is released to DMA. DMA does not interfere with internal memory cycles in any way, although a program running in internal memory would have to wait for the end of DMA before accessing external memory. DMA cannot access internal memory. If DMA extends longer than one refresh interval (Memory Refresh Configuration Coding, table 7.8), the DMA user becomes responsible for refresh. DMA may also inhibit an internally running program from accessing external memory.

DMA allows a bootstrap program to be loaded into external RAM ready for execution after reset. If **MemReq** is held high throughout reset, **MemGranted** will be asserted before the bootstrap sequence begins. **MemReq** must be high at least one period **TDCLDCL** of **ClockIn** before **Reset**. The circuit should be designed to ensure correct operation if **Reset** could interrupt a normal DMA cycle.

Table 7.12 Memory request

SYMBOL	PARAMETER	MIN	NOM	MAX	UNITS	NOTES
TMRHMGH	Memory request response time	4**Tm**-2ns		7**Tm**+7ns		1
TMRLMGL	Memory request end response time	2**Tm**-2ns		5**Tm**+22ns		
TADZMGH	Bus tristate before memory granted	**Tm**-2ns		**Tm**+22ns		
TMGLADV	Bus active after end of memory granted	-10ns		**Tm**+2ns		

Notes

1 These values assume no external memory cycle is in progress. If an external cycle is active, maximum time could be (1 EMI cycle **Tmx**)+(1 refresh cycle **TRfLRfH**)+(6 periods **Tm**).

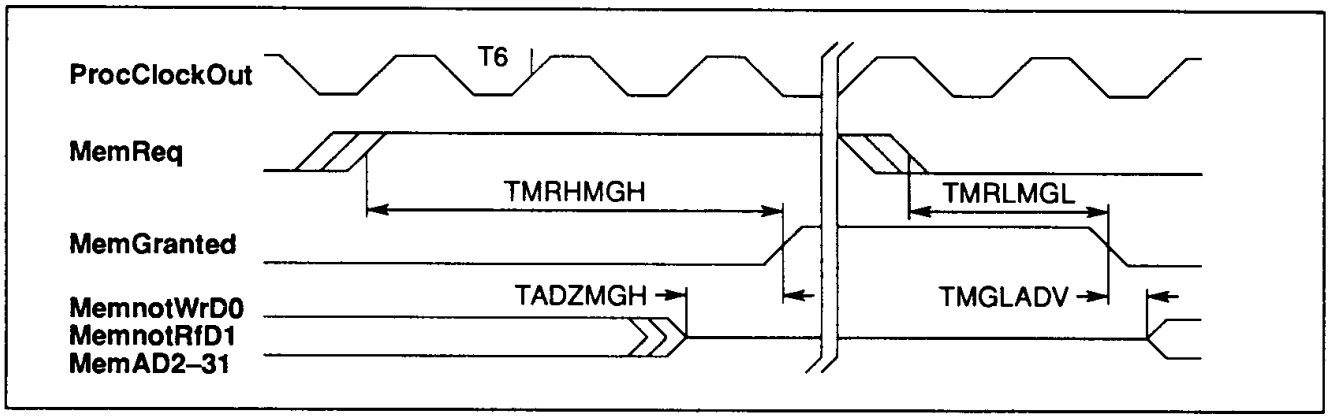


Figure 7.18 IMS T425 memory request timing

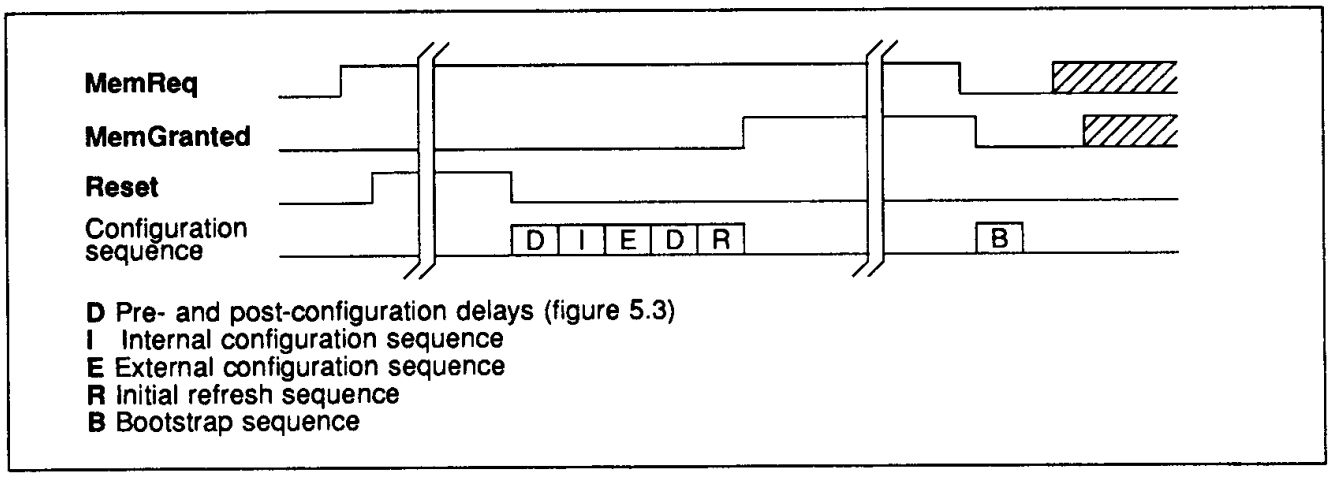


Figure 7.19 IMS T425 DMA sequence at reset

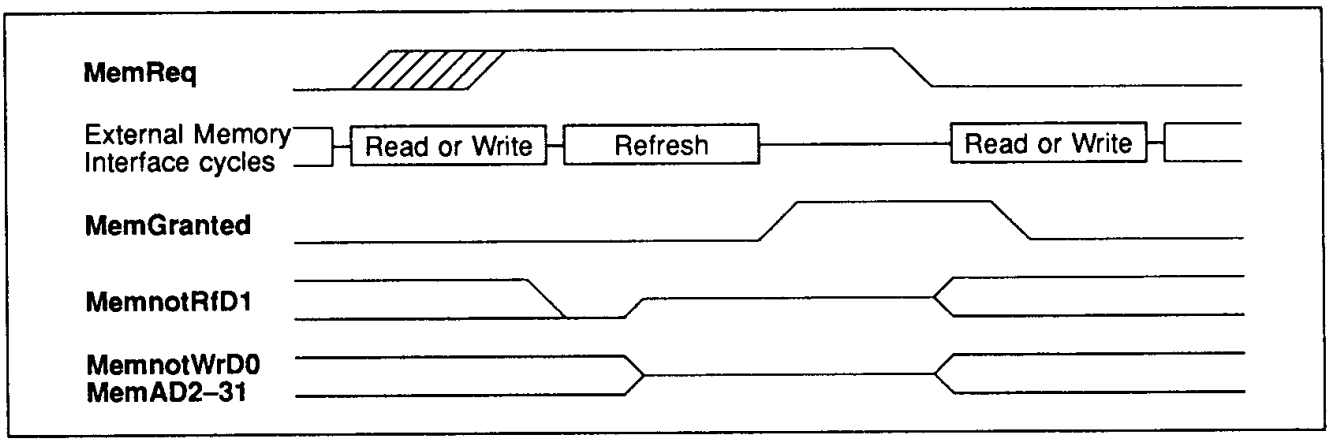


Figure 7.20 IMS T425 operation of MemReq, MemGranted with external, refresh memory cycles

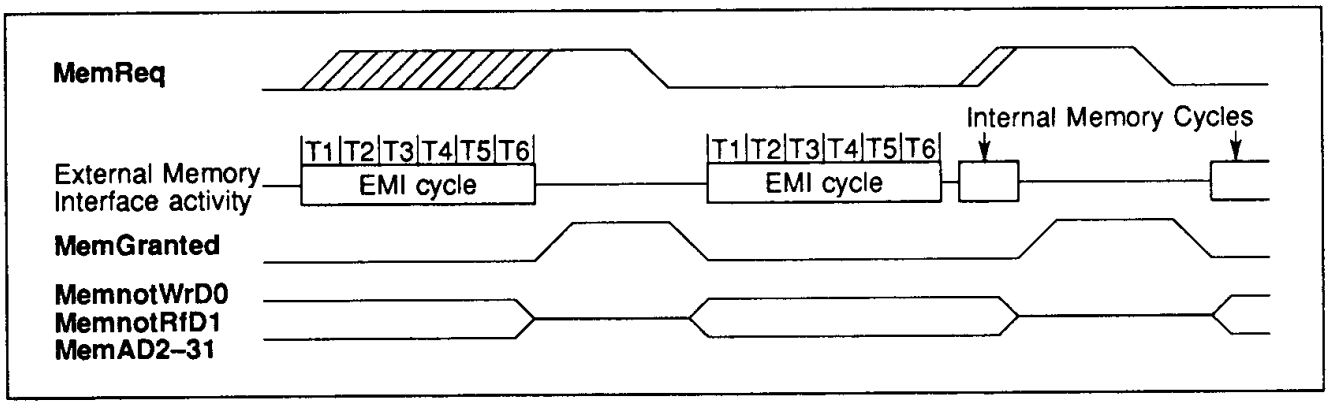


Figure 7.21 IMS T425 operation of MemReq, MemGranted with external, internal memory cycles

8 Events

EventReq and **EventAck** provide an asynchronous handshake interface between an external event and an internal process. When an external event takes **EventReq** high the external event channel (additional to the external link channels) is made ready to communicate with a process. When both the event channel and the process are ready the processor takes **EventAck** high and the process, if waiting, is scheduled. **EventAck** is removed after **EventReq** goes low.

EventWaiting is asserted high by the transputer when a process executes an input on the event channel; typically with the occam **EVENT ? ANY** instruction. It remains high whilst the transputer is waiting for or servicing **EventReq** and is returned low when **EventAck** goes high. The **EventWaiting** pin changes near the falling edge of **ProcClockOut** and can therefore be sampled by the rising edge of **ProcClockOut**.

The **EventWaiting** pin can only be asserted by executing an *in* instruction on the event channel. The **EventWaiting** pin is not asserted high when an enable channel (*enbc)* instruction is executed on the Event channel (during an ALT construct in occam, for example). The **EventWaiting** pin can be asserted by executing the occam input on the event channel (such as **Event ? ANY**), provided that this does not occur as a guard in an alternative process. The **EventWaiting** pin can not be used to signify that an alternative process (ALT) is waiting on an input from the event channel.

EventWaiting allows a process to control external logic; for example, to clock a number of inputs into a memory mapped data latch so that the event request type can be determined. This function is not available on the IMS T414 and IMS T800.

Only one process may use the event channel at any given time. If no process requires an event to occur **EventAck** will never be taken high. Although **EventReq** triggers the channel on a transition from low to high, it must not be removed before **EventAck** is high. **EventReq** should be low during **Reset**; if not it will be ignored until it has gone low and returned high. **EventAck** is taken low when **Reset** occurs.

If the process is a high priority one and no other high priority process is running, the latency is as described on page 269. Setting a high priority task to wait for an event input allows the user to interrupt a transputer program running at low priority. The time taken from asserting **EventReq** to the execution of the microcode interrupt handler in the CPU is four cycles. The following functions take place during the four cycles:

Cycle 1 Sample **EventReq** at pad on the rising edge of **ProcClockOut** and synchronise.

Cycle 2 Edge detect the synchronised **EventReq** and form the interrupt request.

Cycle 3 Sample interrupt vector for microcode ROM in the CPU.

Cycle 4 Execute the interrupt routine for Event rather than the next instruction.

Table 8.1 Event

SYMBOL	PARAMETER	MIN	NOM	MAX	UNITS	NOTE
TVHKH	Event request response	0			ns	
TKHVL	Event request hold	0			ns	
TVLKL	Delay before removal of event acknowledge	0		6**Tm**+7ns		
TKLVH	Delay before re-assertion of event request	0			ns	
TKHEWL	Event acknowledge to end of event waiting	0			ns	
TKLEWH	End of event acknowledge to event waiting	0			ns	

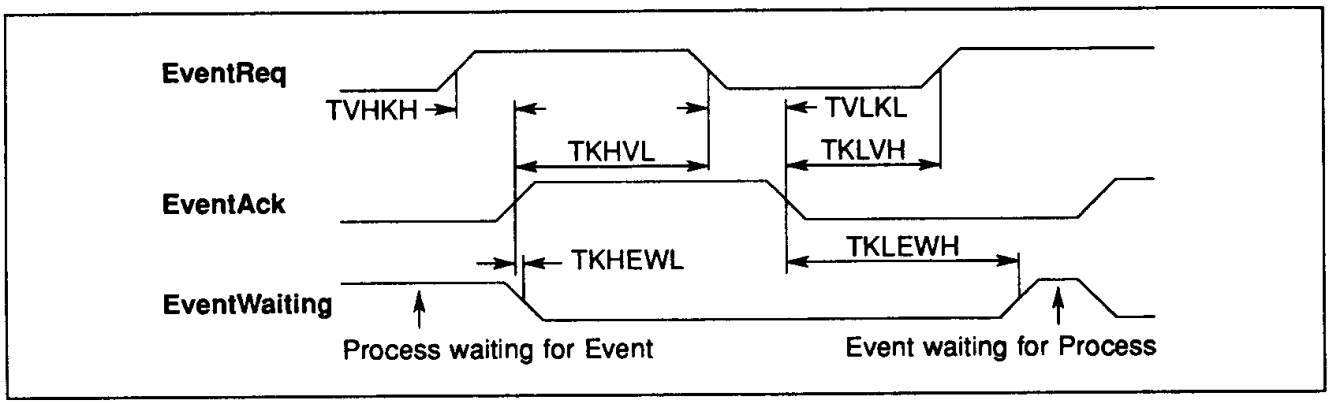


Figure 8.1 IMS T425 event timing

9 Links

Four identical INMOS bi-directional serial links provide synchronized communication between processors and with the outside world. Each link comprises an input channel and output channel. A link between two transputers is implemented by connecting a link interface on one transputer to a link interface on the other transputer. Every byte of data sent on a link is acknowledged on the input of the same link, thus each signal line carries both data and control information.

The quiescent state of a link output is low. Each data byte is transmitted as a high start bit followed by a one bit followed by eight data bits followed by a low stop bit. The least significant bit of data is transmitted first. After transmitting a data byte the sender waits for the acknowledge, which consists of a high start bit followed by a zero bit. The acknowledge signifies both that a process was able to receive the acknowledged data byte and that the receiving link is able to receive another byte. The sending link reschedules the sending process only after the acknowledge for the final byte of the message has been received.

The IMS T425 links allow an acknowledge packet to be sent before the data packet has been fully received. This overlapped acknowledge technique is fully compatible with all other INMOS transputer links.

The IMS T425 links support the standard INMOS communication speed of 10 Mbits/sec. In addition they can be used at 5 or 20 Mbits/sec. Links are not synchronised with **ClockIn** or **ProcClockOut** and are insensitive to their phases. Thus links from independently clocked systems may communicate, providing only that the clocks are nominally identical and within specification.

Links are TTL compatible and intended to be used in electrically quiet environments, between devices on a single printed circuit board or between two boards via a backplane. Direct connection may be made between devices separated by a distance of less than 300 millimetres. For longer distances a matched 100 ohm transmission line should be used with series matching resistors **RM**. When this is done the line delay should be less than 0.4 bit time to ensure that the reflection returns before the next data bit is sent.

Buffers may be used for very long transmissions. If so, their overall propagation delay should be stable within the skew tolerance of the link, although the absolute value of the delay is immaterial.

Link speeds can be set by **LinkSpecial**, **Link0Special** and **Link123Special**. The link 0 speed can be set independently. Table 9.1 shows uni-directional and bi-directional data rates in Kbytes/sec for each link speed; **LinknSpecial** is to be read as **Link0Special** when selecting link 0 speed and as **Link123Special** for the others. Data rates are quoted for a transputer using internal memory, and will be affected by a factor depending on the number of external memory accesses and the length of the external memory cycle.

Table 9.1 Speed Settings for Transputer Links

Link Special	Linkn Special	Mbits/sec	Kbytes/sec	
			Uni	Bi
0	0	10	910	1250
0	1	5	450	670
1	0	10	910	1250
1	1	20	1740	2350

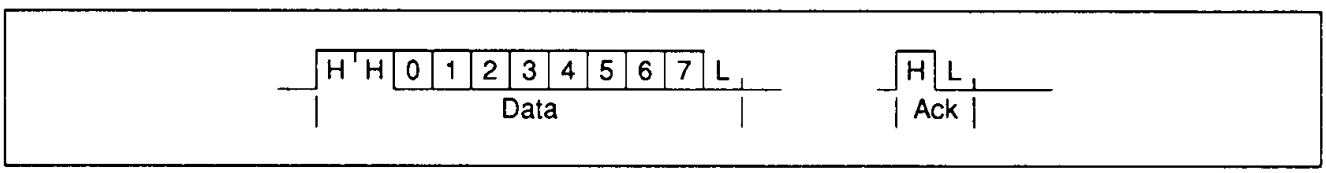


Figure 9.1 IMS T425 link data and acknowledge packets

Table 9.2 Link

SYMBOL	PARAMETER		MIN	NOM	MAX	UNITS	NOTE
TJQr	LinkOut rise time				20	ns	1
TJQf	LinkOut fall time				10	ns	1
TJDr	LinkIn rise time				20	ns	1
TJDf	LinkIn fall time				20	ns	1
TJQJD	Buffered edge delay		0			ns	
TJBskew	Variation in TJQJD	20 Mbits/s			3	ns	2
		10 Mbits/s			10	ns	2
		5 Mbits/s			30	ns	2
CLIZ	LinkIn capacitance	@ f=1MHz			7	pF	1
CLL	LinkOut load capacitance				50	pF	
RM	Series resistor for 100Ω transmission line			56		ohms	

Notes

1 These paramters are sampled, but are not 100% tested.

2 This is the variation in the total delay through buffers, transmission lines, differential receivers etc., caused by such things as short term variation in supply voltages and differences in delays for rising and falling edges.

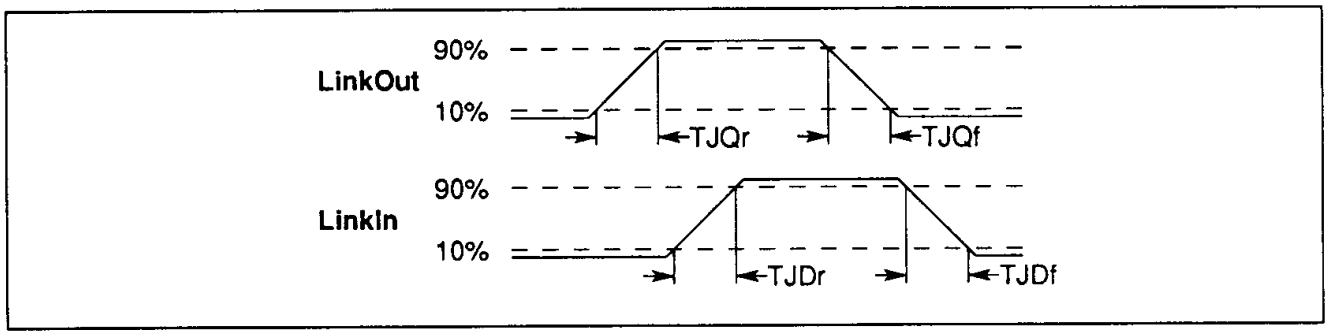


Figure 9.2 IMS T425 link timing

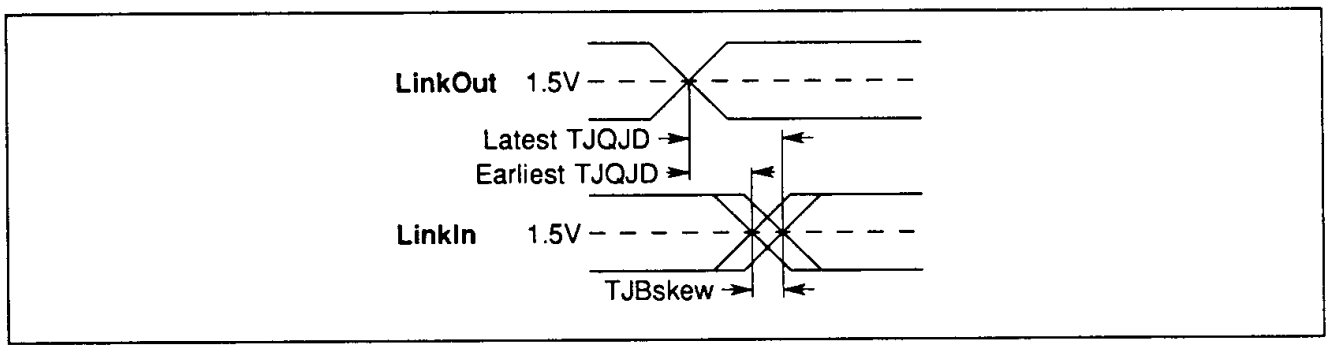


Figure 9.3 IMS T425 buffered link timing

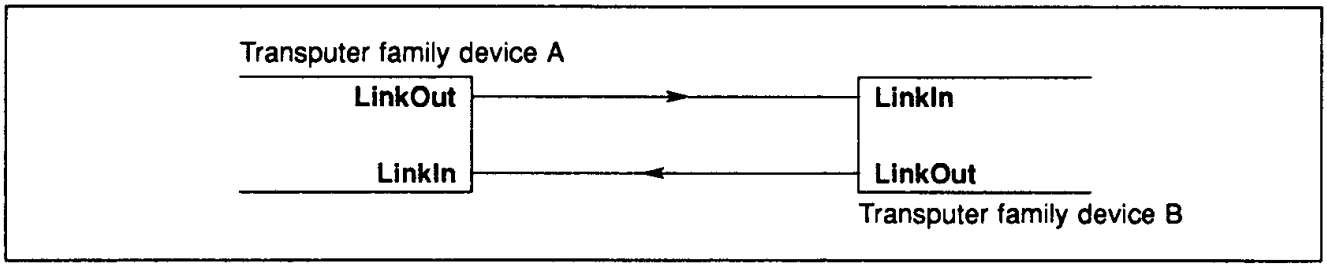


Figure 9.4 IMS T425 Links directly connected

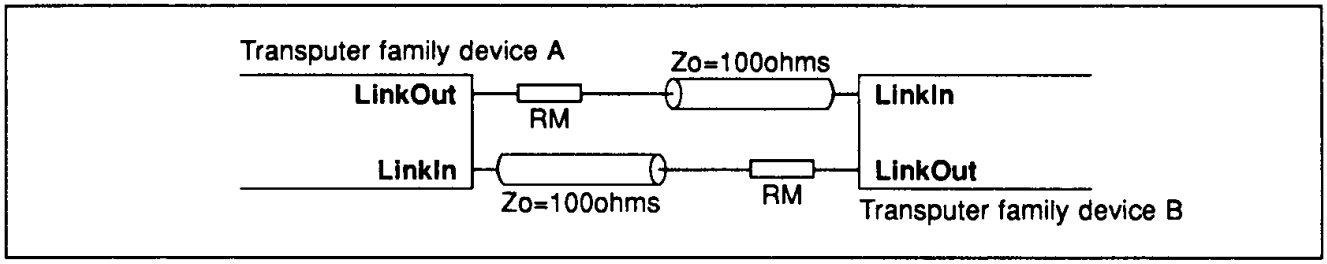


Figure 9.5 IMS T425 Links connected by transmission line

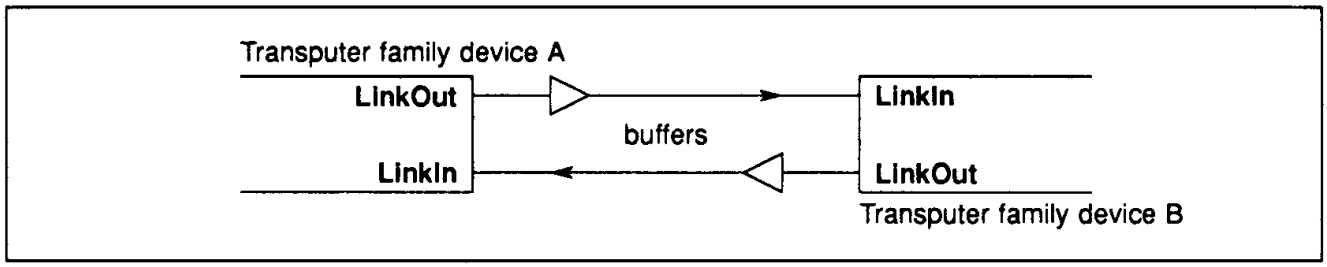


Figure 9.6 IMS T425 Links connected by buffers

10 Electrical specifications

10.1 DC electrical characteristics

Table 10.1 Absolute maximum ratings

SYMBOL	PARAMETER	MIN	MAX	UNITS	NOTE
VCC	DC supply voltage	0	7.0	V	1,2,3
VI, VO	Voltage on input and output pins	-0.5	VCC+0.5	V	1,2,3
II	Input current		±25	mA	4
OSCT	Output short circuit time (one pin)		1	s	2
TS	Storage temperature	-65	150	°C	2
TA	Ambient temperature under bias	-55	125	°C	2
PDmax	Maximum allowable dissipation		2	W	

Notes

1 All voltages are with respect to **GND**.

2 This is a stress rating only and functional operation of the device at these or any other conditions beyond those indicated in the operating sections of this specification is not implied. Stresses greater than those listed may cause permanent damage to the device. Exposure to absolute maximum rating conditions for extended periods may affect reliability.

3 This device contains circuitry to protect the inputs against damage caused by high static voltages or electrical fields. However, it is advised that normal precautions be taken to avoid application of any voltage higher than the absolute maximum rated voltages to this high impedance circuit. Unused inputs should be tied to an appropriate logic level such as **VCC** or **GND**.

4 The input current applies to any input or output pin and applies when the voltage on the pin is between **GND** and **VCC**.

Table 10.2 Operating conditions

SYMBOL	PARAMETER	MIN	MAX	UNITS	NOTE
VCC	DC supply voltage	4.75	5.25	V	1
VI, VO	Input or output voltage	0	VCC	V	1,2
CL	Load capacitance on any pin		60	pF	
TA	Operating temperature range IMS T425-S	0	70	°C	3
TA	Operating temperature range IMS T425-M	-55	125	°C	3

Notes

1 All voltages are with respect to **GND**.

2 Excursions beyond the supplies are permitted but not recommended; see DC characteristics.

3 Air flow rate 400 linear ft/min transverse air flow.

Table 10.3 DC characteristics

SYMBOL	PARAMETER		MIN	MAX	UNITS	NOTE
VIH	High level input voltage		2.0	VCC+0.5	V	1,2
VIL	Low level input voltage		-0.5	0.8	V	1,2
II	Input current	@ GND<VI<VCC		±10	μA	1,2
VOH	Output high voltage	@ IOH=2mA	VCC-1		V	1,2
VOL	Output low voltage	@ IOL=4mA		0.4	V	1,2
IOS	Output short circuit current	@ GND<VO<VCC	36	65	mA	1,2,3,6
			65	100	mA	1,2,4,6
IOZ	Tristate output current	@ GND<VO<VCC		±10	μA	1,2
PD	Power dissipation			1.0	W	2,5
CIN	Input capacitance	@ f=1MHz		7	pF	6
COZ	Output capacitance	@ f=1MHz		10	pF	6

Notes

1 All voltages are with respect to **GND**.

2 Parameters for IMS T425-S measured at 4.75V<**VCC**<5.25V and 0°C<**TA**<70°C.
Input clock frequency = 5 MHz.

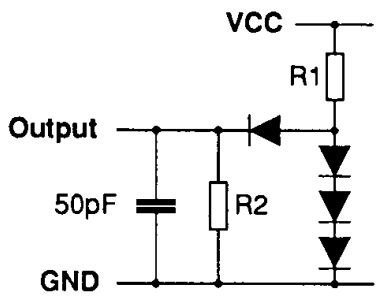
3 Current sourced from non-link outputs.

4 Current sourced from link outputs.

5 Power dissipation varies with output loading and program execution.
Power dissipation for processor operating at 20 MHz.

6 This parameter is sampled and not 100% tested.

10.2 Equivalent circuits



Load for:	R1	R2	Equivalent load:
Link outputs	1K96	47K	1 Schottky TTL input
Other outputs	970R	24K	2 Schottky TTL inputs

Diodes are 1N916

Figure 10.1 Load circuit for AC measurements

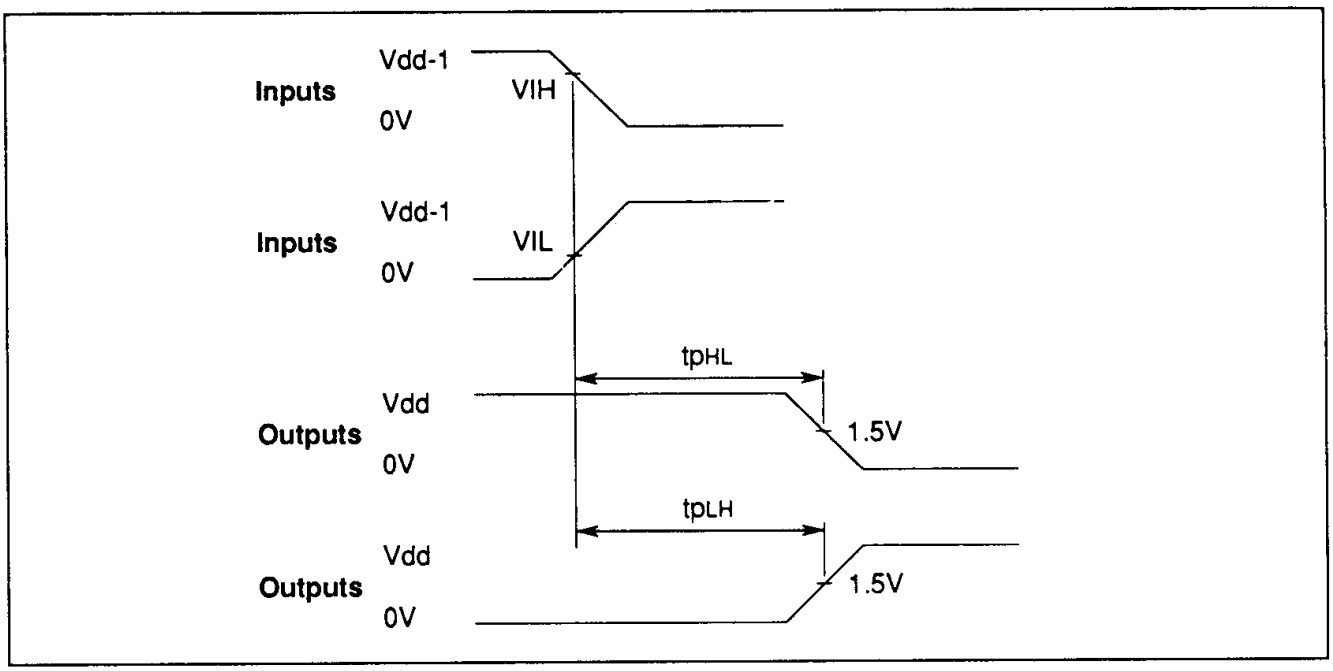


Figure 10.2 AC measurements timing waveforms

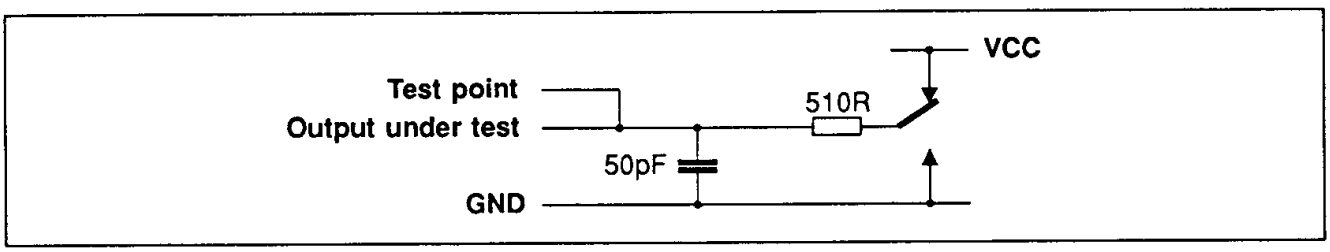


Figure 10.3 Tristate load circuit for AC measurements

10.3 AC timing characteristics

Table 10.4 Input, output edges

SYMBOL	PARAMETER	MIN	MAX	UNITS	NOTE
TDr	Input rising edges	2	20	ns	1,2
TDf	Input falling edges	2	20	ns	1,2
TQr	Output rising edges		25	ns	1
TQf	Output falling edges		15	ns	1
TS0LaHZ	Address high to tristate	**a**	**a**+6	ns	3
TS0LaLZ	Address low to tristate	**a**	**a**+6	ns	3

Notes

1 Non-link pins; see section on links.

2 All inputs except **ClockIn**; see section on **ClockIn**.

3 **a** is **T2** where **T2** can be from one to four periods **Tm** in length.
Address lines include **MemnotWrD0**, **MemnotRfD1**, **MemAD2-31**.

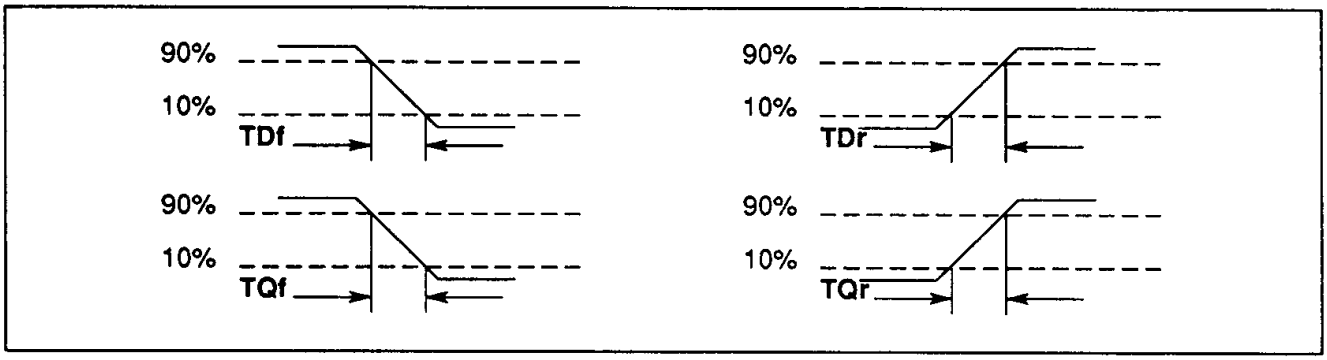


Figure 10.4 IMS T425 input and output edge timing

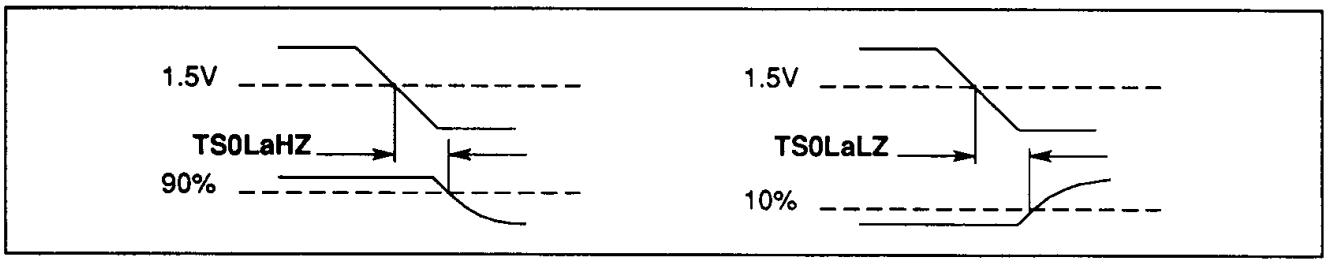


Figure 10.5 IMS T425 tristate timing relative to notMemS0

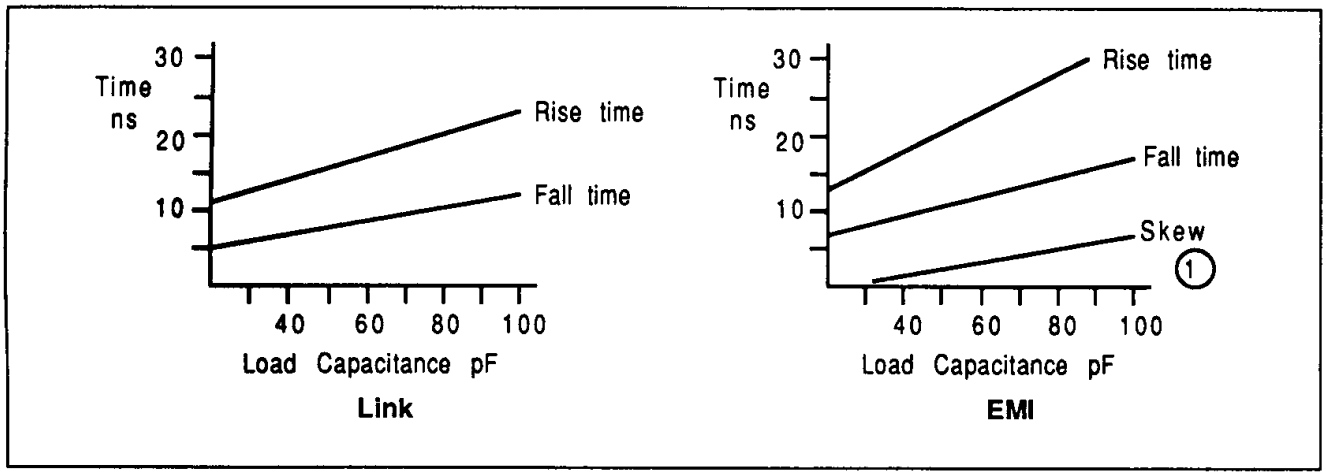


Figure 10.6 Typical rise/fall times

Notes

1 Skew is measured between **notMemS0** with a standard load (2 Schottky TTL inputs and 30pF) and **notMemS0** with a load of 2 Schottky TTL inputs and varying capacitance.

10.4 Power rating

Internal power dissipation P_{INT} of transputer and peripheral chips depends on **VCC**, as shown in figure 10.7. P_{INT} is substantially independent of temperature.

Total power dissipation P_D of the chip is

$$P_D = P_{INT} + P_{IO}$$

where P_{IO} is the power dissipation in the input and output pins; this is application dependent.

Internal working temperature T_J of the chip is

$$T_J = T_A + \theta J_A * P_D$$

where T_A is the external ambient temperature in °C and θJ_A is the junction-to-ambient thermal resistance in °C/W. θJ_A for each package is given in the Packaging Specifications section.

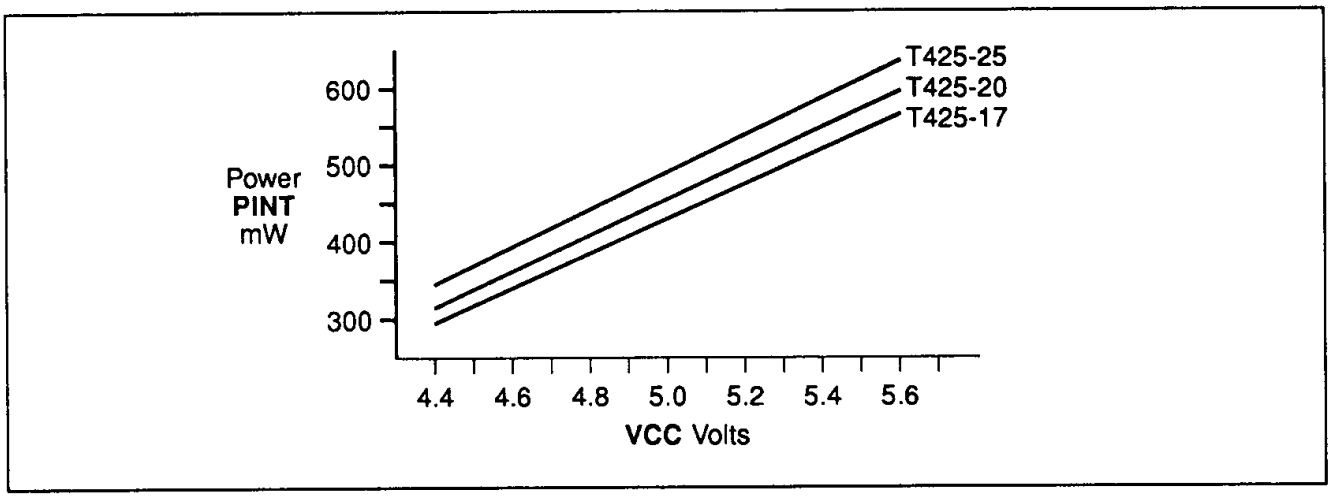


Figure 10.7 IMS T425 internal power dissipation vs VCC

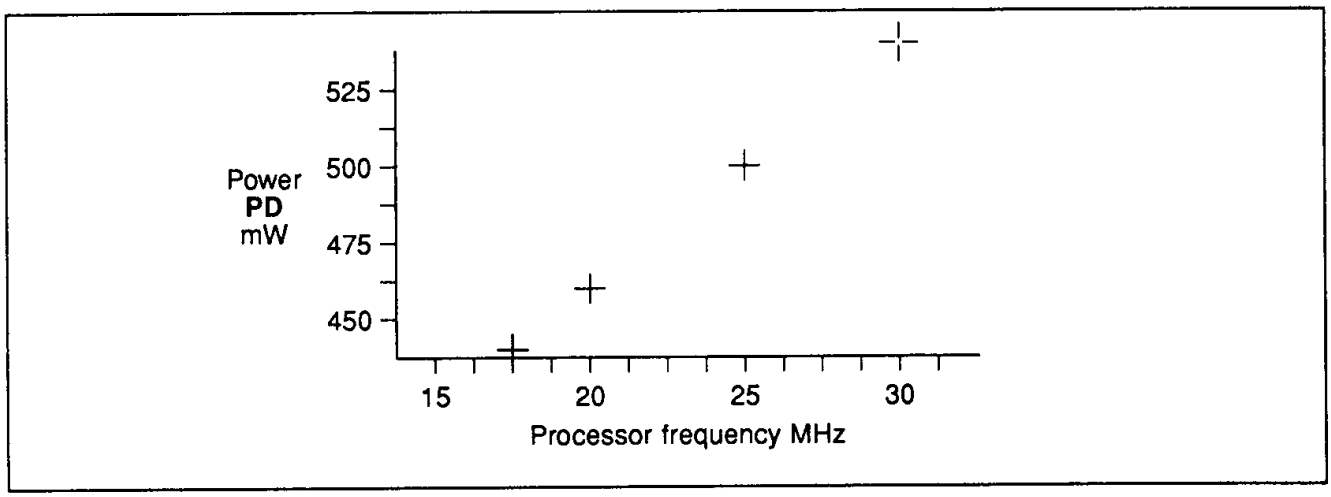


Figure 10.8 IMS T425 typical power dissipation with processor speed

11 Performance

The performance of the transputer is measured in terms of the number of bytes required for the program, and the number of (internal) processor cycles required to execute the program. The figures here relate to occam programs. For the same function, other languages should achieve approximately the same performance as occam.

11.1 Performance overview

These figures are averages obtained from detailed simulation, and should be used only as an initial guide; they assume operands are of type **INT**. The abbreviations in table 11.1 are used to represent the quantities indicated. In the replicator section of the table, figures in braces {} are not necessary if the number of replications is a compile time constant. To estimate performance, add together the time for the variable references and the time for the operation.

Table 11.1 Key to performance table

np	number of component processes
ne	number of processes earlier in queue
r	1 if **INT** parameter or array parameter, 0 if not
ts	number of table entries (table size)
w	width of constant in nibbles
p	number of places to shift
Eg	expression used in a guard
Et	timer expression used in a guard
Tb	most significant bit set of multiplier ((-1) if the multiplier is 0)
Tbp	most significant bit set in a positive multiplier when counting from zero ((-1) if the multiplier is 0)
Tbc	most significant bit set in the two's complement of a negative multiplier
nsp	Number of scalar parameters in a procedure
nap	Number of array parameters in a procedure

Table 11.2 Performance

	Size (bytes)	Time (cycles)
Names		
variables		
in expression	1.1+**r**	2.1+2(**r**)
assigned to or input to	1.1+**r**	1.1+(**r**)
in **PROC** or **FUNCTION** call, corresponding to an **INT** parameter	1.1+**r**	1.1+(**r**)
channels	1.1	2.1
Array Variables (for single dimension arrays)		
constant subscript	0	0
variable subscript	5.3	7.3
expression subscript	5.3	7.3
Declarations		
CHAN OF *protocol*	3.1	3.1
[size]CHAN OF *protocol*	9.4	2.2 + 20.2***size**
PROC	body+2	0
Primitives		
assignment	0	0
input	4	26.5
output	1	26
STOP	2	25
SKIP	0	0
Arithmetic operators		
+ -	1	1
*****	2	39
/	2	40
REM	2	38
>> <<	2	3+**p**
Modulo Arithmetic operators		
PLUS	2	2
MINUS	1	1
TIMES (fast multiply, positive operand)	1	4+**Tbp**
TIMES (fast multiply, negative operand)	1	5+**Tbc**
Boolean operators		
OR	4	8
AND NOT	1	2
Comparison operators		
= constant	0	1
= variable	2	3
<> constant	1	3
<> variable	3	5
> <	1	2
>= <=	2	4
Bit operators		
/\ \/ >< ~	2	2
Expressions		
constant in expression	**w**	**w**
check if error	4	6

Table 11.3 Performance

	Size (bytes)	Time (cycles)
Timers		
timer input	2	3
timer **AFTER**		
if past time	2	4
with empty timer queue	2	31
non-empty timer queue	2	38+**ne***9
ALT (timer)		
with empty timer queue	6	52
non-empty timer queue	6	59+**ne***9
timer alt guard	8+2**Eg**+2**Et**	34+2**Eg**+2**Et**
Constructs		
SEQ	0	0
IF	1.3	1.4
if guard	3	4.3
ALT (non timer)	6	26
alt channel guard	10.2+2**Eg**	20+2**Eg**
skip alt guard	8+2**Eg**	10+2**Eg**
PAR	11.5+(**np**-1)*7.5	19.5+(**np**-1)*30.5
WHILE	4	12
Procedure or function call	3.5+(nsp-2)*1.1 +nap*2.3	16.5+(nsp-2)*1.1 +nap*2.3
Replicators		
replicated **SEQ**	7.3{+5.1}	(-3.8)+15.1*count{+7.1}
replicated **IF**	12.3{+5.1}	(-2.6)+19.4*count{+7.1}
replicated **ALT**	24.8{+10.2}	25.4+33.4*count{+14.2}
replicated timer **ALT**	24.8{+10.2}	62.4+33.4*count{+14.2}
replicated **PAR**	39.1{+5.1}	(-6.4)+70.9*count{+7.1}

11.2 Fast multiply, TIMES

The IMS T425 has a fast integer multiplication instruction *product*. For a positive multiplier its execution time is 4+**Tbp** cycles, and for a negative multiplier 5+**Tbc** cycles (table 11.1). The time taken for a multiplication by zero is 3 cycles.

Implementations of high level languages on the transputer may take advantage of this instruction. For example, the occam modulo arithmetic operator **TIMES** is implemented by the instruction and the right-hand operand is treated as the multiplier. The fast multiplication instruction is also used in high level language implementations for the multiplication implicit in multi-dimensional array access.

11.3 Arithmetic

A set of functions are provided within the development system to support the efficient implementation of multiple length integer arithmetic and floating point arithmetic. In table 11.4 **n** gives the number of places shifted and all arguments and results are assumed to be local. Full details of these functions are provided in the occam reference manual, supplied as part of the development system and available as a separate publication.

When calculating the execution time of the predefined maths functions, no time needs to be added for calling overhead. These functions are compiled directly into special purpose instructions which are designed to support the efficient implementation of multiple length integer arithmetic and floating point arithmetic.

Table 11.4 Arithmetic performance

Function		Cycles	+ cycles for parameter access †
LONGADD		2	7
LONGSUM		3	8
LONGSUB		2	7
LONGDIFF		3	8
LONGPROD		34	8
LONGDIV		36	8
SHIFTRIGHT	(n<32)	4+n	8
	(n>=32)	n-27	
SHIFTLEFT	(n<32)	4+n	8
	(n>=32)	n-27	
NORMALISE	(n<32)	n+6	7
	(n>=32)	n-25	
	(n=64)	4	
ASHIFTRIGHT		SHIFTRIGHT+2	5
ASHIFTLEFT		SHIFTLEFT+4	5
ROTATERIGHT		SHIFTRIGHT	7
ROTATELEFT		SHIFTLEFT	7
FRACMUL		LONGPROD+4	5

† Assuming local variables.

11.4 Floating point operations

Floating point operations for the IMS T425 are provided by a run-time package. This requires approximately 400 bytes of memory for the single length arithmetic operations, and 2500 bytes for the double length arithmetic operations. Table 11.5 summarizes the estimated performance of the package.

Table 11.5 IMS T425 floating point operations performance

		Processor cycles	
		IMS T425	
		Typical	Worst
REAL32	+ -	230	300
	*	200	240
	/	245	280
	< > = >= <= <>	60	60
REAL64	+ -	565	700
	*	760	940
	/	1115	1420
	< > = >= <= <>	60	60

11.4.1 Special purpose functions and procedures

The functions and procedures given in tables 11.7 and 11.8 are provided by the development system to give access to the special instructions available on the IMS T425. Table 11.6 shows the key to the table.

Table 11.6 Key to special performance table

Tb	most significant bit set in the word counting from zero
n	number of words per row (consecutive memory locations)
r	number of rows in the two dimensional move
nr	number of bits to reverse

Table 11.7 Special purpose functions performance

Function	Cycles	+ cycles for parameter access †
BITCOUNT	2+Tb	2
CRCBYTE	11	8
CRCWORD	35	8
BITREVNBIT	5+nr	4
BITREVWORD	36	2

† Assuming local variables.

Table 11.8 Special purpose procedures performance

Procedure	Cycles	+ cycles for parameter access †
MOVE2D	8+(2n+23)*r	8
DRAW2D	8+(2n+23)*r	8
CLIP2D	8+(2n+23)*r	8

† Assuming local variables.

11.5 Effect of external memory

Extra processor cycles may be needed when program and/or data are held in external memory, depending both on the operation being performed, and on the speed of the external memory. After a processor cycle which initiates a write to memory, the processor continues execution at full speed until at least the next memory access.

Whilst a reasonable estimate may be made of the effect of external memory, the actual performance will depend upon the exact nature of the given sequence of operations.

External memory is characterized by the number of extra processor cycles per external memory cycle, denoted as **e**. For the IMS T425, with the fastest external memory the value of **e** is 2; a typical value for a large external memory is 5.

If program is stored in external memory, and **e** has the value 2 or 3, then no extra cycles need be estimated for linear code sequences. For larger values of **e**, the number of extra cycles required for linear code sequences may be estimated at (**e**-3)/4. A transfer of control may be estimated as requiring **e**+3 cycles.

These estimates may be refined for various constructs. In table 11.9 **n** denotes the number of components in a construct. In the case of **IF**, the **n**'th conditional is the first to evaluate to **TRUE**, and the costs include the costs of the conditionals tested. The number of bytes in an array assignment or communication is denoted by **b**.

Table 11.9 External memory performance

	IMS T425	
	Program off chip	**Data off chip**
Boolean expressions	**e**-2	0
IF	3**en**-8	**en**
Replicated **IF**	(6**e**-4)**n**+7	(5**e**-2)**n**+8
Replicated **SEQ**	(3**e**-3)**n**+2	(4**e**-2)**n**
PAR	(3**e**-1)**n**+8	3**en**+4
Replicated **PAR**	(10**e**-8)**n**+8	16**en**-12
ALT	(2**e**-4)**n**+6**e**	(2**e**-2)**n**+10**e**-8
Array assignment and communication in one transputer	0	max (2**e**, **e**(**b**/2))

The following simulation results illustrate the effect of storing program and/or data in external memory. The results are normalized to 1 for both program and data on chip. The first program (Sieve of Erastosthenes) is an extreme case as it is dominated by small, data access intensive loops; it contains no concurrency, communication, or even multiplication or division. The second program is the pipeline algorithm for Newton Raphson square root computation.

Table 11.10 IMS T425 external memory performance

	Program	**e=2**	**e=3**	**e=4**	**e=5**	**On chip**
Program off chip	1	1.3	1.5	1.7	1.9	1
	2	1.1	1.2	1.2	1.3	1
Data off chip	1	1.5	1.8	2.1	2.3	1
	2	1.2	1.4	1.6	1.7	1
Program and data off chip	1	1.8	2.2	2.7	3.2	1
	2	1.3	1.6	1.8	2.0	1

11.6 Interrupt latency

If the process is a high priority one and no other high priority process is running, the latency is as described in table 11.11. The timings given are in full processor cycles **TPCLPCL**; the number of **Tm** states is also given where relevant. Maximum latency assumes all memory accesses are internal ones.

Table 11.11 Interrupt latency

	Typical		Maximum	
	TPCLPCL	**Tm**	**TPCLPCL**	**Tm**
IMS T425	19	38	53	116

12 Package specifications

12.1 84 pin grid array package

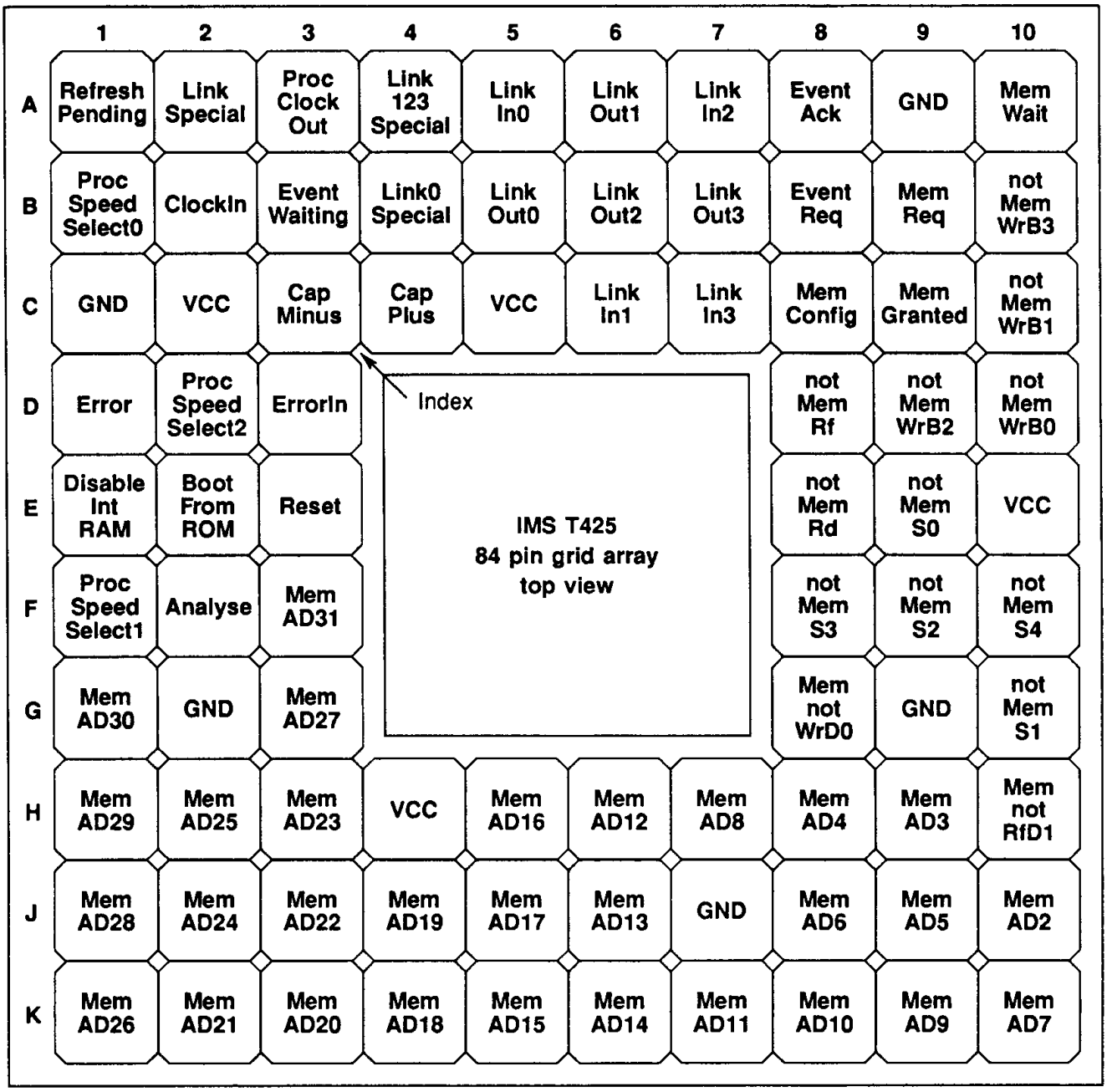


Figure 12.1 IMS T425 84 pin grid array package pinout

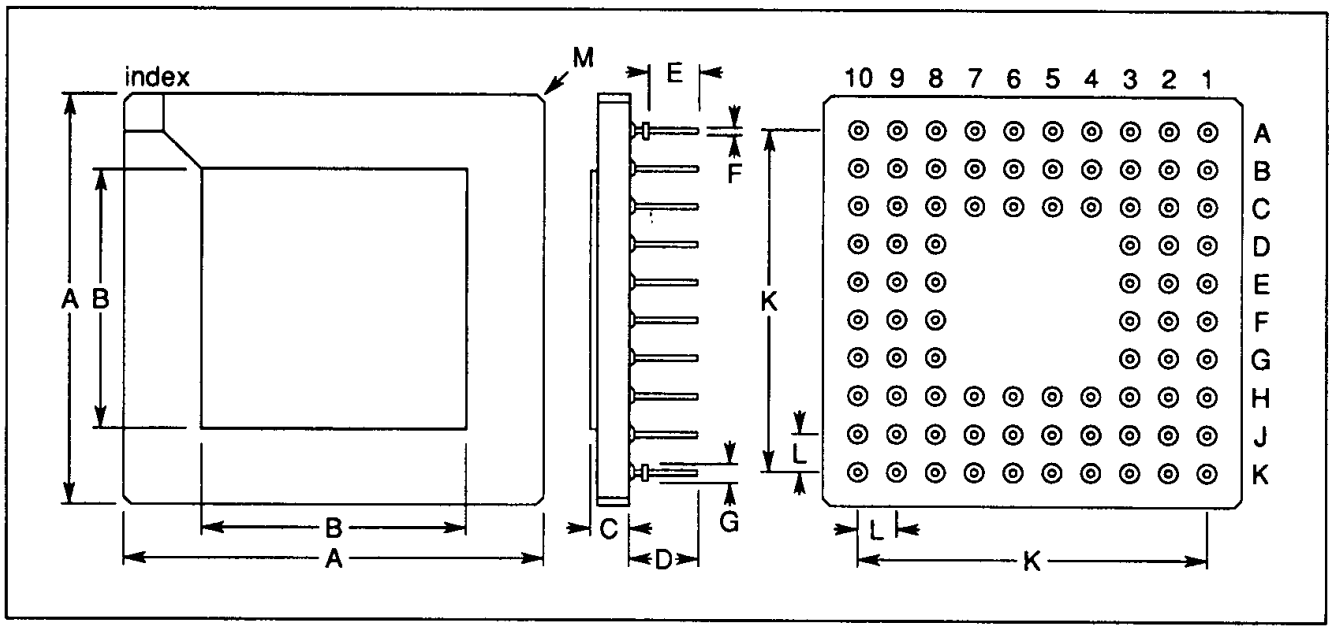


Figure 12.2 84 pin grid array package dimensions

Table 12.1 84 pin grid array package dimensions

DIM	Millimetres		Inches		Notes
	NOM	TOL	NOM	TOL	
A	26.924	±0.254	1.060	±0.010	
B	17.019	±0.127	0.670	±0.005	
C	2.456	±0.278	0.097	±0.011	
D	4.572	±0.127	0.180	±0.005	
E	3.302	±0.127	0.130	±0.005	
F	0.457	±0.025	0.018	±0.002	Pin diameter
G	1.143	±0.127	0.045	±0.005	Flange diameter
K	22.860	±0.127	0.900	±0.005	
L	2.540	±0.127	0.100	±0.005	
M	0.508		0.020		Chamfer

Package weight is approximately 7.2 grams

Table 12.2 84 pin grid array package junction to ambient thermal resistance

SYMBOL	PARAMETER	MIN	NOM	MAX	UNITS	NOTE
θJA	At 400 linear ft/min transverse air flow			35	°C/W	

12.2 84 pin PLCC J-bend package

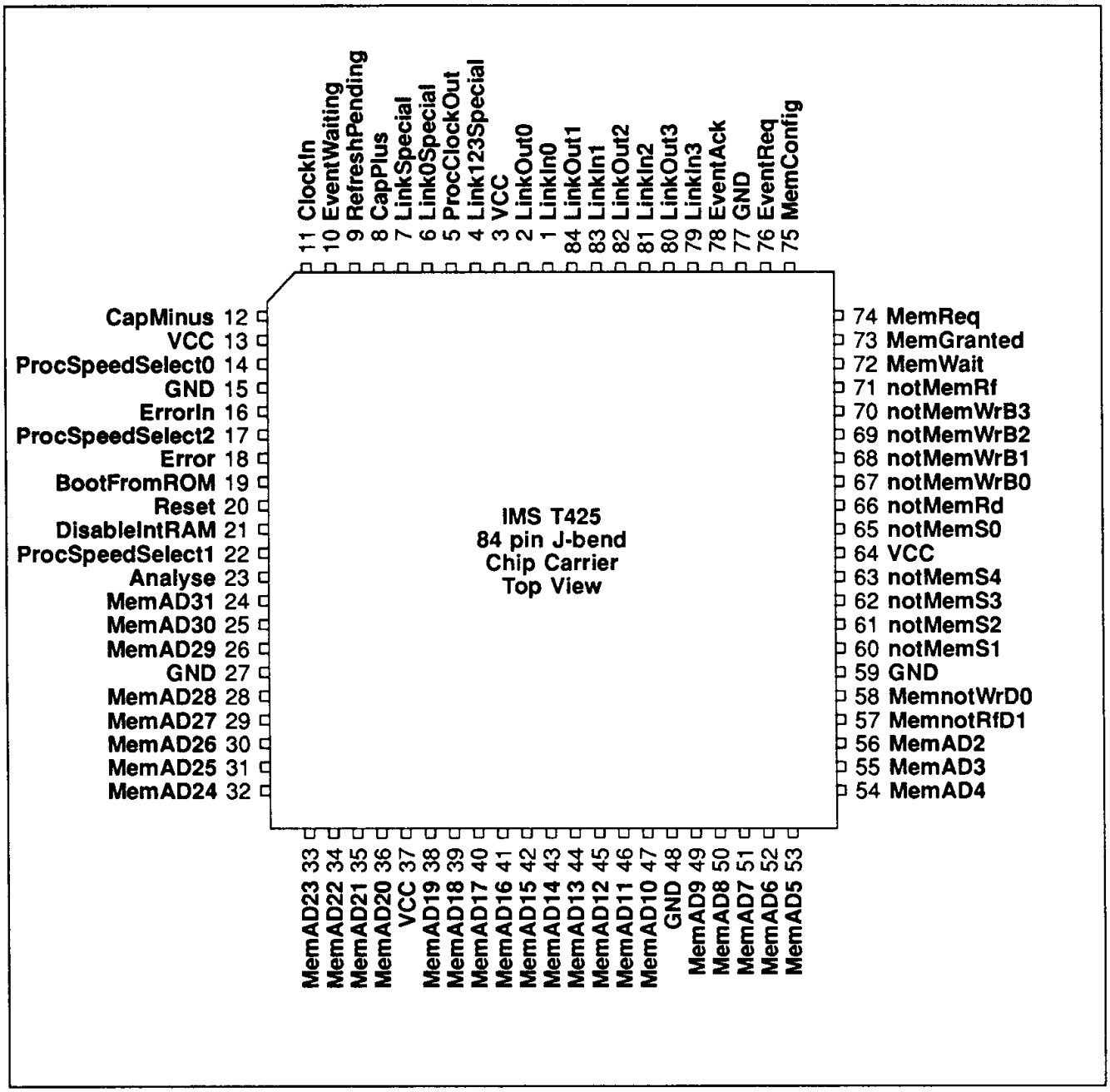


Figure 12.3 IMS T425 84 pin PLCC J-bend package pinout

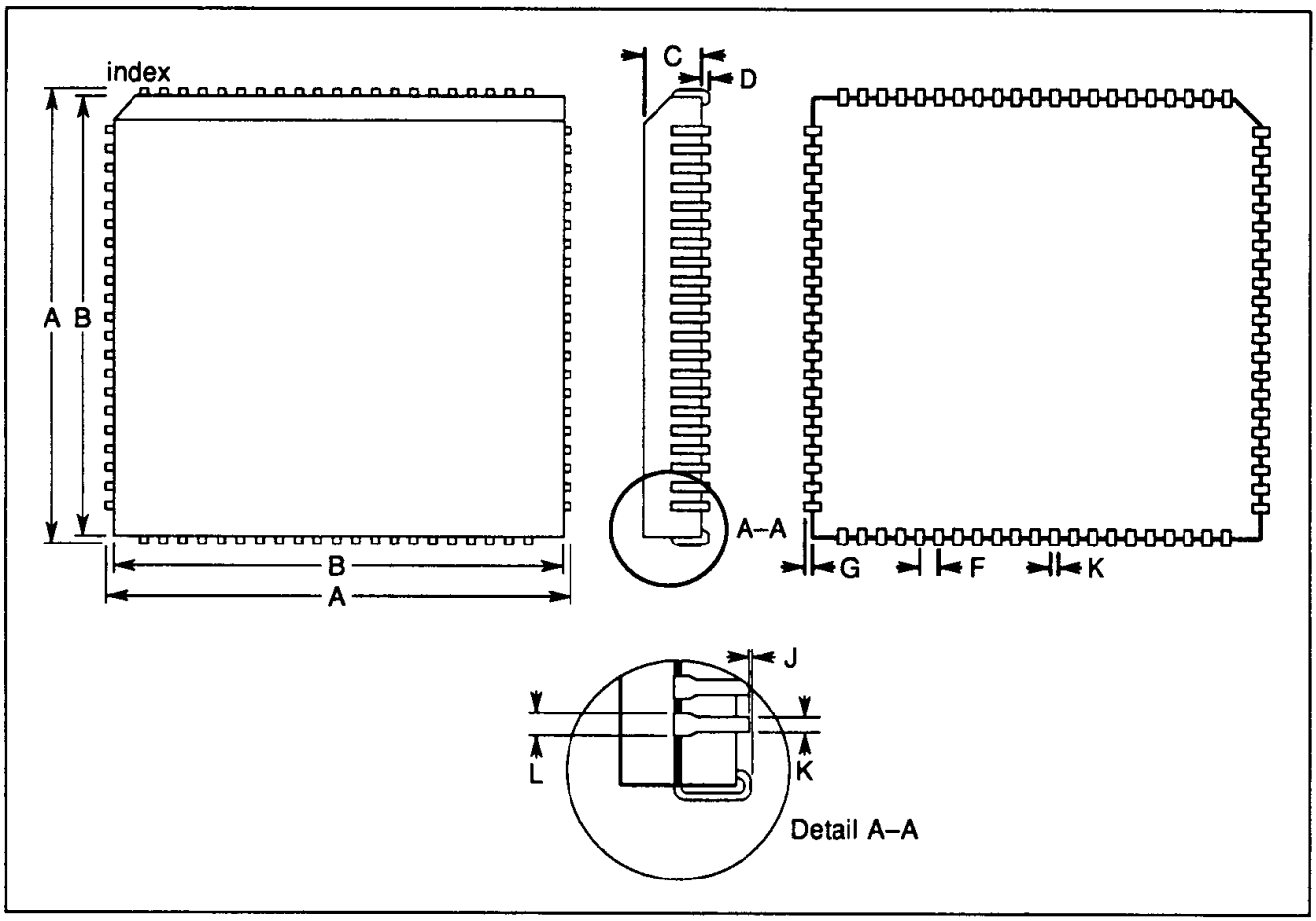


Figure 12.4 84 pin PLCC J-bend package dimensions

Table 12.3 84 pin PLCC J-bend package dimensions

DIM	Millimetres		Inches		Notes
	NOM	TOL	NOM	TOL	
A	30.226	±0.127	1.190	±0.005	
B	29.312	±0.127	1.154	±0.005	
C	3.810	±0.127	0.150	±0.005	
D	0.508	±0.127	0.020	±0.005	
F	1.270	±0.127	0.050	±0.005	
G	0.457	±0.127	0.018	±0.005	
J	0.000	±0.051	0.000	±0.002	
K	0.457	±0.127	0.018	±0.005	
L	0.762	±0.127	0.030	±0.005	

Package weight is approximately 7.0 grams

Table 12.4 84 pin PLCC J-bend package junction to ambient thermal resistance

SYMBOL	PARAMETER	MIN	NOM	MAX	UNITS	NOTE
θJA	At 400 linear ft/min transverse air flow		35		°C/W	

12.3 84 lead quad cerpack package

The leads are unformed to allow the user to form them to specific requirements.

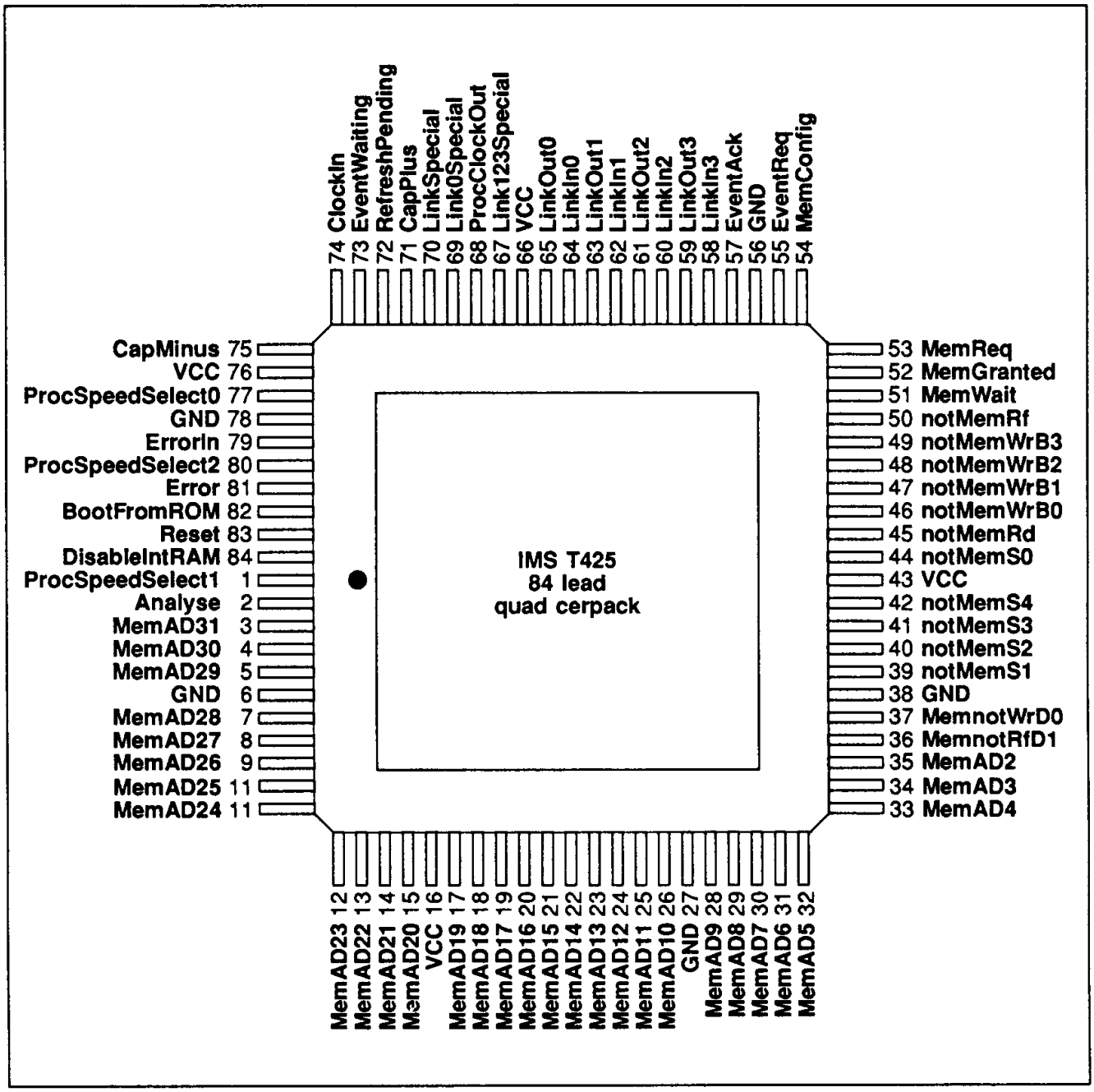


Figure 12.5 IMS T425 84 lead quad cerpack package pinout

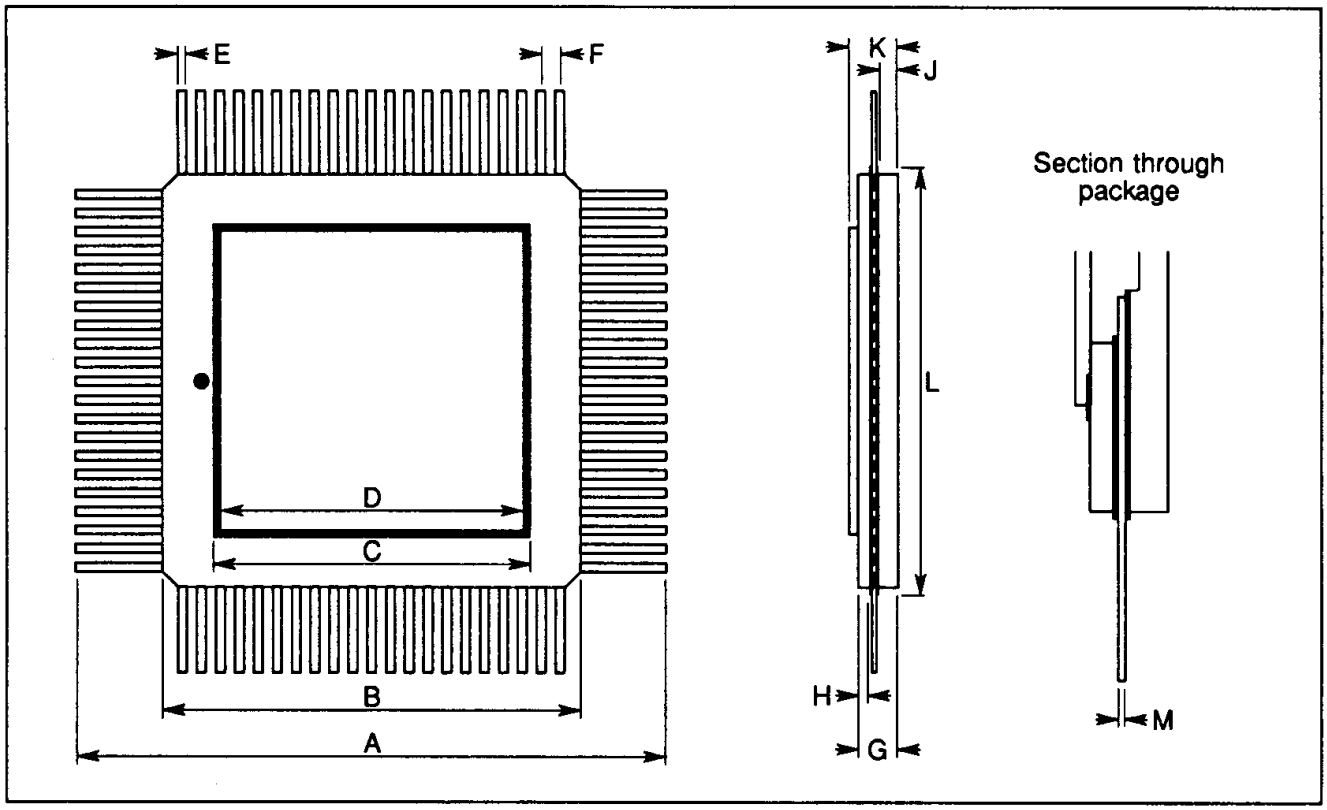


Figure 12.6 84 lead quad cerpack package dimensions

DIM	Millimetres		Inches		Notes
	NOM	TOL	NOM	TOL	
A	38.100	±0.508	1.500	±0.020	
B	26.924	±0.305	1.060	±0.012	
C	20.574	±0.203	0.810	±0.008	
D	19.558	±0.254	0.770	±0.010	
E	0.508		0.020		
F	1.270	±0.051	0.050	±0.002	
G	2.489	±0.305	0.098	±0.012	
H	0.635	±0.076	0.025	±0.003	
J	1.143	±0.102	0.045	±0.004	
K	3.099		0.122		Max.
L	27.940		1.100		Max.
M	0.178	±0.025	0.007	±0.001	

Table 12.5 84 lead quad cerpack package dimensions

13 Ordering

This section indicates the designation of speed and package selections for the various devices. Speed of **ClockIn** is 5 MHz for all parts. Transputer processor cycle time is nominal; it can be calculated more exactly using the phase lock loop factor **PLLx**, as detailed in the external memory section.

For availability contact local INMOS sales office or authorised distributor.

Table 13.1 IMS T425 ordering details

INMOS designation	Processor clock speed	Processor cycle time	PLLx	Package
IMS T425-G17S	17.5 MHz	57 ns	3.5	Ceramic Pin Grid
IMS T425-G20S	20.0 MHz	50 ns	4.0	Ceramic Pin Grid
IMS T425-G25S	25.0 MHz	40 ns	5.0	Ceramic Pin Grid
IMS T425-G30S	30.0 MHz	33 ns	6.0	Ceramic Pin Grid
IMS T425-J17S	17.5 MHz	57 ns	3.5	Plastic PLCC J-Bend
IMS T425-J20S	20.0 MHz	50 ns	4.0	Plastic PLCC J-Bend
IMS T425-G17M	17.5 MHz	57 ns	3.5	Ceramic Pin Grid MIL Spec
IMS T425-G20M	20.0 MHz	50 ns	4.0	Ceramic Pin Grid MIL Spec
IMS T425-Q17M	17.5 MHz	57 ns	3.5	Quad Cerpack MIL Spec
IMS T425-Q20M	20.0 MHz	50 ns	4.0	Quad Cerpack MIL Spec

The timing parameters in this datasheet are based on 17 MHz and 20 MHz parts. Data for higher speeds is based on tests on a limited number of samples and may change when full characterisation is completed.