KM44C256BL T-46-23-15 CMOS DRAM

256KX4 Bit CMOS Dynamic RAM with Fast Page Mode

FEATURES

- Performance range:

	t_{RAC}	t_{CAC}	t_{RC}
KM44C256BL- 7	70ns	20ns	130ns
KM44C256BL- 8	80ns	20ns	150ns
KM44C256BL-10	100ns	25ns	180ns

- Fast Page Mode operation
- $\overline{CAS}$-before-$\overline{RAS}$ refresh capability
- $\overline{RAS}$-only and Hidden refresh capability
- TTL compatible inputs and output
- Early write or output Enable controlled write
- Common I/O using Early Write
- Single +5V±10% power supply
- Low power dissipation
  - I_{CC5}: 200μA
  - I_{CC7}: 300μA (Battery back up mode)
- 512 cycles/64ms refresh
- JEDEC standard pinout
- Available in plastic DIP, SOJ and ZIP

GENERAL DESCRIPTION

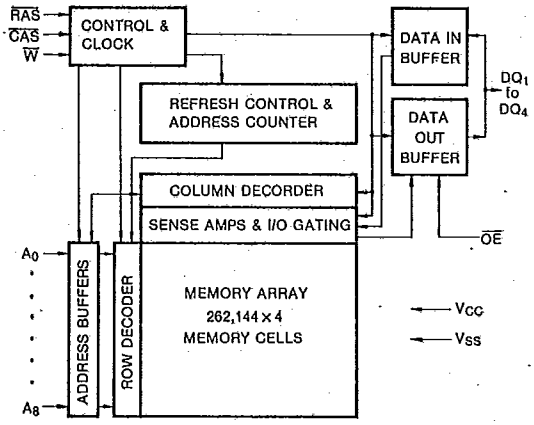
The Samsung KM44C256BL is a CMOS high speed 262,144 x 4 Dynamic Random Access Memory. Its design is optimized for high performance applications such as mainframes and mini computers, graphics and high performance microprocessor systems.

The KM44C256BL features Fast Page Mode operation which allows high speed random access of memory cells within the same row.

$\overline{CAS}$-before-$\overline{RAS}$ refresh capability provides on-chip auto refresh as an alternative to $\overline{RAS}$-only Refresh. All inputs and outputs are fully TTL compatible.

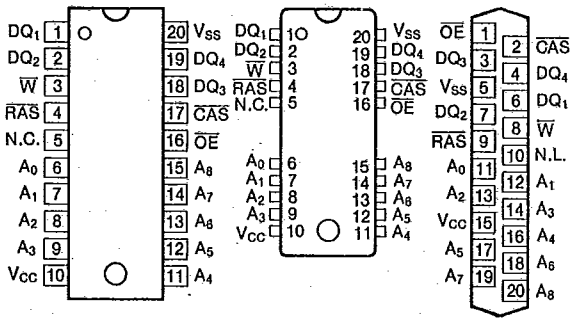
The KM44C256BL is fabricated using Samsung's advanced CMOS process.

FUNCTIONAL BLOCK DIAGRAM



PIN CONFIGURATION (Top Views)

- KM44C256BLP
- KM44C256BLJ
- KM44C256BLZ



Pin Name	Pin Function
A_0-A_8	Address Inputs
$\overline{RAS}$	Row Address Strobe
$\overline{CAS}$	Column Address Strobe
$\overline{W}$	Read/Write Input
$\overline{OE}$	Data Output Enable
DQ_1-DQ_4	Data In/Data Out
V_{CC}	Power (+5V)
V_{SS}	Ground
N.C.	No Connection
N.L.	No Lead

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ABSOLUTE MAXIMUM RATINGS*

Item	Symbol	Rating	Units
Voltage on Any Pin Relative to V_{SS}	V_{IN}, V_{OUT}	−1 to +7.0	V
Voltage on V_{CC} Supply Relative to V_{SS}	V_{CC}	−1 to +7.0	V
Storage Temperature	T_{stg}	−55 to +150	°C
Power Dissipation	P_D	600	mW
Short Circuit Output Current	I_{OS}	50	mA

* Permanent device damage may occur if "ABSOLUTE MAXIMUM RATINGS" are exceeded. Functional operation should be restricted to the conditions as detailed in the operational sections of this data sheet. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

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RECOMMENDED OPERATING CONDITIONS (Voltage referenced to V_{SS}, T_A = 0 to 70°C)

Item	Symbol	Min	Typ	Max	Unit
Supply Voltage	V_{CC}	4.5	5.0	5.5	V
Ground	V_{SS}	0	0	0	V
Input High Voltage	V_{IH}	2.4	—	V_{CC}+1	V
Input Low Voltage	V_{IL}	−1.0	—	0.8	V

DC AND OPERATING CHARACTERISTICS

(Recommended operating conditions unless otherwise noted)

Parameter		Symbol	Min	Max	Units
Operating Current* ($\overline{RAS}$, $\overline{CAS}$, Address Cyling @ t_{RC} = min.)	KM44C256BL- 7	I_{CC1}	—	80	mA
	KM44C256BL- 8		—	70	mA
	KM44C256BL-10		—	60	mA
Standby Current ($\overline{RAS}$ = $\overline{CAS}$ = V_{IH})		I_{CC2}	—	2	mA
$\overline{RAS}$-Only Refresh Current* ($\overline{CAS}$ = V_{IH}, $\overline{RAS}$ Cycling @ t_{RC} = min.)	KM44C256BL- 7	I_{CC3}	—	80	mA
	KM44C256BL- 8		—	70	mA
	KM44C256BL-10		—	60	mA
Fast Page Mode Current* ($\overline{RAS}$ = V_{IL}, $\overline{CAS}$, Address Cycling @ t_{PC} = min.)	KM44C256BL- 7	I_{CC4}	—	65	mA
	KM44C256BL- 8		—	55	mA
	KM44C256BL-10		—	45	mA
Standby Current ($\overline{RAS}$ = $\overline{CAS}$ = V_{CC} − 0.2V)		I_{CC5}	—	200	μA
$\overline{CAS}$-Before-$\overline{RAS}$ Refresh Current* ($\overline{RAS}$ and $\overline{CAS}$ Cyling @ t_{RC} = min.)	KM44C256BL- 7	I_{CC6}	—	80	mA
	KM44C256BL- 8		—	70	mA
	KM44C256BL-10		—	60	mA
Battery Back Up Current Average Power Supply Current, Battery back up Mode ($\overline{CAS}$ = $\overline{CAS}$ Before $\overline{RAS}$ Cycling or 0.2V, $\overline{OE}$ = V_{CC} − 0.2V, $\overline{W}$ = V_{CC} − 0.2V or 0.2V, A_0 ~ A_8 = V_{CC} − 0.2V or 0.2V, I/01 ~ 4 = V_{CC} −0.2V, 0.2V or OPEN: t_{RC} = 125μs, t_{RAS} = t_{RAS} min. ~ 1μs)	KM44C256BL- 7 KM44C256BL- 8 KM44C256BL-10	I_{CC7}	—	300	μA

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DC AND OPERATING CHARACTERISTICS (Continued)

Parameter	Symbol	Min	Max	Units
Input Leakage Current (Any Input $0 \le V_{IN} \le 6.5V$, all other pins not under test = 0V)	I_{IL}	−10	10	μA
Output Leakage Current (Data out is disabled, $0 \le V_{OUT} \le 5.5V$)	I_{OL}	−10	10	μA
Output High Voltage Level (I_{OH} = −5mA)	V_{OH}	2.4	—	V
Output Low Voltage Level (I_{OL} = 4.2mA)	V_{OL}	—	0.4	V

*Notes
1. I_{CC} is specified as average current.
2. I_{CC1}, I_{CC3}, I_{CC4}, and I_{CC5} are dependent on output loading and cycle rates. The specified values are obtained with the output open.
3. In I_{CC3} address can be changed less than three times while $\overline{RAS} = V_{IL}$

CAPACITANCE (T_A = 25°C)

Parameter	Symbol	Min	Max	Unit
Input Capacitance (A_0-A_8)	C_{IN1}	—	6	pF
Input Capacitance ($\overline{RAS}$, $\overline{CAS}$, $\overline{W}$, $\overline{OE}$)	C_{IN2}	—	7	pF
Output Capacitance (DQ_1-DQ_4)	C_{DQ}	—	7	pF

AC CHARACTERISTICS (0°C ≤ T_A ≤ 70°C, V_{CC} = 5.0V ± 10%, See notes 1, 2)

Parameter	Symbol	KM44C256BL-7		KM44C256BL-8		KM44C256BL-10		Unit	Notes
		Min	Max	Min	Max	Min	Max		
Random read or write cycle time	t_{RC}	130		150		180		ns	
Read-modify-write cycle time	t_{RWC}	185		205		245		ns	
Fast page mode cycle time	t_{PC}	45		50		60		ns	
Fast page mode read-modify-Write cycle time	t_{PRWC}	100		105		125		ns	
Access time from $\overline{RAS}$	t_{RAC}		70		80		100	ns	3,4,11
Access time from $\overline{CAS}$	t_{CAC}		20		20		25	ns	3,4,5
Access time from column address	t_{AA}		35		40		50	ns	3,11
Access time from $\overline{CAS}$ precharge	t_{CPA}		40		45		55	ns	3
$\overline{CAS}$ to output in Low-Z	t_{CLZ}	0		0		0		ns	3
Output buffer turn-off delay	t_{OFF}	0	20	0	20	0	20	ns	7
Transition time (rise and fall)	t_T	3	50	3	50	3	50	ns	2
$\overline{RAS}$ precharge time	t_{RP}	50		60		70		ns	
$\overline{RAS}$ pulse width	t_{RAS}	70	10,000	80	10,000	100	10,000	ns	
$\overline{RAS}$ pulse width (Fast page mode)	t_{RASP}	70	100,000	80	100,000	100	100,000	ns	
$\overline{RAS}$ hold time	t_{RSH}	20		20		25		ns	
$\overline{CAS}$ hold time	t_{CSH}	70		80		100		ns	
$\overline{CAS}$ pulse width	t_{CAS}	20	10,000	20	10,000	25	10,000	ns	

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AC CHARACTERISTICS (Continued)

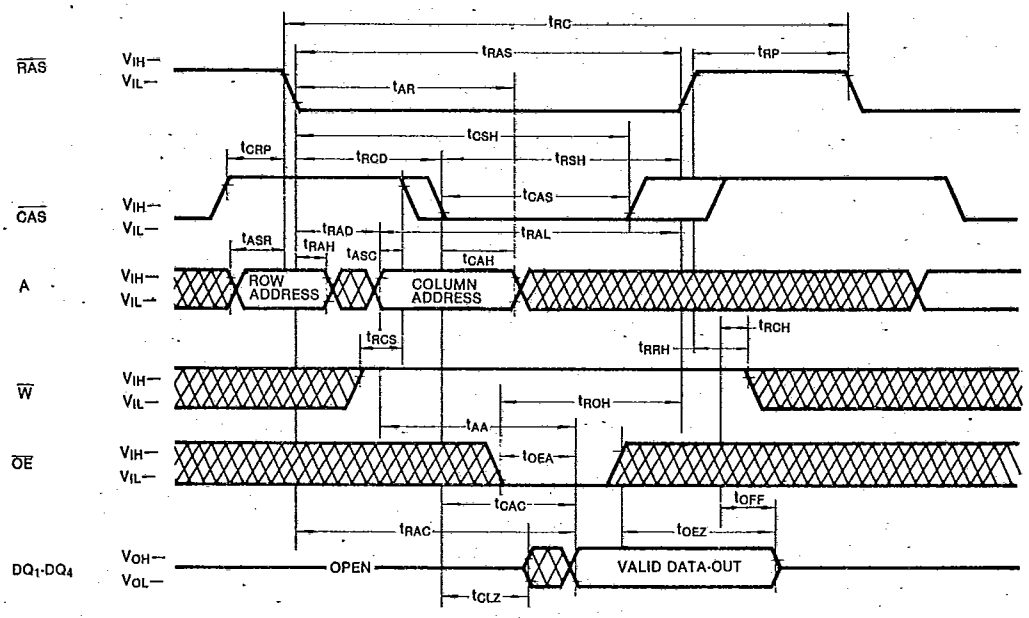
Parameter	Symbol	KM44C256BL-7		KM44C256BL-8		KM44C256BL-10		Unit	Notes
		Min	Max	Min	Max	Min	Max		
$\overline{RAS}$ to $\overline{CAS}$ delay time	t_{RCD}	20	50	25	60	25	75	ns	4
$\overline{RAS}$ to column address delay time	t_{RAD}	15	35	20	40	20	50	ns	11
$\overline{CAS}$ to $\overline{RAS}$ precharge time	t_{CRP}	5		5		5		ns	11
$\overline{CAS}$ precharge time (Fast page mode)	t_{CP}	10		10		10		ns	
Row address set-up time	t_{ASR}	0		0		0		ns	
Row address hold time	t_{RAH}	10		15		15		ns	
Column address set-up time	t_{ASC}	0		0		0		ns	
Column address hold time	t_{CAH}	15		20		20		ns	
Column address hold time referenced to $\overline{RAS}$	t_{AR}	55		65		75		ns	6
Column address to $\overline{RAS}$ lead time	t_{RAL}	35		40		50		ns	
Read command set-up time	t_{RCS}	0		0		0		ns	
Read command hold time	t_{RCH}	0		0		0		ns	9
Read command hold time referenced to $\overline{RAS}$	t_{RRH}	0		0		0		ns	9
Write command hold time	t_{WCH}	15		20		20		ns	
Write command hold time referenced to $\overline{RAS}$	t_{WCR}	55		65		75		ns	6
Write command pulse width	t_{WP}	15		20		20		ns	
Write command to $\overline{RAS}$ lead time	t_{RWL}	20		20		25		ns	
Write command to $\overline{CAS}$ lead time	t_{CWL}	20		20		25		ns	
Data set-up time	t_{DS}	0		0		0		ns	10
Data hold time	t_{DH}	15		20		20		ns	10
Data hold time referenced to $\overline{RAS}$	t_{DHR}	55		65		75		ns	6
Refersh period (512 cycles)	t_{REF}		64		64		64	ms	
Write command set-up time	t_{WCS}	0		0		0		ns	8
$\overline{CAS}$ to $\overline{W}$ delay time	t_{CWD}	50		50		60		ns	8
$\overline{RAS}$ to $\overline{W}$ delay time	t_{RWD}	100		110		135		ns	8
Column address to $\overline{W}$ delay time	t_{AWD}	65		70		85		ns	8
$\overline{CAS}$ setup time ($\overline{CAS}$-before-$\overline{RAS}$ cycle)	t_{CSR}	10		10		10		ns	
$\overline{CAS}$ hold time ($\overline{CAS}$-before-$\overline{RAS}$ cycle)	t_{CHR}	20		25		30		ns	
$\overline{RAS}$ to $\overline{CAS}$ precharge time	t_{RPC}	10		10		10		ns	
$\overline{CAS}$ precharge time ($\overline{CAS}$-before-$\overline{RAS}$ counter test cycle)	t_{CPT}	35		40		50		ns	
$\overline{RAS}$ hold time referenced to $\overline{OE}$	t_{ROH}	20		20		20		ns	
$\overline{OE}$ access time	t_{OEA}		20		20		25		ns
$\overline{OE}$ to data delay	t_{OED}	20		20		25		ns	
Output buffer turn off delay time from $\overline{OE}$	t_{OEZ}	0	20	0	20	0	25	ns	
$\overline{OE}$ command hold time	t_{OEH}	20		20		25		ns	

NOTES

1. An initial pause of 200μs is required after power-up followed by any 8 $\overline{RAS}$ cycles before proper device operation is achieved.
2. V_{IH}(min) and V_{IL}(max) are reference levels for measuring timing of input signals. Transition times are measured between V_{IH}(min) and V_{IL}(max), and are assumed to be 5ns for all inputs.
3. Measured with a load equivalent to 2 TTL loads and 100pF.
4. Operation within the t_{RCD}(max) limit insures that t_{RAC}(max) can be met, t_{RCD}(max) is specified as a reference point only. If t_{RCD} is greater than the specified t_{RCD}(max) limit, then access time is controlled exclusively by t_{CAC}.
5. Assumes that $t_{RCD} \geq t_{RCD}$(max).
6. t_{AR}, t_{WCR}, t_{DHR} are referenced to t_{RAD}(max).
7. This parameter defines the time at which the output achieves the open circuit condition and is not referenced to V_{OH} or V_{OL}.
8. t_{WCS}, t_{RWD}, t_{CWD} and t_{AWD} are non restrictive operating parameters. They are included in the data sheet as electrical characteristics only. If $t_{WCS} \geq t_{WCS}$(min) the cycle is an early write cycle and the data out put will remain high impedance for the duration of the cycle. If $t_{CWD} \geq t_{CWD}$(min) and $t_{RWD} \geq t_{RWD}$(min) and $t_{AWD} \geq t_{AWD}$(min), then the cycle is a read-write cycle and the data out will contain the data read from the selected address. If neither of the above conditions are satisfied, the condition of the data out is indeterminate.
9. Either t_{RCH} or t_{RRH} must be satisfied for a read cycle.
10. These parameters are referenced to the $\overline{CAS}$ leading edge in early write cycles and to the $\overline{W}$ leading edge in read-write cycles.
11. Operation within the t_{RAD}(max) limit insures that t_{RAC}(max) can be met, t_{RAD}(max) is specified as a reference point only. If t_{RAD} is greater than the specified t_{RAD}(max) limit, then access time is controlled by t_{AA}.

TIMING DIAGRAMS

READ CYCLE



TIMING DIAGRAMS (Continued)

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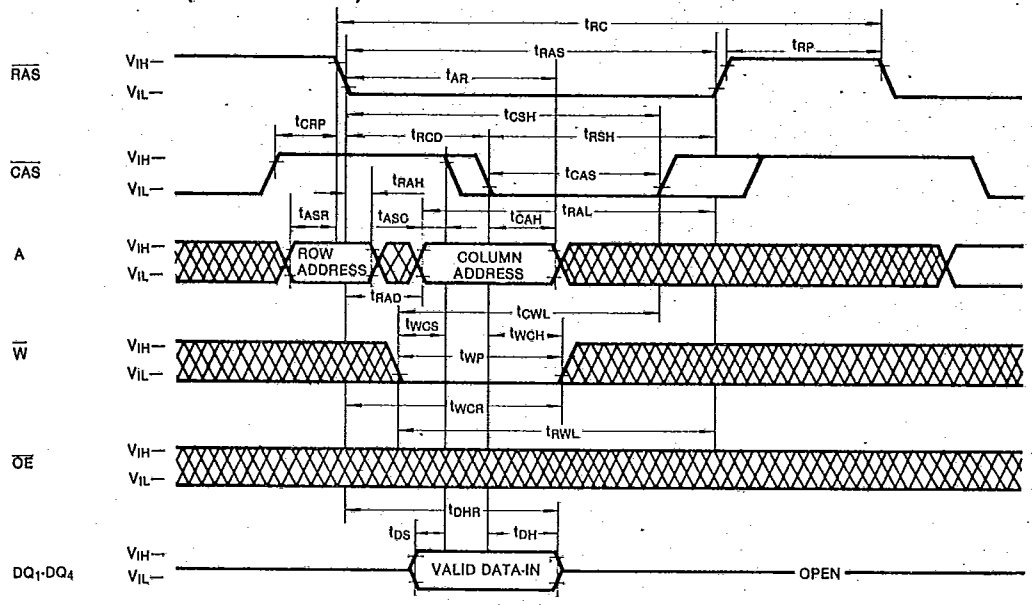
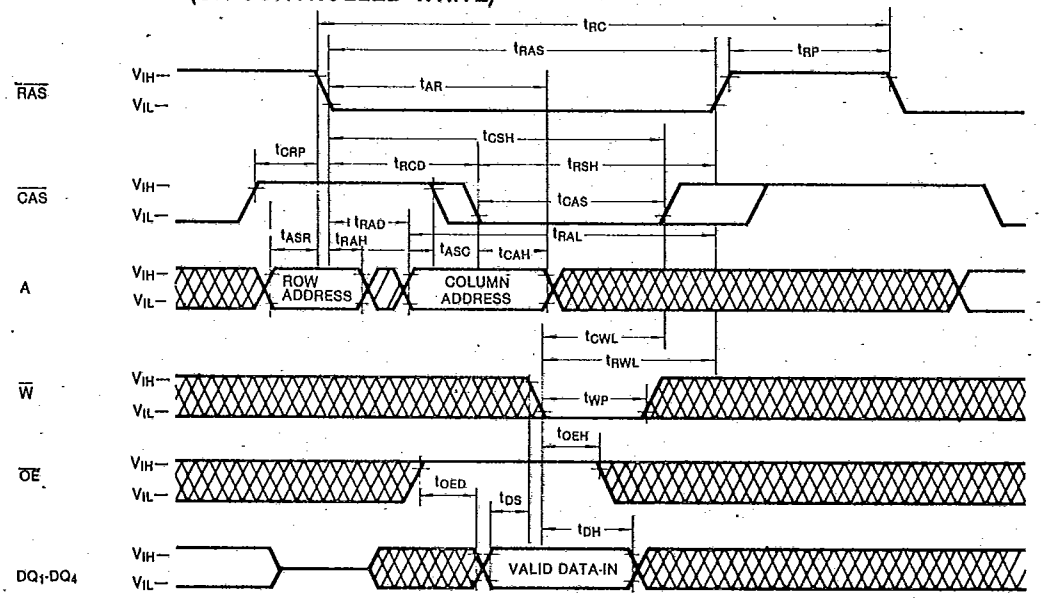
WRITE CYCLE (EARLY WRITE)



WRITE CYCLE (OE CONTROLLED WRITE)



DON'T CARE

TIMING DIAGRAMS (Continued)

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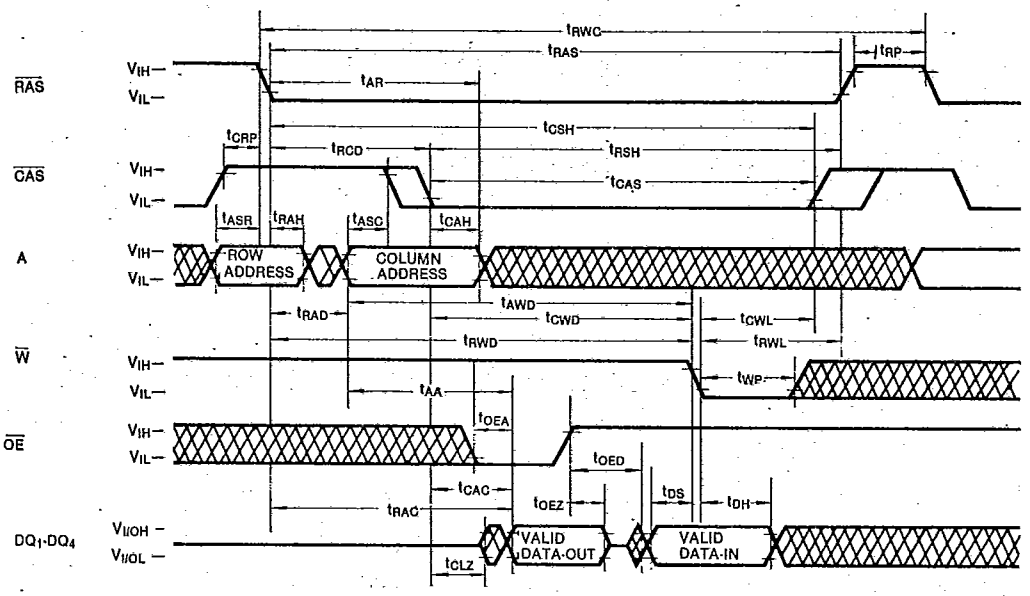
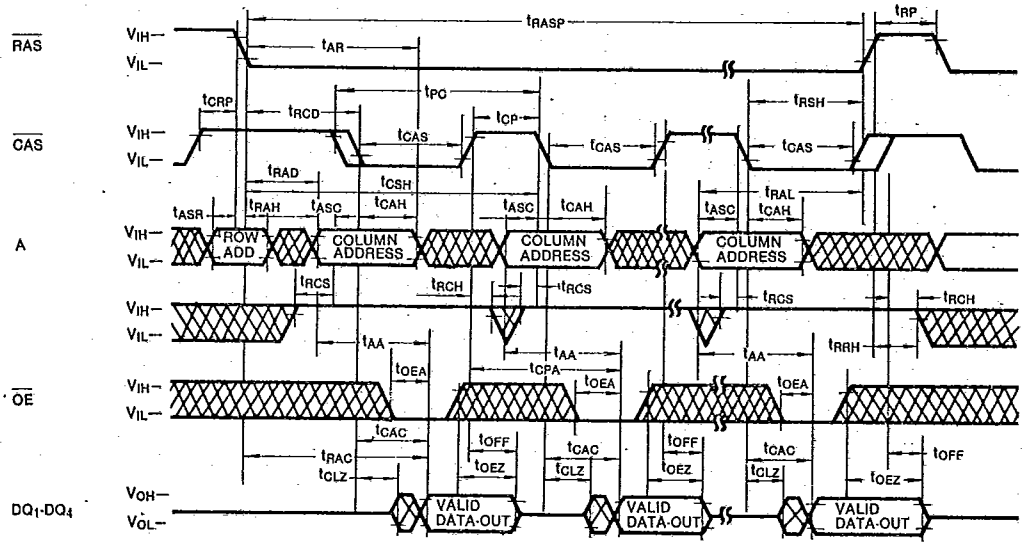
READ-MODIFY-WRITE CYCLE



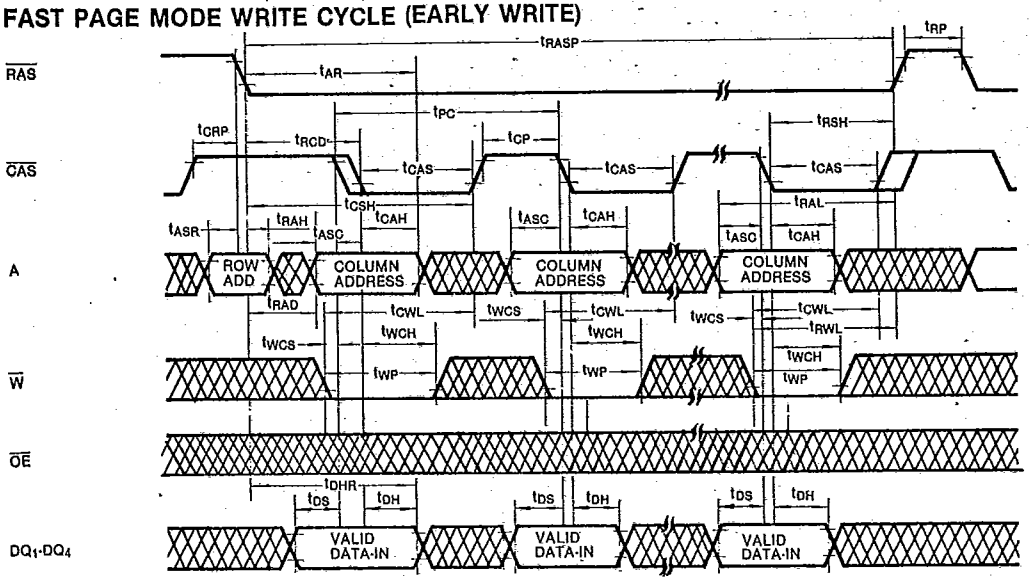
FAST PAGE MODE READ CYCLE



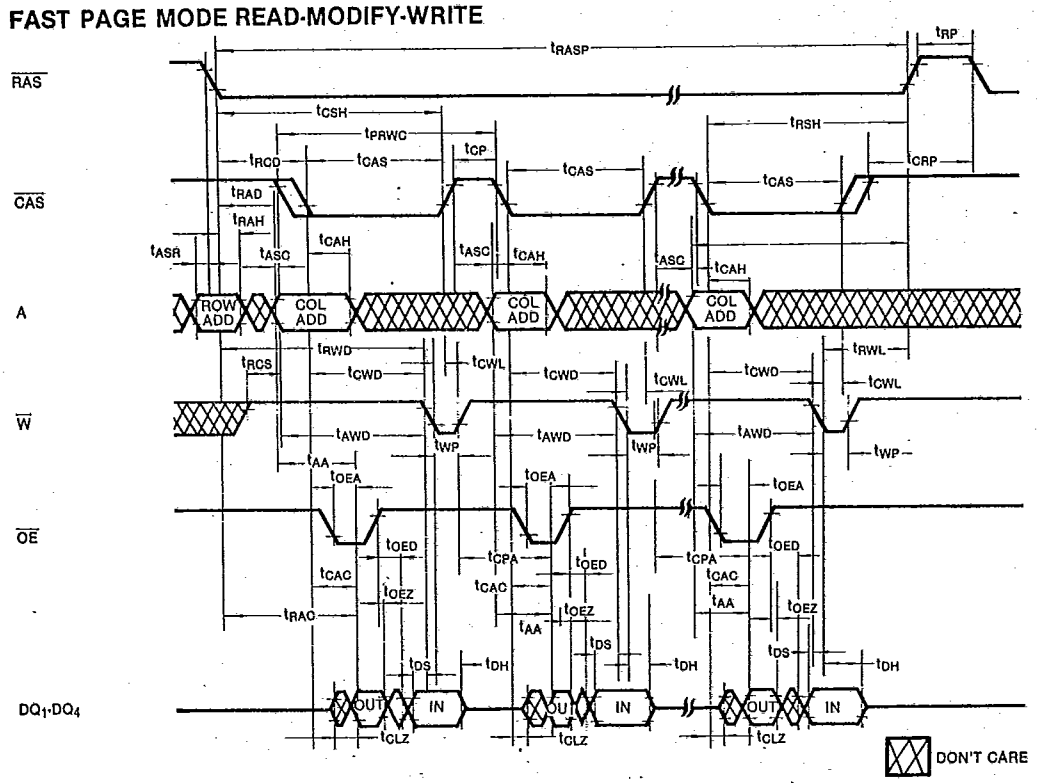
DON'T CARE

TIMING DIAGRAMS (Continued)

FAST PAGE MODE WRITE CYCLE (EARLY WRITE)



FAST PAGE MODE READ-MODIFY-WRITE



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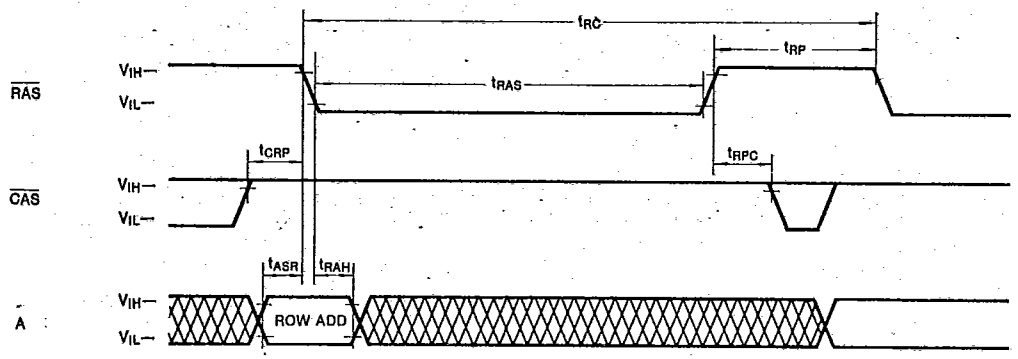
TIMING DIAGRAMS (Continued)

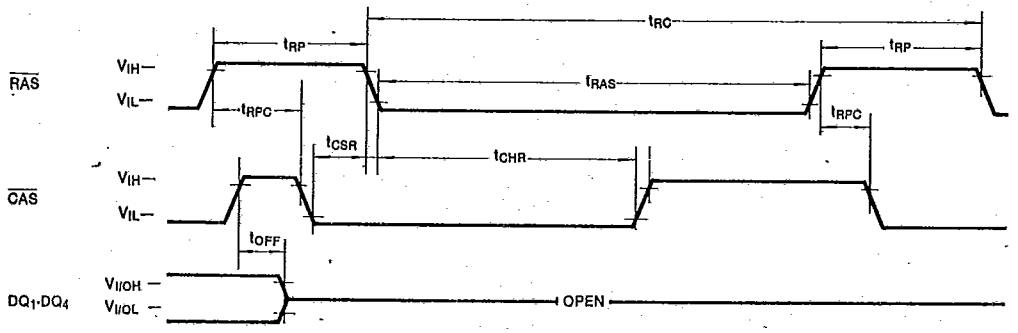
$\overline{RAS}$-ONLY REFRESH CYCLE

Note: $\overline{W}$, $\overline{OE}$ = Don't care



$\overline{CAS}$-BEFORE-$\overline{RAS}$ REFRESH CYCLE

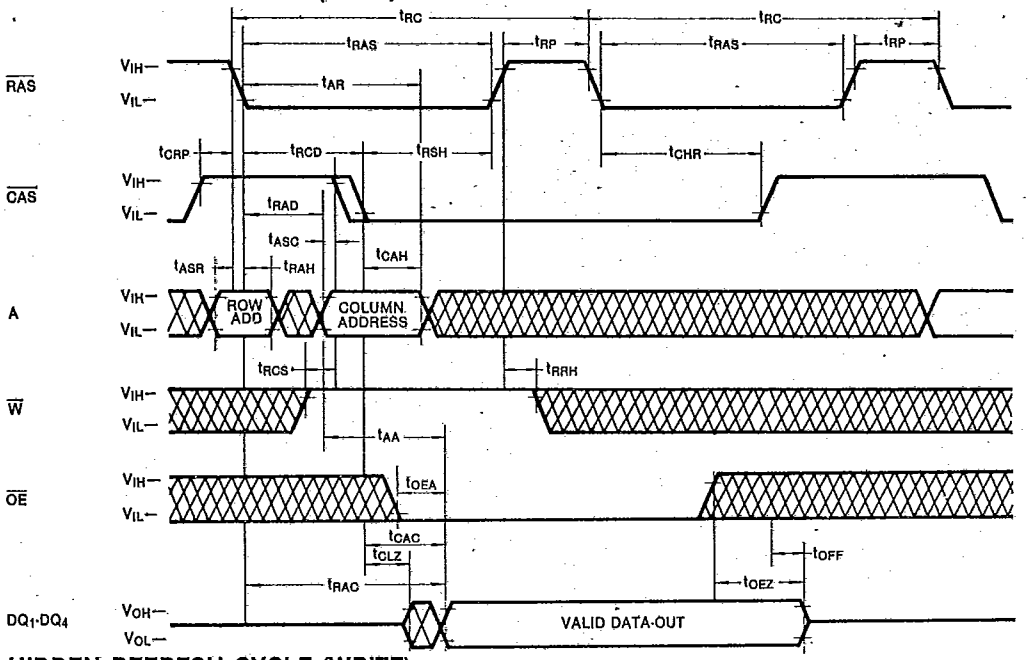
Note: $\overline{W}$, $\overline{OE}$, A = Don't care



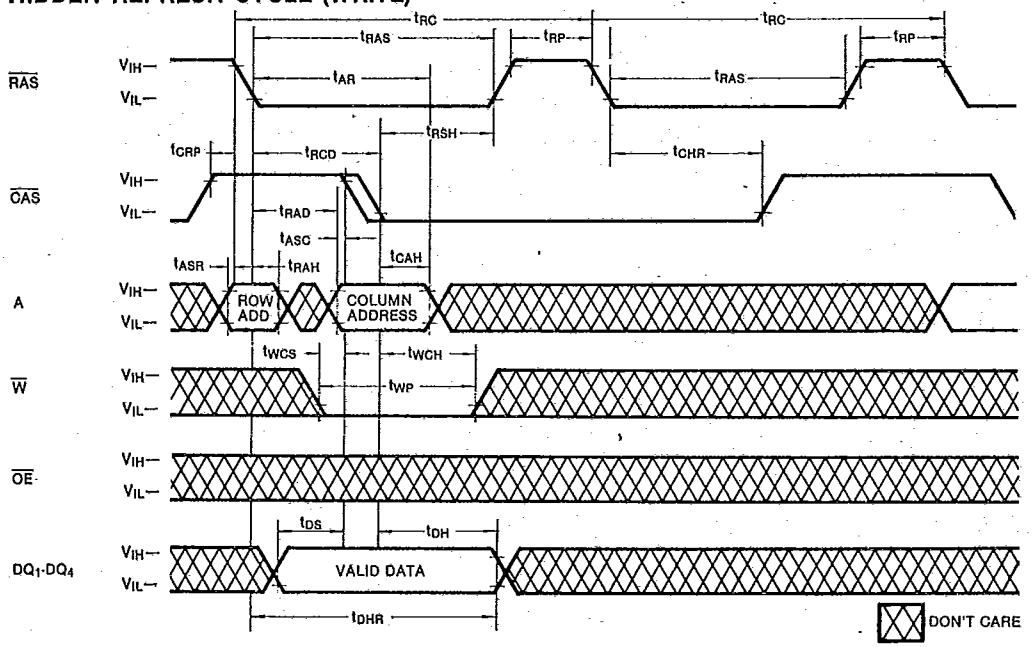
DON'T CARE

TIMING DIAGRAMS (Continued)

HIDDEN REFRESH CYCLE (READ)



HIDDEN REFRESH CYCLE (WRITE)



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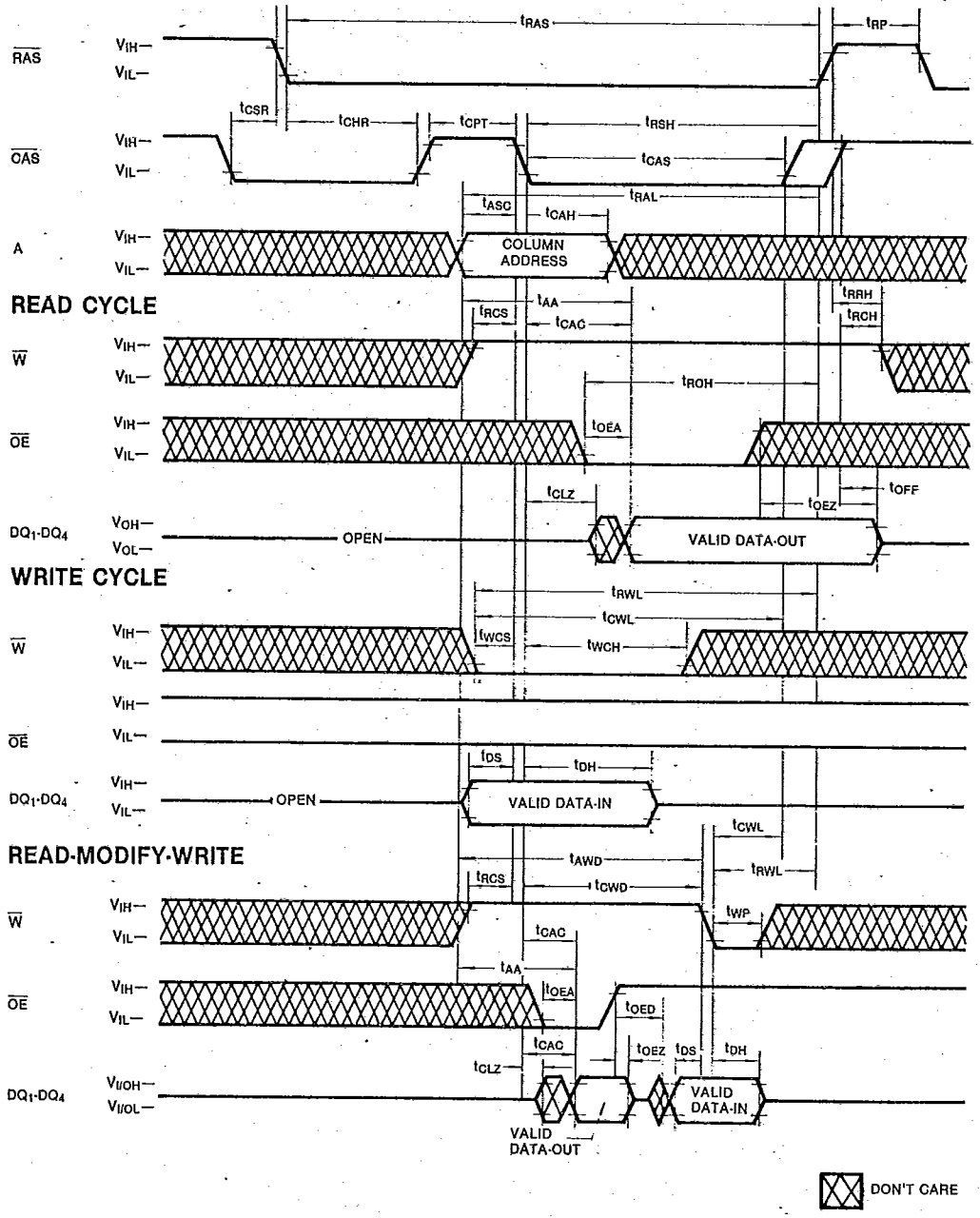
TIMING DIAGRAMS (Continued)

CAS-BEFORE-RAS REFRESH COUNTER TEST CYCLE



DEVICE OPERATION

Device Operation

The KM44C256BL contains 1,048,576 memory locations organized as 262,144 four-bit words. Eighteen address bits are required to address a particular 4-bit word in the memory array. Since the KM44C256BL has only 9 address input pins, time multiplexed addressing is used to input 9 row and 9 column addresses. The multiplexing is controlled by the timing relationship between the row address strobe ($\overline{RAS}$), the column address strobe ($\overline{CAS}$) and the valid row and column address inputs.

Operation of the KM44C256BL begins by strobing in a valid row address with $\overline{RAS}$ while $\overline{CAS}$ remains high. Then the address on the 9 address input pins is changed from a row address to a column address and is strobed in by $\overline{CAS}$. This is the beginning of any KM44C256BL cycle in which a memory location is accessed. The specific type of cycle is determined by the state of the write enable pin and various timing relationships. The cycle is terminated when both $\overline{RAS}$ and $\overline{CAS}$ have returned to the high state. Another cycle can be initiated after $\overline{RAS}$ remains high long enough to satisfy the $\overline{RAS}$ precharge time (t_{RP}) requirement.

$\overline{RAS}$ and $\overline{CAS}$ Timing

The minimum $\overline{RAS}$ and $\overline{CAS}$ pulse widths are specified by t_{RAS}(min) and t_{CAS}(min) respectively. These minimum pulse widths must be satisfied for proper device operation and data integrity. Once a cycle is initiated by bringing $\overline{RAS}$ low, it must not be aborted prior to satisfying the minimum $\overline{RAS}$ and $\overline{CAS}$ pulse widths. In addition, a new cycle must not begin until the minimum $\overline{RAS}$ precharge time, t_{RP}, has been satisfied. Once a cycle begins, internal clocks and other circuits within the KM44C256BL begin a complex sequence of events. If the sequence is broken by violating minimum timing requirements, loss of data integrity can occur.

Read

A read cycle is achieved by maintaining the write enable input ($\overline{W}$) high during a $\overline{RAS}$/$\overline{CAS}$ cycle. The access time is normally specified with respect to the falling edge of $\overline{RAS}$. But the access time also depends on the falling edge of $\overline{CAS}$ and on the valid column address transition.

If $\overline{CAS}$ goes low before t_{RCD}(max) and if the column address is valid before t_{RAD}(max) then the access time to valid data is specified by t_{RAC}(min). However, if $\overline{CAS}$ goes low after t_{RCD}(max) or if the column address becomes valid after t_{RAD}(max), access is specified by t_{CAC} or t_{AA}. In order to achieve the minimum access time, t_{RAC}(min), it is necessary to meet both t_{RCD}(max) and t_{RAD}(max).

The KM44C256BL has common data I/O pins. The this reason an output enable control input ($\overline{OE}$) has been provided so the output buffer can be precisely controlled. For data to appear at the outputs, $\overline{OE}$ must be low for the period of time defined by t_{OEA} and t_{OEZ}.

Write

The KM44C256BL can perform early write and read-modify-write cycles. The differece between these cycles is in the state of data-out and is determined by the timing relationship between $\overline{W}$, $\overline{OE}$ and $\overline{CAS}$. In any type of write cycle, Data-in must be valid at or before the falling edge of $\overline{W}$ or $\overline{CAS}$, whichever is later.

Early Write: An early write cycle is performed by bringing $\overline{W}$ low before $\overline{CAS}$. The 4-bit wide data at the data input pins is written into the addressed memory cells. Throughout the early write cycle the outputs remain in the Hi-Z state. In the early write cycle the output buffers remain in the HI-Z state regardless of the state of the $\overline{OE}$ input.

Read-Modify-Write: In this cycle, valid data from the addressed cell appears at the output before and during the time that data is being written into the same cell location. This cycle is achieved by bringing $\overline{W}$ low after $\overline{CAS}$ and meeting the data sheet read-modify-write cycle timing requirements. The output enable input $\overline{OE}$ must be low during the time defined by t_{OEA} and t_{OEZ} for data to appear at the outputs. If t_{CWD} and t_{RWD} are not met the output may contain invalid data. Conforming to the $\overline{OE}$ timing requirements prevents bus contention on the KM44C256BL's DQ pins.

Data Output

The KM44C256BL has a three-state output buffer which is controlled by $\overline{CAS}$ and $\overline{OE}$. When either $\overline{CAS}$ or $\overline{OE}$ is high (V_{IH}) the output is in the high impedance (Hi-Z) state. In any cycle in which valid data appears at the output, the output goes into the low impedance state in a time specified by t_{CLZ} after the falling edge of $\overline{CAS}$. Invalid data may be present at the output during the time after t_{CLZ} and before the valid data appears at the output. The timing parameters t_{CAC}, t_{RAC} and t_{AA} specify when the valid data will be present at the output. This is true even if a new $\overline{RAS}$ cycle occurs (as in hidden refresh). Each of the KM44C256BL operating cycles is listed below after the corresponding output state produced by the cycle.

DEVICE OPERATION (Continued)

Valid Output Data: Read, Read-Modify-Write, Hidden Refresh, Fast Page Mode Read, Fast Page Mode Read Modify-Write.

Hi-Z Output State: Early Write, $\overline{RAS}$-only Refresh, Fast Page Mode Write, $\overline{CAS}$-on cycle.

Indeterminate Output State: Delayed Write (t_{CWD} or t_{RWD} are not met)

Refresh

The data in the KM44C256BL is stored on a tiny capacitor within each memory cell. Due to leakage the data may leak off after a period of time. To maintain data integrity it is necessary to refresh each of the rows every 64 ms. Either a burst refresh or distributed refresh may be used. There are several ways to accomplish this.

$\overline{RAS}$-Only Refresh: This is the most common method for performing refresh. It is performed by strobing in a row address with $\overline{RAS}$ while $\overline{CAS}$ remains high. This cycle must be repeated for each of the 512 row addresses, (A_0-A_8).

$\overline{CAS}$-before-$\overline{RAS}$ Refresh: The KM44C256BL has $\overline{CAS}$-before-$\overline{RAS}$ on-chip refresh capability that eliminates the need for external refresh addresses. If $\overline{CAS}$ is held low for the specified set up time (t_{CSR}) before $\overline{RAS}$ goes low, the on-chip refresh circuitry is enabled. An internal refresh operation automatically occurs. The refresh address is supplied by the on-chip refresh address counter which is then internally incremented in preparation for the next $\overline{CAS}$-before-$\overline{RAS}$ refresh cycle.

Hidden Refresh: A hidden refresh cycle may be performed while maintaining the latest valid data at the output by extending the $\overline{CAS}$ active time and cycling $\overline{RAS}$. The KM44C256BL hidden refresh cycle is actually a $\overline{CAS}$-before-$\overline{RAS}$ refresh cycle within an extended read cycle. The refresh row address is provided by the on-chip refresh address counter.

Other Refresh Methods: It is also possible to refresh the KM44C256BL by using read, write or read-modify-write cycles. Whenever a row is accessed, all the cells in that row are automatically refreshed. There are certain applications in which it might be advantageous to perform refresh in this manner but in general $\overline{RAS}$-only or $\overline{CAS}$-before-$\overline{RAS}$ refresh is the preferred method.

$\overline{CAS}$-before-$\overline{RAS}$ Refresh Counter Test

A special timing sequence using the $\overline{CAS}$-before-$\overline{RAS}$ refresh counter test cycle provides a convenient method of verifying the functionality of the $\overline{CAS}$-before-$\overline{RAS}$ refresh activated circuitry. The cycle begins as a $\overline{CAS}$-before-$\overline{RAS}$ refresh operation. Then, if $\overline{CAS}$ is brought high and then low again while $\overline{RAS}$ is held low, the read and write operations are enabled. In this mode, the row address bits A_0 through A_8 are supplied by the on-chip refresh counter.

Fast Page Mode

Fast page mode provides high speed read, write or read-modify-write access to all memory cells within a selected row. These cycles may be mixed in any order. A fast page mode cycle begins with a normal cycle. Then, while $\overline{RAS}$ is kept low to maintain the row address, $\overline{CAS}$ is cycled to strobe in additional column addresses. This eliminates the time required to set up and strobe sequential row addresses for the same page.

Power-up

If $\overline{RAS} = V_{SS}$ during power-up, the KM44C256BL might begin an active cycle. This condition results in higher than necessary current demands from the power supply during power-up. It is recommended that $\overline{RAS}$ and $\overline{CAS}$ track with V_{CC} during power-up or be held at a valid V_{IH} in order to minimize the power-up current.

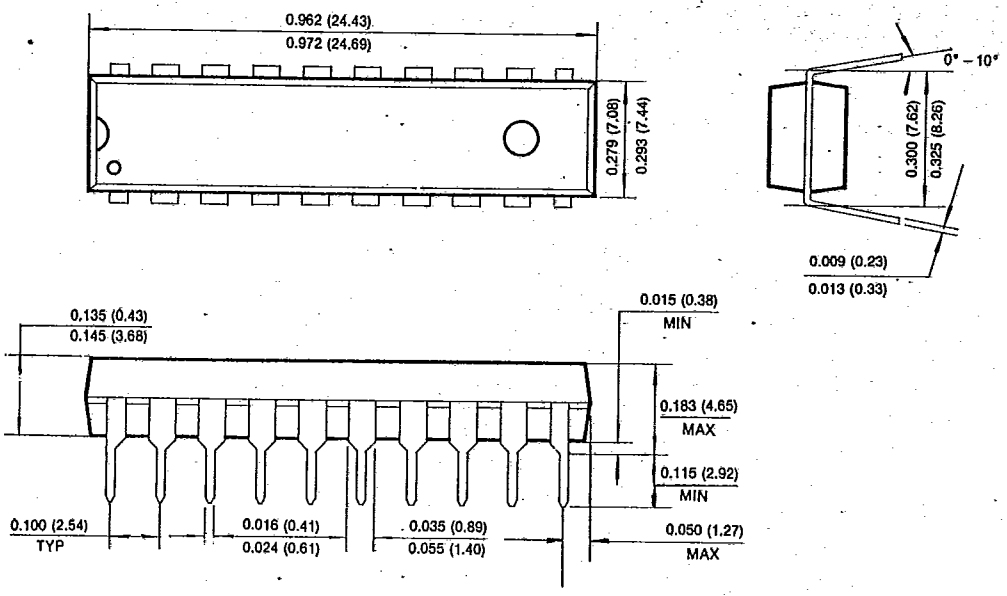
An initial pause of 200μsec is required after power-up followed by 8 initialization cycles, before proper device operation is assured. Eight initialization cycles are also required after any 8 msec period in which there are no $\overline{RAS}$ cycles. An initialization cycle is any cycle in which $\overline{RAS}$ is cycled.

T-46-23-15

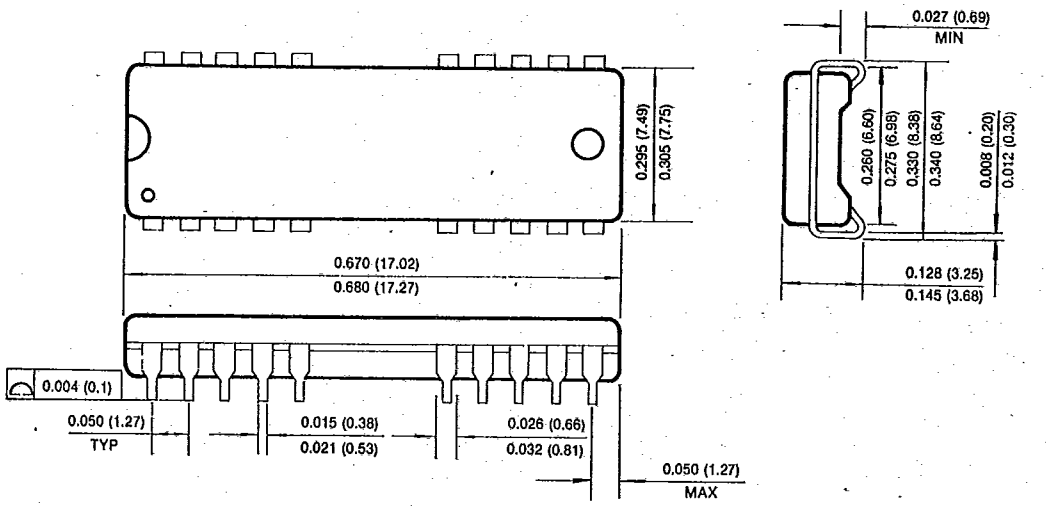
PACKAGE DIMENSIONS

20-LEAD PLASTIC DUAL IN-LINE PACKAGE

Units: Inches (millimeters)



20-LEAD PLASTIC SMALL OUT-LINE J-LEAD



PACKAGE DIMENSIONS (Continued)

20-LEAD PLASTIC ZIGZAG-IN-LINE PACKAGE

Units: Inches (millimeters)