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PRELIMINARY

RICHARD D. PASHLEY

28F010
1024K (128K x 8) CMOS FLASH MEMORY

- **Flash Electrical Chip-Erase**
  - **1 Second Typical Chip-Erase**
- **Quick-Pulse Programming™ Algorithm**
  - **10 μs Typical Byte-Program**
  - **2 Second Chip-Program**
- **10,000 Erase/Program Cycles Minimum**
- **12.0V ±5% V_{PP}**
- **High-Performance Read**
  - **120 ns Maximum Access Time**
- **CMOS Low Power Consumption**
  - **30 mA Maximum Active Current**
  - **100 μA Maximum Standby Current**
- **Command Register Architecture for Microprocessor/Microcontroller Compatible Write Interface**
- **Noise Immunity Features**
  - **± 10% V_{CC} Tolerance**
  - **Maximum Latch-Up Immunity through EPI Processing**
- **ETOX™-II Flash-Memory Technology**
  - **EPROM-Compatible Process Base**
  - **High-Volume Manufacturing Experience**
- **Compatible with JEDEC-Standard Byte-Wide EPROM Pinouts**
  - **32-Pin Plastic Dip**
  - **32-Lead PLCC**
  - **32-Lead TSOP**

(See Packaging Spec., Order # 231369)

Intel's 28F010 CMOS flash memory offers the most cost-effective and reliable alternative for read/write random access nonvolatile memory. The 28F010 adds electrical chip-erasure and reprogramming to familiar EPROM technology. Memory contents can be rewritten: in a test socket; in a PROM-programmer socket; on-board during subassembly test; in-system during final test; and in-system after-sale. The 28F010 increases memory flexibility, while contributing to time- and cost-savings.

The 28F010 is a 1024-kilobit nonvolatile memory organized as 131,072 bytes of 8 bits. Intel's 28F010 is offered in 32-pin plastic dip or 32-lead PLCC and TSOP packages. Pin assignments conform to JEDEC standards for byte-wide EPROMs.

Extended erase and program cycling capability is designed into Intel's ETOX-II (EPROM Tunnel Oxide) process technology. Advanced oxide processing, an optimized tunneling structure, and lower electric field combine to extend reliable cycling beyond that of traditional EEPROMs. With the 12.0V V_{PP} supply, the 28F010 performs a minimum of 10,000 erase and program cycles well within the time limits of the Quick-Pulse Programming™ and Quick-Erase™ algorithms.

Intel's 28F010 employs advanced CMOS circuitry for systems requiring high-performance access speeds, low power consumption, and immunity to noise. Its 120 nanosecond access time provides no-WAIT-state performance for a wide range of microprocessors and microcontrollers. Maximum standby current of 100 μA translates into power savings when the device is deselected. Finally, the highest degree of latch-up protection is achieved through Intel's unique EPI processing. Prevention of latch-up is provided for stresses up to 100 mA on address and data pins, from −1V to V_{CC} + 1V.

With Intel's ETOX-II process base, the 28F010 levers years of EPROM experience to yield the highest levels of quality, reliability, and cost-effectiveness.

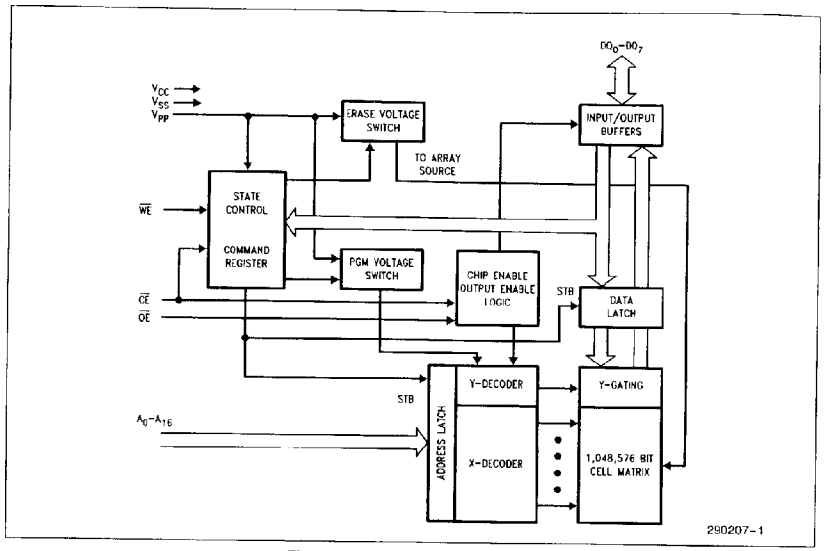


Figure 1. 28F010 Block Diagram

Table 1. Pin Description

Symbol	Type	Name and Function
A_0–A_{16}	INPUT	**ADDRESS INPUTS** for memory addresses. Addresses are internally latched during a write cycle.
DQ_0–DQ_7	INPUT/OUTPUT	**DATA INPUT/OUTPUT:** Inputs data during memory write cycles; outputs data during memory read cycles. The data pins are active high and float to tri-state OFF when the chip is deselected or the outputs are disabled. Data is internally latched during a write cycle.
$\overline{CE}$	INPUT	**CHIP ENABLE:** Activates the device's control logic, input buffers, decoders and sense amplifiers. $\overline{CE}$ is active low; $\overline{CE}$ high deselects the memory device and reduces power consumption to standby levels.
$\overline{OE}$	INPUT	**OUTPUT ENABLE:** Gates the devices output through the data buffers during a read cycle. $\overline{OE}$ is active low.
$\overline{WE}$	INPUT	**WRITE ENABLE:** Controls writes to the control register and the array. Write enable is active low. Addresses are latched on the falling edge and data is latched on the rising edge of the $\overline{WE}$ pulse. **Note:** With $V_{PP} \leq V_{CC} + 2V$, memory contents cannot be altered.
V_{PP}		**ERASE/PROGRAM POWER SUPPLY** for writing the command register, erasing the entire array, or programming bytes in the array.
V_{CC}		**DEVICE POWER SUPPLY** (5V ±10%)
V_{SS}		**GROUND**
NC		**NO INTERNAL CONNECTION** to device. Pin may be driven or left floating.

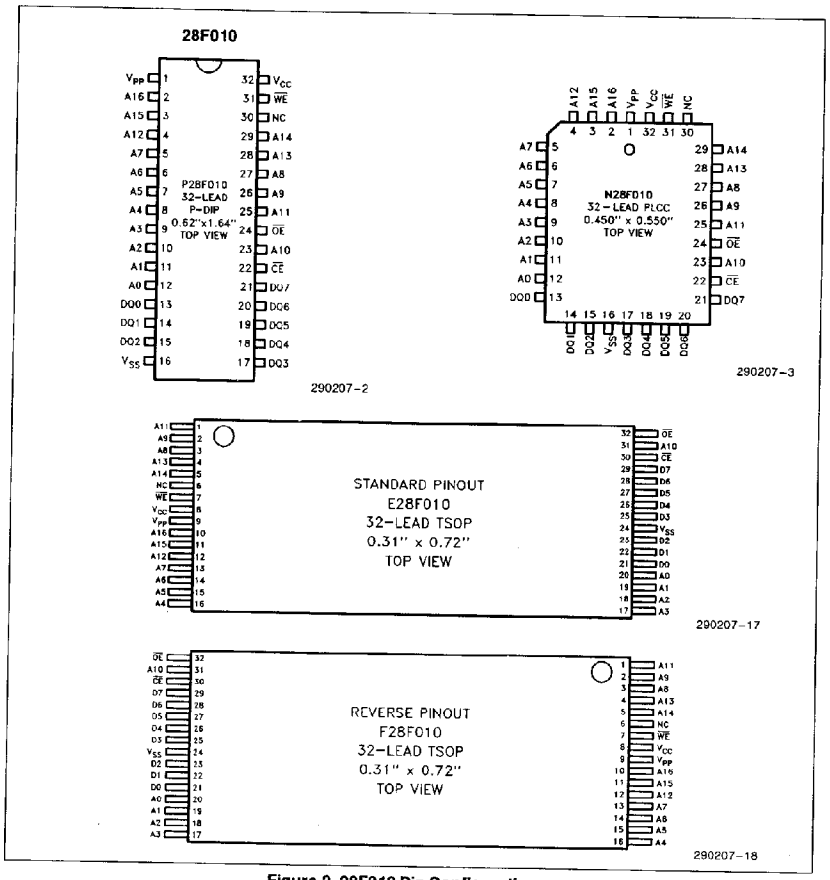


Figure 2. 28F010 Pin Configurations

APPLICATIONS

The 28F010 flash memory provides nonvolatility along with the capability to typically perform over 100,000 electrical chip-erasure/reprogram cycles. These features make the 28F010 an innovative alternative to disk, EEPROM, and battery-backed static RAM. Where periodic updates of code and data-tables are required, the 28F010's reprogrammability and nonvolatility make it the obvious and ideal replacement for EPROM.

Primary applications and operating systems stored in flash eliminate the slow disk-to-DRAM download process. This results in dramatic enhancement of performance and substantial reduction of power consumption — a consideration particularly important in portable equipment. Flash memory increases flexibility with electrical chip erasure and in-system update capability of operating systems and application code. With updatable BIOS, system manufacturers can easily accommodate last-minute changes as revisions are made.

In diskless workstations and terminals, network traffic reduces to a minimum and systems are instant-on. Reliability exceeds that of electromechanical media. Often in these environments, power interruptions force extended re-boot periods for all networked terminals. This mishap is no longer an issue if boot code, operating systems, communication protocols and primary applications are flash-resident in each terminal.

For embedded systems that rely on dynamic RAM/disk for main system memory or nonvolatile backup storage, the 28F010 flash memory offers a solid state alternative in a minimal form factor. The 28F010 provides higher performance, lower power consumption, instant-on capability, and allows an "execute in place" memory hierarchy for code and data table reading. Additionally, the flash memory is more rugged and reliable in harsh environments where extreme temperatures and shock can cause disk-based systems to fail.

The need for code updates pervades all phases of a system's life — from prototyping to system manufacture to after-sale service. The electrical chip-erasure and reprogramming ability of the 28F010 allows in-circuit alterability; this eliminates unnecessary handling and less-reliable socketed connections, while adding greater test, manufacture, and update flexibility.

Material and labor costs associated with code changes increases at higher levels of system integration — the most costly being code updates after sale. Code "bugs", or the desire to augment system functionality, prompt after-sale code updates. Field revisions to EPROM-based code requires the removal of EPROM components or entire boards. With the 28F010, code updates are implemented locally via an edge-connector, or remotely over a communication link.

For systems currently using a high-density static RAM/battery configuration for data accumulation, flash memory's inherent nonvolatility eliminates the need for battery backup. The concern for battery failure no longer exists, an important consideration for portable equipment and medical instruments, both requiring continuous performance. In addition, flash memory offers a considerable cost advantage over SRAM.

Flash memory's electrical chip erasure, byte programmability and complete nonvolatility fit well with data accumulation and recording needs. Electrical chip-erasure gives the designer a "blank slate" in which to log or record data. Data can be periodically off-loaded for analysis and the flash memory erased producing a new "blank slate".

A high degree of on-chip feature integration simplifies memory-to-processor interfacing. Figure 3 depicts two 28F010s tied to the 80C186 system bus. The 28F010's architecture minimizes interface circuitry needed for complete in-circuit updates of memory contents.

With cost-effective in-system reprogramming, extended cycling capability, and true nonvolatility, the 28F010 offers advantages to the alternatives: EPROMs, EEPROMs, battery backed static RAM, or disk. EPROM-compatible read specifications, straight-forward interfacing, and in-circuit alterability offers designers unlimited flexibility to meet the high standards of today's designs.

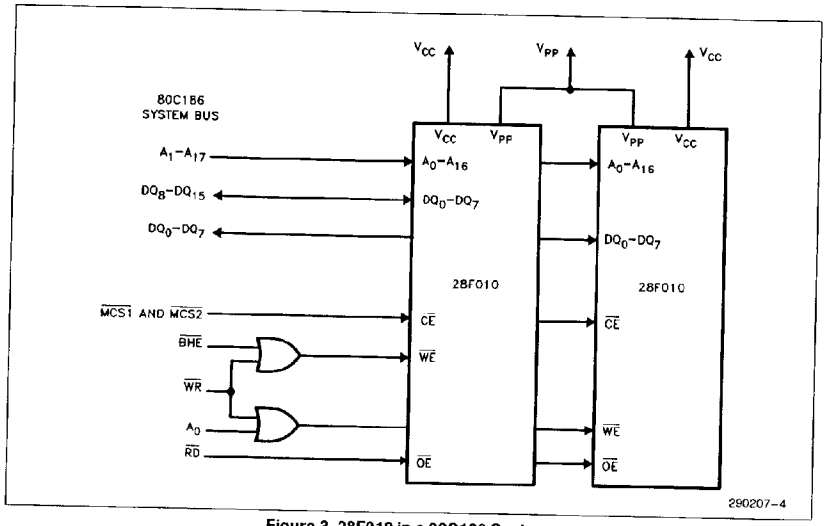


Figure 3. 28F010 in a 80C186 System

PRINCIPLES OF OPERATION

Flash-memory augments EPROM functionality with in-circuit electrical erasure and reprogramming. The 28F010 introduces a command register to manage this new functionality. The command register allows for: 100% TTL-level control inputs; fixed power supplies during erasure and programming; and maximum EPROM compatibility.

In the absence of high voltage on the V_{PP} pin, the 28F010 is a read-only memory. Manipulation of the external memory-control pins yields the standard EPROM read, standby, output disable, and int$_e$ligent Identifier™ operations.

The same EPROM read, standby, and output disable operations are available when high voltage is applied to the V_{PP} pin. In addition, high voltage on V_{PP} enables erasure and programming of the device. All functions associated with altering memory contents—int$_e$ligent Identifier, erase, erase verify, program, and program verify—are accessed via the command register.

Commands are written to the register using standard microprocessor write timings. Register contents serve as input to an internal state-machine which controls the erase and programming circuitry. Write cycles also internally latch addresses and data needed for programming or erase operations. With the appropriate command written to the register, standard microprocessor read timings output array data, access the int$_e$ligent Identifier codes, or output data for erase and program verification.

Successive command write cycles define the durations of program and erase operations; specifically, the program or erase time durations are normally terminated by associated program or erase verify commands. An integrated watchdog timer provides simplified timing control over these operations; thus eliminating the need for maximum program/erase timing specifications. Programming and erase pulse durations are minimums only. When the watchdog timer terminates a program or erase operation, the device enters an inactive state and remains inactive until receiving the appropriate verify command.

The command register is only alterable when V_{PP} is at high voltage. Depending upon the application, the system designer may choose to make the V_{PP} power supply switchable—available only when memory updates are desired. When high voltage is removed,

Table 2. 28F010 Bus Operations

Operation	Pins	V_{PP}[1]	A_0	A_9	$\overline{CE}$	$\overline{OE}$	$\overline{WE}$	DQ_0–DQ_7
READ-ONLY	Read	V_{PPL}	A_0	A_9	V_{IL}	V_{IL}	V_{IH}	Data Out
	Output Disable	V_{PPL}	X	X	V_{IL}	V_{IH}	V_{IH}	Tri-State
	Standby	V_{PPL}	X	X	V_{IH}	X	X	Tri-State
	int$_e$ligent Identifier™ (Mfr)[2]	V_{PPL}	V_{IL}	V_{ID}[3]	V_{IL}	V_{IL}	V_{IH}	Data = 89H
	int$_e$ligent Identifier™ (Device)[2]	V_{PPL}	V_{IH}	V_{ID}[3]	V_{IL}	V_{IL}	V_{IH}	Data = B4H
READ/WRITE	Read	V_{PPH}	A_0	A_9	V_{IL}	V_{IL}	V_{IH}	Data Out[4]
	Output Disable	V_{PPH}	X	X	V_{IL}	V_{IH}	V_{IH}	Tri-State
	Standby[5]	V_{PPH}	X	X	V_{IH}	X	X	Tri-State
	Write	V_{PPH}	A_0	A_9	V_{IL}	V_{IH}	V_{IL}	Data In[6]

NOTES:
1. Refer to D.C. Characteristics. When $V_{PP} = V_{PPL}$ memory contents can be read but not written or erased.
2. Manufacturer and device codes may also be accessed via a command register write sequence. Refer to Table 3. All other addresses low.
3. V_{ID} is the int$_e$ligent Identifier high voltage. Refer to DC Characteristics.
4. Read operations with $V_{PP} = V_{PPH}$ may access array data or the int$_e$ligent Identifier™ codes.
5. With V_{PP} at high voltage, the standby current equals $I_{CC} + I_{PP}$ (standby).
6. Refer to Table 3 for valid Data-In during a write operation.
7. X can be V_{IL} or V_{IH}.

the contents of the register default to the read command, making the 28F010 a read-only memory. Memory contents cannot be altered.

Or, the system designer may choose to "hardwire" V_{PP}, making the high voltage supply constantly available. In this instance, all operations are performed in conjunction with the command register. The 28F010 is designed to accommodate either design practice, and to encourage optimization of the processor-memory interface.

BUS OPERATIONS

Read

The 28F010 has two control functions, both of which must be logically active, to obtain data at the outputs. Chip-Enable ($\overline{CE}$) is the power control and should be used for device selection. Output-Enable ($\overline{OE}$) is the output control and should be used to gate data from the output pins, independent of device selection. Figure 6 illustrates read timing waveforms.

When V_{PP} is high (V_{PPH}), the read operation can be used to access array data, to output the int$_e$ligent Identifier™ codes, and to access data for program/erase verification. When V_{PP} is low (V_{PPL}), the read operation can **only** access the array data.

Output Disable

With Output-Enable at a logic-high level (V_{IH}), output from the device is disabled. Output pins are placed in a high-impedance state.

Standby

With Chip-Enable at a logic-high level, the standby operation disables most of the 28F010's circuitry and substantially reduces device power consumption. The outputs are placed in a high-impedance state, independent of the Output-Enable signal. If the 28F010 is deselected during erasure, programming, or program/erase verification, the device draws active current until the operation is terminated.

int$_e$ligent Identifier™ Operation

The int$_e$ligent Identifier operation outputs the manufacturer code (89H) and device code (B4H). Programming equipment automatically matches the device with its proper erase and programming algorithms.

With Chip-Enable and Output-Enable at a logic low level, raising A9 to high voltage V_{ID} (see DC Characteristics) activates the operation. Data read from locations 0000H and 0001H represent the manufacturer's code and the device code, respectively.

The manufacturer- and device-codes can also be read via the command register, for instances where the 28F010 is erased and reprogrammed in the target system. Following a write of 90H to the command register, a read from address location 0000H outputs the manufacturer code (89H). A read from address 0001H outputs the device code (B4H).

Write

Device erasure and programming are accomplished via the command register, when high voltage is applied to the V_{PP} pin. The contents of the register serve as input to the internal state-machine. The state-machine outputs dictate the function of the device.

The command register itself does not occupy an addressable memory location. The register is a latch used to store the command, along with address and data information needed to execute the command.

The command register is written by bringing Write-Enable to a logic-low level (V_{IL}), while Chip-Enable is low. Addresses are latched on the falling edge of Write-Enable, while data is latched on the rising edge of the Write-Enable pulse. Standard microprocessor write timings are used.

Refer to A.C. Write Characteristics and the Erase/Programming Waveforms for specific timing parameters.

COMMAND DEFINITIONS

When low voltage is applied to the V_{PP} pin, the contents of the command register default to 00H, enabling read-only operations.

Placing high voltage on the V_{PP} pin enables read/write operations. Device operations are selected by writing specific data patterns into the command register. Table 3 defines these 28F010 register commands.

Table 3. Command Definitions

Command	Bus Cycles	First Bus Cycle			Second Bus Cycle		
	Req'd	Operation[1]	Address[2]	Data[3]	Operation[1]	Address[2]	Data[3]
Read Memory	1	Write	X	00H			
Read int$_e$ligent Identifier™ Codes[4]	2	Write	X	90H	Read	IA	ID
Set-up Erase/Erase[5]	2	Write	X	20H	Write	X	20H
Erase Verify[5]	2	Write	EA	A0H	Read	X	EVD
Set-up Program/Program[6]	2	Write	X	40H	Write	PA	PD
Program Verify[6]	2	Write	X	C0H	Read	X	PVD
Reset[7]	2	Write	X	FFH	Write	X	FFH

NOTES:
1. Bus operations are defined in Table 2.
2. IA = Identifier address: 00H for manufacturer code, 01H for device code.
   EA = Address of memory location to be read during erase verify.
   PA = Address of memory location to be programmed.
   Addresses are latched on the falling edge of the Write-Enable pulse.
3. ID = Data read from location IA during device identification (Mfr = 89H, Device = B4H).
   EVD = Data read from location EA during erase verify.
   PD = Data to be programmed at location PA. Data is latched on the rising edge of Write-Enable.
   PVD = Data read from location PA during program verify. PA is latched on the Program command.
4. Following the Read int$_e$ligent ID command, two read operations access manufacturer and device codes.
5. Figure 5 illustrates the Quick-Erase™ Algorithm.
6. Figure 4 illustrates the Quick-Pulse Programming™ Algorithm.
7. The second bus cycle must be followed by the desired command register write.

Read Command

While V_{PP} is high, for erasure and programming, memory contents can be accessed via the read command. The read operation is initiated by writing 00H into the command register. Microprocessor read cycles retrieve array data. The device remains enabled for reads until the command register contents are altered.

The default contents of the register upon V_{PP} power-up is 00H. This default value ensures that no spurious alteration of memory contents occurs during the V_{PP} power transition. Where the V_{PP} supply is hard-wired to the 28F010, the device powers-up and remains enabled for reads until the command-register contents are changed. Refer to the A.C. Read Characteristics and Waveforms for specific timing parameters.

int$_e$ligent Identifier™ Command

Flash-memories are intended for use in applications where the local CPU alters memory contents. As such, manufacturer- and device-codes must be accessible while the device resides in the target system. PROM programmers typically access signature codes by raising A9 to a high voltage. However, multiplexing high voltage onto address lines is not a desired system-design practice.

The 28F010 contains an int$_e$ligent Identifier operation to supplement traditional PROM-programming methodology. The operation is initiated by writing 90H into the command register. Following the command write, a read cycle from address 0000H retrieves the manufacturer code of 89H. A read cycle from address 0001H returns the device code of B4H. To terminate the operation, it is necessary to write another valid command into the register.

Set-up Erase/Erase Commands

Set-up Erase is a command-only operation that stages the device for electrical erasure of all bytes in the array. The set-up erase operation is performed by writing 20H to the command register.

To commence chip-erasure, the erase command (20H) must again be written to the register. The erase operation begins with the rising edge of the Write-Enable pulse and terminates with the rising edge of the next Write-Enable pulse (i.e., Erase-Verify Command).

This two-step sequence of set-up followed by execution ensures that memory contents are not accidentally erased. Also, chip-erasure can only occur when high voltage is applied to the V_{PP} pin. In the absence of this high voltage, memory contents are protected against erasure. Refer to A.C. Erase Characteristics and Waveforms for specific timing parameters.

Erase-Verify Command

The erase command erases all bytes of the array in parallel. After each erase operation, all bytes must be verified. The erase verify operation is initiated by writing A0H into the command register. The address for the byte to be verified must be supplied as it is latched on the falling edge of the Write-Enable pulse. The register write terminates the erase operation with the rising edge of its Write-Enable pulse.

The 28F010 applies an internally-generated margin voltage to the addressed byte. Reading FFH from the addressed byte indicates that all bits in the byte are erased.

The erase-verify command must be written to the command register prior to each byte verification to latch its address. The process continues for each byte in the array until a byte does not return FFH data, or the last address is accessed.

In the case where the data read is not FFH, another erase operation is performed. (Refer to Set-up Erase/Erase). Verification then resumes from the address of the last-verified byte. Once all bytes in the array have been verified, the erase step is complete. The device can be programmed. At this point, the verify operation is terminated by writing a valid command (e.g. Program Set-up) to the command register. Figure 5, the Quick-Erase™ algorithm, illustrates how commands and bus operations are combined to perform electrical erasure of the 28F010. Refer to A.C. Erase Characteristics and Waveforms for specific timing parameters.

Set-up Program/Program Commands

Set-up program is a command-only operation that stages the device for byte programming. Writing 40H into the command register performs the set-up operation.

Once the program set-up operation is performed, the next Write-Enable pulse causes a transition to an active programming operation. Addresses are internally latched on the falling edge of the Write-Enable pulse. Data is internally latched on the rising edge of the Write-Enable pulse. The rising edge of Write-Enable also begins the programming operation. The programming operation terminates with the next rising edge of Write-Enable, used to write the program-verify command. Refer to A.C. Programming Characteristics and Waveforms for specific timing parameters.

Program-Verify Command

The 28F010 is programmed on a byte-by-byte basis. Byte programming may occur sequentially or at random. Following each programming operation, the byte just programmed must be verified.

The program-verify operation is initiated by writing C0H into the command register. The register write terminates the programming operation with the rising edge of its Write-Enable pulse. The program-verify operation stages the device for verification of the byte last programmed. No new address information is latched.

The 28F010 applies an internally-generated margin voltage to the byte. A microprocessor read cycle outputs the data. A successful comparison between the programmed byte and true data means that the byte is successfully programmed. Programming then proceeds to the next desired byte location. Figure 4, the 28F010 Quick-Pulse Programming™ algorithm, illustrates how commands are combined with bus operations to perform byte programming. Refer to A.C. Programming Characteristics and Waveforms for specific timing parameters.

Reset Command

A reset command is provided as a means to safely abort the erase- or program-command sequences. Following either set-up command (erase or program) with two consecutive writes of FFH will safely abort the operation. Memory contents will not be altered. A valid command must then be written to place the device in the desired state.

EXTENDED ERASE/PROGRAM CYCLING

EEPROM cycling failures have always concerned users. The high electrical field required by thin oxide EEPROMs for tunneling can literally tear apart the oxide at defect regions. To combat this, some suppliers have implemented redundancy schemes, reducing cycling failures to insignificant levels. However, redundancy requires that cell size be doubled—an expensive solution.

Intel has designed extended cycling capability into its ETOX-II flash memory technology. Resulting improvements in cycling reliability come without increasing memory cell size or complexity. First, an advanced tunnel oxide increases the charge carrying ability ten-fold. Second, the oxide area per cell subjected to the tunneling electric field is one-tenth that of common EEPROMs, minimizing the probability of oxide defects in the region. Finally, the peak electric field during erasure is approximately 2 MV/cm lower than EEPROM. The lower electric field greatly reduces oxide stress and the probability of failure—increasing time to wearout by a factor of 100,000,000.

The 28F010 is specified for a minimum of 10,000 program/erase cycles. The device is programmed and erased using Intel's Quick-Pulse Programming™ and Quick-Erase™ algorithms. Intel's algorithmic approach uses a series of operations (pulses), along with byte verification, to completely and reliably erase and program the device.

For further information, see Reliability Report RR-60.

QUICK-PULSE PROGRAMMING™ ALGORITHM

The Quick-Pulse Programming algorithm uses programming operations of 10 μs duration. Each operation is followed by a byte verification to determine when the addressed byte has been successfully programmed. The algorithm allows for up to 25 programming operations per byte, although most bytes verify on the first or second operation. The entire sequence of programming and byte verification is performed with V_{PP} at high voltage. Figure 4 illustrates the Quick-Pulse Programming algorithm.

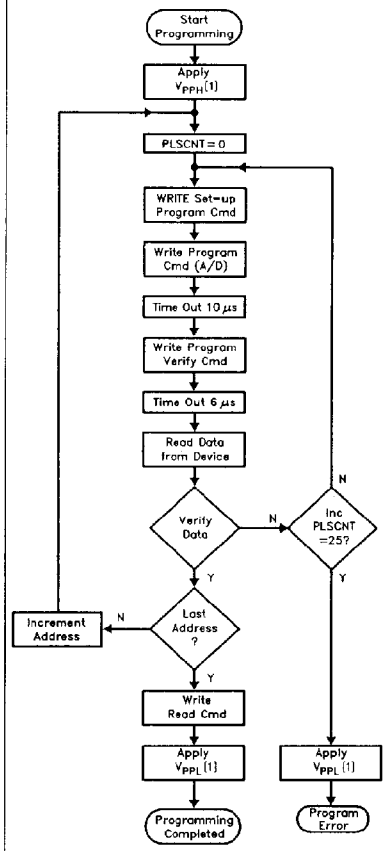
QUICK-ERASE™ ALGORITHM

Intel's Quick-Erase algorithm yields fast and reliable electrical erasure of memory contents. The algorithm employs a closed-loop flow, similar to the Quick-Pulse Programming™ algorithm, to simultaneously remove charge from all bits in the array.

Erasure begins with a read of memory contents. The 28F010 is erased when shipped from the factory. Reading FFH data from the device would immediately be followed by device programming.

For devices being erased and reprogrammed, uniform and reliable erasure is ensured by first programming all bits in the device to their charged state (Data = 00H). This is accomplished, using the Quick-Pulse Programming algorithm, in approximately two seconds.

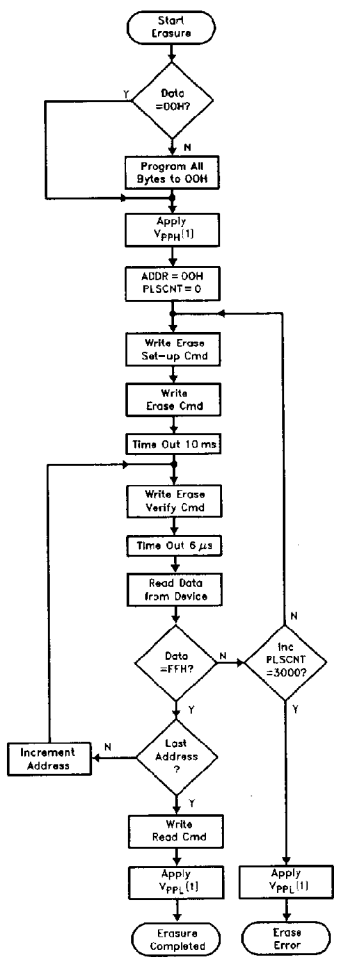
Erase execution then continues with an initial erase operation. Erase verification (data = FFH) begins at address 0000H and continues through the array to the last address, or until data other than FFH is encountered. With each erase operation, an increasing number of bytes verify to the erased state. Erase efficiency may be improved by storing the address of the last byte verified in a register. Following the next erase operation, verification starts at that stored address location. Erasure typically occurs in one second. Figure 5 illustrates the Quick-Erase algorithm.



Bus Operation	Command	Comments
Standby		Wait for V_{PP} Ramp to V_{PPH}(1)
		Initialize Pulse-Count
Write	Set-up Program	Data = 40H
Write	Program	Valid Address/Data
Standby		Duration of Program Operation (t_{WHWH1})
Write	Program(2) Verify	Data = C0H; Stops Program Operation(3)
Standby		t_{WHGL}
Read		Read Byte to Verify Programming
Standby		Compare Data Output to Data Expected
Write	Read	Data = 00H, Resets the Register for Read Operations
Standby		Wait for V_{PP} Ramp to V_{PPL}(1)

NOTES:
1. See D.C. Characteristics for the value of V_{PPH} and V_{PPL}.
2. Program Verify is only performed after byte programming. A final read/compare may be performed (optional) after the register is written with the Read command.
3. Refer to principles of operation.
4. **CAUTION: The algorithm MUST BE FOLLOWED to ensure proper and reliable operation of the device.**

Figure 4. 28F010 Quick-Pulse Programming™ Algorithm



Bus Operation	Command	Comments
		Entire Memory Must = 00H Before Erasure
		Use Quick-Pulse Programming™ Algorithm (Figure 4)
Standby		Wait for V_{PP} Ramp to V_{PPH}(1)
		Initialize Addresses and Pulse-Count
Write	Set-up Erase	Data = 20H
Write	Erase	Data = 20H
Standby		Duration of Erase Operation (t_{WHWH2})
Write	Erase(2) Verify	Addr = Byte to Verify; Data = A0H; Stops Erase Operation(3)
Standby		t_{WHGL}
Read		Read Byte to Verify Erasure
Standby		Compare Output to FFH Increment Pulse-Count
Write	Read	Data = 00H, Resets the Register for Read Operations
Standby		Wait for V_{PP} Ramp to V_{PPL}(1)

1. See D.C. Characteristics for the value of V_{PPH} and V_{PPL}.
2. Erase Verify is performed only after chip-erasure. A final read/compare may be performed (optional) after the register is written with the read command.
3. Refer to principles of operation.
4. **CAUTION: The algorithm MUST BE FOLLOWED to ensure proper and reliable operation of the device.**

Figure 5. 28F010 Quick-Erase™ Algorithm

DESIGN CONSIDERATIONS

Two-Line Output Control

Flash-memories are often used in larger memory arrays. Intel provides two read-control inputs to accommodate multiple memory connections. Two-line control provides for:

a. the lowest possible memory power dissipation and,
b. complete assurance that output bus contention will not occur.

To efficiently use these two control inputs, an address-decoder output should drive chip-enable, while the system's read signal controls all flash-memories and other parallel memories. This assures that only enabled memory devices have active outputs, while deselected devices maintain the low power standby condition.

Power Supply Decoupling

Flash-memory power-switching characteristics require careful device decoupling. System designers are interested in three supply current (I_{CC}) issues—standby, active, and transient current peaks produced by falling and rising edges of chip-enable. The capacitive and inductive loads on the device outputs determine the magnitudes of these peaks.

Two-line control and proper decoupling capacitor selection will suppress transient voltage peaks. Each device should have a 0.1 µF ceramic capacitor connected between V_{CC} and V_{SS}, and between V_{PP} and V_{SS}.

Place the high-frequency, low-inherent-inductance capacitors as close as possible to the devices. Also, for every eight devices, a 4.7 µF electrolytic capacitor should be placed at the array's power supply connection, between V_{CC} and V_{SS}. The bulk capacitor will overcome voltage slumps caused by printed-circuit-board trace inductance, and will supply charge to the smaller capacitors as needed.

V_{PP} Trace on Printed Circuit Boards

Programming flash-memories, while they reside in the target system, requires that the printed circuit board designer pay attention to the V_{PP} power supply trace. The V_{PP} pin supplies the memory cell current for programming. Use similar trace widths and layout considerations given the V_{CC} power bus. Adequate V_{PP} supply traces and decoupling will decrease V_{PP} voltage spikes and overshoots.

Power Up/Down Protection

The 28F010 is designed to offer protection against accidental erasure or programming during power transitions. Power supply sequencing is not required. Internal circuitry in the 28F010 ensures that the command register is reset to the read mode on power up.

A system designer must guard against active writes for V_{CC} voltages above V_{LKO} when V_{PP} is active. Since both $\overline{WE}$ and $\overline{CE}$ must be low for a command write, driving either to V_{IH} will inhibit writes. The control register architecture provides an added level of protection since alteration of memory contents only occurs after successful completion of the two-step command sequences.

ABSOLUTE MAXIMUM RATINGS*

Operating Temperature
- During Read ..... 0°C to +70°C(1)
- During Erase/Program ..... 0°C to +70°C

Temperature Under Bias ..... −10°C to +80°C
Storage Temperature ..... −65°C to +125°C
Voltage on Any Pin with
- Respect to Ground ..... −2.0V to +7.0V(2)

Voltage on Pin A_9 with
- Respect to Ground ..... −2.0V to +13.5V(2, 3)

V_{PP} Supply Voltage with
- Respect to Ground
- During Erase/Program .... −2.0V to +14.0V(2, 3)

V_{CC} Supply Voltage with
- Respect to Ground ..... −2.0V to +7.0V(2)

Output Short Circuit Current ..... 100 mA(4)

Notice: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

NOTICE: Specifications contained within the following tables are subject to change.

NOTES:
1. Operating temperature is for commercial product defined by this specification.
2. Minimum D.C. input voltage is −0.5V. During transitions, inputs may undershoot to −2.0V for periods less than 20 ns. Maximum D.C. voltage on output pins is V_{CC} + 0.5V, which may overshoot to V_{CC} + 2.0V for periods less than 20 ns.
3. Maximum D.C. voltage on A_9 or V_{PP} may overshoot to +14.0V for periods less than 20 ns.
4. Output shorted for no more than one second. No more than one output shorted at a time.

OPERATING CONDITIONS

Symbol	Parameter	Limits		Unit	Comments
		Min	Max		
T_A	Operating Temperature	0	70	°C	For Read-Only and Read/Write Operations
V_{CC}	V_{CC} Supply Voltage	4.50	5.50	V	

D.C. CHARACTERISTICS—TTL/NMOS COMPATIBLE

Symbol	Parameter	Limits		Unit	Test Conditions
		Min	Max		
I_{LI}	Input Leakage Current		±1.0	µA	$V_{CC} = V_{CC}$ Max $V_{IN} = V_{CC}$ or V_{SS}
I_{LO}	Output Leakage Current		±10	µA	$V_{CC} = V_{CC}$ Max $V_{OUT} = V_{CC}$ or V_{SS}
I_{CCS}	V_{CC} Standby Current		1.0	mA	$V_{CC} = V_{CC}$ Max $\overline{CE} = V_{IH}$
I_{CC1}(1)	V_{CC} Active Read Current		30	mA	$V_{CC} = V_{CC}$ Max, $\overline{CE} = V_{IL}$ f = 6 MHz, I_{OUT} = 0 mA
I_{CC2}(1)	V_{CC} Programming Current		30	mA	Programming in Progress
I_{CC3}(1)	V_{CC} Erase Current		30	mA	Erasure in Progress
I_{PPS}	V_{PP} Leakage Current		±10	µA	$V_{PP} \leq V_{CC}$

D.C. CHARACTERISTICS—TTL/NMOS COMPATIBLE (Continued)

Symbol	Parameter	Limits		Unit	Test Conditions
		Min	Max		
I_{PP}	V_{PP} Read Current or Standby Current		200	µA	$V_{PP} > V_{CC}$
			±10		$V_{PP} \leq V_{CC}$
I_{PP2}[2]	V_{PP} Programming Current		30	mA	$V_{PP} = V_{PPH}$ Programming in Progress
I_{PP3}[2]	V_{PP} Erase Current		30	mA	$V_{PP} = V_{PPH}$ Erasure in Progress
V_{IL}	Input Low Voltage	−0.5	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} + 0.5	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 5.8 mA $V_{CC} = V_{CC}$ Min
V_{OH1}	Output High Voltage	2.4		V	I_{OH} = −2.5 mA $V_{CC} = V_{CC}$ Min
V_{ID}	A_9 intelligent Identifier™ Voltage	11.50	13.00	V	
I_{ID}	A_9 intelligent Identifier™ Current		500	µA	$A_9 = V_{ID}$
V_{PPL}	V_{PP} during Read-Only Operations	0.00	6.5	V	**NOTE:** Erase/Program are Inhibited when $V_{PP} = V_{PPL}$
V_{PPH}	V_{PP} during Read/Write Operations	11.40	12.60	V	
V_{LKO}	V_{CC} Erase/Write Lock Voltage	2.5		V	

D.C. CHARACTERISTICS—CMOS COMPATIBLE

Symbol	Parameter	Limits		Unit	Test Conditions
		Min	Max		
I_{LI}	Input Leakage Current		±1.0	µA	$V_{CC} = V_{CC}$ Max $V_{IN} = V_{CC}$ or V_{SS}
I_{LO}	Output Leakage Current		±10	µA	$V_{CC} = V_{CC}$ Max $V_{OUT} = V_{CC}$ or V_{SS}
I_{CCS}	V_{CC} Standby Current		100	µA	$V_{CC} = V_{CC}$ Max $\overline{CE} = V_{CC}$ ±0.2V
I_{CC1}[1]	V_{CC} Active Read Current		30	mA	$V_{CC} = V_{CC}$ Max, $\overline{CE} = V_{IL}$ f = 6 MHz, I_{OUT} = 0 mA
I_{CC2}[1]	V_{CC} Programming Current		30	mA	Programming in Progress
I_{CC3}[1]	V_{CC} Erase Current		30	mA	Erasure in Progress
I_{PPS}	V_{PP} Leakage Current		±10	µA	$V_{PP} \leq V_{CC}$

D.C. CHARACTERISTICS—CMOS COMPATIBLE (Continued)

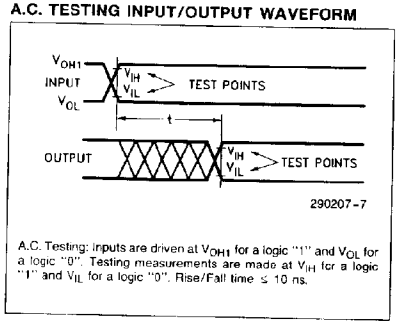
Symbol	Parameter	Limits		Unit	Test Conditions
		Min	Max		
I_{PP1}	V_{PP} Read Current or Standby Current		200	µA	$V_{PP} > V_{CC}$
			±10		$V_{PP} \leq V_{CC}$
I_{PP2}[2]	V_{PP} Programming Current		30	mA	$V_{PP} = V_{PPH}$ Programming in Progress
I_{PP3}[2]	V_{PP} Erase Current		30	mA	$V_{PP} = V_{PPH}$ Erasure in Progress
V_{IL}	Input Low Voltage	−0.5	0.8	V	
V_{IH}	Input High Voltage	0.7 V_{CC}	V_{CC} + 0.5	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 5.8 mA $V_{CC} = V_{CC}$ Min
V_{OH1}	Output High Voltage	0.85 V_{CC}		V	I_{OH} = −2.5 mA, $V_{CC} = V_{CC}$ Min
V_{OH2}		V_{CC} 0.4			I_{OH} = −100 µA, $V_{CC} = V_{CC}$ Min
V_{ID}	A_9 intelligent Identifier™ Voltage	11.50	13.00	V	
I_{ID}	A_9 intelligent Identifier™ Current		500	µA	$A_9 = V_{ID}$
V_{PPL}	V_{PP} during Read-Only Operations	0.00	6.5	V	**NOTE:** Erase/Programs are Inhibited when $V_{PP} = V_{PPL}$
V_{PPH}	V_{PP} during Read/Write Operations	11.40	12.60	V	
V_{LKO}	V_{CC} Erase/Write Lock Voltage	2.5		V	

CAPACITANCE[3] T_A = 25°C, f = 1.0 MHz

Symbol	Parameter	Limits		Unit	Conditions
		Min	Max		
C_{IN}	Address/Control Capacitance		6	pF	V_{IN} = 0V
C_{OUT}	Output Capacitance		12	pF	V_{OUT} = 0V

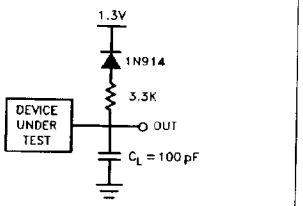
NOTES:
1. Active I_{CC} current of a typical device is 12 mA with nominal V_{CC} at room temperature.
2. Active I_{PP} current of a typical device is 10 mA with nominal V_{PP} at room temperature.
3. Sampled, not 100% tested.

A.C. TESTING INPUT/OUTPUT WAVEFORM



A.C. Testing: Inputs are driven at V_{OH1} for a logic "1" and V_{OL} for a logic "0". Testing measurements are made at V_{IH} for a logic "1" and V_{IL} for a logic "0". Rise/Fall time ≤ 10 ns.

A.C. TESTING LOAD CIRCUIT



C_L = 100 pF
C_L includes Jig Capacitance

A.C. TEST CONDITIONS

Input Rise and Fall Times (10% to 90%) ..... 10 ns
Input Pulse Levels ..... V_{OL} and V_{OH1}
Input Timing Reference Level ..... V_{IL} and V_{IH}
Output Timing Reference Level ..... V_{IL} and V_{IH}

A.C. CHARACTERISTICS—Read-Only Operations

Versions		28F010-120		28F010-150		28F010-200		Unit
Symbol	Characteristic	Min	Max	Min	Max	Min	Max	
t_{AVAV}/t_{RC}	Read Cycle Time	120		150		200		ns
t_{ELQV}/t_{CE}	Chip Enable Access Time		120		150		200	ns
t_{AVQV}/t_{ACC}	Address Access Time		120		150		200	ns
t_{GLQV}/t_{OE}	Output Enable Access Time		50		55		60	ns
t_{ELQX}/t_{LZ}	Chip Enable to Output in Low Z	0		0		0		ns
t_{GLQX}/t_{OLZ}	Output Enable to Output in Low Z	0		0		0		ns
t_{GHQZ}/t_{DF}	Output Disable to Output in High Z		30		35		40	ns
t_{OH}	Output Hold from Address, $\overline{CE}$, or $\overline{OE}$ Change(1)	0		0		0		ns
t_{WHGL}	Write Recovery Time before Read	6		6		6		µs

NOTES:
1. Whichever occurs first.
2. Rise/Fall Time ≤ 10 ns.

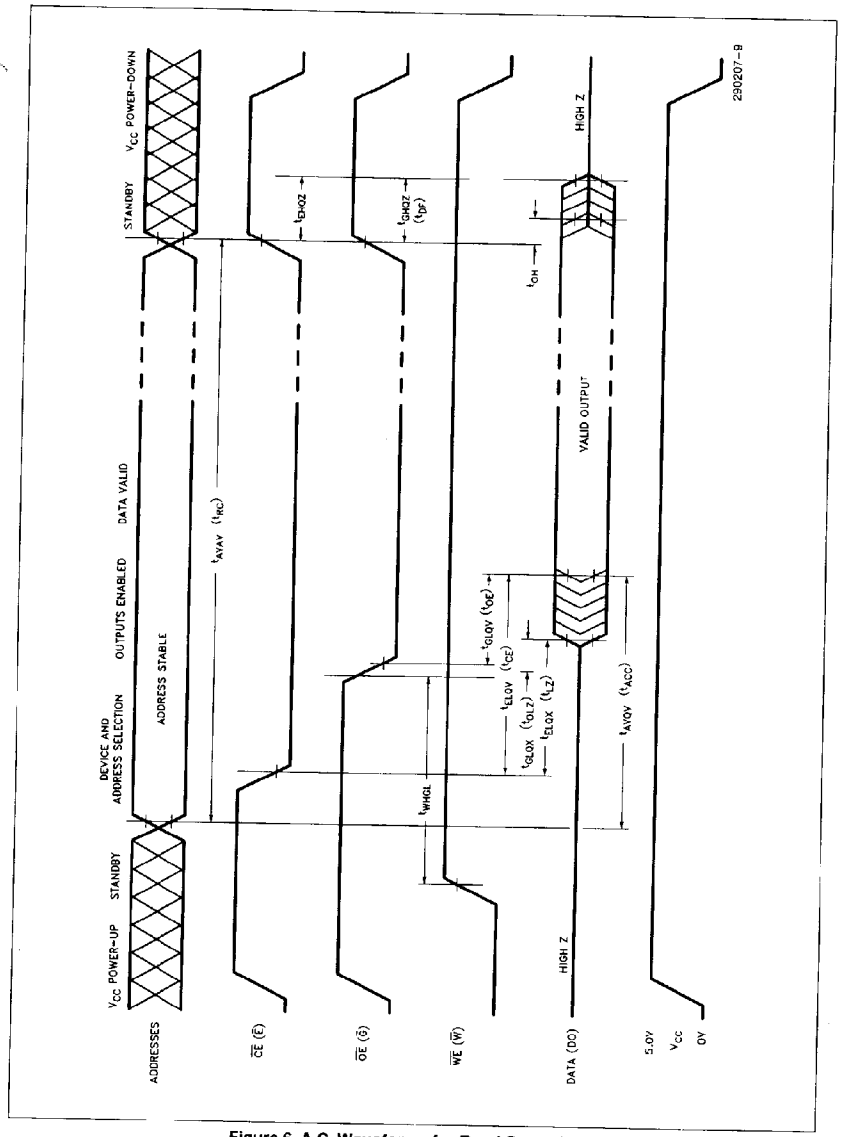


Figure 6. A.C. Waveforms for Read Operations

A.C. CHARACTERISTICS—Write/Erase/Program Operations(1)

Versions		28F010-120		28F010-150		28F010-200		Unit
Symbol	Characteristic	Min	Max	Min	Max	Min	Max	
t_{AVAV}/t_{WC}	Write Cycle Time	120		150		200		ns
t_{AVWL}/t_{AS}	Address Set-Up Time	0		0		0		ns
t_{WLAX}/t_{AH}	Address Hold Time	60		60		75		ns
t_{DVWH}/t_{DS}	Data Set-Up Time	50		50		50		ns
t_{WHDX}/t_{DH}	Data Hold Time	10		10		10		ns
t_{WHGL}	Write Recovery Time before Read	6		6		6		µs
t_{GHWL}	Read Recovery Time before Write	0		0		0		µs
t_{ELWL}/t_{CS}	Chip Enable Set-Up Time before Write	20		20		20		ns
t_{WHEH}/t_{CH}	Chip Enable Hold Time	0		0		0		ns
t_{WLWH}/t_{WP}	Write Pulse Width(2)	50		50		60		ns
t_{WHWL}/t_{WPH}	Write Pulse Width High	20		20		20		ns
t_{WHWH1}	Duration of Programming Operation	10	(3)	10	(3)	10	(3)	µs
t_{WHWH2}	Duration of Erase Operation	9.5	(3)	9.5	(3)	9.5	(3)	ms
t_{VPEL}	V_{PP} Set-Up Time to Chip Enable Low	100		100		100		ns

NOTES:
1. Read timing characteristics during read/write operations are the same as during read-only operations. Refer to A.C. Characteristics for Read-Only Operations.
2. Rise/Fall time ≤ 10 ns.
3. The integrated watchdog timer terminates the programming/erase operations, thereby eliminating the need for a maximum specification.

ERASE AND PROGRAMMING PERFORMANCE

Parameter	Limits									Unit
	28F010-120			28F010-150			28F010-200			
	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Chip Erase Time(3)		0.5(1)	10		0.5(1)	10		0.5(1)	30	Sec
Chip Program Time(4)		2(1)	24(2)		2(1)	24(2)		2(1)	24(2)	Sec
Erase/Program Cycles(5)	10,000	100,000		10,000	100,000		10,000	100,000		Cycles

NOTES:
1. 25°C, 12.0V V_{PP}, 10,000 Cycles.
2. Minimum byte programming time excluding system overhead is 16 µsec (10 µsec program + 6 µsec write recovery), while maximum is 400 µsec/byte (16 µsec x 25 loops allowed by algorithm). Max chip programming time is specified lower than the worst case allowed by the programming algorithm since most bytes program significantly faster than the worst case byte.
3. Excludes 00H Programming prior to Erasure.
4. Excludes System-Level Overhead.
5. Refer to RR-60 "ETOX™ Flash Memory Reliability Data Summary" for typical cycling data and failure rate calculations.

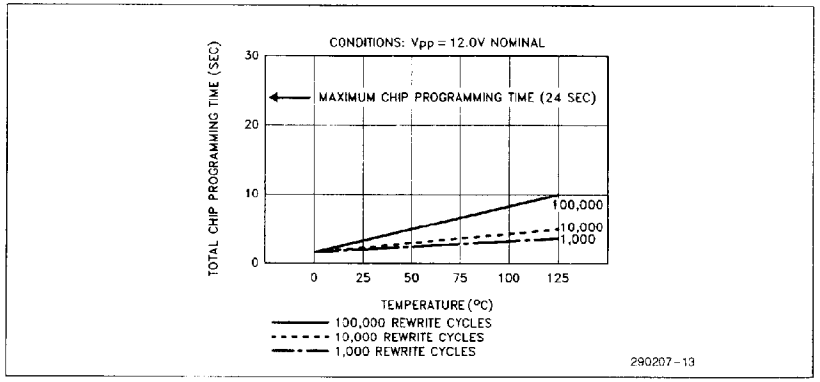


Figure 7. 28F010 Typical Programming Time vs. Temperature

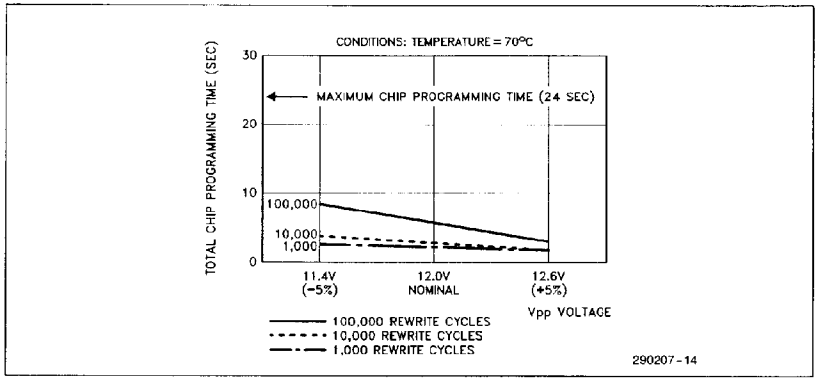


Figure 8. 28F010 Typical Programming Time vs. V_{PP} Voltage

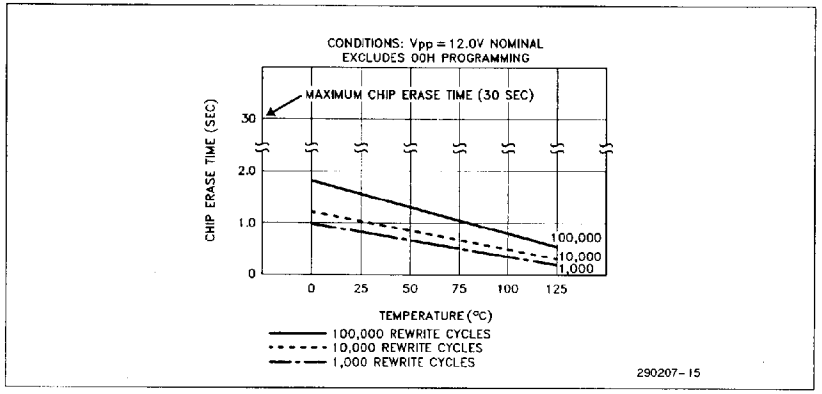


Figure 9. 28F010 Typical Erase Time vs. Temperature

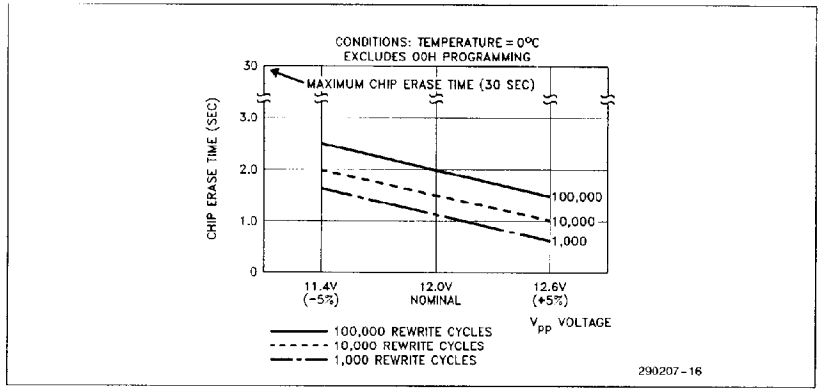


Figure 10. 28F010 Typical Erase Time vs. V_{PP} Voltage

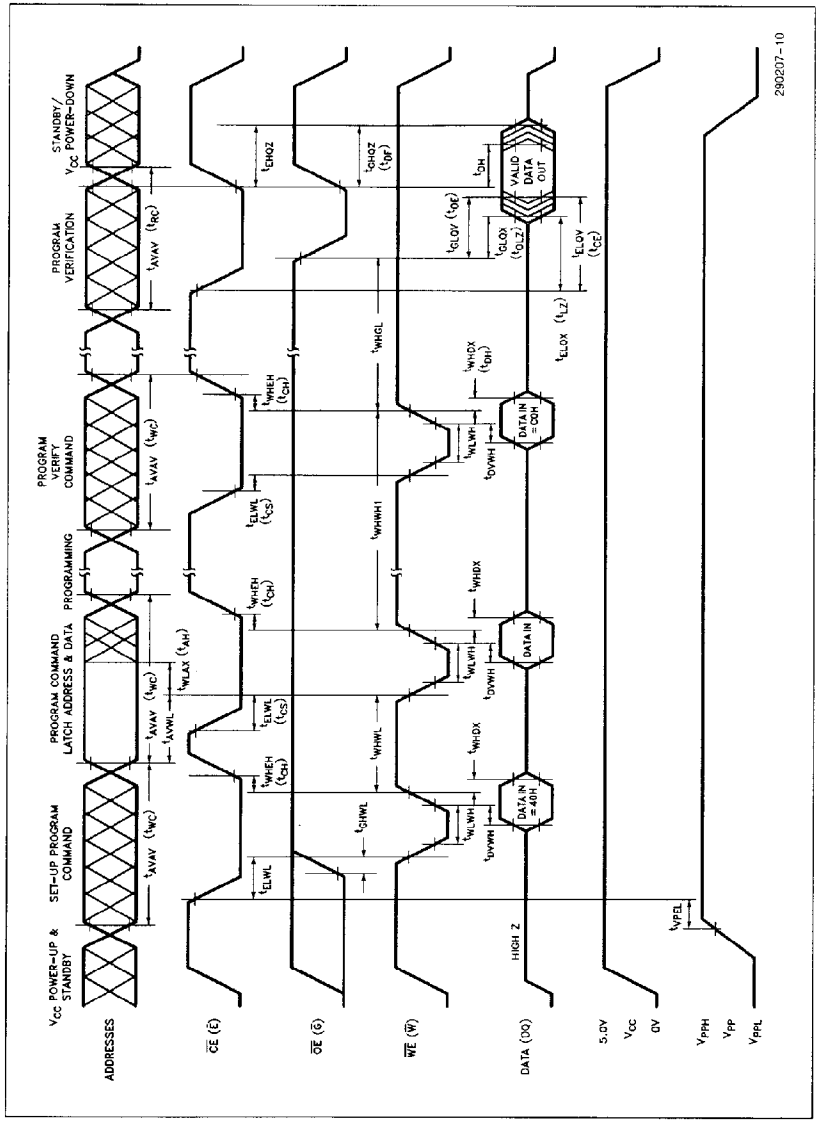


Figure 11. A.C. Waveforms for Programming Operations

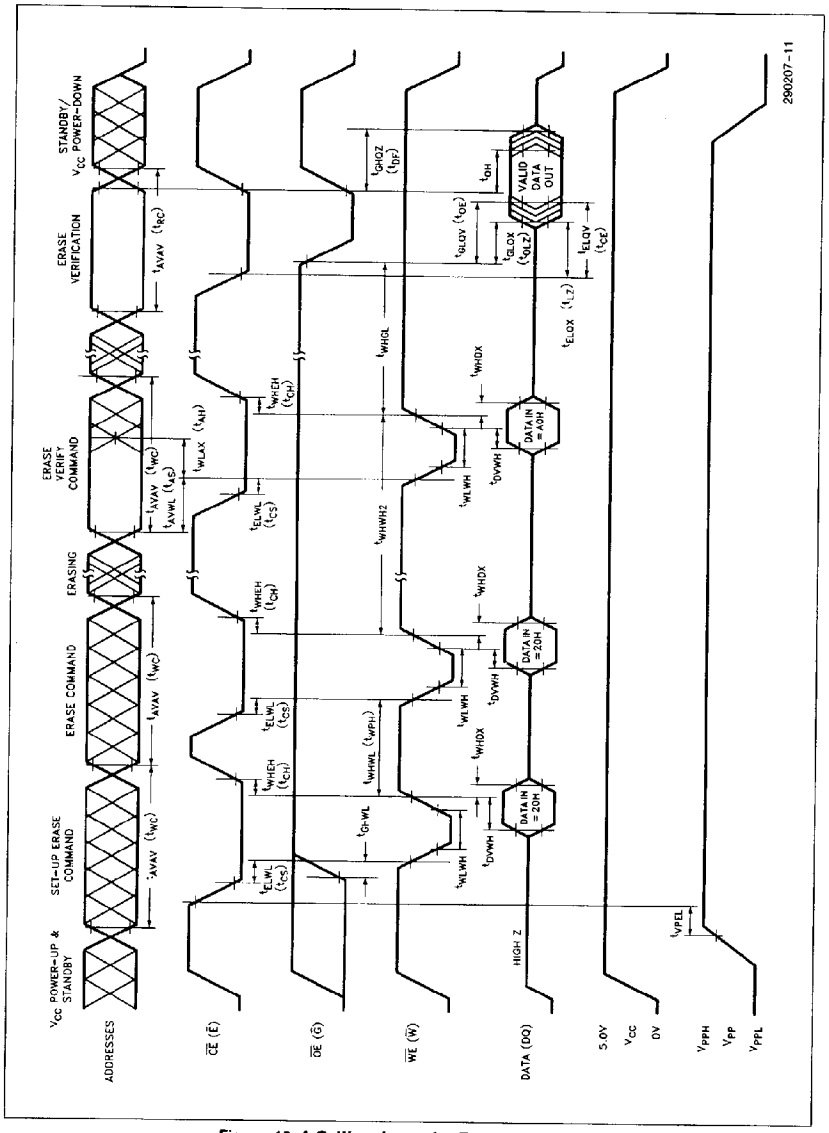
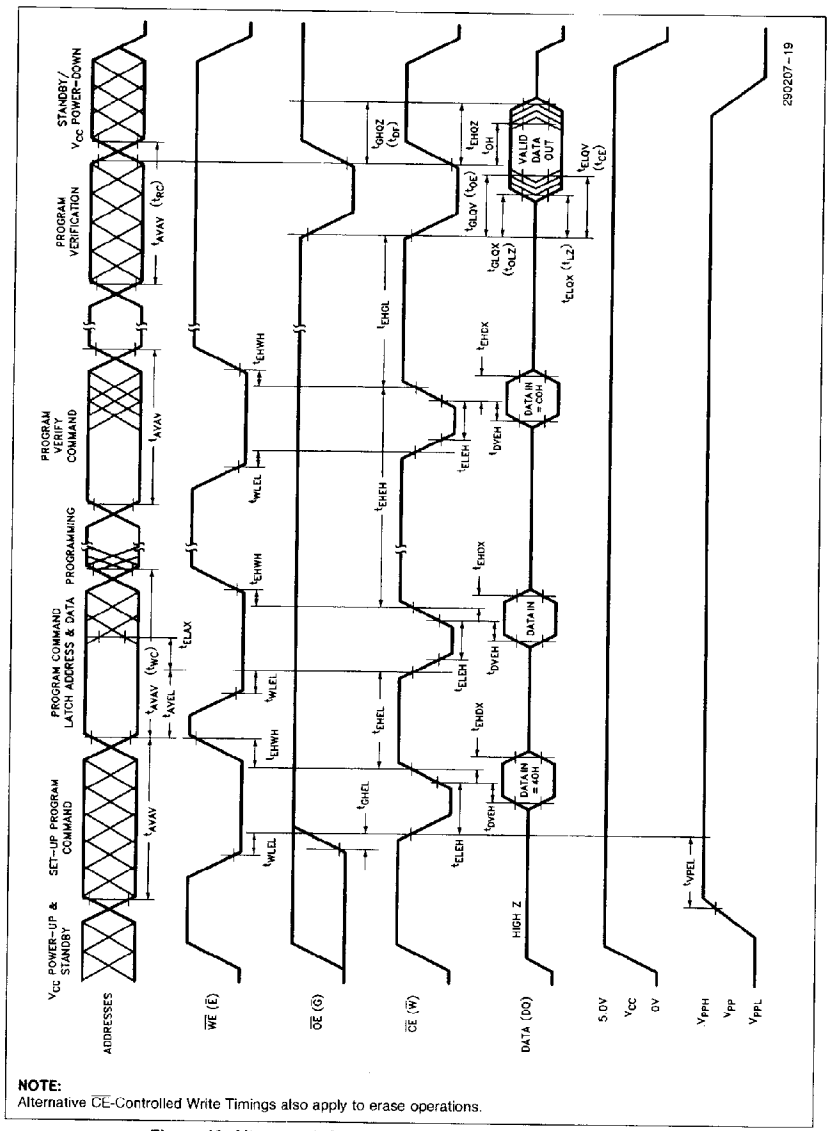


Figure 12. A.C. Waveforms for Erase Operations

ALTERNATIVE $\overline{CE}$-CONTROLLED WRITES

Versions		28F010-120		28F010-150		28F010-200		Unit
Symbol	Characteristic	Min	Max	Min	Max	Min	Max	
t_{AVAV}	Write Cycle Time	120		150		200		ns
t_{AVEL}	Address Set-Up Time	0		0		0		ns
t_{ELAX}	Address Hold Time	80		80		95		ns
t_{DVEH}	Data Set-Up Time	50		50		50		ns
t_{EHDX}	Data Hold Time	10		10		10		ns
t_{EHGL}	Write Recovery Time before Read	6		6		6		µs
t_{GHEL}	Read Recovery Time before Write	0		0		0		µs
t_{WLEL}	Write Enable Set-Up Time before Chip Enable	0		0		0		ns
t_{EHWH}	Write Enable Hold Time	0		0		0		ns
t_{ELEH}	Write Pulse Width(1)	70		70		80		ns
t_{EHEL}	Write Pulse Width High	20		20		20		ns
t_{PEL}	V_{PP} Set-Up Time to Chip Enable Low	100		100		100		ns

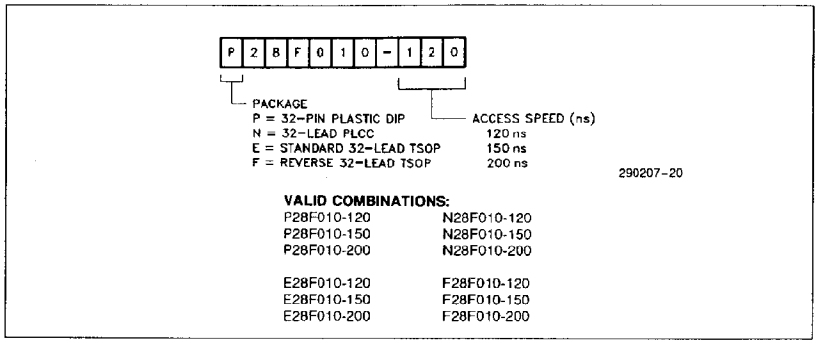
NOTE:
1. Chip-Enable Controlled Writes: Write operations are driven by the valid combination of Chip-Enable and Write-Enable. In systems where Chip-Enable defines the write pulse width (within a longer Write-Enable timing waveform) all set-up, hold and inactive Write-Enable times should be measured relative to the Chip-Enable waveform.



NOTE:
Alternative $\overline{CE}$-Controlled Write Timings also apply to erase operations.

Figure 13. Alternate A.C. Waveforms for Programming Operations

ORDERING INFORMATION



VALID COMBINATIONS:

P28F010-120	N28F010-120
P28F010-150	N28F010-150
P28F010-200	N28F010-200
E28F010-120	F28F010-120
E28F010-150	F28F010-150
E28F010-200	F28F010-200

THIN SMALL OUTLINE PACKAGE (TSOP) DIMENSIONS

	Inches	MM
Package Body Height:	0.038	0.96
Package Body Length:	0.72	18.20
Package Body Width:	0.31	7.80

ADDITIONAL INFORMATION

		Order Number
ER-20,	"ETOX™ Flash Memory Technology"	294005
ER-24,	"The Intel 28F010 Flash Memory"	294008
RR-60,	"ETOX™ Flash Memory Reliability Data Summary"	293002
AP-316,	"Using Flash Memory for In-System Reprogrammable Nonvolatile Storage"	292046
AP-325	"Guide to Flash Memory Reprogramming"	292059

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