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EXECUTIVE SUMMARY

This proposal addresses the Request for Proposal (RFP) from a utility company. The company needs to package two colours of wooden dowels in organizer boxes in various mixed combinations. The solution must be able to package two boxes of dowels in under two minutes, according the the packaging patterns selected by the user.

The proposed solution operates in five stages. Before the operation begins, the user must load the dowels and the boxes into their corresponding reservoirs. The user will also select two of six available packaging patterns. When the user starts the operation, a box will be loaded onto the conveyor belt, which will run continuously to transport it into position for loading. As the box moves slowly across the conveyor belt, the machine will successively drop the wooden dowels into the slots in the box. After the box is completely packaged, the lid will close as the box moves under a bar, at which point it would be ready for pickup. The cost for this solution is under $150.

The project will be divided into three subsystems - circuitry, microcontroller and electromechanical components. Andrew Wong will be responsible for the circuitry, which includes the design and fabrication of a circuit system that efficiently supplies the power required for all electrical components, and allows reliable communication between the PIC microcontroller and the mechanical parts. Sherry Shi will be responsible for programming the PIC microcontroller, which will interact efficiently with the user, control the system to precisely and accurately perform its task, and store and display relevant information. Arushri Swarup will be responsible for the electromechanical components, such as the fabrication of mechanical and structural parts of the machine.

1. PROBLEM FORMULATION

Today, much of the manufacturing industry is adopting automated processes. The advantages of automation include lower costs, better efficiency and higher reliability [1]. Historically, industrial machines are known for their size and power. In modern society however, more compact and energy efficient designs are preferred [2].

This proposal addresses the Request for Proposal (RFP) from a utility company [3]. The company needs to package two colors of wooden dowels in organizer boxes in various mixed combinations.

The design of the system is guided by the specifications outlined in the Request for Proposal, which is found in Appendix C. The main objectives identified by the RFP are:

- Speed and reliability - The machine should be able to pack the most number of boxes in the least amount of time, at least two boxes in under 2 minutes. The packing pattern should be accurate according to the user specification. The packed boxes should be retrievable at the specified pick-up area. The machine should also be constructed durably and function reliably (i.e. with small failure rate) under different operating environments.
- User-friendliness - The machine should look elegant and be safe and easy to operate, with no sensibly noise or vibrations. The user interface should be simple and clear. The data displayed should be precise and accurate. Minimum time and effort should be needed to set up, calibrate or repair the machine. Further, the machine should be compact and portable, with minimal weight.
- Cost efficiency - The machine should maximize all other criteria with minimal cost. The total material cost must cost less than $230 per unit.

2. DESIGN STRATEGY AND CONCEPTS

As a result of the design objectives and requirements, two main themes of the design strategies are simplicity and modularity. This would guide the design to allow ease of manufacturing and maintenance, which would increase reliability. Cost efficiency would also be maximized.

The operation of the solution is composed of several stages:

1. Loading the boxes and dowels in the appropriate area
2. Dispense the box
3. Transport box into position for loading the dowels
4. Dispense and load the dowel of the specified shade into the correct slot in the box. Repeat stages 2 and 3 until loading is complete.
5. Shut the lid of the box
6. Transport the box to the pickup area

2.1 Loading Boxes and Dowels

The boxes and dowels are to be loaded into their reservoirs after the power has turned on. See 2.2 and 2.4 four details on reservoir designs.

2.2 Dispensing of the Box

The first step the robot needs to take in its objective is to load the box into position so that it is ready to be filled with dowels. Aside from simplicity, the main objective of this stage is to be efficient in the use of space.

2.2.1 DROPPING STACKED BOXES

Design: The first idea consisted of a large rectangular container which held boxes stacked with cardboard platforms in between them. The container was suspended on top of the conveyor belt and a hatch on the bottom would slide out for enough time to let one box fall onto the conveyor belt. Refer to Figure 2.2.1.

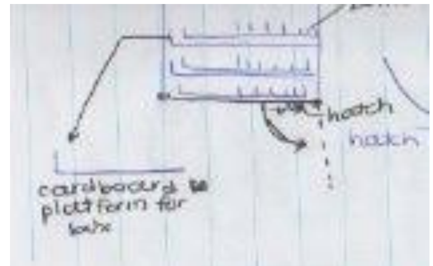


Figure 2.2.1: Dropping staked boxes concept

Advantages: This design is simple, and would require relatively few materials as it only consists of a container and a frame, rendering it a low cost part.

Disadvantages: Two or more boxes may fall out at the same time, rendering this design unreliable.

2.2.2 COUPLED CONVEYOR BELT

Design: This design included two vertically-aligned conveyor belts facing each other rotating in opposite directions. Attached to the belt were pairs of L-brackets that held the box in place until it reached the bottom, at which point the brackets would rotate around releasing the box. The details are shown in Figure 2.2.2. The conveyor belts were driven by one DC motor. The rotation was transferred to the opposite conveyor belt by a system of gears, changing the direction of rotation.

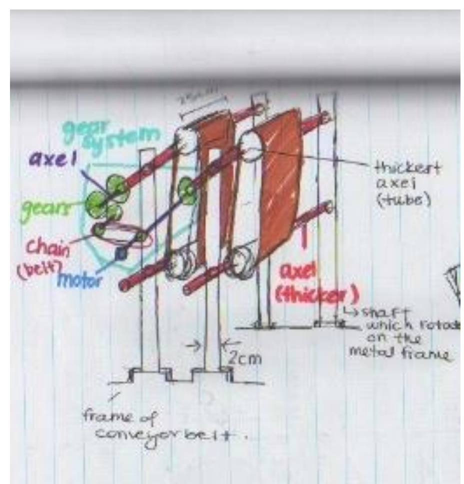


Figure 2.2.2: Coupled Conveyor Belt Concept.

Advantages: This design requires one unidirectional motor, causing it to be cost-effective and easier to control by the microcontroller. Also, the conveyor belts would weigh less relative to a wooden container.

Disadvantages: The main problem with this design was its complexity. Synchronizing the two belts to ensure the boxes lay horizontally on the L-brackets would have been very difficult with the use of the gear system. There were risks of gears slipping and causing the two belts to move at different speeds. Also, perfectly aligning the full mechanism on the frame would have been difficult and would cause angles, possibly resulting in a box that would not fall into place appropriately.

2.2.3 PULLEY ELEVATOR

Design: This design consists of a pulley which is driven by a motor and gearbox to slowly elevate a container, containing boxes stacked on top of a wedge causing the boxes to assume an angle of 30 degrees to the horizontal, see Figure 4. The inner container slides out of its outer stand by a drawer-sliding mechanism. The pulley will be running continually while the robot is switched on. This design is relatively simple compared to the previous designs as it uses a pulley, a simple machine and a single motor which is controlled by gears to amplify its torque to elevate the container of boxes.

Advantages: Speed will be maintained as the motor will be continuously running, and the first box will be at the level of the conveyor belt when the machine commences operation. Use of a simple machine simplifies the design, causing it to be more reliable as there is not an excess of mechanical parts with potential to break down. This design is cost-efficient, as it uses few materials that are cheap, effectively. Refer to Section 7 for cost analysis.

Disadvantages: This design is not very compact, however, it does use space efficiently as it is located behind the conveyor belt where there is enough space for it.

Driving Mechanism: 12 V DC Brush Motor and 2 spur gears with a gear ratio of 20 to amplify the torque needed to elevate the inner container with stacked boxes. Refer to Appendix B-2. A DC brush motor was chosen because they are inexpensive, reliable and simple to control, with 2 wires, relative to brushless DC motors [4]. The motor does not operate at a high torque, therefore, a gearbox is required to slow the speed and amplify the torque enough to lift the inner container.

2.2.4 DESIGN DECISION

Design Selection: Box Loader (Pugh Chart):

Criteria	**2.2.1 Dropping Stacked Boxes**	**2.2.2 Coupled Conveyor Belt**	**2.2.3 Pulley Elevator**
Ease of Building	0	-	+
Reliability	-	-	+
Simplicity	+	-	+

Criteria	2.2.1 Dropping Stacked Boxes	2.2.2 Coupled Conveyor Belt	2.2.3 Pulley Elevator
Cost	0	-	0
Safety	-	0	0
Use of Space	+	+	+
Weight	0	-	0
Total	-1	-4	4

According to the Pugh chart which compares the designs against the objectives outlined earlier, design 2.2.3 Pulley Elevator achieves a score of 4 therefore, it is the proposed design.

The proposed design takes advantage of the smooth surface of the box and gravitational force. A single motor drives a pulley which elevates the slanted stack of boxes upwards until a box moves past the wall of the reservoir, which allows the box to slip onto the conveyor belt.

2.3 Transport of Box

The loading process requires the box to move linearly relative to the dispensing mechanism. The simplest method is to use a conveyor system, as it can efficiently transform the rotational motion of a motor into the desired linear motion.

Once the box has been elevated to the appropriate height, of the conveyor system, it will slide down onto the conveyor belt. During the packing stage, the box will be transported through the system via the conveyor belt driven by a DC motor. The conveyor belt will move the box continuously while the dowels are dispensed into the appropriate slots. Once the box is fully packed, the conveyor belt will transport it to the pickup location as the next box is loaded. To ease calibration, a potentiometer will be connected to the motor.

One of the concerns when designing the conveyor belt is the slack that may result from the flexible belt material. In the following photo, rolling pins along the path are a simple way to keep the boxes levelled and allow the box to travel smoothly. This design is adopted by the proposed design, which consists of a set of rolling dowels between the conveyor belt, evenly spaced along the path. The dowels will keep the boxes levelled while adding minimal friction.

Another concern regarding the conveyor belt is that it keep the box aligned with the dowel dispensing mechanism as it moves along the path. This will be achieved by installing ramps on one side of the path. On the other side, a bar which will facilitate the closing of the box will keep the box in position (see Section 2.5 for more).

Figure 2.3: Rolling pins are used to support the boxes as they move along the conveyor. [7]

2.4 Dowel Dispensing

One of the more complex stages is the dispensing of the dowels. One of the challenges is that the dowels must be dispensed one at a time. The following are some existing methods that allow unit-wise dispensing: candy dispenser, and straw dispenser, as shown in Figures 2.4.1 and 2.4.2. A commonality in the two designs is that the items are loaded and ready to be dispensed when the machine is on standby. The mechanism also blocks the items in the reservoir from leaving when the unit is dispensed.

Figure 2.4.1: Candy Dispenser mechanism. [8]

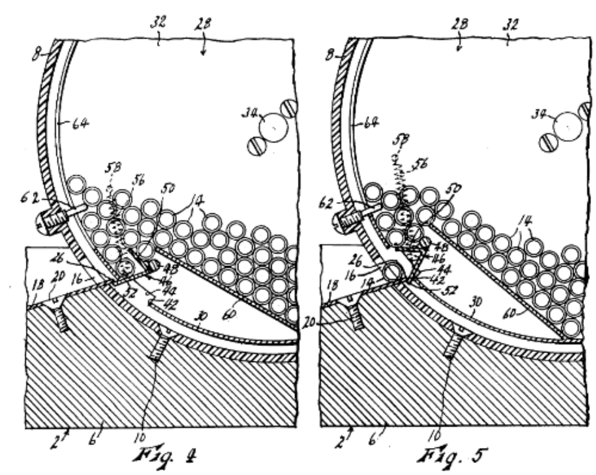


Figure 2.4.2: Candy Dispenser schematic. [9]

2.4.1 VERTICALLY SUSPENDED STACKED-DOWEL RESERVOIR WITH HATCH

Design: This design, brainstormed as one of the preliminary designs entailed a tall, skinny reservoir with a divide down the middle, separating the light and dark dowels. There were two hatches closing off the containers, and when a dowel was to be loaded, the hatch corresponding to the correct reservoir determined by the microcontroller would slide open long enough for one dowel to fall out. This design had the same idea as 2.1.1 Dropping Stacked Boxes, except it has dowels stacked vertically in two reservoirs.

Advantages: This design is simple, and would require relatively few materials as it only consists of a container and a frame, rendering it a low cost part.

Disadvantages: Two or more dowels may fall out at the same time, rendering this design unreliable.

2.4.2 DISPENSING MECHANISMS

The following ideas: 2.4.2.1 and 2.4.2.2 use two tall compartments which horizontally stack the dowels one on top of the other as their reservoir.

2.4.2.1 Candy Dispensing Mechanism

Design: This design consisted of a similar setup as design 3.1, however it used the concept of a gumball dispenser instead. A rotating cylinder would turn toward one side of the reservoir to pick up the corresponding dowel and rotate to load the dowel into the box.

Advantages: Speed is achieved with this design because a single rotating cylinder dispenses a dowel which can be calibrated to take only a couple of seconds.

Disadvantages: Reliability is an issue with this design as dowels have the potential of getting stuck in the dispenser.

2.4.2.2 Train Wheel Dispensing Mechanism

Design: This design uses an idea similar to that of the traditional train wheel which advances due to a shaft attached to a wheel at a position offset from the center. The wheel is constantly rotating causing the shaft to move back and forth. This shaft would be connected to a bar of the same length as a dowel and the back and forth motion would push out a dowel from the corresponding reservoir.

Advantages: This mechanism is designed for speed as there is a single motor rotating a wheel which can be sped up.

Disadvantages: This design is unreliable because the shaft can get stuck on one of the dowels, clogging the reservoir.

2.4.3 RESERVOIR DESIGN

The following designs are for the reservoir that is able to align the dowels horizontally to be dispensed and allow for easy access to the remaining dowels once the machine has stopped its operation

2.4.3.1 Straw-Packing Machine

This design is used by the Keewa Industries Corporation [5]. It consists of a large inverted triangular prism shaped reservoir with pins attached to the walls which, when avalanched by straws, aids in their horizontal alignment. This design was tested in the lab, by horizontally attaching pencils inside a cardboard box and dropping dowels into the reservoir. The design was unsuccessful in aligning the dowels horizontally.

2.4.3.2 Curved, Smooth Reservoir

Design: This design was a thin sheet of metal, curved into a semi-circle. The curved surface with minimal friction would guide the dowels to assume a horizontal position.

Advantages: This reservoir does not call for a mechanical component, deeming it cost-effective as the only material is sheet metal.

Disadvantages: If the dowels had gotten stuck, a vibrator would have to be installed to allow dowels to move and fall into place, adding complexity.

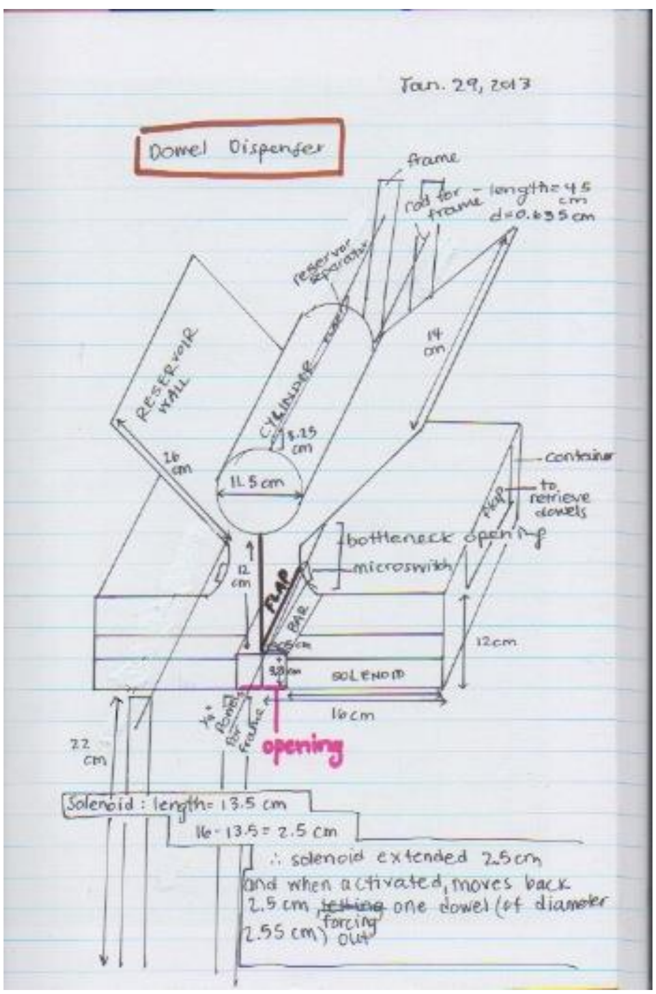


Figure 2.4.3: Design sketch for the suspended cylinder concept.

2.4.3.3 Suspended Cylinder

Design: This design was a plastic cylinder suspended above an inverted triangular prism-shaped reservoir. When prototyped with an 11.5 cm diameter ABS cylinder and a cardboard reservoir, it was observed that dowels, when randomly dropped into the reservoir, hit the curve of the cylinder and fell to align themselves horizontally. Refer to Figure 2.4.4 for a visual representation. The dowels are loaded through the top of the reservoir and fall through a bottle-neck opening where a microswitch senses each dowel and counts. The dowels stay in their reservoir under the opening and rest above a solenoid in the extended position. The solenoid is attached to a bar which is used to block the exit of the reservoir. Upon receiving a signal, the appropriate solenoid will retract allowing one dowel to fall into position, ready to be pushed out. Once the solenoid extends back into its original position, the dowel is pushed out and the exit is once again blocked. The dowel will fall through the exit, into the desired slot in the box. Refer to Figure 2.4.3 for a design sketch.

Figure 2.4.4: Visual Representation for suspended cylinder concept.

Advantages: One of the advantages of this design is that it is simple, and requires few moving parts. Also, there is minimal requirement for the precision of the movement and the movements are within a small area, minimizing the chances of clogging. The solenoid is a reliable because its main purpose is to block the exit, and it does not need to apply much force to the dowel because the dowel will be aligned with the exit point.

Disadvantages: This design is not relatively compact, but it fills up the height dimension of the robot, for which the short frame allows for.

2.4.4 DESIGN DECISION

Design Selection: Dowel Dispenser (Pugh Chart):

Criteria	Weight	2.4.1 Vertically Suspended Stacked-Dowel Reservoir with Hatch	2.4.2.1 Candy Dispensing Mechanism	2.4.2.2 Train Wheel Dispensing Mechanism	2.4.3.1 Straw-Packaging Machine	2.4.3.2 Curved, Smooth Reservoir	2.4.3.3 Cylinder Suspended in a Reservoir
Ease of Building	1	+	0	-	+	-	0
Speed	1	0	+	+	+	0	0
Reliability	5	-	-	-	-	-	+
Simplicity	1	0	0	0	+	+	0
Cost	1	+	+	0	0	+	0
Safety	1	0	+	0	0	+	+
Use of Space	1	0	+	0	0	-	-

Criteria	Weight	2.4.1 Vertically Suspended Stacked-Dowel Reservoir with Hatch	2.4.2.1 Candy Dispensing Mechanism	2.4.2.2 Train Wheel Dispensing Mechanism	2.4.3.1 Straw-Packaging Machine	2.4.3.2 Curved, Smooth Reservoir	2.4.3.3 Cylinder Suspended in a Reservoir
Weight	1	+	+	0	0	+	0
Total	12	-2	0	-5	-2	-3	+5

According to the Pugh Chart, design 2.4.3.3 Cylinder Suspended in a Reservoir achieves a score of +5 therefore it is the proposed design.

2.5 Closing and Locking Lid

2.5.1 WEIGHTED ROTATING FLAP

Design: This design was a large metal flap, connected on the side of the conveyor belt that would snap the lid of the box shut once it was in position. It was powered by a motor.

Disadvantages: The motor would have to be calibrated to only rotate the flap a few degrees. The motor adds unnecessary complexity to the design and use of excess materials is not cost-effective or reliable as there are more areas of failure.

2.5.2 LID CLOSING BAR AND ROLLER

This design contains an aluminum bar which is attached on the frame of the machine at the end of the conveyor belt. The bar is slightly angled and extends to hover over the belt. When the open lid comes in contact with the bar, the angle of the bar closes the lid. This mechanism was tested by the team in the lab by running an open box across the angled bar. The roller hovers over the conveyor belt at the height of a closed box, and therefore once the box is passing under the roller, its lid is shut and the roller locks it. Refer to Appendix B-1 for a sketch of the conceptual design of the machine. The advantage of this design is that it has no electrical parts, rendering it simple and reliable. Since this design uses only two materials, it is cost-effective, simple and aesthetically pleasing.

2.5.3 DESIGN DECISION

Design Selection: Closing and Locking the Loaded Box Lid (Pugh Chart):

Criteria	Weight	2.5.1 Weighted Rotating Flap	2.5.2 Lid Closing Bar and Roller
Ease of Building	1	0	+
Speed	1	-	+
Reliability	5	-	0
Simplicity	1	-	+
Cost	1	-	+
Safety	1	0	+
Use of Space	1	-	+
Weight	1	-	+
Total	12	-10	+7

According to the Pugh Chart, design 2.5.2 Lid Closing Bar and Roller achieves a score of +7 therefore it is the proposed design.

2.6 Transport of Box to Pick Up

The pickup location will be at the end of the conveyor belt.

3. SYSTEM CONTROL

The machine will be controlled by a Microchip PIC18F4620 microcontroller, which will be programmed using the C language. This high-end microcontroller is chosen due to features such as its low power consumption, C compiler optimized architecture, the extended instruction set, the three programmable external interrupts and the enhanced Capture/Compare/PWM module supporting four PWM outputs. In addition to these features, the unit price for the PIC18F4620 is cheaper than some PIC16 microcontrollers (including PIC16F877) at most retailers.

3.1 Main Program

The main program consists of four stages: Idle, Pre-Operating, Operating and Post-Operating.

3.1.1 IDLE STAGE

The program starts in the Idle stage, where the LCD will display an idle message, and the user would have the option to view the operation history stored in the EEPROM or to enter the Pre-Operating state.

3.1.2 PRE-OPERATING STAGE

During the Pre-Operating stage, the program will attempt to obtain and store the information necessary for operation. This includes the desired packaging pattern for each box, up to three boxes, which is obtained from the user through the user interface. The program will then calculate the number of dowels of each color required to complete the operation, and compare this to the number of dowels loaded into the reservoir. The dowel count in the reservoir is obtained from the microswitch embedded near the entrance, which increments a counter every time a dowel enters. This means that it will only be accurate if the dowels are loaded when the PIC is active. If there are enough dowels, the user will be prompted to confirm the information they entered and start the operation. If there is an error in the information entered, the LCD will display an error message and the user will be returned to the beginning of the Pre-Operating stage.

3.1.3 OPERATING MODE

Upon the user's command, the program will enter the Operating mode. The conveyor belt and box loading motors will start at this time and run continuously until the operation is halted. Upon a signal from the microswitch on the conveyor belt, the two solenoids in the dispensing mechanism will dispense dowels at regular intervals, dictated by time delays. This process will continue until all boxes are completely packed or the operation is halted by the Emergency Stop. During the operation, the program will also keep track of the number of boxed packed, the number of dowels dispensed, and operation time (using Timer1).

3.1.4 POST-OPERATING STAGE

When all the boxes are completely packed, the program will enter the Post-Operating stage. At this stage, all moving parts will be disabled. The LCD will display the following information: the packing pattern for each box, the operation time and the number of dowels remaining. The program will finally return to the idle stage. A schematic of the main program is provided below in Figure 3.1.

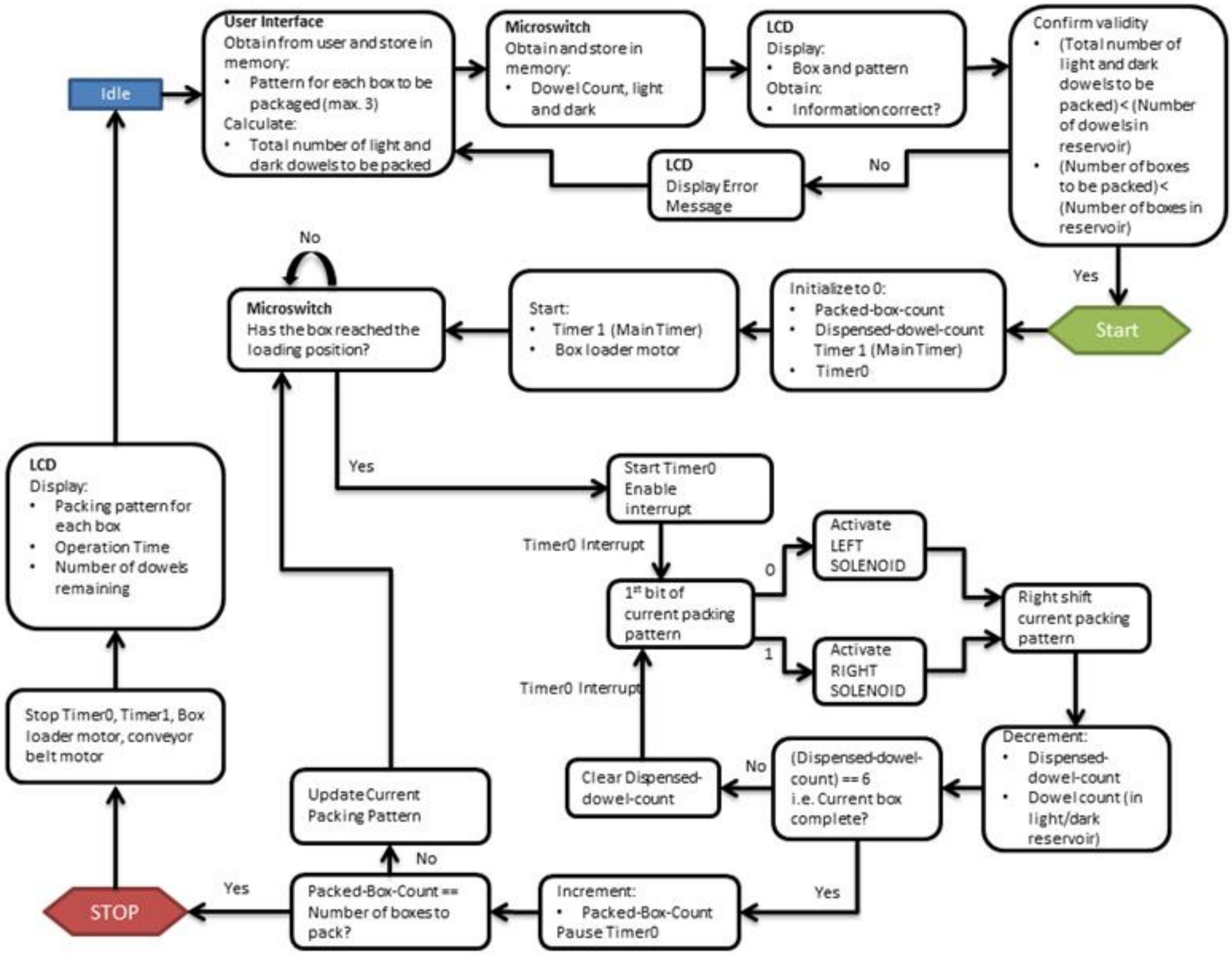


Figure 3.1: Flowchart of the main program.

3.2 User Interface

The machine's user interface plays a major role in fulfilling the objective of user-friendliness. The UI should be self-explanatory and provide simple and clear instructions for users of various skill levels. The information gathered from the user interface will be stored in the EEPROM for use during the operation. The selections can also be edited by the user. Furthermore, the user interface would have configuration and debugging tools to allow the user to calibrate and troubleshoot the machine on the fly. The following schematic outlines the user interface algorithm.

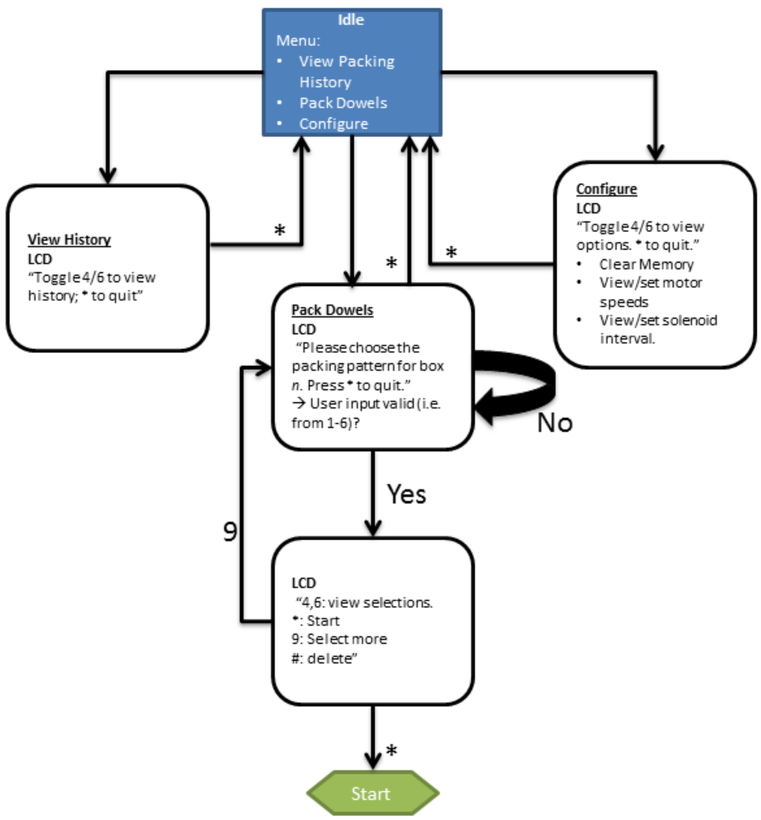


Figure 3.2: Flowchart of the User Interface menus.

3.3 External Modules

The PIC microcontroller will connect to the following external modules:

- HD44780 based LCD
- 4x4 keypad with MM74C922N

- DC Motor (Box Loader)
- DC Motor (Conveyor Belt)
- Two Solenoids (Left and right reservoirs)
- 2 Microswitches (Left and right reservoirs)
- Microswitch (Conveyor belt)
- Emergency Stop Switch

The HD44780 based LCD is a main hardware component of the user interface. Since the HD44780 protocol supports both 8-bit and 4-bit data transfer modes, it will be configured to use the 4-bit mode in the interest of conserving pins. The 4x4 keypad is another key hardware component of the user interface. A MM74C922 hex encoder will be used to simplify the polling process and to conserve pins. The two motors will be connected to the CCP1 and CCP2 pins to take advantage of the PWM function. The two microswitches in the reservoirs will effectively function as counters, thus will be connected to RB2 and RB3, which can be configured to detect external interrupts. The microswitch attached to the conveyor belt detects when a box has arrived in the loading position and when it leaves the loading position. This will be done by polling the input pin. The Emergency Stop Switch will be connected to RB0, which will generate an interrupt upon the positive edge, at which time the Emergency Stop ISR will be initiated. The pin assignment of the external modules are as follows:

Module	**PIC I/O Pin**	**Module**	**PIC I/O Pin**	**Module**	**PIC I/O Pin**
HD44780 (LCD)		**Solenoid (Left reservoir)**	RD1	**MM74C922N (4x4 Keypad)**	
RS	RD2	**Solenoid (Right reservoir)**	RD0	Data Out A	RB4
R/W	GND	**Microswitch (Left reservoir)**	RB2	Data Out B	RB5
E	RD3	**Microswitch (Right reservoir)**	RB3	Data Out C	RB6

Module	PIC I/O Pin	Module	PIC I/O Pin	Module	PIC I/O Pin
D4	RD4	**Microswitch (Conveyor Belt)**	RC4	Data Out D	RB7
D3	RD5	**Emergency Stop Switch**	RB0	Data Available	RB1
D2	RD6	**DC Motor (Box Loader)**		**DC Motor (Conveyor Belt)**	
D1	RD7	IN1	RC1/CCP2	IN1	RC2/CCP1
		IN2	RC3	IN2	RC4

3.4 Emergency Stop ISR

In order to ensure the safety of the user(s), a mandatory component of the design is the Emergency Stop, which stops all moving parts when enabled. During this time, the machine should still being able to communicate with the user, and return to the operation once the user clears the emergency. The following schematic shows the algorithm for the Emergency Stop interrupt.

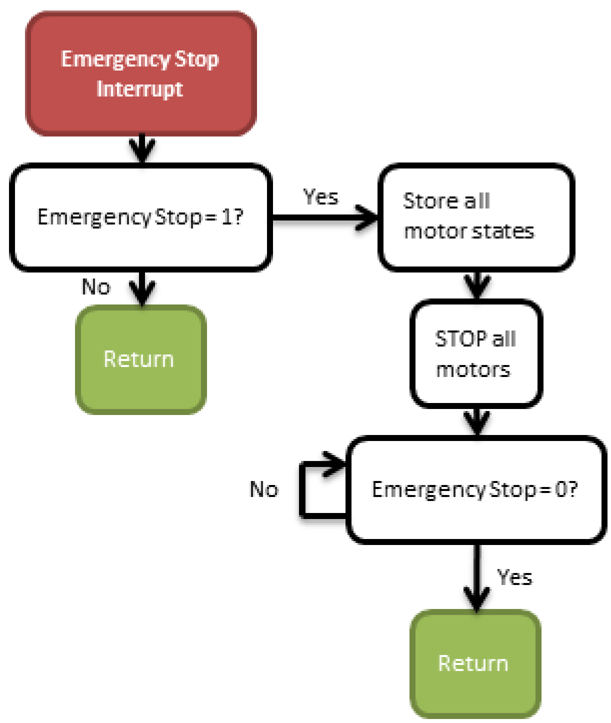


Figure 3.2.4: Emergency Stop ISR Flowchart

4. MOTOR SELECTION

Motor Selection:	Required Torque (Nm):	n - gear ratio:	Motor Selected (Digikey Part Number):	Technical Specifications:
Conveyor Belt:	0.0044	3	P14348-ND	DC Brush Motor
Pulley System:	0.088	20	P14348-ND	12 V 2922RPM

To calculate the required torque for the conveyor belt, the weight of the dowels and belt were calculated and divided by 8, since there are 8 dowels bearing the total load. The force required to move the conveyor belt was 0.35 N. To find torque, this load was multiplied by 1.27 cm, the radius of one of the dowels. The gear ratio was then calculated by $n = T_o/T_i$ where T_i is the input torque, from the motor, and T_o is the output required torque [3]. T_i was obtained as the running torque values of various DC Brush motors from Digikey. The motor which yielded the smallest gear ratio was selected.

For the pulley system, a similar approach was taken. The calculated load of the pulley was 9.22N. The radius of the shaft around which the cable wraps, 0.3175 cm, was used to calculate torque.

5. CIRCUIT DESIGN

The circuits were designed with modularity in mind. As such, each motor part will have its own control board which interfaces the motor with the power supply and the microcontroller. Each controller board will be linked to the microcontroller board which will handle the operation of all motors and sensors.

5.1 General Design

The system will be powered using a 500W computer power supply. A computer power supply was chosen as it converts and regulates AC power to DC power without the need for external circuits. It also provides overvoltage and short-circuit protection [6]. The power supply's 24-pin header will be linked to the main board which will feed power to each section via independent 12V, 5V and 3.3V connections. Signals to and from the PIC microcontroller will be linked to the power lines and delivered to the separate components via a 4-pin bus, carrying +12V and ground from the power supply, and up to 2 signal pins from the microcontroller. This method allows for a high level of modularity as parts can easily be attached or detached from the main board without any de-soldering. Furthermore, since the connector is asymmetrical, connections can only be made in one direction, further reducing the chance of an incorrect connection. See Figure 5.1 for more detail.

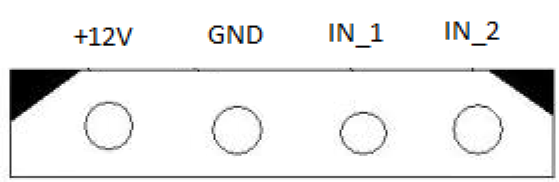


Figure 5.1: Sample configuration of the 4-pin bus. The design allows for up to 2 communication pins with the PIC microcontroller.

5.2 Emergency Stop

The emergency stop switch will be controlled using a Darlington transistor array. When the base is supplied by a 5V voltage (i.e. the emergency switch is closed or off), the transistor will let the control signal from the microcontroller to communicate with the components. When the emergency switch is activated, all of the control signals will be terminated and the PIC will receive a low signal on the emergency stop pin. This will allow the microcontroller to communicate with the user in the event it is triggered. See figure 5.2 for more detail.

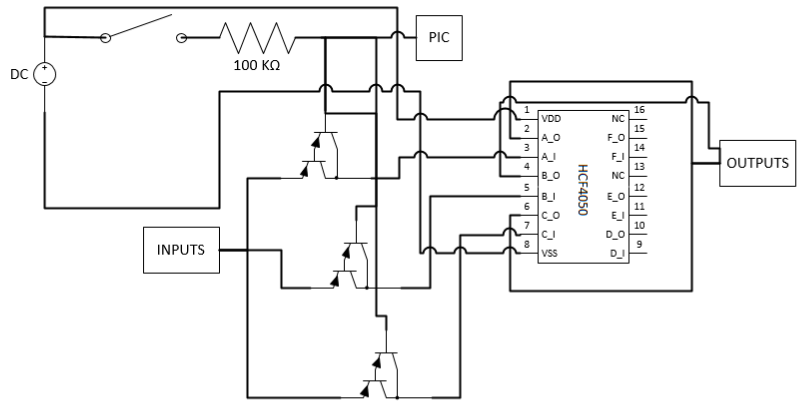


Figure 5.2: Sample configuration of the emergency stop circuit. Note that a HCF4050 buffer is added to shield the microcontroller from the driver circuits. When the switch is on, the transistors will allow the signal from the microcontroller to pass, otherwise it will not, stopping all of the motors instantly.

5.3 Motor Control

The motors will be controlled on a separate circuit from the microcontroller using a SN754410 H-Bridge IC. It will receive a pulse-width modulation (PWM) signal and a direction signal from the microcontroller. An inverter will ensure that pin 3 and 7 will always receive opposite signals, required for the proper operation of the motor. Two of these circuits will be built, one for the pulley lift and the other for the conveyor belt. See Figure 5.3 for more detail.

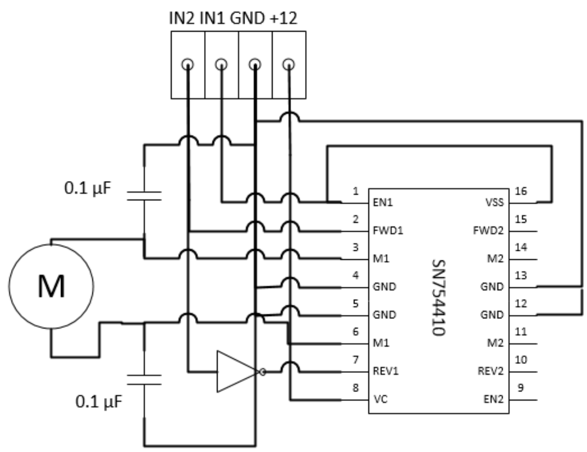


Figure 5.3: Motor driver circuit. A PWM signal will be connected to pin 1 and the direction signal to pin 3 and 7

5.4 Solenoid Control

Similar to the motor control circuit, the solenoid control circuit will be separate from the microcontroller. Since solenoids only require a single input and due to the proximity of the solenoids in this design, a single circuit will be used to drive both solenoids. See Figure 5.4 for more detail.

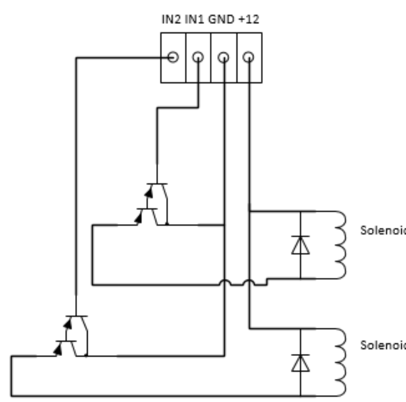


Figure 5.4: Solenoid control circuit.

5.5 Micro-switch Sensors

Similar to the rest of the circuit, the microswitches will be on individual circuits. Instead of receiving a signal from the microcontroller, it will send 5V for no contact and 0V for contact. See Figure 5.5 for more detail.

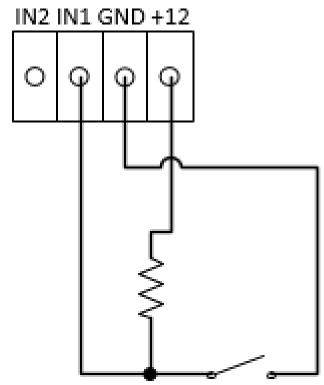
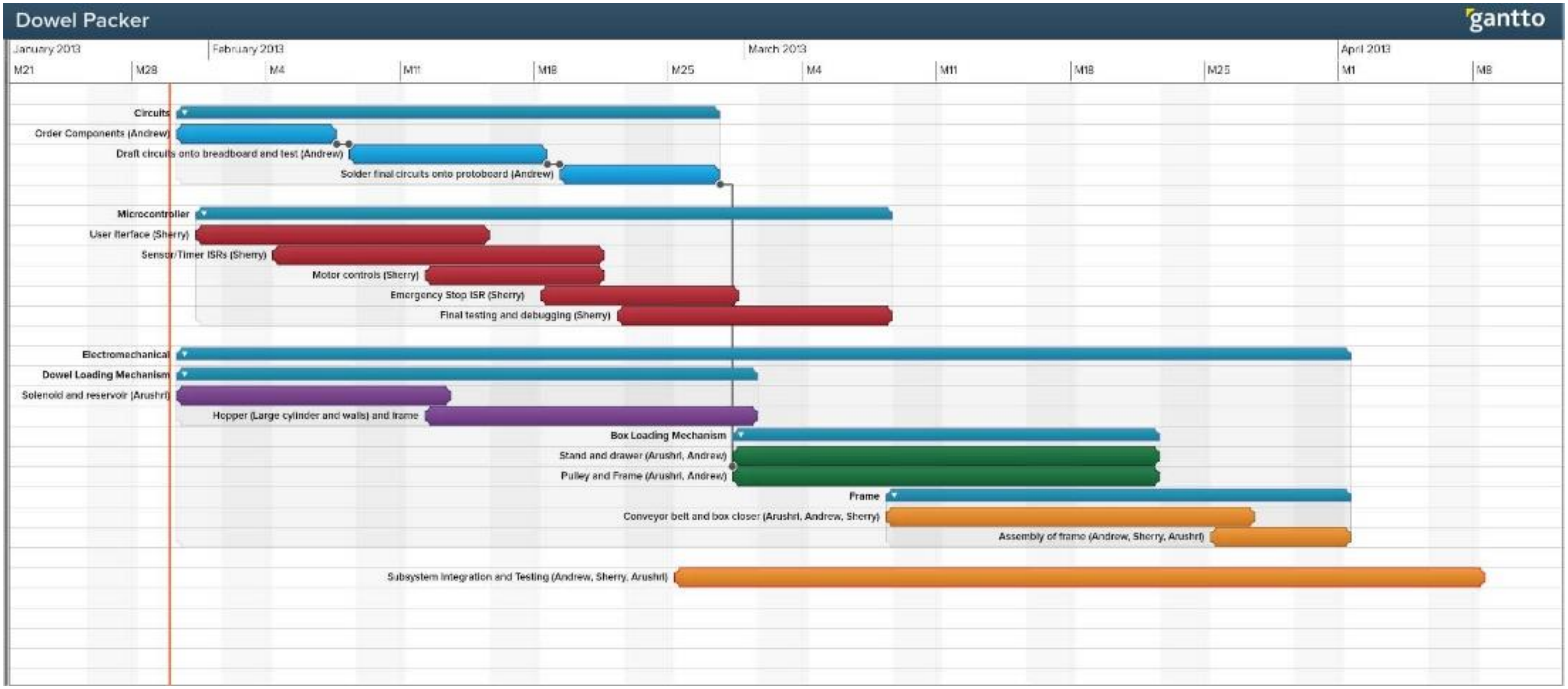


Figure 5.5: Sample microswitch circuit. Note that IN1 are configured as an output to the microcontroller.

6 PROJECT MANAGEMENT

Arushri, our electromechanical member, will be responsible for the construction of the machine itself. The circuits will be built by Andrew, and the microcontroller programmed by Sherry. Since the construction of the machine will take a significant amount of time, Andrew and Sherry will both assist Arushri when each of their subsystems are complete. See section 6.1 for the Gant chart.

6.1 Gant Chart



7 BUDGETING

System:	Part	Material	Dimensions (cm)	Total dimension Needed	Cost ($)	Mass (g)	Supplier	Reference
Box Loading Elevator	Shaft	Alexandria Moulding Hardwood Dowel 1/4 X 48 Blue	5	5 cm	0.028	0.6	Home Depot	http://www.homedepot.ca/product/hardwood-dowel-1-4-x-48-blue/904295
	Gear System		d = 1 , d = 20		1	10	Active Surplus	http://www.activesurplus.ca/en/
	Motor	P14348 DC Brush 12 V motor			7.36	52.26	Digikey	http://www.digikey.ca/product-search/en?x=0&y=0&lang=en&site=ca&KeyWords=P14348-ND
	Pulley	KingChain 3/4 inches Swivel Eye Pulley 2-Cd			1.75	79.4	Home Depot	http://www.homedepot.ca/product/3-4-inches-swivel-eye-pulley-2-cd/984000
	Frame	1x2x8 Framing Lumber	1.905 X 3.81 X 243.84	40 cm	0.17	185.4	Home Depot	http://www.homedepot.ca/product/1x2x8-framing-lumber/954340
	Cable	Select Sisal Twine	100	100 cm	0.04	2.4	Home Depot	http://www.homedepot.ca/product/select-sisal-twine-300-ft-roll/908992
	Sliding Mechanism	Richelieu Euro standard slide 300mm / 12 In.			3.59	0.35	Home Depot	http://www.homedepot.ca/product/euro-standard-slide-300mm-12-in/901991
	Outer Stand	Moulding & Millwork Standard Hardboard 1/8 x 4 x 8	2(5 X 35 X 0.635) + 30 X 5 X 0.635	500 cm^2	0.15	170	Home Depot	http://www.homedepot.ca/product/standard-hardboard-1-8-x-4-x-8/941382
	Inner Container	Moulding & Millwork Standard Hardboard 1/8 x 4 x 8	2(25 X 22 X 0.635) + 22 X 22 X 0.635	1584 cm^2	0.46	538.6	Home Depot	http://www.homedepot.ca/product/non-glare-polystyrene-sheet-050-inch-x-11-inch-x-14-inch/924853
	Wedge (Corrugated Cardboard)	Pratt Retail Specialties, LLC Small Moving Box	25 X 22	550 cm^2	0.11	55	Home Depot	http://www.homedepot.ca/product/small-moving-box/924025
Conveyor Belt	Wooden Dowels	Alexandria Moulding Hardwood Dowel 1 X 72 Natural	d = 2.54, l = 19	152 cm for 8 dowels	6.49	261	Home Depot	http://www.homedepot.ca/product/hardwood-dowel-1-x-72-natural/904289
	Rubber Belt	BP Standard Dry Sheathing	19 X 138	420 cm^2	0.02	9.24	Home Depot	http://www.homedepot.ca/product/standard-dry-sheathing/917430

	Shafts	Alexandria Moulding Hardwood Dowel 1/4 X 48 Blue	d = 0.635, l = 10 cm	160 cm	0.88	19.2	Home Depot	http://www.homedepot.ca/product/hardwood-dowel-1-4-x-48-blue/904295
	Gear System		d = 2 cm, d = 6 cm		1	10	Active Surplus	http://www.activesurplus.ca/en/
	Motor	P14348 DC Brush 12 V motor			7.36	52.26	Digikey	http://www.digikey.ca/product-search/en?x=0&y=0&lang=en&site=ca&KeyWords=P14348-ND
	Frame	1x2x8 Framing Lumber	1.905 X 3.81 X 27	27 cm	0.11	125	Home Depot	http://www.homedepot.ca/product/1x2x8-framing-lumber/954340
Dowel Dispenser	Rod for Frame	Alexandria Moulding Hardwood Dowel 1/4 X 48 Blue	2(d = 0.635, l = 45)	90 cm	0.5	10.8	Home Depot	http://www.homedepot.ca/product/hardwood-dowel-1-4-x-48-blue/904295
	Frame	1x2x8 Framing Lumber	4(1.905 X 3.81 X 22)	88 cm	0.36	407.6	Home Depot	http://www.homedepot.ca/product/1x2x8-framing-lumber/954340
	Dowel-Pushing Bar	1x2x8 Framing Lumber	1.905 X 3.81 X 14	14 cm	0.06	64.8	Home Depot	
	Reservoir Separator	Moulding & Millwork Standard Hardboard 1/8 x 4 x 8	3.25 X 14 X 0.635	45.5 cm^2	0.01	15.5	Home Depot	http://www.homedepot.ca/product/non-glare-polystyrene-sheet-050-inch-x-11-inch-x-14-inch/924853
	Reservoir Walls	Plaskolite Non Glare Polystyrene Sheet - .050 Inch x 11 Inch x 14 Inch	2(26 X 14 X 0.635)	728 cm^2	4.31	99.7	Home Depot	
	Container	Moulding & Millwork Standard Hardboard 1/8 x 4 x 8	4(16 X 14 X 0.635) + 2(12 X 14 X 0.635) + 4(12 X 16 X 0.635)	2000 cm^2	0.58	680	Home Depot	
	Cylinder	IPEX ABS PIPE 4 inches x 6 ft CELL CORE	d = 11.5, l = 14 cm	14 cm	2.88	239.6	Home Depot	http://www.homedepot.ca/product/abs-pipe-4-inches-x-6-ft-cell-core/924332
	Solenoid	Solenoid with Spring/Frame	13.5 X 2.5 X 2	67.5 cm^3	10	131	Design Store	*Multidisciplinary Engineering Design from theory to practice M. Reza Emami 2013 Edition*
	Flap	Thin Plastic Sheet	12 X 14	168 cm^2	1	5	Dollarama	
	Closing Bar	1x2x8 Framing Lumber	2(1.905X 3.81 X 12)	24 cm	0.1	111.2	Home Depot	http://www.homedepot.ca/product/1x2x8-framing-lumber/954340
Closing Mechanism	Roller	Wooden Dowel (Provided)	d = 2.55, l = 10.5	10.5 cm	0.63	25.5	Design Store	*Multidisciplinary Engineering Design from theory to practice M. Reza Emami 2013 Edition*

	Lid-Shutting bar	Alexandria Moulding Hardwood Dowel 1/4 X 48 Blue	d = 0.635, l = 30	30 cm	0.17	3.6	Home Depot	http://www.homedepot.ca/product/hardwood-dowel-1-4-x-48-blue/904295
Frame	Wooden Frame	1x2x8 Framing Lumber	1.905 X 3.81 X 454	454 cm^2	1.91	2102	Home Depot	http://www.homedepot.ca/product/1x2x8-framing-lumber/954340
Electrical Components	**Component:**	**Quantity**	**Unit Price ($)**				**Supplier**	
Microcontroller and Associated Parts:								
	MM74C922N Hex Inverter	1	8		8		Digikey	
	Microchip PIC18F4620	1	5.21		5.21			
	PIC Simple Configuration Board	1	15		15			
	LCD+Keypad with encoder chip	1	6		6		Design Store	
	Real-Time clock and battery	1	5		5			
Diodes, Transistors, Resisters, Op-Amps, LEDS:					0			
	Resistors	10	0.1		1			
	Capacitors	4	0.04		0.16			
	Microswitch with lever	4	0.56		2.24			
	HCF4050 Buffer	1	0.56		0.56			
	1N4001 Power Diode	4	0.12		0.48			
	TIP 147 Transistor	4	1.17		4.68			
	ULN2001 Transistor array	1	0.61		0.61		Digikey	
	PIC controller surface mount AE10008-ND	1	0.55		0.55			
	74HC14 Hex Schmitt Inverter	2	0.56		1.12			
	14 pin DIP surface mount	1	0.24		0.24			
	16 pin DIP Surface mount	1	0.39		0.39			

	Perforated prototype board	1	2.65		2.65			
	SN754410 Motor Driver	2	2.5		5			
Power Distribution Connectors					0			
	Coolmax I-500 Power Supply	1	12.99		12.99		Tiger Direct	
	Cables-to-Go 4-pin Power extension cable	6	0.99		5.94			
	WM3811-ND	1	3.17		3.17		Digikey	
Total Weight of Electronic Components						500		
Total					134.018	5967.01		

8. CONCLUSION

The proposed design will complete the task required in the RFP of loading a box with dowels according to a predetermined pattern. This will be accomplished by mounting an empty box onto a continuous conveyor belt which transports it to a dowel-loader. Once fully loaded it closes the latch and delivers the packed box to the pick-up location. The electromechanical components will be controlled by a PIC microcontroller.

The proposed design meets the outlined objectives: speed, reliability, user-friendliness and cost-efficiency. To excel in these objectives, further prototyping and testing will have to be performed thus some minor changes may be required. The most significant problem that may arise during the synthesis of the design include: timing of the actuators and calibration of the sensors to ensure that the dowels are loaded properly. This factor will have to be thoroughly tested and refined. Further problems include exceeding the weight estimate and the reliability of the lid-closing mechanism. However, the team is confident that this design will be successful and any problems will be overcome.

APPENDIX A - REFERENCES

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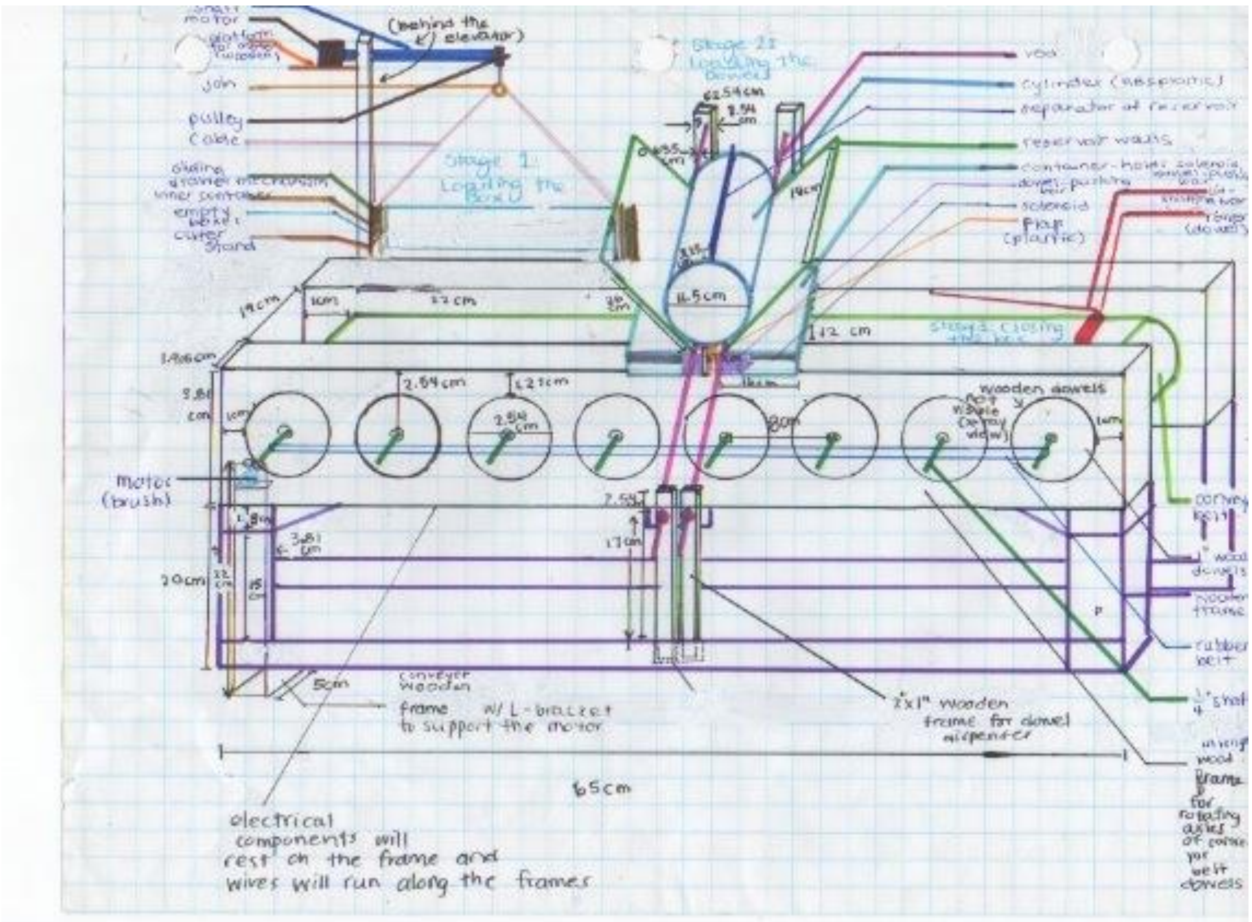
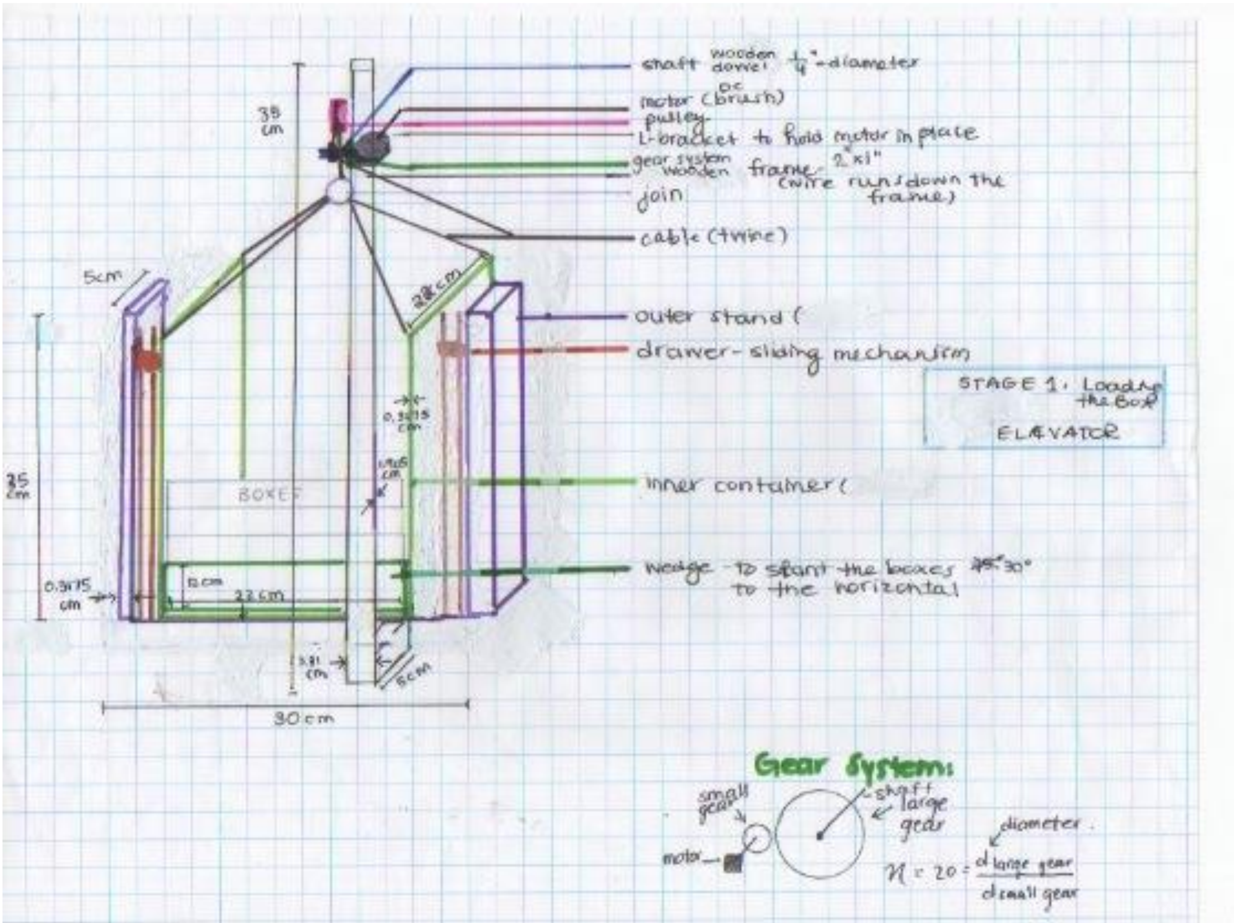
APPENDIX B

B-1: Sketch of the Conceptual Design of the Dowel Packing Machine

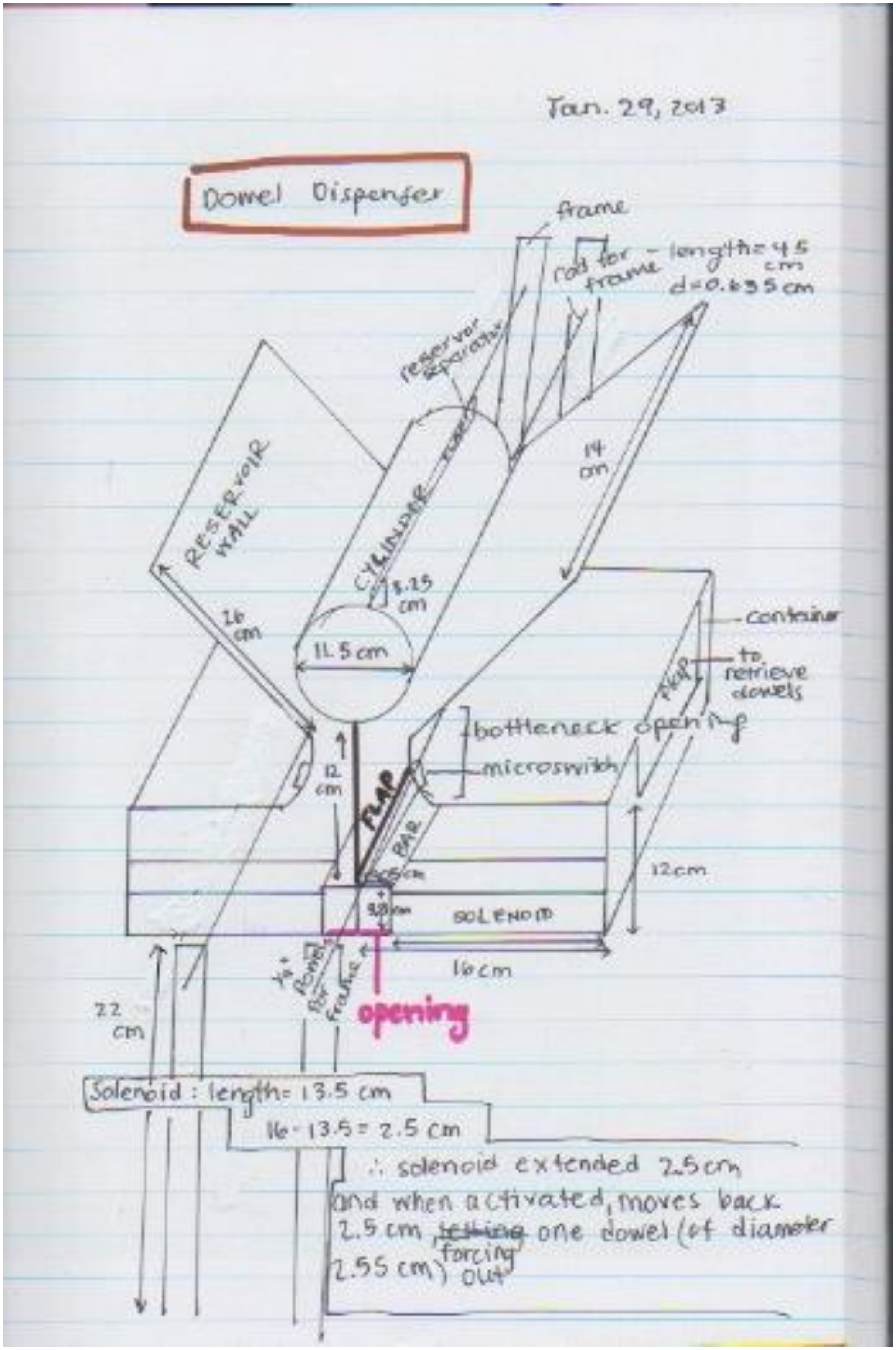
For material cost and weight analysis, refer to section 7.0.



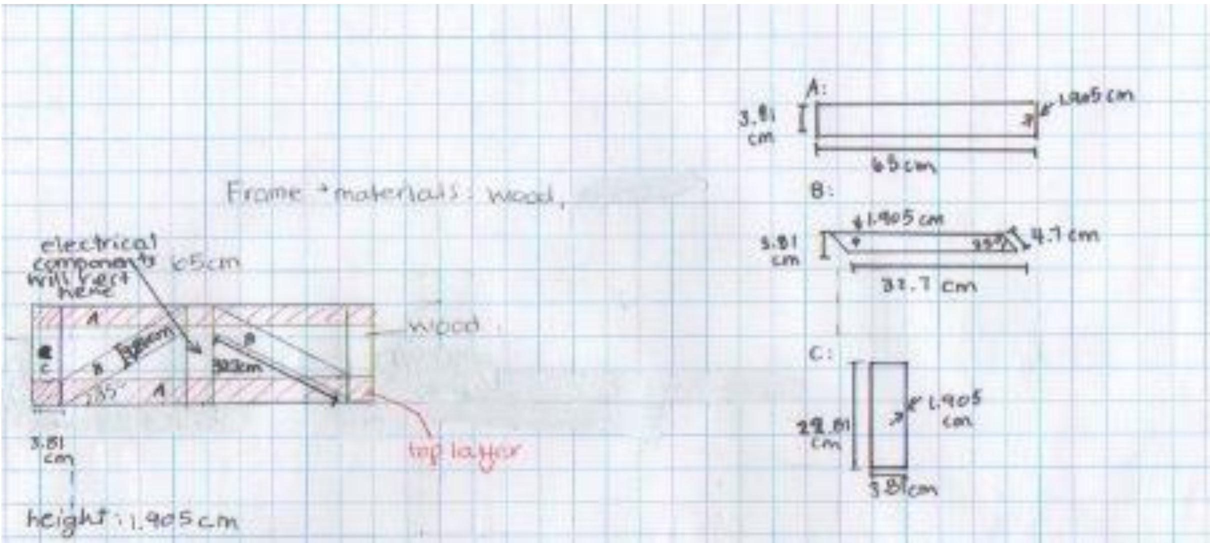
B-2: Diagram of Box Loading Elevator



B-3: Dowel Dispenser



B-4: Frame located underneath the conveyor belt.



Note: these diagrams are not to scale.

APPENDIX C – DATASHEETS

Request for Proposal #3

The Dowel-packer Machine

Need

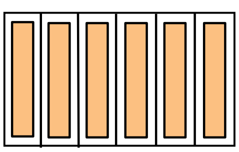
A utility company needs to package two colours of wood dowels in organizer boxes in various mixed combinations.

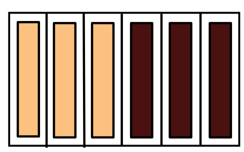
Goal

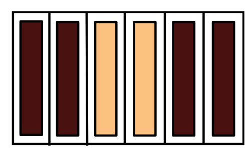
Design and manufacture the proof-of-concept prototype of a machine that can package light and dark wood dowels in organizer boxes in a variety of combinations reliably and quickly, according to the operator's keyed-in requests.

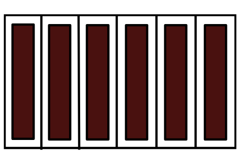
Specifications

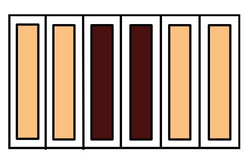
The machine is expected to package 2 boxes, in each 6 wood dowels, in no longer than 2 minutes. Each dowel is cylindrical with a diameter of $25.5^{\pm 0.5}$mm, a height of $105^{\pm 2}$mm and a weight of $25^{\pm 2}$g. The dowels are to be supplied in no particular format into two separate reservoirs in the machine, one for light and one for dark dowels. A maximum number of 12 dowels may be supplied to each reservoir, but their exact number is not known *a priori*. The boxes are made of frosted plastic with a hinged cover with a latch in the middle that snaps when it is closed. The overall dimensions of each box are $209^{\pm 2}$mm (length) by $121^{\pm 2}$mm (width) by $35^{\pm 2}$mm (height). There are 6 compartments in the box, each with the dimensions of $115^{\pm 2}$mm by $32^{\pm 2}$mm by $30^{\pm 2}$mm. The weight of each empty box is $115^{\pm 5}$g. Samples of boxes and dowels are available from the client for a closer examination. A minimum number of 3 boxes should be supplied to the machine for each operation. Methods of loading and delivering dowels and boxes are up to the design, but must be convenient for the operator (e.g., easily accessible and no need for disassembling any parts.) In each box, a combination of light and dark dowels must be placed in the compartments in a pattern specified by the operator through a keypad in the beginning of the operation. Possible patterns are shown below, and there will be two different patterns for the two boxes to be packaged in each operation.

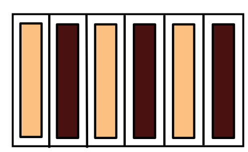
Pattern #1:


Pattern #3:


Pattern #5:


Pattern #2:


Pattern #4:


Pattern #6:


After placing all the dowels in each box, it must be placed in the pickup location/bin with its cover completely closed (snapped). After each operation, the machine is expected to return to the standby mode, display a completion or termination message on the LCD, and be ready to communicate with the operator the operation information. Also, all the remaining dowels must be returned in their reservoir after each operation. The information to be retrieved from the machine after each operation shall include: operation time, number of dowels remaining in each reservoir, and the packaging pattern for each box. The machine shall accept operator's instructions for packaging options through a keypad. The menus displayed on the LCD must be self-explanatory and provide easy navigation for operators of various skill levels. The client requires that the machine be portable with no need for installations, and as such there are constraints on weight and dimensions. Also for safety purposes the machine must have an easily-accessible emergency STOP switch that stops all the mechanical moving parts immediately. The machine can be plugged into the AC outlet.

Operation

The machine is normally in the standby mode. After loading the dowels and boxes, the operator enters on a keypad the instructions about the packaging patterns, and then starts the operation by pressing a <*start*> button on the keypad. The entire packaging process must be done autonomously, and must take no longer than 2 minutes. Upon completion of the operation, all the remaining dowels must be returned in their reservoir, and packed boxes be placed in the pickup area/bin. Then, the machine returns to the standby mode by displaying a completion or termination message on the display. The operator can then communicate with the machine through the keypad and display to retrieve the operation information.

Machine performance will be evaluated depending on the operation time, the quality of packaging (dowels placed properly, covers closed), and the accuracy of the retrieved information, as detailed in the sequel.

Performance Evaluation

The prototype will run two separate but consecutive operations, and the total time, quality, and accuracy of these operations are measured. Reward and Penalty points will be given to the prototype performance according to the following scheme. Each operation is qualified for scoring if the machine delivers at least one packed and closed box (with minimum 5 dowels in it, even if not placed or sorted correctly) to the pickup location/bin within 2 minutes, returns to the standby mode by displaying the completion or termination message at the end of its operation, and prompts for the packaging information.

➢ Each qualified operation	+1000
➢ Each delivered box “packaged correctly”	+500 / box
➢ Each delivered box “closed completely	+500 / box
➢ Missing dowel in the boxes	-300 / dowel
➢ “Damaged” dowel	-500 / dowel
➢ Dowel placed in the correct compartment	+200 / dowel
➢ Box not delivered to the pickup location/bin	-300 / box
➢ Remaining dowels not returned to their reservoir at the end of operation	-500 / reservoir
➢ The recorded pattern for the box shown on the display is incorrect	-200 / box
➢ The displayed number of remaining dowels in each reservoir shown on the display is incorrect	-500 / reservoir
➢ The operation time recorded on the display is “incorrect”	-500
➢ Time penalty:	- 10 per second of operation
➢ Each disqualified operation	0

Bonus Points for Extra Features:

➢ Robustness and Durability	0 to +300
➢ Operability and Sustainability	0 to +300

➢ Elegance and Safety	0 to +300
➢ Extendibility	0 to +300
➢ Dexterity	0 to +600
➢ Compactness and Portability	+500
➢ Real-time Date/Time Display	+400
➢ Permanent Logs	+400
➢ PC Interface	+300

Constraints

a. The entire prototype, excluding the packed boxes, pickup bin, and extended cable to the AC plug, shall completely fit within a 75×75×75 cm^3 envelope at all operation times.
b. The weight of the machine (without the dowels and boxes) shall not exceed 6 kg.
c. The total prototype costs shall not exceed $230CDN.
d. The machine can be plugged in the AC, 110V-60Hz, 3-pin outlet or use its own on-board power supply during the operation.
e. The machine must have an easily-accessible emergency STOP switch that stops all the mechanical moving parts immediately.
f. The machine must be fully autonomous, and no interaction with an external PC or remote control is permitted during the operation. The operation must start by pressing a <*start*> button on the keypad.
g. No installation or instrumentation is allowed in addition to what is devised within the machine.
h. The locations for supplying dowels and boxes and also the pickup location/bin must be specified in the machine clearly.
i. Dispensing the packed boxes and retrieving the returning dowels must be easy with no need for disassembling any parts of the machine.
j. At the end of each run, the machine display must be on prompt to show the following information per operator's request: operation time, number of dowels remaining in each reservoir, and the packaging pattern for each box.
k. The machine user interface for both operation and information retrieval shall be self-explanatory, and provide easy navigation for operators of various skill levels.
l. Each box is "packaged correctly" if all dowels are placed according to the operator's selected pattern for the particular box.
m. Each box is "closed completely" only if the cover is completely closed and the latch is snapped.
n. Each box or dowel (in the box, reservoir or machine) is considered as "damaged" if there are clear defects as a result of the operation, to the referee's discretion.
o. The operation time is the duration between when the <*start*> button on the keypad is pressed and when the termination/completion message is shown on the machine LCD. The operation time shall not exceed 2 minutes. Further, the time required for entering the operator's instructions on the keypad before the operation shall not exceed 1 minute.
p. The recorded operation time is considered "correct" if it is equal to the time measured by the referee ± 5%. Otherwise, it is assumed "incorrect."
q. The machine's response to the operator's inquiry about the packaging statistics is considered "correct" if it is according to the outcome of the performed operation, otherwise it is considered as "incorrect."
r. Each operation is "qualified" for scoring if the machine delivers at least one packed and closed box (with minimum 5 dowels in each, even if not placed or sorted correctly) to the pickup location/bin within 2 minutes, returns to the standby mode by displaying the completion or termination message at the end of its operation, and prompts for the packaging information.

s. Each operation is "disqualified" if the machine structurally collapses, falls over, or hangs or jams unpredictably (for more than 2 minutes) with no termination display, or damages a box, or terminates the operation before delivering at least one packed and closed box (with minimum 5 dowels in each, even if not placed or sorted correctly) to the pickup location/bin, or does not display termination/completion message on the LCD at the end of operation, or the team declares the termination. If any of the above happens to the first run, the team will have 3 minutes to fix the system and run for the second time, should they wish.

t. Each team will have a period of maximum 2 minutes to set up the machine before each run. If the preparation time exceeds 2 minutes, the run will be "disqualified."

u. There will be no control on the conditions of the contest environment.

v. The machine must pose no hazard to the operator, and shall not be perceived as hazardous (e.g., too much vibration or noise or frequent sparks during the operation is perceived as dangerous.)

Extra Design Features

The following features would enhance the machine performance, and increase the Bonus Points:

- **Robustness and Durability:** Machine is durably constructed and functions consistently with a small failure frequency and under different conditions of the operation environment.
- **Operability and Sustainability:** Little time/effort is needed to set up and calibrate the machine, and the machine is modular so that parts can be replaced or repaired easily.
- **Elegance and Safety:** Machine looks elegant, and operates quietly and smoothly with little or no sensible noise or vibration.
- **Extendibility:** Machine can accept dowels and boxes of different sizes and can package more than 3 boxes in each operation with little or no need for modifications.
- **Dexterity:** Machine can perform extra functions, such as labeling, box stacking, etc.
- **Compactness and Portability:** The entire prototype weighs not more than half of the maximum permitted weight and fits within a cubic envelope whose side is 75% of that of the maximum allowed envelope.
- **Real-time Date/Time Display:** Date and time of each inspection are displayed on the LCD in standby mode.
- **Permanent Logs:** Machine stores log information in permanent (EEPROM) memory.
- **PC Interface:** The operation information can be readily downloaded on a PC.

Expected Outcomes

Design and Construction Process: The team must follow a logical and systematic process in accomplishing their tasks of design, analysis, and construction. Conceptual design and system analysis are important steps of this project where the team has to compromise speed, accuracy, reliability, and cost. The detailed process must be reflected in the final report submitted by the team.

Proposal: Each team must work together to generate a proposal documentation on the design. The design proposal should reflect the conceptual design phase, team and project management with the scheduling, the steps to be taken for the detailed design and prototype fabrication, and the methods of manufacturing, integration and debugging to be followed in building the prototype.

Final Report: The final report details the entire process of detail-design, analysis, fabrication, and evaluation.

Final Prototype**:** The final prototype developed by the team should reflect the work presented in the proposal. Any major or significant change in the design of the prototype after submitting the proposal must be agreed upon by the client and justified in the final report. The quality of the prototype may vary widely depending on the background of the team, the difficulty of the concept, and other limitations. Many of the deficiencies of these prototypes can be resolved later in the students' academic career.

Team Dynamics: The team must propose a solution and the plan in the proposal, and remain *loyal* to the proposal during the entire process. Hence, a close interaction between members of the team is required initially to be able to "*plan ahead.*" Early team dynamics may be strained, but interaction increases as the construction and integration of the machine proceed. Maximum team interaction occurs during the system integration, test and demonstration. The instructor will enhance the team dynamics by spending some time with the teams examining the progress. In many cases students remember this team experience (including their teammates) when they are seniors, or even when they are returning alumni. Professional and humane characteristics are expected in all team activities.

Grade evaluation will be heavily weighted to the generated design concepts, proposal, final report, and the way each individual/team has interacted and performed the tasks. Nevertheless, the final product and performance evaluation (competition) will remain as crucial portions in the overall grade.

Statement of Work

Each team is composed of three students. Conceptual design, system analysis, project planning, and system integration and debugging must be performed through a close interaction of all members of the team. However, for the sake of implementation, tasks can be broken into the following categories:

Processing and Control (Microcontroller)
One student shall program all the software for the system. In addition to combinatorial and sequential logic required for the operation algorithm, the keypad and display interface with the microcontroller is also part of this assignment. Some extra coding may also be needed for system debugging. Further utilization of the microcontroller may be needed if the team plans to accomplish some of the Extra Design Features, such as Real-time Date/Time Display, Permanent Logs, and PC Interface. For a low-power, high-end microcontroller, the assembly language would be the most efficient option for programming. Some cross-assemblers can translate C and/or Basic into machine code resulting in a less efficient and tractable code, to a degree that it may deteriorate system functionality. For the processing hardware, the use of the microcontroller board in the Project Kit is permitted if budget allows. Otherwise, the microcontroller student has the responsibility of assembling the microcontroller board. It is required that the microcontroller be functional for basic design features and programmable by the Reading Week, so that system integration and testing may begin right after the Reading Week. Often integration requires additional adjustments to the processor hardware and software. In addition, after the Reading week, the person responsible for the Microcontroller subsystem shall effectively assist the Electromechanical subsystem with duplication or fabrication of components and subassemblies. **The division of Electromechanical tasks among all members must be specified clearly in the project proposal.**

Mechanism and Actuation (Electromechanical)
One student shall be primarily responsible for constructing the structure and frames and incorporating whatever actuators and mechanisms are required in the machine. Nonetheless, after the Reading Week, the Microcontroller and Circuit members will join the Electromechanical member for completing the tasks, according to the plan specified in the proposal. Major subsystems of the Electromechanical category can include: frame and structure, dowel positioning and dispensing, and box closing mechanisms. In addition to design and analysis of these subsystems, their fabrication and/or assembly as well as assigning the locations of the sensors and boards are also parts of the Electromechanical category. Some off-the-shelf mechanisms or platforms can also be used for the above-mentioned subsystems, but this must be clearly addressed in the proposal and authorized by the instructor. Although integration of the entire system might seem as a “mechanical” task by nature, all members of the team should equally and effectively take part in the integration process.

Instrumentation and Interfacing (Circuit)

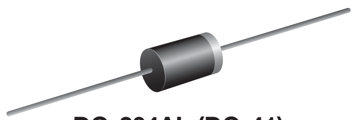
One student shall construct all the digital and analog interfacing electronics to connect the sensors and actuators to the microcontroller board. This includes motor/solenoid driver circuits. All sensors and input/output signal calibration/protection are also part of this category. In those situations where the primary calibration for a transducer is positional in nature, such as a stop switch, the task is still part of the Circuit subsystem, but consultation with the Electromechanical member is advised. For the actuator drivers, the use of driver board in the Project Kit or driver IC's is permitted if the budget allows, but the Circuit member must design and build at least one "open" circuit for a motor (DC or Stepper) in the system and prove their functionality. Dowel detection and position sensing (and possible shaft encoding) could be the major sensory tasks of this subsystem, in addition to the driver circuits and cabling. The Circuit member shall also acquire suitable power supplies for the actuators, circuits, sensors, and the microcontroller. Further, after the Reading Week, the person responsible for circuits shall effectively assist the Electromechanical subsystem with duplication or fabrication of components and subassemblies. **The division of Electromechanical tasks among all members must be specified clearly in the project proposal.**

Discussion

In this design, speed, accuracy, reliability, and cost are competing factors. Designers should first analyze the performance criteria to specify the level of acceptable compromise in each of the above factors. A variety of solutions can be proposed for transporting the dowels from the reservoir to the box, for counting the dowels, and for closing the covers. Hence, a careful analysis of the force and power required for each function is important.

Students might encounter problems with manufacturing the product. With limited experience in shop practices, final prototypes may not always work as anticipated. This can be frustrating to the students. As with any life experience, product fabrication will improve as the students gain maturity, not only in shop activities, but also in the engineering science background. The contest session provides a proof of the paper design. It also demonstrates to students that in real life the result does not always follow the prediction of theory. This is a good time to remind the students that ***"what we have to learn to do, we learn by doing."***

General Purpose Plastic Rectifier



DO-204AL (DO-41)

FEATURES

- Low forward voltage drop
- Low leakage current
- High forward surge capability
- Solder dip 275 °C max. 10 s, per JESD 22-B106
- Compliant to RoHS Directive 2002/95/EC and in accordance to WEEE 2002/96/EC

RoHS COMPLIANT

TYPICAL APPLICATIONS

For use in general purpose rectification of power supplies, inverters, converters and freewheeling diodes application.

Note

- These devices are not AEC-Q101 qualified.

MECHANICAL DATA

Case: DO-204AL, molded epoxy body
Molding compound meets UL 94 V-0 flammability rating
Base P/N-E3 - RoHS compliant, commercial grade

Terminals: Matte tin plated leads, solderable per J-STD-002 and JESD 22-B102
E3 suffix meets JESD 201 class 1A whisker test

Polarity: Color band denotes cathode end

PRIMARY CHARACTERISTICS	
$I_{F(AV)}$	1.0 A
V_{RRM}	50 V to 1000 V
I_{FSM} (8.3 ms sine-wave)	30 A
I_{FSM} (square wave t_p = 1 ms)	45 A
V_F	1.1 V
I_R	5.0 µA
T_J max.	150 °C

MAXIMUM RATINGS (T_A = 25 °C unless otherwise noted)

PARAMETER		SYMBOL	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	UNIT
Maximum repetitive peak reverse voltage		V_{RRM}	50	100	200	400	600	800	1000	V
Maximum RMS voltage		V_{RMS}	35	70	140	280	420	560	700	V
Maximum DC blocking voltage		V_{DC}	50	100	200	400	600	800	1000	V
Maximum average forward rectified current 0.375" (9.5 mm) lead length at T_A = 75 °C		$I_{F(AV)}$	1.0							A
Peak forward surge current 8.3 ms single half sine-wave superimposed on rated load		I_{FSM}	30							A
Non-repetitive peak forward surge current square waveform T_A = 25 °C (fig. 3)	t_p = 1 ms	I_{FSM}	45							A
	t_p = 2 ms		35							
	t_p = 5 ms		30							
Maximum full load reverse current, full cycle average 0.375" (9.5 mm) lead length T_L = 75 °C		$I_{R(AV)}$	30							µA
Rating for fusing (t < 8.3 ms)		I^2t (1)	3.7							A^2s
Operating junction and storage temperature range		T_J, T_{STG}	- 50 to + 150							°C

Note

(1) For device using on bridge rectifier appliaction

ELECTRICAL CHARACTERISTICS (T_A = 25 °C unless otherwise noted)											
PARAMETER	TEST CONDITIONS		SYMBOL	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	UNIT
Maximum instantaneous forward voltage	1.0 A		V_F	1.1							V
Maximum DC reverse current at rated DC blocking voltage		T_A = 25 °C	I_R	5.0							μA
		T_A = 125 °C		50							
Typical junction capacitance	4.0 V, 1 MHz		C_J	15							pF

THERMAL CHARACTERISTICS (T_A = 25 °C unless otherwise noted)									
PARAMETER	SYMBOL	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	UNIT
Typical thermal resistance	$R_{\theta JA}$ [1]	50							°C/W
	$R_{\theta JL}$ [1]	25							

Note

[1] Thermal resistance from junction to ambient at 0.375" (9.5 mm) lead length, PCB mounted

ORDERING INFORMATION (Example)				
PREFERRED P/N	UNIT WEIGHT (g)	PREFERRED PACKAGE CODE	BASE QUANTITY	DELIVERY MODE
1N4004-E3/54	0.33	54	5500	13" diameter paper tape and reel
1N4004-E3/73	0.33	73	3000	Ammo pack packaging

RATINGS AND CHARACTERISTICS CURVES

(T_A = 25 °C unless otherwise noted)

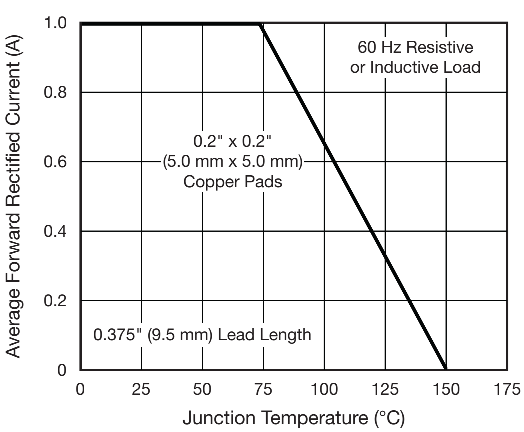


Fig. 1 - Forward Current Derating Curve

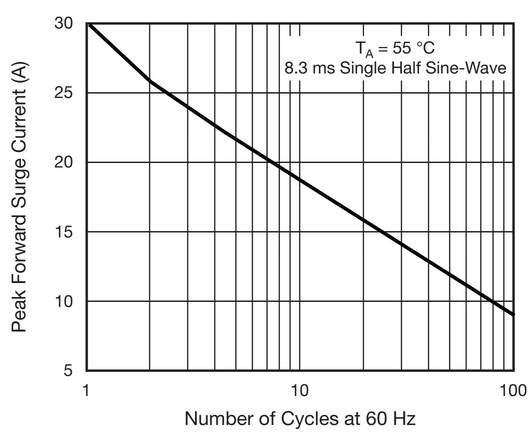


Fig. 2 - Maximum Non-repetitive Peak Forward Surge Current

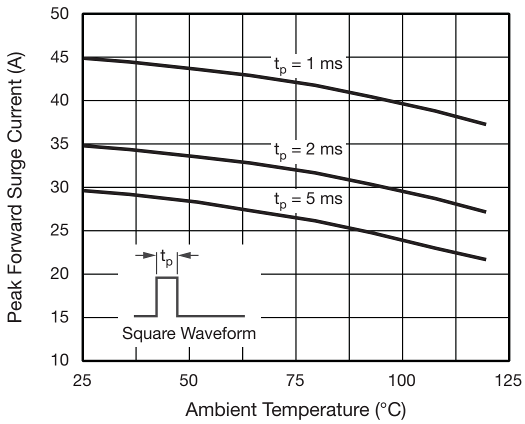


Fig. 3 - Non-Repetitive Peak Forward Surge Current

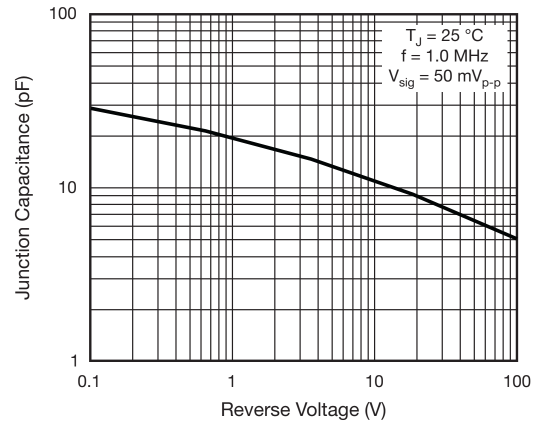


Fig. 6 - Typical Junction Capacitance

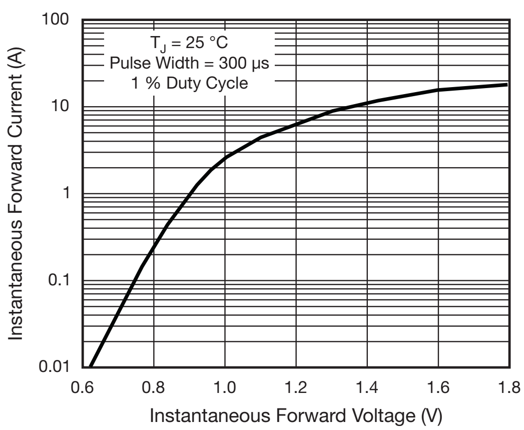


Fig. 4 - Typical Instantaneous Forward Characteristics

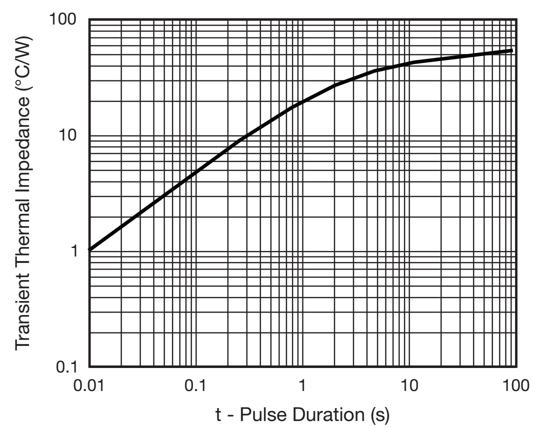


Fig. 7 - Typical Transient Thermal Impedance

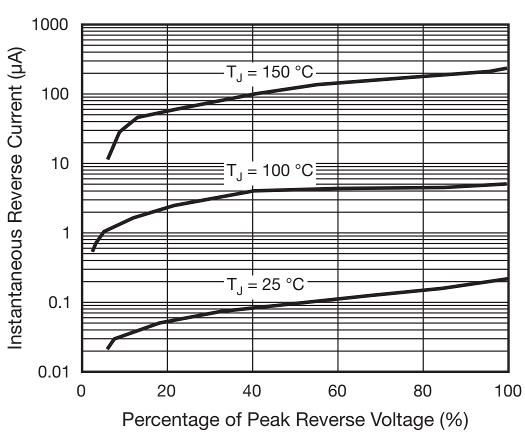
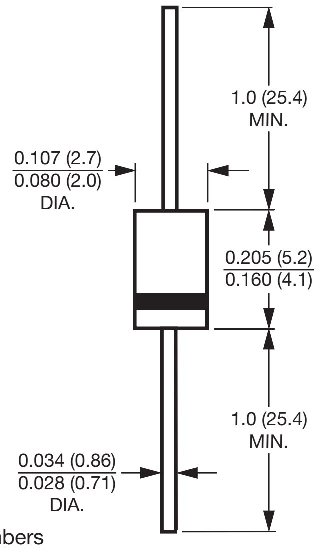


Fig. 5 - Typical Reverse Characteristics

PACKAGE OUTLINE DIMENSIONS in inches (millimeters)

DO-204AL (DO-41)



Note

- Lead diameter is $\frac{0.026\ (0.66)}{0.023\ (0.58)}$ for suffix “E” part numbers

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74HC14; 74HCT14

Hex inverting Schmitt trigger

Rev. 6 — 19 September 2012 | Product data sheet

1. General description

The 74HC14; 74HCT14 is a high-speed Si-gate CMOS device and is pin compatible with Low-power Schottky TTL (LSTTL). It is specified in compliance with JEDEC standard No. 7A.

The 74HC14; 74HCT14 provides six inverting buffers with Schmitt-trigger action. It is capable of transforming slowly changing input signals into sharply defined, jitter-free output signals.

2. Features and benefits

- Low-power dissipation
- ESD protection:
  - HBM JESD22-A114F exceeds 2000 V
  - MM JESD22-A115-A exceeds 200 V
- Multiple package options
- Specified from –40 °C to +85 °C and from –40 °C to +125 °C

3. Applications

- Wave and pulse shapers
- Astable multivibrators
- Monostable multivibrators

4. Ordering information

Table 1. Ordering information

Type number	Package			
	Temperature range	Name	Description	Version
74HC14N	−40 °C to +125 °C	DIP14	plastic dual in-line package; 14 leads (300 mil)	SOT27-1
74HCT14N				
74HC14D	−40 °C to +125 °C	SO14	plastic small outline package; 14 leads; body width 3.9 mm	SOT108-1
74HCT14D				
74HC14DB	−40 °C to +125 °C	SSOP14	plastic shrink small outline package; 14 leads; body width 5.3 mm	SOT337-1
74HCT14DB				
74HC14PW	−40 °C to +125 °C	TSSOP14	plastic thin shrink small outline package; 14 leads; body width 4.4 mm	SOT402-1
74HCT14PW				
74HC14BQ	−40 °C to +125 °C	DHVQFN14	plastic dual in-line compatible thermal enhanced very thin quad flat package; no leads; 14 terminals; body 2.5 × 3 × 0.85 mm	SOT762-1
74HCT14BQ				

5. Functional diagram

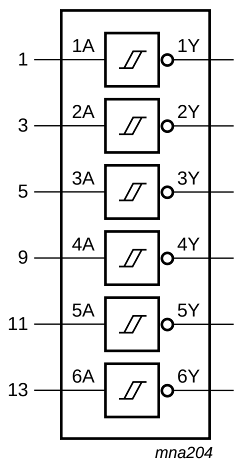


Fig 1. Logic symbol

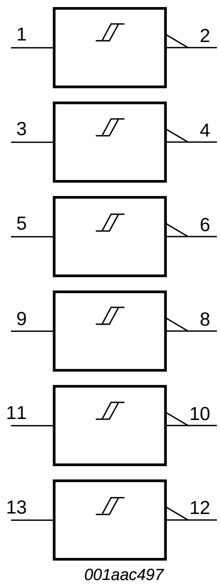


Fig 2. IEC logic symbol

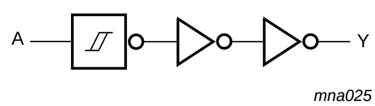


Fig 3. Logic diagram (one Schmitt trigger)

6. Pinning information

6.1 Pinning

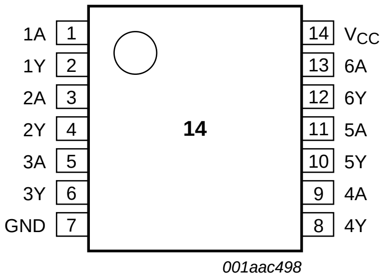
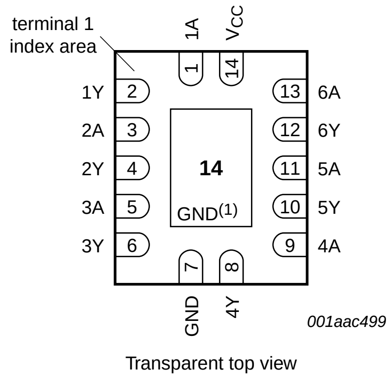


Fig 4. Pin configuration DIP14, SO14 and (T)SSOP14



(1) The die substrate is attached to this pad using conductive die attach material. It cannot be used as a supply pin or input.

Fig 5. Pin configuration DHVQFN14

6.2 Pin description

Table 2. Pin description

Symbol	Pin	Description
1A to 6A	1, 3, 5, 9, 11, 13	data input 1
1Y to 6Y	2, 4, 6, 8, 10, 12	data output 1
GND	7	ground (0 V)
V_{CC}	14	supply voltage

7. Functional description

Table 3. Function table[1]

Input	Output
nA	**nY**
L	H
H	L

[1] H = HIGH voltage level;
L = LOW voltage level.

8. Limiting values

Table 4. Limiting values

In accordance with the Absolute Maximum Rating System (IEC 60134). Voltages are referenced to GND (ground = 0 V).

Symbol	Parameter	Conditions		Min	Max	Unit
V_{CC}	supply voltage			–0.5	+7	V
I_{IK}	input clamping current	$V_I < –0.5$ V or $V_I > V_{CC} + 0.5$ V	[1]	-	±20	mA
I_{OK}	output clamping current	$V_O < –0.5$ V or $V_O > V_{CC} + 0.5$ V	[1]	-	±20	mA
I_O	output current	$–0.5$ V $< V_O < V_{CC} + 0.5$ V		-	±25	mA
I_{CC}	supply current			-	50	mA
I_{GND}	ground current			–50	-	mA
T_{stg}	storage temperature			–65	+150	°C
P_{tot}	total power dissipation		[2]			
	DIP14 package			-	750	mW
	SO14, (T)SSOP14 and DHVQFN14 packages			-	500	mW

[1] The input and output voltage ratings may be exceeded if the input and output current ratings are observed.

[2] For DIP14 package: P_{tot} derates linearly with 12 mW/K above 70 °C.
For SO14 package: P_{tot} derates linearly with 8 mW/K above 70 °C.
For (T)SSOP14 packages: P_{tot} derates linearly with 5.5 mW/K above 60 °C.
For DHVQFN14 packages: P_{tot} derates linearly with 4.5 mW/K above 60 °C.

9. Recommended operating conditions

Table 5. Recommended operating conditions

Voltages are referenced to GND (ground = 0 V)

Symbol	Parameter	Conditions	74HC14			74HCT14			Unit
			Min	Typ	Max	Min	Typ	Max	
V_{CC}	supply voltage		2.0	5.0	6.0	4.5	5.0	5.5	V
V_I	input voltage		0	-	V_{CC}	0	-	V_{CC}	V
V_O	output voltage		0	-	V_{CC}	0	-	V_{CC}	V
T_{amb}	ambient temperature		–40	+25	+125	–40	+25	+125	°C

10. Static characteristics

Table 6. Static characteristics

At recommended operating conditions; voltages are referenced to GND (ground = 0 V).

Symbol	Parameter	Conditions	T_{amb} = 25 °C			T_{amb} = –40 °C to +85 °C		T_{amb} = –40 °C to +125 °C		Unit
			Min	Typ	Max	Min	Max	Min	Max	
74HC14										
V_{OH}	HIGH-level output voltage	$V_I = V_{T+}$ or V_{T-}								
		I_O = –20 μA; V_{CC} = 2.0 V	1.9	2.0	-	1.9	-	1.9	-	V
		I_O = –20 μA; V_{CC} = 4.5 V	4.4	4.5	-	4.4	-	4.4	-	V
		I_O = –20 μA; V_{CC} = 6.0 V	5.9	6.0	-	5.9	-	5.9	-	V
		I_O = –4.0 mA; V_{CC} = 4.5 V	3.98	4.32	-	3.84	-	3.7	-	V
		I_O = –5.2 mA; V_{CC} = 6.0 V	5.48	5.81	-	5.34	-	5.2	-	V
V_{OL}	LOW-level output voltage	$V_I = V_{T+}$ or V_{T-}								
		I_O = 20 μA; V_{CC} = 2.0 V	-	0	0.1	-	0.1	-	0.1	V
		I_O = 20 μA; V_{CC} = 4.5 V	-	0	0.1	-	0.1	-	0.1	V
		I_O = 20 μA; V_{CC} = 6.0 V	-	0	0.1	-	0.1	-	0.1	V
		I_O = 4.0 mA; V_{CC} = 4.5 V	-	0.15	0.26	-	0.33	-	0.4	V
		I_O = 5.2 mA; V_{CC} = 6.0 V	-	0.16	0.26	-	0.33	-	0.4	V
I_I	input leakage current	$V_I = V_{CC}$ or GND; V_{CC} = 6.0 V	-	-	±0.1	-	±1.0	-	±1.0	μA
I_{CC}	supply current	$V_I = V_{CC}$ or GND; I_O = 0 A; V_{CC} = 6.0 V	-	-	2.0	-	20	-	40	μA
C_I	input capacitance		-	3.5	-	-	-	-	-	pF
74HCT14										
V_{OH}	HIGH-level output voltage	$V_I = V_{T+}$ or V_{T-}; V_{CC} = 4.5 V								
		I_O = –20 μA	4.4	4.5	-	4.4	-	4.4	-	V
		I_O = –4.0 mA	3.98	4.32	-	3.84	-	3.7	-	V
V_{OL}	LOW-level output voltage	$V_I = V_{T+}$ or V_{T-}; V_{CC} = 4.5 V								
		I_O = 20 μA;	-	0	0.1	-	0.1	-	0.1	V
		I_O = 4.0 mA;	-	0.15	0.26	-	0.33	-	0.4	V
I_I	input leakage current	$V_I = V_{CC}$ or GND; V_{CC} = 5.5 V	-	-	±0.1	-	±1.0	-	±1.0	μA
I_{CC}	supply current	$V_I = V_{CC}$ or GND; I_O = 0 A; V_{CC} = 5.5 V	-	-	2.0	-	20	-	40	μA
ΔI_{CC}	additional supply current	per input pin; $V_I = V_{CC}$ – 2.1 V; other pins at V_{CC} or GND; I_O = 0 A; V_{CC} = 4.5 V to 5.5 V	-	30	108	-	135	-	147	μA
C_I	input capacitance		-	3.5	-	-	-	-	-	pF

11. Dynamic characteristics

Table 7. Dynamic characteristics

GND = 0 V; C_L = 50 pF; for test circuit see Figure 7.

Symbol	Parameter	Conditions		T_{amb} = 25 °C			T_{amb} = −40 °C to +125 °C		Unit
				Min	Typ	Max	Max (85 °C)	Max (125 °C)	
74HC14									
t_{pd}	propagation delay	nA to nY; see Figure 6	[1]						
		V_{CC} = 2.0 V		-	41	125	155	190	ns
		V_{CC} = 4.5 V		-	15	25	31	38	ns
		V_{CC} = 5.0 V; C_L = 15 pF		-	12	-	-	-	ns
		V_{CC} = 6.0 V		-	12	21	26	32	ns
t_t	transition time	see Figure 6	[2]						
		V_{CC} = 2.0 V		-	19	75	95	110	ns
		V_{CC} = 4.5 V		-	7	15	19	22	ns
		V_{CC} = 6.0 V		-	6	13	15	19	ns
C_{PD}	power dissipation capacitance	per package; V_I = GND to V_{CC}	[3]	-	7	-	-	-	pF
74HCT14									
t_{pd}	propagation delay	nA to nY; see Figure 6	[1]						
		V_{CC} = 4.5 V		-	20	34	43	51	ns
		V_{CC} = 5.0 V; C_L = 15 pF		-	17	-	-	-	ns
t_t	transition time	V_{CC} = 4.5 V; see Figure 6	[2]	-	7	15	19	22	ns
C_{PD}	power dissipation capacitance	per package; V_I = GND to V_{CC} − 1.5 V	[3]	-	8	-	-	-	pF

[1] t_{pd} is the same as t_{PHL} and t_{PLH}.

[2] t_t is the same as t_{THL} and t_{TLH}.

[3] C_{PD} is used to determine the dynamic power dissipation (P_D in μW):

$P_D = C_{PD} \times V_{CC}^2 \times f_i \times N + \sum (C_L \times V_{CC}^2 \times f_o)$ where:

f_i = input frequency in MHz;

f_o = output frequency in MHz;

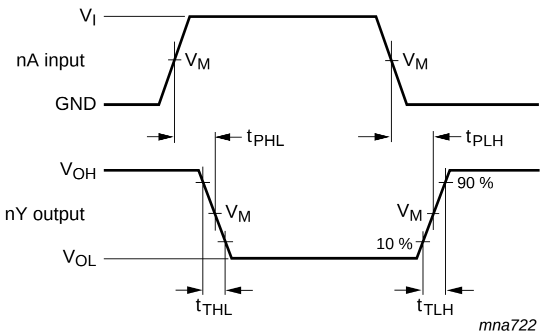
C_L = output load capacitance in pF;

V_{CC} = supply voltage in V;

N = number of inputs switching;

$\sum (C_L \times V_{CC}^2 \times f_o)$ = sum of outputs.

12. Waveforms



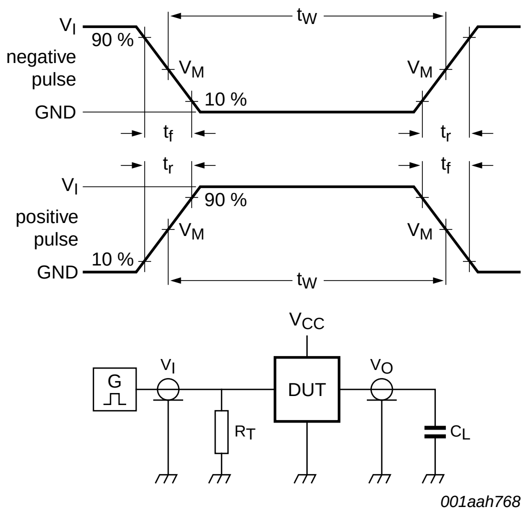
Measurement points are given in Table 8.

V_{OL} and V_{OH} are typical voltage output levels that occur with the output load.

Fig 6. Input to output propagation delays

Table 8. Measurement points

Type	Input	Output		
	V_M	V_M	V_X	V_Y
74HC14	$0.5V_{CC}$	$0.5V_{CC}$	$0.1V_{CC}$	$0.9V_{CC}$
74HCT14	1.3 V	1.3 V	$0.1V_{CC}$	$0.9V_{CC}$



Test data is given in Table 9.

Definitions test circuit:

R_T = termination resistance should be equal to output impedance Z_o of the pulse generator.

C_L = load capacitance including jig and probe capacitance.

Fig 7. Load circuitry for measuring switching times

Table 9. Test data

Type	Input		Load	Test
	V_I	t_r, t_f	C_L	
74HC14	V_{CC}	6.0 ns	15 pF, 50 pF	t_{PLH}, t_{PHL}
74HCT14	3.0 V	6.0 ns	15 pF, 50 pF	t_{PLH}, t_{PHL}

13. Transfer characteristics

Table 10. Transfer characteristics

At recommended operating conditions; voltages are referenced to GND (ground = 0 V); see Figure 8 and Figure 9.

Symbol	Parameter	Conditions	T_{amb} = 25 °C			T_{amb} = –40 °C to +85 °C		T_{amb} = –40 °C to +125 °C		Unit
			Min	Typ	Max	Min	Max	Min	Max	
74HC14										
V_{T+}	positive-going threshold voltage	V_{CC} = 2.0 V	0.7	1.18	1.5	0.7	1.5	0.7	1.5	V
		V_{CC} = 4.5 V	1.7	2.38	3.15	1.7	3.15	1.7	3.15	V
		V_{CC} = 6.0 V	2.1	3.14	4.2	2.1	4.2	2.1	4.2	V
V_{T-}	negative-going threshold voltage	V_{CC} = 2.0 V	0.3	0.52	0.9	0.3	0.9	0.3	0.9	V
		V_{CC} = 4.5 V	0.9	1.4	2.0	0.9	2.0	0.9	2.0	V
		V_{CC} = 6.0 V	1.2	1.89	2.6	1.2	2.6	1.2	2.6	V
V_H	hysteresis voltage	V_{CC} = 2.0 V	0.2	0.66	1.0	0.2	1.0	0.2	1.0	V
		V_{CC} = 4.5 V	0.4	0.98	1.4	0.4	1.4	0.4	1.4	V
		V_{CC} = 6.0 V	0.6	1.25	1.6	0.6	1.6	0.6	1.6	V
74HCT14										
V_{T+}	positive-going threshold voltage	V_{CC} = 4.5 V	1.2	1.41	1.9	1.2	1.9	1.2	1.9	V
		V_{CC} = 5.5 V	1.4	1.59	2.1	1.4	2.1	1.4	2.1	V
V_{T-}	negative-going threshold voltage	V_{CC} = 4.5 V	0.5	0.85	1.2	0.5	1.2	0.5	1.2	V
		V_{CC} = 5.5 V	0.6	0.99	1.4	0.6	1.4	0.6	1.4	V
V_H	hysteresis voltage	V_{CC} = 4.5 V	0.4	0.56	-	0.4	-	0.4	-	V
		V_{CC} = 5.5 V	0.4	0.6	-	0.4	-	0.4	-	V

14. Transfer characteristics waveforms

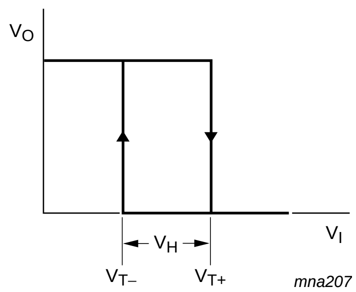


Fig 8. Transfer characteristics

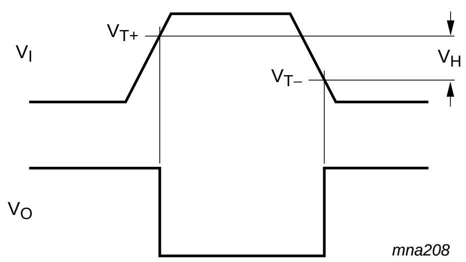
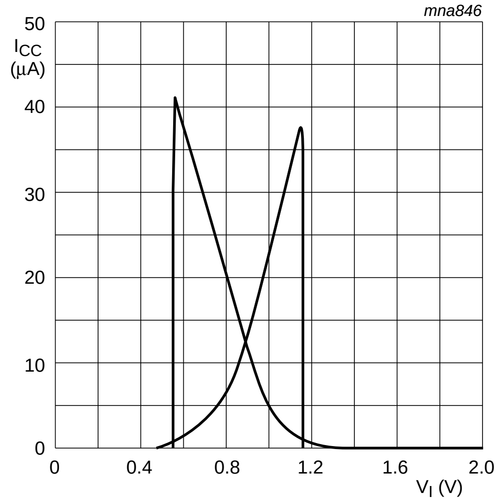
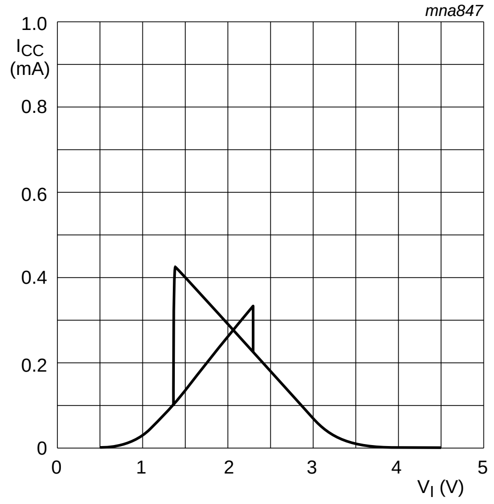


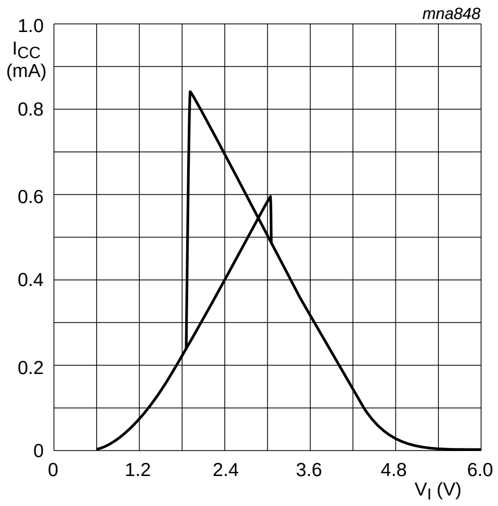
Fig 9. Transfer characteristics definitions



a. V_{CC} = 2.0 V

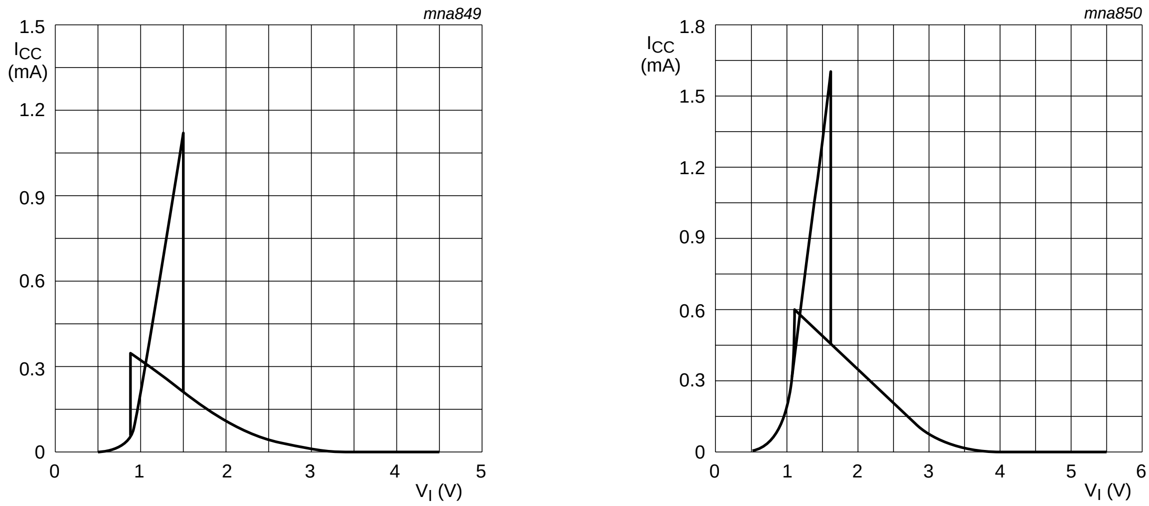


b. V_{CC} = 4.5 V



c. V_{CC} = 6.0 V

Fig 10. Typical 74HC transfer characteristics



a. V_{CC} = 4.5 V

b. V_{CC} = 5.5 V

Fig 11. Typical 74HCT transfer characteristics

15. Application information

The slow input rise and fall times cause additional power dissipation, this can be calculated using the following formula:

$P_{add} = f_i \times (t_r \times \Delta I_{CC(AV)} + t_f \times \Delta I_{CC(AV)}) \times V_{CC}$ where:

P_{add} = additional power dissipation (μW);

f_i = input frequency (MHz);

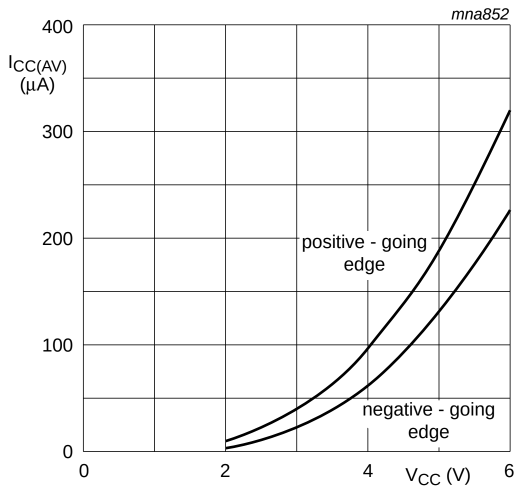
t_r = rise time (ns); 10 % to 90 %;

t_f = fall time (ns); 90 % to 10 %;

$\Delta I_{CC(AV)}$ = average additional supply current (μA).

Average $\Delta I_{CC(AV)}$ differs with positive or negative input transitions, as shown in Figure 12 and Figure 13.

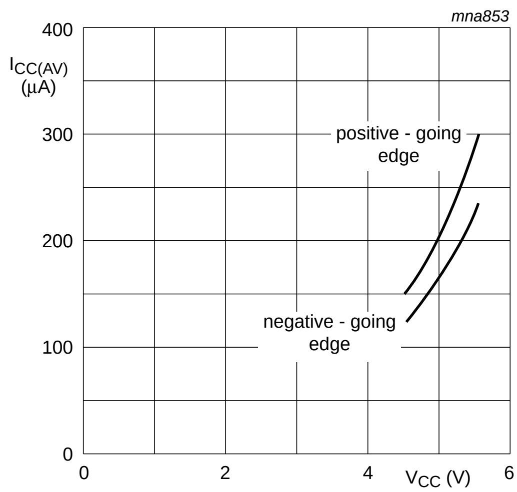
An example of a relaxation circuit using the 74HC14; 74HCT14 is shown in Figure 14.



(1) Positive-going edge.

(2) Negative-going edge.

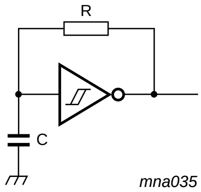
Fig 12. Average additional supply current as a function of V_{CC} for 74HC14; linear change of V_I between $0.1V_{CC}$ to $0.9V_{CC}$.



(1) Positive-going edge.

(2) Negative-going edge.

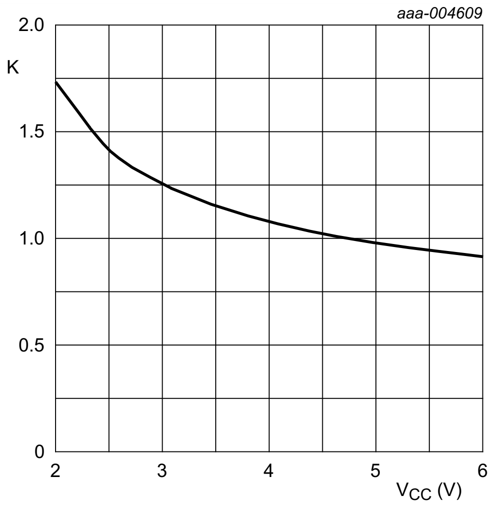
Fig 13. Average additional supply current as a function of V_{CC} for 74HCT14; linear change of V_I between $0.1V_{CC}$ to $0.9V_{CC}$.



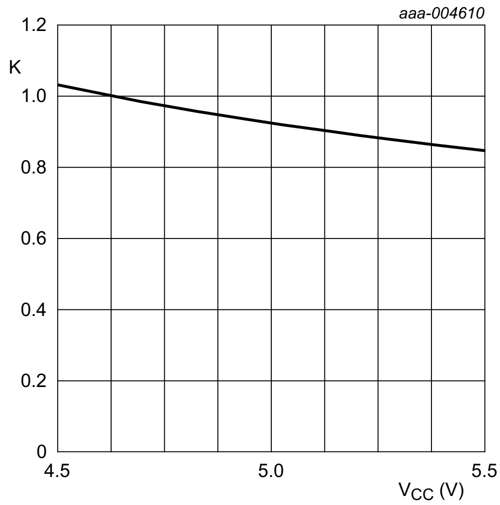
For 74HC14 and 74HCT14: $f = \frac{1}{T} \approx \frac{1}{K \times RC}$

For K-factor see Figure 15

Fig 14. Relaxation oscillator



K-factor for 74HC14

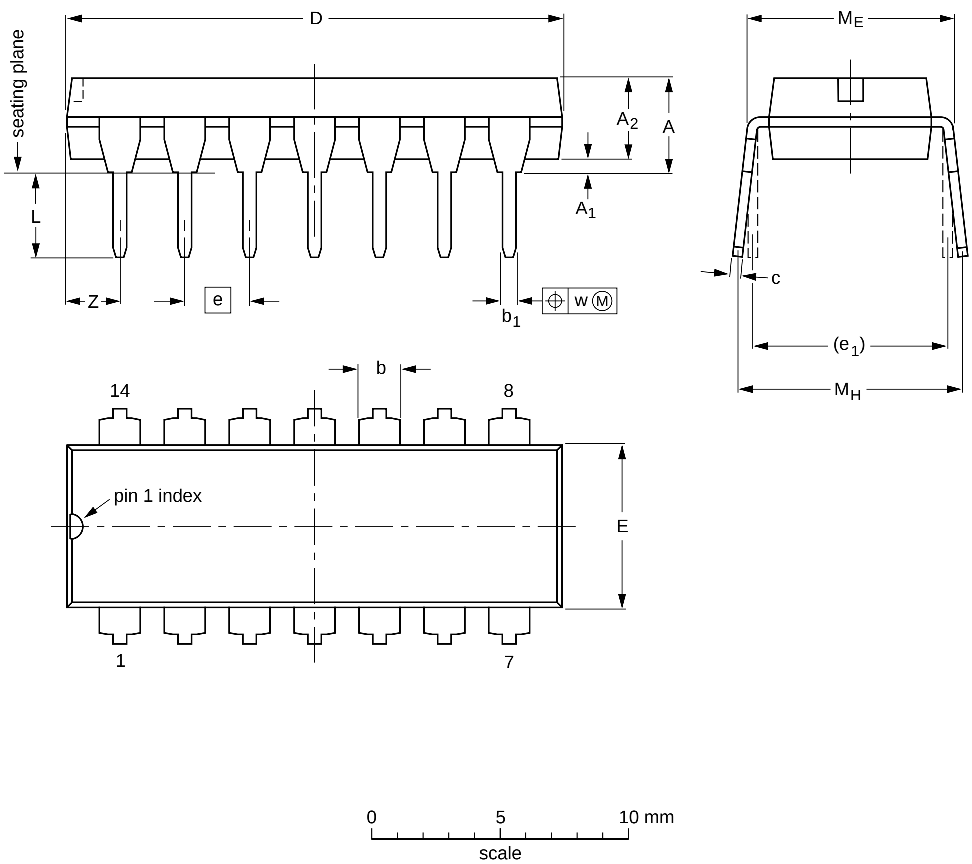


K-factor for 74HCT14

Fig 15. Typical K-factor for relaxation oscillator

16. Package outline

DIP14: plastic dual in-line package; 14 leads (300 mil) **SOT27-1**



DIMENSIONS (inch dimensions are derived from the original mm dimensions)

UNIT	A max.	A_1 min.	A_2 max.	b	b_1	c	D (1)	E (1)	e	e_1	L	M_E	M_H	w	Z (1) max.
mm	4.2	0.51	3.2	1.73 1.13	0.53 0.38	0.36 0.23	19.50 18.55	6.48 6.20	2.54	7.62	3.60 3.05	8.25 7.80	10.0 8.3	0.254	2.2
inches	0.17	0.02	0.13	0.068 0.044	0.021 0.015	0.014 0.009	0.77 0.73	0.26 0.24	0.1	0.3	0.14 0.12	0.32 0.31	0.39 0.33	0.01	0.087

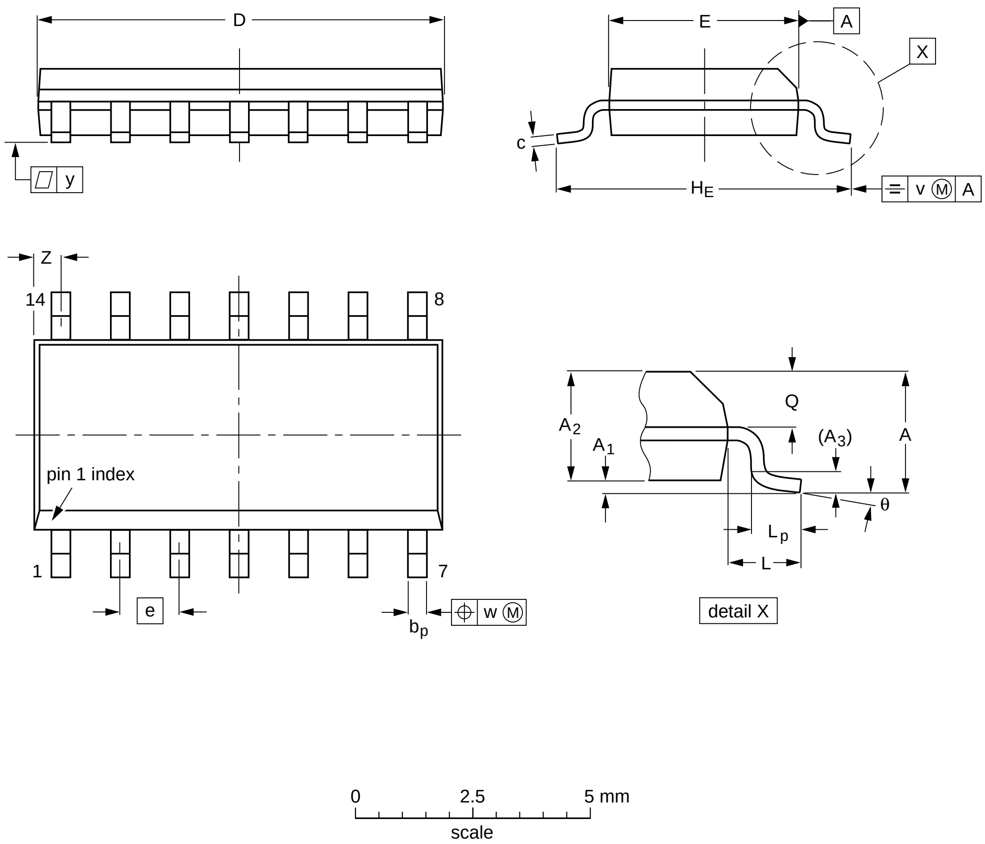
Note

1. Plastic or metal protrusions of 0.25 mm (0.01 inch) maximum per side are not included.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	JEITA			
SOT27-1	050G04	MO-001	SC-501-14			~~99-12-27~~ 03-02-13

Fig 16. Package outline SOT27-1 (DIP14)

SO14: plastic small outline package; 14 leads; body width 3.9 mm **SOT108-1**



DIMENSIONS (inch dimensions are derived from the original mm dimensions)

UNIT	A max.	A_1	A_2	A_3	b_p	c	D(1)	E(1)	e	H_E	L	L_p	Q	v	w	y	Z(1)	θ
mm	1.75	0.25 0.10	1.45 1.25	0.25	0.49 0.36	0.25 0.19	8.75 8.55	4.0 3.8	1.27	6.2 5.8	1.05	1.0 0.4	0.7 0.6	0.25	0.25	0.1	0.7 0.3	8° 0°
inches	0.069	0.010 0.004	0.057 0.049	0.01	0.019 0.014	0.0100 0.0075	0.35 0.34	0.16 0.15	0.05	0.244 0.228	0.041	0.039 0.016	0.028 0.024	0.01	0.01	0.004	0.028 0.012	

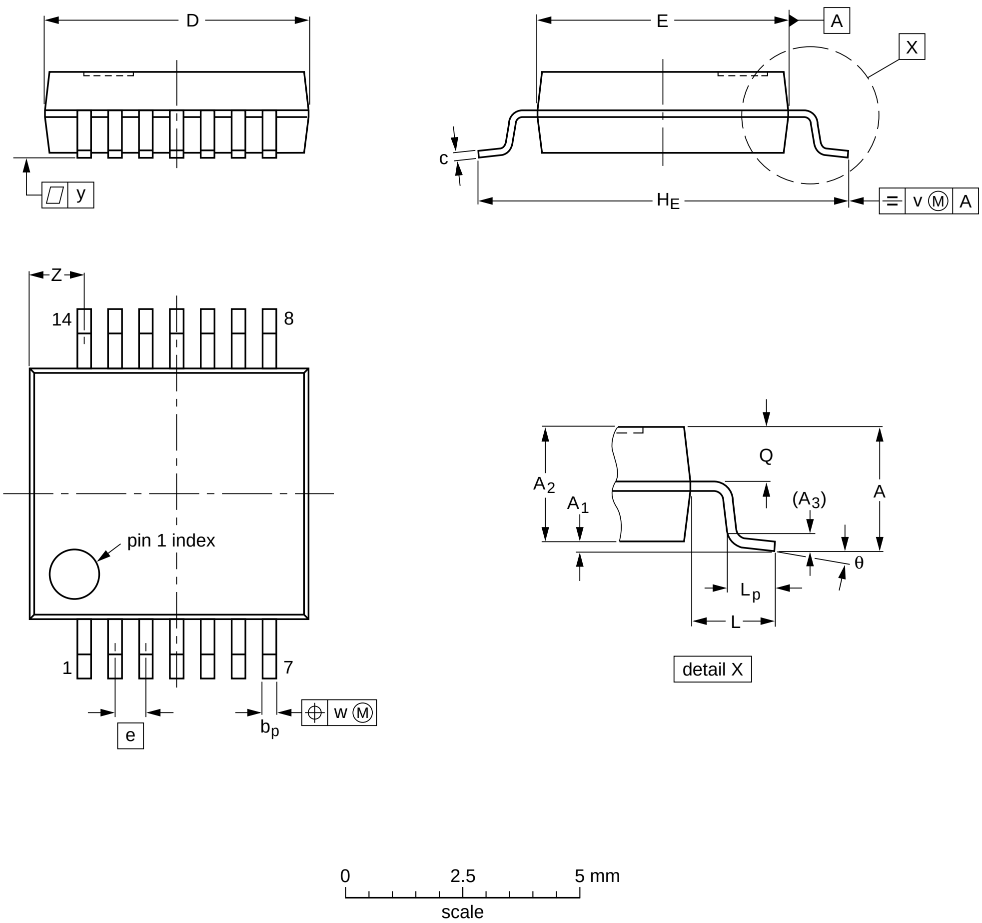
Note

1. Plastic or metal protrusions of 0.15 mm (0.006 inch) maximum per side are not included.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	JEITA			
SOT108-1	076E06	MS-012				~~99-12-27~~ 03-02-19

Fig 17. Package outline SOT108-1 (SO14)

SSOP14: plastic shrink small outline package; 14 leads; body width 5.3 mm **SOT337-1**



DIMENSIONS (mm are the original dimensions)

UNIT	A max.	A_1	A_2	A_3	b_p	c	D (1)	E (1)	e	H_E	L	L_p	Q	v	w	y	Z (1)	θ
mm	2	0.21 0.05	1.80 1.65	0.25	0.38 0.25	0.20 0.09	6.4 6.0	5.4 5.2	0.65	7.9 7.6	1.25	1.03 0.63	0.9 0.7	0.2	0.13	0.1	1.4 0.9	8^o 0^o

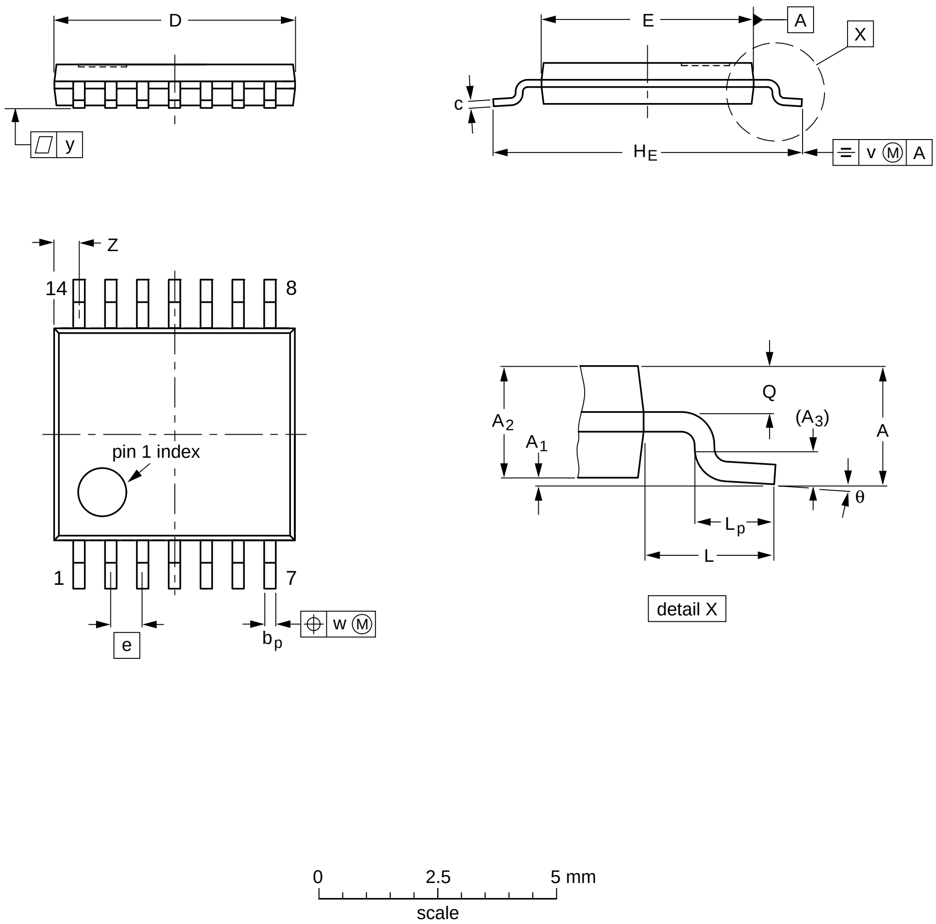
Note

1. Plastic or metal protrusions of 0.25 mm maximum per side are not included.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	JEITA			
SOT337-1		MO-150				~~99-12-27~~ 03-02-19

Fig 18. Package outline SOT337-1 (SSOP14)

TSSOP14: plastic thin shrink small outline package; 14 leads; body width 4.4 mm **SOT402-1**



DIMENSIONS (mm are the original dimensions)

UNIT	A max.	A_1	A_2	A_3	b_p	c	$D^{(1)}$	$E^{(2)}$	e	H_E	L	L_p	Q	v	w	y	$Z^{(1)}$	θ
mm	1.1	0.15 0.05	0.95 0.80	0.25	0.30 0.19	0.2 0.1	5.1 4.9	4.5 4.3	0.65	6.6 6.2	1	0.75 0.50	0.4 0.3	0.2	0.13	0.1	0.72 0.38	8^o 0^o

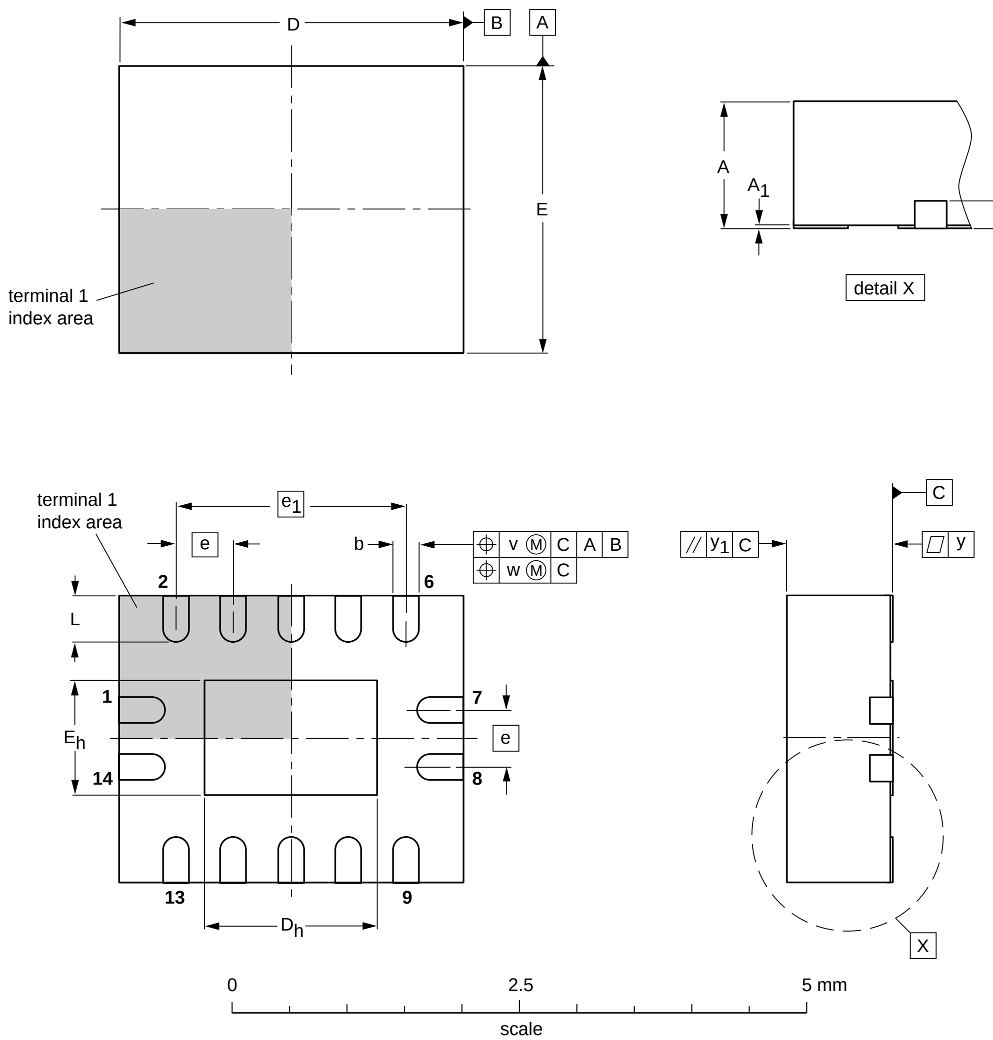
Notes

1. Plastic or metal protrusions of 0.15 mm maximum per side are not included.
2. Plastic interlead protrusions of 0.25 mm maximum per side are not included.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	JEITA			
SOT402-1		MO-153				~~99-12-27~~ 03-02-18

Fig 19. Package outline SOT402-1 (TSSOP14)

DHVQFN14: plastic dual in-line compatible thermal enhanced very thin quad flat package; no leads; 14 terminals; body 2.5 x 3 x 0.85 mm **SOT762-1**



DIMENSIONS (mm are the original dimensions)

UNIT	$A^{(1)}$ max.	A_1	b	c	$D^{(1)}$	D_h	$E^{(1)}$	E_h	e	e_1	L	v	w	y	y_1
mm	1	0.05 0.00	0.30 0.18	0.2	3.1 2.9	1.65 1.35	2.6 2.4	1.15 0.85	0.5	2	0.5 0.3	0.1	0.05	0.05	0.1

Note

1. Plastic or metal protrusions of 0.075 mm maximum per side are not included.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	JEITA			
SOT762-1	- - -	MO-241	- - -			~~02-10-17~~ 03-01-27

Fig 20. Package outline SOT762-1 (DHVQFN14)

17. Abbreviations

Table 11. Abbreviations

Acronym	Description
CMOS	Complementary Metal-Oxide Semiconductor
DUT	Device Under Test
ESD	ElectroStatic Discharge
HBM	Human Body Model
LSTTL	Low-power Schottky Transistor-Transistor Logic
MM	Machine Model

18. Revision history

Table 12. Revision history

Document ID	Release date	Data sheet status	Change notice	Supersedes
74HC_HCT14 v.6	20120919	Product data sheet	-	74HC_HCT14 v.5
Modifications:	• Figure 15 added (typical K-factor for relaxation oscillator).			
74HC_HCT14 v.5	20111219	Product data sheet	-	74HC_HCT14 v.4
Modifications:	• Legal pages updated.			
74HC_HCT14 v.4	20110117	Product data sheet	-	74HC_HCT14 v.3
74HC_HCT14 v.3	20031030	Product specification	-	74HC_HCT14_CNV v.2
74HC_HCT14_CNV v.2	19970826	Product specification	-	-

19. Legal information

19.1 Data sheet status

Document status[1][2]	Product status[3]	Definition
Objective [short] data sheet	Development	This document contains data from the objective specification for product development.
Preliminary [short] data sheet	Qualification	This document contains data from the preliminary specification.
Product [short] data sheet	Production	This document contains the product specification.

[1] Please consult the most recently issued document before initiating or completing a design.

[2] The term 'short data sheet' is explained in section "Definitions".

[3] The product status of device(s) described in this document may have changed since this document was published and may differ in case of multiple devices. The latest product status information is available on the Internet at URL http://www.nxp.com.

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21. Contents

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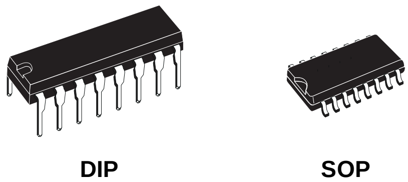
Date of release: 19 September 2012
Document identifier: 74HC_HCT14

HCF4050B

HEX BUFFER/CONVERTER (NON INVERTING)

- PROPAGATION DELAY TIME :
  t_{PD} = 40ns (TYP.) at V_{DD} = 10V C_L = 50pF
- HIGH TO LOW LEVEL LOGIC CONVERSION
- HIGH "SINK" AND "SOURCE" CURRENT CAPABILITY
- QUIESCENT CURRENT SPECIFIED UP TO 20V
- 5V, 10V AND 15V PARAMETRIC RATINGS
- INPUT LEAKAGE CURRENT
  I_I = 100nA (MAX) AT V_{DD} = 18V T_A = 25°C
- 100% TESTED FOR QUIESCENT CURRENT
- MEETS ALL REQUIREMENTS OF JEDEC JESD13B " STANDARD SPECIFICATIONS FOR DESCRIPTION OF B SERIES CMOS DEVICES"



ORDER CODES

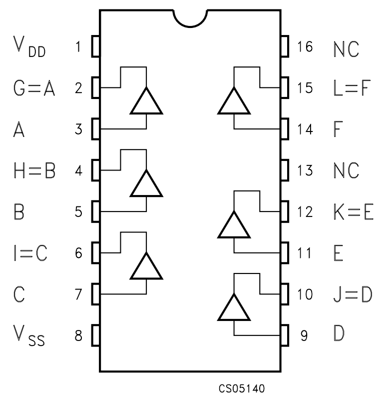
PACKAGE	TUBE	T & R
DIP	HCF4050BEY	
SOP	HCF4050BM1	HCF4050M013TR

DESCRIPTION

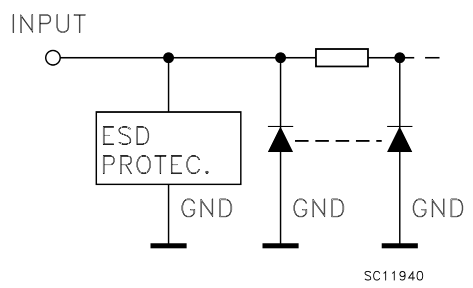
The HCF4050B is a monolithic integrated circuit fabricated in Metal Oxide Semiconductor technology available in DIP and SOP packages.
It is an non inverting Hex Buffer/Converter and feature logic level conversions using only one supply voltage (V_{DD}).

The input high level signal (V_{IH}) can exceed the V_{DD} supply voltage when these devices are used for logic level conversions. This device is intended for use as CMOS to DTL/TTL converters and can drive directly two DTL/TTL loads (V_{DD}=5V, V_{OL}≤0.4V and I_{OL}≤3.2mA.

PIN CONNECTION



INPUT EQUIVALENT CIRCUIT



PIN DESCRIPTION

PIN No	SYMBOL	NAME AND FUNCTION
3, 5, 7, 9, 11, 14	A, B, C, D, E, F	Data Inputs
2, 4, 6, 10, 12, 15	G, H, I, J, K, L	Data Outputs
13 , 16	NC	Not Connected
8	V_{SS}	Negative Supply Voltage
1	V_{DD}	Positive Supply Voltage

TRUTH TABLE

INPUTS	OUTPUTS
A, B, C, D,E, F	**G, H, I, J, K, L**
L	L
H	H

ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_{DD}	Supply Voltage	-0.5 to +22	V
V_I	DC Input Voltage	-0.5 to +18	V
I_I	DC Input Current	± 10	mA
P_D	Power Dissipation per Package	200	mW
	Power Dissipation per Output Transistor	100	mW
T_{op}	Operating Temperature	-55 to +125	°C
T_{stg}	Storage Temperature	-65 to +150	°C

Absolute Maximum Ratings are those values beyond which damage to the device may occur. Functional operation under these conditions is not implied.
All voltage values are referred to V_{SS} pin voltage.

RECOMMENDED OPERATING CONDITIONS

Symbol	Parameter	Value	Unit
V_{DD}	Supply Voltage	3 to 20	V
V_I	Input Voltage	-0.5 to 15V	V
T_{op}	Operating Temperature	-55 to 125	°C

DC SPECIFICATIONS

Symbol	Parameter	Test Condition				Value							Unit
		V_I (V)	V_O (V)	$\lvert I_O \rvert$ (µA)	V_{DD} (V)	T_A = 25°C			-40 to 85°C		-55 to 125°C		
						Min.	Typ.	Max.	Min.	Max.	Min.	Max.	
I_L	Quiescent Current	0/5			5		0.02	1		30		30	µA
		0/10			10		0.02	2		60		60	
		0/15			15		0.02	4		120		120	
		0/20			20		0.04	20		600		600	
V_{OH}	High Level Output Voltage	0/5		<1	5	4.95			4.95		4.95		V
		0/10		<1	10	9.95			9.95		9.95		
		0/15		<1	15	14.95			14.95		14.95		
V_{OL}	Low Level Output Voltage	5/0		<1	5		0.05			0.05		0.05	V
		10/0		<1	10		0.05			0.05		0.05	
		15/0		<1	15		0.05			0.05		0.05	
V_{IH}	High Level Input Voltage		0.5/4.5	<1	5	3.5			3.5		3.5		V
			1/9	<1	10	7			7		7		
			1.5/13.5	<1	15	11			11		11		
V_{IL}	Low Level Input Voltage		4.5/0.5	<1	5			1.5		1.5		1.5	V
			9/1	<1	10			3		3		3	
			13.5/1.5	<1	15			4		4		4	
I_{OH}	Output Drive Current	0/5	2.5	<1	5	-1.25	-6.4		-0.42		-0.42		mA
		0/5	4.6	<1	5	-0.51	-1.6		-0.38		-0.38		
		0/10	9.5	<1	10	-1.25	-3.6		-1		-1		
		0/15	13.5	<1	15	-3.75	-12		-3		-3		
I_{OL}	Output Sink Current	0/5	0.4	<1	5	3.2	6.4		2.6		2.6		mA
		0/10	0.5	<1	10	8	16		6.6		6.6		
		0/15	1.5	<1	15	24	48		19		19		
I_I	Input Leakage Current	0/18	Any Input		18		$\pm 10^{-5}$	±0.1		±1		±1	µA
C_I	Input Capacitance		Any Input				5	7.5					pF

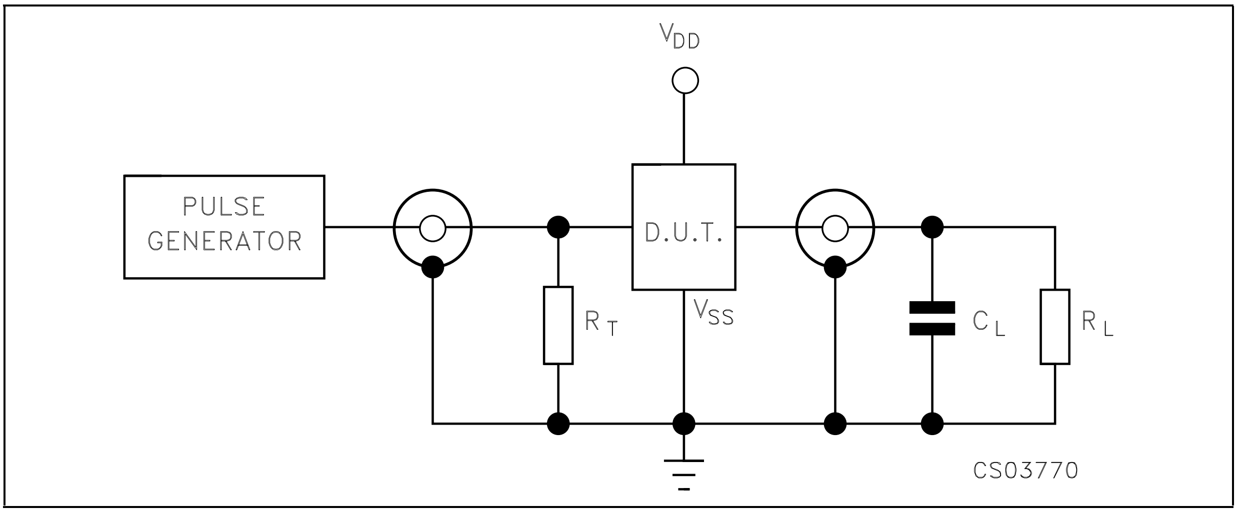
The Noise Margin for both "1" and "0" level is: 1V min. with V_{DD}=5V, 2V min. with V_{DD}=10V, 2.5V min. with V_{DD}=15V

DYNAMIC ELECTRICAL CHARACTERISTICS (T_{amb} = 25°C, C_L = 50pF, R_L = 200KΩ, $t_r = t_f$ = 20 ns)

Symbol	Parameter	Test Condition			Value (*)			Unit
		V_{DD} (V)	V_I (V)		Min.	Typ.	Max.	
t_{TLH}	Output Transition Time	5	5			80	160	ns
		10	10			40	80	
		15	15			30	60	
t_{THL}	Output Transition Time	5	5			30	60	ns
		10	10			20	40	
		15	15			15	30	
t_{PLH}	Propagation Delay Time	5	5			70	140	ns
		10	10			40	80	
		5	10			45	90	
		15	15			30	60	
		5	15			40	80	
t_{PHL}	Propagation Delay Time	5	5			55	110	ns
		10	10			22	55	
		5	10			50	100	
		15	15			15	30	
		5	15			50	100	

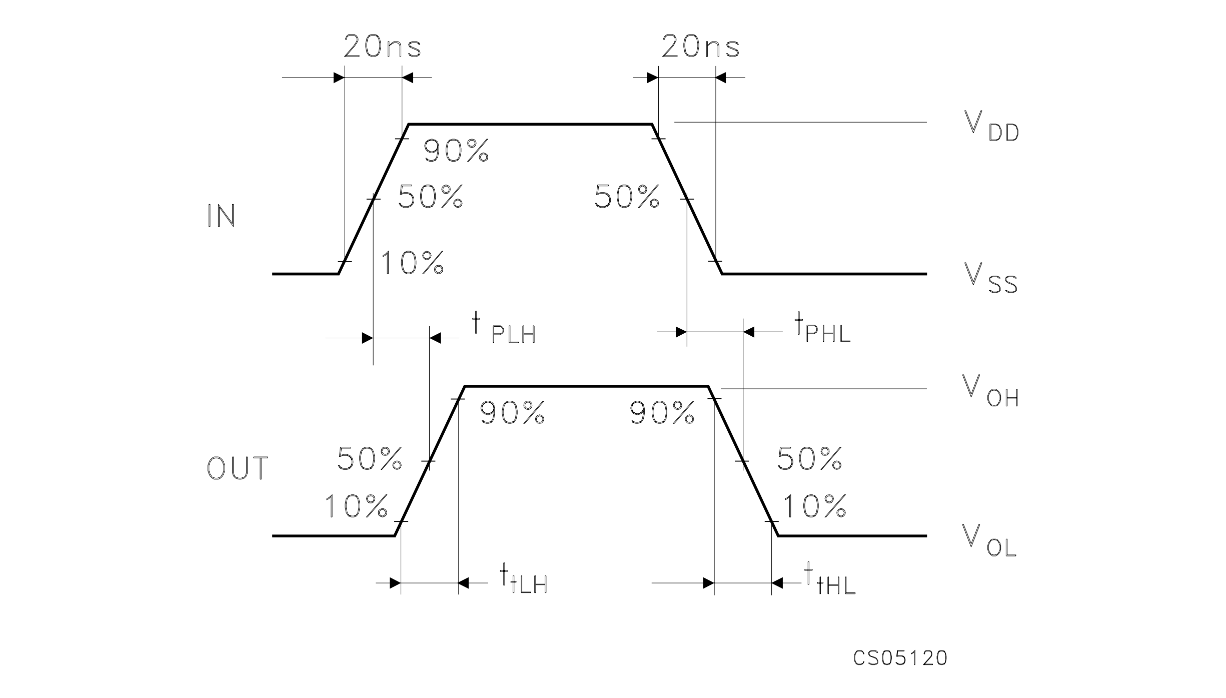
(*) Typical temperature coefficient for all V_{DD} value is 0.3 %/°C.

TEST CIRCUIT



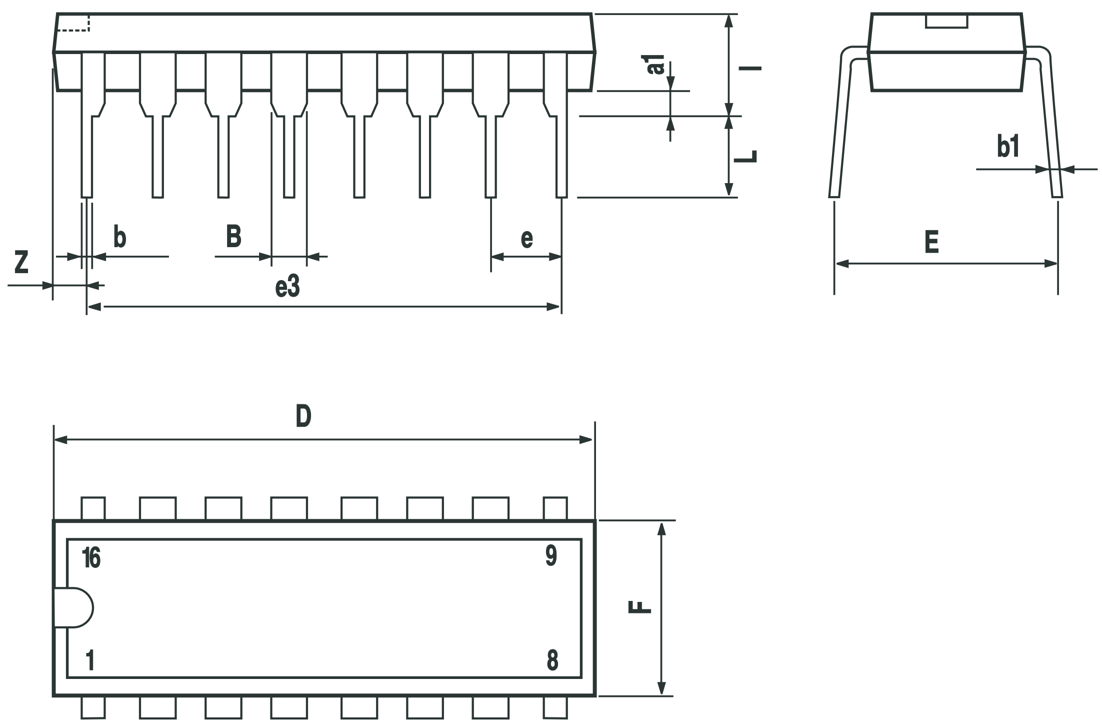
C_L = 50pF or equivalent (includes jig and probe capacitance)
R_L = 200KΩ
R_T = Z_{OUT} of pulse generator (typically 50Ω)

WAVEFORM : PROPAGATION DELAY TIMES (f=1MHz; 50% duty cycle)



Plastic DIP-16 (0.25) MECHANICAL DATA

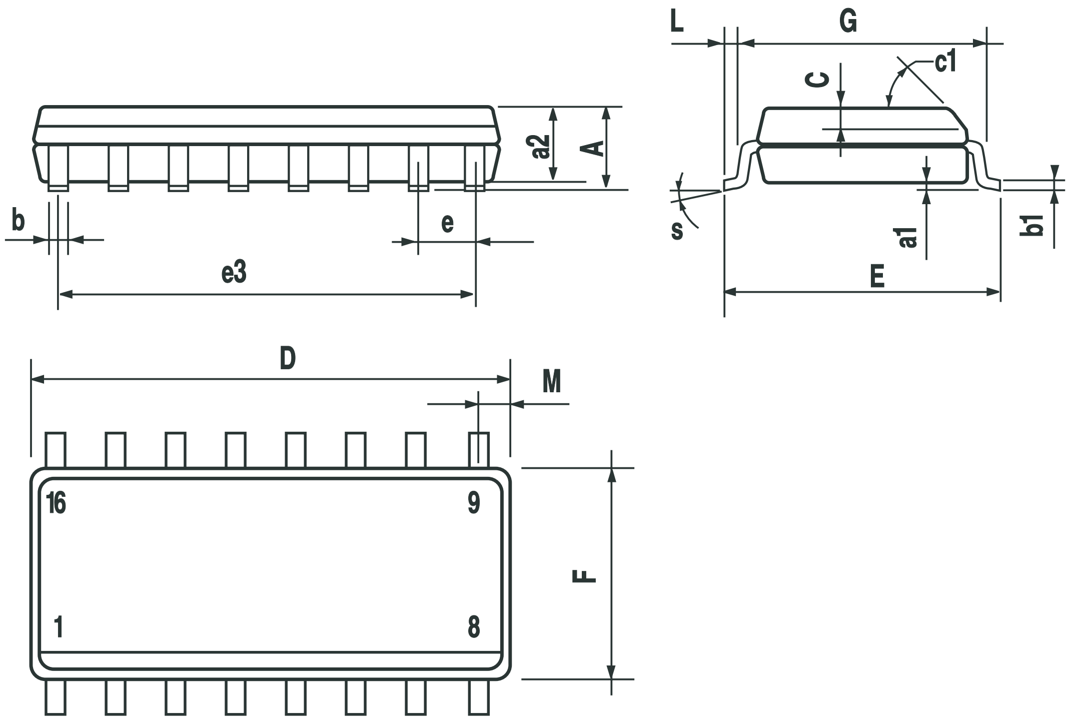
DIM.	mm.			inch		
	MIN.	TYP	MAX.	MIN.	TYP.	MAX.
a1	0.51			0.020		
B	0.77		1.65	0.030		0.065
b		0.5			0.020	
b1		0.25			0.010	
D			20			0.787
E		8.5			0.335	
e		2.54			0.100	
e3		17.78			0.700	
F			7.1			0.280
I			5.1			0.201
L		3.3			0.130	
Z			1.27			0.050



P001C

SO-16 MECHANICAL DATA

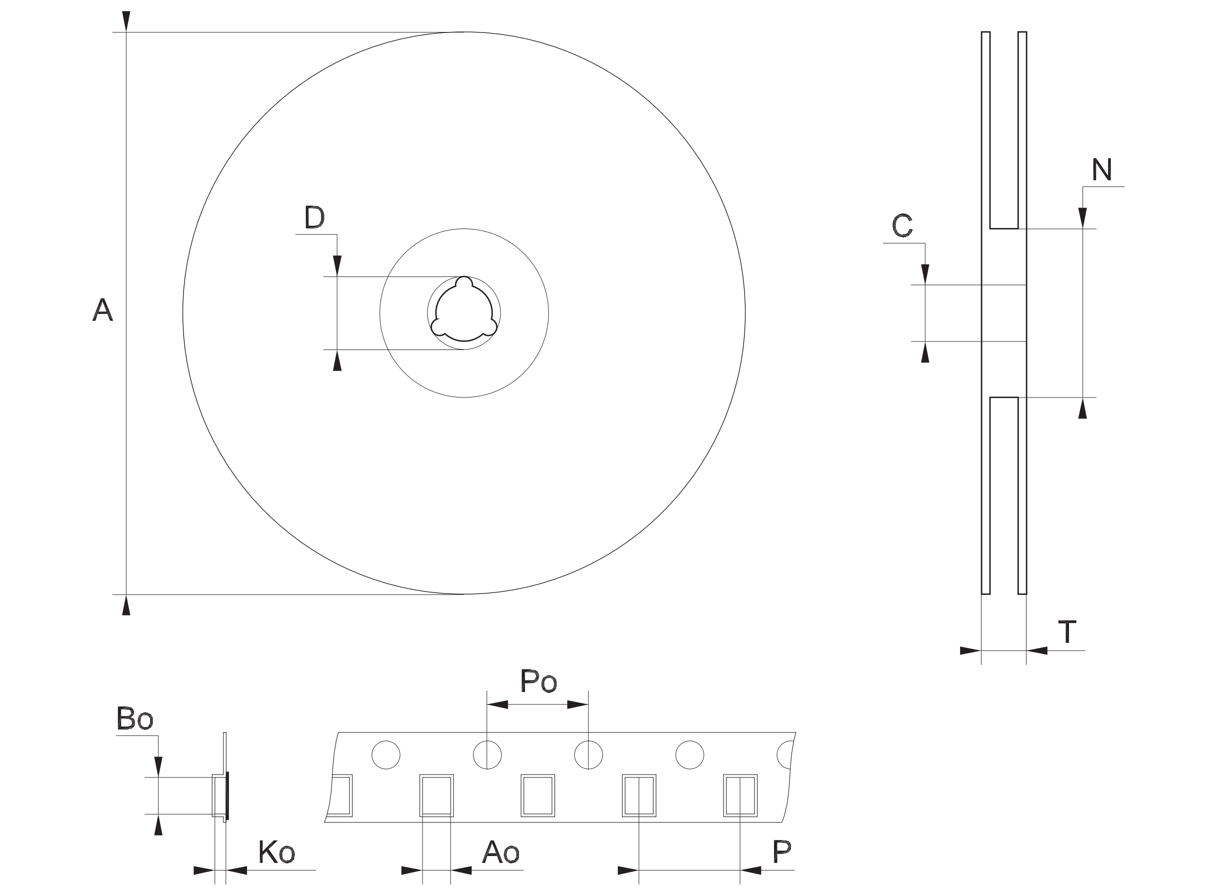
DIM.	mm.			inch		
	MIN.	TYP	MAX.	MIN.	TYP.	MAX.
A			1.75			0.068
a1	0.1		0.2	0.004		0.008
a2			1.65			0.064
b	0.35		0.46	0.013		0.018
b1	0.19		0.25	0.007		0.010
C		0.5			0.019	
c1	45° (typ.)					
D	9.8		10	0.385		0.393
E	5.8		6.2	0.228		0.244
e		1.27			0.050	
e3		8.89			0.350	
F	3.8		4.0	0.149		0.157
G	4.6		5.3	0.181		0.208
L	0.5		1.27	0.019		0.050
M			0.62			0.024
S	8 ° (max.)					



PO13H

Tape & Reel SO-16 MECHANICAL DATA

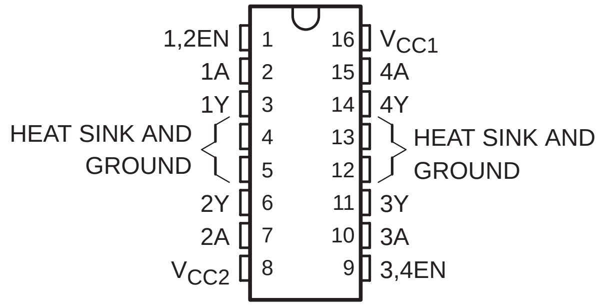
DIM.	mm.			inch		
	MIN.	TYP	MAX.	MIN.	TYP.	MAX.
A			330			12.992
C	12.8		13.2	0.504		0.519
D	20.2			0.795		
N	60			2.362		
T			22.4			0.882
Ao	6.45		6.65	0.254		0.262
Bo	10.3		10.5	0.406		0.414
Ko	2.1		2.3	0.082		0.090
Po	3.9		4.1	0.153		0.161
P	7.9		8.1	0.311		0.319



Note: Drawing not in scale

- **1-A Output-Current Capability Per Driver**
- **Applications Include Half-H and Full-H Solenoid Drivers and Motor Drivers**
- **Designed for Positive-Supply Applications**
- **Wide Supply-Voltage Range of 4.5 V to 36 V**
- **TTL- and CMOS-Compatible High-Impedance Diode-Clamped Inputs**
- **Separate Input-Logic Supply**
- **Thermal Shutdown**
- **Internal ESD Protection**
- **Input Hysteresis Improves Noise Immunity**
- **3-State Outputs**
- **Minimized Power Dissipation**
- **Sink/Source Interlock Circuitry Prevents Simultaneous Conduction**
- **No Output Glitch During Power Up or Power Down**
- **Improved Functional Replacement for the SGS L293**

NE PACKAGE
(TOP VIEW)



FUNCTION TABLE
(each driver)

INPUTS†		OUTPUT
A	EN	Y
H	H	H
L	H	L
X	L	Z

H = high-level, L = low-level
X = irrelevant
Z = high-impedance (off)
† In the thermal shutdown mode, the output is in a high-impedance state regardless of the input levels.

description

The SN754410 is a quadruple high-current half-H driver designed to provide bidirectional drive currents up to 1 A at voltages from 4.5 V to 36 V. The device is designed to drive inductive loads such as relays, solenoids, dc and bipolar stepping motors, as well as other high-current/high-voltage loads in positive-supply applications.

All inputs are compatible with TTL-and low-level CMOS logic. Each output (Y) is a complete totem-pole driver with a Darlington transistor sink and a pseudo-Darlington source. Drivers are enabled in pairs with drivers 1 and 2 enabled by 1,2EN and drivers 3 and 4 enabled by 3,4EN. When an enable input is high, the associated drivers are enabled and their outputs become active and in phase with their inputs. When the enable input is low, those drivers are disabled and their outputs are off and in a high-impedance state. With the proper data inputs, each pair of drivers form a full-H (or bridge) reversible drive suitable for solenoid or motor applications.

A separate supply voltage (V_{CC1}) is provided for the logic input circuits to minimize device power dissipation. Supply voltage V_{CC2} is used for the output circuits.

The SN754410 is designed for operation from −40°C to 85°C.

TEXAS INSTRUMENTS

POST OFFICE BOX 655303 • DALLAS, TEXAS 75265

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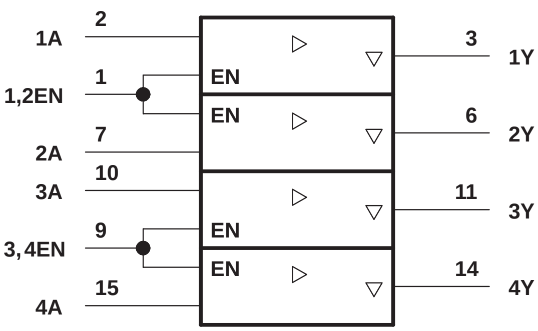
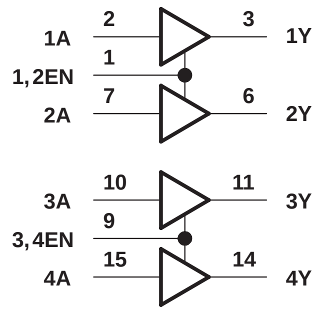
logic symbol†

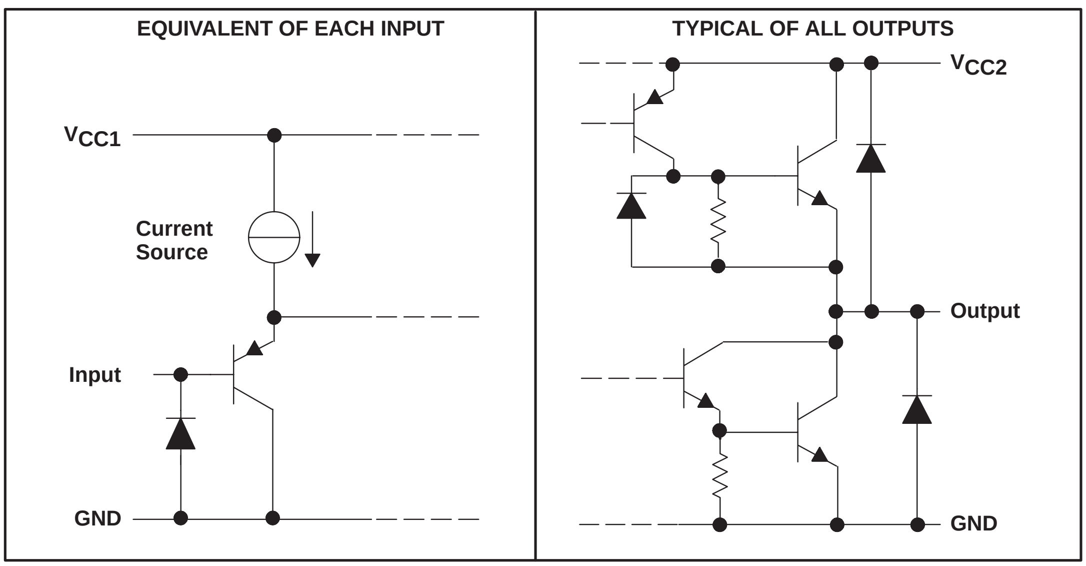


† This symbol is in accordance with ANSI/IEEE Std 91-1984 and IEC Publication 617-12.

logic diagram



schematics of inputs and outputs



TEXAS INSTRUMENTS
POST OFFICE BOX 655303 ● DALLAS, TEXAS 75265
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absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

Output supply voltage range, V_{CC1} (see Note 1)	−0.5 V to 36 V
Output supply voltage range, V_{CC2}	−0.5 V to 36 V
Input voltage, V_I	36 V
Output voltage range, V_O	−3 V to V_{CC2} + 3 V
Peak output current (nonrepetitive, $t_w \leq 5$ ms)	±2 A
Continuous output current, I_O	±1.1 A
Continuous total power dissipation at (or below) 25°C free-air temperature (see Note 2)	2075 mW
Operating free-air temperature range, T_A	−40°C to 85°C
Operating virtual junction temperature range, T_J	−40°C to 150°C
Storage temperature range, T_{stg}	−65°C to 150°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds	260°C

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTES: 1. All voltage values are with respect to network GND.

2. For operation above 25°C free-air temperature, derate linearly at the rate of 16.6 mW/°C. To avoid exceeding the design maximum virtual junction temperature, these ratings should not be exceeded. Due to variations in individual device electrical characteristics and thermal resistance, the built-in thermal overload protection can be activated at power levels slightly above or below the rated dissipation.

recommended operating conditions

	MIN	MAX	UNIT
Output supply voltage, V_{CC1}	4.5	5.5	V
Output supply voltage, V_{CC2}	4.5	36	V
High-level input voltage, V_{IH}	2	5.5	V
Low-level input voltage, V_{IL}	−0.3‡	0.8	V
Operating virtual junction temperature, T_J	−40	125	°C
Operating free-air temperature, T_A	−40	85	°C

‡ The algebraic convention, in which the least positive (most negative) limit is designated as minimum, is used in this data sheet for logic voltage levels.

electrical characteristics over recommended ranges of supply voltage and free-air temperature (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP†	MAX	UNIT
V_{IK}	Input clamp voltage	$I_I = -12$ mA			−0.9	−1.5	V
V_{OH}	High-level output voltage	$I_{OH} = -0.5$ A		$V_{CC2} - 1.5$	$V_{CC2} - 1.1$		V
		$I_{OH} = -1$ A		$V_{CC2} - 2$			
		$I_{OH} = -1$ A, $T_J = 25°C$		$V_{CC2} - 1.8$	$V_{CC2} - 1.4$		
V_{OL}	Low-level output voltage	$I_{OL} = 0.5$ A			1	1.4	V
		$I_{OL} = 1$ A				2	
		$I_{OL} = 1$ A, $T_J = 25°C$			1.2	1.8	
V_{OKH}	High-level output clamp voltage	$I_{OK} = -0.5$ A			$V_{CC2} + 1.4$	$V_{CC2} + 2$	V
		$I_{OK} = 1$ A			$V_{CC2} + 1.9$	$V_{CC2} + 2.5$	
V_{OKL}	Low-level output clamp voltage	$I_{OK} = 0.5$ A			−1.1	−2	V
		$I_{OK} = -1$ A			−1.3	−2.5	
$I_{OZ(off)}$	Off-state high-impedance-state output current	$V_O = V_{CC2}$				500	μA
		$V_O = 0$				−500	
I_{IH}	High-level input current	$V_I = 5.5$ V				10	μA
I_{IL}	Low-level input current	$V_I = 0$				−10	μA
I_{CC1}	Output supply current	$I_O = 0$	All outputs at high level			38	mA
			All outputs at low level			70	
			All outputs at high impedance			25	
I_{CC2}	Output supply current	$I_O = 0$	All outputs at high level			33	mA
			All outputs at low level			20	
			All outputs at high impedance			5	

† All typical values are at $V_{CC1} = 5$ V, $V_{CC2} = 24$ V, $T_A = 25°C$.

switching characteristics, $V_{CC1} = 5$ V, $V_{CC2} = 24$ V, $C_L = 30$ pF, $T_A = 25°C$

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
t_{d1}	Delay time, high-to-low-level output from A input	See Figure 1		400		ns
t_{d2}	Delay time, low-to-high-level output from A input			800		ns
t_{TLH}	Transition time, low-to-high-level output			300		ns
t_{THL}	Transition time, high-to-low-level output			300		ns
t_r	Rise time, pulse input					
t_f	Fall time, pulse input					
t_w	Pulse duration					
t_{en1}	Enable time to the high level	See Figure 2		700		ns
t_{en2}	Enable time to the low level			400		ns
t_{dis1}	Disable time from the high level			900		ns
t_{dis2}	Disable time from the low level			600		ns

PARAMETER MEASUREMENT INFORMATION

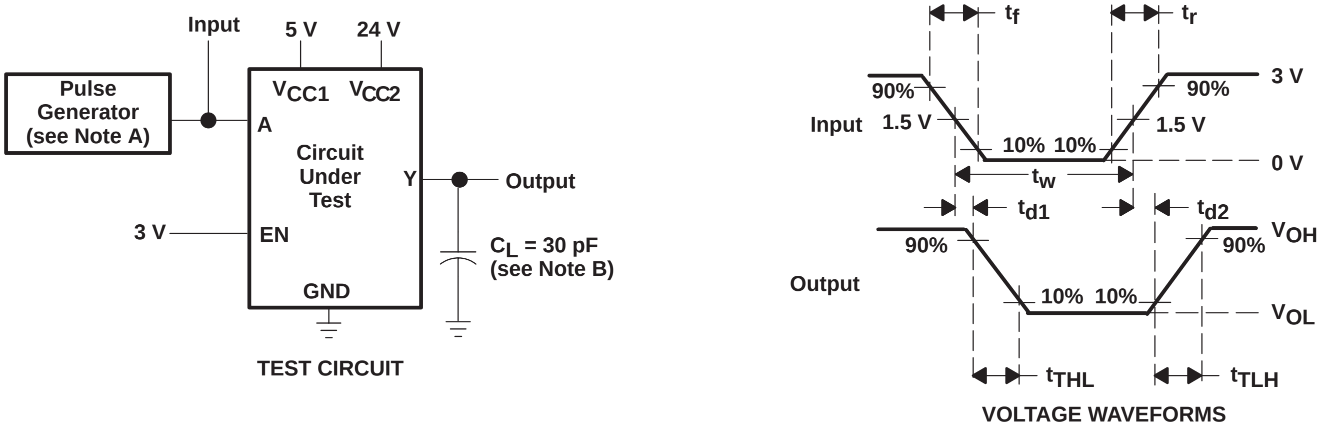

Figure 1. Test Circuit and Switching Times From Data Inputs

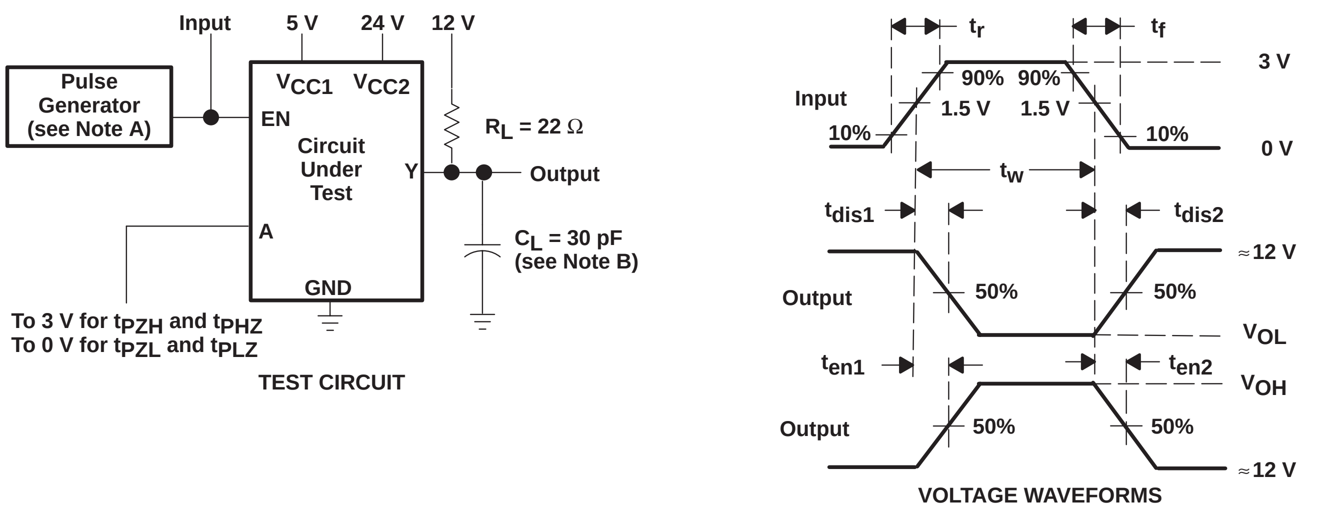

Figure 2. Test Circuit and Switching Times From Enable Inputs

NOTES: A. The pulse generator has the following characteristics: $t_r \leq 10$ ns, $t_f \leq 10$ ns, $t_W = 10$ µs, PRR = 5 kHz, $Z_O = 50\ \Omega$.
B. C_L includes probe and jig capacitance.

APPLICATION INFORMATION

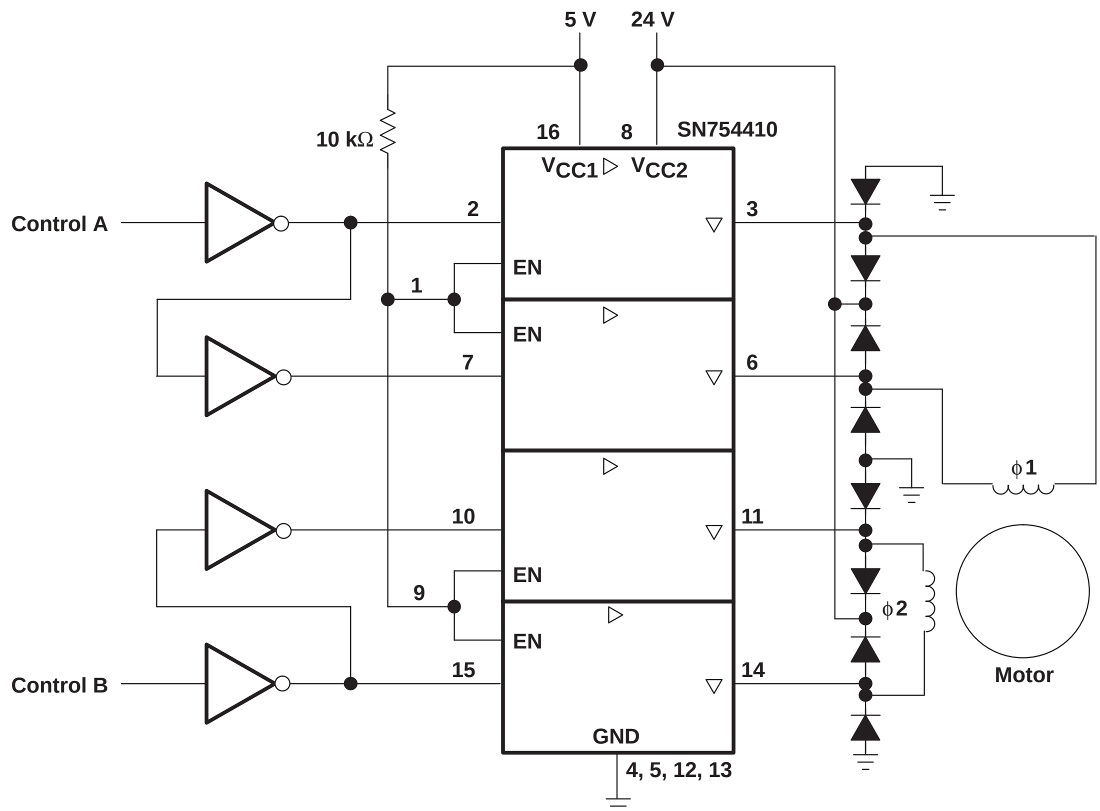

Figure 3. Two-Phase Motor Driver

TEXAS INSTRUMENTS
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PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)
SN754410NE	ACTIVE	PDIP	NE	16	25	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type
SN754410NEE4	ACTIVE	PDIP	NE	16	25	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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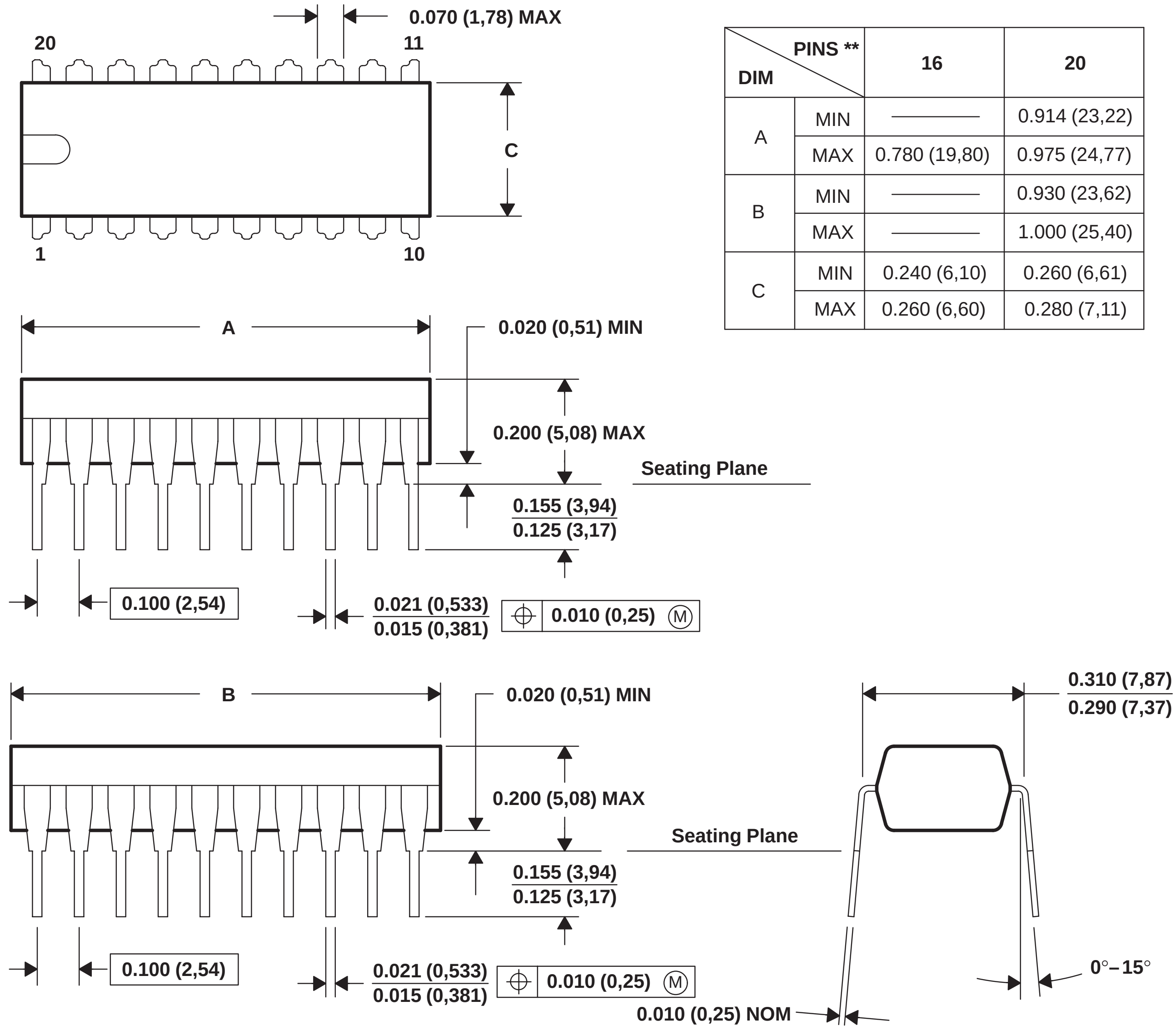
NE (R-PDIP-T**) PLASTIC DUAL-IN-LINE PACKAGE

20 PIN SHOWN



DIM \ PINS **		16	20
A	MIN	———	0.914 (23,22)
	MAX	0.780 (19,80)	0.975 (24,77)
B	MIN	———	0.930 (23,62)
	MAX	———	1.000 (25,40)
C	MIN	0.240 (6,10)	0.260 (6,61)
	MAX	0.260 (6,60)	0.280 (7,11)

NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Falls within JEDEC MS-001 (16 pin only)

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Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Military	www.ti.com/military
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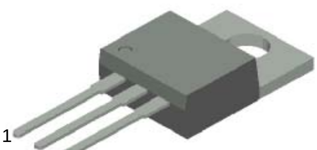
FAIRCHILD SEMICONDUCTOR®

August 2008

TIP145T/146T/147T
PNP Epitaxial Silicon Darlington Transistor

Monolithic Construction With Built In Base-Emitter Shunt Resistors

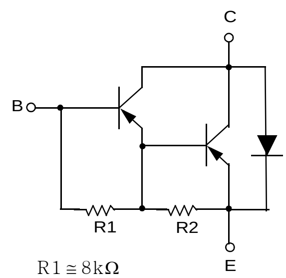
- High DC Current Gain : h_{FE} = 1000@ V_{CE} = - 4V, I_C = - 5A (Min.)
- Industrial Use
- Complement to TIP140T/141T/142T



TO-220

1.Base 2.Collector 3.Emitter

Equivalent Circuit



R1 ≅ 8kΩ
R2 ≅ 0.12kΩ

Absolute Maximum Ratings * T_C=25°C unless otherwise noted

Symbol	Parameter	Value	Units
BV_{CBO}	Collector-Base Voltage : TIP145T : TIP146T : TIP147T	- 60 - 80 - 100	V V V
BV_{CEO}	Collector-Emitter Voltage : TIP145T : TIP146T : TIP147T	- 60 - 80 - 100	V V V
BV_{EBO}	Emitter-Base Voltage	- 5	V
I_C	Collector Current (DC)	- 10	A
I_{CP}	Collector Current (Pulse)	- 15	A
I_B	Base Current (DC)	- 0.5	A
P_C	Collector Dissipation (T_C=25°C)	80	W
T_J	Junction Temperature	150	°C
T_{STG}	Storage Junction Temperature Range	- 65 ~ 150	°C

* These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

Electrical Characteristics * T_C=25°C unless otherwise noted

Symbol	Parameter	Conditions	Min.	Typ.	Max	Units
V_{CEO}(sus)	Collector-Emitter Sustaining Voltage : TIP145T : TIP146T : TIP147T	I_C = - 30mA, I_B = 0	- 60 - 80 - 100			V V V
I_{CEO}	Collector Cut-off Current : TIP145T : TIP146T : TIP147T	V_{CE} = - 30V, I_B = 0 V_{CE} = - 40V, I_B = 0 V_{CE} = - 50V, I_B = 0			- 2 - 2 - 2	mA mA mA
I_{CBO}	Collector Cut-off Current : TIP145T : TIP146T : TIP147T	V_{CB} = - 60V, I_E = 0 V_{CB} = - 80V, I_E = 0 V_{CB} = - 100V, I_E = 0			- 1 - 1 - 1	mA mA mA
I_{EBO}	Emitter Cut-off Current	V_{BE} = - 5V, I_C = 0			- 2	mA
h_{FE}	DC Current Gain	V_{CE} = - 4V, I_C = - 5A V_{CE} = - 4V, I_C = - 10A	1000 500			
V_{CE}(sat)	Collector-Emitter Saturation Voltage	I_C = - 5A, I_B = - 10mA I_C = - 10A, I_B = - 40mA			- 2 - 3	V V
V_{BE}(sat)	Base-Emitter Saturation Voltage	I_C = - 10A, I_B = - 40mA			- 3.5	V
V_{BE}(on)	Base-Emitter On Voltage	V_{CE} = - 4V, I_C = - 10A			- 3	V
t_d	Delay Time	V_{CC} = - 30V, I_C = - 5A I_{B1} = -20mA, I_{B2} = 20mA R_L = 6Ω		0.15		μs
t_r	Rise Time			0.55		μs
t_{stg}	Storage Time			2.5		μs
t_f	Fall Time			2.5		μs

* Pulse Test: Pulse Width≤300μs, Duty Cycle≤2%

Typical Characteristics

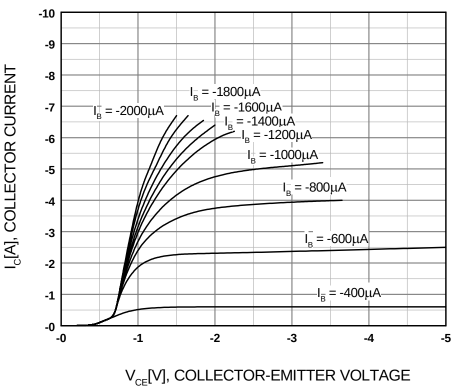


Figure 1. Static Characteristic

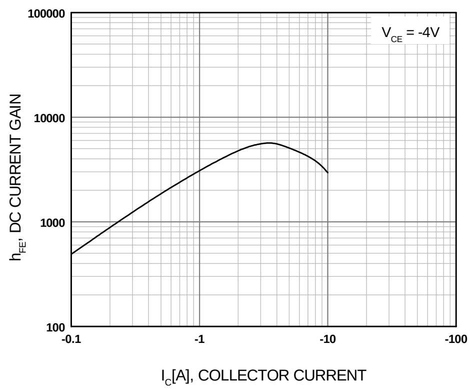


Figure 2. DC current Gain

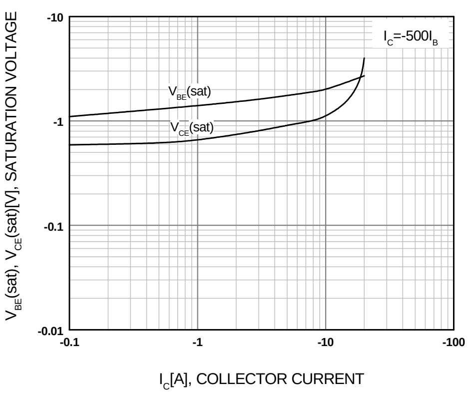


Figure 3. Collector-Emitter Saturation Voltage Base-Emitter Saturation Voltage

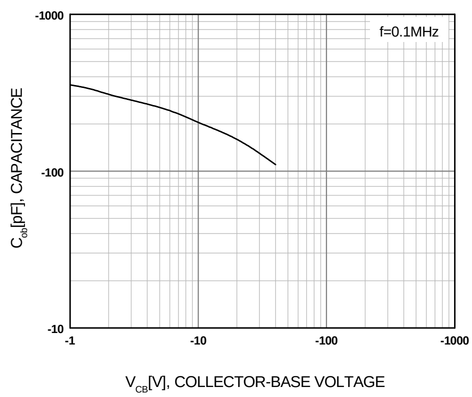


Figure 4. Collector Output Capacitance

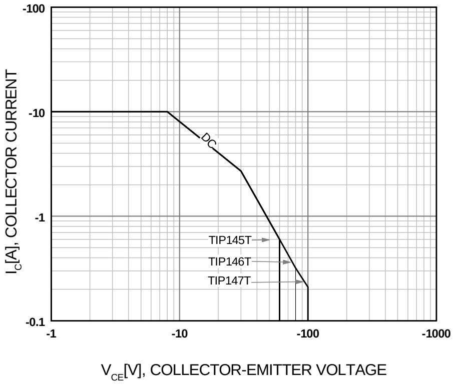


Figure 5. Safe Operating Area

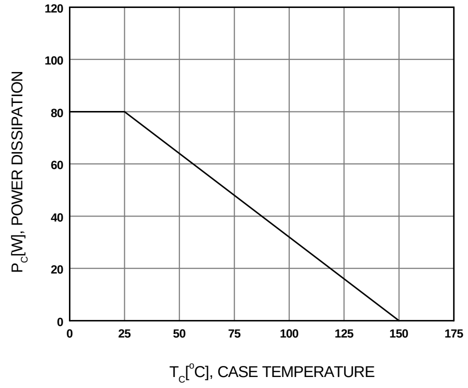
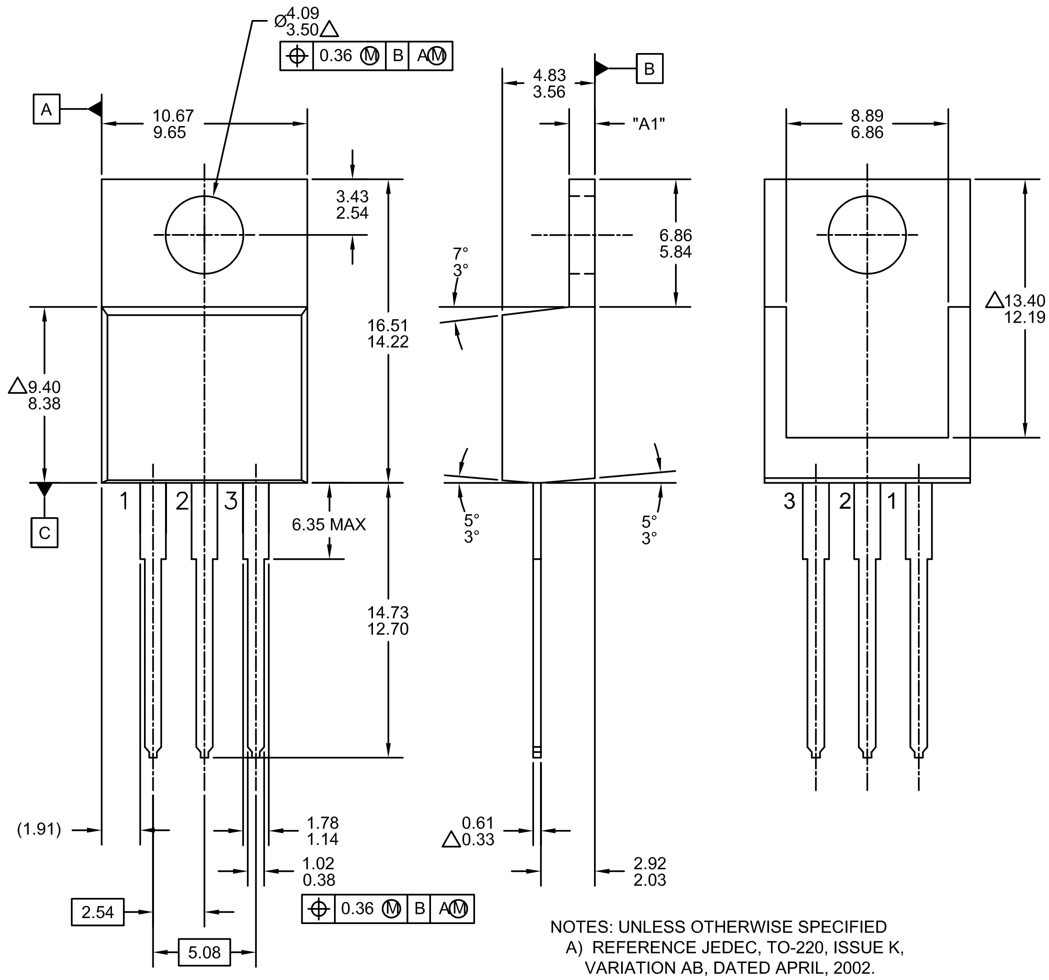
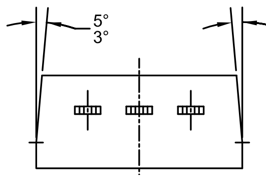


Figure 6. Power Derating

Mechanical Dimensions

TO220





NOTES: UNLESS OTHERWISE SPECIFIED
A) REFERENCE JEDEC, TO-220, ISSUE K, VARIATION AB, DATED APRIL, 2002.
B) ALL DIMENSIONS ARE IN MILLIMETERS.
C) DIMENSIONING AND TOLERANCING PER ANSI Y14.5 - 1973
D) LOCATION OF THE PIN HOLE MAY VARY (LOWER LEFT CORNER, LOWER CENTER AND CENTER OF THE PACKAGE)
E) DOES NOT COMPLY JEDEC STANDARD VALUE.
F) "A1" DIMENSIONS REPRESENT LIKE BELOW:
SINGLE GAUGE = 0.51 - 0.61
DUAL GAUGE = 1.14 - 1.40
G) DRAWING FILE NAME: TO220B03REV6

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Datasheet Identification	Product Status	Definition
Advance Information	Formative / In Design	Datasheet contains the design specifications for product development. Specifications may change in any manner without notice.
Preliminary	First Production	Datasheet contains preliminary data; supplementary data will be published at a later date. Fairchild Semiconductor reserves the right to make changes at any time without notice to improve design.
No Identification Needed	Full Production	Datasheet contains final specifications. Fairchild Semiconductor reserves the right to make changes at any time without notice to improve the design.
Obsolete	Not In Production	Datasheet contains specifications on a product that is discontinued by Fairchild Semiconductor. The datasheet is for reference information only.

Rev. I35

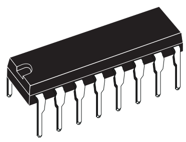
ULN2001, ULN2002
ULN2003, ULN2004

Seven Darlington array

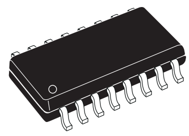
Datasheet — production data

Features

- Seven Darlingtons per package
- Output current 500 mA per driver (600 mA peak)
- Output voltage 50 V
- Integrated suppression diodes for inductive loads
- Outputs can be paralleled for higher current
- TTL/CMOS/PMOS/DTL compatible inputs
- Inputs pinned opposite outputs to simplify layout



DIP-16



SO-16 (Narrow)

Description

The ULN2001, ULN2002, ULN2003 and ULN 2004 are high voltage, high current Darlington arrays each containing seven open collector Darlington pairs with common emitters. Each channel rated at 500 mA and can withstand peak currents of 600 mA. Suppression diodes are included for inductive load driving and the inputs are pinned opposite the outputs to simplify board layout.

The versions interface to all common logic families:

- ULN2001 (general purpose, DTL, TTL, PMOS, CMOS)
- ULN2002 (14 - 25 V PMOS)
- ULN2003 (5 V TTL, CMOS)
- ULN2004 (6 - 15 V CMOS, PMOS)

These versatile devices are useful for driving a wide range of loads including solenoids, relays DC motors, LED displays filament lamps, thermal printheads and high power buffers.

The ULN2001A/2002A/2003A and 2004A are supplied in 16 pin plastic DIP packages with a copper leadframe to reduce thermal resistance. They are available also in small outline package (SO-16) as ULN2001D1/2002D1/2003D1/ 2004D1

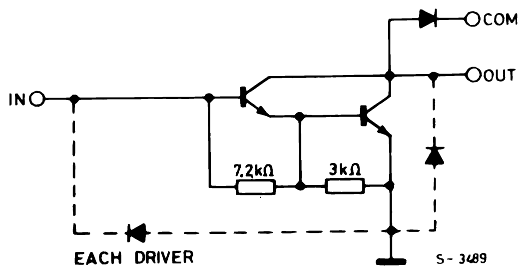
Table 1. Device summary

Order codes	
ULN2001A	ULN2001D1013TR
ULN2002A	ULN2002D1013TR
ULN2003A	ULN2003D1013TR
ULN2004A	ULN2004D1013TR

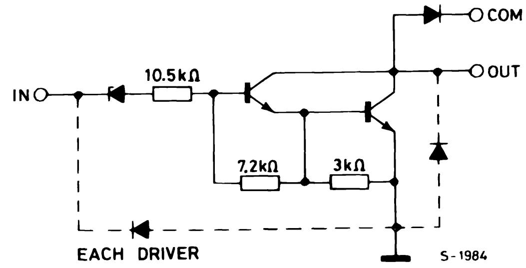
Contents

1 Diagram

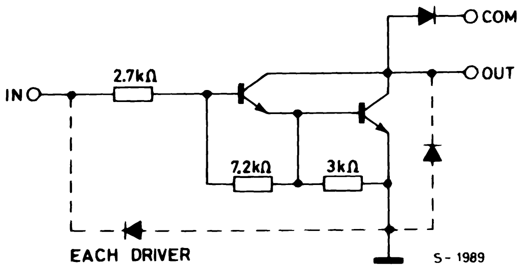
Figure 1. Schematic diagram



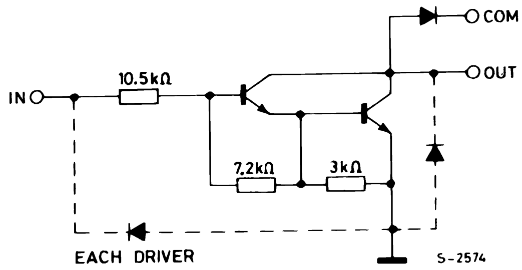
ULN2001 (each driver)



ULN2002 (each driver)



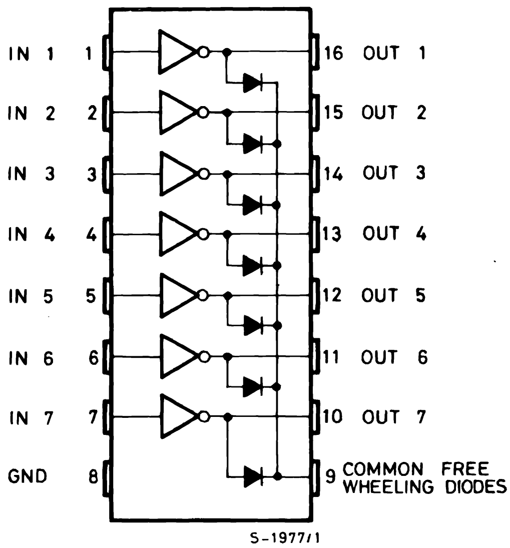
ULN2003 (each driver)



ULN2004 (each driver)

2 Pin configuration

Figure 2. Pin connections (top view)



3 Maximum ratings

Table 2. Absolute maximum ratings

Symbol	Parameter	Value	Unit
V_O	Output voltage	50	V
V_I	Input voltage (for ULN2002A/D - 2003A/D - 2004A/D)	30	V
I_C	Continuous collector current	500	mA
I_B	Continuous base current	25	mA
T_A	Operating ambient temperature range	- 40 to 85	°C
T_{STG}	Storage temperature range	- 55 to 150	°C
T_J	Junction temperature	150	°C

Table 3. Thermal data

Symbol	Parameter	DIP-16	SO-16	Unit
R_{thJA}	Thermal resistance junction-ambient, Max.	70	120	°C/W

4 Electrical characteristics

T_A = 25 °C unless otherwise specified.

Table 4. Electrical characteristics

Symbol	Parameter	Test condition	Min.	Typ.	Max.	Unit
I_{CEX}	Output leakage current	V_{CE} = 50 V, (Figure 3.)			50	µA
		T_A = 85°C, V_{CE} = 50 V (Figure 3.)			100	
		T_A = 85°C for ULN2002, V_{CE} = 50 V, V_I = 6 V (Figure 4.)			500	
		T_A = 85°C for ULN2002, V_{CE} = 50 V, V_I = 1V (Figure 4.)			500	
$V_{CE(SAT)}$	Collector-emitter saturation voltage (Figure 5.)	I_C = 100 mA, I_B = 250 µA		0.9	1.1	V
		I_C = 200 mA, I_B= 350 µA		1.1	1.3	
		I_C = 350 mA, I_B= 500 µA		1.3	1.6	
$I_{I(ON)}$	Input current (Figure 6.)	for ULN2002, V_I = 17 V		0.82	1.25	mA
		for ULN2003, V_I = 3.85 V		0.93	1.35	
		for ULN2004, V_I = 5 V		0.35	0.5	
		V_I = 12 V		1	1.45	
$I_{I(OFF)}$	Input current (Figure 7.)	T_A = 85°C, I_C = 500 µA	50	65		µA
$V_{I(ON)}$	Input voltage (Figure 8.)	V_{CE}= 2 V, for ULN2002 I_C = 300 mA for ULN2003 I_C = 200 mA I_C = 250 mA I_C = 300 mA for ULN2004 I_C = 125 mA I_C = 200 mA I_C = 275 mA I_C = 350 mA			 13 2.4 2.7 3 5 6 7 8	V
h_{FE}	DC Forward current gain (Figure 5.)	for ULN2001, V_{CE} = 2 V, I_C = 350 mA	1000			
C_I	Input capacitance			15	25	pF
t_{PLH}	Turn-on delay time	0.5 V_I to 0.5 V_O		0.25	1	µs
t_{PHL}	Turn-off delay time	0.5 V_I to 0.5 V_O		0.25	1	µs
I_R	Clamp diode leakage current (Figure 9.)	V_R = 50 V			50	µA
		T_A = 85°C, V_R = 50 V			100	
V_F	Clamp diode forward voltage (Figure 10.)	I_F = 350 mA		1.7	2	V

5 Test circuits

Figure 3. Output leakage current

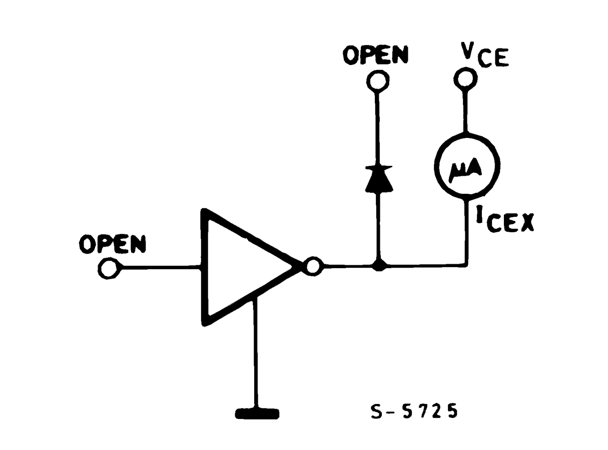


Figure 4. Output leakage current (for ULN2002 only)

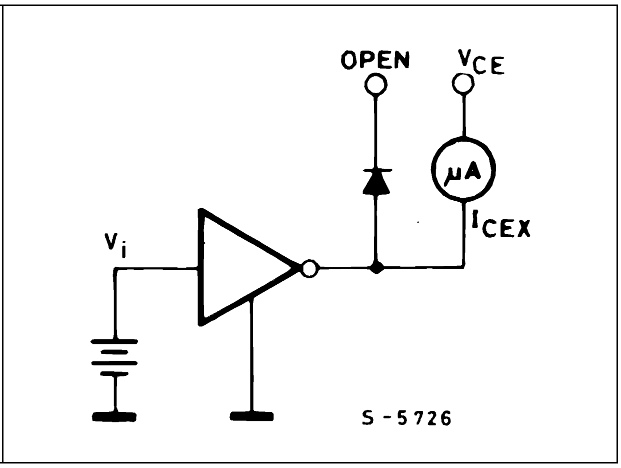


Figure 5. Collector-emitter saturation voltage

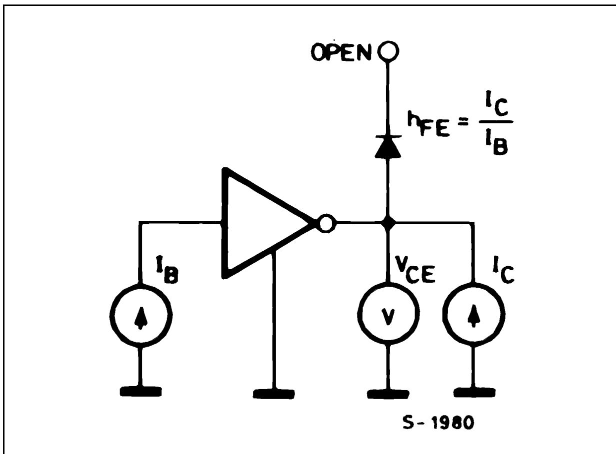


Figure 6. Input current (ON)

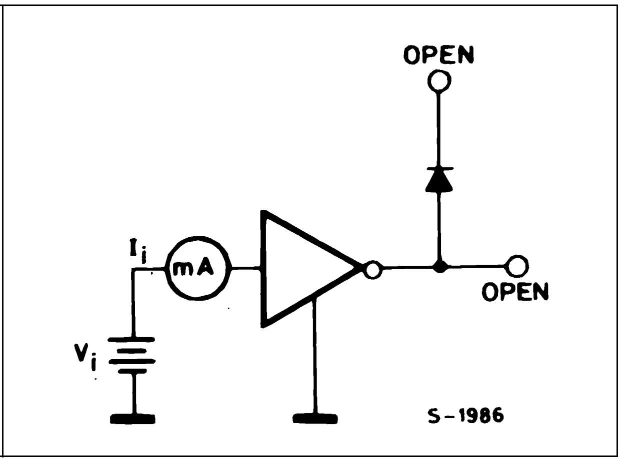


Figure 7. Input current (OFF)

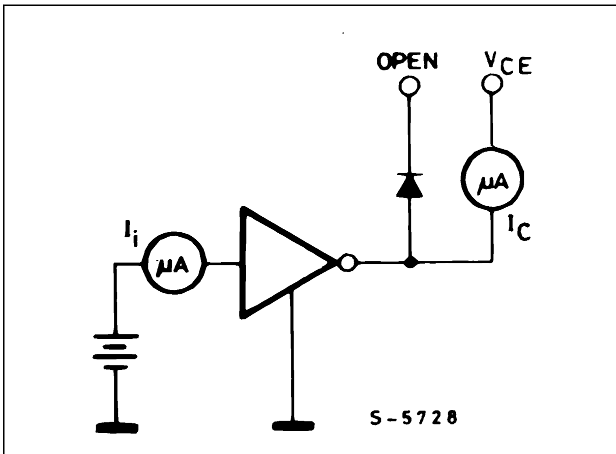


Figure 8. Input voltage

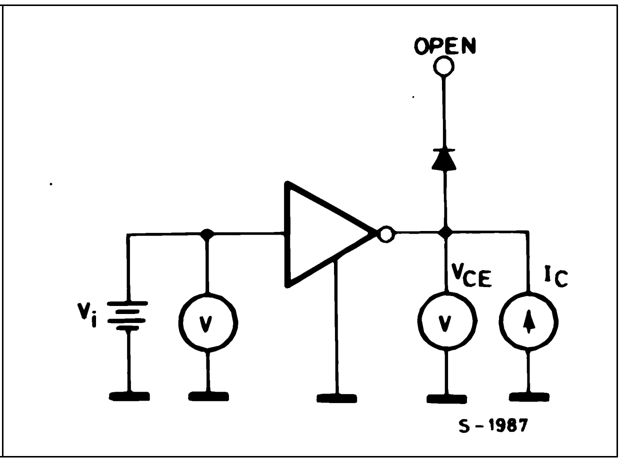


Figure 9. Clamp diode leakage current

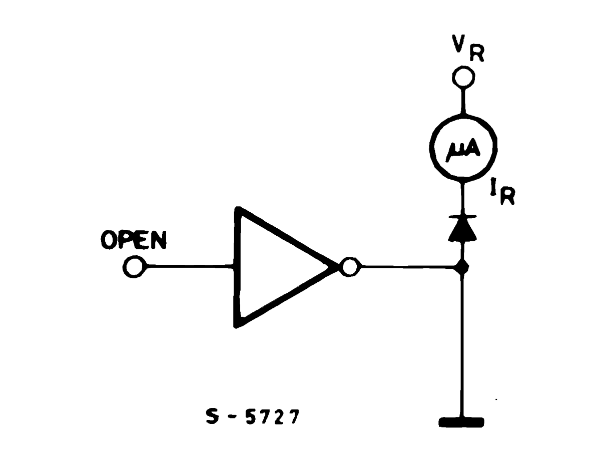
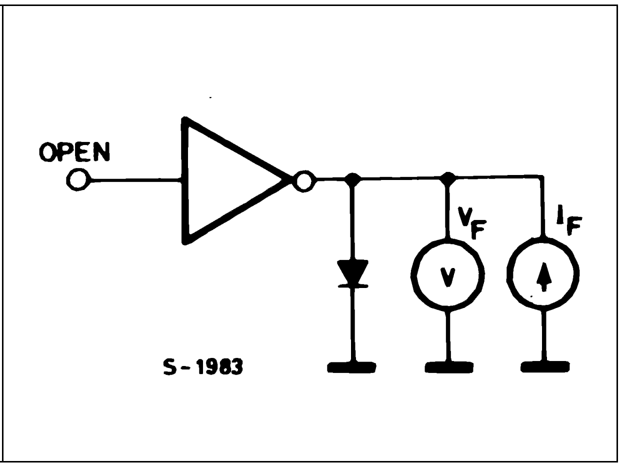


Figure 10. Clamp diode forward voltage



6 Typical performance characteristics

Figure 11. Collector current vs. saturation voltage (T_J = 25°C)

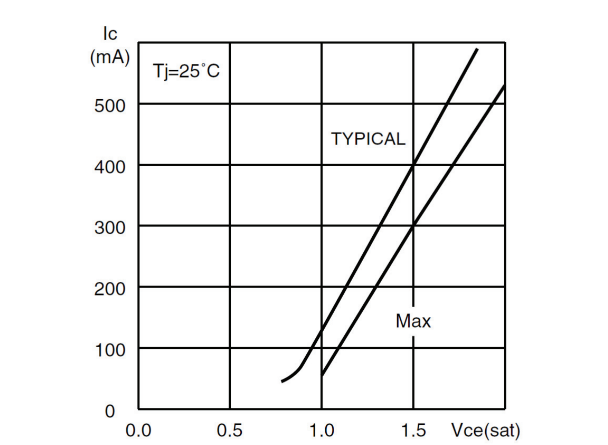


Figure 12. Collector current vs. saturation voltage

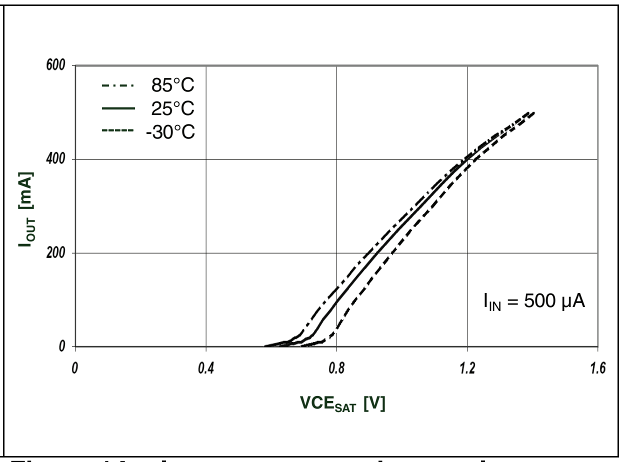


Figure 13. Input current vs. input voltage

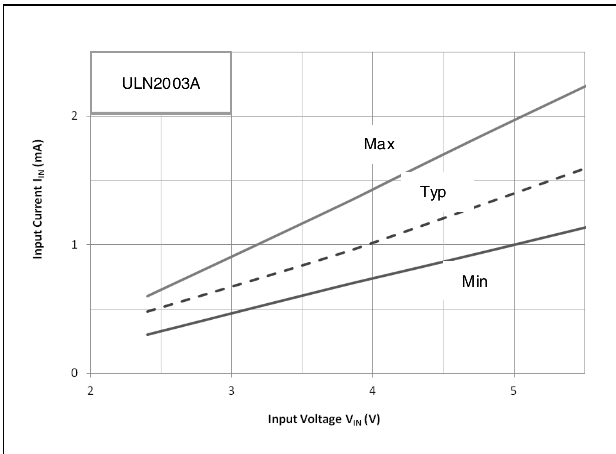


Figure 14. Input current vs. input voltage (Ta = 25°C)

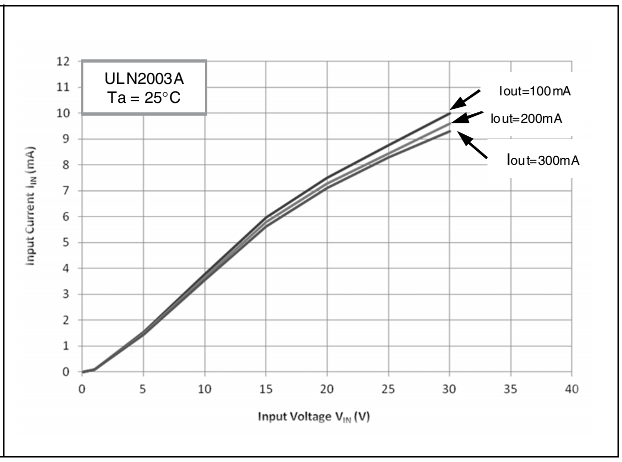


Figure 15. Collector current vs. input current

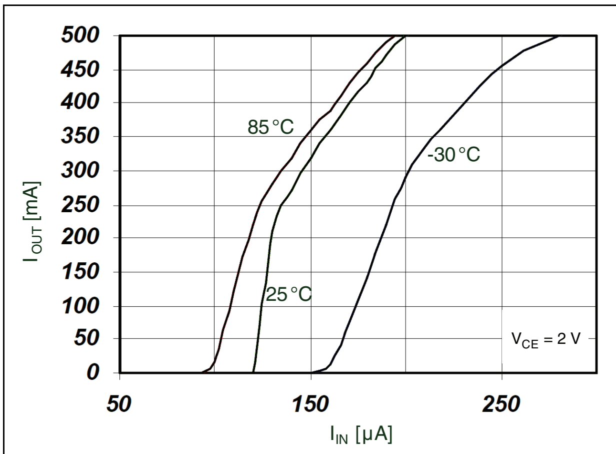


Figure 16. h_{FE} vs. output current

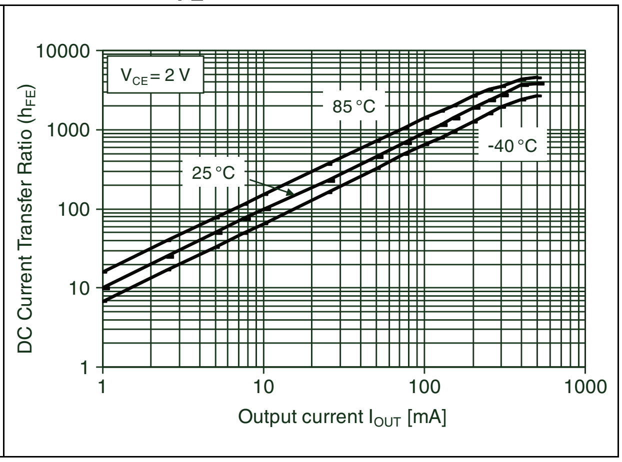


Figure 17. Peak collector current vs. duty cycle (DIP-16)

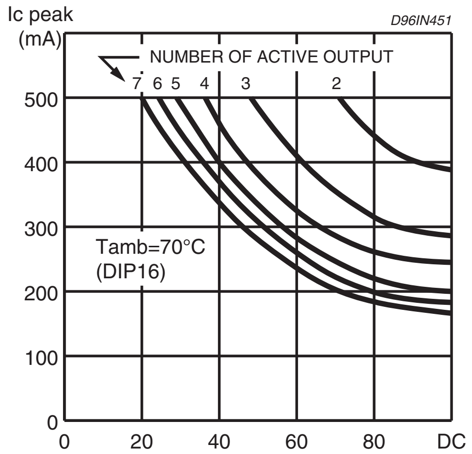
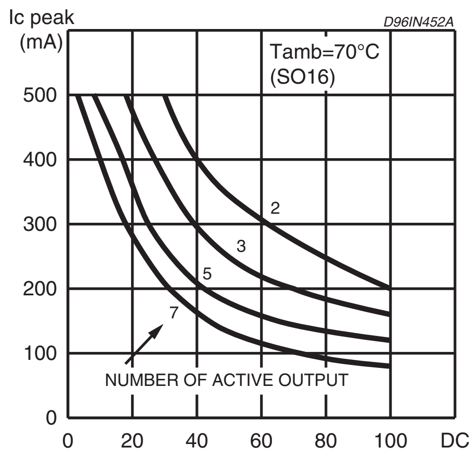


Figure 18. Peak collector current vs. duty cycle (SO-16)



7 Package mechanical data

In order to meet environmental requirements, ST offers these devices in different grades of ECOPACK® packages, depending on their level of environmental compliance. ECOPACK® specifications, grade definitions and product status are available at: www.st.com. ECOPACK® is an ST trademark.

Table 5. DIP-16L mechanical data

Dim.	mm.		
	Min.	Typ.	Max.
A			5.33
A1	0.38		
A2	2.92	3.30	4.95
b	0.36	0.46	0.56
b2	1.14	1.52	1.78
c	0.20	0.25	0.36
D	18067	19.18	19.69
E	7.62	7.87	8.26
E1	6.10	6.35	7.11
e		2.54	
e1		17.78	
eA		7.62	
eB			10.92
L	2.92	3.30	3.81

Figure 19. DIP-16L package dimensions

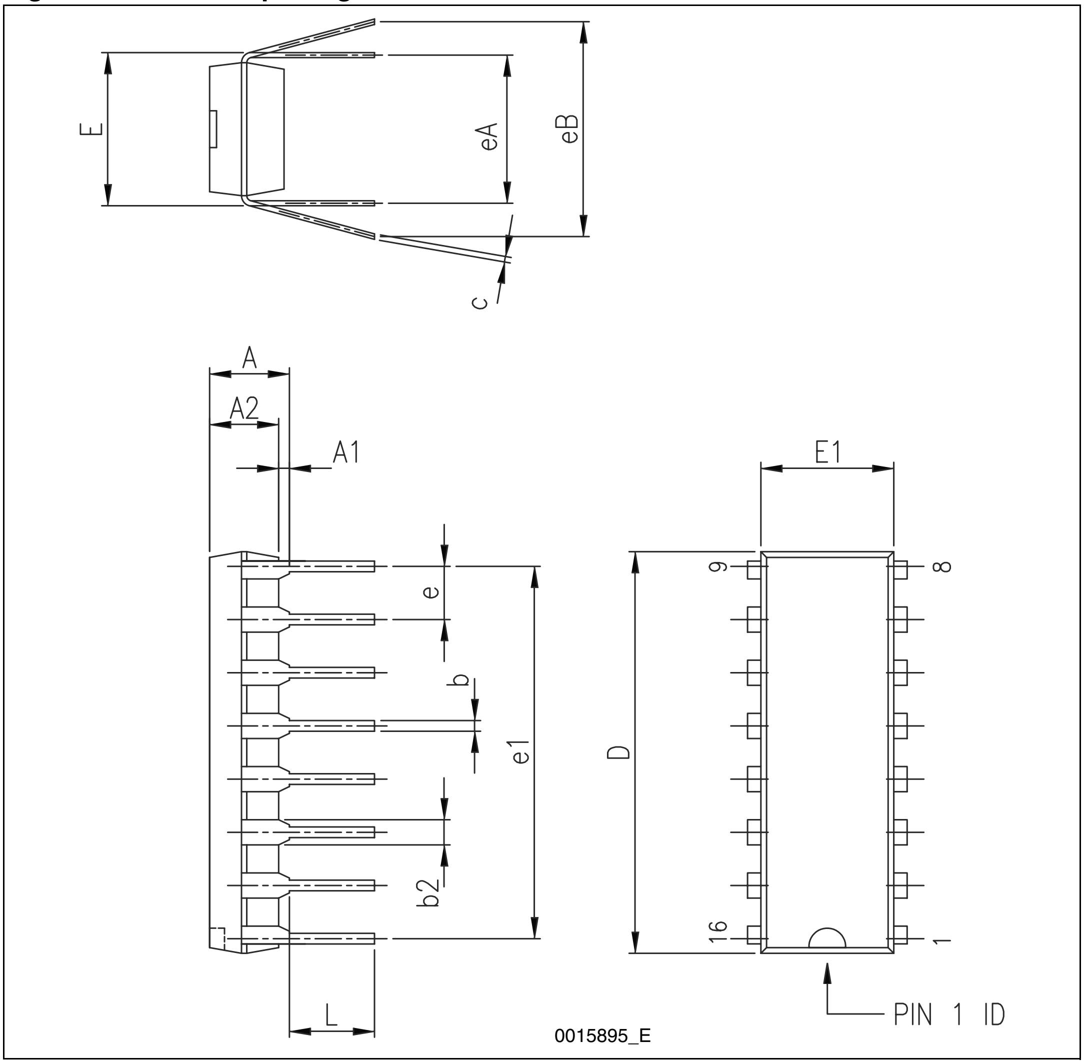
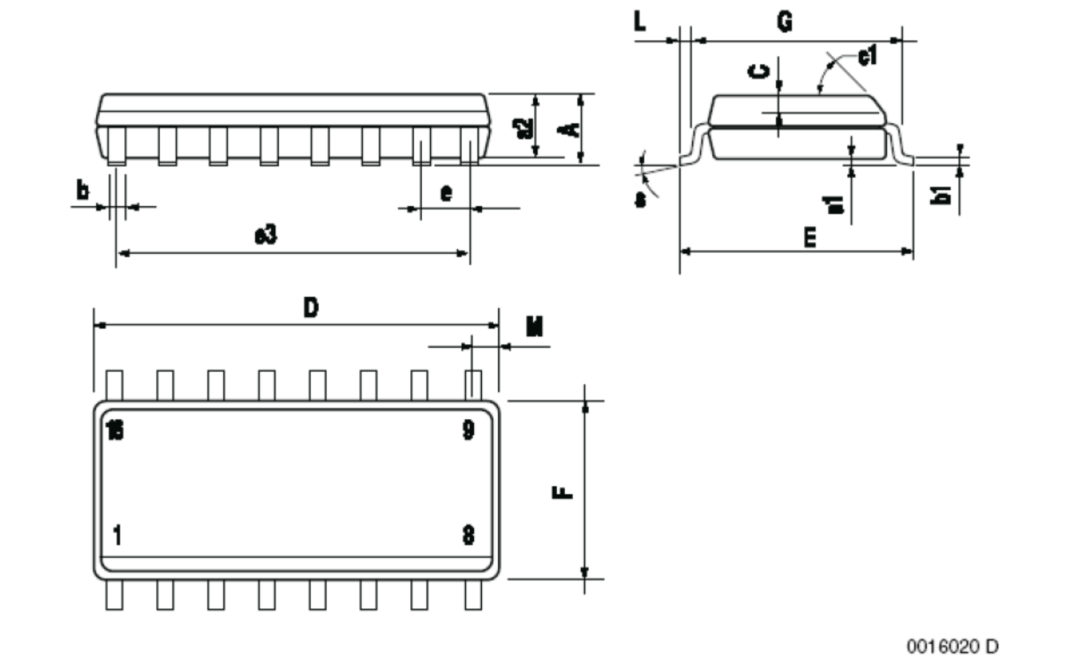


Table 6. SO-16 narrow mechanical data

Dim.	mm.			inch.		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A			1.75			0.069
a1	0.1		0.25	0.004		0.009
a2			1.6			0.063
b	0.35		0.46	0.014		0.018
b1	0.19		0.25	0.007		0.010
C		0.5			0.020	
c1			45°	(typ.)		
D(1)	9.8		10	0.386		0.394
E	5.8		6.2	0.228		0.244
e		1.27			0.050	
e3		8.89			0.350	
F(1)	3.8		4.0	0.150		0.157
G	4.60		5.30	0.181		0.208
L	0.4		1.27	0.150		0.050
M			0.62			0.024
S	8° (max.)					

Figure 20. SO-16 package dimensions



8 Order codes

Table 7. Order codes

Part numbers	Packages
ULN2001A	DIP-16
ULN2002A	DIP-16
ULN2003A	DIP-16
ULN2004A	DIP-16
ULN2001D1013TR	SO-16 in tape and reel
ULN2002D1013TR	SO-16 in tape and reel
ULN2003D1013TR	SO-16 in tape and reel
ULN2004D1013TR	SO-16 in tape and reel

9 Revision history

Table 8. Revision history

Date	Revision	Changes
05-Dec-2006	5	Order code updated and document reformatted.
28-Aug-2007	6	Added *Table 1* in cover page.
07-May-2012	7	Modified: *Figure 12 on page 9*. Added: *Figure 13*, *14*, *15* and *Figure 16 on page 9*.
01-Jun-2012	8	Updated: DIP-16L package mechanical data *Table 5 on page 11* and *Figure 19 on page 12*.

PIC18F2525/2620/4525/4620 Data Sheet

28/40/44-Pin
Enhanced Flash Microcontrollers
with 10-Bit A/D and nanoWatt Technology

Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as "unbreakable."

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break Microchip's code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.

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CERTIFIED BY DNV
ISO/TS 16949:2002

Microchip received ISO/TS-16949:2002 quality system certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona and Mountain View, California in October 2003. The Company's quality system processes and procedures are for its PICmicro® 8-bit MCUs, KEELOQ® code hopping devices, Serial EEPROMs, microperipherals, nonvolatile memory and analog products. In addition, Microchip's quality system for the design and manufacture of development systems is ISO 9001:2000 certified.

PIC18F2525/2620/4525/4620

28/40/44-Pin Enhanced Flash Microcontrollers with 10-Bit A/D and nanoWatt Technology

Power Managed Modes:

- Run: CPU on, peripherals on
- Idle: CPU off, peripherals on
- Sleep: CPU off, peripherals off
- Idle mode currents down to 2.5 µA typical
- Sleep mode current down to 100 nA typical
- Timer1 Oscillator: 1.8 µA, 32 kHz, 2V
- Watchdog Timer: 1.4 µA, 2V typical
- Two-Speed Oscillator Start-up

Flexible Oscillator Structure:

- Four Crystal modes, up to 40 MHz
- 4x Phase Lock Loop (PLL) – available for crystal and internal oscillators)
- Two External RC modes, up to 4 MHz
- Two External Clock modes, up to 40 MHz
- Internal oscillator block:
  - 8 user selectable frequencies, from 31 kHz to 8 MHz
  - Provides a complete range of clock speeds from 31 kHz to 32 MHz when used with PLL
  - User tunable to compensate for frequency drift
- Secondary oscillator using Timer1 @ 32 kHz
- Fail-Safe Clock Monitor
  - Allows for safe shutdown if peripheral clock stops

Peripheral Highlights:

- High-current sink/source 25 mA/25 mA
- Three programmable external interrupts
- Four input change interrupts
- Up to 2 Capture/Compare/PWM (CCP) modules, one with Auto-Shutdown (28-pin devices)
- Enhanced Capture/Compare/PWM (ECCP) module (40/44-pin devices only):
  - One, two or four PWM outputs
  - Selectable polarity
  - Programmable dead time
  - Auto-Shutdown and Auto-Restart

Peripheral Highlights (Continued):

- Master Synchronous Serial Port (MSSP) module supporting 3-wire SPI™ (all 4 modes) and I²C™ Master and Slave modes
- Enhanced Addressable USART module:
  - Supports RS-485, RS-232 and LIN 1.2
  - RS-232 operation using internal oscillator block (no external crystal required)
  - Auto-Wake-up on Start bit
  - Auto-Baud Detect
- 10-bit, up to 13-channel Analog-to-Digital Converter module (A/D):
  - Auto-acquisition capability
  - Conversion available during Sleep
- Dual analog comparators with input multiplexing
- Programmable 16-level High/Low-Voltage Detection (HLVD) module:
  - Supports interrupt on High/Low-Voltage Detection

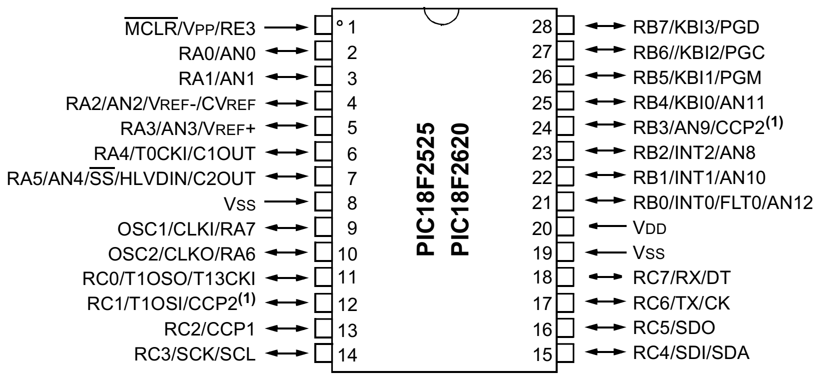
Special Microcontroller Features:

- C compiler optimized architecture:
  - Optional extended instruction set designed to optimize re-entrant code
- 100,000 erase/write cycle Enhanced Flash program memory typical
- 1,000,000 erase/write cycle Data EEPROM memory typical
- Flash/Data EEPROM Retention: 100 years typical
- Self-programmable under software control
- Priority levels for interrupts
- 8 x 8 Single Cycle Hardware Multiplier
- Extended Watchdog Timer (WDT):
  - Programmable period from 4 ms to 131s
- Single-supply 5V In-Circuit Serial Programming™ (ICSP™) via two pins
- In-Circuit Debug (ICD) via two pins
- Wide operating voltage range: 2.0V to 5.5V
- Programmable Brown-out Reset (BOR) with software enable option

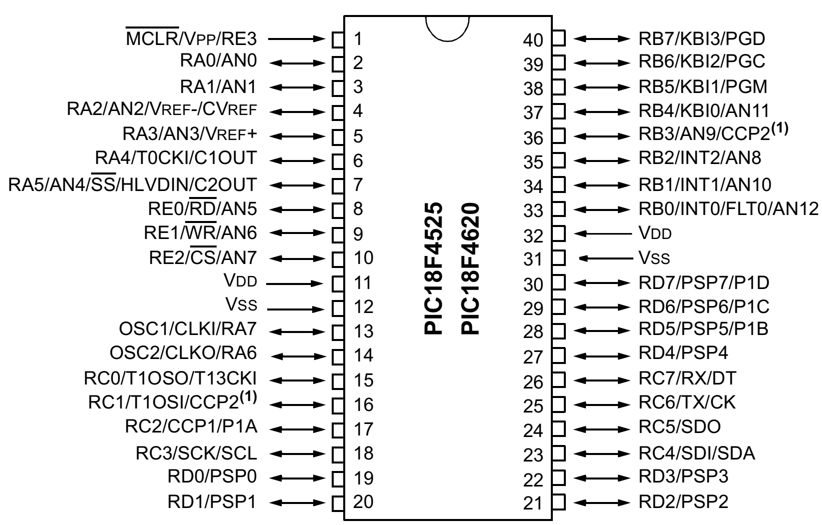
Device	Program Memory		Data Memory		I/O	10-bit A/D (ch)	CCP/ ECCP (PWM)	MSSP		EUSART	Comp.	Timers 8/16-bit
	Flash (bytes)	# Single-Word Instructions	SRAM (bytes)	EEPROM (bytes)				SPI™	Master I²C™			
PIC18F2525	48K	24576	3986	1024	25	10	2/0	Y	Y	1	2	1/3
PIC18F2620	64K	32768	3986	1024	25	10	2/0	Y	Y	1	2	1/3
PIC18F4525	48K	24576	3986	1024	36	13	1/1	Y	Y	1	2	1/3
PIC18F4620	64K	32768	3986	1024	36	13	1/1	Y	Y	1	2	1/3

Pin Diagrams

28-Pin SPDIP, SOIC



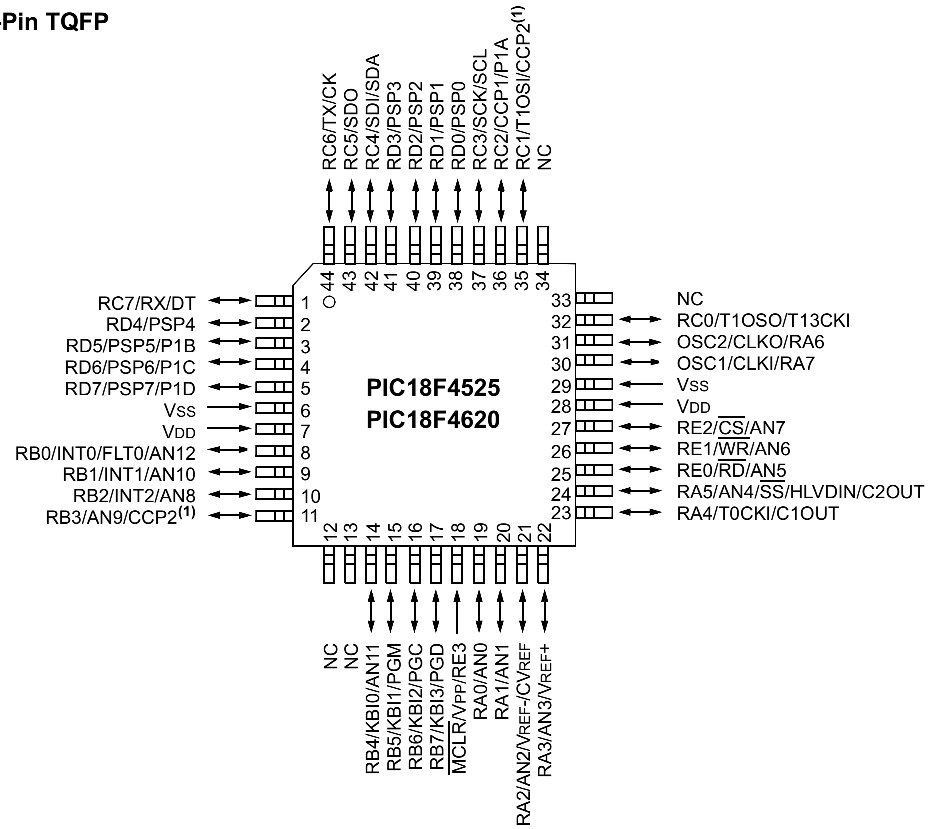
40-Pin PDIP



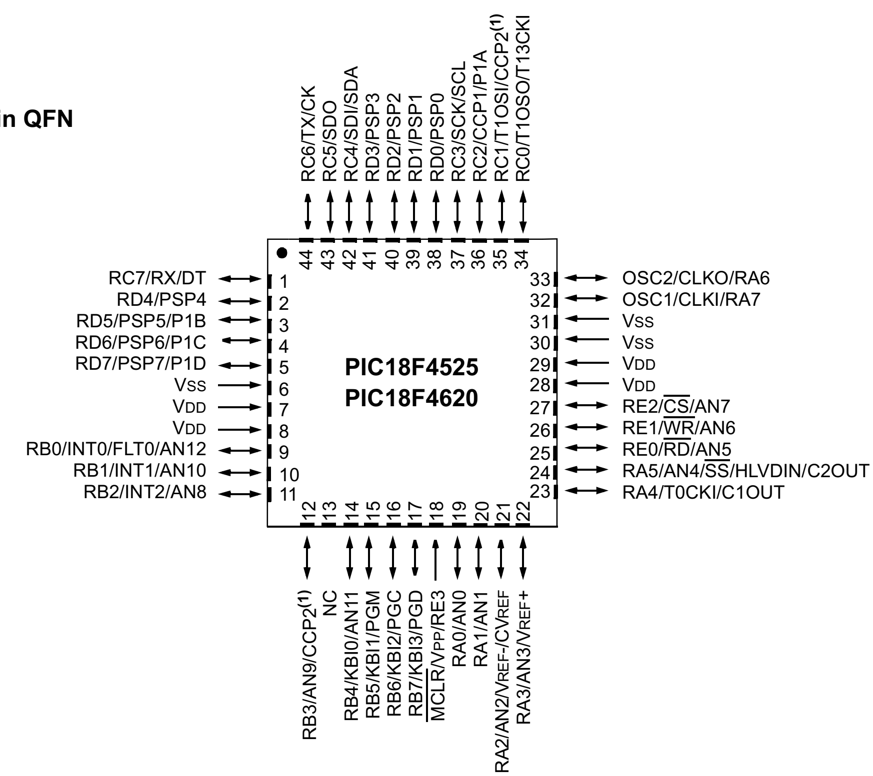
Note 1: RB3 is the alternate pin for CCP2 multiplexing.

Pin Diagrams (Cont.'d)

44-Pin TQFP



44-Pin QFN



Note 1: RB3 is the alternate pin for CCP2 multiplexing.

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NOTES:

1.0 DEVICE OVERVIEW

This document contains device specific information for the following devices:

- PIC18F2525
- PIC18F2620
- PIC18F4525
- PIC18F4620
- PIC18LF2525
- PIC18LF2620
- PIC18LF4525
- PIC18LF4620

This family offers the advantages of all PIC18 microcontrollers – namely, high computational performance at an economical price – with the addition of high endurance, Enhanced Flash program memory. On top of these features, the PIC18F2525/2620/4525/4620 family introduces design enhancements that make these microcontrollers a logical choice for many high-performance, power sensitive applications.

1.1 New Core Features

1.1.1 nanoWatt TECHNOLOGY

All of the devices in the PIC18F2525/2620/4525/4620 family incorporate a range of features that can significantly reduce power consumption during operation. Key items include:

- **Alternate Run Modes:** By clocking the controller from the Timer1 source or the internal oscillator block, power consumption during code execution can be reduced by as much as 90%.
- **Multiple Idle Modes:** The controller can also run with its CPU core disabled but the peripherals still active. In these states, power consumption can be reduced even further, to as little as 4% of normal operation requirements.
- **On-the-fly Mode Switching:** The power managed modes are invoked by user code during operation, allowing the user to incorporate power-saving ideas into their application's software design.
- **Low Consumption in Key Modules:** The power requirements for both Timer1 and the Watchdog Timer are minimized. See **Section 26.0 "Electrical Characteristics"** for values.

1.1.2 MULTIPLE OSCILLATOR OPTIONS AND FEATURES

All of the devices in the PIC18F2525/2620/4525/4620 family offer ten different oscillator options, allowing users a wide range of choices in developing application hardware. These include:

- Four Crystal modes, using crystals or ceramic resonators
- Two External Clock modes, offering the option of using two pins (oscillator input and a divide-by-4 clock output) or one pin (oscillator input, with the second pin reassigned as general I/O)
- Two External RC Oscillator modes with the same pin options as the External Clock modes
- An internal oscillator block which provides an 8 MHz clock and an INTRC source (approximately 31 kHz), as well as a range of 6 user selectable clock frequencies, between 125 kHz to 4 MHz, for a total of 8 clock frequencies. This option frees the two oscillator pins for use as additional general purpose I/O.
- A Phase Lock Loop (PLL) frequency multiplier, available to both the high-speed crystal and internal oscillator modes, which allows clock speeds of up to 40 MHz. Used with the internal oscillator, the PLL gives users a complete selection of clock speeds, from 31 kHz to 32 MHz – all without using an external crystal or clock circuit.

Besides its availability as a clock source, the internal oscillator block provides a stable reference source that gives the family additional features for robust operation:

- **Fail-Safe Clock Monitor:** This option constantly monitors the main clock source against a reference signal provided by the internal oscillator. If a clock failure occurs, the controller is switched to the internal oscillator block, allowing for continued low-speed operation or a safe application shutdown.
- **Two-Speed Start-up:** This option allows the internal oscillator to serve as the clock source from Power-on Reset, or wake-up from Sleep mode, until the primary clock source is available.

1.2 Other Special Features

- **Memory Endurance:** The Enhanced Flash cells for both program memory and data EEPROM are rated to last for many thousands of erase/write cycles – up to 100,000 for program memory and 1,000,000 for EEPROM. Data retention without refresh is conservatively estimated to be greater than 40 years.
- **Self-programmability:** These devices can write to their own program memory spaces under internal software control. By using a bootloader routine located in the protected Boot Block at the top of program memory, it becomes possible to create an application that can update itself in the field.
- **Extended Instruction Set:** The PIC18F2525/2620/4525/4620 family introduces an optional extension to the PIC18 instruction set, which adds 8 new instructions and an Indexed Addressing mode. This extension, enabled as a device configuration option, has been specifically designed to optimize re-entrant application code originally developed in high-level languages, such as C.
- **Enhanced CCP module:** In PWM mode, this module provides 1, 2 or 4 modulated outputs for controlling half-bridge and full-bridge drivers. Other features include auto-shutdown, for disabling PWM outputs on interrupt or other select conditions and auto-restart, to reactivate outputs once the condition has cleared.
- **Enhanced Addressable USART:** This serial communication module is capable of standard RS-232 operation and provides support for the LIN bus protocol. Other enhancements include automatic baud rate detection and a 16-bit Baud Rate Generator for improved resolution. When the microcontroller is using the internal oscillator block, the USART provides stable operation for applications that talk to the outside world without using an external crystal (or its accompanying power requirement).
- **10-bit A/D Converter:** This module incorporates programmable acquisition time, allowing for a channel to be selected and a conversion to be initiated without waiting for a sampling period and thus, reduce code overhead.
- **Extended Watchdog Timer (WDT):** This Enhanced version incorporates a 16-bit prescaler, allowing an extended time-out range that is stable across operating voltage and temperature. See **Section 26.0 “Electrical Characteristics”** for time-out periods.

1.3 Details on Individual Family Members

Devices in the PIC18F2525/2620/4525/4620 family are available in 28-pin and 40/44-pin packages. Block diagrams for the two groups are shown in Figure 1-1 and Figure 1-2.

The devices are differentiated from each other in five ways:

1. Flash program memory (48 Kbytes for PIC18FX525 devices, 64 Kbytes for PIC18FX620).
2. A/D channels (10 for 28-pin devices, 13 for 40/44-pin devices).
3. I/O ports (3 bidirectional ports on 28-pin devices, 5 bidirectional ports on 40/44-pin devices).
4. CCP and Enhanced CCP implementation (28-pin devices have 2 standard CCP modules, 40/44-pin devices have one standard CCP module and one ECCP module).
5. Parallel Slave Port (present only on 40/44-pin devices).

All other features for devices in this family are identical. These are summarized in Table 1-1.

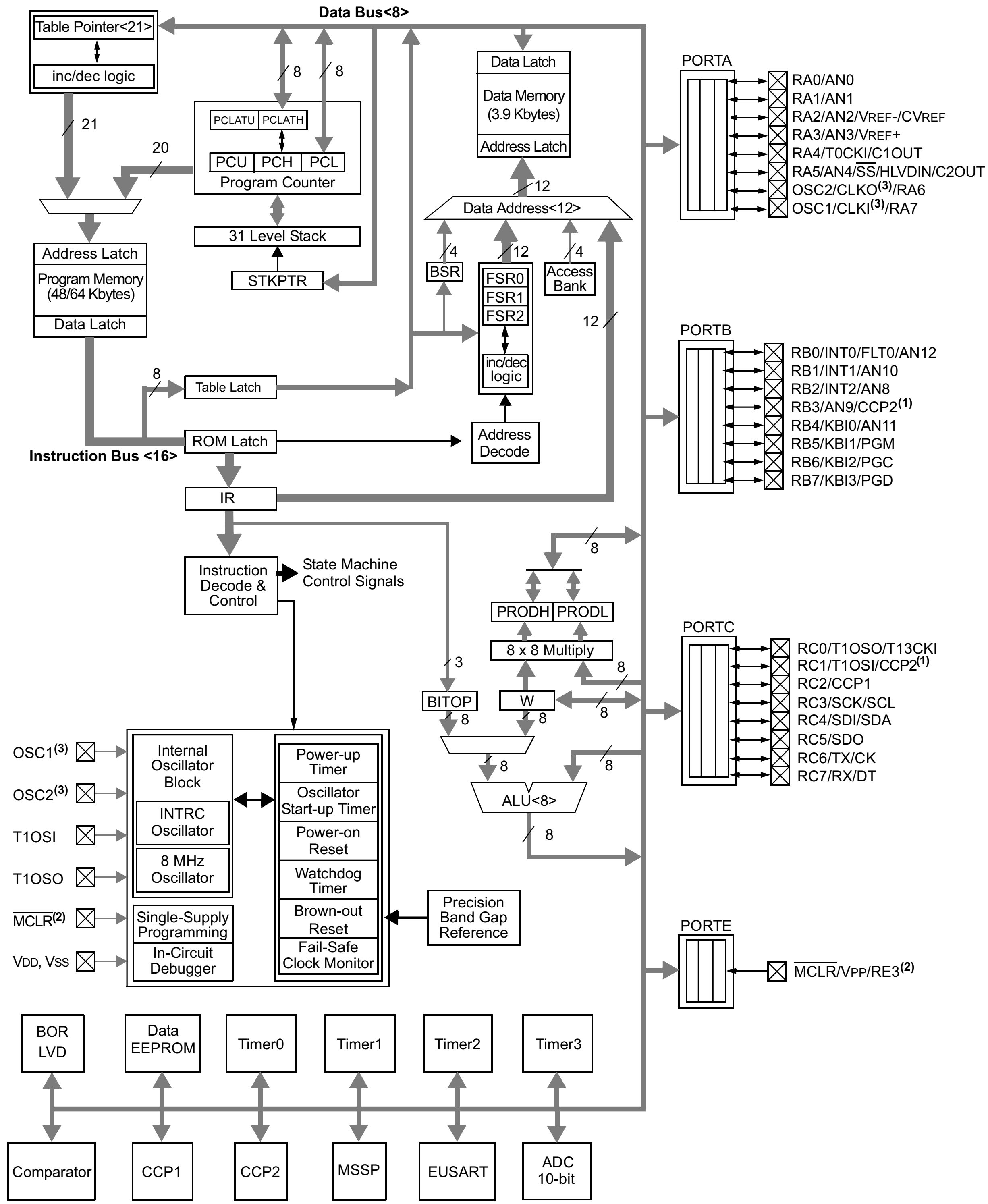
The pinouts for all devices are listed in Table 1-2 and Table 1-3.

Like all Microchip PIC18 devices, members of the PIC18F2525/2620/4525/4620 family are available as both standard and low-voltage devices. Standard devices with Enhanced Flash memory, designated with an “F” in the part number (such as PIC18**F**2620), accommodate an operating V_{DD} range of 4.2V to 5.5V. Low-voltage parts, designated by “LF” (such as PIC18**LF**2620), function over an extended V_{DD} range of 2.0V to 5.5V.

TABLE 1-1: DEVICE FEATURES

Features	PIC18F2525	PIC18F2620	PIC18F4525	PIC18F4620
Operating Frequency	DC – 40 MHz	DC – 40 MHz	DC – 40 MHz	DC – 40 MHz
Program Memory (Bytes)	49152	65536	49152	65536
Program Memory (Instructions)	24576	32768	24576	32768
Data Memory (Bytes)	3968	3968	3968	3968
Data EEPROM Memory (Bytes)	1024	1024	1024	1024
Interrupt Sources	19	19	20	20
I/O Ports	Ports A, B, C, (E)	Ports A, B, C, (E)	Ports A, B, C, D, E	Ports A, B, C, D, E
Timers	4	4	4	4
Capture/Compare/PWM Modules	2	2	1	1
Enhanced Capture/Compare/ PWM Modules	0	0	1	1
Serial Communications	MSSP, Enhanced USART	MSSP, Enhanced USART	MSSP, Enhanced USART	MSSP, Enhanced USART
Parallel Communications (PSP)	No	No	Yes	Yes
10-bit Analog-to-Digital Module	10 Input Channels	10 Input Channels	13 Input Channels	13 Input Channels
Resets (and Delays)	POR, BOR, `RESET` Instruction, Stack Full, Stack Underflow (PWRT, OST), $\overline{\text{MCLR}}$ (optional), WDT	POR, BOR, `RESET` Instruction, Stack Full, Stack Underflow (PWRT, OST), $\overline{\text{MCLR}}$ (optional), WDT	POR, BOR, `RESET` Instruction, Stack Full, Stack Underflow (PWRT, OST), $\overline{\text{MCLR}}$ (optional), WDT	POR, BOR, `RESET` Instruction, Stack Full, Stack Underflow (PWRT, OST), $\overline{\text{MCLR}}$ (optional), WDT
Programmable Low-Voltage Detect	Yes	Yes	Yes	Yes
Programmable Brown-out Reset	Yes	Yes	Yes	Yes
Instruction Set	75 Instructions; 83 with Extended Instruction Set enabled	75 Instructions; 83 with Extended Instruction Set enabled	75 Instructions; 83 with Extended Instruction Set enabled	75 Instructions; 83 with Extended Instruction Set enabled
Packages	28-pin SPDIP 28-pin SOIC	28-pin SPDIP 28-pin SOIC	40-pin PDIP 44-pin QFN 44-pin TQFP	40-pin PDIP 44-pin QFN 44-pin TQFP

FIGURE 1-1: PIC18F2525/2620 (28-PIN) BLOCK DIAGRAM

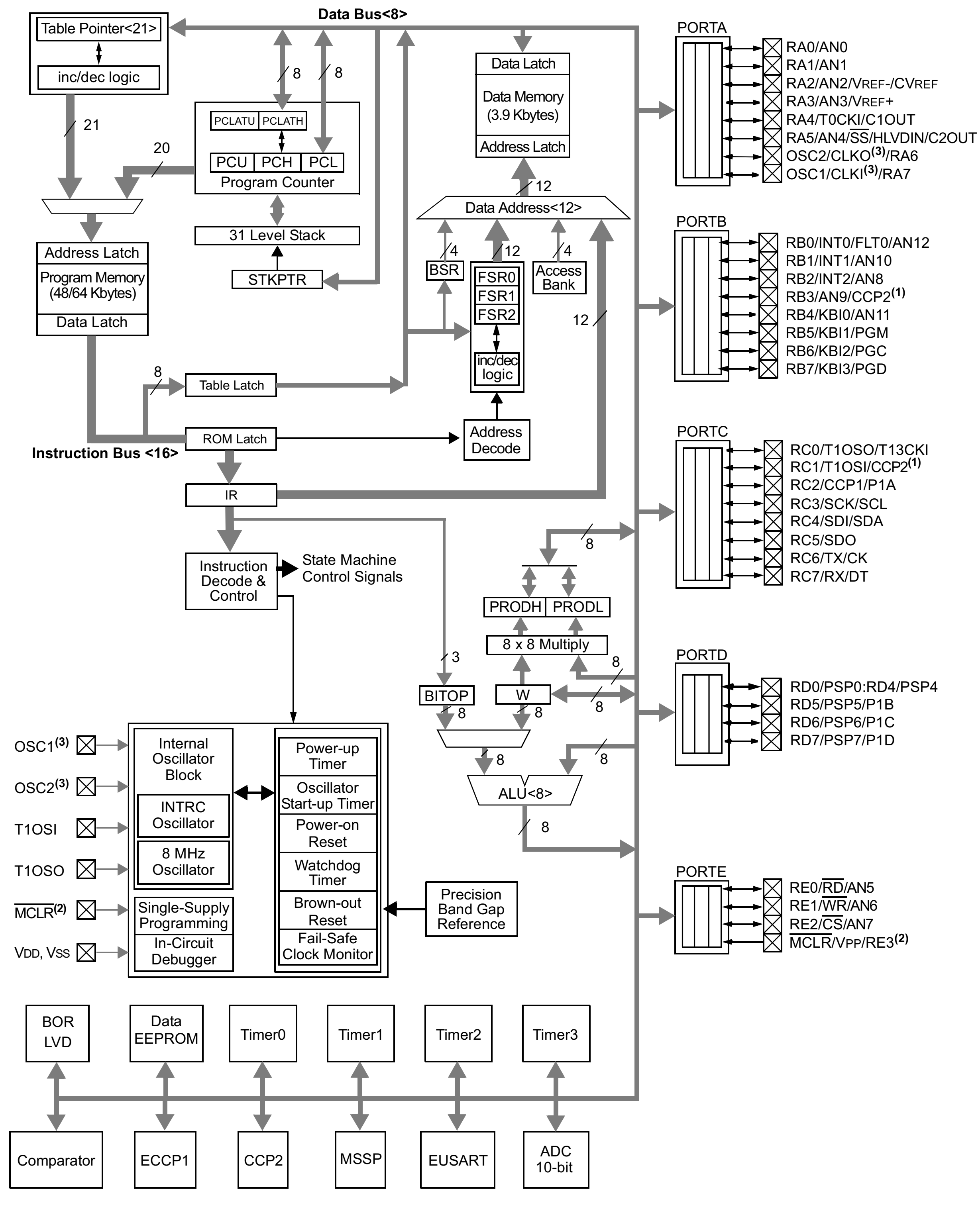


Note 1: CCP2 is multiplexed with RC1 when configuration bit CCP2MX is set, or RB3 when CCP2MX is not set.

2: RE3 is only available when $\overline{\text{MCLR}}$ functionality is disabled.

3: OSC1/CLKI and OSC2/CLKO are only available in select oscillator modes and when these pins are not being used as digital I/O. Refer to **Section 2.0 "Oscillator Configurations"** for additional information.

FIGURE 1-2: PIC18F4525/4620 (40/44-PIN) BLOCK DIAGRAM



Note 1: CCP2 is multiplexed with RC1 when configuration bit CCP2MX is set, or RB3 when CCP2MX is not set.

2: RE3 is only available when MCLR functionality is disabled.

3: OSC1/CLKI and OSC2/CLKO are only available in select oscillator modes and when these pins are not being used as digital I/O. Refer to **Section 2.0 “Oscillator Configurations”** for additional information.

TABLE 1-2: PIC18F2525/2620 PINOUT I/O DESCRIPTIONS

Pin Name	Pin Number SPDIP, SOIC	Pin Number QFN	Pin Type	Buffer Type	Description
$\overline{MCLR}$/VPP/RE3	1	26			Master Clear (input) or programming voltage (input).
$\overline{MCLR}$			I	ST	Master Clear (Reset) input. This pin is an active-low Reset to the device.
VPP			P		Programming voltage input.
RE3			I	ST	Digital input.
OSC1/CLKI/RA7	9	6			Oscillator crystal or external clock input.
OSC1			I	ST	Oscillator crystal input or external clock source input. ST buffer when configured in RC mode; CMOS otherwise.
CLKI			I	CMOS	External clock source input. Always associated with pin function OSC1. (See related OSC1/CLKI, OSC2/CLKO pins.)
RA7			I/O	TTL	General purpose I/O pin.
OSC2/CLKO/RA6	10	7			Oscillator crystal or clock output.
OSC2			O	—	Oscillator crystal output. Connects to crystal or resonator in Crystal Oscillator mode.
CLKO			O	—	In RC mode, OSC2 pin outputs CLKO which has 1/4 the frequency of OSC1 and denotes the instruction cycle rate.
RA6			I/O	TTL	General purpose I/O pin.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output; ST = Schmitt Trigger input with CMOS levels; I = Input; O = Output; P = Power

Note 1: Default assignment for CCP2 when configuration bit CCP2MX is set.

2: Alternate assignment for CCP2 when configuration bit CCP2MX is cleared.

TABLE 1-2: PIC18F2525/2620 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number SPDIP, SOIC	Pin Number QFN	Pin Type	Buffer Type	Description
					PORTA is a bidirectional I/O port.
RA0/AN0	2	27			
RA0			I/O	TTL	Digital I/O.
AN0			I	Analog	Analog input 0.
RA1/AN1	3	28			
RA1			I/O	TTL	Digital I/O.
AN1			I	Analog	Analog input 1.
RA2/AN2/VREF-/CVREF	4	1			
RA2			I/O	TTL	Digital I/O.
AN2			I	Analog	Analog input 2.
VREF-			I	Analog	A/D reference voltage (low) input.
CVREF			O	Analog	Comparator reference voltage output.
RA3/AN3/VREF+	5	2			
RA3			I/O	TTL	Digital I/O.
AN3			I	Analog	Analog input 3.
VREF+			I	Analog	A/D reference voltage (high) input.
RA4/T0CKI/C1OUT	6	3			
RA4			I/O	ST	Digital I/O.
T0CKI			I	ST	Timer0 external clock input.
C1OUT			O	—	Comparator 1 output.
RA5/AN4/$\overline{SS}$/HLVDIN/C2OUT	7	4			
RA5			I/O	TTL	Digital I/O.
AN4			I	Analog	Analog input 4.
$\overline{SS}$			I	TTL	SPI™ slave select input.
HLVDIN			I	Analog	High/Low-Voltage Detect input.
C2OUT			O	—	Comparator 2 output.
RA6					See the OSC2/CLKO/RA6 pin.
RA7					See the OSC1/CLKI/RA7 pin.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output; ST = Schmitt Trigger input with CMOS levels; I = Input; O = Output; P = Power

Note 1: Default assignment for CCP2 when configuration bit CCP2MX is set.

2: Alternate assignment for CCP2 when configuration bit CCP2MX is cleared.

TABLE 1-2: PIC18F2525/2620 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number		Pin Type	Buffer Type	Description
	SPDIP, SOIC	QFN			
					PORTB is a bidirectional I/O port. PORTB can be software programmed for internal weak pull-ups on all inputs.
RB0/INT0/FLT0/AN12	21	18			
RB0			I/O	TTL	Digital I/O.
INT0			I	ST	External interrupt 0.
FLT0			I	ST	PWM Fault input for CCP1.
AN12			I	Analog	Analog input 12.
RB1/INT1/AN10	22	19			
RB1			I/O	TTL	Digital I/O.
INT1			I	ST	External interrupt 1.
AN10			I	Analog	Analog input 10.
RB2/INT2/AN8	23	20			
RB2			I/O	TTL	Digital I/O.
INT2			I	ST	External interrupt 2.
AN8			I	Analog	Analog input 8.
RB3/AN9/CCP2	24	21			
RB3			I/O	TTL	Digital I/O.
AN9			I	Analog	Analog input 9.
CCP2[(1)]			I/O	ST	Capture 2 input/Compare 2 output/PWM 2 output.
RB4/KBI0/AN11	25	22			
RB4			I/O	TTL	Digital I/O.
KBI0			I	TTL	Interrupt-on-change pin.
AN11			I	Analog	Analog input 11.
RB5/KBI1/PGM	26	23			
RB5			I/O	TTL	Digital I/O.
KBI1			I	TTL	Interrupt-on-change pin.
PGM			I/O	ST	Low-Voltage ICSP™ Programming enable pin.
RB6/KBI2/PGC	27	24			
RB6			I/O	TTL	Digital I/O.
KBI2			I	TTL	Interrupt-on-change pin.
PGC			I/O	ST	In-Circuit Debugger and ICSP programming clock pin.
RB7/KBI3/PGD	28	25			
RB7			I/O	TTL	Digital I/O.
KBI3			I	TTL	Interrupt-on-change pin.
PGD			I/O	ST	In-Circuit Debugger and ICSP programming data pin.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output; ST = Schmitt Trigger input with CMOS levels; I = Input; O = Output; P = Power

Note 1: Default assignment for CCP2 when configuration bit CCP2MX is set.

2: Alternate assignment for CCP2 when configuration bit CCP2MX is cleared.

TABLE 1-2: PIC18F2525/2620 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number SPDIP, SOIC	Pin Number QFN	Pin Type	Buffer Type	Description
					PORTC is a bidirectional I/O port.
RC0/T1OSO/T13CKI	11	8			
RC0			I/O	ST	Digital I/O.
T1OSO			O	—	Timer1 oscillator output.
T13CKI			I	ST	Timer1/Timer3 external clock input.
RC1/T1OSI/CCP2	12	9			
RC1			I/O	ST	Digital I/O.
T1OSI			I	Analog	Timer1 oscillator input.
CCP2(2)			I/O	ST	Capture 2 input/Compare 2 output/PWM 2 output.
RC2/CCP1	13	10			
RC2			I/O	ST	Digital I/O.
CCP1			I/O	ST	Capture 1 input/Compare 1 output/PWM 1 output.
RC3/SCK/SCL	14	11			
RC3			I/O	ST	Digital I/O.
SCK			I/O	ST	Synchronous serial clock input/output for SPI™ mode.
SCL			I/O	ST	Synchronous serial clock input/output for I²C™ mode.
RC4/SDI/SDA	15	12			
RC4			I/O	ST	Digital I/O.
SDI			I	ST	SPI data in.
SDA			I/O	ST	I²C data I/O.
RC5/SDO	16	13			
RC5			I/O	ST	Digital I/O.
SDO			O	—	SPI data out.
RC6/TX/CK	17	14			
RC6			I/O	ST	Digital I/O.
TX			O	—	EUSART asynchronous transmit.
CK			I/O	ST	EUSART synchronous clock (see related RX/DT).
RC7/RX/DT	18	15			
RC7			I/O	ST	Digital I/O.
RX			I	ST	EUSART asynchronous receive.
DT			I/O	ST	EUSART synchronous data (see related TX/CK).
RE3	—	—	—	—	See $\overline{MCLR}$/VPP/RE3 pin.
VSS	8, 19	5, 16	P	—	Ground reference for logic and I/O pins.
VDD	20	17	P	—	Positive supply for logic and I/O pins.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output; ST = Schmitt Trigger input with CMOS levels; I = Input; O = Output; P = Power

Note 1: Default assignment for CCP2 when configuration bit CCP2MX is set.
2: Alternate assignment for CCP2 when configuration bit CCP2MX is cleared.

TABLE 1-3: PIC18F4525/4620 PINOUT I/O DESCRIPTIONS

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
$\overline{MCLR}/V_{PP}/RE3$	1	18	18			Master Clear (input) or programming voltage (input).
$\overline{MCLR}$				I	ST	Master Clear (Reset) input. This pin is an active-low Reset to the device.
V_{PP}				P		Programming voltage input.
RE3				I	ST	Digital input.
OSC1/CLKI/RA7	13	32	30			Oscillator crystal or external clock input.
OSC1				I	ST	Oscillator crystal input or external clock source input. ST buffer when configured in RC mode; analog otherwise.
CLKI				I	CMOS	External clock source input. Always associated with pin function OSC1. (See related OSC1/CLKI, OSC2/CLKO pins.)
RA7				I/O	TTL	General purpose I/O pin.
OSC2/CLKO/RA6	14	33	31			Oscillator crystal or clock output.
OSC2				O	—	Oscillator crystal output. Connects to crystal or resonator in Crystal Oscillator mode.
CLKO				O	—	In RC mode, OSC2 pin outputs CLKO which has 1/4 the frequency of OSC1 and denotes the instruction cycle rate.
RA6				I/O	TTL	General purpose I/O pin.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output
ST = Schmitt Trigger input with CMOS levels; I = Input
O = Output; P = Power

Note 1: Default assignment for CCP2 when configuration bit CCP2MX is set.
2: Alternate assignment for CCP2 when configuration bit CCP2MX is cleared.

TABLE 1-3: PIC18F4525/4620 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
						PORTA is a bidirectional I/O port.
RA0/AN0	2	19	19			
RA0				I/O	TTL	Digital I/O.
AN0				I	Analog	Analog input 0.
RA1/AN1	3	20	20			
RA1				I/O	TTL	Digital I/O.
AN1				I	Analog	Analog input 1.
RA2/AN2/VREF-/CVREF	4	21	21			
RA2				I/O	TTL	Digital I/O.
AN2				I	Analog	Analog input 2.
VREF-				I	Analog	A/D reference voltage (low) input.
CVREF				O	Analog	Comparator reference voltage output.
RA3/AN3/VREF+	5	22	22			
RA3				I/O	TTL	Digital I/O.
AN3				I	Analog	Analog input 3.
VREF+				I	Analog	A/D reference voltage (high) input.
RA4/T0CKI/C1OUT	6	23	23			
RA4				I/O	ST	Digital I/O.
T0CKI				I	ST	Timer0 external clock input.
C1OUT				O	—	Comparator 1 output.
RA5/AN4/$\overline{\text{SS}}$/HLVDIN/C2OUT	7	24	24			
RA5				I/O	TTL	Digital I/O.
AN4				I	Analog	Analog input 4.
$\overline{\text{SS}}$				I	TTL	SPI™ slave select input.
HLVDIN				I	Analog	High/Low-Voltage Detect input.
C2OUT				O	—	Comparator 2 output.
RA6						See the OSC2/CLKO/RA6 pin.
RA7						See the OSC1/CLKI/RA7 pin.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output; ST = Schmitt Trigger input with CMOS levels; I = Input; O = Output; P = Power

Note 1: Default assignment for CCP2 when configuration bit CCP2MX is set.

2: Alternate assignment for CCP2 when configuration bit CCP2MX is cleared.

TABLE 1-3: PIC18F4525/4620 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
						PORTB is a bidirectional I/O port. PORTB can be software programmed for internal weak pull-ups on all inputs.
RB0/INT0/FLT0/AN12	33	9	8			
RB0				I/O	TTL	Digital I/O.
INT0				I	ST	External interrupt 0.
FLT0				I	ST	PWM Fault input for Enhanced CCP1.
AN12				I	Analog	Analog input 12.
RB1/INT1/AN10	34	10	9			
RB1				I/O	TTL	Digital I/O.
INT1				I	ST	External interrupt 1.
AN10				I	Analog	Analog input 10.
RB2/INT2/AN8	35	11	10			
RB2				I/O	TTL	Digital I/O.
INT2				I	ST	External interrupt 2.
AN8				I	Analog	Analog input 8.
RB3/AN9/CCP2	36	12	11			
RB3				I/O	TTL	Digital I/O.
AN9				I	Analog	Analog input 9.
CCP2[(1)]				I/O	ST	Capture 2 input/Compare 2 output/PWM 2 output.
RB4/KBI0/AN11	37	14	14			
RB4				I/O	TTL	Digital I/O.
KBI0				I	TTL	Interrupt-on-change pin.
AN11				I	Analog	Analog input 11.
RB5/KBI1/PGM	38	15	15			
RB5				I/O	TTL	Digital I/O.
KBI1				I	TTL	Interrupt-on-change pin.
PGM				I/O	ST	Low-Voltage ICSP™ Programming enable pin.
RB6/KBI2/PGC	39	16	16			
RB6				I/O	TTL	Digital I/O.
KBI2				I	TTL	Interrupt-on-change pin.
PGC				I/O	ST	In-Circuit Debugger and ICSP programming clock pin.
RB7/KBI3/PGD	40	17	17			
RB7				I/O	TTL	Digital I/O.
KBI3				I	TTL	Interrupt-on-change pin.
PGD				I/O	ST	In-Circuit Debugger and ICSP programming data pin.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output; ST = Schmitt Trigger input with CMOS levels; I = Input; O = Output; P = Power

Note 1: Default assignment for CCP2 when configuration bit CCP2MX is set.
2: Alternate assignment for CCP2 when configuration bit CCP2MX is cleared.

TABLE 1-3: PIC18F4525/4620 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
						PORTC is a bidirectional I/O port.
RC0/T1OSO/T13CKI	15	34	32			
RC0				I/O	ST	Digital I/O.
T1OSO				O	—	Timer1 oscillator output.
T13CKI				I	ST	Timer1/Timer3 external clock input.
RC1/T1OSI/CCP2	16	35	35			
RC1				I/O	ST	Digital I/O.
T1OSI				I	CMOS	Timer1 oscillator input.
CCP2(2)				I/O	ST	Capture 2 input/Compare 2 output/PWM 2 output.
RC2/CCP1/P1A	17	36	36			
RC2				I/O	ST	Digital I/O.
CCP1				I/O	ST	Capture 1 input/Compare 1 output/PWM 1 output.
P1A				O	—	Enhanced CCP1 output.
RC3/SCK/SCL	18	37	37			
RC3				I/O	ST	Digital I/O.
SCK				I/O	ST	Synchronous serial clock input/output for SPI™ mode.
SCL				I/O	ST	Synchronous serial clock input/output for I^2C™ mode.
RC4/SDI/SDA	23	42	42			
RC4				I/O	ST	Digital I/O.
SDI				I	ST	SPI data in.
SDA				I/O	ST	I^2C data I/O.
RC5/SDO	24	43	43			
RC5				I/O	ST	Digital I/O.
SDO				O	—	SPI data out.
RC6/TX/CK	25	44	44			
RC6				I/O	ST	Digital I/O.
TX				O	—	EUSART asynchronous transmit.
CK				I/O	ST	EUSART synchronous clock (see related RX/DT).
RC7/RX/DT	26	1	1			
RC7				I/O	ST	Digital I/O.
RX				I	ST	EUSART asynchronous receive.
DT				I/O	ST	EUSART synchronous data (see related TX/CK).

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output
ST = Schmitt Trigger input with CMOS levels; I = Input
O = Output; P = Power

Note 1: Default assignment for CCP2 when configuration bit CCP2MX is set.
2: Alternate assignment for CCP2 when configuration bit CCP2MX is cleared.

TABLE 1-3: PIC18F4525/4620 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
						PORTD is a bidirectional I/O port or a Parallel Slave Port (PSP) for interfacing to a microprocessor port. These pins have TTL input buffers when the PSP module is enabled.
RD0/PSP0	19	38	38			
RD0				I/O	ST	Digital I/O.
PSP0				I/O	TTL	Parallel Slave Port data.
RD1/PSP1	20	39	39			
RD1				I/O	ST	Digital I/O.
PSP1				I/O	TTL	Parallel Slave Port data.
RD2/PSP2	21	40	40			
RD2				I/O	ST	Digital I/O.
PSP2				I/O	TTL	Parallel Slave Port data.
RD3/PSP3	22	41	41			
RD3				I/O	ST	Digital I/O.
PSP3				I/O	TTL	Parallel Slave Port data.
RD4/PSP4	27	2	2			
RD4				I/O	ST	Digital I/O.
PSP4				I/O	TTL	Parallel Slave Port data.
RD5/PSP5/P1B	28	3	3			
RD5				I/O	ST	Digital I/O.
PSP5				I/O	TTL	Parallel Slave Port data.
P1B				O	—	Enhanced CCP1 output.
RD6/PSP6/P1C	29	4	4			
RD6				I/O	ST	Digital I/O.
PSP6				I/O	TTL	Parallel Slave Port data.
P1C				O	—	Enhanced CCP1 output.
RD7/PSP7/P1D	30	5	5			
RD7				I/O	ST	Digital I/O.
PSP7				I/O	TTL	Parallel Slave Port data.
P1D				O	—	Enhanced CCP1 output.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output
ST = Schmitt Trigger input with CMOS levels; I = Input
O = Output; P = Power

Note 1: Default assignment for CCP2 when configuration bit CCP2MX is set.
2: Alternate assignment for CCP2 when configuration bit CCP2MX is cleared.

TABLE 1-3: PIC18F4525/4620 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
						PORTE is a bidirectional I/O port.
RE0/$\overline{RD}$/AN5	8	25	25			
RE0				I/O	ST	Digital I/O.
$\overline{RD}$				I	TTL	Read control for Parallel Slave Port (see also $\overline{WR}$ and $\overline{CS}$ pins).
AN5				I	Analog	Analog input 5.
RE1/$\overline{WR}$/AN6	9	26	26			
RE1				I/O	ST	Digital I/O.
$\overline{WR}$				I	TTL	Write control for Parallel Slave Port (see $\overline{CS}$ and $\overline{RD}$ pins).
AN6				I	Analog	Analog input 6.
RE2/$\overline{CS}$/AN7	10	27	27			
RE2				I/O	ST	Digital I/O.
$\overline{CS}$				I	TTL	Chip Select control for Parallel Slave Port (see related $\overline{RD}$ and $\overline{WR}$).
AN7				I	Analog	Analog input 7.
RE3	—	—	—	—	—	See $\overline{MCLR}$/V_{PP}/RE3 pin.
V_{SS}	12, 31	6, 30, 31	6, 29	P	—	Ground reference for logic and I/O pins.
V_{DD}	11, 32	7, 8, 28, 29	7, 28	P	—	Positive supply for logic and I/O pins.
NC	—	13	12, 13, 33, 34	—	—	No connect.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output
ST = Schmitt Trigger input with CMOS levels; I = Input
O = Output; P = Power

Note 1: Default assignment for CCP2 when configuration bit CCP2MX is set.
2: Alternate assignment for CCP2 when configuration bit CCP2MX is cleared.