The Design and Construction of an Autonomous Mobile Robot

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ME-412 Autonomous Mobile Robots
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Abstract: This paper addresses the construction of an autonomous robot to compete in the Cooper Union annual Robot Tank Battle. The project focused on the design of a robot which could autonomously avoid objects, locate an infrared beacon, and shoot ping pong balls. This paper discusses the mechanical, electrical, and programming solutions to the problem, as well as the issues found with the potential solutions and future work to be done.

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Intro

A robot is a mechanical device that has been programmed to operate within a physical environment to complete a task. It typically takes input from sensors and operates motors to complete said task. They usually operate autonomously; they make decisions based on their programming rather than on user input. Robots, including ours, are constructed of mechanical and electrical systems. These systems work together (along with their programming) in order to complete their assigned tasks.

The mechanical system involves most of the physical components of the robot, including the chassis, the drivetrain, and any attachments needed for the task. For our application, our robot needed a ball-launching mechanism, included in the mechanical system. The drivetrain and attachments are controlled by the electrical system, which both powers and operates the drive control and any functionality of the robot. These functionalities are implemented in software, with this particular implementation using a microcontroller to interface between the software and the electrical system. A typical robot uses sensor data to complete their tasks; the sensor data is sent directly to the controller for processing.

For this project, ultrasonic distance sensors and IR phototransistors were used to collect data about the environment and inform the robot's decisions. The ultrasonic sensors use pulses of sound to calculate the distance between the robot and the surrounding objects, and the IR sensors calculate the intensity of infrared light in order to locate beacons placed in the field (specifically, on the opponent's robot and the home bases).

The shooting mechanism was driven by two motors, which drove wheels to accelerate the ball through a tube. Once the shot was taken, the robot was to return to the home base for reset and reloading.

Design

When designing our robot our team had only one constraint: that the robot fit in a 12” x 12” x 10” volume. Our team considered many iterations of robot designs to conform to this constraint. For example, our initial design was an octogonal prism with two driving motors on the bottom and a single caster for a third point of contact. We thought about implementing this design primarily because it allowed us to have 8 radially symmetric faces on which we could attach our sensors. However, after further consideration, we determined that the radially symmetric array of sensors would not provide a significant increase in the performance of our robot using our proposed strategy and would only be harder to manufacture.

From there, we pivoted to a design which resembles our final one. A cuboid with cutouts on the front, rear, and sides for the sensor and launching mechanism. This design was chosen because of its ease to manufacture and its low cost of implementation.

In terms of the electrical components used in our design, the majority were chosen because of availability, and further components in our electrical subsystems were chosen based on the existing ones. For example, the motors used in the drivetrain were already owned by one of the team members from a previous project. The H-Bridges required to power them were obtained from the Mechatronics Lab. A more in-depth analysis of our design process as it relates to the electrical components for the robot can be seen in the Electrical Systems and Control section.

Through an iterative testing process, a few changes were made to our design, resulting in the current product. One of the biggest changes to the design from the one listed above is the fact that only four of the original eight ultrasonic distance sensors were utilized. This change was made because we realized that the strategy we had decided upon was not improved by having information on what was behind the robot. Therefore, our final design differed in that it only had sensors on the front half of the chassis.

Mechanical Construction

Once we had a suitable design, the actual construction of the robot could begin. To save on construction time and costs, we only considered manufacturing methods that could be implemented using the tools and rapid prototyping systems available to us as students. For this reason, we decided that the simplest course of action was to laser cut a sheet of acrylic to form the chassis. Below is the schematic used to cut the side and rear panels.

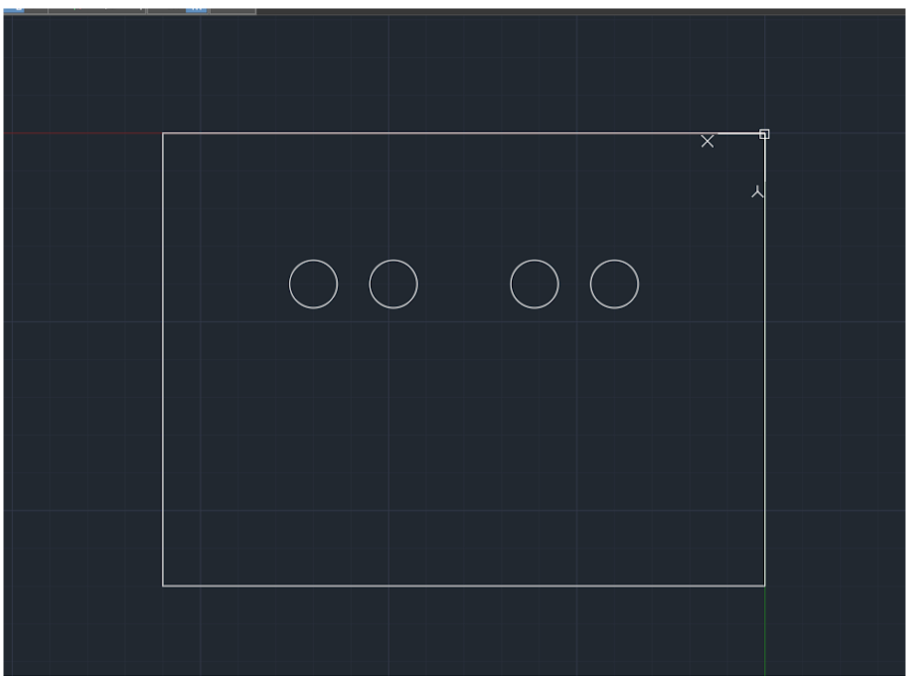


Figure 1: Side and Rear Panels

Below is the schematic used to cut the front panel.

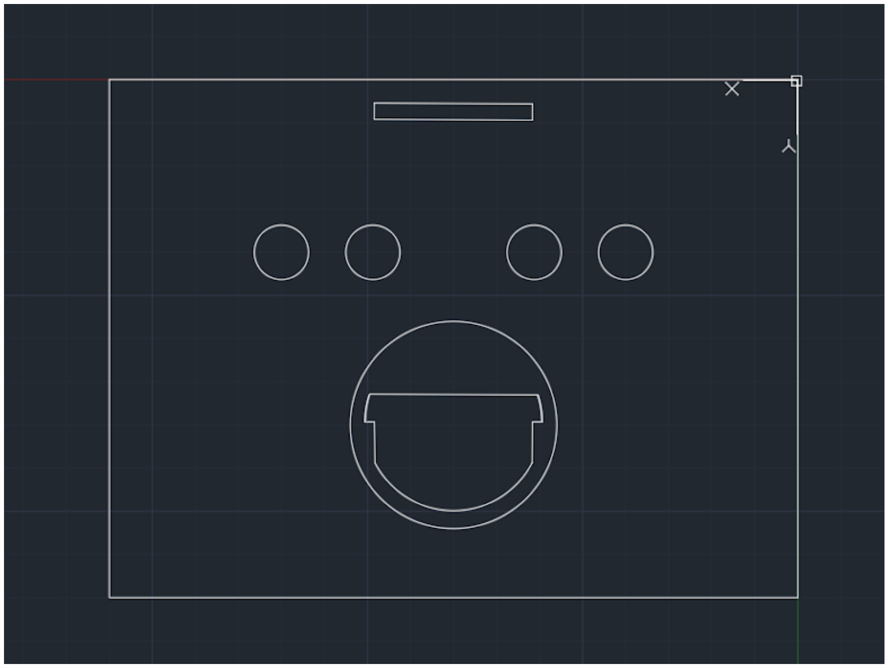


Figure 2: Front Panel

These cuts were made to allow for easy mounting locations for the ultrasonic distance sensors on all four sides. Additionally, the extra cutouts on the front panel were for the exit pipe of the launching mechanism as well as a mounting point for the IR phototransistors (Figure 3).

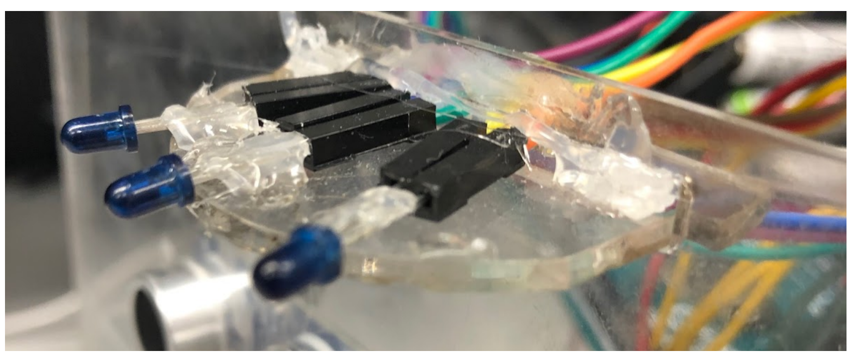


Figure 3: IR sensor mounts

These four side panels were then rigidly connected to one another and to a single base sheet of acrylic using components purchased at a hardware store such as metal brackets, machine screws, and nuts. This completed the construction of the robot chassis.

The base piece of acrylic was used as the plane where the motors for the drivetrain and the caster could be rigidly attached. In both cases, machine screws and nuts were used to connect these components to the robot chassis.

The construction of the launching mechanism took a number of steps. First a length of PVC pipe and an elbow PVC joint were sized and purchased. The sizing was important because the internal diameter must be large enough to fit a ping pong ball inside. The PVC pipe was then cut to the appropriate length. Slits were then cut on either side of the pipe so that the wheels of the launching mechanism would be allowed to engage with the ball. The pipe and elbow joint were then attached together.

A mount was needed in order to attach the launching mechanism subassembly to the top level assembly. In order to get a mount of the correct dimensions quickly, we decided to use another rapid prototyping device, this time a 3D printer. Below is a schematic for that mount.

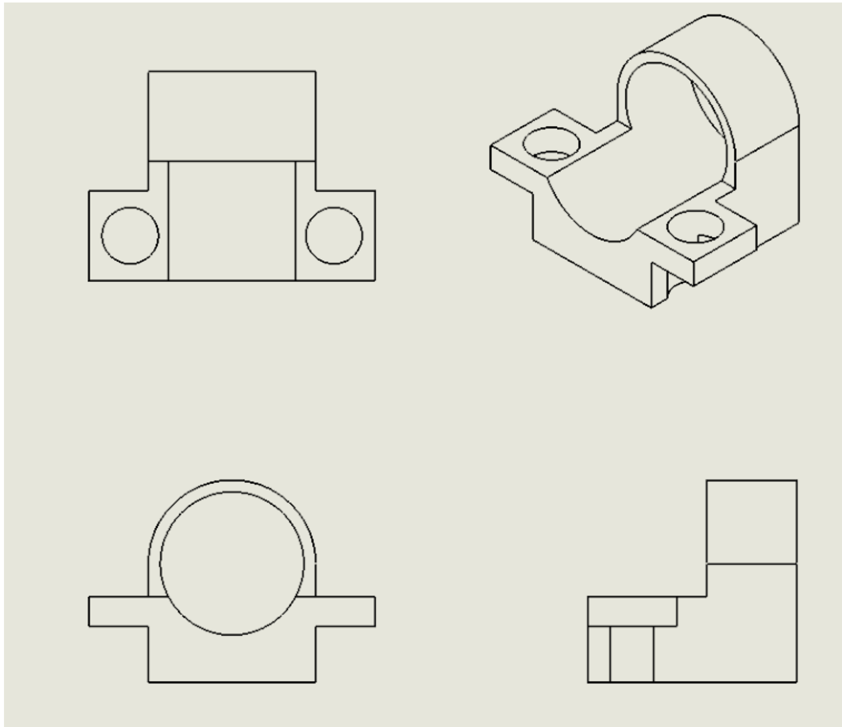


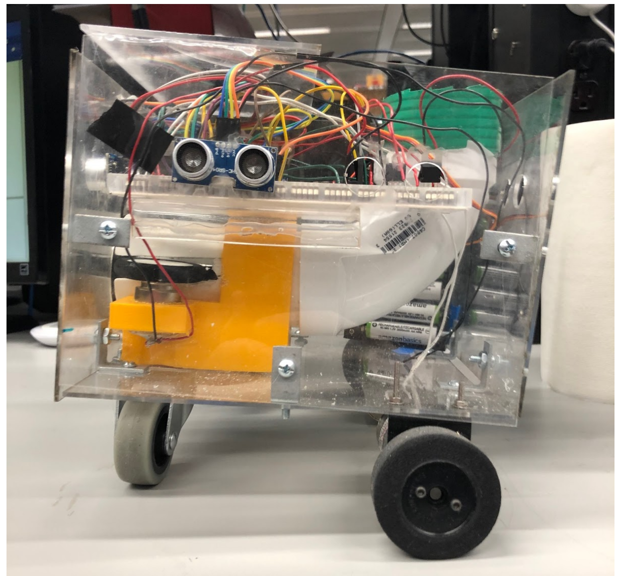
Figure 4: 3D Model of Mount for Launching Mechanism

The central hole was designed to hold the pipe in place. The flat base at the bottom provided for a location to bond the launching mount to the robot chassis. The two cutouts on the flanges on either side were designed to hold the motors that would be used in the launching mechanism. As a last step, a cup was placed at the other end of the PVC elbow joint. This cup would hold the ping pong ball until it was ready to be fired.

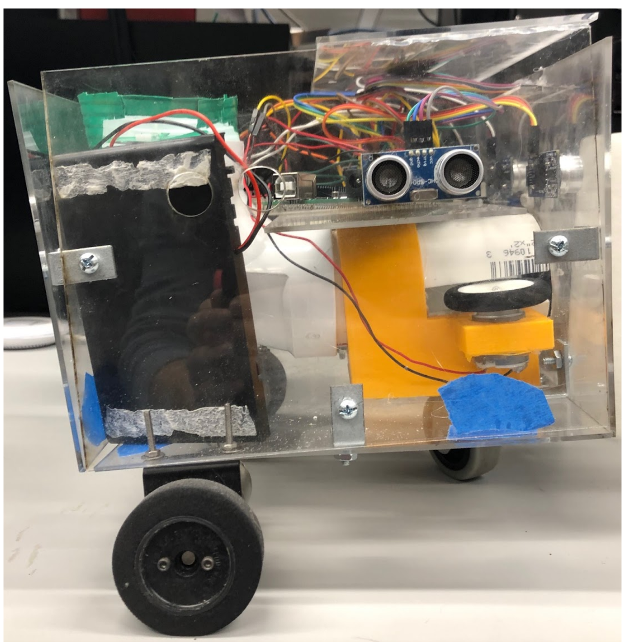
The final step in the physical construction of the robot was to create a location for the electronics. A piece of acrylic was heated and bent into a 90° angle. This angle was then attached to the chassis using adhesives. The remaining flange was then a suitable location for a control panel.

Photos of the completed robot:

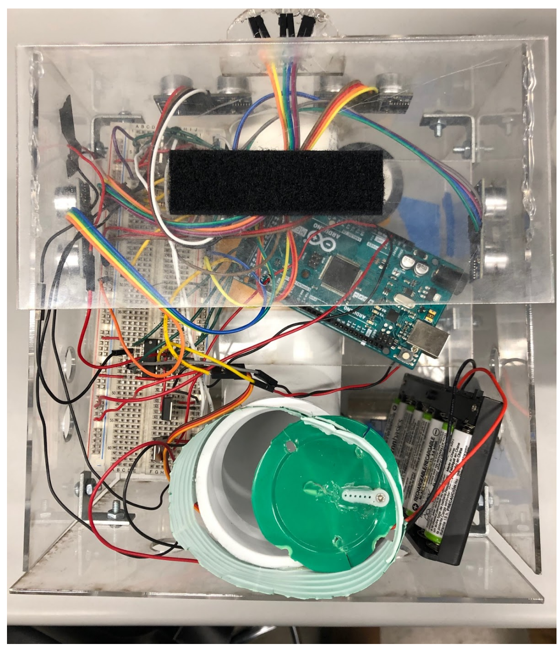
Front view



Left side view



Right side view



Top view

Electrical Systems and Control

The control for the robot was implemented using an Arduino Mega, due to the ease of integration with the sensors and the familiarity of the group with the development process. The Mega was chosen in order to maximize flexibility later in the development process with its large number of IO pins and multiple voltage regulators.

The ultrasonic distance sensors were chosen to calculate the distance from objects surrounding the robot (datasheet attached). The controller sends a pulse to the device, and the device responds with a pulse at a delay directly proportional to the distance.

The infrared sensors are IR phototransistors (see attached datasheet). The IR light causes current to flow through the device, and a 100 kΩ resistor was used to convert the current to voltage. The voltage is then sensed by the Arduino, and used to target the IR beacons (Figure 5).

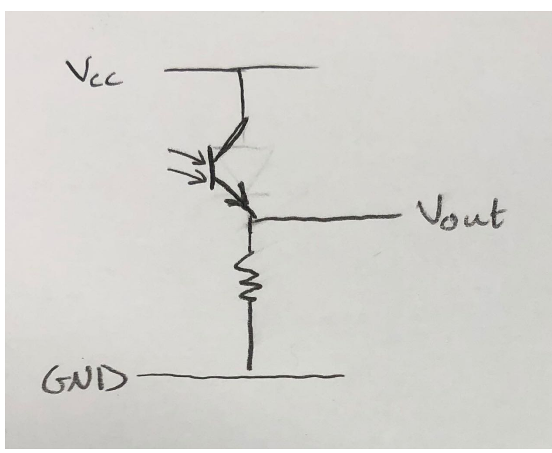


Figure 5

The Arduino could supply enough current to run the servo, but it could not supply enough current to run the motors for the drivetrain or launching mechanism. We therefore used four half H-bridges to supply the drive current (as well as the correct driving voltage) for the devices (see datasheet for usage).

A 12V battery pack consisting of 8 rechargeable AA batteries was used to match the voltage to the voltage rating of the driving motors. 12V exceeded the maximum rating of the voltage input of the Arduino internal voltage regulators, so a 5V regulator was used to supply the voltage to the Arduino. A separate voltage regulator was used to supply the current for the shooting mechanism so that the noise would not impact the Arduino supply.

Rather than include a compass (which would have been unreliable due to the construction of the building in which the testing was done) we made use of internal control. Each turn during the initial stage was approximately 90 degrees, and directional changes are recorded accordingly.

Programming and Strategy

The strategy for gameplay includes three distinct stages: searching, found, and going home.

During the searching phase, the robot starts off pointing in the forward direction. It then drives forward until it encounters an object, and turns to avoid it. It then drives forward until it can turn forward again, and does so. If it runs into a wall before this occurs, it turns around and tries to go around the object on the opposite side. Between each movement, it updates the location of surrounding objects from the distance sensors as well as readings from the IR sensors. If it finds the IR beacon, it moves into the found stage. This behavior means that during a typical run, the robot will make its way to the opposite wall and drive along it until it sees the IR beacon.

In the found phase, the robot searches for the IR beacon. It makes use of an array of sensors to attempt to center itself upon the IR beacon, turning until the center reading is greater than the left or right readings. Once it is centered, it stops moving and shoots at the target. In doing so it spins up the motors, releases the ball, and stops the motors, before moving onto the next phase.

Once the ball is launched, there is no way for the robot to shoot again until it has been reset, and this is on purpose. The robot also ignores IR beacons after this point; since there is no way to differentiate between the enemy robot, the enemy home base, and our own home base, we prioritized reliably getting home rather than getting home quickly.

The use of incremental turns during the found phase also means that the internal direction is no longer accurate. Therefore, we had to develop a technique that would reliably get the robot back to the home base without relying on directionality.

During the going home phase, the robot only has one goal: to get back to the home base. It does this by following the right wall at a given distance in order to make its way around the outer wall of the arena. The choice of how to deal with a starting position not on the wall was difficult, but the combination of hard left turns with slow right shifts provided a fairly reliable return to home base without collisions, enabling us to avoid the costly use of emergency teleports during gameplay. We initially also included hard right turns to aid in obstacle avoidance, but this caused our robot to get stuck if it was too far from the nearest wall, and to miss hitting our home base if there was an obstacle in just the right place. Therefore after a few rounds of gameplay this feature was excluded and this greatly improved the robot's performance.

Results

The robot performed well in gameplay; in fact, our team placed first in competition.

The searching mechanism worked reliably; in most cases, the robot was able to make its way to the opponents home base. It also located the enemy robot in the field on multiple occasions. The launching mechanism worked 100% of the time. The aiming was on occasion off center; on one occasion the robot missed the target by a few inches.

On one occasion, the robot got stuck on an obstacle in the field during the searching phase. This was due to the robot having small blind spots on either side of the front sensors. In future implementations the ultrasonic sensors should be mounted at 45 deg offsets to minimize this error.

On one occasion, the robot targeted it's own home base. This was due to a programming error; the program did not check which direction the robot was facing before it shot, so it saw the beacon and targeted it without realizing that it should ignore it. This feature should be added in future implementations.

The going home strategy was (as mentioned previously) unreliable at the start of gameplay, but due to a design change became more reliable. After the design change, the robot was able to make its way home on multiple occasions, and we did not have to make use of the emergency teleport.

The floor obstacles presented a challenge. The castor and wheels were large enough to make it over the ⅜” obstacle, however the driving motors were mounted on the rear of the robot, which meant that the robot lost traction when attempting to drive forwards over the taller of the two obstacles. Had we flipped the orientation of the drivetrain, this likely would not have been a problem. We also could have included another set of driving motors (bring the total motor/wheel combinations for the drivetrain to 4) in order to decrease the likelihood of getting stuck on such obstacles.

Appendix

Codebase:

```
const int trigPinFR = 44;
const int trigPinFL = 42;
const int trigPinRF = 40;
const int trigPinLF = 38;
const int echoPinFR = 45;
const int echoPinFL = 43;
const int echoPinRF = 41;
const int echoPinLF = 39;

const int servo = 22;
const int shootA = 28;
const int shootB = 29;
const int shootC = 30;
const int shootD = 31;

const int irCenterRight = A13;
const int irCenter = A14;
const int irCenterLeft = A15;
const int irCenterD = A12;

const int driveA = 51;
const int driveB = 53;
const int driveC = 52;
const int driveD = 50;

const int dir_F = 0;
const int dir_R = 1;
const int dir_H = 2;
const int dir_L = 3;

const int searching = 1;
const int found = 2;
const int going_home = 3;
```

```
int counter;
int state;
int dir;

int distFrontL;
int distFrontR;
int distRightF;
int distRightF_prev;
int distRightF_prev_2;
int distLeftF;
int dist;

int readingC;
int readingCL;
int readingCR;
int readingCD;

void setup() {
  pinMode(trigPinFR, OUTPUT);
  pinMode(trigPinFL, OUTPUT);
  pinMode(trigPinRF, OUTPUT);
  pinMode(trigPinLF, OUTPUT);
  pinMode(echoPinFR, INPUT);
  pinMode(echoPinFL, INPUT);
  pinMode(echoPinRF, INPUT);
  pinMode(echoPinLF, INPUT);

  pinMode(servo, OUTPUT);
  pinMode(shootA, OUTPUT);
  pinMode(shootB, OUTPUT);
  pinMode(shootC, OUTPUT);
  pinMode(shootD, OUTPUT);

  pinMode(irCenter, INPUT);
  pinMode(irCenterLeft, INPUT);
  pinMode(irCenterRight, INPUT);
  pinMode(irCenterD, INPUT);
```

```
  pinMode(driveA, OUTPUT);
  pinMode(driveB, OUTPUT);
  pinMode(driveC, OUTPUT);
  pinMode(driveD, OUTPUT);

  dir = dir_F;
  state = searching;
  counter = 0;

  Serial.begin(9600);

}

void loop() {
  switch(state) {

    case searching:
      getDistance();
      if(dir == dir_F){
       if(min(distFrontL,distFrontR) > 20){
         driveForward(300);
       }
       else if(distLeftF > distRightF){
         turnLeft();
       }
       else{
         turnRight();
       }
      }

      else if(dir == dir_R){
       if(distLeftF > 20){
         if(min(distFrontR,distFrontL) > 20){
           driveForward(500);
         }
         turnLeft();
       }
       else if(min(distFrontR,distFrontL) > 20){
         driveForward(300);
```

```
  }
  else{
    turnRight();
  }
}

else if(dir == dir_L){
  if(distRightF > 20){
    if(min(distFrontR,distFrontL) > 20){
      driveForward(500);
    }
    turnRight();
  }
  else if(min(distFrontR,distFrontL) > 20){
    driveForward(500);
  }
  else{
    turnLeft();
  }
}

else{
  if(distLeftF > 20){
    turnLeft();
  }
  else if(distRightF > 20){
    turnRight();
  }
  else if(min(distFrontR, distFrontL) > 20){
    driveForward(300);
  }
  else{
    turnLeft();
  }
}

//if IR detected, find IR
readIR();
if(max(max(readingC, readingCR), max(readingCD, readingCL)) > 30){
```

```
      state = found;
    }
break;

case found:
  readIR();
  if(max(readingC, readingCD) > readingCL & max(readingC,readingCD) > readingCR){
    shoot();
    getDistance();
    while(min(distFrontR,distFrontL) > 15){
      driveForward(100);
      getDistance();
    }
    turnLeft();
    state = going_home;
  }
  else if(readingCR > max(readingC,readingCD) & readingCR > readingCL){
    turnRight(100);
  }
  else if(readingCL > max(readingC,readingCD) & readingCL > readingCR){
    turnLeft(100);
  }

break;

case going_home:
  getDistance();
  if(min(distFrontR,distFrontL) > 30){
    if(distRightF < 5){
        turnLeft(30);
        driveForward(100);
      }
    else if(distRightF > 15){
        turnRight(30);
        driveForward(100);
      }
    else{
        driveForward(200);
    }
```

```
        }

        else{
          turnLeft();
        }

      break;
    }
}


void driveForward(int t) {
    digitalWrite(driveA,LOW);
    digitalWrite(driveB,HIGH);
    digitalWrite(driveC,LOW);
    digitalWrite(driveD,HIGH);
    delay(t);
    stopMoving();
    delay(10);
}

void driveReverse(int t){
    digitalWrite(driveA,HIGH);
    digitalWrite(driveB,LOW);
    digitalWrite(driveC,HIGH);
    digitalWrite(driveD,LOW);
    delay(t);
    stopMoving();
}

void stopMoving(){
    digitalWrite(driveA, LOW);
    digitalWrite(driveB, LOW);
    digitalWrite(driveC, LOW);
    digitalWrite(driveD, LOW);
}

void turnRight(int t){
    digitalWrite(driveA,LOW);
```

```
  digitalWrite(driveB,HIGH);
  digitalWrite(driveC,HIGH);
  digitalWrite(driveD,LOW);
  delay(t);
  stopMoving();
  delay(100);
}

void turnRight(){
  for(int i = 0; i < 3; i = i+1){
    turnRight(200);
    if(state == searching) {
      readIR();
      if(max(max(readingC,readingCR),max(readingCR,readingCL)) > 40){
        state = found;
        return;
      }
    }
  }
  dir = dir + 1;
  if(dir == 4)
    dir = 0;
}

void turnLeft(int t){
  digitalWrite(driveA,HIGH);
  digitalWrite(driveB,LOW);
  digitalWrite(driveC,LOW);
  digitalWrite(driveD,HIGH);
  delay(t);
  stopMoving();
  delay(100);
}

void turnLeft(){
  for(int i = 0; i < 3; i = i+1){
    turnLeft(200);
    if(state == searching) {
      readIR();
```

```
    if(max(max(readingC,readingCR),max(readingCR,readingCL)) > 40){
     state = found;
     return;
    }
   }
  }
  dir = dir - 1;
  if(dir == -1)
   dir = 3;
}

int getDistance(int trigger, int echo){
  distRightF_prev = distRightF;

  digitalWrite(trigger, LOW);
  delayMicroseconds(2);
  digitalWrite(trigger, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigger, LOW);

  dist = pulseIn(echo, HIGH) * 0.034/2;
  return dist;
}

void getDistance() {
  distFrontR = getDistance(trigPinFR,echoPinFR);
  distFrontL = getDistance(trigPinFL,echoPinFL);
  distRightF = getDistance(trigPinRF,echoPinRF);
  distLeftF = getDistance(trigPinLF,echoPinLF);
}

void shoot(){
  startShoot();
  turnServoCW(60);
  turnServoCCW(60);
  stopShoot();
}

void turnServoCCW(int n){
```

```
  for (int i = 0; i<n; i++){
    digitalWrite(servo, HIGH);
    delayMicroseconds(2000);
    digitalWrite(servo, LOW);
    delay(18);
  }
}

void turnServoCW(int n){
  for (int i = 0; i<n; i++){
    digitalWrite(servo, HIGH);
    delayMicroseconds(1000);
    digitalWrite(servo, LOW);
    delay(19);
  }
}

void startShoot(){
  digitalWrite(shootA, LOW);
  digitalWrite(shootB, HIGH);
  digitalWrite(shootC, LOW);
  digitalWrite(shootD, HIGH);
}

void stopShoot(){
  digitalWrite(shootA, LOW);
  digitalWrite(shootB, LOW);
  digitalWrite(shootC, LOW);
  digitalWrite(shootD, LOW);
}

void readIR(){
  readingC = analogRead(irCenter);
  readingCR = analogRead(irCenterRight);
  readingCL = analogRead(irCenterLeft);
  readingCD = analogRead(irCenterD);
}
```

NPN Silicon Phototransistor

OP505, OP505W, OP506, OP506W
OP535, OP705

Features:

- T-1 package style
- Variety of sensitivity ranges
- Choice of narrow or wide receiving angle
- Small package size ideal for space-limited applications
- 0.050" [1.27mm] or 0.100" [2.54mm] Lead spacing

Description:

Each OP505 and OP506 devices consist of an NPN silicon phototransistor, the OP535 device consist of an NPN silicon photodarlington transistor and the OP705 device consist of an NPN silicon phototransistor with a large value resistor integrated between the Base and Emitter for low light signal rejection. All of the devices are molded in a blue-tinted T-1 (3mm) epoxy package

The OP505, OP535 and OP70**5** devices have a narrow receiving angle that provides excellent on-axis coupling while the OP506 device has a wider receiving angle for those applications where a narrow receiving angle of the OP505, OP535 and OP705 is not required. The OP505W and OP506W device have the widest receiving angle and provides relatively even reception over a large area.

Devices are 100% production tested, using infrared light for close correlation with Optek's GaAs and GaAIAs emitters.

Please refer to Application Bulletins 208 and 210 for additional design information and reliability (degradation) data.

Please see your OPTEK representative for custom versions of these devices.

Applications:

- Space-limited applications
- Interruptive applications to detect media which is semi-transparent to infrared light

Ordering Information				
Part Number	**Sensor**	**Viewing Angle**	**Lead Spacing**	**Lead Length**
OP505A	Transistor	20°	0.050" [1.27 mm]	0.50" [12.7 mm]
OP505B				
OP505C				
OP505D				
OP505W		90°		
OP506A		20°	0.100" [2.54 mm]	
OP506B				
OP506C				
OP506W		90°		
OP535A	Darlington	20°	0.050" [1.27 mm]	
OP535B				
OP705A	R_{BE} Transistor			

General Note
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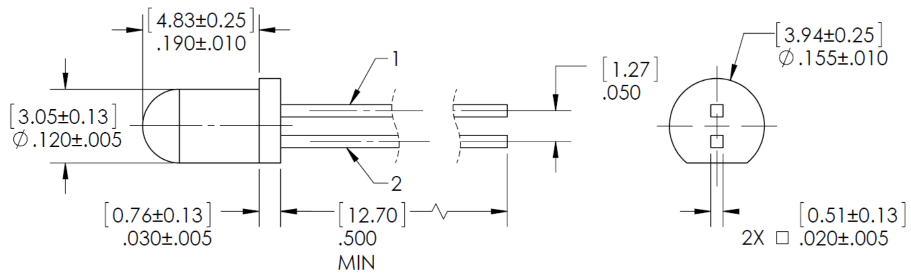
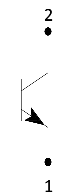
1645 Wallace Drive, Carrollton, TX 75006|Ph: +1 972 323 2200
www.optekinc.com | www.ttelectronics.com

OP505, OP535, OP705

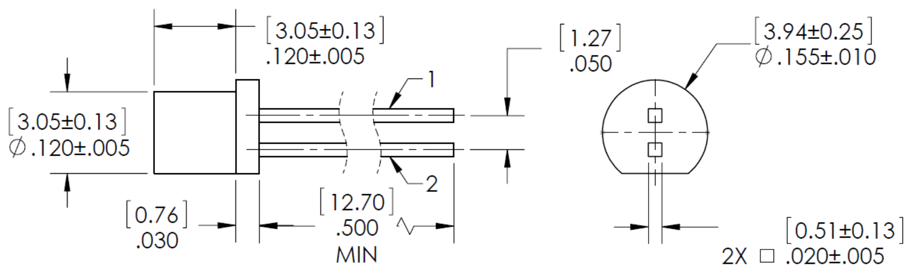


Pin #	Transistor
1	Emitter
2	Collector

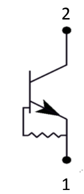
OP505, OP506 OP505W, OP506W



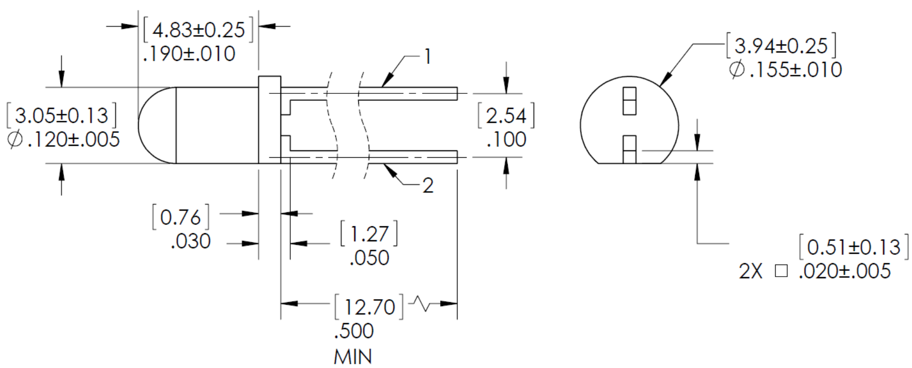
OP505W



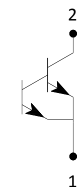
OP705



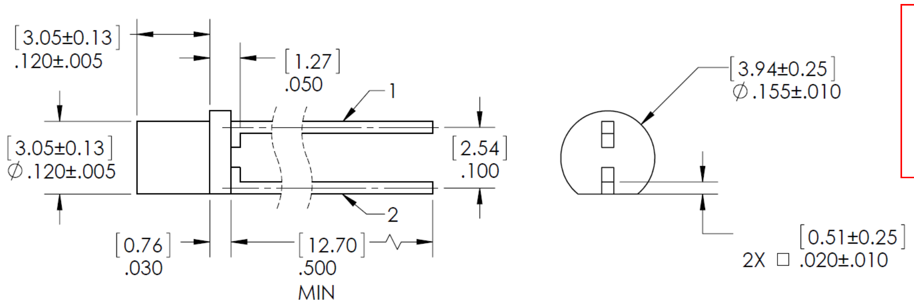
OP506



OP535



OP506W



CONTAINS POLYSULFONE

Methanol and isopropanol alcohols
are recommended cleaning agents.
Housings are soluble in chlorinated hydrocarbons and keytones.
Highly activated or water soluble fluxes may damage body.
Testing reagents before use is recommended prior to use.

TOLERANCES ARE ± .010" [.25] UNLESS OTHERWISE STATED
DIMENSIONS ARE IN INCHES [MILLIMETERS]

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www.optekinc.com | www.ttelectronics.com

Electrical Specifications

Absolute Maximum Ratings (T_A = 25° C unless otherwise noted)	
Storage & Operating Temperature Range	-40°C to +100° C
Collector-Emitter Voltage (OP505, OP506, OP505W, OP506W, OP705)	30 V
Collector-Emitter Voltage (OP535)	15 V
Emitter-Collector Voltage (OP505 and OP506 series only)	5.0 V
Lead Soldering Temperature (1/16 inch (1.6 mm) from case for 5 seconds with soldering iron)	260° C
Power Dissipation	100 mW (2)
Emitter Reverse Current (OP705 series only)	10 mA
Collector DC Current (OP705 series only)	30 mA

Electrical Characteristics (T_A = 25° C unless otherwise noted)
OP505, OP506, OP505W, OP506W, OP705

SYMBOL	PARAMETER	MIN	TYP	MAX	UNITS	TEST CONDITIONS
$I_{C(ON)}$	On-State Collector Current OP505A, OP506A OP505B, OP506B OP505C, OP506C OP505D	 4.30 2.15 1.10 0.55	 - - - -	 - 5.95 3.00 -	mA	V_{CE} = 5 V, E_e = 0.50 mW/cm^2 , Note 3
	OP705A	3.95	-	12.00	mA	V_{CE} = 5 V, E_e = 0.50 mW/cm^2, Note 3
	OP505W, OP506W	0.10	-	-	mA	V_{CE} = 5 V, E_e = 0.75 mW/cm^2, Note 3
$V_{CE(SAT)}$	Collector-Emitter Saturation Voltage OP505, OP506, OP705	-	-	0.40	V	I_C = 250 µA, E_E = 0.5 mW/cm^2, Note 3
	OP505W, OP506W	-	-	0.40	V	I_C = 50 µA, E_E = 0.75 mW/cm^2, Note 3
I_{CEO}	Collector-Dark Current	-	-	100	nA	V_{CE} = 10 V, E_E = 0
$V_{(BR)CEO}$	Collector-Emitter Breakdown Voltage	30	-	-	V	I_C = 100 µA, E_E = 0
$V_{(BR)ECO}$	Emitter-Collector Breakdown Voltage OP505, OP506	5	-	-	V	I_E = 100 µA, E_E = 0
	OP705	0.4	-	-	V	I_E = 100 µA, E_E = 0
$\Delta I_C/\Delta T$	Relative I_C Changes with Temperature	-	1.00	-	% / °C	V_{CE} = 5 V, E_E = 1.0 mW/cm^2
E_{KP}	Knee Point Irradiance (OP705)	-	0.02	-	mW/cm^2	V_{CE} = 5 V, Note 4

Notes:
1. (1) RMA flux is recommended. Duration can be extended to 10 seconds maximum when flow soldering. A maximum of 20 grams force may be applied to the leads when soldering.
2. (2) Derate linearly 1.33 mW/° C above 25° C.
3. (3) Light source is an unfiltered GaAs LED with a peak emission wavelength of 935 nm and a radiometric intensity level, which varies less than 10% over the entire lens surface of the phototransistor being tested.
4. (4) The knee point irradiance is defined as the irradiance required to increase Ic(on) to 50 µA.

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Electrical Specifications

Electrical Characteristics (T_A = 25° C unless otherwise noted)
OP535

SYMBOL	PARAMETER	MIN	TYP	MAX	UNITS	TEST CONDITIONS
$I_{C(ON)}$	On-State Collector Current OP535A OP535B	 10.5 3.5	 - -	 - 32.0	mA	V_{CE} = 5 V, E_E = 0.13 mW/cm², Note 3
$V_{CE(SAT)}$	Collector-Emitter Saturation Voltage	-	-	1.10	V	I_C = 400 µA, E_E = 0.13 mW/cm², Note 3
I_{CEO}	Collector-Dark Current	-	-	100	nA	V_{CE} = 10 V, E_E = 0
$V_{(BR)CEO}$	Collector-Emitter Breakdown Voltage	15.0	-	-	V	I_C = 1.0 mA, E_E = 0
$V_{(BR)ECO}$	Emitter-Collector Breakdown Voltage	5.0	-	-	V	I_E = 100 µA, E_E = 0

General Note
TT Electronics reserves the right to make changes in product specification without notice or liability. All information is subject to TT Electronics' own data and is considered accurate at time of going to print.

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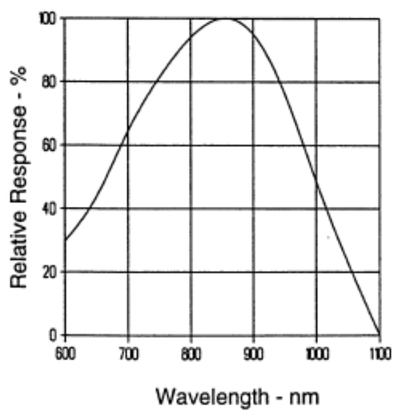
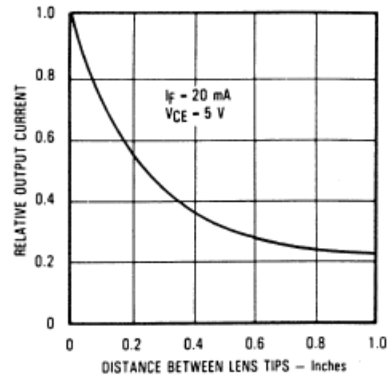
Performance

OP505A, OP505B, OP505C, OP505D

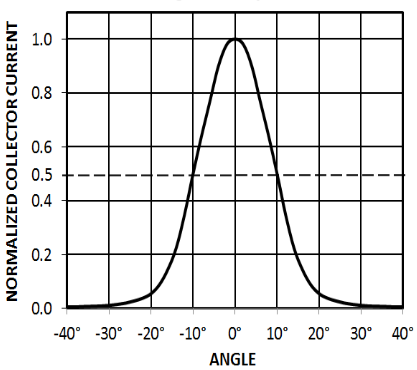
Typical Spectral Response



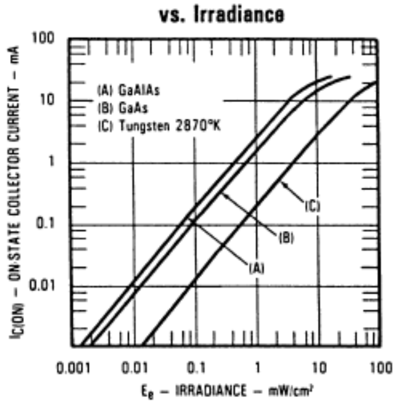
Coupling Characteristics OP165 and OP505



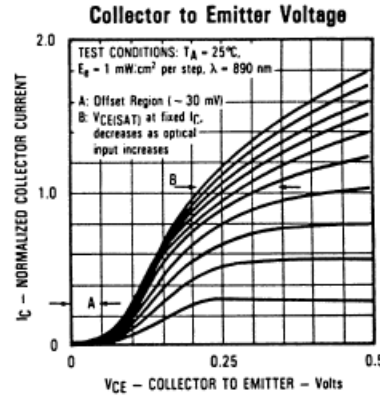
Normalized Collector Current vs. Angular Displacement



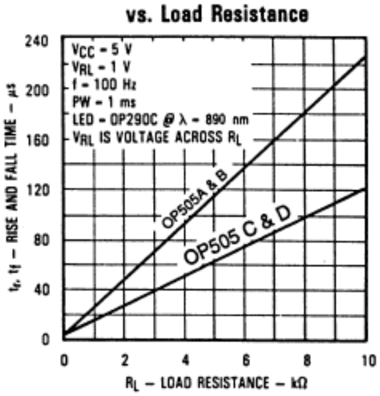
On-State Collector Current vs. Irradiance



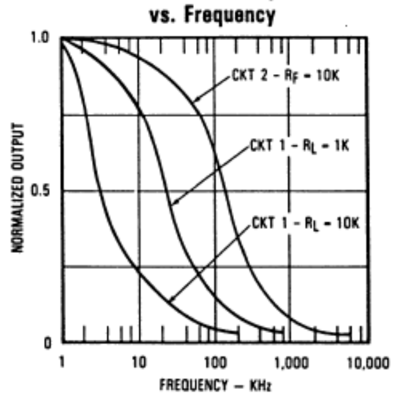
Normalized Collector Current vs. Collector to Emitter Voltage



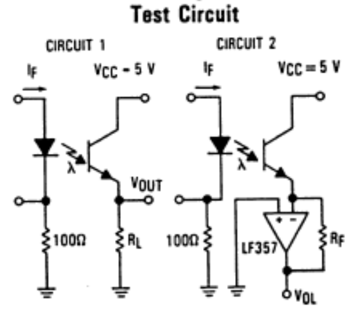
Rise and Fall Time vs. Load Resistance



Normalized Output vs. Frequency



Switching Time Test Circuit



Test Conditions:
Light source is pulsed LED with t_r and $t_f \le$ 500 ns.
I_F is adjusted for V_{OUT} = 1 Volt.

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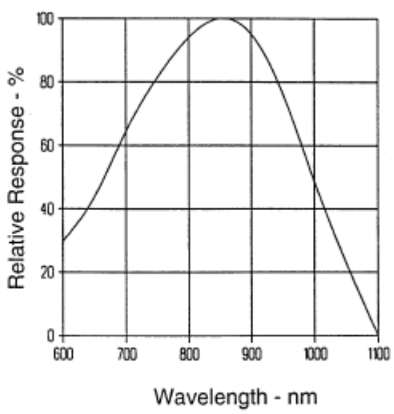
NPN Silicon Phototransistor

OP505, OP505W, OP506, OP506W
OP535, OP705

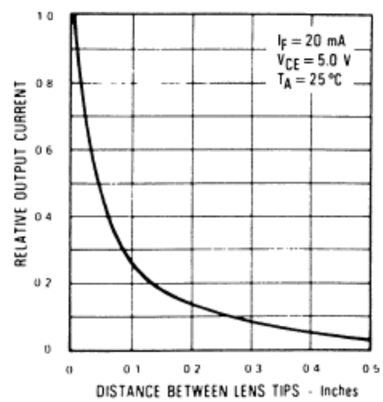
Performance

OP505W

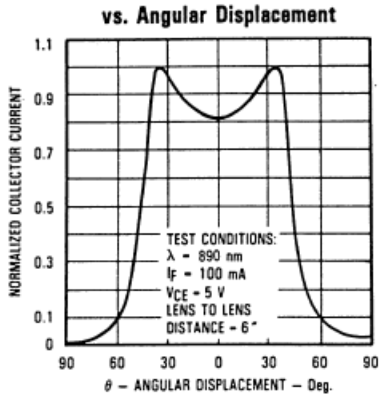
Typical Spectral Response



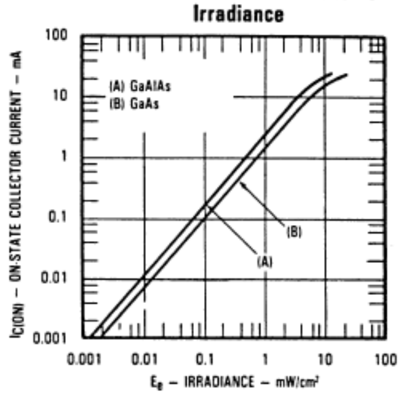
Coupling Characteristics of OP165W and OP505W



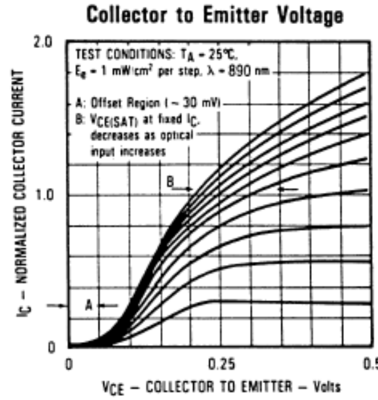
Normalized Collector Current vs. Angular Displacement



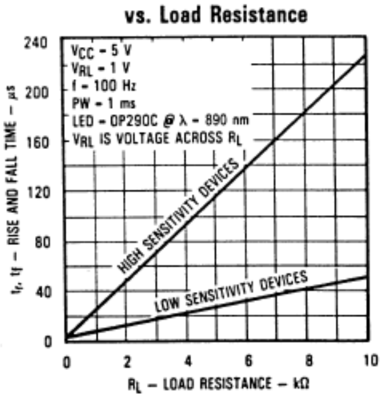
On-State Collector Current vs Irradiance



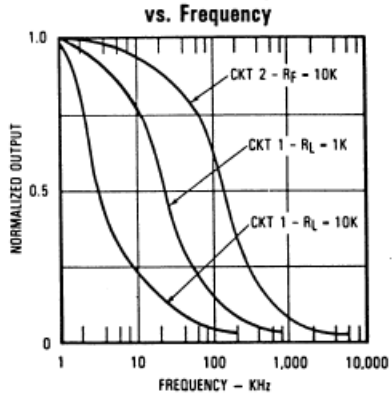
Normalized Collector Current vs. Collector to Emitter Voltage



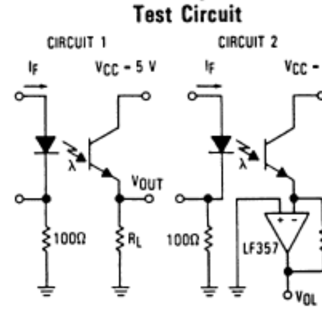
Rise and Fall Time vs. Load Resistance



Normalized Output vs. Frequency



Switching Time Test Circuit



Test Conditions:
Light source is pulsed LED with t_r and t_f ≤ 500 ns.
I_F is adjusted for V_{OUT} = 1 Volt.

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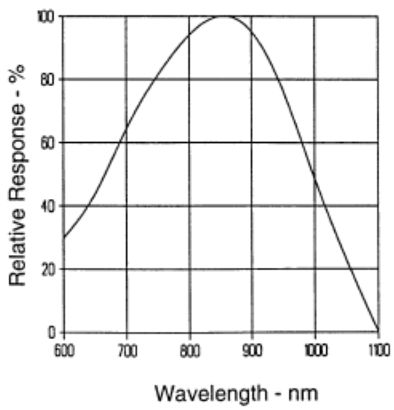
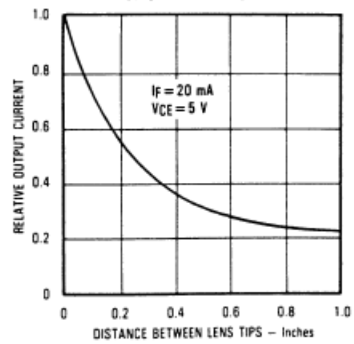
Performance

OP506A, OP506B, OP506C

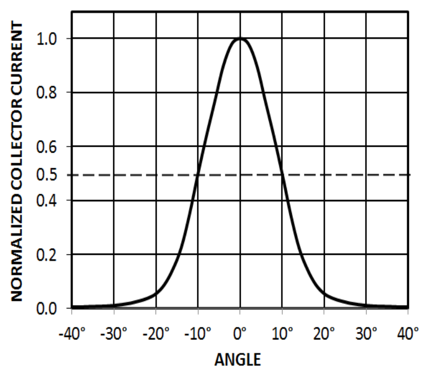
Typical Spectral Response



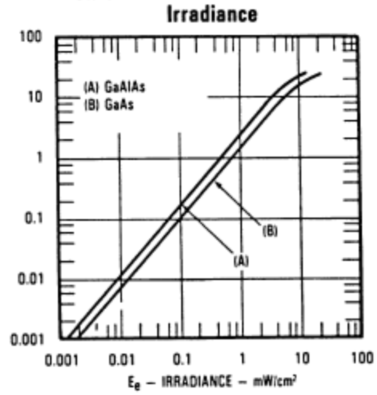
Coupling Characteristics of OP166 and OP506



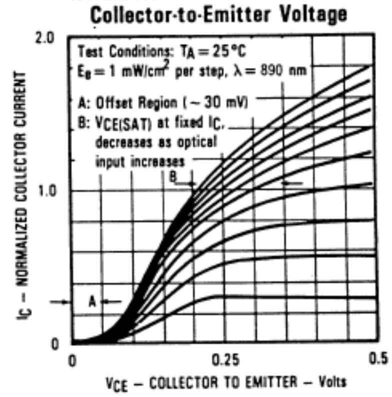
Normalized Collector Current vs. Angular Displacement



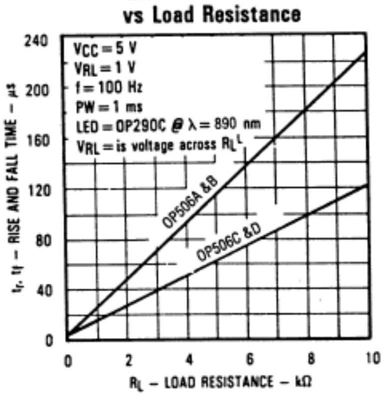
On-State Collector Current vs Irradiance



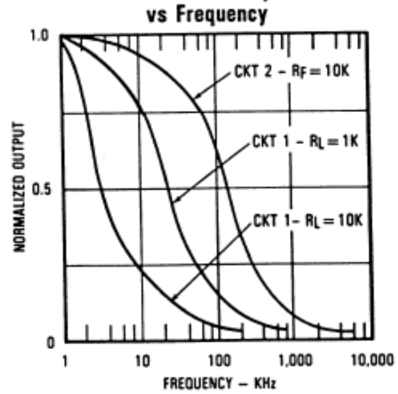
Normalized Collector Current vs Collector-to-Emitter Voltage



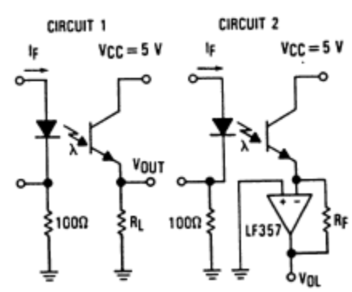
Rise and Fall Time vs Load Resistance



Normalized Output vs Frequency



Switching Time Test Circuit



Test Conditions:
Light source is pulsed LED with t_r and $t_f \leq 500$ ns.
I_F is adjusted for $V_{OUT} = 1$ Volt.

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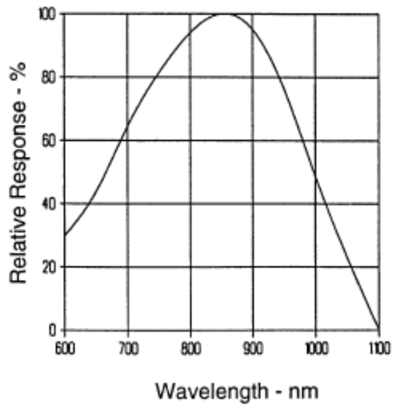
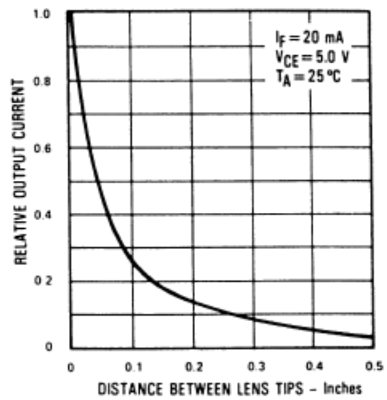
Performance

OP506W

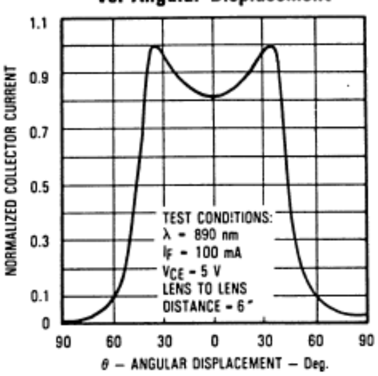
Typical Spectral Response



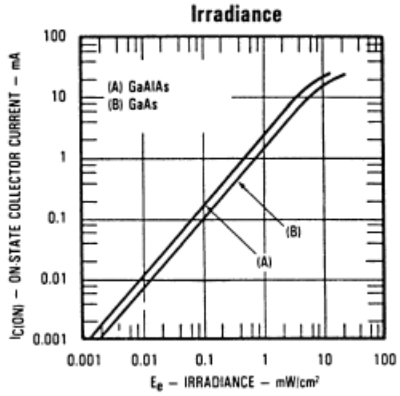
Coupling Characteristics



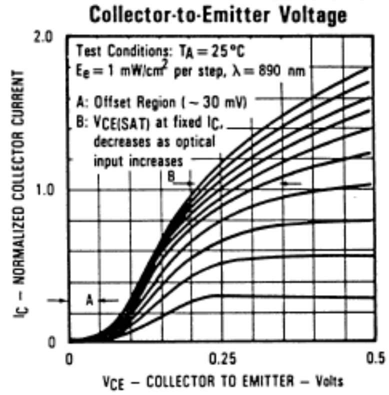
Normalized Collector Current vs. Angular Displacement



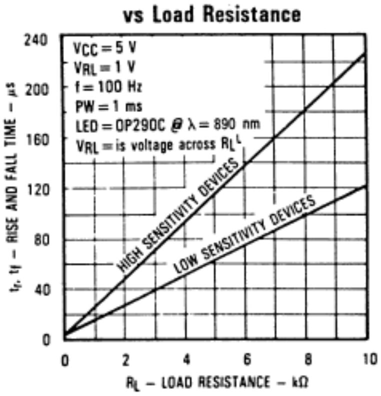
On-State Collector Current vs Irradiance



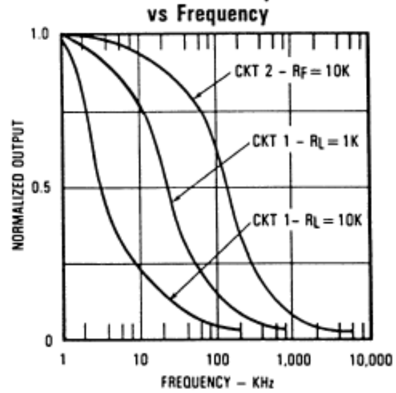
Normalized Collector Current vs Collector-to-Emitter Voltage



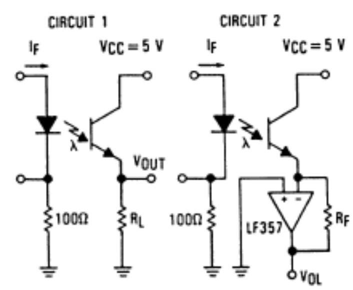
Rise and Fall Time vs Load Resistance



Normalized Output vs Frequency



Switching Time Test Circuit



Test Conditions:
Light source is pulsed LED with t_r and $t_f \leq 500$ ns.
I_F is adjusted for $V_{OUT} = 1$ Volt.

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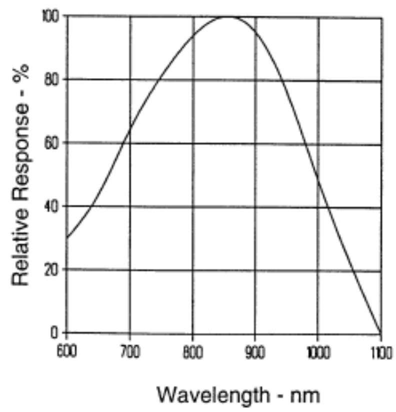
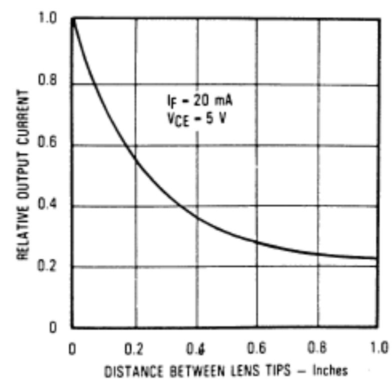
Performance

OP535A, OP535B, OP535D

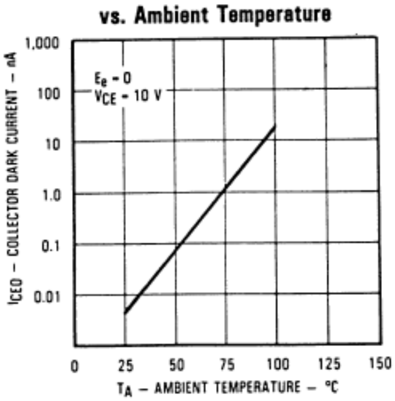
Typical Spectral Response



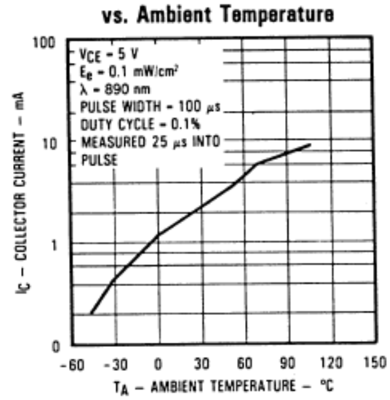
Coupling Characteristics of OP165 and OP535



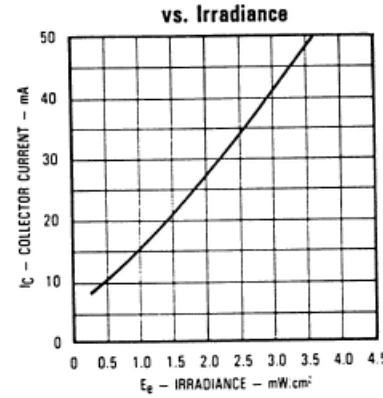
Collector Dark Current vs. Ambient Temperature



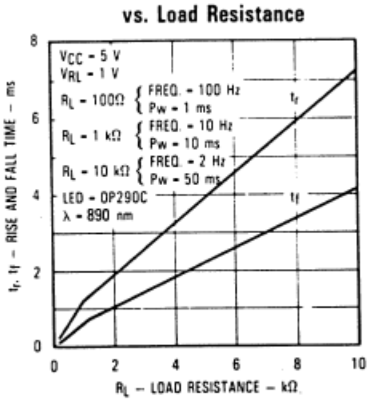
Collector Current vs. Ambient Temperature



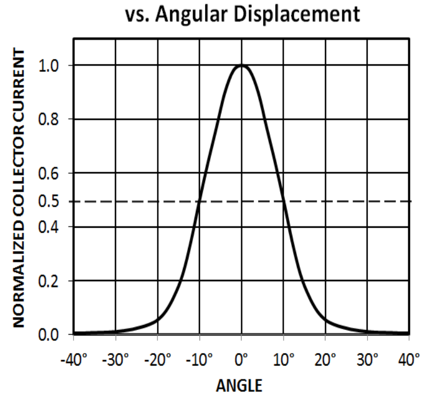
Collector Current vs. Irradiance



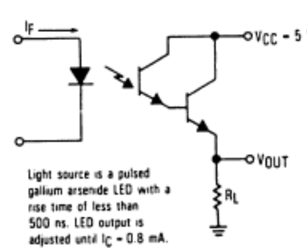
Rise and Fall Time vs. Load Resistance



Normalized Collector Current vs. Angular Displacement



Switching Time Test Circuit



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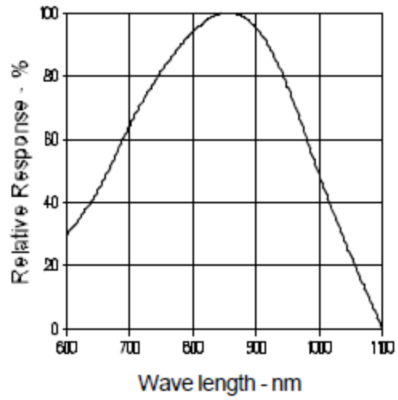
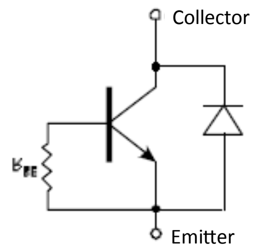
Performance

OP705A

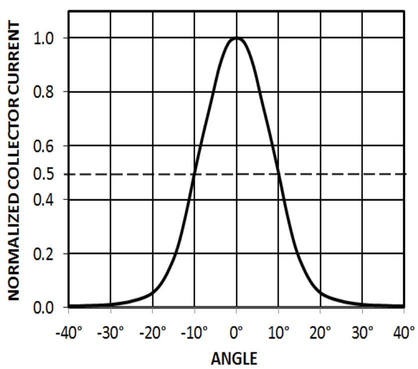
Typical Spectral Response



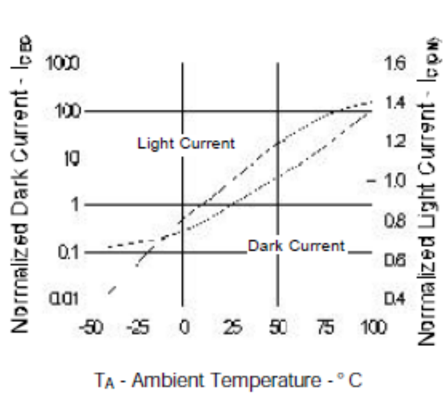
Schematic



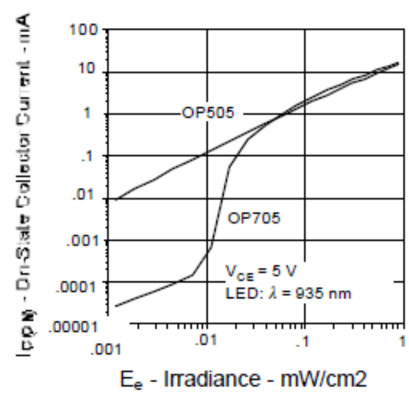
Normalized Collector Current vs. Angular Displacement



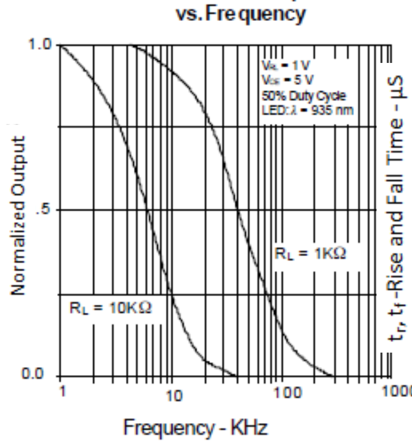
Normalized Light and Dark Current vs. Ambient Temperature



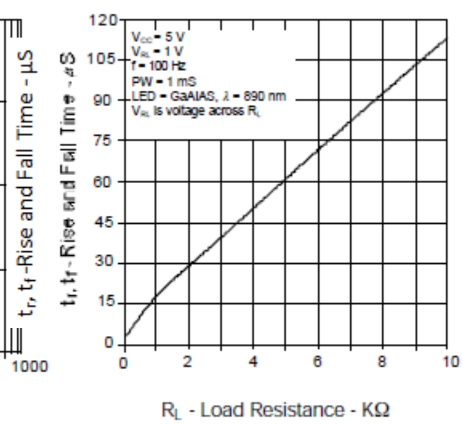
On-State Collector Current vs. Irradiance



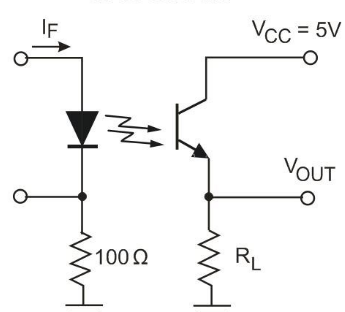
Normalized Output vs. Frequency



Typical Rise and Fall Time vs. Load Resistance



Switching Time Test Circuit



Test Conditions:
Light Source is pulsed LED with tr and tf ≤ 500nS.
I_F is adjusted for V_{OUT} = 1Volt.

General Note
TT Electronics reserves the right to make changes in product specification without notice or liability. All information is subject to TT Electronics' own data and is considered accurate at time of going to print.

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OP506A OP505A OP506B OP505B OP505C OP505D OP505W OP506C OP506D OP506W OP535A OP535B OP705A

Ultrasonic Ranging Module HC - SR04

Product features:

Ultrasonic ranging module HC - SR04 provides 2cm - 400cm non-contact measurement function, the ranging accuracy can reach to 3mm. The modules includes ultrasonic transmitters, receiver and control circuit. The basic principle of work:

(1) Using IO trigger for at least 10us high level signal,

(2) The Module automatically sends eight 40 kHz and detect whether there is a
pulse signal back.

(3) IF the signal back, through high level , time of high output IO duration is the time from sending ultrasonic to returning.

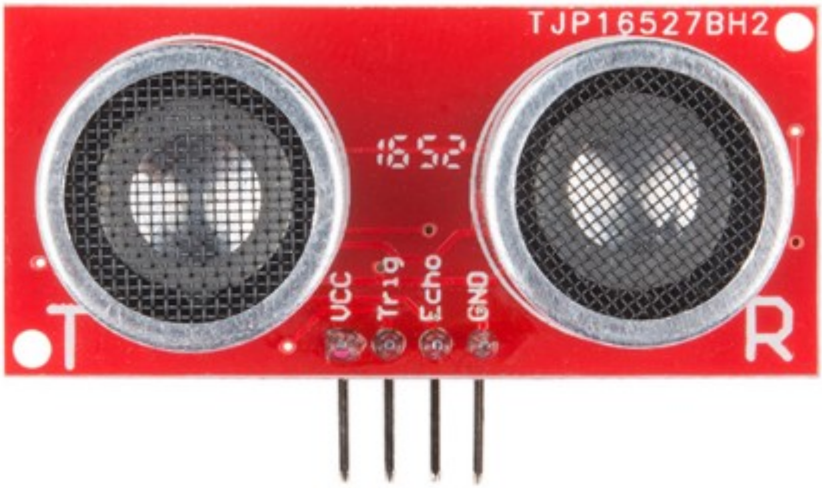
Test distance = (high level time×velocity of sound (340M/S) / 2

Wire connecting direct as following:

- 5V Supply
- Trigger Pulse Input
- Echo Pulse Output
- 0V Ground

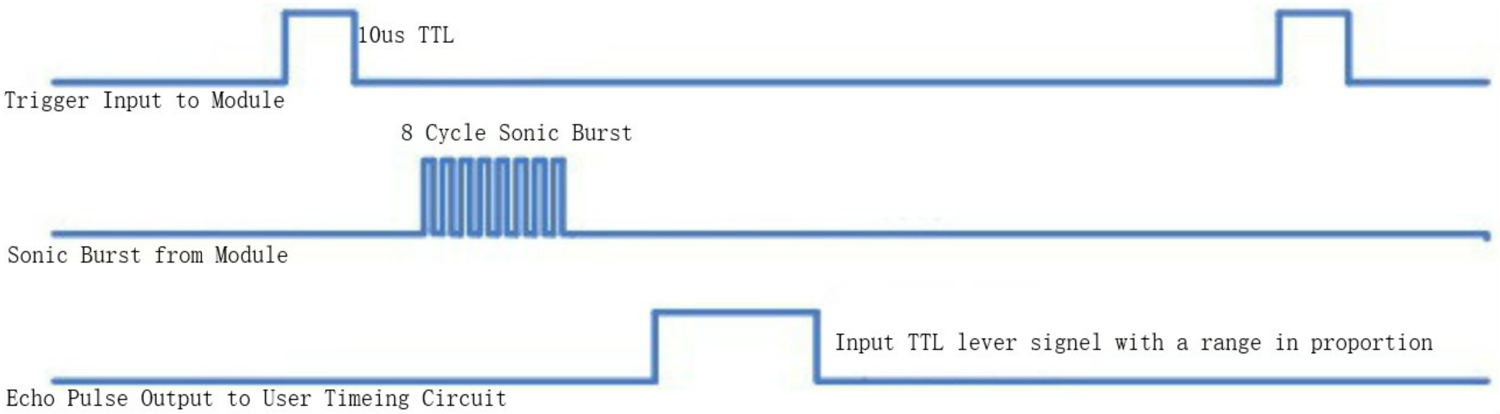
Electric Parameter

Working Voltage	DC 5 V
Working Current	15mA
Working Frequency	40Hz
Max Range	4m
Min Range	2cm
MeasuringAngle	15 degree
Trigger Input Signal	10uS TTL pulse
Echo Output Signal	Input TTL lever signal and the range in proportion
Dimension	45*20*15mm



Timing diagram

The Timing diagram is shown below. You only need to supply a short 10uS pulse to the trigger input to start the ranging, and then the module will send out an 8 cycle burst of ultrasound at 40 kHz and raise its echo. The Echo is a distance object that is pulse width and the range in proportion .You can calculate the range through the time interval between sending trigger signal and
receiving echo signal. Formula: uS / 58 = centimeters or uS / 148 =inch; or: the range = high level time * velocity (340M/S) / 2; we suggest to use over 60ms measurement cycle, in order to prevent trigger signal to the echo signal.



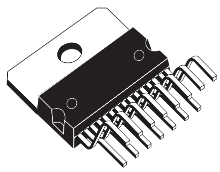
Attention:

●The module is not suggested to connect directly to electric, if connected electric, the GND terminal should be connected the module first, otherwise, it will affect the normal work of the module.
● When tested objects, the range of area is not less than 0.5 square meters and the plane requests as smooth as possible, otherwise ,it will affect the results of measuring.

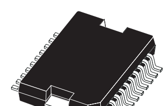
L298

DUAL FULL-BRIDGE DRIVER

- OPERATING SUPPLY VOLTAGE UP TO 46 V
- TOTAL DC CURRENT UP TO 4 A
- LOW SATURATION VOLTAGE
- OVERTEMPERATURE PROTECTION
- LOGICAL "0" INPUT VOLTAGE UP TO 1.5 V (HIGH NOISE IMMUNITY)



Multiwatt15



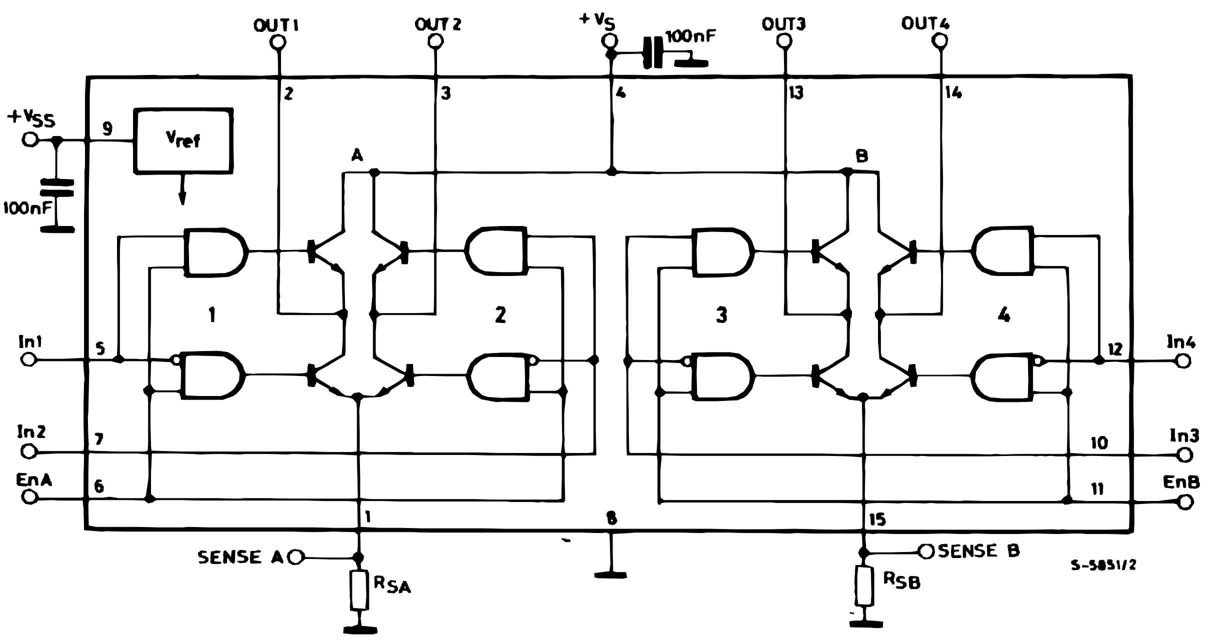
PowerSO20

ORDERING NUMBERS : L298N (Multiwatt Vert.)
L298HN (Multiwatt Horiz.)
L298P (PowerSO20)

DESCRIPTION

The L298 is an integrated monolithic circuit in a 15-lead Multiwatt and PowerSO20 packages. It is a high voltage, high current dual full-bridge driver designed to accept standard TTL logic levels and drive inductive loads such as relays, solenoids, DC and stepping motors. Two enable inputs are provided to enable or disable the device independently of the input signals. The emitters of the lower transistors of each bridge are connected together and the corresponding external terminal can be used for the connection of an external sensing resistor. An additional supply input is provided so that the logic works at a lower voltage.

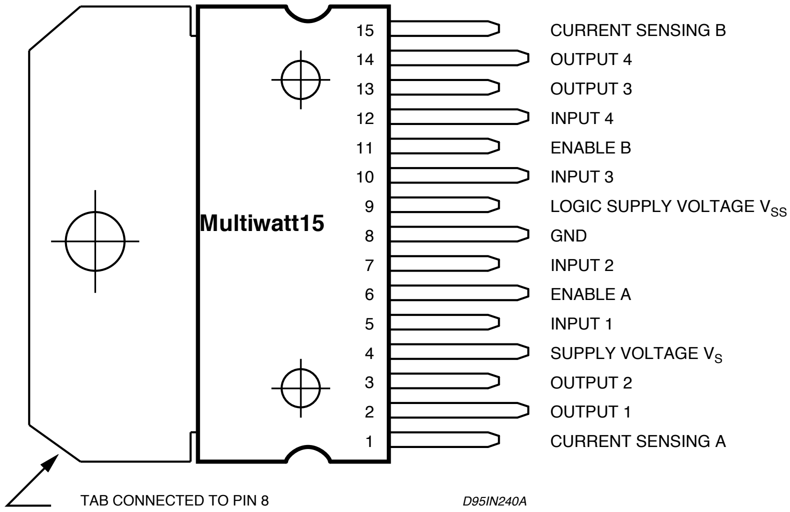
BLOCK DIAGRAM

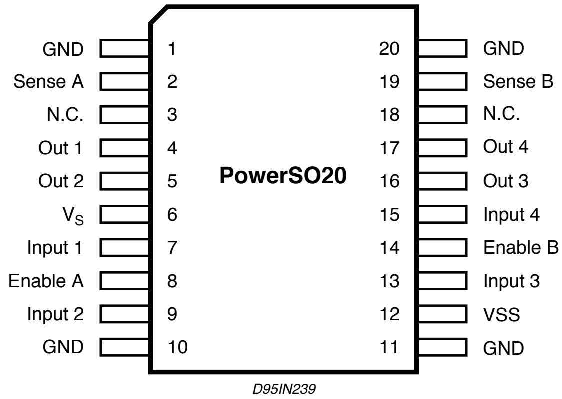


ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_S	Power Supply	50	V
V_{SS}	Logic Supply Voltage	7	V
V_I,V_{en}	Input and Enable Voltage	–0.3 to 7	V
I_O	Peak Output Current (each Channel) – Non Repetitive (t = 100µs) –Repetitive (80% on –20% off; t_{on} = 10ms) –DC Operation	 3 2.5 2	 A A A
V_{sens}	Sensing Voltage	–1 to 2.3	V
P_{tot}	Total Power Dissipation (T_{case} = 75°C)	25	W
T_{op}	Junction Operating Temperature	–25 to 130	°C
T_{stg}, T_j	Storage and Junction Temperature	–40 to 150	°C

PIN CONNECTIONS (top view)





THERMAL DATA

Symbol	Parameter		PowerSO20	Multiwatt15	Unit
$R_{th\ j\text{-}case}$	Thermal Resistance Junction-case	Max.	–	3	°C/W
$R_{th\ j\text{-}amb}$	Thermal Resistance Junction-ambient	Max.	13 (*)	35	°C/W

(*) Mounted on aluminum substrate

PIN FUNCTIONS (refer to the block diagram)

MW.15	PowerSO	Name	Function
1;15	2;19	Sense A; Sense B	Between this pin and ground is connected the sense resistor to control the current of the load.
2;3	4;5	Out 1; Out 2	Outputs of the Bridge A; the current that flows through the load connected between these two pins is monitored at pin 1.
4	6	V_S	Supply Voltage for the Power Output Stages. A non-inductive 100nF capacitor must be connected between this pin and ground.
5;7	7;9	Input 1; Input 2	TTL Compatible Inputs of the Bridge A.
6;11	8;14	Enable A; Enable B	TTL Compatible Enable Input: the L state disables the bridge A (enable A) and/or the bridge B (enable B).
8	1,10,11,20	GND	Ground.
9	12	VSS	Supply Voltage for the Logic Blocks. A100nF capacitor must be connected between this pin and ground.
10; 12	13;15	Input 3; Input 4	TTL Compatible Inputs of the Bridge B.
13; 14	16;17	Out 3; Out 4	Outputs of the Bridge B. The current that flows through the load connected between these two pins is monitored at pin 15.
–	3;18	N.C.	Not Connected

ELECTRICAL CHARACTERISTICS (V_S = 42V; V_{SS} = 5V, T_j = 25°C; unless otherwise specified)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
V_S	Supply Voltage (pin 4)	Operative Condition	V_{IH} +2.5		46	V
V_{SS}	Logic Supply Voltage (pin 9)		4.5	5	7	V
I_S	Quiescent Supply Current (pin 4)	V_{en} = H; I_L = 0 V_i = L V_i = H		13 50	22 70	mA mA
		V_{en} = L V_i = X			4	mA
I_{SS}	Quiescent Current from V_{SS} (pin 9)	V_{en} = H; I_L = 0 V_i = L V_i = H		24 7	36 12	mA mA
		V_{en} = L V_i = X			6	mA
V_{iL}	Input Low Voltage (pins 5, 7, 10, 12)		–0.3		1.5	V
V_{iH}	Input High Voltage (pins 5, 7, 10, 12)		2.3		VSS	V
I_{iL}	Low Voltage Input Current (pins 5, 7, 10, 12)	V_i = L			–10	µA
I_{iH}	High Voltage Input Current (pins 5, 7, 10, 12)	Vi = H ≤ V_{SS} –0.6V		30	100	µA
V_{en} = L	Enable Low Voltage (pins 6, 11)		–0.3		1.5	V
V_{en} = H	Enable High Voltage (pins 6, 11)		2.3		V_{SS}	V
I_{en} = L	Low Voltage Enable Current (pins 6, 11)	V_{en} = L			–10	µA
I_{en} = H	High Voltage Enable Current (pins 6, 11)	V_{en} = H ≤ V_{SS} –0.6V		30	100	µA
$V_{CEsat (H)}$	Source Saturation Voltage	I_L = 1A I_L = 2A	0.95	1.35 2	1.7 2.7	V V
$V_{CEsat (L)}$	Sink Saturation Voltage	I_L = 1A (5) I_L = 2A (5)	0.85	1.2 1.7	1.6 2.3	V V
V_{CEsat}	Total Drop	I_L = 1A (5) I_L = 2A (5)	1.80		3.2 4.9	V V
V_{sens}	Sensing Voltage (pins 1, 15)		–1 (1)		2	V

ELECTRICAL CHARACTERISTICS (continued)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
T_1 (V_i)	Source Current Turn-off Delay	0.5 V_i to 0.9 I_L (2); (4)		1.5		µs
T_2 (V_i)	Source Current Fall Time	0.9 I_L to 0.1 I_L (2); (4)		0.2		µs
T_3 (V_i)	Source Current Turn-on Delay	0.5 V_i to 0.1 I_L (2); (4)		2		µs
T_4 (V_i)	Source Current Rise Time	0.1 I_L to 0.9 I_L (2); (4)		0.7		µs
T_5 (V_i)	Sink Current Turn-off Delay	0.5 V_i to 0.9 I_L (3); (4)		0.7		µs
T_6 (V_i)	Sink Current Fall Time	0.9 I_L to 0.1 I_L (3); (4)		0.25		µs
T_7 (V_i)	Sink Current Turn-on Delay	0.5 V_i to 0.9 I_L (3); (4)		1.6		µs
T_8 (V_i)	Sink Current Rise Time	0.1 I_L to 0.9 I_L (3); (4)		0.2		µs
fc (V_i)	Commutation Frequency	I_L = 2A		25	40	KHz
T_1 (V_{en})	Source Current Turn-off Delay	0.5 V_{en} to 0.9 I_L (2); (4)		3		µs
T_2 (V_{en})	Source Current Fall Time	0.9 I_L to 0.1 I_L (2); (4)		1		µs
T_3 (V_{en})	Source Current Turn-on Delay	0.5 V_{en} to 0.1 I_L (2); (4)		0.3		µs
T_4 (V_{en})	Source Current Rise Time	0.1 I_L to 0.9 I_L (2); (4)		0.4		µs
T_5 (V_{en})	Sink Current Turn-off Delay	0.5 V_{en} to 0.9 I_L (3); (4)		2.2		µs
T_6 (V_{en})	Sink Current Fall Time	0.9 I_L to 0.1 I_L (3); (4)		0.35		µs
T_7 (V_{en})	Sink Current Turn-on Delay	0.5 V_{en} to 0.9 I_L (3); (4)		0.25		µs
T_8 (V_{en})	Sink Current Rise Time	0.1 I_L to 0.9 I_L (3); (4)		0.1		µs

1) 1)Sensing voltage can be –1 V for t ≤ 50 µsec; in steady state V_{sens} min ≥ – 0.5 V.
2) See fig. 2.
3) See fig. 4.
4) The load must be a pure resistor.

Figure 1 : Typical Saturation Voltage vs. Output Current.

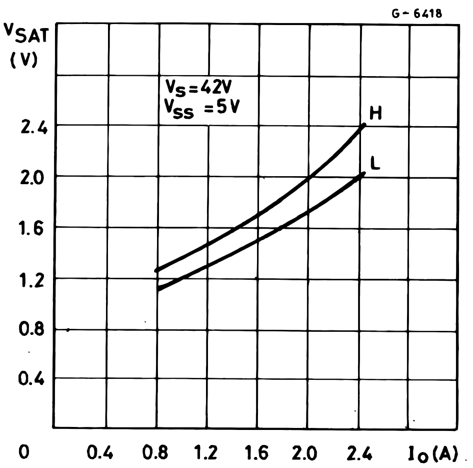
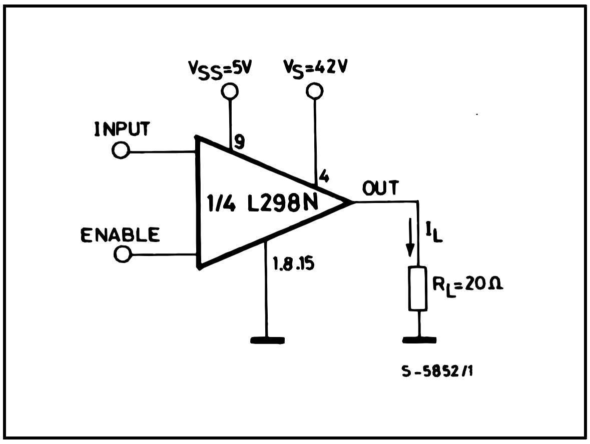


Figure 2 : Switching Times Test Circuits.



Note : For INPUT Switching, set EN = H
For ENABLE Switching, set IN = H

Figure 3 : Source Current Delay Times vs. Input or Enable Switching.

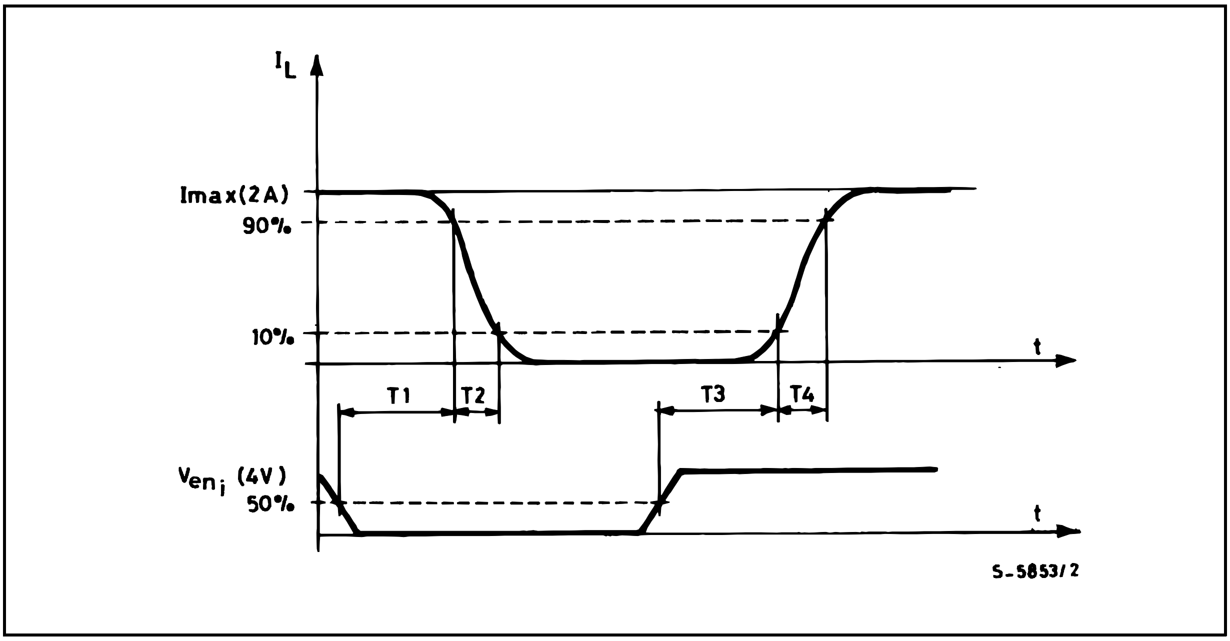
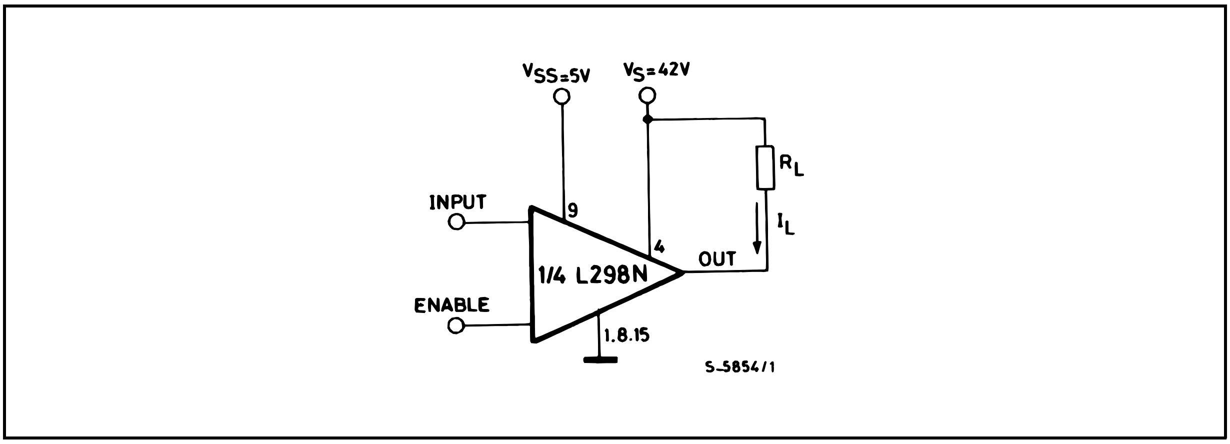


Figure 4 : Switching Times Test Circuits.



Note : For INPUT Switching, set EN = H
For ENABLE Switching, set IN = L

Figure 5 : Sink Current Delay Times vs. Input 0 V Enable Switching.

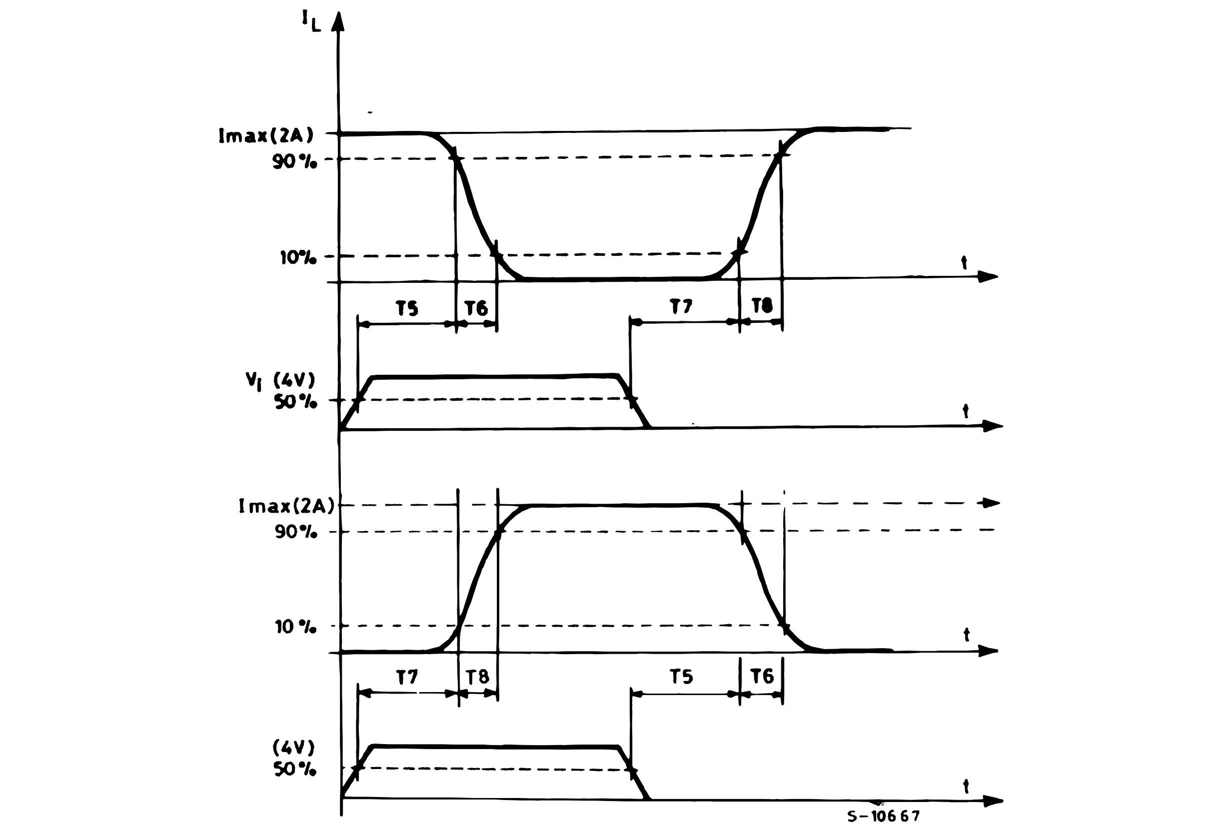
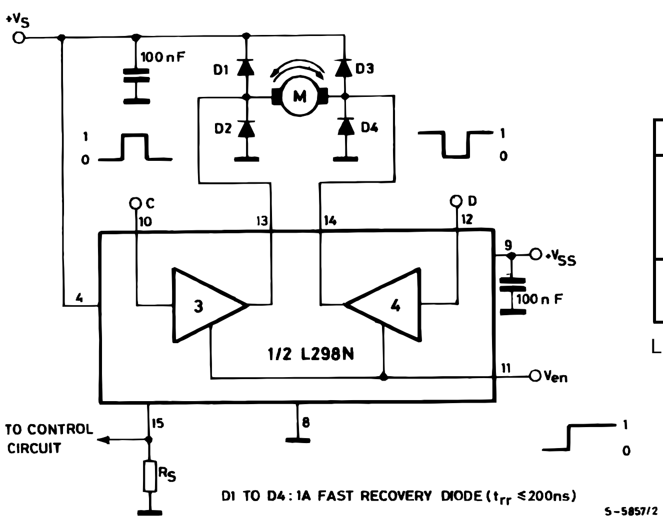


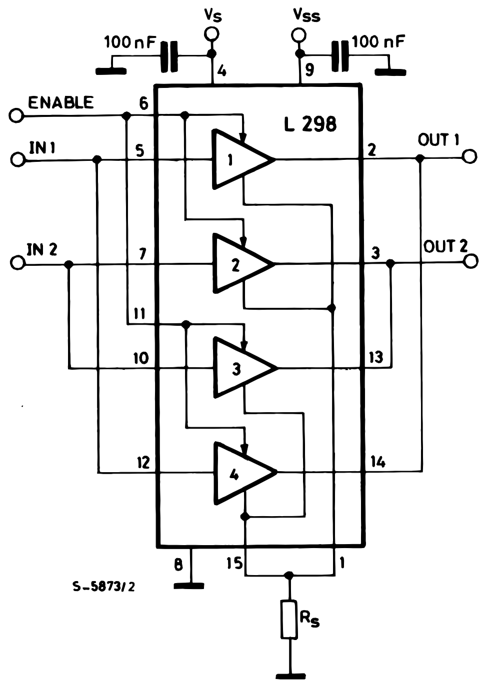
Figure 6 : Bidirectional DC Motor Control.



Inputs		Function
V_{en} = H	C = H ; D = L	Forward
	C = L ; D = H	Reverse
	C = D	Fast Motor Stop
V_{en} = L	C = X ; D = X	Free Running Motor Stop

L = Low H = High X = Don't care

Figure 7 : For higher currents, outputs can be paralleled. Take care to parallel channel 1 with channel 4 and channel 2 with channel 3.



APPLICATION INFORMATION (Refer to the block diagram)

1.1. POWER OUTPUT STAGE

The L298 integrates two power output stages (A ; B). The power output stage is a bridge configuration and its outputs can drive an inductive load in common or differenzial mode, depending on the state of the inputs. The current that flows through the load comes out from the bridge at the sense output : an external resistor (R_{SA} ; R_{SB}.) allows to detect the intensity of this current.

1.2. INPUT STAGE

Each bridge is driven by means of four gates the input of which are In1 ; In2 ; EnA and In3 ; In4 ; EnB. The In inputs set the bridge state when The En input is high ; a low state of the En input inhibits the bridge. All the inputs are TTL compatible.

2. SUGGESTIONS

A non inductive capacitor, usually of 100 nF, must be foreseen between both Vs and Vss, to ground, as near as possible to GND pin. When the large capacitor of the power supply is too far from the IC, a second smaller one must be foreseen near the L298.

The sense resistor, not of a wire wound type, must be grounded near the negative pole of Vs that must be near the GND pin of the I.C.

Each input must be connected to the source of the driving signals by means of a very short path.

Turn-On and Turn-Off : Before to Turn-ON the Supply Voltage and before to Turn it OFF, the Enable input must be driven to the Low state.

3. APPLICATIONS

Fig 6 shows a bidirectional DC motor control Schematic Diagram for which only one bridge is needed. The external bridge of diodes D1 to D4 is made by four fast recovery elements ($t_{rr} \leq 200$ nsec) that must be chosen of a V_F as low as possible at the worst case of the load current.

The sense output voltage can be used to control the current amplitude by chopping the inputs, or to provide overcurrent protection by switching low the enable input.

The brake function (Fast motor stop) requires that the Absolute Maximum Rating of 2 Amps must never be overcome.

When the repetitive peak current needed from the load is higher than 2 Amps, a paralleled configuration can be chosen (See Fig.7).

An external bridge of diodes are required when inductive loads are driven and when the inputs of the IC are chopped ; Shottky diodes would be preferred.

This solution can drive until 3 Amps In DC operation and until 3.5 Amps of a repetitive peak current.

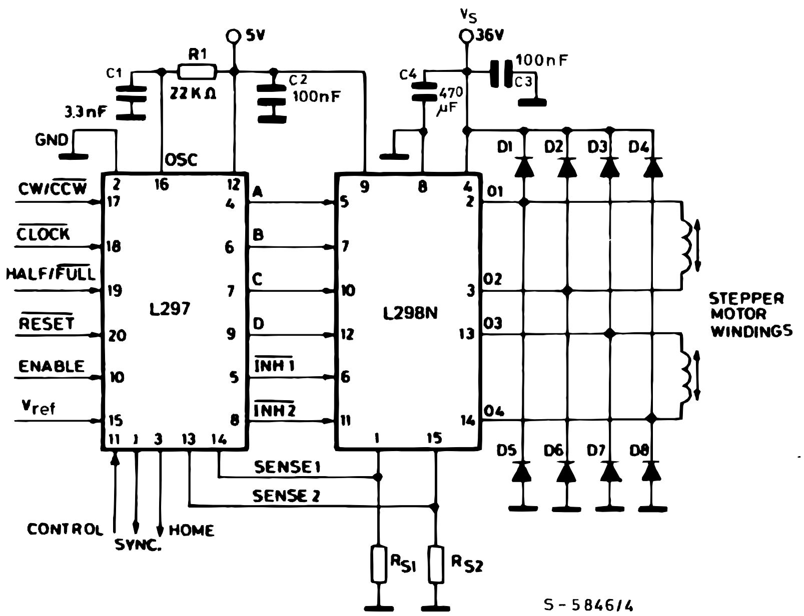
On Fig 8 it is shown the driving of a two phase bipolar stepper motor ; the needed signals to drive the inputs of the L298 are generated, in this example, from the IC L297.

Fig 9 shows an example of P.C.B. designed for the application of Fig 8.

Fig 10 shows a second two phase bipolar stepper motor control circuit where the current is controlled by the I.C. L6506.

Figure 8 : Two Phase Bipolar Stepper Motor Circuit.

This circuit drives bipolar stepper motors with winding currents up to 2 A. The diodes are fast 2 A types.



$R_{S1} = R_{S2} = 0.5\ \Omega$

D1 to D8 = 2 A Fast diodes $\begin{cases} V_F \leq 1.2\ V\ @\ I = 2\ A \\ trr \leq 200\ ns \end{cases}$

Figure 9 : Suggested Printed Circuit Board Layout for the Circuit of fig. 8 (1:1 scale).

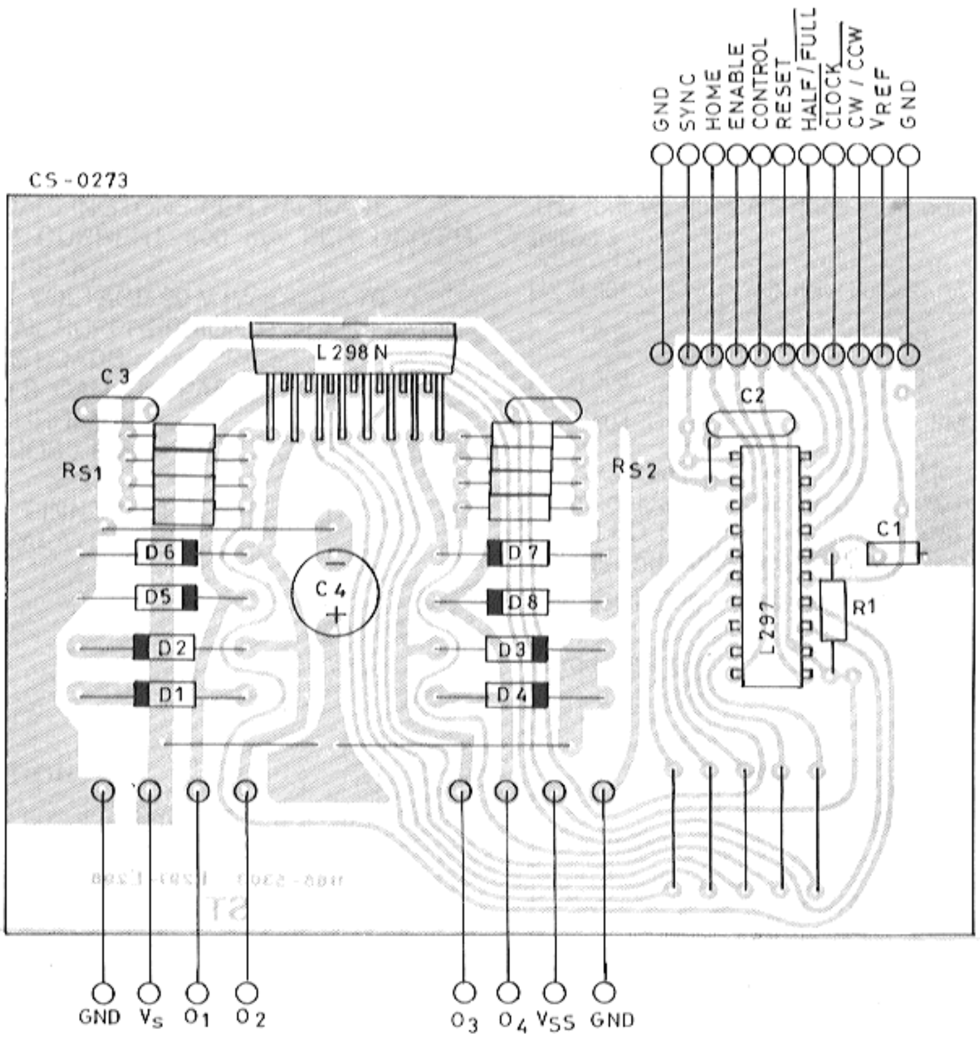
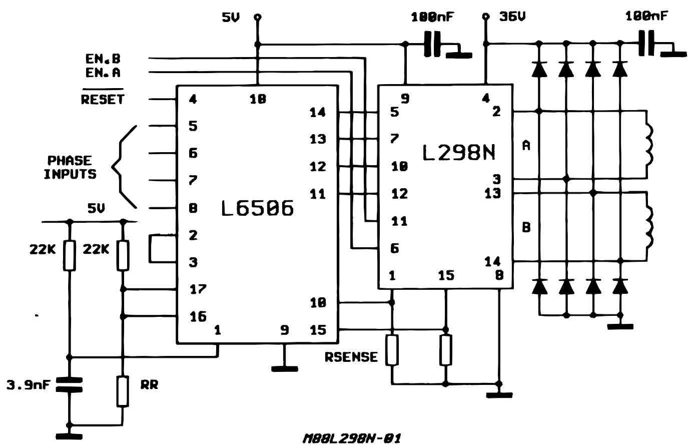


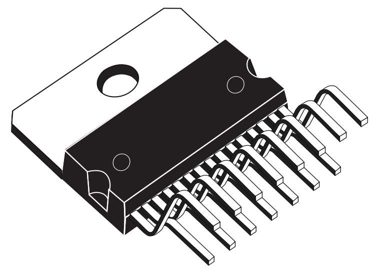
Figure 10 : Two Phase Bipolar Stepper Motor Control Circuit by Using the Current Controller L6506.



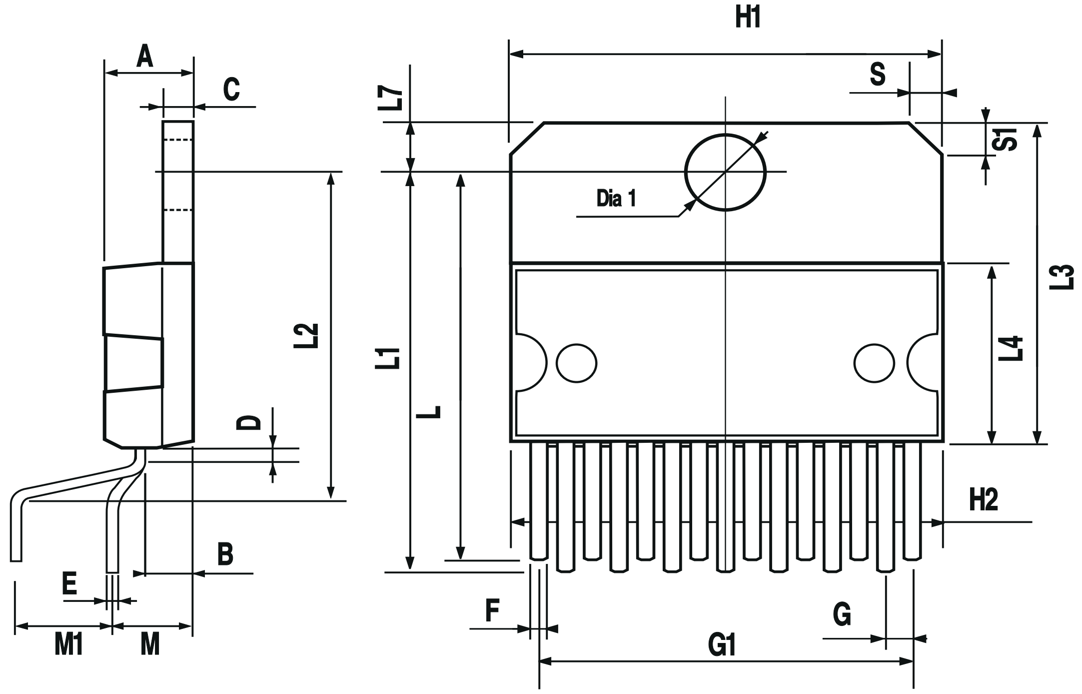
R_R and R_{sense} depend from the load current

DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
A			5			0.197
B			2.65			0.104
C			1.6			0.063
D		1			0.039	
E	0.49		0.55	0.019		0.022
F	0.66		0.75	0.026		0.030
G	1.02	1.27	1.52	0.040	0.050	0.060
G1	17.53	17.78	18.03	0.690	0.700	0.710
H1	19.6			0.772		
H2			20.2			0.795
L	21.9	22.2	22.5	0.862	0.874	0.886
L1	21.7	22.1	22.5	0.854	0.870	0.886
L2	17.65		18.1	0.695		0.713
L3	17.25	17.5	17.75	0.679	0.689	0.699
L4	10.3	10.7	10.9	0.406	0.421	0.429
L7	2.65		2.9	0.104		0.114
M	4.25	4.55	4.85	0.167	0.179	0.191
M1	4.63	5.08	5.53	0.182	0.200	0.218
S	1.9		2.6	0.075		0.102
S1	1.9		2.6	0.075		0.102
Dia1	3.65		3.85	0.144		0.152

OUTLINE AND MECHANICAL DATA

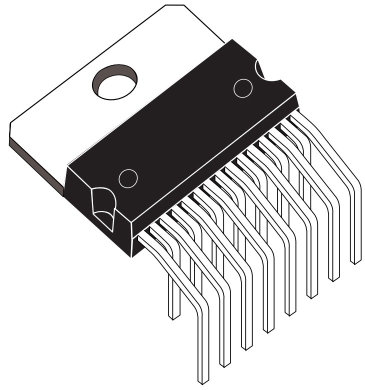


Multiwatt15 V

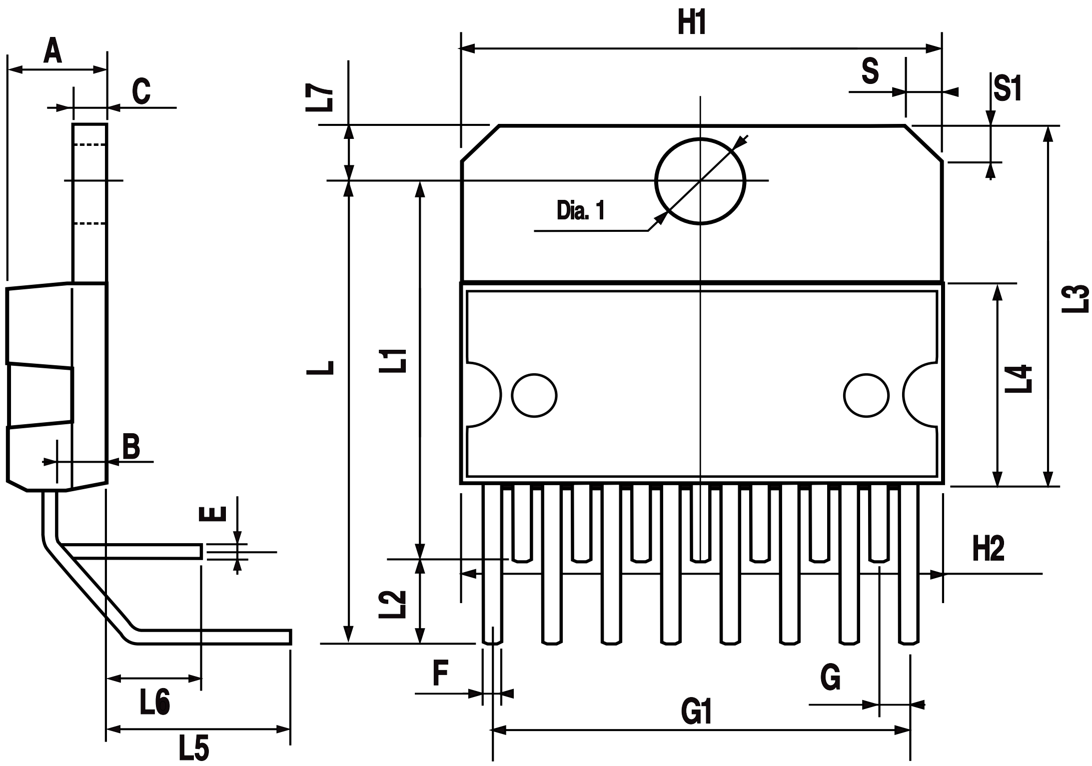


DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
A			5			0.197
B			2.65			0.104
C			1.6			0.063
E	0.49		0.55	0.019		0.022
F	0.66		0.75	0.026		0.030
G	1.14	1.27	1.4	0.045	0.050	0.055
G1	17.57	17.78	17.91	0.692	0.700	0.705
H1	19.6			0.772		
H2			20.2			0.795
L		20.57			0.810	
L1		18.03			0.710	
L2		2.54			0.100	
L3	17.25	17.5	17.75	0.679	0.689	0.699
L4	10.3	10.7	10.9	0.406	0.421	0.429
L5		5.28			0.208	
L6		2.38			0.094	
L7	2.65		2.9	0.104		0.114
S	1.9		2.6	0.075		0.102
S1	1.9		2.6	0.075		0.102
Dia1	3.65		3.85	0.144		0.152

OUTLINE AND MECHANICAL DATA



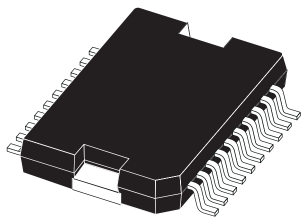
Multiwatt15 H



DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
A			3.6			0.142
a1	0.1		0.3	0.004		0.012
a2			3.3			0.130
a3	0		0.1	0.000		0.004
b	0.4		0.53	0.016		0.021
c	0.23		0.32	0.009		0.013
D (1)	15.8		16	0.622		0.630
D1	9.4		9.8	0.370		0.386
E	13.9		14.5	0.547		0.570
e		1.27			0.050	
e3		11.43			0.450	
E1 (1)	10.9		11.1	0.429		0.437
E2			2.9			0.114
E3	5.8		6.2	0.228		0.244
G	0		0.1	0.000		0.004
H	15.5		15.9	0.610		0.626
h			1.1			0.043
L	0.8		1.1	0.031		0.043
N	10˚ (max.)					
S	8˚ (max.)					
T		10			0.394	

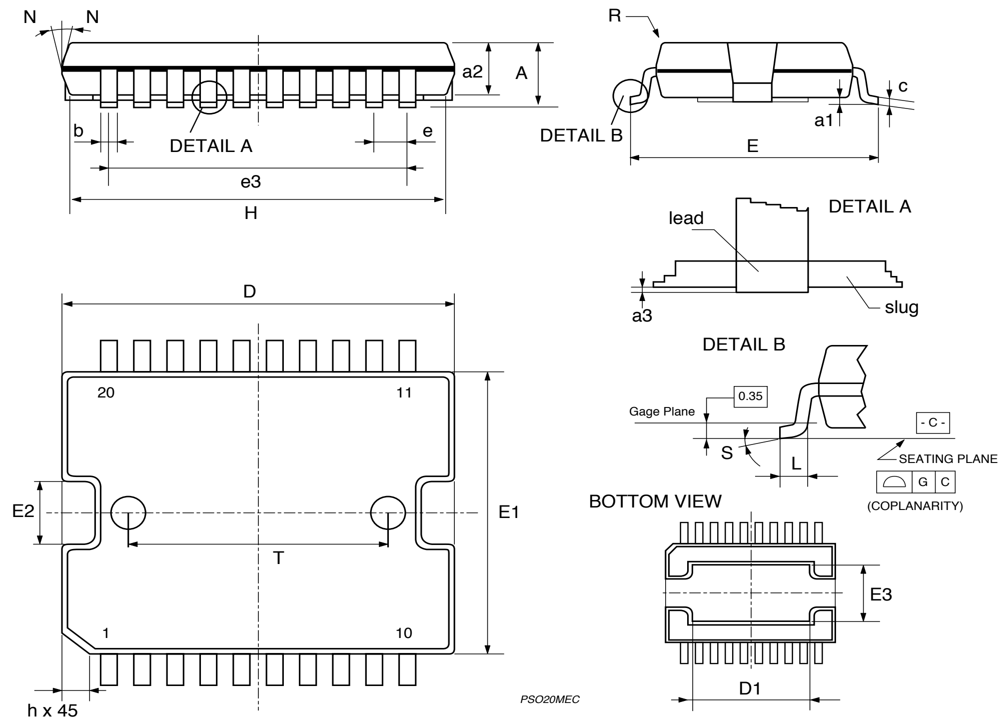
(1) "D and F" do not include mold flash or protrusions.
- Mold flash or protrusions shall not exceed 0.15 mm (0.006").
- Critical dimensions: "E", "G" and "a3"

OUTLINE AND MECHANICAL DATA



JEDEC MO-166

PowerSO20



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